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Bivalvia biostratigraphy of Aksütlü region (Hekimhan, NW Malatya, Türkiye) and paleoclimatological interpretations

Müjde GÜRSOY^a 

^a General Directorate of Mineral Research and Exploration, Şehit Cuma Dağ Natural History Museum, Çankaya Ankara, Türkiye

Research Article

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Paleoclimatology.

ABSTRACT

In this study, Early Miocene bivalve fauna obtained from Hekimhan Aksütlü locality is presented. Abundant and well-preserved ostreid samples are interesting in the area where molluscs have not been studied before. Within the community where ostreids are dominant, eight species have been identified; four species of the Ostreoidea, two Pectinoidea, one Arcoidea and one Cardioidea have been recorded. The Carbon ($^{13}\text{C}/^{12}\text{C}$) and Oxygen ($^{18}\text{O}/^{16}\text{O}$) isotope ratio results of the ostreids and sediments indicate the first findings related to the Miocene Climate Optimum (MCO) Event in Anatolia. Identified bivalves reveal that Akyar Formation was deposited in a shallow and warm sea in Early Miocene.

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1. Introduction

The study area is located in the northwest of the Malatya Basin between Hekimhan and Yazihan in the northwest of the Malatya Basin (Figure 1). The first studies in the basin were carried out by Birand (1938) and subsequently many studies for geological, stratigraphic, paleontological, sedimentological and petroleum exploration purposes were carried out by Stchépinsky (1939, 1944), Ayan and Bulut (1964), Akkuş (1971), Yoldaş (1971, 1972), Sirel (1976), Kurtman (1978), Hakyemez and Örcen (1982), Örcen (1986), Görmüş (1992, 1993), Gürer (1994), Ayyıldız and Önal (2005), Çağlar-Kaya and Önal (2009), Metin et al. (2013), Gedik (2015) and Sevimli et al. (2017).

Malatya Basin developed on Taurides according to Ketin (1959, 1966) and Şengör and Yılmaz (1981), on Bozkır Unity according to Özgül (1976) and Perinçek and Kozlu (1983) and on Keban micro

plate according to Perinçek and Özkaya (1981). The sequence in the north and south of the basin differs in terms of facies and age, it has been evaluated as two separate sub-basins, Hekimhan and Gündüzbey (Önal and Gözübol, 1992; Ayyıldız et al., 2010, 2015). In the Hekimhan Basin, the basement begins with the Kuluncak Ophiolite, which was emplaced before the Maastrichtian. The Maastrichtian Hekimhan Formation unconformably overlies all older units. Paleogene begins with the Paleocene Yağca Formation and continues with the Eocene Darende and Oligocene Selimiye formations. The Neogene units begin with the Early Miocene Akyar Formation, continue with the Middle-Late Miocene Kangal and Yılanlıdağ formations, the Late Miocene Yamadağ volcanics and end with the Pliocene-Quaternary sediments.

The age of the Akyar Formation, which crops out in the Aksütlü region where the studies were carried out, was recorded as Early Miocene with foraminifers

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*Corresponding author: Müjde GÜRSOY, mujde.gursoy@mta.gov.tr

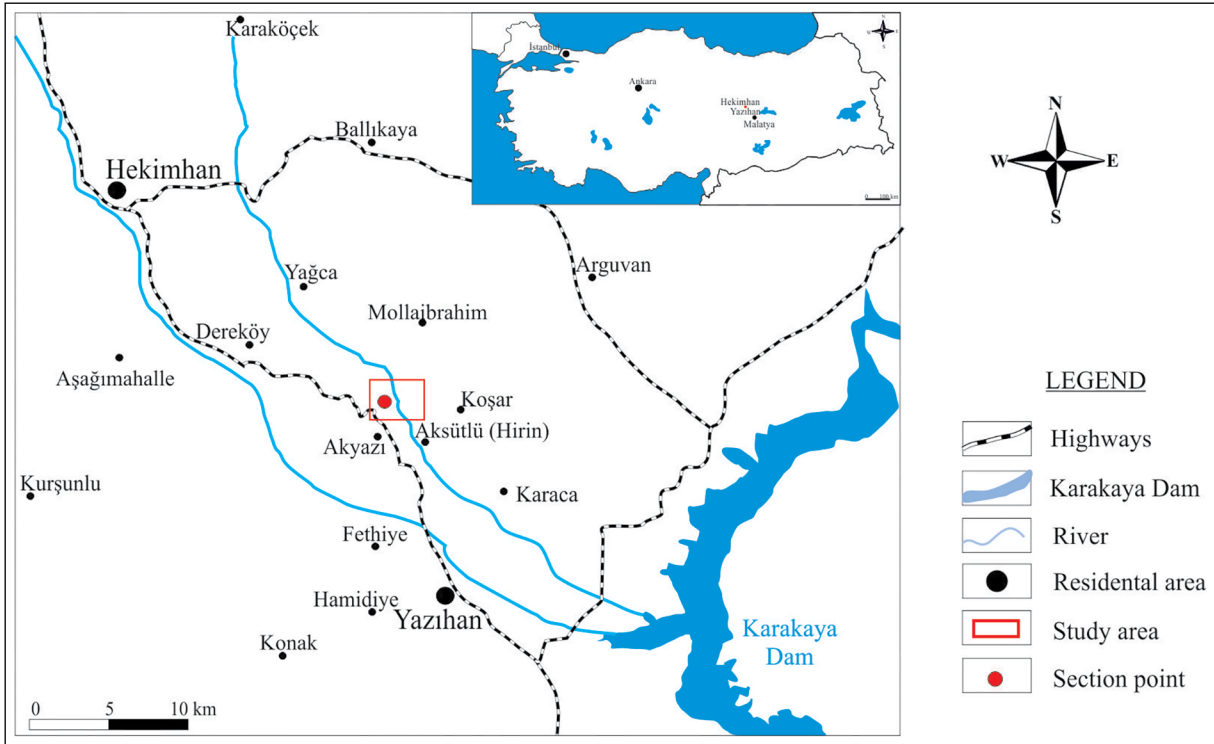


Figure 1- Location map of the study area (edited from Google maps).

(*Operculina* sp., *Amphistegina* sp., *Archaias* sp., *Miogyopsis* sp., *Globigerina ouachitaensis*, *Globigerina praebulloides occlusa*) (Metin et al., 2013). However, there is no detailed systematic study on the common macrofossil population. With the sampling for this purpose, systematic descriptions of bivalve fossils were included. Paleoecology was revealed with the isotope analysis results obtained from ostreids.

2. Material and Methods

This research presents some of the studies carried out in the Hekimhan and Yazihan districts of Malatya province within the scope of the project titled “Cenozoic Fossils, Stratigraphy and Paleogeography of Türkiye” performed therein the Şehit Cuma Dağ Natural History Museum of the General Directorate of Mineral Research and Exploration. The distribution and lower-upper boundary relationships of the Early Miocene Akyar Formation, which crops out in the Aksütlü locality, were observed, and a 10 m measured stratigraphic section was taken by sampling Bivalvia. The samples were cleaned with hydrogen peroxide (H_2O_2) in the Museum Paleontology laboratory,

the necessary measurements were made with a vernier caliper and photographed. For the systematic description of bivalves, Bieler, Carter and Coan in Bouchet and Rocroi (2010) were followed. All identified fossils are deposited in the MTA Natural History Museum Paleontology Department archive. In the systematic section, inventory numbers of the identified specimens are given.

Four *Ostrea* fossils and sediment samples taken from the studies conducted in Aksütlü locality were subjected to carbon and oxygen isotope analysis at the Middle East Technical University Central Laboratories. The determination of $\delta^{13}C$ and $\delta^{18}O$ isotope ratios in the pulverized samples was performed using the Gas Bench-Continuous Flow Isotope Ratio Mass Spectrometry (*Delta Plus XP Isotope Ratio Mass Spectrometer-Thermo Finnigan*) technique. In the analyses, the main standard “NBS19 Limestone (NIST)” ($\delta^{13}C$: 1.95‰ and $\delta^{18}O$: -2.20‰) was analyzed in each experimental set with the standard samples and was used to convert the raw isotope ratios of the samples determined by the device into real isotopic values. The results are determined in permil ‰ relative to VPDB (Vienna Pee Dee Belemnite).

3. Stratigraphy

The geological map of the study area and the generalized stratigraphic section of the basin are given in Figures 2 and 3. The studies were carried out in the Early Miocene Akyar Formation.

3.1. Basement Units

The basement of the Malatya basin is formed by the Paleozoic-Mesozoic Keban metamorphics, the Late Triassic-Late Cretaceous Andırın Formation and the Kuluncak Ophiolite, which completed its first emplacement before the Maastrichtian. The pre-Maastrichtian units are covered by the Kuluncak Ophiolite (Metin et al., 2013; Sümengen, 2016). Metin et al. (2013) stated that it may have formed in the subduction zone in the Lower Cretaceous due to the slicing of the oceanic crust during the closure process in the basin that developed from the Middle-Upper Triassic.

3.2. Cover Units

It is represented by the Maastrichtian Hekimhan Formation, the Paleocene Medik and Paleocene-Eocene Yağca Formations, the middle-late Eocene Darende Formation, the Oligocene Selimiye Formation, Early Miocene Akyar and Late Miocene Karabakır Formations, Late Miocene-Pliocene Yamadağ Volcanics, the Pliocene Zöhrep and Pliocene-Quaternary Beylerderesi Formations.

The Akyar Formation from which the samples were taken was first defined by Ayan and Bulut (1964). Since the best exposed area of the formation is the Akyar valley in the northeast of Yazıhan district, it was also used with the same name by Önal (1998). The same unit was defined by Akkuş (1971) as the Tahtaltepe Formation. The unit was evaluated as late Oligocene-Early Miocene sediments by Ayan and Bulut (1964) and as Aquitanian-Burdigalian sediments

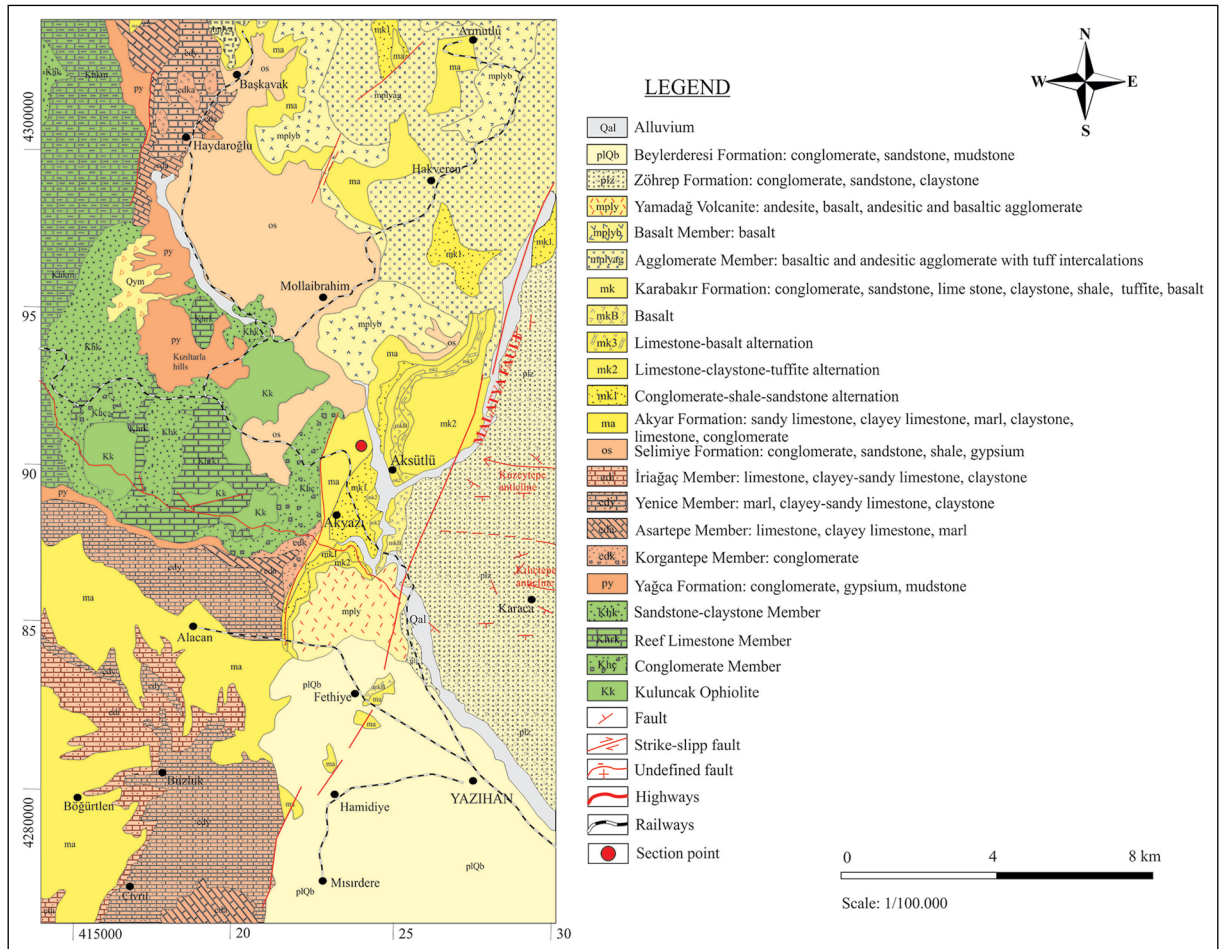


Figure 2- Geological map of the study area [Edited from Sümengen (2016), MTA 1/25.000 scale K 40-d1 ve K 40-d2 sheets].

SYSTEM	SERIES STAGE	FORMATION	LITHOLOGY COLUMN	LITHOLOGICAL EXPLANATION
QUATERNARY				Alluvium (Qal) Hillside debris (Qym) Alluvial fan (Qay) Eski alüvyon (Qeal)
NEOGENE	PLIO- QUATERNARY	Beylerderesi		Beylerderesi Fm. (plQb): conglomerate, sandstone, mudstone
	PLIOCENE	Zöhrep		Zöhrep Fm. (plz): conglomerate, sandstone, claystone
	U. MIOCENE -PLIOCENE	Yamadağ volkaniti		Yamadağ volcanite(mply): basalt, andesite, andesitic and basaltic agglomerate Basalt member (mplya): basalt Andesite member (mplya): andesite Agglomerate member (mplag): Andesitic and basaltic agglomerate with tuff intercalations
	UPPER MIOCENE	Karabakır		Karabakır Fm. (mk): conglomerate, sandstone, shale, limestone, tuffite, basalt Basalt (mkB) Limestone (mk4) Limestone-basalt alternation (mk3) Limestone-claystone-tuffite alternation (mk2) Conglomerate-sandstone-shale alternation (mk1)
	LOWER MIOCENE	Akyar		Akyar Fm.(ma): conglomerate, sandstone, marl, clayey limestone
PALEOGENE	OLIGOCENE	Selimiye		Selimiye Fm. (os): conglomerate, sandstone, shale, gypsum
	MID.-UPP. EOCENE	Darende Karatas volcanite member		Darende Fm. (ed): Conglomerate, limestone, claystone, marl, clayey limestone, basalt İriağaç member (edi): limestone, claystone, clayey limestone, sandy limestone Yenice member (edy): marl, clayey-sandy limestone, limestone Volcanite member (edka): Basalt Asartepe member (eda): limestone, clayey limestone, marl Clastic member (edki): sandstone, siltstone, claystone, mudstone, gypsum Korgantepe member (edk): conglomerate
	PALEOCENE	Yağca		Yağca Fm (py): conglomerate, mudstone, gypsum
		Medik		Medik Fm. (pm): conglomerate, mudstone
CRETACEOUS JURASSIC TRIASSIC		MAASTRICHTIAN	Hekimhan Bahçedam volcanite member	Hekimhan Fm. (Kh): conglomerate, sandstone, siltstone, mudstone, claystone, limestone, marl Clayey limestone-marl member (Khkn): claystone, clayey-sandy limestone, limestone, marl, mudstone, gypsum Sandstone-claystone member (Khk): Sandstone, siltstone, claystone, clayey limestone, marl Volcanite member (Khb): Basalt
		PRE- MAASTRICHTIAN	Kuluncak Ophiolite	Kuluncak ophiolite (Kk): Harzburgite, werlite, lherzolite, serpentinite, pyroxenite, dunite, gabbro, diabase dykes, basalt, limestone, radiolarite, pelagic mudstone
	TRIASSIC- U. CRETACEOUS	Andırın		Andırın Fm. (TrKa): Limestone with megalodonts, dolomite, recrystallized limestone, oolitic limestone, dolomitic limestone, claystone, rudist limestone
		Keban Metamorphites		Keban metamorphics (PzMzk): Marble, dolomite, mica schist, calc-schist, metaconglomerate, metabasite, recrystallized limestone, phyllite, syenite dykes

Unscaled

Figure 3- Malatya Basin generalized stratigraphic section (Edited from Ayyıldız et al., 2010, 2015; Metin et al., 2013; Sümengen, 2016)

by Yoldaş (1971). Hakyemez and Örcen (1982) named the Aquitanian sediments as Çavuşköy and the Burdigalian sediments as Ansurçayı formation. Metin et al. (2013) used the shallow marine Early Miocene sediments as Tahtalıtepe Formation. In this study, the name Akyar was used, adhering to the first defining name (Figure 4).

Generally, it is a horizontally bedded, light coloured unit, consisting of conglomerate, clayey limestone, claystone, marl and limestone alternations, and contains abundant micro- and macrofossils (Figure 5). The formation overlies the Darende Formation with an angular unconformity and is unconformably by the Yamadağ volcanics (Metin et al., 2013; Sümengen,

2016). The Akyar Formation was assigned the Early Miocene age with the foraminifers identified. The base level of the formation contains abundant macro fossils, and the fact that the broken and fragmented fossil shells are indicate a high energy environment. The upper levels of the unit characterize the open platform environment, and reef developments are observed on these levels due to the shallowing (Metin et al., 2013).

3.3. Biostratigraphy

Aksütlü measuring stratigraphic section was studied on MTA 1/25.000 scale K 40 d1 and K 40 d2 sheets. Section coordinates are X: 84414 Y: 424304 Z:

AGE			Ayan and Bulut (1964) NW Malatya	İzdar and Ünlü (1977) NW Malatya	Örcen (1986) NW Malatya	Bozkaya and Yalçın (1992) NW Malatya	Ayyıldız et al (2010) NW Malatya	Metin et al. (2013) NW Malatya	Ayyıldız et al. (2015) NW Malatya	Sümengen (2016) NW Malatya		
QUATERNARY	Holocene											
	Pleistocene	Upper	0.117	Alluvian	Alluvian	Alluvian	Alluvian	Alluvian	Alluvian	Alluvian		
		Middle	0.126									
		Calabrian	0.781									
		Gelasian	1.80									
NEOGENE	Pliocene	Piacensian	2.58									
		Zanclean	3.600	Tuff, marl, agglomerate, basalt	Mısırdere fm.				Zöhrep			
	Miocene	Messinian	5.333	Variegated Detritics		Yamadağ volcanics	Sultansuyu fm.	Yamadağ volcanics	Sultansuyu fm.	Yamadağ volcanics		
		Tortonian	7.246									
		Serravalian	11.63									
		Langhian	13.82									
		Burdigalian	15.97								Limestone, shale	
		Aquitanian	20.44									
			23.03	Andesite								
		PALEOGENE	Oligocene	Chatthian	28.1	Sandy limestone			Dumanlar fm.	Selimiye fm.	Dumanlar fm.	Selimiye fm.
Rupelian	33.9			Limestone, shale	Slightly silicified limestone with <i>Nummulites</i> and <i>Alveolina</i>							
Eocene	Priabonian		37.8	Limestone, shale			Kızılyatak fm.		İriağaç mb. Yenice mb. Asartepe mb. Korgantepe mb.	Yıldıztepe Zorban	Karataş volcanic mb.	
	Bartonian		41.2									
	Lutetian		47.8	Limestone	Gypsum, red clay and marl							
	Ypresian		56									
Paleocene	Thanetian		59.2		Limestone		Medik fm.	Yağca fm.	Salıcak mb. Zorbehan mb.	Yağca fm. Boyalı volcanics	Sarıkız Salıcak üy.	Yağca fm. Medik fm.
	Selandian		61.6									
	Danian		66									
CRETACEOUS	Upper		Maastrichtian	72.1	Marl,sandstone claystone Reefal limestone, conglomerate			Yukarıselimli fm.	Malatya Metamorfics	Kuluncak Ophiolites	Hekimhan fm	Bahçedam volcanic mb. Kuluncak Ophiolites
		Campanian	83.6									
		Santonian	86.3									
		Coniacian	89.8									
		Turonian	93.9									
			99.9									
		Cenomanian	100.5									

Figure 4- Comparison table of previous studies (red frame shows the studied formation).



Figure 5- General view of Akyar Formation, measured stratigraphic section point.

1054 and approximately 10 m measured section was taken by systematic sampling (Figure 6). No lower and upper boundary relationship was observed at the study point.

The base level of the section starts with grayish white coloured silty carbonate limestone and marl detritus. From this section as 1.60 m, samples numbered 44-AKS-1 and 2 were taken from bivalve samples were taken.

Above the detritus level is approximately 1 m thick whitish gray coloured fossiliferous biomicritic limestone layer and mud supported fine-grained laminated marl intercalation level. Fine-grained laminated marl level indicates low energy environment. Large-sized ostreid (44-AKS-3) samples were taken the limestone layer. The overlying fine-

grained laminated pink marl level of approximately 50 cm thick indicates a low energy environment, while the pink colour is due to the oxidizing environment in shallow water. The *Ostrea crassicostata* is the most abundant sample from the base to the middle of the section, so forming the Abundance Biozone (44-AKS-4). Above the pink marl level, there is a grey clayey limestone and then another 50 cm thick pink laminated marl level. The section passes to nodular limestone towards the upper levels and an ostreid horizon of 30 cm thickness can be followed within a level of 1.20 m. A decrease in fossil density is noticeable towards the upper levels of the section. In these levels, the other bivalve species such as *Anadara*, *Gigantopecten*, *Oopecten* and *Lyrocardium* were mostly detected. In general, species diversity is low in the stack dominated by ostreids.

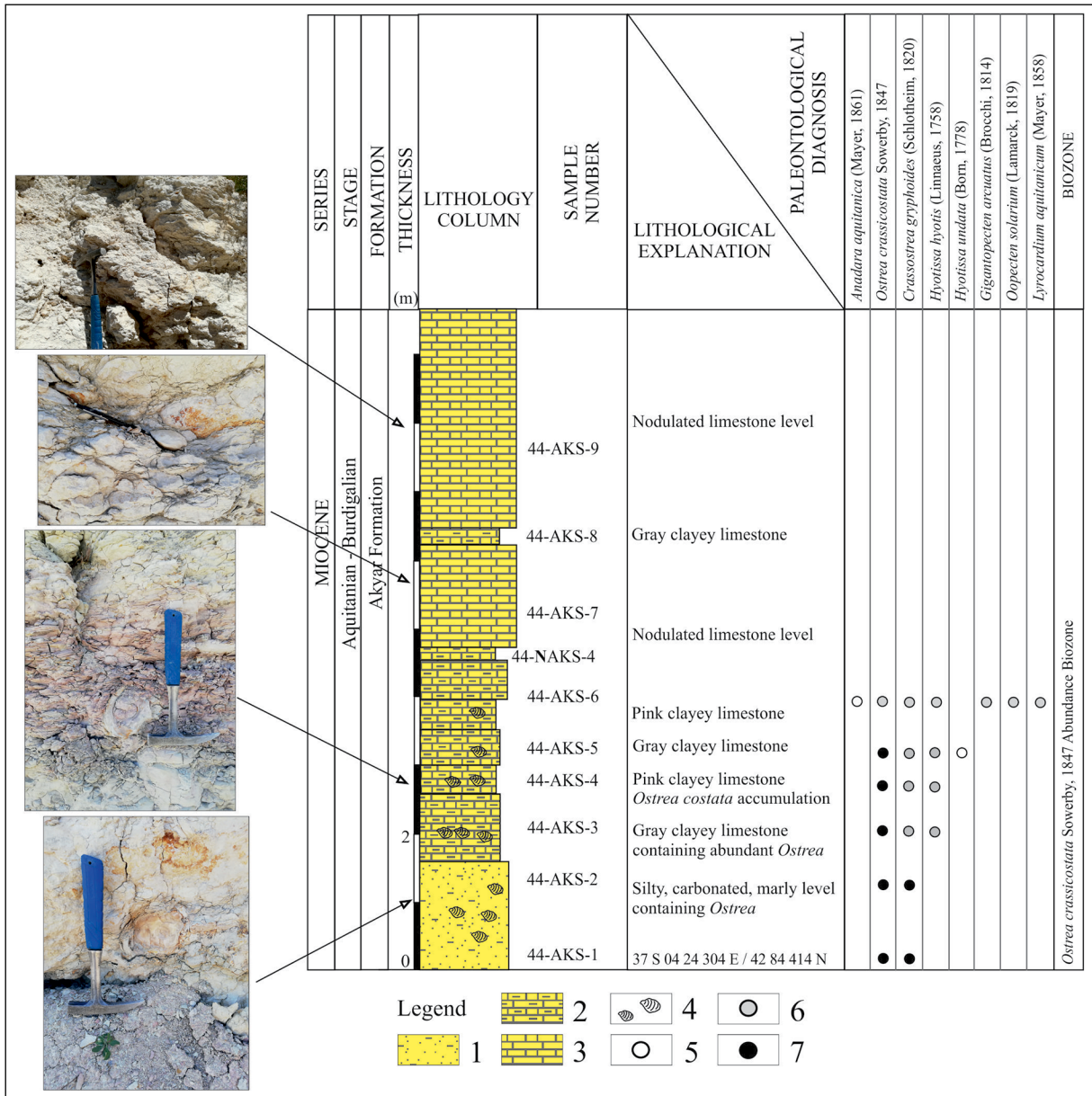


Figure 6- Aksütlü measured stratigraphic section; 1. Marl, 2. Clayey limestone, 3. Nodular limestone, 4. *Ostrea*, 5. Rare, 6. Common, 7. Abundant

Ostrea crassicosata Abundance Biozone: It is the most abundant species in the section. The other species that accompanies in the second densest proportion is *Crassostrea gryphoides*. Especially in marly levels, both species made horizons. Overgrowth is evident. Although the sizes of individuals vary, the average height is 13 cm, width is 12 cm and the shell thickness is 6 cm for the left valve and 2 cm for the right valve.

Ostreids live in coastal, estuarine or lagoonal environments. They tend to form reefs in brackish

waters with lower salinity than sea water, in areas where abundant nutrients come from land. Filter feeding and sessile epifaunal ostreids attach to the bottom with their larger convex left valves (Volety, 2013; Gürsoy and Görmüş, 2020). Their positions within the layer provide information on whether the current in the environment is weak or strong. The position where the lower (left) and upper (right) valves are together within the layer and the convex part of the larger shell shows the bottom of the layer is evidence that the bottom current is low (El-Hedeny, 2007).

In the Aksütlü region, the condition is the opposite. The fossil lower valves, which we generally detect in a sideways position within the layer, are seen in Figures 7a-b. Figure 7c is an image in a horizontal position but with the lower and upper valves are separate. In the Aksütlü locality, the position of the ostreid valves within the layer, leads to the assumption that the current in the environment is strong.

4. Systematic Palaeontology

This section includes systematic definitions of bivalves taken from the Akyar Formation outcrops. Bieler, Carter and Coan *in* Bouchet and Rocroi (2010) was followed for Bivalvia systematics. Abbreviations: MTA-AN: MTA Inventory Number. H: Height, L: Length, W: Width, BA: Body Angle, UA: Umbonal

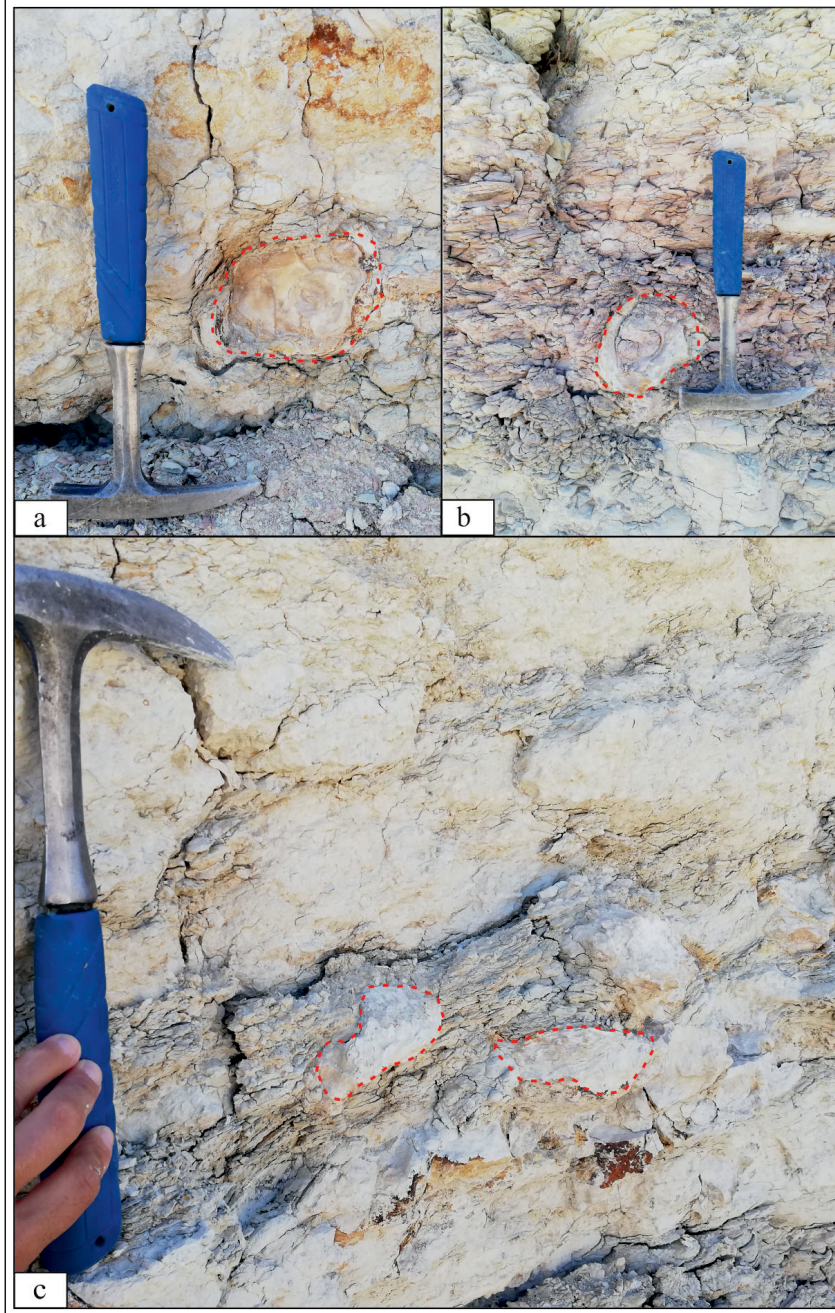


Figure 7- Fossil positions within the layer: a) *Ostrea crassicostata* left (lower) valve, b) *O. crassicostata* left (lower) valve, c) *O. crassicostata* left and right valves.

Angle, Th: Thickness, LAB: Length of Anterior Bourrelet, LPB: Length of Posterior Bourrelet, LR: Length of Resilifer, LLA: Length of Ligamental Area, HUSL: Length of Umbo, HAD: Height Adductor Muscle Scar, LAD: Length of Adductor Scar, AA: Attachment Area, GS: Growth Squama, HS: Hollow Spine; FR: Fold Rib; KC: Katachomata (thin groove-like depressions). VPDB: The Vienna Pee Dee Belemnite isotope reference, VSMOW: The Vienna Standard Mean Ocean Water – isotopic water standard.

Class: Bivalvia Linnaeus, 1758

Subclass: Autobranchia Grobben, 1894

Order: Arcida Stoliczka, 1871

Superfamily: Arcoidea Lamarck, 1809

Family: Arcidae Lamarck, 1809

Genus: *Anadara* Gray, 1847

Type species: *Arca antiquata* Linnaeus, 1758 accepted as *Anadara antiquata* (Linnaeus, 1758)

***Anadara cf. aquitana* (Mayer, 1861)**

Plate I figures 1, 2

1831 *Arca diluvii* Lamarck, Dubois de Montpéreux, p. 63, pl. 7, fig. 10-12.

1861 *Arca aquitana* Mayer, p. 362, no. 59.

2010 *Anadara cf. A. aquitana* (Mayer), Esu and Girotti, 53(1), p. 162, pl. 7, fig. 5-6.

2017 *Anadara aquitana* (Mayer), Gürsoy, p. 82, pl. 2, fig. 2a, b.

Material: Hekimhan Aksütlü village, Akyar Formation, Early Miocene, 44-AKS-6, MTA-AN-2023/42

Description: Small and broken pieces; although the swollen umbo, frequency and slopes of radial costae are similar to *Anadara aquitana*. It was named the *A. cf. aquitana* due to the deformation.

Dimensions: H: 1.2 cm, L: 0.85 cm

Remarks: *Anadara* is small and rare in the Oligocene and large and abundant in the Early Miocene (Schenck and Reinhart, 1938). It is a genus that feeds in suspension in littoral and sandy environments close to the shore and can be affected by salinity changes (Esu and Girotti, 2010). The genus name was emended

by Esu and Girotti (2010) as *Anadara*. Although the species identified is compatible with *A. aquitana*, the identification was left as *Anadara cf. aquitana* due to the few and deformed specimens (Figure 9).

Order: Ostreida Férussac, 1822

Family: Ostreidae Rafinesque, 1815

Subfamily: Ostreinae Rafinesque, 1815

Genus: *Ostrea* Linnaeus, 1758

Type species: *Ostrea edulis* Linnaeus, 1758

***Ostrea crassicosata* Sowerby in Smith, 1847**

Plate I, figures 3, 4, 5, 6

1847 *Ostrea crassicosata* Sowerby in Smith, p. 420, pl. 19, fig. 23.

2014 *Ostrea crassicosata* Sowerby, De Bortoli and Hladilová, p. 28.

2015 *Hyotissa hyotis* (Linné), De Bortoli and Hladilová, s. 97, pl. 2, fig. g, l; pl. 3, fig. d, g. (non *Ostrea crassicosata*)

Material: Hekimhan Aksütlü village, Akyar Formation, Early Miocene, 44-AKS-1-5, MTA-AN-2023/45

Description: Large and thick shell; the ligament area that starts as a quadrangular, combine towards the tip to form a triangle; there are convex bulge on both sides of the ligament area; in the left (lower) shell, the muscle scar is deep and half-moon shaped; thick ribs, spiny structures and growth lamellae are observed on it. The right (upper) valve is flatter, the ligament area is triangular and its upper part is turned inward.

Dimensions: Measurements were made by ignoring the deformation and individual differences in the samples. Left (lower) valve measurements were taken as average: H: 13 cm, L: 11.7 cm, Th: 6 cm, LAB: 1 cm, LPB: 1 cm, LR: 1.35 cm, LLA: 4.6 cm, HUSL: 1.1 cm, HAD: 1.2 cm, LAD: 2.2 cm. Right (upper) valve measurements were taken as average: H: 9.8 cm, L: 8.4 cm, Th: 2.1 cm, LAB: 0.8 cm, LPB: 0.8 cm, LR: 1.25 cm, LLA: 3.4 cm, HUSL: 1.1 cm, HAD: 1.7 cm, LAD: 2.2 cm.

Remarks: The species, which was widespread from Aquitanian to Tortonian, is characteristic with

its longitudinal wrinkles on the shell, ligament area inside the shell and deep muscle scar. Kóky (1996) mentioned the species in his revision of the Badenian mollusc fauna. De Bortoli and Hladilová (2014) identified the species as *O. crassicostata* Sowerby among the Badenian molluscs and revised it as *H. hyotis* (Linné) in their 2015 publication. The photographs of the species differ from our samples in terms of not have hollow spines on the outer of the valves (Figure 9).

Subfamily: Crassostreinae Scarlato and Starobogatov, 1979

Genus: *Crassostrea* Sacco, 1897a

Type species: *Ostrea virginica* Gmelin, 1791 accepted as *Crassostrea virginica* (Gmelin, 1791)

***Crassostrea gryphoides* (Schlotheim, 1813)**

Plate II, figures 1, 2, 3

1768 *Ostracites* Knorr and Walch, p. 140, 152, pl. D, fig. 1-2; pl. D*; pl. D.IV, fig. 1-5; pl. D.IX, fig. 1-2.

1813 *Ostracites gryphoides* Schlotheim, b. 7, p. 52, 72.

1819 *Ostrea crassissima* Lamarck, t. 6, p. 217.

1897a *Ostrea ? gingensis* (Schlotheim), Sacco, t. 23, p. 10, pl. 3, fig. 29.

1998 *Crassostrea gryphoides* (Schlotheim), Pfister and Wegmüller, p. 458, pl. 1, fig. 1-5; pl. 2, fig. 1-4.

2016 *Crassostrea gryphoides* (Schlotheim), Harzhauser et al., pp. 1223-1235.

Material: Hekimhan Aksütlü village, Akyar Formation, Early Miocene, 44-AKS-1-5, MTA-AN-2024/7

Description: The large right (lower) valve thick, long, cup-shaped; the ligament area starts as a quadrangle and get thinner towards the umbo in a triangular shape. The half-moon or kidney-shaped muscle scar is in the middle, is shallow in some individuals and deep in others; Hoernes (1870) stated that the muscle scar is deep in older individuals. On the right valve is thick and decorated with needle-like ends that follow each other in a row in some samples.

Dimensions: Measurements were made by ignoring the deformation and individual differences in the samples. H: 16.7 cm, L: 8 cm, Th: 7 cm, LAB: 0.7 cm, LPB: 0.7 cm, LR: 1.4 cm, LLA: 4 cm, HUSL: 4.4 cm, HAD: 2.6 cm, LAD: 1.6 cm.

Remarks: Lamarck (1819) stated that the species he described as *Ostrea crassissima* was similar to *O. virginica* and that he named it differently because it was thicker. Hoernes (1870, b. 4, p. 452) mentioned that *O. gingensis* is generally long, but has variable length and thickness measurements, and is confused with the thicker *O. crassissima*. He pronounced that the forms of these species are very regular, but they are confused with *O. virginica*, *O. lamellosa* and *O. gingensis* because they are similar. Sacco (1897a) described the species as *Ostrea ? gingensis* from the Helvetian and Tortonian of northern Italy, referring to the species *Ostracites* Knorr and Welch and *Ostracites gingensis* Schlottheim.

Pfister and Wegmüller (1998), stated that the long ostreid form was described by Knorr and Walch (1768) as *Ostracites*, by Schlotheim (1813) as *Ostrea gryphoides*. They also emphasize that the long form was defined by Lamarck (1819), as *Ostrea crassima*, unaware of these studies, which is synonymous with *O. gryphoides*. They also declared that *O. gingensis* is synonymous with *Crassostrea gryphoides*. Georgiades-Dikeoulia et al. (2000) reported that *C. gryphoides* occurred in coastal, tropical-subtropical environments close to the water outflow from land, river mouths and floods. El-Hedeny (2005) and El-Sabbagh and El-Hedeny (2016) reported that the species occurred in shallow marine deposits close to the shore affected by storms. Harzhauser et al. (2016), examined a 600 m thick ostreid bed in Stetten, Austria in the Early Miocene. By examining its growth curves, they revealed that it was a very fast-growing species and therefore contributed to carbonate production in Neogene estuaries and lagoons. Salvi and Mariottini (2017) divided the Family Ostreidae Rafinesque, 1815 into 4 Subfamilies with their molecular taxonomy study: Crassostreinae (*Crassostrea*, *Talonostrea*, *Magallana*); Saccostreinae (*Saccostrea*); Striostreinae (*Striostrea*); Ostreinae (remaining genera). They stated that the species included *Magallana* genus as

Crassostrea ariakensis, *C. belcheri*, *C. bilineata*, *C. madresensis*, *C. dactylena*, *C. gigas*, *C. hongkongensis*, *C. nippona*, *C. rivularis* and *C. sikamea*. Since the *C. gryphoides* was given as a synonym of *C. belcheri*, the species name can be arranged as *Magallana gryphoides*. However, since the species name is still at the stage of taxon inquiring, it was left as *C. gryphoides* (Figure 9).

Family: Gryphaeidae Vialov, 1936

Subfamily: Pycnodontinae Stenzel, 1959

Genus: *Hyotissa* Stenzel, 1971

Type species: *Mytilus hyotis* Linnaeus, 1758 accepted as *Hyotissa hyotis* (Linnaeus, 1758)

***Hyotissa hyotis* (Linnaeus, 1758)**

Plate III, figures 1, 2, 3

1758 *Mytilus hyotis* Linnaeus, v.1, p. 704.

1843 *Ostrea squarrosa* De Serres, t. 20, p. 1163, pl. 3, fig. 4, 4a.

1941 *Pycnodonta hyotis* (Lamarck), Ranson, p. 82-92.

1988 *Hyotissa hyotis* (Linné), Freneix et al., p. 3, pl. 1, fig. 3, 4.

2015 *Hyotissa hyotis* (Linné), De Bortoli and Hladilová, p. 97, pl. 2, figs. g-l, pl. 3, figs. d, g.

Material: Hekimhan Aksütlü village, Akyar Formation, Early Miocene, 44-AKS-3-5, MTA-AN-2024/8

Description: Left (lower) valve: Medium-large thick convex shell, ornamented with alternate tubercular spines and thin concentric lamellae; these ornaments decrease towards the paleal margin. Ligament area is large triangular in shape and has depressions on its edges. Umbo is flattened due to fixation. Muscle scar is deep half moon or close to the circle at the middle of the shell. No chomata trace is observed. Right (upper) valve: It is flatter than the lower valve and almost half as thick. The ligament area is depressed in a triangular shape; the muscle scar is depressed, almost circle in the middle. The shell surface has concentric lamellae.

Dimensions: Measurements were made by ignoring the deformation and individual differences in the samples. Ostreids measurement terminology is shown in the Figure 8. Left (lower) valves: H: 2-15 cm, W: 9.5-12 cm, Th: 5.5-7.2 cm. Right (upper) valves: H: 11-14 cm, W: 9-10.2 cm, Th: 2-4 cm.

Remarks: Ranson (1941), compared the recent and fossil samples of *Pycnodonta hyotis*. Because of the characteristic hinge and muscle scar, he recommended including the *Mytilus hyotis* Linnaeus in the genus *Pycnodonta*. Ranson (1943) mentioned that the species

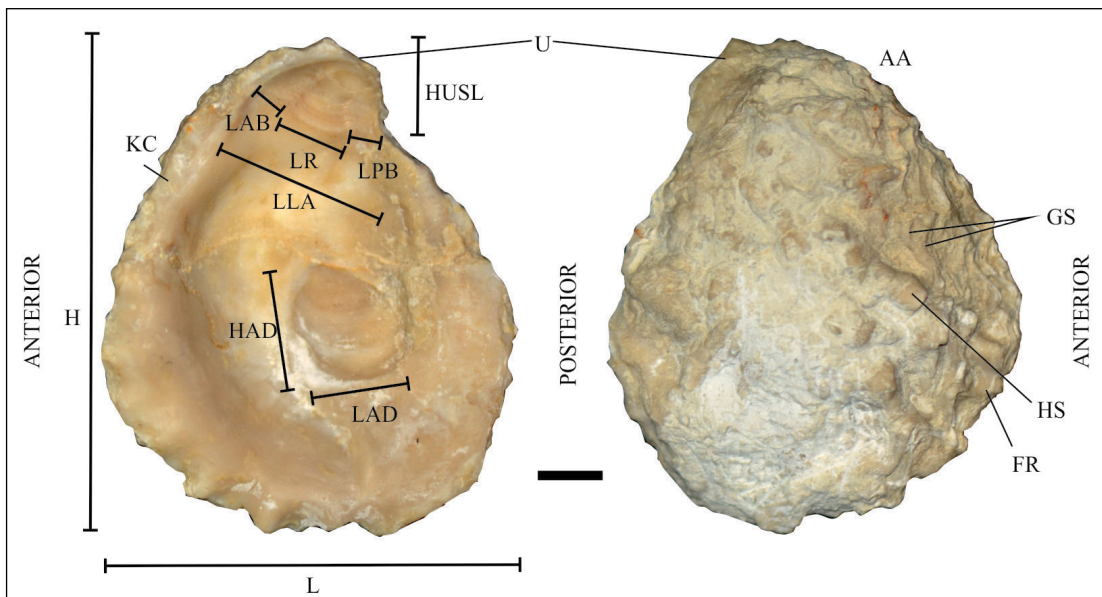


Figure 8- Ostreid inner and outer shell terminology (edited from Malchus, 1990, scale indicates 1 cm).

Ostrea virleti, which has folded valves, was described with the same name by many authors in studies from the Mediterranean to the Indo-Pacific basins in the Neogene. He emphasized that Cox (1927, 1930, 1936) stated that this species was *O. hyotis* in his publications and that it is a synonym. Mongin (1952) described the species he identified as *O. squarrosa* as having a rather large triangular ligament area and the muscle scar that was circular and large, down from the centre. He stated that these two characteristics indicated the species *O. squarrosa*. He emphasized that due to the methods of fixing ostreids to the ground, different deformations could be observed in the shell, and that is this resulted in diversity. De Castro-Coppa (1972) author stated that there are two similar species in the literature, namely *P. squarrosa* (de Serres) and *P. hyotis* (Linné). His specimens are incompatible with the specimens described by De Serres in the Burdigalian deposits in Martiques, but since they are more compatible with Linné's specimens in the tropics, he named them as *Pycnodanta hyotis*. Freneix et al. (1988) accepted the synonymy of two species *Hyotissa squarrosa* and *H. hyotis*, which are generally considered different and successive: the former Miocene and Pliocene, the latter Quaternary-recent.

Binder (2015) conducted a study on pearl grains belonging to the *H. squarrosa* species, which he identified in the Lower Miocene in the Korneuburg basin in Austria. De Bortoli and Hladilová (2015) identified the species *Hyotissa hyotis* among the Badenian ostreids in the Czech Moravian. They reported that the differences in the placement of adductor muscles in *H. squarrosa* and *H. hyotis* were shown as intraspecific variability (Freneix et al., 1988) and *H. squarrosa* is now reported as *Hyotissa hyotis* (Figure 9).

***Hyotissa undata* (Born, 1778)**

Plate III, figures 4, 5

1778 *Ostrea undata* Born, p. 94.

1819 *Ostrea undata* Lamarck, p. 217, no. 15.

1914 *Alectryonia aquitanica* (Mayer), Cossmann and Peyrot, t. 2, p. 394, pl. 19, fig. 5-7; pl. 22, fig. 24.

2003 *Hyotissa undata* (Lamarck), Lozouet et al., p. 7, pl. 18, fig. 4-7; pl. 19, fig. 1-5.

2012 *Hyotissa undata* (Lamarck), Michel et al., p. 122.

2014 *Hyotissa undata* (Lamarck), Londeix, pl. 173, fig. D.

Material: Hekimhan Aksütlü village, Akyar Formation, Early Miocene, 44-AKS-5, MTA-AN-2023/41

Description: Small or medium sized, nearly round shell, ligament ostreid type, triangular and slightly curved towards the posterior edge, umbo flat to convex; no coma is observed on the edges. Muscle scar is in the center, near the posterior edge, round in shape. The outer surface of the shell is decorated with folded and hollow spines and growth layers are seen.

Dimensions: Measurements were made by ignoring the deformation and individual differences in the samples. Ostreids measurement terminology is shown in the Figure 8. H: 7 cm, L: 6 cm, Th: 0.9-1.4 cm, LAB: 0.5 cm, LPB: 0.5 cm, LR: 0.9 cm, LLA: 1.9 cm, HUSL: 1.2 cm, HAD: 2 cm, LAD: 1.6 cm.

Remarks: Raulin and Delbos (1855), Cossmann and Peyrot (1914) and Sacy (1929) stated that the species is a characteristic fossil because it occurs only in the middle Aquitanian. Also, Lozouet et al. (2003), Michel et al. (2012) and Londeix (2014) included it in the Aquitanian stratotypes. It differs from the *Hyotissa hyotis* in terms of size, shell thickness, ligamental area and ornaments of the shell surface (Figure 9).

Order: Pectinida Gray, 1854

Superfamily: Pectinoidea Rafinesque, 1815

Family: Pectinidae Rafinesque, 1815

Subfamily: Pectininae Rafinesque, 1815

Genus: *Gigantopecten* Rovereto, 1899

Type species: *Ostrea latissima* Brocchi, 1814

***Gigantopecten arcuatus* (Brocchi, 1814)**

Plate III, figures 6, 7, 8

1814 *Ostrea arcuata* Brocchi, t. 2, p. 578, pl. 14, fig. 11.

1836 *Pecten arcuatus* (Brocchi), Lamarck, p. 162, no. 28.

1988 *Pecten arcuatus* (Brocchi), Bongrain, p. 189, pl. 13, fig. 1-4.

2006 *Gigantopecten* Rovereto, Waller, p. 24

2006 *Gigantopecten* Rovereto, Waller and Bongrain, pp. 155-157.

2018 *Gigantopecten arcuatus* (Brocchi), Dijkstra and Beu, p. 219.

Material: Hekimhan Aksütlü village, Akyar Formation, Early Miocene, 44-AKS-6, MTA-AN-2023/43

Description: Small and medium sized round shells; lower (right) valve convex, upper (left) valve nearly flat; umbo small swollen, auricles equiangular; shell has 16 thick radial ribs.

Dimensions: H: 2.9 cm, L: 3.3 cm, AL: 1.8 cm, UA: 115°

Remarks: Báldi (1973) and Roger and Demarcq (1974) mentioned that the species living in shallow sublittoral facies is mainly of Mediterranean origin and emerged in the late Oligocene and increased in the Lower Miocene. *P. arcuatus* was included in *Gigantopecten* by Waller (2006). Dijkstra and Beu (2018) mentioned that *P. arcuatus* was included in the genus *Gigantopecten* (Waller, 2006; Waller and Bongrain, 2006) and stated that it lived in the Atlantic and Indo-Pacific regions, generally forming colonies in the littoral zone and buried in soft ground with its convex right valve, and that it was distributed in the Oligocene-Early Miocene (Figure 9).

Genus: *Oopecten* Sacco, 1897b

Type species: *Pecten rotundatus* Lamarck, 1819 accepted as *Oopecten rotundatus* (Lamarck, 1819)

***Oopecten solarium* (Lamarck, 1819)**

Plate III, figure 9

1819 *Pecten solarium* Lamarck, t. 6, p. 179, no. 1.

2004 *Oopecten solarium* (Lamarck), Mandic, p. 140, fig. 5.7.

2024 *Oopecten solarium* (Lamarck), Bošnjak et al., p. 7, fig. 6(1-7).

Material: Hekimhan Aksütlü village, Akyar formation, Early Miocene, 44-AKS-6, MTA-AN-43

Description: It is distinguished from the *Gigantopecten arcuatus* species by its more rounded and flat shape. The round, large shell is very slightly convex, its surface is decorated with 14-16 thick radial ribs cut by very fine growth lines; the auricles are of equal size on both sides.

Dimensions: H: 5.3 cm, W: 5.4 cm, AL: 2 cm, UA: 130°

Remarks: Mandic (2004) cited that although the species *Oopecten solarium*, which he described in the early Badenian Grund Formation, exhibited distinctive features such as a rounded shell, wide umbonal angle, long and low auricles and flattened, well-spaced ribs, it was much confused in the literature. Bošnjak et al. (2024) stated that the species is characteristic in the Central Paratethys Badenian sediments and that it spread from the Burdigalian to the Messinian in the Mediterranean and the East Atlantic (Figure 9).

Order: Cardiida Férussac, 1822

Superfamily: Cardioidea Lamarck, 1809

Family: Cardiidae Lamarck, 1809

Subfamily: Orthocardiinae J. A. Schneider, 2002

Genus: *Lyrocardium* Meek, 1876

Type species: *Cardium lyratum* G. B. Sowerby II, 1840 accepted as *Lyrocardium lyratum* (G. B. Sowerby II, 1840)

***Lyrocardium cf. aquitanicum* (Mayer, 1858)**

Plate III, figure 10

1858 *Cardium aquitanicum* Mayer, t. 7, p. 89, pl. 4, fig. 9.

2019 *Lyrocardium aquitanicum* (Mayer), Lesport et al., p. 34, text-fig. 31, pl. 14, fig. 1-4.

Material: Hekimhan Aksütlü village, Akyar Formation, Early Miocene, 44-AKS-7, MTA-AN-44

Description: The sample is single and internal mold, however, the linule and corselet are quite distinct for diagnosis. The concentric growth lines are observed on the shell surface that cutting the slightly

radial ribs. Both valves are convex and the umbo is swollen.

Dimensions: H: 7.6 cm, W: 6.8 cm, UA: 90°

Remarks: Lesport et al. (2019) identified it in the Aquitanian in Landes and Gironde; they emphasized that the species, which they defined as *Lyrocardium aquitanicum*, was present in the Aquitanian and disappeared in the Burdigalian (Figure 9).

5. Isotope Analysis

In order to reveal paleoclimatological and paleoecological results, stable isotope ratios are evaluated. Isotope analysis best reveals the interaction between the ocean and the atmosphere. Most of the oxygen in the oceans consists of $\delta^{16}\text{O}$ isotope, $\delta^{18}\text{O}$ is in lesser amounts ($\delta^{16}\text{O}$ 98.8%, $\delta^{18}\text{O}$ 0.2%). However, as a result of evaporation that occurs with the increase in temperature, heavier ^{18}O remain, while the lighter $\delta^{16}\text{O}$ evaporates. This causes the $^{18}\text{O}/^{16}\text{O}$ ($^{18}\text{O}/^{16}\text{O}$ ratio expressed as $\delta^{18}\text{O}$ value) ratio in the water to increase. $\delta^{18}\text{O}$ is explained by the equation given below for each mil unit deviation from a certain standard (Boggs, 2012). VPDB standards were first used for oxygen isotopes, and VSMOW is generally used as a standard. In this study are used VPDB standard values for the analyses.

$$\delta^{18}\text{O} = \left\{ \left[\frac{(^{18}\text{O}/^{16}\text{O})_{\text{sample}}}{(^{18}\text{O}/^{16}\text{O})_{\text{standard}}} - 1 \right] \times 1000 \right\} \quad (1)$$

Stable carbon isotope assessments ($^{13}\text{C}/^{12}\text{C}$ ratio expressed as $\delta^{13}\text{C}$ value) are slightly different from oxygen assessments. Carbon isotopes in biogenic carbonates are complex but provide a rich source of information if they are well understood. $\delta^{13}\text{C}$ in the shell typically originates from the dissolved inorganic carbon value in the environment and is a few ‰ lower than this value. It has been determined that kinetic and metabolic factors affect $\delta^{13}\text{C}$ values, although they tend to decrease with age (McConnaughey, 2003; McConnaughey and Gillikin, 2008). Wurster and Patterson (2001) point out that while climatic data can be obtained from $\delta^{18}\text{O}$ values, tropic status, metabolic rate or reproductive system can be interpreted from $\delta^{13}\text{C}$ values.

Boggs (2012) states that the $\delta^{13}\text{C}$ value in marine carbonates reflects the $^{13}\text{C}/^{12}\text{C}$ ratio of dissolved CO_2 in ocean water, and that this ratio indicates the carbon source in CO_2 . He mentions that waters flowing from land to sea have low $^{13}\text{C}/^{12}\text{C}$ ratio and that $\delta^{13}\text{C}$ value is low in lake sediments. He states that $\delta^{13}\text{C}$ changes in oceans and marine organisms indicate changes in water masses and that this $\delta^{13}\text{C}$ value decreases in deep waters. He mentions that the increase in reproduction rates also affects $\delta^{13}\text{C}$ values and that $\delta^{13}\text{C}$ shows positive values with the removal of light carbon. Williams et al. (1988) also mentioned that the upper parts of the water in the euphotic zone are rich in $\delta^{13}\text{C}$. They mentioned that the $\delta^{18}\text{O}$ isotope records of the Cenozoic era are characterized by large changes in absolute values and that these are synchronous on a global scale.

Mollusc shells are recorders of environmental conditions because they are found in different environments and accumulate shell layers one after another. Isotopic data obtained from the shells contain a lot of information about the temperature, water quality, salinity and food potential of the time the animal lived (McConnaughey et al., 1997; Schöne and Surge, 2012). Bivalves, where absolute growth is largely dependent on environmental conditions, live in almost all types of marine environments and tend to grow their shells, which are made of calcium carbonate, more slowly than gastropods (Swan, 1952). The oxygen isotope composition $\delta^{18}\text{O}$ value in shell carbonates provides information about the ambient temperature due to the seawater in which the sedimentation occurred (Freitas et al., 2005).

Westerhold et al. (2020) presented carbon and oxygen isotope reference records of deep-sea benthic foraminifera covering the entire Cenozoic period. In detailed examinations, they determined four different climate conditions for the past 66 million years: *Hothouse*, *Warmhouse*, *Coolhouse*, *Icehouse*. Characteristic features of the four climate states were inferred from $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ isotope data and atmospheric CO_2 concentration estimates. Accordingly, *Hothouse* and *Warmhouse* were effective from the Cretaceous/Paleogene (K/Pg, 66 Ma) boundary to the Eocene-Oligocene (EOT, 34 Ma) transition. In the *Warmhouse* state, global temperature is 5°C higher

Bivalvia		References	Western Europe/ East Atlantic			Central Europe/ Central Paratethys			Mediterranean Basin			Eastern Paratethys			Northern Africa			North America			SW of Asia Arabian Peninsula			Türkiye			Malaya Basin						
			O	E	M	L	P	O	E	M	L	P	O	E	M	L	P	O	E	M	L	P	O	E	M	L	P	O	E	M	L	P	
1	<i>Anadara cf. aquitanica</i> (Mayer, 1861)	Monpéroux, 1831; Mayer, 1861; Buequoy et al., 1882; Sacco, 1898; Cossmann and Peyrot, 1914; Schenck and Remmert, 1938; Esu et al., 2005; Esu and Grotti, 2010; Michel et al., 2012; Gürsoy, 2017	X	X	X	X	X	X	X	X	X						X																X
2	<i>Osrea crassicastrata</i> Sowerby in Smith, 1847	Sowerby in Smith, 1847; Rolle, 1861; Hoernes, 1870; Brive, 1894; Böckh, 1899; Da Costa et al., 1903; Newton, 1911; Stefanni, 1921; Schöpfinsky, 1939, 1946; Kökay, 1996; De Bortoli and Hladilová, 2014, 2015	X	X	X	X	X	X	X	X	X						X	X	X	X												X	
3	<i>Crassostrea gryphoides</i> (Schlothheim, 1813)	Knorr and Walch, 1768; Schlothheim, 1813; Lamarck, 1819; Hoernes, 1870; Sacco, 1897 <i>a</i> ; Cossmann and Peyrot, 1914; Dollfuss and Dautzenberg, 1920; Friedberg, 1936; Schöpfinsky, 1939; Gilbert, 1945; Čespeřnýne-Meznerics, 1953; Erthal-Erentöz, 1958; Pfister and Wegmüller, 1998; Georgiades-Dikeoulia et al., 2000; Schultz, 2001; İslamoğlu and Taner, 2003; Lozouet et al., 2003; El-Hedeny, 2005; Högör, 2008; Hosseinpour and Dastanpour, 2013; De Bortoli and Hladilová, 2015; El-Sabbagh and El-Hedeny, 2016; Harzhauser et al., 2016																															
4	<i>Hvotissa hvotis</i> (Linnaeus, 1758)	Deshayes, 1835; De Serres, 1843; Rautin and Delbos, 1855; Hoernes, 1870; Fuchs, 1879, 1883; Ranson, 1941, 1943; Mongin, 1952; Erthal-Erentöz, 1958; Wedding, 1965; De Castro-Coppa, 1972; Freuix et al., 1988; Bellmann, 1994; Studenska et al., 1998; De Bortoli and Hladilová, 2015; Binder, 2015	X	X	X		X	X	X	X	X						X	X	X													X	
5	<i>Hvotissa undata</i> (Born, 1778)	Linnaeus, 1758; Lamarck, 1819; Mayer, 1858; Reeve and Sowerby, 1873; Cossmann and Peyrot, 1914; Sacy, 1929; Gilbert and Van de Poel, 1965; Lozouet et al., 2003; Michel et al., 2012; Londeix, 2014	X																													X	
6	<i>Gigantopecten arcuatus</i> (Brocchi, 1814)	Brocchi, 1814; Lamarck, 1836; Fuchs, 1870; De Gregorio, 1894; Sacco, 1897 <i>b</i> ; Oppenheim, 1900; Bousiac, 1911; Cossmann, 1921; Flandrin, 1938; Baldi, 1973; Roger and Demarcq, 1974; Baghioni-Mavros et al., 1986; Bongrain, 1988; Waller and Bongrain, 2006	X	X			X	X		X	X						X	X														X	
7	<i>Oopecten solarium</i> (Lamarck, 1819)	Lamarck, 1819; Sacco, 1897 <i>b</i> ; Dollfuss and Dautzenberg, 1920; Friedberg, 1936; Erenitöz-Erthal, 1958; Mandic, 2004; Bošnjak et al., 2024	X	X			X	X	X								X	X	X													X	
8	<i>Lyrocardium cf. aquitanicum</i> (Mayer, 1858)	Mayer, 1858; Sacco, 1899; Cerulli-Irelli, 1908; Cossmann and Peyrot, 1912; Gilbert and Van de Poel, 1970; Lesport et al., 2019	X																													X	

Figure 9- Paleogeographic and stratigraphic distributions of identified species from Aksütli locality (O: Oligocene, EM: Early Miocene, MM: Middle Miocene, LM: Late Miocene, P: Pliocene).

than today's values. The *Hothouse* state corresponds to the Paleocene-Eocene Thermal Maximum (PETM, 56 Ma) and the early Eocene Climatic Optimum (EECO, 47 Ma) and the temperature is 10°C higher than today's values. After the *Warmhouse* state in the Eocene Thermal Optimum (EOT, 34 Ma), the *Coolhouse* state is passed with a gradual and large decrease in temperatures. Large ice sheets appear, creating a monopolar ice sheet in Antarctica, and there is a large increase in continental ice volume. The *Coolhouse* state extends from 34 Ma to 3.3 Ma (mid-Pliocene glacial period) and is divided into two stages, marked by an increase in $\delta^{18}\text{O}$ during the Mid-Miocene Climatic Transition (MMCT). Extremely warm conditions culminating in the Miocene Climatic Optimum (MCO, 17-14 Ma) characterize the first phase, followed by a cooling period and then a second warming phase with an increase in $\delta^{18}\text{O}$. The major change in carbon and oxygen isotope values occurs during the Pliocene. The *Icehouse* state, driven by the emergence of increasing and decreasing ice sheets in the Northern Hemisphere, is fully established during the Pliocene-Pleistocene transition (~3.3 Ma).

Steinthorsdottir et al. (2021a) state that in order to improve the predictions of anthropogenic climate change, it is necessary to have a good knowledge of past climate change events, especially the Middle Miocene Climatic Optimum (MCO), a period of pronounced transient global warming. They pointed out that climatic conditions during the Miocene (23-5 Ma) can be compared to current and near-future conditions because the continental locations and fauna-flora communities are approximately similar to those of today. Steinthorsdottir et al. (2021b) stated that global temperature increased during the Miocene period. They mentioned the existence of the Miocene Climatic Optimum (MCO, ~16.9-14.7 my), which was a warm period of approximately 2 million years, limited by the Early and Late glaciations. They stated that studies on the Miocene and especially the MCO would shed light on present-day climate studies. They emphasized that during the Miocene, including the MCO, most isotope records and CO_2 values were close to or slightly higher than present-day values, while a large number of terrestrial and marine data

indicate an unprecedented global temperature. Studies have shown that the Early-Middle Miocene Climatic Optimum (MCO, ~16.9-14.7 Ma) is the youngest of several warm periods of extremely high temperatures superimposed on a long-term cooling pattern throughout the Cenozoic.

Wilkin (2021), specified that oxygen isotopes can be used to measure past ocean temperatures and carbon isotopes can be used to construct food webs. He emphasizes that oxygen isotope data are more commonly used in temperature calculations using the Anderson and Arthur (1983) and Sharp (2007) equations. He notes that there are limitations to using oxygen isotopes as a method for measuring temperatures over geological time. However, he recommends that before interpreting oxygen isotope data for climatic changes, a number of processes must be considered, such as fractionation at the atmosphere and during crystallization, changes in the original isotopic composition of water, biological fractionation, and diagenesis.

The application made here was carried out for the first time with a small number of samples and is a preliminary study. The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ isotope results and calculations for the four *Ostrea* fossils and sediment samples selected for analysis are given in the table below. The 1σ error margins for the isotope ratios ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) do not exceed 0.2 ‰. The results are close to each other, but $\delta^{13}\text{C}$ varies between -1.4 and -1.8, and $\delta^{18}\text{O}$ varies between -6.3 and -6.8. The results from the sediment analysis are, $\delta^{13}\text{C}$ -2.5 and $\delta^{18}\text{O}$ -6.6 (Table 1).

In the calculations, temperature reckonings were made in three separate formulas using the “NBS19 limestone (NIST)” standard values ($\delta^{13}\text{C}$: 1.95‰, $\delta^{18}\text{O}$: 2.20‰):

1. Shackleton (1967) $T = 16.9 - 4.38 (\delta^{18}\text{O}_c - \delta^{18}\text{O}_{sw}) + 0.10 (\delta^{18}\text{O}_c - \delta^{18}\text{O}_{sw})^2$
2. Anderson and Arthur (1983) $T = 16.4 - 1.14 (\delta^{18}\text{O}_c - \delta^{18}\text{O}_{sw}) + 0.13 (\delta^{18}\text{O}_c - \delta^{18}\text{O}_{sw})^2$
3. Sharp (2007) $T = 15.75 - 4.3 (\delta^{18}\text{O}_c - \delta^{18}\text{O}_{sw}) + 0.14 (\delta^{18}\text{O}_c - \delta^{18}\text{O}_{sw})^2$

Table 1- Isotope results and temperature calculations from Aksütlü locality (F: Fossil samples; S: Sediment samples).

Samples No	$\delta^{13}\text{C}$ (‰)	Average $\delta^{13}\text{C}$ (‰)	$\delta^{18}\text{O}$ (‰)	Average $\delta^{18}\text{O}$ (‰)	Temperature (T°C) $\delta^{18}\text{O}$ Shackleton (1967)	Temperature (T°C) $\delta^{18}\text{O}$ Anderson and Arthur (1983)	Temperature (T°C) $\delta^{18}\text{O}$ Sharp (2007)
44-1F	-1.43		-6.83		39.32	37.95	38.66
44-2F	-1.57		-6.66		38.42	37.05	37.71
44-3F	-1.77	-1.73	-6.70	-6.61	38.64	37.26	37.94
44-4F	-1.42		-6.27		36.38	35.00	35.57
44-5S	-2.48		-6.57		37.95	36.57	37.21

Calculations performed with different formulas showed parallel results. Temperature values range from a minimum of 35°C to a maximum of 39°C. The results are shown to be close to the shallow warm water coral zone when we plot $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values on the Milliman (1974) marine carbonate diagram (Figure 10). Very low $\delta^{18}\text{O}$ values reflect warm climate conditions (Zachos et al., 2001). Hamon et al. (2013) in their studies on early diagenesis in meteoric and brackish water environments, reached the low oxygen isotope results similar to the results in the Aksütlü region. Xiaofeng et al. (2023) mentioned that the diagenetic environment of the carbonate rocks is the sum of various environmental factors such as salinity, temperature and chemical properties. When we evaluate the oxygen and carbonate isotope values in the Xiaofeng et al. (2023) diagram, medium to deep burial and hydrothermal effective environmental conditions are reached (Figure 11).

The obtained results and field observations lead to the conclusion that the sedimentation in the area examined in Aksütlü was in a shallow sea with warm, heavy rainfall and brackish water conditions during the Early Miocene (late Aquitanian-Burdigalian).

6. Conclusion

With this study carried out in Malatya Aksütlü locality, eight bivalve species were systematically studied for the first time and added to General Directorate of Mineral Research and Exploration Museum inventory. According to the taxonomic identifications of bivalves made using Bieler, Carter and Coan *in* Bouchet and Rocroi (2010) Systematics the age of Akyar Formation is Early Miocene (Figure 12).

The estimated study area is shown on the Early Miocene Paleogeographic Map of Popov et al. (2004) (Figure 13). When the studies of Rögl (1998, 1999), Steininger and Wessely (2000), Popov et al. (2004) and Sun et al. (2021) on the Early Miocene Paratethys and Neotethys maps are examined, it is seen that the study area is located in the area between Paratethys and Neotethys.

In environmental interpretations, the ecological conditions of the fauna and especially the species *O. crassicostata* that forms the abundance zone were taken into consideration. Ostreids are reef-forming bivalves that live in brackish water conditions in coastal, estuary or lagoon environments. They tend to accumulate in environments where there is a nutrient flow from land (Gürsoy and Görmüş, 2020). In marly soft ground, adhesion is in the form of individuals growing on top of each other. Individuals growing on top of each other have formed distinct horizons within the stack. In field observations, the proportion of individuals with double valves together and parallel to the layer plane is low. Generally, the valves are separated and in a lateral position. This indicates environmental conditions where energy is high. The resistance of ostreids to physical conditions resulted in their forming the dominant population in the environment. Ostreid accumulations, repeated several times upwards in the sequence, have formed due to occasional shallowing. The large size and abundance of the dominant species lead to the assumption that nutrient flow was suitable.

As explained in detail in the Isotope Analysis section, the Miocene period was a time when global warming occurred and the temperatures known as the Miocene Climatic Optimum (MCO, 16.9-14.7 my)

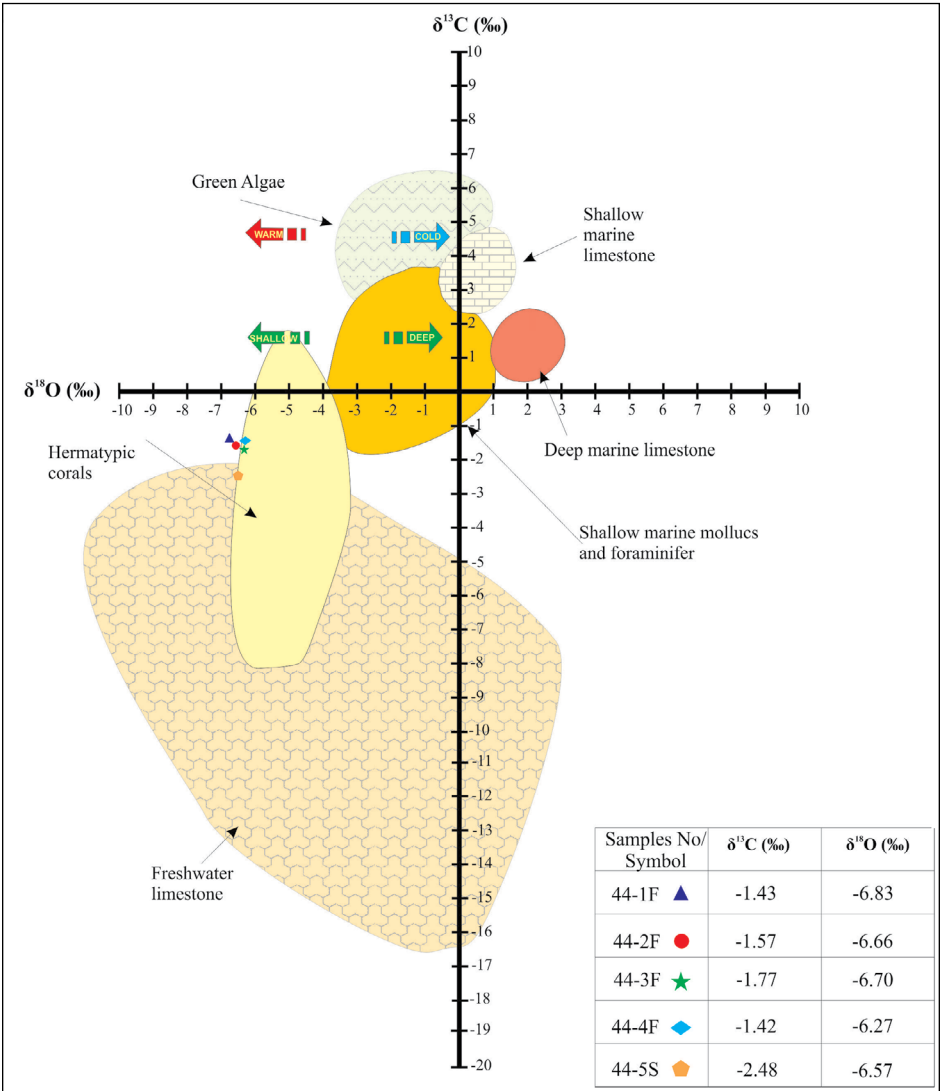


Figure 10- Comparison of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ isotope results according to the types of marine carbonates drawn by Milliman (1974) (edited from Boggs, 2012).

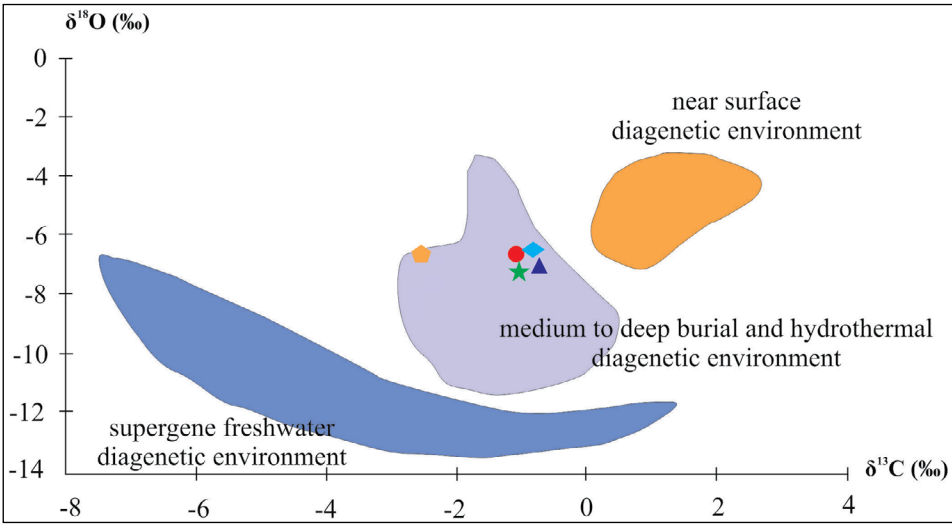


Figure 11- Intersection diagram of carbonate rock values of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ (edited from Xiaofeng et al., 2023).

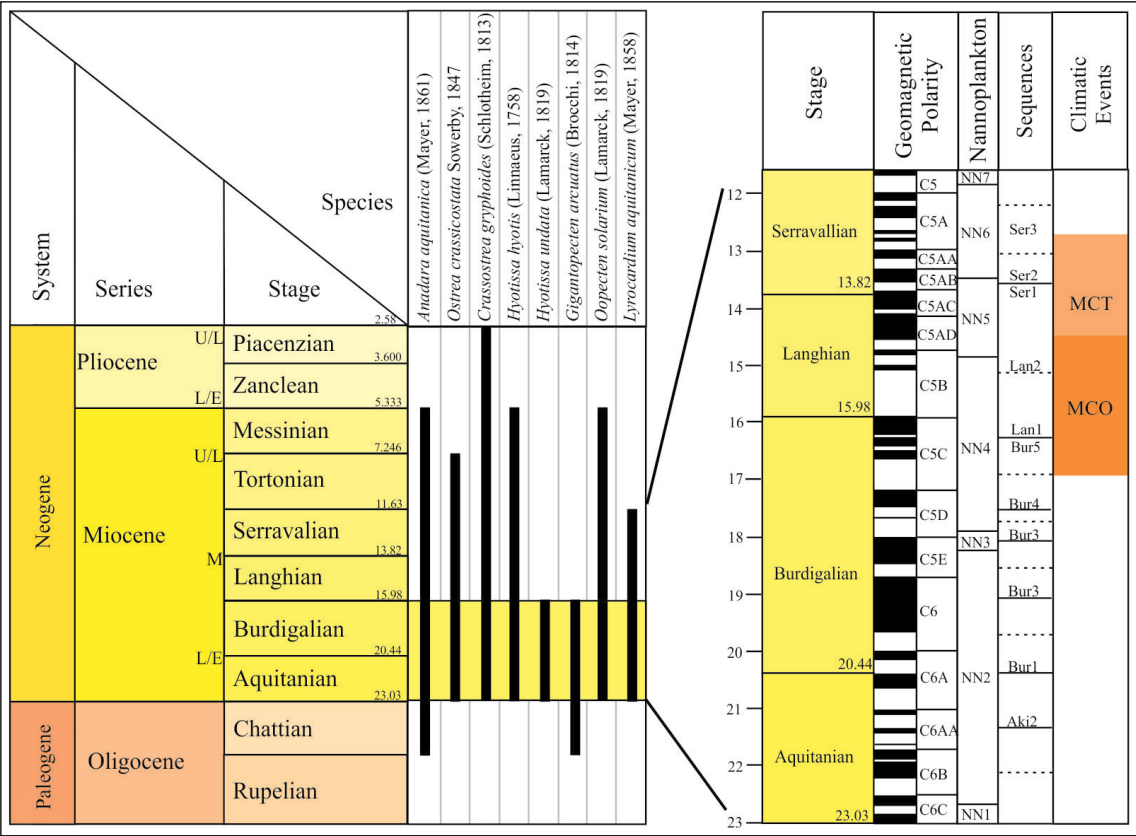


Figure 12- a) Stratigraphic distributions of species identified in Aksütü locality, b) Stratigraphic table showing global climate changes (edited from Hilgen et al., 2012, Steinthorsdottir et al., 2021a and Vernyhorova et al., 2023).

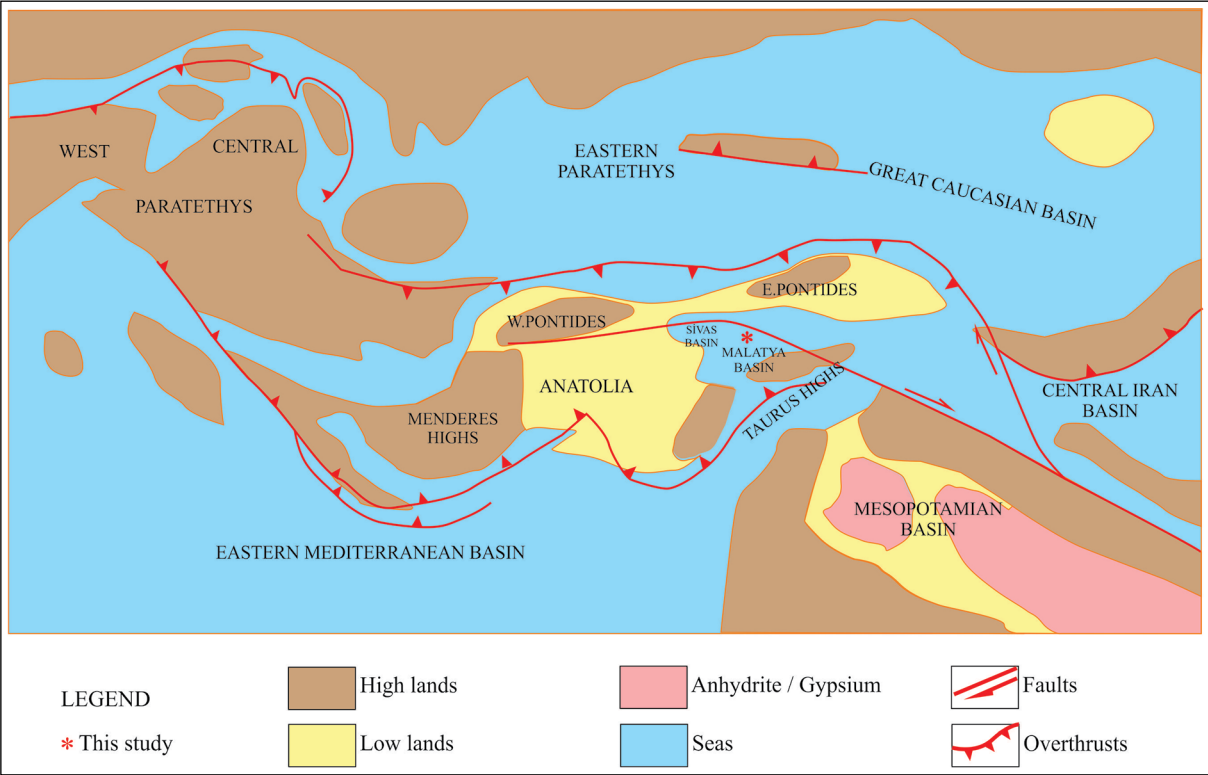


Figure 13- Estimated study area on the Early Miocene Paleogeographic map (edited from Popov et al., 2004).

increased by approximately 10°C worldwide. Within this study, records of the temperature corresponding to the Early Miocene period in the region were revealed for the first time. Carbon and oxygen isotope analysis were performed on samples of *Ostrea crassicostata* forming the abundance zone and the sediment. The average temperature value obtained is 37°C and is close to the MCO temperature values. However, isotope values were affected by the burial depth and diagenetic conditions. Field observations, paleontological and isotope data indicate that the Akyar Formation was deposited in a high-energy, hydrothermal influence, warm shallow marine environment during the Early Miocene.

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PLATE EXPLANATIONS

Plate I

1, 2 *Anadara* cf. *aquitana* (Mayer, 1861)

3 *Ostrea crassicostata* Sowerby in Smith, 1847 – right (upper) valve – a: ventral, b: dorsal, c: lateral views

4, 5, 6 *Ostrea crassicostata* Sowerby in Smith, 1847 – left (lower) valve – a: ventral, b: dorsal, c: lateral views

Scales=1 cm

PLATE I

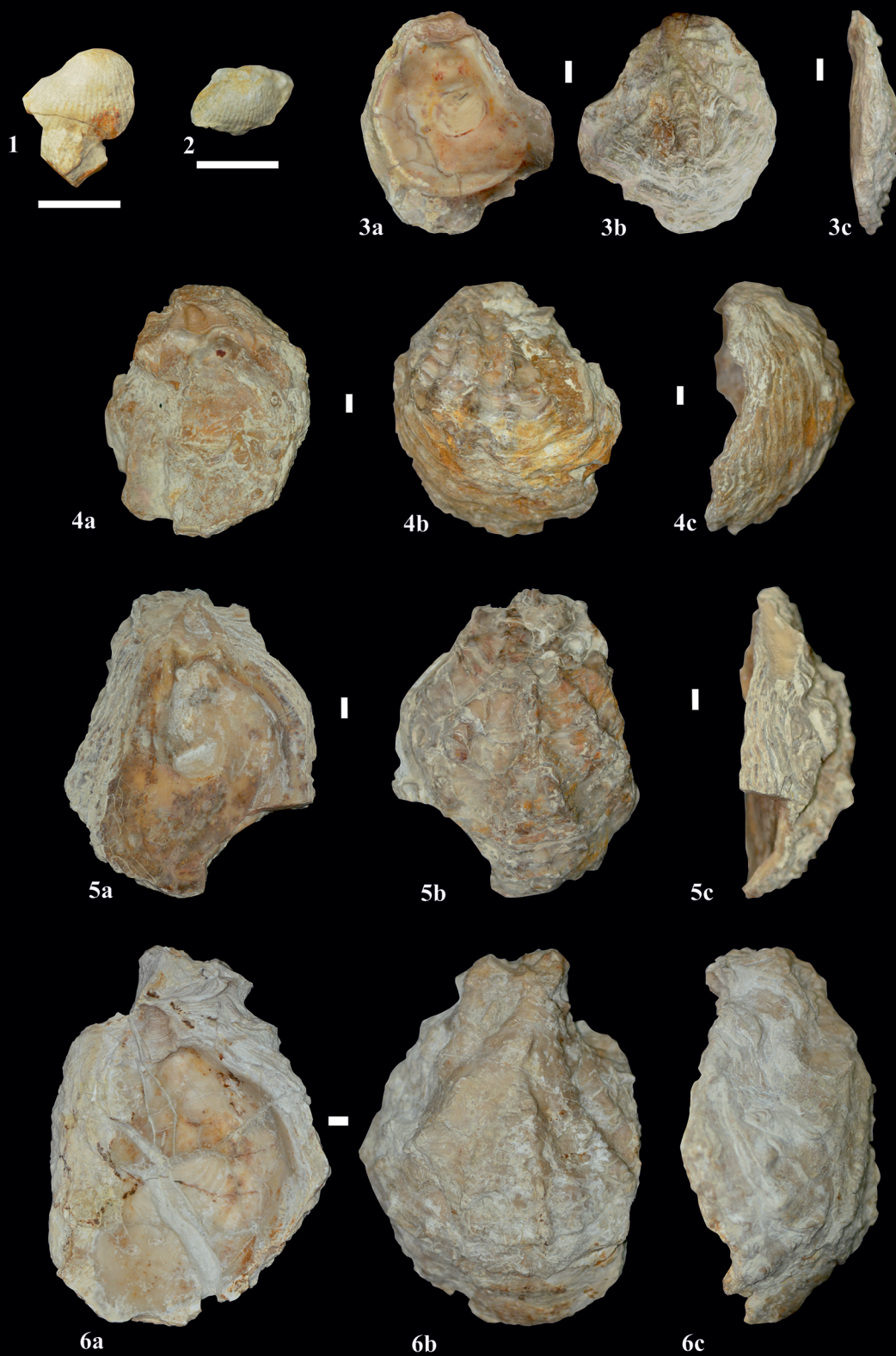


Plate II

1 *Crassostrea gryphoides* (Schlotheim, 1813) – left and right valves – a: umbonal view, b: lateral view, c: dorsal view of the left valve, d: dorsal view of the right valve

2 *Crassostrea gryphoides* (Schlotheim, 1813) – right (upper) valve – a: ventral, b: dorsal, c: lateral views

3 *Crassostrea gryphoides* (Schlotheim, 1813) – left (lower) valve – a: lateral view of the anterior side, b: lateral view of the posterior side, c: ventral, d: dorsal views

Scales=1 cm

PLATE II

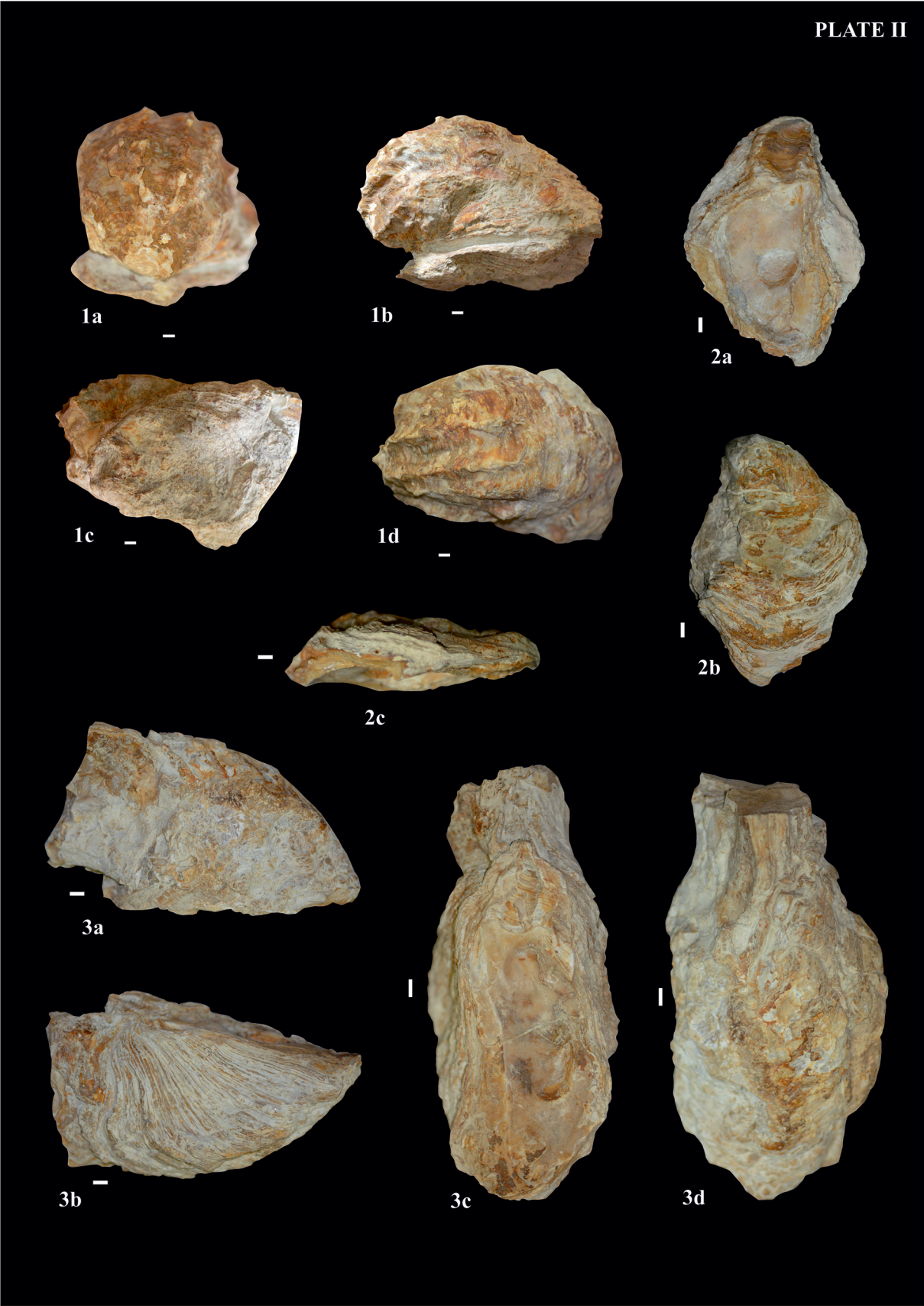


Plate III

- 1 *Hyotissa hyotis* (Linnaeus, 1758) – left (lower) valve – a: ventral, b: dorsal views
- 2 *Hyotissa hyotis* (Linnaeus, 1758) – right (upper) valve – a: ventral, b: dorsal views
- 3 *Hyotissa hyotis* (Linnaeus, 1758) – left (lower) valve – a: dorsal, b: ventral views
- 4 *Hyotissa undata* (Born, 1778) – right (lower) valve – a: dorsal, b: ventral views
- 5 *Hyotissa undata* (Born, 1778) – left (upper) valve – a: ventral, b: dorsal views
- 6, 7, *Gigantopecten arcuatus* (Brocchi, 1814) – a: dorsal, b: lateral views
- 8 *Gigantopecten arcuatus* (Brocchi, 1814) – dorsal view
- 9 *Oopecten solarium* (Lamarck, 1819) – a: dorsal, b: lateral views
- 10 *Lyrocardium* cf. *aquitanicum* (Mayer, 1858) – a: umbonal view, b, c: dorsal views

PLATE III

