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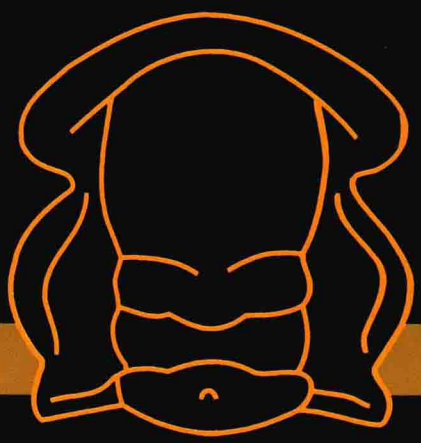

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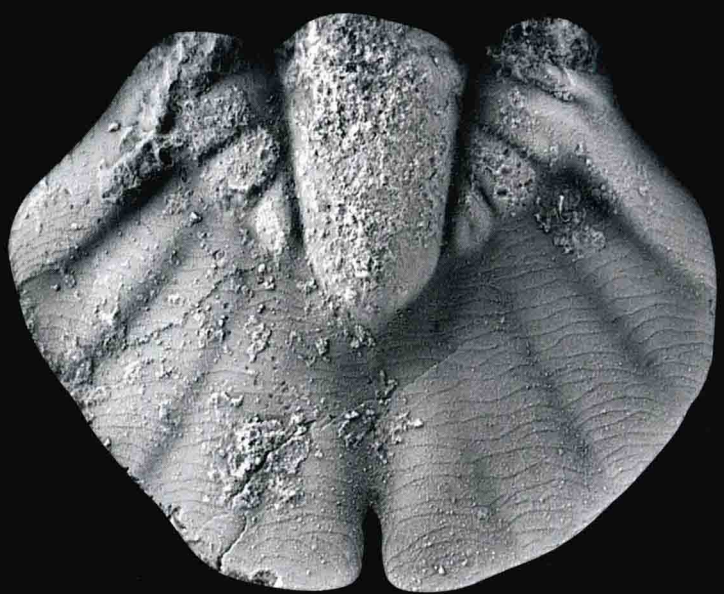
Lower Ordovician trilobites of the Kirtonryggen Formation, Spitsbergen



Richard A. Fortey and David L. Bruton

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Lower Ordovician trilobites of the Kirtonryggen Formation, Spitsbergen

by

Richard A. Fortey and David L. Bruton

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The Kirtonryggen Formation is a thick, Lower Ordovician, palaeotropical, shallow-water carbonate succession exposed in northern Ny Friesland, Spitsbergen, in outcrops adjacent to Hinlopen Strait. The trilobites from the earliest part of the Ordovician of Spitsbergen are described for the first time, based upon two collections made during Cambridge University (1967), and joint Norsk Polarinstitutt and Palaeontologisk Museum, University of Oslo expedition in 1972. This work completes the monographic treatment of the Ordovician trilobites of Spitsbergen, Svalbard archipelago. Previous research on the Ordovician of Svalbard is summarised, especially relating to the faunas of the overlying Valhallfonna Formation (Floian–Dariwillian) which represent diverse, deeper-water biofacies as compared with the faunas described herein. The Kirtonryggen Formation (Ibexian: Tremadocian–early Floian) is divided into three members: in ascending order, Spora, Bassisletta and Nordporten Members, each with distinct trilobites, which are nearly all Laurentian endemics belonging to the Bathyurid biofacies. The sequence is as complete as any on the eastern side of the Laurentian palaeocontinent. The Spora Member is Stairsian in age, with a small fauna dominated by hystricurids and leiostegiids (*Svalbardicurus delicatus* fauna). The Bassisletta Member is sparingly fossiliferous, but includes Tulean-age trilobites, including early representatives of Bathyuridae (*Peltabellia* to *Chapmanopyge* faunas). The Nordporten Member has a widespread Blackhillsian fauna in its upper part (*Petigurus nero* fauna) underlain by a distinctive, but related fauna (*Petigurus groenlandicus* fauna) in its lower part. The older fauna includes species in common with a fauna from Greenland described by Poulsen in 1937 and is late Tulean to earliest Blackhillsian in age. The Tremadocian–Floian boundary is placed late in the *Chapmanopyge* fauna. The Kirtonryggen Formation trilobites include species in common with many localities along the eastern margin of Ordovician Laurentia, and their sequential stacking in Spitsbergen has proved useful in establishing the stratigraphy elsewhere and confirms that individual species were widespread and of biostratigraphic utility. Correlations with Lower Ordovician trilobite faunas previously described from Canada, Greenland, western Newfoundland, Vermont–New York State, Oklahoma and Missouri are discussed. Faunas closely similar to those described from the Nordporten Member occur in Greenland and on the Northern Peninsula, western Newfoundland. In general, the Early Ordovician trilobite faunas in Spitsbergen have undoubted similarities with those known from eastern Laurentia, and less in common with those described from the Great Basin, western USA, the area which has become the stratigraphical standard for Laurentia. Restricted environmental conditions on the heterogeneous carbonate platform may have generated endemics in eastern Laurentia, compared with more open shelf conditions in western Laurentia (on present geography). Fifty-three species belonging to 31 genera are considered, of which 15 species are described as new, 15 identified with previously described taxa and 24 described under open or tentative nomenclature. Three new genera: *Svalbardicurus*, *Harlandaspis* and *Eurysymphysurina*, are proposed, and *Chapmanopyge* is introduced as a replacement name for *Chapmania* Loch, 2007, pre-occupied. Occurrence in Spitsbergen of almost all genera of Bathyuridae allows a review of some of the problems in classification of the family. Alphabetically by genus, new species are as follows: *Bathyurellus diclementsae*, *Bolbocephalus gunnari*, *Catochia hinlopensis*, *Eurysymphysurina spora*, *Illaenus (Parillaenus) primoticus*, *Jeffersonia striagena*, *J. viator*, *Lachnostoma platypyga*, *Leiostegium spongiosum*, *Peltabellia glabra*, *Phaseolops? bobowensi*, *Raymondaspis? pingpong*, *Svalbardicurus delicatus* and *Uromystrum drepanon*. Although shallow-water biofacies predominate, the appearance of asaphids, remopleuridids and shumardiids at the very top of the Kirtonryggen Formation indicates a short-lived deepening prior to the drastic facies change at the base of the Valhallfonna Formation, which is attributed to a foundering of the shelf. The lower Nordporten Member has yielded the earliest known occurrences of three major trilobite superfamilies: Illaenoidea, Proetoidea and Scutelluoidea, respectively, together with the oldest leperditicope 'ostracod'. This is consistent with hypotheses relating the origin of new major clades to inshore habitats. Subsequent Ordovician occurrences of these groups record their expansion on to different palaeocontinents and into deeper-water palaeoenvironments. □ *Biogeography, biostratigraphy, clade origin, Early Ordovician, Spitsbergen, Svalbard, taxonomy, trilobites.*

Richard A. Fortey [raf@nhm.ac.uk], Department of Earth Sciences, The Natural History Museum, LondonSW7 5BD, UK; David L. Bruton [d.l.bruton@nhm.uio.no], Natural History Museum (Geology), University of Oslo, Postboks 1172, Blindern NO-0318 Oslo, Norway; *manuscript received on 28/08/2012; manuscript accepted on 20/05/2013.*

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Introduction

The Ordovician succession adjacent to Hinlopenstretet on northern Ny Friesland on the island of Spitsbergen, the largest of the Svalbard archipelago, is divided into two formations (Fortey & Bruton 1973). The younger of these formations, the Valhallfonna Formation, comprises mostly dark limestones and shales that were deposited in an outer shelf setting. The fossil fauna of the Valhallfonna Formation is remarkably rich, including trilobites, brachiopods, graptolites, conodonts, early vertebrates, radiolarians and molluscs. The admixture of these different elements makes the Valhallfonna Formation of considerable importance in stratigraphic correlation and biofacies recognition, in addition to the intrinsic interest of the well-preserved fossil fauna. Its age spans the Lower-to-Middle Ordovician boundary, the upper strata assigned to the Profilbekken Member being of entirely Whiterockian age, while the underlying Olenidsletta Member is mostly upper Ibexian (= Floian, or formerly Arenigian) in age, but contains the Ibexian–Whiterockian boundary in its upper part. The varied trilobite fauna of the Valhallfonna Formation has been monographed in considerable detail and was seminal in the recognition of trilobite biofacies (Fortey 1975b). The graptolites were described by Cooper & Fortey (1982) and include isolatable material, thus placing the biostratigraphy on a sound international footing. However, apart from a preliminary faunal list in Fortey & Bruton (1973), the trilobite fauna of the thick Kirtonryggen Formation underlying the Valhallfonna Formation has not received further attention. Correlative strata have been recognised recently on the other side of Hinlopenstretet, in Nordauslandet (Stouge *et al.* 2011), but detailed biostratigraphy remains to be done there. This work completes the account of the Ordovician trilobites of Spitsbergen, one of the richest localities known in rocks of this age.

Some of the species typical of the Kirtonryggen Formation were originally described from western Newfoundland by Billings (1865), and Fortey considered that it was essential to revise them before consideration of the Spitsbergen fauna. These trilobites, originating from the St George Group, were revised by Fortey (1979) and Boyce (1989). This has helped to provide a comparative standard for the taxonomy of the trilobites from the upper part of the Kirtonryggen Formation. Further revisions or additions to the Early Ordovician platform trilobite faunas of eastern Laurentia have been made subsequently, with descriptions of species from Oklahoma, New York State, eastern and arctic Canada and Greenland in recent years. Most of these are small faunas from various horizons within the Early Ordovician, Ibexian (Tremadocian–Floian). The particular importance of the Spitsbergen succession is that several different faunas are stacked one after the other in the Kirtonryggen Formation, which allows identification of the relative ages of fossiliferous horizons previously recognised elsewhere. For example, the faunas from Greenland described long ago by Poulsen (1937) can now be placed in their proper sequence.

This work describes the trilobites from northern Spitsbergen from the section through the Kirtonryggen Formation along Hinlopen Strait collected during the 1968 Cambridge University and 1972 Oslo Paleontological Museum field expeditions. The majority of the specimens were collected during the latter trip. The only fossils so far described from the Kirtonryggen Formation include the earliest known leperditicope 'ostracod' from the upper part of the Nordporten Member, named as *Trinesos akroria* by Williams & Siveter (2008), and a few widespread Laurentian articulated brachiopods from the Spora and Nordporten Members (Hansen & Holmer 2011), and some recently reported conodonts (Lehnert *et al.* 2013). The trilobite fauna demonstrates the radiation in Ordovician bathyurid trilobites and other species adapted to an extensive, shallow subtidal to peritidal carbonate shelf that typified a vast area of the ancient Laurentian palaeocontinent during the earlier Ordovician. Furthermore, the fauna proves that some trilobite species were very widespread, making them potent stratigraphical tools to be applied all along the eastern margin (present geography) of former Laurentia. It also reveals that there were some interesting differences between the trilobite faunas of eastern and western Laurentia, typified by the richly fossiliferous, and frequently silicified, sequences of the Great Basin in Utah, Nevada and Idaho (Ross 1951; Hintze 1953; Adrain *et al.* 2009). Apart from the rich variety of endemic bathyurids, the fauna is also of considerable taxonomic interest in yielding the oldest known illaenid, proetid and styginid trilobites. This in turn relates to hypotheses proposing the inshore origin of major clades (Jablonski 2005).

The fauna described here is rich in species, but several of these taxa remain incompletely understood and are described under open nomenclature. Further collecting and research on the faunas of the Kirtonryggen Formation would be worthwhile to characterise these species adequately, but no further expeditions to this remote region have happened over the last four decades.

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Summary of previous research on the Ordovician of Spitsbergen

Since this paper completes the account of the Ordovician of northern Spitsbergen, it may be useful briefly to summarise previous work. Several of the earlier papers describing different aspects of the faunas are published in journals without wide distribution, and some of these are in danger of slipping out of sight. The general reference on the geology of Spitsbergen is Harland (1997), and W. B. Harland was responsible for introducing the first author to Spitsbergen in 1967 on one of the Cambridge University expeditions. *Harlandaspis* is named for him in this work.

Hallam (1958) reported the discovery of Ordovician rocks and fossils in Ny Friesland by the Cambridge University expedition; they were collected near the top of the thick Hecla Hoek Group (Proterozoic–Ordovician). The molluscs and other fragments were indicative of Early Ordovician age and probably of similar age to the trilobites described in this paper. These outcrops near the large glacier known as Oslobreen, south of our study area, were mapped in more detail by a Cambridge University team in the years following, and a more detailed account of the stratigraphy was given by Gobbett & Wilson (1960), who proposed the Kirtonryggen Formation for the Ordovician strata. Gobbett (*in* Gobbett & Wilson 1960) also described the first Early Ordovician trilobite from Ny Friesland, *Hystricurus wilsoni* Gobbett. Interestingly, it is not identical to any hystricurid herein and would probably now be referred to one of the Skullrockian genera erected by Adrain *et al.* (2003). Hence, it is older than the earliest fauna we have discovered from the Spora Member, which is Stairsian in age.

Discovery of the sections along Hinlopen Strait (Hinlopenstretet) occurred accidentally, when the 1966 Cambridge University expedition stopped to collect water from a melt stream, one that later came to be called 'Profilbekken'. G. Vallance was an undergraduate student on that expedition. Preliminary determination of several different trilobites by H. B. Whittington encouraged a focussed collection trip in the summer of 1967, with Vallance assisted by Richard A. Fortey (RAF), during which some of the specimens figured herein were collected. The great diversity and good preservation of the faunas were immediately apparent. An outline account of the regional stratigraphy was published by Vallance & Fortey (1968). RAF then studied a fraction of the faunas for a PhD thesis and published the first paper on the new collections based upon isolated material of the graptolite *Pseudotrigonograptus* (Fortey 1971). In 1972, an expedition of the Palaeontological Museum, Oslo, and the Norsk Polarinstitutt, including G. Henningsmoen, RAF and David L. Bruton (DLB), made extensive new collections from a measured section, from which the majority of the type specimens are derived. Fortey & Bruton (1973) published a map (see also Hansen & Holmer 2011; Lehnert *et al.* 2013) and outlined the regional stratigraphy, establishing the lithostratigraphic units in use today. These units have since been identified in north Eastland (Nordaustlandet) on the opposite side of Hinlopen Strait, and correlation has been made with other sites along the Iapetus borders (Smith & Rasmussen 2008; Stouge *et al.* 2011, 2012).

The fauna of the Valhallfonna Formation was studied intensively over the next decade, RAF devoting much of his time to the task. Two members were recognised: the upper Profilbekken Member including a typical Whiterockian trilobite fauna of North American type and the lower Olenidsletta Member a unique mixture of alternating biofacies yielding deeper-water assemblages of 'Arenigian' age. Four major successive faunas termed 'V_1' to 'V_4' were summarised in a range chart in Fortey (1980a). The first trilobite to be described was the pelagic *Opipeuterella* (Fortey 1973), which is now known to be widespread. The other trilobites of the Valhallfonna Formation were described in three monographs (Fortey 1974, 1975a, 1980a). In particular, the Ordovician radiation of the Olenidae (Fortey 1974) was remarkable and remains unparalleled from collections elsewhere. The co-occurrence of suites of particular genera was clearly related to Ordovician palaeoenvironmental conditions, which were discriminated in the Hinlopen Strait sections for the first time. Fortey (1975b) described them as 'community types', although 'biofacies' is the preferred term for the same concept in modern literature. A sequence running through olenid, nileid and illaenid–cheirurid biofacies with decreasing depth have now been widely recognised elsewhere. The principle that deeper-water assemblages tend to be more independent of geographic barriers is also generally adopted. Dissolution of limestone for graptolites revealed the presence of well-preserved radiolarians, some of which have been described by Fortey & Holdsworth (1971), Holdsworth (1977), and Maletz & Bruton (2007, 2008), also chitinozoa (Bockelie 1980, 1981). The systematics of the graptolites themselves were published by Fortey (1971), Archer & Fortey (1974), and Cooper & Fortey (1982). Correlation with the Australasian graptolite standard was established in these works. Residues from acid preparation included a range of phosphatic fossils. Fragments of

vertebrate bone (*Anatolepis*) were the oldest record of the phylum at that time (Bockelie & Fortey 1976; Bockelie *et al.* 1976). Minute larval 'shells' were attributed to very early growth stages of trilobites (Fortey & Morris 1978), while the enigmatic fossil *Janospira* Fortey & Whittaker, 1976, was subsequently regarded as an aberrant mollusc. Another mollusc was discovered from silicified material and became the type species of a new bivalve genus, *Tironucula* Morris & Fortey, 1976. Conodonts recovered from the residues showed the same relation to biofacies as did the trilobites, a relationship described by Fortey & Barnes (1977). Unfortunately, the systematics of the conodonts were never published from the original collections, which is an omission given the biostratigraphic significance of such a 'mixed province' locality. However, conodonts from samples collected from the Kirtonryggen and Valhallfonna formations have recently been described by Lehnert *et al.* (2013). Hansen & Holmer (2011) have described the brachiopod faunas of the Valhallfonna and Kirtonryggen formations, the former having by far the richer assemblage of deeper-water genera.

The stratigraphic significance of the succession of faunas in the Valhallfonna Formation was summarised by RAF (Fortey 1976, 1980b). The particularly rich succession spanning an interval close to the base of the Whiterockian Laurentian regional stage indicated that knowledge of faunas of macrofossils from the standard Ibexian–Whiterockian successions in the Great Basin, western USA, was incomplete (e.g. Hintze 1953), probably because a sequence boundary is present there. Proposal of a Valhallan Stage to accommodate this interval did not meet with much acceptance, and subsequent definition of the base of the Whiterockian (Ross *et al.* 1997) effectively drew its lower limit to incorporate the Valhallan equivalents in Spitsbergen, equivalent to the upper part of the former 'Arenigian' Series of Europe (see also Fortey & Droser 1996). In modern global terms, the top of the Floian Stage and the base of the Dapingian, and hence the Middle Ordovician, lie at or close to the base of V_3 in the upper part of the Olenidsletta Member.

More general studies of the trilobite faunas showed that the deeper-water genera of the olenid biofacies, and carbonate 'mound' faunas of the illaenid–cheirurid biofacies, tended to have much longer stratigraphical ranges than genera of the open shelf nileid biofacies, where the greatest biodiversity was also present (Fortey 1980c). A similar association with biofacies has been recognised for the brachiopods based on our collections and those made in 2008 by Hansen & Holmer (2010, 2011). The Nordporten Member also yielded the earliest record of a leperditicope arthropod (Williams & Siveter 2008). The biofacies profile was again used to demonstrate the effect of the palaeoenvironment on trilobite cuticle thickness (Fortey & Wilmot 1991), showing that deepest faunas had only thin cuticles, while inshore faunas included species with the thickest cuticles, but that 'thin-shelled' species could also be found in specific niches in shallow-water habitats. This conclusion is reinforced in the present work: within the inshore Bathyurid biofacies, *Petigurus* is remarkably robust, yet the same environment also supported 'thin-shelled' species belonging to such genera as *Licnocephala* (see Fig. 26). Regrettably, our rock collections have not been studied in detail by sedimentologists, but lithological descriptions of parts of our section have been published in Russian by Kosteva & Teben'kov (2006).

Stratigraphy of the Kirtonryggen Formation

Stratigraphic sub-divisions and age

The type section of the Kirtonryggen Formation lies near Oslobreen, south of the Hinlopen Strait outcrop (Gobbett & Wilson 1960; Harland 1997). The present study is based on the northern part of Ny Friesland, where the formation is exposed along the shores adjacent to Hinlopen Strait (Hinlopenstretet), on the western side of the strait opposite the island of Nordaustlandet (Fig. 1). The lithostratigraphy of the Kirtonryggen Formation in this area was outlined by Fortey & Bruton (1973), where preliminary faunal determinations were also given. The lithologies exposed in the Kirtonryggen Formation are overwhelmingly of the type described from shallow-water Ordovician carbonate platforms laid down in tropical palaeolatitudes along the eastern margin of Laurentia, which have long been recognised as constituting a single entity in Early Ordovician times (Swett & Smit, 1972; Swett 1981; James *et al.* 1989; Derby *et al.* 2012 for review). For example, contemporary sequences very similar to those of the Kirtonryggen Formation have been described from the St George Group, western Newfoundland, by Fortey (1979), Knight & James (1988) and Boyce (1989), and from Greenland by Cowie & Adams (1957). New faunal evidence is consistent with this geographical continuity, and biostratigraphical sub-divisions of the carbonate platforms developed elsewhere can be broadly applied to the Spitsbergen

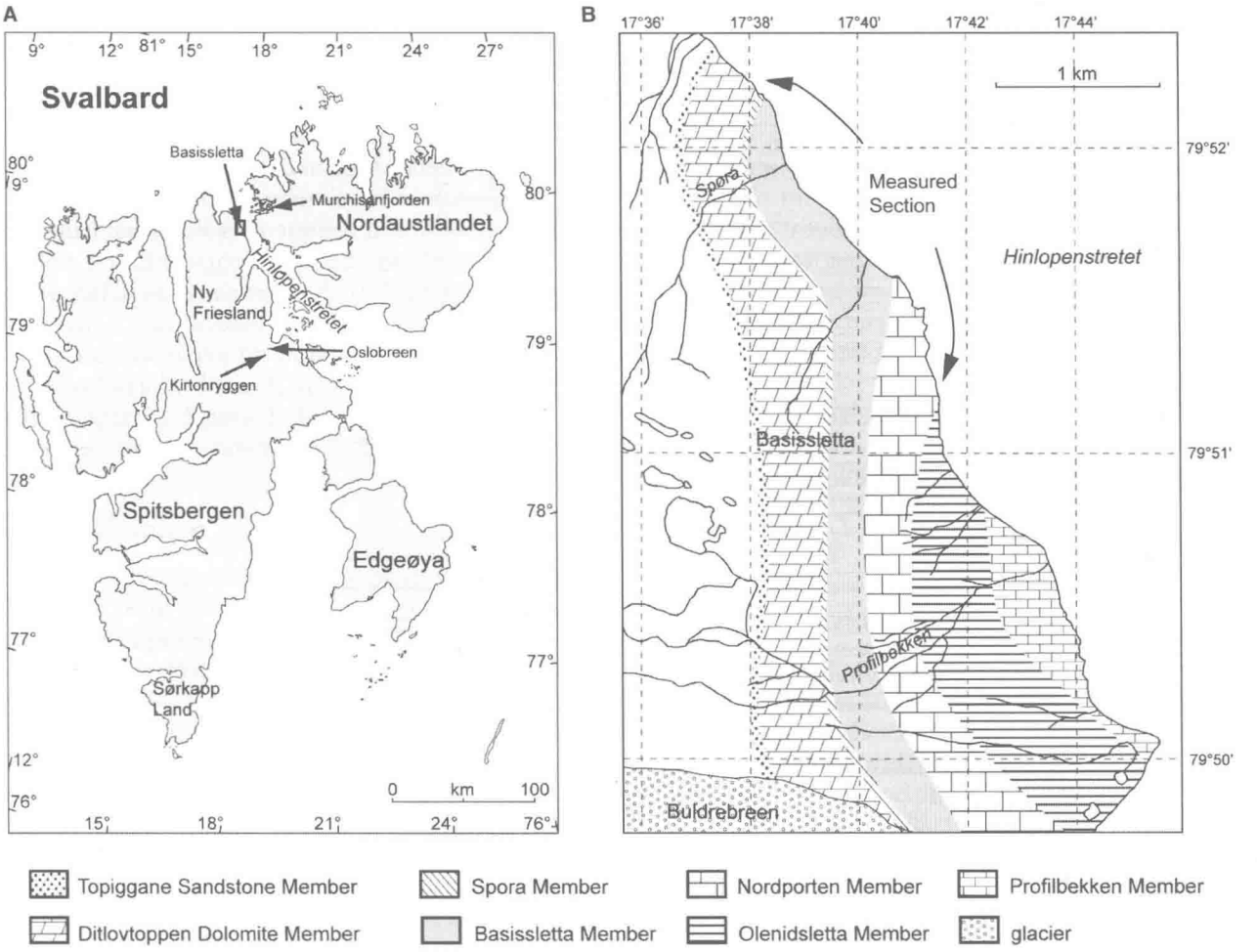
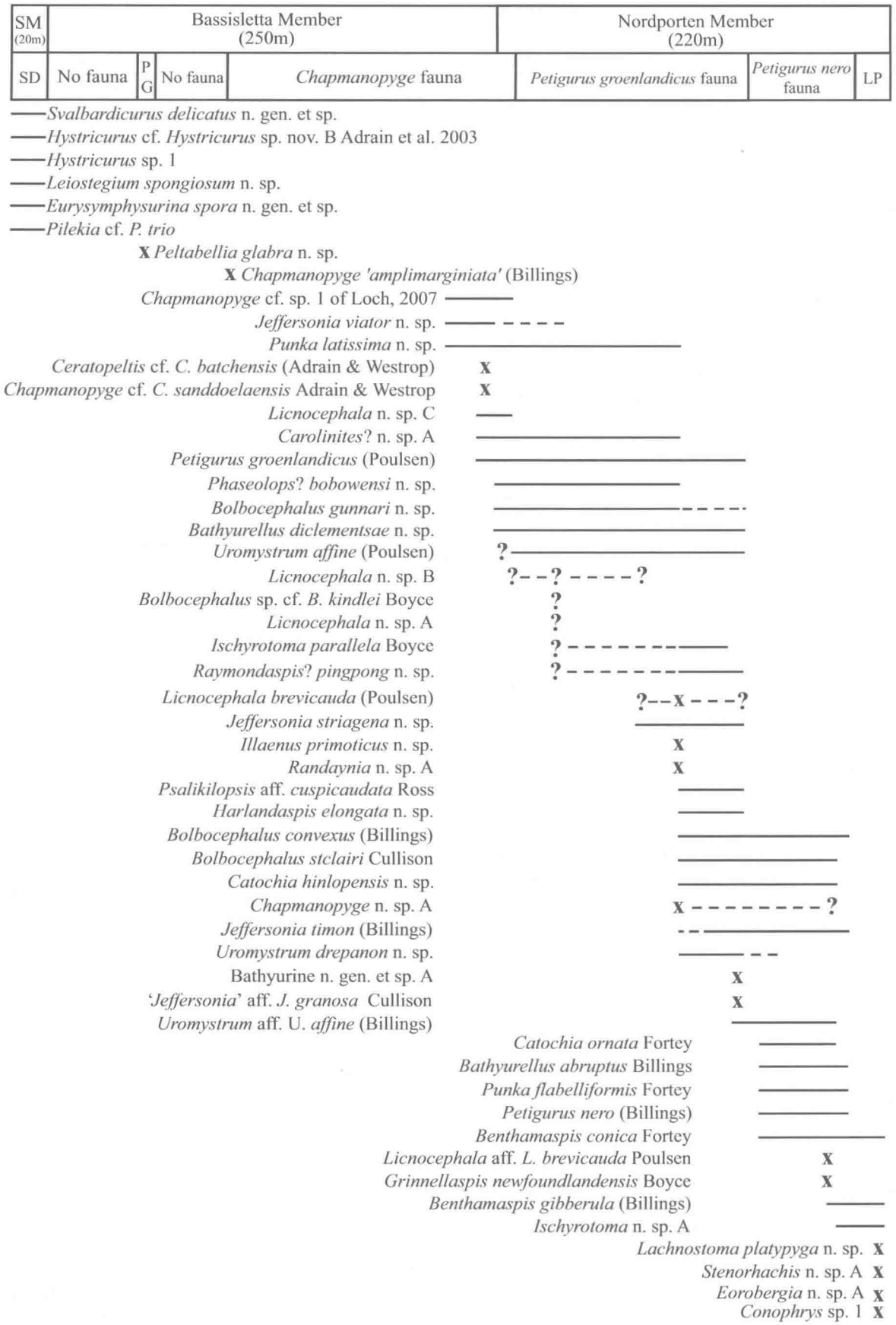


Fig. 1. Locality map for the type section of the Kirtonryggen Formation along Profilstranda, adjacent to northern Ny Friesland, Spitsbergen. After Fortey & Bruton (1973).

sequence. However, as noted below, there are faunal differences between the two sides of the Ordovician Laurentian palaeocontinent which make some difficulties in the straightforward application of the standard sub-divisions of the Ibexian Series detailed by Ross *et al.* (1982, 1997) based upon the succession of the Great Basin, western USA.

The discovery of productive horizons along the type section along Profilstranda was sporadic, the massive, rubbly weathering limestones were not easy to collect, and sections are hard to measure accurately. The considerable number of species that we have been obliged to leave in open nomenclature proves that further collections would extend the fauna. However, the sequence of faunas is well-established, and the range chart (Fig. 2) is related to the type section along Profilstranda. A few useful collections were made inland from isolated outcrops. These cannot be located precisely in the type section, but their approximate horizon can generally be determined with some confidence in relation to collections made from the measured section. In the text and plate descriptions, these specimens are indicated by 'ca.' (circa) before the stratigraphic horizon appropriate to the main coastal section. It is also important to note that the two section measurements of the collections from the Oslo expedition and Cambridge University expedition do not mesh precisely. For the purposes of this paper, the Oslo section is taken as standard, as it was measured in more detail, and the Cambridge collections of illustrated material matched as closely to it as we can manage. This is not ideal, but is the product of different fieldwork conducted several years apart under different ice conditions.

As in northwest Scotland and East Greenland, strata of presumed middle and upper Cambrian age are as yet unproven from finely laminated dolomitic strata of the Tokammane Formation underlying the Kirtonryggen Formation, although there is no angular unconformity above the former. From faunal evidence given below, it is likely that the earliest


SM (20m)
Bassisletta Member (250m)
Nordporten Member (220m)
SD
No fauna
PG
No fauna
Chapmanopyge fauna
Petigurus groenlandicus fauna
Petigurus nero fauna
LP
Svalbardicurus delicatus n. gen. et sp.
Hystricurus cf. Hystricurus sp. nov. B Adrain et al. 2003
Hystricurus sp. 1
Leiostegium spongiosum n. sp.
Eurysymphysurina spora n. gen. et sp.
Pilekia cf. P. trio
X Peltabellia glabra n. sp.
X Chapmanopyge 'amplimarginiata' (Billings)
Chapmanopyge cf. sp. 1 of Loch, 2007
Jeffersonia viator n. sp.
Punka latissima n. sp.
Ceratopeltis cf. C. batchensis (Adrain & Westrop)
Chapmanopyge cf. C. sanddoelaensis Adrain & Westrop
Licnocephala n. sp. C
Carolinites? n. sp. A
Petigurus groenlandicus (Poulsen)
Phaseolops? bobowensi n. sp.
Bolbocephalus gunnari n. sp.
Bathyurellus diclementsae n. sp.
Uromystrum affine (Poulsen)
Licnocephala n. sp. B
Bolbocephalus sp. cf. B. kindlei Boyce
Licnocephala n. sp. A
Ischyrotoma parallela Boyce
Raymondaspis? pingpong n. sp.
Licnocephala brevicauda (Poulsen)
Jeffersonia striagena n. sp.
Illaenus primoticus n. sp.
Randaynia n. sp. A
Psalikilopsis aff. cuspicaudata Ross
Harlandaspis elongata n. sp.
Bolbocephalus convexus (Billings)
Bolbocephalus stclairi Cullison
Catochia hinlopensis n. sp.
Chapmanopyge n. sp. A
Jeffersonia timon (Billings)
Uromystrum drepanon n. sp.
Bathyurine n. gen. et sp. A
'Jeffersonia' aff. J. granosa Cullison
Uromystrum aff. U. affine (Billings)
Catochia ornata Fortey
Bathyurellus abruptus Billings
Punka flabelliformis Fortey
Petigurus nero (Billings)
Benthamaspis conica Fortey
Licnocephala aff. L. brevicauda Poulsen
Grinnellaspis newfoundlandensis Boyce
Benthamaspis gibberula (Billings)
Ischyrotoma n. sp. A
Lachnostoma platypyga n. sp.
Stenorhachis n. sp. A
Eorobergia n. sp. A
Conophrys sp. 1

Ordovician (Tremadocian, Skullrockian) may also be unrepresented by fossiliferous strata in northern Ny Friesland. Since Boyce (1989), Loch (2007) and Adrain *et al.* (2009) have all proposed trilobite-based faunal zones spanning the same interval in Early Ordovician Laurentian strata, there is no reason to add to a burgeoning list of biozones, and an informal terminology is applied in this work. Nonetheless, we can suggest a broad correlation between these different schemes (Fig. 3). The Kirtonryggen Formation was divided by Fortey & Bruton (1973) into three members on lithological grounds, which are also faunally distinct, as summarised by the species ranges in Figure 2. In order from oldest to youngest, these members are as follows:

Spora Member

Rather massive grey limestones, 20 m thick, are fossiliferous from the base of this unit to its top and yield the brachiopod *Syntrophina* along with numerous trilobites. With its rubbly occurrence, it has not proved possible to sub-divide this member, and the fauna appears to be the same throughout. The trilobites are compared in detail in the systematic section, but include the common hystricurid *Svalbardicurus delicatus* n. gen., n. sp., with rarer *Leiostegium spongiosum* n. sp., and *Eurymphysurina spora* n. gen., n. sp. and *Hystricurus* spp. *Svalbardicurus delicatus* is very similar to a species from the Lower Member of the Boat Harbour Formation in western Newfoundland, and we also compared *Leiostegium spongiosum* n. sp. to a species from the same unit (Boyce 1989). The brachiopod *Syntrophina* is commonly recorded in lower Ibexian strata (e.g. Hintze 1953). *Leiostegium* appears in the *Kainella/Leiostegium* (Zone D) Biozone of the standard Ibexian sections in western USA (Ross *et al.* 1997, p. 17), which is the earliest zone of the Stairsian regional stage. We compare a *Pilekia* species closely with *P. trio* Hintze, a species known from 'Zone E' in Utah. Ross *et al.* (1997) stated that the Stairsian interval lies above the lowermost Ordovician regional stage, the Skullrockian, which includes at least three Ordovician trilobite zones apparently not represented in either western Newfoundland or Ny Friesland. The Spora Member fauna appeared suddenly and endured briefly, and is likely early, but not earliest Ibexian (Stairsian, early Tremadocian). Thus, the disconformity beneath the base of the Kirtonryggen Formation also embraces the earliest Ordovician. Ross *et al.* (1997) noted that there is a 'low-diversity interval' among conodont faunas through the equivalent of the greater part of the *Kainella/Leiostegium* trilobite Biozone, and a similar and correlative interval has been identified in the St George Group in western Newfoundland and elsewhere by Ji & Barnes (1994). Lehnert *et al.* (2013) record conodonts of the *Rossodus manitouensis* Zone from this unit.

In the text, we refer to the lower fauna as the *Svalbardicurus delicatus* fauna. The fauna was apparently uniform throughout a massive, rubbly limestone, and the field collections were not sub-divided for this unit.

Bassisletta Member

The 250-m-thick Bassisletta Member is dominated by dolomites, oolites, stromatolites, edgewise conglomerates and other lithologies providing evidence of supratidal, intertidal or very shallow sub-tidal conditions. Not surprisingly, it is difficult to find macrofossils, trilobites included. One horizon 60 m from the base, a limestone between stromatolite 'heads', has yielded well-preserved material of *Peltabellia glabra* n. sp. This species is exceedingly like a species from the Barbace Cove Member of the Boat Harbour Formation that Boyce (1989, p. 150) named as *Peltabellia* sp. cf. *P. peltabella* (Ross). This was in turn placed in the synonymy of *Strigenalis implexa* Loch, 2007 by Loch (2007, p. 47) (see taxonomic discussion below), a species ranging through his *Benthamaspis rhochmotis* and *Petigurus cullisoni* biozones of the Kindblade Formation, Oklahoma. Boyce correlates the Barbace Cove Member with the Tulean Stage of the Ibexian Series, and this is not inconsistent with the assignment in Oklahoma, although Loch points out the differences between the local successions there and in the Nevada/Utah standard. The trilobite occurrence in the Bassisletta Member below the typical later Ibexian faunas of the Nordporten Member is consistent with an early Tulean age for this part of the Bassisletta Member.

Fig. 2. Stratigraphic distribution of trilobite species described in this paper through the three members of the Kirtonryggen Formation. SM, Spora Member; SD, *Svalbardicurus delicatus* fauna; PG, *Peltabellia glabra* fauna; LP, *Lachnostoma platypyga* fauna (top 3 m of Nordporten Member). Specimens found in the Spora Member are indicated as passing through the entire member, which was not subdivided in the original collections. X indicates occurrences from a single horizon. ? indicates specimens from the H collection (p. 9), low in *P. groenlandicus* fauna, exact horizon unknown and tentative extensions of ranges. Solid lines represent certain stratigraphic distribution, and dotted lines portray possible range extensions.

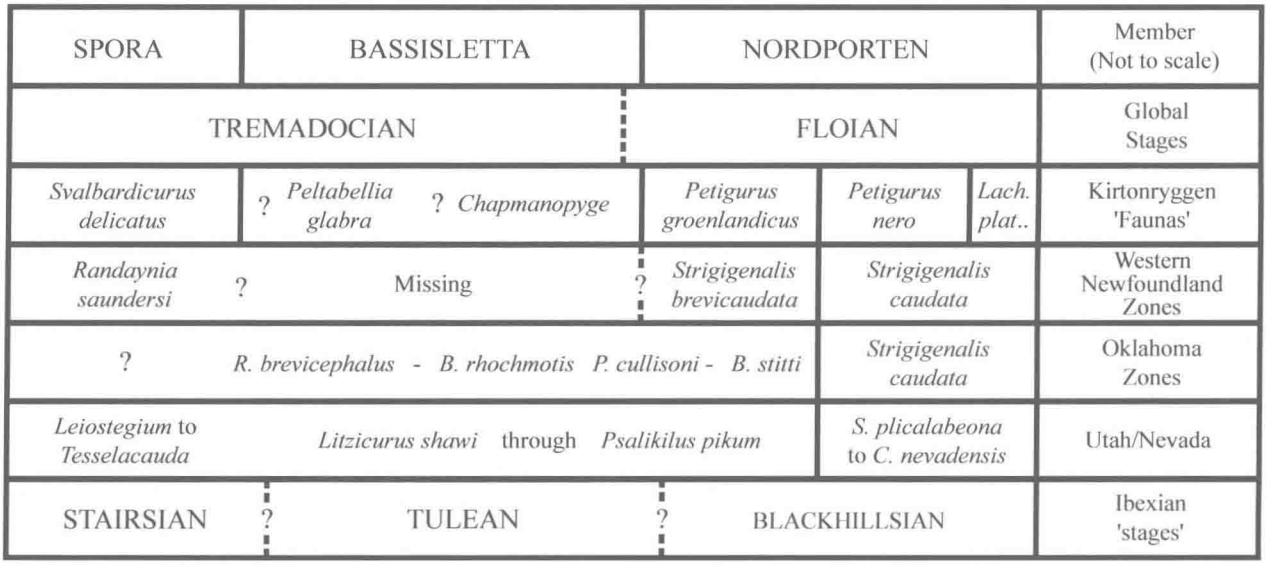


Fig. 3. Suggested correlation of successive Spitsbergen trilobite faunas with zonal schemes suggested elsewhere in Early Ordovician Laurentia. Not to scale.

In the text below, we refer to this fauna as the *Peltabellia glabra* fauna.

The upper part of the Bassisletta Member includes two trilobite faunas: the lower one is incompletely known, but includes *Chapmanopyge* '*amplimarginiata*' (Billings). An upper fauna is better characterised, including a fauna with *Chapmanopyge* cf. sp. 1 (of Loch, 2007), *Punka latissima* n. sp., *Jeffersonia viator* n. sp., *Ceratopeltis* cf. *C. batchiensis* Adrain and Westrop, *Carolinites*? n. sp. A, and a *Chapmanopyge* sp. compared with *C. sanddoelaensis* (Adrain and Westrop). Comparison with the previously described species of these genera detailed in the systematic section suggests that this part of the member is assignable to the upper part of the Tulean Stage. Detailed comparison of *Jeffersonia viator* n. sp. indicates that it may be identical with a species described from the 'Jeffersonian' of Missouri and possibly one from the Baumann Fiord Formation of Ellesmere Island. This interval in the section is under-represented in the collections and would repay further exploration, which is reflected in a number of additional interesting species recorded in open nomenclature.

This collection of faunas is referred to the *Chapmanopyge* fauna in the systematic part. Adrain *et al.* (2009) have finely divided this part of the Early Ordovician into a number of biozones based upon silicified faunas in the Great Basin. Such refinement is hardly possible from our collections. Lehnert *et al.* (2013) record conodonts of the *Macerodus dianae* Zone from the upper part of the Bassisletta Member. This is regarded as upper Tremadocian. However, it is likely that the uppermost part of the *Chapmanopyge* fauna is Floian in age, as concluded from conodonts obtained from samples processed by Dr M. P. Smith and reported below.

Nordporten Member

As already noted by Fortey & Bruton (1973), the 220-m-thick Nordporten Member is rich in fossils compared with the earlier part of the Ibexian succession. Trilobites are invariably disarticulated and sorted into different sclerites, which has presented particular problems in assigning all the exoskeletal parts to some taxa.

The Nordporten Member fauna divides into several successive intervals typified by different assemblages of bathyurid and other trilobites.

1 Lowest fauna, at the very base, intermediate with the younger *Chapmanopyge* fauna with species range extensions upwards of species from the top of the Bassisletta Member. This interval requires further fieldwork for clarification, since the collections may have been 'lumped'.
2 Diverse bathyurid dominated fauna with *Petigurus groenlandicus* Poulsen, 1937, *Uromystrum affine* (Poulsen, 1937), *Harlandaspis elongata* n. gen., n. sp. *Bathyurellus diclementsae* n. sp., *Licnocephala brevicauda* (Poulsen, 1937), *Illaenus primoticus* n. sp., *Raymondaspis? pingpong*, *Phaseolops? bobowensi* n. sp., *Bolbocephalus gunnari* n. sp. *Psalikilopsis* n. sp., and particularly

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known from abundant material 105 m from base of member (115 m from top), but extending from the base to 130 m. We refer to this assemblage as the *Petigurus groenlandicus* fauna below. One collection made by Gunnar Henningsmoen inland away from the type section is probably from the same interval, but includes some species that have not been found elsewhere, and lies within the lower part of the *P. groenlandicus* interval. It is referred to as the 'H collection'.

The fauna of the lower part of the Nordporten Member is termed the *Petigurus groenlandicus* fauna below

3 Diverse bathyurid dominated fauna with *Petigurus nero* (Billings), *Uromystrum drepanon* n. sp., *Grinnellaspis newfoundlandensis* Boyce, *Bathyurellus abruptus* Billings, *Catochia hinlopensis* n. sp., *Punka flabelliformis* Fortey, *Bolbocephalus convexus* (Billings) *Benthamaspis gibberula, B. conica* and others. Many of these species were originally named by Billings (1865) from the Catoche Formation of western Newfoundland, a fauna revised by Fortey (1979) and Boyce (1989). This is the classical 'Upper Canadian' (or Cassinian) fauna of the older literature. It is evidently widespread, as it is found additionally in the Wandel Valley Formation, eastern North Greenland (Fortey 1986) and in the Fort Cassin Formation of Vermont (Brett & Westrop 1996). There is no reason to revise the assessment of its age originally given by Fortey (1979) as corresponding with the *Trigonocerca typica* Biozone (Zone H) of the Great Basin standard, which is now referred to the early Blackhillsian regional stage of the Ibexian (Ross *et al.* 1997, p. 19; Adrain *et al.* 2009). This fauna is present through an interval from 130 to 200 m of the Nordporten Member.

This is referred to as the *Petigurus nero* fauna below.

4 The uppermost 3 m of section comprise more fissile and darker limestones than those below. There is a radical change in faunal composition with the appearance of abundant asaphids attributed to *Lachnostoma platypyga* n. sp. and *Stenorhachis* n. sp. A in the uppermost Kirtonryggen Formation, together with *Conophrys* and a remopleuridid; with the exception of *Benthamaspis*, bathyurids disappear. This is clearly a facies change from the faunas dominated by bathyurid trilobite species underlying it, and we consider that the fauna may not be significantly younger than the *Petigurus nero* fauna. As discussed below, the interval probably represents a deepening event transitional to the conditions pertaining during the deposition of the Valhallfonna Formation and may be stratigraphically condensed.

This is referred to as the *Lachnostoma platypyga* fauna in the systematic account.

Lehnert *et al.* (2013) reported on conodonts from the Nordporten Member. An assemblage indicating the *Oneotodus costatus* Zone was obtained from the uppermost Bassisletta Member and the lower part of the Nordporten Member (*Petigurus groenlandicus* fauna). They report the transition to the *Oepikodus communis* Zone within the upper part of the Nordporten Member (their sample BS 23), which we cannot locate precisely in our section. Since the same conodont fauna continues into the Valhallfonna Formation, however, this does support the interpretation of a facies change rather than a hiatus at the junction of the Kirtonryggen and Valhallfonna formations.

Tremadocian–Floian boundary

The Kirtonryggen Formation is overlain conformably by the Valhallfonna Formation, at the base of which there is a drastic change in lithology and biofacies indicating a great deepening in relative sea level over a very short period of time. Relatively deep-water olenid trilobites and graptolites appear within a metre or so of the contact in the basal part of the Olenidsletta Member of the Valhallfonna Formation, in black limestones and shales, and all the typical trilobites of the Kirtonryggen Formation disappear. So striking is the change in the field that we first considered that there could be a thrust contact, but excavation has revealed a continuous section. Bathyurid trilobites do not reappear until the top of the section in the Profilbekken Member of the Valhallfonna Formation.

The graptolite fauna appearing at the base of the Olenidsletta Member of the Valhallfonna Formation immediately overlying the Nordporten Member is indicative of the Bendigonian Stage (*Tetragraptus fruticosus* Biozone) of the Australian graptolite sequence (Cooper & Fortey 1982). This correlates in turn with the early, but not earliest Floian Stage (*quondam* = early Arenigian) of the international standard Ordovician chronostratigraphy (e.g. Webby *et al.* 2004, p. 44). This graptolite evidence also proves that the time equivalents of the underlying earliest Floian, *Tetragraptus* (*Etagraptus*) *approximatus* Biozone (together with part of the lower *T. fruticosus* Biozone), should be present in the

upper part of the Kirtonryggen Formation. However, there is no direct evidence for correlation between shelly and graptolitic facies that can be provided by the faunas described in this work, which are entirely comprised of species confined to shallower regions of the Ordovician Laurentian platform. The upper fauna of the Nordporten Member, the *Petigurus nero* fauna/*Lachnostoma platypyga* fauna, is surely early Floian (and Blackhillsian) in age, as deduced from its stratigraphic position beneath the *fruticosus* Biozone fauna and also as inferred from coeval faunas in western Newfoundland (e.g. Boyce *et al.* 2011). However, the location of the Tremadocian–Floian boundary within the Kirtonryggen Formation is not obvious. The *Petigurus groenlandicus* fauna underlying the *P. nero* fauna is generally very similar to the younger assemblage as far as its generic composition is concerned, although it has a distinct suite of species. It could be plausibly regarded as an earlier Blackhillsian fauna. Conodonts obtained from a sample derived from 105 m from the base of the Nordporten Member (Dr M. P. Smith, written comm. 2013) are all long-ranging Midcontinent Province species with Tulean–Blackhillsian range (*Oneotodus costatus* Ethington and Brand, *Parapanderodus striatus* (Graves and Ellison), *Tropodus comptus* (Branson and Mehl)) (e.g. Repetski, 1982) that do not refine the correlation.

However, a 2267-gm sample from the top beds of the Bassisletta Member (top of the *Chapmanopyge* fauna) provided a more indicative conodont fauna on which Dr M. P. Smith reports as follows (written comm. 2013):

'The species present are listed below (csu ranges refer to the composite standard of Sweet & Tolbert (1997)):

Diaphorodus sp.
Drepanodus arcuatus Pander (420–999 csu)
Oepikodus sp.
Oistodus bransoni Ethington and Clark 1981 (556–874 csu)
Oneotodus costatus Ethington and Clark 1981 (492–906 csu)
Parapanderodus striatus (Graves and Elllison) (353–1223 csu)
Tropodus comptus (Branson and Mehl) (485–916 csu)
Ulrichodina abnormalis (Branson and Mehl) (489–911 csu)
Ullrichodina simplex (Ethington and Clark 1981) (599–864 csu)

For the most part, these are long-ranging coniform species. However, the highly distinctive *Ulrichodina simplex* first appears at a short distance above the base of the *O. communis* Zone and provides constraint on the maximum age of the sample in the composite section – in the Ibex section, this corresponds to the middle of member 3 of the Fillmore Formation (lower G2, *Protopliomerella contracta* Zone) (Ross *et al.* 1997).

Further constraint is provided by *Oepikodus* sp. that has a denticulated posterior process, a moderately inflated basal cavity and very long adenticulate anterior and lateral processes. It is similar to, but not conspecific with, *O. communis* and *Oepikodus* sp. A of Smith (1991). Age constraint is provided by the genus *Oepikodus*. At Cow Head, where conodont and graptolite ranges may be readily correlated, *Oepikodus* species appears first in the uppermost part of Bed 9, whereas the FAD of *Tetragraptus approximatus* is in the lowermost part of the 50-m-thick Bed 9 (Stouge & Bagnoli 1988). No *Oepikodus* species are known below the base of the Floian, and the sample may be referred to the Floian.'

The conclusion can be drawn that the upper Tulean fauna of the top part of the *Chapmanopyge* fauna is also close to earliest Floian, which is consistent with the type Tulean sequences in the Great Basin, western USA. The *Petigurus groenlandicus* fauna soon replaces the underlying *Chapmanopyge* fauna. Styginid, proetid and illaenid trilobites appear within the same interval, coinciding with a general increase in species-richness (Fig. 2). The appearance of more widespread conodont species and also reported by Dr Smith (also Fortey & Barnes 1977) would be consistent with this. In that the carbonate platform should respond passively to eustatic sea level changes, and it is reasonable to infer that this increase in diversity corresponded with a relative flooding event. The lithological change to include 3-m-thick units of grey, coarsely crystalline bioclastic grainstone is consistent with this interpretation. This part of the section would repay more detailed sampling than has been carried out at present. The base of the Floian (Arenig) has long been recognised as coinciding with a eustatic sea level rise (Fortey 1984; Nielsen 2004) introducing faunal change. The much more drastic change at the base of the Valhallfonna Formation is likely to be the result of the shelf foundering, because there is no event on the eustatic curve that could account for such a dramatic change in litho- and biofacies.

Correlation with other areas of Ordovician Laurentia

The succession of trilobite faunas in the Kirtonryggen Formation permits correlation with other Ordovician carbonate formations along what remains of the eastern margin of the Laurentian palaeocontinent, as seen by modern coordinates (we maintain this usage throughout this work). Previously described Early

Ordovician trilobites are often known from small samples, and their localities are scattered. However, the comparisons below are made on the basis of identical species and are reasonably secure, especially where more than one common species is known. The correlative formations are arbitrarily considered in the order of their approximate proximity to Spitsbergen. It should be noted at this point that many authors sub-divide Spitsbergen into terranes that may have been well separated in the Early Ordovician. A major transcurrent fault is posited dividing eastern from western Spitsbergen (Harland 1997 and references therein), and the eastern terrane includes the Ordovician successions with which we are concerned. Continental reconstructions of Ordovician Laurentia (e.g. Cocks & Torsvik 2011, fig. 8) favour an Ordovician position of this eastern Spitsbergen terrane adjacent to northeastern Greenland. We have no reason to question such a placement, although it will be clear from the discussions below that the trilobites are sufficiently widespread to fail to be critical in assessing palaeogeography, other than proving certainly that the Kirtonryggen Formation was deposited as part of the east (present geography) Laurentian bathyurid 'province' and sedimentary regime (Poulsen 1951; Swett 1981). Greenland terminology follows Smith & Bjerreskov (1992).

Greenland

Eastern North Greenland. – A small collection from the Wandel Valley Formation was briefly described and illustrated by Fortey (1986). The fauna includes *Petigurus nero*, *Punka flabelliformis*, *Bathyurellus abruptus* and *Benthamaspis* species all known from the *Petigurus nero* fauna from the Upper part of the Nordporten Member of the Kirtonryggen Formation and from the Catoche Formation of western Newfoundland (Fortey 1979; Boyce 1989). On the basis of Boyce's divisions of the latter, the Greenland fauna would correlate with his *Strigigenalis caudatus* Biozone, within the Blackhillsian Stage of the Ibexian in terms of the Great Basin standard.

Eastern Greenland. – The Kap Weber Formation yielded a number of trilobites to the Lauge Koch Expedition that were described by Poulsen (1937). Many are fragments, and it is not certain that they were collected from one horizon. However, in this work, we suggest that the following species are in common between the lower fauna of the Nordporten Member, *Petigurus groenlandicus* fauna, and that of the Kap Weber Formation described by Poulsen (1937): *Petigurus groenlandicus*, *Bolbocephalus convexus*, *Bathyurellus diclementsae* n. sp. and *Licnocephala brevicauda*. Some of these determinations rely on identifying our more complete material with Poulsen's often incompletely preserved type specimens, which is always open to the possibility of error. The discussions below will provide more detail under the species concerned. However, it seems likely that the co-occurrence of several species together permits some confidence in the correlation and that Poulsen's fauna most probably originates from within a relatively short stratigraphic interval. This is the fauna below the widespread *Petigurus nero* fauna, and one that has yielded a wider range of species from Spitsbergen. *Petigurus groenlandicus* itself has a long stratigraphic range, but its co-occurrence with the other species listed is within the lower part of the Nordporten Member. Hansen & Holmer (2011) also recognised Poulsen's (1937) brachiopod species *Archaeorthis groenlandicus* in Spitsbergen. Correlation outside the eastern Laurentia is more problematic, but this fauna is regarded as equivalent to early Blackhillsian, a determination consistent with new conodont evidence.

A stratigraphically earlier fauna described by Poulsen (1937) is probably older than that from the Spora Member of the Valhallfonna Formation, *Svalbardicurus delicatus* fauna. Revision of *Hystricurus nudus* Poulsen, 1937, shows that it is a species of *Millardicurus* and likely of Skullrockian age (McCobb *et al.* in press).

Cowie & Adams (1957) collected trilobites from a fuller sequence through the Kap Weber Formation than the original collections described by C. Poulsen (1937); these are currently under study by Lucy McCobb of the National Museum of Wales. Preliminary reports suggest (McCobb *et al.* 2011) the presence of younger Blackhillsian faunas in this part of northeast Greenland, that is, faunas equivalent to the top of the Kirtonryggen Formation and the overlying Valhallfonna Formation.

Western North Greenland. – A limited trilobite fauna described from the Poulsen Cliff Formation (Fortey & Peel 1990) includes *Chapmanopyge sminue* and therefore invites comparison with the occurrence of a very similar species at the top of the Bassisletta Member and in the basal bed of the Nordporten Member in Spitsbergen. The fauna of the Poulsen Cliff Formation is therefore older than that typical of the faunas with *Petigurus* in Spitsbergen. It may equate with the younger part of the Tulean Stage of the standard Ibexian divisions.

Canada

Ellesmere Island. – Poulsen (1946) described the trilobites of the Oxford University Ellesmere Island expedition. The collections are important as it includes the type species of *Benthamaspis* and *Grinnellaspis*. Both of these genera are known from the Nordporten Member, and the type species of the former is possibly identical to the species from the *Petigurus nero* fauna. If so, it is likely that equivalents of the *Petigurus nero* fauna are present in Ellesmere Island. A recent account of the Baumann Fiord Formation trilobite fauna (Adrain & Westrop 2005) is based on more and better material, which again is a typical Bathyurid Biofacies fauna. Several species serve as a link with Spitsbergen and the Kirtonryggen Formation, especially the topmost Bassisletta Member, but the evidence is not strong. From Spitsbergen *Ceratopeltis* cf., *C. batchensis* is compared tentatively with an Ellesmere Island species, and a pygidium of *Jeffersonia viator* n. sp. is similar to one from Baumann Fiord (Adrain & Westrop 2005, figs 10.15–10.16), while *Licnocephala sanddoelaensis* Adrain & Westrop, 2005, would now be placed in *Chapmanopyge*, and apparently has related species in the Kirtonryggen Formation; these together inviting comparison of the Baumann Fjord fauna with the top of the *Chapmanopyge* fauna in Spitsbergen.

Western Newfoundland. – Platform limestones of Early Ordovician age assigned to the St George Group outcrop along much of the western coast of Newfoundland, with representative successions on the Port-au-port Peninsula, extending northwards along the coast of the Great Northern Peninsula to Cape Norman, except where interrupted by the shelfward obduction of the Cow Head Group. About halfway up the Peninsula, around the village of Port au Choix, well-exposed bedded limestones of the St George Group were visited *via* access from the sea by early collectors (including Richardson) and yielded the trilobite and mollusc specimens described by Elkanah Billings in the early years of the Canadian Geological Survey (Billings 1865). Many of these species provide the senior names for Ibexian bathyurid trilobites. In the south, the Port-au-port Peninsula has been studied particularly for the sequence of conodont faunas obtained by dissolution of the Ordovician limestones (Ji & Barnes 1994), with trilobite-based correlations added by Boyce & Knight (2010). Boyce *et al.* (2011) have shown that early Tremadocian (Skullrockian) trilobites are present in the Watts Bight Formation on the Port-au-port Peninsula, which are older than any proved from northern Spitsbergen. Further north, the trilobites first studied by Billings from the Catoche Formation in the vicinity of Port au Choix were redescribed by Fortey (1979). They include many species identical with those of the *Petigurus nero* fauna of the upper part of the Nordporten Member of the Kirtonryggen Formation in Spitsbergen, described herein. These include the following: *Petigurus nero* (Billings), *Bolbocephalus convexus* (Billings), *Bathyurellus abruptus* Billings, *Punka flabelliformis* Fortey and *Benthamaspis gibberula* (Billings), and *B. conica* Fortey. This Blackhillsian fauna is identical between these distant localities, and they must be of the same age. Boyce (1989) extended stratigraphical studies based upon trilobites into older strata in western Newfoundland and introduced a series of zonal names to summarise trilobite species distributions. He described finds from the lowest beds of the Catoche Formation and the underlying Boat Harbour Formation. In further close comparison with the Spitsbergen sequence, we here identify Boyce's *Leiostegium proprium* 'interval zone' (Boyce & Stouge 1997) in the lower member of the Boat Harbour Formation of Newfoundland with the Spora Member at the base of the Kirtonryggen Formation. The zonal fossil is related to *L. spongiosum* n. sp. in Spitsbergen; our type species of *Svalbardicurus* n. gen. is closely related to *S. seelyi* from western Newfoundland and a coarsely tuberculate hystricurid close to, if not identical with, the species named by Boyce (1989) as *Hystricurus oculilunatus*, Ross, which Boyce (1989) records from his overlying '*Randaynia saundersi* interval zone'.

Between these two correlatable faunas lies a stratigraphic interval in which there is less comparison between the Early Ordovician of Spitsbergen and western Newfoundland. In the Spitsbergen sequence, this interval includes the Bassisletta Member and the lower part of the Nordporten Member, a thickness of more than 300 m of carbonates. Boyce (1989, fig. 7) marks a hiatus (marked by pebble beds) in the Newfoundland succession to include at least some of this interval. In Spitsbergen, the Bassisletta Member comprises a considerable thickness of shallow-water dolomites that may equate with a period of non-deposition in Newfoundland. Our *Peltabellia glabra* fauna fits within this 'gap', and there is no direct evidence for its time equivalent in western Newfoundland. Nor does Boyce (1989) record trilobites suggestive of the *Chapmanopyge* fauna. So it is likely that there is a period of non-deposition and/or erosion, or at least unfossiliferous strata, which renders the western Newfoundland platform succession incomplete. Following the Newfoundland hiatus, Boyce's (1989) *Strigigenalis brevicaudata* 'lineage zone' underlies an undoubted equivalent of the *Petigurus nero* fauna in Spitsbergen, which is assigned

to Boyce's *Strigigenalis caudata* Zone. This underlying interval should, therefore, include the equivalents of the *Petigurus groenlandicus* fauna in the Nordporten Member in Spitsbergen. We do not have the Newfoundland zonal fossil (*S. brevicaudata*) in Spitsbergen, and the only species in common is *Uromystrum affine* (Poulsen) (see p. 83 for discussion) and *Ischyrotoma parallela* Boyce; generally, a more diverse fauna is present in Spitsbergen than in Newfoundland through this interval, one that includes the earliest *Illaenus,* styginid and proetid records. Boyce & Stouge (1997) matched conodont and trilobite occurrences through the same Newfoundland successions and concluded that the boundary between Floian (= basal Arenigian) and Tremadocian strata was at the base of their *Strigigenalis brevicaudata* 'lineage zone'. This is compatible with our view that the Tremadocian–Floian boundary lies somewhat below the base of the *Petigurus groenlandicus* fauna in Spitsbergen.

In summary, there are two good stratigraphical ties near the top and bottom of the Kirtonryggen Formation into the succession of western Newfoundland. The mid-part of the Kirtonryggen Formation includes faunas as yet unrecognised in Newfoundland, indicative of a stratigraphic gap there ('Boat Harbour unconformity').

It should be recalled here that the Early Ordovician stage names used by Boyce (1989) and Boyce & Stouge (1997) in Newfoundland were divisions of the classical 'Canadian Series' – in ascending order, Gasconadian, Demingian, Jeffersonian and Cassinian – based originally upon rock successions from various parts of eastern Laurentia. Nautiloid faunas (e.g. Flower 1964, 1968) were crucial to the understanding of these divisions, and the virtual disappearance of students of this important group of molluscs, as well as a wish for uniformity, has contributed to a comparative neglect of this scheme of local chronostratigraphy. Modern usage attempts to correlate with the standard Ibexian stage nomenclature based upon the successions in the Great Basin, western USA (Ross *et al.* 1997), despite the differences in the faunas there from those on the eastern side of the Laurentian continent. Taylor *et al.* (*in* Derby *et al.* 2012, p. 22) have advocated continued use of the older-stage terms for at least the upper part of the Ibexian.

Mingan Islands, Quebec. – A brief account of trilobites in the Mingan Islands by Twenhofel (1938) has been recently updated by Shaw & Bolton (2011). The Romaine Formation includes a meagre fauna that can be compared with one from the earlier part of the Kirtonryggen Formation. We have cautiously identified a species originally described by Billings (1859) as *Bathyurus amplimarginiatus* as present in the Bassisletta Member and referred it to *Chapmanopyge.* Shaw & Bolton (2011) assigned this species to *Peltabellia.* It is accompanied by a *Bolbocephalus* species. If these determinations are correct, it indicates the presence of Tulean strata and points to the absence in the Mingan Islands of the *Petigurus nero* fauna, which is otherwise widespread. The overlying Mingan Ordovician trilobite faunas all prove much younger Ordovician ages than the Kirtonryggen Formation.

Northwest Scotland

Fortey (1992) summarised what little is known about the trilobites from the thick shallow-water limestone succession that extends in a narrow band of outcrop running from the Isle of Skye in the south to Durness in the north. The presence of *Petigurus nero* is evidence for the equivalents of the younger fauna of the Nordporten Member, Kirtonryggen Formation, in Scotland. A free cheek of a *Jeffersonia* species is like that illustrated here in Figure 10C from lower in the same member. This is suggestive of a spread of age equivalents to the Spitsbergen succession in northwest Scotland, although the evidence from trilobites is sparse. However, a succession of nautiloid faunas (Evans 2011) proves the existence in Scotland of a relatively complete Ibexian succession.

USA

New York State and Vermont. – This is the type area of the 'Cassinian Stage' of the Canadian Series, which has now been superseded terminologically by the Blackhillsian Stage of the Ibexian (also = early Floian and = early Arenigian). Brett & Westrop (1996) revised the relevant trilobite fauna of the Fort Cassin Formation and proved its undoubted correlation with the Catoche Formation of western Newfoundland. It equates in turn with the upper part of the *Petigurus nero* fauna in Spitsbergen, although the only species in common is probably one of *Benthamaspis* (see p. 62). The underlying Rochdale ('Fort Ann') Formation includes *Svalbardicurus seelyi*, which is closely related to the type species of that genus, described below, from the Spora Member of the Kirtonryggen Formation. Boyce (1989) recorded *S. seelyi* from the lower member of the Boat Harbour Formation in western Newfoundland. These occurrences are likely of similar age, depending on the eventual stratigraphic range of species of *Svalbardicurus.* The equivalents of the *Petigurus groenlandicus* and *Chapmanopyge* faunas have not been

proved in this area of the eastern USA. Recently, Landing *et al.* (2012) have described additional trilobites from the Rochdale Formation, which includes middle–late Stairsian trilobites that invite comparison with those of the Spora Member; these authors correlate the appearance of this fauna with a Tremadocian eustatic sea level rise. Their '*Hystricurus*' sp. nov. might also be better accommodated within *Svalbardicurus* n. gen., while a coarsely tuberculate hystricurid is also present alongside a species of *Leiostegium* similar to that from Spitsbergen. It seems plausible that the same eustatic event is reflected in a similar fauna.

Oklahoma and Missouri. – Loch's (2007) account of the trilobite fauna of the Kindblade Formation of Oklahoma permits correlation with the upper part of the Kirtonryggen Formation, although there are relatively few species in common, and several taxonomic questions emerge. At the top of the succession in Oklahoma, the *Strigigenalis caudata* Zone is stated to be the equivalent of the interval carrying the same name in western Newfoundland, where many elements of our *Petigurus nero* fauna are also known to be present. Faunas underlying the *S. caudata* Zone in Oklahoma should, therefore, include equivalents of the *Petigurus groenlandicus* fauna. However, Loch's (2007) *Bolbocephalus stitti* Zone does include a few species in common with its presumed equivalent in Spitsbergen. We have identified our new species *Bolbocephalus gunnari* with Loch's *Bolbocephalus* sp. 2 (see p. 31), which Loch (2007, p. 28) states has a range extending through the zones underlying the *B. stitti* Zone: that is, *Benthamaspis rhochmotis* Zone extending into the *Petigurus cullisoni* Zone. However, in his summaries of zonal species distributions, it is listed (Loch 2007, p. 11) from the *P. stitti* Zone, but from neither of the underlying two zones. The species has a long range in the lower part of the Nordporten Member. A second *Bolbocephalus* species, here recorded as *B. stclairi* Cullison, is apparently identical to a cranidium figured by Loch (2007 pl. 7, fig. 8) also from the *B. stitti* Zone (Loch 2007, p. 85). More problematic is the species Loch (2007) named as *Gelasinocephalus pustulosus* (see also pp. 54, 89). We regard this species as a dimeropygid closely related, if not identical, to *Ischyrotoma parallela* Boyce, 1989, which we record from the lower part of the Nordporten Member herein. Given the ambiguities involved with these three species, it is not possible to be more precise than to say that some part of the *B. stitti* Zone, and/or *Petigurus cullisoni* Zone and *B. rhochmotis* Zone in the Kindblade Formation, Oklahoma, includes equivalents of the *Petigurus groenlandicus* fauna that extends through the lower part of the Nordporten Member in Spitsbergen.

As in the Bassisletta Member in Spitsbergen, in Oklahoma, there is an underlying interval in which the common bathyurelline is *Chapmanopyge* (see p. 63). Loch (2007) divided this interval into two zones: *Rananasus brevicephalus* Zone (below) and *Jeffersonia granosa* Zone (above). The top of the Bassisletta Member has yielded a species of *Chapmanopyge*, which we consider the same as Loch's *Chapmania* cf. sp. 1, a species from the *J. granosa* Zone. A small collection made 140 m below that yielding *Chapmania* cf. sp. 1 has sparse material attributed to *Chapmanopyge* '*amplimarginata*' (Billings), a species closely similar to *C. taylori* Loch, 2007, from his *R. brevicephalus* Zone. It seems likely that the upper half of the Bassisletta Member may equate to at least parts of the earliest two zones recognised by Loch (2007) in the Kindblade Formation. This includes our *Chapmanopyge* fauna. With the exception of the uppermost beds, this fauna is poorly represented by species in Spitsbergen, and trilobites have not been recovered from much of the very shallow-water, dolomitic succession. This interval of the Ibexian is much richer in species in Oklahoma, where earlier representatives of genera that were to become significant in the Nordporten Member have been recovered.

Further correlation into the Ozark Uplift, Missouri, still depends on the work of Cullison (1944), who illustrated many trilobites (mostly internal moulds) at rather small size. A few originals of his *Jeffersonia* species are illustrated herein. This is the type area of the previously used Jeffersonian Stage of the Canadian Series. Loch (2007) reillustrated a number of the species in common with the Kindblade Formation on which correlation largely depends, and his summary (Loch 2007, text-fig. 7) cannot be refined by any of our discoveries. Broadly speaking, the Cotter Formation of Cullison (1944) includes the equivalent of the *Petigurus nero* fauna (see also Boyce 1989) and the upper part of the Kirtonryggen Formation. Thompson (1991) has changed the stratigraphical nomenclature in Missouri, such that this interval is now termed the Bull Shoals Member of an expanded Cotter Formation. Two further members below that (formerly Theodosia Formation of E. O. Ulrich and Cullison) presumably include the equivalents of the lower part of the Kirtonryggen Formation and the *P. groenlandicus* fauna. Faunas with *Chapmanopyge* are found in the still older Rich Fountain Formation of Cullison (1944) (= Jefferson City Formation of Thompson, 1991). Our only addition to correlative data is the identification of *Jeffersonia viator* n.

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