Hirnantia sagittifera (Brachiopoda) and *Mucronaspis mucronata s.l.* (Trilobita) in the Upper Ordovician of the East Baltic: taxonomy and distribution

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Abstract. The brachiopod *Hirnantia sagittifera* (M'Coy) and trilobite morphs of the genus *Mucronaspis* from the topmost Ordovician Porkuni Stage of the central East Baltic are described and compared with those from the Hirnantian Stage of other regions. These important Hirnantian taxa occur in the Livonian Tongue of the Central Baltoscandian Facies Belt of the Baltic Basin, where the Porkuni Stage is represented by the non-graptolitic Kuldiga and Saldus formations. *Hirnantia sagittifera* appears in the lowermost part of the Porkuni Stage and is rather widely distributed in the basin in spite of its rare finds in each locality. Our study of trilobites of the genus *Mucronaspis* has enabled us to observe morphological changes in its exoskeleton in time and to identify a succession of five morphotypes (morphs). In some characteristics these morphs are similar to those of different alleged species of the genus *Mucronaspis* (*M. olini*, *M. danai*, *M. ganabina*, *M. mucronata*) but they cannot be definitely assigned to any of these species due to some variances. However, here for the first time a stratigraphically ordered collection is presented, which deserves attention in revising the taxonomy of highly variable *Mucronaspis*. The described brachiopods and trilobites occur mainly in the strata correlated with the *Normalograptus extraordinarius* graptolite Biozone. However, the uppermost finds of both taxa come from strata correlated with the *N. persculptus* Biozone.

Key words: Brachiopoda, Trilobita, taxonomy, Upper Ordovician, East Baltic.

INTRODUCTION

The topmost Ordovician Porkuni Stage in the East Baltic is characterized by a variety of lithologies and faunas which show the differentiation of the basin during substantial sea level changes associated with the Gondwana glaciation. The invasion of the Hirnantian faunas into the Livonian Tongue of the Central Baltoscandian Facies Belt of the Baltic Basin began contemporaneously with the development of a reef facies in the northern (North Estonian Facies Belt; Fig. 1) and of carbonate deposits of restricted thickness in the southeastern Baltic areas (Lithuanian Facies Belt).

The brachiopods and trilobites identified in the Porkuni Stage of the Livonian Tongue in the central East Baltic represent the typical Hirnantian fauna (Hints et al. 2010) with common species known from Sweden (Bergström 1968), Norway (Brenchley & Cocks 1982; Cocks 1982) and Poland (Podhalańska 2009). Männil (1966) was the first to correlate the topmost Ordovician strata in western Latvia with the Tommarp Beds (= *Dalmanitina* Beds; Jaanusson 1982c) in Sweden by the occurrence of common brachiopods and trilobites. According to the present stratigraphical understanding,

the Tommarp Beds together with the overlying Glisstjärn Formation in Dalarna belong to the Hirnantian Stage (Ebbestad & Högström 2007) and are correlated with the Kuldiga and Saldus formations in the East Baltic (Ainsaar et al. 2010). The last Baltic formations have been described in several papers (Kaljo et al. 2001; Hints et al. 2010). Thus here we only mention that the more or less fossiliferous Kuldiga Formation consists of marlstones with a variable content of silt. The Saldus Formation is represented by marlstones and laminated silty to oolitic limestones. The revised spatial distribution of both units is presented in Fig. 1.

The brachiopod–trilobite dominated *Hirnantia–Dalmanitina* (Rong & Zhan 2006; Amstrong 2007) or *Dalmanitina–Hirnantia* (Lespérance 1974; Jaanusson 1979) fauna unifies different Hirnantian brachiopod and trilobite associations whose distribution areas overlap or are facially related in the carbonate and siliciclastic lithologies. Because of its extended range along the depth gradient (from lower BA2 to BA3; Rong & Harper 1988; Zhan et al. 2010), the brachiopod *Hirnantia sagittifera* associates with several other brachiopods, which have ecologically or regionally more restricted distribution. *Hirnantia* is one of the eponymic names for
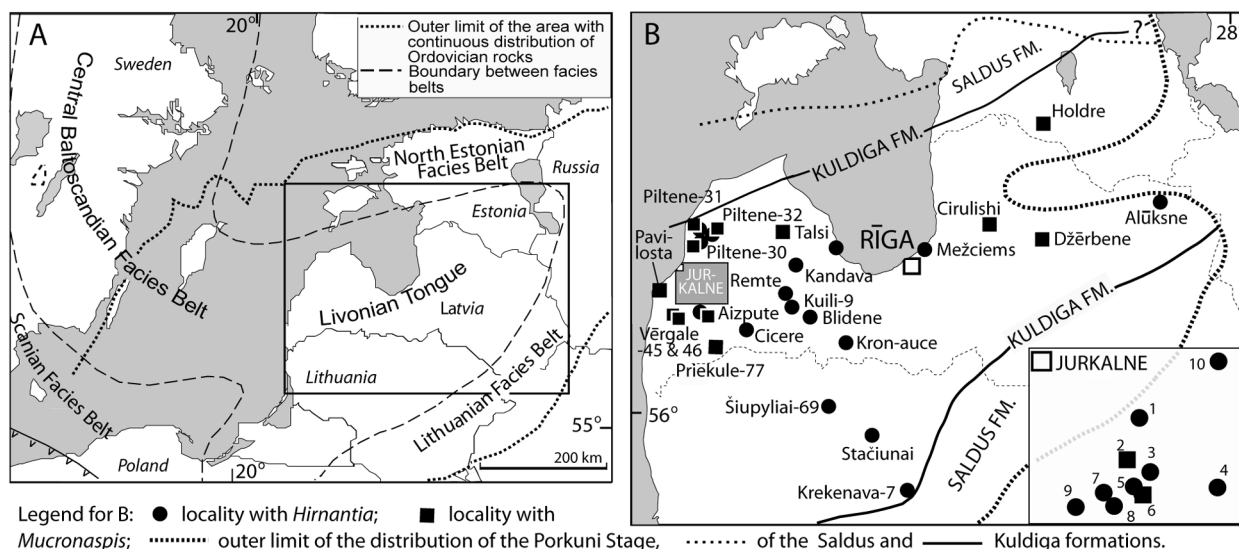
Fig. 1. A, distribution of the Ordovician rocks and facies belts in the Baltic Basin; **B**, location of drill core sections with the limits of the distribution areas of the Kuldiga and Saldus formations. Drill cores: 1, Stirnas-18; 2, Pliekalne-14; 3, Dižrungi-17; 4, Vilcini-19; 5, Adze; 6, Dreimani; 7, Riekstini-15; 8, Mežmali-16; 9, Mežvagari-13; 10, Edole-65.

several associations and communities (Wright 1964; Brenchley & Cocks 1982; Rong 1984, 1986; Rong et al. 2002; Křiž & Steinová 2009; Zhan et al. 2010).

The Ordovician trilobites, earlier determined as belonging to *Dalmanitina* Reed, 1905, have been treated as the subgenus *Dalmanitina* (*Mucronaspis*) or the genus *Mucronaspis* Destombes, 1963. Currently the taxonomy and systematics of dalmanitid trilobites are under revision. We use here the generic name *Mucronaspis*, because two species, *M. mucronata* (Brongniart, 1822) and *M. olini* (Temple, 1952), are more closely related to other species assigned to the subgenus *Dalmanitina* (*Mucronaspis*) and the genus *Eudolatites* Delo, 1935 than to those of the subgenus *Dalmanitina* (*Dalmanitina*).

The aim of the present paper is to outline the distribution of two characteristic and common species of the Hirnantian fauna in the East Baltic: the brachiopod *H. sagittifera* and the trilobite morphs identified as *M. mucronata s.l.* In Baltoscandia the brachiopod *H. sagittifera* has been taxonomically studied in Sweden and Norway (Bergström 1968; Brenchley & Cocks 1982; Cocks 1982). In the East Baltic *H. sagittifera* has been recorded in seven drill cores (cores S7 and S8, in the coastal sea, Ulst 1972; Krekenava, Paškevičius 1997; Šiupyliai-69, Paškevičienė et al. 2001; Piltene-30, Riekstini-15, Hints & Harper 2002, Kaljo et al. 2008; Stirnas-18, Hints et al. 2010; Fig. 1). Data on the occurrence of species of *Mucronaspis* in Latvia are scanty (Talsi-55, Ciruliši, Ulst et al. 1982; Piltene-30, Piltene-32, Gailite 1968), although the wide distribution

of *M. mucronata* in the Kuldiga Formation, rarely in the Saldus Formation, is mentioned by several authors (Gailite 1968; Ulst 1972; Ulst et al. 1982). In the southern East Baltic (in Lithuania), *M. mucronata* is known from the lowermost Porkuni Veineikiai Formation (Paškevičius 1997).

The taxonomic study of the East Baltic representatives of *H. sagittifera* and *Mucronaspis* morphs and comparison with finds from Scandinavia and other regions provide additional criteria for the identification of these taxa and elucidate their potential in biostratigraphy. Special attention is paid to the morphological changes in trilobite exoskeleton. As a result, we could follow the succession of five morphotypes (morphs) in time and suggest the possible occurrence of more than one species of *Mucronaspis* in the East Baltic. Up to now data on the Baltic Hirnantian macrofauna have been presented in stratigraphical papers. This paper is the first special study aimed to improve the understanding of the corresponding species in the East Baltic region. The necessity of a detailed taxonomic study of Hirnantian brachiopods identified in different basins under one and the same name appeared lately also during the revision of *Dalmanella testudinaria* (Dalman) (Jin & Bergström 2010).

MATERIAL

The samples yielding the studied brachiopods and trilobites were collected by Latvian and Estonian

researchers from drill cores in the East Baltic mainly in the 1960s and 1970s. Restudy of samples available in different collections supplemented the locality list of *Hirnantia sagittifera* with 10 new ones in addition to those published earlier. The trilobites described in this paper are represented by over 100 specimens from 22 cores. In some cases the topmost Ordovician has been sampled in detail (for example the Stirnas-18 drill core; Hints et al. 2010). In many other cores, however, the sampling density is much lower and the stratigraphy of the section is less known. Still, the brachiopods and trilobites described below have been identified in different parts of the Kuldiga and Saldus formations around the central East Baltic (Fig. 1).

The depths of the samples correspond to the initial core depths and have not been revised later on the basis of geophysical data. An exception is the Mežmali-16 core, the stratotype section of the Kuldiga Formation (Ulst et al. 1982; Hints et al. 2010), where the depths have been revised according to the unpublished original description of L. Gailite and R. Ulst and geophysical data.

The material described is deposited at the Latvian Museum of Natural History in Riga (institutional abbreviation LDM) and Institute of Geology at Tallinn University of Technology (institutional abbreviation GIT).

SYSTEMATIC PALAEONTOLOGY

BRACHIOPODA
Family DRABOVIIDAE Havlíček, 1950
Subfamily DRABOVIINAE Havlíček, 1950
Genus *Hirnantia* Lamont, 1935
Hirnantia sagittifera (M'Coy, 1851)
Figure 2

1984 *Hirnantia sagittifera* (M'Coy); Rong, pp. 139–141, pl. 6, figs 1–17; pl. 7, figs 1–8; pl. 12, fig. 15; text-figs 10, 11 (contains synonymy to 1984).

1986 *Hirnantia sagittifera* (M'Coy, 1851); Benedetto, p. 444, pl. 1, figs 11–15; pl. 2, figs 1–3.

2000 *Hirnantia sagittifera* (M'Coy); Harper, p. 829, fig. 603, 1a–g.

2000 *Hirnantia sagittifera* (M'Coy); Chen et al., fig. 8i, r.

2002 *Hirnantia sagittifera* (M'Coy); Benedetto, pl. 1, fig. 30.

2006 *Hirnantia sagittifera*; Chen et al., p. 192, fig. 10 (22, 24).

2006 *Hirnantia sagittifera*; Brenchley et al., p. 16, fig. 12A, C, F.

2007 *Hirnantia sagittifera* (M'Coy, 1851); Zhan & Jin, p. 68, fig. 44H, I.

2008 *Hirnantia sagittifera* (M'Coy, 1851); Cocks, p. 167 (contains partial synonymy).

2008 *Hirnantia sagittifera* (M'Coy, 1851); Jin & Zhan, pp. 52–53, pl. 36, figs 1–16.

Lectotype. Internal mould of dorsal valve, SM A41217, from Aber Hirnant, North Wales (Temple 1965, p. 395, pl. XI, fig. 8; see Cocks 2008, p. 167).

Description. The East Baltic specimens of *H. sagittifera* have a large dorsibiconvex shell (Table 1), about four fifths as long as wide, with maximum width in the middle of the shell. The ventral valve is weakly convex, almost flat in the middle part of the large specimen. The dorsal valve is moderately convex, with maximum convexity in the posterior half. An elusive sinus-like groove occurs in the middle of the dorsal valve. The ventral interarea (GIT 542-1; LDM G 328-125; Fig. 2A, B) is 5 mm high, apsacline and weakly concave near the beak; several parallel growth lines occur in its anterior part. The delthyrium is triangular, as high as wide, acute-angled at the beak. The radial ornamentation is finely multicostellate to ramicostellate, with about 11 costae around the ventral umbo, about 35 costae and costellae at the 5 mm growth stage and more than 100 along the 6–7 cm long commissure. On the anterior edge up to 10 costellae occur in 5 mm. The number of costellae increases by bifurcation. Several posterolateral costellae (up to 6–7) are curved towards the valve posterior edge (Fig. 2C). One incomplete valve (LDM G 328-125; Fig. 2C, D) has a fila, which separates the sectors of costa with the bifurcating costellae.

The ventral interior is known from one specimen. Triangular teeth with short convergent dental plates occur in the form of small subtriangular outgrowths at 1 mm distance from the edge of the delthyrium. Small bulges (accessory teeth?) occur between the teeth and the margin of the delthyrium (Fig. 2F). Dental plates merge with the ridges bordering laterally and anteriorly the heart-shaped muscle field, which is three fourths as wide as long (Fig. 2A). The length of the muscle field is about one third of the valve length. Tiny radial grooves about 1.2 mm in length border the interior valve margin.

The dorsal interior is known from two moulds (LDM G 295/58; Fig. 2I, J), showing a variously developed short median septum and a quadripartite muscle field whose length from the umbo is about one third of the valve length. The anterior pair of adductors is semi-oval, posterior pair triangular; adductors are separated by a pair of transverse septa and median septum. The brachiophore plates diverge at an angle of about 90°. The triangular depressions between the brachiophore
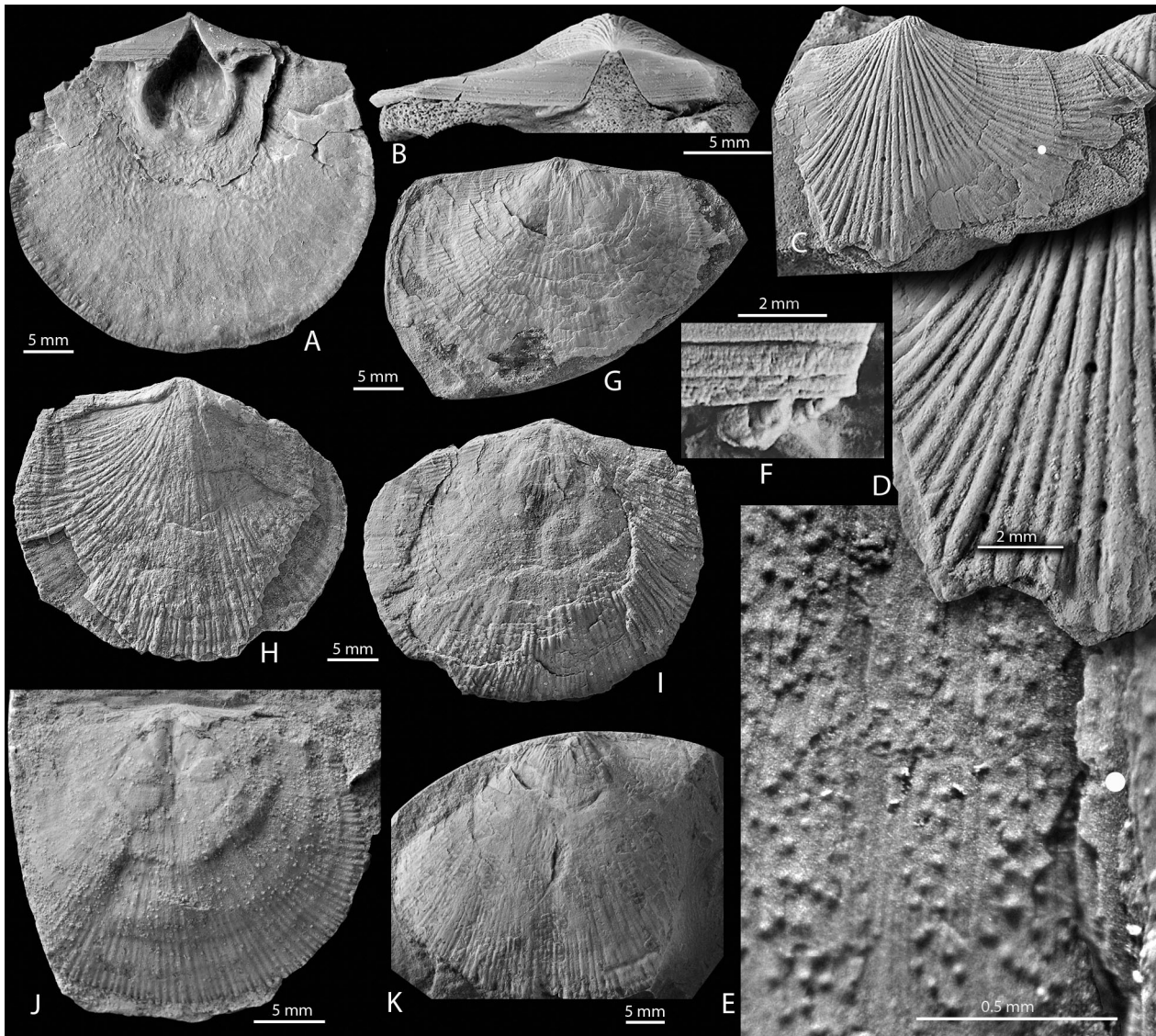
Fig. 2. A–J. *Hirnantia sagittifera* (M'Coy), western Latvia, Porkuni Stage, Kuldiga Formation. A and F, ventral valve GIT 542-1, interior and view of the teeth with the thickening; Piltene-30 drill core, 938.0 m. B–E, incomplete ventral valve, LDM G 328-125, posterior and exterior views, views of the radial ornamentation with filae between costellae and of the broken valve surface showing the density of punctae; Piltene-30 drill core, depth 945.0 m. White spots on C and E mark one and the same place on the valve surface. G, incomplete dorsal valve LDM G 328-122; Piltene-31 drill core, depth 972.4 m. H, I, ventral and dorsal views of the shell LDM G 328-124; Piltene-32 drill core, depth 923.5 m. J, mould of dorsal interior, LDM G 295/58, Kandava drill core, depth 930.5 m. **K**, *Hirnantia* cf. *sagittifera*, incomplete dorsal valve GIT 542-8, split during crushing the sample; Engure drill core, depth 882.8 m.

plates and posterior adductor fields on both sides of the median septum apparently represent anteriorly extending parts of the bottom of the notothyrial chamber depressed into the valve floor. Details of cardinalia are unknown. The shell is finely punctated. The punctae occur on ribs and in interspaces. On some specimens the punctae, sometimes with pyritic fillings, are gleaming in the fibrous layer of broken specimens (Fig. 2E). On the valve inner surface (GIT 542-1; Fig. 2E) punctae are irregularly placed, being somewhat rarer in interspaces of costae and costellae. Exopunctae mentioned by Temple (1965) were not seen on the studied specimens.

Discussion. The genus *Hirnantia* includes the largest dalmanellids in the Baltic Ordovician. Among the older punctate brachiopods only *Reuschella* (Hints 1975) has

Table 1. Measurements (in mm) of *Hirnantia sagittifera* (+ the real size is somewhat large; c., approximate size)

Specimen	Length		Width	Length of the area	Number of costae in 5 mm	Muscle field	
	Ventral	Dorsal				Length	Width
Ventral valve GIT 542-1	33.3	–	36.6	c. 32	–	13	8.6
Dorsal valve GIT 542-8	–	34.3+	c. 49	–	6?	–	–
Dorsal valve LDM G 328-122	–	24+	36.5	30	–	–	–
Shell LDM G 328-124	26.8	25.8	31.9	c. 25	6–10	–	–
Dorsal valve LDM G 295/58	–	24.2	c. 30	c. 20	–	–	–

a similar shell size. Most of the studied *Hirnantia sagittifera* specimens are incomplete (part of the shell has been cut by drilling or was split within the shell during crushing of rock samples). However, the large incomplete dalmanellids with a strongly convex dorsal valve in all probability belong to *H. sagittifera*. All these specimens are listed in the section 'Material'.

Hirnantia sagittifera is a rather variable species, especially in size and outline (Temple 1965; Cocks 1982; Rong 1984; Cocks & Torsvik 2002). The Baltic specimens of *H. sagittifera*, together with the Norwegian (Cocks 1982) and Swedish (Bergström 1968) representatives, have the largest shells in comparison with those from several other regions (Poland, Great Britain; Temple 1965; Cocks 1982; Brenchley et al. 2006). Large specimens of *Hirnantia* species with a shell width over 40 mm have also been described from China (Rong 1979) and South America (in Argentina, Benedetto 1986). The Chinese species *H. magna* Rong differs from the Baltic *H. sagittifera* in more delicate costellae, a laterally more stretched shell outline and an almost equal size of the anterior and posterior adductor fields of the dorsal valve.

The ventral valve of the Chinese subspecies *H. sagittifera fecunda* Rong (Rong 1979; Sheng 1982, pl. I, fig. 6, pl. II, figs 6, 9) differs from the Baltic one in having a wider adductor field, forming about 1/3 of the width of the muscle field. By this feature *H. s. fecunda* is similar to Polish *H. sagittifera*.

The specimens of *H. sagittifera* from Quebec, Canada (Lespérance & Sheehan 1976) differ from the shells in Baltoscandia, Spain (Villas et al. 1999) and Eastern Canada (Anticosti Island; Jin & Zhan 2008) in having the maximum shell width in front of cardinal extremities rather than at mid-length. The specimens from Quebec (Lespérance & Sheehan 1976, pl. 109, fig. 7) and Ireland (in Kildare Limestone, Wright 1968) probably have straight posterior costellae extending almost parallel to the posterior margin. The posterior costellae of the East Baltic specimens curve towards the interarea. The taxonomic value of this feature is not clear, although it

indicates some differences in the growth of the shell. The Baltic and Quebec (Villas et al. 1999, pl. I, figs 4, 7) specimens differ from the Polish specimens of the Holy Cross Mountains (Temple 1965, pl. XIV) in having a heart-shaped ventral muscle field, which in the last specimens is bilobed with a wide adductor field. Rong (1984) considered those differences in the outline of the ventral muscle as the result of intraspecific variation. The dorsal muscle field of the Baltic specimens is rather similar to that of specimens from different regions (Bohemia, Marek & Havliček 1967, pl. 11, fig. 23; Wales, Cocks & Price 1975, pl. 84, fig. 2; Ireland, Wright 1968, fig. 5b; Bretagne, Argentina, Benedetto 1986, pl. 2, fig. 2; Melou 1987, pl. 1, fig. 3a; Anticosti Island, Jin & Zhan 2008, pl. 36, fig. 13). Some differences are revealed in the relative length of the adductor field in relation to the valve length.

The precise identification of dalmanellid brachiopods is complicated in case of incompletely preserved specimens. The almost even distribution of tiny punctae on the studied specimens of *H. sagittifera* and *H.* cf. *sagittifera* seems to be a feature that may help to differentiate the small and incompletely preserved specimens of that genus from specimens of *Dalmanella testudinaria*, which have two types of pores (Jin & Bergström 2010). Larger, easily visible pores of the latter species are arranged in radial rows (Jin & Bergström 2010).

Material. The studied specimens were collected from 22 drill cores (see Fig. 1). Part of the specimens (with depths in brackets) were identified under open nomenclature as *Hirnantia* cf. *sagittifera*, because of insufficient preservation.

Drill cores: Adze (846.70 m); Aizpute (1000.3 m); Alūksne (872.45–872.52 m); Blidene-5 (815.75–816.00 m, ?819.3 m); Cicere, 898.0–898.2 m (897.8–898.0 m); Dižrunģi-17, 895.7 m (895.9 m); Engure, 882.80 m (882.45 m); Kandava-25 (930.3 and 930.5 m); Kroņauce (1053.7 m); Kuili (898.0–898.2 m), 948.5 m; Mežciems (379.5 m); Mežmali-16 (903.50, 912.00, 912.35–

912.85, 914.35, 914.50, 914.8 m); Mežvagari-13, 872.1, 872.50, 877.3–877.6 and 879.10 m (877.30–877.60 m); Piltene-30, 938.0 m (938.5 m), 945.0 m; Piltene-31, 971.2–971.4 m (977.8 m); Piltene-32, 923.5 m; Pliekalne-14, 884.8 m; Remte (965–966 m); Riekstini-15 (855.7 and 857.5 m; *Conochitina scabra* Biozone, Brenchley et al. 2003); Ruhnu, 616.90 m, (616.5 and 616.6 m) (lowermost *C. scabra* Biozone, Kaljo et al. 2001); Stirnas-18 (910.00 m, lowermost *C. scabra* Biozone, Hints et al. 2010); Vilcini, 910.8 m.

Distribution. *Hirnantia sagittifera* and *H.* cf. *sagittifera* described in this paper occur mainly in the Kuldiga Formation in the lower half of the Porkuni Stage. The only specimen of *H.* cf. *sagittifera* from the upper Porkuni Saldus Formation was found in the Alūksne core (NE Latvia) about 2 cm above the Kuldiga–Saldus boundary. Following the correlation of the Porkuni Stage and its Kuldiga and Saldus formations with the global standard accepted here (Kaljo et al. 2001, 2008; Hints et al. 2010), the total stratigraphical range of the described brachiopods comprises the Hirnantian *Normalograptus extraordinarius* Biozone and at least the lower part of the *N. persculptus* graptolite Biozone. The species of *Hirnantia*, however, belong only to the former biozone in the sections located west of the study area (core No. S7 in the Baltic Sea, Ulst 1992; in Poland, Podhalańska 2009), where the topmost Ordovician is represented by graptolitic shales. *Hirnantia sagittifera* and related species supposedly have somewhat different stratigraphical ranges in different parts of the Baltic Basin. At that the distribution of shelly fauna, including brachiopods, follows the development of carbonate facies. That is a well-known phenomenon in China (Zhan et al. 2010).

TRILOBITA
Family DALMANITIDAE Vogdes, 1890
Genus *Mucronaspis* Destombes, 1963
Mucronaspis mucronata (Brongniart, 1822) *s.l.*
Figures 3–5

Remarks. Unusually wide morphological variation, various states of preservation and different combinations of morphological characteristics in species level taxonomy applied in different studies (e.g. Troedsson 1918; Temple 1952; Budil 1996) have complicated the understanding of species of the genus *Mucronaspis*. That concerns also the Baltoscandian taxa *Mucronaspis mucronata*, *M. m. kiaeri* and *M. olini*.

In the East Baltic only *M. mucronata* has been identified (Männil 1966; Ulst et al. 1982). Its distribution range comprises different lithologies of the Porkuni Stage. The specimens described below are identified as *M. mucronata s.l.* following the established

characteristics, of which some are not constantly developed or are shared with other species. However, the vertical distribution of the Baltic specimens, which is the largest known vertical distribution range (up to 15.6 m in the Riekstini-15 core) in Baltoscandia, makes it possible to follow morphological changes through time (or, alternatively, to record new immigrations from other areas, i.e. the migration). These changes deserve attention in future taxonomic studies of species of *Mucronaspis* and in establishing relationships between East Baltic representatives and those from other regions.

Five morphological groups of specimens were identified in the study area. They are considered as morphs and comprise specimens (cephala and/or pygidia) that deviate in some respect from the complete set that is diagnostic for previously recognized species. They conform with *M. mucronata* in having an eye reaching back to the basal lobes. This is a key character of this species which is usually pointed out and therefore would place the specimens under that heading. However, we believe that the range of morphs (from A to E) may hide more than one species, and we therefore apply a *sensu lato* label here. The succession of these morphs (from A to E) is shown on the background of the Stirnas-18 core section (Hints et al. 2010) from where about 60 specimens were collected. The described morphs occur mainly in the Kuldiga Formation of the Porkuni Stage, with morphs A and B in the Bernati and morphs C, D and E in the Edole Member (Fig. 3). Only morph E reaches the upper Porkuni Saldus Formation.

Morph A (pygidia GIT 585-4-1, GIT 585-3-1, Figs 3A, 4O–S; and possibly hypostome GIT 585-2-1, Fig. 5P, Q).

The pygidium has seven(?) pleurae, which curve strongly backwards at the second third of their extension, so that the tip of the most anterior one reaches as far back as to the level of the fifth axial ring. The pleural furrows run from the axial furrow laterally in a straighter line than the interpleural furrows to meet the latter at the doublural region. Both furrows are deep, but become very shallow just before their junction. The anterior band of pleurae is nearly equal in width to the posterior band on the first three pleurae, becoming gradually slightly narrower on the posterior pleurae. At the doublural region the posterior pleural bands expand and become bulbous, ending in a small spinous tip that is also reflected ventrally on the doublure, which is rather wide. The axis is narrow and relatively low; a long flat posterior spine rises slightly up rearwards.

Occurrence. The Bernati Member of the Kuldiga Formation; drill cores and depths: Stirnas-18, 910.2 m; Riekstini, 860.5 m; Vilcini, 912.7 m.
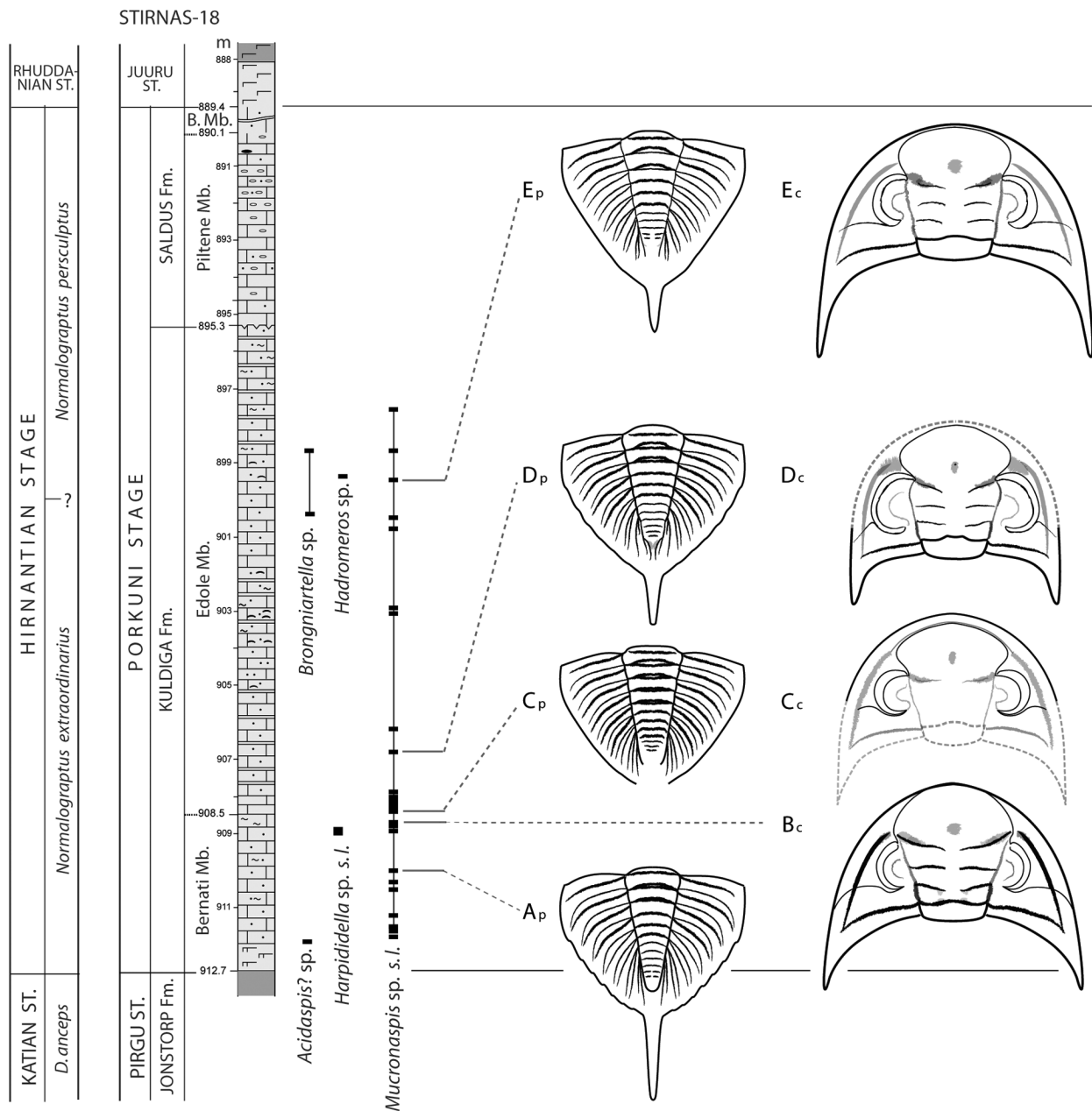
Fig. 3. Distribution of trilobites in the Stirnas-18 drill core section and the morphs of *Mucronaspis mucronata* (Brongniart) *s.l.* – A$_p$ (pygidium GIT 585-3-1), B$_c$ (cephalon GIT 585-6-1), C$_p$ (pygidium GIT 585-7-1), C$_c$ (cephalon GIT 585-8-1), D$_p$ (pygidium GIT 585-10-1), D$_c$ (cephalon GIT 585-9-1), E$_p$ (pygidium GIT 585-11-1), E$_c$ (cephalon GIT 585-12-4). For description of the section and correlation with the global units see Hints et al. (2010). *D.*, *Dicellograptus*; St., Stage; Fm., Formation; Mb., Member; B., Broceni.

Comparison. This type of pygidium fits with *M. olini* in the number of segments and the form of their bulbous endings, but the development of the pleural bands is different. The type specimen of *M. olini* from the Röstånga section in Scania, Sweden (Temple 1952, pl. 3: 7), has noticeably narrower anterior bands starting already from the second segment onwards, and these are parallel-sided, i.e., the pleural furrows run parallel to the interpleural furrows. Beside that it is much shorter and wider in its overall shape and has a much wider axis than the described morph A. However, the course of the furrows and the relation of the bands of pleura may be a visual effect related to the width of lateral lobes (in wider pygidia the parallel-sided area of pleural bands
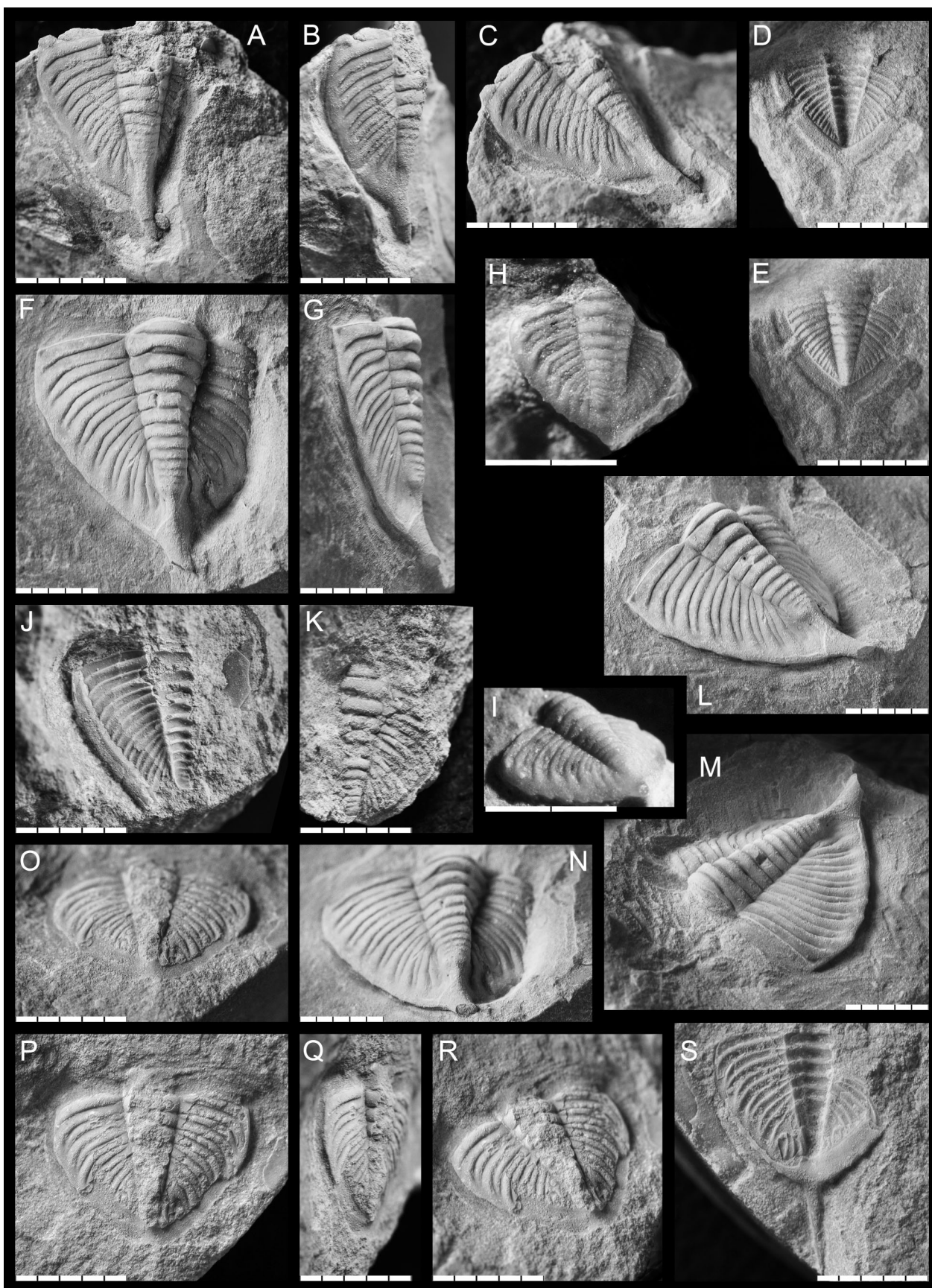
becomes accordingly more extended). If this is the case, and if the length/width ratio is considered as of little significance in species determination (as in the case of *M. m. kiaeri* in Norway, where wide and narrow morphs occur together; see Owen 1981), this morph appears to be closer to *M. olini* than to *M. mucronata*. A possible co-occurrence of wide and narrow pygidia is met in a section at Nyhamn in Scania (Herta Schmidt's collection at the Senckenberg Museum, Germany), where some pygidia resemble the type specimen of *M. olini* (Schmidt 1935, p. 123, fig. 1), but some resemble those from Latvia in their narrower pygidia or in their gradually changing pleural bands. Unfortunately, the exact appearance of these specimens in the Nyhamn section is not known, so the co-occurrence of these varieties cannot be proven. As long as *M. olini* is diagnosed as having anterior bands of pleurae half as wide as the posterior bands and *M. mucronata* as having bands of equal width, we would determine this Latvian morph A as *M. mucronata s.l.* It is noteworthy that Latvian drill cores have not yielded any cephala with short anteriorly placed eyes characteristic of the type specimen of *M. olini*, even not within those situated on the same bedding plane as the 'olini-type' pygidia listed above.

A juvenile pygidium from the Vilcini core (912.7 m), considered as belonging to morph A, shares most of the features (except the length/width ratio) with a juvenile from the upper part of the Králův Dvůr Formation, Bohemia. This juvenile pygidium, earlier determined as *Songxites gemmagog* (Šnajdr 1987; Budil 1996), most probably represents an immature *Mucronaspis grandis* (Barrande, 1852) and not the genus *Songxites* Lin, 1981 with a distribution in South China.

Morph B (cephalon GIT 585-6-1, Figs 3B, 5M–O).

The cephalon has a relatively short arching occipital ring (LO) that becomes even shorter laterally; the bulbous subquadratic basal glabellar lobe (L1) is separated from the middle lobe by a shallow furrow; the anterior lobe is slightly rhombic. The anterior border is notably short (sag), the lateral border is relatively wide (tr), rounded in cross section at the rear and delimited from the librigenal field by a deep and wide border furrow. This furrow dies out shortly before meeting the anterior suture, where the glabella is slightly stretched out over the sutural line, reaching the free cheek. The eyes are large at the base, but covered by a much smaller palpebral lobe, which rises a little above the glabellar plane, so that the visual surface is highly tilted horizontally to provide a view upwards. The palpebral lobe is much shorter (exsag) than the opposing glabellar lateral lobes L2 and L3 together. The axial furrow is relatively straight but tilted laterally, i.e., the glabella is expanding anteriorly. The posterior suture runs slightly anteriorly from behind the eyes, then continues transversally. The posterior border runs back at about 20° to the axial line.

Occurrence. The boundary beds of the Bernati and Edole members of the Kuldiga Formation; drill cores and depths: Stirnas-18, 908.7 m; Priekule-77, 1428.5 m; Ikla 536.4 m; possibly Riekstini, 859.4 m; Vergale, 1004.5 and 1004.2 m; Dižrungi-17, 893.4 m.

Comparison. The described cephala, occurring stratigraphically close to the pygidia of morph A, are here considered to belong to a separate morph, but further studies may prove that they belong together. The tubercles on the glabella, deeply incised lateral furrows and large eyes, reaching rearwards the basal lobes, indicate that the cephalon of this morph is more distinct from *M. olini* than is the pygidium of morph A. The specimens of morph B are closely similar to the lectotype of *Mucronaspis danai* (Meek & Worthen, 1866) from the Leemon Formation, Illinois, in Laurentia (see Lespérance 1988, p. 368, fig. 5). The differences are small and include the size of the eyes and course of the posterior edge of the genal region. The other figured specimen of *M. danai* (*ibid.* p. 368, fig. 7) has a wider genal area with longer posterior fixigena and the frontal lobe is more distinct at the surrounding furrows, so resembling cephala of *M. grandis* from Bohemia. The two latter taxa are closest to the oldest representative of *M. mucronata* from the *Staurocephalus* Beds, in Scania, Sweden (see Temple 1952, pl. 3: 4), which occurs below the *Dalmanites* Beds.

Morph C (pygidium GIT 585-7-1, Figs 3C, 4J, K; cephalon GIT 585-8-1, Figs 3C, 5J–L).

Fig. 4. Pygidia of *Mucronaspis mucronata* (Brongniart) *s.l.* organized from top to bottom, following their appearance in the Stirnas-18 drill core, Latvia. **A–E**, morph E: A–C, GIT 585-12-1, dorsal, lateral and posterolateral views of an incomplete exoskeleton (899.5 m); D, E, GIT 585-11-1, dorsal view of a ventrally exposed incomplete exoskeleton and an inverted photograph of the same specimen (900.8 m). **F–I, L–N**, morph D: F, G, L–N, GIT 585-10-1, dorsal, lateral, and tilted posterolateral, anterolateral and posterior views of a nearly complete exoskeleton (906.2 m); H, I, GIT 585-9-2, dorsal and posterodorsal views of a juvenile pygidium with the preserved exoskeleton (906.8 m). **J**, **K**, morph C: GIT 585-7-1, GIT 585-7-2, ventral and dorsal sides of a pygidium with the exoskeleton divided between the two sides and the terminal spine left outside the core (908.4 m). **O–S**, morph A: O–R, GIT 585-4-1, posterior, dorsal, lateral and tilted posterolateral views; S, GIT 585-3-1, ventral view of an exoskeleton mainly preserved on the ventral side showing recovered injury (910.2 m). Scale bars show division in millimetres.
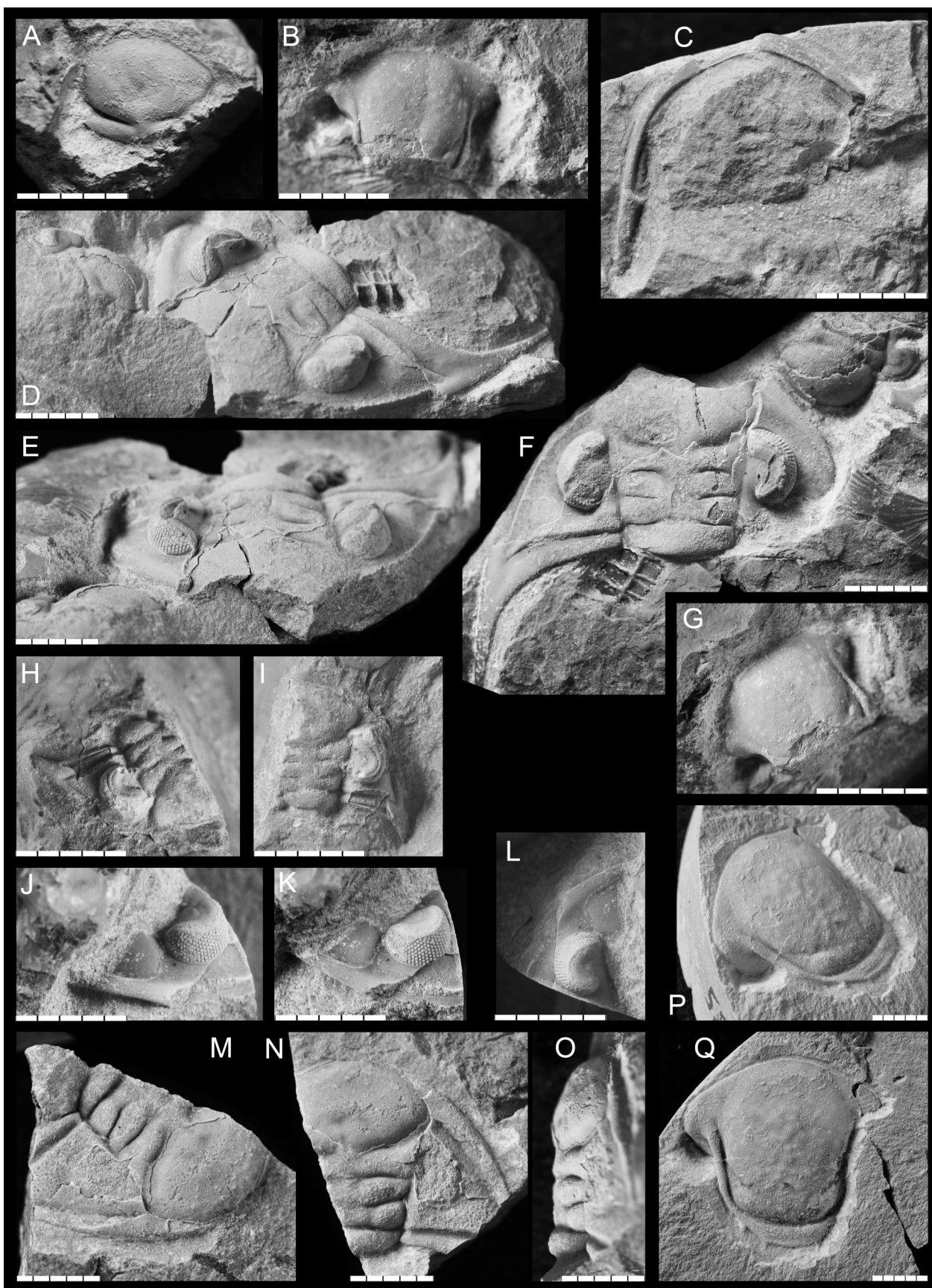
The pygidium has eight pleurae, which are divided nearly equally in width by slightly curving pleural furrows, which run parallel to the interpleural furrows. The doublure is narrow and the wide axis reaches far back. A fragmentary cephalon has a wide and rather flat anterior border (the widest on specimens from the Stirnas section), eyes rising high above the glabella with a rather vertical visual surface, bearing 35 files with 7 or 8 lenses; the glabella reaching antero-laterally the rounded suture, meeting a rather shallow lateral border furrow.

Occurrence. Edole Member of the Kuldiga Formation; drill cores and depths: Stirnas-18, 908.4 and 908.1 m; Vilcini, 910.5 m; Riekstini, 856 m. Cephala: Piltene-30, 943.7 m; Ikla, 535.8 m.

Comparison. By its wide anterior border in the cephalon, this morph is closest to *M. mucronata kiaeri* from the Oslo region. However, the Norwegian specimens differ from Baltic representatives and between each other in the size and position of the eyes, which affects the course of the sutures and the shape of the librigenal field. Similarly large eyes reaching far back and a wide anterior border are met with in the Bohemian species *Mucronaspis ganabina* (Šnajdr, 1987). However, unlike morph C, *M. ganabina* has rather short and narrow genal spines.

Morph D (pygidium GIT 585-10-1, Figs 3D, 4F, G, L–N; cephalon GIT 585-9-1, Fig. 5H, I).

The pygidium differs from previous types in its prominent axis that is notably more elevated above the pleural field and ends abruptly on the pleural region distant from the border area. A weakly developed ninth pair of pleurae can be distinguished behind the axis. The anterior band of pleurae is slightly narrower than the posterior band in all pleurae except for that of the first one. The pygidial spine is short, roundedly subtriangular in cross section. The cephalon is narrow and has relatively large eyes not rising above the glabella. The eyes as well as the palpebral lobe are longer than L2 and L3 together. The anterior lobe of the glabella is elliptic and the occipital lobe is longer (sag) than the basal lobes. The genal area is narrow and the spine short but wide at its base.

Occurrence. Kuldiga Formation; drill cores and depths: Stirnas-18, 906.2 and 906.8 m; Aizpute, 991.8 m; Adze, 844.1 m; Kuili, 948 m; Piltene-30, 943.35 and 943.5 m; Ikla, 533.0 and 533.4 m.

Comparison. Specimens of morph D are very similar to some *M. mucronata* specimens from greenish mudstone of the *Dalmanitina* Beds in Stawny, Holy Cross Mountains, Poland, which are considered to represent the *Normalograptus extraordinarius* graptolite Biozone (e.g. Kielan 1956, pl. 4: 4; 1960, pl. 20: 4, 10, ?11). In Poland the *Mucronaspis mucronata* Zone comprises most part of the Hirnantian Stage below the strata with graptolites of the *Normalograptus persculptus* Biozone (Podhalańska 2009).

Morph E (pygidia GIT 585-12-1, GIT 585-12-2, GIT 585-11-1, Figs 3E, 4A–E; cephala GIT 585-12-3, GIT 585-12-4, Figs 4E, 5D–F; hypostome GIT 585-12-5, Fig. 5B, G).

The pygidia have pleurae with anterior bands slightly narrower than posterior bands, pleural and interpleural furrows of nearly equal width and depth, which run nearly straight parallel to each other and reach rather close to the border, being not deeply incised. The apodemes are less prominent on the axis, and the pseudo-half-rings could be traced only on the first two rings. The lateral border shows no pleural spines either dorsally or ventrally. The pygidial spine extends posteriorly as a continuation of the axis. The cephalon is rather wide; the glabella is nearly parallel-sided, expanding slightly at the frontal lobe. The lateral glabellar lobes are transversely parallel-sided, becoming gradually shorter (exsag) anteriorly (L1>L2>L3), and the relatively long occipital lobe (LO) is long also at the axial furrow, where the posterior border is half as long as LO. The lateral border furrow is wide and rather shallow. The posterior border furrow is much deeper and narrower, running nearly transverse, behind the eyes, then curving slightly back at the long prominent

Fig. 5. Cephala and hypostoma of *Mucronaspis mucronata* (Brongniart) and *M. mucronata s.l.*, organized from top to bottom following their appearance in the Stirnas-18 drill core, Latvia. **A–G**, morph E: A, GIT 585-13-1, dorsal view of a fragmentary cranidium possibly belonging to this type, showing narrow S3 lobes and the relatively anterior position of the median depression of the frontal lobe (897.6 m); B, G, GIT 585-12-5, dorsal and tilted posterolateral views of an incomplete hypostome (899.5 m); C, GIT 585-14-1, ventrally exposed cephalon (898.7 m); D–F, GIT 585-12-3, GIT 585-12-4, tilted anterolateral, anterior and dorsal views of a large cephalon together with a much smaller one (899.5 m). **H, I**, morph D: GIT 585-9-1, tilted anterolateral and dorsal views of an incomplete cephalon with pyritized exoskeleton (906.8 m). **J–L**, morph C: GIT 585-8-1, two anterolateral views and a dorsal view of a fragmentary cephalon showing a wide anterior border as observed in *M. mucronata kiaeri* of the Oslo Region (908.1 m). **M–O**, morph B: GIT 585-6-1, tilted anterolateral, dorsal and lateral views of an incomplete exoskeleton (908.7 m). **P, Q**, possibly belongs to morph A, or to an earlier one: GIT 585-2-1, tilted posterolateral and dorsal views of a hypostome showing border-spines diagnostic of the genus *Mucronaspis* (910.5 m). Scale bars show division in millimetres.

genal spine. The visual surface of the large eye is tilted by 60° and bears 32 files with 8 or 9 lenses.

Occurrence. The upper part of the Kuldiga Formation; drill cores and depths: Stirnas-18, 899.5 m (and possibly above 897.6 and 898.7 m); Riekstini, 847.2 m; possibly in the following drill cores: Vilcini, 908.2 m; Aizpute, 988.7 m; Mežmali, 910.8 m; Piltene-30, 939.6 m; Talsi, 867 m; or also in the Saldus Formation of the Ciruliši, 636.1 m, and Pavilosta, 1079 m, drill cores.

Comparison. Morph E resembles most *M. mucronata* from sandy mudstone of the Dalmanitina Beds in Zalesie, Holy Cross Mountains, Poland (Kielan 1956, pl. 4: 3), claimed to belong to the *N. persculptus* graptolite Biozone. Also a pygidium figured by Budil (1996, pl. 1, fig. 3) from the uppermost beds of the Kosov Formation in Prague-Řepy is very similar to this morph.

Part of the specimens among morph E (shown above as possible occurrences) differ slightly from those in the Stirnas-18 and Riekstini cores and indicate the possible existence of still another morph, the latest one to occur in the East Baltic. Unfortunately, its representative in the Stirnas core is exposed from the ventral side and needs further preparation (Fig. 5C). These are in general of small size with genal field shrinking and glabella expanding in anterior direction. Distinct posterior and lateral furrows mark well the genal lobes, which end in slender genal spines nearly as long as the glabella. The glabella expands strongly anteriorly and bears relatively small lateral lobes (L1, L2, L3), a large subpentagonal anterior lobe and a short occipital lobe. Eyes are relatively large with a nearly vertical visual surface. These characters match those of a specimen from unit C in the Upper Boda Limestone Member at Osmundsberget, Siljan District, Sweden (see Suzuki et al. 2009, p. 306, fig. 6G), supporting the alleged Hirnantian age for that member (Suzuki et al. 2009). The occurrence of this morph suggests unit C to be correlative via the Stirnas (Hints et al. 2010) and Riekstini (Brenchley et al. 2003) cores with the second peak of the Hirnantian excursion of the carbon isotope curve. It possibly occurs also in the Loka Formation of Västergötland, Sweden (see Temple 1952, pl. 1, fig. 5), and in the Orneta Formation at the Peribaltic Depression in Poland (see Modliński 1973, pl. 5, fig. 11). This morph is very similar to *M. mucronata juna* Šnajdr, 1987 from the Kosov Formation in Bohemia, which was afterwards synonymized with *M. mucronata* by Budil (1996). The main differences are the narrower genal area and smaller eyes of the Bohemian taxon, which is rather different from the type specimen coming from Västergötland, Sweden, and could fit into *Mucronaspis mucronata* only in our *sensu lato* meaning of this group. The specimens, identified as *Dalmanitina* (*D.*) *olini* from Mirny Creek, Omulev Mountains, Kolyma (Chugaeva 1983; Koren′ &

Sobolevskaya 2008), actually better match with this morph, and due to their large eyes cannot be included into *M. olini*.

Distribution. The succession of the described five morphs of *M. mucronata* falls into the interval of the shallowing upwards environments and changes in the composition of benthic and planktic faunas (Hints et al. 2010). Morphs A and B occur (in the Stirnas-18 core) with the *Hindella– Cliftonia* brachiopod Association in the lower part of the *Conochitina scabra* chitinozoan Biozone (Fig. 3). The distribution of morphs C and D falls into the interval with decreased diversity and frequency of brachiopods and essential changes in the composition of chitinozoans and scolecodonts. In the Latvian drill cores the interval with the low-diversity *Dalmanella testudinaria* Association seems to be barren of trilobites. The uppermost morph E comes from the strata where *D. testudinaria* is supposedly associated with some new species and where the zonal conodont *Amorphognathus ordovicicus* is possibly missing (see Hints et al. 2010).

It should be mentioned that *Mucronaspis* in the East Baltic, as well as in other regions, is associated with the homalonotid trilobite genus *Brongniartella* Reed, 1918, which occurs in different stratigraphical levels.

DISCUSSION

In the East Baltic the described Hirnantian taxa *Hirnantia sagittifera* and *Mucronaspis mucronata s.l.* are distributed in the carbonate deposits of the Livonian Tongue of the Central Baltoscandian Facies Belt. Their stratigraphical ranges comprise the Kuldiga and Saldus formations of the Porkuni Regional Stage, correlated with the topmost Ordovician *Normalograptus extraordinarius* and *N. persculptus* graptolite biozones of the Hirnantian Stage (Kaljo et al. 2008; Ainsaar et al. 2010; Hints et al. 2010). *Hirnantia sagittifera* and *H.* cf. *sagittifera* have rather wide spatial distribution in different parts of the Livonian Tongue (Fig. 1). The first specimens of these brachiopods co-occur (Mežvagari-13 core) with *Cliftonia* sp. and *Dalmanella testudinaria* in the lowermost Kuldiga Formation (about 2 m above the red-coloured rocks of the Jonstorp Formation, Pirgu Stage; topmost Katian), which represents the relatively deepwater part of the stage. However, the oldest, pre-Hirnantian representatives of *Hirnantia* have been recorded from the Mediterranean region (Havliček 1976; Boucot et al. 2003). Due to insufficient biostratigraphical resolution it cannot be stated that *H. sagittifera* ranges to the very base of the Kuldiga Formation (in the *S. taugourdeaui* chitinozoan Biozone; Nõlvak et al. 2007; Hints et al. 2010). Because of rare occurrence of specimens of *H. sagittifera* in each core sections, we cannot talk about any *Hirnantia*

Association such as that identified in the lowermost Hirnantian in Norway (in the boundary beds of the Husbergøya Shales and Langøyene Sandstone) (Brenchley & Cocks 1982; Owen et al. 1990). The main importance of *H. sagittifera* in the East Baltic region lies in its diagnostic value in the correlation of Baltic sections with those of the Hirnantian Stage and identification of the *Hirnantia* brachiopod fauna (*s.l.*).

The oldest Baltoscandian representative of *Mucronaspis*, *M. mucronata s.l.*, appears in the *Staurocephalus* Beds (Zone), which have been identified in the upper part of the Lindegård Mudstone (in Scania) (Bergström et al. 1999), in the uppermost part of the Ulunda Mudstone (in Västergötland) (= Ålleberg Beds; Jaanusson 1963) and Nittsjö Beds (in Östergötland and Siljan) (Jaanusson 1963, 1982b, 1982c; Bergström et al. 1999). In most cases the mentioned units are traditionally regarded as pre-Hirnantian (Jaanusson 1982a; Ebbestad & Högström 2007; Schmitz & Bergström 2007). However, the Ulunda Mudstone (Beds) in the Kullatorp core (= Nittsjö Formation, in Jaanusson 1963) (Västergötland) and the upper part of the Lindegård Mudstone in the Röstånga (in Scania) core are tentatively included into the Hirnantian Stage (Bergström et al. 1999). In the Smedsby Gård drill core (Östergötland), the upper part of the Nittsjö Formation (Beds) is correlated also with the Hirnantian Loka Formation (Bergström & Bergström 1996).

In Latvia the co-occurrence of the proetid trilobites *Rorringtonia scanica* (Olin, 1906) and *Harpidella* (*s.l.*) sp., and an odontopleurid associated with the first *Mucronaspis* species in the Bernati Member, the lower part of the Kuldiga Formation, indicates the *Staurocephalus* Beds. These taxa co-occur with the index trilobite *Staurocephalus clavifrons* (Dalman, 1828) in Scania and Poland (Kielan 1960; Owens 2004). However, in the Stirnas and Riekstini cores in Latvia (Brenchley et al. 2003; Hints et al. 2010) these trilobites occur together with the zonal chitinozoan *Conochitina scabra* of the Porkuni Stage. This fact seems to support the Hirnantian age of the mentioned trilobite zone in the East Baltic. However, a temporal shift of the corresponding trilobite association cannot be excluded as the distribution of *Mucronaspis* and associated trilobites may be strongly influenced by the local ecological conditions (Bergström 1982).

The morphs of *Mucronaspis* described above may have a potential for providing more detailed biostratigraphy. Similar successions of morphs in more than one section (e.g. Stirnas-18, Vilcini, Riekstini, Piltene-30) can be used as a basis for intraregional correlation of sections with similar lithologies. The question of the morph within species or subspecies status needs further study, including comparison with Scandinavian specimens from outcrops. Still, it should be mentioned that the lowermost specimens, identified in the Stirnas core as morph A, have their greatest similarity with *M. olini* from the lowermost Hirnantian of Sweden. However, some fragmentary specimens below those in the Stirnas core and in some other drill cores may represent an earlier morph. Morph C resembles *M. mucronata kiaeri* and morphs D and E seem to be most similar to *M. mucronata s.l.* from Poland.

Morph E may become useful in correlation: at least in the Stirnas-18 core (Hints et al. 2010) this morph occurs above the last zonal conodont *Amorphognathus ordovicicus* in the upper part of the Kuldiga Formation, which possibly belongs to the topmost Ordovician *Normalograptus persculptus* graptolite Biozone. The last specimens of *M. mucronata s.l.*, whose relationship with morph E is not clear, are found in siliciclastic (Ulst et al. 1982; Piltene-30, Piltene-32 and Ciruliši cores) and oolitic carbonates (Gailite 1968; Pavilosta core) of the Saldus Formation. These resemble specimens of *Mucronaspis* co-occurring with the graptolite *N. persculptus* in its upper range in Kolyma (Koren′ & Sobolevskaya 2008), and in Bohemia (Budil 1996; Štorch & Lloydell 1996).

CONCLUSIONS

1. The East Baltic specimens of *Hirnantia sagittifera* have large shells like those in Sweden, Norway and China in comparison with specimens in Poland and Great Britain. Differences from specimens of other regions lie mainly in radial ornament arrangement, shell outline and the muscle field of the ventral valve.

2. The East Baltic *Hirnantia sagittifera* is one of the earliest invaders among Hirnantian brachiopods into the Baltic Basin. It appears in the lowermost part of the Porkuni Stage, at least in the strata belonging to the *Conochitina scabra* Biozone. *Hirnantia sagittifera* associates with the earliest representatives of *Cliftonia* and *Hindella*.

3. Trilobites referred to the genus *Mucronaspis* have the longest in Baltoscandia continuous stratigraphic range in drill cores. A study of these trilobites resulted in the identification of five successive morphs. These deserve attention in stratigraphic correlation and future study of the taxonomy of dalmanitid trilobites.

4. The stratigraphic range of the studied important Hirnantian taxa in the East Baltic coincides well with that in regions where the Hirnantian Stage is represented by carbonate deposits.

5. The age of the Hirnantian shelly fauna in relation to the *N. extraordinarius* and *N. persculptus* graptolite biozones is somewhat different in different parts of the Baltic Basin, yet corresponding to both biozones in the study area.

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Hirnantia sagittifera (Brachiopoda) ja *Mucronaspis mucronata s.l.* (Trilobita) Baltikumi Ülem-Ordoviitsiumis: taksonoomia ning levik

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On kirjeldatud esmakordselt Baltikumi Ülem-Ordoviitsiumi Porkuni lademes esinevaid globaalse Hirnantia lademe juhtvormide hulka kuuluvaid taksoneid: brahhiopoodi *Hirnantia sagittifera* (M'Coy) ja triloboiite perekonnast *Mucronaspis* (Destombes, 1963). Brahhiopood *H. sagittifera* on koja morfoloogiliste tunnuste põhjal kõige sarnasem sama liigi esindajatega Skandinaaviast ja Hiinast, erinedes teiste regioonide sama liigi esindajatest mõnevõrra suuruse, rõõnestuse detailide ning mõnede sisepinna struktuuride poolest. Trilobiidid, mis varasemates uuringutes olid tuntud kui liiki *Mucronaspis mucronata* kuuluvad, osutusid morfoloogiliste tunnuste poolest küllaltki erinevateks. See võimaldas eritleda viis ajaliselt üksteisele järgnevat morfotüüpi, millel on ilmselt märkimisväärne tähtsus dalmanitiidsete trilobiitide taksonoomia revideerimisel. Uuritud brahhiopoodide ja trilobiitide stratigraafiline levik Baltikumis ning läbilõigete korrelatsioon globaalse graptoliidiskaalaga näitab, et Hirnantia ladet iseloomustav brahhiopoodide ja trilobiitide fauna on Baltoskandias eriaegne, läbides mitu biotsooni, nagu see on teada ka Hiinas.