10. Notes on the Lower Ordovician of Falbygden.

By

Per Thorslund.

(With Pl. II.)

This paper is based on investigations carried out in the field one week in 1933 and ten days last autumn. On the first occasion the author went to Falbygden for the purpose of studying the Chasmops beds, but his attention was soon drawn to the geological conditions and problems connected with the Lower Ordovician. The first sections studied were those of the western slopes of Mösseberg, referred to below as Änga, Stora Backor and Kleva. Here the Lower Ordovican zones were found to be of considerable thickness, and rather complete compared with those known from other parts of Falbygden. A visit to the Ödegården quarry, situated at the eastern limit of the Cambro-Ordovician of this district, proved that the same part of Ordovician was here less than one fifteenth as thick as at Änga, and further that some zones present in the latter section are absent. These investigations gave the impression that this series was growing more complete with increasing thickness from east to west in Falbygden, that the western parts of Hökensås was probably a coastal slope in Lower Cambrian times, and that parts of this slope had emerged during periods of greater regression of the sea, at least in the interval between late Cambrian and early Ordovician. However, this interpretation was soon somewhat modified, as it was observed that at Tomten, a quarry on the northern slope of Mösseberg, this Ordovician series was of about the same thickness and development as at Ödegården, and as Westergård had observed (1922, p. 67) that the Lower Didymograptus Shale and its underlying glauconitic limestone at Stensåsen, a village with quarries about 10 km NE of Ödegården, between them measured about 2 m in thickness.

In order to solve the above problems of the early Ordovician sedimentation, the writer revisited the district last autumn, when he was given an opportunity to make a regional study of the Ordovician series of strata below the Limbata limestone in Falbygden. Some of the results then obtained are given below. The main purpose of the investigation — an interpretation of the conditions prevailing at the formation of bedded limestone — will also be discussed, but far from all the material collected by the writer, is nevertheless not presented in this paper. A solution of that problem became clear to the writer, however, already in 1933. The expenses of my journey were then paid by professor C. Wiman, who has always given me his unstinted support and highly appreciated friendship during my studies. The courtesy of the Director of the Geological Survey of Sweden, Dr A. Gavelin, rendered my 1936 investigations possible. It is my pleasing duty to express here my deep gratitude to these gentlemen for their valuable help in promoting the object of this paper.

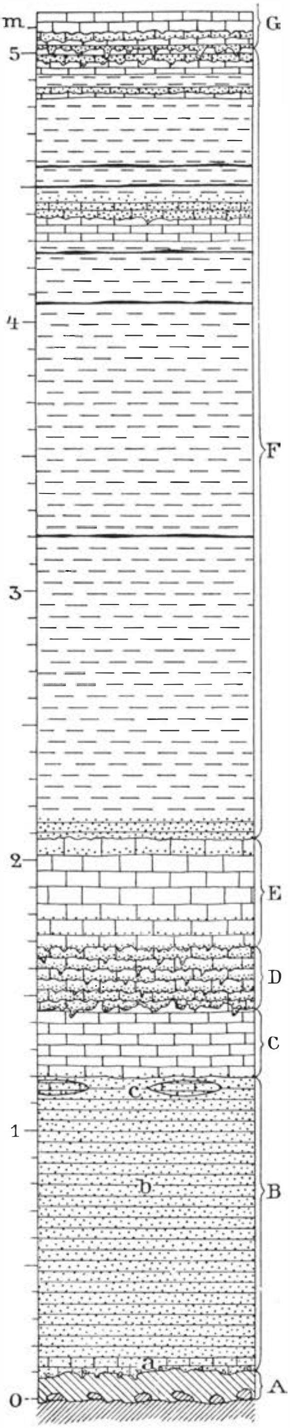
Description of sections.

Änga, Stora Backor.

Ceratopyge limestone containing *Euloma ornatum* ANG. etc. was found in 1878 by v. Schmalensée on the western slope of Mösseberg, in the parish Vilske Kleva (Linnarsson 1879). That locality has never been identified since, nor had any find of Ceratopyge limestone containing the index fossils since been recorded in this part of Mösseberg (cf. v. Post 1906). During my investigations in this district in 1933 I also visited an old quarry at Änga, St. Backor, just below the road 2 km NNE of the church (Fig. 9). A fairly good section through the Upper Cambrian and Lower Ordovician was exposed there at the time, but last autumn conditions were more favourable owing to limestone and alum shale having been quarried in the mean-time. As will be seen from the following description, fossiliferous Ceratopyge limestone is present in this section, which — in other respects, too — contains notable stratigraphic details. Very likely, v. Schmalensée's collection was made in this locality, or at least in this neighbourhood. An examination of his collection corroborates this opinion (see p. 151).

A thick bed of stinkstone lenses in the Upper Cambrian alum shale is exposed in the bottom of the quarry. This is partly conglomeratic, and embraces at least the *Parabolina spinulosa* and *Orusia lenticularis* zone. The latter species was found in the matrix of the conglomerate, but the fossils of the stinkstone bed were not investigated further. This bed is overlaid by about 7.5 m of alum shale belonging to the *Peltura scarabaeoides* zone, which terminates in a bed of stinkstone, partly conglomeratic and containing, just beneath the Cambro-Ordovician boundary: *Peltura scarabaeoides* (WAHLENB.), *Sphaerophthalmus alatus* (BOECK), *S. majusculus* LINRS., and *Ctenopyge* cfr *linnarssoni* WGD.

The following strata of the series above the Cambro-Ordovician boundary have been distinguished (see Fig. 1).



A. Stinkstone with *Dictyonema flabelliforme* EICHW. f. typica, about 0.1 m thick. Its basal part is conglomeratic and contains pebbles of stinkstone from the substratum (Fig. 2). In one of these pebbles *Peltura scarabaeoides* and *Sphaerophthalmus major* LAKE were observed, others contain the same assemblage as the immediate substratum. The matrix of the conglomerate, and the upper part of the bed, consists of finely crystalline stinkstone containing pyrite. The surface of this bed is uneven and furnished with small pits (Fig. 3).

B. Beds rich in glauconite, about 1.10 m thick. The following minor divisions can be distinguished.

a. Limestone, coarse and fine crystalline, rich in pyrite and small grains of glauconite, containing phosphorite pebbles mainly in the lower part, and small pieces or grains of coal in the upper two thirds. As seen by Fig. 3, it fills the superficial pits of the substratum.

b. This part of the section consists of thin-bedded deposits, mainly composed of rather small grains of glauconite and numerous small fragments of brachiopods with phosphatic shell in a somewhat calcareous matrix of shaly matter; between the 1—2 cm thick beds there are small nodules of thin seams of anthracitic coal; thin slices or lenses of brownish dark shale are common in the bedding-planes; small rounded grains, and up to larger more or less angular pebbles, of phosphorite

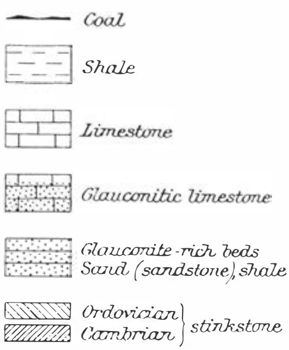


Fig. 1. Section at Änga, St. Backor. The lettering is explained in the text.

are present in the beds, which in the basal part of the minor division are sometimes very rich in pyrite, which gives them a hard consistency and a yellow-green colour. Besides indeterminable fragments of linguloidean and oboloidean brachiopods, the author observed *Acrotreta* sp. and small conodonts obviously identical with those described from the Ceratopyge Shale of the North Baltic district (Wiman 1903, p. 66, Pl. III, Figs. 40—43). — Of this minor division some parts — poor in shaly matter and pyrite — easily weather into sand.

c. This part is about 0.3 m thick and built up of the same materials as the substratum though poor in shaly and richer in calcareous matter, while the glauconite is more coarse-grained; it further contains rounded quartz grains though generally sparsely. Owing to its lithological com-

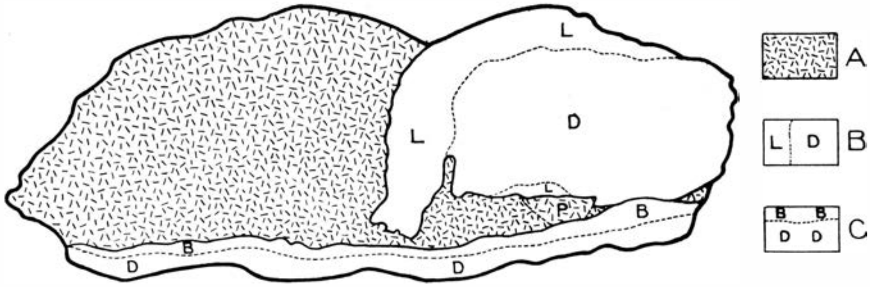


Fig. 2. Section of a piece of the conglomeratic part of the stinkstone containing *Dictyonema flabelliforme*. Änga, St. Backor. — Natural size. — A. Stinkstone with *Dictyonema flabelliforme*. B. Pebble of light (L) and dark (D) stinkstone containing *Peltura scarabaeoides*, *Sphaerophthalmus alatus*, *S. majusculus* and *Ctenopyge sp.* C. Brownish (B) and dark (D) stinkstone of the substratum (zone of *Peltura scarabaeoides*). P. Pyrite incrusting the stinkstone A.

position, it apparently weathers very rapidly into sand. In its upper part there is a bed of indistinctly bounded glauconitic limestone lenses frequently containing *Ceratopyge forficula* (SARS), *Shumardia pusilla* (BRÖGGER), *Eoorthis christianiae* (KJER.), *Acrotreta* sp. and *Lingulella* sp. Brachiopods are also met with in other parts of the minor division.

C. Limestone, 0.25—0.28 m thick, grey to dark-grey, with thin blue-green bands in the upper part, hard, dense, finely crystalline, with glauconite grains in its basal layer; the following fossils were found; *Cyrtometopus speciosus* (DALM), *Niobe obsoleta* LINRS. and *N. insignis* LINRS., *Symphysurus angustatus* (SARS et BOECK), *Apatocephalus* cfr *serratus* (SARS et BOECK), *Euloma ornatum* ANG., *Ceratopyge forficula*, *Eoorthis christianiae,* and *Lingulella* sp.

D. Glauconitic limestone, 0.22—0.25 m, in patches of coarsely crystalline structure, but mainly fine-grained or finely crystalline, generally coloured by dark- to blue-green glauconite grains; partly rich in pyrite; weathers into glauconitic sand and indistinctly and irregularly bounded limestone lenses.

This massive limestone bank is built up of several layers interwoven as indicated in Fig. 1. From one of the layers »fingers» or »plugs» project into its substratum, in other words, the upper surface of the latter is uneven, with vertical, irregular depressions, in which the top layer has subsequently been deposited (cf. p. 159). The top and bottom parts of D consist throughout of layers containing glauconite grains, the basal part also small pebbles and grains of phosphorite. Some small limestone pebbles are possibly derived from the immediate substratum C, the upper surface of which is very uneven and relatively deeply pitted. A couple of layers in the centre of D are both less rich in glauconite at the top, but are

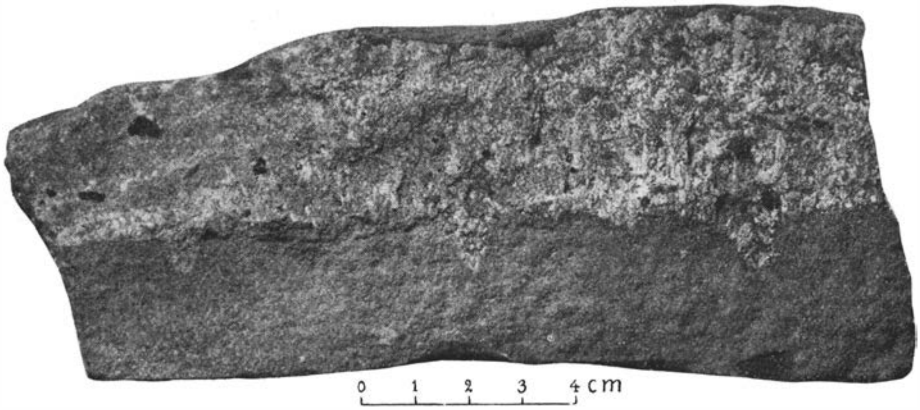


Fig. 3. Piece of rock from the Änga section, St. Backor, showing the boundary between the stinkstone (with *Dictyonema flabelliforme*) and the superimposed glauconitic limestone. The small dark spots in the centre of the latter are pieces or grains of coal, the black, larger spots are phosphorite pebbles.

instead traversed by richly glauconite-bearing »plugs» from the overlaying strata.

This limestone is poor in fossils; *Eoorthis christianiae, Acrotreta* sp., and fragments of obolelloid brachiopods were observed.

E. Limestone, 0.35—0.4 m; its lower half grey, fine-grained, argilloceous, and occasionally intercalated with thin layers of grey shale; its upper half grey to blueish grey, and of finely crystalline structure; glauconite occurs sparingly in the basal layers, but more commonly in the uppermost part. Fossils observed in the lower half: *Megalaspis planilimbata* ANG., *Symphysurus breviceps* ANG., *Eoorthis christianiae, Acrotreta* sp. In the upper half: *Megalaspis planilimbata* and *M. stenorrhachis* ANG., *Niobe laeviceps* (DALM.), *Symphysurus breviceps, Eoorthis christianiae.*

F. Shale, about 2.85 m, greenish grey to dark-grey, intercalated with and overlain by partly glauconitic limestone; at its base there is a layer of glauconitic sand, 0.05—0.08 m thick; the shale contains glauconite just above this layer and also just above the limestone bed about 0.5 m below the top. Seams of coal, 1—10 mm in thickness, can be followed as far as the shale is exposed in the quarry; their position is shown in Fig. 1. Graptolites, *e. g. Phyllograptus densus* TQT, *Tetragraptus* sp. and *Didymograptus extensus* HALL, were observed, but no complete collection of the fossils occurring throughout the shale was made.

G. Limestone, some metres thick, greenish-grey to light grey, and partly argillaceous in its lower parts, mottled reddish grey to browny-red in its upper parts; the basal glauconite-bearing layers are interwoven, as in part D of the section. *Megalaspis limbata* (S. et B.) was found in the lower part, just above the glauconitic limestone.

The above-subdivisions of this section might be recognized as belonging to the following zones:

G.	zone	of	*Megalaspis limbata.*
F + E + D.	»	»	» *planilimbata.*
C + B.	»	»	*Ceratopyge forficula.*
A.	»	»	*Dictyonema flabelliforme* f. typica.

The occurrence of the index fossil (cf. above) determinates the lower boundary of the *M limbata* zone in or just above the glauconitic limestone above the Lower Didymograptus Shale. There are also indications that the zones of *M. planilimbata* and *M. limbata* do not conform to one another in Falbygden. The irregularities of the upper surfaces of the glauconitic limestone layers above the Lower Didymograptus Shale indicates erosion (probably mainly chemical erosion) and thus due to changes of sea-level at the time when this limestone was deposited. This unconformity (cf. Fig. 8) is further corroborated by the fact that the zone of *Isograptus gibberulus* MBG has never been recorded in this district (cf. Bulman 1936, p. 12—13). Probably, however, the shales containing the *Isograptus gibberulus* zone fauna is here in part replaced by the lower strata of the *Limbata* limestone.

As to the glauconitic limestone D, the absence of index fossils makes it doubtful whether this should be referred to the *Ceratopyge forficula* zone or to the *M. planilimbata* zone. In view of the sharp boundaries and sudden lithological alterations, and of the very uneven upper surface of subdivision C, an unconformity between subdivisions C and D is in the author's opinion very probable. A break of the sedimentation after the deposition of the Ceratopyge limestone is, moreover, also indicated in other parts of Falbygden, where this limestone has been recognized by its fossils. We are thus apparently justified in regarding subdivision D as the basal bed of the *M. planilimbata* zone.

As to the fauna of the lower half of E, further examination would most likely supplement the list of fossils, as the species recorded were found in two relatively small pieces of limestone. Possibly, evidence would then be obtained of its equivalence with the lowest part of the *M. planilimbata* zone of Billingen, which according to Westergård (1928, p. 42) contains, among other species, *Shumardia* (*nericiensis* WIM.?) and *Megalaspides dalecarlicus* (HOLM).

M. planilimbata has not been encountered in subdivision F; but this part of the section must nevertheless be included in the *M. planilimbata* zone. The graptolites found indicate that it belongs to the *Phyllograptus densus* zone, which has previously been correlated with the (upper part of the) Planilimbata limestone by several authors. This correlation is made all the more probable by the fact that the author has found the index fossil in limestone lenses interbedded in the richly graptolite-bearing zone of *P. densus* at Gäle, a locality near the lake Näckten in Jemtland.

Subdivisions B and C of the section are considered to represent the *Ceratopyge forficula* zone, although the zone fossil has not yet been found in the lower part of B (= a + b). This circumstance may be due to conditions, primary and/or secondary (weathering), unfavourable for preserving fossils of that kind. Subdivision B of the section appears to be equivalent to »the zone of Shumardia» in Öland and Scania (Moberg and Segerberg 1906), and to the Ceratopyge Shale in Norway (Brögger 1882). In another locality in Falbygden, Stenbrottet, the development of the lower part of the *Ceratopyge forficula* zone is similar to that of subdivision B.

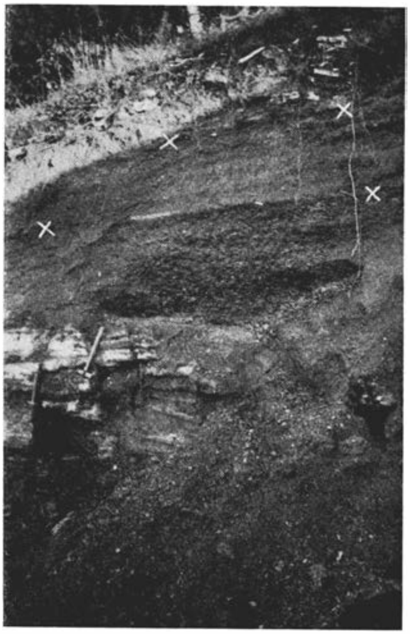


Fig. 4. Showing part of a section of the Ordovician at Änga, St. Backor. The small hammer is stood on the Ceratopyge limestone, the larger hammer marks the fossiliferous Planilimbata limestone. x—x seams of coal.

Note. The colour of the shale can be observed to alternate from lighter to darker bands. (See the upper half of Fig. 4).

A study of Schmalensée's collection from Kleva has proved that the bulk of this has come from a limestone lithologically similar to C in the section described. The following fossils were recognized in the collection, *Euloma ornatum, Symphysurus angustatus, Nileus limbatus* BRÖGGER, and *Eoorthis christianiae.* — Besides, there are two small pieces of glauconitic limestone containing *Ceratopyge forficula, Shumardia pusilla, Eoorthis christianiae,* and *Lingulella?* sp. These pieces were apparently taken from a bed corresponding to Bc of the section.

Leaby.

Near the road passing through the village Leaby, about 2 km ESE of the northern end of Ålleberg, there is an old quarry in which Cambrian and Ordovician strata are partly exposed. It is about 60 years since any work was done here, and the consequent weathering, falls, etc. prevents the Lower Ordovician series of strata discussed in this paper from being carefully studied without more digging. When visiting this spot for a couple of hours, the author was able to make the following observations.

The Cambrian alum shale ends in a bed of stinkstone, in which the following fossils were observed just beneath the Cambro-Ordovician boundary: *Peltura scarabaeoides*, *Sphaerophthalmus alatus* and *S. majusculus*, *Ctenopyge bisulcata* (PHILLIPS) and *C.* cfr *linnarssoni* WGD.

The Cambrian stinkstone is overlain by alum shale, about 0.42 m thick, which terminates in a bed of straticulated stinkstone, 0.08 m thick. The following fossils has been found in this series of strata from above downwards:

Stinkstone with undeterminable species of *Bryograptus*.

In the shale just beneath the stinkstone: *Clonograptus tenellus* LINRS. var., and *Bryograptus hunnebergensis* MBG.

About 1—2 dm below the stinkstone: *Dictyonema flabelliforme* (EICHW.) f. typica, *Clonograptus tenellus*.

In the lower part of the shale: only *Dictyonema flabelliforme* f. typica, but very abundant rhabdosomes.

In the contact-zone between the Cambrian stinkstone and the Dictyonema Shale there was a thin layer of brown-black, somewhat calcareous mud or clayey material. This is probably due to weathering of a layer of stinkstone (cf. Westergård 1922, p. 57).

There must accordingly be two sub-zones of the Dictyonema Shale in this locality. The upper of these, or the sub-zone of *Clonograptus tenellus* (with var.) and *Bryograptus hunnebergensis*, is now for the first time recorded from Falbygden.

The series of strata above the Dictyonema beds in this section was too disturbed by secondary weathering and falls to give any indisputable facts with reference to the primary stratigraphical conditions, and it was not thoroughly examined by the author. The Dictyonema series was overlain by a greenish-grey layer, about 0.25 m thick, consisting of clayey material in which pieces of greenish-grey and black shales were embedded, the latter obviously derived from the substratum. This breccia-like layer was followed by more or less thin-bedded limestone, some layers in the lower part of which (about 0.30 m thick) were very rich in glauconite.

Kleva.

A section through the Lower Ordovician series of strata in Alm's quarry, about 800 m SSW of Kleva church, was described by v. Post in 1906. The author visited this locality in 1933, and can add but little to v. Post's description beyond what can be learnt from a comparison between the somewhat schematical figures given (v. Post 1906, p. 470, fig. 2; this paper Pl. II). There is some difference in our interpretations of the limestone bed immediately above the Dictyonema Shale. Its position in the series of strata and a comparison between this section and that described from Stenbrottet (v. Post 1906, p. 474—477) inclined v. Post to regard it the equivalent of the Ceratopyge limestone. As he himself says, however, the fossils found were not sufficiently informative for this interpretation.

The author has studied v. Post's original material in the collections of the Geological Survey of Sweden; his examination of the limestone bed in question has proved that most probably it corresponds to the series of strata at St. Backor called B, C, D and E above. It is composed of several thin layers interwoven in the manner described from D in the St. Backor section. But, as v. Post has already noted, two subdivisions are clearly distinguishable; they are separated by an erosion surface, and distinguished by lithological differences. The mainly grey lower part is conglomeratic in the basal layers — where relatively large pepples of phosphorite are common — changing from coarsely to finely cristalline structure from the bottom upwards, rich in pyrite and very small grains of glauconite; just beneath the upper surface at least, it contains small rounded quartz grains. The upper subdivision begins with a thin, probably complex layer of dark-green limestone coloured by abundant grains of glauconite of varying size; small pebbles of phosphorite are common, but no quartz grains were observed; concretions of pyrite are present. This layer sends »plugs» or »fingers» down into the substratum, the contact to which is very sharp. As seen in the section, the following layer of dense, dark-grey limestone, rather poor in glauconite, is cut into irregular pieces by »fingers» from the superposed layer, the bottom of which is very rich in glauconite. The rest of the upper part consists of dark, finely crystalline limestone intercalated with very thin, somewhat undulating bands or lenses of greenish grey limestone rich in glauconite, and obviously composed of at least three layers. It is overlain by a thin bed of glauconite-rich shale, followed closely by the Lower Didymograptus Shale, *viz.* the *Phyllograptus densus* zone.

A comparison between the above limestone bed and the series of strata in the St. Backor section designated B, C, D and E, leads to the conclusion that the lower part of the former was probable deposited contemporaneously with the greater part of B + C in the latter. The lower part of the limestone bed at Kleva must thus be considered to represent the *Ceratopyge forficula* zone in that locality, and its upper part to be equivalent with the greater part of D + E of the St. Backor section. The varying thicknesses are apparently due to conditions prevailing immediately before and during the deposition of the strata.

As noted by v. Post, the upper surface of the Dictyonema beds at Kleva has been exposed to chemical erosion. The description and figures given by him (op. cit., p. 470, fig. 2) also show that there is unconformity between these beds and the Ceratopyge limestone. The degree of unconformity in the distance between the places Kleva and St. Backor is indicated in Pl. II. A break in the succession of strata is moreover indicated by the fact that the zone of *Clonograptus tenellus* and *Bryograptus hunnebergensis* is missing in all the Falbygden sections hitherto studied except at Leaby. It must also be added that other important facts favour this interpretation, *e.g.* the absence of another zone of the Ceratopyge series of strata — that of *Symphysurus incipiens* BRÖGGER.

Stenbrottet.

The lower Ordovician series of strata at Stenbrottet, a quarry near Orreholmen, has been dealt with by several early authors (Linnarsson 1880, v. Post 1906, Westergård 1909 and 1922). The most complete and detailed description is given by v. Post, who was the first to record a very richly fossil-bearing Ceratopyge limestone in this locality. To his account will here be added only some notes to explain the section illustrated in Pl. II. This section was measured in the northern wall of the quarry adjoining the road. On the whole, it may be considered a diminished picture of the St. Backor section, and is in fact so in respect of all the zones distinguished except that of *Dictyonema flabelliforme*.

According to Westergård (1909, p. 35) the limestone lenses in the glauconitic beds above the Dictyonema Shale contain several trilobites typical of the *Ceratopyge forficula* zone. To the list of fossils given by this author may be added *Shumardia pusilla*.

The lower part of the superposed limestone also belongs to the *C. forf.* zone, and contains the very rich fauna recorded by v. Post (1906, p. 476). Its upper surface is very uneven, with more or less deep, irregular pits and grooves. The upper, thicker part consist of limestone very rich in glauconite, intercalated with thin layers of purer limestone in its uppermost part, where *Eoorthis christianiae* and fragments of a large trilobite, probably *Megalaspis planilimbata*, were observed. For the stratification in the upper part, see Pl. II and the description of subdivision D of the St. Backor section (p. 148).

The limestone bed briefly described above can be followed in the walls all round the quarry. It is overlain by shale, blueish-to greenish-grey with thin layers of darker colour. A breccia-like layer in the lower part of the section contains pieces of the surrounding shale embedded in clayish matter. A similar breccia has been noted at Leaby (p. 152) and like formations have previously been recorded by Westergård (1931, p. 52—53) in sections through the Lower Didymograptus Shale in the northern part of Billingen. With Westergård I think they are due to sliding. Westergård considers them of late geological age, possibly Quaternary. At all events they must be regarded as of age post-Silurian, and in the author's opinion the possibility of a connection between their formation and the fault-action that has evidently taken place in the district (cf. Fig. 9) must be taken into consideration.

The shale is overlain by greyish limestone, in the lower part of which there are a few layers of glauconitic limestone. *Megalaspis limbata* is found close above the latter, or about 1.5 dm above the contact to the shale.

Fossiliferous Ceratopyge limestone also occurs in the adjacent quarry at Mossagården, and has also been recorded in Djupadalen, about 5 km N of Leaby (Westergård 1928, p. 39). The Dictyonema-Ceratopyge series has hitherto not with any certainty been found in Falbygden except in the localities described or mentioned above. Thus, in all other quarries examined by the author, the lowest zone of Ordovician recognized by fossils is the *Megalaspis planilimbata* zone, and it is doubtful whether there actually are any Ceratopyge beds in them present (cf. p. 161). The following descriptions of sections in some of these quarries are given as examples of the development of the Lower Ordovician series of strata (cf. Pl. II).

Tomten.

In this locality, situated about 2 km N of Torbjörntorp, the Cambrian stinkstone immediately below the Cambro-Ordovician boundary contains *Peltura scarabaeoides, Sphaerophthalmus alatus* and *Ctenopyge pecten* (according to Westergård 1922, p. 71). The basal part of Ordovician is conglomeratic and very rich in glauconite, sometimes also in pyrite. The bottom layers contain pebbles and grains, mainly of phosphorite, but also of fossiliferous stinkstone, usually more or less phosphoritic, containing the same species as the immediate substratum of Ordovician. The matrix consists of dark to dark-grey, glauconitic limestone, in which rounded, sometimes relatively large quartz grains are present, though infrequently. The quartz-bearing part varies in thickness, and is about 5 cm thick in the section measured. It is overlain by a few very thin layers of limestone rich in glauconite, with relatively small phosphorite pebbles; a thin bed of grey, partly glauconitic shale then follows, containing films or thin lenses of coal. The superposed bedded limestone, about 25 cm thick, dark-grey, somewhat bituminous and partly glauconite-bearing, is rich in fossils, of which *Megalaspis planilimbata* and *Symphysurus breviceps* are abundant. This Planilimbata limestone and the mainly light-grey Limbata limestone are separated by a straticulated limestone, about 15 cm thick, dark to dark-grey and rich in glauconite. The stratification of this limestone, and of the basal part of the section, is illustrated in the figure (cf. also p. 148, D).

Flittorp.

In an old quarry about 500 m N of Flittorp village (parish of Tiarp), two sections within 20 m of one another were measured. Section »I» in Pl. II shows the succession of strata above Cambrian stinkstone containing *Peltura scarabaeoides, Sphaerophthalmus alatus,* and *S. majusculus,* while Section »II» shows the strata above the Cambrian alum shale, at the side of or between stinkstone lenses.

In »I» the Ordovician strata begin by a series of thin layers of glauconitic limestone, the basal part of which contains phosphorite pebbles. This is overlain by dark-grey, somewhat bitumineous limestone, in which *Megalaspis limbata, Nileus armadillo* var. *depressa* (S. et B.) and *Holometopus limbata* ANG. were found 16—17 cm above the Cambro-Ordovician boundary. *Megalaspis planilimbata* was observed in the glauconitic limestone, 11—12 cm above the same boundary.

Section »II» is in all essentials a copy of the one described from Tomten, and its basal, conglomeratic part also contains small quartz grains; the two only differ in thickness here and there, as seen in the figures (Pl. II). The uppermost part of the Cambrian alum shale is darkish chocolate-brown, somewhat phosphoritic, and nearly free from bitumen. It varies in thickness, but it is never more than a few cm thick. Similar strata are always found in sections where alum shale is overlain by glauconitic beds, and are thus also present at the top of the Dictyonema shale.

Ödegården.

In this locality, too, the Ordovician substratum belongs to the *Peltura scarabaeoides* zone and consists of large lenses of stinkstone relatively close together and surrounded by alum shale. The lenses are partly conglomeratic and contain, according to Westergård (1922, p. 67), *Peltura scarabaeoides, Sphaerophthalmus alatus, S. majusculus* and *Ctenopyge pecten.*

In the section illustrated in Pl. II, stinkstone forms the substratum of the Ordovician series of strata, the basal portion of which is conglomeratic.

The lowermost part of this series is built up mainly of pebbles of dense, fine to medium crystalline stinkstone, and — less commonly — of phosphorite and pieces of coal. The matrix consists of limestone rich in glauconite in which small grains of quartz are occasionally observed. The composition and thickness of this conglomerate vary in the walls of the quarry, often thinning to nothing. It is overlain by a light-crystalline limestone, coloured by plentiful grains of glauconite and numerous pebbles and grains of phosphorite. Its top layer is one of fossiliferous, light-grey limestone, 1.5—2 cm thick, less rich in glauconite and pebbles of phosphorite. In another section of the quarry, but obviously at the same level — 5—6 cm above the Cambro-Ordovician boundary — as this layer, the following species were collected in a similar limestone: *Megalaspis planilimbata, Symphysurus breviceps, Niobe laeviceps, Agnostus*(?) sp. and *Eoorthis christianiae*.

About 10 cm of the uppermost part of this section consist mainly of glauconite-rich limestone with small pebbles or grains of phosphorite, which become smaller and less frequent towards the top. It is covered by dark-grey, slightly bituminous bedded limestone, containing *Megalaspis limbata*.

The glauconitic and partly conglomeratic limestone of this section is composed of several thin layers bearing the same relationship to one another as in the other sections described. Thin seams or lenses of coal are present in the *Megalaspis planilimbata* zone, in several parts of the quarry, and also in the upper part of the Cambrian (cf. Westergård 1922, p. 67; Hedström 1922).

Conclusions of stratigraphical importance.

Many problems of great interest arise from a study of the Lower Ordovician in Falbygden. One of these is connected with the occurrence of phosphorite pebbles in the basal Ordovician strata, a problem, which was rather keenly discussed in Sweden towards the end of last century (Andersson 1895, 1896, 1897; Hedström 1896). It is not intended to touch upon this problem in the present paper, as in the author's opinion it is of the first importance to collect by detailed stratigraphical investigations material from which a conception may be obtained of the conditions, under which the phosphorite-bearing limestone has been deposited.

With regard to the completeness and thickness of the Lower Ordovician zones in the different parts of Falbygden, one would be inclined to speak of a transgressive overlap from SW or WSW towards NE and ENE respectively in that district. The facts presented in the preceding chapter are favourable to this interpretation. However, they also indicate that the transgression of the Ordovician sea did not consist merely in a continued elevation of the sea-level, but was a complex phenomenon. Actually, it was a result of many changes of sea-level[1], the smallest components of which, as indicated by the series of strata, were oscillations. Each layer of limestone was deposited in the course of one such oscillation. The two phases of that oscillation are often reflected by the lithological composition of the limestone (cf. for inst. Andersson 1895, p. 183, and this paper, Fig. 6) and sometimes also by the fossil contents, as the transgression limestone is richer in fossils than the regression limestone. The thickness and lithological composition of a layer are evidently due to several factors, such as for inst. the primary dept of water, the amplitude and duration of the oscillation. Accordingly, the regression limestone sometimes follows immediately upon the transgression limestone, and successively and indiscernibly merges with it, and sometimes, the two are separated by

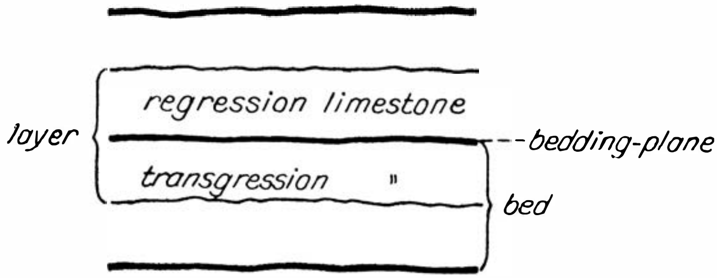


Fig. 5. The relationship between layer and bed, as explained in the text by the author.

shale or shaly matter. Examples of the former condition are abundant in the sections described, for inst. in the subdivision D of the St. Backor section (cf. also Fig. 6), and of the latter in the uppermost part of the *Planilimbata* zone of the same section. A bedding-plane of the superimposed *Limbata* limestone may thus separate the transgression limestone from the regression limestone of a layer. The suggested interpretation is diagrammatically illustrated in Fig. 5. The author is here introducing a distinction between layer and bed that has not formerly been usual. This is done for the sake of expediency, in order to give a simple explanation without the introduction of new terms. *Layer* is thus used to denote the total sedimentation during an oscillation, *i. e.* a sedimentation unit, while *a bed* denotes the material deposited between two bedding-planes, and is in the most simple case accordingly composed of adjacent portions of two layers — as suggested in Fig. 5, — but may also, in other cases, contain one or more layers.

[1] The idea of changes of level during the deposition of the Orthoceras limestone was first mooted by H. Hedström (1896). As will be clear from the following, the author agrees with this opinion, which will be more fully developed with reference to the series of strata dealt with in this paper.

This distinction is based on the geological significance that must be attributed to the surfaces separating the layers. These surfaces are very distinct in some parts of the series examined. An example — *viz.* the small section illustrated in Fig. 6 — may help to explain what kind of evidence these surfaces can give. The piece of limestone reproduced is from the Tomten quarry, and was taken some distance from the section described on p. 155.

Fig. 6. A piece of limestone from the Tomten quarry showing from below upwards: Cambrian stinkstone, the Cambro-Ordovician boundary, and two Ordovician layers. The small black spots are glauconite grains, the larger are phosphorite pebbles. — Natural size.

The lower portion of the piece consists of stinkstone with *Peltura scarabaeoides*. The surface of the stinkstone is more or less deeply pitted. Similar surfaces bound the layers of the superimposed limestone. The lithological composition of different parts of the layers has already been described (Andersson 1895, p. 183, Westergård 1928, p. 39; cf. also Hedström 1896, p. 562) and is indicated in Fig. 6. It may be added that in the basal part of the third layer of an adjacent section there was a phosphatized stinkstone pebble, 16 cm long, 9 cm wide and about 1.5 cm thick, containing abundant fragments of Cambrian trilobites (*Peltura scarabaeoides* and *Sphaerophthalmus alatus*).

In all probability, these surfaces were formed under analogous conditions, during periods of non-sedimentation at least. As to the surface of the stinkstone, the latter fact is easily demonstrated by reference to stratigraphical evidence. As said above, the stinkstone is in the zone of *Peltura scarabaeoides,* and the covering layer cannot be correlated with any lower part of the Ordovician than the upper portion of the *Ceratopyge forficula* zone. Two zones of the Swedish Upper Cambrian, and at least the main part of the *Dictyonema-Ceratopyge*-series, are accordingly missing in this section. On this fact, and the conditions at the Cambro-Ordovician boundary in the Änga quarry, St. Backor, the writer bases his conclusion that the regression of the Cambrian sea was complete in Falbygden. During the following Ordovician transgression the surface of the stinkstone was definitely developed, probably mainly by chemical erosion. The Lower Ordovician limestone surfaces must have been formed in a similar manner, but probably more quickly than the sub-Ordovician surface.

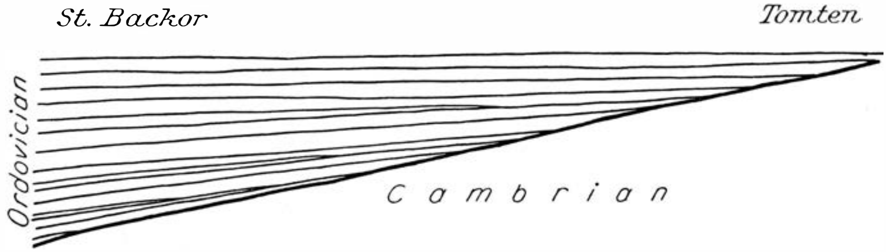


Fig. 7. Sketched section illustrating the suggested interpretation of the Ordovician transgressive overlap in Falbygden. The thick line indicates the Cambro-Ordovician boundary, the finer lines denote the surfaces of some layers.

The examined sections show that the thickness and completeness of the Lower Ordovician series vary in different parts of Falbygden. Compare for inst. the St. Backor and Tomten sections. According to the suggested interpretation of the changes of sea-level, these differences would mean that many more oscillations during the Ordovician transgression are recorded by deposits in the former place than in the latter, *i. e.* the Ordovician sea reached St. Backor earlier than it reached Tomten. It will of course also be necessary to take into consideration that the more or less consolidated sediments would have been decomposed during the intermittent transgression. The interpretation of the variations in the Lower Ordovician series — mainly underneath the *Planilimbata* zone — in the district St. Backor—Tomten is diagrammatically sketched in Fig. 7. The dip of the sub-Ordovician surface, which is somewhat exaggerated in this figure, will be dealt with in a later chapter.

The oscillations, during which the individual layers were deposited, gradually accumulated into units of a higher order. This is also supported by the faunistic evidence of the series of strata.

In the Lower Ordovician of Falbygden we record the *Dictyonema* series, the *Ceratopyge forficula* zone, and the *Megalaspis planilimbata* zone. Each of these stratigraphical units has been deposited during an oscillation of a higher order, *viz.* during an oscillatory transgression and the following oscillatory regression. The evidence for this interpretation is given in the preceding chapter — see the descriptions of the St. Backor and Kleva sections.

The correlation in Pl. II, requires some additional notice. As mentioned above (p. 155) the presence of the *Ceratopyge forficula* zone has not been corroborated by the finding of index fossils at all the localities examined. In that respect the correlation is thus only tentative.

The presence of quartziferous strata in the Lower Ordovician of Falbygden and Billingen was recorded by Palmgren (1872) for the first time. Grains of quartz are comparatively common in the upper part of the subdivision B — belonging to the *Ceratopyge forficula* zone — of the St. Backor section, and were observed in those portions of the other sections that are correlated with this zone.

The sub-Ordovician surface.

Stratigraphical investigations have proved that the Ordovician substratum in Falbygden and the adjacent Billingen district belongs to the Upper Cambrian zone of *Peltura scarabaeoides*. According to measurements taken by Westergård (1922, p. 77) the thickness of this zone varies comparatively slightly in different localities; it appears to be thickest, about 7 m, on the western slopes of Mösseberg, and is about 5 m thick elsewhere in Falbygden, where it is completely exposed; as far as is known, it does not exceed 6 m in thickness in Billingen.

The Upper Cambrian terminates in a bed of stinkstone lenses, which are sometimes collected into actual banks, and sometimes separated by alum shale. The sub-Ordovician surface is more or less undulating in the walls of many quarries, and the alum shale often forms the substratum of the Ordovician strata in the depressions. The surface irregularities were gradually filled up and smoothed out during the deposition of the Lower Ordovician series. Owing to the above-mentioned undulation, and to the conditions prevailing during this deposition, the zones of this series are of somewhat varying thickness and development in adjacent sections. This is exemplified by the two profiles from Flittorp (Pl. II).

The depressions in the sub-Ordovician surface and in the subsequently formed erosion surfaces were not entirely filled up until the Limbata limestone was deposited, and the bedding-planes are approximately horizontal above the lowermost part of this limestone (Fig. 8). Measurements of the thickness of the Ordovician strata below the Limbata limestone in different sections will give figures, which of course are only approximately comparable, owing to the impossibility of fixing an equivalent upper limit for the measurement, or of identifying the same bedding-plane in the Limbata limestone in different parts of the district. However, as the local depressions were obviously not very deep a comparison between the measurements taken will give us a good idea of the general dip of the sub-Ordovician surface at the time of the Ordovician transgression.

The following measurements (in metres) of the thickness in question have been taken by the author in Falbygden:

St. Backor 5.1	Uddagården 0.5	Flittorp 0.3 —
Kleva 5	Nya Berga 0.4[1]	Ödegården 0.2 +
Stenbrottet 1.6 +	Bäckabo 0.4[2]	Övertorp 0.3[3]
(Leaby 1 +)	Tomten 0.5 —	Smedsgården 0.9[4]

Fig. 8. Illustrating angular unconformity — mainly by erosion — in the Lower Ordovician in the Nya Berga quarry, 2 km N of Uddagården. The chisel points to the Cambro-Ordovician boundary, the hammer lies on an approximately horizontal beddingplane of the light-grey Limbata limestone. The dark bed below the erosion surface consists of limestone rich in glauconite.

This list clearly shows that the sub-Ordovician surface was almost horizontal in the district within which the localities Uddagården-Övertorp of the above list are situated (cf. Fig. 9), and that from there it dipped towards S or SW. Furthermore, the Smedsgården measurement seems to indicate a dip of the surface towards N or NE. This is corroborated by the fact that the Ordovician strata below the upper limit of the Lower Didymograptus Shale at Stenåsen are 2.1 m thick (Westergård 1922, p. 67).

The present writer can find nothing in literature to show that the junction of the *Limbata* limestone to the *Planilimbata* zone has been determined anywhere on Billingen. It is therefore more difficult to come to a conclusion regarding the dip of the sub-Ordovician surface in that district. We have, however, measurements comparable with that mentioned from Stenåsen. The following list is taken from Westergård (1922, 1926—1928, 1931):

[1] about 2 km N of Uddagården.
[2] » 1 » S » Torbjörntorp stopping-place.
[3] » 2.3 km N of Ödegården.
[4] » 3.5 » NNW of Ödegården.

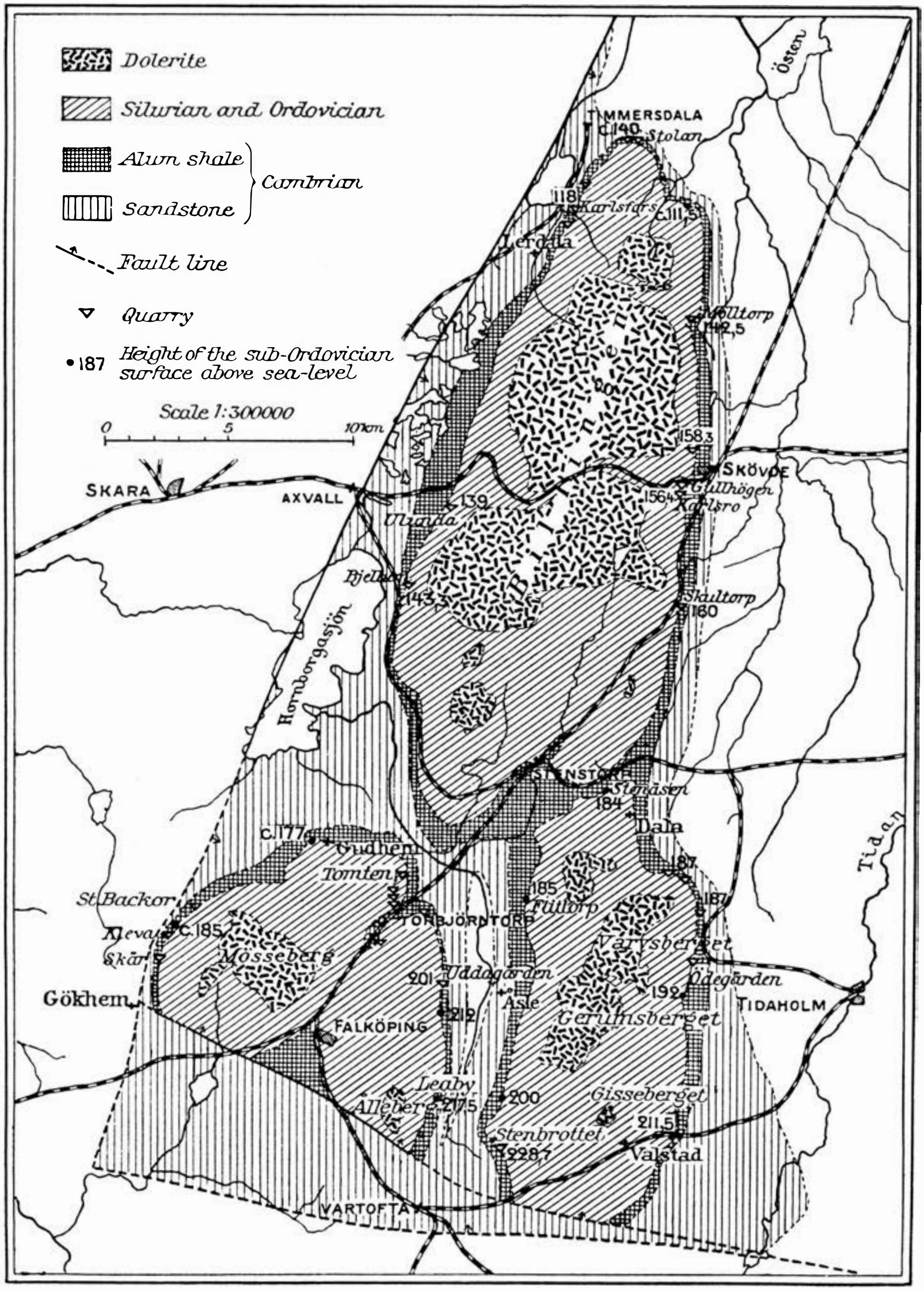


Fig. 9. Map of the Cambro-Silurian district of the Billingen-Falbygden region. — After H. Munthe (1905).

Skultorp	2.2—1.7	m	Rökstorp (1.5 km SSW of Ulunda)	0.65	m
Karlsro	0.25	»	Ulunda	1.3	m
Gullhögen	0.25	»	Karlsfors	2.3	»
Mölltorp	0.15	»	Stolan	2.1	»

In this list, the Ulunda figure seems to be the only one directly comparable with the Falbygden values, as the glauconitic limestone above the Lower Didymograptus Shale was also included in that locality. The Lower Didymograptus Shale is missing at Karlsro, Gullhögen, and Mölltorp, and the figures from there give the thickness of the glauconitic limestone below the bedded, greyish Orthoceras limestone.

These values seem to indicate that the sub-Ordovician surface was on approximately the same level in the eastern portion of the northern part of Billingen (Mölltorp-Karlsro) as in the corresponding part of Falbygden (Ödegården-Övertorp-Flittorp), and that it sloped gently both to the NW and the SW from central Billingen.

If all these values are collated, however, we find that a N—S profile through the Falbygden-Billingen region indicates greater undulations of the sub-Ordovician surface, and that the general dip of that surface was westerly. The latter circumstance, combined with the occurrence of quartziferous deposits in the Lower Ordovician, seems to indicate that outcrops of Archaean rocks occurred in the western parts of Hökensås during the Ordovician transgression.

The dip of the sub-Ordovician surface is also shown in Fig. 9, where its altitude above sea level at a number of places is given (after Munthe, 1905, 1906; Johansson, 1916). As indicated by a comparison of the altitude figures, the present dip — due to faults — is on the whole towards the NNW, with some minor anomalies, however, *e. g.* within central and northern Billingen (cf. Högbom, 1931, p. 70), and in the Åsle valley that separates the eastern and western parts of Falbygden. Possibly, these anomalies are due to flexures in connection with the fault-action.

List of references.

G. F. F. = Geologiska Föreningens Förhandlingar.
S. G. U. = Sveriges Geologiska Undersökning.
K. V. A. = Kungl. Svenska Vetenskapsakademien.

ANDERSSON, J. G. (1895), Über cambrische und silurische phosphoritführende Gesteine aus Schweden. Bull. of the Geol. Inst. of Upsala. Vol. II, Part 2.

——. (1896), Redogörelse för studier öfver svenska kambrisk-siluriska, fosforitförande bergarter. G. F. F. Bd 18.

——. (1897), Om fosforitbildning och fosforitförande sediment. G. F. F. Bd 19.

BRÖGGER, W. C. (1882), Die silurischen Etagen 2 und 3 im Kristianiagebiet. — Kristiania.

BULMAN, O. M. B. (1936), On the graptolites prepared by Holm. Part VII. K. V. A. Arkiv för zoologi. Bd 28 A, No. 17.

HEDSTRÖM, H. (1896), Till frågan om fosforitlagrens uppträdande och förekomst i de geologiska formationerna. G. F. F. Bd. 18.

——. (1922), Om vanadinhaltigt stenkol i Västergötlands kambro-silur. S. G. U. Ser. C, N:o 318. Årsbok 16, N:o 8.

HÖGBOM, A., WESTERGÅRD, A. H. och LUNDQVIST, G. (1931), Beskrivning till kartbladet Lugnås. S. G. U. Ser. Aa, N:o 172.

LINNARSSON, G. (1879), Ceratopygekalk och undre graptolitskiffer på Falbygden i Västergötland. G. F. F. Bd 4.

——. (1880), Dictyonemaskiffer vid Orreholmen i Västergötland. G. F. F. Bd 5.

JOHANSSON, E. S. T. (1916), Dagbok till kartbladet Lugnås. S. G. U:s Arkiv.

MOBERG, J. CHR. och SEGERBERG, C. O. (1906), Bidrag till kännedomen om Ceratopygeregionen etc. Meddelande från Lunds Geol. Fältklubb. Ser. B, N:o 2.

MUNTHE, H. (1905), De geologiska hufvuddragen af Västgötabergen och deras omgifning. G. F. F. Bd 27.

——. (1906), Beskrifning till kartbladet Falköping. S. G. U. Ser. Aa, N:o 120.

——. (1906), Beskrifning till kartbladet Tidaholm. S. G. U. Ser. Aa, N:o 125.

PALMGREN, L. (1872), Om svenska fosforitförande konglomerat. Bihang till K. V. A:s Handlingar. Bd 1, N:o 6.

VON POST, L. (1906), Bidrag till kännedomen om Ceratopygeregionens utbildning inom Falbygden. G. F. F. Bd 6.

WESTERGÅRD, A. H. (1909), Studier öfver Dictyograptusskiffern och dess gränslager. Lunds Univ. Årsskrift, N. F. Afd. 2. Bd 5, N:o 3.

——. (1922), Sveriges olenidskiffer. S. G. U. Ser. Ca, N:o 18.

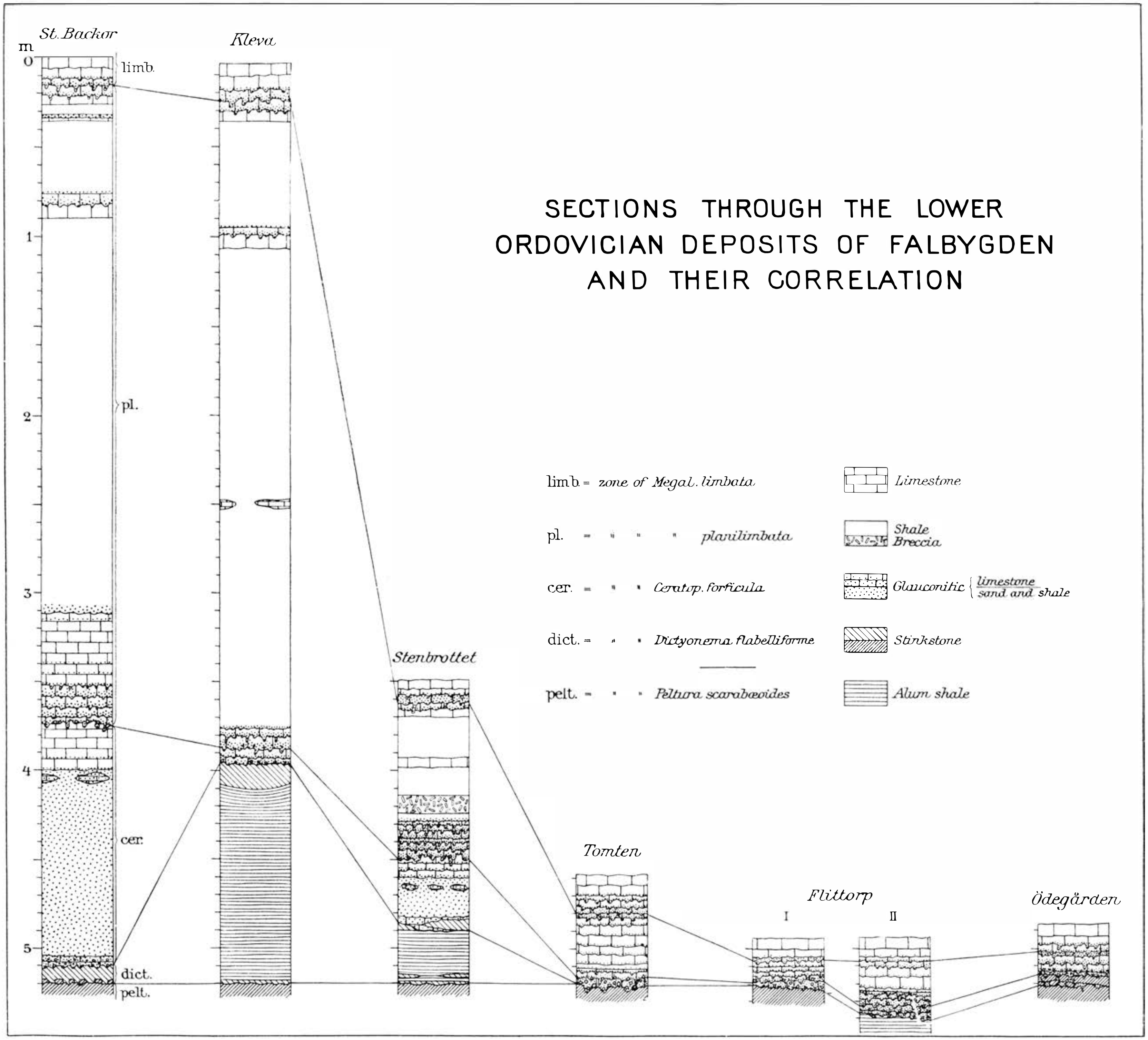
——. (1926, 1927), Dagböcker till kartbladet Skövde. S. G. U:s Arkiv.

——. (1928), Beskrivning till kartbladet Skövde. S. G. U. Ser. Aa, N:o 121. 2:dra uppl.

——. (1931), see Högbom, A. och Lundqvist, G.

WIMAN, C. (1902), Studien über das Nordbaltische Silurgebiet. Bull. of the Geol. Inst. of Upsala. Vol. 6.

Printed 19/2 *1937*.


SECTIONS THROUGH THE LOWER ORDOVICIAN DEPOSITS OF FALBYGDEN AND THEIR CORRELATION
St. Backor
Kleva
Stenbrottet
Tomten
Flittorp
I
II
Ödegården
m
0
1
2
3
4
5
limb.
pl.
cer.
dict.
pelt.
limb. = zone of Megal. limbata
pl. = " " " planilimbata
cer. = " " Ceratop. forficula
dict. = " " Dictyonema flabelliforme
pelt. = " " Peltura scarabæoides
Limestone
Shale
Breccia
Glauconitic { limestone / sand and shale
Stinkstone
Alum shale