CORRELATION NOTES ON SCOTTISH-NORWEGIAN CALEDONIAN GEOLOGY

BY

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With 4 textfigures

Abstract: The writer points to a number of mostly structural features that seem to favour a correlation of the Moinian of Scotland with the metamorphic ("Eocambrian") Sparagmitian of Scandinavia, and possibly also of the Torridonian with the unmetamorphic pre-tillite Sparagmitian. The Scottish Portaskaig-Schiehallion boulder bed is correlated with the tillites of the Upper Sparagmitian, and the higher Dalradian with the (lower) Cambro-Silurian of the Scandinavian Caledonian zone.

The joint work with Dr. E. B. Bailey in preparing a recently published contribution on the Caledonides of northwestern Europe (references, 2) has greatly stimulated the interest of the writer in Scottish-Scandinavian correlation problems. Recent investigations in a Norwegian district of very highly metamorphosed "sparagmite" made it evident to him that the rocks of the said district have much in common with the Scottish Moinian flagstones, and aroused a wish of personally seeing the Moinian as well as other rock complexes of the far north-west of Scotland.¹

In June 1938 he had the opportunity of visiting, under the guidance of Dr. Bailey, parts of the Isle of Skye with its great variety of Caledonian structures, and further, in the company of Dr. J. E. Richey, Dr. W. Q. Kennedy and Mr. R. C. B. Jones of the British Survey, and of Prof. C. E. Tilley of Cambridge, the Moine district around Mallaig. To these colleagues, and especially to Dr. Bailey, the writer wishes to express his most sincere thanks for the highly interesting days spent in these districts of fascinating Scottish geology. Furthermore, he is particularly obliged to Dr. Richey for having read through the manuscript and proposed various editorial changes.

¹ On a previous occasion the writer visited the Ballachulish district (Brit. Assoc. excursion, led by Bailey, 1928).
A great many geologists have, in the course of time, commented upon points of likeness between Scotland and Scandinavia. I shall here mainly refer to the paper of G. Frödin of 1922 (5) which exclusively deals with such correlation problems. Judging from known Scandinavian conditions, Frödin could not subscribe to the view "that the Dalradian and Moinian regions, like their metamorphic transformation to crystalline schist, belong to a powerful pre-Torridonian folding zone" as this "would mean that the Scandinavian Mountain schists are pre-Cambrian" (p. 234). Frödin states his view on the Moine and Dalradian in the following lines: "Besides Caledonian intrusions and patches of Lewisian rocks, we will therefore have to expect in the north-west, in the Moinian, metamorphic derivatives, above all of the Torridonian and the Cambrian, possibly also of somewhat younger Paleozoic sediments. In the Dalradian in the south-east, on the other hand, we have to anticipate especially those of Ordovician and Gothlandian age, besides possibly Cambrian and Torridonian ones" (p. 233—234). Concerning the metamorphism of the Moinian and the Dalradian, he points to the likeness to that of the "Seve" and "Köli" groups respectively of Central Scandinavia. As regards the Torridonian, Frödin states that this series and the central Scandinavian sandstone of Dalecarlia¹ are in the main equivalent both from a geological and petrological point of view.

Th. Vogt who knew parts of the Scottish Highlands from personal studies (and has made a valuable contribution to the understanding of the stratigraphy of the Dalradian by pointing out the up- and down direction in crossbedded sandstones) in a lecture to the Norwegian Geological Society in 1935 (23), indicated the general likeness of the metamorphic rocks of the Loch Leven district (with mica schist, limestone, quartzite) to those of Nordland of Norway which are believed to be of Cambro-Ordovician age. The present writer (2, p. 70) has found this correlation a very plausible one and further (p. 71) has pointed out the evident likeness between the highly metamorphic Sparagmite sandstones of parts of Norway and the quartz-felspar-mica flaggy Moine rock.

As to British geologists, opinions on the age both of the Dalradian and Moinian have differed and still differ widely. Recent discussions of the problems are given in (19) and (17). The writer

¹ The "Dala sandstone" of Jotnian age.
Fig. 1. Maps showing symmetry of Caledonian features of Scotland and Finnmark (drawn to the same scale).
would like to draw attention especially to the view held by Peach, and illustrated in a diagram of the Caledonian zone of Scotland (16, fig. 27), that the Moinian represents metamorphosed Torridonian, and the Dalradian metamorphosed Cambrian (= Cambro-Ordovician), because the general idea of the diagram in major points harmonizes well with the conception of the Caledonian structures of parts of Scandinavia as it was first put forward by Törnebohm (22). Bailey, in the joint work mentioned above (2, p. 30) has suggested that the Dalradian and the Sparagmite series of Norway are in part stratigraphical equivalents.

In fig. 1 the writer has placed the greater part of Scotland and of Finnmark (in the extreme north of Norway) symmetrically one above the other and has indicated a number of main geological features. The correspondence shown seems, to the writer, surprisingly great. This is largely due to the fact that when thinking of N.W. Highland structures, the writer, like probably most geologists, has principally in mind the sections of the more northern part of the ground dealt with in the famous N.W. Highland Memoir (15), with its narrow zone of deformation, west of the Moine thrust.

In fig. 2 two particular sections are chosen, which accentuate the fact that we have locally both in Scotland and in Finnmark a peripheral belt of thrust unmetamorphic psammitic sediments in front of the thrust metamorphic complex,
in which we find psammitic rocks largely in the form of flaggy, commonly more or less gneissose schists.

The age of the unmetamorphic thrust rocks in Finnmark seems to be clear: the Porsanger sandstone\(^1\) with arenaceous shales and dolomite on top, corresponds to the (relatively autochthonous) "older sandstone division" of the Tanafjord to the east, which with a slight, yet distinct angular unconformity is overlain by the younger, tillite bearing division. The latter passes upwards into fossiliferous (middle) Cambrian sandstone.

As to the age of the metamorphic psammitic and phyllitic rocks N.W. of the inner thrust, there can be no doubt that at any rate the greater part of the complex is of the same general age as the Sparagmitian rocks to the south and east. As a matter of fact the inner thrust seems to die out, or a any rate becomes less obvious, north-eastwards in the peninsula east of the Tanafjord. The sediments are here rather moderately metamorphosed and a marked thrust plane, like that seen further to the south-west, was not observed on the north coast. The folded sediments of the Nordkyn Peninsula are mainly quartzites and phyllites which may very naturally be regarded as metamorphic equivalents of the lower sandstone division as developed in the Tanafjord district (cp. 6, p. 159). The occurrence of a conglomerate of tillite-type (with fragments of carbonate rocks and quartzite) in a metamorphic, tectonically highly disturbed rock complex at Duksfjord, east of the North Cape, is another point of interest, helping us to determine the age of the metamorphic sedimentary rocks of the north-western part of Finnmark.

The metamorphic thrust complex, north of the inner thrust, changes its petrological character as we pass westwards, a rather monotonous series of felspathic siliceous flagstone and not quartzites making up the greater part of the complex in the Alta district. Whether we are here just dealing with different facies or with beds of somewhat different age is not yet known.

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\(^1\) During the early reconnaissance work of the writer in Finnmark 1914—17, the existence of a thrust plane below the Porsanger sandstone was not noticed, and the said sandstone (and consequently also the more eastern sandstone formations) therefore were regarded as younger than the Hyolithus zone (9, 11, fig. 4). Later investigations by the writer in the Sparagmite district of Southern Norway made it, however, evident that the Finnmark Series and the Sparagmite Series had so many points in common that a different age would seem to be improbable. In 1929 the district south of the Porsangerfjord was studied more closely, and the thrust found (12).
As to the far northwest of Finnmark, the occurrence of mica schist and limestone (in Sørøy) may indicate that we are here in the "Nordland" series of presumably Cambro-Ordovician age.

In Southern Norway the relation between (relatively) autochthonous and thrust parts of the Sparagmite formation is more complicated, and only for certain areas do we know the conditions fairly well. In the eastern part of the area of the map (fig. 3) we notice a widely distributed thrust mass of moderately metamorphosed sparagmite (with thin dolomitic layers) lying (with gentle dips) above unmetamorphic red sparagmite of great thickness, locally with also low Cambro-Silurian beds preserved below the thrust plane. This "Kvitvola" thrust plane seems to pass above the imbricate structures (with thrust Archaean and Sparagmitian) which is typical of parts of the Femund district (cp. recent maps and papers by G. Holmsen, 7, 8), conditions strongly reminiscent of certain parts of the N.W. Highlands of Scotland.

The metamorphic Sparagmitian rocks towards the north-west pass below the darker, more pelitic schists of the Trondheim syncline, rocks of varying metamorphism, from chloritic and phyllitic to gneissose. Primarily the sedimentary rocks were mainly shales, often arenaceous or calcareous. Psammitic, conglomeratic and massive limestone beds are of importance especially in the northern part of the area. Further, volcanic Lower Ordovician rocks are typical, with pillow structures preserved locally. As to the age of the sediments of the Trondheim syncline, finds of fossils from various horizons of
the Ordovician and, in a far north-eastern locality, also from the Lower Silurian, give us a general idea of it.

On the north-western side of the south-western part of the Trondheim syncline very highly metamorphic, no doubt Sparagmitian, psammitic rocks crop out, recumbently interfolded with hornblende and mica schists of the Trondheim series (13 and observations made 1938). They lie above a "basal gneiss series" which also contains fairly massive fine-grained granites etc.

We may now summarize a few main points. In both Scotland and Scandinavia we meet in the peripheral areas of Caledonian deformation a thick series of unmetamorphic sediments, mainly sandstones older than the fossiliferous Lower Cambrian. More centrally psammitic, more or less metamorphic rocks occur, and still further away from the Caledonian front metamorphic sediments with more of pelitic sediment. The latter in S. Norway are certainly younger than the metamorphic psammitic series, and also in Scotland such an age relation is fairly commonly assumed. That the Dalradian of Scotland, at any rate to a large extent, corresponds to metamorphic Cambro-Silurian sediments of Scandinavia has previously been held by several Scandinavian geologists. Judging from the structural similarities indicated above, the present writer thinks that there are strong reasons for going further in the comparison and for correlating the Moinian and the Torridonian respectively with the metamorphic and unmetamorphic Sparagmitian, or parts of it.

As stated by Bailey (2, p. 33) the Torridonian is very generally correlated with the Jotnian of Fennoscandia, though the petrological likeness of the arkoses of the Torridonian and the Sparagmite formation has also been emphasized by writers (cp. e. g. 16, p. 72). Recently v. Eckermann (4), on the basis of personal studies in both districts, has emphasized the close lithological agreement between the Torridonian sediments and the late Jotnian sediments of Dalecarlia; he has, however, also pointed to some marked differences (Jotnian igneous rocks missing in the Torridonian etc.). The present writer (2, p. 73) has remarked on the corresponding position of the Torridonian and Jotnian sediments in the foreland in front of the big thrusts. A main structural feature of likeness is the existence of a distinct angular unconformably between these formations and the Cambrian (or in Fennoscandia the sub-Cambrian peneplane). As to the Sparagmitian of Southern Norway, no angular unconformity is
known in or above the series, and the sediments in question are evidently developed only in the district of strong deformation and do not occur outside it.

The more intimate study of Scottish literature and especially the personal visit to Skye, where not only the Torridonian sediments are very highly influenced by Caledonian crust movements, but where the thrust mass of only moderately metamorphic “Tarskavaig Moine” exists between typical Torridon and typical Moine, accentuated for the writer the likeness to conditions in the Sparagmite district of Southern Norway, where sparagmites occur in all stages of metamorphism. The detailed comparison between Scotland and Finnmark has, furthermore, shown so much correspondence that the age correlation Torridonian—Sparagmitian may seem to be possible. A typical feature of the Finnmark Sparagmitian is the existence of a distinct angular unconformity between the younger, tillite-bearing sandstone division and the older sandstone series (cp. e. g. 9, the lower section, pl. XX, to the right). Also in Southern Norway the time directly preceding the deposition of the tillite must have been one of unrest (with vertical movements) as emphasized by the writer already in 1920. This pre-tillite period of unrest corresponds to Koch’s “Scandic phase” in Greenland (14, p. 122). During this phase denudation of older Sparagmitian (the “Greenlandian”) sediments took place.

A possible conclusion, then, seems to be that the Torridonian corresponds to the pre-tillite Sparagmitian (older division of Finnmark) and that the tillite sediments and beds lying immediately above them in Norway, are missing in the Scottish area, west of the Moine thrust. We must here emphasize that in the Tana district of Finnmark we do not yet know where to place the base of the Cambrian (corresponding to the Scottish basal Cambrian quartzite).

Such an inter-Sparagmitian “Scandic” period of crust movements, probably with block-faulting, and with tilting in N. W. Scottish and N. Norwegian districts, would then be responsible for the local pre-Cambrian denudation of the Torridonian in the N. W. Scottish Foreland.

In this connection we may consider the conditions in the eastern part of the map area of fig. 3. In the far S. E. the pre-tillite Sparagmitian is missing below the Kvitvola nappe (10), farther north-west it is developed in great thickness, while in a zone still farther to
The north-west it is again missing. The Cambro-Silurian, with underlying tillite, must in these districts have been deposited on a floor of widely varied character.

The writer has held, and recently has been supported by Føyn in his view, that after the deposition of the older sandstone division a fault-line was developed along the present south coast of the Varangerfjord (to the extreme S.E. in fig. 1), with denudation of the sediments to the south in pre-tillite and tillite time. Sandstone and shale, with the upper of the two tillite zones at some height from the base, lie west of the upper end of the fjord directly on the Archæan basement. The writer is also inclined to believe that a somewhat similar pre-tillite fault was developed in the eastern part of the map (fig. 3), between the area of the thick red sparagmites and the eastern district, where no representatives of the older sediments exist. In one locality here tillite seems to rest directly on the Archæan. I point to these conditions because they might possibly be considered in the discussion of the remarkable features along the inner side of the Outer Hebrides of Scotland, with a marked shear zone and a conglomerate (generally regarded as Torridonian) with local boulders, including sheared gneiss, occurring at Stornoway.¹

The Tarskavaig Moine would naturally be compared with the moderately metamorphic Sparagmitian masses, like for example those of the Kvitvola thrust mass in the eastern part of fig. 3.

Discussing the age of the Moinian J. Phemister (17, p. 34) summarizes a number of objections which have been raised against a parallelization between Torridonian and Moinian, viz. (I) the lack of proof that the metamorphism is of Caledonian age, (II) the in-frequency of conglomerates and the absence of breccias in the Moine Series; (III) the contrast between the N. to S. variation in lithology and thickness of the Torridonian and the lithological constancy of the Moine assemblage in this direction; and (IV) the absence of intrusive sheets in the Torridonian. Objections similar to the three latter ones might have been raised also against the correlation of the

¹ If this conglomerate should turn out to be a relatively young deposit (it has been regarded as Triassic by Stevens) its tectonical position would be much like that of the Tertiary conglomerate of Prince Charles Foreland, Spitsbergen (cp. the writer’s paper “Some Points of Structural Resemblance between Spitsbergen and Great Britain etc.”, Det Norske Videnskaps-Akademi i Oslo, Avhandlinger, 1925, No. 4, Fig. 2).
unmetamorphic and metamorphic Sparagmitian of Norway. The un-
metamorphic Sparagmitian in the more southern part of the map
area of fig. 3 is to a large extent of a very coarse arkose character,
with several horizons of coarse conglomerate (besides conglomerate
of basal type). Considering now the northern parts of the map area,
we generally find a monotonous sequence of more or less meta-
morphic, non-conglomeratic sparagmites interbedded with pelitic schists,
covering very large districts. As to igneous plutonic intrusions, they
occur in the thrust metamorphic complex of the north-western parts
of Finnmark, while they are totally missing in the unmetamorphic
sedimentary series to the south-east.

We shall not here go much into the question of the lithological
resemblance of the Torridonian and the pre-tillite Sparagmitian of
Scandinavia. The fact that in the latter region carbonate rocks (in the
south mainly limestone, in Finnmark mainly dolomite) are charac-
teristic constituents of the sequence, cannot be said to be an objection
of importance since, firstly, limestone occurs also in the Torridonian
(especially in Colonsay), secondly, the carbonate rocks become very
scarce towards the N. W. in the Sparagmitian of Scandinavia. As to
the character of the bedding, current bedding is very characteristic
of parts of the Torridonian and is locally developed and preserved
also in the Moinian (as for example at Mallaig). The typical unmeta-
morphic sparagmites of Southern Norway are commonly very massive,
with no distinct bedding in the banks, or else have parallel bedding.
In eastern Finnmark, however, we have good examples of current
bedding in the older sandstone division. Reusch has published an
illustration of red "false-bedded" sandstone at the Varanger fjord
(20, fig. p. 39) and the writer has reported on current bedded sand-
stone in Løkvikfjell on the north coast of the Varanger Peninsula
not far from the Tanafjord. It might be added that the grey and
red sandstones of the Varanger Peninsula commonly are very fel-
spathic.

The Jotnian sandstone (Dala sandstone), occurring in the eastern
part of the map (fig. 3), must without any doubt be older than the
sparagmites and has been separated from the latter by a period
of marked crust movements. The Jotnian sandstones in Fennoscandia
generally lie fairly horizontal, but to the extreme west, near the
western border of the Trysil—Dala area of the map, marked folding
occurs, with locally even vertical dip. This deformation is older than
the sub-Cambrian peneplane of denudation (which has continued west­
wards in the stratigraphical plane between the Cambrian and the Sparag­
mitian) as the said peneplane truncates the folded Jotnian. The coarse
arkoses of the (relatively) autochthonous Sparagmitian west of the
area of Jotnian sandstone are also very different from the rocks of
the latter series, and finally igneous intrusions are common in the
Jotnian sediments, but are totally missing in the adjacent Sparagmitian.

Turning now once more to the Dalradian, the Schiehallion
boulder bed zone, in Islay represented by the Portaskaig conglom­
erate, is a horizon of particular interest. The Portaskaig conglomerate
overlies, according to Bailey (1), the Blair Atholl Series, with the Islay
limestone as a characteristic member. This limestone is oolitic in
certain layers, and in the upper part dolomitic. There also occur
dolomitic bands with conglomeratic character, possibly to be regarded
as intraformational conglomerates. In Islay the dolomitic topmost
bed of the Islay limestone is overlain by a few feet of dark shale
or slate and these by the Portaskaig conglomerate, which in its lower
portion shows some bedding and is split up by bands of quartzite
and dolomite, and in its upper part is unbedded, and glacial-like.
The most conspicuous fragments in the deposit are nordmarkite of
unknown source, and pieces of dolomite. Locally dolomite boulders
are dominant. Dolomite conglomerates, or breccias, of intraformational
type, are described also from the Portaskaig conglomerate series.
Again one recognizes main points in common with Finnmark (and
other northern tillite-localities): on the east side of the Tanafjord we
find as the uppermost part of the “lower sandstone division” beds
of shale and dolomite, with bands of grey dolomite conglomerate or
breccia of intraformational type. As to the tillites of the Tana—Varanger
district, dolomites is commonly the dominant rock in the fragments,
especially in the lower tillite-zone. Dolomite layers and intraform­
amtional dolomite breccias are known also from the tillite-bearing series
(9, fig. 24, p. 169). Oolitic carbonate rocks occur in eastern Finn­
mark both in the lower sandstone division (9, pl. XVI) and in boulders
in the tillite rocks (12, fig. 16).

Above the Portaskaig-Schiehallion boulder bed follow in the
“Iltay Nappe” (2, p. 37), the thick Perthshire quartzite series, and
the Ben Eagach black schists, Ben Lawers calc-schists, Ben Lui
schists, Loch Tay limestone, Pitlochry schists, Green beds, Ben
Ledi grit and schists, Aberfoyle slate and Leny grit. In a comparison
with Scandinavian stratigraphy a correlation of the Ben Eagach black schists with the Middle Cambrian-basal Ordovician dark pelitic schists, the Loch Tay limestone with the Snaasen limestone (cp. Vogt's table, p. 232), the Green beds with the volcanic Lower Ordovician horizon, might be tentatively proposed. Peach's view of the Islay (Perthshire) quartzite as Cambrian would fit well into such a stratigraphical system.

The stratigraphical relation between the series of the "Il'tay Nappe" and that of the "Ballappel Foundation" with its quartzites, slates, limestones, is as yet not exactly known. What seems to be a fact is that the sediments of the latter, with the Eilde Quartzite as its oldest member, come on top of the Moine series.

To sum up, the following correlations would seem to be probable.

Scotland. Norw ay.
Main part of the "Il'tay Nappe" succession. Cambro-Silurian of the Trondheim and Nordland districts.
Schiehallion boulder bed. Tillite of upper Sparagmitian.
Torridonian (?) and Moinian. Unmetamorphic and metamorphic pre-tillite Sparagmitian.

The existence of rocks so highly metamorphic as the Moine schists above unmetamorphic (Torridonian and Cambro-Ordovician) sediments indicate transport of the schists for a very long distance in Scotland (if we assume the metamorphism to be of Caledonian age). In Southern Norway sparagmitic rocks with a similar high degree of metamorphism are not generally met with till we reach north of the Trondheim syncline. We may refer to Read's description of Moine Granulites from the Strath Oykell and Lower Loch Shin districts (18, p. 132) and to Barth's of metamorphic sparagmite from the Opdal district of Norway (3, p. 56; cp. especially Read's fig. 3, C. and Barth's fig. 1, 3).

With the assumption of a very long travel of the thrust masses the fact that there does not occur in the metamorphic areas of Scotland any stratigraphical unit of the character of the Durness limestone (dolomite) series, finds a natural explanation. The said extreme development of carbonate rock belongs to a distinctly western facies, which is also represented in East Greenland and Bear Island,
while in more easterly facies, as seen in the north-western parts of Norway, the lower Ordovician seems to become gradually a horizon of largely pelitic character.

To a facies much like that of the central Trondheim district the "Highland Border rocks" of Scotland would probably correspond. As to the zone S.E. of the Dalradian, the conditions of Western Ireland (cp. Bailey, 2, p. 46) seem to be of particular interest. There is here a very great thickness of Arenig rocks (black shales, cherts, grits, conglomerates, pillow lavas etc.) and a still greater development of younger Ordovician, Ashgillian, sediments, mainly sandstone (arkose).

Such a succession reminds one considerably of the sequence Bymark—Hovin Group near Trondheim. Immediately to the south-east, in Ireland, Silurian beds directly overlie the Connemara schists which are probably pre-Cambrian. In the Olden district of N.W. Jämtland (Sweden) a pre-Cambrian granite seems to have been exposed in Upper Ordovician times (21). This Olden granite occurs in an area which lies in line with a series of anticlines or domes where Archaean rocks crop out in windows, flanking the central South-Scandinavian syncline to the south-east (fig. 4) and reminiscent of the conditions along the Midland Valley zone of Scotland and Ireland, which is also bordered towards the south-east by areas of relatively old rocks.

References.


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