## Supplementary Information for:

# Predatory behaviour and taphonomy of a Jurassic belemnoid coleoid (Diplobelida, Cephalopoda)

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# Supplementary Information

## Appendix 1: Volume calculations

### Head:

1. *Clarkeiteuthis conocauda* (Supplementary figure 6A)

$$cos\alpha = \frac{\frac{r}{2}}{r} \rightarrow \alpha = cos^{-1}\frac{\frac{r}{2}}{r} = \frac{\frac{1.9}{2}}{1.9} = 60° \rightarrow \gamma = 2 \cdot \alpha = 120° = 2.09439rad$$

$$A_{Segment} = \frac{r^2}{2}(\gamma - sin\gamma) = \frac{1.625^2}{2}(2.09439 - sin2.09439) = 1.622cm^2$$

$$A_{Remainder} = r^2\pi - A_{Segment} = 6.67cm^2$$

$$V = A_{Remainder} \cdot h = 6.67cm^2 \cdot 1.5cm = 10.56cm^3$$

2. *Passaloteuthis*

$$cos\alpha = \frac{\frac{r}{2}}{r} \rightarrow \alpha = cos^{-1}\frac{\frac{r}{2}}{r} = \frac{\frac{1.2}{2}}{1.2} = 60° \rightarrow \gamma = 2 \cdot \alpha = 120° = 2.09439rad$$

$$A_{Segment} = \frac{r^2}{2}(\alpha - sin\alpha) = \frac{1.2^2}{2}(2.09439 - sin2.09439) = 0.884cm^2$$

$$A_{Remainder} = r^2\pi - A_{Segment} = 3.64cm^2$$

$$V = A_{Remainder} \cdot h = 3.64cm^2 \cdot 2.2cm = 7.94cm^3$$

3. *Hibolithes semisulcatus*

$$cos\alpha = \frac{\frac{r}{2}}{r} \rightarrow \alpha = cos^{-1}\frac{\frac{r}{2}}{r} = \frac{\frac{3}{2}}{3} = 60° \rightarrow \gamma = 2 \cdot \alpha = 120° = 2.09439rad$$

$$A_{Segment} = \frac{r^2}{2}(\alpha - sin\alpha) = \frac{3^2}{2}(2.09439 - sin2.09439) = 5.528cm^2$$

$$A_{Remainder} = r^2\pi - A_{Segment} = 22.75cm^2$$

$$V = A_{Remainder} \cdot h = 22.75cm^2 \cdot 5cm = 113.73cm^3$$

## Body:

(Supplementary figure 6B)

1. *Clarkeiteuthis conocauda*

$$V = \frac{h\pi}{3}(R^2 + Rr + r^2) = \frac{7.75\pi}{3}(1.75^2 + 1.75 * 2.375 + 2.375^2) = 104.364cm^3$$

2. *Passaloteuthis*

$$V = \frac{h\pi}{3}(R^2 + Rr + r^2) = \frac{6.77\pi}{3}(1.2^2 + 1.2 * 1.96 + 1.96^2) = 108.856cm^3$$

3. *Hibolithes semisulcatus*

$$V = \frac{h\pi}{3}(R^2 + Rr + r^2) = \frac{10.5\pi}{3}(3^2 + 3 * 3.5 + 3.5^2) = 349.109cm^3$$

## Rostrum solidum:

(Supplementary figure 6C)

1. *Clarkeiteuthis conocauda*

$$V = r^2\pi h\tfrac{1}{3} = \ 0cm^3$$

2. *Passaloteuthis*

$$V = r^2\pi h\frac{1}{3} = \ 0.82cm^2 \cdot \pi \cdot 9.82cm \cdot \frac{1}{3} = 6.88\ cm^3$$

3. *Hibolithes semisulcatus*

$$V = r^2\pi h\frac{1}{3} = \ 0.62cm^2 \cdot \pi \cdot 15.5cm \cdot \frac{1}{3} = 6.24\ cm^3$$

## Rostrum cavum/ sheath:

(Supplementary figure 6C)

1. *Clarkeiteuthis conocauda* (Sheath)

$V = V_1 - V_{phragmocone}$

$V_1 = r_1{}^2 \pi h \frac{1}{3} = 2.4^2 \cdot \pi \cdot 6.4 \cdot \frac{1}{3} = 38.604 cm^3$

$V_{phragmocone} = r_2{}^2 \pi h \frac{1}{3} = 2.375^2 \cdot \pi \cdot 6.375 \cdot \frac{1}{3} = 37.656 cm^3$

$V_{Total} = V_1 - V_2 = 0.948 cm^3$

2. *Passaloteuthis* (Rostrum cavum)

$V = V_1 - V_{phragmocone}$

$V_1 = \frac{\pi h}{3} \cdot (R^2 + Rr + r^2) = \frac{\pi 1.75}{3} \cdot (0.82^2 + 0.82 \cdot 1.47 + 1.47^2) = 9.94 cm^3$

$V_{phragmocone} = r^2 \pi h \frac{1}{3} = 1.47^2 \cdot \pi \cdot 1.75 \cdot \frac{1}{3} = 3.97 cm^3$

$V = V_1 - V_{phragmocone} = 9.94 cm^3 - 3.97 cm^3 = 5.97 cm^3$

3. *Hibolithes semisulcatus* (Rostrum cavum)

$V = V_1 - V_{phragmocone}$

$V_1 = \frac{\pi h}{3} \cdot (R^2 + Rr + r^2) = \frac{\pi 7.6}{3} \cdot (2^2 + 2 \cdot 0.62 + 0.62^2) = 44.763 cm^3$

$V_{phragmocone} = r_1{}^2 \pi h \frac{1}{3} = 2^2 \cdot \pi \cdot 7.6 \cdot \frac{1}{3} = 31.834 cm^3$

$V = V_1 - V_{phragmocone} = 44.763 cm^3 - 31.834 cm^3 = 10.920 cm^3$

**Arms:**

(Supplementary figure 6D)

1. *Clarkeiteuthis conocauda*

Approximation: $f(x) = \sqrt{ax}$

I. $\sqrt{a \cdot 5.625} = 0.3125$

II. $a \cdot 5.625 = 0.0977$

III. $a = 0.01736$

IV. $f(x) = \sqrt{0.01736 \cdot x}$

$$V_{Onearm} = \pi \int_a^b f(x)^2 dx = \pi \int_0^{5.625} \sqrt{0.01736 \cdot x}^2 dx = 0.863 cm^3$$

$$V_{10arms} = 8.63 cm^3$$

2. *Passaloteuthis*

Approximation: $f(x) = \sqrt{ax}$

V. $\sqrt{a \cdot 10.76} = 0.38$

VI. $a \cdot 10.76 = 0.14$

VII. $a = 0.01321$

VIII. $f(x) = \sqrt{0.01321x}$

$$V_{Onearm} = \pi \int_a^b f(x)^2 dx = \pi \int_0^{10.76} \sqrt{0.01321x}^2 dx = 2.40 cm^3$$

$$V_{10arms} = 24.02 cm^3$$

3. *Hibolithes semisulcatus*

Approximation: $f(x) = \sqrt{ax}$

IX. $\sqrt{a \cdot 7} = 0.5$

X. $a \cdot 7 = 0.25$

XI. $a = 0.0357$

XII. $f(x) = \sqrt{0.0357x}$

$$V_{Onearm} = \pi \int_a^b f(x)^2 dx = \pi \int_0^7 \sqrt{0.0357x}^2 dx = 2.75cm^3$$

$$V_{10arms} = 27.5cm^3$$

## Proostracum:

(Supplementary figure 6E)

1. *Clarkeiteuthis conocauda*

$$A_{Rectangleminimum} = 2 \cdot r_{minimum} \cdot (h_{total} - r_{minimum}) = 2 \cdot 0.5cm \cdot (3.5cm - 0.5cm) = 3cm^2$$

$$A_{Rectanglemaximum} = 2 \cdot r_{maximum} \cdot (h_{total} - r_{maximum}) = 2 \cdot 1cm \cdot (6cm - 1cm) = 10cm^2$$

$$A_{Semicircleminimum} = \frac{r^2\pi}{2} = \frac{0.5^2\pi}{2} = 0.393cm^2$$

$$A_{Semicirclemaximum} = \frac{r^2\pi}{2} = \frac{1^2\pi}{2} = 1.571cm^2$$

$$V_{minimum} = \left(A_{Rectangleminimum} + A_{Semicircleminimum}\right) \cdot 0.01cm = 0.034cm^3$$

$$V_{maximum} = \left(A_{Rectanglemaximum} + A_{Semicirclemaximum}\right) \cdot 0.05cm = 0.579cm^3$$

2. *Passaloteuthis*

$$A_{Rectangle} = 2 \cdot r \cdot (h_{total} - r) = 2 \cdot 1.1cm \cdot (6 - 1.1) = 10.71cm^2$$

$$A_{Semicircle} = \frac{r^2\pi}{2} = \frac{1.1^2\pi}{2} = 1.87cm^2$$

$$V_{minimum} = \left(A_{Rectangle} + A_{Semicircle}\right) \cdot 0.01cm = 0.126cm^3$$

$$V_{maximum} = \left(A_{Rectangle} + A_{Semicircle}\right) \cdot 0.05cm = 0.629cm^3$$

3. *Hibolithes semisulcatus*

$$A_{Rectangle} = 2 \cdot r \cdot (h_{total} - r) = 2 \cdot 2.4cm \cdot (9 - 2.4) = 31.68cm^2$$

$$A_{Semicircle} = \frac{r^2\pi}{2} = \frac{2.4^2\pi}{2} = 9.05cm^2$$

$$V_{minimum} = \left(A_{Rectangle} + A_{Semicircle}\right) \cdot 0.01cm = 0.407cm^3$$

$$V_{maximum} = \left(A_{Rectangle} + A_{Semicircle}\right) \cdot 0.05cm = 2.036cm^3$$

## Phragmocone

(Supplementary figure 6G)

1. *Clarkeiteuthis conocauda*

$$V_1 = {r_1}^2 \pi h \frac{1}{3} = 2.375^2 \cdot \pi \cdot 6.375 \cdot \frac{1}{3} = 37.66cm^3$$

$$V_2 = {r_2}^2 \pi h \frac{1}{3} = 2.370^2 \cdot \pi \cdot 6.370 \cdot \frac{1}{3} = 37.47cm^3$$

$$V_{Total} = V_1 - V_2 = 0.188cm^3$$

2. *Passaloteuthis*

$$V_1 = {r_1}^2 \pi h \frac{1}{3} = 1.8^2 \cdot \pi \cdot 6.3 \cdot \frac{1}{3} = 21.38cm^3$$

$$V_2 = {r_2}^2 \pi h \frac{1}{3} = 1.795^2 \cdot \pi \cdot 6.295 \cdot \frac{1}{3} = 21.24cm^3$$

$$V_{Total} = V_1 - V_2 = 0.136cm^3$$

3. *Hibolithes semisulcatus*

$$V_1 = {r_1}^2 \pi h \frac{1}{3} = 2^2 \cdot \pi \cdot 7.6 \cdot \frac{1}{3} = 31.83cm^3$$

$$V_2 = {r_2}^2 \pi h \frac{1}{3} = 1.995^2 \cdot \pi \cdot 7.595 \cdot \frac{1}{3} = 31.66cm^3$$

$$V_{Total} = V_1 - V_2 = 0.179cm^3$$

## Phragmocone sections

(Supplementary figure 6)

Approximation: $f(x) = \sqrt{ax}$

I. $\sqrt{a \cdot \frac{r}{5}} = r$

II. $\frac{ar}{5} = r^2$

III. $\frac{a}{5} = r$

IV. $a = 5r$

V. $f(x) = \sqrt{5r \cdot x}$

$V = A \cdot h$

$$A = 2\pi \int_0^{\frac{r}{5}} f(x) \cdot \sqrt{1 + f'(x)^2} dx = 2\pi \int_0^{\frac{r}{5}} \sqrt{5r \cdot x} * \sqrt{1 + \frac{5r^2}{4x}}\ dx$$

*Clarkeiteuthis conocauda* total volume: 0.696 $cm^3$ (see Supplementary table 1).

*Passaloteuthis* total colume: 0.507 $cm^3$ (see Supplementary table 2).

*Hibolithes semisulcatus* total volume: 0.3886 $cm^3$ (see Supplementary table 3).

## Supplementary Reference

84. Fuchs, D. Fossil erhaltungsfähige Merkmalskomplexe der Coleoidea (Cephalopoda) und ihre phylogenetische Bedeutung. *Berliner Paläobiol. Abh.* **8**, 1–122 (2006).

# Supplementary Tables

| Septum | Radius (cm) | Height (cm) | A ($cm^2$) | Volume ($cm^3$) |
|---|---|---|---|---|
| 1 | 2.313 | 0.005 | 25.985 | 0.130 |
| 2 | 2.188 | 0.005 | 22.636 | 0.113 |
| 3 | 2.000 | 0.005 | 13.056 | 0.065 |
| 4 | 1.875 | 0.005 | 15.442 | 0.077 |
| 5 | 1.813 | 0.005 | 14.197 | 0.071 |
| 6 | 1.625 | 0.005 | 10.831 | 0.054 |
| 7 | 1.563 | 0.005 | 9.829 | 0.049 |
| 8 | 1.438 | 0.005 | 7.996 | 0.040 |
| 9 | 1.250 | 0.005 | 5.660 | 0.028 |
| 10 | 1.125 | 0.005 | 4.364 | 0.022 |
| 11 | 0.938 | 0.005 | 2.785 | 0.014 |
| 12 | 0.750 | 0.005 | 1.609 | 0.008 |
| 13 | 0.650 | 0.005 | 1.134 | 0.006 |
| 14 | 0.600 | 0.005 | 0.932 | 0.005 |
| 15 | 0.550 | 0.005 | 0.754 | 0.004 |
| 16 | 0.500 | 0.005 | 0.598 | 0.003 |
| 17 | 0.450 | 0.005 | 0.463 | 0.002 |
| 18 | 0.400 | 0.005 | 0.348 | 0.002 |
| 19 | 0.350 | 0.005 | 0.252 | 0.001 |
| 20 | 0.300 | 0.005 | 0.174 | 0.001 |
| 21 | 0.250 | 0.005 | 0.113 | 0.001 |
| 22 | 0.200 | 0.005 | 0.066 | 0.000 |

**Supplementary table 1.** Volume calculations for the septa of *Clarkeiteuthis conocauda.*

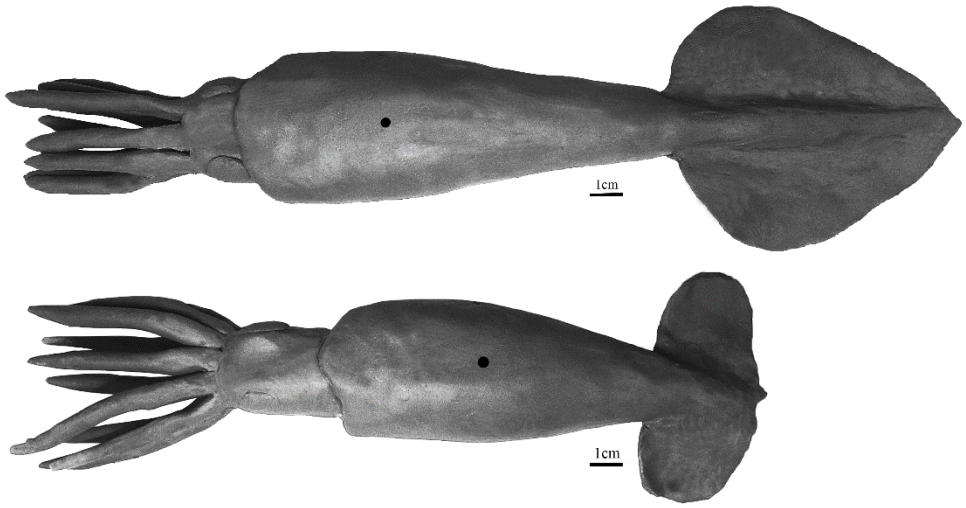
| Septum | Radius (cm) | Height (cm) | A ($cm^2$) | Volume ($cm^3$) |
|---|---|---|---|---|
| 1 | 1.8 | 0.005 | 13.955 | 0.069775 |
| 2 | 1.7 | 0.005 | 12.1121 | 0.0605605 |
| 3 | 1.6 | 0.005 | 10.4233 | 0.0521165 |
| 4 | 1.56 | 0.005 | 9.78989 | 0.0489495 |
| 5 | 1.52 | 0.005 | 9.18019 | 0.045901 |
| 6 | 1.4 | 0.005 | 7.49004 | 0.0374502 |
| 7 | 1.32 | 0.005 | 6.47594 | 0.0323797 |
| 8 | 1.28 | 0.005 | 6.00173 | 0.0300087 |
| 9 | 1.24 | 0.005 | 5.54899 | 0.027745 |
| 10 | 1.2 | 0.005 | 5.11737 | 0.0255869 |
| 11 | 1.1 | 0.005 | 4.12851 | 0.0206426 |
| 12 | 1 | 0.005 | 3.26409 | 0.0163205 |
| 13 | 0.9 | 0.005 | 2.51841 | 0.0125921 |
| 14 | 0.8 | 0.005 | 1.88548 | 0.0094274 |
| 15 | 0.7 | 0.005 | 1.35898 | 0.0067949 |
| 16 | 0.6 | 0.005 | 0.932085 | 0.0046604 |
| 17 | 0.5 | 0.005 | 0.597666 | 0.0029883 |
| 18 | 0.4 | 0.005 | 0.347844 | 0.0017392 |
| 19 | 0.3 | 0.005 | 0.17397 | 0.0008699 |
| 20 | 0.2 | 0.005 | 0.066265 | 0.0003313 |

**Supplementary table 2.** Volume calculations for the septa of *Hibolithes semisulcatus*.

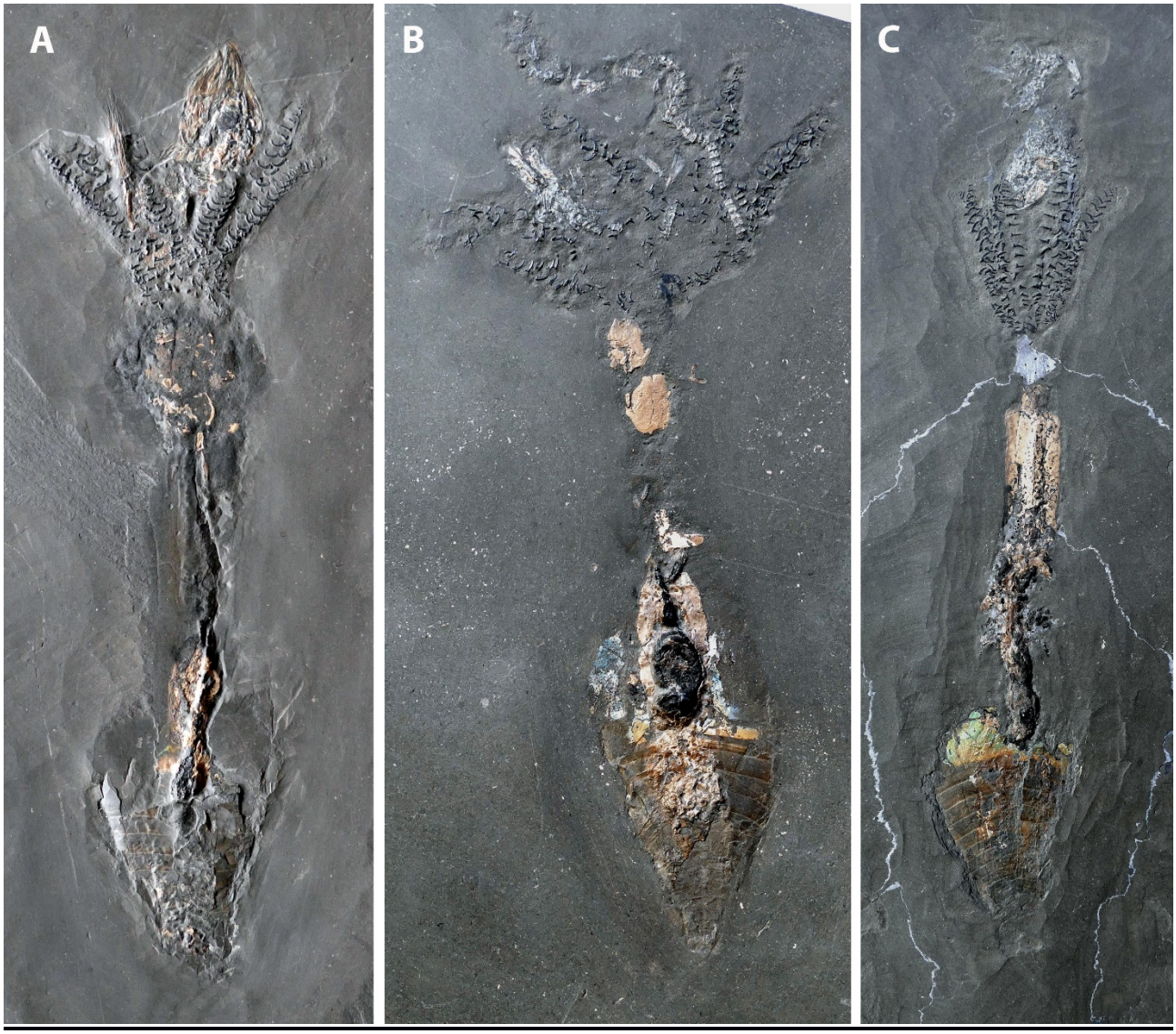
| Septum | Radius (cm) | Height (cm) | A ($cm^2$) | Volume ($cm^3$) |
|---|---|---|---|---|
| 1 | 2.000 | 0.005 | 13.056 | 0.065 |
| 2 | 1.800 | 0.005 | 13.955 | 0.070 |
| 3 | 1.700 | 0.005 | 12.112 | 0.061 |
| 4 | 1.500 | 0.005 | 8.884 | 0.044 |
| 5 | 1.350 | 0.005 | 6.846 | 0.034 |
| 6 | 1.300 | 0.005 | 6.236 | 0.031 |
| 7 | 1.200 | 0.005 | 5.117 | 0.026 |
| 8 | 1.000 | 0.005 | 3.264 | 0.016 |
| 9 | 0.800 | 0.005 | 1.886 | 0.009 |
| 10 | 0.740 | 0.005 | 1.557 | 0.008 |
| 11 | 0.680 | 0.005 | 1.266 | 0.006 |
| 12 | 0.620 | 0.005 | 1.010 | 0.005 |
| 13 | 0.560 | 0.005 | 0.788 | 0.004 |
| 14 | 0.500 | 0.005 | 0.598 | 0.003 |
| 15 | 0.440 | 0.005 | 0.438 | 0.002 |
| 16 | 0.380 | 0.005 | 0.307 | 0.002 |
| 17 | 0.320 | 0.005 | 0.203 | 0.001 |
| 18 | 0.260 | 0.005 | 0.124 | 0.001 |
| 19 | 0.200 | 0.005 | 0.066 | 0.000 |

**Supplementary table 3.** Volume calculations for the septa of *Hibolithes semisulcatus*.

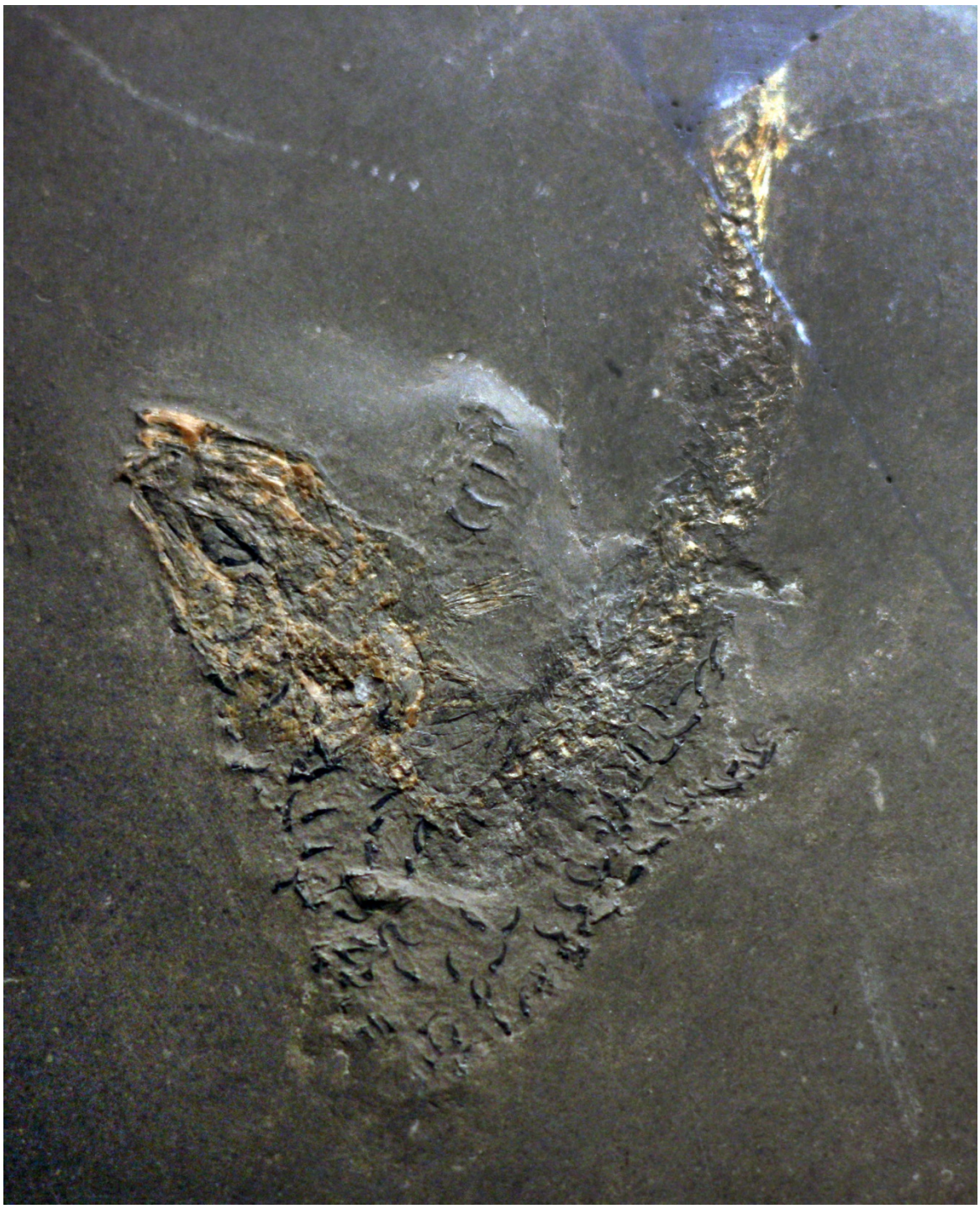
# Supplementary Figures




**Supplementary figure 1:** Top: Clay model of *Hibolithes semisculatus*, half natural size. Bottom: life-sized reconstruction of *Clarkeiteuthis conocauda.* Both made from clay. The black dot marks the center of buoyancy in each specimen. Fin sizes and shapes are hypothetical.

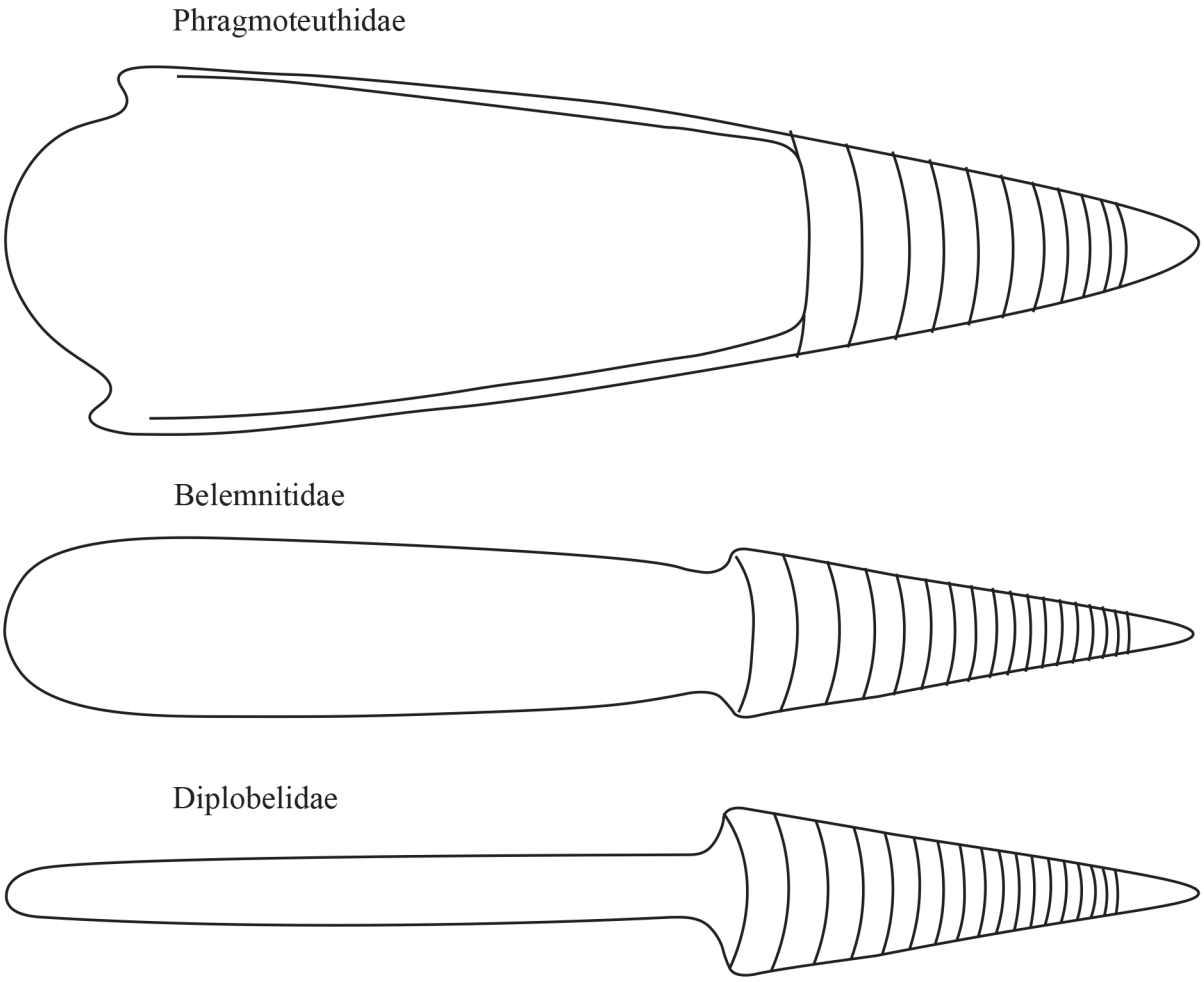



**Supplementary figure 2:** Additional specimens of *Clarkeiteuthis conocauda* with *Leptolepis bronni* in its arm crown; Posidonienschiefer, Toarcian, Early Jurassic of Holzmaden (Germany); all photos courtesy G. Schweigert (Stuttgart). A, specimen figured by J. Klaschka[10]. B, C, two specimens from the collection of G. Weber (Rechberghausen), both from the Koblenzer beds. B, note the fractured vertebral column and the head of the comparatively large fish pointing out of the arm crown; arms are spread. C, in this specimen, the rather small fish lies with the head facing the buccal mass; the arms are well preserved and contracted. Also note the partially phosphatized proostracum.

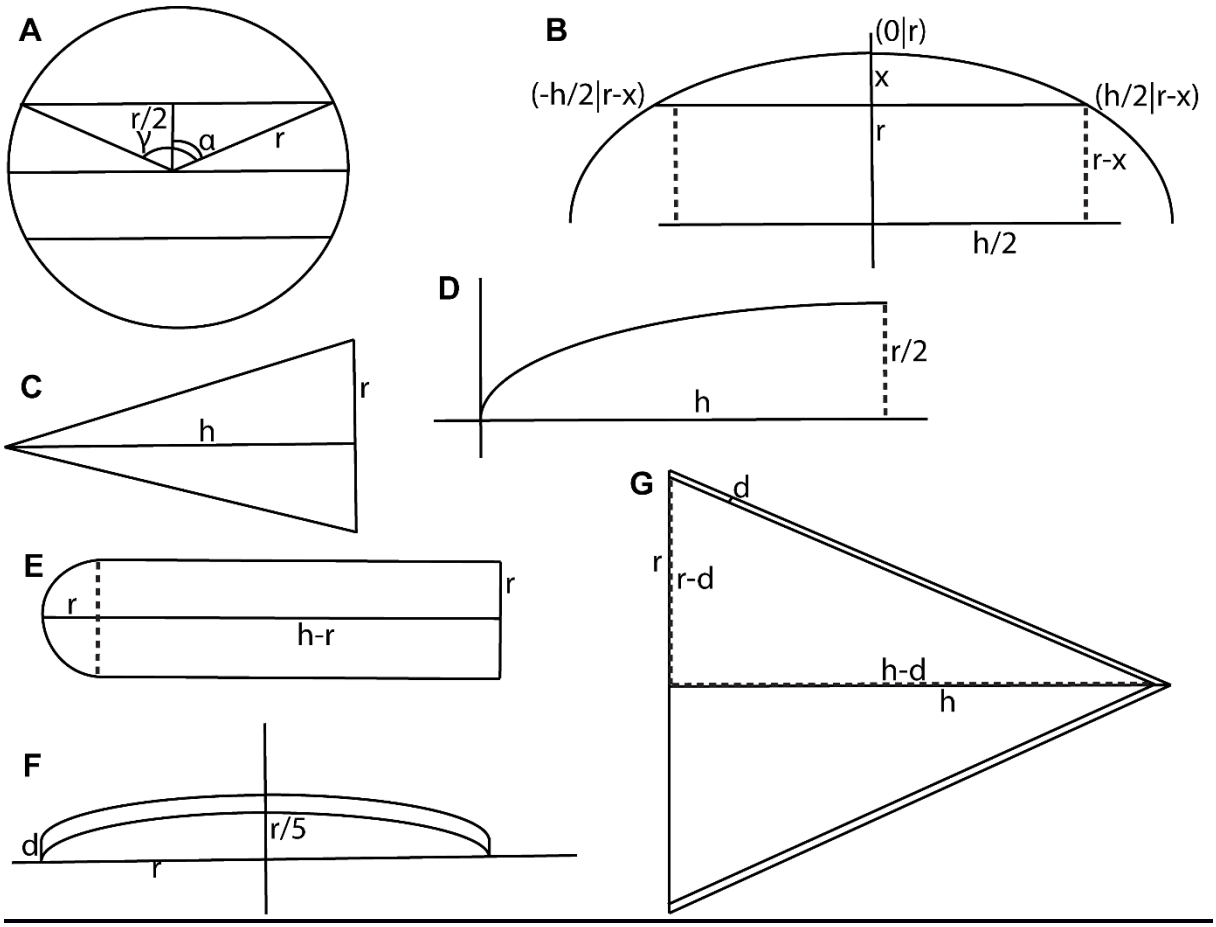


**Supplementary figure 3.** Counterpart of the main specimen of *Clarkeiteuthis conocauda* with *Leptolepis bronni* in its arm crown; Posidonienschiefer, Toarcian, Early Jurassic of Holzmaden (Germany). In this case, only the arm crown with the fish is preserved.


**Supplementary figure 4:** *Hibolithes* sp. indet., PIMUZ 24398; Herznach Formation, Callovian, Liesberg (Basel-Land, Switzerland). The specimen was whitened with $NH_4Cl$. 1. ventral, 2. lateral, 3. dorsal view the rostrum solidum.




**Supplementary figure 5:** Reconstructions of the hard parts (phragmocone and proostracum; without rostrum) of the Phragmoteuthida, Belemnitida and Diplobelida[83,84].




**Supplementary figure 6:** Graphs showing details of the geometric forms used for the volume calculations. A, graph of the head cross section. B, Graph of the body (longitudinal). C, Graph of the rostrum. D, Graph of an arm. E, Graph of the proostracum. F, *Graph of* one *septum* (cross section). G, graph of the whole phragmocone (without septa).