The exceptional Pliocene marine faunal assemblages of west central Portugal have been known since the late 19th century. They include highly diverse molluscan faunas whose study is far to be completed. Discovered nearly 40 years ago, Vale do Freixo (Carnide, Pombal) is perhaps the most outstanding fossil site. Nevertheless, the bivalves remain relatively unknown. This study focuses on the taxonomy of this relevant group of marine Mollusca. The research, based on a detailed sampling of three fossiliferous beds from the Carnide Formation, yielded a list of 85 species belonging to 75 genera and 32 families. Forty-three species are new for the Carnide area and twenty-three are reported for the first time in the Portuguese Pliocene, increasing to 115 the number of known species in the Mondego Basin in the Beira Litoral.

Keywords: Pliocene. Bivalvia. Taxonomy. Vale do Freixo. Portugal.

Introduction

The occurrence of fossil sites with well-preserved and highly diverse Pliocene marine faunal assemblages has long been reported from the mountain ranges of the Portuguese West Margin of Iberia (e.g. Carvalho and Colom, 1954; Carvalho, 1961, 1971; Choffat, 1889; Cox, 1936, 1941; Dollfus and Cotter, 1909; Rocha and Ferreira, 1953; Teixeira and Zbyszewski, 1951; Zbyszewski, 1959). These sites occur in the northern Estremadura, and southern Beira Litoral provinces, between the towns of Caldas da Rainha and Pombal, where a thick Neogene marine, deltaic and alluvial deposits crop out (Cunha, 1992, 2019; Cunha et
Besides its implication for the regional stratigraphy and depositional history of the Cenozoic Mondego Basin (Pais et al., 2012) and the diapiric valleys of Estremadura, this palaeontological record stands out because their paleobiogeographical position in the Pliocene Atlantic realm of southwestern Europe, midway from the Mediterranean and the northwest African margins to the colder waters of Biscay Bay, Channel and British Islands.

After the monograph of Dollfus and Cotter (1909), where the taxonomical composition and diversity of the bivalve faunas from the Caldas da Rainha outcrops and other related “classical sites” were first discussed, other works followed. The works of Brébion (1971, 1974), Cox (1936, 1941) and Zbyszewski (1959) focused on the rich assemblages of gastropods from these areas.

Cartographical work in the region of Carnide (Pombal) gave Teixeira and Zbyszewski (1951) the opportunity to study several new fossil sites, enlarging considerably the number of Portuguese Pliocene mollusc species. Several decades later, when quarry works discovered the Vale do Freixo outcrop near the southern end of Carnide village, Silva (1993, 2001) described a rich gastropod fauna collected from the well-exposed Pliocene beds. Further works (e.g. Silva et al., 2006, 2010, 2011) enhanced the importance of this fossil site for the Pliocene studies in Portugal, as well as for correlations with other coeval European sites, promoting a better knowledge of the Atlantic mollusc faunas of this interval and their interchanges with the closest biotic realms.

However, the bivalve fauna from Vale do Freixo was not studied in detail. Following on from the unpublished MsC dissertation of Pimentel (2018), the aim of this work is to update and discuss the taxonomic list of these bivalves based on the study of many newly collected specimens from the Vale do Freixo fossil site.

GEOGRAFICAL AND GEOLOGICAL SETTING

The fossil site of Vale do Freixo is located near Carnide, a rural village in the municipality of Pombal, in the Beira Litoral, west Portugal (Fig. 1). The sampled outcrops are located in a disabled quarry, with the coordinates: 39°53’00.35”N; 8°43’49.45”W. The site is in a private farm, accessible with the permission of the owner.

The Pliocene beds are almost horizontal and extend over both sides of the nearby Carnide Valley, where they follow an alignment of slightly sloped hills cut in siliciclastic beds. Vale do Freixo and other correlative fossiliferous occurrences correspond to scattered lenticular beds exposed along the western side of the valley.

The fossiliferous beds overlie unconformably middle Miocene greyish claystones (Amor Formation, Pais et al., 2010, 2012). They locally record the basal parasequence of the succession described as Barração Group, with marine to alluvial and lacustrine facies (Pais et al., 2010, 2012, 2013). The 1:50,000 Geological Map of Portugal (23-A, Pombal set) reports this unit as “P - Marine Pliocene of Vale do Freixo (Portugal)”.

al., 1993, 2008, 2009; Ramos, 2008). These successions form a Pliocene shallow marine unit (Carnide Formation), transgressive on a substrate of Miocene claystones or Lower Jurassic carbonates and evaporites, and often starting with a basal conglomerate with well-rounded clasts and abraded bioclasts of Glycymeris and other rather large bivalves. Locally, the Carnide Formation is very fossiliferous, yielding highly diverse fossil fauna, which includes molluscs and other invertebrates, as well abundant foraminifera, ostracods and other microfossils useful for biostratigraphical studies (e.g. Cachão, 1989, 1990; Cardoso, 1984; Diniz et al., 2016; Pais et al., 2010, 2013; Silva, 2001).
The transgressive parasequence (Fig. 2) consists of a continuous condensed bed of dark greyish, poorly graded, oligomictic conglomerate (bed “2”) rich in well-rounded quartz and quartzite clasts, and concentrations of disarticulated valves of *Glycymeris*, among other medium to large-sized bivalves, with their commissures facing down. This basal conglomerate is 0.5m thick on average, and has an erosive transgressive base. The following highstand bed is a greyish, poorly graded, medium- to fine-grained, massive sandstone (bed “3”; 0.4m), quite rich in well-preserved fossils, including many articulated infaunal bivalves. It is overlain by a fairly graded, yellowish to light-brown fine-grained sandstone (bed “4”; 0.3m), also rather fossiliferous, with many infaunal tellinid bivalves in life position, showing residues of original color and of hinge ligament. The topmost bed is a thin, light-brownish, highly plastic clay with erosive base and variable lateral thickness (bed “5”; 0.05 to 0.15m), suggesting a local lack of accommodation space related to the return to a regressive trend. It is likely that this impermeable non-fossiliferous layer has contributed to the exceptional preservation of the fossil assemblages in the underlying beds, through the inhibition of water percolation (Pimentel, 2018; Pimentel et al., 2019).

The top of the fossiliferous section of Vale do Freixo (Carnide Formation) is an erosive surface. The section is overlain by the siliciclastics of the Ilha Formation (*sensu* Carvalho, 1998), which consist of medium to coarse-grained micaceous sandstones with small, well-rounded, gravel clasts of whitish quartzite scattered in the matrix. This rather monotonous sequence of apparently non-fossiliferous beds suggests deposition near an intertidal environment with high energetic oscillation (Carvalho et al., 2005c).

Cachão (1990) determined the Pliocene age of the Vale do Freixo fossil assemblages based on calcareous nanofossils, CN12a biozone of Okada and Bukry (1980) and the NN16 unit of Martini (1971). Moreover, Silva (2001) and Silva et al. (2010) suggested that the rich gastropod fauna could be coeval with the Mediterranean Pliocene Molluscan Unit 1 (MPMU1) (Monegatti and Raffi, 2001; Raffi and Monegatti, 1993), and thus essentially somewhat older than 3.0Ma. It has been estimated that the chronostatigraphical range of the fossiliferous interval extens from the top of the Zanclean to the lower half of the Piacenzian (3.70-3.61Ma to 3.0Ma). On the other hand, on the basis of the 87Sr/86Sr isotopic data obtained from the valves of *Palliolum excisum*, Silva (2001) placed the lower boundary at 3.52Ma.

**MATERIALS AND METHODS**

Sampling was made bed by bed, following the stratigraphic section. Most specimens were collected individually, which was complemented by a volumetric bulk sample for each bed. Fieldwork also included taphonomic observations. Because large specimens occurred in unconsolidated sediments, they were easily extracted in the outcrop.

In the laboratory, the mechanical preparation and cleaning were often difficult due to the extreme fragility of many fossil shells, such as those of Tellinidae, Lucinidae and Mactridae. For these shells, the use of water to remove the sediment matrix was avoided, and a less aggressive meticulous dry cleaning was adopted.

Bulk-samples collected for volumetric purposes were washed through a column of sieves with meshes from 2mm to 0.125mm. Macro and microfossils from these fractions were picked up using a binocular and classified into taxonomic groups. The bivalve specimens were classified into genus and species.

A bulk collection of c.1,400 specimens was obtained. Several specimens were partially covered by matrix, and others consolidated with application of a film of transparent glue dissolved in acetone.

For the commonest species, we selected the best-preserved specimens. For the remaining species, the criterion was to use all specimens, even if incomplete or badly preserved. All specimens were numbered and catalogued with the references RP-VF2-B001 to RP-VF2-B061, RP-VF3-B001 to RP-VF3-B738, and RP-VF4-B001 to RP-VF4-B385. The collection is housed in the Earth Sciences Department of the University of Coimbra.

**UPDATED LIST OF BIVALVES AND TAXONOMIC NOTES**

The present taxonomical study allowed the identification of 82 species of Bivalvia plus three species left in open nomenclature (*Modiolus sp.*, *Gregariella sp.*, *Ensis cf. siliqua*). Systematics follows Bieler et al. (2010, 2014), Carter et al. (2011) and Huber (2015) for Tellinidae, and Pérez (2019) for Carditidae.
FIGURE 2. A) General field view of the Pliocene fossil site of Vale do Freixo (Carnide, Pombal, west Portugal). B) Stratigraphic section of the outcrop with the beds enhanced by different colours: a= Scleractinian corals; b= Bryozoans; c= Terebratulid brachiopods; d= Bivalves (Protobranchia and Pteriomorpha); e= Bivalves (Heteroconchia); f= Gastropods; g= Serpulid worms; h= Echinoids; i= Crustaceans; j= Fish remains; k= Unconformities; l= Laminated structure; m= Gradual transition; n= Borings; o= Hard-ground surface; p= Grain-size finning upwards; q= Micaceous grains; r= Iron nodules and impregnations; s= Manganese impregnations. C) Detail of Vale do Freixo fossil site (1= Amor Fm.; 2 to 6= Carnide Fm.).
For the specific determination, we used the works of Brocchi (1814), Bucquoy et al. (1887-1898), Chirli (2014, 2015, 2016), Dollfus and Cotter (1909), Huber (2010, 2015), Lauriat-Rage (1981, 1982, 1986), Lozano-Francisco (1997), Nobre (1938-1940), Poppe and Goto (1993) and Sacco (1897a, 1897b, 1898a, 1898b, 1899, 1900, 1901).

The updated bivalve list proposed here for the Vale do Freixo fossil site includes several new occurrences in the Pliocene of Portugal (*) (Figs. 3; 4) and many species known in other Portuguese sites, but not yet reported in the region of Carnide (**). The bivalve species are:

**Class:** Bivalvia LINNAEUS, 1758

**Subclass:** Protobranchia PELSENEER, 1889

**Order:** Nuculida DALL, 1889

**Superfamily:** Nuculoidea GRAY, 1824

**Family:** Nuculidae GRAY, 1824

**GENUS** Ennucula IRIDALE, 1931

*Ennucula laevigata* (J. Sowerby, 1818) (*)

**GENUS** Nucula DELAMARCK, 1799

*Nucula nucleus* (LINNAEUS, 1758)

**Order:** Nuculanida J.G. CARTER, D.C. CAMPBELL AND M.R. CAMPBELL, 2000

**Superfamily:** Nuculanoidea H. ADAMS AND A. ADAMS, 1858 (1854)

**Family:** Nuculanidae H. ADAMS AND A. ADAMS, 1858 (1854)

**GENUS** Lembulus RISSO, 1826

*Lembulus pella* (LINNAEUS, 1758)

**Subclass:** Autobranchia GROBBEN, 1894

**Infraclasse:** Pteriomorphia BEURLEN, 1944

**Order:** Mytilida FÉRUSSAC, 1822

**Superfamily:** Mytiloidea RAFINESQUE, 1815

**Family:** Mytilidae RAFINESQUE, 1815

**Subfamily:** Modiolinae G. TERMIER AND H. TERMIER, 1950

**GENUS** Modiolus DELAMARCK, 1799

*Modiolus* sp. (**)

**Family:** Crenellidae GRAY, 1840

**Subfamily:** Musculinae IRIDALE, 1939

**GENUS** Gregariella MONTEROSATO, 1883

*Gregariella* sp. (*)

**Order:** Arcida STOLICZKA, 1871

**Superfamily:** Arcoidea DELAMARCK, 1809

**Family:** Arcidae DELAMARCK, 1809

**GENUS** Arca LINNAEUS, 1758

*Arca tetragona* POLI, 1795 (**)

**GENUS** Barbatia GRAY, 1842

*Barbatia mytiloides* (BROCCHI, 1814)

**Subfamily:** Anadarinae REINHART, 1935

**GENUS** Anadara GRAY, 1847

*Anadara diluvii* (DELAMARCK, 1805) (**)

*Anadara pectinata* (BROCCHI, 1814) (**)

**Family:** Noetiidae STEWART, 1930

**GENUS** Striarca CONRAD, 1862

*Striarca lactea* (LINNAEUS, 1758)

**Family:** Glycymerididae DALL, 1908 (1847)

**Subfamily:** Glycymeridinae DALL, 1908 (1847)

**GENUS** Glycymeris DA COSTA, 1778

*Glycymeris glycymeris* (LINNAEUS, 1758)

**Order:** Ostreidea FÉRUSSAC, 1822

**Superfamily:** Ostreoidea RAFINESQUE, 1815
FIGURE 3. A-B) *Ennucula laevigata* (right valve RP-VF3-B650); C-D) *Gregariella* sp. (left valve RP-VF4-B382); E-F) *Neopycnodonte cochlear* (left valve RP-VF3-B348); G-H) *Hinnites escolanians* (left valve RP-VF2-B012); I-K) *Heteronemia squamula* (left valves RP-VF3-B737 and RP-VF3-B738); L-M) *Pododesmus squama* (left valve RP-VF3-B597); N-O) *Limaria loscombi* (left valve RP-VF3-B364); P-Q) *Goodallia triangularis* (right valve RP-VF4-B347); R-S) *Parvicardium scriptum* (right valve RP-VF3-B735); T-U) *Centrocardita aculeata* (left valve RP-VF3-B012); V-W) *Megaxinus transversus* (left valve RP-VF4-B067); X-Y) *Loripinus fragilis* (left valve RP-VF3-B736); Z-AA) *Phaxas pellucidus* (articulated specimen RP-VF4-B275); AB) *Hiatella rugosa* (left valve RP-VF3-B017); AC) *Bosemprella incarnata* (right valve RP-VF4-B338); AD-AE) *Gari tellinella* (left valve RP-VF4-B190); AF-AQ) *Oudardia compressa* (right valve RP-VF4-B326 and left valve RP-VF4-B329); AH-AI) *Corbula revoluta* (right valve RP-VF3-B377). Scale bars= 1cm.
Family: Ostreidae RAFINESQUE, 1815
Subfamily: Ostreinae RAFINESQUE, 1815

Genus *Ostrea* LINNAEUS, 1758
*Ostrea edulis* LINNAEUS, 1758

Family: Gryphaeidae VIALOV, 1936
Subfamily: Pycnodonteinae STENZEL, 1959

Genus *Neopycnodonte* STENZEL, 1971
*Neopycnodonte cochlear* (POLI, 1795) (*)

Superfamily: Pinnioidea LEACH, 1819
Family: Pinnidae LEACH, 1819

Genus *Atrina* GRAY, 1842
*Atrina fragilis* (PENNANT, 1777)

Superfamily: Pterioidea GRAY, 1847 (1820)
Family: Pteriidae GRAY, 1847 (1820)

Genus *Pteria* SCOPOLI, 1777

*Pteria hirundo* (LINNAEUS, 1758)

Order: Pectinida GRAY, 1854a

Superfamily: Pectinoidea RAFINESQUE, 1815

Family: Pectinidae RAFINESQUE, 1815
Subfamily: Pectininae RAFINESQUE, 1815

Genus *Aequipecten* P. FISCHER, 1886
*Aequipecten opercularis* (LINNAEUS, 1758) (**)

Genus *Flexopecten* SACCO, 1897
*Flexopecten flexuosus* (POLI, 1795) (**)

Genus *Pecten* O.F. MÜLLER, 1776

*Pecten benedictus* DE LAMARCK, 1819

Subfamily: Palliolinae KOROBKOV IN EBERZIN, 1960

Genus *Palliolum* MONTEROSATO, 1884
*Palliolum excisum* (BRONN, 1831)

Subfamily: Pedinae BRONN, 1862
GENUS *Hinnites* Defrance, 1821

*Hinnites crispus* (Brocchi, 1814) (**)

*Hinnites ercolanianus* Cocconi, 1873 (*)

GENUS *Mimachlamys* Iredale, 1929

*Mimachlamys varia* (Linnaeus, 1758) (**)

GENUS *Talochlamys* Iredale, 1929

*Talochlamys multistriata* (Poli, 1795)

Family: *Propeamussiidae* Abbott, 1954

GENUS *Similipecten* Winckworth, 1932

*Similipecten similis* (Laskey, 1811)

Superfamily: *Anomioidea* Rafinesque, 1815

Family: *Anomiidae* Rafinesque, 1815

GENUS *Heteranomia* Winckworth, 1922

*Heteranomia squamula* (Linnaeus, 1758) (*)

GENUS *Pododesmus* Philippi, 1837

*Pododesmus squama* (Gmelin, 1791) (*)

Order: *Limida* Moore, 1952

Superfamily: *Limoidea* Rafinesque, 1815

Family: *Limidae* Rafinesque, 1815

GENUS *Lima* Bruguière, 1797

*Lima lima* (Linnaeus, 1758) (**)

GENUS *Limaria* Link, 1807

*Limaria loscombi* (G. B. Sowerby I, 1823) (*)

*Limaria tuberculata* (Olivi, 1792)

Infraclasse: Heteroconchia Hertwig, 1895

Superorder: Imparidentia Bieler, Mikkelsen and Giribet, 2014

Order: *Carditida* Dall, 1889

Superfamily: Crassatelloidea *Férussac*, 1822

Family: *Astartidae* d’Orbigny, 1844 (1840)

GENUS *Astarte* J. Sowerby, 1816

*Astarte fusca* (Poli, 1791)

GENUS *Digitaria* s.v. Wood, 1853

*Digitaria digitaria* (Linnaeus, 1758)

GENUS *Goodallia* Turton, 1822

*Goodallia triangularis* (Montagu, 1803) (*)

Superfamily: *Carditoidea* *Férussac*, 1822

Family: *Carditidae* *Férussac*, 1822

Subfamily: *Carditinae* *Férussac*, 1822

GENUS *Cardita* Bruguière, 1792

*Cardita calyculata* (Linnaeus, 1758) (**)

Subfamily: *Venericardiinae* Chavan, 1969

GENUS *Cardites* Link, 1807

*Cardites antiquatus* (Linnaeus, 1758) (**)

GENUS *Megacardita* Sacco, 1899

*Megacardita striatissima* (Caillaud, in Mayer, 1868)

Subfamily: *Carditamerinae* Chavan, 1969

GENUS *Centrocardita* Sacco, 1899

*Centrocardita aculeata* (Poli, 1795) (*)

Subfamily: *Scalaricarditinae* Pérez, 2019

GENUS *Scalaricardita* Sacco, 1899

*Scalaricardita scalaris* (J. De C. Sowerby, 1825)

Order: *Lucinida* Gray, 1854a

Superfamily: *Lucinoidea* J. Fleming, 1828

Family: *Lucinidae* J. Fleming, 1828
**Subfamily:** Codakiinae \(\text{KOROBKOV}, 1954\)

**GENUS Lucinoma** \(\text{DALL}, 1901\)

*Lucinoma borealis* \(\text{LINNAEUS}, 1767\)

**Subfamily:** Lucininae \(\text{J. FLEMING}, 1828\)

**GENUS Megaxinus** \(\text{BRUGNONE}, 1880\)

*Megaxinus transversus* \(\text{BRONN}, 1831\) (*)

**Subfamily:** Pegophyseminae \(\text{J. DA YLOR AND GLOVER, 2011}\)

**GENUS Loripinus** \(\text{MONTEROSATO}, 1884\)

*Loripinus fragilis* \(\text{PHILIPPI}, 1836\) (*)

**Order:** Adapedonta \(\text{COSSMANN AND PEYROT, 1909}\)

**Superfamily:** Solenoidea \(\text{DE LAMARCK, 1809}\)

**Family:** Pharidae \(\text{H. ADAMS AND A. ADAMS, 1856}\)

**Subfamily:** Pharinae \(\text{H. ADAMS AND A. ADAMS, 1856}\)

**GENUS Pharus** \(\text{GRAY}, 1840\)

*Pharus legumen* \(\text{LINNAEUS}, 1758\)

**GENUS Phaxas** \(\text{LEACH IN GRAY, 1852}\)

*Phaxas pellucidus* \(\text{PENNANT, 1777}\) (*)

**Subfamily:** Cultellinae \(\text{DAVIES, 1935}\)

**GENUS Ensis** \(\text{SCHUMACHER, 1817}\)

*Ensis cf. siliqua* \(\text{LINNAEUS, 1758}\)

**Superfamily:** Hiattellidae \(\text{GRAY, 1824}\)

**Family:** Hiattellidae \(\text{GRAY, 1824}\)

**GENUS Hiattella** \(\text{BOSC, 1801}\)

*Hiattella rugosa* \(\text{LINNAEUS, 1767}\) (*)

**Order:** Cardiida \(\text{FERUSSAC, 1822}\)

**Superfamily:** Cardioidae \(\text{DE LAMARCK, 1809}\)

**Family:** Cardiidae \(\text{DE LAMARCK, 1809}\)

**Subfamily:** Cardiinae \(\text{DE LAMARCK, 1809}\)

**GENUS Procadium** \(\text{TER POORTEN AND LA PERNIA, 2017}\)

*Procadium diluvianum* \(\text{DE LAMARCK, 1819}\)

**Subfamily:** Lymnocardiinae \(\text{STOLICZKA, 1870}\)

**GENUS Acanthocardia** \(\text{GRAY}, 1851\)

*Acanthocardia aculeata* \(\text{LINNAEUS, 1758}\) (**)

**GENUS Papillicardium** \(\text{SACCO, 1899}\)

*Papillicardium papillosum* \(\text{POLI, 1791}\) (**)

**GENUS Parvicardium** \(\text{MONTEROSATO, 1884}\)

*Parvicardium scriptum* \(\text{BUCQUOY, DAUTZENBERG AND DOLLFUS, 1892}\) (**)

**Subfamily:** Laevicardiinae \(\text{KEEN, 1951}\)

**GENUS Laevicardium** \(\text{SWAINSON, 1840}\)

*Laevicardium crassum* \(\text{GMELIN, 1791}\)

**Subfamily:** Orthocardiinae \(\text{SCHNEIDER, 2002}\)

**GENUS Europicardium multistriatum** \(\text{BROCCHI, 1814}\)

**Superfamily:** Tellinoidea \(\text{DE BLAINVILLE, 1814}\)

**Family:** Tellinidae \(\text{DE BLAINVILLE, 1814}\)

**Subfamily:** Arcopagiinae \(\text{M. HUBER, LANGLEIT AND KREIPL, 2015}\)

**GENUS Arcopagia** \(\text{T. BROWN, 1827}\)

*Arcopagia corbis* \(\text{BRONN, 1831}\)

*Arcopagia crassa* \(\text{PENNANT, 1777}\)

**Subfamily:** Gastraninae \(\text{M. HUBER, LANGLEIT AND KREIPL, 2015}\)

**GENUS Gastrana fragilis** \(\text{LINNAEUS, 1758}\) (**)

**Subfamily:** Macomininae \(\text{OLSSON, 1961}\)

**GENUS Macomopsis** \(\text{SACCO, 1901}\)

*Macomopsis elliptica* \(\text{BROCCHI, 1814}\)
Subfamily: Tellininae de Blainville, 1814

**GENUS Bosemprella** M. Huber, Langleit and Kreipl, 2015

*Bosemprella incarnata* (Linnaeus, 1758) (*)

**GENUS Oudardia** Monrosato, 1884

*Oudardia compressa* (Brocchi, 1814) (*)

**GENUS Peronidia** Dall, 1900a

*Peronidia albicans* (Gmelin, 1791) (**)

**GENUS Donax** Linnaeus, 1758

*Donax variegatus* (Gmelin, 1791)

**GENUS Abra** de Lamarck, 1818

*Abra alba* (W. Wood, 1802) (**)

*Abra prismatica* (Montagu, 1808)

**Order:** Venerida Gray, 1854a

**Superfamily:** Chamoidea de Lamarck, 1809

**Family:** Chamaeidae de Lamarck, 1809

**GENUS Chama** Linnaeus, 1758

*Chama Gryphoides* Linnaeus, 1758 (**)

**Superfamily:** Mactroidea de Lamarck, 1809

**Family:** Mactridae de Lamarck, 1809

**Subfamily:** Mactrinae de Lamarck, 1809

**GENUS Mactra** Linnaeus, 1767

*Mactra Stultorum* (Linnaeus, 1758)

**GENUS Spisula** Gray, 1837

*Spisula Subtruncata* (da Costa, 1778)

*Spisula Solida* (Linnaeus, 1758)

**Superfamily:** Lutrariinae Gray, 1853

**GENUS Lutraria** de Lamarck, 1799

*Lutraria Lutraria* (Linnaeus, 1758) (**)

**Family:** Cardilidae P. Fischer, 1887

**GENUS Cardilia** Deshayes, 1835

*Cardilia Michelottii* Deshayes, 1844 (*)

**Superfamily:** Ungulinoidae Gray, 1854b

**Family:** Ungulinidae Gray, 1854b

**GENUS Diplodonta** Bronn, 1831

*Diplodonta rotundata* (Montagu, 1803) (*)

**GENUS Callista** Poli, 1791

*Callista Chione* (Linnaeus, 1758)

**GENUS Chamelea** Mörch, 1853

*Chamelea gallina* (Linnaeus, 1758)

**GENUS Circomphalus** Mörch, 1853

*Circomphalus Foliaceolamellosus* (Dilwyn, 1817)

**GENUS Clausinella** Gray, 1851

*Clausinella fasciata* (da Costa, 1778)

**GENUS Dosinia** Scopoli, 1777

*Dosinia Lupinus* (Linnaeus, 1758)

**GENUS Gouldia** C.B. Adams, 1847

*Gouldia Minima* (Montagu, 1803) (*)

**GENUS Pitar** Römer, 1857

*Pitar Rudis* (Poli, 1795) (*)
La Perna et al. (2017) proposed a new species designation for Cardita striatissima var. abbreviata dolleus and cotter, 1909 as Megacardita redoniana n. sp., and considered that its subordination to Megacardita Sacco, 1899 was provisory (la Perna et al., 2018). By this reason, we opted by a conservative view of the Vale do Freixo specimens as C. striatissima, in line with Lauriat-Rage et al. (1989), and Carvalho et al. (2005b) who made a quantitative study of infraespecific variation for the sample-populations of beds “2” and “3”.

Cardita scalaris J.C. de Sowerby, 1825 is here placed in genus Scalaricardita Sacco, 1899 and for the Carditidae we followed the systematic scheme suggested by Pérez (2019).

Cardium hians brocchi, 1814 in Procercardium ter poorten and la perna, 2017. The mention of this species in the Pliocene beds of Alfeite and S. Joanes (Zbyszewski, 1943), and in the Carnide area (Teixeira and Zbyszewsky, 1951; Zbyszewski, 1959) seem to correspond to occurrences of P. diluvianum for the Portuguese Neogene.

After la Perna (2017), Cardium multicostatum brocchi, 1814, which has been widely cited as Trachycardium multicostatum (brocchi, 1814), should be allocated to Europicardium popon, 1977.

In line with the propositions of Fisher-Piette and Métivier (1971) and Canapa et al. (2003), that the genus Paphia Röding, 1798 should be restraint to the Indo-Pacific Realm, we considered Tapes Megerle von Mühlfeld, 1811 as the most adequate genus for Venus vetula de Basterot, 1825.

DISCUSSION

The whole assemblage of bivalve molluscs here identified from beds “2” to “4” of Vale do Freixo amounts 85 species (Tables 1; 2) distributed in 32 families and 75 genera. The families with more species are Veneridae (11 species), Pectinidae and Tellinidae (eight species each). Its taxonomical composition and high-diversity are in line with previous observations based on the gastropod fauna (Gili et al., 1995; Landau et al., 2006, 2007; Landau and Silva, 2006a, b; Silva, 1991, 1993, 1995, 2001, 2002, 2003; Silva et al., 2000, 2006, 2010, 2011; Silva and Landau, 2007, 2009), who suggest an inner shelf depositional environment with sandy substrates and normal salinity conditions, ranging in the infralittoral zone within depths of 24m and above.

The richness and abundance of the bivalves are similar to those of the gastropods. The molluscan faunas also contain scaphopods and polyplacophora (Dell’Angelo and Silva, 2003).
They occur with a diverse fossil content of macrofaunal elements, including small scleractinian corals, branched and incrusting bryozoans, a terebratulid brachiopod, serpulid worms, balanoids (Ferreira et al., 2019) and decapod crustaceans, spatangoid and epifaunal echinoids, and small fishes (Nolf and Silva, 1997). The microfauna is also very abundant, including benthic and planktonic foraminifera, ostracods and dinoflagellates (Vieira et al., 2006). These assemblages contain many elements that suggest a location in the subtropical Mean Monthly Sea Surface Temperature (MMSST), in a position close to the seashore and slightly protected from the direct influence of the open ocean (e.g. Silva and Landau, 2009).

One of the results of the present study is the increase of the number of bivalve species of the Carnide area from 48 to more than 90. The bivalve diversity of Vale do Freixo is higher than other analogous fossil assemblages of the Estremadura mountain ranges, such as those studied by Dollfus and Cotter (1909), with 78 species belonging to 27 families. Nevertheless, a new sampling and taxonomical review will be required for these faunas and their collections conserved at the Geological Museum, in Lisbon. The number of Pliocene bivalve species known for the Mondego Basin also increase to 115 as a result of this study.

| Table 1. Bivalvia species from Vale do Freixo and their occurrence in other Beira Litoral and Estremadura localities. Subclasses Protobranchia and Autobranchia, Infraclass Pteriomorpha. CN= Carnide (b= Igreja de Carnide, c= Vale da Bouchada, d= Vale Farpado, e= Vale da Cabra); MR= Monte-Real; PM= S. Pedro de Moel (g= Mina, h= Senhora da Vitória); NZ= Nazaré (i= Famalicão, j= Bom Jesus, k= Salir do Porto) and CR= Caldas da Rainha (l= Nadadouro, n= Águas Santas); see Figure 1 for the localities. Data from: Carvalho et al., 2005a; Choffat, 1889; Dollfus and Cotter, 1909; Cox, 1941; Teixeira and Zbyszewski, 1951; Zbyszewski, 1959, Zbyszewski and Metalino de Almeida, 1960; Zbyszewski et al., 1961, Pimentel et al., 2018. |

| Vale do Freixo (Carnide) | CN (b-e) | MR (f) | PM (g-h) | NZ (l- k) | CR (l-n) |
|-------------------------|---------|--------|----------|-----------|----------|
| *Ennucula laevigata* (J. Sowerby, 1818) | X | X | X | X | X |
| *Nucula nucleus* (Linnaeus, 1758) | X | X | X | X | X |
| *Lembus pella* (Linnaeus, 1758) | X | X | X | X | X |
| *Modiolus* sp. | X | X | X | X | X |
| *Gregariella* sp. | X | X | X | X | X |
| *Arca tetragona* Poli, 1795 | X | X | X | X | X |
| *Barbatia mytiloides* (Brocchi, 1814) | X | X | X | X | X |
| *Anadara diluvi* (Lamarck, 1805) | X | X | X | X | X |
| *Anadara pectinata* (Brocchi, 1814) | X | X | X | X | X |
| *Striarca lactea* (Linnaeus, 1758) | X | X | X | X | X |
| *Glycymeris glycymeris* (Linnaeus, 1758) | X | X | X | X | X |
| *Ostrea edulis* Linnaeus, 1758 | X | X | X | X | X |
| *Neopycnodonte cochlear* (Poli, 1795) | X | X | X | X | X |
| *Atrina fragilis* (Pennant, 1777) | X | X | X | X | X |
| *Pteria hirundo* (Linnaeus, 1758) | X | X | X | X | X |
| *Aequipecten opercularis* (Linnaeus, 1758) | X | X | X | X | X |
| *Flexopecten flexuosus* (Poli, 1795) | X | X | X | X | X |
| *Pecten benedictus* Lamarck, 1819 | X | X | X | X | X |
| *Paliliolum excisum* (Bronn, 1831) | X | X | X | X | X |
| *Hinnites crispus* (Brocchi, 1814) | X | X | X | X | X |
| *Hinnites ercolaniensis* Cocconi, 1873 | X | X | X | X | X |
| *Mimachlamys varia* (Linnaeus, 1758) | X | X | X | X | X |
| *Talochlamys multistriata* (Poli, 1795) | X | X | X | X | X |
| *Similpecten similis* (Laskey, 1811) | X | X | X | X | X |
| *Heteranomia squamula* (Linnaeus, 1758) | X | X | X | X | X |
| *Pododesmus squama* (Gmelin, 1791) | X | X | X | X | X |
| *Lima lima* (Linnaeus, 1758) | X | X | X | X | X |
| *Limaria loscombi* (G.B. Sowerby I, 1823) | X | X | X | X | X |
| *Limaria tuberculata* (Olivi, 1792) | X | X | X | X | X |
| Vale do Freixo (Carnide) | CN (b-e) | MR (f) | PM (g-h) | NZ (i-k) | CR (l-n) |
|-------------------------|----------|--------|----------|----------|----------|
| Astarte fusca (POLI, 1791) | X | X | X | | |
| Digitaria digitaria (LINNAEUS, 1758) | X | X | X | | |
| Goodallia triangularis (MONTAGU, 1803) | | | | | |
| Cardita calyculata (LINNAEUS, 1758) | X | | | | |
| Cardites antiquatus (LINNAEUS, 1758) | X | | | | |
| Megacardita striatissima (MAYER, 1868) | X | X | X | | |
| Centrocardita aculeata (POLI, 1795) | | | | | |
| Scalaricardita scalaris (SOWERBY, 1825) | X | X | | | |
| Lucinoma borealis (LINNAEUS, 1767) | X | | | | |
| Megaxinus transversus (BRENN, 1831) | | | | | |
| Loripinus fragilis (PHILIPPI, 1836) | | | | | |
| Pharus legumen (LINNAEUS, 1758) | X | | X | | |
| Phaxas pellucidus (PENNANT, 1777) | X | | X | | |
| Ensis siliqua (LINNAEUS, 1758) | X | X | X | | |
| Hiatella rugosa (LINNAEUS, 1767) | X | | | | |
| Procardium diluvianum (LAMARCK, 1819) | | X | X | | |
| Acanthocardia aculeata (LINNAEUS, 1758) | X | X | X | | |
| Papillicardium papillosum (POLI, 1791) | | | | | |
| Parvicardium scriptum (BUQUOY, DAUTZENBERG AND DOLLFUS, 1892) | X | X | X | | |
| Laevicardium crassum (GMELIN, 1791) | X | | | | |
| Europticardium multicostatum (BROCCI, 1814) | | | | | |
| Arcopagia corbis (BRONN, 1831) | X | X | X | | |
| Arcopagia crassa (PENNANT, 1777) | X | | X | | |
| Gastrana fragilis (LINNAEUS, 1758) | | X | X | | |
| Macromopsis elliptica (BROCCI, 1814) | X | | | | |
| Boscemprella incarnata (LINNAEUS, 1758) | X | | | | |
| Oudardia compressa (BROCCI, 1814) | X | | | | |
| Peronidia albicans (GMELIN, 1791) | X | | | | |
| Donax variegatus (GMELIN, 1791) | X | | | | |
| Gari depressa (PENNANT, 1777) | X | | | | |
| Gari tellinella (LAMARCK, 1818) | | | | | |
| Gari fervensis (GMELIN, 1791) | | X | | | |
| Abra alba (W. WOOD, 1802) | X | | | | |
| Abra prismatica (MONTAGU, 1808) | X | | | | |
| Chama gryphoides LINNAEUS, 1758 | X | | | | |
| Mactria stultorum (LINNAEUS, 1758) | X | | | | |
| Spisula subtruncata (DA COSTA, 1778) | X | | | | |
| Spisula solida (LINNAEUS, 1758) | X | X | | | |
| Lutraria lutraria (LINNAEUS, 1758) | | X | | | |
| Cardilia michelottii DESHAYES, 1844 | | | | | |
| Diplodonota rotundata (MONTAGU, 1803) | | | | | |
| Callista chione (LINNAEUS, 1758) | X | X | | | |
| Chamelea gallina (LINNAEUS, 1758) | X | | | | |
| Circmophalus foliaceolamellatus (DILLWYN, 1817) | X | X | | | |
| Clausinella fasciata (DA COSTA, 1778) | X | X | X | | |
Comparing the Pliocene bivalves of Vale do Freixo with similar assemblages reported from basins not faraway, as the Estepona Basin (Vera-Peláez and Lozano-Francisco, 2001) and Vélez Málaga area (Malaga Basin, southern Spain), despite not being entirely synchronous, range to 173 species and 46 families of bivalve molluscs (Lozano-Francisco, 1997, 1998; Vera-Peláez et al., 1995). This assemblage represents a variety of facies, including deeper water deposits, unlike those of the Mondego Basin, in Portugal.

On the southern Atlantic coast of the Iberian Peninsula, the Guadalquivir Basin (Huelva, SW of Spain) records more than 120 species (e.g. Andrés, 1983, 1984, 1985, 1987, 1989; Andrés and Porta, 1987; Castano et al., 1988; González-Delgado, 1979; González-Delgado et. al., 1995; Landau, 1984; Lozano-Francisco and Landau, 1999) and 34 families (González-Delgado et al., 1984) of bivalve molluscs.

The 178 species of bivalve molluscs from the Redonian (Pliocene) of the Loire Basin, northwest of France, cited by Lauriat-Rage (1981), despite the strategic geographical position on the edge of the Pliocene French-Iberian Bioprovince, it is not easy for us to establish a general comparison given their heterochronic character from the upper Miocene to the Pliocene. Only the Redonian sites in the Nantes area and Vendée, Loire-Atlantique, would be of early Pliocene age (e.g. Brault et al., 2004; van Dingenen et al., 2015) and could be correlative in some extent to the Vale do Freixo assemblage. In addition, Landau et al. (2020) considered the provincialism of the Zanclean (Pliocene) gastropods, including those of the Portuguese fossil site, enough to create a distinct Ligurian molluscan subprovince. Other Brittany Redonian localities would be of Miocene age (e.g. Brébian, 1964; Dollfus, 1900, 1904; Mercier et al., 2000; Monegatti and Raffi, 2010; Néraudeau et al., 2002, 2003).

According to ter Poorten and la Perna (2017), the Early Pliocene to Early Pleistocene large cardiid Procardium diluvianum occurred from the Atlantic Guadalquivir Basin to the eastern Mediterranean. This range area probably extended southwards, along the west coast of Africa. We include Vale do Freixo and the Mondego Basin in the Atlantic margin of West-Central Portugal as the northernmost known area of distribution for this genus, during the Pliocene.

Cardilia michelottii DESHAYES, 1844 has been cited in the Italian Miocene (Doderlein, 1862), Pliocene (e.g. Bronn, 1848; Chirli, 2015; Deshayes, 1844; Fischer, 1861; Manzoni, 1868, 1870; d’Orbigny, 1852; Pantanelli, 1892; Piclet, 1855; Sacco, 1889, 1901; Signorelli and Raven, 2018; Sismonda, 1847) and Pleistocene (Cerulli-Irelli, 1909; Clerici, 1888; Ponzi and Meli, 1887). The genus Cardilia has also been mentioned in the list of Pliocene bivalves from Huelva (Spain) – C. michelottii (Landau, 1984) and C. cf. sulcata (Galán Ávila et al., 2002). A single specimen was found in Vale do Freixo (Pimentel, 2018; Pimentel et al., 2018, 2019) with a morphology close to C. michelottii from the Italian Neogene (e.g. Sacco, 1901, pg.: 32; pl. VI, figs. 26-30; Cerulli-Irelli, 1909, pg.: 145 [161], pl. XVI [XXVI], fig. 6; Chirli, 2015, pg.: 83, pl.19, figs. 7-10). However, there are a few morphological differences to note, including the less circular outline of the valve, with the anterior and posterior margins less concave and the umbo-paleal diameter much larger than the anteroposterior (Pimentel et al., 2019). More specimens and following studies on the Italian, Huelva and Vale do Freixo valves would be necessary to solve this puzzle, and to verify if an Atlantic Pliocene species of this family does exist, close to the Mediterranean C. michelottii.

The original species name Scintilla recondita P. FISCHER, 1872, has been assigned to genus Sportella DESHAYES, 1858 (e.g. Monterosato, 1872; Locard, 1886; Sacco, 1899; Cossignani and Ardovini, 2011), and Spaniorinus DALL, 1900b (e.g. Andrés, 1987; González-Delgado et al., 1984). All specimens studied here correspond to those figured by Chiri (2015) which lack the fine radial ornamentation.

### TABLE 2. Continued

| Vale do Freixo (Carnide) | CN (b-e) | MR (f) | PM (g-h) | NZ (i-k) | CR (l-n) |
|-------------------------|---------|--------|----------|----------|----------|
| Dosinia lupinus (LINNAEUS, 1758) | X | | | | |
| Goudia minima (MONTAGU, 1803) | | | | | |
| Pitar rudis (POLI, 1795) | | | | | |
| Tapes vetula (BASTEROT, 1825) | X | X | | | |
| Timoclea ovata (PENNANT, 1777) | X | X | | | |
| Venus casina LINNAEUS, 1758 | X | | X | X | |
| Venus verrucosa LINNAEUS, 1758 | | | | | |
| Spaniorinus reconditus (FISCHER, 1872) | | | | | |
| Scacchia oblonga (PHILIPPI, 1836) | | | | | |
| Corbula gibba (OLIVI, 1792) | X | | | | |
| Corbula revoluta (BROCCHI, 1814) | | | | | |

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defined in the original description and figured by Huber (2015, pg.: 162). This difference led us to classify the specimens of Vale do Freixo as Spaniorinus ambiguus (NYST and WESTENDORP, 1839) in previous works (Pimentel, 2018; Pimentel et al., 2018). However, its elliptical outline and dimensions match with Spaniorinus reconditus (P. FISCHER, 1872) referenced as well in the Pliocene of Huelva, in southern Spain (e.g. González-Delgado et al., 1984). In addition, the description of the hinge in the genus Sportella in Deshayes (1858, pg.: 593) matches that of our specimens. It seems imperative to revise and clarify these specimens from the Iberian Pliocene.

CONCLUSIONS

The Vale do Freixo fossil site, in the West Portuguese Margin of Iberia, yielded the most diverse and well-preserved marine faunal assemblages of Pliocene age reported in the area.

Twenty-three of the reported Bivalvia species were unknown in the Portuguese Pliocene (Ennucula laevigata, Gregariella sp., Neopycnodonte cochlear, Hinmites ercolanianus, Heteranomia squamula, Pododesmus squama, Limaria loscombi, Goodallia triangularis, Centrocardita aculeata, Megaxinus transversus, Loripinus fragilis, Phaxas pellucidus, Hiattella rugosa, Parvocardium scriptum, Bonepermella incarnata, Oudardia compressa, Gari tellinella, Cardilia michelottii, Diplodonta rotundata, Gouldia minima, Pitar rudis, Spaniorinus reconditus and Corbula michelottii). Moreover, twenty species are reported for the first time in the Pliocene of the Carnide area, in Pombal, in addition to the species mentioned above (Modiolus sp., Arca tetragona, Anadara diluvii, Anadara pectinata, Aequipecten opercularis, Flexopecten flexuosus, Hinmites crispus, Mimachlamys varia, Lima lima, Cardita calyculata, Cardites antiquatus, Acanthocardia aculeata, Papillicardium papillosum, Gastrana fragilis, Peronidia albicans, Gari depressa, Abra alba, Chama glyrphoides, Lutraria lutraria and Scacchia oblonga). Consequently, the diversity of Pliocene bivalves in the Mondego Basin has increased to 115 species.

The Mondego Basin should correspond to the northernmost Piacenzian occurrence area for thermophilic bivalve molluscs such as Cardilia michelottii and Procardium diluvianum. Further studies on cardiliidae specimens from Huelva and Vale do Freixo would be needed to verify that a distinct Pliocene cardiliid species of Atlantic distribution does exist, although close to the Mediterranean Cardilia michelottii. It would be also convenient to revise the taxonomic status of the Spaniorinus specimens from the Iberian Pliocene. The results of the present work on the Pliocene bivalves of Portugal emphasize the importance of the Mondego Basin and the Estremadura mountain ranges, in the biogeographic knowledge of the Atlantic marine faunas of Europe, and their relations with the Mediterranean and North-African warmer ones.

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