Supplementary material for Caswell, Coe and Cohen 2009

A compilation of Late Pliensbachian and Early Toarcian marine biotic changes

Table 1: Biotic changes close to the Pliensbachian – Toarcian boundary. The reader is referred to paper Fig. 4 for a graphical representation of these data (with the exception of those indicated below). The proportion of species extinctions is given; where extinction at family/order level has been established by the author this has been indicated; biotic changes amongst the phytoplankton are reported as the percentage decrease in relative abundance (rel. abund. decrease); NQ = biotic changes have not been quantified; assem. comp. change = composition of the faunal assemblage changes. Pls. = Pliensbachian; Toa. = Toarcian.

Taxon	Geographic locality	Stratigraphic position	Proportion sp. extinctions	Other faunal changes	References
Brachiopods	NW Caucausus	Pls. –Toa.	54/54		Ruban 2004
	Hungary	Pls. -Toa.	15/17		Vörös 1995
	Andean Basin	Pls. –Toa.	10/19		Riccardi *et al.* 1990
Bivalves	Andean Basin	Pls. –Toa.	31/55 [*, †]		Riccardi *et al.* 1990; Damborenea 2002; Aberhan & Baumiller 2003
Macroinverts.	Yorkshire	*c.* 0.5 m above Pls. –Toa.	9/29 [*]		Little 1995
Ammonites	Subboreal Submediterranean Mediterranean	*elisa* Subzone	5/7 4/4 6/23		Cecca & Macchioni 2004
	Yorkshire		1/1 family Amaltheidae		Little 1995
	Subboreal Submediterranean Mediterranean	*hawskerense-Paltum* Subzone boundary	1/3 1/3 12/32		Cecca & Macchioni 2004

Ostracods	Ilminster, Somerset, UK	Pls. –Toa.	8/11 family Metacopina		Boomer 1992
	Luisitanian Basin, Portugal	lower *tenuicostatum* Zone	15/35 family Metacopina		Boomer *et al*. 1998
	Andean Basin	nr. Pls. –Toa.	20/20		Riccardi *et al.* 1990
Forams	Arctic subrealm	*viligaensis* Zone	6/22		Zakharov *et al.* 2006
	NW Caucausus	nr. Pls. –Toa.	79/80		Ruban & Tsyzka 2005
	Andean Basin	nr. Pls. -Toa	29/29		Riccardi *et al.* 1990
	SW Germany S France Yorkshire Leicestershire	Pls. – Toa.	1/43	assemb. comp. change	Hylton 2000
Radiolarians	Japan	Pls. –Toa. ‡	3/10	assemb. comp. change; origination of 13 sp. & 3 genera	Hori 1997
Calcareous nannofossils & dinoflagellates	Marche Umbria Basin, Italy	lower *tenuicostatum* Zone	1/6	assemb. comp. also changes §	Palliani & Riding 1999
	S Alps, Italy	Pls. –Toa.		rel. abund. decrease 40% §	Erba 2004
	Switzerland	Pls. – Toa.		rel. abund. decrease 55% §	Erba 2004
	N Spain	Pls. –Toa.		rel. abund. decrease 53%	Tremolada *et al.* 2005

Table 2: Summary of biotic changes during the early Toarcian. The reader is referred to paper Fig. 4 for a graphical representation of these data (with the exception of those indicated below). The proportion of species extinctions is given; where extinction at family/order level has been established by the author this has been indicated; biotic changes amongst the phytoplankton are reported as the percentage decrease in relative abundance (rel. abund. decrease); NQ = biotic changes have not been quantified; assem. comp. change = composition of the faunal assemblage changes. Pls. = Pliensbachian; Toa. = Toarcian.

Taxon	Geographic locality	Stratigraphic position	Proportion sp. extinctions	Rel. abund. decrease (%)	References
Brachiopods	Celtiberian chain, Spain	top *tenuicostatum* Subzone	NQ		Gahr 2005
	Luisitanian Basin	top *tenuicostatum* Subzone	NQ		Gahr 2005
	Spain	*tenuicostatum-falciferum* zone boundary	9/9 Order Spiriferinida		Garcia Joral & Goy 2000
	Britain, Portugal, France	*falciferum* Zone ‡	Family Koninckinidae; Order Athyridida **		Almeras & Faure 1990; Vörös 2002
	Swiss Alps & Jura Mts.	Toa. Stage ‡	38/48 **		Ruban 2004; Sulser 1999
	Andean Basin	between early & mid Toa. ‡	7/12 **		Riccardi *et al.* 1990
Bivalves	Celtiberian chain, Spain	top *tenuicostatum* Subzone	NQ		Gahr 2005
	Luisitanian Basin	top *tenuicostatum* Subzone	NQ		Gahr 2005
	S France	*tenuicostatum-falciferum* zone boundary	NQ		Riegraf 1985
	Siberia	An unspecified point in the *tenuicostatum* Zone	19/24		Nikitenko & Shurygin 1992
	N Siberia & NE Russia	An unspecified point in the *tenuicostatum Zone*	13/29		Zakharov *et al.* 2006
	Andean Basin	nr. *tenuicostatum-falciferum* Zone boundary	19/33 †		Riccardi *et al.* 1990; Damborenea 2002
Macroinverts.	Yorkshire, UK	upper *semicelatum* Subzone	16/22 *		Little 1995; Little 1996
	Yorkshire, UK	*tenuicostatum-falciferum* zone boundary	6/10 *		Little 1995
	SW Germany	upper *semicelatum* Subzone	8/13 *		Riegraf 1985; Little 1996
	S France	*tenuicostatum-falciferum* Subzone boundary	NQ *		Riegraf 1985
Ammonites	Subboreal Submediterranean Mediterranean	early *semicelatum* Subzone	1/1 3/4 23/25		Cecca & Macchioni 2004
	Yorkshire	upper *semicelatum* Subzone	1/1		Little 1995
Ostracods	Truc de Balduc, S France	late *semicelatum* Subzone	21/26		Riegraf 1985
	SW Germany	late *semicelatum* Subzone	34/38		Riegraf 1985

	Mochras borehole, Wales	*tenuicostatum-falciferum* subzone boundary	10/18		Boomer & Whatley 1992
	Siberia	*tenuicostatum-falciferum* subzone boundary	2/4		Nikitenko & Shurygin 1992
	Ilminster, Somerset	*exaratum* Subzone	5/13		Boomer 1992
Foraminifera	Truc de Balduc, S France	upper *semicelatum* Subzone	44/75		Riegraf 1985
	SW Germany	upper *semicelatum* Subzone	85/129		Riegraf 1985
	SW Germany S France Yorkshire Leicestershire	nr. top *tenuicostatum* Zone	9/47		Hylton 2000
	SW Germany S France Yorkshire Leicestershire	during *falciferum* Zone [‡]	3/38 [**]		Hylton 2000
	Arctic Subrealm	nr. *tenuicostatum-falciferum* subzone boundary	6/15		Zakharov *et al.* 2006
Dinoflagellates	Brown Moor borehole, Yorkshire	end *semicelatum* Subzone	5/10 [§]		Palliani *et al.* 2002
	Germany	end *semicelatum* Subzone		20% [§]	Prauss *et al.* 1991
Calcareous nannofossils	Brown Moor borehole, Yorkshire	end *semicelatum* Subzone		100% [§]	Palliani *et al.* 2002
	Cantabria, Spain	base *semicelatum* Subzone		30%	Tremolada *et al.* 2005
Spore pollen	N Siberia	between *viligaensis* & *propinquum* zones (Fig. 2)	16/18 [**]		Zakharov *et al.* 2006

[*] Bivalve extinctions were found to be selective with higher extinction intensities amongst the infauna than the epifauna (Aberhan & Baumiller 2003)

[†] Aberhan and Fürsich (1996) interpreted the bivalve data from the Andean Basin to indicate that 50% of these species became extinct on a global scale

[‡] Stratigraphic resolution is questionable

[§] The assemblage is replaced by an opportunistic fauna of sphaeormorphs and prasinophytes

[**] This information is not represented on Fig. 2

Systematics of the key faunal elements

Pseudomytiloides dubius

Class BIVALVIA Linné, 1758

Subclass PTERIOMORPHIA Beurlen, 1944

Order PTERIOIDA Newell, 1965

Suborder PTERIINA Newell, 1965

Superfamily PTERIOIDEA Gray, 1847

Family INOCERAMIDAE Giebel, 1852

Genus PSEUDOMYTILOIDES Koshelkina, 1963

Pseudomytiloides dubius (Sowerby, 1823)

1823 *Inoceramus dubius* Sowerby, p. 162, pl. 584, fig. 3

1829 *Inoceramus dubius* var. Phillips, pl. xii, fig. 14

1884 *Perna dubius* (Sowerby) Simpson, p. 179

1960 *Pseudomytiloides matsumotoi, Parainoceramus* cf. *matsumotoi* Hayami and *Parainoceramus* sp. ex gr. *matsumotoi* Hayami, p. 296-298, pl. 15, figs. 2-10

Material: Thousands of samples have of *Pseudomytiloides dubius* been collected from Whitby for this study. The majority of these are set in a matrix of dark- to pale-grey mudrock. The valves are mostly compressed. Inflated specimens are found attached to calcium carbonate concretions at particular horizons (e.g. bed 42 and bed 34; Fig. 1). In most cases some calcitic shell is preserved and in some specimens the calcite is coated with a thin layer of pyrite (Fig. 1). Six key specimens, collected from Hawsker Bottoms, which extend the previously reported range of the species are discussed here. The material includes three internal and one external mould from bed 1 (Figs. 2a-b); one internal mould from the laminated layer in bed 2 (Fig. 2c); and one external mould from the middle of bed 3 (Fig. 2d). The British Museum, London, UK specimens 47379 (Holotype), L3892 and 47460 were examined for comparison.

Remarks: A species of *Parainoceramus* has previously been found in these beds (Little 1995) but the specimens reported here (Figs. 2.4 - 2.7) do not fit with the description of *Parainoceramus*. In contrast to *Parainoceramus P.*

dubius has a very short hinge line and strong commarginal folds. These features are clearly exhibited by the specimens found during this study and which extend the range.

Figure 1: Un-compacted valves of *P. dubius* on a calcium carbonate concretion from Port Mulgrave with original shell material and pyrite; millimetre scale (BM PI MB 980). Specimen found loose but is probably from bed 34.

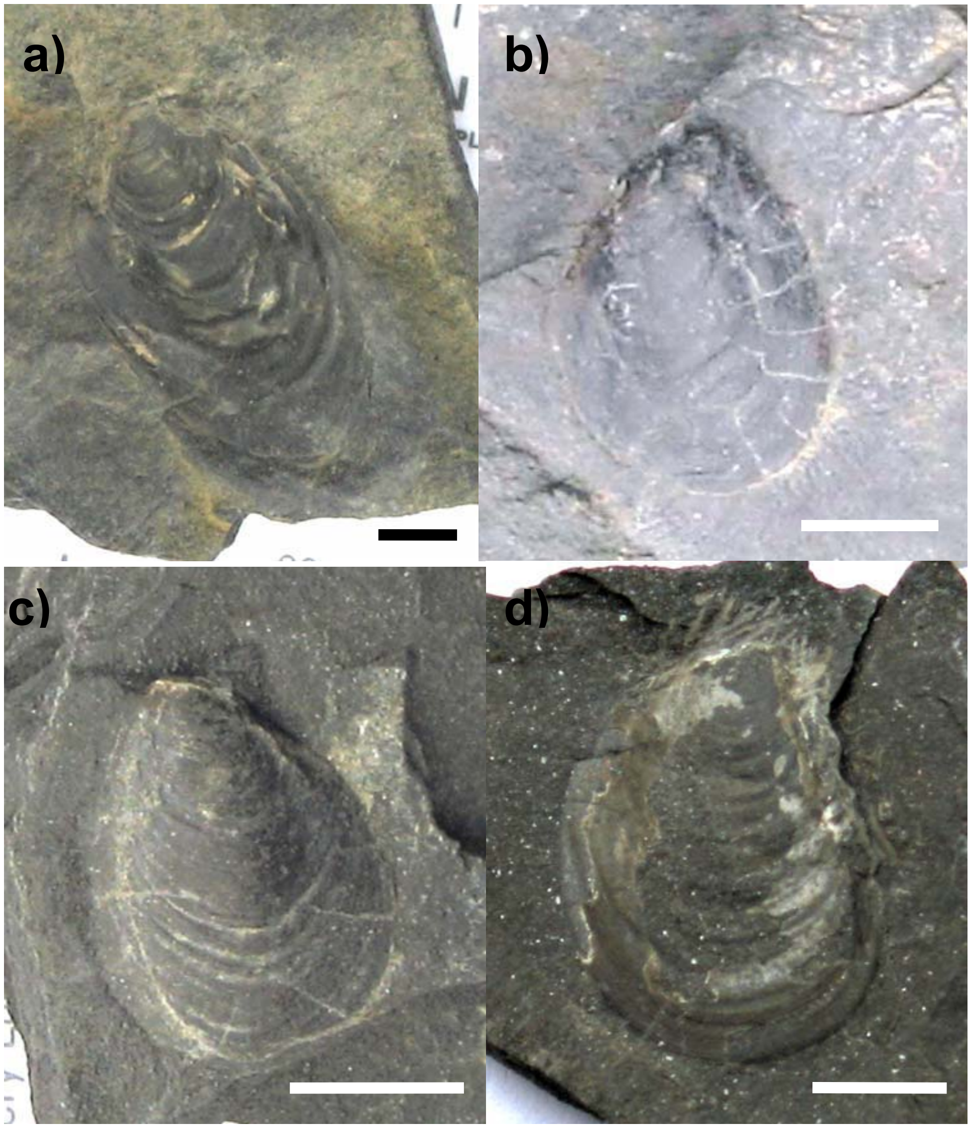

Figure 2: (a) External mould of *P. dubius* from bed 1 at Hawsker Bottoms; scale = 5 mm (BM PI MB 981); (b) internal mould of *P. dubius* from bed 1 at Hawsker Bottoms; scale = 5 mm (BM PI MB 982); (c) internal mould of *P. dubius* from the upper laminated layer in bed 2 at Hawsker Bottoms; scale = 1 cm (BM PI MB 983); (d) external mould with some shell material of *P. dubius* from 2.2 cm below the middle of bed 3 at Hawsker Bottoms; scale = 5 mm (BM PI MB 984).

Bositra

Superfamily PECTINOIDEA Rafinesque, 1815

Family POSIDONIIDAE Frech, 1909

Genus BOSITRA De Gregorio, 1886

Bositra buchi (Roemer, 1836)

1836 *Posidonia buchii* Roemer, p. 81, pl. 4, fig. 8

1851 *Posidonia ornati* Quenstedt, p. 517, pl. 42, fig. 16

1852 *Posidonomya alpina* Gras. p. 11, pl. 1, fig. 1

1858 *Posidonia bronni* Zieten var. *parva* Quenstedt, p. 260, pl. 37, fig. 8

Material: Seven specimens were found for the extension of the range of this species and include external moulds set in a matrix of mudrock from: 12 and 28 cm below and 5 cm above the base of bed 39 at Port Mulgrave; 259 and 389 cm (Fig. 4) below the centre of bed 42 at Port Mulgrave; and 16 cm below (Fig. 3) and 104 cm above the centre of the lower line of nodules in bed 42 at Saltwick Bay.

Remarks: Specimens from the British Museum, London, UK (LL17409-17410) were examined for comparison. This species exhibits wide morphological variability between populations (Conti and Monari 1992; Jaitly *et al.* 1995; Aberhan 1998).

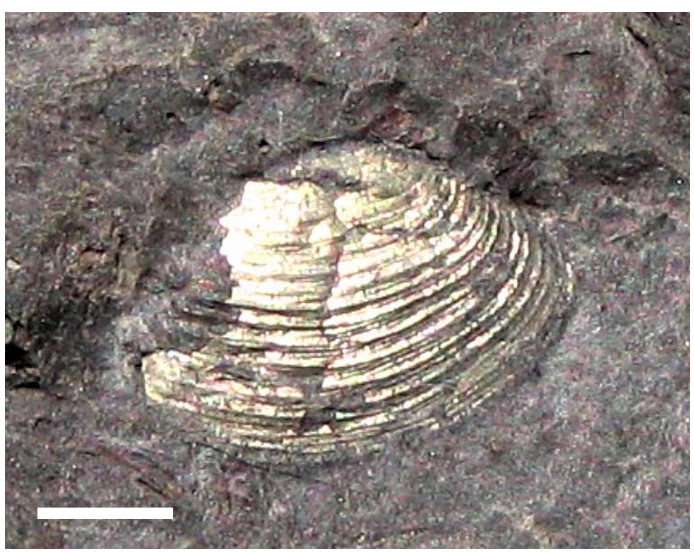

Figure 3: Pyritised external mould of *B. buchi* from 16 cm below the lower bed 42 nodules at Saltwick Bay; scale = 5 mm.

Figure 4: External mould of *B. buchi* from 389 cm below bed 42 nodules at Port Mulgrave; millimetre scale (BM PI MB985).

Bositra radiata (Goldfuss, 1836)

1836 *Posidonia radiata* Goldfuss, p. 119, pl. 114, fig. 2

1833 *Posidonomya bronni* Voltz in Zieten, pl. lxvii, fig. 4

1834 *Posidonomya bronni* Goldfuss, p. 119, pl. cxiii, fig. 7

1858 *Posidonia bronni* Zieten var. *magna* Quenstedt, p. 260, pl. 37, figs. 8-9

1928 *Posidonomya* (?*Daonella*) *radiata* (Goldfuss); Guillaume, p. 219, pl. 10,

Material: Key specimens that extend the range of *B. radiata* were found between 16 cm below and 32 cm above the top of bed 39 (Fig. 5) at Port Mulgrave and Hawsker Bottoms.

Remarks: In SW Germany both *Bositra radiata* (*Posidonia bronni* var *magna*, *Steinmannia bronni* of authors) and *Bositra buchi* (*Posidonia bronni* var *parva*, of authors) are present but their stratigraphic distributions differ. *B. radiata* is found at the base of the Posidonienschiefer in the *semicelatum* Subzone whilst *B. buchi* is only found in the upper part of the formation from the middle of the *commune* Subzone (Kauffman 1981; Riegraf *et al.* 1984; Oschmann

1994; Urlichs *et al.* 1994; Little 1996). Oschmann (1994) and Kauffman (1981) also report *B. radiata* from the *falciferum* Zone of the Posidonienschiefer. Röhl (1998) considers that *B. radiata* and *B. buchi* are the same species, in different sizes and that they are both *B. buchi*. Jefferies and Minton (1965) considered them to be separate species; *P. bronni magna* which reaches up to 5 cm in length and *P. bronni parva* which is <1 cm in length. Observations of small specimens of both species made during this study do not suggest that these are one species in different size ranges. The most distinguishing features are that *B. buchi* is suborbicular in shape (Figs 3 and 4) whereas *B. radiata* is oval-orbicular or oval, and *B. radiata* has distinct auricles and fine radiating ribs whereas *B. buchi* has neither (Figs 3-5).

Figure 5: B. radiata shell plaster from 11 cm above the top of bed 39 at Hawsker Bottoms (BM PI MB 993); millimetre scale.

Meleagrinella substriata

Family OXYTOMIDAE Frech, 1909

Genus MELEAGRINELLA Whitfield, 1885

Meleagrinella substriata (Münster, 1831)

1831 *Monotis substriatus* Münster, in Leonhard and Bronn p. 406
1836 *Monotis substriata* Goldfuss p. 138, pl. cxx, fig. 7
1855 *Avicula minima*, *A. nitiscens*, *A. tumidulus*, *A. crescens* Simpson, p. 182
1876 *Monotis substriatus* Münster, Tate and Blake p.372

Material: The four key specimens that were found during this study and extended the range are as follows: one internal mould of the left valve (LV) (Fig. 6a) from 45.25 cm below the lowest bed 34 nodules at Port Mulgrave; one external mould of the LV with small amount of shell material attached (Fig. 6b) from bed 12 at Hawsker Bottoms; one pyritised convex right valve (RV) (Fig. 6c) from 3.5 cm below bed 33 nodules at Port Mulgrave; one pyritised left valve (Fig. 6d) from 21 cm below the middle of bed 37; one internal mould of the LV (Fig. 6e) from 44.5 cm above the upper bed 33 nodules at Port Mulgrave.

Remarks: Meleagrinella is closely related to *Oxytoma* and can appear to be externally similar but the LV of *Meleagrinella* (Figs 6a, b, d, and e; (pl. 4, figs. 20, 24, 26-28, 31 Duff 1978)) can be distinguished from the LV of *Oxytoma* (Fig. 3f; (pl. 4, figs. 7, 11, 15, 16-18, 21-23 Duff 1978; pl. 6 figs. 10-11, text-figure 15 Damborenea 1987; pl. 9, figs. 9-14 Aberhan 1998) by its greater inflation, finer ornament, more acute angle of the riblets, smaller posterior auricle and lack of an anterior auricle. The RV of these two species both have weak radial riblets but may be distinguished by the smaller anterior and posterior auricles of *Meleagrinella* (Fig. 6c; (pl. 14 fig. 32 Duff 1978), the posterior auricle of *Oxytoma* extends beyond the posterior margin of the shell (pl. 4 figs. 9 & 13 Duff 1978; text fig. 15, pl. 6, figs. 9 & 12 Damborenea 1987; pl. 9 fig. 8 Aberhan 1998) whereas that of *Meleagrinella* does not. The posterior auricle of *Meleagrinella* is broad, flattened and pointed whereas the posterior auricle of *Oxytoma* is very elongate and sharply pointed. The anterior auricle of *Oxytoma* is larger, pointed, has a deep byssal notch, and is strongly differentiated from the body of the shell by a strong auricular sinus.

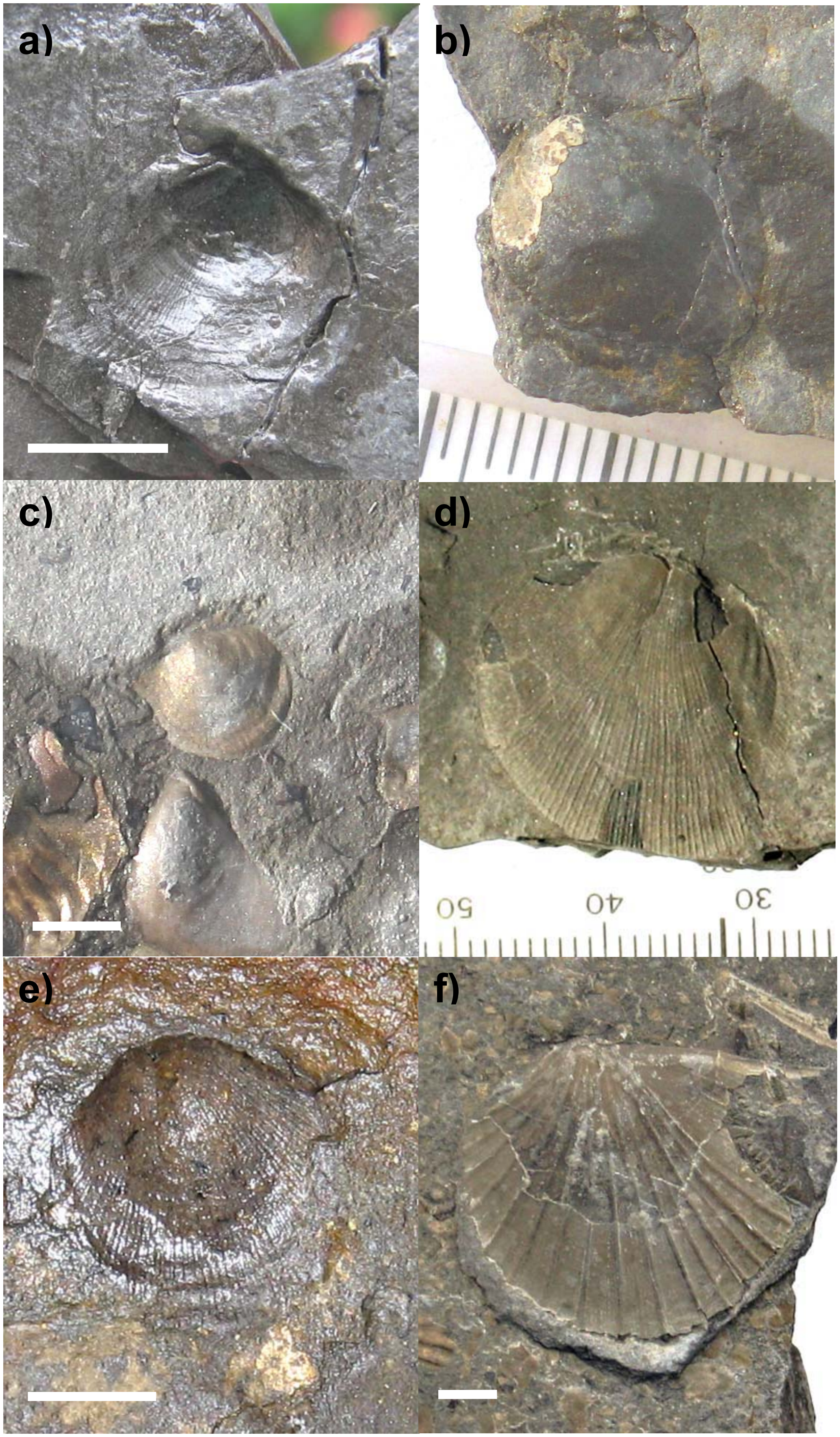
a)
b)
c)
d)
50
40
30
e)
f)

Figure 6: (a) Internal mould of LV of *M. substriata* from 45.25 cm below the lowest bed 34 nodules at Port Mulgrave (BM PI MB 986); scale = 5 mm; (b) external mould of LV of *M. substriata* with a small amount of shell material attached from 10 cm above the base of bed 12 at Hawsker bottoms (BM PI MB 987); millimetre scale; (c) pyritised convex RV of *M. substriata* from Port Mulgrave, with small *Pseudomytiloides* and ammonite fragments(BM PI MB 988). Sample is from 3.5 cm below the lowest bed 33 nodules at Port Mulgrave; scale = 5 mm; (d) pyritised LV of large *M. substriata* from Kettleness 21 cm below the middle of bed 37 (BM PI MB 990); millimetre scale; (e) external mould of left LV of *M. substriata* from 44.5 cm above the upper bed 33 nodules at Port Mulgrave (BM PI MB 991); scale bar = 3 mm; (f) LV of *Oxytoma inequivalve* from 149.6 cm below the lower bed 33 nodules at Port Mulgrave (BM PI MB 992); scale bar = 5 mm.

Goniomya rhombifera

Subclass ANOMALODESMATA Dall, 1899
Order PHOLADOMYOIDA Newell, 1965
Superfamily PHOLADOMYACEA Gray, 1847
Family PHOLADOMYIDAE Gray, 1847
Genus GONIOMYA Agassiz, 1841
Subgenus GONIOMYA Goldfuss, 1840

Goniomya rhombifera (Goldfuss, 1844)

1844 *Lysianassa rhombifera* Goldfuss, p. 264, pl. 154, fig. 11
1845 *Goniomya heteropleura* Agassiz, p. 24, pl. 1d, figs. 9 & 10
1847 *Goniomya heteropleura* d'Orbigny
1848 *Goniomya rhombifera* (Goldfuss); Bronn, p. 548
1858 *Mya rhombifera* Quenstedt, p. 82, pl. 10, fig. 5
1867 *Goniomya rhombifera* (Goldfuss): Dumortier, p. 52, pl. xvii, fig. 5

Material: Four key specimens were found that extend the range of *Goniomya rhombifera*. They were all set in a matrix of mudrock and were found at Port Mulgrave, near Whitby. Specimens of *G. rhombifera* were found from 6 cm, 16 cm, 35 cm and 65 cm below the base of bed 39. These specimens were three external moulds (Figs. 7-8) and one partially pyritised external mould (Fig. 9) of *G. rhombifera*.

Remarks: *G. rhombifera* can be clearly distinguished from *Goniomya hybrida* (Münster) by differences in the ornament. In *G. hybrida* the oblique anterior and posterior ribs meet and form a series of v's (p. 263, pl. 154, fig. 10a, Goldfuss, 1844). In *G. rhombifera* the posterior and anterior ribs do not meet but are separated by an intervening rib parallel to the growth lines (p. 264, pl. 154, fig. 11, Goldfuss 1844).

Figure 7: External mould of *G. rhombifera* from 16 cm below the top of bed 39 at Port Mulgrave; millimetre scale (BM PI MB 994).

Figure 8: External mould of *G. rhombifera* from 35 cm below the base of bed 39 at Port Mulgrave; scale bar =1 cm.

Figure 9: Partially pyritised external mould of *G. rhombifera* from 65 cm below the base of bed 39 at Port Mulgrave (BM PI MB 995); scale bar = 1 cm.

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