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Caledonian Metamorphism in Svalbard, with Some Remarks on the Basement*

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Abstract: Four zones of Caledonian rocks can be distinguished in Svalbard. The geosynclinal sedimentary piles are 15—20 km thick; the lower part is eugeosynclinal and the middle and upper parts are miogeosynclinal in character. The four zones represent two sets of paired metamorphic zones, each of which is composed of the intermediate T/P facies series and the high T facies series. The high T facies series resulted from the strong influence of migmatisation, while the blueschists of the W zone are thought to be a high P variety of the intermediate T/P facies series. Migmatisation occurred later than regional metamorphism. The former took place in the Silurian-Devonian period, as shown by most of the K/Ar ages, while the latter can be correlated with the Cambrian hiatus indicated by the preliminary studies of the Rb/Sr isochrone ages. Chemical characteristics of the igneous rocks in the geosynclinal piles do not show with certainty any oceanic basement and a continental one is inferred from the pebbles of conglomerates. The chemistry of syn — late orogenic gabbros of the NE zone indicates an island-arc condition during the Caledonian orogeny in this area.

Zusammenfassung: Die Gesteine kaledonischen Alters werden in Svalbard in vier Zonen gegliedert. Die geosynklinalen sedimentären Folgen sind 15 bis 20 km mächtig, wobei der liegende Teil eugeosynklinalen, die mittleren und oberen Bereiche miogeosynklinalen Charakter besitzen. Die vier Zonen bilden zwei Reihen paariger metamorpher Bereiche, wovon jeder aus einer intermediären Druck-Temperatur-Faziesserie und einer Hochtemperatur-Faziesserie zusammengesetzt ist. Die Hochtemperatur-Faziesserie war das Ergebnis einer starken Überprägung durch die Migmatisierung, während von der Glaukophanschieferfazies der Westzone angenommen wird, daß sie eine Hochdruckmodifikation der intermediären Druck-Temperatur-Fazies darstellt. Die Migmatisierung erfolgte später als die Regionalmetamorphose. Die erstere ereignete sich im Silur-Devon, wie die meisten der K/Ar-Altersbestimmungen zeigen, während die letztere mit dem kambrischen Hiatus korreliert werden kann, wie die vorläufigen Ergebnisse der Rb/Sr-Isochrone ergeben haben. Die chemischen Eigenschaften der magmatischen Gesteine in der geosynklinalen Folge zeigen mit Sicherheit kein ozeanisches Krustenmaterial, während ein kontinentaler Untergrund von den Geröllen der Konglomerate abgeleitet wird. Die Chemie der syn- bis spätorogenen Gabbros der Nordostzone zeigt Inselbogen-Verhältnisse während der kaledonischen Orogenese in diesem Gebiet.

Caledonian rocks and structures are the fundamental framework of Svalbard. In this paper a summary of Caledonian metamorphism will be given and some problems concerning the basement of the Caledonian geosyncline will be discussed.

THE CALEDONIAN GEOSYNCLINE

The geosynclinal sedimentary piles involved in the Caledonian orogeny in Svalbard are called the Hecla Hoek succession. Their total thickness is about 15—20 km and they are of Precambrian to Lower Paleozoic age. These rocks are exposed along the western and northern sides of the Svalbard archipelago, 650 km in the N-S direction along the general trend of Caledonian structures and 500 km in the E-W direction across this trend. The rocks occur in four zones of a roughly N-S trend, and are separated by zones of younger structures (Fig. 1): the W (subdivided into the WS and the WC areas), the NW, the NC and the NE zones, each zone forming an independent tectonic unit.

The lithologic characteristics of the geosynclinal sediments in the four zones are simplified in Fag. 2. The lower limit of the succession is thought to be about 1,000 m. y. b. p., which is estimated from the 800—900 m. y. Rb/Sr isochrone age of the volcanic rocks of the Lower Hecla Hoek succession (RÅHEIM, pers. com., 1978) and the 1,275 m. y. Rb/Sr whole rock isochrone age of the granite-gneiss boulders of the Upper Hecla Hoek succession (EDWARDS & TAYLOR, 1974), both in the NE zone. The upper limit is marked by the fossil evidence of the Ordovician-Silurian period in the WC area (SCRUTTON et al., 1976). The lower parts of the Hecla Hoek succession in each zone are

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eugeosynclinal to some extent, while the middle and upper parts are miogeosynclinal and are dominated by quartzite, limestone-dolomite and areno-argillaceous rocks. Recently, two horizons of basic rocks have been recognized in the Middle and Upper Hecla Hoek in the W zone, and the intermediate volcanic rocks (the Kapp Hansteen Formation) of the NE zone have shown its stratigraphic position to be younger than that

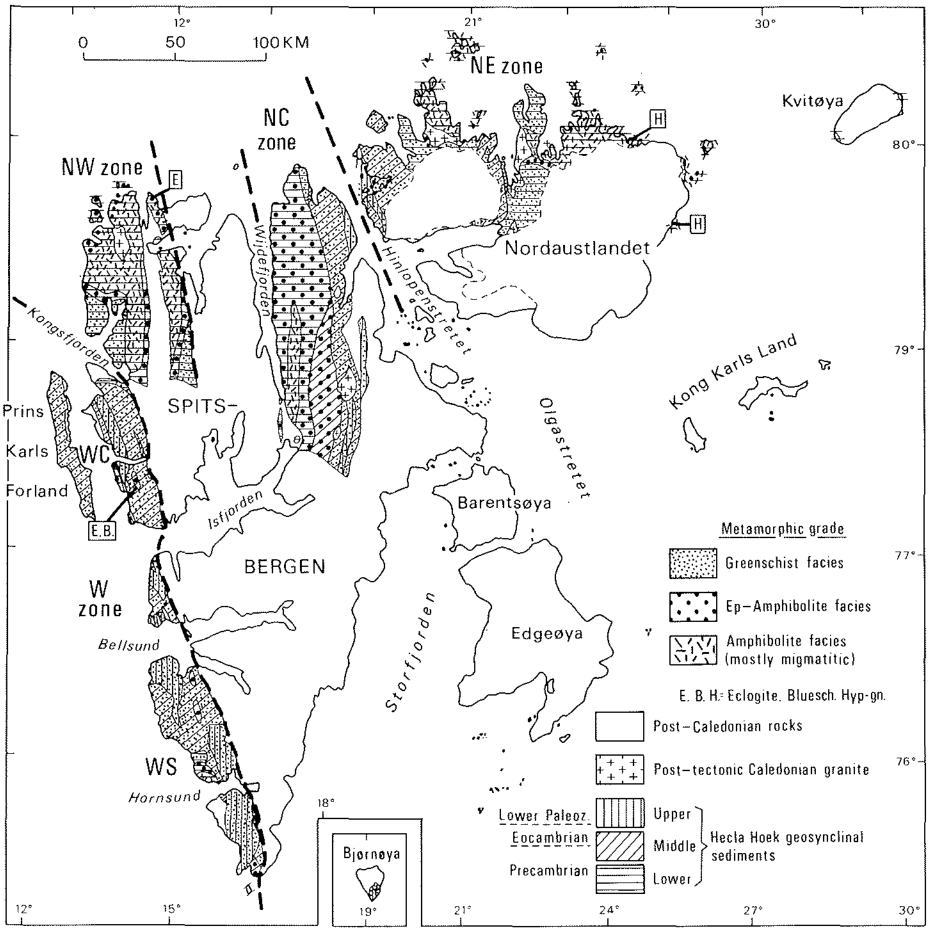

Fig. 1: Distribution of the Hecla Hoek rocks and their metamorphic grade in Svalbard.
Abb. 1: Verteilung der Hekla-Hoek-Gesteine und ihre Metamorphosegrade in Svalbard.

of the argillo-arenaceous sediments (the Brennevinsfjorden and the Austfonna Formations). The amount of volcanigenic rocks does not exceed 10 % of the Lower Hecla Hoek succession and a typical ophiolitic assemblage does not occur in any zone. There is no distinct difference in the amount of volcanigenic rocks in the four zones and the contrast between the eu- and mio-geosynclinal character can always be observed between the lower and the middle-upper successions.

CALEDONIAN METAMORPHISM

The metamorphic grade increases roughly parallel to the stratigraphic depth in all zones, as shown by the general positions of isogrades in Fig. 2; a reverse relationship can rarely be observed. This evidence gives the impression that metamorphism influenced upon the geosynclinal piles is a single prograde series in general, although local complexities do occur.

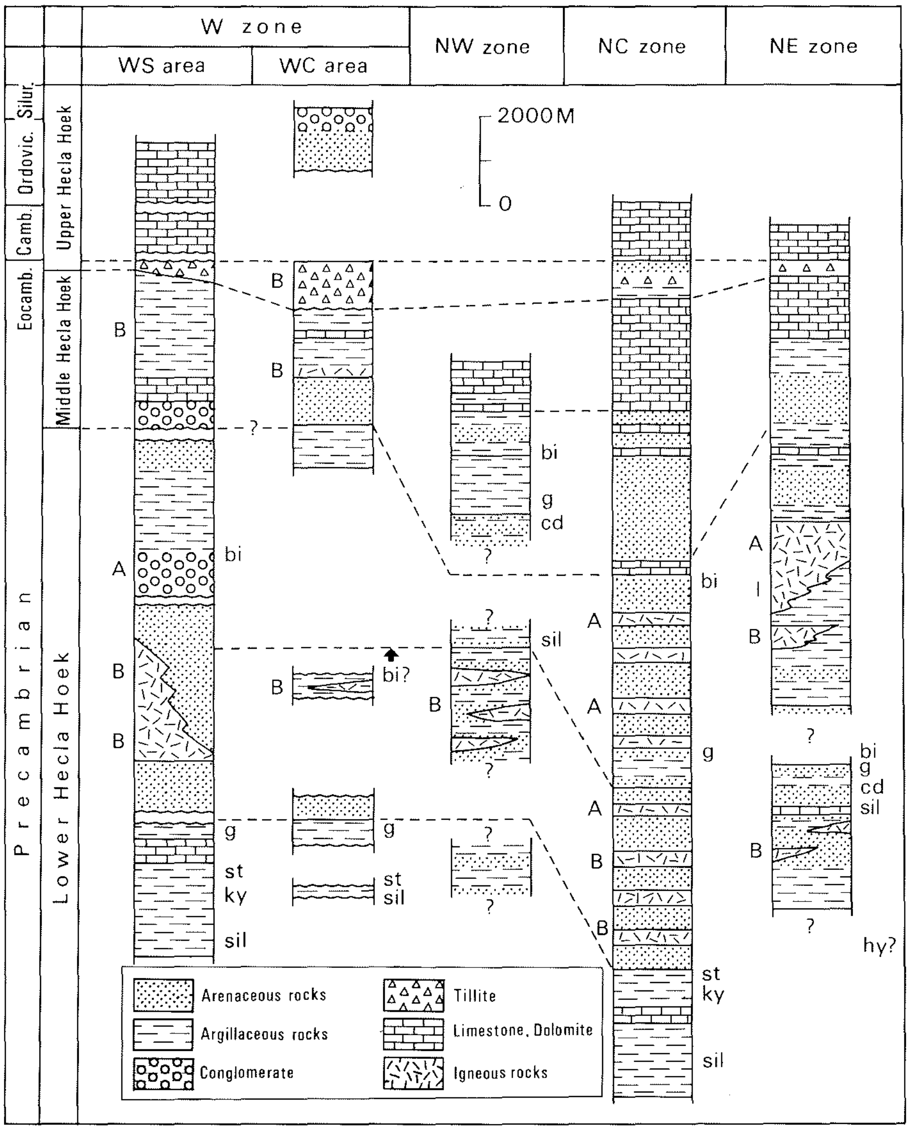

Fig. 2: Simplified lithostratigraphic columns of the Hecla Hoek rocks from the four zones in Svalbard. A, I, and B along the left side of the columns: acidic, intermediate, and basic igneous activities respectively. bi, g, cord, st, ky, sil, and hy along the right side of the colums: rough position of the isogrades of the minerals.

Abb. 2: Vereinfachte lithostratigraphische Profilsäulen der Hekla-Hoek-Folgen von den vier Zonen in Svalbard. A, I und B rechts der Profilsäulen bedeuten A = saurer, I = intermediärer und B = basischer Magmatismus. Bi (= Biotit), g (= Granat), cord (= Cordierit), st (= Staurolith), ky (= Disthen), sil (= Sillimanit) und hy (Hypersten) auf der rechten Seite geben ungefähr die Lage der Isograden der Minerale an.

Metamorphism of the WC area and the NW zone has been studied in detail by the present author, while the WS area and the NC zone have been investigated mainly by Polish and British expeditions respectively. The NE zone is now being studied in detail by the staff of the Norsk Polarinstitutt. Some metamorphic characteristics will be outlined below, ranging through the W to the NE zone.

The W zone

Two phases of deformation are evident from the analyses of mesoscopic structural elements in Hornsund, Bellsund, St. Jonsfjorden and Prins Karls Forland: the older one is mainly in the E-W trend, with considerable variations and the younger one in the NNW-SSE trend, both having been disturbed by Tertiary movements. BIRKENMAJER (1975) has suggested a few possible Precambrian deformations, his theory being based on the presence of unconformities and the granite pebbles of conglomerates in the Hecla Hoek successions of the WS area. However, linear structures representing the older deformation phase were found in the Middle and Upper Hecla Hoek rocks of the WC area, thus indicating their Caledonian origin. The younger trend is superimposed by the Tertiary deformation, roughly in the same trend, and is therefore difficult to distinguish from the latter. However, the specific style of the folds and the associated mineralisation, neither of which are found in the post-Middle Paleozoic rocks, give evidence of their Caledonian origin. These two deformation phases can be used as timemarkers for Caledonian metamorphism in the W zone.

The older phase of deformation created the cleavages associating with the kyanite-, staurolite- and garnet-bearing mineral assemblages which represent the intermediate T/P metamorphic facies series. The Tertiary movements made only retrogressive changes of the Caledonian assemblages. A stage of static re-crystallization of micas has been reported elsewhere in the WS area and is definitely older than the Tertiary deformation (SMULIKOWSKI, 1965, 1968).

Similarly, two phases of re-crystallization have been observed in the high-grade metamorphic rocks which occur along the eastern and western sides of the Forlandsundet Graben in the WC area (HJELLE et al., 1979). The older assemblages here, including sillimanite, garnet and micas, were strongly modified by mechanical crushing with an introduction of quartz, and large unoriented biotite flakes grew at a later date, regardless of the schistosities; these flakes, however, were folded by chevron folds of the younger deformation phase. Thus static thermal re-crystallization of the W zone definitely dates from the Caledonian period.

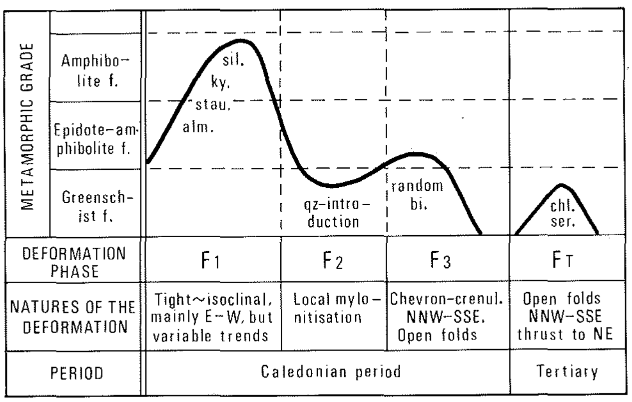

Fig. 3: Sequence of Caledonian metamorphic events in the W zone of Svalbard.

Abb. 3: Abfolge kaledonischer metamorpher Ereignisse in der Westzone von Svalbard.

From the above description, it may be concluded that there were two phases of re-crystallization in the W zone, occurring within the time range between the two deformation phases of the Caledonian period: an intermediate T/P facies series of regional metamorphism associated with the formation of cleavages during the older phase of deformation, and static thermal metamorphism which occurred later than the formation of cleavages, but which is older than the younger phase of deformation (Fig. 3). The albite-granite pebbles of the conglomerate of the Middle Hecla Hoek succession in the WS area were considered to be derived from the underlying middle Lower Hecla Hoek rocks, and Precambrian metamorphism has been suggested by BIRKENMAJER (1975). However, an apparent similarity of these pebble-rocks with the underlying ones is not enough to correlate them with certainty, and more definite data, such as their age and sedimentological support etc., are required.

The blueschists and eclogite of the WC area make a particular rock association, with isolated occurrences as thrust schuppen in the Upper Hecla Hoek rocks (OHTA, 1979). The eclogite occurs as small tectonic blocks in the calcareous schists, and is converted into glaucophane-bearing rocks along the cracks and margins. Chloritoid-phengite-quartz schist also has glaucophane idioblasts and shows a partly feather amphibolite texture. Typical blueschist is composed of almost pure glaucophane groundmass with various amounts of large size garnet. Basic dykes of a few meters in thickness cut the dolomite bed sharply, making a garnet-bearing skarn zone in the latter, and the dyke rocks were

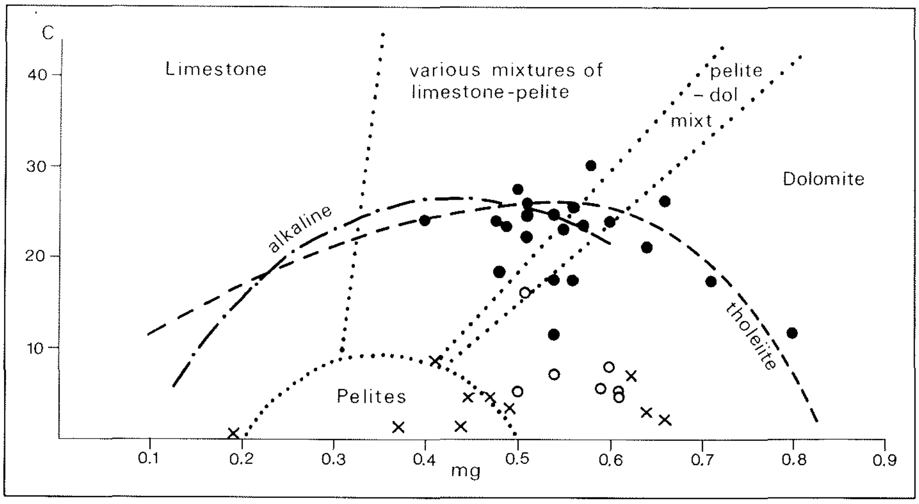

Fig. 4: Original rocks of the blueschists from Motalafjella, the WC area (the Niggli-value diagram). broken curve: differentiation trend of tholeiitic rocks, chained curve: differentiation trend of alkaline rocks, dot: epidote-amphibolite without alkaline-amphibole, open circle: glaucophane-bearing schist, cross: mica-quartz schist without alkaline-amphibole.

Abb. 4: Ursprungsgesteine der Glaukophanschiefer von Motalafjellet, des Westzentral-Gebietes (Niggli-Werte-Diagramm). Gerissene Linie: Differenzierungstendenz tholeiitischer Gesteine, strichpunktierte Linie: Differenzierungstendenz alkalischer Gesteine, Punkt: Epidot-Amphibolit ohne Alkali-Hornblende, offener Punkt: Glaukophan-führende Schiefer, Kreuz: Glimmer-Quarz-Schiefer ohne Alkali-Hornblenden.

converted into pure glaucophane schist. The bulk chemical analyses of blueschists show that the original rocks are mixtures of pelitic sediments and the early differentiates of basic magma (Fig. 4). No transitional relation has been observed from the blueschist to the associated epidote amphibolites. The origin of the eclogite is unknown, while the associated glaucophane rocks are evidently retrogressive products from the former.

Three mineral assemblages indicating different physical conditions of formation are distinguished in these basic rocks (Fig. 5). The physical conditions of the formation of the eclogite were calculated from the partitioning of Fe and Mg in the garnet-pyroxene paragenesis to be of minimum P = 9.7 kb and T= 540—570° C, and of the blueschist, using the Si $^{+4}$ values of phengite referring to the oxygen isotope temperature for the Californian type IV blueschists, P = 8 kb, when T = 400—550° C. These data are summarized together with those of other rocks in Fig. 7. Characteristic is the lack of the low-grade side of the high P metamorphic facies series of the eclogite and blueschists. The conversion from eclogite to blueschist resulted from an isothermal retrogressive process of pressure, while the epidote amphibolites and the chloritoid-quartz schists make a series of intermediate T/P type metamorphism of about 25° C/km temperature gradient. Although the origin of the eclogite is unknown, the formation of the blueschists can be considered to be a high pressure deviation of the intermediate T/P metamorphic facies series and is classified as the high temperature glaucophane schist facies of WINKLER (1967) and

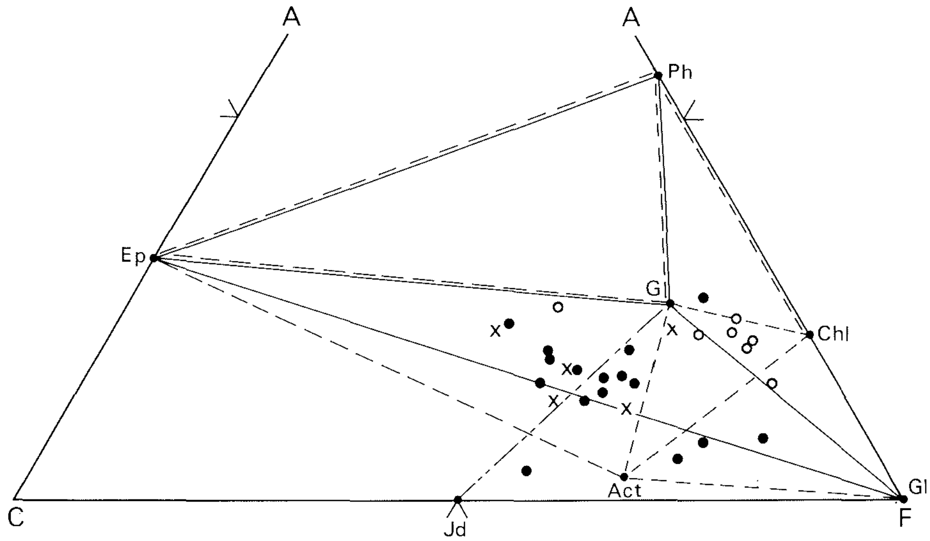

Fig. 5: ACF diagram of the basic rocks from the WC area, indicating three assemblages. Broken tie line: epidote actinolite greenschists facies, solid tie line: glaucophane schist facies, chained tie line: eclogite. Dot: epidote amphibolite, open circle: glaucophane schist, cross: mica-quartz schist.

Abb. 5: ACF-Diagramm der basischen Gesteine aus dem Westzentral-Gebiet mit drei Mineralvergesellschaftungen. Gerissene Linie: Epidot-Aktinolith-Grünschiefer-Fazies, ausgezogene Linie: Glaukophan-Schiefer-Fazies, strichpunktierte Linie: Eklogite, Punkt: Epidot-Amphibolit, offener Punkt: Glaukophan-Schiefer, Kreuz: Glimmer-Quarz-Schiefer.

TAYLOR & COLEMAN (1968). A local tectonic overpressure is enough to produce this type of blueschist and it is not necessary to introduce a subduction zone in the present case as HORSFIELD (1972) did.

The NW zone

This zone is characterized by an intensive development of migmatites, which form two zones of a roughly N-S trend. The major anticlinorium in the western part has its axis slightly plunging to the south; thus the deeper rocks are exposed towards the north. The stratigraphic position of the original rocks is difficult to determine because of strong metamorphic modifications, but the rocks are roughly correlated to the lower Middle and Lower Hecla Hoek successions.

The metamorphic events are summarized in Fig. 6. Migmatisation of the F2-F3 stage covers most of the area and the low-grade rocks remain in the northeastern and southwestern parts and in a N-S zone between two migmatite zones. In the latter two localities, the effects of migmatisation gave all the intermediate grade rocks high T type metamorphic mineral assemblages, and it is difficult to classify the type of metamorphism in the low grade phyllites. The conversion of cordierite into almandine garnet can often be observed in the pelitic gneisses. This indicates that the thermal gradient of metamorphism roughly coincides with the andalusite-kyanite inversion line (30° C km) in the amphibolite facies range (HIRSCHBERG & WINKLER, 1968).

However, in the northeastern part, GEE (1966) reported kyanite-staurolite assemblages in the pelitic gneiss associating with eclogite. Small remnants of kyanite were also found in the cordierite-sillimanite-garnet-two-mica gneiss paleosomes of migmatite in Danskøya in the northwestern part of this zone. The corundum-spinel crots found in the

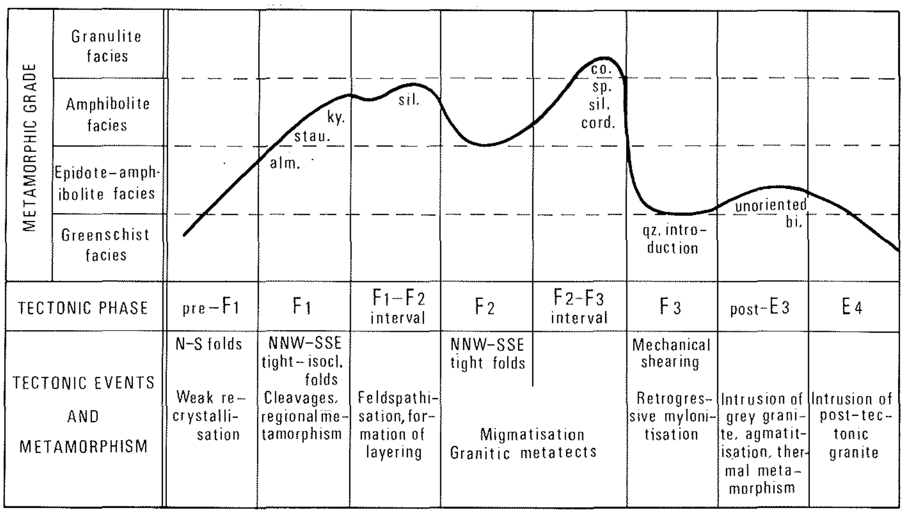

Fig. 6: Caledonian tectonic and metamorphic events in the NW zone of Svalbard.
Abb. 6: Kaledonische tektonische und metamorphe Ereignisse in der NW-Zone von Svalbard.

neighbouring area are considered to have been converted from former staurolite or chloritoid porphyroblasts (HJELLE & OHTA, 1974). This evidence indicates that the F1 metamorphism in the NW zone is of an intermediate T/P facies series.

The NC zone

This zone has been studied over a long period, mostly by Cambridge expeditions, and the best preserved succession of Hecla Hoek rocks of about 20 km in thickness was established (WILSON, 1958; HARLAND, 1959; GAYER & WALLIS, 1969. HARLAND et al., 1966; GAYER, 1969). The present author has been working in this area since 1978.

Dominant structures with a N-S strike determine the rock distribution, and the main anticline, whose core is composed of the highest grade of metamorphic rocks, occurs along the western part of the zone in the southwestern part of Ny Friesland. The western limb of the anticline is cut by the Wijdefjorden fault, while the eastern limb shows a series of prograde metamorphism. The biotite isograde roughly coincides with the top of the Lower Hecla Hoek rocks in the northern part of this zone, while it passes obliquely through the Middle Hecla Hoek rocks in the southern part of Ny Friesland. The Upper Hecla Hoek rocks along the Hinlopenstretet in the east have been left almost entirely unmetamorphosed and contain well-preserved Lower Paleozoic fossils (FORTEY & BRUTON, 1973).

The main anticline shows an axial culmination in south-western Ny Friesland, where kyanite-, staurolite- and sillimanite-bearing assemblages have been reported. These minerals show a strong preferred orientation controlled by cleavages and layered structures developed along the axial plane of tight isoclinal folds. This is the main

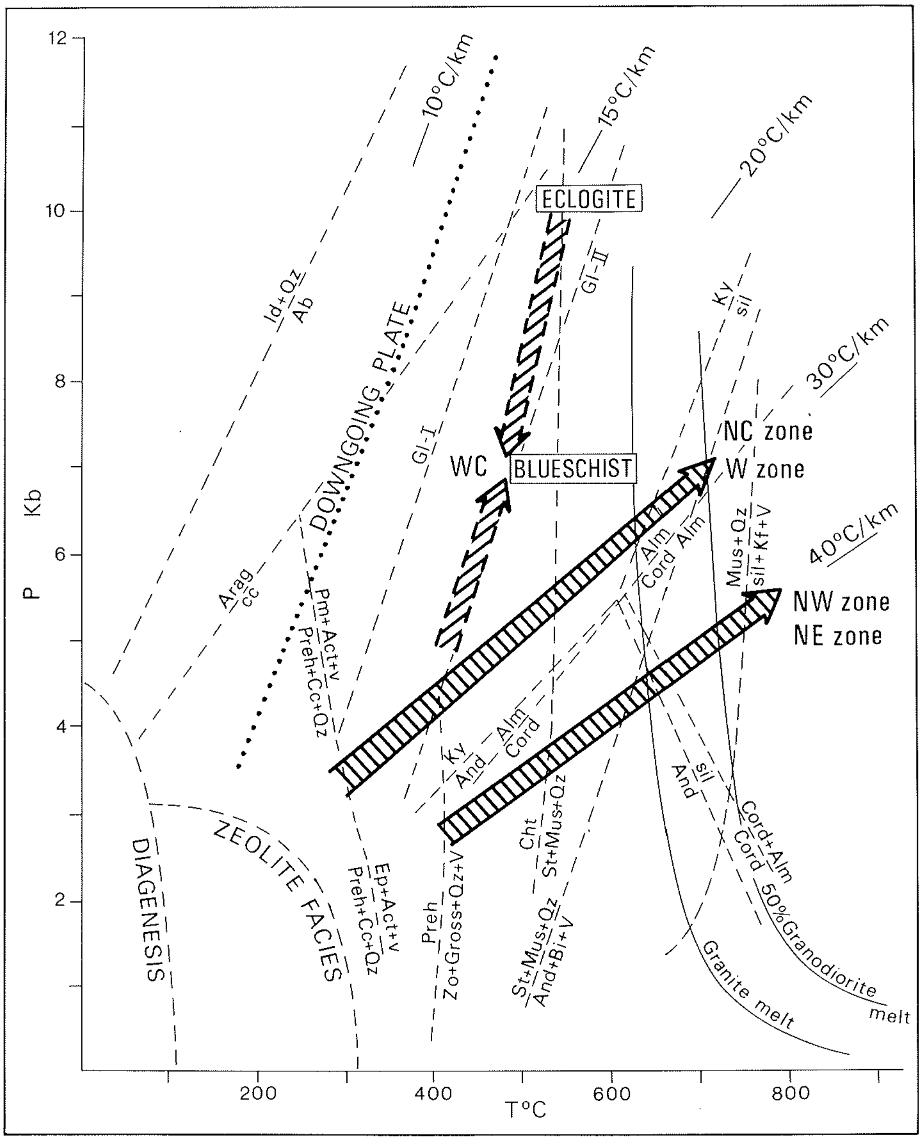

Fig. 7: Metamorphic facies series of Caledonian rocks in the four zones of Svalbard.
Abb. 7: Metamorphe Faziesserien kaledonischer Gesteine in den vier Zonen Svalbards.

regional Caledonian event and the metamorphism is of the intermediate T/P facies series. The cleavages and layered structures were involved in the main anticline structure, and the axial culmination indicates the upheaval of the highly metamorphosed core, probably composed of migmatites. Since the migmatites did not reach the level of the present surface, the thermal effect was weak even in the crestal part of the anticline, and the character of the regional metamorphism has been well preserved.

Owing to the similar structural trends of the earlier regional metamorphism and later migmatite upheaval, it is difficult to recognize the tectonic phases simply from the studies of mesoscopic structural elements; however, detailed petrographic analyses will solve this problem.

The NE zone

Intensive migmatites and intrusive granite developed in the northern and eastern parts of Nordaustlandet, weakly metamorphosed Hecla Hoek rocks occur in the western and middle parts of this area, and the southern part is covered by Upper Paleozoic strata. The migmatites and granites show sharp intrusive contact with the Hecla Hoek rocks. The highest grade of metamorphism achieved in the latter is lower than the biotite isograde even in the middle Lower Hecla Hoek rocks, and the type of metamorphism is unknown. All biotite-bearing rocks are related to the high temperature contact metamorphism of the migmatites and granites, and almandine, andalusite and staurolite were formed locally. The migmatites include numerous paleosomes of schistose and gneissose rocks, most of them have sillimanite, cordierite and almandine garnet with a large proportion of micas. Rhombic pyroxene-bearing, garnet-mica-amphibole gneisses have been found in the north-eastern and eastern parts of Nordaustlandet (HJELLE et al., 1978), indicating that the highest grade was the granulite facies before the invasion of the migmatitic metatects. It is notable that a large amount of syn- to late-tectonic gabbros occurs in the north-eastern part of Nordaustlandet and on adjacent islands (OHTA, 1978).

		I PAIR		II PAIR	
		W	NW	NC	NE
Dominating metamorphic facies series		Intermediate T/P	High T	Intermediate T/P	High T
Caledonian events	Post-tectonic granite		Hornemantoppen granite (410—385)	Newtontoppen granite (402—385)	Rijpfjorden granite (380—340)
	Migmatisation phase (m. y.)	No migmatite (375)	High T series (And. Cord. Alm. Sill. Co. Sp.) large amount of migmatites (450—379)	weak invasion of apophyses (436—365)	High T series (Bi. Alm. And. St. Cord. Sill.) large amount of migmatites (430—355)
	regional metamorphism phase	Intermediate T/P (Cht. Alm. St. Ky. Sill.) (584—402)	Intermediate T/P (St. Ky. Sill.) (541)	Intermediate T/P (St. Ky. Sill.) (?)	(lower than Bi-isograd) (530±)
Evidences suggesting the basement		Granite pebbles in tillite. Rhyolite pebbles in upper L. H. H. Basic rocks in L., M., & U. H. H. Eclogite	Basic rocks in L. H. H. Eclogite	Acidic & basic rocks in L. H. H.	Syn- & late-tectonic gabbros. Granite pebbles in tillite. Acid-intermediate volcanics in L. H. H. Hypersthene-bearing gneisses.

Tab. 1: Summaries of metamorphism in the four zones of Svalbard and the evidence to suggest the basement.

Tab. 1: Zusammenfassung der Metamorphose-Ereignisse in den vier Zonen von Svalbard und Hinweise auf die Deutung des Untergrundes.

SUMMARY OF CALEDONIAN METAMORPHISM

Four zones of Caledonian metamorphic rocks in Svalbard represent two sets of apparently paired metamorphic zones (MIYASHIRO, 1973), as shown in Tab. 1 and Fig. 7. However, the high T facies series of the NW and NE zones is caused by the development of intensive migmatites, and regional metamorphism which preceded migmatisation is of the intermediate T/P facies series, although that of the NE zone is uncertain. Considering the tectonic history (Tab. 1), the two sets of apparently paired metamorphic zones are results of the different extents of migmatisation in a later period of Caledonian orogeny and the preceding regional metamorphism is probably the result of the intermediate T/P facies series in all four zones.

It is generally said that the zones of different metamorphic facies series are closely related to the different nature of geosynclinal sedimentary piles: the high P type facies series to the more eugeosynclinal one. The Hecla Hoek successions of the four zones in Svalbard do not show any lithological contrast with each other; instead, the contrast is found between the Lower and the Middle-Upper successions. This evidence is confirmed by the same metamorphic facies series in all four zones.

According to the radiometric ages, the end of the migmatisation period was about 350 m. y. ago, and it was followed by the post-tectonic granite. The regional metamorphism had its climax about 530 m. y. ago. The former age corresponds to the so-called main Caledonian event elsewhere, while the latter can be correlated with the early Caledonian phase as established in north-western Finmark, northern Norway (PRINGLE, 1971) and Scotland (PANKHURST & PIDGEON, 1973), which is represented by the Middle and Upper Cambrian hiatus of the Upper Hecla Hoek successions. This is confirmed by the fact the Ordovician-Silurian Bulltinden Formation of the WC area includes pebbles of phyllites and schists which are probably derived from the underlying Middle and Lower Hecla Hoek successions.

Although the origin is complex, the two sets of paired metamorphic zones are exhibited on the present-day surface. The contrast between the paired zones is not as strong as between the younger pairs which consist of the high P type and the high T type metamorphic facies series. This weak contrast between the paired zones and the lack of distinct lithologic differences in the geosynclinal piles are characteristic for the Svalbard Caledonides.

THE BASEMENT OF THE HECLA HOEK GEOSYNCLINE

There may be some diastrophisms in the Upper Proterozoic to Eocambrian period, and the Hecla Hoek geosynclinal sediments might have been subjected to metamorphism and deformation, as BIRKENMAJER (1975) has suggested for the WS area. Even so, there is good reason to believe that the development of the Hecla Hoek geosyncline forms a large unit in the geotectonic history of Svalbard.

A possible Archean basement of the geosyncline has been suggested for the NE zone, based on the facts that the grade of metamorphism decreases towards the east in the sediments and that a wide migmatite complex with gentle undulating structures occurs (SANDFORD, 1926, 1954; SOKOLOV et al., 1968). Gneissic paleosomes of the migmatites in the NW zone have been considered by KRASILSČIKOV (1973) and RAVICH (1979) as being derivatives from the basement.

The facts in favour of a continental basement nature are the pebbles and boulders of granite in the conglomerates of the Hecla Hoek successions: elsewhere in the tillite of the Upper Hecla Hoek and in the Slyngfjella Conglomerate of Middle Hecla Hoek in the WS area. The granite-gneiss boulders from the tillite of the NE zone were dated at 1,257±45 m. y. by the Rb/Sr whole rock isochrone method and the high initial $Sr^{87/86}$ ratio, 0.72172±0.00056 obtained, implies that these rocks are from even older crustal rocks (EDWARDS & TAYLOR, 1974).

The occurrence of K_2O rich rhyolite pebbles (K_2O wt % = 9.40 and 10.21; SMULIKOWSKI, 1968) in the conglomerate of the Vimsodden Formation in the upper Lower Hecla Hoek of the WS area, suggests a source area for the pebbles with a continental crust. The feldspar porphyroblastic gneisses of the Planetfjella Group of upper Lower Hecla Hoek in the NC zone are thought to be derived from acidic volcanic rocks (WALLIS, 1969). Some of them include a significant amount of potash feldspar, suggesting a potash alkaline acidic volcanic rock origin. These rocks have a significance similar to the rhyolite pebbles of the Vimsodden conglomerate.

The paleosomes of granulite facies rocks in the migmatites of the NE zone are another possible indication of a crystalline basement. If the correlation of the Kapp Hansteen Formation of this zone to the Planetfjella Group of the NC zone is correct, then the areno-argillaceous rocks of the Brennevinsfjorden, Kapp Platen and Austfonna Formations are comparable to the middle and lower Lower Hecla Hoek successions. The biotite isograde of Caledonian regional metamorphism had not been achieved in the lowest part of the metasediment successions in the NE zone, while the paleosomes had the mineral parageneses of the granulite facies. The granulitic paleosomes could not have been produced by the migmatisation which occurred under the conditions of the amphibolite facies. Thus, a large gap of metamorphic grade is estimated between the lower part of the Lower Hecla Hoek successions and the granulitic paleosomes, and this may indicate the difference between the geosynclinal sediments and the basement. On the other hand, an ancient oceanic basin, i. e. Paleo-Atlantic or Iapetus, has been inferred from the existence of abundant basic volcanic rocks in the Lower Hecla Hoek succession of the NC zone (HARLAND & GAYER, 1972), and a mid-oceanic spreading centre was induced from the gabbro-amphibolites of the WS area during the Lower Hecla Hoek period (BIRKENMAJER, 1975). HORSFIELD (1972) concluded that the

	Alkaline basalt			Subalkaline basalt			Transitional basalt			Total
	High-K basalt	K-alkaline basalt	Na-alkaline basalt	Low K-subalk. basalt	Flood basalt	High-Al basalt	Low-K transitional basalt	K-rich transitional basalt	Na-rich transitional basalt	
WC area	0	1	0	1	3	0	2	0	3	10
WS area	0	2	4	1	1	1	2	1	5	17
Total	0	3	4	2	4	1	4	1	8	27

	Alkaline and transitional basalt							Subalkaline and transitional basalt	
	High-K series	Potash series			Sodic series				
		Trachybasalt		Potassic basalt	Hawaiite		Sodic basalt	Flood basalt	High-Al basalt
WC area	0	0	(1)	1	2	(5)	3	8	1
WS area	0	2	(3)	1	9	(11)	2	6	5
Total	0	2		2	11		5	14	6

Tab. 2: Classification of the selected basic rocks from the W zone of Svalbard.

Tab. 2: Einteilung ausgewählter basischer Gesteine der Westzone Svalbards.

blueschists of the WC area were formed from the oceanic basic rocks involved in a subduction zone during the Caledonian orogeny.

However, the mere existence of abundant basic rocks is not enough to suggest an oceanic basement, but detailed examination of the nature of the basic rocks is necessary. For this purpose, uncontaminated basic rocks were selected from available bulk chemical analyses sampled from the W zone and classified according to MIDDLEMOST (1975), as shown in Tab. 2. The ratio of alkaline and subalkaline rocks is 2:1 in the WS area and 1:4 in the WC area. This dissimilarity indicates the difference in the stratigraphic position of the basic rocks of the two areas; however, the existence of potash-alkaline rocks, although present in small amounts, is notable. In the classification which includes the transitional rocks, Na-rich hawaiite and flood basalt are dominant in both areas. Comparing the TiO_2 and P_2O_5 with the average oceanic rocks (Tab. 3), the dominant rocks of the present areas are not similar to the oceanic ones: the present hawaiites have a distinctly lower TiO_2 and P_2O_5 than the oceanic ones, and the present flood basalts are similar to the continental tholeiites. Low potash subalkaline rocks are said to be typical of oceanic floor basalt. This type of rock does exist in the present areas, however, occurring as lamprophyre and porphyrite dykes which cut shallow sea sediments; thus they are not likely to be of the oceanic floor type. The TiO_2 and P_2O_5 also confirm a non-oceanic origin. On the whole, as far as we know up until now, the basic rock assemblages of the W zone are not of an oceanic type at all, and more systematic studies are required for any significant conclusion to be drawn on the tectonic setting of the area.

	low K sub-alkaline basalt			sub-alkaline basalt						
	ocean foor basalt			flood basalt		Svalbard			Svalbard	
	ocean floor	sea Mt. & ocean floor	Svalbard WC area	continental TH (Karroo)	oceanic TH (Hawaii)	WC area	WS area	high Al basalt (Japan & Korea)	WC area	WS area
TiO_2	1.5	1.3	3.3	1.1	2.5	1.6	1.7	0.8	2.3	1.5
P_2O_5	0.13	0.13	0.22	0.13	0.30	0.12	0.15	0.14	0.30	0.33
No. of data	44	19	1	21	200	4	7	11	2	4

	alkaline basalt							
	potash series		Svalbard		sodic series		Svalbard	
	Ocean ridges (Gough isl.)	deep subducted zone (Japan)	WC area	WS area	Canary isl.	Hawaii isl.	WC area	WS area
TiO_2	3.3	2.2	2.5	1.8	2.6	3.4	2.0	1.8
P_2O_5	0.33	0.70	0.25	0.61	0.84	0.70	0.24	0.25
No. of data	10	27	3	3	22	62	4	10

Tab. 3: Comparison of average TiO_2 and P_2O_5 between the basic rocks of the W. zone of Svalbard and various rock types from different tectonic settings.

Tab. 3: Vergleich des durchschnittlichen Gehalts an TiO_2 und P_2O_5 zwischen den basischen Gesteinen der Westzone Spitzbergens und verschiedenen Gesteinstypen unterschiedlicher tektonischer Position.

Basic rocks exist in relatively small amounts in the NW zone and have been strongly modified by migmatisation. It is almost impossible, therefore, to work out their original nature. In the NC zone, the Harkerbreen Group of the middle Lower Hecla Hoek succession includes a large amount of amphibolite and gabbroic rocks, but no chemical study has yet been undertaken.

Intermediate and acidic volcanic rocks predominate in the upper Lower Hecla Hoek successions of the NE zone. The Kapp Hansteen Formation, in particular, has a succession of more than a few km in thickness, composed of andesite and porphyrite. This volcanism is certainly not of an oceanic type. Syn- to late-tectonic Caledonian gabbros are widespread in the north-eastern part of Nordaustlandet. One of them in Storøya shows distinct layered structure and cumulative textures, indicating a stratiform basic complex. The later differentiates of this complex are calc-alkaline quartz dioritic rocks which occupy about half of the exposures. The basic rocks, both of Storøya and Kvitøya, show a relatively high concentration of iron in the middle stage of the differentiation and are of a tholeiitic nature. Some high Al basalts are also accompanied (OHTA, 1978). This association of rock types is typical of the recently formed island-arc areas: the well-developed island-arc with a continental crust of about 20—30 km in thickness

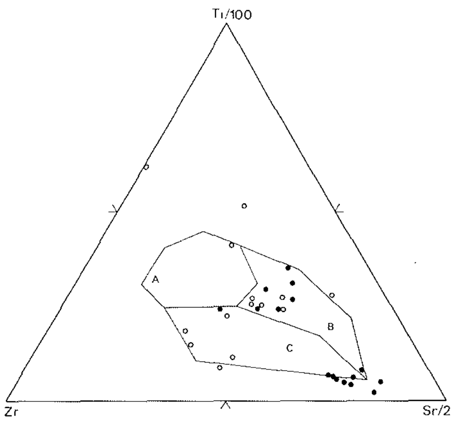

Fig. 8: Trace element ratios of the Caledonian gabbros from the NE zone of Svalbard (after PEARS & CAN, 1973). A: oceanic floor basalts, B: low potash basalts of island-arcs, C: calc-alkalic basalts. Dot: Kvitøya gabbros, open circle: Storøya gabbros.

Abb. 8: Spurenelement-Gehalte der kaledonischen Gabbros aus der NE-Zone von Svalbard (nach PEARS & CAN 1973). A: Basalte des Ozeanbodens, B: Kaliarme Basalte der Inselbögen, C: Kalk-Alkali-Basalte. Punkt: Kvitøya-Gabbros, offener Punkt Storøya-Gabbros.

(MIYASHIRO, 1975). From these results and the trace element ratios shown in Fig. 8, it may be concluded that the eastern part of the NE zone had a continental crust of moderate thickness during the period of Caledonian orogeny.

To sum up: according to our present knowledge of the basic rocks, an oceanic crust basement to the Hecla Hoek geosyncline is not likely. A continental basement is more likely.

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