

On the stratigraphic position of the Delden Member (Breda Formation, Overijssel, the Netherlands) with implications for the taxonomy of *Pygocardia* (Mollusca, Bivalvia)

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Re-identification of parts of the mollusc fauna of the Delden Member, especially *Pygocardia* and *Panopea* species, from the vicinity of Delden (Overijssel prov., the Netherlands) and comparison with other Neogene faunas from the southern North Sea Basin imply a late Early to early Late Pliocene age for the Delden fauna, that usually is attributed to the Miocene. Shell measurements performed for this study revealed that the species definitions for Pliocene North Sea Basin *Pygocardia* are inadequate.

KEY WORDS: Delden Member, the Netherlands, Mollusca, *Panopea*, *Pygocardia*, biochronology.

Introduction

During (and since) excavation of the Twickelsche Vaart (1771 - 1778) and the Twentekanaal (1930 - 1940) near Delden (Overijssel prov., Netherlands) Neogene sediments were exposed in which a phosphoritic mollusc fauna was found. From these glauconitic sands, now known as the Delden Member (Van den Bosch *et al.*, 1975), numerous fossils of mainly bivalve and some gastropod molluscs, the brachiopod *Lingula dumortieri* Nyst, 1843 as well as some shark teeth have been collected. The faunas have been compared to other Neogene faunas of the Southern North Sea Basin by various authors, but no definitive age assignment could be made on the basis of the mollusc moulds. Janssen (in Van den Bosch *et al.*, 1975: 103) stated "the Delden Member should be placed without any doubt in the Pliocene". However, he mentioned that the reported occurrence of Miocene mollusc species (*Panopea menardi* Deshayes and *Scaphella bolli* (Koch)) would need additional study in order to confirm the Pliocene age. Aim of this paper is to study these species, as well as the *Pygocardia* species of the Delden Member in order to establish its age. Different *Scaphella* and *Panopea* species occur in the North Sea Basin Miocene and Pliocene, and different species and forms of *Pygocardia* are known from different intervals within the Pliocene, allowing for comparison with the Delden fauna.

Already in 1778, J.A. de Luc, visited the exposure during the excavation of the Twickelsche Vaart and reported from this exposure "une immense quantité de conchites sablonneuses ou de grès moulés dans des coquilles" (cited in Van Deirse, 1931). The Delden Member was first described by Staring in 1860, who used the name "Leem van Delden". A review of the history of these exposures was given by Van Deirse (1931) and Van den Bosch & Janssen (1965). The name "Leem van Delden" was later changed in "Afzetting van Delden" or Delden Member (Van den Bosch *et al.*, 1975). The Delden Member (that is part of the Breda Formation) consists of fine to coarse silty quartz sand, containing glauconite and abundant goethite grains. Commonly phosphorites occur, sometimes forming beds. In these beds locally numerous molluscan moulds and casts are present. The Delden Member differs from the Zenderen Member below and overlying Lievelede Member in containing abundant goethite, phosphorites and in general having a coarser grain size (Van den Bosch *et al.*, 1975). Two exposures in the Delden Member have yielded a particularly rich molluscan fauna, viz. an exposure near the Delden quay (during excavation of the Twentekanaal in the 20th century), and an exposure in the floor of the Twickelsche Vaart (figure 1). In total 33 species of molluscs have been mentioned from these two exposures. The exposure in the Twentekanaal is inaccessible nowadays. The outcrop in the Twickelsche Vaart has long been accessible, but in recent years the water level was artificially in-

creased complicating access to the fossiliferous layers. Many of the moulds from the Twickelsche Vaart are covered with a black coating resulting from pollution during the period 1930-1953. Currently, it is not permitted to trespass the banks of the Twickelsche Vaart.



Figure 1. View of the Twickelsche Vaart, ca. 1954 (photo J. Bosch)

Based on whale remains, Van Deirse (1931) suggested a Late Miocene age for the Delden Member, although these suggestions were partially based on correlations with faunas from the Antwerpen region whose stratigraphic age was possibly incorrectly established (R. Marquet, pers. comm.). The elasmobranch-fauna of the Zenderen Member that underlies the Delden member, exposed ca 600 m to the east along the Twentekanaal was described by M. van den Bosch (*in*: Van den Bosch & Janssen, 1965). These authors indicated a Late Miocene age. Thirty-three invertebrate fossil species (mainly molluscs) were described by Janssen in 1966 from the Zenderen and the Delden members of the Twentekanaal. Janssen concluded that the invertebrate fauna of the Twentekanaal most probably could be correlated with the Belgian 'Deurnian' (=Deurne Sand Member, Tortonian), the youngest Miocene unit in the Antwerp region. This conclusion was based on the occurrence of 4 mollusc species exclusively known from the Miocene of the North-Sea basin, including the bivalve *Panopea menardi* Deshayes, 1828. In the Delden fauna, Janssen also reported 10 species that he indicated as known from both Miocene and Pliocene units of the Southern North Sea Basin, including *Pygocardia rustica* (Sowerby, 1818). However, Van den Bosch *et al.* (1975) found several indications for a Pliocene age of the Delden Member, comparable with the age of the Kattendijk-sands in the Antwerp-region (Belgium). The mouldic preservation of the mollusc-fossils hampered their identification. For example, moulds of the bivalve *Panopea* were identified by these au-

thors as *P. menardi* Deshayes, 1828, known only from Middle Miocene deposits. The authors noted the contradictory nature of the occurrence of this species in supposed Pliocene deposits.

The geological map of the region (Van den Bergh & Gaemers, 1993), and successive publications (Gaemers, 1993) indicated a Late Miocene (cf. Messinian) age for the Delden Member. The base of the Delden Member was placed in Late Miocene foraminiferal zone FC1, and the top in the Late Miocene-Early Pliocene zone FC2 (Van den Bergh & Gaemers, 1993), but these authors located the Delden Member entirely within the Late Miocene.

In this work, the mollusc fauna of the Delden Member is re-identified, in several cases based on extensive series of measurements. The fauna is compared with other Neogene faunas from the southern North Sea Basin, in order to estimate an age for the Delden fauna.

Material & Methods

Panopea moulds from the Delden Member were measured for five characters, from which four ratios were calculated (see below). The measurements were compared to measurements of three Neogene species from the southern North Sea Basin, viz. *Panopea (Panopea) kazakova* Glibert & Van de Poel, 1966 (Miocene), *Panopea (Panopea) menardi* Deshayes, 1828 (Miocene) and *Panopea (Panopea) faujasi* Ménard de la Groye, 1807 (Pliocene). We follow Nyst (1881) in considering *Panopea ipswisiensis* (Valenciennes, 1839) a junior synonym of *Panopea faujasi*. There is some debate going on as to the taxonomic status of *P. faujasi*. Marquet (2005) makes a strong argument for *P. faujasi* to be a junior synonym of *P. glycimeris* (Von Born, 1778), especially since the type of *P. faujasi* is from the Italian Pliocene. However, there are a number of subtle differences between North Sea Basin specimens and the Atlantic/Mediterranean specimens, amongst others in the inclination of the axis of the sinus (Van Nieulande, pers. comm.), which merit further study. Although Marquet is probably right that *P. faujasi* is not the correct name for the North Sea Basin material, we use the name here pending further taxonomic study.

Pygocardia moulds from the Delden Member were measured for three characters, from which three ratios were calculated (see below). The Delden material was compared to three *Pygocardia* taxa from the Antwerp Pliocene, viz. *P. rustica tumida* (Nyst, 1836), *P. rustica tumida* forma *solida* Janssen, Peeters & Van der Slik, 1984 and *P. rustica rustica* (Sowerby, 1818).

Material studied:

- | | |
|-----|---|
| GDH | coll. Netherlands Institute of Applied Geoscience – NITG-TNO, Utrecht (formerly Rijks Geologische Dienst, Haarlem). |
| HBH | coll. H.C.J. Bosch, Hilversum (to be included in TMH). |
| NME | coll. Natuurmuseum, Enschede. |
| RGM | coll. Naturalis, Nationaal Natuurhistorisch Museum, (formerly Rijksmuseum van Geologie en Mi- |

neralogie), Leiden.
 TMH coll. Teylers Museum, Haarlem.
 FNN coll. F.A.D. van Nieulande, Nieuw en St. Joosland.

Numbers between brackets refer to measured specimens.

Panopea spec. (*Panopea* from the Delden Member)
 Twentekanaal (Overijssel prov., the Netherlands): former outcrop west of the St. Anna bridge, at the Delden quay. Pliocene, Breda Formation, Delden Member. HBH (5), RGM (5), NME (8) (all moulds).
 Twickelsche Vaart, Delden (Overijssel prov., the Netherlands). Pliocene, Breda Formation, Delden Member. HBH (4), RGM (9) (all moulds).

Panopea (Panopea) kazakova Glibert & Van de Poel, 1966
 Antwerp (Antwerp prov., Belgium), E-3 motorway construction pit. Miocene, Edegem sands. HBH (5), RGM (8).

Panopea (Panopea) menardi Deshayes, 1828
 Antwerp (Antwerp prov., Belgium), E-3 motorway construction pit at Berchem/Borgerhout. Miocene, Berchem Formation, Antwerpen Sand Member. HBH (2), RGM (10).
 Antwerp (Antwerp prov., Belgium), Ploegstraat. Miocene, Antwerpen Sand Member. HBH (10), RGM (13).
 Ootmarsum (Overijssel prov., the Netherlands), outcrop in Kuipersberg. Miocene, Breda Formation, Aalten Member, Miste Bed. HBH (10), RGM (4), NME (2) (all moulds).
 Winterswijk (Gelderland prov., the Netherlands), Miste. Miocene, Breda Formation, Aalten Member, Miste Bed. HBH (3 valves, 1 pair).
 Dingden (Nordrhein-Westfalen, Germany), outcrop in bottom of the Königsbach at the Königsmühle. Miocene, Ville Formation, Bislich Member. HBH (2), RGM (8). Same outcrop, Ville Formation, Dingden Member: HBH (2).

Panopea (Panopea) faujasi Menard de la Groye, 1807
 Antwerpen area (Antwerpen and Oost-Vlaanderen prov., Belgium), various localities. Pliocene Kattendijk Formation: HBH (4), RGM (9).
 Ekeren (Antwerpen prov., Belgium), Fifth dock. Pliocene, Lillo Formation, Luchtbal and basal Oorderen Member. GDH (3), RGM (3).
 Kallo (Oost Vlaanderen prov., Belgium). Fourth Dock, tunnel construction site. Pliocene, Lillo Formation, Oorderen Member. RGM (12), NME (4), HBH (5).
 Antwerpen (Antwerpen prov., Belgium), Kempen Kanaal Bassin. Pliocene, Lillo Formation, Kruisschans Member. GDH (2).
 Antwerpen area (Antwerpen prov., Belgium), Zandvlietsluis. Pliocene, Lillo Formation, 'Austruweel Sands'. HBH (3).

Pygocardia rustica s.l. (*Pygocardia* from the Delden Member)
 Twentekanaal (Overijssel prov., the Netherlands): former outcrop west of the St. Anna bridge, at the Delden quay. Pliocene, Breda Formation, Delden Member. HBH (1 mould and 3 casts).

Twickelsche Vaart, Delden (Overijssel prov., the Netherlands). Pliocene, Breda Formation, Delden Member. HBH (1 cast, 3 moulds).

Aalten (Gelderland prov., the Netherlands): outcrop in bottom of stream "t Klooster". Pliocene, Breda Formation, ?Delden Member. HBH (1 cast, 1 mould).

Pygocardia rustica rustica (Sowerby, 1818)
 Kruisschans (Antwerpen prov., Belgium), Boudewijnsluis: Pliocene, Lillo Formation, Oorderen Member. HBH (4).
 Kallo (Oost Vlaanderen prov., Belgium), 'lock-tunnel-dock 4': Pliocene, Lillo Formation, Oorderen Member. HBH (9).

Pygocardia rustica rustica forma *extensa* Janssen, Peeters & Van der Slik, 1984.
 Kallo (Oost Vlaanderen prov., Belgium), 'lock-tunnel-dock 4': Pliocene, Lillo Formation, Oorderen Member. HBH (2).

Pygocardia rustica tumida (Nyst, 1836)
 Ekeren (Antwerpen prov., Belgium), Amerikadock: Pliocene, Kattendijk Formation. HBH (4).
 Kallo (Oost Vlaanderen prov., Belgium), 'lock-tunnel-dock 4': Pliocene, Kattendijk Formation. HBH (11).

Pygocardia rustica tumida forma *solida* Janssen, Peeters & Van der Slik, 1984
 Kallo (Oost Vlaanderen prov., Belgium), 'lock-tunnel-dock 4': Pliocene, Kattendijk Formation. HBH (13).
 Ekeren (Antwerpen prov., Belgium), Amerikadock: Pliocene, Kattendijk Formation. HBH (1).

Scaphella spec.
 Twentekanaal (Overijssel prov., the Netherlands): former outcrop west of the St. Anna bridge, at the Delden quay. Pliocene, Breda Formation, Delden Member. NME (2), RGM (1).

The following characters were measured (figure 2):

- H shell height
- L shell length
- F distance anterior margin to umbo as measured along L, measured for *Panopea* only
- S depth of pallial sinus, as measured along L, for *Panopea* only
- S distance of maximum depth of pallial sinus to line perpendicular to umbo, for *Panopea* only. The deepest point of pallial sinus is located on the anterior (+) or posterior (-) side.
- T semidiameter, for *Pygocardia* only

Hi and Ti (for *Pygocardia*) refer to dimensions measured on the inner side of specimens preserved as shells in order to compare the data with those measured from the Delden moulds. Ti50 (for *Pygocardia*) refers to semidiameter dimensions proportionally recalculated for a shell length of 50 mm.

The following ratios were calculated for *Panopea* material:

- F/L position of the umbo
- L/H length/height ratio
- S/L relative depth of pallial sinus
- s/L relative position top of pallial sinus in respect to the umbo

For *Pygocardia* specimens:

- L/H length/height ratio and
- L/T length/semidiameter ratio

were calculated. In order to facilitate comparison between the Delden and Antwerp material, these characters were also recalculated for shell lengths of 50 mm.

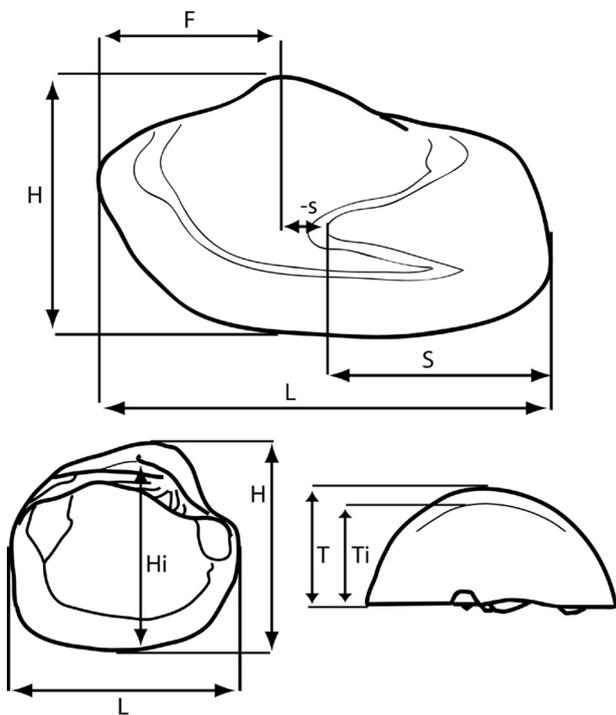


Figure 2. Characters used in measurements. Above *Panopea*, below *Pygocardia*. See text for explanation.

For the Antwerp Pliocene deposits the stratigraphic subdivision of Vandenberghe *et al.* (1998) is followed, who recognize two formations: Kattendijk and Lillo. The latter is subdivided into Luchtbal, Oorderen and Kruisschans members.

Results

On the identity of *Panopea*

The Miocene species (*P. menardi* and *P. kazakova*) have the location of the deepest incision of the pallial sinus clearly on the posterior side of the shell, whereas the position of this point in both the Delden specimens and in *P. faujasi* is either below the umbo or slightly to the anterior side (figure 3).

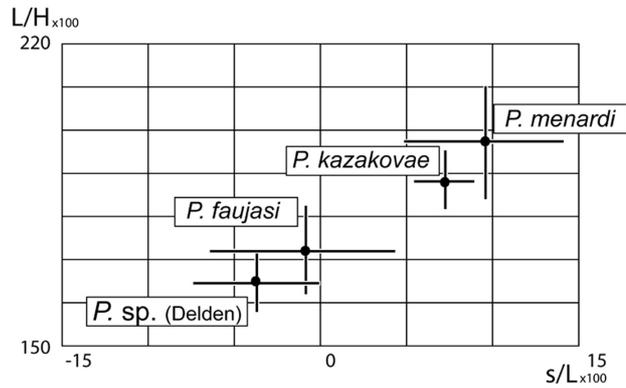


Figure 3. L/H versus s/L ratios for the different *Panopea* populations. Average plus/minus standard deviation is shown. The two Miocene species (*P. kazakova* and *P. menardi*) show broad overlapping high L/H and s/L values, whereas the Pliocene *P. faujasi* and the Delden *Panopea* show broad overlapping low L/H and s/L ratios. Almost no overlap exists between the Miocene group and the *faujasi*/Delden group.

	n		L	L/H	F/L	S/L	s/L
<i>P. menardi</i>	66	mean	64,3	2,0	40,8	69,4	9,4
		sd	18,9	0,1	3,7	3,3	4,6
		max	102,0	2,3	50,0	76,0	21,0
		min	31,0	1,7	33,0	62,0	0,0
<i>P. kazakova</i>	13	mean	92,9	1,9	43,2	62,8	6,4
		sd	13,9	0,1	2,8	1,4	1,1
		max	110,0	2,0	49,0	65,0	8,0
		min	63,0	1,8	39,0	61,0	5,0
<i>P. faujasi</i>	45	mean	95,6	1,7	42,0	56,1	-1,3
		sd	20,0	0,1	4,7	5,3	5,9
		max	145,0	1,9	51,0	65,0	13,0
		min	27,0	1,5	33,0	47,0	-13,0
<i>P. spec.</i> (Delden)	31	mean	71,5	1,6	40,8	55,0	-3,9
		sd	4,4	0,1	4,8	3,4	3,8
		max	80,0	1,8	48,0	59,0	7,0
		min	60,0	1,5	33,0	46,0	-8,0

Table 1. Measurements and ratios for *Panopea* species. L (length), F/L (position of the umbo), L/H (length/height ratio), S/L (depth of pallial sinus as measured from anterior margin), s/L (depth of pallial sinus in respect to umbo). Mean, standard deviation, maximum and minimum values are given.

Hence, the Delden *Panopea* is assigned to *P. faujasi*. No differences for these ratios were found between the Delden *Panopea* and *P. faujasi* from the Kattendijk Formation and from the Lillo Formation (not shown in table). However, morphological differences within the Antwerp Pliocene *Panopea faujasi* exist. The posterodorsal margin in *Panopea faujasi* from the Kattendijk Formation usually is elevated (figure 4-4). In Lillo Formation specimens the anterodorsal margin is usually almost in line with posterodorsal margin (figs 4-5 and 4-6). The anterior side of Kattendijk specimens is mostly rounded angular dorsally and ventrally, where the anterior margin of Lillo specimens usually is more evenly

rounded. All well-preserved Delden specimens have the postero-dorsal and ventral angulations (figure 4-3). The elevation of the posterodorsal margin resembles the Kattendijk material, but intermediates exist towards Lillo specimens. The Delden specimens also have a comarginal groove that

indicates a thickened ventral shell margin. Delden specimens are smaller than the Antwerp specimens. Thus, the Delden *Panopea* appears in several respects to include both Kattendijk as well as intermediates between Kattendijk and Lillo *Panopea faujasi* from the Antwerp Pliocene.

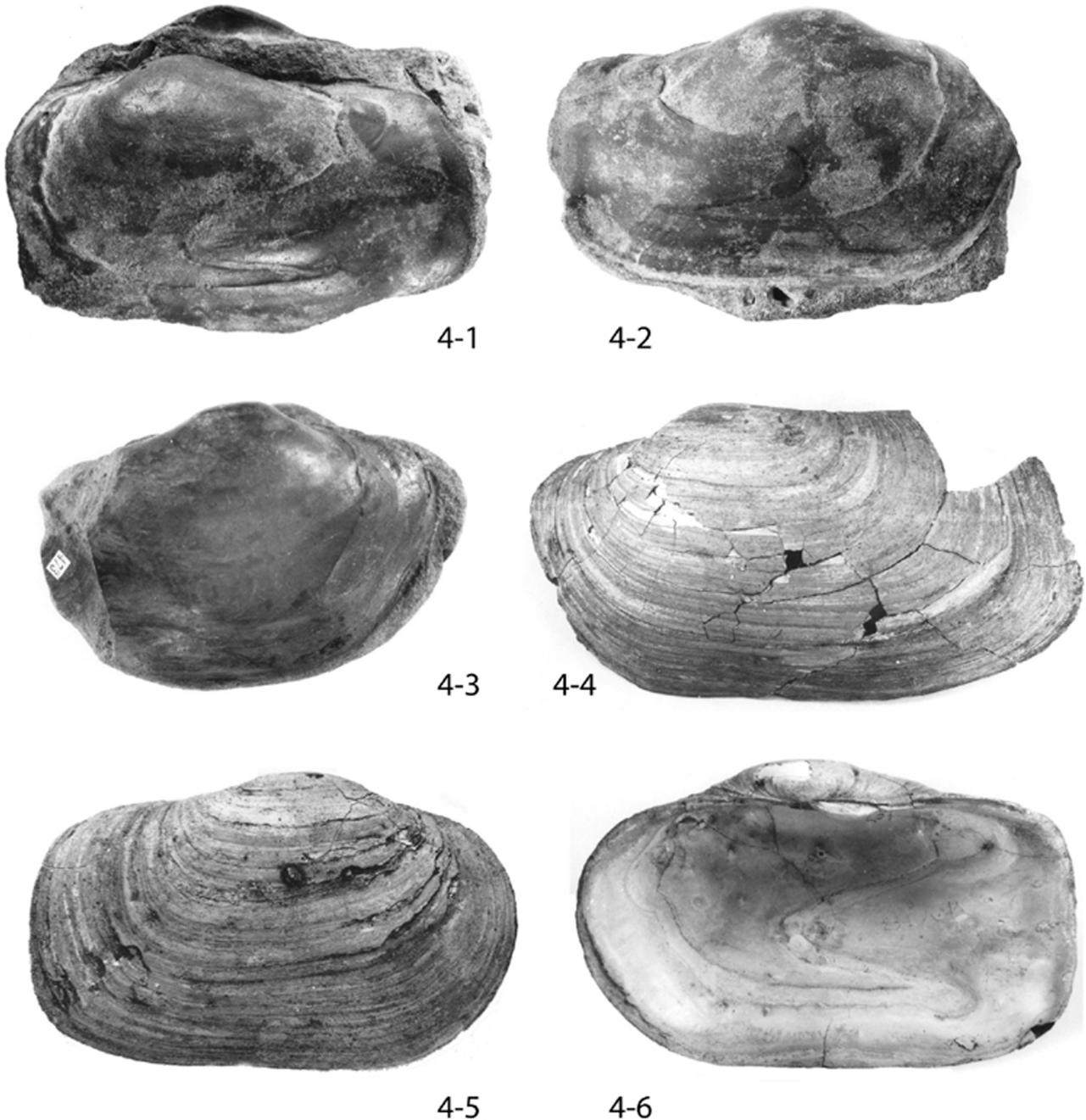


Figure 4. *Panopea* species. 4-1 – 4-3: *P. spec.*, Twente Kanaal (Overijssel, Netherlands), Breda Formation, Delden member, 4-1 and 4-2 HBH 471, L. 76 mm; 4-3 HBH 473, L. 69 mm, mould, note the well-defined antero-dorsal margin; 4-4 – 4.6: *P. faujasi*; 4.4: Kallo (Oost-Vlaanderen, Belgium), Kattendijk Formation, HBH 4833, RV, L. 114 mm; 4-5 and 4-6: Kallo (Oost-Vlaanderen, Belgium), Lillo Fm., Oorderen member. HBH 4839, RV, L. 88 mm, external and internal view respectively.

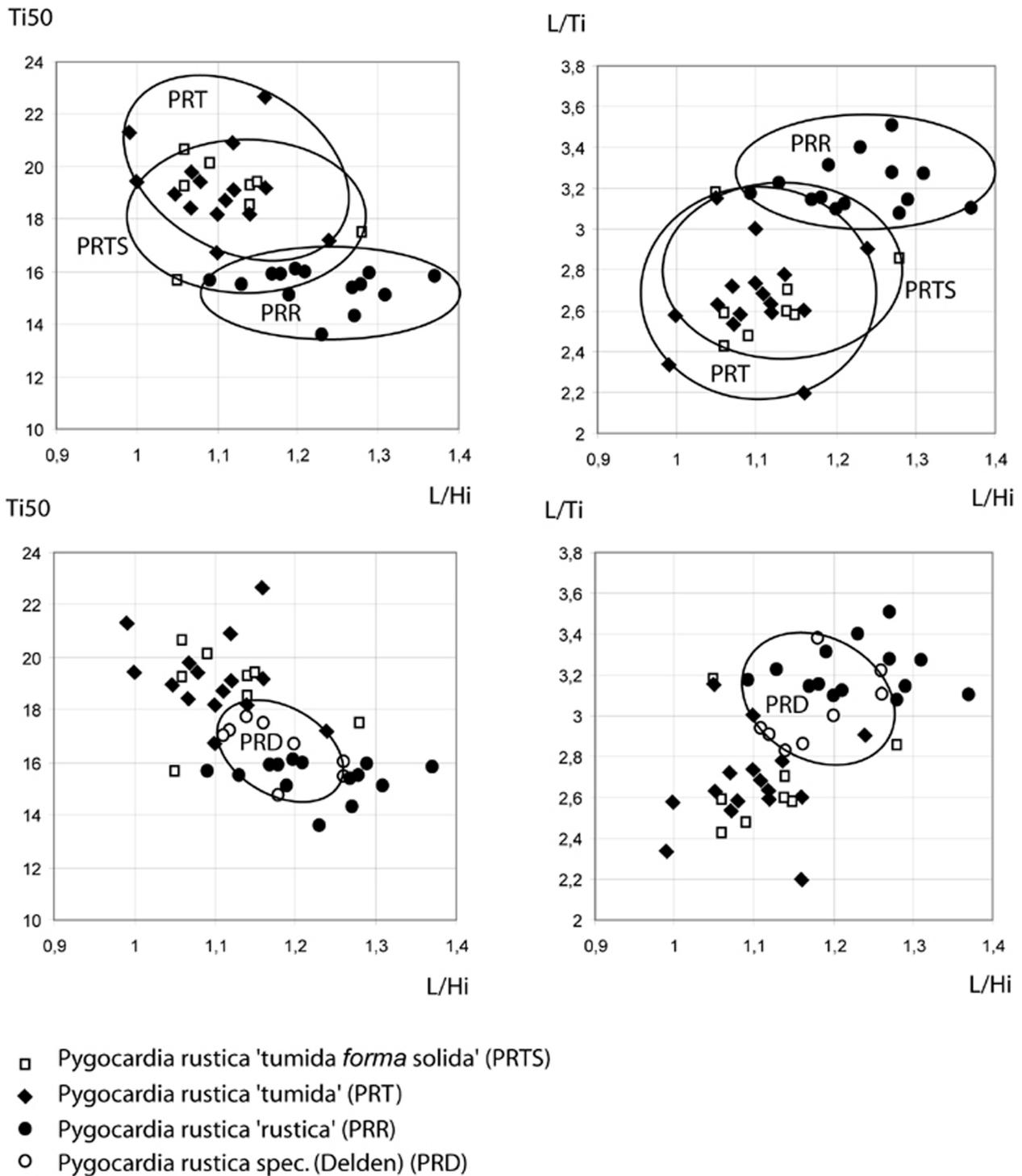


Figure 5. L/T vs L/H and T50 vs L/H ratios for *Pygocardia*. For the Antwerp specimens internal ratios were used (Ti, Hi and Ti50) in order to compare with the moulds of the Delden Member. In the Antwerp material two groups are distinguished (upper graphs), viz. *P. rustica* 'rustica' and *P. rustica tumida* (that includes the 'forma solida'). The Delden *Pygocardia* blurs the distinctness of the Antwerp groups (lower graphs). Taxonomic implications are discussed in the text.

On the identity of *Pygocardia*

Several moulds of *Pygocardia rustica* s.l. were found in the Delden Member. *Pygocardia* was initially reported from the Late Miocene Deurne Sands of the Antwerp region, but it was later excluded from these deposits and restricted to

Pliocene deposits of the Southern North Sea Basin (Janssen & Van der Mark, 1969). A number of (stratigraphic) forms/subspecies of *Pygocardia rustica* have been listed by Janssen *et al.* (1984) from Pliocene deposits of the Antwerp region, viz. *P. rustica rustica* (Sowerby, 1818: Lillo Formation: Luchtbal Member, Oorderen Member and Kruisschans

Member), *P. rustica rustica* forma *extensa* (Janssen *et al.*, 1984: unknown stratigraphic distribution, but here recorded from the Oorderen Member), *P. rustica tumida* (Nyst, 1836: Kattendijk Formation and (possibly reworked in the) Luchtbal Member) and *P. rustica tumida* forma *solida* (Janssen *et al.*, 1984: Kattendijk Formation and (again possibly reworked in the) Luchtbal Member). The *Pygocardia rustica tumida* figured by Jansen *et al.*, 1984 (figure 184a, b) is here attributed to *P. rustica rustica*.

Shell characteristics for the Delden specimens and Antwerp specimens are listed in Table 2 and illustrated in figure 5.

	n		L	L/Hi	L/Ti	Ti50
<i>P. spec. 'Delden'</i>	8	mean	52,63	1,18	3,03	16,58
		sd	4,63	0,06	0,19	1,03
		min	46,50	1,11	2,81	14,80
		max	59,00	1,26	3,38	17,80
<i>P. rustica rustica</i>	16	mean	64,00	1,22	3,21	15,46
		sd	7,09	0,08	0,12	0,68
		min	49,00	1,09	3,08	13,60
		max	73,50	1,37	3,51	16,10
<i>P. rustica tumida</i> forma <i>solida</i>	8	mean	47,60	1,12	2,68	18,81
		sd	7,25	0,08	0,24	1,60
		min	35,00	1,05	2,42	15,70
		max	57,50	1,28	3,18	20,70
<i>P. rustica tumida</i>	17	mean	50,49	1,09	2,66	18,98
		sd	6,35	0,06	0,23	1,68
		min	35,00	0,99	2,20	15,70
		max	61,00	1,24	3,18	22,70

Table 2. Measurements and ratios for *Pygocardia* species. L (length), L/Hi (length/height ratio), L/Ti (length/semi-diameter ratio), Ti50 semidiameter at L 50 mm. Mean, standard deviation, minimum and maximum values are given.

Based on the measurements (which are admittedly not exhaustive), the separation in two species of the Antwerp material (*Pygocardia rustica rustica* and *P. r. tumida*) makes sense (figure 5). Only a slight overlap in the different ratios exists. In the latter the forma *solida* cannot be distinguished based on the measured characteristics. The Delden *Pygocardia* material blurs the well-defined boundary between *P. rustica rustica* and *P. r. tumida* groups (figure 5). The shell characteristics overlap with those of *P. rustica rustica* and those of *P. r. tumida*, but not with *P. r. t. forma solida*.

A single specimen from the Twickelsche Vaart (coll. HBH) should possibly be attributed to *P. rustica rustica* forma *extensa* Janssen *et al.*, 1984. We have seen *P. rustica* forma *extensa* in one of the shell beds of the Oorderen member in the Antwerp area. Robert Marquet (pers. comm.) studied the Antwerp material in greater detail and concluded them to be ecophenotypic forms of *P. rustica rustica*. In conclusion, based on shell morphology, Pliocene North Sea Basin specimens of *Pygocardia* should all be classified as *P. rustica*. Three forms (forma *rustica*, forma *extensa* and forma *tumida*) can be used for stratigraphic and/or ecological purposes.

mida) can be used for stratigraphic and/or ecological purposes.

Other potentially stratigraphic useful mollusc species

Previously, moulds of *Scaphella* fragments from the Delden Member were assigned to *S. bolli* (Koch, 1861) by Janssen (1966). Three moulds of *Scaphella* were studied for this work. The moulds all represent slender specimens. Slender specimens are known from the Miocene *S. bolli* but also from the Pliocene *S. lamberti* (for the latter see Marquet, 1998). On one of the moulds remains of spiral micro sculpture were found. *Scaphella lamberti* and *S. bolli* have different spiral micro sculpture. The former consists of densely packed spirals with comparatively small interspaces, whereas *S. bolli* is characterised by the presence of relatively widely, but irregularly spaced spiral threads. The nature and density of spirals on the Delden specimen did not enable us to assign it to any of these two species with certainty. The Delden material is therefore referred to as *Scaphella spec.*

Moulds of *Glossus* with such a round shape as illustrated in Janssen (1966, pl. 2, fig. 1 and p. 108, fig. c) can safely be identified as *G. humanus* (Linnaeus, 1758), known from Pliocene deposits of the Southern North Sea Basin. *Digastaria excurrens* (Wood, 1853) is, as mentioned by Van den Bosch *et al.* (1975) too, an exclusive Pliocene species. In boreholes from SW Netherlands (A.C. Janse, pers. comm.) this species is not uncommon in intervals with yellow calcirudites that resemble the Luchtbal Member from the Antwerp region. Finally, Janssen (1966) mentioned the gastropod *Actaeon noae* Sowerby, 1822. This species is unknown from Miocene deposits of the North Sea Basin.

Discussion

Age

The mollusc fauna of the Delden Member is clearly of a Pliocene age. Miocene species reported in literature were based on misidentifications. The *Pygocardia* specimens of the Delden Member appear to be intermediates between forms found in the Kattendijk and Lillo Formation in the Antwerp region. The *Panopea* moulds yield both typical Kattendijk forms and intermediate forms between Kattendijk and Lillo, although Marquet (2005) attributed these differences to ecophenotypy. We assume that the sampled fossiliferous intervals of the Delden should be located in the stratigraphic hiatus that exists between both formations in the Antwerp region (Marquet, 2002). It cannot be ruled out that the Delden interval may correspond in time with the Luchtbal Member, since very little material is available from that interval for comparison with the Delden.

New dinoflagellate age estimates for the Antwerp area (Louwey *et al.*, 2004) indicate the top of the Kattendijk Formation to be as young as 4,4 Ma (Zanclean). The Oorderen Member is indicated as older than 2,74 Ma, possibly covering the basal Piacenzian. No certain dating exists from the Luchtbal,

whose age must be between 2,74 and 4,4 Ma. The age of the Delden member is therefore Late Zanclean to Early Piacenzian.

The possibility that the Delden Member correlates to the Luchtbal Member in the Antwerp area, that in turn is correlated to the basal part of the Oosterhout Formation in the SW Netherlands, opens the possibility that the boundary between the Breda Formation and Oosterhout Formation is diachronous. This also remains the case after a proposed revision of the Breda-Oosterhout boundary by Weerts *et al.* (2000).

The occurrence of *Conus* sp. in the Delden or Zenderen member (Janssen, 1966) needs explanation, as this genus is known only from Miocene deposits. One mould of *Conus* spec. has been found in Zenderen member deposits by J. Bosch (HBH 492) in the Twentekanaal exposure about half a km east of the Sint Annabridge, which shows that Janssen's specimen too came from this interval, that must be of a Miocene age. Remarkably, Marquet (1980) found a *Conus* specimen in a phosphoritic Pliocene fauna from Broechem (Antwerpen prov., Belgium). The two faunas are otherwise very different, the Broechem fauna being much more diverse than the Delden fauna.

Ecophenotypy

It is well known that many morphological characteristics of bivalves are influenced to a great deal by the environment in which they live (ecophenotypy). For example, shell size and thickness can relate to physical disturbance or to grain-size of the sediments in which these animals are living. So, how are we sure that the observed morphological variation in the *Pygocardia* and *Panopea* groups does not reflect merely ecophenotypic variation? Bluntly, we cannot say for sure. In the Antwerp series distinct forms have been found to have very specific stratigraphic distributions (although many of the literature references will need a critical re-evaluation). But it cannot be excluded that these, too, merely reflect different depositional regimes present at different times, and are not a result of evolution per se. However, the presence of forms in the Delden Member for both *Pygocardia* and *Panopea* that appear to be morphologically intermediate between Kattendijk and Lillo specimens of the Antwerp area, based on different shell-characters, makes it plausible that we are not dealing with ecophenotypic variation. However, the general small size and assumed larger shell thickness of the Delden *Panopea* specimens (compared to the Antwerp specimens) appears to reflect slower growth rates, which can be ecophenotypically derived.

Conclusions

Mollusc faunas from the Delden Member from the vicinity of Delden (Overijssel prov., the Netherlands) indicate an Early to early Late Pliocene age. It is likely that the fossiliferous intervals comprise only the upper part of the Delden Member, the base of which might be of a Miocene age. As a result, the top of the Breda Formation in the E. Netherlands should be located in the Pliocene, not in the Miocene. It is

entire possible that the boundary with the overlying Oosterhout Formation is diachronous. *Pygocardia* taxa from the Pliocene of the southern North Sea Basin should all be assigned to *Pygocardia rustica* (Sowerby, 1818). For stratigraphic purposes the recognition of three forma's is recommendable (forma *rustica*, *extensa* and *tumida*). Apart from a single *P. rustica* forma *extensa*, the morphological range of Delden specimens all fall between *P. rustica* forma *tumida* and *P. rustica* forma *rustica* from the Antwerp Pliocene.

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