A REVIEW OF THE CARBONIFEROUS AND PERMIAN ROCKS OF THE WEST COAST OF VESTSPITSBERGEN

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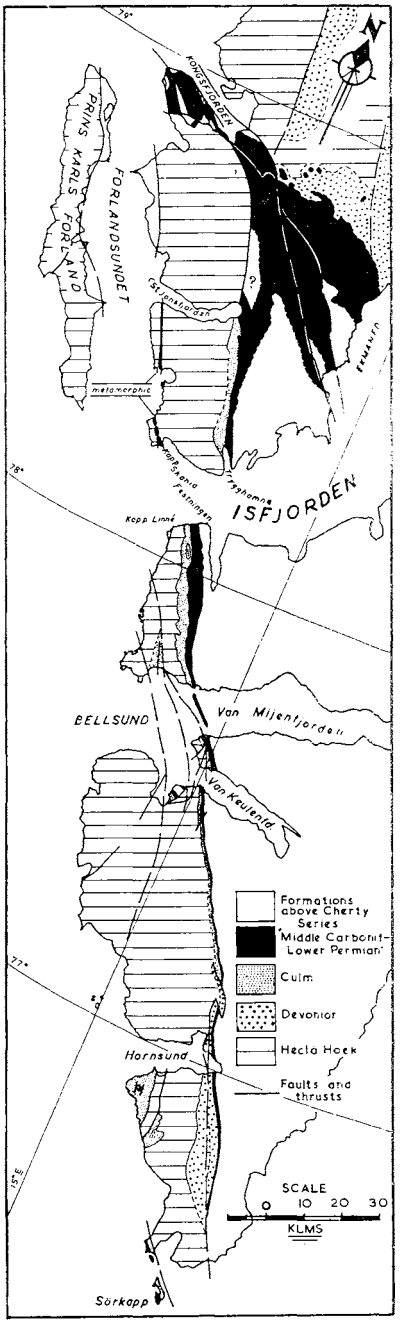
A b s t r a c t. The Carboniferous and Permian rocks near the west coast of Vestspitsbergen have been studied only at a few widely separated points, between which considerable variations in character and thickness take place. These variations are probably due to gentle warping of the underlying Devonian and Hecla Hoek basement, coupled locally with fault movement. Various sedimentary and stratigraphical problems are pointed out, including the delimitation of the Culm and the red formations below the Cyathophyllum Limestones. Extensive reworking of early Carboniferous deposits is suggested. The red beds are probably cyclothemic and the presence of marine bands, as at St. Jonsfjorden, should provide useful datum horizons. During Cyathophyllum Limestones times deposition seems to have been more uniform but thickest in the north and at Isfjorden. Variations in the chert sequence appear to be small. The problem of the "Wittenburg facies" above the cherts is mentioned.

Introduction.

GENERAL SETTING

The Carboniferous and Permian rocks in western Vestspitsbergen form a generally very narrow belt running from Kongsfjorden southwards some 300 km to Sørkapp. South of St. Jonsfjorden it is seldom



more than two or three kilometres across and the strata are for the most part steeply inclined to the east, locally becoming overturned. Between the outcrop of the lowest Carboniferous rocks and the west coast lies an area of Hecla Hoek (metamorphic) formations from 10 to 35 km wide. Some Devonian sediments also are present near Hornsund and locally there are faulted outliers of Lower Carboniferous lying some way west of the main outcrop. Between St. Jonsfjorden and Isfjorden Middle or Upper Carboniferous beds have been caught up between thrust faults in the Hecla Hoek (WEISS, 1953; BAKER, FORBES, HOLLAND, 1952).

From Bröggerhalvøya southeastwards to Ekmanfjorden and central Vestspitsbergen extends a broad outcrop of the Carboniferous and Permian, while an extensive area of the same beds runs across north-eastern Vestspitsbergen to Nordaustlandet.

The present paper reviews the Carboniferous and Permian formations near the west coast and points out some of the stratigraphical and sedimentary problems connected with them.

Fig. 1. Sketch map of geology of Western Vestspitsbergen.

PREVIOUS WORK

Some of the earliest systematic investigations into the stratigraphy of the Carboniferous and Permian in western Vestspitsbergen were carried out by A. G. NATHORST (1910) and later by HOEL during the (ISACHSEN) Prince of Monaco's expeditions (HOEL, 1915), but the first major contributions are those of HOLTEDAHL (1911, 1913), who travelled over much of the ground between Kongsfjorden and Bellsund and established the broad stratigraphical divisions.

ORVIN's description (1934) of the geology of the Kongsfjord region gives the first detailed account of the stratigraphy and structure of the Carboniferous on the west coast. The same author in 1936 visited Ahlstrandodden, Reinodden and Hornsund to make a brief examination of the Upper Palaeozoic rocks there. In 1937 he published with HOEL an account of the section west of Festningen on the southern side of Isfjorden, while FREBOLD (1937) described the Upper Carboniferous and Lower Permian stratigraphy and brachiopod and lamellibranch faunas.

In his "Outline of the Geological History of Spitsbergen" (1940) Orvin summarizes the available data and briefly illustrates the lateral variations in the Carboniferous and Permian rocks. He emphasizes the large distances separating the areas in which the succession is known and indicates some of the difficulties of correlation. Details of two further Carboniferous-Permian sections on the west coast are now to hand. The Birmingham University expedition of 1948 gave WEISS (1949) the opportunity to record the succession at Trygghamna on the northern side of Isfjorden, and during a second expedition in 1951 P. A. GARRETT and D. W. GOSSAGE reconnoitred the geology at the head of St. Jonsfjorden. A subsequent joint expedition from Birmingham University and University College, Exeter, permitted Garrett and the present writer to continue that work in 1954.

DIFFICULTIES

Geological work in Vestspitsbergen is often made somewhat difficult by scree, gravels, moraine, snow and ice which may obscure the solid formations. The softer, more fissile rocks are usually covered with a heavy mantle of weathered debris. Harder formations often give rise to dangerous and inaccessible slopes. Continuity of outcrop

is frequently broken by the glaciers, many of which undoubtedly lie along zones of unconformity or faults, and critical areas are obscured. The Tertiary earth-movements had great effect and, although ORVIN (1940) has indicated the broad pattern of the folding, thrusting and faulting, the picture is locally much more complicated than may be gathered from the literature. Shale and evaporite horizons have acted as zones of interstratal movement in St. Jonsfjorden, and probably elsewhere as well. These difficulties tend to slow up stratigraphical work but it is nevertheless already apparent that the changes in lithology and sequence from place to place pose real and important problems.

THE "STANDARD" SUCCESSION

It is difficult to draw up a detailed "standard" succession for the Carboniferous and Permian rocks of Vestspitsbergen. The west coast sequence varies greatly from place to place and is in some respects different from that in the central region. However, the following scheme may be adopted as representative for the west coast.

Usually accepted age	*Facies and Formation names*
?Lower Permian – Eotriassic	Rapidly alternating dark brown and buff sandstones and shales.
Upper Carboniferous – Lower Permian	Bedded cherts, siliceous shales, mudstones and limestone. *Brachiopod Cherts*
Upper Carboniferous	Yellow grey, fossiliferous limestones, sometimes silicified or sandy. *Cyathophyllum Limestones*
?Middle Carboniferous	Red sandstones, conglomerates and shales.
Lower Carboniferous	Pale quartzitic sandstones and conglomerates, rare thin black shales and "coals". *Culm.*

THE PROBLEMS

Deposition in Vestspitsbergen during the Carboniferous and Permian periods appears to have been on a fairly stable shelf, which suffered from time to time movement along generally north-striking faults. This resulted in differing successions being laid down between the central and the western areas. (SEE GEE, HARLAND, MCWHAE, 1952; MCWHAE, 1953). Palaeontological data are meagre and the ages of the various formations are by no means everywhere accurately fixed. Until many more collections have been made the correlation of the different series will largely rest on lithological criteria and this is by no means trustworthy.

For the greater part of the west coast area the outstanding problems are:

1. To determine accurately the limits and boundaries of the various formations and their relationships to one another.
2. To produce a dating based upon detailed palaeontological evidence.
3. To account for lateral changes in lithology and thicknesses, and to determine whether or not they are diachronic.

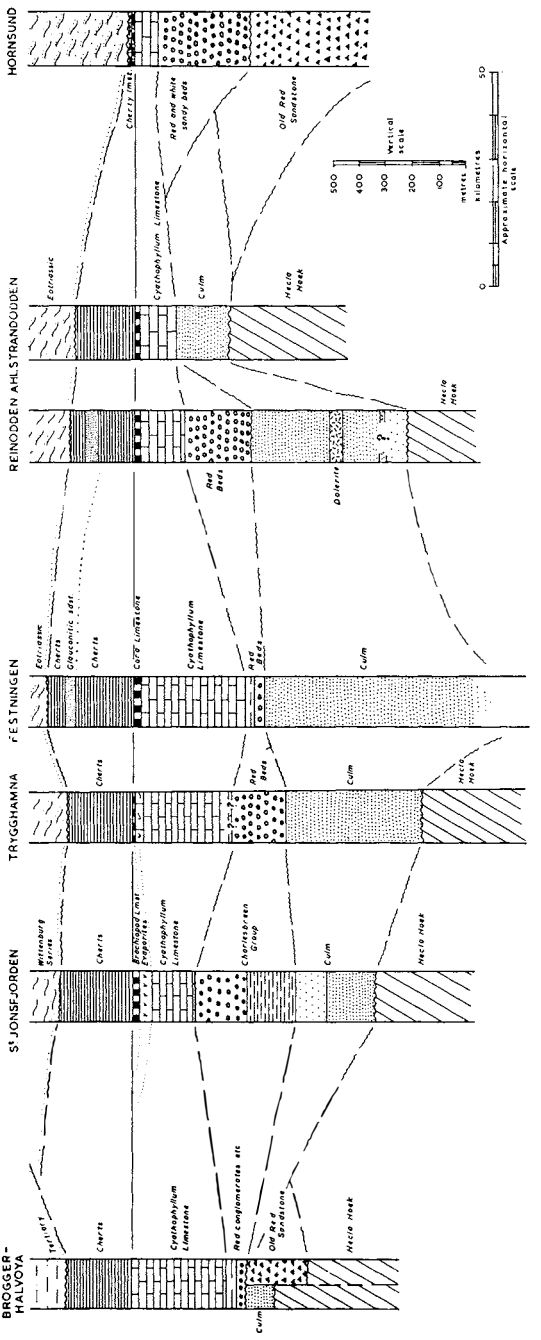
Coupled whith these are the problems of correlation with central and eastern Vestspitsbergen, other arctic regions, and Europe.

Carboniferous and Permian sections on the West Coast

Knowledge of the Carboniferous and Permian rocks on the west coast is virtually limited to sections exposed where the great fjords cross the Tertiary fold-belt. These are at Kongsfjorden, St. Jonsfjorden, Trygghamna, Festningen, Reinodden and Ahlstrandodden in Bellsund, and at Hornsund, and are briefly described below (Fig. 2). The writer knows no detailed sections recorded south of Hornsund.

(a) KONGSFJORDEN (ORVIN, 1934)

At Bröggerhalvøya, on the south side of Kongsfjorden, 125 m or so of Culm rest on both Hecla Hoek and Devonian formations, and consist of light sandstones, conglomerates, thin dark shales and a coal seam. The thin Middle Carboniferous appears to be represented by alternating conglomerates and limestones which are said to form a



passage into the (Upper Carboniferous) Cyathophyllum Limestone. The latter includes also dolomites in the lower part, and shales and cherts above. Some of the beds are "ashphaltic". The Lower Spirifer or Cora Limestone of the south is not recorded and some 250 m of Brachiopod Cherts are next present. They include a 40 m glauconitic sandstone which is not found around Isfjorden. Tertiary beds rest unconformably on the Cherts.

(b) ST. JONSFJORDEN (GARRETT AND DINELEY, forthcoming)

The Culm here is presumed to rest directly on Hecla Hoek rocks and it includes two formations. The Tryggghamna Formation is at least 200 m thick and consists of pale or cream massive quartzites,

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Fig. 2. Comparative sections in the Carboniferous and later rocks of Western Vestspitsbergen.

conglomerates and rare black shales. It has yielded no fossils beyond plants. The Vegard Sandstone Formation is more thinly bedded pinkish quartzose sandstones and thin shales and forms a passage, some 125 m thick, into the overlying red Charlesbreen Group (Middle Carboniferous). This group also consists of two formations – thick red shale below and massive quartzites and conglomerates above, in all about 440 m. Thin evaporites occur at two levels in the shales. Two distinct marine bands occur in the upper group which appears to be cyclothemic. The "Cyathophyllum Limestones" (220 m) follow with probable unconformity and include remarkable cellular-weathering limestones and thick evaporites immediately below the Brachiopod Limestones. Some 240 m of the Brachiopod Cherts complete the Palaeozoic sequence and are overlain by an immense thickness of thinly bedded dark shales and sandy strata, here called the Wittenburg Series.

(bi) CARBONIFEROUS ROCKS ON FORLANDSUNDET

Mention has been made elsewhere (BAKER, FORBES, HOLLAND, 1952; WEISS, 1953) of the fossiliferous Middle – Upper(?) Carboniferous rocks lying between the Hecla Hoek Formations between St. Jonsfjorden and Trygghamna. The Carboniferous beds are intensely deformed but their original sedimentary characters are often discernible. The grade of metamorphism shown is, so far, not recorded in Carboniferous outcrops elsewhere and in this and certain other respects these Carboniferous rocks resemble the Western Series of the local Hecla Hoek. The latter include "bean-conglomerate" quartzites near Thorkelsenfjellet and at other points to the south, and numerous fine-grained quartzites are inter-bedded with (thinner) green chlorite-grade pelitic rocks. WEISS (1953, p. 280) notes the rapid compositional variation of the rock types in the Western Series and this again bears strong resemblance to that in the upper part of the Culm or, more closely, to that in the Charlesbreen Group. It may be possible that the Western Series of the Hecla Hoek rocks at Forlandsundet is indeed greatly deformed Carboniferous material, but at present this matter can only be one for conjecture. Further discussion is not possible here and further field work is needed to elucidate the problems concerning this strip of deformed Carboniferous strata. South of Kapp Skania no further *highly deformed* Carboniferous wedges are recorded within the main Hecla Hoek outcrop, but their occurrence is not impossible.

(c) TRYGGHAMNA (WEISS, 1949)

The following is based on unpublished work by Weiss, who found the Culm (with a coarse basal conglomerate) resting directly on the Hecla Hoek. It consists of 700–800 m of coarse pale yellow or white quartzitic sandstones and conglomerates. Many of these are strongly cross-bedded and ripple-marked with abundant plant remains preserved as carbonaceous impressions. Black carbonaceous shales occur, some of them containing enough carbon to be described as coals. Red beds like those at St. Jonsfjorden succeed the Culm. A thickness of 125 m is estimated by Weiss but it seems possible that a further 200 m may exist below Trygghamna. Strong evidence of faulting was found in these rocks. Light grey fossiliferous "Cyathophyllum Limestones", estimated to reach 500 m, come next. Traces of cellular-weathering limestones and gypsum were noted. Four to five metres of "Spirifer Limestone" (=Lower Spirifer Limestone, Cora Limestone, Brachiopod Limestones) occur above, followed by some 364 m of cherty beds. The nature and relationships of the strata above the cherts were not investigated.

(d) FESTNINGEN (HOEL and ORVIN, 1937)

The Festningen (Kapp Starostin) coastal section lies on the southern side of Isfjorden, about 20 km south of Trygghamna. Only the upper parts have been described in detail and the lower boundary of the Carboniferous has not been fixed. The Lower Carboniferous is very thick, probably more than 700 m, but it has not been subdivided. HOEL (1925, p. 15) gives the Culm as 980 m thick between Isfjorden and Bellsund, but appears to include all beds below the Cyathophyllum Limestone. The Middle Carboniferous is thin, given as about 60 m including conglomerates, sandstones and shales. It gives way above to 450 m or so of Upper Carboniferous limestones, the top 180 m of which are designated as "Cora Horizont". The exact thickness of the "Cora Limestone" is not made clear, but the "Horizont" caps the thick limestones and is overlain by about 360 m of cherts. Triassic beds lie unconformably upon the cherts.

(e) REINODDEN

Reinodden lies between Recherchefjorden and Van Keulenfjorden on the southern side of Bellsund, 65 km south-south-east of Isfjorden.

The beds are here inverted and greatly faulted. ORVIN's section (1940, pl. II) shows Lower Carboniferous about 700 m thick, the upper part of which is shaly. The Middle Carboniferous is indicated as lying unconformably above and consisting of some 250 m of red and grey conglomerates, sandstone and shales (cf. 1940, p. 25, 200 m). Above the Upper Carboniferous Cyathophyllum Limestone, given as about 140 m, lie 4–5 m of Cora Limestone and 260 m or more of cherty beds. The Triassic unconformably caps the sequence.

(f) AHLSTRANDODDEN

Though the section here is situated only about 7 km east of Reinodden, it is significantly different. Tertiary earth-movements may have reduced the distance originally separating the two sections by 5 km, possibly much more. ORVIN (1940, pl. II) shows 200 m of Lower Carboniferous sandstone, etc., resting on the Hecla Hoek and directly overlain by about 140 m of Cyathophyllum Limestone. The Cora Limestone is present and the cherts reach approximately 260 m when they are overlain by the Triassic.

ORVIN (1940, p. 25) reports that a series equivalent to the Lower Gypsum-Anhydrite Series at Billefjorden is 30 m thick at Bellsund. He does not say what evaporites are present.

(g) HORNSUND

Southwards some 50 km along the strike from Van Keulenfjorden lies the Hornsund section. Here ORVIN (1940, pl. II) records Middle Carboniferous resting directly on Devonian and represented by 450 m or so of alternating greyish white and red conglomerates, sandstones and red shales, followed by grey sandstone and finally limestones and sandstones. No recognition of the Cyathophyllum Limestones or Cora Limestones is made. Cherty limestone, about 12 m thick, is regarded as disconformable Lower Permian and is in turn overlain by the Triassic.

The Sediments

Very few details are available concerning the petrography of the Carboniferous and Permian sediments. Only general terms have been used in describing the composition and sedimentary features of most of

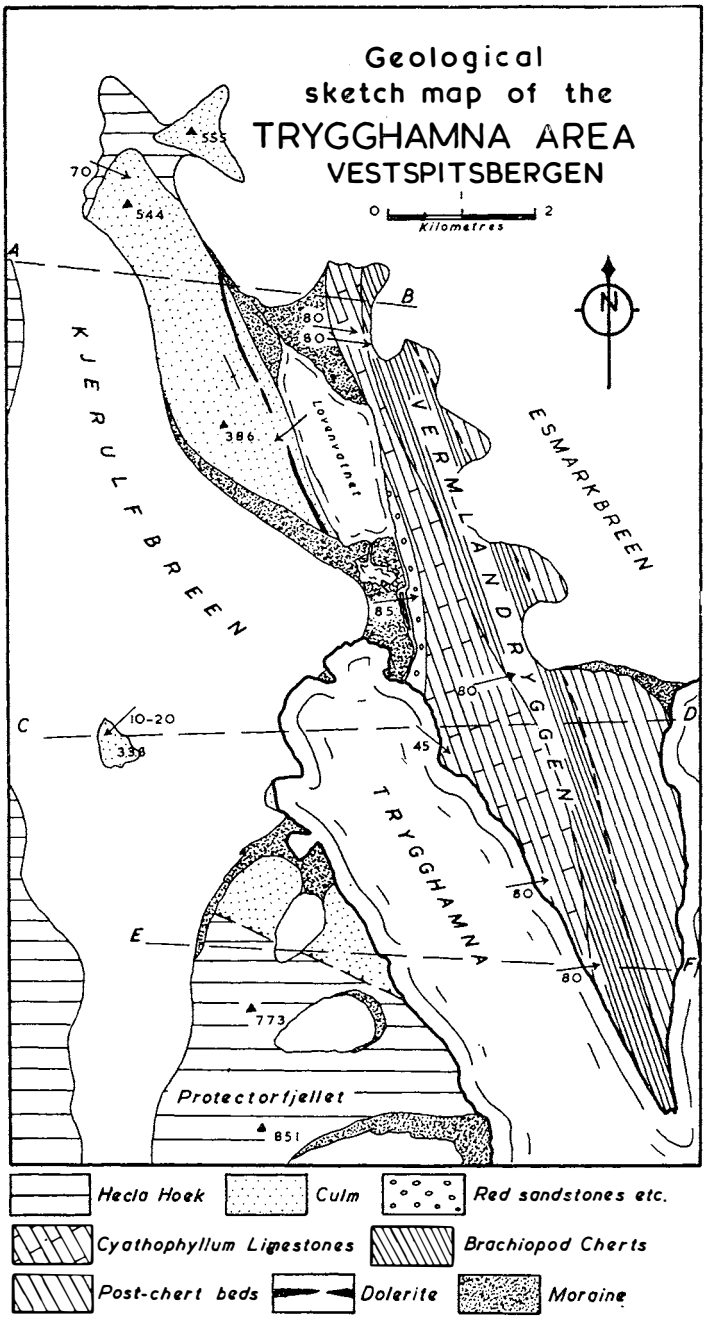

Fig. 3. Geological Sketch map of the Trygghamna area (WEISS).

the various deposits. The need for accurate sedimentological work on these formations is obvious and they offer excellent opportunity for such study. Nevertheless, the known lithological characteres and associations of the beds suggest very strongly deposition on a shelf, stable, though locally affected by small but rapid vertical movements. As yet the nature of these movements and their effects on sedimentation are not properly understood. It is clear that the shelf was very extensive and several authors appear to include within it Bjørnøya, Novaya Zemlya and Greenland and the fringes of Siberia. However correct this may be, it would seem that at least during Lower and Middle Carboniferous times comparatively local tectonic conditions were of major importance to the sedimentation. The following discussion of the sediments is based on the existing literature and the author's field observations. No doubt it is incomplete and inaccurate in several respects, but its purpose is to call attention to the existing problems.

In attempting to interpolate between the known sections, it should be remembered that the length of the outcrop under discussion is some 300 km while the maximum thickness encountered is about 1.6 km. The sediments are thus in the form of very thin sheets and the continuity of the facies and even complete individual formations is likely to have been broken by relatively slight tectonic activity.

Prior to the deposition of the Culm, strong earth-movements affected the Hecla Hoek and Devonian and the central north-south fault zone of Vestspitsbergen was produced. To the west of this lies the region which subsequently acted as a relatively stable though slowly sinking block. Earth-movements at later dates have tended to produce structures with a strong north-south component, controlled by tectonic features in the pre-Carboniferous basement.

a. LOWER CARBONIFEROUS *CULM*

The dominant rock type in the Culm is quartzose or quartzitic sandstone and conglomerate, pale grey or yellowish in colour. The basal conglomerates, however, include quantities of well rounded Hecla Hoek and Devonian fragments. Higher, these materials are very subordinate to vein quartz pebbles. (A few beds are pink- or yellow-stained by iron compounds). There is little felspar or mica and a generally orthoquartzitic character prevails. To the conglomerates, which are often of well rounded and apparently uniform vein quartz pebbles, the term "bean-conglomerate" may often aptly be given.

The bedding planes are usually sharply defined and the individual beds extensive. Cross-bedding is probably general and many beds are current ripple-marked. Carbonized plant impressions, often very large, are abundant in some of the quartzites and may show a rough alignment of the largest fragments. These fossils represent typical Lower Carboniferous pteridosperms, filicales, lycopods, etc., and have been extensively studied by Nathorst (1920). Animal life seems to be almost completely unrepresented.

These features point to shallow water deposition and littoral conditions have been suggested. NATHORST (1910) regarded the Culm as of freshwater and brackish water origin, (swamp and estuarine). The absence of alkalies and iron compounds has been ascribed to humic action. Carbonaceous strata, however, appear to form only an extremely small fraction of the Culm, and the leaching of alkalies, etc., by a local flora is not regarded as a very satisfactory hypothesis. Certainly, humic action may have assisted but it may be pointed out that unstable and soluble minerals are usually rare in orthoquartzitic sediments and this reflects on the physical rather than the biological aspect of their accumulation. In any case, it seems reasonable to believe that much of the Culm sediment was derived from the denudation of Hecla Hoek formations, which locally include enormous quartzites, and from the Old Sandstone sediments which similarly contained much available quartz. The basal Culm unconformity is probably one produced by slow thorough planation, during which the re-working of sediments would be effected perhaps several times.

Black carbonaceous shales and "coals" are found in the lower part of the Culm but they are often streaky and lenticular. The "coal" is invariably very ashy. Except at Pyramiden in central Vestspitsbergen, coal seams in the accepted sense are apparently lacking,and with them the true seat-earths or underclays. At Pyramiden the thickest coal seam reaches about 7 m, but this includes more than 1 m of interleaved shales. The carbonaceous material seems often thus to be cannel-like, allochthonous rather than autochthonous. The relationship of the thicker "coals" to the enclosing sediments in the Spitsbergen Culm would appear to remain a problem of considerable importance.

Finally, the use of the term "Culm" calls for comment. It is now

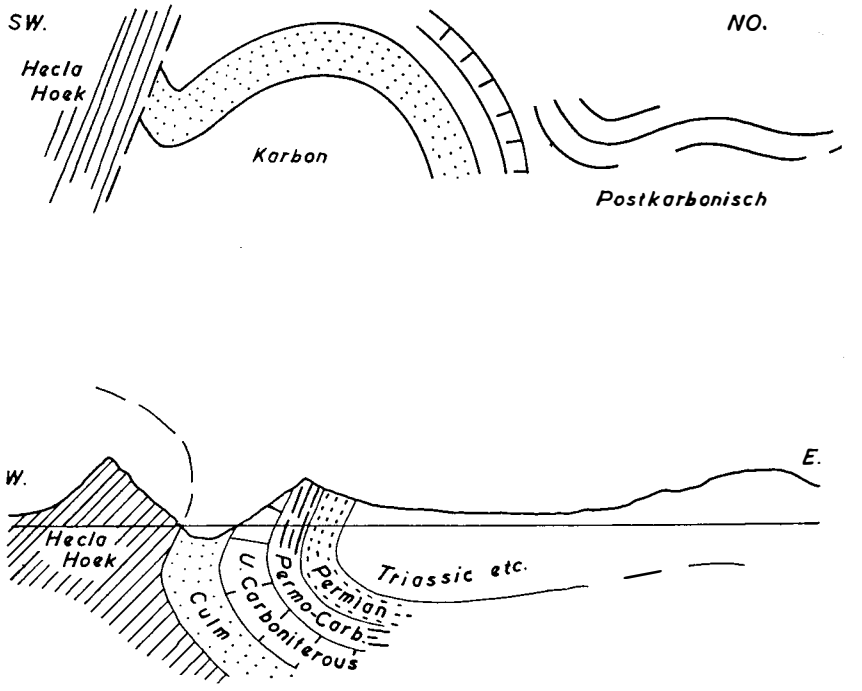

Fig. 4. The structure of the Trygghamna area according to (a) HOLTEDAHL and (b) ORVIN.

so firmly established that the substitution of another would cause confusion. Plant remains and even "coals" ("culm"), it is true, are locally found, but they may be thought of generally as drifted material. Yet it should be remembered that the Lower Carboniferous beds of Vestspitsbergen seem to bear little or no affinity to the Culm Measures of S. W. England nor to the Kulm of Germany, both of which are now regarded as fairly deep water accumulations with greywackés typically developed.

b. ?MIDDLE CARBONIFEROUS *RED BEDS*

While deposition was continuous from Culm times into the Middle Carboniferous in western Vestspitsbergen, it was interrupted by earth-movements and elevation in the central and eastern areas. Movements along the faults which had been initiated during Upper Devonian

times were responsible for this. Erosion was active in the Ekmanfjorden region and apparently also at Hornsund, both areas where these faults are well in evidence. In the areas of continued deposition the movements were accompanied by the facies change from Culm to red beds. As might be expected, the thickness and character of the red beds varies greatly from one place to another (see comparative section, fig. 2). In the Billefjord area the Culm facies appears perhaps to have persisted into Middle Carboniferous times (see GEE, HARLAND, MCWHAE, 1952). ORVIN (1940, p. 24) stresses that the age of the conglomerates below the Middle and Upper Carboniferous limestones may vary, though they have not as yet been very extensively studied.

The writer has been particularly interested in the red beds (Charlesbreen Group) at St. Jonsfjorden where they are well developed and rest conformably as far as can be seen – on the pink-white Vegard Sandstone Formation. The Charlesbreen Group is undoubtedly the equivalent of the red beds found elsewhere and it may subsequently be shown that the features described below are widespread. At the base of the shales in the lower part of the red beds thin evaporites and limestones are present, and gypsum is found again higher up. For some little way below the lowest massive (Tårnkanten) sandstone the shales are black and contain a bone-bed horizon. The massive sandstones are quartzose, quartzitic or calcareous. Felspar is present in very small quantity in one or two beds but is otherwise very rare. A study of this and the few other minerals besides quartz would be of great interest. Cross-bedding is usual and sometimes it is peculiarly contorted or disturbed in its upper part, suggesting flow-casting. Current and oscillation ripplemarks, erosion surfaces and other sedimentary features indicate extreme shallowness of deposition. Dessication cracks affect the thin shales between the coarser beds. The undersides of the sandstones and conglomerates are usually very sharply defined, but the beds often grade upwards into finer sediments.

The conglomerates deserve special mention. They often include pebbles of vein quartz, but may frequently contain large quantities of clay pellets and calcareous and ironstone nodules or flakes of limestone, perhaps derived by contemporaneous erosion from the red shales and marls. (Calcareous nodules appear in many of the clay-grade red

sediments.) Mixed with this material may be rolled fossils. Thin limestone bands have often been desiccated into small curled plates before being incorporated within the overlying sandstone so that the latter seems to possess a basal edgewise or sharpstone conglomerate.

Fossils are sporadically distributed, are often silicified or even jasperised and appear to have been rolled and worn. Marine forms include productid, spiriferid and schizophorid brachiopods, isolated crinoid ossicles and broken corals. Rare lingulae are present at some horizons and fragmentary plant remains occur locally.

At St. Jonsfjorden fossils are also present in two distinct marine bands – black shales with grey argillaceous limestone. The fauna of each band is abudant and distinctive and should prove to be great value in correlation. Spiriferid and stropheodontid brachiopods are by far the most numerous fossils, but other brachiopods, small pelecypods and corals occur, and a single trilobite fragment has been found. These marine bands are obviously most important marker horizons and should be sought wherever the red bed facies is developed. It is suggested that the red Tårnkanten Sandstones of St. Jonsfjorden are cyclothemic, the marine bands indicating sudden depression and transgression followed by long phases of deltaic-littoral accumulation.

A sharp break break between these beds and the Cyathophyllum Limestones is postulated at St. Jonsfjorden, but elsewhere a continuous passage seems to be the case. That the red beds mark a phase of semi-continental and littoral accumulation is generally accepted. Much of the material appears to be reworked and the Culm desposits of central Vestspitsbergen may have locally provided the sediment. Where the exposures are good, it should be a matter of no difficulty to collect evidence showing the principal direction of the streams depositing the sandstones and conglomerates. In eastern Vestspitsbergen Hecla Hoek detritus may have been incorporated, but on the west coast there seems to be little of this material in evidence. The Lower Gypsiferous Series of Billefjorden appears to be confined virtually to the tectonic basin there, overlapping on to the west coast area only at St. Jonsfjorden as far as is known. The Passage Beds which follow the Lower Gypsiferous Series give way upwards to the Cyathophyllum Limestones.

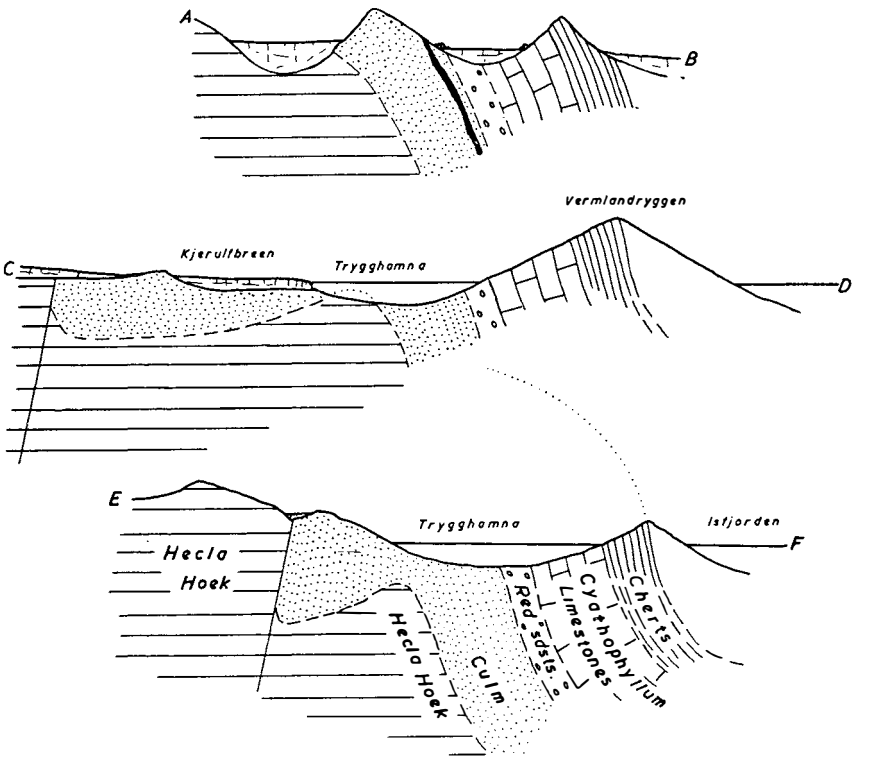

Fig. 5. Sections across the Trygghamna area: present interpretation.

c. Upper carboniferous *CYATHOPHYLLUM LIMESTONES*

These consist of thinly to massively bedded, fairly pure grey limestones often porcellanous, interleaved with grey shale and silicified. Locally they are fossiliferous with large corals in the growth position. Some beds may have a large (fusulinid) microfauna and crinoid stems and fronds are locally abundant. Bituminous matter is common. Drusy cavities and stylolites are sometimes present. A few sandy beds show the transition from the red beds below.

In the St. Jonsfjord – Trygghamna region a cellular-weathering facies is developed. It appears to be an epigenetic feature associated with the presence of evaporites, and is not recorded elsewhere on the west coast. An investigation of this peculiar facies is at present under way.

The evaporites themselves are similarly geographically restricted and may well be in direct continuity with the Upper Gysiferous Series of central Vestspitsbergen. They consist of white and dark "papery" shales, thin argillaceous limestones and masses of gypsum-anhydrite. (Salt is not recorded.) Their original thickness is difficult to assess as they have flowed during the Tertiary earth-movements. Deposition was probably under a shallow lagoonal environment, but we have no knowledge of the boundary conditions.

d. *"BRACHIOPOD LIMESTONE"*

Though only a small unit, this facies deserves special consideration. At the base of the cherty beds a thin yellow-weathering, often silicified limestone, is often present. It has been variously termed Lower Spirifer Limestone, Cora Limestone, Limestone "A" (GEE, HARLAND, MCWHAE, 1952) and Brachiopod Limestone. Lithologically it is very like the underlying Cyathophyllum Limestones, upon which it rests with a sharp conformable junction, but it is usually crowded with spiriferids, productids and other thick-shelled heavy brachiopods. Conodonts have been found at Trygghamna and the limestone also includes fragmental bryozoans. In St. Jonsfjorden it is associated with a thin yellow-grey finely laminated silty limestone, the laminae of which are often intensely contorted. Nathorst found the Cora Limestone to include sandy beds and water worn fossils, and has suggested that it is typically of shallow-water type, formed under brackish conditions. The laminated limestone suggests a shallow lagoonal environment, but in St. Jonsfjorden there is no evidence suggesting brackish water deposition of the very fossiliferous beds. Nevertheless, these limestones are usually regarded as marking the transgression which occurred towards the end of Carboniferous times.

e. UPPER CARBONIFEROUS – LOWER PERMIAN *BRACHIOPOD CHERTS*

The distinctive chert formation consists of siliceous shales and siltstones, silicified mudstones and limestones, massive, thin and rybbly cherts. The colour is generally dark when fresh, but may lighten on weathering. Fossils are principally confined to the shales and limestones and include large sturdy brachiopods, molluscs, blas-

toids and bryozoans (FREBOLD, 1937). Some beds contain very large numbers of siliceous sponges. It has always been assumed that the chert beds are primary and that the silicification of the shales and limestones took place very shortly after deposition, possibly in the interval preceding the deposition of the Eotriassic strata. The cherts appear everywhere to be overlain by unconformable later beds, but the exact dating of the period of pre-Trias uplift and erosion remains open to question (DINELEY & GARRETT, forthcoming).

The depositing sea is thought to have been "not more than 300 m in depth, and it must have been connected with the sea at East Greenland and the Ural" (ORVIN, 1940), where similar formations occur. A bed of glanconitic sandstone in the cherts at Kongsfjorden indicates a warm shallow sea. Apart from this bed, detrital material is at a minimum. The source areas of the sediment must have been reduced almost to base level and large areas of quartzitic rocks may have been exposed, providing the necessary silica.

f. LOWER PERMIAN – TRIASSIC *"WITTENBURG FACIES"*

Doubt can be thrown upon the generally accepted Eotriassic age of the beds following the cherts at St. Jonsfjorden (DINELEY & GARRETT, forthcoming), but, leaving aside the problem of their age, the beds above the cherts there appear to be essentially similar to those elsewhere in much of western Vestspitsbergen. For convenience their facies may be named after Wittenburgfjella at the head of St. Jonsfjorden. The sequence consists of rapidly alternating and generally thin-bedded silty brown micaceous shales, sandstones often with basal pellet layers, and quartzites. The coarser strata are strongly cross-bedded and ripple-bedded. Micro-ripples are common in the finer beds. There is a great variety of surficial markings, including desiccation marks and "load-cast" and morphologically similar structures, tracks and trails, and immense numbers of "fucoids". Fossils are unevenly distributed; some of the sandstones and siltstones contain numerous nektonic pelecypods. There are occasional silicified limestones crowded with pelecypod and gasteropod remains which have been current segregated into cross-bedded lenticles. A few of the pellet beds contain poorly preserved fish scales and bones.

The sedimentary features and fossils suggest comparatively rapid

accummulation in shallow water – perhaps even tidal, with a low-lying but prolific area of sediment supply. The uplift following the deposition of the cherts was obviously not violent, being sufficient to give little angular discordance between cherts and "Wittenburg facies". True continental conditions prevailed at no great distance and the Mesozoic epeiric sedimentation had commenced.

Summary and conclusions

Carboniferous and Permian times saw the deposition of thin sheets of sediment over the greater part of Vestspitsbergen. Some formations are, however, apparently confined to central Vestspitsbergen or are perhaps represented on the west coast by a slightly different facies. It seems that near-continental conditions prevailed during Lower and Middle Carboniferous times, following a period of active erosion. Subsequent deposition was essentially in shallow water and punctuated by periods of local uplift or non-deposition. The eastern boundary of the west coast region may have been defined by faults, initiated in Upper Devonian times and perhaps later moving below a thin sedimentary cover. Tilting and differential movement of fault blocks in the Hecla Hoek basement may have taken place from time to time. Small vertical movements would have had considerable effect on a region in which deposition was very shallow and the source area low-lying. During Middle Carboniferous times the reworking of Lower Carboniferous and Devonian sediments was probably widespread, and the climate hot, perhaps arid. Detrital supply was at a minimum during Upper Carboniferous and Lower Permian times, with evaporites, limestones, cherts and fine shales being deposited. Tectonic activity seems to have been nil.

The principal and obvious problem to be solved is that of the red beds below the Cyathophyllum Limestones. Clearly from place to place they vary in character, thickness and relationships to the limestones. Where there is unbroken continuity from the Culm white quartzites into the red sandstones and shales it may be a matter of some difficulty to select a suitable boundary between these two groups. Field workers so far have had to choose arbitrary limits which

it may not be practicable to apply over larger areas. Palaeontological data are few and generally not easy to use in the field.

Subsidence and accumulation appears to have been more active in the St. Jonsfjorden – Trygghamna and Hornsund areas than elsewhere in the west during middle Carboniferous times. At Hornsund this may have been the development and filling of a local graben, while north of Isfjorden it may have been only a slight northward shift of the marked area of subsidence active during Culm times. Possibly this also was influenced by faults, but gentle warping of the basement seems more likely.

The red formations may prove to be widely cyclothemic, the rhythms being associated with gentle uplift of the source area and sudden brief marine incursions. Unless removed by later erosion the marine bands found at St. Jonsfjorden should be widespread and invaluable in correlating and dating the red bed units.

The Upper Carboniferous limestones deposited at St. Jonsfjorden include evaporites and peculiar breccia-like beds, suggesting a shallow area of restricted circulation, perhaps linked directly with the Billefjord evaporite basin. At Bellsund deposition was also thin, but no peculiar limestone facies is reported there.

In consequence to the above, two principal studies suggest themselves. They are:

1. An investigation of the Middle – Upper Carboniferous beds in the area immediately to the west of Ekmanfjorden where fault tectonics may have influenced sedimentation, and where the succession of central Vestspitsbergen probably changes to that found at Kongsfjorden and at St. Jonsfjorden.

2. An investigation of the detailed stratigraphy and palaeontology of the Middle Carboniferous red beds at many more points along their strike southwards from Kongsfjorden. Explanations must be sought for the variations in thickness and relationships to the underlying beds.

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