**APPENDIX S1**

*Tables and table captions*

**TABLE S1.** List of the taxa found in the Peniche belemnite assemblage from Peniche from the Upper Pliensbachian to Lower Toarcian.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  | *Hastitidae* sp. indet. | *P. bisulcata* | *C. longiforma* | *Par.aff. zieteni* | *P. milleri* | *Passaloteuthis* sp. juv | *Acrocoelites* sp*.* indet. | *B. amaliae*  | indeterminable |  |  |
| **Zone** | **Subzone** | **bed** | **bed** |  |  |  |  |  |  |  |  |  | **n** | **total** |
| Levisoni | Elegantulum/ Levisoni | P10 | P133 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 9 | 2 | 11 |
| Polymorphum | Semicelatum | P9c | P24 | 0 | 3 | 8 | 0 | 1 | 1 | 0 | 0 | 1 | 13 | 14 |
| P9b | P20 | 0 | 0 | 12 | 2 | 0 | 0 | 0 | 0 | 3 | 14 | 17 |
| P9a | P16 | 0 | 3 | 29 | 1 | 1 | 1 | 0 | 0 | 1 | 35 | 36 |
| P8 | P14 | 0 | 9 | 57 | 2 | 1 | 1 | 0 | 0 | 5 | 70 | 75 |
| P7 | P12 | 0 | 5 | 20 | 2 | 4 | 2 | 0 | 0 | 6 | 33 | 39 |
| P6 | P8 | 0 | 14 | 31 | 5 | 1 | 5 | 0 | 0 | 12 | 56 | 68 |
| Mirabile/ Paltum | P5 | P984 | 12 | 27 | 65 | 3 | 0 | 4 | 0 | 0 | 68 | 111 | 179 |
| Emaciatum | Elisa/ Hawskerense | P4 | P982 | 32 | 26 | 106 | 8 | 2 | 0 | 0 | 0 | 35 | 174 | 209 |
| P3b | P976 | 6 | 8 | 31 | 2 | 0 | 0 | 0 | 0 | 3 | 47 | 50 |
| P3a | P961 | 3 | 20 | 0 | 3 | 7 | 9 | 0 | 50 | 6 | 92 | 98 |
| P2 | P949 | 3 | 26 | 0 | 0 | 7 | 0 | 0 | 43 | 12 | 79 | 91 |
| Apyrenum | P1 | P925 | 0 | 12 | 0 | 0 | 10 | 6 | 0 | 15 | 1 | 43 | 44 |

**TABLE S2.** List of the belemnite specimens collected in the Peniche section from the Upper Pliensbachian to Lower Toarcian interval.

**TABLE S3.** Micro-CT phoenix v|tome|x s 240 (Research Edition) scanner settings for the scanned belemnite specimens from the Peniche section. The reconstruction was made with the GEDatos|x 2.4 software. Subsequent image stack processing (e.g. subsampling), as well as the measurements and volume acquisition, was derived using Studio Volume Graphics Max™ v 3.0 software (Heidelberg). See Rita *et al.* (2019).

**TABLE S4.** List of the belemnite specimens collected in the Rodiles section (Asturian Basin) from the Upper Pliensbachian to Lower Toarcian interval (unpublished data, PR field collection).

**TABLE S5.** List of the belemnite specimens collected in the Fresney-le-Puceux section (Normandy, Western Paris Basin) from the Upper Pliensbachian to Lower Toarcian interval (unpublished data, PR field collection).

**TABLE S6.** Diversity dataset comprising of a compilation of both literature and field belemnite data. Key: S = species richness; n=number of specimens.

**TABLE S7.** Main morphometric parameters of the *Bairstowius amaliae* specimens found in the Peniche (Lusitanian Basin, Portugal) belemnite assemblage of the Upper Pliensbachian: total preserved length (L); length of the rostrum solidum (apical length, l); alveolar angle (AA); dorso-ventral diameter (Dv), lateral diameter (Dl) at the protoconch level, cross section distance from protoconch to ventral side (Rv) or to dorsum side (Rd), eccentricity of the protoconch (E) and compression index (CI).

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Specimen | AA (°) | Rd (mm) | Rv (mm) | E | L /l (with epirostrum) (mm) | L/l(orthorostrum) (mm) | Dv (mm) | Dl (mm) | CI |
| 2018.10.843 | 20.31 | 2.95 | 3.08 | -2.16 | 63.38/49.38 | 49.01/35.25 | 6.03 | 5.61 | 1.07 |
| 2018.10.809  | 19.42 | 2.76 | 2.63 | 2.41 | 88.19/66.19 | 51.00/29.00 | 5.39 | 4.82 | 1.12 |
| 2018.10.815 | 22.22 | 2.99 | 2.82 | 2.93 | 58.62/46.48 | 52.70/41.46 | 5.81 | 5.1 | 1.14 |
| 2018.10.887 | 22.93 | 2.24 | 2.55 | -6.47 | - | 58.15/44.65 | 4.79 | 4.56 | 1.05 |
| 2018.10.911 | 22.73 | 1.78 | 1.78 | 0 | - | 43.44/33.13 | 3.56 | 3.51 | 1.01 |

**TABLE S8.** Main morphometric parameters of the Hastitidaesp. indet. specimensfound in the Peniche (Lusitanian Basin, Portugal) belemnite assemblage of the Upper Pliensbachian – lowermost Toarcian interval: total preserved length (L); length of the rostrum solidum (apical length, l); alveolar angle (AA); dorso-ventral diameter (Dv), lateral diameter (Dl) at the protoconch level, cross section distance from protoconch to ventral side (Rv) or to dorsum side (Rd), eccentricity of the protoconch (E) and compression index (CI).

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Specimen | AA (º) | Rd (mm) | Rv (mm) | E | L (mm) |  l(mm) | Dv (mm) | Dl (mm) | CI |
| 2018.10.473 | 23.12 | 2.31 | 2.37 | -1.28 | 33.03 | 20.23 | 4.68 | 5.02 | 0.93 |
| 2018.10.508 | 19.25 | 1.79 | 2 | -5.54 | 15.43 | 10.85 | 3.79 | 3.95 | 0.95 |
| 2018.10.495 | 25.02 | 2.27 | 2.26 | 0.22 | 30.67 | 18.61 | 4.53 | 4.87 | 0.93 |
| 2018.10.490 | 22.23 | 1.61 | 1.79 | -5.29 | 25 | 18.01 | 3.4 | 3.6 | 0.94 |
| 2018.10.507 | 21.9 | 1.92 | 2.03 | -2.78 | 26 | 14.65 | 3.95 | 4.26 | 0.93 |

**TABLE S9.** Main morphometric parameters of the Catateuthis longiforma specimens found in the Peniche (Lusitanian Basin, Portugal) belemnite assemblage of the Upper Pliensbachian - lowermost Toarcian interval: alveolar angle (AA), compression index (CI), lateral (Dl) and dorso-ventral diameter (Dv) at the protoconch level, eccentricity of the protoconch (E), length of the rostrum solidum (apical length, l), total preserved length (L) and cross section distance from protoconch to dorsum side (Rd) or to ventral side (Rv).

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Specimen | AA (°) | Rd (mm) | Rv (mm) | E | L /l (with epirostrum) (mm) | L/l(orthorostrum) (mm) | Dv (mm) | Dl (mm) | CI |
| 2018.10.475 | 22.92 | 2.11 | 1.93 | 4.46 | - | 23.05/16.66 | 4.04 | 3.86 | 1.05 |
| 2018.10.279 | 22.21 | 2.93 | 2.01 | 18.33 | - | 23.77/20.78 | 5.02 | 4.92 | 1.02 |
| 2018.10.284 | 22 | 2.95 | 3.26 | -5.28 | - | 34.17/21.94 | 5.87 | 5.59 | 1.05 |
| 2018.10.288 | 18.78 | 2.7 | 2.93 | -4.09 | 29.87 | 21.68 | 5.63 | 4.85 | 1.16 |
| 2018.10.136 | 23.66 | 2.29 | 2.41 | -2.60 | 48.6 | 38.58 | 4.61 | 4.73 | 0.97 |
| 2018.10.497 | 24.72 | 3.57 | 3.23 | 5.00 | 66.62/52.89 | 41.87/27.6 | 6.8 | 6.45 | 1.05 |
| 2018.10.499 | 26.84 | 3.25 | 3.16 | 1.42 | 48.01/39.98 | 30.69/19.51 | 6.35 | 6.18 | 1.03 |

**TABLE S10.** Main morphometric parameters of the *Parapassaloteuthis* aff. *zieteni* specimens found in the Peniche (Lusitanian Basin, Portugal) belemnite assemblage of the Upper Pliensbachian-lowermost Toarcian interval: alveolar angle (AA), compression index (CI), lateral (Dl) and dorso-ventral diameter (Dv) at the protoconch level, eccentricity of the protoconch (E), length of the rostrum solidum (apical length, l), total preserved length (L) and cross section distance from protoconch to dorsum side (Rd) or to ventral side (Rv).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Specimen | AA (°) | Rd (mm) | Rv (mm) | E | l (mm) | L (mm) | Dv (mm) | Dl (mm) |
| 2018.10.199 | 23.97 | 4 | 3.18 | 11.42 | 20.02 | 38.09 | 7.18 | 6.96 |
| 2018.10.201 | 23.35 | 4.84 | 4.2 | 7.08 | 25.43 | 36.43 | 9.04 | 8.97 |
| 2018.10.202 | 22.84 | 5.02 | 4.22 | 8.66 | 22.51 | 35.71 | 9.24 | 9 |
| 2018.10.155 | 24.28 | 5.09 | 3.74 | 15.29 | 24.16 | 34.4 | 8.83 | 8.72 |
| 2018.10.079 | 21.3 | 4.36 | 3.47 | 11.37 | 21.28 | 29.37 | 7.83 | 7.44 |

**TABLE S11.** Main morphometric parameters of the *Passaloteuthis bisulcata* specimens found in the Peniche section (Lusitanian Basin, Portugal) of the Upper Pliensbachian - lowermost Toarcian interval: alveolar angle (AA), compression index (CI), lateral (Dl) and dorso-ventral diameter (Dv) at the protoconch level, eccentricity of the protoconch (E), length of the rostrum solidum (apical length, l), total preserved length (L) and cross section distance from protoconch to dorsum side (Rd) or to ventral side (Rv).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Specimen | AA (°) | Rd (mm) | Rv (mm) | E | L (mm) | l (mm) | Dv (mm) | Dl (mm) |
| 2018.10.263 | 20.43 | 7.86 | 6.09 | 12.84 | 53.34 | 36 | 13.78 | 14.41 |
| 2018.10.261 | 24.36 | 10.13 | 6.57 | 22.56 | 92.58 | 51.61 | 15.78 | 14.69 |
| 2018.10.390 | 20.04 | 8.39 | 6.33 | 14.48 | 89.32 | 50.27 | 14.23 | 14.9 |
|
| 2018.10.391 | 22.45 | 6.82 | 4.61 | 18.46 | 60.45 | 37.03 | 11.97 | 11.86 |

**TABLE S12.** Main morphometric parameters of the *Passaloteuthis milleri* specimens found in the Peniche (Lusitanian Basin, Portugal) belemnite assemblage of the Upper Pliensbachian - lowermost Toarcian interval: alveolar angle (AA), compression index (CI), lateral (Dl) and dorso-ventral diameter (Dv) at the protoconch level, eccentricity of the protoconch (E), length of the rostrum solidum (apical length, l), total preserved length (L) and cross section distance from protoconch to dorsum side (Rd) or to ventral side (Rv).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Specimen | AA (°) | Rd (mm) | Rv (mm) | E | L (mm) | l (mm) | Dv (mm) | Dl (mm) |
| 2018.10.888 | 25.24 | 4.29 | 4.17 | 1.42 | 52.38 | 25.81 | 8.44 | 8.37 |
| 2018.10.186 | 23.48 | 3.63 | 3.16 | 6.89 | 34.82 | 22.87 | 6.82 | 6.59 |

**TABLE S13.** Main morphometric parameters of the *Passaloteuthis* sp. juv. specimens found in the Peniche (Lusitanian Basin, Portugal) belemnite assemblage of the Upper Pliensbachian - lowermost Toarcian interval: alveolar angle (AA), compression index (CI), lateral (Dl) and dorso-ventral diameter (Dv) at the protoconch level, eccentricity of the protoconch (E), length of the rostrum solidum (apical length, l), total preserved length (L) and cross section distance from protoconch to dorsum side (Rd) or to ventral side (Rv).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Specimen | AA (°) | Rd (mm) | Rv (mm) | E | L (mm) | l (mm) | Dv (mm) | Dl (mm) |
| 2018.10.890 | 22.19 | 3.9 | 2.89 | 15.33 | 38.93 | 20.04 | 6.59 | 6.65 |
| 2018.10.893 | 24.07 | 3.6 | 2.81 | 12.19 | 36.89 | 18.93 | 6.48 | 6.62 |

**TABLE S14.** Main morphometric parameters of one of the *Acrocoelites* sp. indet. specimens found in the Peniche (Lusitanian Basin, Portugal) belemnite assemblage of the Lower Toarcian: lateral diameter (Dl) and dorso-ventral diameter (Dv) at the protoconch level, total preserved length (L) and length of the rostrum solidum (apical length, l).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Specimen | L (mm) | l (mm) | Dv (mm) | Dl (mm) |
| 2018.10.002 | 141.26 | 98.94 | 13.78 | 12.95 |

**TABLE S15.** Palaeobioeographic distribution of belemnite families during the Late Pliensbachian (Margaritatus Zone) to the Early Toarcian (Levisoni Zone) in the NW Tethys (Euro-Boreal and Mediterranean/Submediterranean domains) and Arctic Domain: Russia (N Siberia, Sachs and Nalnjaeva 1967), Cleveland Basin (Caswell and Coe 2014), Swabo-Franconian Basin (Schlegelmilch 1998; Riegraf et al. 1984), Western Paris Basin (Weis et al. 2018 and additional unpublished data), Eastern Paris Basin (Luxembourg, Linger section, unpublished data), Morocco (South Riffian Basin; Sanders et al. 2015), Causses Basin (Pinard et al. 2014), Italy (Apennines; Weis et al. 2015), Lusitanian and Asturias basins (this work) and Austria (Northern Calcareous Alps; Weis and Thuy 2015).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Family | **Passaloteuthididae** | **Hastitidae** | **?Holcobelidae** | **Megateuthididae** |
|  |   | Genus | ***Nannobelus*** | ***Coeloteuthis*** | ***Passaloteuthis*** | ***Gastrobelus*** | ***Pleurobelus*** | ***Parapassaloteuthis*** | ***Micropassaloteuthis*** | ***Catateuthis*** | ***Subhastites*** | **NA** | ***Bairstowius*** | ***Lissajousibelus*** | ***Simpsonibelus*** | ***Youngibelus* (= *Cusp.*)** | ***Acrocoelites*** | ***Rarobelus*** | ***Arcobelus*** | ***Megateuthis*** | ***Odontobelus*** |
| Toarcian (Levisoni Zone) | **Arctic Domain** | Russia/Siberia |   |   | o |   |   |   |   | o |   |   |   |   |   |   | o | o | o | o | o |
| **Euro Boreal Domain** | Cleveland B. |   |  |  |  |  | o |  |   |  |  |   |   | o | o | o |  |  |  |   |
| Swabo-Franconian B. |   |  |  |  |  |  |  |   |  |  |   |   |  | o | o |  |  |  |   |
| W Paris B. |   |  |  |  |  |  |  |   |  |  |   | o |  |  | o |  |  |  |   |
| Causses B. |   |  |  |  |  |  |  |   |  |  |   |   |  |  | o |  |  |  |   |
| Asturian B. |   |  |  |  |  |  |  |   |  |  |   |   |  |  | o |  |  |  |   |
| **(Sub)Mediterranean Domain** | Lusitanian B. |   |   |   |   |   |   |   |   |   |   |   |   |   |   | o |   |   |   |   |
| South Riffian B. |   |   | ? |   |   | o |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Italy |   |   |   |   |   |   |   |   |   |   |   |   |   | o |   |   |   |   |   |
| Toarcian (Polymorphum Zone) | **Euro Boreal Domain** | Cleveland B. |   |   | o |   |   | o |   | o |   |   |   |   |   |   |   |   |   |   |   |
| Swabo-Franconian B. |   |  | o |  |  | o | o |   |  |  |  |   |  |  | o |  |  |  |   |
| W Paris B. |   |  | o |  |  | o |  | o |  |  |  | o |  |  |  |  |  |  |   |
| E Paris B. |   |  | o |  |  |  |  |   |  |  |  |   |  |  | ? |  |  |  |   |
| Causses B. | not well constrained stratigraphically |
| Asturian B. |   |  | o |  |  | o |  | ? | o | o |  | o |  |  |  |  |  |  |   |
| **(Sub)Mediterranean Domain** | Lusitanian B. |   |   | o |   |   | o |   | o |   | o |   |   |   |   |   |   |   |   |   |
| South Riffian B. |   |   | o |   |   | o |   | o |   |   |   |   |   |   |   |   |   |   |   |
| Italy |   |   | o |   |   |   |   | o |   |   |   |   |   |   |   |   |   |   |   |
|  Pliensbachian (Emaciatum Zone) | **Euro Boreal Domain** | Cleveland B. |   |   | o |   |   | o |   | o |   |   |   |   |   |   |   |   |   |   |   |
| Swabo-Franconian B. |   |  | o | o |  | o |  | o |  |  |  |   |  |  |  |  |  |  |   |
| W Paris B. |   |  | o |  |  |  |  | o |  |  |  | o |  |  |  |  |  |  |   |
| E Paris B. |   |  | o |  |  | o |  | o |  | o |  |   |  |  |  |  |  |  |   |
| Causses B. | not well constrained stratigraphically |
| Asturian B. |   |  | o |  |  | o |  | ? | o | o |  |   |  |  |  |  |  |  |   |
| **(Sub)Mediterranean Domain** | Lusitanian B. |   |   | o |   |   | o |   | o |   | o | o |   |   |   |   |   |   |   |   |
| South Riffian Basin | no belemnites observed |
| Italy |   |   |   |   | o |   |   | o |   |   |   |   |   |   |   |   |   |   |   |
| Pliensbachian (Margaritatus Zone) | **Euro Boreal Domain** | Cleveland B. | no published data available at this resolution |
| SF Basin |   | o | o | o | o |  |  |   | o |  |  |   |  |  |  |  |  |  |   |
| Austria | o | o | o |  |  |  |  |   |  |  |  |   |  |  |  |  |  |  |   |
| W Paris B. |   |  | o |  | o |  |  |   |  |  |  |   |  |  |  |  |  |  |   |
| E Paris B. |   |  |  |  |  |  |  |   |  |  |  |   |  |  |  |  |  |  |   |
| Causses B. |   |  | o |  | o | ? |  | o |  |  |  |   |  |  |  |  |  |  |   |
| Asturian B. | no published data available |
| **(Sub)Mediterranean Domain** | Lusitanian B. | no published data available |
| South Riffian Basin | no belemnites observed |
| Italy |   |   | o |   | o |   |   | o |   |   |   |   |   |   |   |   |   |   |   |

*Figures and figure captions*

**FIGURE S1.**

 

**FIG. S1**.  Analysis of similarities (ANOSIM) plot showing dissimilarity between and within ammonite zones of belemnite assemblage composition. Bold horizontal bar in box indicates median; bottom of box indicates 25th percentile; top of box indicates 75th percentile; whiskers extend to the most extreme data point; width of bar directly proportional to sample size. The ANOSIM statistic R is based on the difference of mean ranks between groups and within groups. Key: Between, between-group dissimilarity.



**FIG. S2.** Number of belemnite species (S) during the Upper Pliensbachian-Middle Toarcian (Apyrenum - Variabilis Subzone) in the Western Tethys Ocean (this work; Riegraf *et al.* 1984; Caswell and Coe 2014).