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Lower Ordovician trilobites of the Kirtonryggen Formation, Spitsbergen



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Contents

Introduction	2
Summary of previous research on the Ordovician of Spitsbergen	3
Stratigraphy of the Kirtonryggen Formation	4
Stratigraphic sub-divisions and age	4
Tremadocian–Floian boundary	9
Correlation with other areas of Ordovician Laurentia	10
Greenland	11
Canada	12
Northwest Scotland	13
USA	13
Occurrence of trilobites in the Kirtonryggen Formation	15
Field occurrence	15
Biofacies and biogeography	15
Peculiarities of the Spitsbergen faunas	16
Eastern and western Laurentia	17
Origin of major trilobite clades	18
The family Bathyuridae	19
The problem of type species	20
Morphology of Bathyuridae	21
Systematic Palaeontology	23
Order Aulacopleurida Adrain, 2011	23
Family Hystricuridae Hupé, 1953	23
Genus <i>Svalbardicurus</i> n. gen.	23
<i>Svalbardicurus delicatus</i> n. sp.	24
Genus <i>Hystricurus</i> Raymond, 1913	26
<i>Hystricurus</i> cf. <i>Hystricurus</i> sp. nov. B Adrain <i>et al.</i> , 2003	26
<i>Hystricurus</i> sp. 1	27
Order Proetida Fortey & Owens, 1975	28
Family Bathyuridae Walcott, 1886	28
Sub-family Bathyurinae Walcott, 1886	28
Genus <i>Bolbocephalus</i> Whitfield, 1890	28
<i>Bolbocephalus gunnari</i> n. sp.	30
<i>Bolbocephalus convexus</i> (Billings, 1865)	31
<i>Bolbocephalus stclairi</i> Cullison, 1944	33
<i>Bolbocephalus</i> sp. cf. <i>B. kindlei</i> Boyce, 1989	35
Genus <i>Catochia</i> Fortey, 1979	35
<i>Catochia hinloppensis</i> n. sp.	35
<i>Catochia ornata</i> Fortey, 1979	37
Genus <i>Jeffersonia</i> Poulsen, 1927	37
<i>Jeffersonia striatigena</i> n. sp.	38
<i>Jeffersonia viator</i> n. sp.	42
<i>Jeffersonia timon</i> (Billings, 1865)	44
' <i>Jeffersonia</i> ' aff. <i>J. granosa</i> Cullison, 1944	46
Genus <i>Peltabellia</i> Whittington, 1953	46
<i>Peltabellia glabra</i> n. sp.	47
Genus <i>Petigurus</i> Raymond, 1913	49
<i>Petigurus nero</i> (Billings, 1865)	49
<i>Petigurus groenlandicus</i> Poulsen, 1937	50
Genus <i>Psalikilopsis</i> Ross, 1953	52
<i>Psalikilopsis</i> n. sp. aff. <i>P. cuspidata</i> Ross, 1953	53
Bathyurine n. gen. n. sp. A	54
Sub-family Bathyurellinae Hupé, 1953	55
Genus <i>Bathyurellus</i> Billings, 1865	55
<i>Bathyurellus abruptus</i> Billings, 1865	56
<i>Bathyurellus diclementsae</i> n. sp.	57
Genus <i>Benthamaspis</i> Poulsen, 1946	60
<i>Benthamaspis gibberula</i> (Billings, 1865)	60
<i>Benthamaspis conica</i> Fortey, 1979	62
Genus <i>Ceratopeltis</i> Poulsen, 1937	63
<i>Ceratopeltis</i> cf. <i>C. batchensis</i> Adrain & Westrop, 2005	63
Genus <i>Chapmanopyge</i> n. gen.	63
<i>Chapmanopyge</i> cf. sp. 1 (Loch, 2007)	65
<i>Chapmanopyge</i> 'amplimarginiata' (Billings, 1865)	65
<i>Chapmanopyge</i> cf. <i>C. sanddoelaensis</i> (Adrain & Westrop, 2005)	67
<i>Chapmanopyge</i> n. sp. A	68

Genus <i>Grinnellaspis</i> Poulsen, 1946	68
<i>Grinnellaspis newfoundlandensis</i> Boyce, 1989	68
Genus <i>Harlandaspis</i> n. gen.	68
<i>Harlandaspis elongata</i> n. sp.	71
Genus <i>Licnocephala</i> Ross, 1951	74
<i>Licnocephala brevicauda</i> (Poulsen, 1937)	74
<i>Licnocephala</i> n. sp. A	75
<i>Licnocephala</i> n. sp. B	76
<i>Licnocephala</i> ? n. sp. C	76
Genus <i>Punka</i> Fortey, 1979	76
<i>Punka latissima</i> n. sp.	77
<i>Punka flabelliformis</i> Fortey, 1979	79
Genus <i>Uromystrum</i> Whittington, 1953	80
<i>Uromystrum affine</i> (Poulsen, 1937)	81
<i>Uromystrum</i> aff. <i>U. affine</i> (Poulsen, 1937)	84
<i>Uromystrum drepanon</i> n. sp.	85
Family Dimeropygidae Hupé, 1955	86
Genus <i>Ischyrotoma</i> Raymond, 1925	86
<i>Ischyrotoma parallela</i> (Boyce, 1989)	87
<i>Ischyrotoma</i> n. sp. A	89
Family Proetidae Salter, 1864	90
Genus <i>Phaseolops</i> Whittington, 1963	90
<i>Phaseolops</i> ? <i>bobowensi</i> n. sp.	90
Family Telephinidae Marek, 1952	92
Genus <i>Carolinites</i> Kobayashi, 1940	92
<i>Carolinites</i> ? n. sp. A	92
Order Corynexochida Kobayashi, 1935	94
Family Illaenidae Hawle & Corda, 1847	94
Genus <i>Illaenus</i> Dalman, 1827	94
Subgenus <i>Illaenus</i> (<i>Parillaenus</i>) Jaanusson, 1954	94
<i>Illaenus</i> (<i>Parillaenus</i>) <i>primotius</i> n. sp.	94
Family Leioptegidae Bradley, 1925	96
Genus <i>Leioptegium</i> Raymond, 1913	96
<i>Leioptegium spongiosum</i> n. sp.	96
Family Styginidae Vogdes, 1890	98
Genus <i>Raymondaspis</i> Přibyl, 1948	98
<i>Raymondaspis</i> ? <i>pingpong</i> n. sp.	98
Order Asaphida Salter, 1864	100
Superfamily Asaphoidea Salter, 1864	100
Family Asaphidae Salter, 1864	100
Genus <i>Lachnostoma</i> Ross, 1951	100
<i>Lachnostoma platypyga</i> n. sp.	101
Genus <i>Stenorhachis</i> Hintze & Jaanusson, 1956	102
<i>Stenorhachis</i> n. sp. A	102
Family Remopleuridae Hawle & Corda, 1847	104
Genus <i>Eorobergia</i> Cooper, 1953	104
<i>Eorobergia</i> n. sp. A	104
Superfamily Cyclopygoidea Raymond, 1925	105
Family Symphysurinae Kobayashi, 1955	105
Genus <i>Eurysymphysurina</i> n. gen.	105
<i>Eurysymphysurina</i> spora n. sp.	106
Genus <i>Randaynia</i> Boyce, 1989	107
<i>Randaynia</i> n. sp. A	108
Order Phacopida Salter, 1864	110
Family Pilekiidae Sdzuy, 1955	110
Genus <i>Pilekia</i> Barton, 1915	110
<i>Pilekia</i> cf. <i>P. trio</i> Hintze, 1953	110
Incertaine Ordinis	111
Family Shumardiidae Lake, 1907	111
Genus <i>Conophrys</i> Callaway, 1877	111
<i>Conophrys</i> sp. 1	111
Incertaine sedis	111
Gen. et sp. indet. 1	111
Gen. et sp. indet. 2	111
Proetid metaprotaspis	112
Acknowledgements	112
References	112

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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 Polarinstittutt 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 Bathyrurid 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 Bathyruridae (*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 Bathyruridae allows a review of some of the problems in classification of the family. Alphabetically by genus, new species are as follows: *Bathyrurellus diclementsae*, *Bolbocephalus gunnari*, *Catochia hinloppensis*, *Eurysymphysurina spora*, *Iliaenus* (*Parillaenus*) *primitivus*, *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.*

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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 Okla-

homa, 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 akro-ria* 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.

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, *Hystericurus wilsoni* Gobbett. Interestingly, it is not identical to any hystericurid 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 Polarinstitut, 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 ‘V₁’ to ‘V₄’ 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 V₃ 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 Bathyrud biofacies, *Petiguris* 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

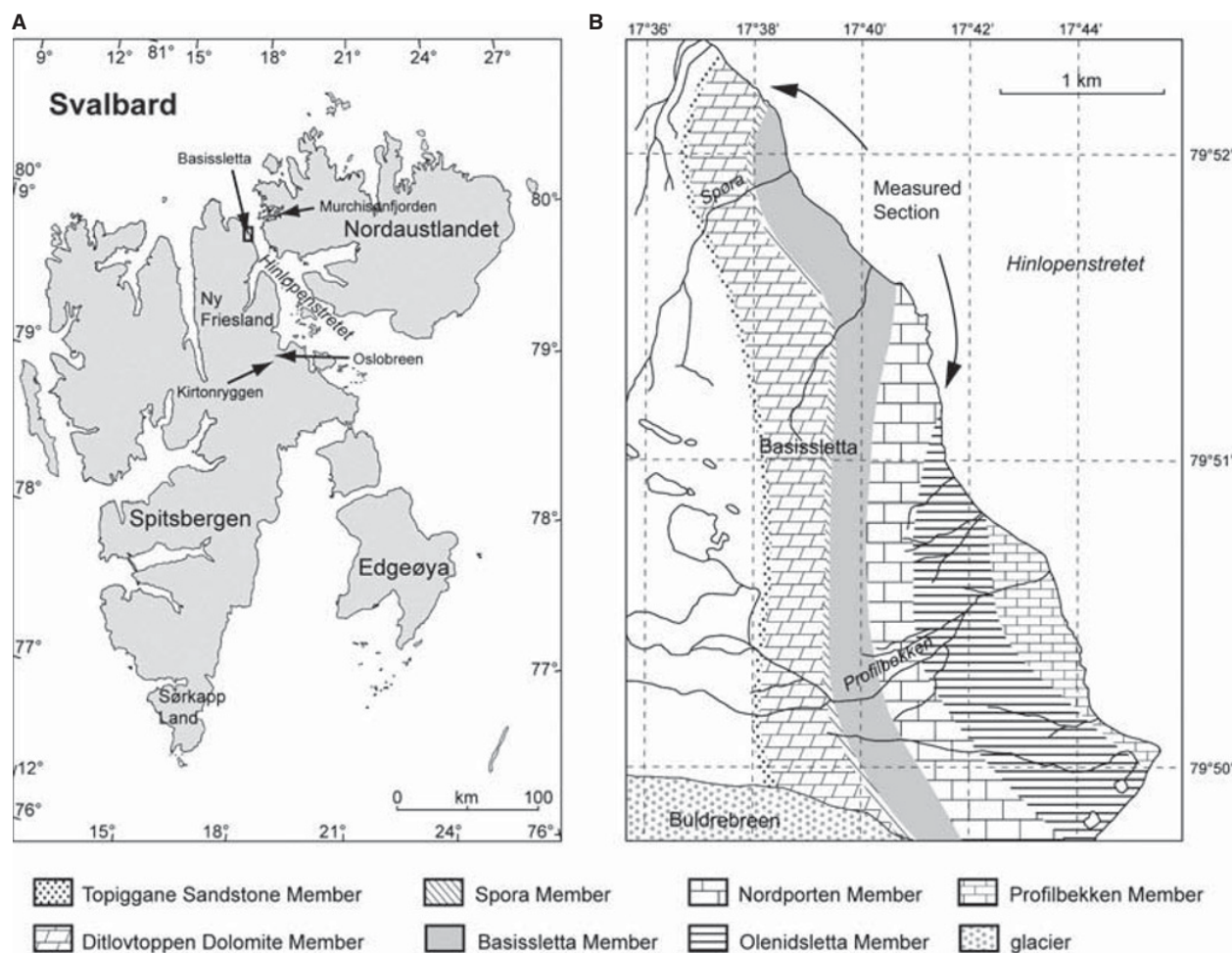


Fig. 1. Locality map for the type section of the Kirtonryggen Formation along Profilstranda, adjacent to northern Ny Friesland, Spitsbergen. After Fortey & Bruton (1973).

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 col-

lections 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	P G	No fauna	Chapmanopyge fauna	Petigurus groenlandicus fauna	Petigurus nero fauna	LP

— *Svalbardicurus delicatus* n. gen. et sp.

— *Hystericurus* cf. *Hystericurus* sp. nov. B Adrain et al. 2003

— *Hystericurus* 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) **X**

Chapmanopyge cf. *C. sanddoelaensis* Adrain & Westrop **X**

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) ? - - - - - **X** - - - - ?

Jeffersonia striagena n. sp. —————

Iliaenus primoticus n. sp. **X**

Randaynia n. sp. A **X**

Psalikilopsis aff. *cuspidata* Ross ———

Harlandaspis elongata n. sp. ———

Bolbocephalus convexus (Billings) —————

Bolbocephalus stclairi Cullison —————

Catochia hinloppensis n. sp. —————

Chapmanopyge n. sp. A **X** - - - - - ?

Jeffersonia timon (Billings) - - - - -

Uromystrum drepanon n. sp. ——— - - -

Bathyurine n. gen. et sp. A **X**

'*Jeffersonia*' aff. *J. granosa* Cullison **X**

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 **X**

Grinnellaspis newfoundlandensis Boyce **X**

Benthamaspis gibberula (Billings) ———

Ischyrotoma n. sp. A ———

Lachnostoma platypygma n. sp. **X**

Stenorhachis n. sp. A **X**

Eorobergia n. sp. A **X**

Conophrys sp. 1 **X**

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 *Leioostegium spongiosum* n. sp., and *Eurympophysurina spora* n. gen., n. sp. and *Hystericurus* 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 *Leioostegium 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). *Leioostegium* appears in the *Kainella/Leioostegium* (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/Leioostegium* 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 *Benthamaopsis 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.

SPORA	BASSISLETTA		NORDPORTEN			Member (Not to scale)
TREMADOCIAN			FLOIAN			Global Stages
<i>Svalbardicurus delicatus</i>	? <i>Peltabellia glabra</i>	? <i>Chapmanopyge</i>	<i>Petigurus groenlandicus</i>	<i>Petigurus nero</i>	<i>Lach. plat..</i>	Kirtonryggen 'Faunas'
<i>Randaynia saundersi</i>	?	Missing	? <i>Strigigenalis brevicaudata</i>	<i>Strigigenalis caudata</i>		Western Newfoundland Zones
?	<i>R. brevicephalus</i> - <i>B. rhochmotis</i> <i>P. cullisoni</i> - <i>B. stitti</i>			<i>Strigigenalis caudata</i>		Oklahoma Zones
<i>Leiostegium</i> to <i>Tesselacauda</i>	<i>Litzicurus shawi</i> through <i>Psalikilus pikum</i>			<i>S. plicalabeona</i> to <i>C. nevadensis</i>		Utah/Nevada
STAIRSIAN	?	TULEAN	?	BLACKHILLSIAN		Ibexian 'stages'

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* '*amplimarginata*' (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 diana* 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), *Illaeus primotius* n. sp., *Raymondaspis*? *pingpong*, *Phaseolops*? *bobowensi* n. sp., *Bolbocephalus gunnari* n. sp. *Psalikilopsis* n. sp., and particularly