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THE CAMBRIAN, ORDOVICIAN, AND SILURIAN IN VÄSTERGÖTLAND, NÄRKE, DALARNA, AND JÄMTLAND, CENTRAL SWEDEN

GUIDE TO EXCURSIONS NOS A 23 AND C 18

By

P. THORSLUND AND V. JAANUSSON

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Excursion No A 23: Aug. 4th—Aug. 14th, 1960

Excursion No C 18: Aug. 26th—Sept. 5th, 1960

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Introductory Notes

By

PER THORSLUND

Outside the Scandinavian mountain range the Cambro-Silurian rocks are preserved in different ways within a number of areas. Between these there exist fairly easily demonstrable differences especially in the tectonic structure and the composition of the rock sequence. An exception is the Cambrian sequence the lithological succession of which is similar in different areas, and which exhibits a change from sediments rich in sand and poor in lime in its lower portion to shales rich in kerogen (alum shale) and with a variable content of lime in its upper portion. A general survey of the Ordovician and Silurian deposits reveals a pronounced dominance of limestones in the sequence of the Baltic and southern Bothnia, a corresponding dominance of shales in Scania, and an alternation of these types of sediments within the other areas. Exceptions are found in the great foreland area of the Caledonian mountains in Jämtland and adjacent parts of Ångermanland and Västerbotten. In this, the largest area within our country with a continuous Cambro-Silurian rock floor, we meet with special conditions that are obviously connected with the position of the original area of sedimentation at the western margin of the Baltic shield in the north-European Precambrian block and with the development in the Caledonian geosyncline during the Ordovician and Silurian periods.

The nature and the small thickness of the sediments disclose their epicontinental nature and their deposition or formation in shallow seas. They evidently appear to have originated essentially in connection with eustatic changes of level that had led to transgressions over the Baltic shield. At its south-western margin in Scania we must, however, count also with vertical movements of the earth's crust as a cause of the particularly great thickness of the late Silurian deposits in this region. A similar presumably trough-shaped subsidence has probably taken place also during the Ordovician along the north-western margin of the block east of the Caledonian eugeosyncline.

Provided that the Cambrian deposits are fossiliferous, correlation between the mostly rather distant areas does not present any difficulties. This is the result of the uniform character of the shelly Cambrian faunas in the different series and their biostratigraphical components. Such problems have, however, always existed within the Ordovician and Silurian systems, and have been caused by the great faunistic differences between their limestones and shales, i.e. by the occurrence of two facies characteristic for these systems, viz. the shelly and the graptolitic facies, respectively. A rich and differentiated flora and fauna has likewise contributed to the formation of local masses of limestone, so-called reef limestones. The fossils occurring in these bodies are seldom found outside the particular facies, and on this account it has sometimes been difficult to attribute to these limestones their correct places in the stratigraphical scheme.

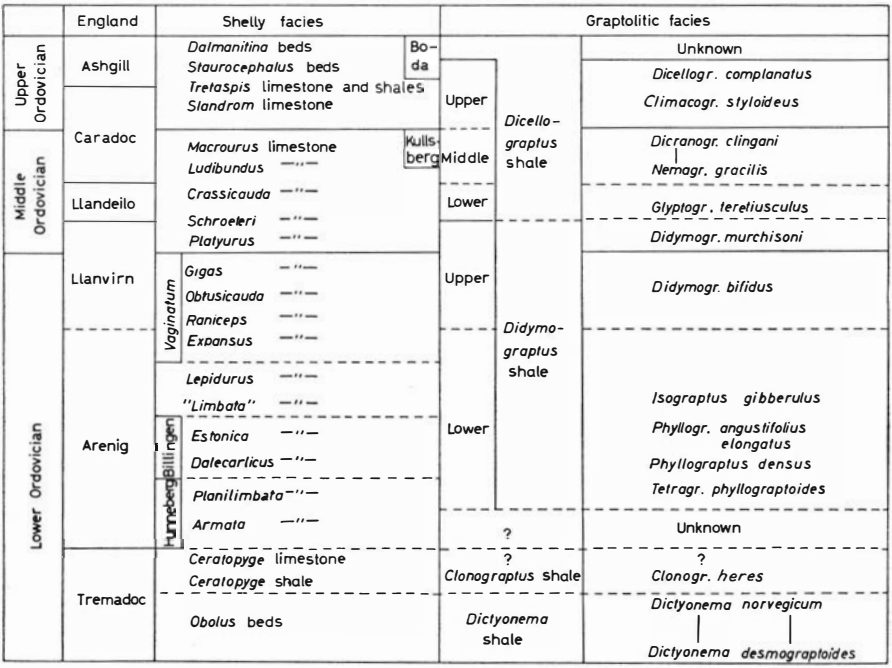
The correlation on the basis of biostratigraphical data is aided to a certain extent by the layers of metabentonite which occur in the Middle Ordovician *Ludibundus* division and the contemporaneous graptolite shales on one hand, and on the other hand in the (Silurian) Upper Llandovery shales and contemporaneous calcareous sediments. On account of the fact that these volcanic sediments have been spread almost instantaneously from the geological point of view they now enable us to pick out synchronous surfaces of sedimentation, and in this way to obtain an exact correlation of certain smaller portions in the sedimentary series of the different areas.

The above brief review containing some general points of view with regard to the sequence in our different Cambro-Silurian areas is intended only as an introduction to the short descriptions which are added to the guides for the excursion areas. In order to facilitate understanding stratigraphic tables with the classification adopted in this paper are given below.

CAMBRIAN

Upper Cambrian Olenid Series	*Acerocare*	
	Peltura scarabaeoides	
	Peltura minor	
	Protopeltura praecursor	
	Leptoplastus and *Eurycare*	
	Parabolina spinulosa and *Orusia*	
	Olenus and *Agnostus obesus*	
	Agnostus pisiformis	
Middle Cambrian *Paradoxides* Series	*Forch-hammeri* stage	*Lejopyge laevigata*
		Solenopleura brachymetopa (Andrarum Limestone)
		Ptychagn. lundgreni and *Goniagn. nathorsti*
	Paradox-issimus stage	*Ptychagn. punctuosus*
		Hypagn. parvifrons
		Tomagn. fissus and *Ptychagn. atavus*
		Ptychagn. gibbus
	Oelandicus stage	*Paradoxides pinus*
		Paradoxides insularis
Lower Cambrian Series	*Strenuella linnarssoni*	
	Holmia kjerulfi	
	Volborthella and *Platysolenites*	
	Discinella holsti	

ORDOVICIAN



SILURIAN

England	Graptolite zones	Scania	Västergötland (Kinnekulle)	Dalecarlia	Jämtland	Gotland
Ludlow	(Graptolitic facies unknown in Sweden)	Öved-Ramsåsa (100 —300m.)		? Orsa sandstone ?		Sundre 10m Hamra 40 Burgsvik 50 Eke 15 Hemse 100 Klinteberg 100
	Monogr. scanicus " *nilssoni*	*Colonus* shale (c. 600m.)				Mulde 25 Halla 15 Slite 100
Wenlock	*Cyrtogr. lundgreni* and *Monogr. testis* *Cyrtogr. rigidus* *Monogr. riccartonensis* *Cyrtogr. murchisoni*	*Cyrtograptus* shale (c. 350 m.)		*Burnastus limest.*	Ekeberg greywacke	Tofta 10 Högklint 35
Llandovery Upper	" *lapworthi* *Monogr. spiralis* " *discus* " *turriculatus* " *sedgwicki*		*Retiolites* shale (26m.)	Styggfors " *Retiolites* shale	? Bångsåsen shales	Upper Visby 15 Lower Visby Grey mudstone Red -"-
Llandovery Middle	*Cephalogr. cometa* *Petalolithus folium*	*Rastrites* shale (c. 120 m.)	*Rastrites* shale (29.4 m.)	*Rastrites* shale (c. 50m.)	Berge limestone	Mudstone and limestone
Llandovery Lower	*Monogr. gregarius* " *revolutus* *Rhaphidogr. extenuatus* *Akidogr. acuminatus* *Glyptogr. persculptus*			Poorly fossiliferous grey and red marly shales ?	Ede quartzite ? Upper Kyrkås	Hiatus

Notes on the Geology and Stratigraphy of Västergötland

By

PER THORSLUND

In the exploration of the Cambro-Silurian sequence of our country the mountains of Västergötland are classical ground, thanks especially to the work of Gustaf Linnarsson in the second half of the nineteenth century. Here the sequence is spread over a fairly large area comprising Billingen and the mountains of Falbygden (Mösseberg, Varvsberget, etc., *cf.* Fig. 1), whereas the occurrence in Mts Halleberg, Hunneberg, Kinnekulle, and the "mountain" of Lugnås can be regarded as outposts of this area. The easily eroded sediments have been preserved in their extension thanks to protection by dolerites, once as sills within the Silurian shales, and also to downward movement along faults. In Mts Halleberg and Hunneberg the dolerites cut obliquely across Cambrian and Lower Ordovician sediments.

Most of the mountains are terraced plateau mountains, and thus terminated above by wide plane surfaces of dolerite. Exceptions are provided by the "mountain" of Lugnås which is a comparatively low hill without dolerite covering, and where no higher part of the sequence is represented than the Upper Cambrian zone of *Parabolina spinulosa,* and by Mt Kinnekulle resembling in its upper part the frustrum of a cone with a small cap-like remnant of dolerite on the very top. The beds rest practically horizontally upon the sub-Cambrian peneplane that is locally exposed in the plains near the plateau mountains. Between the mountains the peneplane extends in a hardly modified condition, and continues westward around Lake Vänern, where we find in the flat Archaean surface of Dalsland fissures filled with fossiliferous Cambrian sandstone.

This briefly described geomorphology imprints upon the mentioned part of the province a stamp that is peculiar among the Cambro-Silurian regions of our country. With regard to the sequence of strata it is admittedly possible to point to many details of development and changes in horizontal direction, but there exists with few exceptions a close agreement with contemporaneous formations of Närke.

In the Lower Cambrian sandstone series two divisions can be distinguished, viz. the *Mickwitzia* sandstone which is rich in clayey matter and in part thin-bedded, and on top of it the light, thick-banked *Lingulid* sandstone that consists of almost pure quartz sand. The series has an average thickness of about 30 m, in Mt Kinnekulle 34 (10 + 24) metres. Its heads form in several places steep cliffs, called locally "sandstensklev". The coarse basal beds, that are encountered in depressions of the not very deeply weathered underlying gneiss, consist of coarse sandstone rich in felspar, arkose, or conglomerate with fragments of different rocks and minerals, amongst others rounded pieces of quartz with wind-worn surfaces, occasionally in the form of dreikanters, and of a rock rich in siderite probably derived from a continental sediment. The sandstone divi-

sions and especially the lower of them contain numerous casts of tracks of trilobites and other organisms. They are found upon clayey and shaly bedding planes upon which we also find radially symmetrical natural casts of medusae, while the sandstone layers contain vertical, straight and simple or U-shaped fillings of tubes of worms as is usual in the sandstones of the Lower Cambrian.

Close to or at the very boundary towards the Middle Cambrian series the lingulid sandstone possesses a conglomeratic bed with well rounded pebbles of dark phosphoritic sandstone. A similar conglomerate, but with a matrix very rich in glauconite occasionally introduces the Middle Cambrian series which otherwise begins with a phosphoritic sandstone rich in glauconite or with a greenish-grey glauconitic shale. These beds belong to the *Paradoxissimus* stage. The stratigraphic gap at the boundary in question thus represents not only the uppermost zone of the Lower Cambrian the sediments of which are known in our country in Scania and in the marginal Caledonian mountains of Lappland, but also the *Oelandicus* stage of the Middle Cambrian.

With the exception of the comparatively thin basal beds the Middle Cambrian series and the entire Upper Cambrian of Västergötland are developed as alum shales with bituminous limestone (stinkstone). The combined thickness of these series amounts to 22—23 m. The content of limestone is high, but varying; remarkable in this respect is Mt Kinnekulle, since there the quantity of limestone in the Upper Cambrian series increases considerably in western direction, and forms up to one half of the beds in the alum shale terrace at the western slopes of the mountain. The series contain two persistent conglomeratic horizons, occurring in the limestone beds. One of the horizons is the thin *Exporrecta* conglomerate representing the middle zone of the *Forchhammeri* stage, the other is the partly conglomeratic so-called "great stinkstone bed" in the lower part of the Upper Cambrian series, a usually more than 1 m thick bed comprising 3—4 of the lowermost zones of the series. In addition to these there occur in several places conglomerates in the upper stinkstone beds of the *Peltura* zone. — In Mt Kinnekulle the uppermost stinkstone beds contain chert.

The content of natural oil in the alum shale varies in vertical direction, and is greatest in the beds immediately above the great stinkstone bed. It is also subject to a certain variation in horizontal direction, and is greatest in Mt Kinnekulle, where content of oil and thickness of the layers rich in oil increase towards the north-eastern part of the mountain. On account of distillation which probably has taken place in connection with the intrusion of the dolerite sills the content of oil is considerably smaller in the other mountains, and in Mts Halleberg and Hunneberg the shale is almost completely coked. A product of the distillation is the so-called vanadium-bearing coal, an easily crumbling asphaltite, occurring in thin layers or as a film upon the bedding planes, but also as fillings of vertical fissures within the sequence at the boundary between the Cambrian and Ordovician systems of Mt Billingen and in Falbygden.

In Västergötland the alum shale has been extensively used mainly as fuel in lime-kilns, but also as raw material in the manufacture of Ytong, a porous building stone. Its relatively high content of uranium, especially in Mt Billingen, has opened new possibilities for its exploitation. This content has its maximum in the "kolm", a kind of coal rich in ashy material which occurs as lenses within the *Peltura* beds, and which is most abundant in the northern part of Mt Billingen.

The alum shale group includes the Tremadocian *Dictyonema* shale, which in Västergötland is fairly thin, attaining only in exceptional cases a thickness of little more than 1 m, and which occurs only in the southern part of Falbygden and in Mt Hunneberg. The sequence of strata in Västergötland exhibits furthermore a stratigraphic gap of varying size at the lower boundary of the Ordovician system. Biostratigraphically this gap can be demonstrated in the alum shale group within the parts of the area, where it contains also the *Dictyonema* shale. Within other parts it is well marked also lithologically, and as a rule larger.

Lithologically the Ordovician sequence, which in Mt Kinnekulle reaches a thickness of 115 m, can be divided into two divisions. The lower of these comprises the lower and middle series of the system, and is built up mainly of beds of limestone, whereas the upper one represents the Upper Ordovician series, and consists of mudstones and shales with few beds of limestone. The boundary between these two divisions is indicated by the plane of the upper terrace from which the slopes rise steeply to the dolerite plateau, especially on the eastern and western side of Mt Kinnekulle.

The *Ceratopyge* beds of the Lower Ordovician series consist in several places of both soft glauconitic shale and hard limestone, and are found in the same areas as the *Dictyonema* shale, but in addition also in Mt Kinnekulle. The following Hunneberg and Billingen stages have a much greater extension. Their sediments have been deposited during times of intermittent transgressions with a main direction from west towards east within Västergötland. The repeated interruptions of the sedimentation are marked in Mt Billingen and the Falbygden by numerous surfaces of discontinuity in the limestone beds. The preponderant direction of the transgressions has been determined by a comparison between the stratigraphic completeness of the sequences of the stages in different localities. This comparison has shown that at Mt Hunneberg the sedimentation has been going on without noticeable interruption from the deposition of the *Ceratopyge* limestone into the upper Billingen stage or as far as the sequence of strata is preserved in the mountain, that on the western slopes of Mt Mösseberg the Hunneberg stage is incompletely represented, while the Billingen stage is well developed and relatively thick, and that these two stages thin out, become increasingly incomplete, and are occasionally lacking in the slopes of the mountains of eastern Falbygden that face the mountain Hökensås. In Mt Hunneberg graptolite shales occur also in the Hunneberg stage which otherwise consists mainly of glauconitic limestone, while the Billingen stage is represented in several places by the Lower *Didymograptus* shale or, as e.g. in the northern part of Mt Billingen, is developed with a mixed facies, graptolitiferous clayey shales with intercalations of limestone.

The shelly facies of the Hunneberg and Billingen stages and the succeeding "*Limbata*" limestone form the basal part of the so-called Orthoceratite limestone which is a group of bedded limestones with a thickness of the beds between some few centimetres and 10—12 cm. Its examination is still incomplete in several respects. Stratigraphically the group reaches up into the Middle Ordovician series, where it can in part consist of grey calcareous mudstone and knobby limestone. Its thickness amounts to about 50 m in Mt Kinnekulle, but is 5—10 m smaller in Mt Billingen and the Falbygden. It occupies the largest surface of the Cambro-Silurian formations in Västergötland. With regard to the colour, which is reddish brown or grey in different shades, the group in Mt

Kinnekulle has since old been divided into four divisions. But since the colour changes in horizontal direction such a division is without value for correlation. In Mt Kinnekulle two divisions of red limestone have been distinguished of which the lower one has a thickness of nearly 20 m, comprises the entire "*Limbata*" limestone, and extends upwards into the *Vaginatum* limestone. It is this co-called "lower red rock" that is mainly quarried here for the manufacture of cement. This group, with the exception of its upper clayey portions, is exploited for the same purpose in Mt Billingen near Skövde, where the bedded limestone corresponding to the "lower red rock" of Mt Kinnekulle is mainly greyish. From the lower portions of the group limestone is taken in several places for burning, but also other parts of it have been quarried for industrial purposes.

Above the Orthoceratite limestone the Middle Ordovician series is rich in mudstones, and consists apart from them of beds of marly limestone, and on the very top, at least in Mt Kinnekulle, of dark graptolite shale with *Dicranograptus clingani*. Within this series the greatest interest attaches to the beds of metabentonite within the *Ludibundus* division. In Mt Kinnekulle they are more numerous and thicker than elsewhere. The mudstones and beds of limestone which directly underlie these beds are strongly silicified, sometimes resembling chert. From the geomorphological point of view the occurrence of the soft and loamy bentonite beds ought to have contributed in an essential degree to the formation of the upper terrace plane, its notch in the steep slopes of the mountains being situated below the head of the thickest among these layers. The upper bentonite bed is a horizon with numerous springs, the bentonite swelling when moistened, and thus preventing the continued descent of the water from the overlying fissured rocks.

The Upper Ordovician series is separated from the Middle Ordovician by a break, and begins with a division of dark, grey, or green, occasionally calcareous shales and mudstones which within certain regions are overlain by a bed of "masur limestone". The basal beds consist usually of dark or black shales containing in Kinnekulle a graptolite fauna with *Climacograptus styloideus*. The "masur limestone", which is a finely nodular dark calcilutite traversed by narrow fissures filled with calcite, is overlain by reddish brown, partly greenish mudstones with a well preserved shelly *Tretaspis* fauna. On top of them there follow within Mt Billingen and the Falbygden dark and grey-mottled shales with scattered beds of limestone. The *Staurocephalus* beds are represented by such a grey-mottled dark shale which by its fossil contents can be distinguished in the mountains of the Falbygden, but not in Mt Billingen. In Mt Kinnekulle it probably has its counterpart in partly fine-sandy mudstone.

The lithological development of the uppermost stage of the Ordovician, the *Dalmanitina* beds, is somewhat varying in horizontal direction, but displays everywhere a characteristic feature in an otherwise pelitic sedimentary sequence. The stage is obviously formed by shallow water deposits. In Mts Kinnekulle and Billingen it includes a bed of limestone which in part has fine-sandy portions. In Mt Kinnekulle it merges into calcareous sandstone, and is delimited by surfaces of discontinuity, while the mountains of the Falbygden exhibit a thick-banked, greyish blue, calcareous siltstone with intercalations of limestone. On weathering it assumes a brownish grey colour. In Mt Ålleberg the siltstone contains portions with cross-bedding and a bed of limestone in part rich in

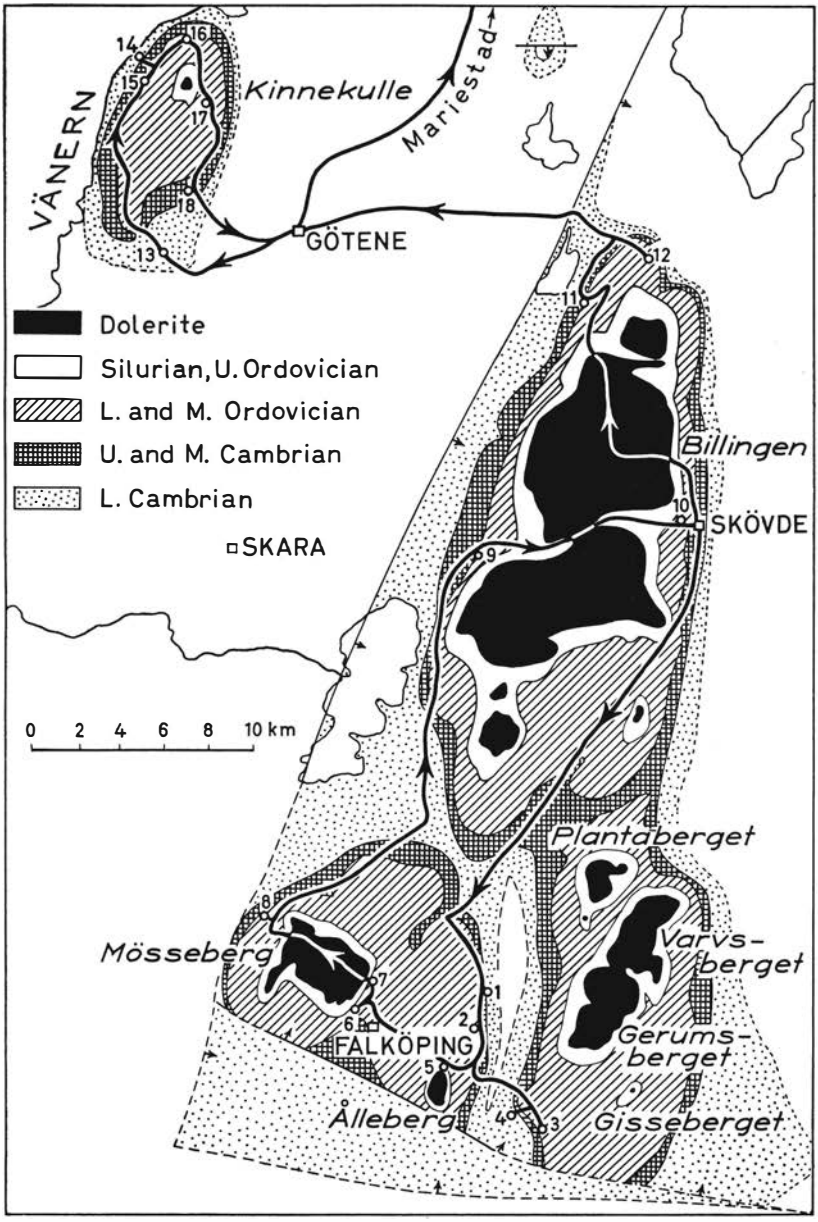


Fig. 1. Map of Mt Kinnekulle and the Billingen-Falbygden district. After H. Munthe.

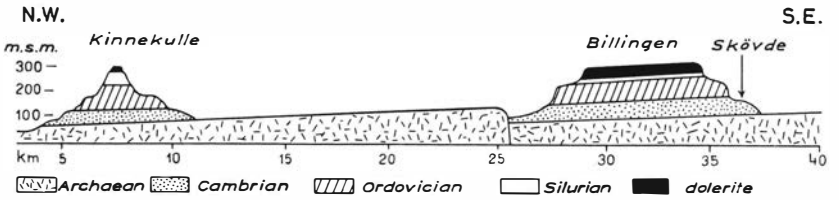


Fig. 2. Diagrammatic section from Västergötland.

corals. The latter is locally developed as a conglomerate with pebbles of grey limestone. Also the occurrence of ripple-marks in thin-bedded calcareous siltstone in Mt Billingen points to deposition in shallow water.

Of the Silurian we find in Västergötland only the lower division or Llandovery series. It is most complete in Mt Kinnekulle, where the thickness has been measured to 55.4 metres. Of these 26 m belong to the *Retiolites* shale. Upon the other mountains the dolerite rests almost everywhere directly upon the *Rastrites* shale, and only in Mt Billingen the sequence of strata has in one locality N.E. of Öglunda been found to be terminated above by a *Retiolites* shale of ca. 2 m thickness. The Silurian sediments are burned or otherwise influenced by the heat of the dolerite magma. The depth of these changes varies. From the lithological point of view the sediments are variable, and consist by no means exclusively of black graptolite shales, but to the greatest part of grey and dark mudstones with intercalations of black mudstone or shale. The lower and middle portions of the sequence sporadically contain layers or lenses of limestone, while the uppermost portion possesses parts of reddish mudstone, thin layers of metabentonite spread within the sediments of the three lower zones and thin fine-sandy intercalations in the lower *Retiolites* sediments of Kinnekulle.

Västergötland, Road-Log

By

P. Thorslund and V. Jaanusson

FIRST DAY

Start from Skövde (22,700 inhabitants) at 8^{30} a.m. The bus runs S.S.W. along the S.W. slope of Mount Billingen to Torbjörntorp village, where it crosses an ancient outlet of the Baltic ice-dammed lake, and continues S.S.E. upon the flat surface formed by Lower Ordovician limestones to Djupadalen.

STOP 1. Djupadalen (= Deep Valley), eroded into the lowermost Lower Ordovician limestones, Upper and Middle Cambrian shales, and the topmost Lower Cambrian sandstones. The lowermost part of the section exposes glau-

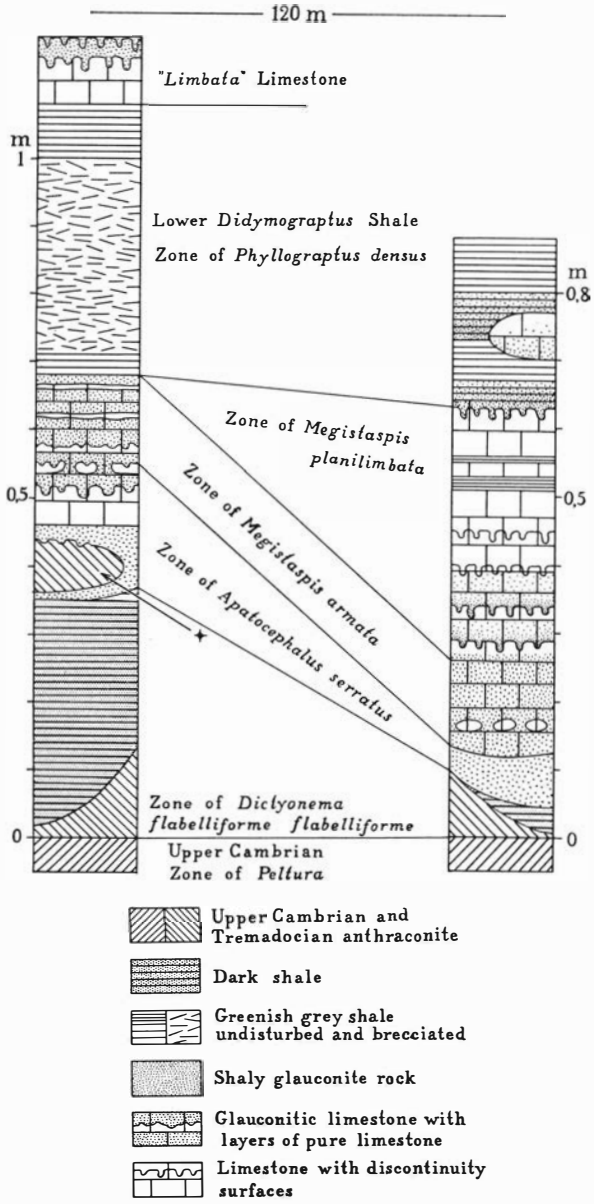


Fig. 3. Diagrammatic sections of the Lower Ordovician sequence at Stenbrottet. After T. Tjernvik. The section to the right is situated 120 m S. W. of that to the left. *x* points to a boulder of stinkstone from the zone of *D. flabelliforme*.

conitic sandstone of the Middle Cambrian *Paradoxides paradoxissimus* stage overlying, with a conglomerate at the base, the Lower Cambrian sandstone. The overlying sequence consists of dark brown poorly fossiliferous shale with large limestone lenses ("orsten") which are occasionally rich in well-preserved fossils. The shale sequence includes the Middle Cambrian *Paradoxides paradoxissimus* and *P. forchhammeri* stages, and the Upper Cambrian with the zone of *Peltura scarabaeoides* on the top.

The bus drives southwards along the western slope of the Åsle valley. Mt Gerumsberget across the valley.

STOP 2. Neolitic passage graves 0.3 km N. of Karleby church.

The bus drives farther southwards (Ålleberg Mountain to the right), and crosses the Åsle valley.

STOP 3. Stenbrottet (Orreholmen). Upper Cambrian bituminous shales ("alum shales") overlain by Lower Ordovician beds. The Lower Ordovician sequence begins with shale containing limestone nodules, and belonging to the Lower Tremadocian zone of *Dictyonema flabelliforme*. The sub-Ordovician surface is highly uneven, and the thickness and development of the basal Ordovician beds varies in different parts of the quarry. In the N.E. corner of the quarry the *Dictyonema* shale is overlain by *Ceratopyge* limestone, missing in the S.W. corner. In the latter place limestones of the zone of *Megistaspis planilimbata* attain 0.37 m in thickness, but in the N.E. corner the Billingenian *Didymograptus* mudstone directly overlies the zone of *Megistaspis armata*. For further details, see Fig. 3. Note the discontinuity ("corrosion") surfaces in the limestone at several levels.

STOP 4. Rännefalan. A well-developed delta built by streams entering from glacier ice into an ice-dammed Gotiglacial lake. Notice the steep and lobate distal slopes of the delta.

The bus drives in western direction across the Åsle valley to Ålleberg.

STOP 5. Ållebergsände (Northern end of Mt Ålleberg). Ascend the hill. Upper Ordovician and Lower Silurian mudstones, shales, and siltstones with some limestone beds. The section is as follows (measured by G. Henningsmoen in 1944):

Silurian. 3 m +. Mudstone and shale.
Ordovician.
Dalmanitina beds 2.50 m
0.70 m. Calcareous siltstone, in the middle part speckled.
0.40 m. Limestone with irregular layers or spots of shale, in places cross-bedded. Tetracorals occassionally abundant.
1.40 m. Calcareous siltstone.
Tretaspis beds 6.55 m +
0.85 m. Speckled mudstone contaning the fauna of the zone of *Staurocephalus clavifrons*.
0.85 m. Black mudstone.
0.35 m. Speckled mudstone with intercalations of black mudstone.
0.50 m. Dark, in part speckled mudstone with a reddish tint.
4.00 m +. Reddish brown mudstone with intercalations of green mudstone.

To Falköping (13,800 inhabitants). Stop for lunch. The mountain W. of the city is Mösseberg.

The bus drives to Bestorp on the S.W. slope of Mt Mösseberg.

STOP 6. Bestorp. Almost complete section through the Upper Ordovician mudstones and the lowermost Lower Silurian. The section is as follows (meas-

ured by G. Henningsmoen in 1944, lower part revised by P. Thorslund and V. Jaanusson in 1959):

Silurian. 3 m +. Mudstone and shale
Ordovician.
Dalmanitina beds 1.5—2.0 m
1.5—2.0 m. Calcareous siltstone with a thick bed of dense limestone.
Tretaspis beds *c.* 27.50 m
8.15 m. Dark grey to black shale and mudstone, speckled close to the top.
10.06 m. Brownish red mudstone with intercalations of some greenish grey beds.
4.85 m. Covered.
c. 2.60 m. Grey to green mudstone, in part speckled.
0.60 m. Brownish red mudstone.
0.15 m. Grey to green mudstone in part speckled.
0.08 m. Dark, dense limestone.
1.01 m. Dark grey to black mudstone, in part speckled.
Middle Ordovician?
3.64 m +. Dark, dense, regularly bedded limestone with intercalations of thin layers of shale.

Northwards along the eastern slope of Mt Mösseberg to the road across the mountain.

STOP 7. Contact between the Silurian (Llandoverian) graptolitic shales and the dolerite. Notice the burnt condition of the shales below the dolerite.

The bus ascends to the top plateau of Mt Mösseberg, and drives across the mountain in north-western direction upon the dolerite plateau. It descends the mountain on its W. side, and turns to the right at the first turning. Before and after the turn small quarries in the Middle Ordovician *Crassicauda* Limestone to the right.

STOP 8. Stora Backor. Upper Cambrian bituminous shales with limestone beds and lenses ("orsten") and Lower Ordovician glauconite sandstone, limestone, and mudstone. For details, see Fig. 4. Asphaltite as drops or thin layers in the glauconitic basal Ordovician beds and in the *Didymograptus* shale.

The bus drives along the N.W. slope of Mt Mösseberg and along the W. slopes of S. Billingen.

STOP 9. Varnhem church and ruins of the monastery. After a fire in 1234 the present church was built in traditional style (between Roman and Gothic). The floor near the altar, made of stone and adorned with carved foliage, contains the tombstone of Birger Jarl (d. 1266), regent of Sweden and the probable founder of Stockholm.

The bus drives across Billingen to Skövde. Note dolerite in road-cuts. Dinner in Skövde.

SECOND DAY

Start from Skövde at 8^{00} a.m. A short drive to the Gullhögen cement factory.

STOP 10. Uppermost beds of the Upper Cambrian shale and Lower and Middle Ordovician limestones. Particular attention will be paid to the contact between the Cambrian and Ordovician Systems and to the lowermost Middle Ordovician *Platyurus* Limestone (here only 14 cm thick). The section is as follows (unpublished data by V. Jaanusson):

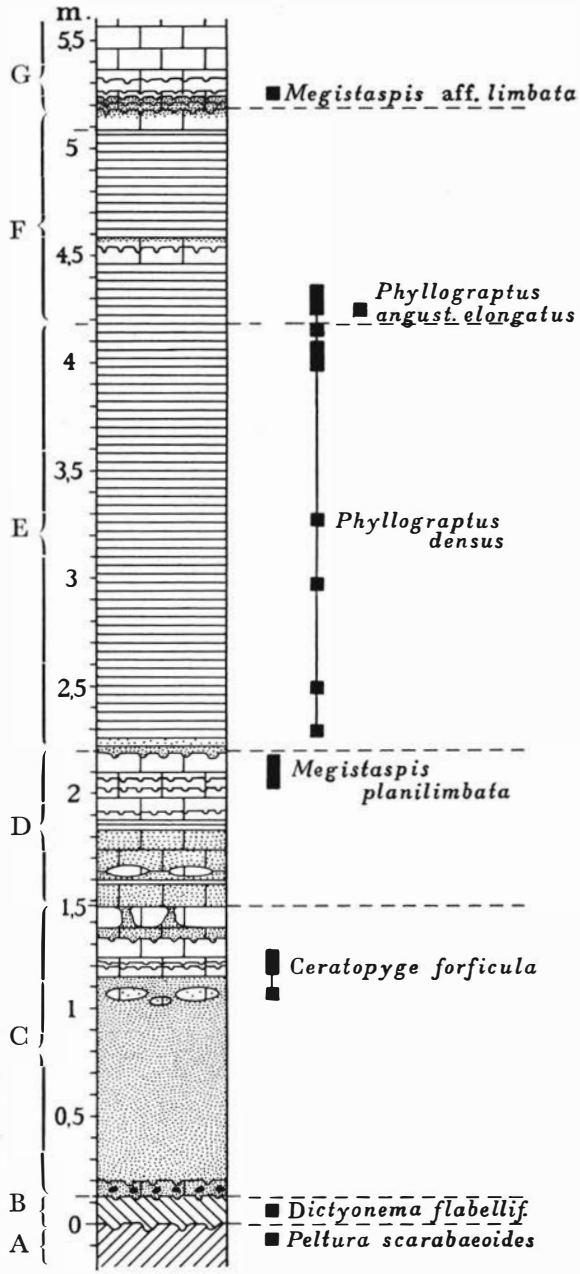


Fig. 4. Diagrammatic section of the lower Ordovician sequence of Stora Backor. After Tjernvik. For legend, see Fig. 3. *A*, Upper Cambrian; *B-C*, Tremadocian; *D-G*, Arenigian. *B*, zone of *Dictyonema flabelliforme? flabelliforme*; *C*, zone of *Apatokephalus serratus*; *D*, zone of *Megistaspis planilimbata*; *E*, zone of *Phyllograptus densus*; *F*, zone of *Phyllograptus angustifolius elongatus*; *G*, "*Limbata*" limestone.

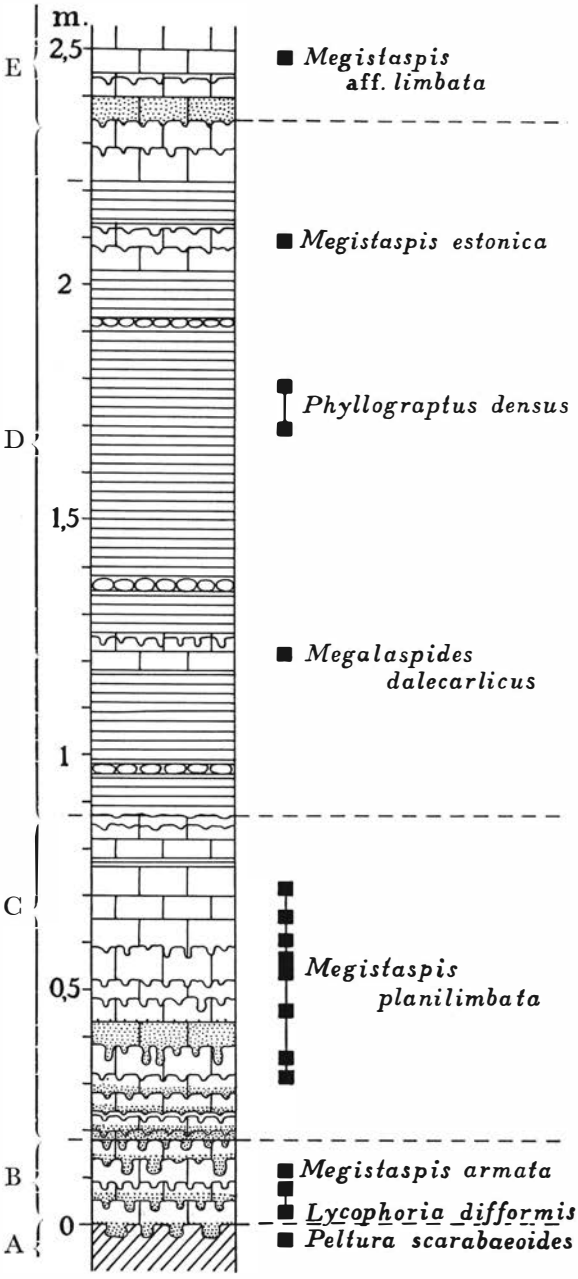


Fig. 5. Diagrammatic section of the Lower Ordovician sequence of Stora Stolan. After T. Tjernvik. For legend, see fig. 3. *A*, Upper Cambrian; *B-E*, Arenigian.

Middle Ordovician 15 m +.
Crassicauda and *Schroeteri* beds
Grey, occasionally reddish brown spotted limestones, in part nodular with intercalations of mudstone ..... 15 m +
Platyurus Limestone
Reddish brown limestone, in part abounding in chamosite ooids. Lower and upper boundary defined by discontinuity surfaces ..... 0.14 m
Hiatus comprising the lower zone of the *Platyurus* beds.
Lower Ordovician 21.2 m
Vaginatum and "*Limbata*" Limestones
Reddish brown argillaceous limestone ..... 0.6 m
Finely nodular reddish brown limestone ..... 1.5 m
Reddish brown limestone ..... 8.1 m
Alternating grey, greyish brown, and pale reddish brown limestone .. 2.2 m
Light grey limestone ..... 8.1 m
Billingen Stage
Grey limestone, in part rich in glauconite, in the lower part with pebbles derived from the underlying beds. Lower and upper boundary defined by discontinuity surfaces ..... 0.7 m
Hiatus comprising the Hunneberg Stage and the Tremadocian Subseries
Upper Cambrian
Hiatus comprising the uppermost Upper Cambrian zone and two subzones of the *Peltura* zone
Dark bituminous shale with lenses of stinkstone ..... 8 m +

Back to Skövde and farther northwards. The bus ascends the eastern slope of Mt Billingen (dolerite in the road cutting), and crosses the dolerite plateau of northern Billingen.

STOP 11. Karlsfors. Asphaltite containing vanadium occurs as intercalations between beds of Lower Ordovician limestone. The content of V is up to 0.24 %.

The bus drives N.E. along the W. slope of Billingen. The fault line toward the Archaean is seen along the western shore of Lake Lången.

STOP 12. Stolan. Sections in the quarries show uppermost Lower Cambrian sandstone, Upper Cambrian bituminous shale, and Lower Ordovician limestone and shale. The Cambrian sandstone is overlain by a brown sandstone conglomerate with pebbles of phosphoritic sandstone. Middle Cambrian shale in the "mill section" includes a bed of stinkstone, conglomeratic in the upper part and containing *Oligomys exporrecta,* and below yielding *Hypagnostus parvifrons.* The lower part of the Upper Cambrian subzone of *Peltura scarabaeoides* in Mt Billingen contains 300 g U per ton of shale. At Stolan it is particularly rich in small lenses and thin lenticles of an argillaceous coal (kolm) containing ca. 1.5 mg. Ra Br_2 per ton of kolm. A key to the Lower Ordovician sequence is given in Fig. 5.

View of the sub-Cambrian peneplain to the north.

The bedrock on the northern slopes of Mt Billingen is uncovered in a comparatively wide area due to the erosion of the ancient outlet from the Baltic Ice Lake in a western direction into the Ice Sea. When the margin of the retreating ice reached northernmost Billingen, the level of the Baltic Ice Lake was about 26 m higher than the sea-level. Through the new outlet north of Billingen it was suddenly lowered almost to the level of the sea west of Billingen. Big boulders of Cambrian sandstone broken and moved by the tremendous current are found in large quantities on the east-western ridge, Timmersdala-vallen, which the bus passes after leaving Stolan. The bus ascends the steep slope along the fault line north of Lake Lången, and continues to Götene. Lunch.

STOP 13. Husaby church. The oldest preserved church in Västergötland, parts of the steeple probably from the late eleventh century. One of the earliest see of a bishop in Sweden. At the western entrance to the church two memorial stones from the early twelth century formerly assumed to belong to Olof Skötkonung (the first Christian King of Sweden) and his wife Estrid.

Bus continues on the western side of Kinnekulle (Lake Vänern to the left), and descends to the beach of Lake Vänern.

STOP 14. Råbäck Harbour. Thin Lower Cambrian basal conglomerate upon weathered gneiss. Note the ripple-marks in the basal sandstone beds. On the beach are numerous erratic boulders of red Jotnian sandstone. Upon the pier of the harbour numerous boulders of Lower Cambrian sandstone with *Monocraterion*.

The bus ascends to the outcrop region of the Upper Cambrian beds.

STOP 15. Trolmen. Upper Cambrian limestone and shale. Notice that here the section is richer in limestone than in the previously visited sections of the Billingen-Falbygden region. For details, see Fig. 6.

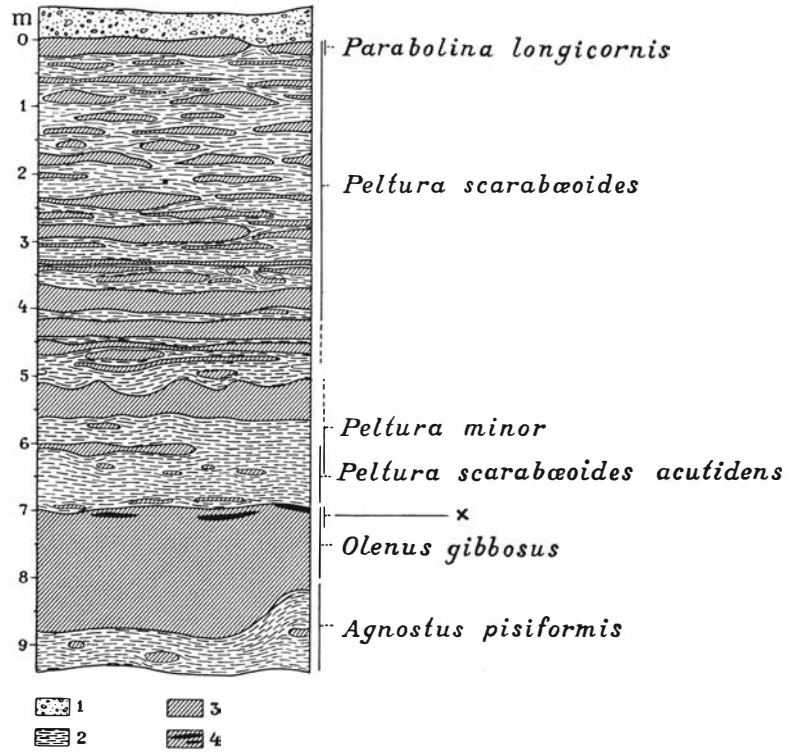


Fig. 6. Diagrammatic section of the Upper Cambrian sequence at Råbäck quarry (adjacent to the Trolmen quarry). After A. H. Westergård. *x* points to the range of *Ctenopyge flagellifera* and *Protopeltura praecursor; Leptoplastus ovatus* and *Eurycare latum; Orusia lenticularis* and *Parabolina spinulosa*. In this part the sequence is very condensed. Legend: 1, Quaternary deposits; 2, Alum shale; 3, Stinkstone ("orsten"); 4, Stinkstone conglomerate.

STOP 16. Hällekis quarry. Lower Ordovician *"Limbata"* and lowermost *Vaginatum* limestone quarried for manufacture of cement. Greenish grey mudstones underlying the *"Limbata"* limestone have yielded graptolites of the zone of *Didymograptus hirundo*. The sequence of the southern part of the quarry is thrust towards N.W., the throw being *c.* 5 m.

The bus ascends the northern side of Kinnekulle. View towards east over the flat Archaean surface which roughly coincides with the sub-Cambrian peneplain. Mt Billingen in the background.

STOP 17. Mossen. Middle Ordovician (Upper *Ludibundus*) metabentonite has been quarried in a now abandoned and partly water-filled quarry. The available section comprises Upper *Ludibundus* Limestone above the main bentonite beds and the overlying *Dicranograptus clingani* shale (0.97 m thick in the nearby Kullatorp boring). Notice a bed of metabentonite within the Upper *Ludibundus* Limestone. Close to the entrance are heaps of debris of Upper *Ludibundus* limestone and chert removed from the quarry. There the commonest fossil is *Asaphus (Neoasaphus) ludibundus* (chiefly pygidia).

STOP 18. Brattefors. A quarry in the Upper Cambrian bituminous shales with beds and lenses of limestone. At six places within the quarry the Upper Cambrian beds are dislocated around tubular depressions 6 to 22 m in diameter. The beds within the depressions are sank relative to the surrounding rocks (in one of the depressions by at least 5 m). The visible filling of the depressions consists of Tremadocian *Ceratopyge* beds surrounded by Upper Cambrian beds. The latter exhibit a concentrical dip growing steeper towards the depressions, and have apparently been subjected to heating, since the shale is brittle, and drops of asphaltite occur in some places. The above dislocations have been interpreted as caused by explosions of gas from the bituminous shales that have been heated by some unknown source of magma. The Upper Cambrian sequence is also traversed by some long fissures almost 1 m wide, and filled with material from the overlying Lower Ordovician beds. The fissures have evidently originated in connection with the explosions.

The bus continues to Mariestad (10,800 inhabitants). Dinner.

Notes on the geology and stratigraphy of Närke

By

P. Thorslund

The main part of the rock floor below the plain of Närke is formed by Cambrian and Lower Ordovician strata. They are sunk and preserved thanks to faults that are well visible topographically along great distances. The Ordovician beds, which stratigraphically extend upwards into the lowermost *Vaginatum* limestone, are preserved within relatively small areas close to the bordering faults. Also within the plain itself some faults with small throw are found. They have resulted only in local deviations from the otherwise practically horizontal position of the strata. More obvious are the disturbances that have

been brought about by the Quaternary inland ice, and that appear mainly within the shaly areas, i.e. areas without a cover of Ordovician limestone. Here the pressure of the inland ice has as a rule produced sliding movements along the soft and slippery clayey shales of the Middle Cambrian. The numerous drumlins of the plain often contain a nucleus of detached shaly masses.

The preserved sequence of strata in Närke displays (in its correlatable parts) a few differences from that of Västergötland. We thus distinguish in the Cambrian portion three different lithological divisions or groups, of which the middle one comprises mainly the *Oelandicus* beds, and is almost lacking in Västergötland (*cf.* p. 00). There are, furthermore, no Tremadocian beds in Närke.

The thickness of the Lower Cambrian sandstone which as in Västergötland consists of two divisions is smaller than in that area, and seems to increase from N.W. towards S.E. It is thus 15.7 m at Klara mine (N.W. of Lanna) and 18.5 m at Bresäter (S. of Kvarntorp). The *Mickwitzia* sandstone is the thicker division, viz. 9.5—11 m, and is characterized by its content of clayey layers and beds of "kråksten", a Swedish term for portions of sandstone, as a rule fairly rich in clay, in which the original stratification has been more or less completely destroyed by burrowing organisms. The division often lacks a basal conglomerate, a fact that can be explained by the circumstance that within wide areas the *Mickwitzia* sandstone rests upon an almost perfectly plane surface of denudation. As in Västergötland the Lingulid sandstone is a fairly pure and thick-banked quartz sandstone.

Within the group of the Middle Cambrian clayey shales the greenish *Oelandicus* shale with its basal glauconitic and phosphoritic sandstone shows a thickness which decreases from east towards west, 15 and 7 m, respectively, while the *Paradoxissimus* shale shows the opposite behaviour, being 0.3—5 m thick in the east, but ca. 12 m in the west. Stratigraphically the group of clayey shales comprises the upper part of the *Oelandicus* stage and the lower part of the *Paradoxissimus* stage.

The alum shale group is of especially great importance in Närke as source of energy and raw material for the manufacture of Ytong (cp. p. 00). On account of the fact that the Middle Cambrian *Forchhammeri* stage is very incompletely represented the alum shale belongs essentially to the Upper Cambrian. The *Forchhammeri* stage has usually an inconsiderable thickness, not more than 1 m, and is sometimes missing. The group has its greatest thickness in the region around Yxhult, the maximum being 19.3 m at Hynneberg, 1 km S.W. of Yxhult. The shale is characterized by the low content of stinkstone above the often conglomeratic "great stinkstone bed" and also by a maximum and average content of natural oil that surpasses that of the corresponding group in any other part of our country. The shale is richest in oil in the south-eastern part of the area, where it can rise occasionally to 8 % within a bed. In the section which is quarried for distillation and which in the region around Yxhult contains roughly 13.6 m of shale the average content of oil is somewhat higher than 5.4 %. The content of U is 235 g per ton shale in the part (4.5 m thick) of the sequence which begins 1 m above the base of the subzone of *Peltura scarabaeoides*.

Like the Middle Cambrian also the Upper Cambrian series is incompletely developed stratigraphically. Particularly noticeable is the gap in the uppermost

Cambrian at the boundary of the system, where the Lower Ordovician limestone series rests with basal transgressional deposits upon shales or upon bleached stinkstone belonging to the uppermost but one zone of the *Peltura* beds. At the lithologically very distinct boundary of the system the stratigraphic gap is further accentuated by the absence of Tremadocian sediments and by the incomplete development or occasional absence of the lower part of the Hunneberg stage.

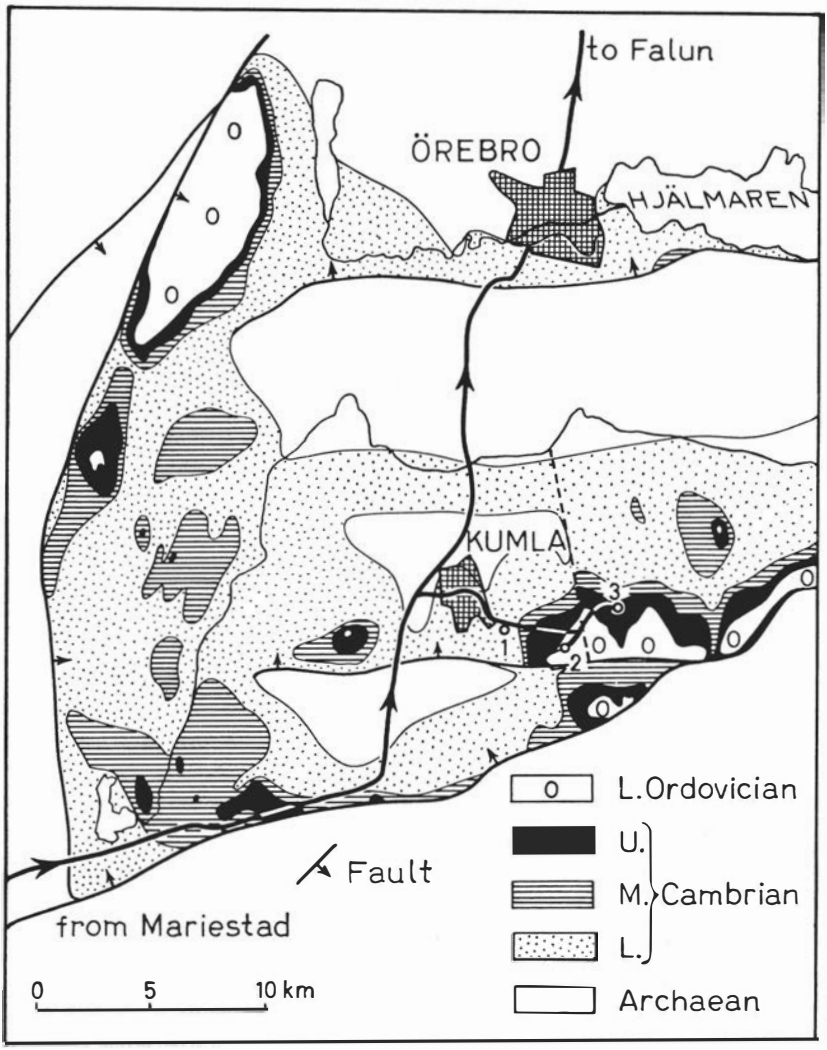


Fig. 7. Map of the main part of the Cambro-Ordovician district in the province of Närke, After J. Eklund.

In the localities in the west and south, where the sequence is best preserved, the Lower Ordovician limestone series has a thickness not surpassing 20 metres. This series is characterized by a rhythmic sedimentation which is especially evident in the Billingen stage and the upper Hunneberg stage, and which reveals the oscillations of sea-level during the deposition. A similar rhythm in the sedimentation is found in the Early Ordovician sediments of other areas (Fig. 00, p. 00 and Fig. 00, p. 00), but ought to be best developed in Närke. The numerous surfaces of discontinuity thus indicate interruptions of the sedimentation, and delimit its different cycles. When it is as complete as possible, each of these cycles consists of two beds of limestone with an intercalated layer of clayey shale or marl.

The group of Ordovician limestones of Närke within which the reddish, as yet little studied *"Limbata"* limestone has the greatest thickness, has been extensively exploited for the stone industry and for the manufacture of quicklime. At Lanna it is quarried as raw material for cement.

Närke, Road-Log

By

P. Thorslund

THIRD DAY

From Mariestad (start at 8^{00} a.m.) to Kumla passing through the hilly Archaean terrain that separates the Palaeozoic districts of Västergötland and Närke. When entering into the province of Närke, the western and southern faults, which border the Cambro-Ordovician area, are obvious morphologically. Short stop at a road-cutting through drumlins.

STOP 1. Älvesta. Quarry in the Lower Cambrian sandstone showing the beds at the boundary between the *Mickwitzia* sandstone, with intercalations of light grey clay and greenish shale, and the overlying Lingulid sandstone which consists of a white, pure orthoquartzite. *Diplocraterion* is common in some beds of the former sandstone. Boulders of basal Middle Cambrian sandstone, conglomeratic in parts and dark from phosphoritic matter occur in the hips at the quarry.

STOP 2. Hynneberg (near Yxhult). Quarry in the Upper Cambrian alum shale, here relatively poor in intercalations of bituminous limestone, and the Lower Ordovician limestones. The latter comprise the Hunneberg stage (zone of *Megistaspis planilimbata*), Billingen stage (zones of *Megalaspides dalecarlicus* and *Megistaspis estonica*), and the *"Limbata"* limestone (zone of *Megistaspis lata*) at the top.

The manufacture of the artificial building material, Ytong, from alum shales will be demonstrated. Stop for lunch.

STOP 3. Kvarntorp. The processes for the extraction of oil, sulphur, am-

monium, etc. from the Upper Cambrian alum shale will be demonstrated at the works.

From Kumla to Falun through the Archaean terrain of the province of Västmanland and southern Dalarna. Dinner in Falun.

Notes on the Geology and Stratigraphy of Dalarna

By

P. THORSLUND

In Dalarna the Palaeozoic beds are found in the north-western part and in the so-called Siljan region. Farthest in the north-west they occur within the eastern border of the Caledonian mountain range, and form a continuation of similarly situated Cambrian and Lower Ordovician deposits in Härjedalen and south-western Jämtland, consisting preponderantly of sandstone and alum shales, and bedded limestone, respectively.

In the ring-shaped Palaeozoic belt of the Siljan region, where the strata are disturbed by numerous faults as well as by some minor overthrusts, the Cambrian system is missing. The oldest Ordovician deposits are the Tremadocian *Obolus* beds in the southern and eastern parts of the region, while as far as is known the late Precambrian rocks (porphyry, Digerberg sandstone, etc.) in the north-west are covered by younger deposits, consisting at Orsa of a thin basal conglomerate without shells or fragments of obolids, sandy glauconitic clay, and on top of it the richly fossiliferous Arenigian *Planilimbata* limestone. Recent investigations have shown the Djupgrav conglomerate, that occurs in the north near Skattungbyn with a thickness of more than 3 metres, and which had been deposited upon Jotnian sandstone, to contain in its upper part a thin bed of alum shale with *Dictyonema sociale*. On this account the conglomerate must be considered contemporaneous with the *Obolus* beds. It has probably been deposited in a depression of the sub-Ordovician surface, and has been protected there from denudation during subsequent regression in early Ordovician time. The Ordovician sea has obviously invaded from the south-east both the Siljan region and large parts of the isthmus, that during Cambrian times separated the continental shelf of the Caledonian geosyncline from the shallow epicontinental sea over the Baltic area and Central Sweden. An increasingly lessening depth towards north-west has been traced also in certain parts of the rest of the Ordovician sequence, where oscillations of the sea-level could be registered.

The Ordovician of the Siljan region is characterized by its comparative wealth in limestones, among which the reef-like formations attract the greatest interest. These were previously united under the name *Leptaena* limestone, but have been established as formed during two different phases, and are now called Kullsberg limestone and Boda limestone, respectively. The fossiliferous Silurian deposits consist mainly of graptolite shales, and represent, though not quite completely, the Llandovery and the lower portion of the Wenlock. No

fossils have so far been found in the Orsa or Grinding sandstone. Its place in the Palaeozoic scheme is therefore uncertain. It is separated from the fossiliferous Silurian by a stratigraphic gap, probably of considerable size. Presumably the sandstone lies somewhere near the boundary between Silurian and Devonian. The study of the sequence is made very difficult by the extensive cover of Quaternary deposits and the complicated tectonics.

Ordovician. In the places, where the Ordovician basal deposits consist of beds with *Obolus,* the underlying Precambrian granites and gneisses are weathered to variable depth. Gravel resulting from the weathering of granite is found in this position e.g. near Altsarbyn and in the railroad-cut near Sjurberg in the parish of Rättvik, and in the old phosphorite mine at Mt Klittberg in the parish of Boda. The *Obolus* beds are usually represented by a conglomerate that consists mainly of redeposited gravel and larger fragments of the Precambrian rocks together with granules of phosphorite and mainly fragmentary shells of *Obolus apollinis.* At Gärdsjö also erratic boulders of a soft sandstone has been found with well preserved and therefore probably not redeposited shells of *Obolus,* amongst others of the thin-shelled *O. triangularis.*

The Lower Ordovician consists otherwise preponderantly of Orthoceratite limestone. A mixed facies formed by limestone beds with the fauna of the zone of *Megalaspides dalecarlicus* alternating with shales with *Phyllograptus densus* has been observed only near Skattungbyn. In several places the basal beds contain layers of glauconitic clay. Oolithic limestone, which near Skattungbyn (Leskusänget) is rich in ferriferous ooids of remarkable size, occurs within the *Expansus* limestone, occasionally also within the *Raniceps* limestone.

In the Lower Ordovician of the district gaps can be established. Thus sediments corresponding to the *Ceratopyge* limestone are altogether missing as well as those to the *Lepidurus* limestone. Faunistically less obvious gaps are common especially within the lower stages, and are indicated by surfaces of discontinuity (cp. Fig. 10).

In the Middle Ordovician the lowermost part is developed as Orthoceratite limestone which is overlain by often knobby limestones, richer in clayey matter.

Apart from the exceptions, which will be dealt with in greater detail below, the Upper Ordovician consists of basal *Slandrom* limestone with banks of knobby calcilutite, black *Tretaspis* shale with a mixed shelly and graptolite fauna (zone of *Climacograptus styloideus*), greenish grey *Tretaspis* limestone, red *Tretaspis* beds of marl and finely nodular limestone, *Staurocephalus* beds of greenish grey calcareous mudstone and argillaceous limestone, and, at the very top, of grey calcareous *Dalmanitina* shale with a basal bank of fine-sandy limestone (so-called clink-limestone).

Within the uppermost Middle Ordovician and the upper parts of the Upper Ordovician, formations with a local facies, the above-mentioned reef-like limestones, set their imprint upon the sequence and to a certain extent also upon the landscape of today, occurring as they do in ridges and slopes some of them being easily recognizable as well delimited elevations. Their nucleus consists of a massy limestone, the reef limestone proper, containing nests or lens-shaped portions full of shells which form a kind of pseudo-conglomerate (coquina limestone). The organisms which have been accumulated in this way are especially trilobites and brachiopods, more rarely gastropods and cephalopods. It is a remarkable fact that as a rule each of these nests contains shells of only

one species or of species belonging to a single genus. In spite of its wealth of shells the main contributors to the formation of the limestone seem to be algae. This is suggested especially by the ribbon-like, lamellar, and branching structures which resemble *Collenia,* and traverse great portions of the massy limestone. In the upper reef horizon, the Boda limestone, great quantities of the green alga (Codiacean) *Palaeoporella* is noticed.

Each occurrence of the reef limestone is accompanied by a so-called surrounding facies, consisting of reddish or greenish parcels of strata composed of pale beds of limestone, which gradually, with increasing distance from the reef, become thinner, and of coloured, more or less marly beds, that in the same direction increase in thickness and number, and thus interdigitate between the limestone beds. The wealth of fossils is great also in this surrounding facies. Especially common fossils are brachiopods and cystoids and also bryozoans (near Kullsberg) or tabulate corals (near Boda). Occasionally fragmentary stems of pelmatozoans are so abundant that certain beds consist entirely of them. The fauna of the surrounding facies, which thus represents marginal sediments of the reef limestone, differs essentially from that of the latter. As a third facies, the so-called normal facies, we have then to consider the deposits which are contemporaneous with the reef limestones and their surrounding facies, and which extend between the sometimes rather widely spaced localities of the former. At present 34 localities of the reef-like limestone are known. Ten among them consist of Kullsberg limestone, and consequently belong to the older reef horizon. In three places the Boda limestone has been found to be deposited above the Kullsberg limestone. — On account of its high content of $CaCO_3$ the reef limestones have been quarried on a gradually increasing scale in order to satisfy different demands. This has also benefitted the knowledge of their faunae, stratigraphy, and structure. An idea of the size of these lenticular bodies can be obtained from the following figures: Length for Kullsberg 300 m, for Boda 1 km; greatest thickness for Kullsberg 40 m, for Boda 100 m.

The beds of the normal facies which occur in the Middle and Upper Ordovician, and which are contemporaneous with the reef limestones and their surrounding deposits differ from them not only lithologically, but also faunistically. They exhibit on the other hand a far-reaching agreement with contemporaneous deposits within other regions, where reef limestones of corresponding age are lacking. On the other hand, species that are characteristic for the fauna of the Boda limestone have been found in far distant occurrences of similar limestones, e.g. in northern England, and in Ireland.

The thickness of the Ordovician sequence in the regions between the occurrences of the reef limestone has been calculated to an average of 130 metres.

Silurian. The graptolitiferous strata of the Lower Silurian consist preponderantly of dark shales. They differ thereby from the lighter sediments, rich in shells, of the Upper Ordovician and of the little examined grey and reddish, in part calcareous shales, poor in fossils, that can be observed immediately below the Silurian graptolite shales. These shales with few fossils occur within the regions between the Boda limestones. No distinct boundary between the systems can be observed in these regions. It is thus unknown, to what extent these shales belong to the Silurian. At the occurrences of the Boda limestone the boundary between the systems is on the other hand distinct, and there we find an obvious stratigraphical gap that widens towards these limestone bodies. During the dif-

ferent phases of the Lower Silurian the latter had obviously protruded to a varying extent from the surrounding sediments. These limestones are in several places traversed by fissures filled with black graptolitiferous shales belonging to the Middle Llandovery. This indicates that no sediments of Early Llandovery age had been deposited upon them. At Mt Osmundsberg the limestone is locally overlain by a conglomeratic basal bed which together with the following shale, rich in limestone, belongs to the lowermost zone of the Upper Llandovery.

The graptolite shales sometimes enclose beds with lenticular or spherical concretions of dark limestone and scattered light layers of bentonitic clay. They are overlain by a grey, in part reddish division consisting of thin-bedded

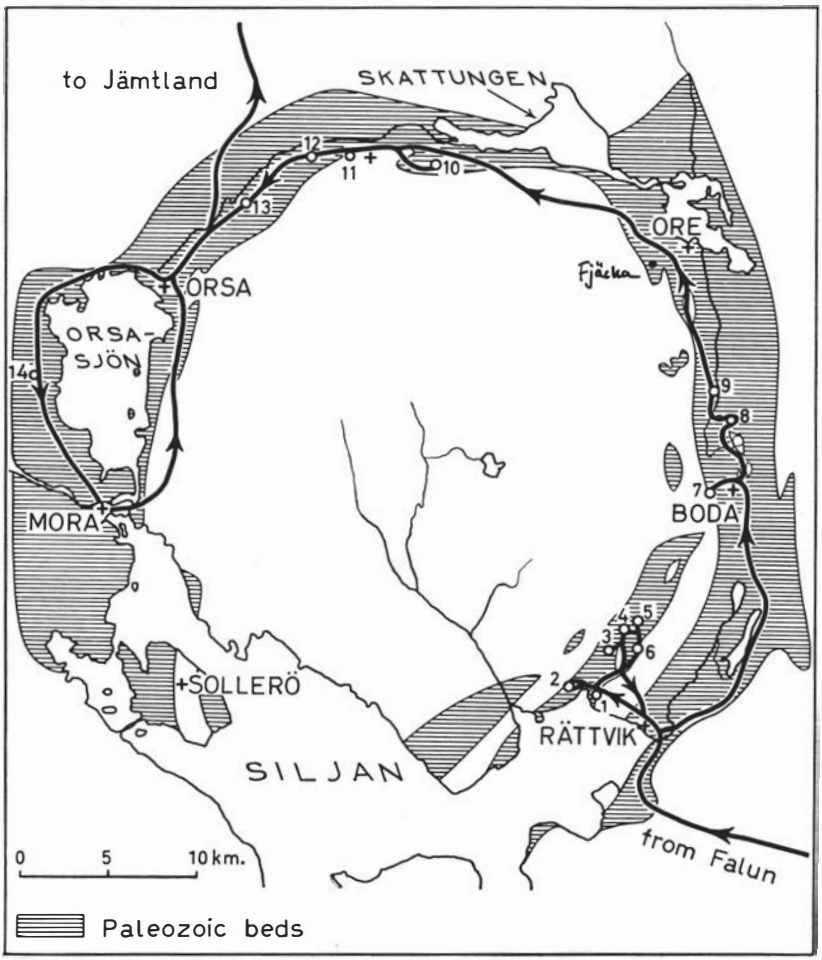


Fig. 8. Map showing the distribution of Palaeozoic beds in the Siljan district, Dalarna. After P. Thorslund.

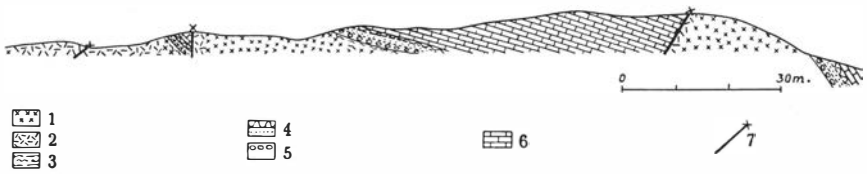


Fig. 9. Railway-cut at Sjurberg. After P. Thorslund. Legend: 1, fresh Archaean granite; 2, brecciated granite; 3, weathered granite; 4, basal Arenigian beds; 5, Tremadocian conglomerate; 6, Orthoceratite limestone; 7, fault.

dense limestone and thin beds of shale. This division forms an upper part of the *Retiolites* shales of the region, and has been named Styggfors limestone from its type locality, but also cement limestone. The youngest fossiliferous beds belong to the so-called *Bumastus* limestone at Nederberga in the parish of Orsa, where they are also found in original contact with the Orsa sandstone. The basal sandstone beds are coarse-grained, in part conglomeratic and cross-bedded. The main mass of this youngest Palaeozoic sedimentary formation in Dalarna consists otherwise of a fine-grained, soft, sometimes calcareous quartz sandstone. Its colour varies from almost white to red, its clayey, shaly bedding planes show occasionally beautiful mud cracks. It was formerly fairly widely used especially in the manufacture of grinding stones.

The Siljan District, Road-Log

By

P. Thorslund and V. Jaanusson

FOURTH DAY

Start from Falun (18,600 inhabitants) at 8^{30} a.m. A short visit to Falu mine exploited for copper ore since the middle of the eleventh century. During the 17th century the mine was the largest producer of copper in the world.

The bus drives 47 km N.W. to the Siljan district. After *c.* 44 km a panorama over the Lake Siljan region.

Close to the church of Rättvik are exposures of a calcareous sandstone, quite unfossiliferous and of unknown age, probably a facies of Orsa sandstone.

STOP 1. Sjurberg section. Lower Ordovician limestones with glauconitic rocks and a conglomerate (Tremadocian) at the base overlying weathered Archaean granite. For details, see Figs. 9 and 10.

STOP 2. Vikarbyn. Lower and lowermost Middle Ordovician limestones in a section excavated in 1947. The dip is almost vertical. The following section is exposed (measured by V. Jaanusson and H. Mutvei in 1947):

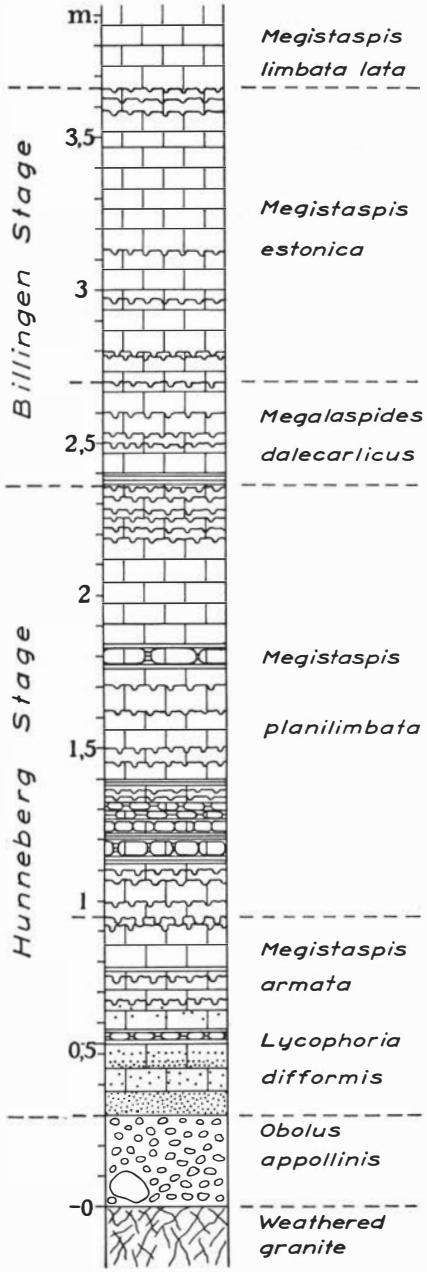


Fig. 10. Diagrammatic section through the basal Ordovician beds in the railway-cut at Sjurberg. After T. Tjernvik.

Middle Ordovician

Crassicauda Limestone 7.25 m +

6.30 m +. In the upper part nodular to finely nodular, in the lower part fairly thick-bedded, grey, fine-grained to dense limestone.

0,95 m. Beds or lenses of grey, fairly dense limestone intercalated by thick beds of greenish grey calcareous mudstone.

Schroeteri Limestone 2.70 m

2.50 m. Grey, thick-bedded, in the upper part fine-grained, and intercalated by greenish grey mudstone, in the lower part coarse-grained and in part coquinoid limestone.

0.20 m. Variegated, greenish grey reddish brown-spotted, thick-bedded, coarse-grained, in part coquinoid limestone.

Platyurus Limestone 3.70 m

0.70 m. Mottled reddish brown and greenish grey, thick-bedded, coarse-grained, in part coquinoid limestone (= zone of *Illaenus planifrons*).The lower boundary is formed by a surface with deep furrows probably representing re-worked mud cracks. Notice the small pebbles of reddish brown limestone above the surface.

3.00 m. Intensely reddish brown, fine-grained limestone intercalated by reddish brown finely nodular limestone (= zone of *Angelinoceras latum*).

Lower Ordovician

Vaginatum Limestone

4.45 m. Intensely reddish brown, thick-bedded, fine-grained limestone (= roughly the zones of *Megistaspis gigas* and *M. obtusicauda*).

1.25 m +. Grey, oolitic, coarse-grained, thick-bedded, limestone.

The continuity of the section is disturbed here by a flexure and some small faults.

3.75 m +. Reddish brown, thick-bedded, fine-grained limestone.

1.00 m. Grey, coarse-grained, oolitic limestone.

0.45 m. Light grey, coarse-grained to coquinoid limestone with scattered ooids.

1.10 m. Thin- to thick-bedded, somewhat nodular, grey to dark grey oolitic limestone (= roughly the zone of *Asaphus expansus*). The lower boundary is formed by a distinct discontinuity surface.

Hiatus comprising at least part of the *Lepidurus* limestone.

2.0 m +. Reddish brown thick-bedded limestone.

Stop for lunch in Vikarbyn.

The bus continues in eastern direction, passes the lake Nittsjö (to the right), and turns to the north. Close after the turning an exposure in a Kullsberg reef lentil (Sätra reef) to the left (*cf.* Fig. 11).

STOP 3. Amtjärn. A lentil of the Kullsberg Limestone which has to a large extent been quarried away. The beds dip almost vertically. On either end (N. and S.) the transition of the reef limestone facies into the reddish brown and greenish, bedded reef flank facies can be seen. The reef lentil is overlain by the Upper Ordovician beds (Black *Tretaspis* shale in the entrance to the northern quarry and Slandrom limestone in the entrance to the small southern quarry, *cf.* Fig. 12). Reef flank deposits include conglomeratic beds, best seen close to the southern end of the northern quarry and in the southern quarry. The common fossils in the reef flank deposits are cystoids [*Caryocystites lagenalis* Regnéll, *Haplosphaeronis oblonga* Ang., *Heliocrinites granatum* (Wahlenb.)], the peculiar crinoid *Cornucrinus,* brachiopods [*Ptychoglyptus* n. sp., *Nicolella* n. sp., *Platystrophia lynx* (Eichw.), *Eoplectodonta* n. sp., etc.] and various bryozoans.

STOP 4. Skålberget. A lentil of the Middle Ordovician Kullsberg Limestone superimposed by a lentil of the Upper Ordovician Boda Limestone. The dip is nearly vertical. Much of the reef lentils has been removed, and the transition of the reef limestone into the bedded reef flank deposits is well visible in the northern end of both quarries. Between the reef lentils a condensed lowermost

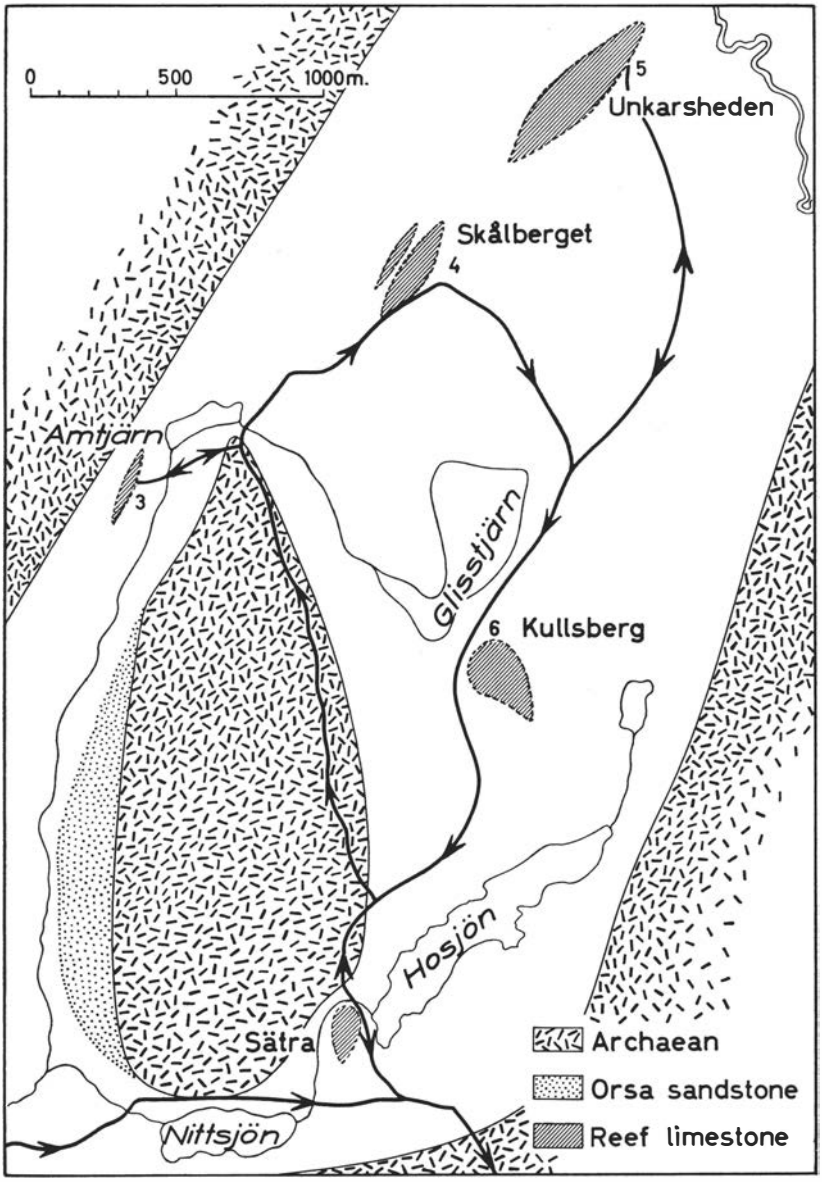


Fig. 11. Sketch-map of the area around Kullsberg.

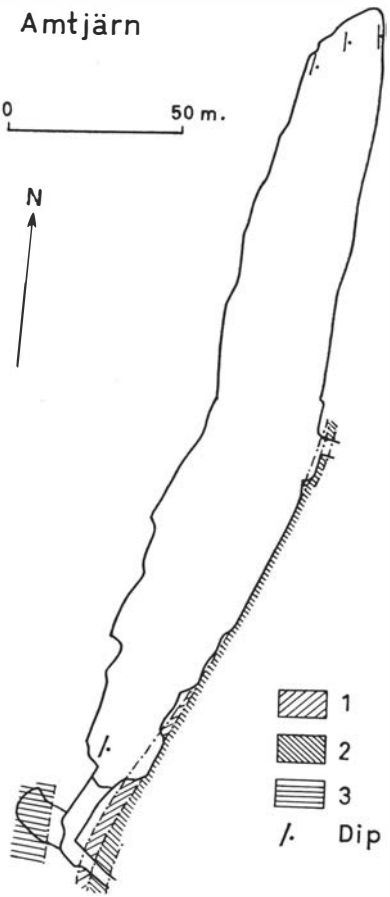


Fig. 12. Map of the Amtjärn quarry. After V. Jaanusson and J. Martna, original. Legend: 1, limestone beds corresponding to the Slandrom limestone; 2, Black *Tretaspis* shale; 3, *Ludibundus* beds below beds of bentonitic clay. Dips of the reef flank deposits.

Upper Ordovician sequence is exposed in three sections. The common fossils in the reef flank deposits of the Boda Limestone are brachiopods [*Plectatrypa* n. sp., *Hyattidina* sp., *Christiania* sp., *Eoplectodonta schmidti* (Lindstr.), etc.] the cystoid *Eucystis,* and small corals and bryozoans.

STOP 5. Unkarsheden. A quarry in the Upper Ordovician Boda limestone. The quarry is situated within the central parts of the reef lentil, and only some vertically dipping reef flank deposits are exposed. Notice the almost complete absence of stratification and the occasional occurrence of laminated structures of $CaCO_3$ interpreted as recrystallized algae. Lower Silurian shales with limestone lenses to the left of the entrance and in the fissures of the Boda limestone.

STOP 6. Kullsberg. Type locality of the Middle Ordovician Kullsberg reef lentil which is here almost entirely quarried. At the entrance of the quarry are sections through steeply dipping Llandoverian shales and Upper Ordovician beds, the latter overlain by massy Kullsberg limestone as a result of thrust faulting. A water-filled pit within the quarry indicates the location of the Kullsberg limestone below the thrust plane. Flank deposits of the overthrust reef limestone are exposed in the walls of the abandoned quarry. A specimen of *Platylichas lingua* Warburg will be demonstrated. — Back to Rättvik for dinner.

FIFTH DAY

Start from Rättvik at 8^{30} a.m. The bus drives N.E. and N. within the Palaeozoic belt of the Siljan area. Boda church is situated upon a reef lentil of the Boda limestone, the type locality of this division.

STOP 7. Styggforsen, 1.8 km E. of Boda church. A waterfall, 24 m high, with the water dropping from the Archaean granite down into a deep canyon eroded along a fault into brecciated granite, Orsa sandstone, and Silurian limestones and shales. The Silurian sequence comprises Upper Llandoverian beds; exposures of the zone of *Monograptus spiralis* will be briefly examined.

STOP 8. Osmundsberget. A large hill formed by the Boda limestone and adjacent beds overthrust towards N.W. According to borings the thrust mass contains also a lentil of Kullsberg limestone (*cf.* Fig. 13), and rests locally upon Orsa sandstone *c.* 70 m below the surface of the hill. Beds of the thrust mass underlying and overlying the Boda limestone are exposed on the southern and eastern slopes, and the steeper northern and western slopes, respectively. A quarry in the N.E. displays sections through the peripheral part of the big Boda limestone lentil. At the entrance are richly fossiliferous beds of reddish and greenish marls interdigitating light limestone. Massive reef limestone with steeply dipping bedded limestone on either side are seen within the quarry. The limestone contains occasional small lenses of coquinoid limestone formed by shells of brachiopods (*Meristella terebratulina* etc.), trilobites (illaenids, *Holotrachelus, Eobronteus*), or of cephalopods or gastropods. On the steep western slope another quarry cuts into the massive reef limestone which is overlain by

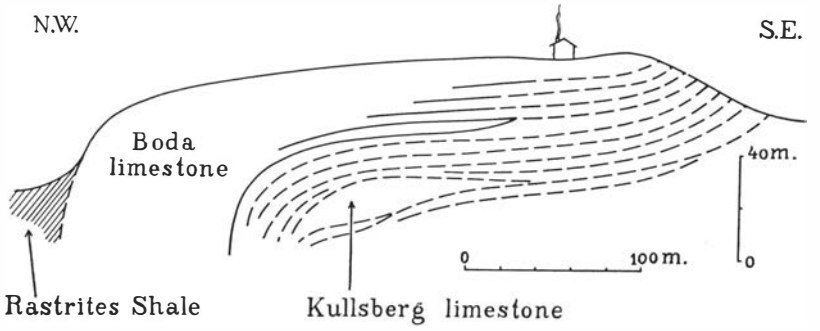


Fig. 13. Diagrammatic cross-section of the hill Osmundsberg. After P. Thorslund, orig.

Middle and Upper Llandoverian shales. As in the north-eastern quarry the limestone contains small lenses of coquinoid limestone abounding in fossils, and in some places the rock is interwoven by fragments of the calcareous algae *Palaeoporella variabilis* or ribbon-like algal structures of the *Collenia* type. The limestone is in part dark from asphaltite.

The Middle Llandoverian sequence consists of a conglomeratic limestone at the base overlain by a thin layer of dark shale with *Monograptus sedgwicki*. The Upper Llandovery is represented mainly by dark and grey shales belonging to the zones of *Monograptus turriculatus* and *M. discus,* and contains some beds of light metabentonite. Beds of limestone, in part rich in glauconite, are concentrated at the base of the *M. turriculatus* zone.

Stop for lunch.

STOP 9. Gulleråsen-Sanden. Section through the Upper Ordovician and Llandoverian beds at a small rivulet in the northern part of the village and 1.2 km N. of a large lentil of Boda limestone, named Lissberget (= the small mountain). The beds dip 50° E. The oldest exposed beds belong to the *Dalmanitina* stage and consist of some beds of calcareous siltstone with ripple marks overlain by *c.* 36 m greenish grey and reddish shales with inclusions of finely nodular limestone. Eastward grey shales grade into darker Llandoverian shales, and the oldest graptolite-bearing beds have yielded *Rhaphidograptus toernquisti* (E. & W.), *Monograptus revolutus* Kurck, *Climacograptus medius* Törnq., etc., of the uppermost Lower Llandoverian age. Farther eastwards are outcrops of shales of the lowermost Upper Llandoverian zone of *Monograptus turriculatus* with some fairly thick beds of light metabentonite.

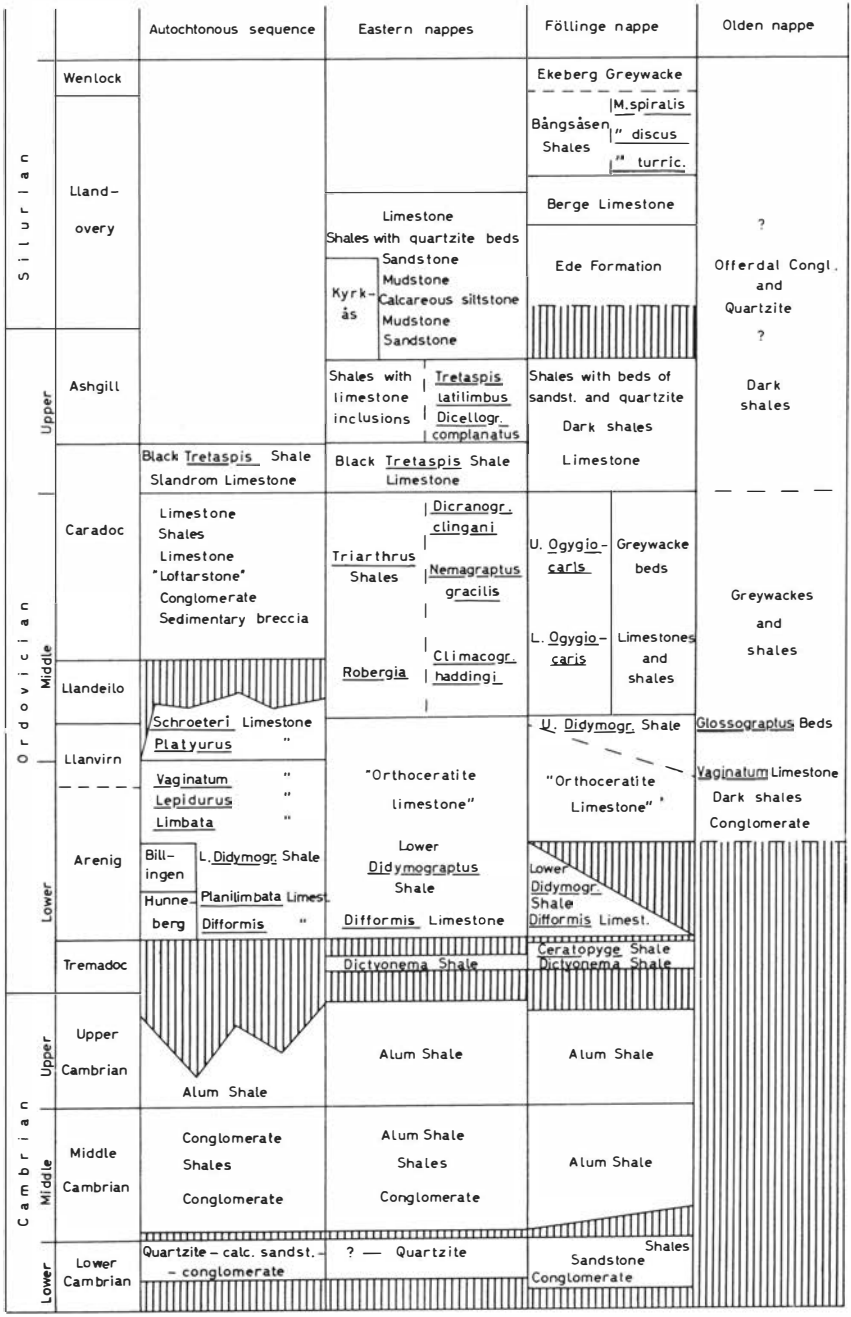
STOP 10. Leskusängen. A quarry in Lower Ordovician limestones. The sequence is in ascending order: Reddish brown limestone ("*Limbata*" limestone), dark grey oolitic limestone (*Expansus* and lowermost *Raniceps* limestone), and reddish brown limestone (middle and upper *Raniceps* limestone).

STOP 11. Djupgrav. The road cuts through vertical beds of Jotnian sandstone overlain by basal Ordovician (Tremadocian) conglomerate. The latter is *c.* 3 m thick, and consists of rounded pebbles of pre-Cambrian rocks, mostly sub-Jotnian porphyries, in a matrix of coarse sandstone. As a result of faulting the sequence is repeated along the road. The topmost bed of the conglomerate, *c.* 30 cm thick, is darker than the main part of the conglomerate below, and is separated from the latter by a very thin layer of mostly greyish shale. In the western exposure this layer is partly developed as a black shale, and contains *Dictyonema sociale*. The conglomerate is overlain by the Arenigian sequence the basal bed of which consists of sandy glauconitic clay followed by limestone beds abounding in discontinuity surfaces.

STOP 12. Kallmora. Old quarries in reddish Orsa sandstone showing ripple marks and cross-bedding.

STOP 13. Kallholn. A large quarry in the central part of a Boda limestone lentil. The limestone is traversed by several joints filled mostly with a dark, often somewhat calcareous shale. Finds of graptolites show that the shale belongs to the Llandoverian *Rastrites* shale, particularly to the zone of *Monograptus leptotheca*. The joint-fillings are thus considerably younger than the surrounding Upper Ordovician limestone, and older than the Llandoverian beds found to overlie the Boda limestone at Osmundsberg or Skålberget.

STOP 14. Bonäs. A wide area with Finiglacial dunes limited in eastern


Autochtonous sequence
Eastern nappes
Föllinge nappe
Olden nappe
Silurian
Ordovician
Cambrian
Wenlock
Lland-
overy
Ashgill
Caradoc
Llandeilo
Llanvirn
Arenig
Tremadoc
Upper Cambrian
Middle Cambrian
Lower Cambrian
Upper
Middle
Lower
Ekeberg Greywacke
M.spiralis
Bångsåsen Shales
" discus
" turric.
Berge Limestone
Limestone
Shales with quartzite beds
Sandstone
Mudstone
Kyrk-ås
Calcareous siltstone
Mudstone
Sandstone
Ede Formation
Offerdal Congl. and Quartzite
?
Shales with limestone inclusions
Tretaspis latilimbus
Dicellogr. complanatus
Shales with beds of sandst. and quartzite
Dark shales
Limestone
Dark shales
Black Tretaspis Shale
Slandrom Limestone
Black Tretaspis Shale
Limestone
Limestone
Shales
Limestone
"Loftarstone"
Conglomerate
Sedimentary breccia
Dicranogr. clingani
Triarthrus Shales
Nemagraptus gracilis
Robergia
Climacogr. haddingi
U. Ogygio-carls
L. Ogygio-carls
Greywacke beds
Limestones and shales
Greywackes and shales
Schroeteri Limestone
Platyurus "
U. Didymogr. Shale
Glossograptus Beds
Vaginatum "
Lepidurus "
Limbata "
"Orthoceratite limestone"
"Orthoceratite Limestone"
Vaginatum Limestone
Dark shales
Conglomerate
Bill-ingen
L. Didymogr. Shale
Hunne-berg
Planilimbata Limest.
Difformis "
Lower Didymograptus Shale
Difformis Limestone
Lower Didymogr. Shale
Difformis Limest.
Ceratopyge Shale
Dictyonema Shale
Dictyonema Shale
Alum Shale
Alum Shale
Alum Shale
Conglomerate
Shales
Conglomerate
Alum Shale Shales
Conglomerate
Alum Shale
Quartzite – calc. sandst. – conglomerate
? — Quartzite
Shales
Sandstone
Conglomerate

direction by a 10—20 m high steep, cut into silt and formed by the abrasion of an ancient stage of Lake Siljan.

Dinner in Mora.

Notes on the Cambro-Silurian of Jämtland

By

P. THORSLUND

The Cambro-Silurian area of Jämtland along and east of the border of the Scandinavian mountain range, i.e. the region with the so-called eastern Cambro-Silurian, exceeds in extension any other area with Palaeozoic rocks in Sweden. An account of this area has to take into consideration first of all its tectonic structure, this being of essential importance for the understanding of the sequence of the strata and its varying composition within different portions of the area.

Tectonically the main part of the Cambro-Silurian beds belong to the allochthonous masses in front of the mountain range, and form their most important element. Only a relatively narrow belt along the Precambrian in the east consists of autochthonous beds or of beds which have undergone only a short transport from their original position. This belt is broadest at the south-eastern bay of Lake Storsjön (*cf.* Fig. 14, p. 42). The allochthonous Cambro-Silurian beds are strongly compressed and folded. In east-western direction a number of successive and superimposed overthrust masses of nappes can be distinguished. The thrustplanes of the eastern masses have a gentle dip towards north-west. The two westernmost overthrust units (Föllinge and Olden) occupy a mainly horizontal position. When compared with the eastern ones they ought to be designated as major nappes.

From the stratigraphic point of view (p. 34) the distinguishable tectonic elements comprise a varying number of stages of the Cambro-Silurian sequence. Silurian strata are missing in the autochthonous, and the Upper Ordovician is represented only by the basal Upper Ordovician *Tretaspis* beds. In the eastern nappes the Silurian is restricted to the Lower and Middle Llandovery. These stages are encountered within comparatively narrow belts, mainly in synclines of comparatively great amplitude. Higher Silurian stages, representing the Upper Llandovery and presumably also the lowermost Wenlock, are found within synclines in the Föllinge nappe. In the western major nappes the Cambrian strata seem to thin out in western direction. Within the Olden nappe they have not been observed. Also a great part of the Lower Ordovician is unrepresented in this nappe. Neither could, in the absence of fossils, its upper stratigraphical termination be indicated more closely. — In the autochthonous as well as in the allochthonous sequence stratigraphical gaps have been established. They are most pronounced in the autochthonous.

Lithological changes are especially obvious in certain stages of the sequence. The difference in the facies between two neighbouring tectonic units, either between the autochthonous and the easternmost part of the allochthonous

or between two adjacent nappes, is striking along lines running in S.E.—N.W. direction. The above circumstance implies the possibility to arrive on the basis of the lithology at an indication to the effect that the correlatable strata belong to different tectonic units. In this way a guidance for the determination of a thrust limit is obtained within areas with few outcrops.

From the eastern to the western parts of the Jämtland area the Ordovician sequence exhibits a general change of facies, expressed by a diminishing content of limestones and an increasing wealth of shales and sandstones. This change is most marked in the Middle Ordovician.

In the autochthonous the Middle Ordovician exhibits local changes of facies about 20 km S.S.W. of Östersund in the so-called Lockne area. There it can be shown that the easily observable horizontal lithological changes within the same stratigraphic unit are conditioned by sedimentation in a relatively strongly undulating coastal region.

Within each of the eastern minor nappes changes of facies can be traced only along the front ends of the nappes, *i.e.* in S.W.—N.E. direction. Within the more extensive western nappes such changes in this direction seem to be evident. This applies at least to the Föllinge nappe within which the layers of greywacke-like sandstone in the Middle Ordovician become more numerous towards the N.E., and gradually replace both the limestone layers and the packets of shale with limestone lenses that outcrop, amongst others, upon the island Norderön in Lake Storsjön. Thus, for instance, several representatives of the fauna of the *Ogygiocaris* shale have recently been found 5 km W. of Föllinge (50 km N. of Norderön) within a packet of thick beds of greywacke with thin layers of shale, *i.e.* within the lithological facies which has considerable thickness and great extension within the western major nappes. A noticeable change of facies towards an increased content of sand can, however, be proved within the Ordovician sequence also right across the broad Föllinge nappe, from S.E. towards N.W. Generally speaking Middle Ordovician beds of sandstone seem to occur within the overthrust region in close proximity to the eastern boundary of the area in the north, where they have been encountered within the allochthonous immediately west of Hammerdal, 70 km N.E. of Östersund. — The change described here evidently implies that the overthrusts extend across the boundaries of regions with identical facies within a stratigraphic unit.

Combined lithological and faunistical observations permit conclusions about the directions of transgressions and of transportation of sediments. The numerous conglomerates and biostratigraphic gaps within the autochthonous indicate sedimentation near the coast. Within the Lockne area even details in the shape of the coastline at the time of the Middle Ordovician *Ludibundus*-transgression can be reconstructed. The direction of transgression in early Cambrian times is indicated by the increase in the thickness of the Lower Cambrian strata towards the west within the region of Lake Storsjön (at Brunflo < 0.5 m, at Marby, 30 km W.N.W. of Brunflo, > 10 m). The composition and the relatively inconsiderable thickness of the basal sediments at Brunflo seem to point to their deposition in a shallow sea without an abundant transport of sediment from the eastern coastal zone. The strata from the last age of the Middle Cambrian exhibit an obvious correspondence to the development in the Early Cambrian. The thin *Exporrecta* conglomerate within

the autochthonous thus finds its counterpart in the west (at Marby) in alum shale with limestone lenses belonging to the zone of *Solenopleura brachymetopa* of the *Forchhammeri* stage. The *Oelandicus* stage, on the other hand, is of considerable thickness within the autochthonous and the easternmost minor nappes, but could not be established farther towards the west. The autochthonous Upper Cambrian contains conglomerates and great quantities of stinkstone.

The development during the early Ordovician does not differ in principle from that during the Cambrian. The large gap at the boundary towards the Cambrian, which in the autochthonous shows local variations, is in the allochthonous partly filled by *Dictyonema* shale and by *Ceratopyge* shale that has recently been discovered. No *Ceratopyge* limestone has been observed in Jämtland. The richly glauconitiferous beds with *Lycophoria difformis*, which are conglomeratic in the autochthonous, are of great extension, and thus indicate the commencement of a more extensive transgression in the Ordovician. They form the basal part of the Hunneberg stage, which in western direction from the authochthonous becomes thicker and contains a successively increasing number of shaly beds. The contrary seems to be the case in the following Billingen stage which in the autochthonous and the minor nappes in the extreme east seems to consist of relatively thick *Phyllograptus* shales, but which is feebly represented already upon the island Andersön in Lake Storsjön, and thins out farther towards the west. Thus the *Oelandicus* stage of the Middle Cambrian and the Billingen stage of the Lower Ordovician seem to exhibit a parallel development with a transport of sedimentary material from an eastern continental area. In the western nappes in the vicinity of Lake Storsjön no fossils have been found that would permit the establishment of the occurrence of the above mentioned stages in the Lower Ordovician. According to recent investigations they are not included in the front portion of the Föllinge nappe upon the islands Utöarna in Lake Storsjön. At Laxsjö and along Vattudalen (at Vedjeön) *Difformis* limestone has, however, been observed in this nappe.

We have still only a limited knowledge about the uppermost Lower Ordovician and the lowermost Middle Ordovician which are mostly developed as "Orthoceratite limestone". This is explained in part by the fact that stratigraphical information based upon fossils can be obtained almost exclusively in the autochthonous, since determinable fossils can be extracted only in extremely rare cases from the strongly compressed limestone beds of the allochthonous. In the autochthonous, where they reach a total thickness of several tens of metres, these limestones bear a "Baltic" stamp. Within the Lockne area the different divisions of this limestone sequence lie upon the Precambrian, with residual breccia at the base. The sequence also contains local intraformational conglomeratic layers, amongst others on top of the *Platyurus* limestone. Also surfaces of discontinuity and mud cracks occur.

Within the easternmost nappes the thickness of the "Orthoceratite limestone" is sometimes still fairly large, *e.g.* in the parish of Lit north of Östersund. It decreases considerably in westerly direction, and in the Olden nappe constitutes an unimportant part (< 10 m) of the sequence. It is small also within the Föllinge nappe, especially in its northern and western parts (Laxsjö, Vedjeön). Finds of fossils *(Megistaspis, Pliomera)* have proved the occurrence of the *Vaginatum* limestone at Laxsjö.

Within the allochthonous a change of facies leading to an increase of shaly beds can be established in western direction, and can be shown to affect mainly the lower parts of the Middle Ordovician. It is recognizable in the *Schroeteri* division in the allochthonous of the eastern part of the Storsjö region, but more pronounced in the western nappes. The change cuts, however, across the tectonic main lines, since the lower portion of the Middle Ordovician is developed as shales with limestone lenses containing the graptolites of the Upper *Didymograptus* shale already at the eastern border of the allochthonous along Vattudalen, while obviously no similar development occurs within the region of Lake Storsjön. To the west of Vattudalen the inclusions of limestone in the shale disappear, and within the Föllinge nappe (at Flykälen) sandy beds begin to occur. In the front of the Olden nappe at Laxviken the probably corresponding strata containing graptolites, amongst other *Glossograptus,* consist of sandy shales and quartzites. A transport of sedimentary material from western regions can thus be established in this part of the sequence.

It is uncertain, whether or not the shale below the thin limestone division in the Olden nappe has been deposited contemporaneously with a lower portion of the eastern "Orthoceratite limestone". It is, however, not improbable, since the shale with *Isograptus gibberulus,* correlated with the "*Limbata*" limestone, could be proved to occur in southernmost Västerbotten in the continuation of the area of Jämtland.

With regard to the problems of changes of level and transport of material the rest of the Middle Ordovician of Jämtland supplies elucidating and interesting facts. The gap below the *Ludibundus* beds within the authochthonous is of locally varying magnitude, and shows, from the stratigraphical point of view, a general increase towards the east. The changes of level, indicated by it, were probably not of exclusively eustatic nature, since certain facts favour the assumption of epeirogenetic movements, a tilting of the eastern Archaean with the superimposed Cambrian and Lower Ordovician strata. These facts are gathered from a study of composition and position of the basal *Ludibundus* conglomerate. The latter contains pebbles not only from the eastern Precambrian and the Ordovician beds but also from Cambrian beds in places situated more than 10 km from the regions within the autochthonous that might be considered their source. The Cambrian beds that supplied the fragments have consequently been elevated, prior to the transgression, to an exposed position which allowed their disintegration and the transport in western direction over stratigraphically higher packets of strata. — Thereby also the region of origin of the clastic material in the Middle Ordovician beds of the autochthonous has been indicated.

Within the Lockne area the *Ludibundus* beds lie upon different portions of the Lower Ordovician, upon Cambrian, and directly upon weathered Precambrian, where the latter had formed islands or ridges. In the foregoing we have hinted at the connections of the changes of facies with the sedimentation upon a broken topography of the bottom and the resulting currents. A richly fossiliferous reef-like *Ludibundus* limestone of local distribution occurs mostly immediately on top of the weathered Precambrian, and has probably been formed in connection with a locally vivid circulation of the water. The contemporaneous beds rich in clayey shales ought to have been deposited in more quiet water and less exposed places.

Within the allochthonous no gap has so far been established at the base of

the *Ludibundus* beds or their corresponding strata. In spite of the fact that the Middle Ordovician beds of the easternmost minor nappe in the region of Skute are situated only some kilometres west of occurrences of thick *Ludibundus* conglomerate in the Lockne area this conglomerate or correlatable beds with clastic material are missing in this nappe. This fact supplies an indication about the length of the overthrust, since we have from the autochthonous examples of the occurrence of conglomerate with pebbles of Precambrian rocks which had been transported over 10 km, and within Åsarna over a considerably greater distance, from their eastern occurrence *in situ*.

In the western nappes the gap is filled by graptolitiferous beds. All of them belong to, or are contemporaneous with the lower *Ogygiocaris* shale, a formation which is best exposed upon Andersön and in the front of the Föllinge nappe upon Norderön, and which contains numerous inclusions of dark limestone with both graptolites and a shelly fauna. A similar mixed faunistic facies characterizes also the limestone lenses in the upper *Ogygiocaris* shale which upon the mentioned islands are separated from the lower division by limestone beds with *Telephina biseriata*. — Within the allochthonous immediately east of Andersön, *i.e.* upon Frösön and its northern and southern vicinity, the corresponding portions of the Middle Ordovician consist mainly of graptolite shales with intercalations of limestone containing species of *Triarthrus* that are missing in the *Ogygiocaris* shales. The species of *Ogygiocaris* and *Telephina* which are abundant in the latter are on the other hand not represented or extremely rare in these *Triarthrus* shales. These are without sandy intercalations, while thin ($<$ 15 cm) finely sandy, occasionally quartzitic layers are found in the upper *Ogygiocaris* shales with *Nemagraptus gracilis* of Andersön. Number and thickness of these sandstone layers increase towards the west, and already upon Norderön up to 1 m thick beds of a relatively coarse greywacke-like sandstone are found in the upper *Ogygiocaris* shale. In the western parts of the Föllinge nappe and in the Olden nappe the Middle Ordovician consists mainly of such, occasionally thick beds of greywacke with thin, often sandy shaly layers. Fragments of Precambrian rocks of western origin are common in the greywacke. In the Olden nappe the corresponding sequence of strata exhibits structures and thicknesses pointing to deposition in a geosyncline.

The above account thus shows that the material for the Middle Ordovician sequence of the allochthonous has been supplied mainly by western continental masses, and that the transport of sand from these regions reached farthest to the east during the time of *Nemagr. gracilis* or contemporaneously with the sedimentation of the basal *Ludibundus* beds in the autochthonous.

According to our present knowledge the Upper Ordovician exhibits a noteworthy development and change in east-western direction within the *Dalmanitina*-stage only. The *Tretaspis* beds consist mainly of shales mostly with limestone lenses. However, a limestone formation, exhibiting a somewhat varying development in western direction, seems always to form the base of the sequence, at least as far as the Föllinge nappe. Within the autochthonous, where the top of the available sequence is formed by the Black *Tretaspis* shale (zone of *Climacograptus styloideus*), the limestone is represented by a "masur" limestone, the Slandrom limestone. A similar dark calcilutite, rich in bituminous matter, is found in the easternmost allochthonous, where the *Tretaspis* beds are best visible in the Skute nappe. Along the railway line west of Skute the

Tretaspis beds show a development which greatly resembles that in the normal facies of the Siljan district, *viz.* from bottom to top: Slandrom limestone, black shale, greyish mudstone with layers and lenses of dark limestone, brownish, partly greenish grey *Latilimbus* mudstone with scattered lenses of limestone, and topmost a finely sandy, calcareous shale that might correspond to the so-called *Staurocephalus* shale of more southern regions. Within the allochthonous the changes in western direction seem to be the following: the compact Slandrom limestone becomes thin-bedded with interdigitating shaly beds, the limestone beds within the middle part disappear, and their place is taken by shale, and beds of sandstone and also of quartzite appear in the upper part of the sequence. The latter beds occur within the Föllinge nappe in Offerdal, and thus indicate a transport of sediment from the west. In this nappe the uppermost Ordovician strata consist of dark mudstone, formerly called "Brachiopod shale", which amongst others contains *Tretaspis latilimbus* and *Dalmanitina mucronata,* and probably corresponds to the *Staurocephalus* shale.

Only within the eastern allochthonous, *viz.* at Rannåsen in Östersund, could the occurrence of the *Dalmanitina* stage be established by fossils. Here a rich fauna of trilobites (*Dalm. mucronata, Brongniartella, Illaenus* s. l.), cephalopods, lamellibranchs, and brachiopods is found in a black mudstone that is underlain by a thick series of orthoquartzite, sandy shales, and shales interbedded with thin layers of quartzite. Immediately above the mudstone follows a brownish-weathering bed of hard calcareous siltstone. The quartzite beds contain conglomerates with well rounded pebbles of the size of a hazelnut consisting of quartzite and vein quartz. In some places they contain small inclusions of black shales, and exhibit surfaces with ripple-marks and mud cracks.

Above the siltstone follows again black mudstone with graptolites *(Climacogr.* aff. *normalis)* and, on top of it, a fairly thick series of quartzitic sandstone with scattered intercalations of dark shale. According to the delimitation which has to be adopted in our country between Ordovician and Silurian the beds above the siltstone belong to the Silurian. The sequence of strata at Rannåsen forms a group, and this group has been given the name *Kyrkås* from the parish in which it covers a wide area. Consequently the boundary between the Ordovician and Silurian system lies within this group.

It has been established that at least Lower Kyrkås is found in the eastern minor nappes as far as the Föllinge nappe, that its thickness and extension is considerable in the eastern nappes, and that the clastic material has arrived from an eastern continental mass. The Skute nappe is without the thick sandstone sequence that occurs in lower Kyrkås within the mentioned region.

Rannåsen is the only place within the allochthonous, where the boundary between Ordovician and Silurian could be established so far. Within the Skute nappe the beds between the *Tretaspis* division in the railway cuttings west of Skute and the Silurian limestone at Gärde could admittedly be studied only in part, but seem to consist of the following beds, in ascending order: calcareous sandstone of moderate thickness, brachiopod-bearing shales, and on top a fairly thin division of dark quartzite with layers of shale. Between the latter, which have been observed close to an outcrop of the brachiopod-bearing shales, and the partly pure limestone at Gärde exist transitional beds with upwardly increasing content of lime. It is possible that here the boundary between Ordovician and Silurian is situated just below the quartzitic division.

In the Föllinge nappe the beds are in several places well visible between the uppermost *Tretaspis* stage, *i.e.* the shale that has been correlated with the *Staurocephalus* shale, and the Silurian *Berge limestone,* previously called *Pentamerus* limestone (type locality at Berge in the parish of Offerdal). These beds consist at the base of an unfossiliferous bed of quartzite, about 4 m thick, and above it a succession of beds grading into the limestone. The sequence contains richly fossiliferous calcareous sandstone with *Phacops* cf. *elliptifrons* after which it has since long been called the *Phacops* quartzite, and in addition layers of quartzite and thin layers of shale. The fauna, in which tabulate corals and brachiopods are particularly abundant, is Silurian and comparable to a part of the division 6 in Norway. Also the underlying unfossiliferous bed of quartzite is usually referred to the "*Phacops* quartzite". A stratigraphic gap seems to exist between the *Tretaspis* division and this quartzite bed. Also the sharp lithological boundary between them points in this direction. The name *Ede formation* (or quartzite) is proposed here for the quartzite bed and its overlying "*Phacops* quartzite" (type locality at Ede, 1 km S.E. of Offerdal church).

The Silurian strata younger than the Berge limestone occur in the Föllinge nappe only. For this reason a review of these strata becomes mainly stratigraphic.

The Berge limestone has its widest extent in the Föllinge nappe. In the eastern allochthonous it occurs also within the Skute nappe, where its lower part protrudes in front of the overlying Bjerme nappe. In the Föllinge nappe the limestone has a thickness of about 75 m, and consists of both reef limestone and bedded limestone. The limestone formation belongs to the Middle and lowermost Upper Llandovery, since it is immediately overlain by shales belonging to the zone of *Monograptus turriculatus,* more exactly its lower subzone with *Rastrites linnaei.* Together with the zone of *Monograptus discus* these shales form a lower division of black graptolitic shales containing large lenses of limestone and also beds and thin layers of solidified volcanic ashes, "metabentonite". The thickest of them is situated at the base of the shales, and is *c.* 0.5 m thick.

On top of these graptolitic shales follows a division of dark shales of varying composition. It is characterized by its relatively high content of thin layers of limestone and finely sandy intercalations. It contains portions of black shales, but most of the shales are dark or, occasionally, light grey. The finely sandy, sometimes calcareous shales which enter into the upper portion of the division contain thin layers of quartzite and thin lenses of dark dense limestone. In this upper part only *Monogr. priodon* has been encountered so far, but the lower portion, which is in part visible in a road cutting at Bångåsen in Offerdal, contains a rich fauna of graptolites with *Retiolites,* representing the uppermost part of the *discus* zone or the zone of *Monogr. spiralis.*

On top of these divisions, the *Bångåsen shales,* we find the youngest Silurian beds that have been observed so far in Jämtland. They can be seen in a road cutting at Ekeberg, and belong to the same syncline as the shales at Bångåsen. They consist of greywacke-like sandstone with layers of shale. The sandstone beds are in part fairly thick, up to 2 m. In an intraformational conglomerate with fragments of dark shale *Favosites gotlandicus* forma *forbesi* has been found. The find of this fossil establishes the Silurian age of this formation, the *Ekeberg greywacke,* which exhibits great lithological similarity with the Middle

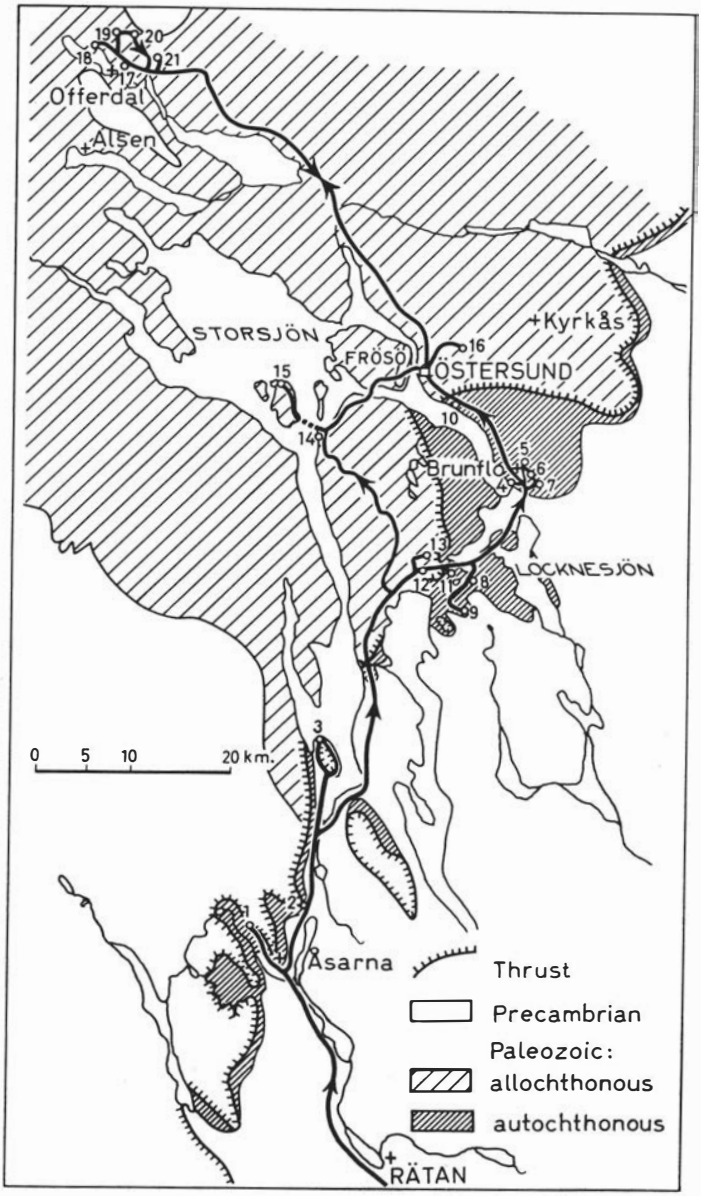


Fig. 14. Map of the Storsjön district, Jämtland. After P. Thorslund.

Ordovician sequences of strata of the western nappes, and which obviously likewise has obtained its material from western continental masses.

By way of summary we can point out that the eastern Cambro-Silurian of Jämtland consists of shallow-water deposits, laid down in a wide trough, a miogeosyncline, which had probably become deeper in Middle Ordovician times. It extended along the Caledonian eugeosyncline with its wealth of volcanites, but was separated from the latter by land areas that supplied the material for the main part of the clastic sediments. This is evident from the preponderantly western extension of these sediments and from their thickness which is great in the west with a decrease in eastern direction. In comparison the quantities of material that have been brought from the east, and deposited in the eastern coastal portions of the basin appear to be small. Here, however, the effects of the changes of level are obvious in the succession of strata.

Jämtland, Road-Log

By

P. Thorslund

SIXTH DAY

Start from Mora at 8^{30} a.m.

The bus runs roughly N. through the hilly and rocky Archaean terrain with scattered villages in valleys and upon southern slopes of heights ("lider"). It traverses northern Dalarna and the eastern part of the province of Härjedalen before entering the southern part of Jämtland after a drive of *c.* 140 km.

STOP 1. (Stor-)Hallen. A section showing the Eocambrian (Varegian) Vemdal quartzite thrust upon the autochthonous Cambro-Ordovician sequence (*cf.* Fig. 15). The topmost beds of the latter belong to the *Ludibundus* division with a conglomerate at the base. The conglomerate contains pebbles derived mostly from the underlying Ordovician limestones, but also from Cambrian stinkstone and Archaean granite. The Vemdal quartzite nappe, i.e. the southern

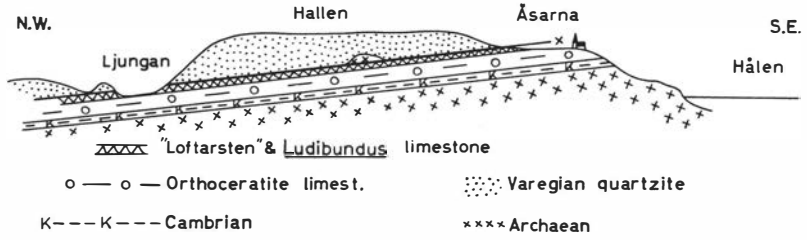


Fig. 15. Diagrammatic section from the Ljungan River to Lake Hålen. After B. Asklund.

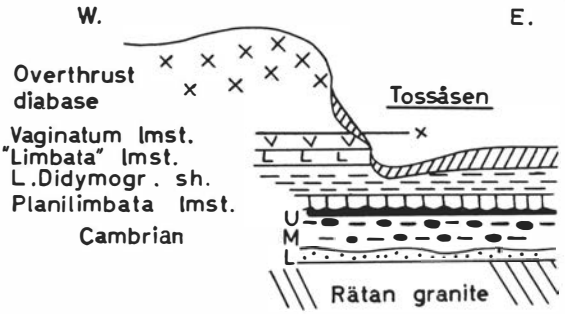


Fig. 16. Diagrammatic section through the sequence at Tossåsen. After B. Asklund.

continuation of the Olden nappe, contains a slice of crushed granite at the thrust plane.

STOP 2. Tossåsen. The allochthonous Vemdal quartzite nappe, with an inclusion of greenstone in the southern slope of the Mt Tossåsen, lies upon autochthonous Lower Ordovician Orthoceratite limestone (*cf.* Fig. 16). Exposures of Upper Cambrian beds and of the Lower Ordovician Hunneberg and Billingen stages will be examined. At the boundary between Cambrian and Ordovician conglomeratic Arenigian limestone with *Lycophoria difformis* rests upon the Upper Cambrian *Leptoplastus* zone with a discontinuity surface at the top.

STOP 3. Hoverberg. An outlier of the Vemdal nappe mainly consisting of Archaean porphyry. A road-cut at the northern end of the mountain exposes autochthonous basal Lower Cambrian conglomerate (with *Torellella laevigata*) upon Archaean granite. The slopes above it show outcrops of light Vemdal quartzite.

The road along the eastern side of the mountain runs mainly upon the plain

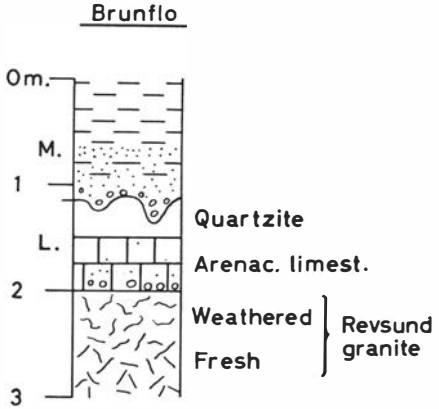


Fig. 17. Diagrammatic section through the Cambrian sequence at the beach of the Brunflo Bay. After P. Thorslund, original. *L*, Lower Cambrian; *M*, Middle Cambrian.

granite floor roughly coinciding with the sub-Cambrian peneplain. The mountain ridge S.E. of Hoverberg and Lake Storsjön is another outlier of the Vemdal nappe.

The bus continues to Östersund (24.000 inhabitants, capital of the province of Jämtland).

SEVENTH DAY

The bus leaves Östersund at 8^{30} a.m., and continues southward to Brunflo along the eastern coast of Lake Storsjön.

STOP 4 A. Boulders of the Lower Cambrian sequence at the beach of Brunflo Bay (*cf.* Fig. 17). The stratigraphic succession is (in ascending order): (a) Archaean Revsund granite (somewhat disintegrated, large crystals of felspar), (b) arenaceous limestone with *Torellella laevigata* and pebbles of phosphorite, (c) dark orthoquartzite, (d) basal conglomerate of the Middle Cambrian and the succeeding dark shale with sandy beds (*Oelandicus* stage).

STOP 4 B. Section at Brunflo Hotel. Middle Cambrian shale with large lenses of limestone (beds with *Paradoxides oelandicus* and *P. jemtlandicus*) overlain by a bed with *Exporrecta* conglomerate (Middle Cambrian *Forchhammeri* stage) and the lowermost Upper Cambrian (with *Agnostus pisiformis* and species of *Olenus*).

STOP 4 C. Pieces from a covered road-cutting showing the boundary between the Cambrian (zone of *Parabolina spinulosa*) and Ordovician systems (basal Arenigian zone of *Lycophoria difformis*) in a ditch close to the parting of the road to Brunflo church. A castellated tower (11th or 12th century) at the church.

STOP 5. Vamsta. A quarry in the grey Orthoceratite limestone (Middle Ordovician *Schroeteri* stage) showing folding and short thrusts.

STOP 6. Gusta. A quarry in the Lower Ordovician *Vaginatum* limestone showing overthrusts in the upper part of the exposed sequence above a surface of slicken sides along a bedding-plane.

STOP 7. Lunne. A quarry in the "Upper red" Orthoceratite limestone (uppermost Lower and lowermost Middle Ordovician). Close to the top of the height are glacially striated outcrops of grey limestone (*Schroeteri* stage) rich in cephalopods. The overlying beds (conglomerate with pebbles of limestone, probably belonging to the base of the *Ludibundus* beds) can be examined in boulders occurring there in situ. View from the height over the Archaean landscape in the S.E. and the Cambro-Silurian area of Jämtland to the Scandinavian mountain range in the N.W. Notice the distinct boundary between these two types of landscapes.

Pause for lunch in Brunflo.

STOP 8. The area S.W. of Tandsbyn (cf. Figs. 18 and 19). The rocks are uncovered over a considerable area owing to the fact that here was once the eastern outlet of a late Finiglacial ice-dammed lake (during the Skute phase of the great Jämtland ice-dammed lake). (a) *Ludibundus* limestone similar to the reef limestones of the Siljan district in a natural exposure S. of the railway. The reef limestone overlies Archaean granite, and has at its base a sedimentary breccia consisting of angular pebbles of this granite. (b) Railway-cutting close to the above reef limestone showing the usual development of the *Ludibundus*

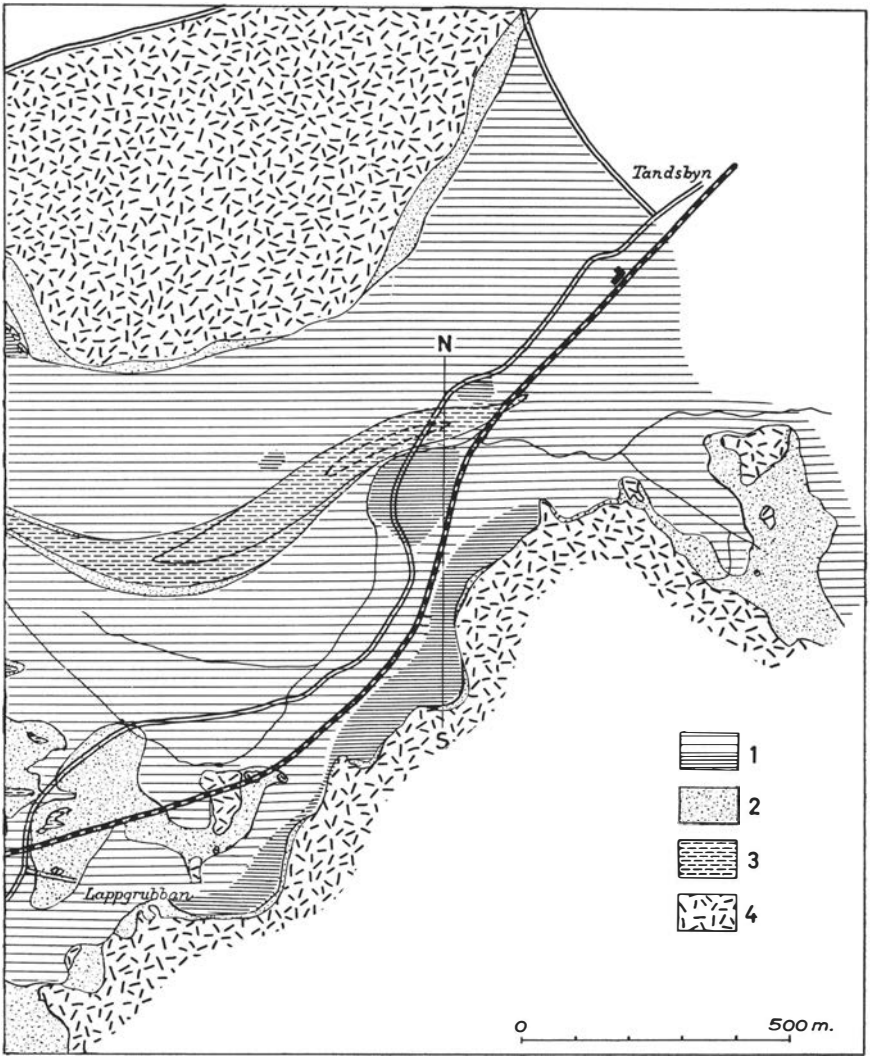


Fig. 18. Map of the Central Lockne area. After P. Thorslund. Legend: 1, middle and upper beds of the Middle Ordovician and (densely striated) the reef-like limestone of the *Ludibundus* division. 2, sedimentary breccia, lof tarstone and conglomerate at the base of the *Ludibundus* division, 3, Cambrian and Lower Ordovician. 4, Archaean, largely with a cover of Ordovician arkose-like breccia.

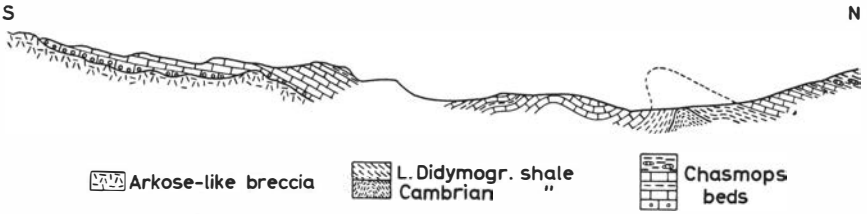


Fig. 19. Section along N.-S. in Fig. 18. After P. Thorslund.

beds in the autochthonous of Jämtland. On top of a basal conglomerate lies a distinctive rock termed "loftarsten". It may be characterized as a calcareous sandstone consisting of angular grains of quartz and felspar together with chloritic scales derived from granite, and mixed with dark calcareous mud, fragments of shale, limestone, and fossils. The loftarsten is mostly overlain by some thick beds of relatively pure limestone. The bulk of the *Ludibundus* beds above the loftarsten consists of dark shale with lenses of limestone to nodular limestone. (c) (Time permitting.) Coarse clastic basal *Ludibundus* beds resting concordantly on Orthoceratite limestone.

STOP 9. Kloxåsen. View toward S.W. over the sub-Cambrian peneplain. The main part of the mountain on the other side of the valley in that direction is formed by an outlier of a nappe of Cambro-Ordovician beds resting upon autochthonous beds and, at the eastern extremity, upon Archaean rocks. — Outcrops of arkose-like breccia on small hills among the dislocated Cambro-

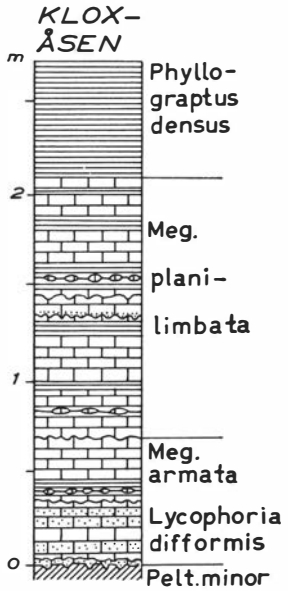


Fig. 20, Diagrammatic section through the Lower Ordovician sequence at Kloxåsen. After T. Tjernvik.

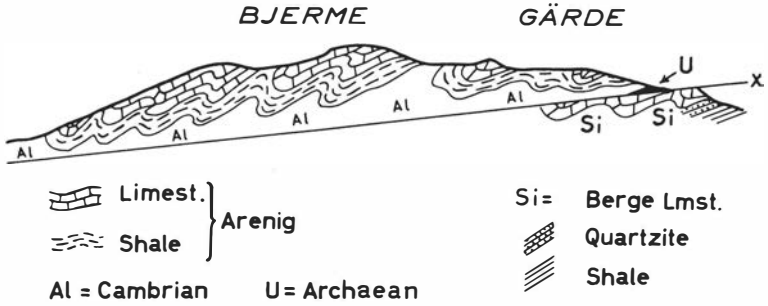


Fig. 21. Diagrammatic section through the frontal part of the Bjerme nappe at Gärde. After P. Thorslund, original. *Si* and underlying beds belong to the Skute nappe.

Ordovician rocks will be briefly examined. Attention will be paid on the sections of lowermost Ordovician (cf. Fig. 20) and Cambrian (especially *Oelandicus* shale).

STOP 10. Torvalla railway section. The lowermost *Ludibundus* beds overlie, with a conglomerate at the base, the Orthoceratite limestone belonging probably to the topmost *Schroeteri* stage. Upon the conglomerate rest beds of loftarsten and limestone (with *Echinosphaerites aurantium*).

The bus returns to Östersund. Dinner.

EIGHTH DAY

The bus leaves Östersund at 8^{30} a.m.

STOP 11. Skute. Leave the bus 1 km E. of Skute railway-stop. Go through the wood (*c.* 0.4 km) to the railway. Railway-cuttings through strongly dislocated autochthonous sequence in front of the first nappe (Skute minor nappe). Follow the railway line to Skute. Outcrops through the Upper Cambrian shales of the Skute nappe. The bus drives 1.5 km westwards, and passes a road-cut through the Lower Ordovician Orthoceratite limestone.

STOP 12. Stengärde. Railway-cutting through the Upper Ordovician beds of the Skute nappe. The base of the section is formed by the Slandrom limestone grading upwards into thin-bedded dark limestone with dark shale overlain by 6 to 10 m black shale with large limestone lenses in the lower part (Black *Tretaspis* shale, zone of *Pleurograptus linearis*). Further westwards the following section (after P. Thorslund) is exposed at the railway (in ascending order):

1. Dark grey shale with layers or lenses of dark limestone. Visible thickness c. 11 m.
2. Thin-bedded, dark, almost compact limestone. Exposed thickness 2 m.
3. Reddish brown, in part greenish grey mudstone with scattered thin lenses or layers of limestone. Corresponds lithologically to the Red *Tretaspis* mudstone or limestone of the other Cambro-Silurian districts of Sweden. Thickness c. 7 m.
4. Dark grey calcareous shale with limestone lenses. Visible thickness 2 m.
5. Hard, grey and dark grey arenaceous limestone. Exposed thickness less than 1 m.

The bus continues up the slope to Bjerme village, traversing the thrust-plane of the Bjerme nappe and the frontal part of this nappe which along the road consists of folded Lower Ordovician limestones and shales (cf. Fig. 21).

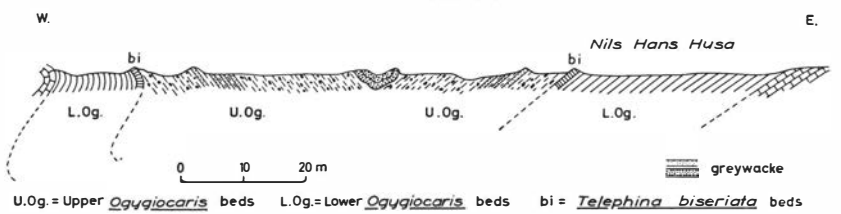


Fig. 22. Diagrammatic section from W. to E. along the northern coast of Norderön. After P. Thorslund, original.

STOP 13. Gärde. After a short walk exposures of the uppermost beds of the sequence of the Skute nappe. Uppermost Ordovician brachiopod-bearing mudstones and Silurian Berge limestone; between them badly exposed strata consisting of dark Silurian quartzite interbedded with dark shales. On top of the limestone are black Cambrian shales with dislodged slices or lumps of strongly crushed (mylonitic) Archaean granite belonging to the very front of the Bjerme nappe.

The bus runs back to Stengärde, and continues to Fåker. View of the fairly wide area S. of Bjerme with gently rolling hills or drumlins consisting mainly of Cambrian shales belonging to the frontal part of the Bjerme nappe. The bus continues N.W. over allochthonous Ordovician, Cambrian, and Eocambrian beds.

STOP 14. Sunne. Eocambrian (Varegian) quartzite with inclusion of a detached portion of crushed Archaean porphyry at its base.

The bus passes Sunne church with remnants of a castellated tower (13th century), and takes the ferry to Norderön.

STOP 15. "Nils Hans' houses" (caves) on the northern shore of Norderön. Section through a syncline of the frontal part of the Föllinge nappe (cf. Fig. 22). Middle Ordovician *Ogygiocaris* shales with limestone lenses and beds of limestone and greywacke (miogeosynclinal facies).

Back to Östersund. Dinner.

NINTH DAY

Start from Östersund at 8^{30} a.m.

STOP 16. Rannåsen quarry, the type locality of the Kyrkås group (*cf.* Fig. 23 C). In the eastern wall an intercalation of black mudstone with fossils of the *Dalmanitina* stage (*Dalmanitina mucronata, Brongniartella platynota,* etc.) between beds consisting mainly of grey orthoquartzite. The southern wall and the sections at the entrance expose the lower part of the group with darker and more thin-bedded quartzite intercalated with pelitic layers which increase in thickness downwards in the sequence. Intraformational conglomerates, cross-bedding, clay galls, mud cracks, and ripple marks are occasionally exposed.

After returning to Östersund the bus passes a hill of Kyrkås quartzite at Ås, *c.* 10 km N.W. of Östersund.

STOP 17. Ede, the type locality of the Llandoverian Ede quartzite, situated

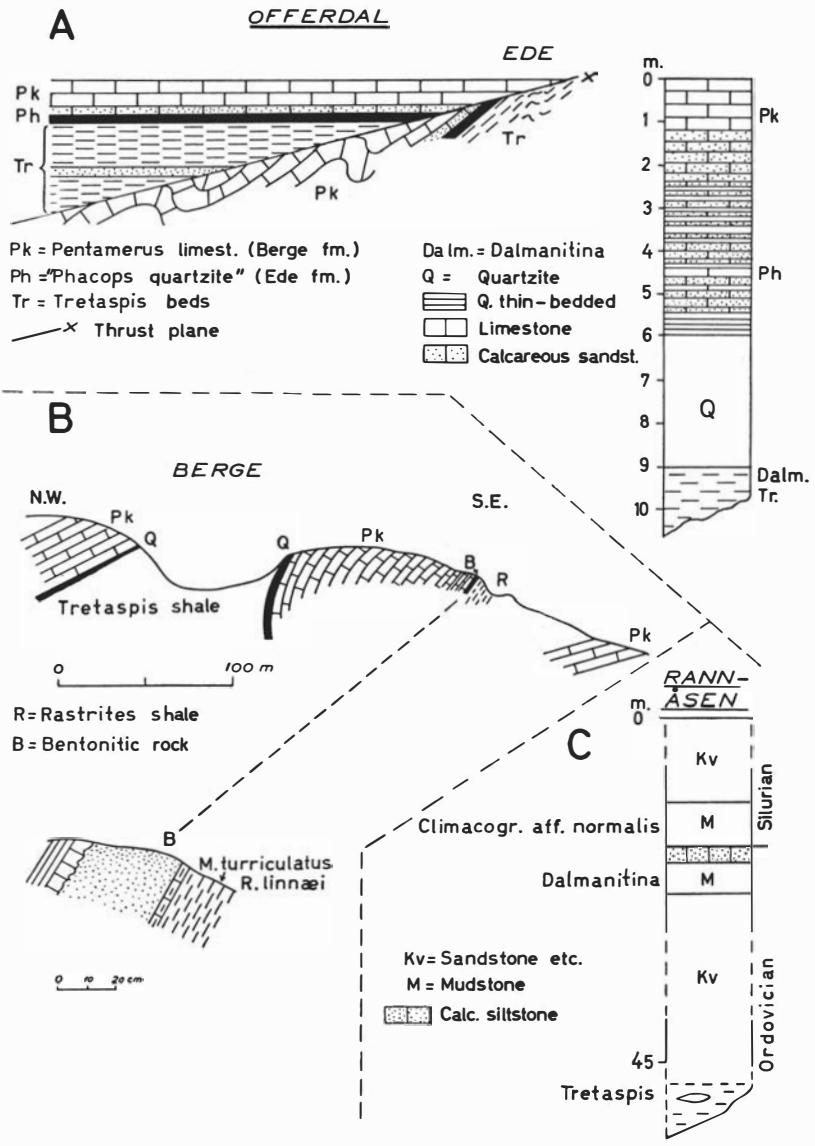


Fig. 23. *A*, diagrammatic sections of the Upper Ordovician and Silurian sequence of the Föllinge nappe at Ede (after P. Thorslund, original). *B*, diagrammatic cross-section through the sequence at Berge (after P. Thorslund). *C*, diagrammatic section through the Kyrkås quartzite at Rannåsen (after P. Thorslund, original).

in the Föllinge nappe. A short walk over the outcrop area of the Berge limestone to a steep slope where beds thrust (*c.* 1 km) over the latter limestone are exposed (*cf.* Fig. 23 A). The lowermost exposed beds of the overthrust mass consist of brachiopod-bearing dark mudstone with intercalations of sandy beds. Higher up in the sequence are outcrops of dark shale or slate ("Brachiopod shale") and bluish grey quartzite (Ede quartzite). The top of the exposed section shows basal beds of the Berge limestone.

STOP 18. Hälle. Outcrops in the Föllinge nappe on the northern shore of Lake Hällsjön showing the top of the Berge limestone and basal beds of the Upper Llandoverian Bångåsen shales with layers of solidified metabentonite. Mt Hälleberget on the other side of the lake is a southern outlier of the Offerdal nappe, and consists of schists overthrust on Ordovician beds of the Olden nappe.

The frontal portion of the Olden nappe with beds of the (Middle) Ordovician greywacke and dark shale can be observed *c.* 1 km W. of Hälle upon the slopes of the Kaxås hill.

STOP 19. Bångåsen, Föllinge nappe. Road-cutting at the type locality of the Bångåsen shale. Dark grey graptolitic shale with lighter thin layers of limestone. Transverse schistosity and jointing.

STOP 20. Ekeberg, Föllinge nappe. The type locality of the Silurian Ekeberg formation. Thick-bedded greywacke with an intraformational conglomerate containing *Favosites.*

STOP 21. Berge, Föllinge nappe. The type locality of the Berge limestone (*cf.* Fig. 23 B). The sequence is folded and traversed by minor thrust planes. In the road-cutting the following section will be examined (in descending order):

Berge limestone 1.6 m +.
Dark grey mudstone with lenses of limestone and with a continuous bed of limestone at the base.
Bångåsen shale 1.15 m +.
(a) Grey to greenish grey consolidated metabentonite ..... 0.55 m
(b) Dark grey to black graptolitiferous shale with a thin bed of calcareous mudstone on the top ..... 0.60 m

Upon the slope above the road section are exposures of the Berge limestone and of the Ede quartzite.

Back to Östersund. Dinner.

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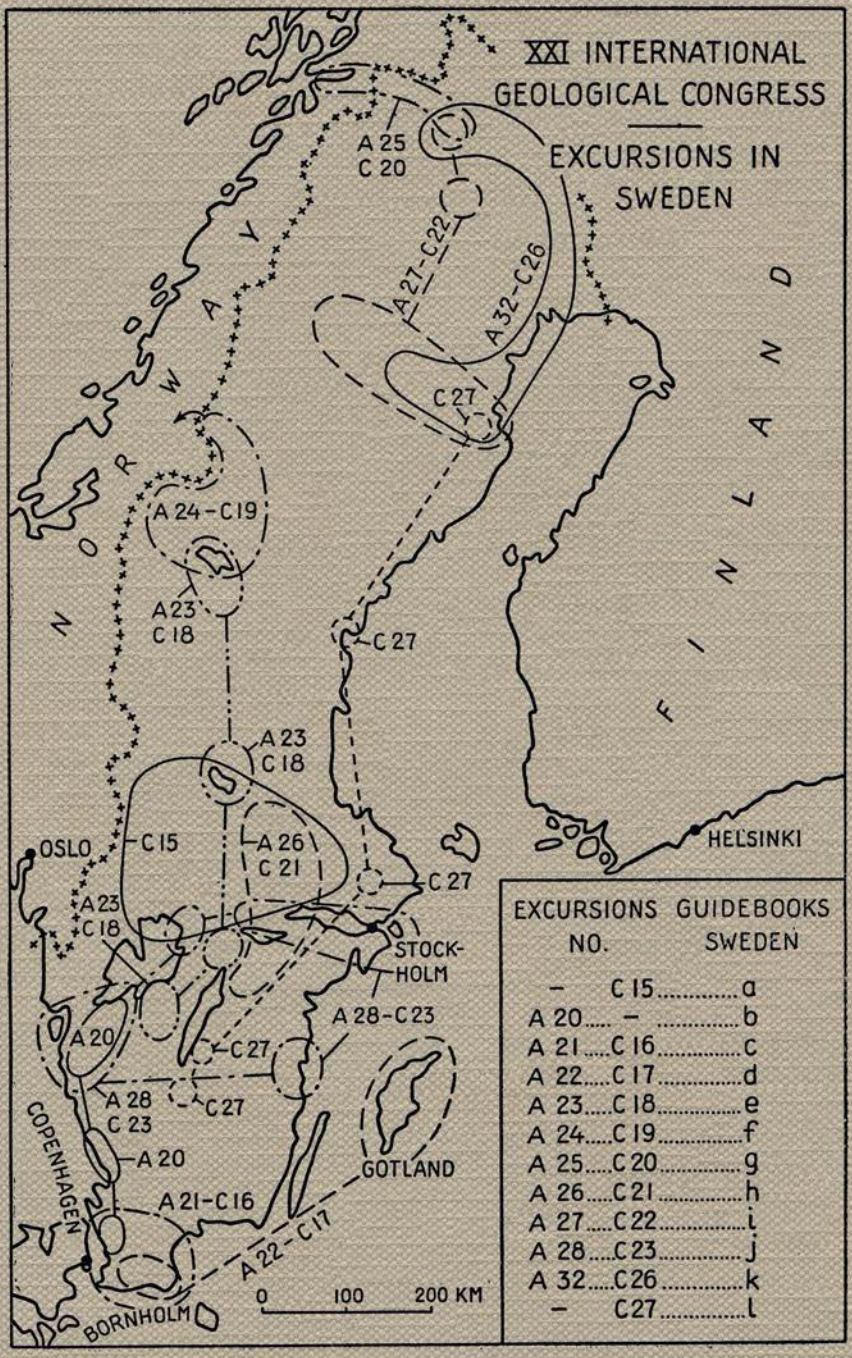
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