ON RHYTHMIC SEDIMENTATION IN THE RHAETIC-LIASSIC BEDS OF SWEDEN

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ABSTRACT

The Rhaetic-Liassic beds of Sweden range from the Rhaetic up to the Lias γ and are divided into at least 5 main stages, viz., the Rhaetic, the Lower and Upper Helsingborg ($\alpha_1 - \alpha_2$), the Döshult (α_3), and Katslösa (γ) stages. Each begins with a rather thick non-marine basal member and the Katslösa stage, entirely marine. In the Rhaetic and Helsingborg stages rhythmic sedimentation, involving 12 cycles, is well developed. Each cycle begins with non-marine beds, contains clays and coal in the upper part, and is terminated by a calcareous or ferruginous bed with marine fossils. The main part of the inorganic sediments may have been transported from south-east to north-west along the Variscan fault; but the coarse basal sediments at least are derived from Archaean rock, which probably surrounded the whole basin, and still bounds it on the east.

I. GENERAL STRATIGRAPHY

THE Rhaetic-Liassic, or the Höganäs Series, of Sweden is confined to the southernmost part of the country, Scania. It is built up of grey and white sandstones, grey and dark clays, contains thin coal beds and is sometimes calcareous or ferruginous along thin horizons (siderite). The lower part is rich in plant fossils of Rhaetic and Liassic age, and a multitude of zones have been established by the Swedish palaeobotanist A. G. Nathorst. Upwards in the series, plants become rare and marine fossils appear. In the lower part of the column lamellibranchs dominate the fauna, but the top beds also contain gastropods, ammonites, belemnites, crinoid stems, brachiopods, ostracods and foraminifera.

The most complete succession is developed in N.W. Scania. It is partly non-marine, partly marine, and the strata were deposited under humid conditions.

The underlying beds, the Kågeröd Series, consist of red or green coarse arkoses, sandstones and conglomerates—made up of half-weathered detritus from Archaean rocks—with chocolate-brown clays at the top. The colour indicates ferric oxide. The Kågeröd is quite devoid of fossils, having been laid down during arid or semi-arid climatic conditions. It belongs to the Permo-Triassic desert facies and rests on Silurian or Ordovician beds. Because of their position below the Rhaetic, the red beds are generally considered to be Upper Triassic in age (Keuper). The present writer has suggested that they belong to the same age as the coarse conglomerates of the Oslo region, having formed during the period of high relief established by the Variscan earth-movements. Close to the Variscan fault line (see below) they thin out rapidly, overlapping the Archaean region in the east. In the opposite direction they grow thicker, attaining more than 1,000 ft.

The Rhaetic-Liassic beds are in every respect different from the Kågeröd as regards minerals, grain-size, colour, stratification, organic remains, etc. The transition accordingly indicates a remarkable break in the succession.

There is, nevertheless, a tendency for the Rhaetic-Liassic beds to develop " Kågeröd " facies at certain horizons. These are quite devoid of red coloration, however, but are badly stratified and often cross-bedded, with angular grains of quartz and weathered feldspar not infrequently exceeding 5 mm. diameter. They are rich in white clay and contain lenses of siderite, coal grains and plant remains. But animal fossils are entirely absent. They form basal sediments and provide a convenient key to the classification of the formation.

Four main divisions are distinguishable in the lower part of the Rhaetic-Liassic, each beginning with a well-marked basal member:

(1) The Rhaetic—30 or 50 metres in thickness—begins with the Vallåkra member, a redeposited Kågeröd sediment. Then follow well stratified sandstones and clays, with two coal beds which are worked in the coal mines. The upper coal bed forms the topmost Rhaetic stratum in most places, but it is sometimes succeeded by either a thin dark clay with Rhaetic plants, or marine clays with lamellibranchs. The Rhaetic or *Lepidopteris*-flora is rich in species and occurs at several horizons, mostly in connection with the coal beds. Nathorst distinguished 3 plant-bearing zones, but it is doubtful whether they persist for far, except in a narrow marginal part of the basin. Animal fossils have been encountered at three horizons, of which two at least are marine. One of these contains the *Avicula contorta*-fauna.

(2) The Lower Helsingborg Stage introduces the Lias and begins with the cross-bedded, coarse Boserup member. It continues with sandstones and clays containing thin coal-seams (only locally explored), and contains the Helsingborg and Pålsjö floras. These provided the basis for the four plant-bearing zones of Nathorst's stratigraphical table. Only three may stand however. All belong to the *Thaumatopteris*-flora. In addition, marine beds, such as *Mytilus*-, *Cardinia*- and "*Pullastra*"-banks, occur at different horizons, all characterized by *Ostrea hisingeri*. This species was described by Sven Nilsson as far back as 1831, and is probably the same as *O. liassica* Strickland.

(3) The Upper Helsingborg Stage begins with the basal Fleninge member, which is similar to the Boserup. Fine sandstones and clays, with thin coal-seams of no economic value, form the remainder. Several horizons with poorly preserved plant remains occur, and marine beds with scanty lamellibranch faunas—mostly *Ostrea hisingeri* and *Cardinia*—are also known.

The leading fossils of the two Helsingborg stages are species of *Cardinia* and *Modiola*, *Ostrea hisingeri*, *Gutbiera angustifolia*, *Thaumatopteris schenki* (in the lower part) and species of *Nilssonia* and *Dictyophyllum*.

The thickness is about 200 metres, the upper stage being somewhat thicker than the lower.

The Helsingborg stages correspond to the Cardinien-Lias, or Lias α_1 and α_2, of the German succession. It is, however, impossible to determine whether or not their mutual boundary actually coincides with that between the *planorbis* and the *angulatum* zones.

(4) The Döshult Stage begins with the coarse cross-bedded Döshult Sandstone and contains beds with *Avicula suecica* Hébert, *Gryphaea arcuata* and *Coroniceras*, the so-called *Avicula*- and *Ammonites*-banks of the old scheme. It corresponds to α_3, or the Arieten-Lias. The total thickness is 170 or 70 metres.

II. CYCLIC SEDIMENTATION

The four divisions of the Rhaetic and Lias α described above represent a sequence of cyclic sedimentation, every cycle being characterized by coarse-grained sediments at the base and fine clays and coal beds towards the top. The sediments are mainly non-marine, probably deltaic or fluviatile. It is well known, however, that thin calcareous or ferruginous beds with marine shells occur at several different horizons. According to the old conception, marine beds should dominate the Lias, and the Rhaetic should be entirely non-marine. The Rhaetic-Liassic boundary was therefore wrongly placed in the upper part of the Lower Helsingborg Stage. Careful investigations of a great many sections and drilling-cores in the coal basin have brought to light a number of marine beds in the Rhaetic, as well as in the Lias. These occur at horizons traceable over great distances, correlated by means of characteristic fossils such as *Cardinia follini*, "*Pullastra*" *elongata* and *Cardinia* n.sp., each of which occurs only in one bed. A thorough study of the successions in several drilling-cores has shown that these marine beds form boundaries between cycles of a lower order.

The Rhaetic consists of three such small cycles, and the Helsingborg Stages of nine, *viz.*: four in the lower and five in the upper. Each of these Liassic cycles is terminated above by marine beds with *Ostrea hisingeri* and, sometimes, *Modiola hoffmanni* Nilss. The non-marine parts also have their characteristic fossils, chiefly plants. The lowest Rhaetic cycle, the Vallåkra, contains, in every known exposure and drill-hole, one or two beds rich in spherulitic siderite. The spheruliths average 1 mm. in diameter and show radiating structure. They may be considered as characteristic, for they do not occur elsewhere.

The lower Liassic cycles are well characterized by fossils, but this is not the case with the upper ones, apparently because the latter cover a much smaller area and have been pierced only by a few drillings. This is due to the fact that the worked beds—coal and clays—being situated in the Rhaetic, have hitherto been explored only in areas where they are fairly near the surface and where, in consequence, the upper stages are missing.

The following cycles make up the succession in the Rhaetic and Lias $\alpha_1 - \alpha_2$:

THE UPPER HELSINGBORG STAGE

(12) *The Ostrea-Bank Cycle:* mainly at Oregården:
Calcareous sandstone and siderite. The *Ostrea*-bank.
Clay with fish-scales and indeterminable lamellibranchs.
Coal and clay with plants (*Gutbiera*, *Dictyophyllum*).
Cross-bedded arkose-like sandstone.
Conglomerate and vertical plants.

(11) Mainly at Oregården and Klappe:
Calcareous sandstone and siderite, *Ostrea hisingeri*, *Modiola*, *Gervillia.*
Clays with coal-seams and plants (*Gutbiera* and *Equisetites*).
Sandstone.

(10) Calcareous sandstone and siderite.
Clay with fragmentary plants and coal-seams.
Sandstone, partly feldspathic.

(9) Calcareous sandstone and siderite, gastropods, lamellibranchs.
Clays with scales, plants (*Gutbiera*) and coal.
Sandstone.

(8) *The Fleninge Cycle:*
Clay with scales and ostracods; or bone-bed.
Calcareous sandstone, siderite, and sandstone with *Ostrea hisingeri*, *Modiola hoffmanni* and *Cardinia.*
Clay with coal and plants (*Nilssonia* and ferns).
The coarse Fleninge Beds.

THE LOWER HELSINGBORG STAGE

(7) *The Ramlösa Cycle:*
Calcareous sandstone and siderite with the "*Pullastra*"-bank (at many places); *Ostrea hisingeri* and *Modiola hoffmanni.*
The zone of *Cyclas nathorsti.*
Clay with coal and plants (the Pålsjö flora).
Sandstone.

(6) *The Pålsjö Cycle:*
Calcareous sandstone and siderite. Bone-bed. *Modiola.*
Grind-sandstone with *Cardinia follini* (the *Cardinia*-bank).
Sandstone with *Modiola* and *Ostrea hisingeri* (the *Mytilus*-bank).
Clay and sandstone with plants (*Dictyophyllum*, *Equisetites*).
Coarse sandstone.

(5) Calcareous sandstone and siderite, *Ostrea hisingeri*, *Modiola.*
Clay with coal-seams.

Sandstone with plants.
Coarse sandstone.

(4) *The Boserup Cycle:*
Calcareous sandstone, siderite or bone-bed. *Ostrea hisingeri.*
Clay with the Helsingborg flora.
The coarse Boserup Beds.

THE RHAETIC STAGE

(3) *The A-Cycle:*
Calcareous sandstone. Clay with *Mytilus* (or *Modiola*).
Dark clay with *Lepidopteris ottonis.*
The Upper Coal-Bed (A) with *Lepidopteris ottonis.*
Underclay.
Sandstone, partly coarse.

(2) *The B-Cycle:*
Calcareous sandstone and siderite. Clay with fishes, stegocephalians and lamellibranchs.
The Lower Coal Bed (B).
Underclay with the *Lepidopteris*-flora.
Sandstone.

(1) *The Vallåkra Cycle:*
Clay with the *Avicula contorta*-fauna.
Spherosiderite.
Basal sandstones and clay with indeterminable plants.

III. THE SOURCE OF THE SEDIMENTS

The map (Fig. 1) shows the present geological structure of the area, dominated by the breaking up and faulting of the whole basin. The faults are certainly much younger than the sediments. Thus Söderåsen horst, though quite devoid of sediments, has cut through a region in which the Rhaetic-Liassic sediments gradually get finer south-westwards. However, at least one fault is older than Mesozoic, the rocks on both sides of it being covered by remnants of the Kågeröd. This is the Variscan displacement, referred to above. It runs along the south-west side of Kullen and Söderåsen and further towards the south-east, separating the Palaeozoic from the Archaean.*

This fault-line played an important rôle during Rhaetic-Liassic sedimentation. Along its north-eastern side the Archaean is still covered in places with remnants of very coarse sandstones or arkoses (sometimes conglomeratic), but no coal or black clay. The latter appear to the west of Söderåsen, together with the out-thinning coarse sandstones of the Rhaetic and basal Liassic stages (see below). Between the Höör district and the Engelholm basin the Archaean gneiss is covered, so far as is known, only by Quaternary deposits. Here, at Brandsberga and Kolleberga, Liassic pebbles occur in great numbers and in such a position that they must surely indicate the presence of undiscovered solid rock in the immediate vicinity. The pebbles are rich in fossils belonging to Lias α_3 or γ. They also contain large angular and rounded pieces of half-weathered Archaean, just like that which outcrops. Rhaetic and Lower Liassic deposits which formed at this place were therefore removed at least by Lias γ time. Accordingly, exposures of Archaean rock existed during early Liassic time only 15 or 20 km. from the present coalfield.

Between Brandsberga and the coalfield to the west there now lies the gneissic fault block of Söderåsen, rising to an altitude of about 200 m. Along its western side Söderåsen is bordered by narrow strips of brecciated Cambrian sandstone, Silurian shale and Kågeröd red beds. Then follow the lower members of the Höganäs Series—the Rhaetic with its two coal beds and the lowest Liassic beds.

*The Lower Palaeozoic (Cambrian, Ordovician and Silurian) amounts to a thickness of about 1500 m. south-west of the Variscan fault.

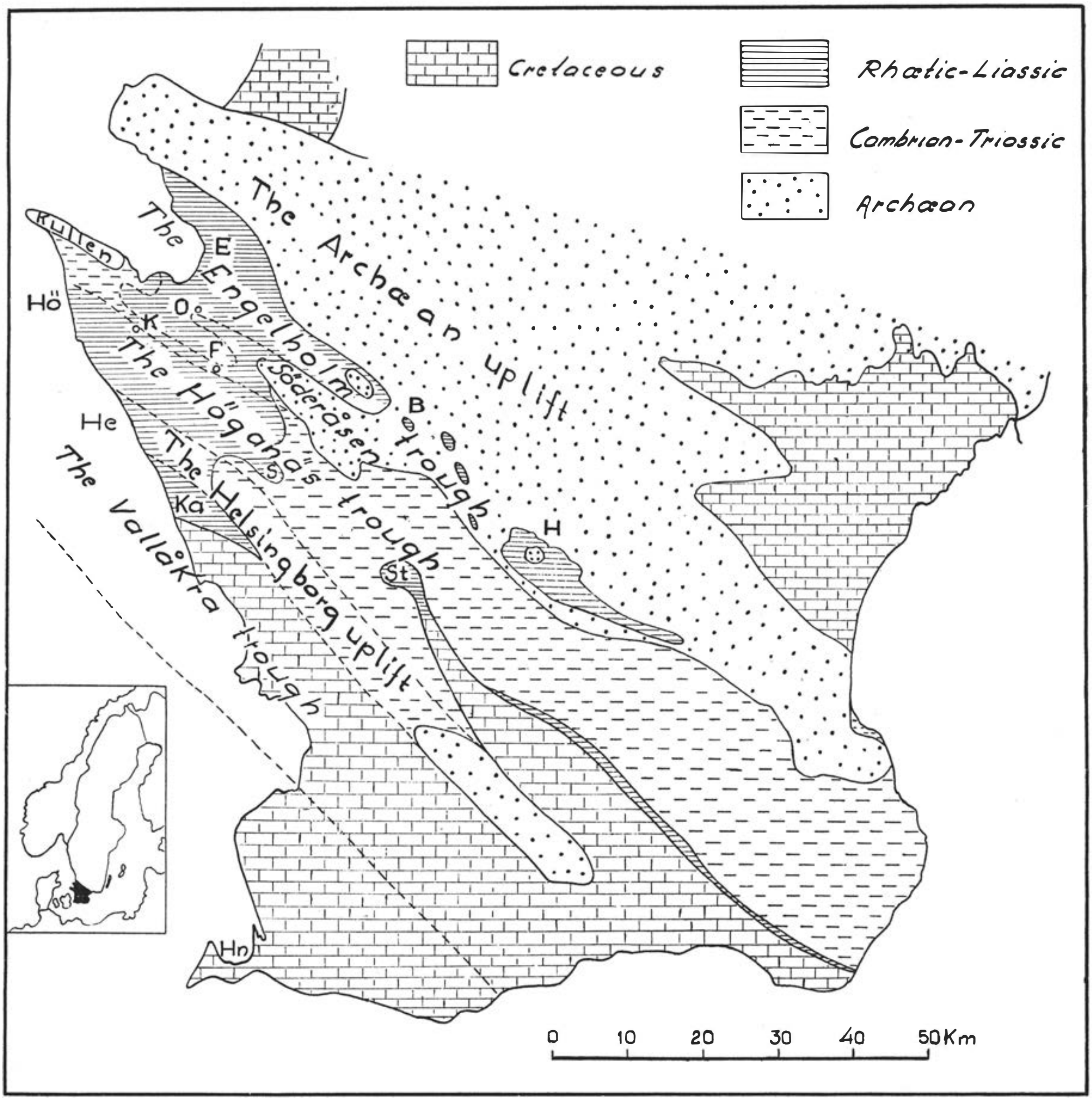

FIG. 1.—*Map of Scania, showing the distribution of the Rhaetic-Liassic beds and some tectonic elements, mostly of younger date.*

B = Brandsberga, E = Engelholm, F = Fleninge, H = Höör, He = Helsingborg, Hn = Höllviken, Hö = Höganäs, K = Klappe, Ka = Katslösa, O = Oregården, S = Skromberga, St = Stabbarp.

Profiles at right angles to the horst show a gradual diminution in grain-size of the country rock south-westwards. Close to the horst the sediments are dominated by coarse sandstones with angular grains of quartz and weathered feldspar, 1-5 mm. in size, set in a loose cement rich in kaolin. These light arkose-like sandstones are especially well developed between and above the coal beds. The Vallåkra is darker, being green or dark grey, with big angular grains of quartz and feldspar occurring in the clay. Thin clay-beds may already occur in this belt. South-westwards, the sandstones get finer and thinner, and the clays grow thicker (Fig. 2). At the same time the coal beds change. First they divide into one clay bed and one coal-seam, separated by 4 or 5 m. of sandstone. The clay bed then changes into coal, the heavy sandstone into thin clay, and this in turn changes to a bed of fireclay within the coal bed. The transformation (Fig. 3) takes place in both coal beds within a semicircular region below the horst. To the north and south, the coal beds come much closer together. On the south, the landward part has been removed by erosion, but to the south-west we have still the coalfield of Skromberga. There, the main coal beds (A and B) are separated by black clay 4 or 5 m. thick. Northwards, the coal beds reach the immediate vicinity of the horst, and are separated from each other by less than one metre of country rock, sandstone and clay.

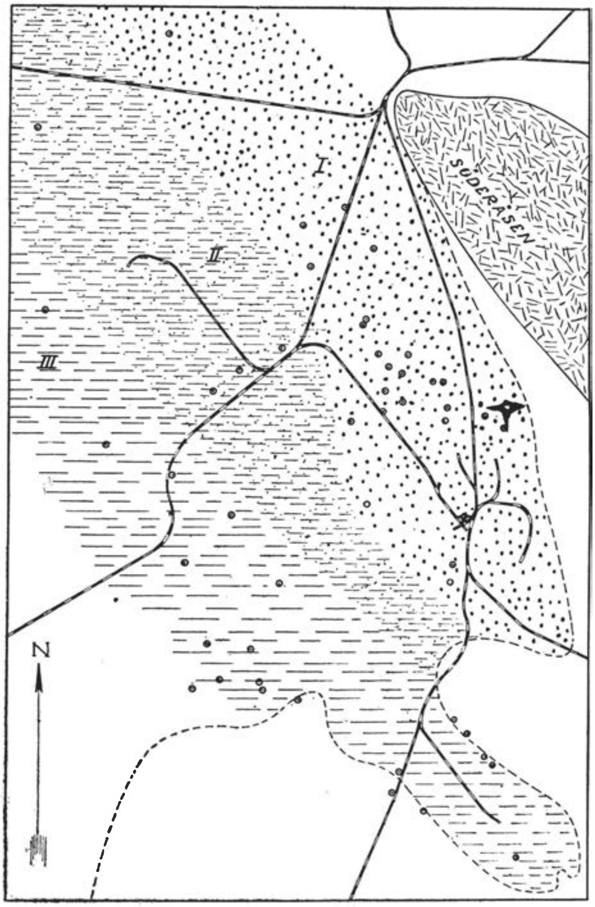

FIG. 2.—*Rhaetic sediments, south-west of Söderåsen.*

I—mainly coarse sandstone; II—fine sandstone and clay; III—mainly clay.

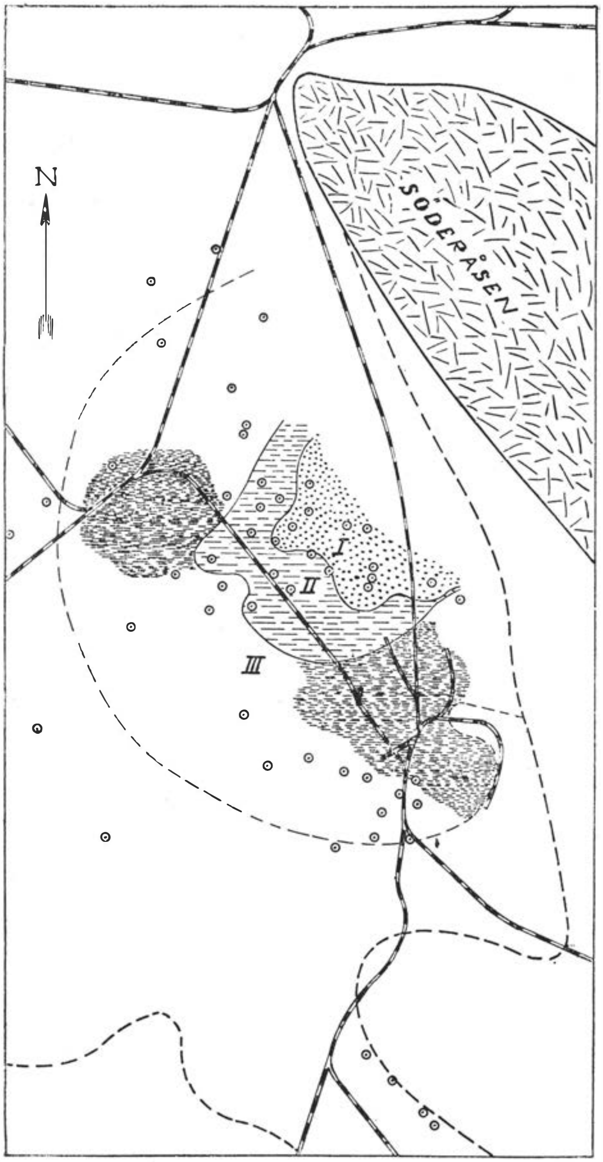

FIG. 3.—*The Upper Coal Bed near Söderåsen.*

I—the coal is split up by sandstone 3 or 5 m. thick; II—the sandstone is replaced by a much thinner clay; III—the coal bed contains fireclay.

The distribution of the sediments outlined above leads to a picture of deltaic deposits within and between the coal beds in a sharply demarcated region below Söderåsen. Borings close to Söderåsen have pierced coarse sandstones, but no coal beds.

The vertical interval between the coal beds is 6 or 10 m. in the collieries near Söderåsen, but farther to the west and north-west, at Helsingborg and Höganäs, it is 25 or 30 m. Concurrently, the coal thins out, and at Höganäs only the lower coal bed is exploited. None is worked at Helsingborg.

These facts prove that, during Rhaetic and earliest Liassic time, detritus was transported from north-east to south-west, at right angles to the Variscan fault-line.

Higher in the series the influence of the Archaean rocks is also well established. For instance the Fleninge Beds are developed mainly near the present north-western end of Söderåsen. At Fleninge they are situated 80 metres above the Rhaetic-Liassic boundary. On account of their high stratigraphical position they have been removed over a vast area of the marginal part of the basin near Söderåsen. They have, however, been identified at several places in Helsingborg, where the coarse beds are rich in pebbles of siderite and coal. But in the region between the Helsingborg uplift and Fleninge they seem to be represented by ordinary medium-grained sandstones.

Still higher in the series, the coarse Döshult Sandstones have been followed, in outcrops and borings, from the coast south of Höganäs to the vicinity of Engelholm. Along this direction (west to east) they become gradually thinner and finer grained, and finally merge into clay. This undoubtedly indicates transport in a direction opposite to that deduced from the lower part of the column.

Another important fact is that whilst in the Engelholm basin the succession consists almost entirely of clays with only a few thin sandstone beds, in the Höganäs trough sandstones dominate the Liassic succession.

The mineral composition of the coarse sediments indicates derivation from Archaean rocks (or the Kågeröd arkoses). Further, the sediments clearly originated in the basin borders to the east or the west, the latter—in Denmark—being now covered with younger Mesozoic sediments.

Since the coarsest sediments are restricted to special members of the succession, intermittent uplift of the borderland occurred.

There is no clear evidence regarding the source of the fine-grained sandstones and clays. Previous authors have claimed general transport from the present Archaean region in the east, north-east, or north. But since the deep boring at Vilhelmsfelt, near Engelholm, showed that the Engelholm basin was filled up by sediments deposited more to the seaward than those of the Höganäs field, this idea has had to be abandoned. Transport in an opposite direction is not, of course, out of the question, but we must consider also the possibility of transport along the tectonic lines, i.e. along the Variscan fault. Is such transport likely to have taken place from the north-west or from the south-east? The distribution of the marine beds in the Rhaetic and the Helsingborg stages shows that the sea invaded the basin from the north-west. Transport must accordingly have been from the south-east. Towards the south-east only small remnants of these stages are represented or preserved. Thus in the Höganäs trough the small Stabbarp field contains chiefly Liassic deposits which are remarkably thin and seem to thin out further in the same direction. According to a recent boring in the south-western corner of Scania (at Höllviken) it is uncertain whether the Lias is developed there at all. In S.E. Scania and on the island of Bornholm corresponding beds are encountered but, though quite thick locally, they seem in general to be rather scantily developed. A similar state of affairs is found on the southern side of the Baltic. This meagre development of the oldest Jurassic sediments may indicate a land surface to the south-east in a vast region that might thus have contributed much of the fine sandstone and clay. These would have been transported partly by rivers running along the main fault-line, and partly by tributaries coming in from the sides, the latter giving rise to local deltaic deposits.

The above account has been concerned mainly with sedimentation in the Rhaetic and the Lias $\alpha_1 - \alpha_2$. The Lias α_3 embracing, among others, the Döshult Sandstone and the beds with *Avicula*, *Gryphaea* and *Coroniceras*, is rather coarse, but indicates more decidedly marine conditions than do the earlier beds. This is still further emphasized by the youngest known Liassic beds, the Lias γ or the Katslösa Stage, representing a marine transgression which reached not only S.E. Scania and Bornholm, but also the old land beyond the Baltic Sea. The Katslösa beds are rich in thin conglomerates and iron-oolites with well-rounded quartz-grains, 5 or 10 mm. in size or even larger, indicating an adjacent coast line.

IV. SUMMARY

Rhythmic sedimentation in coal measure deposits has attracted much interest during the last 20 years. As a rule, the thickness of coal-bearing formations is considerable, though all were laid down in shallow water—even in river deltas and river plains above sea-level. This was made possible by regional subsidence. In a recent paper, Haites and Thiadens,* dealing with the Dutch (Carboniferous) coalfield, interpreted the repetition of coal beds as river deposits laid down in a region of slow continuous subsidence. The coals were frequently split by meandering, and very often beds were washed out by the rivers. The intervening sediments (the country rock) do not, in effect, really separate the different coal beds. Over sufficiently large areas the coals become reunited via " splits," thus joining up to form thick series of strata between two major marine transgressions. This interesting theory is in direct opposition to the prevalent ideas regarding rhythm in coal basin sediments. The rhythm is, in fact, a mere show, independent of any kind of rhythmic process in the earth's crust.

I unhesitatingly agree with the above authors in their interpretations of the Dutch coalfield, and consider it is quite probable that this kind of sedimentation took place in most coalfields containing thick supramarine sediments. But in regions where the sea invaded a basin repeatedly we cannot ignore intermittent changes of level. In the lowest Lias of Sweden, moreover, there is another important factor to be taken into account, *viz.* the up-warping of the Archaean borders and their denudation.

The Rhaetic-Liassic sediments of N.W. Scania were deposited in a region of intermittent crustal movement, resulting in a cyclic succession of strata about 250 metres thick. The coal basin was surrounded by Archaean rocks on the north-east and probably also on the south-west. Each upheaval of the Archaean borders initiated a new phase of rapid sedimentation, finally resulting in silting up of the basin. Then, due to subsidence, the sea inundated the more low-lying parts and remained there until fresh upheaval of the margin re-introduced a new cycle, again with continental deposits at its base. The marine waters were assuredly very shallow and the salinity low, as indicated respectively by the thin sedimentary cycles (mostly about 20 metres) and the scanty thin-shelled lamellibranch faunas.

(Literature on the Rhaetic-Lias of Sweden: *Geologiska Fören. Stockholm Förhandl.*, 69, 1947, pp. 292 and 431.)

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