

# THE STRATIGRAPHY OF THE LLANDOVERY SERIES ON BORNHOLM

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BJERRESKOV, M.: The stratigraphy of the Llandovery Series on Bornholm. *Bull. geol. Soc. Denmark*, vol. 21, pp. 34-50. Copenhagen, September 7th, 1971.

The results of an investigation of the graptolitic shale of Llandovery age along Øleå on Bornholm are presented. A section through the shale is made and the thickness of the Llandovery Series estimated to be between 110 and 130 m. 15 bentonite layers are reported. A revised zonation is proposed and discussed. The Llandovery Series comprises the *Rastrites* Shale and the lower part of the *Cyrtograptus* Shale. No marked transition is observed between the two shales and the subdivision of the Llandovery Series is abandoned.

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The lower Silurian, the Llandovery, is exposed in Denmark only on the eastern part of Bornholm in a rivulet called Øleå. The Llandovery Series comprises the *Rastrites* Shale and the lower part of the *Cyrtograptus* Shale and is in general developed as a dark grey graptolitic shale.

In the present investigation the fieldwork was carried out in the summers 1967-70, when unusually dry weather provided good conditions for collecting graptolites in the bed of the rivulet. The opportunity was also taken to measure the section with a level. The most important results of the investigation in the *Rastrites* Shale were published by the present author under the name Sjørring (1969).

The present work deals mainly with the *Rastrites* Shale since this comprises all the graptolite zones in the Llandovery except the uppermost one. The lower part of the *Cyrtograptus* Shale has not been fully investigated. A description of the fauna in the shales is in preparation.

The author wants to express gratitude to Dr. V. Poulsen for helpful advice during the work. Miss V. Jensen-Haarup and Mr. H. Egelund made the drawings and the English manuscript was kindly improved by Dr. R. G. Bromley.

## Previous work

Linnarsson (1881) was the first to describe and name the *Rastrites* Shale from Klubbudden in Sweden and he reported a graptolite fauna corresponding to zones 20–22 of Elles & Wood (1913). Tullberg (1882) in Scania, and Törnquist (1890, 1892) in Dalarne added some Elles and Wood zones to the *Rastrites* Shale. According to Törnquist (1892) the *Rastrites* Shale in Sweden comprised all the Llandovery graptolite zones except the uppermost one, i.e. zones 16–24 of Elles & Wood (1913). The genus *Rastrites* was lacking in some of the graptolite zones (Wærn, 1960a).

Grönwall (1899) was the first who made an important investigation of the corresponding layers on Bornholm. He recorded 25 graptolite species and divided the shale into 5 graptolite zones. In Grönwall & Milthers (1916) the zonation was reiterated and the thickness of the shale reported to be 30–40 m.

Later on Pedersen (1922) made an investigation of the *Rastrites* Shale on Bornholm. He described 17 exposures along Øleå and 55 graptolite species, including 5 new species were recorded. On this basis he revised the zonation proposed by Grönwall (1899). The *Rastrites* Shale as defined by Pedersen (1922) comprised zones 16–22 of Elles & Wood (1913) and the upper boundary of the shale was distinguished by the disappearance of the genus *Rastrites*.

In the present investigation the *Rastrites* Shale is taken as comprising zones 16–24 of Elles and Wood according to the Swedish definition (Törnquist, 1892).

The *Cyrtograptus* Shale was first mentioned in Sweden by Tullberg (1882); the shale comprised the Elles and Wood zones 25–31. In 1899 Grönwall divided the *Cyrtograptus* Shale on Bornholm into 5 zones which were reiterated in Grönwall & Milthers (1916). Investigations were taken up by Laursen (1940) who proposed the same zonal division as Grönwall (1916) except for the uppermost zone, the zone of *M. riccartonensis*, which he discarded.

In Sweden, Wærn (1960a) divided the graptolitic Llandovery into four local stages, which Poulsen (1966) considered valid also for Bornholm.

## The boundaries of the Llandovery Series

The Llandovery Series is preserved in fault-blocks on the south-eastern part of Bornholm (Gry, 1960) but is only exposed along the rivulet Øleå (fig. 1). Here the strike and dip of the fault-block are about 90°/1–6°S. Thus

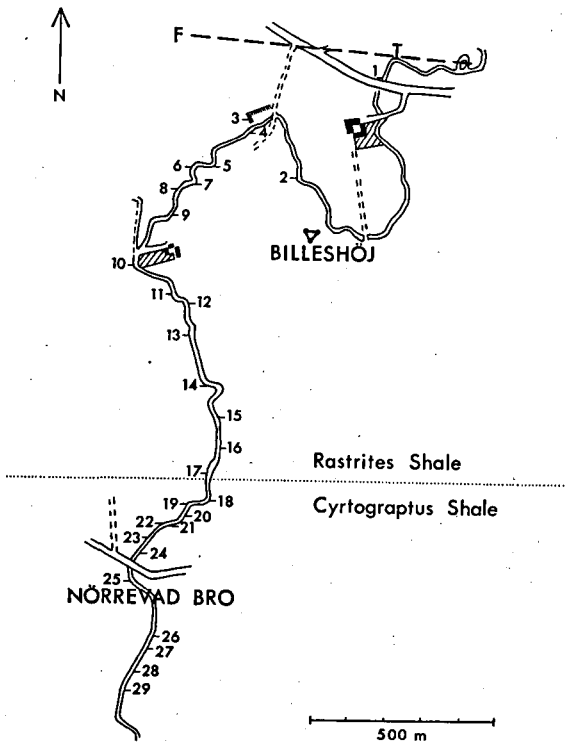


Fig. 1. Sketch-map showing the Llandovery exposures along the rivulet Øleå, south-eastern part of Bornholm. F = fault; T = outcrop of *Tretaspis* Shale. Locality numbers partly after Pedersen (1922).

the oldest parts of the shale are outcropping in the northern part of the fault-block.

A small, strongly inclined outcrop of grey shale is found about 200 m north of Køllergård (fig. 1, loc. T). Poulsen (1968) found that the shale here belongs to the *Staurocephalus clavifrons* Zone (a part of the Upper Ordovician *Tretaspis* Shale) and represents the northern part of the fault-block.

Just north of the road at Køllergård a hard, dark grey shale was found in the bottom of the rivulet (loc. 1). This shale probably belongs to the *Rastrites* Shale. If the sequence from the *Tretaspis* Shale to the *Rastrites* Shale is complete, the whole Tommarp Stage should occur over a distance of 80 m. This stage has not been observed elsewhere on Bornholm and it is probable, as stated by Poulsen (1966) that a hiatus exists between the Ordovician and the Silurian. It is not known whether the hiatus includes the basal part of the Silurian.

The transition between the Llandovery Series and the Wenlock Series is found in the middle part of the *Cyrtograptus* Shale about 400 m south of Nørrevad Bro.

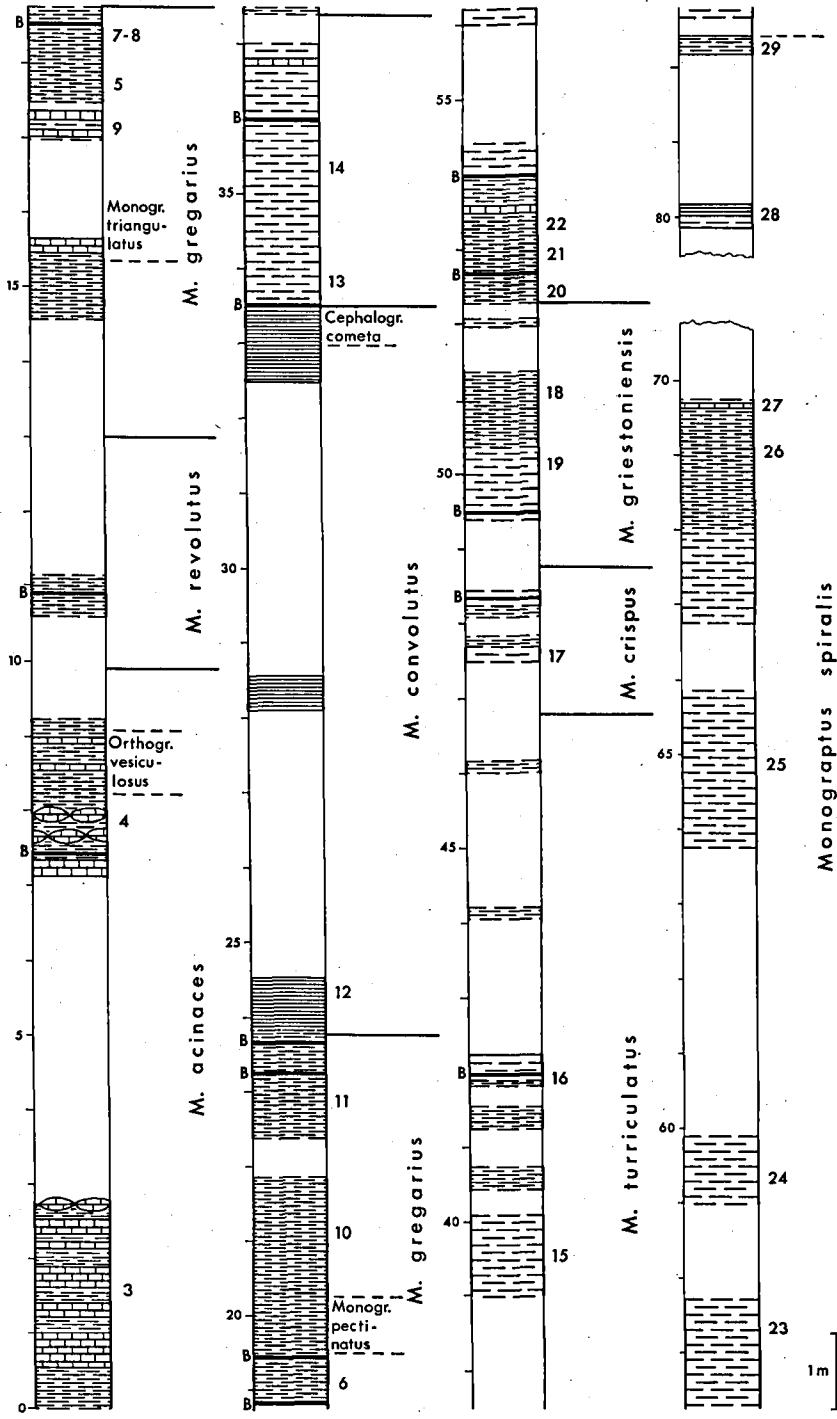


Fig. 2. Section through the Llandoverly along Øleå, Bornholm. Ruled lines = black shale; broken lines = dark or light shale, gradation in intensity of symbol indicates gradation from dark to light shale; rectangle symbol = limestone; B = bentonite; blank parts = unexposed parts of section. Numbers on right hand side of columns = localities.

## The thickness of the Llandovery

Sections representing the well-exposed part of the *Rastrites* Shale in the banks along Øleå are shown in fig. 2 (loc. 3–17). The thickness was measured to be 50 m, and about 30 m shale are estimated to occur between loc. 1 and loc. 3 (an old limestone quarry). About 20 m shale may be added on the grounds that the basal part of the *Rastrites* Shale supposedly occurs just south of the *Tretaspis* Shale.

The uppermost part of the Llandovery, i.e. the lowest part of the *Cyrtograptus* Shale (loc. 17–29) was measured to be about 30 m in Øleå (fig. 2). The total thickness of the Llandovery on Bornholm therefore must be between 110 and 130 m.

## Bentonite

About 15 bentonite layers have been observed in the Llandovery Series, ranging in thickness from 0.5–12 cm. 10 rusty thin bands up to 1 cm in thickness were also found (not figured), probably representing weathered bentonite layers; the total number of bentonite layers may be about 25.

40 bentonite layers are reported from the Llandovery Series in Dalarne, Sweden (Wærn, 1960b), but a direct correlation with the layers on Bornholm has not been possible. The bentonite layers in Sweden are most frequent in the zone of *M. turriculatus* (Wærn, 1960b). On Bornholm the greatest number of bentonite layers have been found in the zone of *M. gregarius*, possibly due to the extensive exposure of this zone.

Only four bentonite layers have previously been reported from the Llandovery on Bornholm (Laursen, 1940, and Rosenkrantz, 1962).

## Stratigraphic zonation and discussion

The detailed graptolite fauna of the various graptolite zones on Bornholm is shown in table 2 (appendix) and a comparison with the Swedish zonation appears in table 1.

The oldest exposed part of the Llandovery (loc. 1) consists of a very hard, grey lime-rich shale. Only a few diplograptids were found. One of the graptolites seems to bear a close resemblance to *Glyptograptus persculptus* (Salter), possibly indicating that the locality belongs to the zone 16 of Elles and Wood (the zone of *G. persculptus*). The lack of monograptids is no evidence for Elles and Wood zones 16–17 (Rickards & Hutt, 1970).

SWEDEN		DENMARK (BORNHOLM)		
Stages	Wærn (1960a)	Laursen (1940) and Pedersen (1922)	Bjerreskov (1971)	
Kullatorp	<i>C. lapworthi</i>	Cyrtoagraptus Shale	<i>C. lapworthi</i>	
	<i>M. spiralis</i>		<i>M. spiralis</i>	
Klubbudden	<i>M. griestoniensis</i>	Cyrtoagraptus Shale	<i>M. griestoniensis</i>	
	<i>M. crispus</i>		<i>C. grayi</i>	
	<i>M. runcinatus</i>		<i>M. turriculatus</i>	
Silvberg	<i>M. sedgwickii</i>	Cyrtoagraptus Shale	? <i>M. sedgwickii</i>	
	<i>C. cometa</i>		<i>C. cometa</i> band	
Bollerup	<i>P. folium</i>	Rastrites Shale	<i>M. convolutus</i>	
	<i>M. gregarius</i> ( <i>M. argenteus</i> )		<i>M. gregarius</i>	?
	<i>M. revolutus</i>		<i>M. acinaces</i>	<i>M. revolutus</i>
<i>D. extenuatus</i>	<i>C. vesiculosus</i> band <i>M. acinaces</i>			
<i>A. acuminatus</i>	Rastrites Shale	?	?	
<i>G. persculptus</i>				
		Upper Llandoverly		
		Middle Llandoverly		
		Lower - Middle Llandoverly		

Table 1. Llandoverly graptolite zones in Sweden and on Bornholm.

### The zone of *Monograptus acinaces*

The shale in this zone is grey to dark grey with a small lime content. Five bands of dark grey, unfossiliferous concretionary limestone are found at loc. 3 (fig. 2). Higher in the sequence the bands are separated into lenses with a maximum diameter of 1 m (loc. 4). At the top of the zone the shale is still dark grey and with a small lime content.

*Monograptus acinaces* Törnquist, the only *Monograptus* in this zone, is one of the most frequent graptolites. In the lower part of the zone a fauna poor in species as well as in specimens is found. *Cystograptus vesiculosus* (Nicholson) occurs in a 50 cm thick band in the upper part of the zone; but only the characteristic juvenile stages with large sicula and first two thecae are found. Other important species in this zone are *Dimorphograptus confertus* (Nicholson) and *Rhaphidograptus toernquisti* (Elles and Wood).

The thickness of the zone is more than 10 m; neither of the zonal boundaries are exposed.

Pedersen observed *C. vesiculosus* in the zone of *M. gregarius*, but the material was collected from loose blocks (note in unpublished prize dissertation). The graptolite is a zonal fossil in Great Britain (Elles & Wood, 1913, and Toghill, 1968) and Germany (Stein, 1964, 1965, and Jaeger, 1964), but is not well suited as zonal fossil on Bornholm. No change in the fauna is observed in the band with *C. vesiculosus*.

In Sweden the *Dimorphograptus extenuatus* Zone (Wærn, 1960a) must be regarded as equivalent to the *M. acinaces* Zone on Bornholm, where *Dimorphograptus extenuatus* Elles and Wood has not been observed. Toghill (1968) defined the base of the *C. vesiculosus* Zone as the level, where *C. vesiculosus* has reached its maximum frequency, contemporaneous with the appearance of the monograptids and the dimorphograptids. On Bornholm these graptolites seem to appear earlier than *C. vesiculosus*.

### The zone of *Monograptus revolutus*

The shale in this zone is dark grey and rich in pyrite at horizons where lime is lacking, as is usual in this facies (Rickards, 1964). The lower boundary of the zone is defined by the appearance of *Monograptus revolutus* Kurck, but the base of the zone is not exposed. The top is defined by the appearance of *Monograptus gregarius* Lapworth.

It is not possible to measure the exact thickness of the *M. revolutus* Zone since the boundaries are not exposed. Frequent graptolites are *M. revolutus*, *R. toernquisti*, *Monograptus incommodus* Törnquist, and *Monograptus atavus* Jones.

The equivalent to the *M. revolutus* Zone in other regions is the zone of *Monograptus cyphus* (Elles and Wood zone 18) (Stein, 1965, and Jaeger, 1964). *Monograptus cyphus* Lapworth seems to be rare in Sweden, where *M. revolutus* also is zonal fossil at this level (Wærn, 1960a). The graptolites observed in this zone on Bornholm agree with the fauna in Dalarne (Wærn, 1960a).

#### The zone of *Monograptus gregarius*

The shale in this zone is grey to dark grey and contains well-preserved pyritised graptolites at a few horizons. The shale has a low lime content. Near the base of the zone four dark grey limestone bands are seen, each is about 10 cm thick.

The base of the zone is defined by the appearance of *M. gregarius*. At the same level *Monograptus triangulatus* (Harkness) appears and is abundant. *R. toernquistii* and *M. revolutus* are abundant in the lower part. Near the top of the subzone of *M. triangulatus*, *Rastrites longispinus* Perner appears for the first time and is abundant. *M. revolutus*, *R. toernquistii* and *Petalograptus ovatoelongatus* (Kurck) are also common. *M. triangulatus* disappears 10 cm above the base level of *Monograptus pectinatus* Richter.

In the subzone of *M. pectinatus* the most abundant graptolites are *P. ovatoelongatus*, *Monograptus communis* Lapworth, and *R. longispinus*. *Diplograptus bornholmensis* Pedersen appears at the top of the subzone of *M. pectinatus*. In the upper third of the *M. gregarius* Zone *D. bornholmensis* is the dominant graptolite and *M. communis* is quite frequent. A few specimens of *Monograptus argutus* Lapworth and *Monograptus leptotheca* Lapworth have been found at this level.

In the uppermost part of the *M. gregarius* Zone large numbers of juvenile specimens (only sicula and the first theca are developed) of *M. gregarius* are found in a bed rich in pyrite. At the same level *Monograptus convolutus* (Hisinger) appears. Frequent graptolites are *Climacograptus scalaris* (Hisinger), *Pseudoclimacograptus retroversus* Bulman and Rickards, *Pseudoclimacograptus undulatus* (Kurck), and *Monograptus lobiferus* (M'Coy). Above the pyrite-rich bed *M. gregarius* disappears.

The thickness of the zone is about 10 m.

Two subzones, characterised by *M. triangulatus* and *M. pectinatus* can be distinguished on Bornholm. The lower boundaries of the subzones are defined by the respective appearance of the two graptolites, the upper boundary of the subzone of *M. pectinatus* by the disappearance of this species.



The entire zone of *M. gregarius* is also developed in Sweden (Wærn, 1960a) where, however, the two subzones have not been separated. In Scania *M. triangulatus* is found throughout the *M. gregarius* Zone (Törnquist, 1897), whereas no information is available on the distribution of *M. pectinatus*.

In Frankenwald the zone of *M. gregarius* comprises, as on Bornholm, the subzone of *M. triangulatus* and *M. pectinatus* (Stein, 1965). Elles & Wood (1913) indicated the opposite succession of the subzones in Great Britain (*M. pectinatus* = *Monograptus fimbriatus* (Nicholson)). Sudbury (1958) combined the two subzones, but in Rheidol Gorge *M. triangulatus* is found at a lower level than *M. pectinatus*. Toghill (1968) stated that *M. triangulatus* occurs throughout the *M. gregarius* Zone in the Birkhill Shales, but is most abundant in the lower part. *M. pectinatus* is found at a level above the abundant *M. triangulatus*.

In Bohemia the corresponding layers are divided into three zones, the zones of *M. triangulatus*, *M. pectinatus* and *Monograptus pribyli* (Bouček, 1960). *Monograptus pribyli* (Bouček) has not been found on Bornholm.

In Great Britain the uppermost subzone in the *M. gregarius* Zone is the subzone of *M. argenteus* (Elles and Wood, 1913) or the subzone of *M. leptotheca* (Sudbury, 1958). On Bornholm *Monograptus argenteus* (Nicholson) has not been found and *Monograptus leptotheca* is very rare; nearly all determinations by Pedersen (1922) are wrong, instead mainly *Monograptus regularis* Törnquist was found. The highest subzone of the *M. gregarius* Zone on Bornholm remains a problem. Wærn (1960a) stated that he has not observed *M. leptotheca* in Sweden. However, the present author's studies on material in collections in Lund, Sweden, has made it clear that *M. leptotheca* is present, but often wrongly assigned to species.

#### The zone of *Monograptus convolutus*

In this zone the Llandovery shales attain their maximum darkness and become highly fossiliferous. Towards the top of the zone the shales are nearly black, are devoid of any lime content, but are rich in pyrite.

*M. convolutus* which characterises the zone is not abundant at the base. Here *Rastrites peregrinus* Barrande is quite frequent together with *Petalograptus folium* (Hisinger), which disappears in the upper part of the zone. The most common species throughout the zone are *M. lobiferus*, *Monograptus limatulus* Törnquist and *Orthograptus bellulus* (Törnquist). *Monograptus clingani* Carruthers is seen in the middle of the sequence. In the uppermost 55 cm *Cephalograptus cometa* (Geinitz) occurs in great numbers, but no other changes in the fauna are apparent. The distinction of the

*C. cometa* band, which Pedersen (1922) placed at the top of the *M. convolutus* Zone, is retained.

The thickness of the zone is about 10 m; the lower boundary of the zone is defined by the appearance of *M. convolutus*, the upper by the disappearance of this species.

In Scania, Sweden, Törnquist (1897) replaced the *M. convolutus* Zone with the zones of *P. folium* and *C. cometa* and this division was repeated by Wærn (1960a). On Bornholm *P. folium* occurs only at the base of the zone and *C. cometa* at the very top.

On Bornholm *M. lobiferus* is more frequent than *M. convolutus* and has the same vertical extension as the zonal fossil, but contrary to Toghil (1968) *M. lobiferus* is not here used for definition of the base of the *M. convolutus* Zone.

The *C. cometa* Zone shows the widest extension of the black Silurian graptolitic shales in Fennoscandia (Wærn, 1948). This agrees with the sequence on Bornholm, where the shale at this level is more black than the remaining part of the Silurian sequence.

#### The zone of *Monograptus turriculatus*

At the top of the preceding zone a sudden change in lithology and fauna occurs (middle part of loc. 13). Just above the black shale a 0.5 cm thick bentonite layer underlies a 65 cm light-grey silty bed. In this bed only trace fossils (10 cm long pyritic cylindrical bodies about 2 mm in width and situated parallel to the bedding planes) occur, probably burrows of worms. The silty bed is overlain by an argillaceous and unfossiliferous light-grey shale. 215 cm above the bentonite layer the graptolites reappear, still within a light-grey shale. From this level upwards the shale gradually becomes darker throughout the Upper Llandovery, but never as black as at the top of the *M. convolutus* Zone. In the upper part of the Llandovery only a few, thin bands of limestone occur. 4.5 m under the top of the zone of *M. turriculatus* a 50 cm grey-greenish unfossiliferous mudstone bed is seen; at the very top the shale is dark grey with pyritised graptolites.

Where graptolites reappear 215 cm above the bentonite the only old forms present are *Petalograptus palmeus* (Barrande) and *Glyptograptus tamariscus* (Nicholson). All the other graptolites make their first appearance at this level.

The base of the zone is defined by the appearance of *Monograptus turriculatus* (Barrande). Important species throughout the zone are *Monograptus nudus* (Lapworth) and *Monograptus marri* Perner. In the lower part *Monograptus planus* (Barrande), *Monograptus runcinatus* Lapworth,

and *Rastrites maximus* Carruthers are frequent. In the middle part an early form of *Monograptus priodon* (Bronn) and *Monograptus exiguus* (Nicholson) appear, and at the top *Monograptus galaensis* Lapworth, *Monograptus pseudobecki* Bouček and Přibyl, and *Monograptus proteus* (Barrande) become abundant.

The thickness of the zone is about 11.5 m.

In 1969 Sjørring (Bjerreskov) maintained a *Monograptus sedgwickii* Zone between the zones of *M. convolutus* and *M. turriculatus*. Additional material from the base of the earlier zone of *M. sedgwickii* yielded many small specimens of *M. turriculatus* which in Germany and Bohemia (Jaeger, 1964) is characteristic of the basal part of the *M. turriculatus* Zone. Moreover, the more abundant material contained further specimens which seem to be transitional forms between *Monograptus sedgwickii* (Portlock) and *Monograptus halli* (Barrande). For these reasons the zone of *M. sedgwickii* is now included in that of *M. turriculatus*.

*M. runcinatus* has only been found in the lower half of the zone and was not recorded by Pedersen (1922). In Sweden *M. runcinatus* is zonal fossil above the *M. sedgwickii* Zone (Törnquist, 1897, and Wærn, 1960a). *R. maximus* and *M. turriculatus* have nearly the same vertical range on Bornholm and there is no basis for separating a *R. maximus* band (Elles & Wood, 1913) or a *R. maximus* Zone (Toghill, 1968).

In Germany *M. sedgwickii* occurs associated with old species: *C. cometa*, *Monograptus denticulatus* Törnquist, and *Monograptus decipiens* Törnquist (Stein, 1965) and with new species as *M. nudus* and *M. planus*. In Great Britain *M. sedgwickii* is mainly observed together with old species (Lapworth, 1876, and Toghill, 1968).

On Bornholm the transitional sequence between the zones of *M. convolutus* and *M. turriculatus* is devoid of graptolites. In the *M. turriculatus* Zone only two old species have survived and a new graptolite fauna appears with *M. planus*, *M. nudus* and especially *R. maximus*, only found in the *M. turriculatus* Zone (Schauer, 1967, Toghill, 1968, and Rickards, 1970).

The non-graptolitic sequence on Bornholm above the *M. convolutus* Zone may represent the upper part of the *M. convolutus* Zone and the entire zone of *M. sedgwickii*.

In Great Britain the transition from Middle to Upper Llandovery is placed between the *M. convolutus* Zone and the *M. sedgwickii* Zone (Toghill, 1968). On Bornholm the conspicuous change in fauna and lithology at this level suggests that the same procedure may apply here. On Bornholm the transition includes the *M. sedgwickii* Zone.

In Sweden the *M. turriculatus* Zone was established by Linnarsson (1881) and repeated by Regnéll (1960). However, at the base of the Klubbudden

Stage Wærn (1960a) used *M. runcinatus* as zonal fossil. He stated (1960a) that the boundary between Middle and Upper Llandovery used in Great Britain is not applicable in Sweden. Here the zones of *M. convolutus* and *M. sedgwickii* are intimately connected and a change from dark to light coloured shale occurs between the zones of *M. sedgwickii* and *M. runcinatus*.

On Bornholm as in Jämtland, Sweden, and Mjösa, Norway, (Wærn, 1960a) a non-graptolitic sequence is overlain by graptolitic shales from the basal part of the *M. turriculatus* Zone.

The lower half of the ? *M. proteus* Zone (Sjørring, 1969) is now included in the upper part of the *M. turriculatus* Zone. *M. proteus* has a wide vertical range, making correlation difficult. Furthermore the fauna of the lower part of the ? *M. proteus* Zone is identical with that from the upper part of the previous *M. turriculatus* Zone.

#### The zone of *Monograptus crispus*

The shale in this zone is dark grey and with a high content of pyrite and well-preserved pyritised graptolites in the lower part.

*Monograptus crispus* Lapworth is recorded for the first time on Bornholm, but is not frequent. This species has earlier been found in a boring at Slagelse, Sjælland (Sorgenfrei & Buch, 1964).

At the base of the zone two new important graptolites, *Monograptus veles* (Richter) and *Monograptus tullbergi* Bouček have been recorded. Other abundant graptolites in the zone are *M. priodon*, *M. exiguus* and *M. proteus*. The base of the zone is defined by the appearance of *M. crispus* and the top by the appearance of *Monograptus griestoniensis* (Nicol). The boundaries are not exposed, and therefore the thickness may be estimated to be approximately 2.5 m.

The upper part of the ? *M. proteus* Zone (Sjørring, 1969) is now included in the *M. crispus* Zone. *M. veles* now appears at the base of the *M. crispus* Zone, the species occurs together with *M. turriculatus* in Germany and Bohemia (Jaeger, 1964, and Bouček, 1960).

So far the *M. crispus* Zone is the highest level at which the genus *Rastrites* has been observed. Pedersen (1922) reported the occurrence of *Rastrites* up to the top of the *M. turriculatus* Zone where he placed the upper boundary of the *Rastrites* Shale. In Sweden the *M. proteus* Zone (= the *M. crispus* Zone of Elles and Wood) has been included in the *Rastrites* Shale (Törnquist, 1890). However, the genus *Rastrites* does not occur above the Elles and Wood zone 22 (the *M. turriculatus* Zone) in Sweden (Wærn, 1960a).

### The zone of *Monograptus griestoniensis*

In the lower half of the zone mainly light coloured unfossiliferous green-greyish mudstone beds occur. Towards the top the mudstone becomes darker and rich in well-preserved pyritised graptolites.

The most abundant species ranging throughout the zone are *Monograptus vomerinus* (Nicholson), *M. veles*, *M. priodon*, and *M. tullbergi*. *Retiolites geinitzianus geinitzianus* (Barrande) appears and becomes frequent in the middle part of the sequence. *M. crenulatus* sensu Elles and Wood occurs at the top of the zone.

The thickness of the zone is about 3.5 m.

The appearance of *R. geinitzianus geinitzianus* in this zone delimits the basal part of what has previously been called the "Retiolites Shale". The term was first used by Törnquist (1875) and later by Johnstrup (1889) on Bornholm instead of the *Cyrtograptus* Shale.

### The zone of *Monograptus spiralis*

The base of the zone is defined by the disappearance of *M. griestoniensis* and is marked by a non-graptolitic 1.5 m thick bed. The shale is here light green-grey and locally (loc. 20) some trace fossils occur (10 cm long and 1–2 mm in width, cylindrical and parallel to the bedding planes. Above this bed two horizons with well preserved pyritised graptolites are found. Here *Monograptus spiralis* (Geinitz) occurs together with a frequent and slender form of *M. vomerinus*; *M. exiguus*, *Monograptus cultellus* Törnquist and *Monograptus continens* Törnquist are also common.

Towards the middle part of the zone the shale gradually becomes greenish with a few, 5 cm thick bands of dark graptolitic shale. At the middle of the zone a 10 m thick unfossiliferous light grey-green mudstone bed is seen. This bed is overlain by 2 m dark grey shale and in the upper 1.5 m *M. spiralis*, *M. vomerinus* forms and *M. priodon* are the main representatives of a well preserved pyritised graptolite fauna (loc. 26). A 1.5 cm limestone band occurs at the top of the exposure.

At loc. 29 a dark grey shale with pyritised graptolites is found. Here *Cyrtograptus lapworthi* Tullberg? makes its appearance and *M. spiralis* is observed at the highest level. *R. geinitzianus geinitzianus* and *R. geinitzianus angustidens* Elles and Wood are the dominant graptolites. *Stomatograptus grandis* (Suess), *Monograptus linnarssoni* Tullberg, and *Monograptus speciosus* Tullberg are rare.

The upper boundary of the zone is situated where *M. spiralis* disappears and *C. lapworthi*? appears. The zone of *M. spiralis* is about 30 m thick.

The uppermost graptolite zone in the Llandovery in Great Britain is the *M. crenulatus* Zone (Elles & Wood, 1913). However, *Monograptus crenulatus* Törnquist is not very well defined (Obut, 1960, and Jaeger, 1964). The species described by Törnquist (1881) seems to be identical with *M. vomerinus*, but on Bornholm *M. crenulatus* sensu Elles and Wood occurs in the upper part of the *M. griestoniensis* Zone. The zone of *M. crenulatus* (Laursen, 1940 and 1942) is now abandoned.

The *Cyrtograptus grayi* Zone, the lowermost zone in the *Cyrtograptus* Shale on Bornholm (Laursen, 1940), is no longer used as a formal unit. This zone comprised the zones of *M. crispus* and *M. griestoniensis*, but not the zone of *M. spiralis* (Poulsen, 1966).

The Kullatorp Stage in Sweden (Wærn, 1960) comprises the zones of *M. spiralis* and *C. lapworthi*. The base of the stage is characterised by a thin unfossiliferous mudstone bed, overlain by a horizon in the *M. spiralis* Zone rich in graptolites (Wærn, 1960a). On Bornholm the *M. griestoniensis* Zone and the *M. spiralis* Zone are separated by a light 1.5 m non-graptolitic mudstone bed. However, in the middle part of the *M. spiralis* Zone a 10 cm unfossiliferous greenish mudstone bed occurs.

Tullberg (1883) divided the lowest part of the *Cyrtograptus* Shale in Sweden into the zones of *C. grayi*, *M. spiralis*, and *C. lapworthi*. Here the *C. lapworthi* Zone is reported as the uppermost zone in the Llandovery, but the upper boundary of the Kullatorp Stage, e.g. the boundary between the Llandovery and Wenlock is still open to discussion (Wærn, 1960a).

The present investigations of the *C. lapworthi* Zone on Bornholm are not completed, but the fauna including *M. linnarssoni*, *R. geinitzianus geinitzianus* and *R. geinitzianus angustidens* seems to be rather similar to the *Cyrtograptus centrifugus* fauna in the basal Wenlock in Howgill Fells (Rickards, 1965 and 1967).

There is no evidence for a *Stomatograptus grandis* Zone on Bornholm as in Bohemia (Bouček, 1960).

On Bornholm no marked lithological changes have been observed in the passage from the *M. spiralis* Zone to the *C. lapworthi*? Zone. The exposures are few and the lithology changes frequently within the sequence from light unfossiliferous mudstone to dark graptolitic shale.

## Conclusions

Wærn (1960a) divided the Llandovery into four stages. On Bornholm only one major natural boundary can be seen, e.g. the boundary between Middle and Upper Llandovery. The previous procedure of dividing the Silurian on Bornholm into the *Rastrites* Shale and the *Cyrtograptus* Shale is no longer justifiable. The genus *Rastrites*, on Bornholm as well in Sweden (Wærn, 1960a), is not common in the *Rastrites* Shale and does not occur in all of the included graptolite zones (Elles and Wood zones 16–24). The lowest 30 m of the *Cyrtograptus* Shale have yielded very few specimens of *Cyrtograptus*. *Rastrites* Shale and *Cyrtograptus* Shale as stage names are not in accordance with the current stratigraphical nomenclature (Hedberg, 1960) and should therefore be abandoned. At the present it appears most practical to restrict the divisions of the Silurian on Bornholm to the Llandovery and Wenlock Series.

## Dansk sammendrag

Resultaterne af en undersøgelse af Nedre Silur (Llandovery) graptolitskifer fra Øleå på Bornholm forelægges. Der er fremstillet et profil gennem skiferne, og mægtigheden af Llandovery er målt til mellem 110 og 130 m. En række graptolitarters vertikale udbredelse er analyseret og på dette grundlag er der foretaget en zoneinddeling, som er forsøgt korreleret med tilsvarende udenlandske aflejringer.

Idet der hverken er observeret nogen faunistisk eller lithologisk grænse mellem *Rastrites* Skiferen og *Cyrtograptus* Skiferen, er de to gamle betegnelser, som er i uoverensstemmelse med de nugældende nomenklaturregler, opgivet. På nuværende stadium af undersøgelsen er Siluret på Bornholm kun opdelt på serieniveau i Llandovery og Wenlock.

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