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Stratigraphy and palaeoceanography of late Pleistocene molluscs from the northern coast of the Persian Gulf

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We report an extraordinary discovery of marine Pleistocene strata from the north of the Persian Gulf. The Dayyer section contains a rich molluscan fauna including 26 bivalve species, Sr^{87}/Sr^{86} data showing that the succession is not older than 153 ka (late Pleistocene). These strata are time-equivalents of the Bakhtiari Formation, but have a very different fossil content and facies. Comparing the Dayyer molluscan community to the present-day fauna of the Persian Gulf shows that many fossil species are absent in the recent waters. The palaeoceanographic distribution of the identified bivalves shows the presence of many of them in the Plio-Pleistocene strata of the Mediterranean Basin. This may point to a temporary connection between the Persian Gulf and Mediterranean Basin during the late Pleistocene and the extinction of many bivalves in the past 153 ka.

Key words: Pleistocene, Persian Gulf, Dayyer section, molluscs, palaeogeography.

INTRODUCTION

Quaternary researches in the southwestern Asia are restricted to a few studies describing the sedimentology and lithostratigraphy of some outcrops on the Arabian Peninsula (Uchupi et al., 1996, 2002; Williams and Walkden, 2002; Kirkham and Evans, 2008, 2020; Evans, 2011). Other research has focused on the sea level changes during the Holocene (Lambeck, 1996; Stevens et al., 2014; Lokier et al., 2015). Bailey et al. (2007) studied the Late Quaternary stratigraphy and sea level changes of the Red Sea and adjacent areas (including the Persian Gulf). Kennett and Kennett (2006) and Sheikhly et al. (2017) noted the impact of Persian Gulf shoreline fluctuations on the configuration of Mesopotamian cultures in the late Pleistocene – Holocene time interval. Some individual papers have analysed late Pleistocene to Holocene sea level change in the northern part of the Persian Gulf (Taghizadeh et al., 2012; Lak, 2014; Rezaee and Zarezadeh, 2014).

The Pleistocene strata of the Zagros area are included in the Bakhtiari Formation. The type section of the Bakhtiari Formation was described by James and Wynd (1965) from the Godar Landar valley, north of the Masjed-Soleiman area, south-west Iran. It is composed of 550 m of massive hard conglomerates and is exposed across all of Zagros.

Besides some general lithostratigraphical and sedimentological studies on the Pleistocene of the High Zagros and the Zagros Folded Zone by James and Wynd (1965) and Motiei (1993), there is no published evidence concerning these strata along the southern Iranian coast. However, the strata equivalent to the Bakhtiari Formation in the Iranian coastal belt lithologically are different from those of the type section. So, these Pleistocene marine strata of the northern margin of the Persian Gulf are studied here, their molluscan fauna being studied in detail for the first time. Notably, there are many differences between the fossil and living faunas of the study area, that encouraged us to survey the palaeoceanographic distribution and possible migration path of the component species.

MATERIAL AND METHODS

All data and samples of this study were collected in two field trips, in the winter of 2018 and autumn of 2019. Samples are collected from seven prolific beds (A1–7). The mollusc samples were analysed in the laboratory of palaeontology, University of Hormozgan. After water-washing the specimens, we used a slender frez machine with rough to soft augers in order to re-

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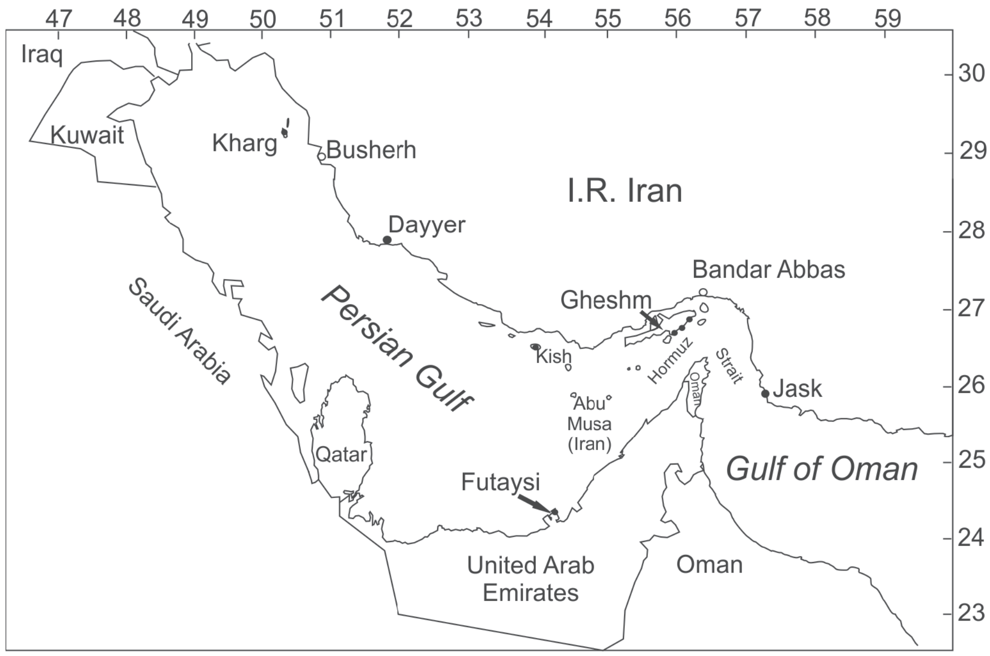

Fig. 1. Location of the Dayyer section and the other sites in the south of Iran and United Arabian Emirates

Sites of the Quaternary strata outcrops are shown by black dots. The Kharg, Gheshm and Futaysi sections were studied by Motiei (1993), Rezaee and Zarezadeh (2014) and Kirkham and Evans (2008, 2020), respectively

move rock particles from the specimen surfaces. All specimens are deposited in the Department of Geology, Faculty of Sciences, University of Hormozgan under the repository codes HUIM194 to HUIM226. We could not extract some of specimens from the hard matrix, so these remained in the field.

GEOGRAPHIC AND GEOLOGICAL SETTINGS

The studied section is located near Dayyer Port, 180 km south-east of the Bushehr Province capital, in southern Iran (Fig. 1). This section, 23.55 m thick in total, includes two parts: the lower part A (17.45 m thick) is located just to the ring-road of Dayyer city at 27°50'34.58" N, 51°55'7.25" E. and the upper part B (6 m thick) 2.8 km west of Dayyer town, near Oli village at 27°50'2.69"N, 51°53'51.66" E.

The Persian Gulf is a narrow foreland shallow sea between the Zagros belt and the Arabian platform (Purser, 1973). The Neogene geological history of the Persian Gulf shows that the northern margin of this basin has mostly marked by the arrival and deposition of huge amounts of terrigenous sediments. These deposits are known as the Fars Group (Gachsaran, Mishan and Aghajari formations), deposited during Miocene–Pliocene time.

The sedimentary characteristics of the Aghajari Formation, the youngest member of the Fars Group, show gradual change from carbonate to clastic deposits (Sahraeyan et al., 2013; Hassani and Hosseinipour, 2017). This facies shift indicates that marine regression started from the late Miocene and continued at least to the end of the Neogene. Deposition of the Bakhtiari Formation conglomerates shows that regression continued during the Pleistocene as a result of the post-collisional orogenic environment (Kalantari, 1992; Motiei, 1993; Fakhari, 1994a). This non-marine conglomeratic facies of the Bakhtiari Formation can be seen in the High Zagros and Folded Zagros belts, but another lithofacies is exposed along the northern coasts of the Persian Gulf and on some islands (e.g., Kharg and Gheshm; Fig. 1). The latter lithofacies is mostly composed of fossiliferous limestones and sandstones with a few conglomerate beds. The heterogeneous lithology of the Bakhtiari Formation from the north to the south of the Zagros during the main marine regression may be related to the different palaeogeographic settings of the southernmost part of the Zagros area. In general, lithology and field observations suggest that the Bakhtiari Formation (in the south of Zagros) was deposited in a marine environment; that completely differs from that represented by this formation in the other parts of Zagros. Our research deals with the stratigraphic settings of the shell beds, that contain molluscs (mainly bivalves), which can help us to understand the palaeoceanography and evolution of the studied area.

Kalantari (1992) and Motiei (1993), based on its stratigraphic position, assumed a Pleistocene age for the Bakhtiari Formation. Rahiminejad et al. (2011) and Amiri-Bakhtiar and Noorani-Nejad (2013), based on the presence of some fossils (especially foraminifers) in the middle part of this formation inferred the range of late Oligocene to Pliocene. As erosion of the Eocene to Pliocene strata in the nearshore areas and coasts of the northern margin of the Persian Gulf is now commonly in progress, reworked fossils of many extinct foraminifer genera can easily be found in the recent coastal and marine deposits. Therefore, a similar phenomenon may be responsible of the presence of reworked Oligocene–Pliocene foraminifers in the Pleistocene Bakhtiari Formation. On the other hand, based on earlier researches (e.g., Kalantari, 1992; Vega et al., 2010, 2012; Kroh et al., 2011; Daneshian et al., 2012; Hosseinipour et al., 2014; Gholamalian et al., 2016, 2020; Hassani and Hosseinipour, 2017) the precise age of the underlying Fars Group (especially the Mishan and Aghajari formations) is early Miocene to late Pliocene; so it seems that the Bakhtiari Formation cannot be older than Pleistocene.

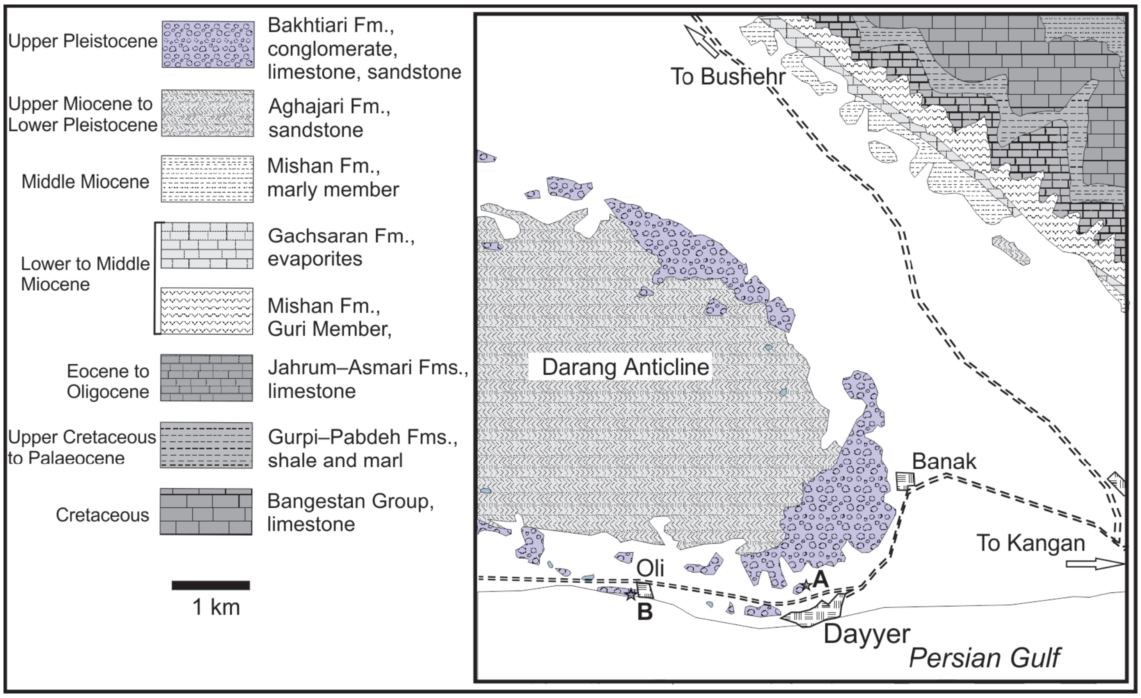

Fig. 2. Geological map of the Dayyer area (redrawn from Fakhari, 1994b)

A and B are locations of the lower and upper parts of the studied section

The studied area in the south of Zagros is a part of the Coastal Fars Zone. Very large anticlines with a NW–SE trend are the most important geological structure of this area. The studied section is located on the southeastern flank of the Darang anticline. Upper Cretaceous to Quaternary deposits are exposed in this anticline (Fig. 2).

As noted above, the studied strata are time-equivalent to the Bakhtiari conglomerate Formation. The studied strata in the Dayyer area disconformably overlie the upper Miocene–Pliocene marine sandstones of the Aghajari Formation indicating the gap of early to middle Pleistocene interval (Fig. 3A).

The studied section includes 14 units with a total thickness of 23.55 m (Figs. 3 and 4). The top of section is conformably overlain by recent coastal marine deposits (Fig. 4).

MALACOFAUNA

26 bivalve species belonging to 23 genera were collected from the Dayyer section. These species are: *Arca imbricata* Poli, 1795, *Arca plicata* (Dillwyn, 1817), *Anadara pectinata* (Brocci, 1814), *Pecten jacobeaus* (Linnaeus, 1758), *Flabellipecten flabelliformis* (Brocci, 1814), *Flabellipecten costisulcatus* (Almera and Bofill, 1897), *Chlamys ruschenbergerii* (Tryon, 1869), *Spondylus exilis* Sowerby, 1895, *Spondylus crassicosta* Lamarck, 1819, *Crassostrea* sp., *Lopha virleti* (Cox, 1936), *Alectryonella plicatula* (Gmelin, 1791), *Pinna rudis* Linnaeus, 1758, *Isognomon* sp., *Chama pacifica* Broderip, 1835, *Pinctada radiata* (Leach, 1814), *Placuna placenta* (Linnaeus, 1758), *Venus* cf. *verrucosa* Linnaeus, 1758, *Dosinia acetabulum* (Conrad, 1832), *Circentia callipyga* (Born, 1778), *Callista umbonella* (Lamarck, 1818), *Lithophaga avitensis* (Mayer-Eymar, 1898), *?Lutraria* sp., *Trachycardium flexicostatum* Vokes, 1989, *Cardites bicolor* (Lamarck, 1819), and *Tucetona* sp. (Figs. 5–7).

In addition, seven gastropod species were also identified; *Conus textile* Linnaeus, 1758, *Pleuroploca* sp., *Cerithium columna* Sowerby, 1834, *Turritella fultoni* Melvill, 1897, *Oliva bulbosa* Röding, 1798, *Cypraea* sp. and *Natica* sp.

Age determination of the section studied section is based on Sr^{87}/Sr^{86} analysis by an Isoprim Isotope Ratio Mass Spectrometer instrument in the Central Laboratory of the University of Hormozgan, Iran. Two mollusc shells (*Conus textile* and *Pecten jacobeaus* from beds A1 and A5 respectively) were analysed (see Fig. 4 for sample locations). The Sr^{87}/Sr^{86} data obtained ranges from 0.709183 to 0.709201; by plotting our data on the curves of Burke et al. (1982) and McArthur et al. (2001), the studied section is dated 153 ka (upper Pleistocene).

DISCUSSION AND PALAEOGEOGRAPHY

Motiei (1993) first reported Quaternary fossiliferous strata from Kharg Island, 220 km north-west of the Dayyer section. Rezaee and Zarezadeh (2014) also studied the sedimentary environments of similar strata in coastal exposures on Gheshm Island. Sharoonizadeh and Afghah (2017) studied the general stratigraphy of these beds on Gheshm and Kish islands. None of these studies provided detailed palaeontological evidence.

On the southern margin of the Persian Gulf, the Fuwayrit Formation with the lower conglomeratic Futaysi Member and the Dabbiya Member fossiliferous limestones in the United Arabian Emirates and Qatar (Kirkham and Evans, 2008, 2020) may be equivalent to the studied succession. Unfortunately, there is no available palaeontological data from these strata. Shneider et al. (2005) and Yilmaz et al. (2020) described Pleistocene fossiliferous conglomerates (Marmara and Sungur formations) in NW and SW Turkey that may correlate with the strata studied here (Fig. 8).

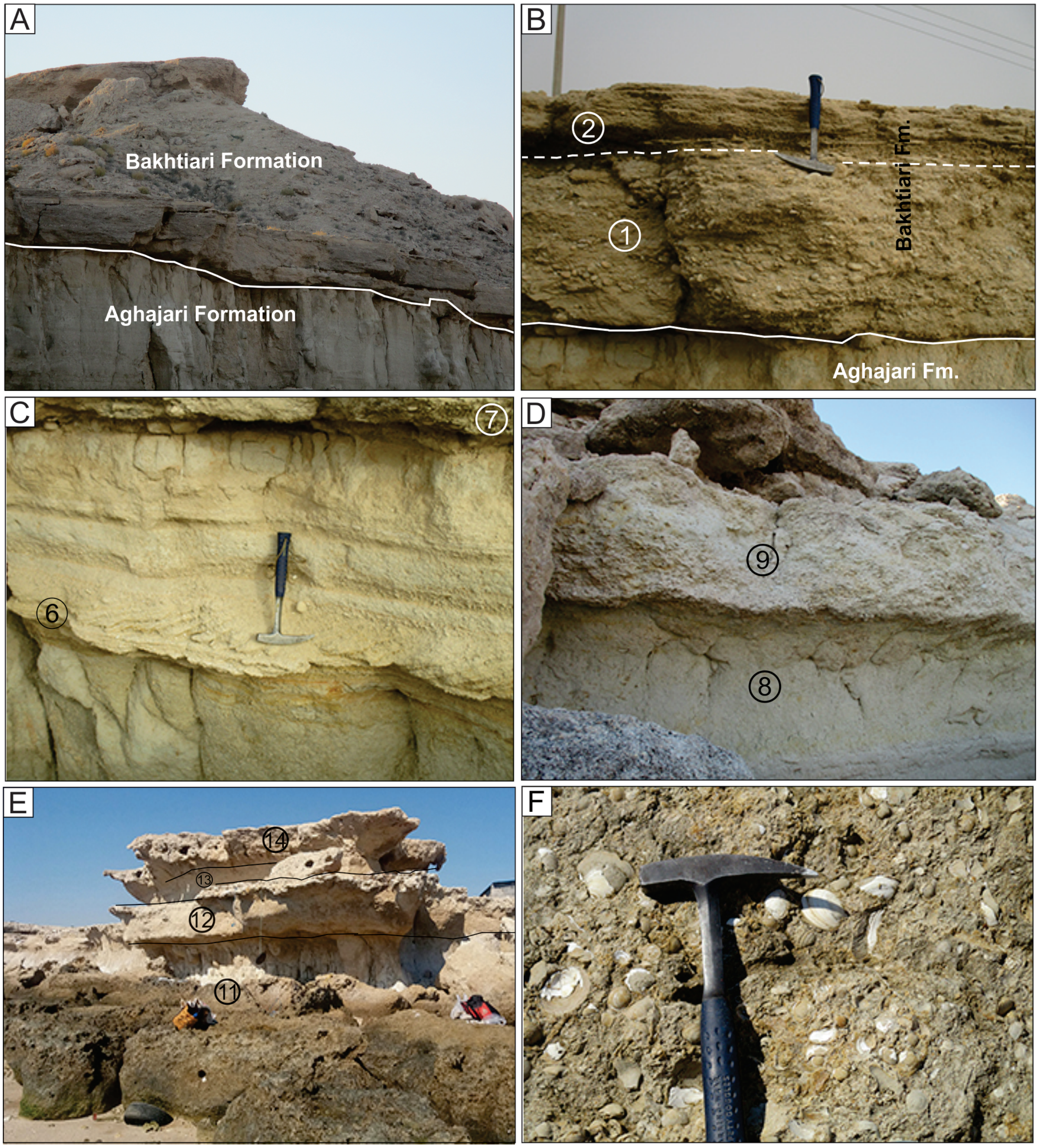

Fig. 3. Field photos of parts A and B of the Dayyer section

A – general view of part A, lower part of the Bakhtiari Formation; white line shows the disconformity between the Aghajari and Bakhtiari formations; **B** – units 1 and 2 of the Bakhtiari Formation in part A; **C** – sandstones of unit 6 and thin conglomerate bed (unit 7); **D** – fossiliferous units 8 and 9; **E** – general view of part B, upper part of Bakhtiari Formation, with marked units 11 to 14; **F** – abundant veneroid shells of *Dosinia acetabulum* in the basal part of unit 11

Molluscs from the present-day Persian Gulf include 203 extant bivalve species belonging to 142 genera (Hossein-Zadeh Sahafi et al., 2001; Amini Yekta et al., 2012, 2014); though only 13 of these species have been reported from Pleistocene strata. This means that only 13 out of 26 fossil bivalve species identified from the studied strata now are living in the Persian Gulf waters. These data show the dissimilarity of the fossil collected fauna to the modern fauna.

Thirteen species are absent in the modern fauna of the Persian Gulf: *Pecten jacobeaus* (Linnaeus, 1758), *Flabellipecten flabelliformis* (Brocci, 1814), *Flabellipecten costisulcatus* (Almera and Bofill, 1897), *Lopha virleti* (Cox, 1936),

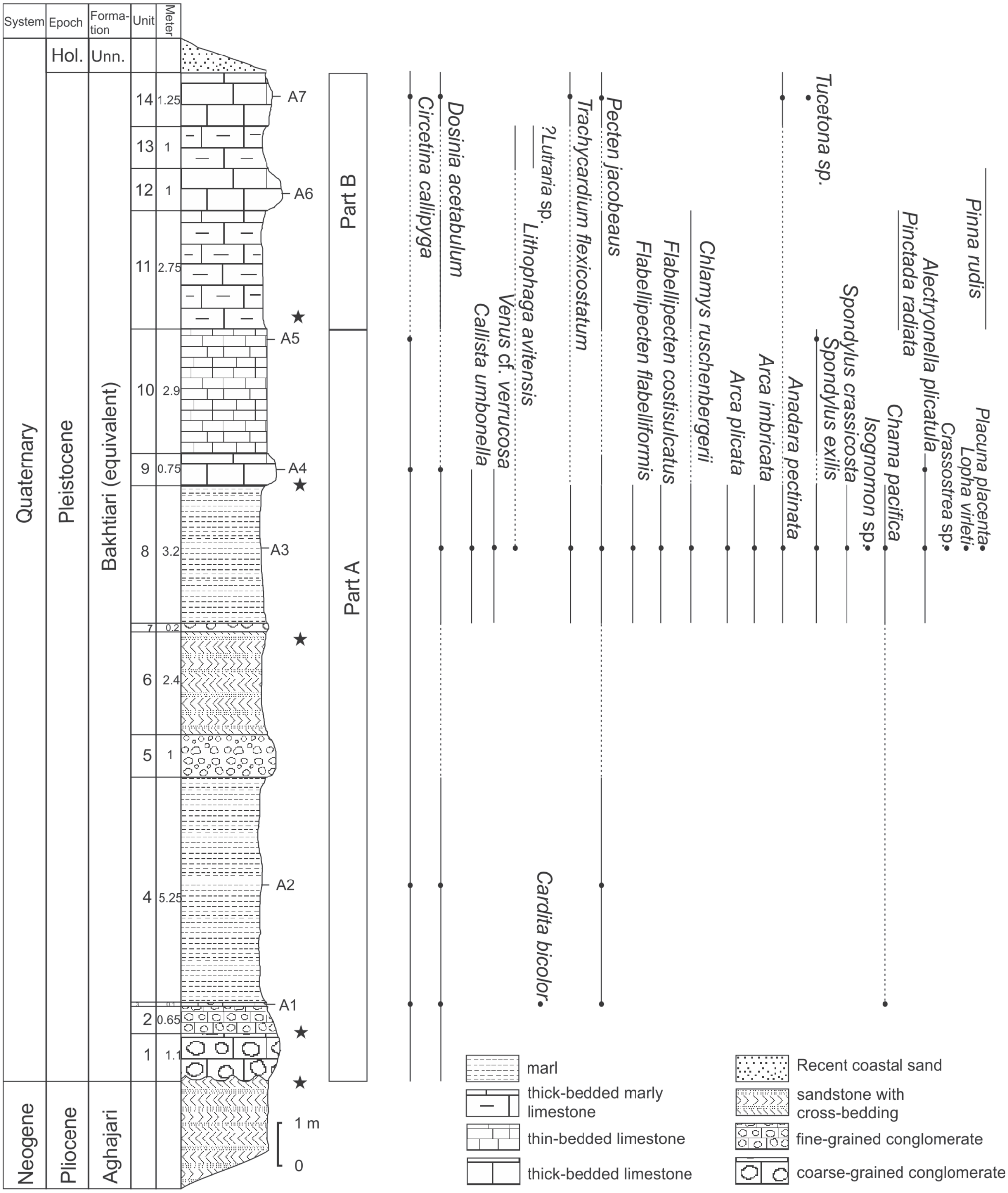

Fig. 4. Stratigraphic column of studied succession with distribution of bivalves

Continuous and dashed lines show the abundant and rare populations of each species respectively; A1–7 are collected samples; asterisks are the locations of photos of Figure 3

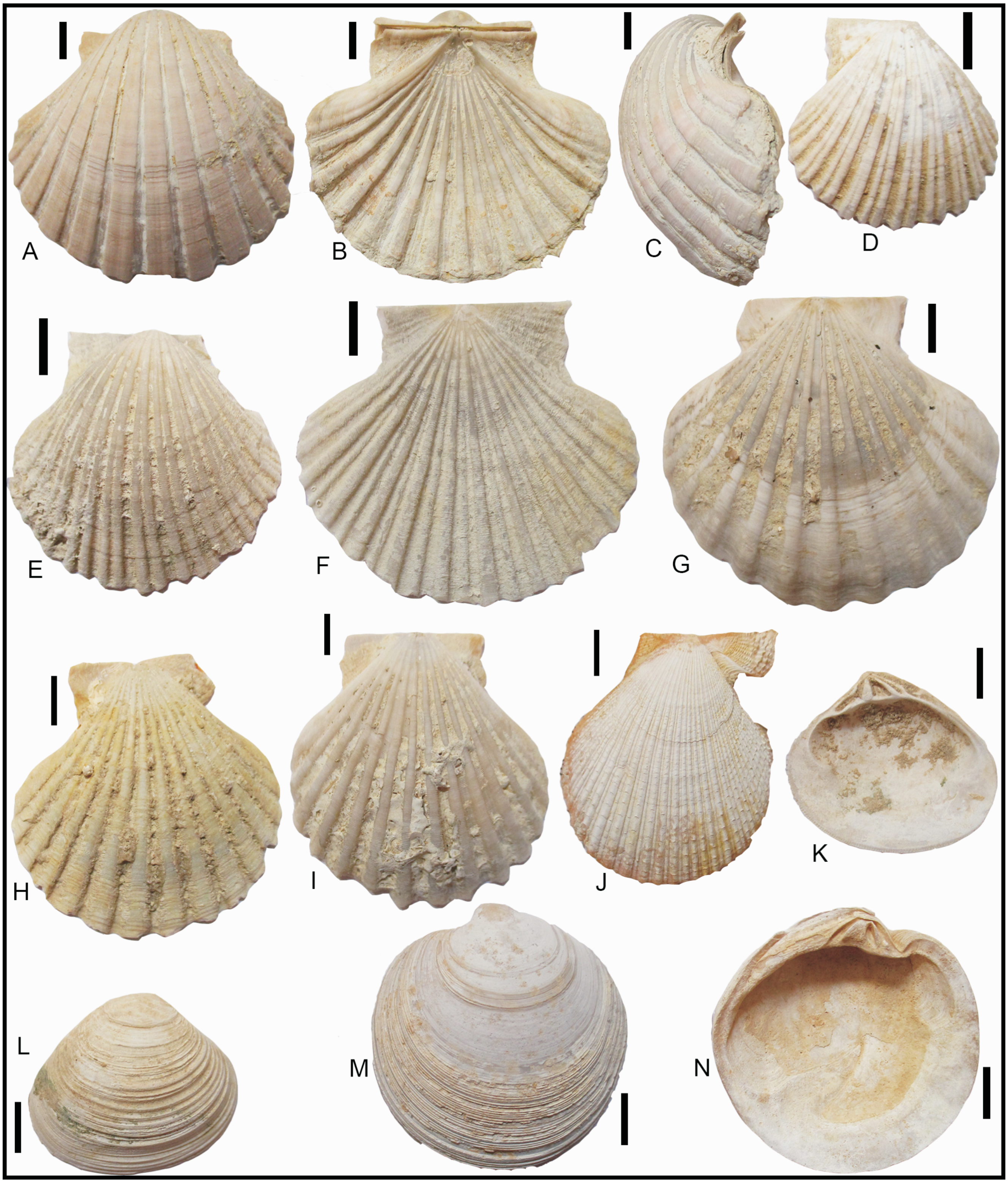

Fig. 5. Pectinid and some veneroid bivalves from the Dayyer section

A–C – *Pecten jacobeaus* (Linnaeus, 1758) HUIM194, sample A3, Dayyer section, left valve, right valve and lateral views; **D–F** – *Flabellipecten costisulcatus* (Almera and Bofill, 1897): D – HUIM195, sample A3, Dayyer section, left valve; E – HUIM196, sample A3, Dayyer section, left valve; F – HUIM197, sample A3, Dayyer section, right valve; **G–I** – *Flabellipecten flabelliformis* (Brocci, 1814): G – HUIM198, sample A3 Dayyer section, left valve; H – HUIM199, sample A3, Dayyer section, left valve; I – HUIM200, sample A3, Dayyer section, left valve; **J** – *Chlamys ruschenbergerii* (Tryon, 1869), HUIM201, sample A3, Dayyer section, left valve; **K, L** – *Circentia callipyga* (Born, 1778), HUIM202, sample A3, Dayyer section, inner and outer view of right valve; **M, N** – *Dosinia acetabulum* (Conrad, 1832), HUIM203, sample A3, Dayyer section, outer and inner views of left valve. All scale bars = 1cm

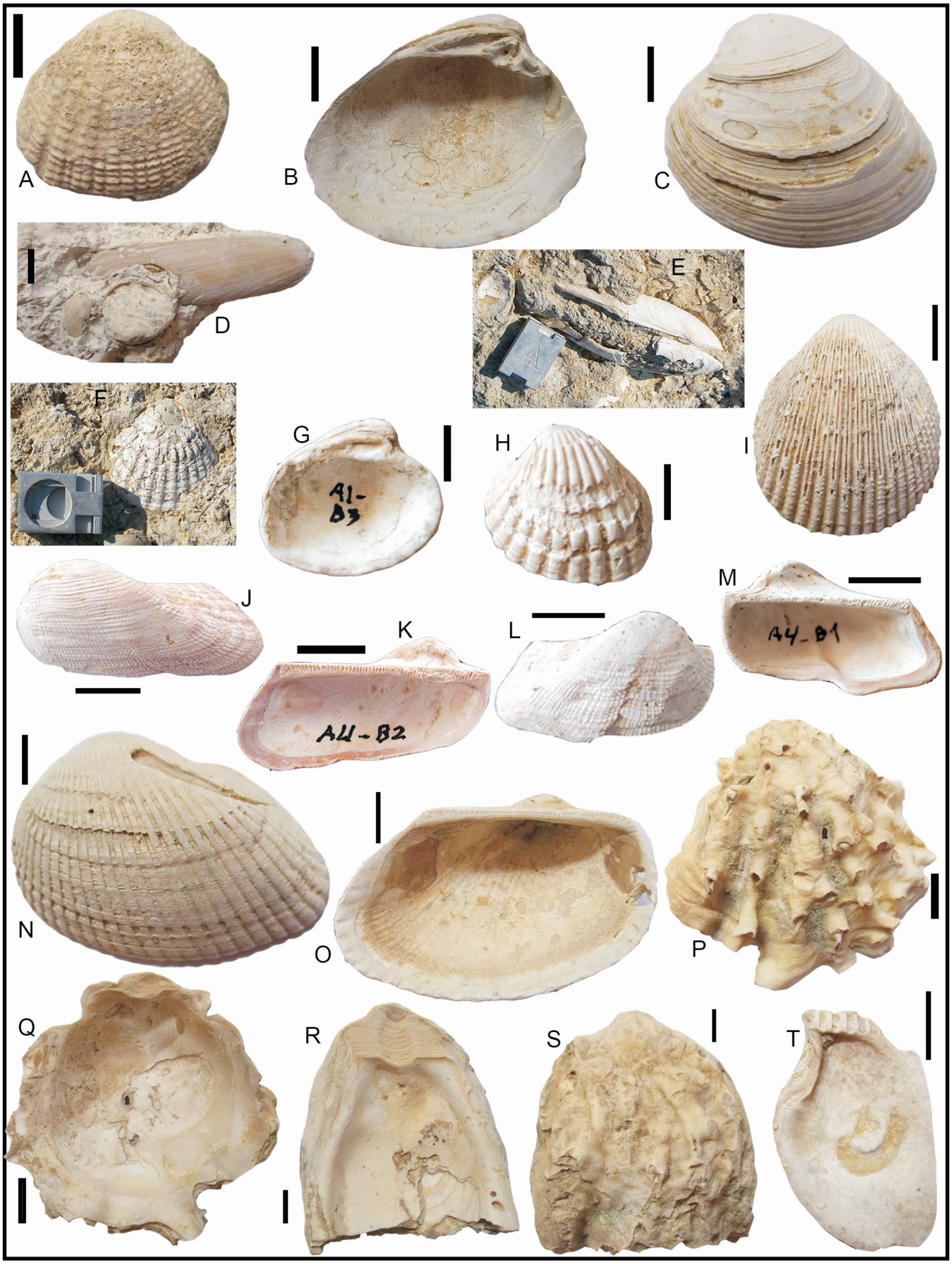

Fig. 6. Veneroid, arcoid and pterioid bivalves of the Dayyer section

A – *Venus* cf. *verrucosa* Linnaeus, 1758, HUIM204, sample A3, Dayyer section, outer and inner views of right valve; **B, C** – *Callista umbonella* (Lamarck, 1818), HUIM206, sample A3, Dayyer section, outer and inner views of left valve; **D** – *Lithophaga avitensis* (Mayer-Eymar, 1898), HUIM205, sample A3, Dayyer section, outer view of left valve; **E** – *?Lutraria* sp., HUIM207, unit 13, Dayyer section, dorsal view; **F** – *Tucetona* sp., HUIM211, sample A7, Dayyer section, outer view of left valve; **G, H** – *Cardites bicolor* (Lamarck, 1819), HUIM209, sample A1, Dayyer section, outer and inner views of left valve; **I** – *Trachycardium flexicostatum* Vokes, 1989, HUIM208, sample A3, Dayyer section, outer view of right valve; **J, K** – *Arca imbricata* Poli, 1795, HUIM210, sample A4, Dayyer section, outer and inner views of left valve; **L, M** – *Arca plicata* (Dillwyn, 1817) HUIM212, sample A4, Dayyer section, outer and inner views of right valve; **N, O** – *Anadara pectinata* (Brocci, 1814), HUIM213, sample A3, Dayyer section, outer and inner views of left valve; **P, Q** – *Lopha virleti* (Cox, 1936), HUIM214, sample A3, Dayyer section, outer and inner views of left valve; **R, S** – *Crassostrea* sp., HUIM215, sample A3, Dayyer section, inner and outer views of left valve; **T** – *Isognomon* sp., HUIM216, sample A3, Dayyer section inner view of right valve. All scale bars = 1cm

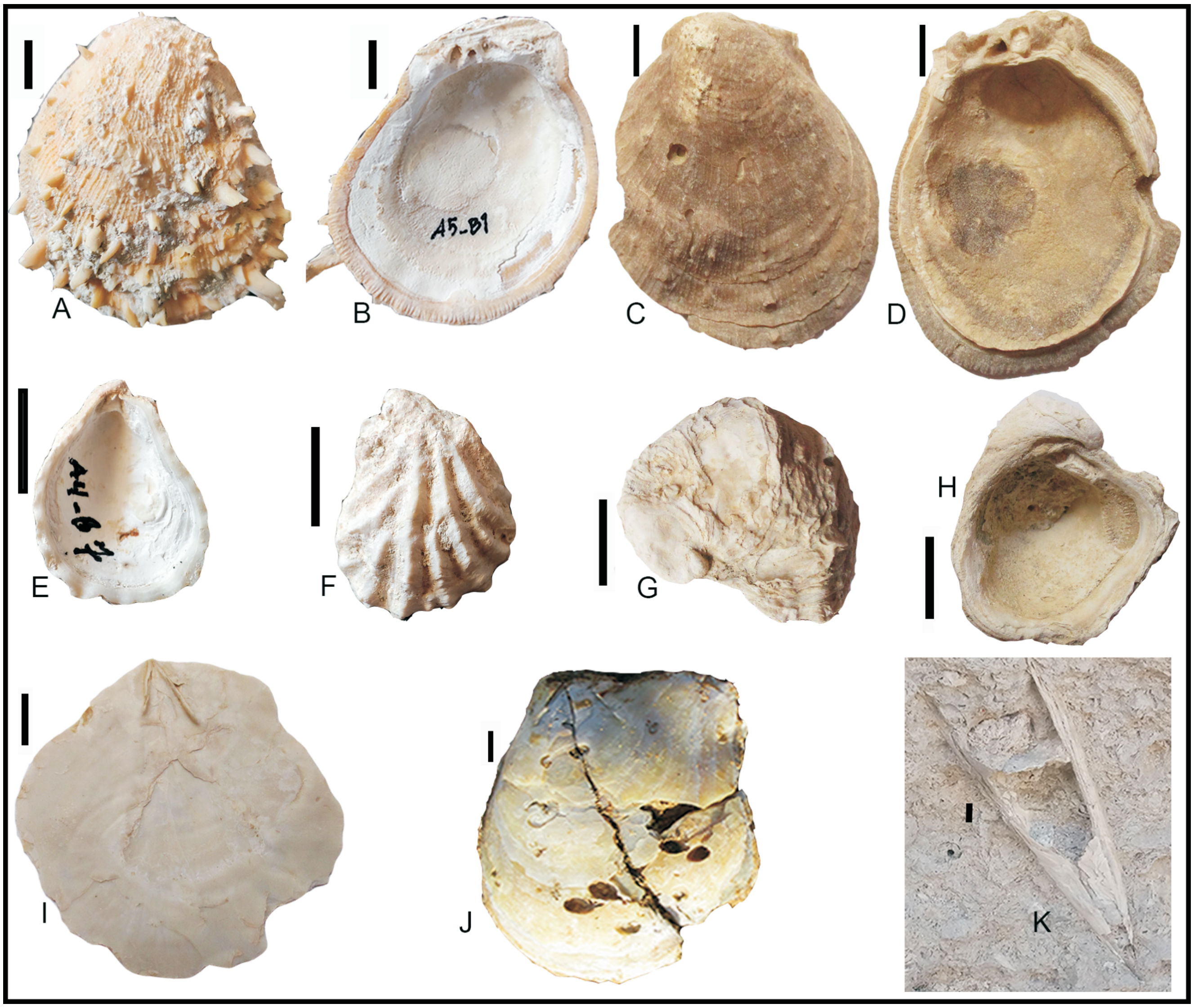

Fig. 7. Pterioid and mytiloid bivalves from the Dayyer section

A, B – *Spondylus exilis* Sowerby 1895, HUIM217, sample A3, Dayyer section, outer and inner views of left valve; **C, D** – *Spondylus crassicosta* Lamarck, 1819, HUIM218, sample A3, Dayyer section, outer and inner views of left valve; **E, F** – *Alectryonella plicatula* (Gmelin, 1791), HUIM219, sample A4, Dayyer section, outer and inner views of right valve; **G, H** – *Chama pacifica* Broderip, 1835, HUIM220, sample A3, Dayyer section, outer and inner views of right valve; **I** – *Placuna placenta* (Linnaeus, 1758), HUIM221, sample A3, Dayyer section; **J** – *Pinctada radiata* (Leach, 1814), HUIM222, unit 11, Dayyer section; **K** – *Pinna rudis* Linnaeus, 1758, HUIM223, unit 11, Dayyer section. All scale bars = 1cm

Alectryonella plicatula (Gmelin, 1791), *Spondylus crassicosta* Lamarck, 1819, *Lithophaga avitensis* (Mayer-Eymar, 1898), *Dosinia acetabulum* (Conrad, 1832), *Trachycardium flexicostatum* Vokes, 1989, *?Lutraria* sp., *Arca imbricata* Poli, 1795, *Arca plicata* (Dillwyn, 1817), *Anadara pectinata* (Brocci, 1814). We find these species in large populations in the Dayyer section. In addition, *Flabellipecten costisulcatus* has been observed by the authors on the eastern coast of Hormuz Strait, near Jask port (Fig. 8). Otherwise, these species are present in the Pliocene and Pleistocene strata of the Mediterranean Sea and nearby regions (Fig. 8).

For example, *Pecten jacobeaus* (Linnaeus, 1758), *Fabellipecten flabelliformis* (Brocci, 1814), *Fabellipecten costisulcatus* (Almera and Bofill, 1897) and *Anadara pectinata* (Brocci, 1814) are recorded from the Plio-Pleistocene of Italy (Caprotti 1976; Raffi et al., 1985; Ciampalini et al., 2014; Leesen, 2016). Nielsen et al. (2006) recorded *P. jacobeaus* (Linnaeus, 1758) from the Pleistocene strata of the Rhodes area of Greece. Rico-Garcia (2008) identified these species from the Cadiz area, south of Spain. Also Jiménez et al. (2009) reported *Fabellipecten flabelliformis* (Brocci, 1814) from the Almeria area, southeastern Spain. Büyükmeriç et al. (2018) recovered a similar fauna *Pecten jacobeaus* (Linnaeus, 1758), *Fabellipecten flabelliformis* (Brocci, 1814), *Fabellipecten costisulcatus* (Almera and Bofill, 1897) from the Pliocene beds of SE Turkey (Fig. 8).

The distribution of these species in the Plio-Pleistocene strata of southern Europe and the discovery of them in the Pleistocene beds of the south of Iran demonstrate a marine connection between southwestern Asia and the Mediterranean, and species migration during that time. It seems that a temporary connection existed between southern Mesopotamia and Levant, but more evidence is needed (Fig. 8). Stow et al. (2020), during their studies on the Euphrates river system, traced an extended seaway from the Persian Gulf to north-west Iraq and north-east Syria. The major siliciclastic and minor car-

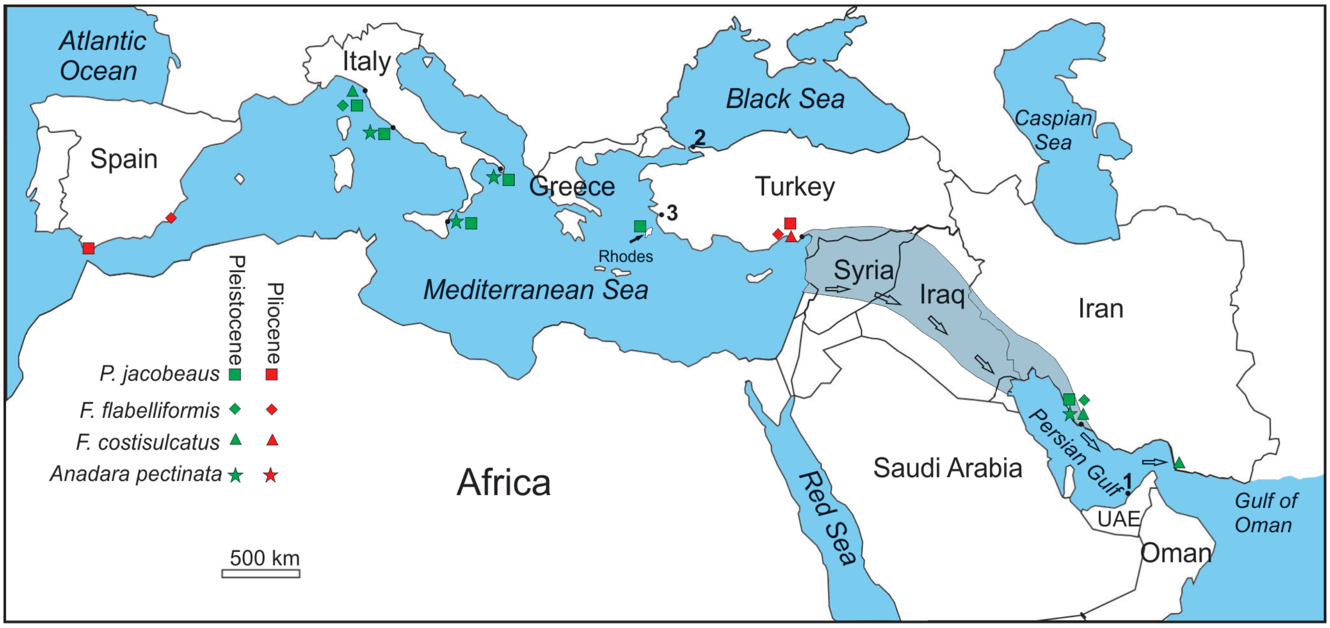

Fig. 8. Palaeogeographic map of south-west Asia and southern Europe in the late Pleistocene

Arrows show the migration path of species from the Mediteranean Basin to the Persian Gulf and the east of the Hormuz Strait during the Pleistocene. The grey area shows the temporary marine sea-way that connected the Persian Gulf to the Mediterranean Sea. 1, 2 and 3 are locations of successions in the United Arab Emirates and Turkey that are lithologically equivalent to the Dayyer section

bonate composition of the studied strata indicates that they were deposited in a regressive regime. Demir et al. (2007) and Trifonov et al. (2013) stated that the rate of Arabian Plate uplift increased during the late Early Pleistocene and resulted in the closure of marine and lacustrine basins.

The presence of cross-bedding in the micro-conglomerates of the middle parts of our section and hydraulic sorting of some grains and shells points to relatively strong currents perhaps influenced by the regional uplift of the area. However, the presence of some of the Mediterranean taxa in the collected assemblage those are absent in recent Persian Gulf waters indicates a temporary connection between these two basins during the Mid to Late Pleistocene. On the other hand, the absence of these species in the present Persian Gulf waters may point to the extinction of them in this basin between 153 ka ago and now.

CONCLUSIONS

The faunal content and facies of the Pleistocene deposits in the north of the Persian Gulf differs completely from those of the type section of the Pleistocene Bakhtyari Formation in the other parts of Zagros. Reconsideration to the samples of Rahiminejad et al. (2011) from the Bakhtiari Formation by us revealed the reworking of many foraminifers from Oligo-Miocene strata (Asmari, Mishan and Aghajari formations), ruling out this as a depositional age. The deposits from the Dayyer section are composed of fossiliferous (mainly molluscan) limestones, sandstones and conglomerates. Precise age determination based on Sr^{86}/Sr^{87} data indicates that the whole section is not older than 153 ka and indicates the Pleistocene. Similar strata have been reported from some islands and also from the southern coasts of the Persian Gulf. The mollusc assemblage of these strata is very different from the present community of the Persian Gulf. Many of the molluscs identified (especially bivalves) have been reported from Pliocene and Pleistocene strata of the Mediterranean Basin. This shows a temporary connection of the Persian Gulf to the Mediterranean Sea that led to the migration of those taxa during the Pleistocene. The absence of these taxa from the present waters of the Persian Gulf may point to extinctions that took place during the past 153 ky.

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