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A new Late Ordovician *Hirnantia* brachiopod Fauna from NW Turkey, its biostratigraphical relationships and palaeogeographical setting

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Abstract – Late Ordovician fossils, including the distinctive *Hirnantia* brachiopod Fauna, have been found in Lower Palaeozoic successions in Istanbul and Bolu (Yığılca), western Pontides, NW Turkey. The Middle Ordovician (Sandbian) faunas belong to the cooler-water Mediterranean Province, and they are followed by Katian brachiopods including *Sulevorthis*, *Nicolella*, *Hesperorthis*, *Glyptorthis*, *Saukrodictya* and *Kullervo* and ostracods such as *Piretella*, *Eochilina* and *Klimphores*, which represent deposition in warmer waters; however, the Mediterranean Province usually cooler-water brachiopods *Drabovia* and *Leptestiina* also occur. The Pendik Formation includes thin bryozoan-rich limestones which probably represent the Boda Global Warming Event. The overlying turbidites contain a *Hirnantia* Fauna, developed within a brachiopod–diplograptid association. Above them there are characteristic Llandovery (Rhuddanian–Aeronian) brachiopods, such as *Leangella*, *Eoplectodonta*, *Stricklandia* and *Hindella* with the corals *Halysites*, *Paleofavosites* and *Streptelasma*. In the Bolu area, Katian brachiopods such as *Mcewanella*, *Dalmanella*, *Glyptorthis*, *Christiania*, *Oligorhynchia*, *Nicolella*, *Howellites* and *Drabovinella* also occur, but there the overlying *Hirnantia* Fauna is developed within a *Hirnantia–Mucronaspis* association. The fauna and sediments indicate that the western Pontides were not very cold during the latest Ordovician. Despite Turkey being placed in higher latitudes by previous authors, it seems more probable that the Pontides were at somewhat lower palaeolatitudes, perhaps at about 40° S in those times; however, the precise palaeogeographical position of the terrane remains uncertain: there are no Hirnantian glaciogenic rocks there, such as are found in the Taurides of southern Turkey.

Keywords: Ordovician, *Hirnantia* Fauna, Turkey, brachiopods.

1. Introduction

Northwestern Turkey formed the independent Pontides Terrane during Early Palaeozoic time. The eastern part of the Pontides has yielded some Ordovician (Tremadocian to Sandbian) shelly faunas (Dean *et al*. 2000), but the western sector, which includes Istanbul (Fig. 1), is less well known. In this paper, faunal assemblages of Middle and Late Ordovician and Early Silurian ages are described, chiefly brachiopods from the Istanbul and Bolu (Yığılca) areas in the western Pontides. Since the Istanbul conurbation has expanded enormously over the past 60 years, many previous outcrops have now vanished. The rocks are poorly fossiliferous, with many taxa represented only by one or more variably preserved specimens; however, about 500 fossils have been collected by one of us (CS) over many years from Istanbul and the Bosphorus area, and about 200 specimens were collected in 1983 by S. Biberoğlu and M. Özaltın from Yığılca, north of Bolu (Figs 2, 3). Since these fossils are poorly known, apart from in preliminary papers (Sayar, 1979*a,b*) and a limited publication (Sayar, 1979*c*), all in the Turkish language, we feel it is desirable to present these data to a wider audience here. In particular, the important *Hirnantia* Fauna of latest Ordovician (Hirnantian) age is recognized for the first time in Turkey, and the Early Palaeozoic geographical location of the Pontides Terrane is also discussed.

In the western Pontides, the Lower Palaeozoic consists of coarse clastic successions unconformably and transgressively overlying the crystalline basement rocks (Tokay, 1952). In Istanbul, Paeckelmann (1938) recorded the 400–500 m thick fossiliferous beds as the 'Graywacke Horizon', which he thought was of Devonian (Gedinnian) age, as the uppermost part of his Late Silurian to Gedinnian Quartzite Series, which was later termed the Gözdağ Formation by Önalan (1981) and is upgraded here to group status. The 'Graywacke Horizon', now termed the Kayalıdere Formation, is divided into lower shales (150 m) above which are turbidites (200 m). The succession can be divided into five chronostratigraphic subunits according to their lithologies and fossil contents as described below (Fig. 4).

2. Middle Ordovician to Lower Silurian rocks and fossils of Istanbul

The oldest fossiliferous beds around Istanbul and in the Bosphorus area at Kocaeli (Bithynia) are the

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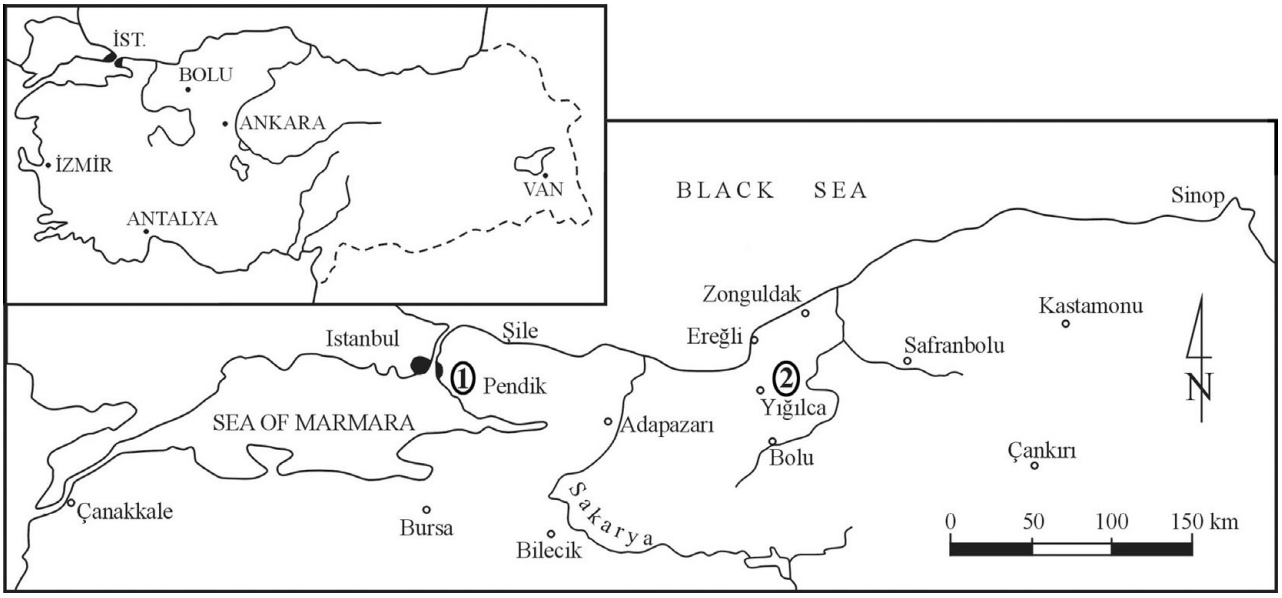

Figure 1. The Middle and Upper Ordovician faunal localities from the western Pontides, NW Turkey.

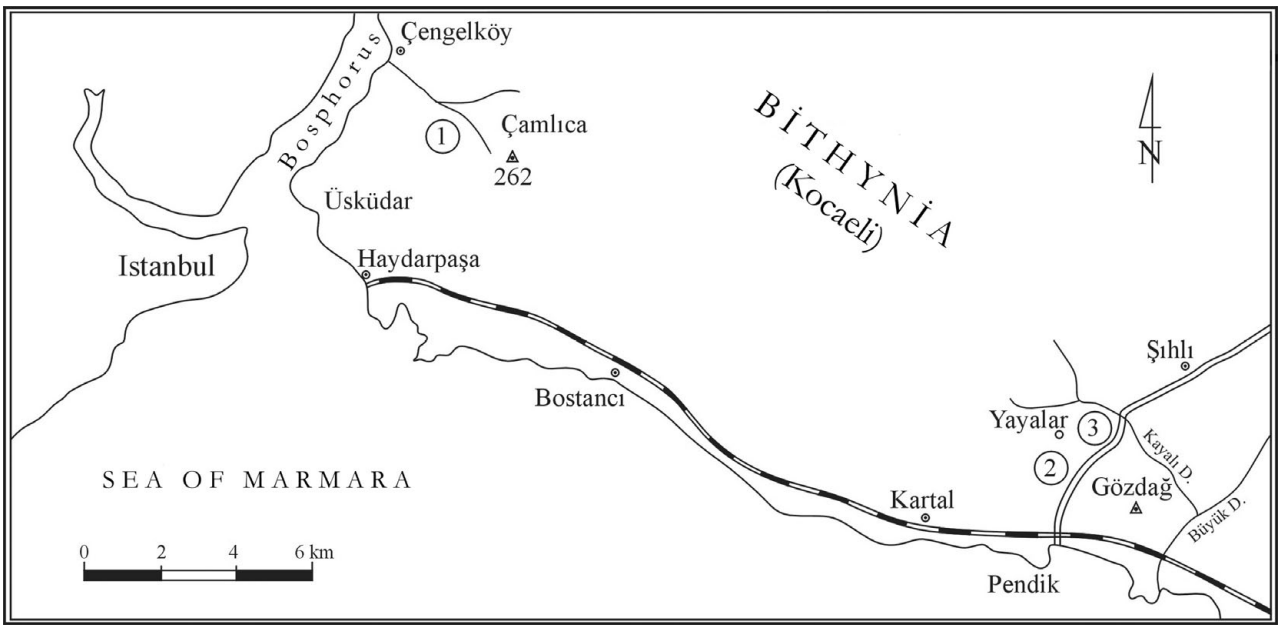

Figure 2. The Istanbul and Kocaeli area.

Ordovician Gözdağ Group, which conformably overlies the Aydos Formation (Önalan, 1981). Below the Aydos Formation lie purple-coloured clastic sediments more than a kilometre thick (the Palaeozoic basement of the region), which are mainly conglomerates, sandstones and shales. These were originally termed the 'Arkose Horizon' by Paeckelmann (1938), then generally called the 'Arkose Series' and finally renamed the Kurtköy Formation by Önalan (1981). The Kurtköy Formation is found at several localities over a large area of the western Pontides; however, no age-diagnostic fossils have been found in it, and so it is simply considered here to be of probable Cambrian to Early Ordovician age (Figs 4–6). The Gözdağ Group is conformably overlain by the Upper Silurian '*Halysites* Limestone' of Paeckelmann (1938), later termed the Dolayoba Formation (125 m) by Önalan (1981), which is a typical reef limestone with some shaly interbeds and with very common *Halysites* coral colonies and typical and diverse cosmopolitan brachiopods. The Gözdağ Group, which is more than 400 m thick, consists of the following formations.

2.a. Çengelköy Shales and Chamosite

The oldest fossiliferous beds are the Çengelköy Shales and Chamosite (100 m), originally termed the 'Laminated Shales and Chamosite' by Arıç (1955) and Sayar (1964, 1984), which conformably overlie the unfossiliferous Aydos Formation (0–350 m), previously termed the 'Quartzite Horizon' by Paeckelmann (1938). The following conulariids and brachiopods are

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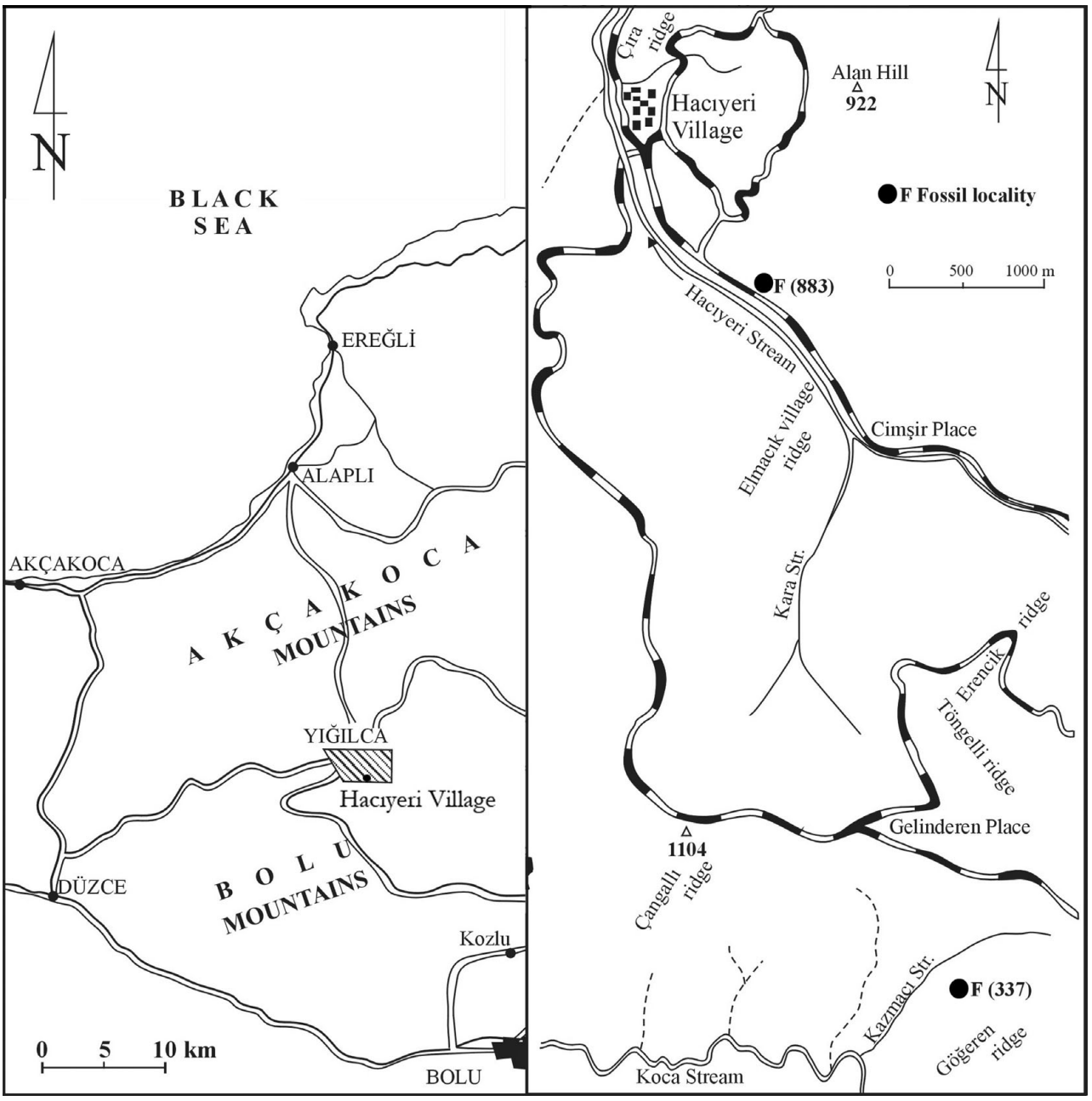

Figure 3. The Yığılca area, north of Bolu.

identified from the Çengelköy Shales and Chamosite: *Exoconularia istanbulensis* Sayar, *Exoconularia bohemica* (Barrande), *E.* (*Metaconularia*) *consobrina* (Barrande), *E.* cf. *pyramidata* (Hoenenghaus), *Archaeoconularia fecunda* (Barrande), *Paracraniops* aff. *pararia* (Williams), *Orbiculoidea* aff. *stincharensis* (Reed), *Onniella* aff. *flava* (Havlíček) and *Aegiromena* aff. *descendens* (Havlíček). These fossils are of Middle Ordovician (Darriwilian–Sandbian) age and have close affinity with the Mediterranean Province (Arıç, 1955; Sayar, 1964, 1970, 1984; Havlíček & Vanek, 1966) (Figs 4, 6).

2.b. Pendik Bryozoan Shales

The second unit, the higher levels of fine clastic sediments of the 'Bryozoan Shales' or Pendik Bryozoan Shales (50 m), conformably overlies the Çengelköy Shales and Chamosite and is seen 1.5 km north of Pendik, Istanbul. These fossiliferous shales have interbeds of bryozoan-rich limestone, which are the first occurrence of carbonate deposition in the thick and otherwise arenaceous clastic successions around Istanbul and the Bosphorus area. The brachiopods and ostracods from the bryozoan shales demonstrate a Late Ordovician (Katian) age (Figs 4, 6I). Brachiopods identified include *Sulevorthis* (*Orthambonites*) *calligramma* (Dalman), *Nicolella actoniae* (Sowerby), *Hesperorthis* aff. *craigensis* (Reed), *Glyptorthis maritima* Wright, *Saukrodictya hibernica* Wright, *Saukrodictya* cf. *porosa* Havlíček, *Drabovia* sp., *Hirnantia transgrediens* Havlíček, *Onniella* aff. *bancrofti* Havlíček, *Kullervo* sp., *Sowerbyites* aff. *hibernicus* Mitchell, *Leptestiina prantli* Havlíček, *Anisopleurella*

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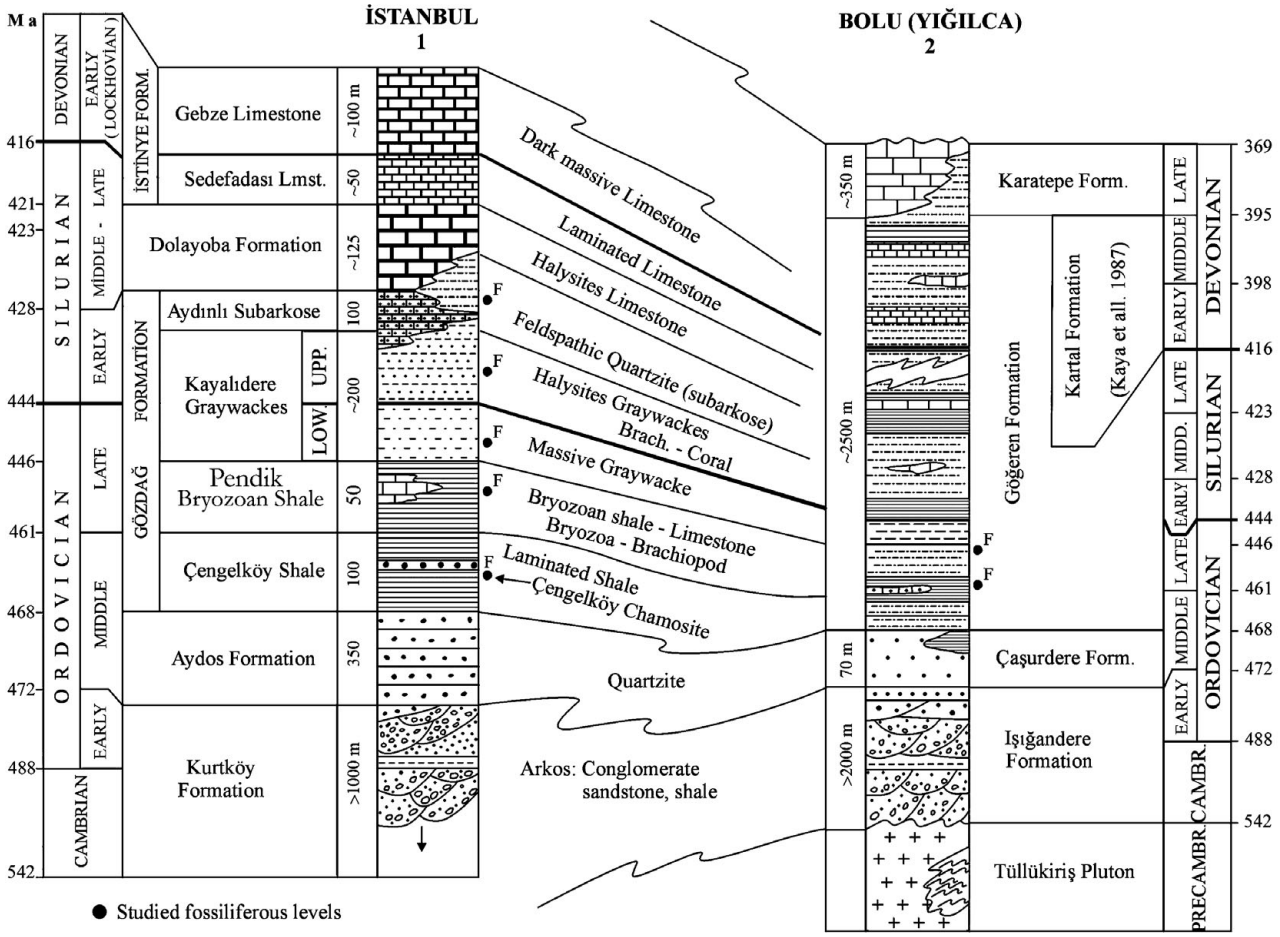

Figure 4. Lithostratigraphical and chronostratigraphical correlation of the Lower Palaeozoic sequences of Istanbul and the Bolu (Yığılca) area, western Pontides.

tricostellata Cooper, '*Strophomena*' sp. and *Christiania* sp., which occur with endemic ostracods including *Piretella bithynia* Sayar & Schallreuter, *Klimphores anatolica* Sayar & Schallreuter and *Eochilina paeckelmanni* Sayar & Schallreuter, and with the bryozoans *Reteporina* sp. and *Atactotoechus* sp. and pelmatozoan columnals (Sayar, 1984; Sayar & Schallreuter, 1989). This faunal assemblage seems provincially mixed, with *Anisopleurella* and the strophomenid more characteristic of the Avalonia–Baltic Province, but *Drabovia*, *Leptestiina* and *Howellites* representing the Mediterranean Province. Both the lithological and faunal characteristics suggest that the region became warmer during Early Katian time.

2.c. Lower Kayalıdere Formation

This formation consists of turbidites, which are 200 m thick near Pendik. It contains the distinctive *Hirnantia* brachiopod Fauna and diplograptid graptolites, and thus these beds help define the Ordovician–Silurian boundary locally (Sayar, 1979*a,b*). The massive but relatively fine-grained, greenish-grey rocks are about 80–100 m thick, and were recorded as the '*Halysites* Graywackes' of Gedinnian age by Paeckelmann (1938). These turbidites conformably overlie the Pendik Bryozoan Shales at 5–6 km northeast of Pendik. They contain a 'brachiopod–diplograptid' fauna, and the following fossils are identified: the brachiopods *Toxorthis proteus* (Temple), *Dolerorthis* aff. *sowerbyana* (Dalman), *Hesperorthis* sp., *Comatopoma* sp., *Skenidioides* aff. *asteroidea* (Reed), *Resserella* aff. *llandoveriana* Williams, *Hirnantia sagittifera* (M'Coy), *Leangella* aff. *scissa* (Davidson), *Eoplectodonta rhombica* (M'Coy), *Leptaena rugosa* (Dalman), *Plectothyrella* cf. *crassicostis* (Dalman) and *Protatrypa* aff. *thorslundi* Boucot & Johnson and the diplograptids *Glyptograptus* aff. *persculptus* Salter, *Climacograptus* aff. *normalis* Lapworth and *Climacograptus* sp., as well as some small *Thamnopora* tabulate coral colonies and pelmatozoan columnals. These fossils are a *Hirnantia* Fauna of latest Ordovician (Hirnantian) age, and help to define the Ordovician–Silurian boundary in the Istanbul and Bosphorus areas (Sayar, 1979*a–c*).

2.d. Upper Kayalıdere Formation

The formation continues upwards as coarse-grained, brownish turbidites (Sayar, 1975, 1979*a–c*), which

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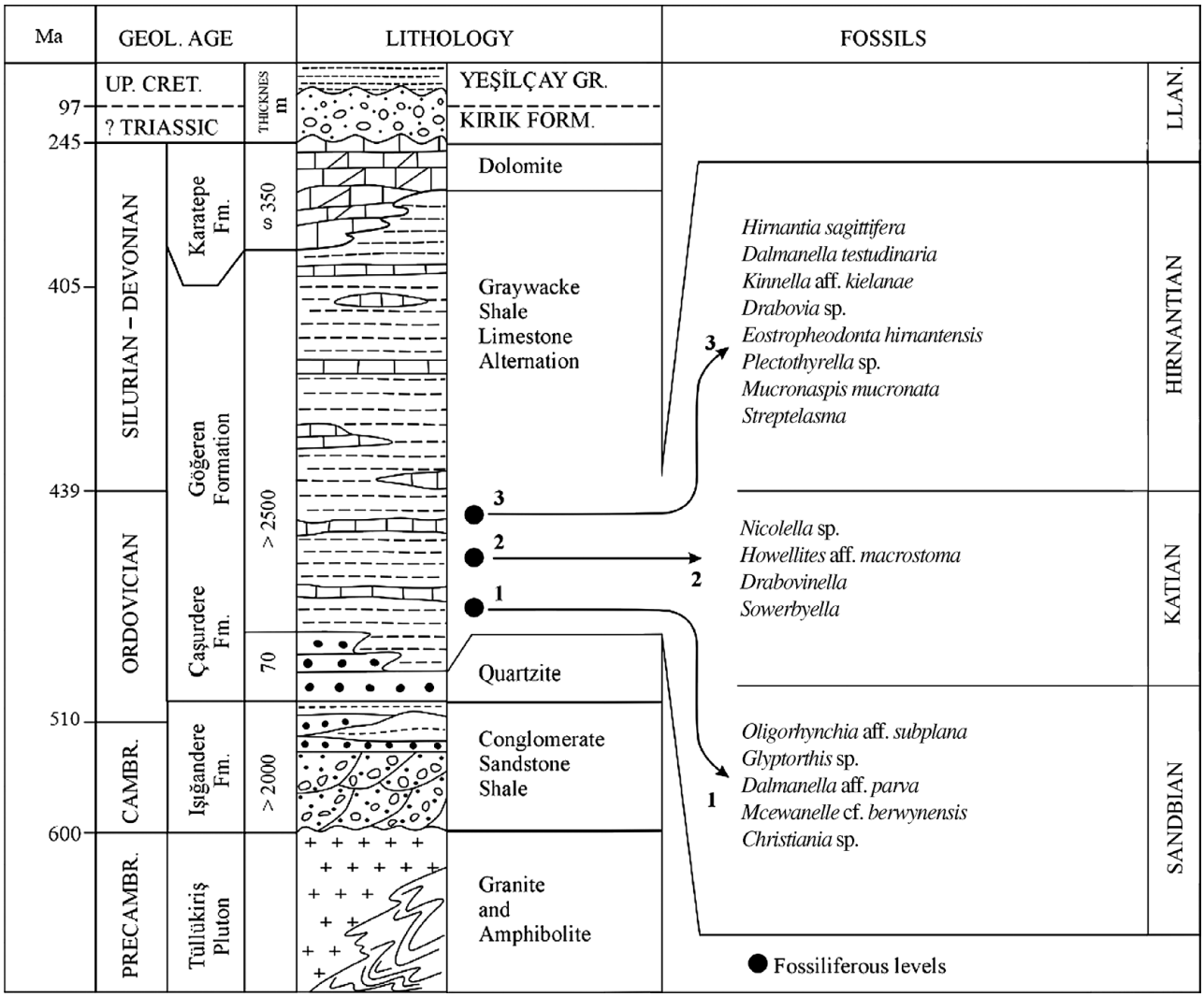

Figure 5. Generalized stratigraphic section of the Lower Palaeozoic sediments in the Bolu (Yığılca) area, with the fossiliferous levels indicated.

were also originally part of the '*Halysites* Graywackes' considered Gedinnian in age by Paeckelmann (1938). The Upper Kayalıdere Formation rocks contain typical Early Silurian (Rhuddanian–Aeronian) brachiopods, such as *Leangella scissa* (Davidson), *Eoplectodonta duplicata* (Sowerby), *Stricklandia lens* (Sowerby) *prima* Williams, *Stricklandia lens* (Sowerby) *typica* Williams and *Hindella crassa* (Sowerby), with the corals *Goniophyllum* cf. *pyramidale* (Lindström), *Halysites*, *Palaeofavosites* and *Streptelasma* (Sayar, 1979*a–c*). Above these beds lies the 'Feldspathic Quartzite' or Upper Quartzite of Sayar (1964), later termed the Aydınlı Formation or Aydınlı Subarkose (0–100 m) by Önalan (1981), which have typical Llandovery fossils of Late Aeronian to Telychian age (Sayar, 1964, 1975) (Figs 1, 2).

3. Middle Ordovician to Lower Silurian rocks and fossils of the Bolu (Yığılca) Area

Brachiopods were also collected from shales and turbidites with limestone intercalations more than 2500 m thick, named the Göğeren Formation in the valley of the Hacıyeri and Kazmacı streams (Fig. 6, sections I to VI), near Hacıyeri Village, 3 km south of Yığılca district, Adapazarı sheet G.26-b2, in the 'gred net' (31–32) (71–72) and (27–28) (72–73) on 1:25 000 scale topographic maps, north of Bolu. Fossiliferous levels with diverse brachiopods appear first at 200–250 m above the base of the formation (Figs 1, 3; F.337; F.883). The rocks were named the Karadere and Hacıyeri formations by Görmuş (1982) and, like those at Istanbul, were also originally regarded as Devonian in age. Then S. Biberoğlu and M. Özaltın (unpub. M.Sc. theses, Mining Faculty İTÜ, 1984) renamed them the Göğeren Formation and realised that they represented continuous sedimentation from the Ordovician to the end of the Devonian because of their contained fossils. The Ordovician and Silurian successions (Figs 4, 5) and the Ordovician–Silurian boundary were first identified through studies of brachiopods from the lower beds of the Göğeren Formation (Figs 5, 6) by C. Sayar in those unpublished theses. The following brachiopods have been identified from the lower beds of the Göğeren Formation: *Mcewanella* cf. *berwynensis* (MacGregor), *Dalmanella*

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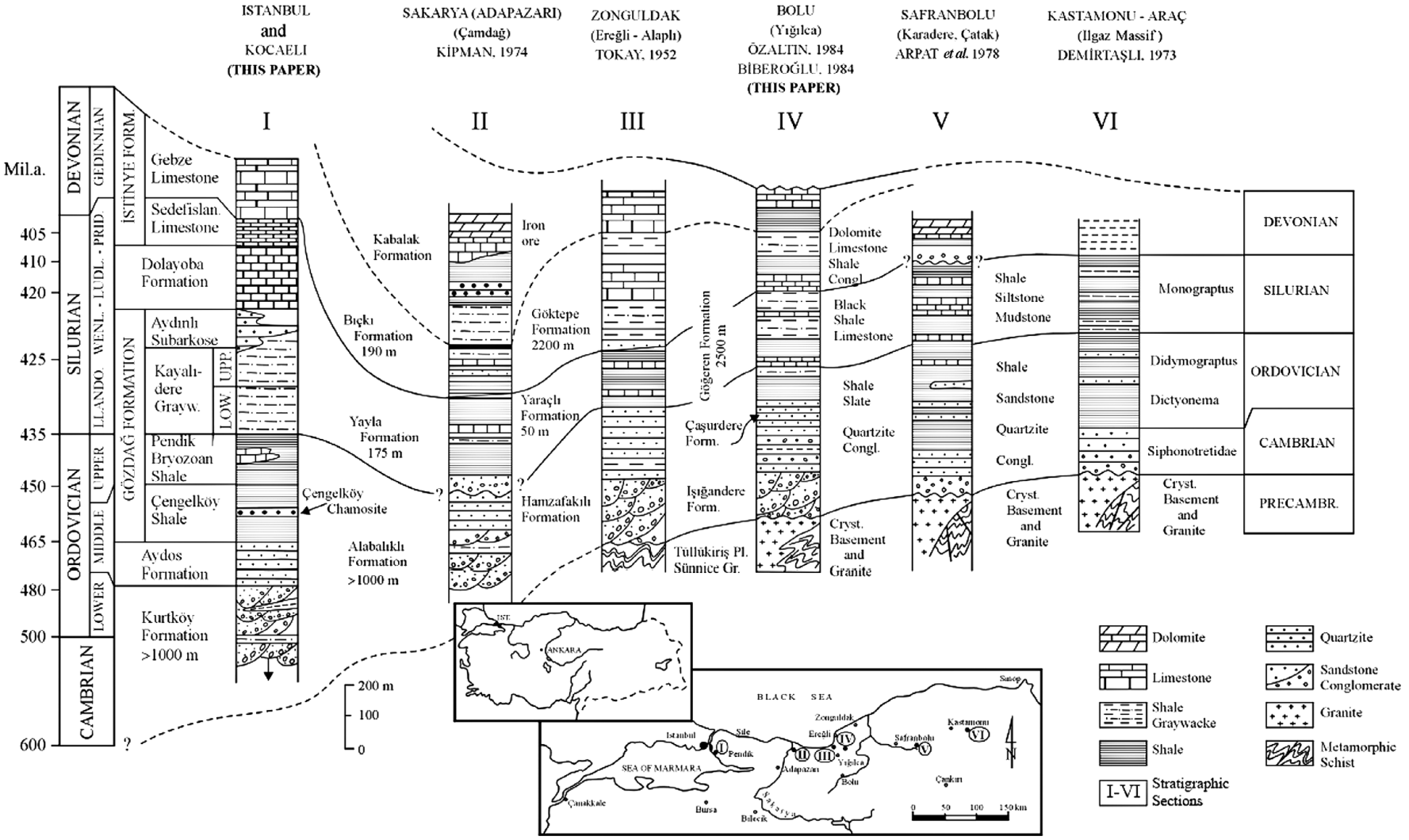

Figure 6. Lithostratigraphic and chronostratigraphic correlation of the Lower Palaeozoic sequences in the western Pontides. I – Istanbul–Kocaeli; II – Sakarya; Adapazarı (Çamdağ); III – Zonguldak (Ereğli–Alaplı); IV – Bolu (Yığılca); V – Zonguldak (Safranbolu); VI – Kastamonu–Araç (Ilgaz Massif). Includes data from Demırtaşli (1973) and Arpat *et al*. (1978).

aff. *parva* Williams, *Glyptorthis* sp., *Christiania* sp. and *Oligorhynchia* aff. *subplana* Cooper, with some Bryozoa colonies and crinoid columnals. Those fossils indicate a general Middle Ordovician age. Above the latter there are brachiopods including *Mcewanella* sp., *Nicolella* sp., *Howellites* aff. *macrostoma* (Barrande), *Drabovinella* sp. and *Sowerbyella* sp., with some Bryozoa and tetradellid ostracods, a trilobite pygidium and pelmatozoan columnals. This fauna is of Late Ordovician (Katian) age and, as at Istanbul, appears to represent a mixture of provincial representatives. The higher beds in the Göğeren Formation have a *Hirnantia* Fauna of latest Ordovician age within a *Hirnantia–Mucronaspis* association, including the brachiopods *Hirnantia sagittifera* (M'Coy), *Dalmanella testudinaria* (Dalman), *Ravozetina rava* (Marek & Havlíček), *Drabovia* sp., *Saukrodictya* sp., *Dedzetina* sp., *Kinnella* aff. *kielanae* (Temple), *Eostropheodonta hirnantensis* (M'Coy), *Coolinia dalmani* Bergström and *Plectothyrella* cf. *crassicostis* (Dalman); the trilobite *Mucronaspis* cf. *mucronata* (Brogniart); and the coral *Streptelasma* sp. This fauna proves the Hirnantian age and indicates that the local Ordovician–Silurian boundary must be immediately above that fossiliferous level.

4. Palaeogeography and conclusions

Ordovician geography had complicated developmental phases during Ordovician and Silurian times. Those evolving phases are shown in different ways in the varied palaeogeographic reconstruction maps prepared from palaeomagnetic, plate tectonic, palaeobiogeographic and lithofacies data by, for example, Gahagan & Ross (1988), McKerrow, Dewey & Scotese (1991) and Cocks & Torsvik (2002). However, all authors are agreed that the supercontinent of Gondwana dominated about half of the southern hemisphere. At Gondwana's northern margin lay most of southern Europe and southwestern Asia, including much of Turkey. That area included Armorica (France and related areas), Spain, the Italian area and Bohemia (Perunica), which at the end of the Silurian became crustal fragments separated by rifting from Gondwana when the Palaeotethys Ocean opened (McKerrow, Dewey & Scotese, 1991; Torsvik & Cocks, 2011). In contrast, further to the west, Avalonia (including England and Wales) had left Gondwana during approximately Cambrian–Ordovician time, with a widening Rheic Ocean between it and Gondwana (Cocks & Fortey, 2009); by the Middle Ordovician (Sandbian) the Avalonian faunas did not form part of the Mediterranean Faunal Province of the rest of the area. Those Sandbian fossils of Avalonia have more affinity with the warmer Baltica Province of northern Europe than those of Gondwana, and by end of the Katian the Avalonian and Baltic faunas had largely merged.

Turkey was divided into three parts in Late Ordovician time: a northern sector, the Pontides (considered in this paper); a southern sector, the Taurides; and between the two a central sector from which no Early Palaeozoic fossils are known, although there are Ordovician metagranites dated at 467 Ma (Okay, Satır & Shang, 2008), and which is not discussed further here. Some authors, for example, Kozur & Göncüoğlu (1998), have split the Pontides into a western Istanbul Terrane and an eastern Zonguldak Terrane, but we regard the Pontides as unified in the Early Palaeozoic. The Taurides, from which many Early Palaeozoic faunas have been described, some reviewed by Dean, Uyeno & Rickards (1999), was an integral part of the core of the Gondwana supercontinent (Torsvik & Cocks, 2011). However, an Ordovician conodont fauna which has close affinity with North European and North Atlantic Province forms was recorded from the Hadim area, Konya (Central Anatolia), within the middle Taurus Belt by Gedik (1977, p. 46). The Taurides also contain extensive lithological evidence for the Hirnantian glaciation (Monod *et al*. 2003), in contrast to the Pontides, although no *Hirnantia* Fauna has yet been recorded from the Taurides.

The Pontides carried Early Palaeozoic faunas that are generally different from those of the Taurides, and thus its palaeogeographical position is not yet clear. There is no reason to suppose that the Pontides formed an integral part of the core of Gondwana during the Ordovician, and, because of the lithological and faunal differences in the Hirnantian, it seems probable that it did not lie close to the Taurides then. The Pontides did not join the Central and Tauride sectors of modern Turkey until the Paleocene–Eocene at about 55 Ma (Okay, Satır & Shang, 2008). Dean *et al*. (2000) described Early (Tremadocian) to Middle (Darriwilian) Ordovician shelly faunas from the Zirze area in the eastern Pontides, and concluded that, particularly in the Tremadocian, the trilobites and other fossils were very similar to those in southern England and Wales, which were parts of the independent continent of Avalonia. However, in the western Pontides considered here, the Sandbian (Early Caradoc) shallower shelf faunas listed above suggest that NW Turkey remained at least a marginal part of the southern European Mediterranean Province.

In the Istanbul and Bosphorus area, the first clear indication of warmer-water faunas is seen in the Upper Ordovician Pendik Shales, in which some brachiopod genera, such as *Nicolella*, *Sulevorthis* (*Orthambonites*), *Saukrodictya* and *Kullervo*, are the same as in Avalonia–Baltica, although others, such as *Leptestiina* and *Drabovia*, still demonstrate links with the Mediterranean Province. The ostracods *Klimphores*, *Piretella* and *Eochilina* also show faunal affinity to northern and western Europe. Although the Pontides bryozoan reefs and associated brachiopods and ostracods can only be generally dated to Katian in age, it seems most likely that they were deposited during Middle Katian times within the Boda Global Warming Event (Fortey & Cocks, 2005). Comparable small bryozoan patch reef developments are known from many places in the Middle Katian, for example,

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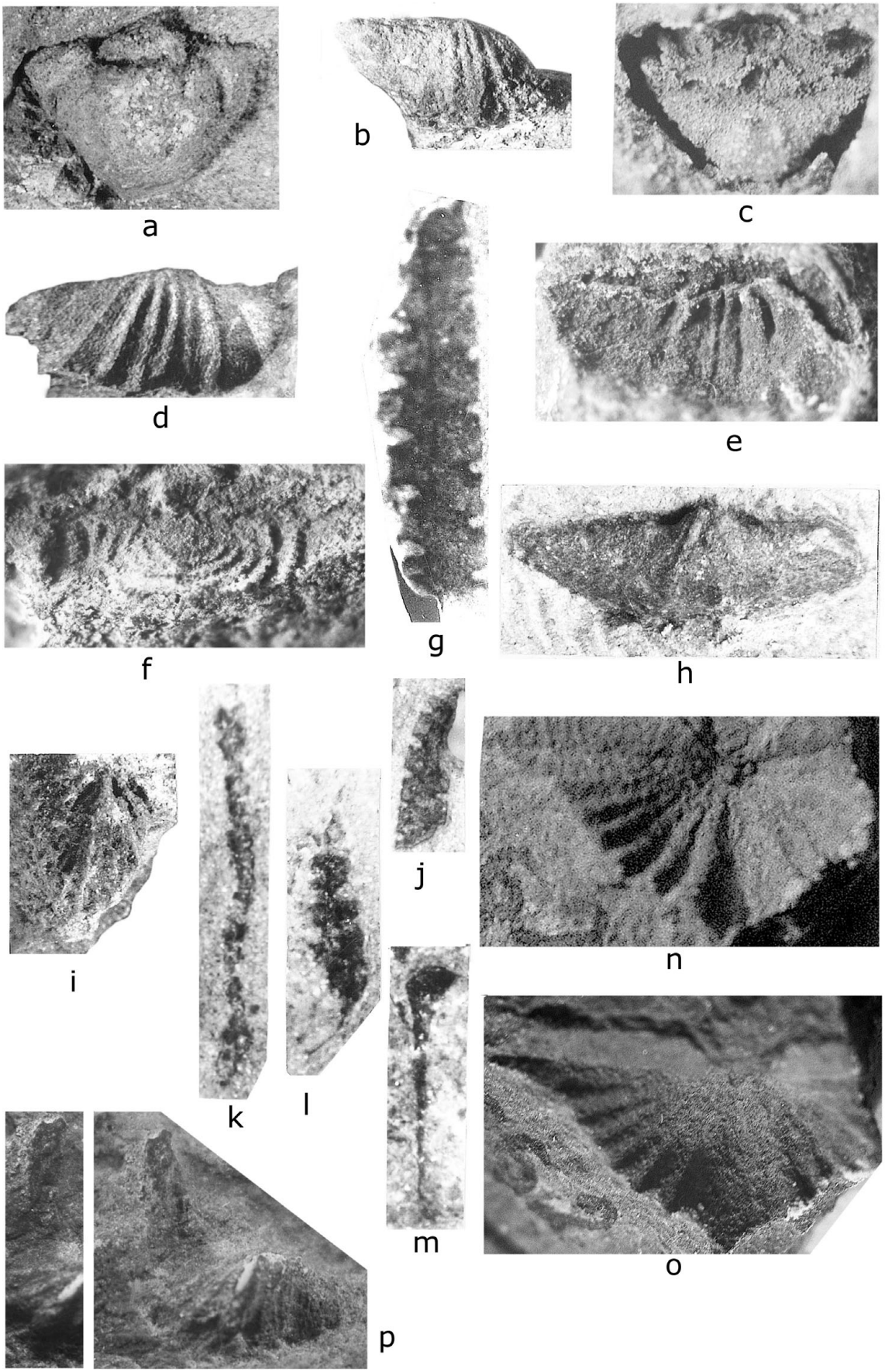

Figure 7. All specimens come from the Lower Kayalıdere Formation, Pendik, Istanbul. (a, c) *Leangella* aff. *scissa* (Davidson, 1871); (a) ventral internal mould, İTÜ.620, × 6; (c) brachial view of exterior of conjoined valves, showing interarea, delthyrium and cardinal process, İTÜ.624, × 11. (b, d, e) *Eoplectodonta rhombica* (M'Coy, 1852); (b) dorsal internal mould, İTÜ.641a, × 5.5; (d) ventral internal mould, İTÜ.719d, × 5; (e) dorsal valve inner surface, İTÜ.652a, × 5. (f) *Leptaena rugosa* Dalman, 1828, ventral valve external

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Morocco, Scandinavia, Siberia and Kazakhstan, some of which were reviewed by Webby (1984). In Morocco, like the Pontides, the bryozoan limestones are the only carbonates seen within a very thick clastic succession, although the brachiopods found there (Havlíček, 1971) are less diverse than those in the Pontides. Thus the lithological and faunal features suggest that the western Pontides might have been located within temperate-water seas connected to northern Europe and the Baltic region during Late Ordovician time.

In the palaeogeographic reconstruction maps of the Ordovician prepared on the basis of palaeomagnetic data, plate tectonics, palaeobiogeography and palaeoclimatology, Turkey was shown as a single unit placed at latitudes of about 60–70° S in the Sandbian (458 Ma) and 50–60° S at the Ordovician–Silurian boundary (443 Ma) by Ziegler *et al*. (1977) and Gahagan & Ross (1988). However, from the faunas described here, it seems more likely that the Pontides were probably independent of the rest of Turkey and situated at about 30–40° S. But the precise Ordovician location of the Pontides remains uncertain.

5. Systematic notes on the brachiopods

All the fossils discussed and described here are deposited in the Palaeontology Laboratory of the General Geology Department in the Mining Faculty, Istanbul Technical University (İTÜ). Bibliographic references to genera and above are not given here since all are in the *Treatise on Invertebrate Paleontology* (Kaesler 1997–2006). Measurements are in millimetres: L – length; W – width.

Superfamily STROPHOMENOIDEA King, 1846
Genus *Leptaena* Dalman, 1828
Leptaena rugosa Dalman, 1828
Figure 7f

Remarks. One ventral external mould, İTÜ.633c (L, 5.8 mm; W, 10.7 mm), from the Lower Kayalıdere Formation, Pendik, Istanbul is known. It is a typical specimen of *L. rugosa*, which was described by Dalman (1828) from the Dalmanitina Beds (Hirnantian), Västergötland, Sweden, and was revised by Marek & Havliček (1967) and Bergström (1968). This Turkish specimen was recorded by Sayar (1979*c*, p. 90, pl. 24, figs 1, 2) as *Leptaena martinensis* Cocks, 1968, but the latter is now known to be a synonym of *L. rugosa*. The Istanbul form is smaller than the lectotype of *L. rugosa*.

Genus *Eostropheodonta* Bancroft, 1949
Eostropheodonta hirnantensis (M'Coy, 1851)
Figure 8i

Remarks. One external mould of a dorsal valve, İTÜ.Y.1–7 (L, 13.2 mm; W, 14.4 mm), from Locality 337, Göğeren Formation, Hacıyeri Village, south of Yığılca, Bolu. The hinge line is straight, shorter than the maximum width (12 mm), with small denticles on hinge line; shell ornamented by radial parvicostellate ribs and concentric growth lines, about 5–6 ribs per 2 mm near the front margin. The species was originally described as *Orthis hirnantensis* by M'Coy (1851) from the Hirnant Formation (Hirnantian) of North Wales, and was revised and a lectotype selected by Temple (1965). The Bolu specimen is smaller than the lectotype (L, 20.5 mm, W, 25.7 mm). *E. hirnantensis* from beds of Hirnantian age at Glyn Ceiriog, North Wales (Hiller, 1980), is slightly more transverse.

Superfamily PLECTAMBONITOIDEA Jones, 1928
Genus *Leangella* Öpik, 1933
Leangella aff. *scissa* (Davidson, 1871)
Figures 7a, c, 9i

Remarks. Twenty-one specimens from the Lower Kayalıdere Formation (Hirnantian) and 44 specimens of *Leangella* from the Upper Kayalıdere Formation (Rhuddanian–Aeronian) have been studied from the same locality at Pendik, Istanbul (Sayar, 1979*c*, p.78, pl. 17, figs 6–8; pl. 18, figs 1–9). The Hirnantian form, identified here as *Leangella* aff. *scissa*, differs in its smaller size, relatively longer shell and more concave dorsal valve than the Rhuddanian specimens of true *Leangella scissa* (Sayar, 1979*c*, p. 76, pl. 14, figs 3–5; pl. 15, figs 1–7; pl. 16, figs 1–5; pl. 17, figs 1–5). The species was originally described as *Leptaena scissa* by Davidson (1871), and revised as *Leangella scissa* by Cocks (1970) from the Upper Haverford Mudstone Formation (Rhuddanian) of Haverfordwest, Pembrokeshire, Wales. *Leangella* cf. *scissa* from Hirnantian rocks at Västergötland, Sweden (Bergström, 1968), differs in its longer shell and flatter cardinal angles. *Leangella* cf. *scissa* from the Dolhir Formation (Late Katian) of North Wales (Hiller, 1980), is more transverse and has a larger ventral muscle area than the Istanbul specimens. The *Leangella* aff. *scissa* from Istanbul is similar to the *Leangella* aff. *cylindrica* (Reed, 1917) of Cocks (1982), from Hirnantian beds in the Oslo-Asker District, Norway, in its shell outline, and longer and more convex ventral valve.

mould, İTÜ.633c, × 6. (h) *Eoplectodonta* aff. *rhombica* (M'Coy, 1852), ventral internal mould, İTÜ.635, × 6. (i) *Protatrypa* aff. *thorslundi* Boucot & Johnson, 1964, dorsal internal mould, İTÜ.668, × 6. (n, o) *Plectothyrella* cf. *crassicostis* (Dalman, 1828), exterior and interior of dorsal mould, İTÜ.622, × 6. (g, j) *Climacograptus* aff. *normalis* Lapworth, 1877; upper part of rhabdosome and deformed reverse side, İTÜ.712a, b, × 7.5. (k) *Glyptograptus* sp. aff. *nicholsoni* Toghill, 1970, deformed rhabdosome fragment, İTÜ.792, × 7.5. (l) *Glyptograptus* cf. *persculptus* (Elles & Wood, 1907), a complete juvenile rhabdosome, İTÜ.585, × 16. (m) ?*Climacograptus* sp., proximal end of sicula (virgella), İTÜ.119, × 16. (p) ?*Diplograptus* sp., rhabdosome fragment, İTÜ.717, on the pedicle valve of *Eoplectodonta* sp., İTÜ.603, × 7.2.

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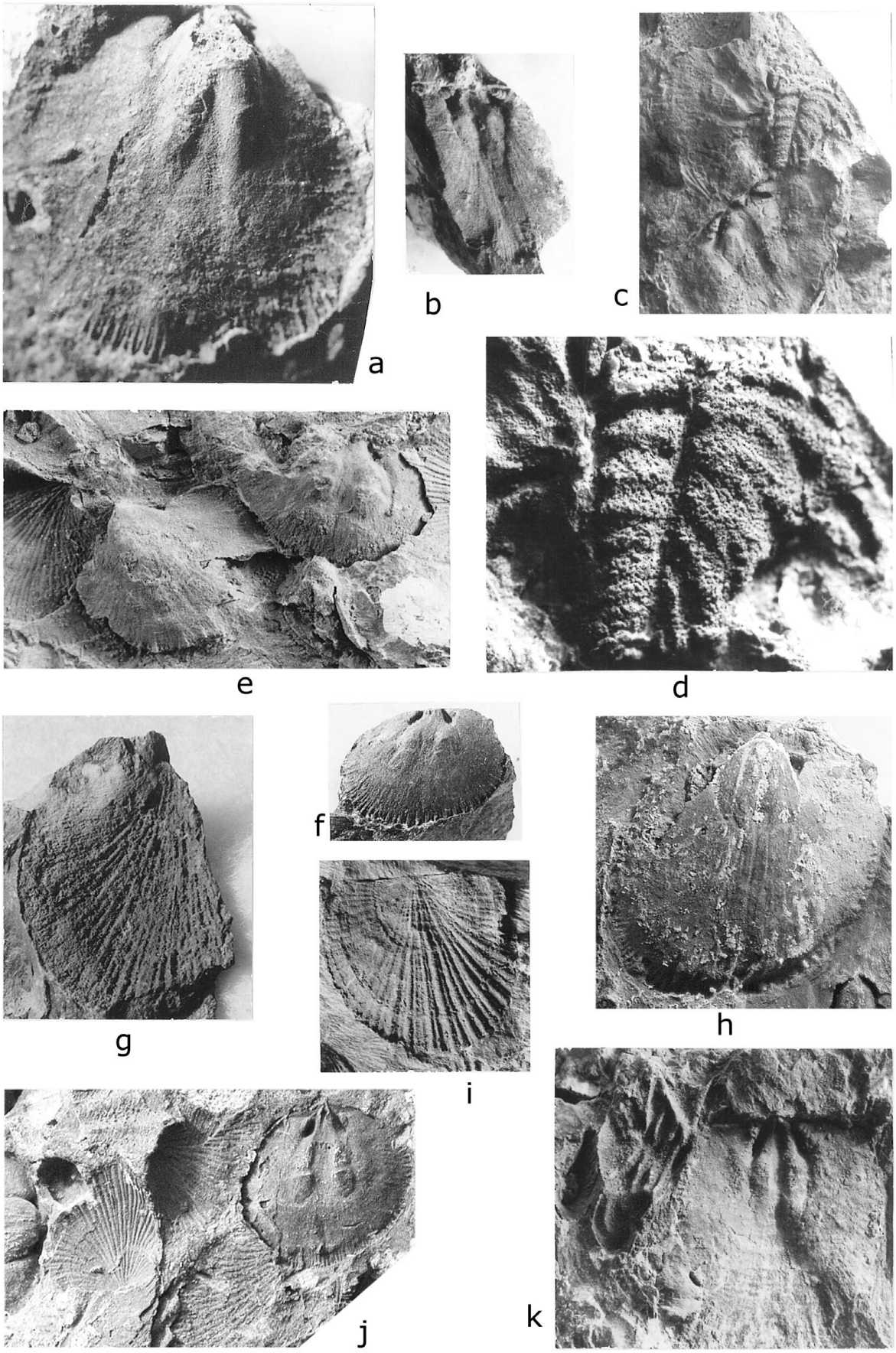

Figure 8. All specimens come from Locality 337 in the Göğeren Formation, Haciyeri Village, south of Yığılca, Bolu, apart from (b) and (g, h), which come from Locality 883, also at Haciyeri. (a, b) *Ravozetina rava* (Marek & Havlíček, 1967); (a) ventral valve internal mould, İTÜ.Y.21b, × 7; (b) dorsal valve internal mould, İTÜ.Y.5a, × 3. (c, d) *Dedzetin*a sp., dorsal internal mould, İTÜ.Y1–8a, on its upper right *Mucronaspis* aff. *mucronata* (Brongniart, 1822); incomplete pygidium, the left part and posterior extremity (spine)

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Genus *Eoplectodonta* Kozlowski, 1929
Eoplectodonta rhombica (M'Coy, 1852)
Figures 7b, d, e, 9m, ?7h

Remarks. The Istanbul material is mostly semicircular to transversely oval in outline, and was previously recorded as *Eoplectodonta duplicata* (Sowerby, 1839) by Sayar (1979*c*, p. 83, pl. 19, figs 1–6; pl. 20, figs 1–13; pl. 21, figs 1–8; pl. 22, figs 1–10) and designated then as the 'Normal Form' (L, 3.5–8 mm; W, 7–14 mm) İTÜ.652a; but some more transverse, shorter and smaller specimens (L, 3.5–4.5 mm; W, 7–13 mm) were identified as *Eoplectodonta* aff. *duplicata* (Sowerby, 1839) and grouped as an 'Alate Form' (Sayar, 1979*c*, pp. 83–90, pl. 22, figs 19–22; pl. 23, figs 1–8). The latter, including the external mould of a brachial valve İTÜ.642a from the Lower Kayalıdere Formation of Pendik, are smaller and more transverse with acute cardinal angles and smaller ventral muscle areas, and are reassigned here to *Eoplectodonta* aff. *rhombica* (M'Coy, 1852) (Fig. 7h), İTÜ.635. *E. rhombica* was originally described as *Leptaena sericea* (Sowerby) var. *rhombica* by M'Coy (1852) from the Crag Hill Beds (Late Katian) of Horton-in-Ribblesdale, Cumbria, England, and was revised as *Eoplectodonta rhombica* by Cocks (1982). The Istanbul specimens are closely related but lack rugae on the posterior margin, in a similar way to *Eoplectodonta* cf. *rhombica* from the Early Katian of Pomeroy, Ireland, described by Mitchell (1977). *Eoplectodonta* aff. *rhombica* from Istanbul (Fig. 7h) shows similarity to some specimens of *Eoplectodonta* cf. *rhombica* (Williams, 1963) from the Early Katian of Girvan, Scotland, and seems also closely related to *Eoplectodonta* sp. 1 described by Harper (1989) from the Late Katian of Girvan.

Family CHILIDIOPSOIDEA Boucot, 1959
Genus *Coolinia* Bancroft, 1949
Coolinia dalmani Bergström, 1968
Figure 10e

Remarks. One ventral internal mould, İTÜ.Y.3 (L, 8.6 mm; W, 16.2 mm); from Locality 337, Göğeren Formation, Hacıyeri Village, south of Yığılca, Bolu, is characteristic of the species. The ornament can be seen internally on the left flank, and is three ribs per millimetre at 5 mm in front of the umbo. The species was described by Bergström (1968) from the lower Dalmanitina Beds (Hirnantian), at Stommen, Västergötland, Sweden, and by Cocks (1982). The Bolu specimen is smaller than the holotype (40 mm wide). *Coolinia* (*Fardenia*) *comes* (Marek & Havliček, 1967) from the Hirnantian of Bohemia is 17 mm wide and differs in its stronger internal ribbing, and the anterolateral ends of the dental plates are less curved than the Bolu material.

Superfamily ORTHOIDEA Woodward, 1852
Genus *Toxorthis* Temple, 1968
Toxorthis proteus Temple 1968
Figure 9a, b

Remarks. One ventral internal mould, İTÜ.562 (L, 4.5 mm; W, 8 mm), and one dorsal interior, İTÜ.563 (L, 4 mm; W, 9 mm), were recovered from the Lower Kayalıdere Formation at Pendik (Sayar, 1979*c*, pp. 50–51, pl. 2, figs 3–8). *Toxorthis proteus* was described by Temple (1968) from the Keisley Limestone (Hirnantian) of Westmoreland, Northern England. The Istanbul material is similar to the holotype but the dorsal valve has three median ribs in the sulcus (one of them bifurcated) and more distinctive concentric growth lamellae at the anterior margin.

Genus *Dolerorthis* Schuchert & Cooper, 1931
Dolerorthis aff. *sowerbyana* (Davidson, 1869)
Figure 9c

Remarks. Only one ventral internal mould, İTÜ.577 (L, 4.5 mm; W, 5.5 mm), with an ornament of 10–12 angular radial ribs was described from the Lower Kayalıdere Formation at Pendik by Sayar (1979c, p.51, pl. 3, figs 1–8). The species was originally described from Rhuddanian siltstones near Meifod, Wales, by Davidson (1869) and revised by Temple (1970). The Istanbul specimen is smaller, more convex and has fewer radial ribs than the holotype. The dorsal valve is unknown.

Genus *Hesperorthis* Schuchert & Cooper, 1931
Hesperorthis sp.
Figure 9e

Remarks. One ventral internal mould part and counterpart, İTÜ.574a (L, 6 mm; W, 7 mm), from the Lower Kayalıdere Formation, Pendik, was described by Sayar (1979*c*, pp. 52–3, pl. 4, figs 1–3). It is of medium size, subquadrate and moderately convex; cardinal margin straight, nearly equal to the width; interarea high and apsacline; cardinal angles subrounded; ventral muscle area subtriangular; subcordial poorly preserved thick radial ribs on shell. On the same specimen there is a ferruginous rhabdosome of *Climacograptus* sp. (İTÜ.574b).

broken, İTÜ.Y.1–8b, × 2; (d) the same specimen enlarged, × 10. (e, f) *Hirnantia sagittifera* (M'Coy, 1851); (e) lower left, ventral internal mould İTÜ.Y.1a, upper right, dorsal internal mould, İTÜ.Y.1b, × 2; (f) dorsal internal mould compressed posteriorly, İTÜ.Y.17, × 2.5. (g, h, k) *Dalmanella testudinaria* (Dalman, 1828); (g, h) counterpart ventral external and internal moulds, İTÜ.Y.16a, b × 2.3; (k) dorsal internal mould, İTÜ.Y.2–2, with *Mucronaspis* aff. *mucronat*a (Brongniart, 1822), external mould of incomplete cranidium, longitudinally compressed, İTÜ.Y.2–1b, (on the cranidium, the glabella, three furrows and the left eye are visible), × 2.5. (j) *Drabovia* sp., internal and external moulds of dorsal valve, İTÜ.Y.11, × 2.5. (i) *Eostropheodonta hirnantensis* (M'Coy, 1851); external mould of dorsal valve, İTÜ.Y.1–7, × 2.5.

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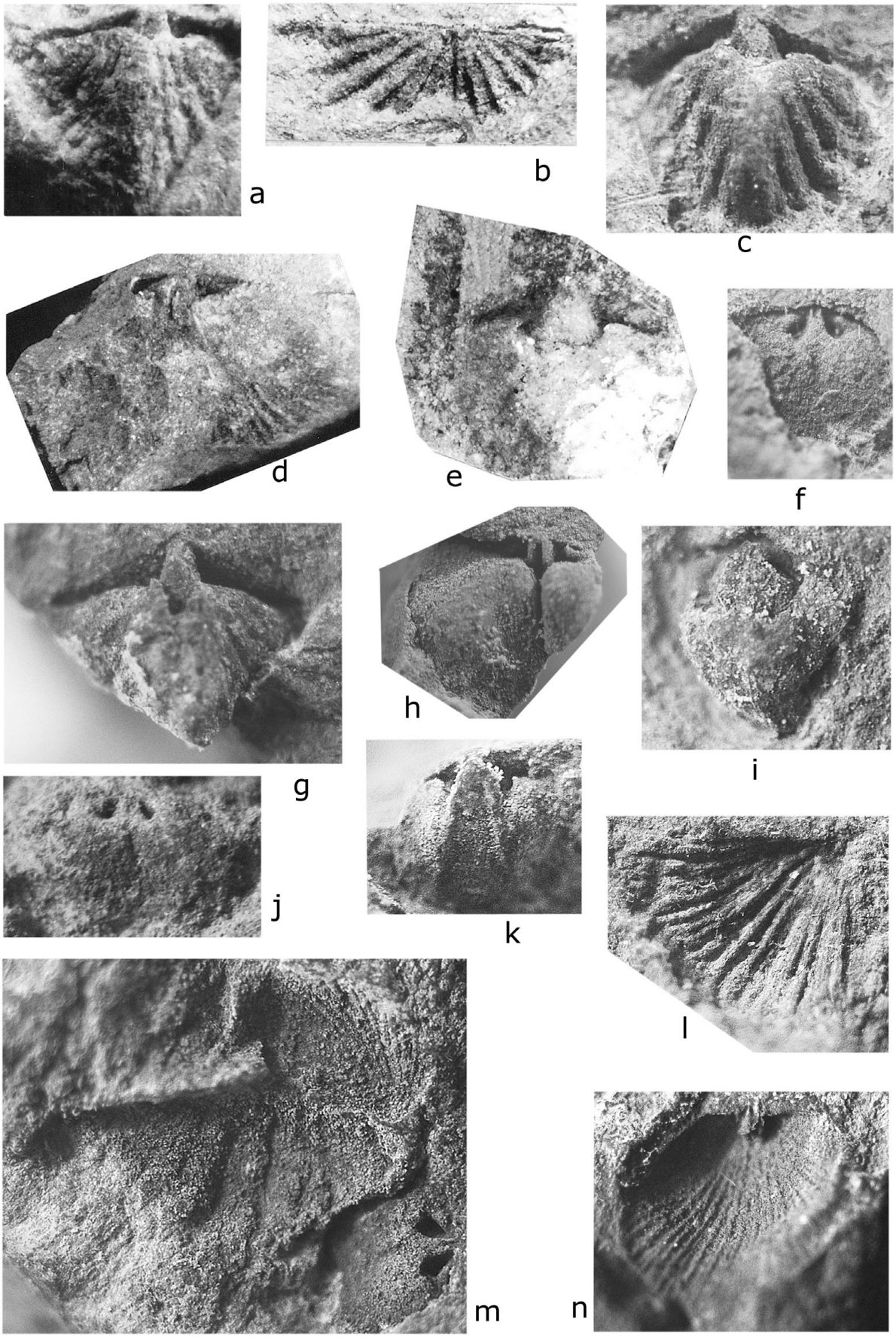

Figure 9. All specimens come from the Lower Kayalıdere Formation, Pendik, Istanbul. (a, b) *Toxorthis proteus* Temple, 1968; (a) internal mould of deformed ventral valve, İTÜ.562; (b) dorsal interior, İTÜ.563, both × 6. (c) *Dolerorthis* aff. *sowerbyana* (Davidson, 1869), ventral internal mould, İTÜ.577, × 8. (d) *Comatopoma* sp., internal mould of dorsal valve, poorly preserved,

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Superfamily PLECTORTHOIDEA Schuchert & Le Vene, 1929
Genus *Comatopoma* Havlíček, 1951
Comatopoma sp.
Figure 9d

Remarks. One dorsal valve internal mould, İTÜ.682, from the Lower Kayalıdere Formation, Pendik, was described by Sayar (1979*c*, pp. 52–3, pl. 4, fig. 4). This specimen shows close affinity to *Comatopoma sororium* Marek & Havlíček, 1967 (Havlíček, 1977) from the Kosov Formation (Hirnantian) of Bohemia. The shell is oval in shape and gently convex; the hingeline is straight with the cardinal angles rounded; the widest part of the shell is nearly mid-length. There is a wide shallow sulcus from the umbo to the anterior margin; the orthocline dorsal interarea is less than 1 mm high; the cardinal process is blade-like; the brachiophore supports are long and thin but with strong sockets; the dorsal muscle scars are elliptical; and there is multicostellate internal ribbing (3–4 per millimetre) near the anterior margin.

Superfamily SKENIDIOIDEA Kozłowski, 1929
Genus *Skenidioides* Schuchert & Cooper, 1931
Skenidioides aff. *asteroidea* (Reed, 1917)
Figure 9g, h

Remarks. About 12 internal and external moulds of ventral and dorsal valves, but no conjoined valves, were found in the Lower Kayalıdere Formation at Pendik, and identified as *Skenidioides* aff. *asteroidea* Reed, by Sayar (1979*c*, pp. 57–60, pl. 5, figs 5–8; pl. 6, figs 1–10; pl. 7, figs 1–7). *Skenidioides asteroidea* was originally described as *Scenidium lewisi* Davidson, var. nov. *asteroidea* by Reed (1917) from the Starfish Bed at Thraive Glen in the Drummuck Group (Katian), Girvan, Scotland. The Turkish material shows a close relation to it, but the holotype has fewer ribs (20) and acute cardinal angles. *Skenidioide*s cf. *asteroidea* described by Wright (1964) from the Portrane Limestone (Hirnantian), near Dublin, Ireland, and by Hiller (1980) from north Wales, are close to the Istanbul form, but the Portrane material is smaller and has fewer ribs (12–21). The Welsh material is nearly the same size but also has fewer ribs. *Skenidioides scoliodus* Temple (1968), from the Keisley Limestone (Hirnantian), northern England, differs in its small size (L, 0.5–2.5 mm; W, 0.5–3 mm), deep dorsal sulcus and longer median septum.

Superfamily DALMANELLOIDEA Schuchert, 1913
Genus *Dalmanella* Hall & Clarke, 1892
Dalmanella testudinaria (Dalman, 1828)
Figure 8g, h, k

Remarks. Several internal and external moulds of both ventral and dorsal valves, including İTÜ.Y.16a (L, 18.7 mm; W, 24.3 mm); İTÜ.Y 2–2 (L, 14.2 mm; W, 15.8 mm), a dorsal internal mould (Fig. 8k) with a cranidium of *Mucronaspis* aff. *mucronata* (Brongniart); and İTÜ.Y 2–1b, were found at Locality 337 in the Göğeren Formation at Hacıyeri Village, south of Yığılca, Bolu. The species was originally described as *Orthis testudinaria* by Dalman (1828), from the Dalmanitina Beds (Hirnantian) of Östergötland, south central Sweden, and revised as *Dalmanella testudinaria* by Williams & Wright (1963), Temple (1965), Marek & Havliček (1967), Bergström (1968) and Jin & Bergström (2010). Bergström (1968) concluded that the different sizes and shell thicknesses in some *Dalmanella testudinaria* populations might be the result of environmental variations.

Genus *Ravozetina* Havliček, 1974
Ravozetina rava (Marek & Havliček, 1967)
Figure 8a, b

Remarks. One ventral valve internal mould, İTÜ.Y 21b (L, 9.4 mm; W, 9.1 mm) from Locality 337, and one dorsal valve, İTÜ.Y 5a (L, 11.2 mm), from Locality 883, were both found in the Göğeren Formation at Hacıyeri Village, south of Yığılca, Bolu. The species was originally described as *Onniella rava* by Marek & Havliček (1967) from the Kosov Formation (Hirnantian) of Bohemia, and was revised as *Ravozetina rava* by Havliček (1977). The Bolu material is similar but rather larger than the holotype from Bohemia and the pedicle valve is more rounded and has finer internal ribs.

Genus *Dedzetina* Havliček, 1951
Dedzetina sp.
Figure 8c, d

Remarks. Only one dorsal internal mould, İTÜ.Y 1–8a (L, 10 mm; W, 13 mm) (Fig. 8c, d), together with a trilobite pygidium, probably *Mucronaspis mucronata* (İTÜ.Y 1–8b), was found at Locality 337, Hacıyeri Village, south of Yığılca, Bolu. The brachiophore supporting plates are thin and strongly divergent (100–110°); the large muscle field is shield-shaped, medianly divided by a strong ridge and surrounded laterally by a low ridge; the posterior adductors are separated from larger anteriors by low transverse ridges converging posteriorly. It is similar to *Dedzetina microstoma*,

İTÜ.682, × 6. (e) *Hesperorthis* sp., ventral internal mould, İTÜ.574a and (Gr to the left) a poorly preserved *Climacograptus* sp., İTÜ.574b, × 6. (g, h) *Skenidioides* aff. *asteroidea* (Reed, 1917); (g) internal mould of ventral valve, İTÜ.545a, × 7.6; (h) dorsal internal mould, İTÜ.550a, × 6. (i) *Leangella* aff. *scissa* (Davidson, 1871), ventral internal mould, İTÜ.621, × 7.5. (j, l) *Hirnantia* cf. *sagittifera* (M'Coy, 1851); (j) internal mould of dorsal valve (young form) İTÜ.582, × 7.5; (l) external mould of ventral valve, İTÜ.584b, × 6.5. (f, k, m, n) *Resserella* aff. *llandoveriana* Williams, 1951; (f) dorsal internal mould, İTÜ.642b, × 5.5; (k) ventral internal mould, İTÜ.592, × 11; (m) ventral external mould and dorsal internal mould together with dorsal internal mould of *Eoplectodonta rhombica* (M'Coy, 1852), İTÜ.642a, × 8; (n) ventral external mould, İTÜ.633b, × 7.

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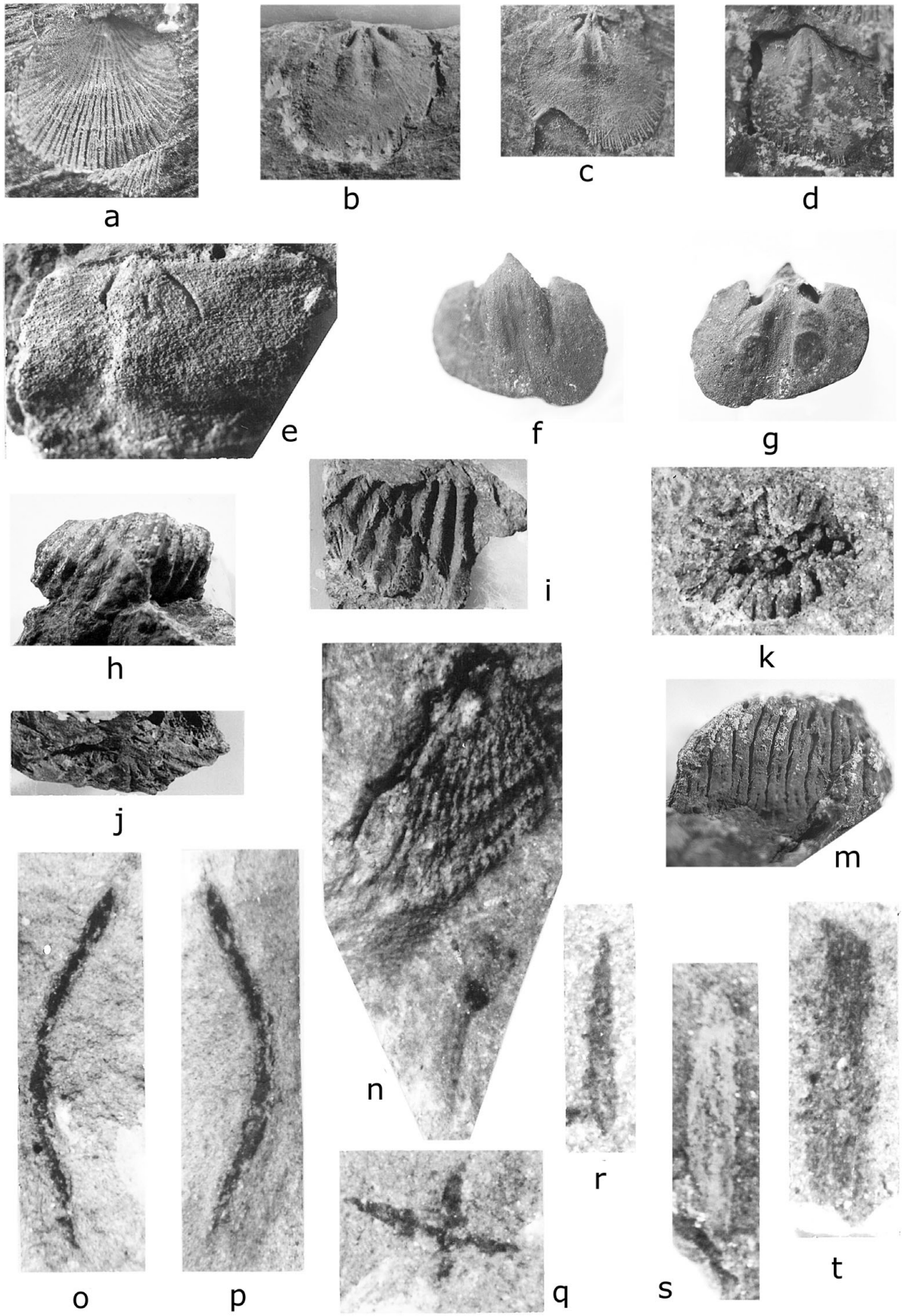

Figure 10. (a, e, h–j, m) come from Locality 337 in the Göğeren Formation, Haciyeri Village, south of Yığılca, Bolu, (b–d, f, g) from Locality 883, also at Haciyeri, and (n–t) from the Lower Kayalıdere Formation, Pendik, Istanbul. (a–c) *Drabovia* sp.; (a) dorsal external mould, İTÜ.Y.1–5, × 2.5; (b, c) dorsal internal moulds, İTÜ.Y.5, İTÜ.Y.5.1, × 2.4. (d, f–g) *Kinnella* aff. *kielanae* (Temple, 1965); (d) ventral internal mould, İTÜ.Y.12a, × 2; (f, g) ventral and dorsal views of internal mould of conjoined valves, İTÜ.Y.23, × 4. (e) *Coolinia dalmani* Bergström, 1968, internal mould of deformed ventral valve, İTÜ.Y.3, × 4.3. (h–j) *Plectothyrella* cf. *crassicostis*

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which was described by Havlíček (1977) from the Králûv Dvûr Formation (Late Katian) of Bohemia. The single specimen from Bolu is similar in shape and internal features to *Dedzetina microstoma*, but the holotype has thick brachiophore supports. *Dedzetina* cf. *microstoma* described by Harper (1989) from Girvan also has thicker brachiophore supporting plates than the Bolu form; however, there is not enough Turkish material for more precise assignment.

Genus *Resserella* Bancroft, 1928
Resserella aff. *llandoveriana* Williams, 1951
Figure 9f, k, m, n

Remarks. Sayar (1979*c*, pp. 70–2, pl. 11, figs 1–12; pl. 12, figs 1–11) described *Resserella* aff. *llandoveriana* from internal and external moulds of ventral and dorsal valves, including İTÜ.642b, İTÜ.592, İTÜ.633b (L, 1.5–7.5 mm; W, 1.8–9 mm). *Resserella llandoveriana* was described by Williams (1951) from the Haverford Mudstone Formation (Rhuddanian) of Pembrokeshire, Wales. The small *Resserella* aff. *llandoveriana* from the Lower Kayalıdere Formation (Hirnantian) is scarce and its radial ribs are thicker than those of larger specimens such as the holotype. However, true *R. llandoveriana* occurs in the Upper Kayalıdere Formation at Pendik, which is of Early Llandovery (Rhuddanian) age (Sayar, 1979*c*).

Superfamily ENTELETOIDEA Waagen, 1884
Genus *Drabovia* Havlíček, 1951
Drabovia sp.
Figures 8j, 10a–c

Remarks. External and internal moulds of dorsal valves and one external mould of a ventral valve were found at Locality 337 (including İTÜ.Y.11 and İTÜ.Y.1–5) and Locality 883 (İTÜ.Y.5 and İTÜ.Y.5–1), both in the Göğeren Formation, Hacıyeri Village, South of Yığılca, Bolu (L, 9.1–12 ; W, 9.5–10 mm). The Hirnantian Bolu specimens are of smaller size and have a larger dorsal muscle area and finer fascicostellate ribs than *Drabovia postrema* Havlíček, 1951 (Havlíček, 1977) from the Bohdalec Formation (Katian) of Bohemia. The latter is subrectangular to transversely oval, with coarser fascicostellate ribs and has thin, long, slightly divergent brachiophore supporting plates. The Bolu form has a thin, blade-like cardinal process shorter than the brachiophores, which are thick and diverge at 75–85°; the dental sockets are small, and the dorsal muscle field is oval, surrounded by a low ridge, and is quadripartite, with long triangular to elliptical posterior adductors located in front of the brachiophore supports and separated from subrectangular anterior scars by a low transverse ridge.

Genus *Hirnantia* Lamont, 1935
Hirnantia sagittifera (M'Coy, 1851)
Figures 8e, f, 9j, l

Remarks. This species is not common, but includes İTÜ.582 (L, 3.5 mm; W, 5 mm), a juvenile specimen (Fig. 9j), and İTÜ.584b (Fig. 9l), a ventral external mould showing the ornament, from the Lower Kayalıdere Formation, Pendik; and İTÜ.Y.1a and 1b (Fig. 8e), ventral (L, 10.9 mm; W, 14.5 mm) and dorsal (L, 13.6 mm; W, 15.4 mm) internal moulds, and İTÜY.17 (Fig. 8f) from localities 337 and 883, respectively, in the Göğeren Formation at Hacıyeri Village, south of Yığılca, Bolu. Sayar (1979*c*, pp. 61–3, pl. 8, figs 1–8) described this material as *Hirnantia* cf. *sagittifera*. The species was originally described as *Orthis sagittifera* by M'Coy (1851) from the Hirnant Limestone (Hirnantian) of Aber Hirnant, North Wales and was revised as *Hirnantia sagittifera* by Lamont (1935), Temple (1965), who chose and figured the lectotype (Sedgwick Museum Cambridge A41217; L, 16.3 mm; W, 15.2 mm), and Marek & Havliček (1967). Juvenile forms from the Lower Kayalıdere Formation (Fig. 9j; L, 2.5–5 mm; W, 3.5–6 mm) are somewhat different, but the adults are similar to those from Wales and Bohemia; however, the Bolu material is similar to British, Baltic and Bohemian specimens.

Genus *Kinnella* Bergström, 1968
Kinnella aff. *kielanae* (Temple, 1965)
Figure 10d, f, g

Remarks. One pair of conjoined valves internal mould (Fig. 10f, g), İTÜ.Y.23 (L, 7 mm; W, 9.2 mm), and one ventral internal mould, İTÜ.Y.12a, were found at Locality 883 in the Göğeren Formation at Hacıyeri Village, south of Yığılca, Bolu. Temple (1965) described *Hirnantia? kielanae* from the Dalmanitina Beds (Hirnantian) of the Holy Cross Mountains, Poland, which was revised by Marek & Havliček (1967) and as *Kinnella kielanae* by Bergström (1968). The Bolu specimens show differences in the long oval muscle area of the ventral valve and the wider median ridge of the dorsal valve than that of the holotype. The Bohemian subspecies *Kinnella kielanae proclinis* Havliček (1977) differs in its oval shape with a circular ventral muscle area and in a narrower median ridge in the dorsal valve.

(Dalman, 1828), counterpart ventral internal and external moulds with beak and umbo compressed, İTÜ.Y.4a, b, × 2.2. (k) ?*Thamnopora* sp., transversely broken small tabulate coral colony, İTÜ.664, × 6. (m) *Streptelasma* sp., internal mould of flattened corallite affected by tectonic deformation İTÜ.Y.14, × 2.3. (n) *Climacograptus* sp. aff. *normalis* Lapworth, 1877, proximal fragment with sicula and some poorly preserved theca; in the upper left is dorsal external mould of *Skenidioides* aff. *asteroidea* (Reed, 1917), İTÜ.719;720a, × 10. (o, p) ?*Climacograptus* sp., deformed internal and external moulds, the counterpart of a distal end fragment, İTÜ.718a, × 7; (q) synrhabdosome of a diplograptid with four individuals, İTÜ.743a, × 10, one partly broken. (r–t) Diplograptidae gen. et. sp. indet., (r) İTÜ.728, × 10. (s) İTÜ.737, × 10. (t) İTÜ.735, × 7.

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Superfamily RHYNCHOTREMATOIDEA Schuchert, 1913
Genus *Plectothyrella* Temple, 1965
Plectothyrella cf. *crassicostis* (Dalman, 1828)
Figures 7n, o, 10h–j

Remark. One dorsal valve, İTÜ.662 (L, 6.4 mm; W, 18 mm) from the Lower Kayalıdere Formation, Pendik, and İTÜ.Y.4a, b (L, 17.2 mm), the internal and external moulds of a pedicle valve, were found at Locality 337 in the Göğeren Formation at Hacıyeri Village, south of Yığılca, Bolu, and were described as *Plectothyrella crassicosta* by Sayar (1979*c*, p. 100, pl. 27, figs 1–2). The species was originally described as *Atrypa*? *crassicostis* by Dalman (1828) from the Dalmanitina Beds (Hirnantian) of Västergötland, Sweden. It is a senior synonym of *Plectothyrella platystrophoides* Temple (1965), which was revised by Marek & Havliček (1967), as recognized by Bergström (1968) and Cocks (1982). *Plectothyrella* cf. *crassicostis* from Istanbul and Bolu differs from the Swedish *P. crassicostis* in being smaller, more transverse rather than elongate, less globose in outline and in having fewer radial ribs.

Superfamily ATRYPOIDEA Gill, 1871
Genus *Protatrypa* Boucot, Johnson & Staton, 1964
Protatrypa aff. *thorslundi* Boucot & Johnson, 1964
Fig. 7i

Remarks. Two dorsal internal moulds dorsal, İTÜ.668 and İTÜ.669 (L, 8.5 mm; W, 5.5 mm), were found in the Lower Kayalıdere Formation at Pendik (Sayar, 1979*c*, p. 109, pl. 31, figs 6–8). The species was originally described by Boucot & Johnson (1964) from the Ede Quartzite (Aeronian) of Jämtland, Sweden, but the dorsal valve of the Istanbul specimen differs in being more convex and more elongate than the type material. *Protatrypa malmoeyensis* Boucot, Johnson & Staton, 1964 from the Aeronian of Norway, and *P. septentrionalis* (Nikiforova *in* Nikiforova & Andreeva, 1961) from Llandovery beds of the Siberian Platform both have a longer hinge line and a less convex shell.

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