

THE SEQUENCE IN THE LOWER ALLOCHTHON OF JÄMTLAND

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Tremadoc In places where black shales are strongly folded or tectonically disturbed, it is difficult to distinguish between Upper Cambrian and Tremadoc shales. However, in several areas the presence of the Tremadoc has been proved. The recorded maximum thickness of the Tremadoc black shales is about 5 m but mostly the thickness is less than 1.5 m; whether these figures represent the primary thickness or not cannot be safely established. In the Dictyonema Shale only the Zone of Dictyonema flabelliforme has been proved, with D. flabelliforme, Bienvillia wimani and Boeckaspis mobergi. In the Moholmen section, central Storsjön area, the presence of the Upper Tremadoc Ceratopyge Shale (Zone of Platypeltoides incipiens) is indicated by Peltocare cf. norvegicum and Parabolinella n.sp. (with a pronounced ocular ridge) (Karis, unpublished).

Recently a thin (0.3 m) black bituminous limestone was found between the Upper Cambrian dark shale and the Latorp Limestone in a road-section about 1 km west of Oviken new church, south-west Storsjön area. The fossil content has still to be fully studied, but appears similar to the Upper Tremadoc at Moholmen (Karis, unpublished).

Latorp Limestone In the Lower Allochthon of Jämtland, the Lower Arenig Latorp Limestone is generally thin. It varies from about 1.5 m in the south-west Storsjön area (Österåsen and Fjällsågen, 10-15 km west of Oviken) to about 0.5 m in the Andersön section. This unit seems persistent across large areas and can be identified in sections as far west of the Caledonian thrust front as Föllinge and at localities on the western shore of Storsjön 20 km due west of Östersund. In the eastern Lower Allochthon the zones of Megistaspis (Ekeraspis) armata and Megistaspis (Varvaspis) planilimbata are present, while in the western sections (Andersön) only the former has been recognised (Tjernvik 1956). The base of this limestone is glauconitic in many localities.

Töyen Shale This shale is apparently developed throughout the Lower Allochthon and in places attains an estimated thickness of about 15 m. The shale facies evidently began earlier in the Lower Allochthon than in many areas of the Autochthon. The zones of Tetragraptus phyllograptoides and Didymograptus balticus have been recorded from Andersön (Tjernvik 1956), where higher zones are probably missing. In adjacent localities, graptolites of the Zone of Didymograptus hirundo have been found (e.g. the Bynäset section, west Frösön, 7 km west of Östersund). The Töyen Shale occurs through a comparable interval in the south-west Storsjön area (Österåsen and Svartbodarna road, west of Oviken).

The dating of this unit is generally difficult since the shale is strongly folded and cleaved, and fossils can only be obtained from a very few levels. Specimens of the trilobite Gog have been found at several localities, (e.g. at Sanne, Hackås and on Andersön (Fortey 1975) and Frösön, from the zones of Tetragraptus phyllograptoides and Phyllograptus densus).

Isö Limestone The grey, generally thick-bedded, calcilutitic Isö Limestone is widely distributed in the Lower Allochthon, from the lowermost nappes in the east, to the vicinity of Ås and Aspås in the western part of the central Storsjön area, and Föllinge north of Östersund (similar, undated rocks appear in the antiforms west of Åre). The type area is the island of Isön, in Storsjön immediately south-west of Andersön. There the whole sequence is strongly folded, in parts inverted, but without any major breaks. The upper and lower boundaries, with the Andersö and Töyen Shales respectively, are exposed. The estimated thickness is about 40 m.

Only a few levels within the Isö Limestone have yielded diagnostic faunas. The basal part of the limestone in the type area falls within the Zone of Didymograptus hirundo, and in a nodular calcilutite about 5 m above the base, trilobites from the Zone of Asaphus (Asaphus) expansus have been recovered. In the uppermost 2 m of the Isö Limestone, Paraceraurus exsul (Beyrich) and Pseudomegalaspis patagiata (Törnquist) are common, indicating beds equivalent to the Folkeslunda Limestone. The Isö Limestone has the same age range throughout most of the central Storsjön area.

To the north of Östersund in the Lower Allochthon of the eastern Häggenås area, the Holen, Segerstad, Folkeslunda and lower Dalby equivalents can be recognized within the Isö Formation in the Örån section upstream of the road to Storhögen. An almost identical development is seen in the Autochthon of Högfors section (Stop 3:4) about 3 km south-east of Häggenås.

In the south-west Storsjön area the thickness of the Isö Limestone decreases rapidly. Across a distance of approximately 2 km within a tectonic unit, the thickness changes from about 12 m to 1.2-0.8 m; in sections through the same interval about 800 m further north-west, the unit is missing. This thinning-out can be seen from the village Kläppe along the road to Svartbodarna, about 12 km WNW of Oviken. The thin limestone wedge is rich in macrofossils (trilobites, brachiopods), which indicate the Zone of Asaphus (Asaphus) expansus (Karis, unpublished). To the west the limestone is replaced by the Föllinge Turbidites.

Andersö Shale This formation, formerly termed Ogygiocaris Shale, is widely distributed in the Lower Allochthon. In the type area on the northern shore of Andersön the formation rests on the probable Folkeslunda equivalent of the Isö Limestone. According to Hadding (1913) the lower part comprises a dark shale with limestone lenses (Zone of Glyptograptus teretiusculus, about 6 m), the middle is dark, bedded limestone (1.5-2 m), and the upper part is dark shale with lenses of limestone and sandy intercalations becoming particularly common towards the top (more than 10 m; Zone of Nemagraptus gracilis and Zone of Dicranograptus clingani in the upper part). The identification of the Zone of Dicranograptus clingani has been questioned and seems improbable.

West, north-west and north of the central Storsjön area the shale is generally thinner. The Zone of Glyptograptus teretiusculus is the most widely developed. Throughout the outcrop area, the formation commonly shows graded bedding indicating turbidite sedimentation. The thinly laminated units of the central Storsjön area represent more distal turbidites. Limestone lenses or layers commonly separate graded units on Andersön and Norderön. On Andersön and especially on northern Norderön, cycles of graded siltstone 1-5 cm thick occur throughout the sequence. On Norderön there are also thicker cycles 10-15 cm thick in

the lower part, and a few beds of greywacke 0.5-0.8 m thick in the upper part of the formation. On Norderön channel-fillings, 1 m wide and filled with cross-bedded coarse silt, have been observed. The turbidite sedimentation in the Andersö Shale appears to be related to the Oviken and other antiforms (see also Föllinge formation).

In the beds of the Zone of Glyptograptus teretiusculus some limestone lenses are rich in shelly macrofossils, particularly trilobites such as Ogygiocaris sarsi regina Henningsmoen, O. sarsi lata Hadding, Pseudomegalaspis patagiata (Törnquist), Nileus sp., Botryoides bronni (Sars), Triarthrus humilis Hadding, Robergia microphthalma (Linnarsson), and Telephina (Telephina) bicuspis (Angelin). In the lower part of the Zone of Nemagraptus gracilis, the dark bedded limestone contains a mixed shelly and graptolite fauna, characterized by Telephina (Telephops) biseriata (Asklund) and was previously referred to as Biseriata Limestone. From the shaly equivalents of the Zone of Nemagraptus gracilis, Ogygiocaris sarsi lata, Botryoides efflozescens (Hadding), Robergia microphthalma, Telephina (Telephops) granulata (Angelin) and other trilobites have been recorded.

In the area west and north-west of Hammerdal, 30-40 km north of Östersund, a sequence of dark shales resting on Isö Limestone has recently been shown to contain graptolites of the Zone of Didymograptus purchisoni, and thus comparable to the Upper Didymograptus Shale. However, on lithological criteria this shale is difficult to distinguish from the Andersö Shale and it is mapped within this formation. The fairly soft shale is isoclinally folded throughout the area. In sections along a road south-east of Björvallen, 12-15 km west of Hammerdal, the thickness of the unit is estimated to be at least 12 m. There are indications of a comparable shale in the lower part of the Lower Allochthon in the Östersund area. The lateral facies relationships of the shales with limestone and turbidite developments are not yet studied (L. Karis, unpublished).

The upper boundary of the Andersö Shale is at present difficult to define. In some areas the shale is overlain by Dalby equivalents (see below) while in other areas, for example at Lugnvik in Östersund, the Andersö Shale grades into the Örå Shale without an intervening

limestone (Stop 3:6).

Dalby equivalents On the islands of Frösön and Andersön, and probably also on Verkon farther to the west, the Andersö Shale is overlain by a limestone unit of argillaceous bedded and nodular calcilitites. The lower, bedded part is very poor in fossils whereas the upper, nodular limestone has yielded fossils indicating a correlation with the upper Dalby Limestone. The limestone is overlain by Örå Shale. In the western Lit-Häggenås area, about 15 km north of Östersund, the Andersö Shale is overlain by bedded, dark grey limestone with distinct argillaceous intercalations. The limestone, at least 5.4 m thick, contains Asaphus (Neosaphus) cf. ludibundus and Echinosphaerites aurantium. The apparently limited distribution of upper Dalby equivalents may chiefly be a reflection on the generally poor exposure through this interval.

At Lugnvik (Stop 3:6), the complex of bentonitic beds, which in the central confacies belt marks the boundary between the Dalby and Skagen Limestones, occurs within a continuous sequence of dark shales. A few tephra layers from the same complex have recently been recorded in the Örån section (Stop 3:3).

Örå Shale The Örå Shale consists of dark grey to black, partly calcareous, silty, graptolitic shale with intercalations of dark grey limestones. In the type section, about 100 m downstream from the bridge where the Storhögen road crosses the river of Örån (Häggenås area; Stop 3:3), the unit is at least 9 m thick. The lower boundary is not exposed, and the contact with the overlying Slandrom Limestone is obscured by folding and thrusting. In the central Lockne area, shales of similar lithology and fauna overlie Dalby Beds, and there are also largely comparable relationships in the Lower Allochthon.

The Örå Shale occurs widely in the central and northern Storsjön areas without significant lithological variation. Thorslund (1940) used the term Upper Chasmops Beds for this unit. Its equivalents in the Siljan district and in Östergötland are the Skagen and Moldå topoformations.

A silty shale-mudstone in approximately the same stratigraphical position

as the Örå Shale occurs beyond the area where the Slandrom Limestone is developed (e.g. at Lugnvik, Stop 3:6 and localities 15 and 25 km north-west of Lugnvik). However, the stratigraphical range of this mudstone facies is uncertain, and it may incorporate equivalents to the Fjäckå, Slandrom and upper Dalby Formations. For practical purposes these shales are included in the Kogsta Formation.

The graptolite fauna in the Örå Shale indicates the Zone of Dicranograptus clingani (Thorslund 1940 recorded the index fossil itself) and possibly also the upper part of the Zone of Diplograptus multidentis. Trilobites are not uncommon in the interbedded limestones, particularly Triarthrus linnarssoni Thorslund, Ampyxella cf. aculeata (Angelin), and others.

Slandrom Limestone The lithology is similar to that in the autochthonous sequence. In the Lower Allochthon the Slandrom Limestone occurs mainly in two regions, in the Skute and Lit-Häggenås areas. In intermediate areas the corresponding portion of the sequence is developed as a dark silty shale with thin intercalations of dark limestone. At Örån the thickness of the formation is 7.3 m (Thorslund 1940).

Föllinge greywackes and turbidites The formation is composed of a monotonous sequence of greywackes and silty mudstones, mostly showing graded bedding (Stop 4:2). In some areas the thickness is in the order of several hundreds of metres. The formation has its maximum development and coarsest sediments (locally including conglomerates) in the south-west, around the Oviken antiform, and in the north towards the Olden and other antiforms (Fölling-Holmsö area north of Östersund and in the Tåsjö area, north Jämtland and south Lapland). Between these areas is a belt extending roughly from Östersund to Offerdal along Lake Nälidsjön in which equivalent beds are considerably finer grained.

The oldest dated Föllinge beds occur east of the Oviken antiform. At Iffelnäs, approximately 4 km south-east of Hallen church, basal Föllinge greywackes resting on the Töyen Shale have yielded graptolites of the Zone of Phyllograptus angustifolius elongatus. On the road from Kläppe to Svartbodarna, approximately 12 km WNW of Oviken, the Föllinge beds

rest on Töyen Shale of Didymograptus hirundo Zone age. Over large areas the Föllinge turbidites are divided by a tongue of Andersö Shale (mainly the Zone of Glyptograptus teretiusculus) into a lower and an upper part. The tongue of shale can be seen at Hallen church, 28 km west of Östersund, and about 10 km west of Föllinge, where it divides the Föllinge turbidites into parts of approximately equal thickness. In the transition from turbidites to shaly siltstones of the Kogsta Formation in the Mattmar area a fossiliferous shale is developed. This shale development has not been observed elsewhere. The shale is less than 10 m thick, and graptolites indicate the Zone of Diplograptus multidentis. In the Alsen area 15 km north of Mattmar and 3 km north-west of Kogsta the transition from the Föllinge greywackes to the Kogsta Siltstone covers about 3 m of beds, and the basal Kogsta Formation has yielded graptolites indicating the Zone of Dicranograptus clingani.

Kogsta Siltstone In the west the Kogsta Siltstone rests on the Föllinge turbidites, and is developed as a monotonous sequence of dark, shaly siltstones, about 30-40 m thick. The type section is in the Alsen area, about 12 km south-west of Offerdal, where the basal part of the formation has yielded graptolites indicating the Zone of Dicranograptus clingani and the top is overlain by the Ede Quartzite. Recent collections here suggest that the upper Kogsta beds contain a Hirnantian brachiopod fauna (M.G. Bassett, pers. comm.), and similar faunas are now known from several localities across the Lower Allochthon. About 12 km south-west of Ånge, Tretaspis seticornis and Diplograptus pristis have been found in the lower part of the Kogsta Formation.

In western areas where the Slandrom Limestone is developed, silty Kogsta beds rest directly on the limestone. However, in eastern areas (e.g. in the railway section at Stengårde, Skute area), a dark shale is developed above the Slandrom Limestone and within the basal Kogsta Formation. This shale is equivalent to the Fjäckå Shale and the higher siltstones are roughly equivalent to the Jonstorp Formation in the Siljan district, except that they probably also include beds of early Hirnantian age.

The lower Kogsta Formation in siltstone facies is mostly poor in fossils; in addition to Tretaspis seticornis and Diplograptus pristis, it includes

Tretaspis latilimbus (Linnarsson) and Dionide euglypta (Angelin). The upper part of the formation is known to contain Dalmanitina (Mucronaspis) mucronata (Brongniart) together with Hirnantian brachiopod faunas.

Within the Upper Ordovician part of the Kogsta Siltstone a conspicuous limestone unit is developed locally. It has its maximum development in and immediately north of Östersund. In the north-eastern outskirts of Östersund Dicellograptus complanatus has been recorded from underlying beds which suggests that the limestone may be roughly equivalent to the Üglunda Limestone of the Jonstorp Formation.

The Kyrkås and Ede Quartzites Coarse quartzite siltstones of two different developments conclude the Ordovician sequence. The Kyrkås Quartzite occurs in the east; its westernmost occurrences are at Landsom, approximately 15 km north-west of Östersund, and on the islands of Andersön and Frösön. The main development of the Ede Quartzite is in the west; a similar thin quartzite unit is known from south-east of the westernmost occurrences of the Kyrkås Quartzite, for example at Stengårde in the Skute area. West of its major outcrop area, Ede quartzite is present below the Middle Allochthon Åre amphibolites. Törnebohm's (1896) interpretation of nappe displacement in Jämtland involved his recognition of this quartzite unit here.

The maximum known thickness of the Kyrkås Quartzite is 45 m. Of the 35 m at Rannåsen (Stop 3:5), at least the lower 15 m is Ordovician. The formation is composed mainly of grey, thin bedded, coarse, quartzitic siltstones with intercalations of fine, shaly siltstone. The bedding is disturbed by occasional shallow channels filled with mud-flake conglomerates. Sedimentary structures include oscillation and current ripples, megaripples in some thicker bedded portions of the sequence, cross-bedding and mud cracks. At Storhögen, west of Kyrkås, large-scale slumping has been observed about 12 m above the base of the formation.

The Ede Quartzite (Stop 4:1) is a much thinner unit, usually not more than 6 m thick. Generally its lower part, 1.5 to 2 m thick (rarely up to 3.8 m, e.g. Mattmar), is a bluish-grey, massive (primarily thick bedded) quartzite. The upper part consists of thin bedded siltstones,

quartzites and limestones, showing sedimentary structures such as cross-bedding and ripples.

The stratigraphical relationship between these two clastic formations has been disputed. The Kyrkås Quartzite has been regarded as partly Ordovician and partly Silurian, and Ede Quartzite as exclusively Silurian (Thorslund in Thorslund & Jaanusson 1960). Recently, useful marker horizons have been discovered which aid in the correlation. The markers consist of three or (westwards) more beds of porphyry-rich sediments. North-west of Offerdal and above dated Kogsta Siltstone there are coarse porphyry-rich sandstones and conglomerates among dark bedded quartzites, the Rönnöfors Conglomerate, best exposed at Rönnöfors (20 km north-west of Offerdal) where its total thickness is 10-15 m. The marker horizons appear to be feather-edge deposits derived from the same source, fining and thinning towards the east. At Ede and other nearby localities, the markers occur as argillaceous intercalations in the uppermost 0.5 m of the Kogsta Shale and in the basal metre of the Ede Quartzite. In the Kyrkås Quartzite they are developed in the basal part (e.g. in the Storhögen Quarry 1.5 km west of Kyrkås) at a level below the fossiliferous siltstone with Dalmanitina (Mucronaspis) mucronata and Brongniartella sp. as developed at Rannåsen (for fauna, see Stop 3:5) (L. Karis, unpublished). Thus the basal parts of the Ede and Kyrkås Quartzites appear to be roughly contemporaneous. The available evidence indicates that the Ordovician-Silurian boundary falls within both the Kyrkås and Ede Quartzites, but the level of the boundary is at present difficult to define.

It was supposed previously that the silt and sand of the Kyrkås Quartzite was supplied from a land area east of the Autochthon. However, recent studies indicate that the sediment for both the Kyrkås and Ede Quartzites was, to a great extent, derived from local western sources (L. Karis, unpublished).