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ANNA SIEDLECKA

Investigations of
Permian cherts and associated rocks
in southern Spitsbergen

Part I. – Petrological study of the
Permian cherts and associated rocks in southern Spitsbergen

Part II. – Sponges and problematic
fossil-bodies from Permian cherty rocks in Spitsbergen



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Part I

Petrological study of the Permian cherts and associated rocks in southern Spitsbergen

Abstract

Lithostratigraphical units of Permian age composed of dark, carbonaceous, bedded cherts, or consisting mainly of such cherts, crop out in southern Spitsbergen in the Sørkapp, Hornsund and Bellsund areas. In the Sørkapp area parts of the chert-bearing Permian deposits, here called the Tokrossøya Beds, crop out on the islands Tokrossøya, Sørkappøya and Stjernøya, and on the peninsula of Øyrlandet. The upper part of the Tokrossøya Beds consists of interbedded (1) quartzitic sandstones, (2) fossiliferous, calcareous sandstones and siltstones, and (3) arenaceous and cherty biocalcarenes. Lower Tokrossøya Beds are composed mainly of (1) arenaceous, calcareous spiculitic cherts, and (2) arenaceous, calcareous spiculites. On Øyrlandet in the section in Sandhamna, Lower and Upper Tokrossøya Beds consist of quartzites, quartzitic sandstones, and cherty sandstones together with less common arenaceous and cherty carbonate rocks. The thickness of the Tokrossøya Beds reaches up to c. 425 m.

Chert-bearing Permian beds, the so-called Brachiopod Cherty Limestone, occur in the Hornsund area in the inner part of this fjord. These are only a few metres in thickness and consist of arenaceous and calcareous spiculitic cherts and calcareous spiculites.

A lithostratigraphical unit, Permian in age, consisting mainly of dark cherty rocks, underlies large areas of central Spitsbergen. It also crops out in the outer Isfjorden and extends further southwards from the famous coast-section west of Festningen to the Bellsund area. This unit, the Brachiopod Cherts, has been studied in sections on Axeløya and near Sundodden in Bellsund. These beds, reaching up to c. 400 m in thickness, consist mainly of calcareous, fossiliferous, fine-crystalline cherts and of fine-crystalline cherts some of which are extremely rich in glauconite. Spiculites, biocalcarenes, and calcareous siltstones are also present.

Features common to the cherts of the above-mentioned three areas are (1) their impure, calcareous, arenaceous, and carbonaceous character, and (2) the presence of siliceous sponge spicules. The spicules either consist of chalcedony or are calcified; transitional stages between these two kinds of preservation have often been observed.

Sedimentary environment of the investigated beds is considered on the basis of their primary (pre-diagenetic) features, such as textures, properties of the detrital constituents, and the presence of indicators, e. g. glauconite or carbonaceous matter. In addition, some analogies with similar lithological associations from other regions have been taken into account. In general, the investigated rocks are thought to have been accumulated in an epicontinental marine environment; the maximum transgression of the sea is recorded by cherty rocks which originated in relatively deep, quiet, poorly aerated waters presumably filling depressions in the outer shelf. Shallowing and regression of the sea is indicated by the appearance of biocalcarenes and arenaceous rocks, including quite typical littoral sediments.

The origin of cherts, as they appear today, is associated both with sedimentary processes and

with diagenetic reorganization. Parent sediments of cherts were presumably muds rich in opaline sponge spicules and including calcareous organic debris. The diagenetic processes which followed mainly embraced: (1) solution of a part of the opaline sponge spicules within the sediment and development of carbonate pseudomorphs after them; (2) silicification of remains of calcareous fossils and of a part of the groundmass; (3) recrystallization of the undissolved opaline sponge spicules into chalcedony; and (4) recrystallization of carbonates constituting fossils and cement.

Permian cherty rocks of Spitsbergen are similar to cherts present in the Phosphoria Formation of the western United States and to some deposits of the Delaware Basin in Texas and New Mexico. Similarity between the described cherty rocks and cherts of the Permian Fantasque Formation of north-eastern British Columbia is also manifest. They may also be compared with some sediments from the Lower Permian of Cisuralia as well as with certain Carboniferous cherty rocks of the British Isles.

Introduction

Petrological studies of the Late Palaeozoic rocks of Svalbard were begun by the present author in 1960 on the Polish Spitsbergen Expedition to the Hornsund area. Stratigraphical profiles of Carboniferous, Permian, and Triassic beds on Treskelen were investigated during this time at the request of S. SIEDLECKI and K. BIRKENMAJER, and the results of a part of this work have already been published (SIEDLECKA 1968). During the years 1962–65 the author received many more hand specimens of Carboniferous and Permian rocks from Svalbard collected by her husband, Dr. S. SIEDLECKI, firstly on the Polish Spitsbergen Expeditions and then on Norsk Polarinstitutt's expeditions to Svalbard. The most complete part of the collection is that comprising specimens of Permian cherts and associated rocks from southern Spitsbergen and these rocks are described in the present paper.

Dark-coloured, hard, cherty rocks forming a distinct lithological unit within the Late Palaeozoic sediments of Spitsbergen have been reported by many geologists since the early part of the nineteenth century. Two prominent features of these rocks were always emphasized: 1) their "cherty" character, and 2) the occurrence of brachiopods, especially productids. Various names have been used for these rocks, including "Productus Limestone and Flint" (NORDENSKIÖLD 1876), "Productus-chert" (HINDE 1888) and "Productusführende Kieselgesteine" (NATHORST 1910; FREBOLD 1937). Later, the term "Brachiopod Cherts" was introduced by GEE, McWHAE and HARLAND (1953) in describing these same rocks from Central Spitsbergen. Similar cherty rocks occurring in the Hornsund area have been described as Brachiopod Cherty Limestone and Cherty Limestone (BIRKENMAJER & CZARNIECKI 1960; BIRKENMAJER 1964), while lithologically similar beds appearing at Sørkapp have more recently been termed Tokrossøya Beds by SIEDLECKI (1964).

The cherty rocks of Spitsbergen are Permian in age; a more precise establishment of their position within the Permian period and of correlations between the above-mentioned lithostratigraphical units is rather difficult. The age of the Brachiopod Cherts was regarded in older publications as Permo-Carboniferous, and later as corresponding with Artinskian or even with Kungurian. The problem is complicated by the fact that the brachiopod fauna present in the Brachiopod

Cherts includes both Lower and Upper Permian species and does not correspond exactly with any of the chronostratigraphical units known from classical sections of Russian Permian. On account of this, STEPANOV (1957) proposed the term "Svalbardian" for the period the Brachiopod Cherts in Svalbard were accumulated. This proposition was accepted by some geologists although the question of the precise age of the Brachiopod Cherts is still being discussed.

The petrology of the Permian cherty rocks of Spitsbergen has previously been studied by HINDE (1888) who described some hand specimens of these rocks collected by NATHORST from the Isfjord and Bellsund areas. HINDE (1888) emphasized the occurrence of siliceous sponge spicules in these specimens and regarded the cherts as being of primary organic origin. Following HINDE's work, little attention was given to the problem of the petrology and origin of Permian cherts in Spitsbergen for many years.

The present author has made a petrological study of the Permian cherty rocks from three areas in southern Spitsbergen. These are: the Sørkapp area, the Hornsund area, and the Bellsund area.

The present study is based mainly on a microscopic examination of these rocks. Quantitative ratios between the main constituents of the rock have been established using either a Swift Automatic or Leitz point counter.

Remarks on terminology

Because the earlier investigators were mostly interested in stratigraphical and palaeontological rather than petrographical problems, the lithology of the Permian cherty rocks has not previously been described in detail. Lithological terms which have been used to describe the rocks belonging to the Brachiopod Chert unit are listed in Table 1.

Table 1

NORDENSKIÖLD (1866)	"mørk kisel med Productus, Spirifer . . .", (p. 14)
— (1874/1875)	"Productus-kalk och flinta," (p. 257)
— (1876)	". . . impure limestone rich in silica . . .", "black flint . . .", (p. 66)
DUNIKOWSKI (1884)	"Feuerstein", "Mergel- und Thonschiefer", "Schwarzer Schiefer" etc.
HINDE (1888)	". . . chert and siliceous rocks", (p. 242)
FREBOLD (1937)	"Kieselgestein", "flint"
HOEL and ORVIN (1937)	"Kieselgestein", "Kieselschiefer", "Kieselhaltig Kalkstein", "Kieselhaltig Kalksteinschiefer" etc.
GEE, HARLAND, MCWHAE (1953)	". . . predominantly chert with subordinate beds of cherty limestones, sometimes containing Productus" (p. 314)
BIRKENMAJER (1964) (in Hornsund)	"cherty limestone", "dolomitic limestone" etc. (pp. 78, 81–83, 85, 87)
SIEDLECKI (1964) (on Tokrossøya)	"siliceous and calcareous rocks", "spongiolite" (pp. 161–162)
WINSNES (1966)	"chertstone", "chert-sandstone", adj. "cherty"

The terminology adopted by the present author is descriptive. The particular terms which are used are thought to explain both chemical and textural properties of the described rocks. Most of the terms have been used and defined previously; in certain cases, however, where existing terms have seemed to be unsatisfactory, new terms have been introduced and defined. In spite of these additions, the entire revised terminology may be referred to general geological terminology of the sedimentary rocks as well as to published descriptive classifications of these rocks.

Miscellaneous rocks which are difficult to classify often occur within the investigated sequences. These rocks consist of organodetrital, terrigenous and authigenic components occurring in fairly equal amounts and in schemes of classification are usually situated near the boundaries between the main groups of sedimentary rocks. The particular layers or parts of layers of various rocks, because of small changes of quantitative ratios between the main constituents, must therefore be referred to limestones, or sandstones or different siliceous rocks. The author is aware that such division is artificial and its genetic significance doubtful, but it may prove to be useful in a descriptive work.

The various descriptive terms which have previously been defined or understood in different ways or which are rather seldom used are summarized below; in order to avoid any possible confusion their definitions are also given. Usages introduced by the author are also summarized and defined below.

Cherty rocks — a general term referring to rocks containing relatively large amounts of authigenic silica.

Arenaceous cherty limestone — limestone with an admixture of clastic quartz grains and with concentrations of authigenic silica.

Quartzite — “. . . pure quartz sandstones, in which the totality of the quartz grains have been submitted to a secondary overgrowth of quartz.” (CAROZZI 1960, p. 31.)

Quartzitic sandstone — “. . . silica-cemented pure quartz sandstones, in which the secondary overgrowth of quartz affects the majority but not all of the quartz grains present in the sediment.” (CAROZZI 1960, p. 13.)

Quartz-cemented sandstone — “. . . rock in which the grains, devoid of secondary overgrowth, are cemented by a fine mosaic of quartz granules. . .” (CAROZZI 1960 p. 13.)

Chalcedony-cemented sandstone — pure quartz sandstone with a chalcedony cement (CAROZZI 1960, p. 10).

Cherty sandstone — sandstone with a very abundant (min. 20%) chalcedony cement. Sand grains appear to be floating within the chalcedony cement. Although terrigenous quartz may be <50%, it is always the main constituent.

Spiculitic sandstone — quartz sandstone with a chalcedony cement containing an abundance (<20% of the whole rock) of siliceous sponge spicules. Terrigenous quartz grains, sometimes forming <50% of the rock, are the main constituent.

Spiculitic chert — rock consisting mainly of microcrystalline silica and sponge spicules. Spiculitic chert usually includes an admixture of terrigenous quartz, carbonate concentrations and different calcareous debris of fossils; some of the

spicules may be calcified. Because of these differences the spiculitic cherts mentioned in the present paper are described as “calcareous”, “fossiliferous” or “arenaceous” as the case may be.

Fine-crystalline chert — rock consisting mainly of fine- and crypto-crystalline silica and containing impurities similar to those of the spiculitic cherts. Rarely, indistinct sponge spicules may be recorded.

Spiculite — “. . . rocks . . . almost entirely made up of a felted concentration of spicules of siliceous sponges.” (CAROZZI 1960, p. 294, after CAYEUX 1929.)

Calcareous spiculite — spiculite made up of calcareous (calcified) sponge spicules.

The Sørkapp area

This area is here taken as comprising the islands Tokrossøya, Sørkappøya and Stjernøya, and the peninsula Øyrlandet (see Fig. 1). Permian rocks of the Sørkapp area were studied by S. SIEDLECKI during his stay in Spitsbergen in the summers 1960, 1962, and 1964. Some of the results of these investigations have been published in the paper “Permian succession on Tokrossøya” (SIEDLECKI 1964) in which the sequence exposed along the north coast of Tokrossøya is described, the Permian rocks being divided into the so-called “Lower Tokrossøya Beds” and “Upper Tokrossøya Beds”. Later, on the basis of his new observations in the Sørkapp area (summer 1962, summer 1964), SIEDLECKI (see Introduction in the paper of MALECKI, 1968) revised this stratigraphy and concluded that the “Lower Tokrossøya Beds” are in reality younger than the “Upper Tokrossøya Beds”; accordingly “Upper” should now read “Lower” and vice versa.

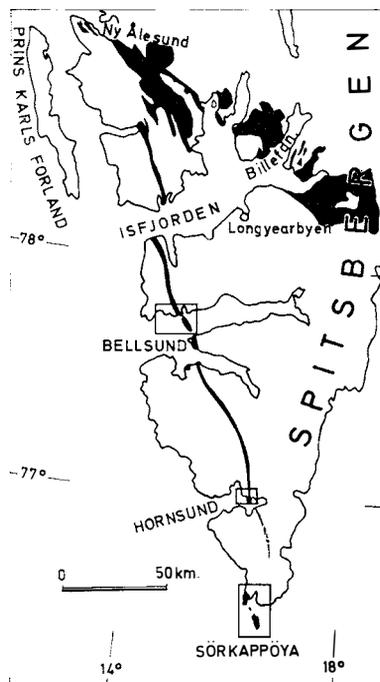


Fig. 1. Key map showing the investigated areas. Occurrences of the Permian cherty rocks are marked in black.

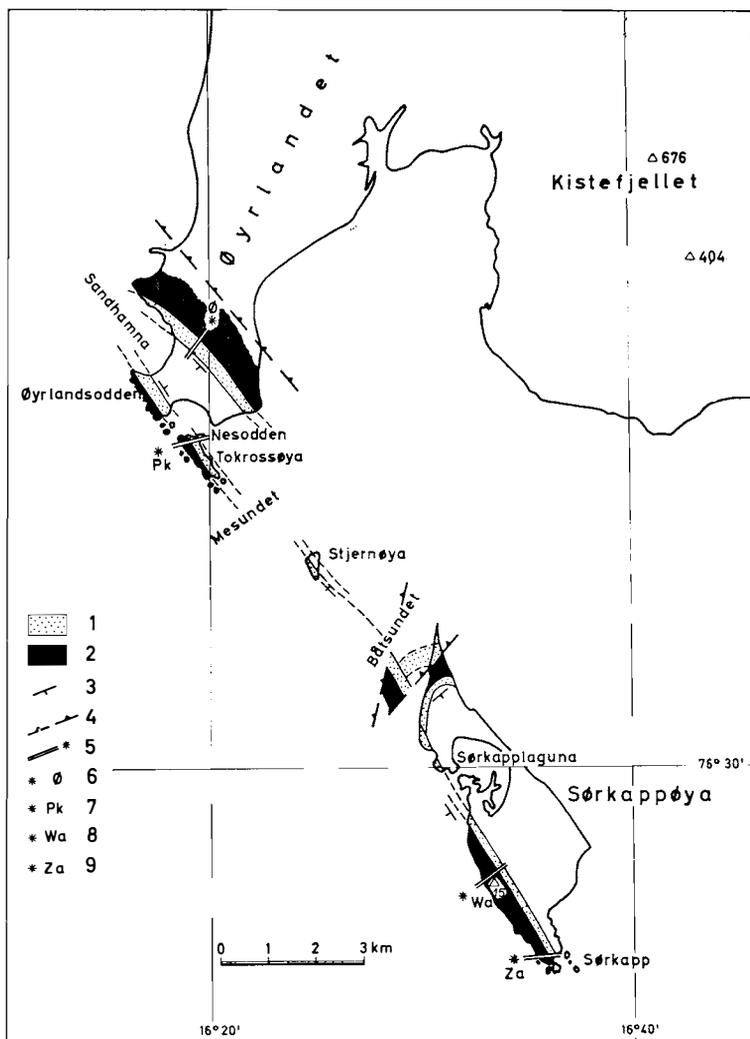


Fig. 2. Contour map of the Sørkapp area. Geology after S. SIEDLECKI (unpublished data). 1 - Upper Tokrossøya Beds; 2 - Lower Tokrossøya Beds; 3 - strike and dip; 4 - faults; 5 - geological profiles described; 6 - profile near Sandhamna on Øyrlandet; 7 - profile on Tokrossøya; 8 - profile near the 15 m trigonometrical point on Sørkappøya; 9 - profile at Sørkapp on Sørkappøya.

Apart from the type-locality, Tokrossøya Beds also appear on Øyrlandet, Stjernøya and Sørkappøya (see map, Fig. 2). The petrological study of the Tokrossøya Beds from the type locality is based on an examination of thin-sections of rocks from the geological profile described by SIEDLECKI (1964). The petrology of these beds from the other localities is, on the other hand, based on SIEDLECKI's unpublished descriptions of geological profiles and on a study of his collection of rock samples. Descriptions of the geological profiles are given below.

For the most part the Lower Tokrossøya Beds consist of impure, dark, carbonaceous and cherty rocks with a poor fauna. The only prominent organic debris, visible exclusively under the microscope, are minute spicules of the siliceous

sponges. The Upper Tokrossøya Beds comprise different types of sandstones, siltstones with abundant fauna, and impure, arenaceous and cherty biocalcarenites. On Øyrlandet, in the section near Sandhamna, clastic and calcareous rocks prevail throughout the entire Tokrossøya Beds sequence.

TOKROSSØYA
(thin-sections with symbols Pk)

Petrology

Carbonate-cemented quartz sandstones. — These rocks occur only within the Upper Tokrossøya Beds (usage after the revision by S. SIEDLECKI) and are indicated on the profile published by S. SIEDLECKI (1964, pp. 159–61) as well as on the figure redrawn (with some alterations) from the cited paper as beds 1, 5, 10 and 13 (see Fig. 3 in pocket on backflap). The rocks are described briefly by this same author as medium-grained, light-grey sandstones with calcareous matrix. They contain glauconite and some fragments of fossils.

Under a microscope the sandstones appear medium-grained, massive and usually quite well sorted (Fig. 4). Grains of terrigenous quartz are subrounded or rounded, the roundness index¹ $K\% = 40$. The grains are closely packed within the carbonate cement.

Quartz grains are isometrical and some of them show undulatory extinction. Overgrowths of autigenic quartz are usually visible on the surface of the quartz grains.

Some fragments of aphanitic siliceous rocks also occur in the sandstones together with small amounts of body-fossil remains, these consisting of fragments of brachiopod shells and spines (0.5 mm in diameter and 2 mm in length) belonging to productids.

Glauconite is a characteristic constituent of the sandstones. It occurs in small rounded grains c. 0.1–0.2 mm or occasionally up to 0.4 mm in diameter.

Zircon and tourmaline and iron-oxide concentrations occur as accessories.

The sandstone cement consists of carbonates (Fig. 5); both calcite and dolomite

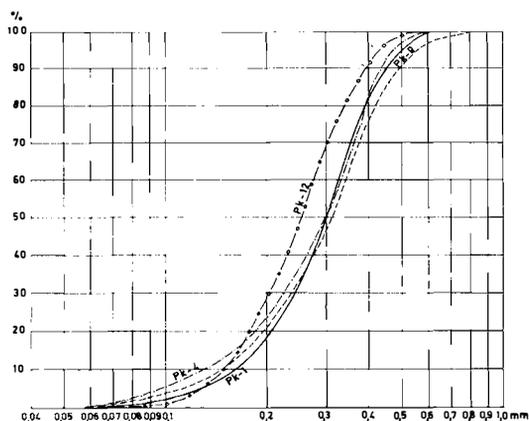


Fig. 4. *Granulometric composition of the carbonate-cemented quartz sandstones from the Tokrossøya Beds on Tokrossøya.*

¹ Following the method described by RUCHIN (1961, p. 558).

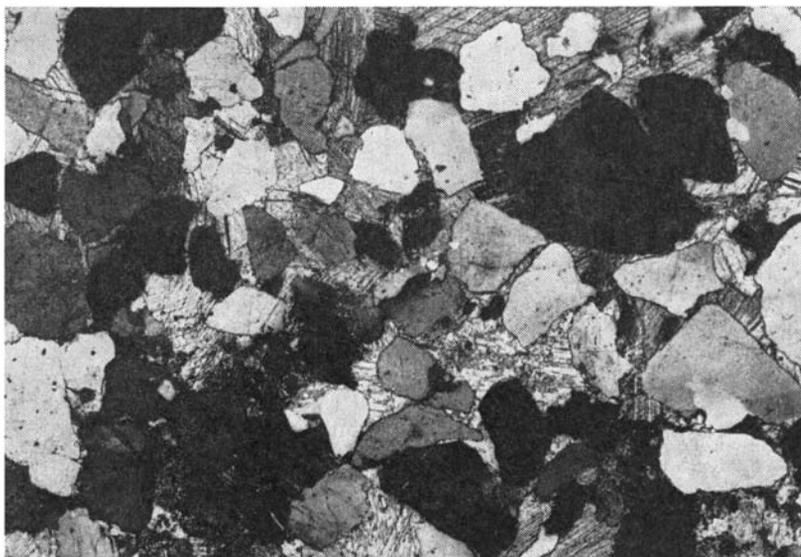


Fig. 5. Carbonate-cemented quartz sandstone. Upper Tokrossøya Beds, Tokrossøya, thin-section Pk-9, crossed nicols, $\times 31.2$.

are present. Calcite occurs as anhedral grains sometimes exhibiting very well-developed polysynthetic twinning. These grains are usually 0.2–0.5 mm, rarely up to 1 mm in size, and one such grain is seen to fill an interstitial void. In parts of some of the examined thin-sections grains of calcite up to 2 mm in size have been observed, these enclosing small quartz grains. Dolomite occurs as scattered rhombic crystals up to 0.1 mm in size. The carbonate cement of the sandstones is considered by the author as probably having been derived mainly from the solution of small carbonate fossil particles which were deposited contemporaneously with detrital quartz and other minerals. Small amounts of fine-crystalline authigenic silica also occur within the cement.

Table 2
Carbonate-cemented quartz sandstones, Tokrossøya

Thin-section Bed	Pk-1 1	Pk-4 5	Pk-9 10	Pk-12 13
Terrigenous quartz	72.3	64.8	74.3	74.6
Fragm. of siliceous aphanitic rocks	+	1.6	+	0.4
Debris of fossils	+	+	–	–
Carbonate cement	26.2	33.6	22.6	24.8
Authigenic silica	0.8	+	–	+
Glauconite	0.2	+	1.8	–
Iron-oxides, pyrite	0.4	+	1.2	0.1
Zircon	–	–	0.2	+
Tourmaline	–	–	–	+

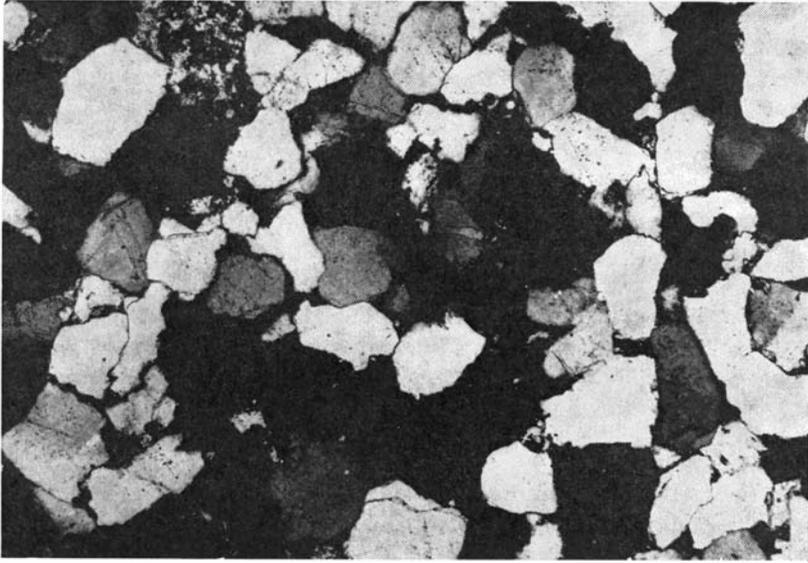


Fig. 6. *Quartzitic sandstone. Upper Tokrossøya Beds, Tokrossøya, thin-section Pk-21, crossed nicols, ×50.*

Quartzitic sandstone (bed 22, see Figs. 3 and 6). — This is a medium-grained, well sorted quartz sandstone with a few particles of finely crystalline siliceous rocks. The terrigenous material is subrounded. Secondary quartz rims are common and fine-crystalline authigenic silica occurs adjacent to the rims. The sandstone is porous. Some of the interstitial voids are filled with carbonates which are seen as anhedral crystals or rhombs c. 0.1–0.2 mm across. In addition, pyrite, iron-oxides, carbonaceous matter, and zircon have been observed and a few fragments of brachiopod shells are also present.

The carbonate infilling of these interstitial voids seems to be secondary, probably originating from the solution of small particles of calcareous shells or skeletons.

Modal percentages of the main constituents of the quartzitic sandstone are as follows:

Terrigenous quartz	73.3 %
Authigenic silica with admixture of pyrite and carbonaceous matter	23.2 %
Carbonates	3.5 %

Fossiliferous, calcareous sandstones and siltstones. — These rocks occur only in the upper part of the Upper Tokrossøya Beds and are interbedded with the carbonate-cemented quartz sandstones described above. In the profile published by S. SIEDLECKI (1964) horizons of these rocks are numbered: 2, 3, 6, 7, 8, 9, 11, 12, 14, and 15. See also Fig. 3 in the present paper.

Generally, the rocks of this group show quite large quantitative differences in composition (see Table 3) and for this reason they may, when seen in the field, show varying lithological features. The rocks are finegrained and quite well sorted

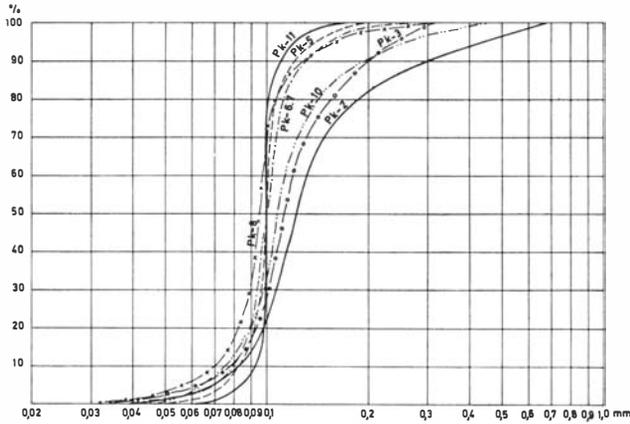


Fig. 7. *Granulometric composition of the fossiliferous, calcareous sandstones and siltstones from the Tokrossøya Beds on Tokrossøya.*

(see Figs. 7, 8) with the addition of some larger quartz grains and rock particles. Fragments of body-fossils are usually much larger than other constituents. Structurally these rocks often show a planar arrangement of detrital constituents.

Quartz grains are subrounded, some of them showing a secondary overgrowth. Fragments of siliceous rocks consist of aphanitic silica.

Detritus of fossils is common. There are particles of spiriferid and productid shells, spines of productids, fragments of bryozoans and some small gastropods. The fragments are calcitic, some of them being completely recrystallized with the primary structure of the shells destroyed. Moreover, within many of the calcitic fragments secondary spherulitic chalcedony concentrations are present.

Sponge spicules occur also in these rocks. Usually they are not very common and appear to form concentrations irregularly distributed throughout the rock.

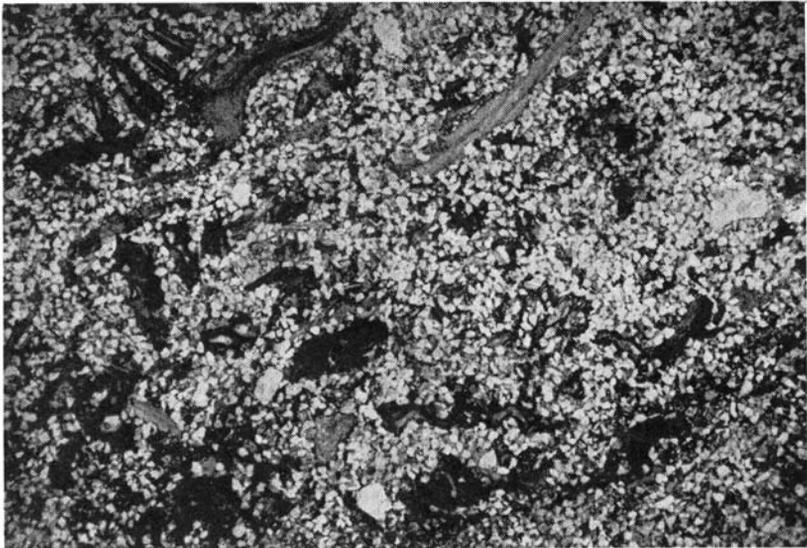


Fig. 8. *Fossiliferous, calcareous siltstone. Upper Tokrossøya Beds, Tokrossøya, thin-section Pk-7, plane polarized light, $\times 12.5$.*

The sponge spicules consist most frequently of secondary calcite, their internal structure usually having been destroyed with each spicule being replaced by one crystal of calcite. In some thin-sections through concentrations of spicules, their properties and state of preservation could be studied in detail. The spicules are straight, seldom curved; more complicated forms have not been observed. They are broken with fragments usually reaching 0.4–0.7 mm in length and less frequently up to 2 mm.

Beside the most commonly appearing calcareous variety, siliceous spicules were observed in these particular concentrations. The siliceous spicules consist of microcrystalline or fibrous chalcedony. An axial canal, if preserved, is usually enlarged and filled with fibrous chalcedony, or, sporadically, with calcite. In addition, spicules in part chalcedonic with visible axial canal and in part consisting of calcite were observed. It is obvious that the calcite is replacing chalcedony and destroying the internal structure of these particular spicules. Therefore, the calcitic spicules were described above as calcified and regarded as complete calcareous pseudomorphs after primarily siliceous spicules.

Small rounded grains of glauconite also occur within the described rocks, while zircon, tourmaline, muscovite, feldspar, (?)rutile and (?)apatite are present as accessories.

The cement of these rocks is heterogenous, consisting of carbonates and silica with additions of hydromicas. Some of the cement, composed of (1) a fine-grained mixture of silica, carbonates and iron-oxides or (2) of silica, carbonates, hydromicas and iron-oxides, is presumably of sedimentary and early diagenetic origin. Pure carbonate cement and well-defined concentrations of pure silica occur together with the mixed primary cement. Carbonate cement consists of anhedral crystals of calcite 0.2–0.5 mm in size, and of rhombohedra of dolomite 0.05–0.2 mm across though usually about 0.1 mm. Concentrations of silica are isolated, enclosed within the carbonate cement and distinctly corroded by carbonates.

The carbonate cement and pure silica concentrations seem to be developed in a later burial stage. The carbonates have probably been derived by the solution and recrystallization of carbonate fossil remains, while the pure silica concentrations have probably resulted from the solution of siliceous sponge spicules and, perhaps also, other siliceous organisms. Derivation of silica from other sources is, of course, not excluded.

In some places debris of calcareous shells and carbonate cement become more and more abundant and sandstones grade into arenaceous organodetrital limestones. These limestones occur locally within the sandstone layers.

Modal percentages of the constituents of the fossiliferous calcareous sandstones and siltstones are presented in Table 3.

Arenaceous, calcareous spiculitic cherts. — These rocks are common in the Lower Tokrossøya Beds and occur also in the lower part of the Upper Tokrossøya Beds. The rocks have been described by S. SIEDLECKI (1964) as limestones containing a variety of impurities, and also as siliceous shales and cherts (bed Nos.: 18, 23, 24, see Fig. 3).

The arenaceous, calcareous cherts from the Permian of Tokrossøya consist of

Table 3
Fossiliferous, calcareous sandstones and siltstones, Tokrossøya

Thin section Bed No.	Pk-2 2	Pk-3 3	Pk-5 6	Pk-6 7	Pk-7 8	Pk-8 9	Pk-10 11	Pk-11 12	Pk-13 14
Terrigenous quartz grains	59.9	43.8	38.3	50.0	33.0	53.0	55.8	51.8	50.7
Fragments of siliceous rocks	0.2	1.5	+	1.4	2.0	0.9	0.9	1.1	0.8
Debris of fossils (excl. sponge spicules)	8.6	4.9	11.2	6.5	24.2	8.2	—	0.2	+
Siliceous sponge spicules	—	10.6	—	—	—	—	—	—	—
Calcareous sponge spicules	—	1.6	1.2	—	+	—	—	+	+
Carbonate cement	29.5	30.7	13.2	3.1	10.1	5.9	6.3	19.0	7.8
\ calcite			16.1	3.5	17.3	16.1	20.0	4.2	5.0
\ dolomite			4.3	7.0	4.8	5.0	14.0	7.0	17.0
Authigenic silica	1.3	4.0	—	12.4	25.8	6.6	6.7	—	13.4
Mixed carbonate-silica aggregates	—	—	—	1.7	1.0	0.5	2.8	+	1.6
Pyrite and iron oxides	0.1	1.8	1.6	1.6	1.4	1.4	3.0	1.7	1.7
Glauconite	0.3	1.1	—	—	—	—	—	—	—
Zircon	+	+	+	+	+	—	—	+	+
Tourmaline	—	—	+	—	+	—	—	+	+
Muscovite	—	—	+	+	+	—	—	+	+
Feldspar	—	—	—	+	+	—	—	—	+
Rutile	—	—	—	—	+	—	—	—	—
Apatite	—	—	—	—	—	—	—	+	—

sponge spicules, clastic quartz, fragments of various fossils and of glauconite cemented by abundant silica and in part also by carbonates. Microstructurally these rocks are massive though with a linear element discernible in the planar orientation of sponge spicules.

Sponge spicules are abundant, calcareous spicules being much more common than the siliceous type. The sponge spicules are usually straight rod-shaped or slightly curved, although traces of more complicated forms have been observed in a few cases. Diameters of the spicules range from 0.03 to 0.15 mm. The spicules are usually broken and/or cut by the plane of the thin-section so making it difficult to measure their length, but some larger fragments are found which attain lengths of 0.5 mm, 1.6 mm, and 1.75 mm. The dimensions of three complete spicules have been measured, these being 0.05 × 1.0 mm, 0.05 × 1.3 mm and 0.08 × 1.5 mm.

Calcareous spicules (see Fig. 9) are composed of anhedral crystals of calcite, one spicule usually consisting of one or a few crystals. Axial canals, enlarged and filled with brownish, microcrystalline silica or glauconite are present within some of these spicules. In the author's opinion the calcareous spicules are thought to represent the complete pseudomorphs after siliceous spicules analogous to those in the fossiliferous, calcareous sandstones described above (see p. 15).

Siliceous spicules (see Fig. 10) are less abundant than the calcified variety, and their contours are usually indistinct; they consist of white chalcedony, often the sole feature enabling one to differentiate them from the brownish siliceous cement. The orientation of the chalcedony of the spicules is rather random and usually it is not possible to distinguish between walls and axial canal. In only one of the thin-sections investigated has a large quantity of well-preserved siliceous spicules, consisting of fibrous chalcedony, been observed. In these particular spicules thin walls and large (enlarged) axial canals are distinctly visible. The walls consist of



Fig. 9. *Arenaceous calcareous spiculitic chert. Sponge spicules are mostly calcified, their outlines well defined. Lower Tokrossøya Beds, Tokrossøya, thin-section Pk-23a, plane polarized light, × 50.*



Fig. 10. *Arenaceous calcareous spiculitic chert. Sponge spicules consist mostly of chalcidony; their outlines are poorly defined. Matrix consists mainly of carbonates and fine-crystalline brownish silica. Lower Tokrossøya Beds, Tokrossøya, thin-section Pk-22b, plane polarized light, × 50.*

fibres which are oriented perpendicularly to the axis of the spicule: thus, in cross-section the fibres display a radial structure. Fibres of the chalcedony which fills the axial canal are either oriented randomly or show the same orientation as the fibres in the walls. Sponge spicules have also been observed consisting partly of silica and partly of calcite, the latter replacing the silica.

Body-fossil remains other than sponge spicules have also been recorded, fragments of productid shells and bryozoans being the most common and the larger fragments (a few millimetres in size) usually being partially silicified. In addition small gastropods and small foraminifera have been observed.

Grains of terrigenous quartz present in the spiculitic cherts are subangular or subrounded and 0.03–0.1 mm in size. Glauconite occurs either as small rounded grains or as an infilling of the axial canals of the sponge spicules.

The cement of the arenaceous, calcareous spiculitic cherts consists of:

- a. fine-grained authigenic silica (chalcedony) including a brownish carbonaceous pigment;
- b. carbonates, which occur as scattered anhedral crystals or rhombs (?dolomite).

The carbonates seem to belong to the same generation as those which formed pseudomorphs after siliceous sponge spicules.

Quantitative ratios of the main constituents of these rocks are shown in Table 4, p. 19.

Arenaceous and cherty biocalcaremites. — These rocks (Fig. 3, beds 16 and 17) are closely related petrologically to the fossiliferous calcareous sandstones and siltstones. The ratio of bioclastic to terrigenous material changes gradually and there is a transition between the sandstones or siltstones and the biocalcaremites. Authigenic silica increases rapidly in some parts of the biocalcaremites making them similar in many respects to the calcareous cherts. Two different kinds of limestone may be distinguished:

1) Biocalcaremites consisting mainly of fragments of calcareous skeletons and shells (bryozoans and brachiopods) and of abundant calcite cement. The organic remains are angular or subangular and reach up to 5 mm in size. Sponge spicules also occur. Terrigenous quartz grains are subangular and not larger than 0.15 mm. They are sparsely distributed in an abundant calcite cement which probably originated by the recrystallization of small particles of calcareous organic detritus. Fine-crystalline carbonate cement is also preserved, sometimes with an admixture of silica. The latter may appear as small isolated concentrations. Glauconite and carbonaceous matter are present while plagioclase and zircon occur as accessories.

Quantitative ratios of the main constituents are variable over small distances; their average values are as shown in Table 5.

2) Cherty limestones, closely related to arenaceous, calcareous spiculitic cherts (see p. 15). These limestones consist of calcareous (calcified) sponge spicules, carbonates, fragments of bryozoans and brachiopods and a relatively large amount of authigenic silica (see Table 6). Features of the various main constituents and of the accessories are analogous to these in the calcareous spiculitic cherts. The average amount of calcareous components in these rocks, however, is c. 55%

Table 4
Arenaceous, calcareous spiculitic cherts, Tokrossøya

Thin section Bed No.	Pk-17 18	Pk-17a 18	Pk-22 23	Pk-22a 23	Pk-22b 23	Pk-23 24	Pk-23a 24	Pk-24 24
Authigenic silica	72.4	70.6	57.4	41.4	51.8	42.8	45.8	53.3
Siliceous sponge spicules	5.2	4.2	15.2	10.6	26.4	14.0	4.4	10.4
Calcareous sponge spicules	1.4	2.0	9.6	13.8	4.8	13.6	28.2	12.6
Other body-fossil remains	+	0.4	0.2	+	1.6	0.6	0.2	1.5
Carbonates	3.0	2.0	8.6	24.4	10.2	21.2	15.0	12.5
Terrigenous quartz grains	16.8	19.4	8.8	9.4	4.6	7.6	6.4	8.7
Glauconite	1.2	1.4	0.2	0.4	0.6	0.2	+	1.0
Muscovite	+	-	+	+	-	+	+	-
Plagioclase	+	-	-	-	-	-	-	-

while that of the authigenic silica is 33.5%; because of these proportions the rocks must be considered as limestones. It seems most probable that these limestones are of diagenetic origin (calcification of siliceous sponge spicules).

Arenaceous, calcareous spiculite. — The arenaceous, calcareous spiculite occurs in the lowermost part of the Lower Tokrossøya Beds (Fig. 3, bed 25). It consists mainly of calcitic sponge spicules and their fragments. Spicules are simple, straight, seldom curved; usually one spicule consists of one calcite crystal. The spicules are of different sizes:

1. Small spicules, c. 0.01–0.05 mm in diameter and up to 0.6 mm in length;
2. large spicules, c. 0.1–0.25 mm in diameter and c. 0.5–1.0 mm in length.

The smaller spicules (?microscleres) are much more abundant than the larger ones which are usually scattered among the small. In some larger spicules an axial canal is preserved.

The spicules are closely packed and cemented by carbonates comprising anhydral crystals or euhedral rhombs. In some parts of this spiculite small amounts of fine-crystalline authigenic silica occur also.

Fragments of skeletons of bryozoans and small particles of brachiopod shells were observed in a few instances. Terrigenous quartz grains are subangular or

Table 5
Biocalcaremites, Tokrossøya

Thin-section Bed	Pk-15 16	Pk-16 17
Terrigenous quartz	23.6	26.0
Calcareous spicules	0.6	+
Other body-fossil remains	41.4	30.0
Calcitic cement	29.0	37.2
Authigenic silica	5.4	6.0
Glauconite	+	0.8
Plagioclase	+	-
Zircon	-	+

Table 6
Cherty limestones, Tokrossøya

Thin-section Bed No.	Pk-18 19	Pk-18a 19	Pk-18b 19	Pk-19 20	Pk-20 21
Authigenic silica	33.0	32.2	40.0	29.0	33.6
Siliceous sponge spicules	0.8	1.0	3.2	0.8	1.6
Calcareous sponge spicules	24.8	28.6	23.0	19.6	20.3
Remains of other fossils	7.8	8.2	8.0	8.4	11.2
Carbonates	22.6	19.0	16.4	31.6	24.3
Terrigenous quartz grains	8.4	9.2	7.2	7.0	7.5
Glauconite	2.6	1.8	2.2	3.6	1.5
Plagioclase	—	+	—	—	—
Tourmaline	—	—	+	—	—
Total amount of carbonate	55.2	55.8	47.4	59.6	56.8
Average amount of carbonate	54.96				

subrounded and are about 0.08–0.15 mm in size. Glauconite also occurs in this spiculite; it is found either as small irregular grains, probably of direct origin, or as part of the infilling of organic remains.

The calcareous spiculite is, in the author's opinion, a limestone of diagenetic origin. This rock was probably composed primarily of siliceous sponge spicules which have been completely calcified during the diagenetic processes. It is, however, also possible that the spicules were originally calcareous belonging to the Calcispongia. No transitional stages of preservation of spicules have been observed in this calcareous spiculite and for this reason a determination of its precise origin is rather difficult.

SØRKAPPØYA

Field observations of Permian rocks on Sørkappøya were carried out by S. SIEDLECKI in the summers of 1962 and 1964. Two geological sections have been described but not yet published. With S. SIEDLECKI's permission descriptions of these profiles are reproduced below.

The Tokrossøya Beds are here inverted and dip towards the south-west. The description is taken from NE to SW, starting with the youngest member of the Upper Tokrossøya Beds and then descending (stratigraphically) through the sequence. A definite contact between these Upper Tokrossøya Beds and the next (younger) stratigraphical unit is not visible, but the boundary is marked by a prominent step in the topography formed by the uppermost layers of the Upper Tokrossøya Beds, east of which there occurs a swamp devoid of rock exposure. According to S. SIEDLECKI, however, the swamp is underlain by soft Eo-Triassic shales.

“Profile near the 15 m trigonometrical point” (locality shown in Fig. 2; thin-section symbol: Wa; thin-section numbers correspond to the numbers of the beds in this description).

Upper Tokrossøya Beds:

1. Sandstone, medium- and fine-grained, in part nodular. The sandstone is friable, disintegrating into small angular fragments. Sandstone forms thick and medium-sized beds and is yellowish-grey in colour. It contains a rich fauna of productids and spiriferids. The uppermost 20–40 cm thick layer is somewhat more compact than the others. 2.0 m
2. Sandstone, thin-bedded, flaggy, friable, light grey in colour. Shells of small spiriferids are abundant. 2.5 »
3. Sandstone, nodular, friable, yellowish-grey. Rich fauna of spiriferids and productids. 0.5 »
4. Sandstone, thin-bedded, compact, dark grey. Poor fauna of brachiopods. 0.5 »
5. Sandstone, thin-bedded, in part shaly, friable, grey in colour. This bed disintegrates intensively, forming a depression covered partly by weathering products and partly by vegetation. 9.0 »
6. Sandstone, nodular, compact, grey in colour; on the weathered surfaces it is brownish-grey. Abundant fauna of large productids and spiriferids. 2.5 »
7. Sandstone, hard and compact, yellowish-grey in colour; on the weathered surfaces it becomes nearly white. This sandstone forms one large lense disappearing both to the south-east and to the north-west. Fossils have not been found. 1.2 »
8. Sandstone, friable, brittle, yellowish-grey in colour. Fossils have not been found. 1.5 »
9. Sandstone, nodular, yellowish-grey in colour. A fauna of productids, spiriferids and bryozoans is abundant but poorly preserved. 5.5 »
10. Sandstone, shaly, brittle, somewhat nodular. It forms a morphological depression. A fauna (as above) is quite abundant. 2.5 »
11. Sandstone, shaly, compact in the lower part and brittle higher up. 2.5 »
12. Sandstone forming thick and medium-sized layers, yellowish-grey in colour; on the weathered surfaces it becomes brownish-grey. A fauna is very abundant. 6.5 »
13. Sandstone, thin-bedded, weakly cemented. An abundant fauna is present. 3.5 »
14. Sandstone, nodular, hard. A fauna is very abundant. 2.7 »
15. Shales, arenaceous, grey in colour; a poor fauna has been observed. The shales form a depression in the topography. 3.0 »
16. Sandstone, hard, without fauna. 2.0 »
17. Sandstone, hard, nodular, with poor fauna. 4.0 »
18. Sandstone medium- and fine-grained, hard, light grey and yellowish. Small dimples occur on the weathered surfaces. In the upper part the sandstone is less compact than lower down. 1.2 »
19. Sandstone, thin-bedded, brittle, in part shaly, grey-brown in colour. Fossils are frequent but are preserved solely as imprints. 5.0 »
20. Sandstone, shaly, brittle, disintegrates easily. 25.0 »
21. Limestone, nodular, brittle although somewhat more compact than the adjacent beds. An abundant fauna occurs here. 16.5 »
22. a) Limestone, shaly, forming a depression in the topography. Poor fauna. 10.0 »
 b) Limestone, thick-bedded, somewhat harder. Poor fauna. 2.5 »
 c) Limestone, arenaceous, shaly, soft. 4.5 »
 d) Limestone, shaly, somewhat harder than (c); it becomes reddish on weathered surfaces. Bryozoans occur frequently in the uppermost part of the bed. 2.5 »
23. Sandstone, cherty, brittle, reddish on weathered surfaces. A fauna of productids, spiriferids and bryozoans is very abundant. A few layers (5 cm – 15 cm in thickness) of cherty black shales, including some brachiopods and bryozoans, occur within this bed. 6.5 »
24. This part of the profile is covered by polygonally patterned ground. Fragments of cherty sandstones, with a fauna similar to that occurring above, are found here. 75.0 »

Lower Tokrossøya Beds:

- | | |
|---|-----------|
| 25. Cherts, mostly shaly with some 5 cm–15 cm thick layers. The rocks are black in colour. Many sponge-like bodies and some brachiopods have been observed. | 16.0 m |
| 26. Cherts, thin-bedded, with subordinate shaly cherts. Layers are up to 20 cm in thickness. The rocks are black in colour; on the weathered surfaces they become whitish and disintegrate into cube-like fragments. A poor brachiopod fauna is present. The lithology of these rocks is typical for the Lower Tokrossøya Beds. | 26.0 » |
| 27. Cherts, black, mostly shaly with some thicker layers. A very poor fauna has been found. The 15 m trigonometrical point which gives its name to the profile is situated on these rocks. | 34.0 » |
| 28. Cherts, thin bedded (layers 5–10 cm, seldom up to 15 cm in thickness) with shaly intercalations. Cherts and cherty shales form large interbedded lenses. Shales disintegrate more easily than cherts and form depressions between small ridges or ledges consisting of the resistant cherts. | 40.0 » |
| 29. Siliceous shales, black, with a distinct fissility. The shales grade into the adjacent, thicker bedded rocks. Within the shales occur thin lenses of ankeritic and dolomitic rocks which are rusty or reddish on weathered surfaces. | 41.0 » |
| 30. Cherts, thin-bedded (layers up to 20 cm) black or dark grey. Some layers become rusty on the weathered surfaces, probably because of the presence of dolomitic or ankeritic material. Some productids and pectenids have been found. This bed forms an irregular break of slope about 42 m from the sea shore. | 13.5 » |
| 30a. Beach gravels with some poor outcrops of black and dark grey cherty shales. | c. 42.0 » |
| 31. Cherts, thick-bedded, black, cropping out on the west coast of the island, partly within the tidal zone. | c. 12.0 » |

“The Sørkapp profile” (see Fig. 2; symbol of the thin-sections: Za, thin-section numbers correspond to the numbers of the beds in the following description).

The succession is again inverted, dips being towards the south-west, and is described in a similar manner to that of the previous profile — bed No. 1 is the youngest member of the sequence and therefore occurs at the north-eastern end of the profile.

Upper Tokrossøya Beds:

- | | |
|---|--------|
| 1. Sandstones, calcareous, usually compact and fine-grained, light grey to dark grey in colour, yellowish on weathered surfaces. The sandstones are thick-bedded. They contain fossils in certain horizons and show differences in the type and intensity of weathering. Generally, a rich fauna is present, especially brachiopods. Bryozoans and pelecypods also occur. Some layers are possibly arenaceous cherts or spongiolites. These sandstone beds represent the most typical lithology of the Upper Tokrossøya Beds. | 25.0 m |
| Unexposed. Probably the same rocks as described above. | 12.5 » |
| 2. Limestones, grey, brownish-grey on weathered surfaces, thick-bedded, containing an abundant brachiopod fauna. A few small fragments of bryozoans have also been observed. Some layers show similarities to the cherts characteristic of the Lower Tokrossøya Beds. | 28.5 » |
| 3. Limestone, flaggy (layers up to 10 cm), somewhat cherty, and cherts, dark grey or black. A rich fauna of brachiopods (usually silicified) is present. Bryozoans occur frequently in some layers, the latter probably corresponding to the Bryozoan Horizons on Tokrossøya. | 11.0 » |

Lower Tokrossøya Beds:

4. Cherty rocks, black, very hard, usually thin-bedded, disintegrating into cube-like particles. Fossils (mainly brachiopods) are common in some layers although not as abundant as in the Upper Tokrossøya Beds. In some layers a fauna is absent. Well preserved sponges have quite often been observed but they are very difficult to extract from the rock. 27.0 m
- Gap in observations. 15.5 »
5. Monotonous series of black or dark grey, usually very hard cherty rocks. These rocks form 10–50 cm thick layers often showing fissility; some shaly intercalations have also been observed. These rocks, dipping steeply and exhibiting a cleavage, form sharply crested ridges and display a rhombohedral joint and cleavage pattern. A poor fauna of productids and pectenids has been found in these rocks. c. 114 »
6. The same rocks as those described above (5) may be observed over a distance of about 40 m beyond the sea-shore at low tide.

Petrology

The Permian rocks of Sørkappøya are similar to those from Tokrossøya, and in spite of some slight differences the same types of rocks could be differentiated in both localities.

Carbonate-cemented quartz sandstones (Beds and thin-sections: Wa-8, 9, 14). — The carbonate-cemented quartz sandstones are quite well sorted and are medium- or fine-grained (see Fig. 11). They consist mainly of terrigenous quartz grains and abundant carbonate cement. The other constituents are grains of siliceous rocks, concentrations of microcrystalline authigenic silica and glauconite grains (see Table 7). Remains of fossils are quite common.

Terrigenous quartz grains are isometrical, subangular or subrounded; average roundness index $K\% = 50$. Fragments of siliceous rocks consist of microcrystalline silica which often contains a brown pigment. Some fragments also contain spherulitic chalcedony.

Cement consists of relatively large (often 1–2 mm in size) anhedral crystals of carbonates. In places a poikilitic texture is developed. Carbonate crystals frequently display a distinct cleavage and twinning. Calcareous fossil fragments occur within

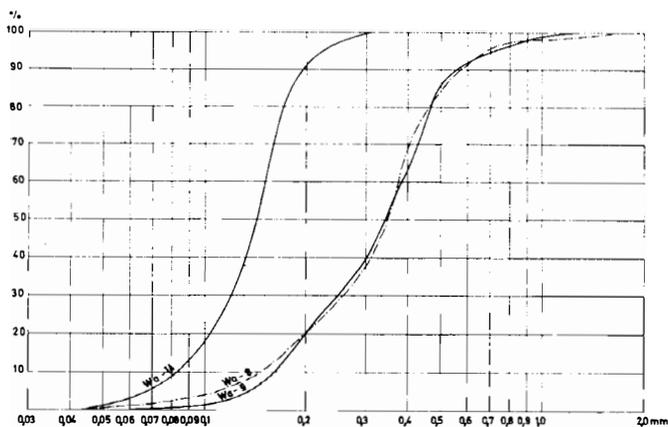


Fig. 11. Granulometric composition of the carbonate-cemented quartz sandstones from the Tokrossøya Beds on Sørkappøya.

Table 7
Carbonate-cemented quartz sandstones, Sørkappøya

Thin-section Bed No.	Wa-8 8	Wa-9 9	Wa-14 14
Terrigenous quartz grains	46.0	60.2	50.7
Fragments of fine-crystalline siliceous rocks	1.2	4.8	0.7
Debris of fossils	11.0	2.6	+
Carbonate cement	40.0	31.4	47.3
Authigenic silica	1.4	0.6	1.3
Glauconite	0.4	0.4	+
Iron-oxides, pyrite	+	-	-
Zircon	-	-	-
Tourmaline	-	-	+

the cement, the fragments measuring up to 4 mm in size and usually being poorly preserved and difficult to determine. Some fragments of brachiopod shells, productid spines and bryozoans have been identified however. Boundaries between the fossil fragments and the carbonate cement are often indistinct, while the structure of shells and skeletons has usually been destroyed by recrystallization. Different stages of this transformation may be observed.

The main differences between the carbonate-cemented quartz sandstones from Sørkappøya and those from Tokrossøya are (1) a more abundant carbonate cement and (2) more abundant detritus of fossils in the sandstones from Sørkappøya.

Quantitative ratios between the constituents of the carbonate-cemented quartz sandstones from Sørkappøya are shown in Table 7.

Quartzitic sandstones (thin-sections Wa-7a, Wa-7b, Wa-15b, Wa-16, Wa-18 from beds No. 7, 15, 16, 18). — The quartzitic sandstones occur only in the Upper Tokrossøya Beds on Sørkappøya and probably constitute transitions into carbonate-cemented quartz sandstones. The quartzitic sandstones were observed only in the profile "Near the 15 m trigonometrical point". These rocks are medium-grained, well sorted (see Figs. 12, 13), massive and somewhat porous. Quartz grains are usually closely packed, though in places grains "floating" in cement have been observed.

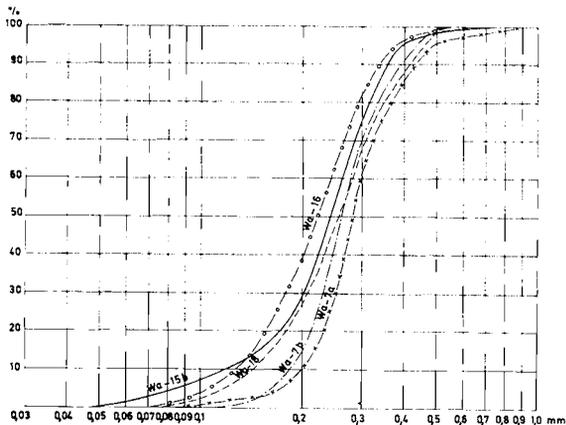


Fig. 12. *Granulometric composition of the quartzitic sandstones from the Tokrossøya Beds on Sørkappøya.*

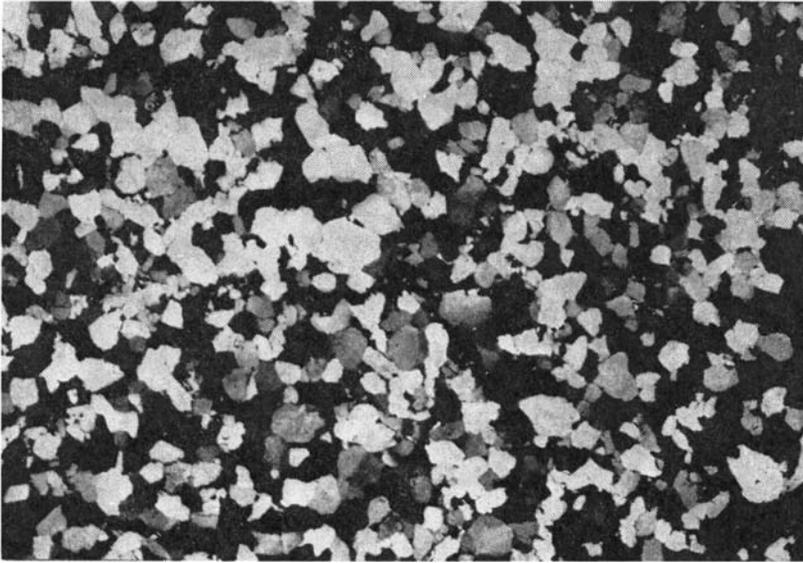


Fig. 13. *Quartzitic sandstone. Upper Tokrossøya Beds, Sørkappøya, thin-section Wa-7a, $\times 12.5$.*

Terrigenous quartz grains are isometrical, rounded or subrounded. Secondary quartz rims are well developed and the boundaries between the clastic grains and the secondary quartz are quite distinct on account of the occurrence of small amounts of clay minerals and/or iron-oxides on the surfaces of the clastic grains. The secondary rims are often irregular in shape, a feature which is closely related to the roundness of the clastic grains as well as to the shape of interstitial voids. Concentrations of microcrystalline authigenic silica are also present. This silica is usually mixed with clay minerals, hydromicas and iron-oxides and contains a brown pigment. The presence of these impurities in the silica is thought to have probably prevented its recrystallization and thus precluded the development of overgrowths.

In parts of the quartzitic sandstones some interstitial voids are filled by carbonates. Anhydrous crystals are prominent and commonly one such crystal fills one interstitial void. Some of the carbonate crystals are much larger (up to 2 mm) than the quartz grains and several grains of quartz may appear to be "floating" within one carbonate crystal. Some of the carbonate cement concentrations are also found to contain preserved traces of organic remains but these are not recognizable in detail. These traces suggest, however, that the carbonate cement is derived from the recrystallization of calcareous fossil fragments which were deposited contemporaneously with the terrigenous constituents. Other explanations for the genesis of the cement are less conceivable.

In the quartzitic sandstones small amounts of siliceous rock fragments, iron-oxides, pyrite, glauconite, muscovite, zircon, tourmaline and rarely biotite are also present. The siliceous rock fragments consist of microcrystalline silica which usually contains a brown pigment. It is sometimes difficult to distinguish between the authigenic silica concentrations and the siliceous rock fragments,

Table 8
Quartzitic sandstones, Sørkappøya

Thin-section Bed No.	Wa-7a 7	Wa-7b 7	Wa-15b 15	Wa-16 16	Wa-18 18
Terrigenous quartz grains	68.5	68.6	61.7	63.0	69.9
Siliceous rock fragments	0.3	0.6	0.3	0.5	0.9
Secondary quartz rims	26.8	27.2	26.9	33.5	18.4
Microcryst. authigenic silica + clay and iron-oxides admixtures	2.0	3.6	0.7	2.8	0.7
Carbonates	—	—	9.6	—	10.0
Iron-oxides, FeS ₂	2.4	+	+	+	+
Glauconite	+	+	0.8	0.2	0.1
Muscovite	—	+	—	+	—
Zircon	+	+	—	+	—
Tourmaline	—	—	—	+	—
Biotite	—	—	—	+	—

especially where the silica is corroded by carbonates. Glauconite occurs as small rounded grains.

Quantitative ratios of the constituents of the quartzitic sandstones in the Upper Tokrossøya Beds of Sørkappøya are shown in Table 8.

Fossiliferous, calcareous sandstones and siltstones (thin-section and bed numbers: Wa-1, Wa-2, Wa-3, Wa-4, Wa-5, Wa-6, Wa-10, Wa-11, Wa-12, Wa-13, Wa-15a, Wa-17, Wa-19, Wa-20, Za-1). — These rocks occur within the Upper Tokrossøya Beds (Fig. 3). The sandstones and siltstones are usually well sorted (Fig. 14 shows the granulometric composition of some of these rocks) and consist mainly of terrigenous quartz grains, carbonate cement, fragments of fossils and authigenic silica (Figs. 15, 16).

Quartz grains are subrounded or subangular; overgrowth of authigenic silica in some places has resulted in the cementation of several small clastic grains into one larger grain.

Carbonate cement is heterogenous; it varies in quantity in different parts of

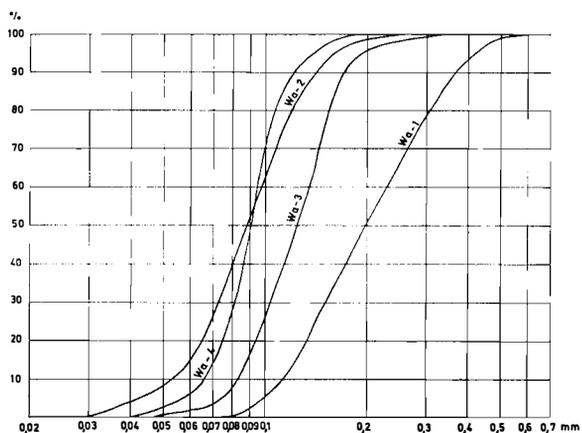


Fig. 14. *Granulometric composition of the fossiliferous, calcareous sandstones and siltstones from the Tokrossøya Beds on Sørkappøya.*



Fig. 15. *Fossiliferous, calcareous fine-grained sandstone. Upper Tokrossøya Beds, Sørkappøya, thin-section Wa-1, crossed nicols, $\times 12.5$.*

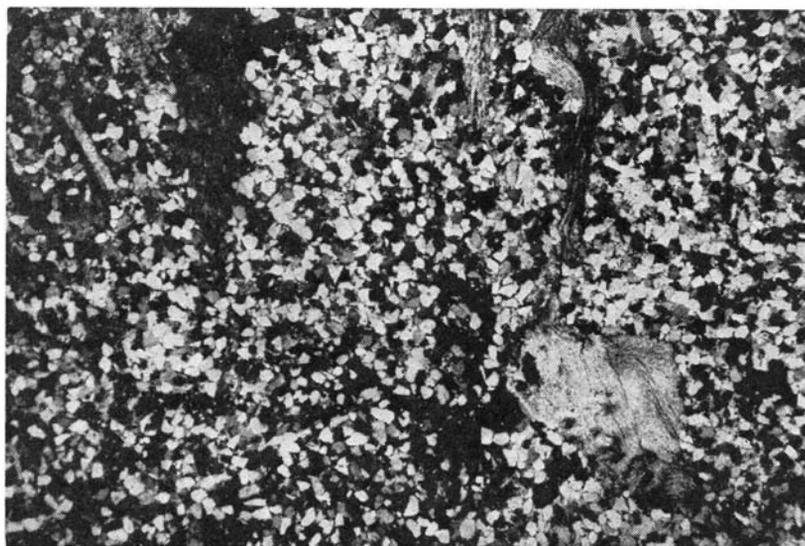


Fig. 16. *Fossiliferous calcareous siltstone. Upper Tokrossøya Beds, Sørkappøya, thin-section Wa-6, crossed nicols, $\times 12,5$.*

the rock and its texture is variable. Moreover, there is a distinct connection between the carbonate cement and fossil particles. The variations of texture of the carbonate cement are as follows:

1. fine-grained concentrations;
2. anhedral crystals with distinct cleavage and twinning. Some of the crystals reach up to c. 1 mm in size and display a poikilitic texture;
3. concentrations of anhedral crystals of different size, comprising body-fossil particles. Different states of preservation of the fossil particles can be seen; some of them are strongly recrystallized, others well preserved;
4. scattered euhedral rhombs 0.03–0.08 mm in size, commonly with rusty rims surrounded by iron-oxides. These rhombs are probably ankerite-dolomite.

Fossil particles vary appreciably in size; in the thin-sections examined they reach up to 5 mm. Fragments of brachiopod shells, spines of productids and bryozoans have been observed. All these particles consist of carbonates, but the larger particles are usually partly filled with fibrous or spherulitic chalcedony. Small calcitic debris of fossils are more strongly recrystallized than the larger ones.

Concentrations of pure microcrystalline authigenic silica are relatively uncommon whereas mixed aggregates of microcrystalline silica and fine-crystalline carbonates occur quite often in these rocks and are an important constituent of its cement. Some hydromicas, clay minerals, iron-oxides and brown pigment are usually also present in these concentrations. Quantitative relations between silica and carbonates in these concentrations are variable though usually silica is predominant. It is clear that microcrystalline silica is a primary constituent which has been corroded and replaced by carbonates.

Glauconite is an important, though not abundant constituent of the fossiliferous fine-grained sandstones and siltstones. It occurs as irregular grains, usually full of cracks, which are sometimes referred to as lobate-grains (CAROZZI 1960, p. 47, HADDING 1932, p. 95), and which fill the interstitial voids. This glauconite is presumably authigenic. Some rounded grains of glauconite, larger than the quartz grains and having smooth surfaces, may be considered as being allochthonous. Furthermore, some of the microcrystalline concentrations of silica are somewhat greenish in colour, this possibly being due to a glauconite pigment.

Modal percentages of the constituents of fossiliferous calcareous sandstones and siltstones from Sørkappøya are presented in Table 9.

Arenaceous, cherty limestones (thin-section and bed numbers: Wa-21, Wa-22, Za-2, Za-3, Za-4a). — These rocks are petrologically closely related to the fossiliferous, calcareous sandstones and siltstones, differences between the two groups being almost entirely of a quantitative nature. Calcitic sponge spicules, not observed in the calcareous sandstones, appear in the arenaceous, cherty limestones. The latter exhibit very irregular quantitative ratios between the main constituents and this irregularity may even be considered as a characteristic feature. These impure limestones are obviously similar to the arenaceous, cherty organodetrital limestones from Tokrossøya. There is, however, a difference in the quantity of fossil fragments preserved in these two limestones.

Table 10 shows the results of determinations of the quantitative ratios between the main constituents of the arenaceous, cherty limestones from Sørkappøya.

Arenaceous, calcareous spiculitic cherts (bed and thin-section numbers: Wa-23a, Wa-24, Wa-25, Wa-26, Wa-27, S-37-64 (bed 27), Wa-28, Wa-29, Wa-33, Wa-34, Za-4b, Za-5). — The Lower Tokrossøya Beds on Sørkappøya consist mainly of the arenaceous, calcareous spiculitic cherts. These rocks are usually very hard, dark grey or black in colour and occur either in massive layers or in similar layers showing a fissility. They consist of authigenic silica, sponge spicules, carbonates, quartz grains and, in small amounts, different body-fossil remains, glauconite, hydromicas, carbonaceous matter and accessory muscovite, plagioclase, and tourmaline (Figs. 17 and 18).

Authigenic silica is microcrystalline; in thin sections it displays a brownish colour, probably caused by the presence of a carbonaceous pigment. This microcrystalline silica forms the abundant cement of the cherts.

Sponge spicules are the second most important constituent of the cherts. They show some variations of shape, size, and mineral composition, but a study of their morphology and size is incomplete as they have so far been observed only in thin-sections. The spicules are rod-like, straight or somewhat curved; more complicated forms have not been observed. Two groups of spicules may be differentiated on the basis of size:

Small spicules: c. 0.02–0.03 mm in diameter,
c. 0.8–1.0 mm in length.

Large spicules: c. 0.06–0.1 mm in diameter.

Both the small and the large spicules are generally broken; whole large spicules were not observed at all. The small spicules are much more common than the larger ones. The spicules consist of (1) silica or (2) carbonates (Fig. 18). The siliceous spicules have indistinct outlines and consist of colourless, fine-crystalline chalcedony, showing no orientation of fibres. In some cases axial canals have been observed; these canals are filled with somewhat larger chalcedony crystals. Under crossed nicols the siliceous spicules are very difficult to locate, but with plane polarized light they are more easily visible since the chalcedony of the cement is brownish stained while the spicule chalcedony is colourless.

The calcareous spicules show no internal texture and each spicule consists of one anhedral carbonate crystal, usually with apparent twinning planes. Outlines of the calcareous spicules are distinct.

A few spicules consist partly of silica and partly of carbonates and it can be observed that the fine-crystalline silica has gradually been dissolved and replaced by carbonates. Some of the spicules have preserved axial canals filled with glauconite.

In the cherts which macroscopically display a fissility, sponge spicules are seen to lie parallel to the bedding planes; in the massive layers spicules are devoid of any orientation.

Carbonates (besides the carbonates replacing the sponge spicules) are scattered throughout the siliceous cement as anhedral or rhombic crystals.

Table 9
Fossiliferous, calcareous sandstones and siltstones, Sørkappøya

Bed and thin-section	Wa-1	Wa-2	Wa-3	Wa-4	Wa-5	Wa-6	Wa-10	Wa-11	Wa-12	Wa-13	Wa-15a	Wa-17	Wa-19	Wa-20	Za-1
Terrigenous quartz grains	48.2	67.2	51.0	43.5	44.5	54.4	68.4	59.7	67.2	59.8	61.0	67.8	59.6	53.4	60.2
Siliceous rock fragments	+	0.4	3.2	3.2	3.5	1.4	0.2	1.0	0.2	0.8	0.8	0.8	0.2	0.8	+
Debris of fossils	16.3	+	7.0	7.5	15.0	11.0	2.2	6.8	1.8	1.6	12.8	+	4.0	2.4	2.0
Carbonate cement	35.4	12.0	38.6	43.3	29.4	31.4	21.6	23.0	24.0	26.2	9.6	20.8	28.6	32.6	19.4
Authigenic silica	0.1	17.8	+	2.7	4.3	1.8	2.4	1.8	1.2	2.7	4.0	3.2	1.4	3.6	9.0
Mixed aggregates of silica, carbonates, carbonaceous matter etc.	+	+	+	+	+	+	5.0	7.5	5.2	7.0	10.8	5.4	5.6	5.0	7.4
Glauconite	+	2.6	0.2	1.0	3.2	+	0.2	0.2	0.4	1.9	1.0	2.0	0.6	2.2	2.0
Pyrite and iron-oxides	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+
Zircon	-	+	+	-	-	+	+	+	-	-	+	+	-	+	-
Tourmaline	-	+	+	-	-	+	+	+	-	-	+	+	-	+	-
Feldspar	-	+	+	-	-	-	-	+	-	-	+	-	-	-	+

Table 10
Arenaceous, cherty limestones, Sørkappøya

Thin-section Bed No.	Wa-21	Wa-22	Za-2	Za-3	Za-4a
	21	33	2	3	4
Terrigenous quartz grains	34.2	32.8	28.3	33.0	25.0
Siliceous rock fragments	0.2	0.2	+	+	+
Calcite sponge spicules	1.8	5.0	6.0	1.2	2.5
Debris of different fossils (sponge spicules excl.)	5.4	1.6	8.0	15.2	6.0
Carbonates	13.8	29.6	31.5	16.6	59.0
Carbonate-silica and clay-mineral aggregates	40.8	23.0	16.4	14.0	0.6
Authigenic silica	3.2	6.4	8.3	19.0	5.2
Iron-oxides and FeS ₂	+	+	+	+	+
Glauconite	0.6	1.4	1.5	1.0	0.6
Tourmaline	+	-	+	-	-
Siliceous sponge spicules	-	-	-	-	1.1
Plagioclase	-	-	-	-	+
Muscovite	-	-	-	-	+

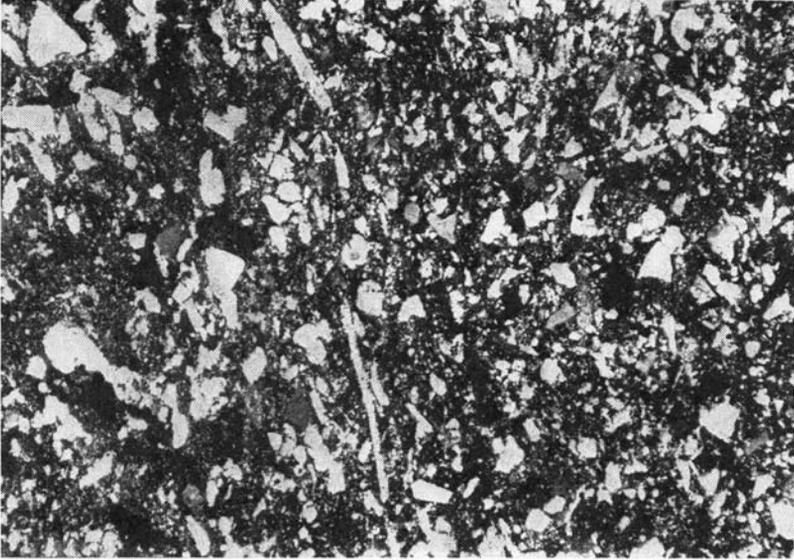


Fig. 17. *Arenaceous calcareous spiculitic chert. Lower Tokrossøya Beds, Sørkappøya, thin-section Wa-26, crossed nicols, $\times 50$.*

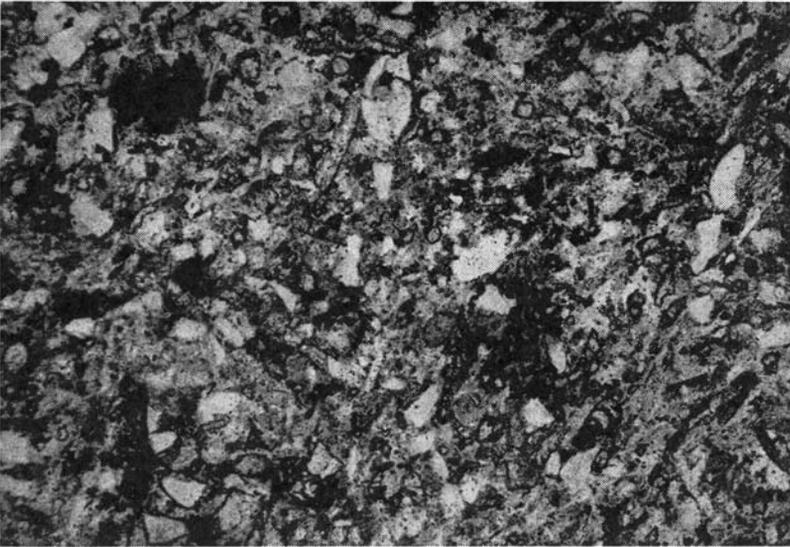


Fig. 18. *Arenaceous calcareous spiculitic chert. Outlines of the chalcedony spicules are poorly defined while the calcified spicules are distinct. Lower Tokrossøya Beds, Sørkappøya, thin-section Wa-34, plane polarized light, $\times 50$.*

Table 11
Arenaceous, calcareous spiculitic cherts, Sørkappøya

Bed and thin-section	Wa-23a	Wa-24	Wa-25	Wa-26	Wa-27	S37-64	Wa-28	Wa-29	Wa-33 ¹	Wa-34	Za-4b	Za-5
Fine-crystalline silica	28.8	49.8	38.5	51.2	50.0	44.2	48.8	25.4	23.4	41.8	40.4	27.2
Siliceous spicules	0.4	1.4	0.8	15.2	24.2	16.0	22.2	6.2	2.2	12.8	2.6	+
Calcified spicules	22.8	20.4	18.7	8.6	4.0	4.5	17.2	4.2	36.4	4.6	2.8	1.4
Other, calcareous fossil remains	4.8	2.2	1.9	—	—	—	—	—	—	—	11.8 ²	—
Carbonates + clay min.	18.2	12.2	17.2	8.4	11.6	20.3	3.0	12.8	21.4	15.4	18.2	21.2
Quartz grains	24.4	12.8	22.1	16.0	10.2	10.0	7.8	19.2	16.6	18.6	21.8	35.8
Glauconite	0.6	1.2	0.8	0.6	+	0.5	1.0	1.2	+	0.6	0.2	1.2
Muscovite	—	+	+	+	+	—	—	+	+	+	—	+
Plagioclase	—	—	—	—	+	—	—	—	—	—	—	—
Tourmaline	—	—	—	—	+	—	—	+	—	+	—	—
Carbonaceous matter	+	+	+	+	+	4.5	+	4.8	+	6.2	2.2	4.0
Mixed aggregates of carbonates, silica, hydromicas	+	+	+	+	+	+	+	26.2	+	+	+	9.2

¹ A transitional rock between calcareous spiculitic cherts and calcareous spiculites. ² Bryozoans.

Fossil remains other than sponge spicules have also been observed. These included some fragments of brachiopod shells, skeletons of bryozoans and other unrecognizable particles.

Terrigenous quartz grains are usually subangular or subrounded and are about 0.03–0.2 mm in size.

Glauconite occurs in small rounded or irregular grains, intensively green in colour, and is sometimes found filling the axial canals of spicules or cavities within other fossil remains.

Quantitative relations between the main constituents of the arenaceous, calcareous spiculitic cherts are shown in Table 11.

In summary it may be concluded that:

1. carbonates, both those forming the spicules and those occurring as scattered anhedral or rhombic crystals, seem to be of secondary, diagenetic origin;
2. siliceous and carbonate constituents of cherts are irregularly distributed; in some places concentrations of quite closely packed siliceous sponge spicules occur and these possibly represent sponge remains preserved "in situ". Calcareous spicules or carbonates replacing siliceous cement predominate in the other parts of the rock. An abundance of calcareous spicules and carbonate cement is especially prominent in thin-section Wa-33 making it similar to the calcareous spiculites from Tokrossøya. This rock may be considered as a transition between calcareous spiculitic chert and calcareous spiculite.

Arenaceous, calcareous spiculites (thin-section and bed numbers: Wa-23, Wa-30, Wa-31, Wa-32. — These rocks consist mainly of calcareous sponge spicules (see Fig. 19), although carbonates are also commonly present as anhedral crystals and

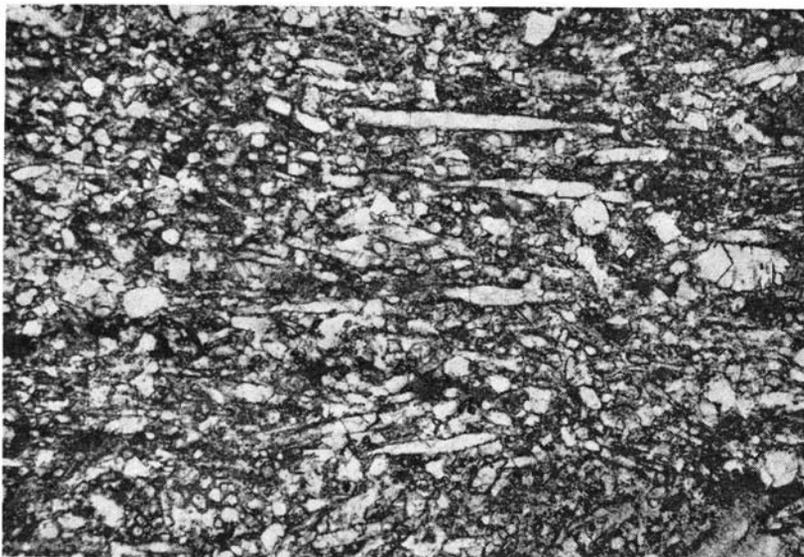


Fig. 19. *Arenaceous calcareous spiculite*. Lower Tokrossøya Beds, Sørkappøya, thin-section Wa-23, plane polarized light, $\times 50$.

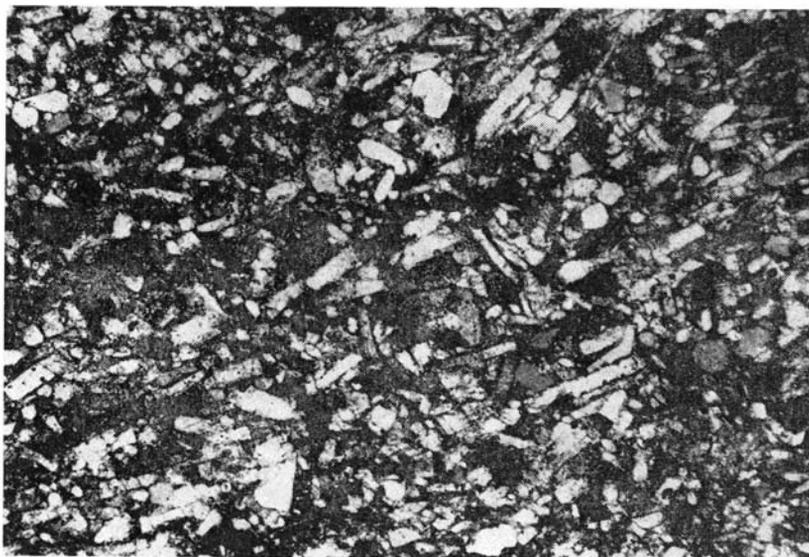


Fig. 20. *Arenaceous calcareous spiculite*. Lower Tokrossøya Beds, Sørkappøya, thin-section Wa-30, crossed nicols, $\times 50$.

euohedral rhombs. In some bands sponge spicules are arranged parallel to the bedding planes; usually, however, they are rather randomly oriented (Fig. 20). The sponges picules are straight, simple in shape, usually about 0.05 mm in diameter and generally broken (and/or cut by planes of the thin-sections); the biggest fragments are c. 1 mm in length.

In addition to the carbonates, terrigenous quartz grains, authigenic silica,

hydromicas, and carbonaceous matter are present. Terrigenous quartz grains are angular or subangular and reach up to 0.2 mm in size. Small irregular grains of glauconite were seldom observed.

STJERNØYA

(thin-section symbol — Sj.)

Only the Upper Tokrossøya Beds crop out on Stjernøya. Lower Tokrossøya Beds occur south-west of the island as submarine cliffs.

The lithologies of the Upper Tokrossøya Beds on Stjernøya are analogous to those observed in the type-area on Tokrossøya. The fauna is also similar; bryozoans, however, do not occur in definite horizons as on Tokrossøya but are scattered throughout the entire Upper Tokrossøya Beds. An especially abundant bryozoan fauna has been observed on Stjernøya in the lowermost part of the Upper Tokrossøya Beds, near the SW coast of the island (S. SIEDLECKI, pers. comm.). No detailed measurement of the Stjernøya section has been carried out.

Hand specimens as well as thin-sections of the rocks of the Upper Tokrossøya Beds from Stjernøya display a great similarity to the arenaceous, calcareous spiculitic cherts from profiles on Tokrossøya and Sørkappøya although sponge spicules are not abundant here. These rocks consist mainly of authigenic silica carbonates, and clastic quartz grains. The silica is usually microcrystalline while carbonates appear either as somewhat larger anhedral crystals or as rhombohedra. Besides mixed fine-crystalline aggregates of carbonates and silica are present. The rocks comprise remains of bryozoans, brachiopods and sponge spicules, the spicules consisting either of chalcedony or of calcite which, in the author's opinion, is a product of replacement. Glauconite is common and usually occurs as rounded well-defined grains. Feldspar and muscovite occur as accessories. Two modal analyses have been carried out on thin-sections to show quantitative ratios between the various constituents (Table 12).

Table 12
Arenaceous, calcareous cherts, Stjernøya

Thin-section	Sj-1	Sj-2
Terrigenous quartz grains	25.1	16.4
Authigenic silica	31.0	36.2
Carbonates	22.6	14.2
Concentrations of fine-crystalline silica mixed with carbonates	6.4	5.6
Siliceous sponge spicules	0.6	+
Calcareous sponge spicules	1.4	2.6
Bryozoan & brachiopod remains	9.8	23.6 (mainly bryoz.)
Glauconite	2.0	0.6
Carbonaceous matter	1.0	0.8
Feldspar	+	+
Muscovite	-	-

ØYRLANDET

Øyrlandet was visited by S. SIEDLECKI in the summer of 1964 and a section through the Permian rocks cropping out north-east of Sandhamna (see Fig. 2) has been described by him. Hand specimens of the rocks from this profile form the basis of the present author's petrological study. A description of the section of Permian rocks near Sandhamna is, with SIEDLECKI's permission, reproduced below. The description is supplemented with notes on features observed in the hand specimens.

Profile NE of Sandhamna

Structurally the Tokrossøya Beds are here the right way up; strata again dip towards the south-west (Fig. 2). The lithological description begins with the oldest horizon of the Lower Tokrossøya Beds at the NE end of the profile (on the shore of an unnamed lake). Thin-section symbol: Ø, thin-section numbers are those of the relevant bed.

Lower Tokrossøya Beds:

1. Sandstones, fine- and medium-grained, slightly yellow in colour, whitish on weathered surfaces. Some traces of floral detritus have been observed here. The sandstones are poorly exposed. up to 10 m
2. Limestones, arenaceous, fine-grained, yellow in colour, including scattered quartz pebbles reaching 5 mm in diameter. Very small, black, often elongated particles, probably representing the detritus of flora, are very common. White concretions of silica impregnating limestone are also present. The concentrations are usually irregular, though some of them have shapes reminiscent of brachiopods or sponges. The limestones form layers up to 0.5 m in thickness. 8.5 »
3. Sandstones, medium- and coarse-grained, often with quartz pebbles reaching 10 mm in diameter. The sandstones are yellow in colour, whitish on the weathered surfaces. Silica concentrations also occur in the sandstones, these being irregular or in shapes resembling shells, up to 5 cm in size. The sandstones are thick-layered and are quite prominent topographically. 9.0 »
4. Conglomeratic sandstones, poorly sorted, with abundant quartz pebbles up to 10 mm in diameter. The sandstones are whitish or yellowish in colour and form thin layers. Very small particles of floral detritus and some traces of bryozoan skeletons also occur. The sandstones form a depression in the topography. 5.0 »
5. Sandstones, yellowish-grey in colour, calcareous, fine- and medium-grained, with rare quartz pebbles up to 0.5 mm in size. Very small particles of floral detritus also occur. 5.0 »
6. Limestones, cherty, flaggy, dark grey in colour, rust-brown on weathered surfaces. Poorly preserved brachiopod imprints are often present. 8.0 »
7. Sandstones, light grey and yellowish in colour with small brown particles resembling floral detritus. The sandstones form thin layers which disintegrate easily forming a depression in the topography. 4.0 »
8. Cherty shales and limestones analogous to bed No. 6. 4.0 »

Upper Tokrossøya Beds:

9. Limestones, light grey in colour with intercalations of cherty sandstones and shales; a fauna of brachiopods and bryozoans, characteristic of the Upper Tokrossøya Beds, occurs in these limestones. 10.0 »

10. Sandstones, nodular, dark grey, rusty-brown on weathered surfaces. In the sandstones a very abundant but poorly preserved fauna of brachiopods and bryozoans is present. The sandstones change laterally into a more shaly and limy facies. 2.0 m
11. Sandstones, dark grey, somewhat yellowish or rusty, fine-grained, with an abundant but poorly preserved fauna of brachiopods and bryozoans, the shells and skeletons of which are usually silicified. Some layers show traces of slumping. 5.0 »
12. Limestones, forming alternating thin and thick layers, dark grey, rusty on weathered surfaces, arenaceous, with an abundant brachiopod fauna. A 1 m thick layer of light yellowish-grey sandstone occurs within this bed. 10.0 »
13. Limestones, thin-bedded, grey-brown or dark grey in colour, fine-grained, with abundant fauna typical of that in the Upper Tokrossøya Beds. Some cherty layers and unfossiliferous sandstones also occur. 10.0 »

Besides the profile described above, some observations have been made by S. SIEDLECKI in other localities on Øyrlandet and specimens of Permian rocks from Nesodden and Øyrlandsodden (see Fig. 2) have been collected. Thin-sections of these rock specimens have also been studied by the author.

The NE Sandhamna profile through the Tokrossøya Beds differs lithologically from other profiles of these beds in the Sørkapp area. The Lower Tokrossøya Beds, which in other localities are represented mainly by cherty rocks, here comprise for the most part light-coloured sandstones, grits and pebbly sandstones. Rock-types which have been differentiated microscopically are described below.

Petrology

Carbonate-cemented quartz sandstone (bed 5, thin-section Ø-5a). – The carbonate-cemented quartz sandstone is quite well sorted (Fig. 21), consisting mainly of subrounded or rounded quartz grains c. 0.3–0.7 mm in size. Roundness index $K\% = 55$. Overgrowths of secondary quartz are common but well formed secondary quartz rims are rather rare. Besides quartz, a few grains of fine-crystalline siliceous rocks are present. The clastic grains are closely packed. The sandstone is porous; only a part of the interstitial voids is filled with carbonates which form rhombohedra 0.03–0.08 mm in size. Some iron-oxide concentrations and glauconite grains have also been observed.

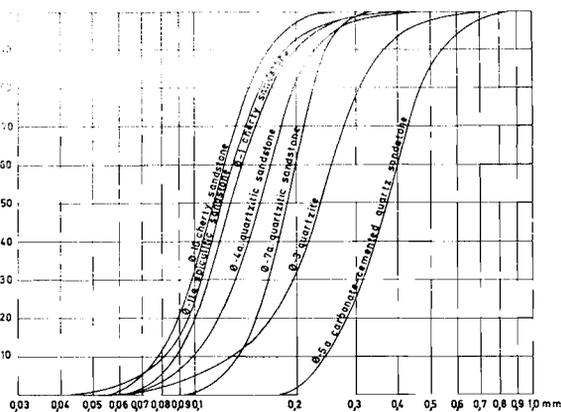


Fig. 21. Granulometric composition of the sandstones from the Tokrossøya Beds on Øyrlandet.

Quantitative ratios between the main constituents of this sandstone are as follows:

Clastic quartz	68.4 %
Authigenic quartz (overgrowths)	12.0 »
Carbonates	19.6 »

Silica-cemented quartz sandstones. — The silica-cemented quartz sandstones may be subdivided on the basis of the character of the cement:

1. Quartzite (bed 3, thin-section Ø3).

The quartzite is quite well sorted (Fig. 21) consisting of isometrical subrounded quartz grains 0.25–0.5 mm in diameter. The grains are closely packed and each is surrounded by a secondary quartz rim. These rims are clearly visible on account of the presence of impurities, mainly rusty-yellow iron-oxides, on the surfaces of the clastic grains. Larger iron-oxide concentrations as well as rare flaky minerals have also been observed.

2. Quartzitic sandstones (beds 4, 7; thin-sections Ø-4, Ø-4a, Ø-7a).

Two kinds of quartzitic sandstone may be distinguished:

a) A quartzitic sandstone (bed 4) consisting of subrounded quartz grains which are usually 0.1–0.3 mm in diameter. Some larger grains, reaching up to 1 mm or more in size (this sandstone also includes quartz pebbles — see description of the profile) are scattered among the smaller ones. Besides quartz, some fragments of fine-crystalline siliceous rock are present. The grains are mostly closely packed and cemented partly by a secondary overgrowth of quartz and partly by fine-crystalline quartz usually including an admixture of iron oxides and clay minerals. In some parts of the rock iron-oxide concentrations are quite abundant. Rare concentrations of small (c. 0.04 mm) rhombs of dolomite may also be observed. Muscovite, tourmaline and zircon occur as accessories.

b) Quartzitic sandstone (Ø-7a) consisting of subrounded ($K\% = 50$) isometrical quartz grains (0.2–0.25 mm in diameter) which are usually not closely packed. Secondary quartz overgrowths occurring around these grains grade into fine-crystalline silica so that the external boundaries of these quartz rims are denticulate or diffuse.

3. Spiculitic sandstone (bed 11, thin-section Ø-11a).

The spiculitic sandstone consists of subangular quartz grains c. 0.1–0.25 mm in diameter, “floating” within an abundant cement. The main constituent of the cement is chalcedony and this itself is found to contain many chalcedony sponge spicules, the abundance of which has given rise to the term “spiculitic” sandstone. The chalcedony sponge spicules are simple and straight but broken such that their true lengths cannot be measured. Their diameters are usually c. 0.1 mm, sometimes up to 0.2 mm. Axial canals enlarged and filled with chalcedony are visible. Some of the sponge spicules consist of calcite which is conspicuously of secondary origin. Calcite spicules appear as rods composed of one individual crystal and are devoid of any trace of an internal structure. These calcitic pseudo-

morphs after siliceous spicules are not always complete; in some cases only a part of the chalcedony spicule having been replaced by calcite. Calcite also occurs in the rock as anhedral crystals and as small rhombs (c. 0.03 mm in size) scattered through the cement.

Fossil remains other than spicules are also present, these consisting predominantly of fragments of brachiopod shells which are usually partially silicified. Glauconite occurs in small amounts either as rounded grains c. 0.1 mm in diameter or as irregular concentrations filling interstitial voids. Carbonaceous matter, muscovite and tourmaline have also been observed.

Quantitative ratios of the constituents of the spiculitic sandstone are as follows:

Grains of clastic quartz	41.0 %
Chalcedony cement	23.3 »
Chalcedony sponge spicules	22.8 »
Calcitic sponge spicules	3.2 »
Carbonates (excl. calcitic sponge spicules)	7.0 »
Glauconite	0.1 »
Fossil remains (excl. sponge spicules)	2.2 »
Carbonaceous matter	0.4 »
Muscovite	+
Tourmaline	+

4. Cherty sandstones (beds 1, 9, 10; thin-sections: 1, 1a, 9a, 10).

The cherty sandstones are petrologically closely related to the spiculitic sandstone and to the quartzitic sandstones. They consist mainly of subangular ($K\% = 30$) quartz grains c. 0.1–0.2 mm in diameter (Fig. 21), and abundant chalcedony or quartz-chalcedony cement (Fig. 22). Some quartz grains are enlarged by secondary quartz overgrowth. Chalcedony, or quartz-chalcedony cement comprises siliceous sponge spicules. The spicules are usually strongly recrystallized; some of them, however, display preserved axial canals which have commonly been enlarged and filled with chalcedony. Spicules are straight, rod-shaped, c. 0.1–0.15 mm in diameter. Megascopic (2–20 mm) ellipsoidal or rounded concentrations of silica are also present in this sandstone. Under the microscope these concentrations show different properties and may be divided into: 1) concentrations of chalcedony sponge spicules, usually with a hole in the middle filled with authigenic quartz. These concentrations seem to be remains of small sponges; 2) chalcedony geodes without any traces of sponge spicules or other organic remains.

Within the cement of the cherty sandstones carbonates occur forming: 1) pseudo-morphs after sponge spicules (as in the spiculitic sandstone); 2) anhedral crystals, or concentrations of crystals possibly representing recrystallized detritus of fossils; 3) rhombs (c. 0.03–0.08 mm in size), either scattered or in concentrations.

Fossil remains other than sponge spicules are also present. They are unevenly distributed throughout the rock and represented mainly by fragments of brachiopod shells and spines, usually calcareous and in part silicified.

Glauconite is present usually as irregular fillings of interstitial voids c. 0.08–

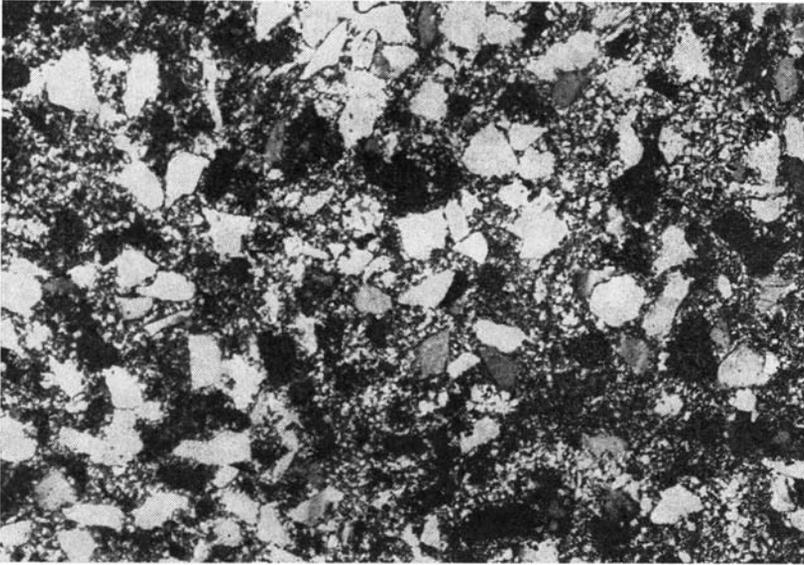


Fig. 22. *Cherty sandstone. Lower Tokrossøya Beds, Øyrlandet, thin-section Ø-1, crossed nicols, × 50.*

0.15 mm in size. Other components occurring in small amounts are carbonaceous matter, muscovite, tourmaline, and zircon.

Quantitative ratios between the constituents of the cherty sandstones are shown in Table 13.

Arenaceous and cherty limestones (beds and thin-sections: Ø-2, Ø-2a, Ø-2b, Ø-6a, Ø-8, Ø-8a, Ø-9, Ø-10a, Ø-12a, Ø-13, Ø-13a).— These rocks are most common in the profile NE of Sandhamna. They were described macroscopically primarily as sandstones but microscopic investigations have shown that their main constituents are indeed carbonates and authigenic silica, not clastic quartz. Macroscopically the rocks of this group may display quite variable properties (colour, layer thickness, hardness etc.) due to the varying quantitative ratios of the constituents. These variations, caused by an uneven distribution of constituents, may

Table 13
Cherty sandstones, Øyrlandet

Thin-sections Bed No.	Ø-1 1	Ø-1a 1	Ø-9a 9	Ø-10 10
Clastic quartz grains	42.8	45.8	52.0	36.4
Chalcedony & quartz cement	39.0	39.2	38.2	28.8
Chalcedony spicules	4.8	2.2	1.0	10.8
Calcitic spicules	+	+	+	4.4
Carbonates (excl. calc. spic.)	11.0	11.6	8.0	13.0
Debris of fossils (excl. sponge spicules)	+	+	+	5.8
Glauconite	—	—	0.8	0.4
Carbonaceous matter	1.2	0.8	+	0.4
Tourmaline	+	+	+	—
Zircon	—	+	+	—
Muscovite	1.2	0.4	+	—

sometimes be more conspicuous within one single bed than between different beds. Because of this feature, a more detailed classification of the rocks of this group would not appear to serve any useful purpose.

In the arenaceous and cherty limestones in addition to clastic quartz, carbonates and authigenic silica, sponge spicules and other fossil remains, carbonaceous matter, iron oxides and glauconite are present. A few grains of tourmaline and zircon have also been observed.

Quartz grains are usually subangular, seldom subrounded; both isometrical and elongated grains are present. The quartz grains are c. 0.03–0.5 mm in size, and some of them are enlarged by overgrowth of secondary quartz.

Authigenic silica (mainly chalcedony) is found as: 1) irregular concentrations, without distinct boundaries, impregnating the rock; 2) replacement after fragments of brachiopod shells. In these replacements fibrous chalcedony is beautifully developed; 3) concentrations which display properties of geodes with an outer chalcedonic layer and an interior filled with inward projecting crystals.

Carbonates occur either as anhedral crystals or as rhombs c. 0.02–0.1 mm in size. The anhedral crystals consist mainly of calcite and their abundance is suggestive of the rock being of a more limy character. An abundance of rhombohedra is characteristic of the more dolomite parts of these carbonate rocks. It is noteworthy that the amounts of the different carbonates present may change rapidly over small distances even within any one layer.

Fossil remains are represented by sponge spicules and particles of bryozoan skeletons and brachiopod shells. Sponge spicules are siliceous or calcitic. Siliceous spicules are strongly recrystallized and consist of chalcedony or granular quartz; an axial canal is not preserved. Calcitic spicules each consist of one calcite crystal and are regarded by the author as pseudomorphs after originally siliceous spicules. Confirmatory evidence of this is seen in spicules consisting only partly of silica, this being corroded and gradually replaced by carbonate. Analogous replacive features have already been recorded in the previously described rocks from Øyrlandet as well as in rocks from other localities in the Sørkapp area. The sponge spicules are usually 0.05–0.25 mm in diameter. Their length is not known because they are broken and also because they could be observed only in thin-sections. The longest particles reach up to 2.5 mm. In shape the sponge spicules are simple and rod-like. Glauconite occurs both as well defined rounded grains and as indistinctly bounded irregular concentrations filling interstitial voids. These grains and concentrations are c. 0.05–0.15 mm in size.

Quantitative ratios of the constituents of the arenaceous cherty limestones and dolomites are presented in Table 14.

Permian rocks at Nesodden are represented by light coloured carbonate-cemented quartz sandstones similar to bed No. 5 in the profile NE of Sandhamna. At Øyrlandsodden dark grey arenaceous and calcareous spiculitic cherts are present (Fig. 23), these being similar to the cherts from Tokrossøya, Sørkappøya, and Stjernøya but not represented in the rock collection from the section NE of Sandhamna.

Table 14

Arenaceous and cherty limestones from the Tokrossøya Beds on Øyrlandet (Profile NE of Sandhamna)

Thin-section	Ø-2	Ø-2a	Ø-2b	Ø-6a	Ø-8	Ø-8a	Ø-9	Ø-10a	Ø-12a	Ø-13	Ø-13a
Terrigenous quartz grains	46.7	11.7	10.0	9.4	24.4	12.0	7.0	33.4	16.8	21.7	11.2
Authigenic silica	4.0	0.3	+	25.6	26.6	26.0	32.4	19.0	6.2	5.6	13.8
Carbonates	48.6	88.0	90.0	53.0	37.0	58.4	45.4	35.6	56.6	59.0	49.6
Calcareous sponge spicules	-	-	-	1.0	+	-	-	4.4	3.8	3.4	17.0
Siliceous sponge spicules	-	-	-	7.6	6.2	0.6	7.0	1.0	0.4	-	-
Other fossil remains (usually brachiopods & bryozoans)	-	-	-	2.0	2.4	0.8	+	5.2	16.0	9.4	7.0
Carbonaceous matter & iron-oxides staining the rock	0.6	-	+	0.4	2.8	2.0	7.2	1.0	0.2	0.9	+
Glauconite	-	-	+	1.0	0.6	0.2	1.0	0.4	+	+	1.4
Tourmaline	+	-	-	-	-	-	-	-	-	-	-
Zircon	-	-	-	-	+	-	-	+	-	-	-

The Hornsund area

Cherty rocks of Permian age, similar to those described from the Sørkapp area, also occur in Hornsund in the area between Burgerbukta and Treskelodden. These rocks have been described by BIRKENMAJER (1964) as a unit called the Brachiopod Cherty Limestone. This bed, reaching up to c. 12 m in thickness, consists mainly of carbonaceous cherty limestones and dolomites containing brachiopods and sponges. Phosphorite concretions (often phosphoritized sponges) have also been recorded (BIRKENMAJER 1964). The present author, during her stay in Hornsund in 1960, collected some hand specimens of these rocks from Treskelen

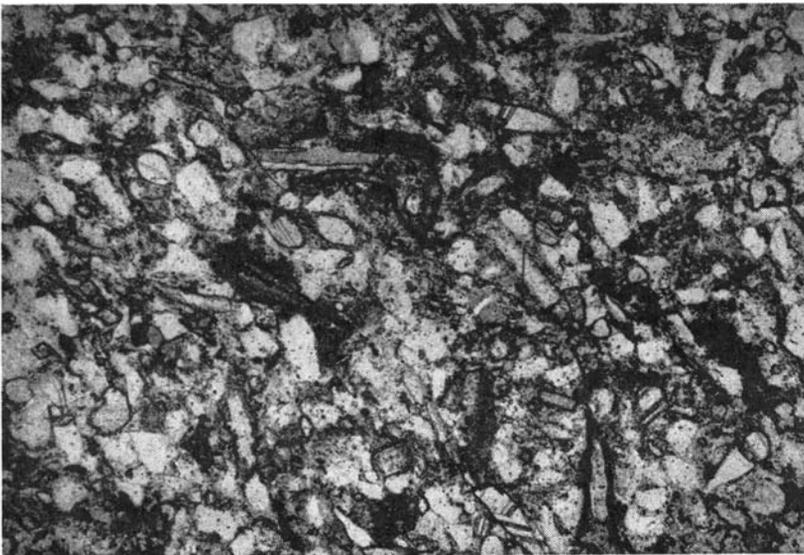


Fig. 23. *Arenaceous calcareous spiculitic chert. Sponge spicules either consist of chalcedony or are calcified. Lower Tokrossøya Beds, Øyrlandet, Øyrlandsodden, thin-section Ø-15, plane polarized light, × 50.*

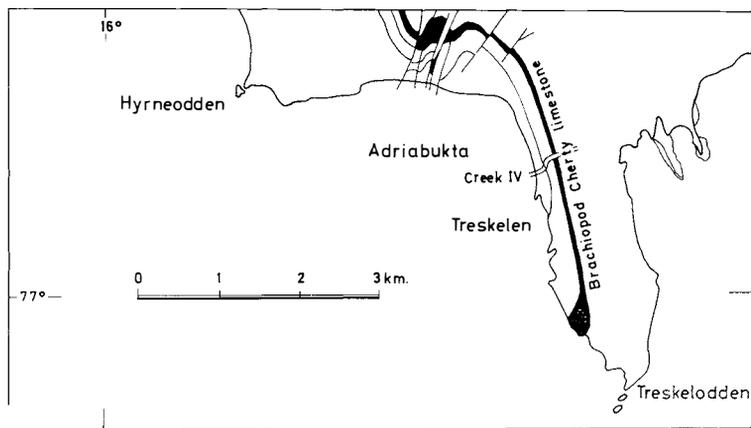


Fig. 24. Occurrence of the Brachiopod Cherty Limestone in the Hornsund area (simplified, after BIRKENMAJER 1964).

in the so-called Creek IV (Fig. 24), where thickness of Brachiopod Cherty Limestone is below 5 m. A petrological description of these rock specimens follows.

Specimens of the upper c. 2.5 m thick layer are representative of calcareous spiculite. This rock consists mainly of broken calcareous sponge spicules. The spicules are simple, rod-shaped and c. 0.05 mm in diameter. The cement of the rock consists principally of carbonates forming fine-crystalline concentrations, as well as of fine rhombic crystals. Fine-crystalline silica is a subordinate constituent of the cement. Some fragments of bryozoans, brachiopod shells, and small foraminifera have been observed. In addition, angular quartz grains <0.1 mm in size, glauconite, and carbonaceous matter are present.

Specimens from the lower c. 2 m thick layer are of arenaceous and calcareous spiculitic cherts or spiculites (Fig. 25). These rocks consist of sponge spicules cemented by authigenic fine-crystalline silica, carbonates and, in part, presumably by phosphates. The phosphate seems to be mixed with the authigenic fine-crystalline silica and a definite microscopic establishment of occurrence and of the precise amount of phosphates present is rather difficult. Macroscopically phosphates have not been reported from this bed, but have been observed in the subjacent conglomerate (BIRKENMAJER 1964).

Sponge spicules present in these cherts are c. 0.03–0.08 mm in diameter; the length of the longest fragment observed is c. 0.5 mm. The spicules are usually simple, rod-shaped or slightly curved. These are mainly chalcedony spicules with enlarged axial canals filled with randomly oriented chalcedony, or sometimes with carbonates. Some of the spicules are partially or completely replaced by calcite. Small angular quartz grains, hydromicas, and rarely, glauconite occur as accessories. Some fragments of brachiopods and other, unrecognizable fossil remains are present in the described rock specimens.

The Brachiopod Cherty Limestone is a thin unit characterized by a stable lithology (BIRKENMAJER 1964). Therefore, although the above petrological description is concerned with specimens from only one locality (Creek IV), it may probably be applied to rock samples from other localities.

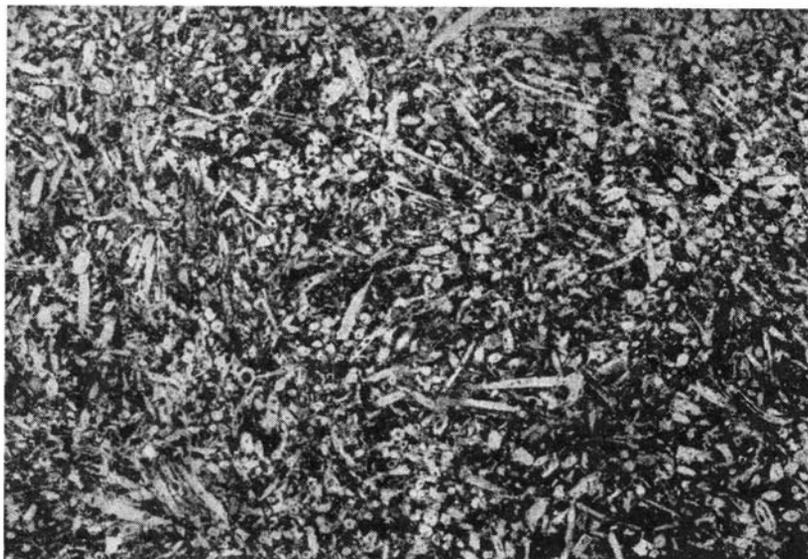


Fig. 25. *Spiculite*. *Sponge spicules consist of chalcedony; matrix is stained by pyrite, iron-oxides and carbonaceous matter. Brachiopod Cherty Limestone, Hornsund, Treskelen, thin-section P-3, plane polarized light, $\times 31.2$.*

The Bellsund area

Geological investigations in the Bellsund area were carried out by S. SIEDLECKI during the summer of 1965. Carboniferous and Permian sediments have been investigated in detail, especially those on the northern side of Bellsund and on the island Akseløya. SIEDLECKI's description of profiles of Brachiopod Cherts from Sundodden and Akseløya (localities shown on Fig. 26) are reproduced below. These descriptions have been supplemented by observations of hand specimens collected by him. Petrological investigations have been carried out studying thin-sections of these hand specimens. Unfortunately some of the specimens collected, especially those from the upper part of the Brachiopod Cherts, were lost in a boat accident in Bellsund, and therefore the petrological investigations are incomplete and are based primarily on specimens representing the lower part of the Brachiopod Cherts.

AKSELØYA

Profile at Vestodden (thin-section symbol — A)

The beds here dip c. 65–80° NE. Description begins with the lowermost beds.

Beach gravels and terrace; no outcrops of older rocks.

Dolerite (diabase) sill

c. 50 m

Terrace consisting of beach gravels and pebbles

c. 40 »

1. Limestones, dark grey, bituminous, yellowish on weathered surfaces. The layers are c. 5–20 cm in thickness. Fossil remains are usually lacking; only a few traces of sponges have been observed. Irregular cherty bands and lenses have been observed in the upper part of the bed.

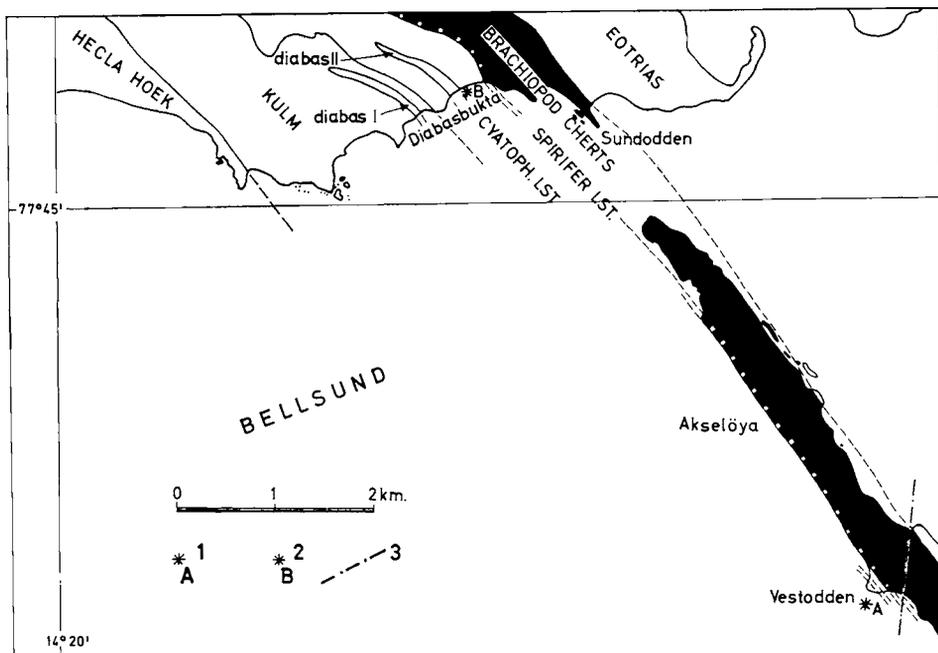


Fig. 26. Locality map of part of the Bellsund as discussed in the present paper. Geology after S. SIEDLECKI (unpublished data); 1 - profile at Vestodden; 2 - profile at Sunddoden; 3 - fault.

This bed belongs to the *Cyatophyllum Lmst.* Its top surface, the stratigraphic boundary between the *Cyatophyllum Lmst.* and the *Spirifer Lmst.*, is uneven which, rather than representing an original erosion surface, appears to be caused by the occurrence of cherty lenses and balls.

c. 3 m

Spirifer Lmst. ("Limestone A"):

2. Calcarenite, grey with abundant productus fauna. 0.2 »
3. Limestone, cherty with an abundant but poorly preserved fauna of small productids and gastropods. 0.08 »
4. Limestone, light grey, thick-bedded with a very rich fauna of brachiopods (spiriferids and productids) and bryozoans and some pelecypods. The fossils are usually silicified. c. 12.5 »

Brachiopod Cherts:

5. Shale, cherty, black, without fauna in lowermost part, and then cherts, nodular, with small brachiopods. 0.3 »
6. Chert, black, shaly, with quite abundant fauna of small brachiopods in the upper part. 1.05 »
7. Chert, black, without fauna; this grades into the subjacent bed. 0.35 »
8. Cherts, black, nodular, forming layers 5-35 cm in thickness. Some shaly bands occur among the nodular cherty layers. Generally, however, the whole bed is very monotonous. The rocks are hard, friable, with numerous joints, disintegrating into cube-like fragments or, where distinctly nodular, into individual nodules. Some layers become slightly grey or reddish on weathered surfaces. This latter property is probably due to the occurrence of siderite in the rock. c. 95 »
9. Shales, cherty, black, dark brown on weathered surfaces. A fairly abundant fauna of bryozoans (fenestellids) and sponges and some small productids is present in the shales. Weathering of the shales has produced a 2-5 m deep topographical hollow. c. 14 »

10. A monotonous, predominantly cherty bed with some shaly intercalations. The latter, reaching up to c. 1.5 m in thickness, are more frequent in the lower part of the bed. Cherts are dark grey; on weathered surfaces they are rusty yellow and can be observed as lighter-coloured band on Akseløya. A fauna of sponges, productids and spiriferids is quite abundant but poorly preserved. Lenses and layers of limestones and calcareous shales with a rich and well preserved fauna of *Spiriferella keilhavi*, other brachiopods, and crinoid stems has been found in this bed. North of the line of profile these layers increase in number and thicknesses, individual layers reaching up to 0.5 m. A cairn marking the highest point of the island is situated on this horizon. c. 35 m
11. Cherts, nodular, black or dark grey, with a very poor fauna. c. 44 »
12. Cherts and cherty limestones, grey, light brown on weathered surfaces. Individual layers are usually thick, some more than 1 m. Within this bed, especially in its middle part, an abundant but poorly preserved fauna of brachiopods (spiriferids) and bryozoans (*Fenestella* sp. and forms belonging to the order Trepostomata) is present. *Fenestella* sp. occurs chiefly in the lowermost part and Trepostomata predominantly in the middle part of this bed. 21.0 »
13. Cherty rocks, grey, usually friable, and mostly covered by the products of weathering. A poorly preserved productid fauna occurs in the uppermost layers of this bed. 12.0 »
14. Cherts, nodular in the lower part and shaly higher up. The nodular beds are whitish on the weathered surfaces. A poorly preserved fauna occurs locally. Bryozoans, especially *Fenestella* sp., have been observed. c. 50 »
15. Cherts, grey, whitish on weathered surfaces, thick-bedded, with some intercalations of shales. 16.0 »
16. Cherts, grey, poorly exposed and mostly covered by weathering products. This horizon is marked by a topographic depression. 15.0 »
17. Cherts, grey, readily weathered, with intercalations of yellowish cherts, more resistant than the grey variety, disintegrate slowly and form ledges between depressions underlain by the grey cherts. 20.0 »
18. Cherts, grey, yellowish on weathered surfaces, and containing a quite abundant, but poorly preserved fauna of productids. 12.0 »
19. Cherts, grey, easily disintegrating into small angular particles. These beds are poorly exposed. c. 45 »
20. Cherts, dark grey, forming thick layers. A fauna of productids, spiriferids and bryozoans is quite abundant although poorly preserved. Some shaly intercalations have been observed. c. 40 »
21. Cherts, forming thick layers and containing a fairly abundant fauna similar to that described above. This is the uppermost bed present in the Vestodden profile. 15.0 »
North of this section, however, a further c. 30–50 m of black cherts crop out, these disintegrating readily and sometimes being whitish on weathered surfaces. These layers usually contain a poor fauna and their lithology resembles that of the Lower Tokrossøya Beds from the Sørkapp area.

Superjacent beds do not crop out; however, it is probable that the black cherts are overlain by a soft shaly series belonging to the Eo-Triassic.

NORTHERN SIDE OF BELLSUND

Profile at Sundodden (see Fig. 26) (thin-section symbol – B).

The profile description starts with the lowermost beds cropping out west of Sundodden. The boundary between the Brachiopod Cherts and Spirifer Limestone is visible only at low-tide and is about 15 m below the first bed of the following description.

1. Cherts, black, nodular, forming 0.05–0.3 m thick layers disintegrating into separate nodules. Some sponges have been observed in this horizon. 17.5 m
2. Shales, cherty, black, with quite good fissility. Some chert lenses (up to 40 cm in thickness), similar to those described above, are present. Lenses of grey crinoidal limestones or of shaly limestones with scattered fragments of large crinoids also occur, especially in the southern part of the outcrop. These lenses are up to 0.2 m in thickness and 1.0 m in length. Round-shaped sponges and some brachiopods are present in the cherty shales. 3.8 »
3. Cherts, black, nodular, in layers 0.1–0.4 m thick, with intercalations of black cherty shales. 8.5 »
4. Cherts, black, nodular, in part shaly, readily disintegrating and poorly exposed. 20.0 »
5. Cherts, nodular, grey black, rusty yellow on weathered surfaces. In the lowermost part the cherts are shaly. No fauna. 15.0 »
6. Cherts, black and dark grey, indurated, forming thick beds. The cherts are rusty yellow on weathered surfaces. A poor brachiopod and bryozoan fauna has been observed. 10.0 »
7. Cherts, black and bluish, shaly or nodular, poorly exposed and forming a depression in the topography. 2.5 »
8. Cherts, bluish-grey and black, indurated, rusty yellow on weathered surfaces. Traces of a very poorly preserved fauna of brachiopods and bryozoans (*Trepostomata*) have been observed. 3.0 »
- Gap in observation, probably shales. 1.5 »
9. Interbedded layers of black nodular cherts or shaly cherts. A fauna of round-shaped and cylindrical sponges is common in the nodular cherts. Some small productids and a few corals have also been observed. There is a gradual transition into the next bed. 7.5 »
10. Cherts, black, shaly or nodular with lenses of light grey crinoidal limestones containing brachiopods and bryozoans. The limestones are sometimes partially sili-cified. Some traces of sliding of sediment have been observed. The limestone lenses reach up to 0.5 m in thickness. In the shaly cherts a brachiopod fauna is quite common.
Helicoprion svalis Siedlecki, new species (SIEDLECKI 1970) has been found in this bed. c. 15 »
11. Cherts, nodular, indurated, usually thick-bedded, locally with a poor fauna of bryozoans, brachiopods and sponges. The cherts are grey or bluish-grey and dis-integrate into angular particles. There is a gradual transition into the superjacent bed. c. 45 »
12. Cherts, usually nodular, forming thick layers, grey, rusty yellow on weathered surfaces. An abundant fauna occurs in the upper part of this bed. Productids, spiriferids, bryozoans (*Trepostomata*) and sponges have been observed. c. 19 »
13. Cherts, black, distinctly nodular forming 0.1–0.4 m thick layers. Some brachiopods and sponges have been observed in this horizon. c. 35 »
14. Shales, black, cherty, with a distinct fissility. 0.8 »
15. Cherts and shales with an abundant faunal detritus and some scattered productids and spiriferids. Cross-bedding has been observed here. 1.0 »
16. Shales, dark grey, cherty, weathering easily into elongated angular particles. 0.9 »
17. Cherts, dark grey, thin-bedded, in part shaly, containing a fairly abundant fauna of big brachiopods. This rock is transected by calcite veins. 1.25 »
18. Cherts, dark grey, yellowish on weathered surfaces, with a quite abundant fauna of brachiopods. The cherts comprise four thick layers. 1.90 »
19. A 0.85 m thick layer of dark grey chert with sponges occurs in the lowermost part; at the top of this layer brachiopods are found. Above this comes 0.3 m of shaly cherts and then a 0.6 m thick cherty layer with an abundant brachiopod fauna. Overlying this layer is a 1.0 m thick layer of chert, shaly or nodular, which weathers quite readily. 2.75 »

- | | |
|---|----------|
| 20. Interbedded layers of indurated, nodular, shaly cherts, dark grey, either unfossiliferous or with a very poor fauna of brachiopods. | c. 9.0 m |
| 21. Cherts, indurated, somewhat nodular, black, grey or bluish both on the fresh and weathered surfaces. The cherts are in layers 0.1–0.3 m thick. No fossils have been found. | 18.75 » |
| 22. Cherts, nodular, thin-bedded, bluish-grey; on the weathered surfaces they are somewhat yellowish. A fairly abundant fauna of big brachiopods is present in this bed. | 1.8 » |
| 23. A bed similar to that described as No. 22, with a more abundant fauna in some layers. | 2.1 » |
| 24. As above. | 4.3 » |
| 25. Cherts, grey, yellowish on weathered surfaces, in part nodular, containing an abundant fauna. This bed occurs at the head of the Sundodden peninsula and grades into the beds forming the peninsula itself. | c. 10 » |

On Sundodden:

- | | |
|--|----------|
| 26. The western part of the Sundodden peninsula consists of nodular cherts similar to those described as bed No. 21. On the Sundodden point, cherts, nodular, grey or bluish-grey, indurated, without fauna are present. | 9.1 » |
| 27. Cherts, nodular, seldom shaly, dark grey, becoming rusty on weathering. The cherts contain an abundant and well-preserved fauna. | 20.0 » |
| 28. Cherts, nodular, indurated, thick-bedded, with a very poor fauna. These cherts form a sharply crested ridge on Sundodden. | c. 58 » |
| 29. Cherts, partly nodular (especially in the lower part of the bed), grey; on weathered surfaces grey or yellowish. A poor fauna is present only in the lower part of the bed. | c. 45 » |
| Aggregate thickness of the Brachiopod Cherts at Sundodden: | c. 400 » |

Petrology

A common feature of cherts, the dominant rocks in the above described sections, is the salient admixture of impurities, mostly in the form of carbonates, terrigenous quartz and carbonaceous matter. Variations in their composition and microstructures allow a subdivision into four types:

1. Calcareous, fossiliferous spiculitic cherts;
2. calcareous, fossiliferous fine-crystalline cherts;
3. fine-crystalline cherts, and
4. fine-crystalline, glauconitic cherts.

Other rocks occurring in the described sections and subordinate to the cherts are: spiculites, biocalcarenites, and calcareous siltstones.

Calcareous, fossiliferous spiculitic cherts (Akseløya, bed No. 8, thin s. A-8b; bed No. 12, thin s. A-12, A-12b. Upper part of the section at Sundodden, from bed No. 26 upwards; thin-sections: S-40, S-41-65, S-43-65, S-45-65, S-46-65). — Sponge spicules are the main constituent of these rocks (Figs. 27, 28, 29). The spicules are usually randomly oriented, simple in shape and most of them consist of colourless chalcedony. Axial canals are usually filled with brownish chalcedony although some infilling consists either of glauconite or of carbonate. Furthermore, calcified spicules (totally or partially calcified) have been recorded.

The spicules are usually c. 0.025–0.03 mm in diameter; the longest fragment observed was 0.5 mm though generally they are c. 0.25–0.3 mm in length. A few distinctly thicker spicules, reaching 0.1 mm in diameter are also present. Spicules are cemented by fine-crystalline silica and carbonates. The latter are also present as somewhat larger rhombic crystals scattered throughout the carbonate-silica cement. Some of these crystals exhibit rusty-brown rims of iron-oxides, which suggests that they are either ferriferous dolomite or siderite. Small angular grains of terrigenous quartz are also present in these rocks.

Debris of calcareous fossil remains (brachiopods, bryozoans, rarely crinoids or small foraminifers) occurs in the calcareous spiculitic cherts in varying amounts. Where this debris is abundant, cherts show a similarity to silicified calcarenites; with a paucity of fossil debris the rock approaches a spiculite. Remains of some brachiopods and bryozoans are partially replaced or filled with fibrous chalcedony.

Glauconite infillings and rounded grains occur frequently; some grains are distinctly corroded by carbonates. Carbonaceous matter and pyrite are present, usually as accessories. Modal analyses of calcareous fossiliferous spiculitic cherts from the Bellsund area are summarized in Table 15.

Calcareous, fossiliferous fine-crystalline cherts (Akseløya, bed 9, thin-section A-9; bed 10, thin-section A-10d; Sundodden, thin-sections B-3, B-5). — These rocks are characterized megascopically by uneven shaly partings and the occurrence of scattered fossil fragments, large crinoid stems (up to 14 mm across) being predominant. Microscopic examination shows that the rocks consist mainly of fine-crystalline, brownish chalcedony with an admixture of carbonates, minute flakes of clay minerals, quartz dust, carbonaceous matter and pyrite. Indistinct minute sponge

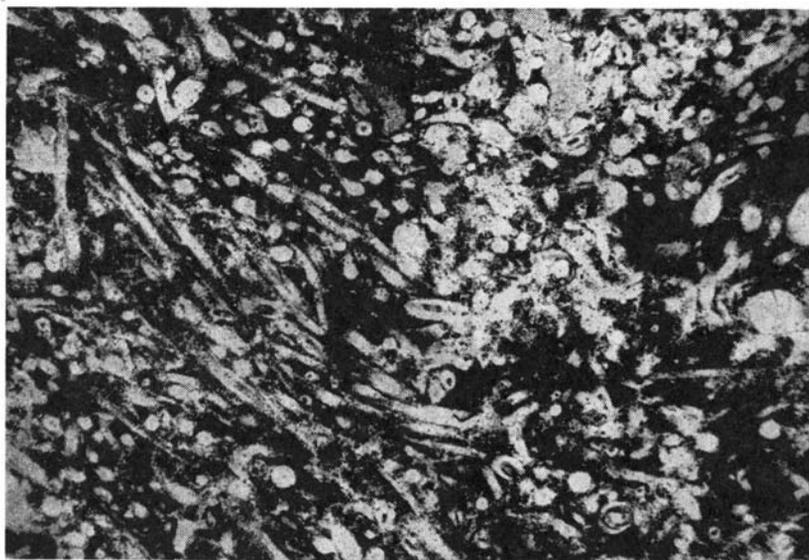


Fig. 27. *Calcareous fossiliferous spiculitic chert. Sponge spicules consist mostly of chalcedony; matrix consists of fine-crystalline silica and carbonates. Brachiopod Cherts, Akseløya, thin-section S-40-65, plane polarized light, ×50.*

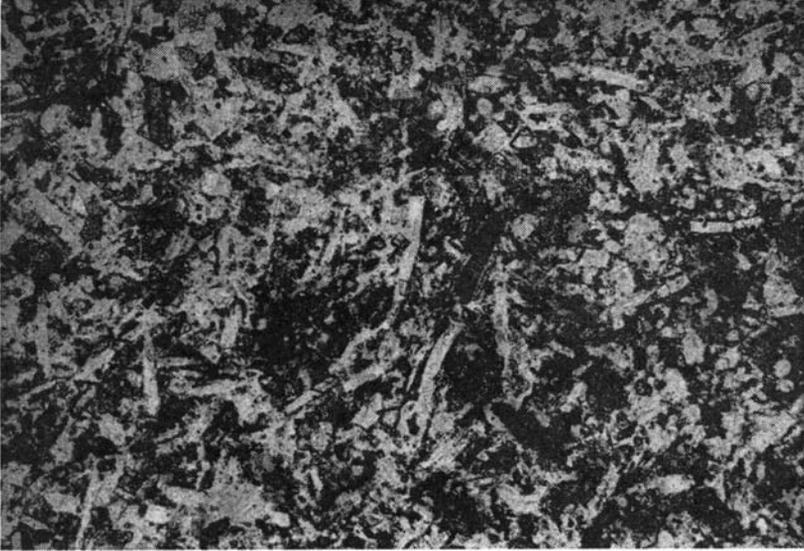


Fig. 28. *Calcareous, fossiliferous spiculitic chert. Sponge spicules consist of chalcedony. Matrix consists of fine-crystalline silica and scattered carbonate rhombs. Brachiopod Cherts, Akseloya, thin-section A-8b, plane polarized light, $\times 50$.*

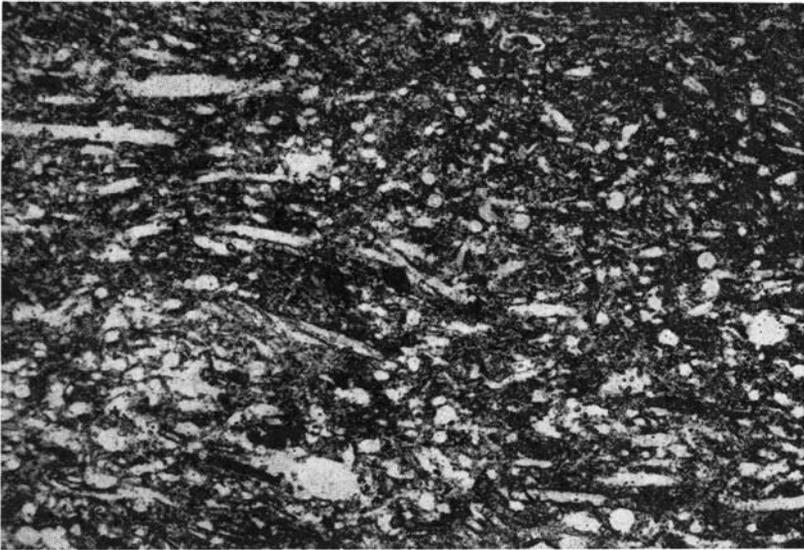


Fig. 29. *Calcareous spiculitic chert. Note planar arrangement of the sponge spicules. Brachiopod Cherts, Bellsund, W of Sundodden, thin-section S-45-65, plane polarized light, $\times 50$.*

Table 15
Calcareous fossiliferous spiculitic cherts, the Bellsund area

	Akseløya			Sundodden				
	A-8b	A-12	A-12b	S-40-65	S-41-65	S-42-65	S-43-65	S-46-65
Calcareous remains of brachiopods, bryozoans, crinoids, some partly silicified	0.2	23.0	26.0	21.4	38.6	17.0	26.6	0.4
Siliceous sponge spicules	46.4	33.0	28.4	37.6	13.6	45.0	39.0	45.6
Calcified sponge spicules	0.6	+	0.2	1.0	0.4	2.0	3.2	0.2
Fine-crystalline silica	18.2	+	9.2	12.2	22.4	8.0	5.2	6.6
Carbonates (often rhombs)	18.8	—	0.4	5.8	6.0	7.0	+	7.4
Mixed fine-crystalline silica with carbonates and clay minerals	15.2	33.6	30.0	20.6	16.2	20.8	23.8	36.2
Terrigenous quartz	0.2	10.4	5.8	+	+	+	+	2.4
Glauconite	0.4	+	—	1.4	2.8	0.2	2.2	1.2

spicules have been recorded from some horizons. The spicules, either randomly distributed or in a parallell orientation, consist of chalcedony; their outlines have been rendered diffuse by recrystallization. Crinoid stems, bryozoans and brachiopods scattered throughout these rocks either consist wholly of carbonates or are partially silicified. Depending on the amount of fossil remains present, the described rocks may show similarities either to biocalcarenes or to homogenous fine-crystalline cherts. Within the specimens examined this amount ranges from 20 to 40%.

Fine-crystalline cherts (Akseløya, bed 10, thin-section A-10a; lower part of the section at Sundodden, thin-sections B-1, B-2, B-4). — These rocks consist mainly of fine-crystalline brownish chalcedony and of terrigenous quartz dust (grains up to 0.03 mm in size), minute flakes of hydromicas, and carbonates. Carbonaceous matter and pyrite also occur. Minute sponge spicules consisting of chalcedony have sometimes been observed, these largely having been obliterated by recrystallization. Calcareous fragments of fossils are seldom present and are usually <1 mm in size (Figs. 30, 31).

Fine-crystalline glauconitic cherts (Akseløya, bed 6, thin-section A-6; bed 7, thin-section S-39-65). — The brownish groundmass of these rocks, similar to that described above, is fine-crystalline and consists of silica with an admixture of carbonates, terrigenous quartz (c. 0.02–0.08 mm in diameter), clay minerals, carbonaceous matter and pyrite. Carbonates are often present as somewhat larger isolated crystals, these probably representing recrystallized fragments of fossils. The most characteristic and prominent mineral of these rocks (up to 25% of the mode) is glauconite. It occurs primarily as round or oval grains 0.08–0.25 mm in diameter, though usually c. 0.15 mm. Pyrite dust or even fine cubes of this mineral are present within most of the glauconite grains. Carbonates often corrode the outer parts of glauconite grains forming thin rims around them.

In these rocks small (c. 3×10 mm) and rather indistinct structures of oval



Fig. 30. *Fine-crystalline chert with a bryozoan fragment in the middle. Brachiopod Cherts, Akseløya, thin-section A-10a, crossed nicols, $\times 31.2$.*

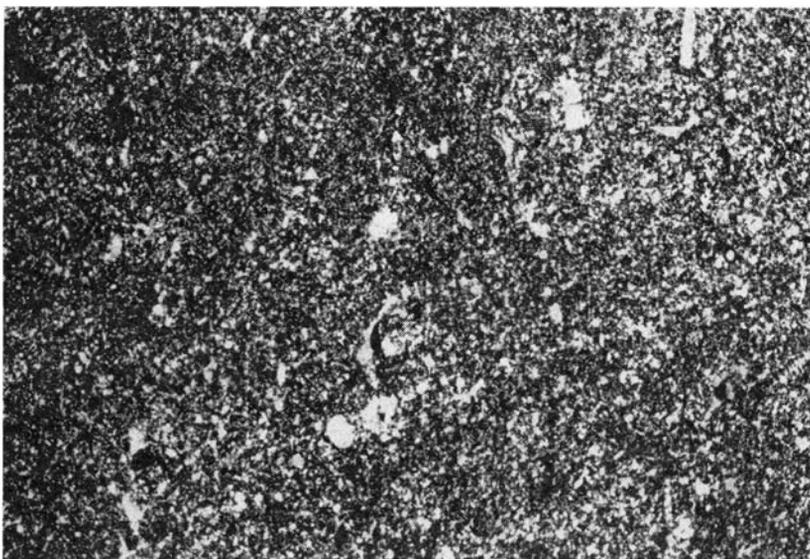


Fig. 31. *Fine-crystalline chert. Traces of sponge spicules consisting of chalcidony are visible. Brachiopod Cherts, Bellsund, Sundodden, thin-section B-1, crossed nicols, $\times 31.2$.*

outline are present, these probably being of organic origin. The structures are somewhat darker stained than the surrounding groundmass, and carbonaceous matter and glauconite tend to be concentrated within them.

As the above description reveal, the observed differentiation of the cherts originated in part during sedimentation and in part during diagenesis. The amount of admixed calcareous fossil fragments in the rock has clearly determined the calcareous and fossiliferous character of the cherts, while more or less advanced recrystallization and destruction of siliceous sponge spicules (which, in the author's opinion, were the main constituent of all these varieties of chert) is considered as responsible for their local spiculitic or fine-crystalline character.

Differences have also been observed between the cherts from the Sørkapp and Bellsund areas. Spiculitic cherts from these areas are similar in appearance but in those from the Sørkapp area (pp. 15–34) the spicules are often calcified and cemented by a siliceous or silica-rich cement. In the Bellsund area, spicules from the spiculitic cherts consist dominantly of chalcedony and are cemented by a calcareous, or carbonate-rich cement. This differing mode of occurrence of silica and carbonates in the spiculitic cherts from the two areas seems, to the author, to be associated with a more advanced diagenetic reorganization in the cherts of the Sørkapp area. Moreover, it is noteworthy that an admixture of quartz clasts is more prominent in the Sørkapp cherts than in those from Bellsund.

Spiculites (section on Akseløya, bed 8, thin-sections: A-8, A-8a; bed 11, thin-section A-11). – The spiculites consist of randomly oriented, closely packed siliceous sponge spicules (Fig. 32). The spicules consist of light brown chalcedony and a similar light-brown chalcedony constitutes the cement. They are simple monaxons

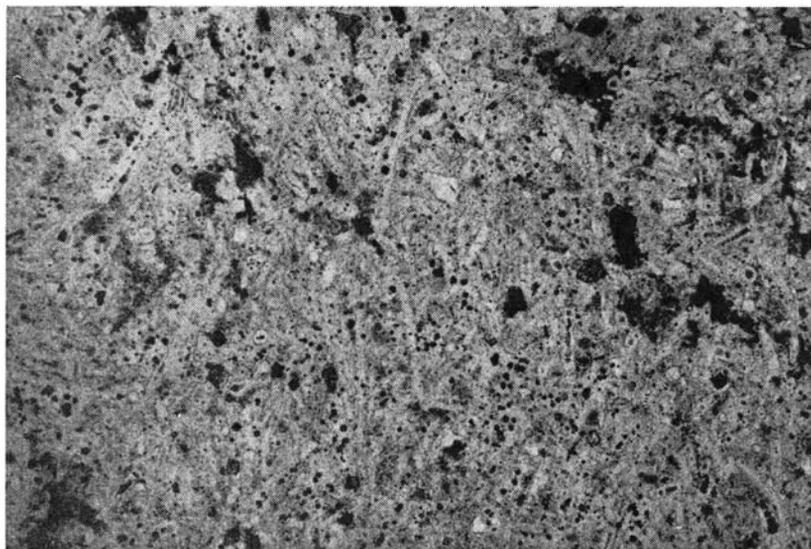


Fig. 32. *Spiculite*, *Sponge spicules with poorly defined outlines consist of chalcedony. Fine-crystalline siliceous matrix comprises scattered carbonate rhombs and pyrite. Brachiopod Cherts, Akseløya, thin-section A-8a, plane polarized light, × 50.*

of style and oxea type. They are about 0.03 mm in diameter; the longest fragment observed in thin-section measured 0.65 mm but lengths of about 0.3 mm are more common. Because of recrystallization of the silica the outlines of the spicules are not very distinct, and their recognition has often been facilitated by the dark brown colour of siliceous secondary infillings of axial canals. A few spicules are calcified. Scattered grains of glauconite, rhombs of carbonates, pyrite, concentrations of carbonaceous matter and small grains of terrigenous quartz have been recorded. Small, irregular, brownish mineral aggregates, isotropic or very weakly anisotropic, have been in many interstices observed; these represent impure, crypto-crystalline silica but may partly consist of phosphates.

Some larger (c. 5×1 mm) elongated irregular cavities are filled with a brownish fibrous chalcedony similar in colour to that filling the axial canals of spicules and which presumably belongs to the same diagenetic generation of silica. In addition, thin veins of colourless quartz, partially replaced by carbonates, are present. These veins cut across concentrations of brownish chalcedony and represent the youngest generation of silica in these spiculites.

Biocalcarenites (section on Akseløya, bed 10, thin-section A-10e, A-10f, A-10g; section at Sundodden, bed 2, bed 10, thin-section B-6). — The biocalcarenite layers and lenses, present within the cherty rocks on Akseløya, are light grey in colour and consist mainly of fragments of crinoid stems, of debris of bryozoans and of minute fragments of algae. Crinoid stems are visible megascopically and reach up to 12 mm in diameter; usually, however, they are < 5 mm. Complete shells of large brachiopods are quite common while fragments of brachiopod shells and spines of productids constitute accessory components of the described rocks. Organic debris is never rounded. Small glauconite grains were seldom recorded. The matrix between the detritical particles consists of fine-grained calcilutite. Interstices are filled with secondary calcite. In some parts of the biocalcarenites an admixture of siliceous sponge spicules and of authigenic silica partly replacing both cement and organic debris can be observed (Figs. 33, 34). The silica is usually fine-crystalline; fibrous chalcedony is rarely present.

Calcareous siltstone (section on Akseløya, bed 10, thin-section A-10c). — Fine, subangular quartz grains (c. 60%) are cemented by carbonates with an admixture of flaky minerals. Throughout this cement (c. 25% of the mode) are disseminated small spots and, locally, euhedral crystals of pyrite (c. 15%). Glauconite, zircon and tourmaline were seldom observed.

Remarks on the chemistry of cherts

Some chemical analyses have been carried out for two principal reasons. In the first place it was necessary to determine the complete characteristics of the investigated rocks and confirm the results obtained from the study of thin sections. Microscopic examination provides abundant information about structures, textures and the main constituent minerals of the cherts, but only approximate



Fig. 33. *Biocalcarenite*. Fossil remains are in part silicified. Matrix consists mainly of minute siliceous sponge spicules. *Brachiopod Cherts, Akseløya, thin-section A-10b, plane polarized light, ×12.5.*

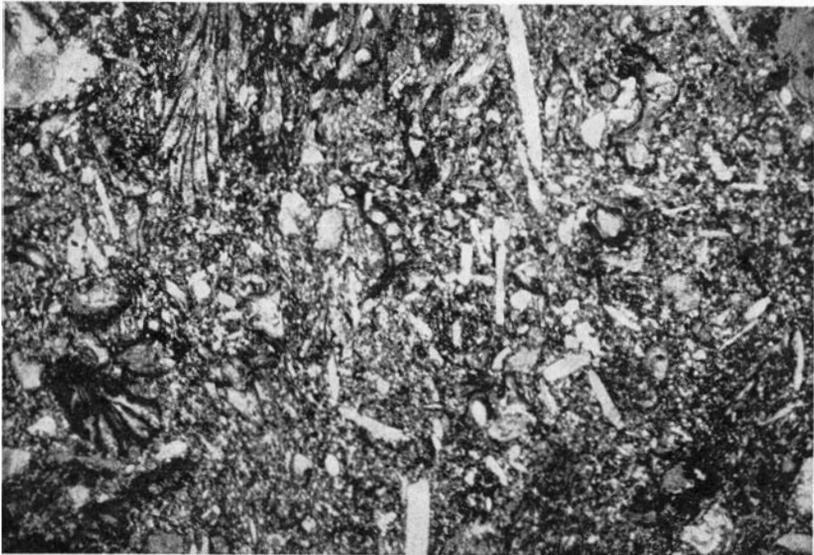


Fig. 34. *Biocalcarenite*. Bryozoan fragments prevail. Minute siliceous sponge spicules are the predominant component of the matrix. *Brachiopod Cherts, Akseløya, thin-section A-10d, plane polarized light, ×12.5.*

data concerning their precise mineral composition, i.e. chemistry. In particular the following characters should be clarified by chemical analyses: 1) changes in the amount of silica in particular specimens of cherts; 2) quantitative ratios between the two major constituents, silica and carbonates; 3) relations between calcite and dolomite; 4) discovery of possible admixtures within the microcrystalline parts of the rocks, which are difficult to distinguish under the microscope, for example phosphates.

The data obtained (see Table 16) indicate that:

1. The total amount of silica in the cherts which have been analyzed ranges from c. 47% to c. 82%, reaching up to c. 95% in the spiculites.

2. There is close relation between the proportions of silica and carbonates present, these being the main constituents of the rocks.

3. In specimens rich in carbonates it is calcite which dominates over other carbonates (mainly dolomite).

4. A relatively large amount of Al_2O_3 occurs in most of the analysed specimens, represented by quite large amounts of hydromicas and clay minerals, more in fact than was thought on the basis of the microscopic examination. The amount of K_2O is dependent on the amount of glauconite in the rock (compare the microscopic and chemical data for specimen A-6) and also bears a relationship to the amount of minute hydromica flakes which were recorded. Phosphates, the occurrence of which was expected from the examination of thin-sections, are present only in minor amounts and do not appear to show any marked preference for any particular rock-type.

The second reason for obtaining the chemical analyses was because of the similarity of facies which these cherts and associated rocks show to the Phosphoria Formation (more about this similarity on pp. 63–64), rich in phosphates and including scattered deposits of zinc, vanadium, nickel, molybdenum and uranium. The amounts of Zn, Ni, V and Mo in the three selected specimens (see Table 16), however, are not regarded as satisfactory enough for a true comparison to be made, and a more systematic investigation of the metal contents of these rocks is clearly necessary before any conclusions can be reached.

Sedimentary environment

The problem of the sedimentary environment of the Brachiopod Cherts and their lithological counterparts in the Hornsund and Sørkapp areas has not attracted the attention of previous geologists. The presence of marine fauna and the general character of sediments, together with some palaeogeographical data has, however, resulted in a general acceptance of a shallow-water, marine origin for the rocks in question (e.g. ORVIN 1940, DINELEY 1958, BIRKENMAJER 1964, SIEDLECKI 1964). Only ORVIN (1940, p. 28) has ventured a more definite opinion on this subject in stating that "cherty rocks of Spitsbergen are thought to have been deposited in a sea not more than 300 m in depth..." More detailed considerations of this topic, based on the present petrological study and on the

Table 16
Chemical analyses of cherts from the Bellsund and Sørkapp areas

No.	Name of rock	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	H ₂ O	H ₂ O ⁺	CO ₂	P ₂ O ₅	Org.	Sum	V	Ni	Mo	Zn
A-10d	Calcareous, fossiliferous fine-crystalline chert	54.03	0.34	8.11	0.96	1.69	0.01	1.58	15.57	0.43	1.84	0.39	2.47	12.33	0.02		99.77	60 ppm	30 ppm	—	10 ppm
B-3	→	47.35	0.23	6.08	0.82	0.99	0.02	1.57	21.63	0.17	1.35	0.26	2.24	17.26	0.03		100.00				
A-8	Spiculite	94.85	0.04	1.09	0.36	0.32	0.00	0.41	0.74	0.10	0.19	0.13	0.87	0.76	0.19		100.05				
B-1	Fine-crystalline chert	79.10	0.35	8.80	0.84	1.29	0.00	1.60	1.41	0.26	2.23	0.44	2.41	1.28	0.01		100.02	30 ppm	60 ppm	<3 ppm	<10 ppm
B-2	→	82.37	0.28	6.96	0.17	1.14	0.00	1.11	1.58	0.25	1.69	0.33	1.40	1.64	0.02	0.92	99.86				
A-12	Calcareous, fossiliferous spiculitic chert	62.94	0.25	2.56	0.12	2.05	0.03	0.92	16.34	0.14	0.29	0.04	1.69	12.70	0.03	0.31	100.41				
A-6	Fine-crystalline glauconitic chert	64.30	0.28	7.66	4.70	2.41	0.00	2.14	5.12	0.28	2.54	0.53	2.94	4.78	0.12	2.04	99.84				
Wa-27	Arenaceous, calcareous spiculitic chert	79.31	0.03	4.70	0.87	0.33	0.10	0.16	5.69	0.58	0.59	0.18	1.76	4.61	0.02	0.50	99.33				
Wa-25	→	69.40	0.02	4.38	0.53	0.75	0.00	0.41	11.91	0.35	0.80	0.19	1.35	9.31	0.02		99.42				
Wa-34	→	79.22	0.02	3.82	0.49	0.70	0.00	0.35	6.96	0.40	0.46	0.04	1.56	5.53	0.02	0.41	99.98				
Za-5	→	76.81	0.27	6.21	0.94	1.10	0.02	0.47	5.49	0.44	0.92	0.11	1.80	4.44	0.05	0.79	99.86				~10 ppm

application of data obtained by several students of ancient and recent marine environments and sediments, will be presented below.

Quite an important indicator of the marine environment, and common to all the rocks described in the previous chapters, is glauconite. This mineral has been found in almost all thin-sections studied, in cherts, carbonate rocks, and sandstones, in quantities usually less than 3% but exceptionally up to 25% of the mode. Some of this glauconite, especially the rounded, well-defined grains, might have been redeposited locally; lobate grains filling interstitial voids, however, may be thought of as authigenic.

The environment of formation of glauconite is relatively well known. Since HUMMEL's (1922) investigations, glauconite has been regarded as one of the most characteristic products of halmyrolysis. Physical conditions of formation of this mineral, investigated and discussed by many authors (e.g. HADDING 1932, CLOUD 1955, EHLMANN et al. 1963, PRATT 1963, LECLAIRE 1964, PORRENGA 1967) and summarized by CLOUD (1955, p. 490), are approximately as follows: 1) marine environment; 2) normal salinity; 3) slightly reducing conditions; formation of glauconite is facilitated by the presence of decaying organic matter which helps to produce reducing conditions; 4) waters of an average temperature of around 14°C-15°C; 5) rather slow sedimentation. Moreover, SHEPARD (1964) emphasized that glauconite, common on continental shelves, is lacking in bay sediments. Glauconite may occur at depths from 10–2000 m (according to data summarized by PORRENGA, 1967) or even more (4000 m, after MURRAY and RENARD 1891), and in view of this it cannot be considered as an indicator of the depth of formation of sediments. However, as emphasized by

FAIRBRIDGE (1967), the optimum zone of glauconitization is from c. 15 to c. 500 m. FAIRBRIDGE (1967) also pointed out that glauconitization is not favoured by cooler waters as suggested by CLOUD (1955), being common in recent warm shelf seas.

Other indicators of sedimentary environment observed in the various rock-types investigated, and which supplement the data given by glauconite will be considered below.

CHERTS

Parent sediments of the cherts from the Brachiopod Cherts, Brachiopod Cherty Limestone and Lower Tokrossøya Beds were muds consisting of siliceous sponge spicules, terrigenous quartz grains, fine lime clasts and organic, carbonaceous matter. These muds included faunal skeletons buried 'in situ' or redeposited. The carbonaceous matter provides direct evidence of reducing conditions, probably only slightly reducing in this case because it is present as a minor constituent. Of the fossils present in the cherts, only the sponges are preserved in situ and may be thought of as indicators of the depositional environment of the host sediment. These sponges belong to the Lithistida and represent mainly the genus *Haplistion* (SIEDLECKA 1970). Lithistids, however, both modern and ancient, may occur in quite variable conditions, at different depths and in different sediments and are therefore not particularly satisfactory indicators of sedimentary environment. After FINK's (1960, p. 26) observations, late Palaeozoic lithistids of the Texas region "...are in general equally abundant in rocks of the shelf and basin facies." Usually, however *Calcispongia* predominate in shallow-water calcareous shelf deposits. Lithistids of the Palaeozoic on the other hand lived in still, relatively deep, muddy waters of inter-reef or fore-reef tracts (OKULITCH & NELSON 1957). Modern lithistids occur chiefly below the zone of penetration of light (DE LAUBENFELS 1955, p. E44) but are generally less common than *Hyalospongia* at depths of 1000 m and more (DE LAUBENFELS 1957). Lithistids are not particularly abundant in the Permian cherty rocks of Spitsbergen; their growth and development was probably hindered by rather unfavourable conditions. The main hindrance was presumably a scarcity of oxygen which is necessary for the life of these aerobic organisms. Sponge spicules which are abundant in the cherts are redeposited and, although a significant factor in the origin of cherts, cannot be considered as indicators of sedimentary environment.

Summarizing the discussed features, indicative of sedimentary environment, it may be supposed that the Permian cherty rocks of Spitsbergen were deposited in rather still, semi-stagnant waters, in depressed areas on the shelf (presumably the outer shelf) and in slightly reducing conditions in which carbonaceous matter and glauconite originated and which, at the same time, hindered the development of a benthos fauna restricted here to a few species of sponges. Other fossils, such as brachiopods, bryozoans, crinoids etc. are redeposited and were probably washed into the depressed area (or areas) by bottom currents from a shallower sublittoral environment. The siliceous sponge spicules of the cherts are remains of siliceous sponges other than lithistids and their history of deposition is hard to establish. The difficult and complicated problem of the origin of the cherts as they appear today will be considered in more detail below.

CARBONATE ROCKS

Carbonate rocks are represented mainly by biocalcarenes consisting chiefly of fragments of benthonic organisms such as bryozoans, brachiopods and, in the Bellsund area, crinoids. The biocalcarenes are usually impure (arenaceous, cherty), forming transitions into cherts and into sandstones. The transitions into cherts resulted of an uneven distribution of calcareous and siliceous fragments of skeletons of which these carbonate and cherty rocks essentially consist. The impure biocalcarenes associated with cherts originated in a similar sedimentary environment to that of the latter, though probably during periods of stronger bottom current activity. These currents transported quite large fragments of bryozoans, often big brachiopods and crinoids. In particular cases, trends of bottom currents, the current velocity and the distance from the settlement of benthos fauna were important factors. Prominent in geological sections of Upper Tokrossøya Beds are carbonate rocks (usually arenaceous and cherty) with an abundant redeposited fauna; these rocks originated in shallower water and on better aerated parts of the shelf-sea floor than those closely connected with the development of cherts. They were also presumably situated closer to settlements (?patch-reefs) of benthos fauna.

Well defined lenses and beds of relatively pure light-coloured biocalcarenes, consisting also of bryozoan, brachiopod and crinoid particles, have been observed within dark cherty rocks in the profiles at Sundodden and Akseløya (the Bellsund area). These rocks might be interpreted as the outer parts of reef talus interdigitating with dark muddy bottom deposits. Reefs are as yet unknown from the Permian of Svalbard; abundant redeposited reef organisms, however, are clear indications that reefs did in fact exist.

The carbonate rocks are usually arenaceous and in the Sørkapp area there is a gradual transition between these rocks and the fossiliferous sandstones and siltstones. This transition depicts a gradual change of sedimentary environment.

THE FOSSILIFEROUS, FINE-GRAINED SANDSTONES AND SILTSTONES

The sandstones and siltstones consist principally of fine, poorly rounded and poorly sorted quartz grains. Quite abundant particles of bryozoans and brachiopods are much larger in size and not rounded. Entire shells of brachiopods are present while glauconite and small amounts of carbonaceous matter also occur. These features show that the fossiliferous sandstones and siltstones originated in a sublittoral environment in which the activity of bottom currents and the influence of continental environment (terrigenous quartz) were more prominent than in the case of the deposition of the cherty or carbonate rocks. Bryozoans and big brachiopods suffered only a short transport (they are not rounded) from the milieu of strong currents and wave activity which destroyed the settlements of this benthonic fauna.

SILICA-CEMENTED AND CARBONATE-CEMENTED SANDSTONES

Silica-cemented and carbonate-cemented sandstones occur in the Upper Tokrossøya Beds, and on Øyrlandet also in the Lower Tokrossøya Beds. These sandstones are well sorted, medium-grained or medium- and fine-grained and consist of relatively well rounded quartz grains. Both marine faunal remains and small particles of continental flora are occasionally present. Glauconite has also been recorded in all investigated specimens. Taking these various features into account it is thought that parent sediments of these sandstones were probably well sorted beach sands or sand waves deposited within or near the tidal area. Faunal and floral remains were occasionally mixed with these sands, perhaps during periods of stronger wave activity. The uneven distribution of siliceous and calcareous faunal remains has resulted in a differentiation of the sands, during diagenetic processes, into carbonate-cemented and various silica-cemented sandstones.

The occurrence of sandstones (usually glauconitic) above the Brachiopod Cherts in central Spitsbergen has been reported from many localities by several authors (ORVIN 1934, 1940, GEE et al. 1952, DINELEY 1958, WINSNES 1966). It is probable that these sandstones correspond to those of the Upper Tokrossøya Beds from Sørkapp and originated in similar conditions.

In general it may be concluded that parent sediments of the rocks of the Permian of Spitsbergen, as considered in the present paper, were deposited in an epicontinental marine environment characterized by normal salinity, slightly reducing conditions and periods of bottom current activity. A period of maximum transgression of the sea is reflected in appearance of muds rich in sponge spicules which accumulated in relatively deep and quiet water. A gradual shallowing and regression of the sea is recorded by an accumulation of bioclasts and of quartz sand and silt containing faunal fragments. The period of maximum regression is marked by the littoral sandy sediments in Sørkapp and central Spitsbergen and by a hiatus in the Hornsund area (BIRKENMAJER 1964).

Origin of cherty rocks

As described previously, the Permian cherty rocks of southern Spitsbergen are dark, dense and indurated layered rocks consisting from a chemical point of view of silica and carbonates. It is not possible to differentiate between e.g. pure chert nodules or lenses, or layers within or between carbonate host rocks; there are always transitions from more siliceous to more carbonate-rich rocks and quantitative differences are often determinable only under the microscope. In the Bellsund area cherty rocks sometimes show a nodular disintegration; this is usually absent in the Sørkapp area.

In considering the origin of these cherty rocks, the silica and carbonates may be regarded partly as allochthonous and partly as autochthonous components of the rocks. Terrigenous quartz grains and spicules of siliceous sponges represent detrital silica. Allochthonous detrital carbonates are represented by carbonate skeletons and particles of skeletons of a marine fauna of bryozoans, brachiopods,

crinoids etc. Autochthonous chalcedony fills and replaces skeletons of bryozoans and shells of brachiopods originally consisting of carbonate (aragonite, calcite); it also fills the axial canals of siliceous sponge spicules and constitutes part of the cement. Chemical autochthonous components of the sediment are those carbonates which form pseudomorphs after siliceous sponge spicules, and the carbonates present as a component of the cement.

It would seem that, of the various constituents of the cherty rocks, the siliceous sponge spicules played an especially important role in the origin of these rocks. This opinion agrees with that of HINDE (1888) who stated that the cherts of Spitsbergen were derived from detached spicules of siliceous sponges. The siliceous sponge spicules (including their calcitic pseudomorphs) usually display quite simple shapes in the manner of styles and oxeas. Under the microscope they were observed in different randomly oriented sections; if other more complicated forms of spicules were present in any quantity they would be expected to appear in thin-sections fairly frequently. However, in about 150 thin-sections examined only a few spicules of more complicated shape have been recorded. Thus, the spicules are thought by the author to be mainly monaxons which formed skeletons (or participated in the formation of skeletons) of Demospongea other than lithistids, the entire bodies of which are preserved in the cherts. The simple monaxial form of the spicules was also emphasized by HINDE (1888) who even supposed these spicules to belong to *Reniera clavata* Hinde, and *Reniera bacillum* Hinde. In some places (in thin-sections) the present author has observed concentrations of simple siliceous spicules cemented by clean authigenic quartz and chalcedony. These concentrations, regarded as a distinctive rock-type, constitute spiculite. They may, where preserved in situ or only slightly moved, represent remains of no longer recognizable Demospongea. A few quite well preserved individual bodies of organic origin (? sponges) consisting of spicules similar to those above, have been found chiefly in the Sørkapp area (SIEDLECKA 1970, Part II of this volume). Monaxons are also present in material filling the canals of Lithistida. These canals were wrongly interpreted by DUNIKOWSKI (1884) as skeleton fibres, the sponges being considered by the same author as Monactinellida. All these observations lead to the conclusion that both lithistids and other Demospongea (and perhaps even other classes too) grew on the sea floor at the time of formation of the cherts. Lithistids could be preserved because of their rigid and compact skeletons. Sponges, which on the contrary did not form net-like solid skeletons, were destroyed after the death of the animals. Spicules were then left as a detritus scattered and transported by currents on the sea-floor, and subsequently partially dissolved and often included within sediment as one of its important constituents.

The quantity of siliceous sponge spicules preserved indicates that sponge development was quite significant. Such an abundant and flourishing growth of these animals could be connected with a somewhat higher than usual content of silica in the sea water. It is not impossible that quite strong volcanic activity during the Permian period could have assisted in enriching the sea water in silica. Decomposition of volcanic glass in the sea water and a coeval precipitation of silica by sponges could be regarded as contributing to their development. Many authors have emphasized the connection, or the possibility of a connection be-

tween the development of siliceous organisms (mainly diatoms and radiolarians) and volcanism (e. g. RUBEY 1929, TALIAFERRO 1933, BRAMLETTE 1946, GOLDSTEIN and HENDRIKS 1953, WIESER 1963, KOTLARCYK 1966).

Terrigenous quartz grains and redeposited calcareous remains of brachiopods, bryozoans and others, accumulated on the sea floor contemporaneously with opaline sponge spicules. All these bio- and lithoclastic components are often fairly well scattered throughout the groundmass of the cherty rocks. Such a distribution suggests a chemical or biochemical precipitation, contemporaneous with deposition of the allochthonous constituents, although it is also possible that the groundmass has been derived from minute organic debris which has since been recrystallized and has thus lost its true identity. In the groundmass two principal chemical constituents are present — silica and carbonates — the conditions of precipitation of which needs to be considered. The primary chemical precipitation of groundmass constituents must be connected with such main factors as the composition and degree of saturation of the bottom sea-water solution, pH values, and the possible presence of organisms indirectly effecting precipitation. Investigations of recent sedimentary processes in the seas, analyses of waters from these seas and numerous laboratory experiments may provide some data on this question. Contents of silica in present-day sea waters are very low. KRAUSKOPF (1959) reports 0.1–0.4 ppm SiO_2 in surface waters and 5–10 ppm in deep waters. The solubility of amorphous SiO_2 is, after KRAUSKOPF's investigations, 50–80 ppm at 0°C and 100–140 ppm at 25°C (solubilities of other forms of silica are lower). According to BRUEVICH (1953), the maximum content of silica in sea water is 26.7 mg/l and in water filling voids of bottom sediments up to 70 mg/l. The highest contents reported are, however, much lower than those of saturated solutions and, if conditions in the Permian seas were similar, direct chemical precipitation of silica was highly improbable. There were sponges (and other silica-secreting organisms?) which could precipitate silica from such undersaturated solutions and form their own skeletons. Although other organisms could possibly indirectly effect the precipitation of silica, there is, however, no way of confirming such a process. Direct primary precipitation of carbonates is more feasible (water of present-day seas is more or less saturated with CaCO_3), although, again based on investigations of recent seas and recent carbonate sediments (e. g. TAFT 1967), inorganic precipitation can rarely be proved. In general, a predominance of biochemical processes over purely chemical in the formation of limestones seems now to be universally accepted (CAROZZI 1960). In conclusion, it would appear that the primary groundmass of cherty rocks consisted essentially of minute organic debris (calcareous and siliceous) rather than having been chemically precipitated. If, however, such a process of precipitation ever occurred, it would rather have been restricted to a precipitation of carbonates.

The mechanical processes of transport and accumulation of bio- and lithoclastic material were, after burial, followed by a chemical, diagenetic reorganization of silica and carbonates. The diagenetic reorganization consisted essentially of solution and reprecipitation of both these compounds and reversal silica-carbonate replacement. The physico-chemical conditions favouring these processes (especially solution and precipitation of silica) are not quite clear and have

been considered by many authors. CORRENS (1950) suggested that pH variability is the main factor controlling reversal solution and reprecipitation of silica and carbonates. ALEXANDER et al. (1954), however, established that solubility of amorphous silica is independent of pH values from 2 to 9.5, these data being somewhat later confirmed by DAPPLES (1959). It was also shown by experiment (KRAUSKOPF 1959) that solubility of silica increases rapidly in extremely alkaline waters. WALKER (1962) enlarged on the explanation given by CORRENS (1950) and stated that processes of reversal silica-carbonate replacement are controlled by pH variability and take place in a highly alkaline environment (pH above 9). There is, however, no agreement among research workers of silica geochemistry as to whether such extremely alkaline waters are common in nature (e. g. WALKER 1960, WALKER 1962, DAPPLES 1967). Further, LOVERING and PATTERN (1962) proved experimentally that precipitation of silica evidently increases in the presence of CO₂ and WALKER (1962) assumed that variations in the amount of CO₂ (in high alkaline conditions), derived e. g. from decaying organic matter, may result in variations in pH values.

In summary, besides a saturation of solutions, a high alkaline environment, pH variability and the presence and variability of CO₂ are essential factors which together effect silica-carbonate reversal solution and precipitation.

Returning again to the Permian cherty rocks of Spitsbergen, it may be assumed that solution of some of the opaline sponge spicules, before the silica saturation point of interstitial solutions was reached, was one of the first stages of post-burial processes. Amorphous silica is metastable at low temperatures (SIEVER 1962) and therefore the solution of opaline skeletons of sponges after the death of these animals could begin relatively easily, as in the case of diatoms (LEVIN 1961, SIEVER 1962). At the same time a reversal process of carbonate-silica precipitation could commence beginning with carbonate precipitation contemporaneously with solution of sponge spicules. In the alternating process of carbonate-silica crystallization, precipitation of silica was presumably ascendant and therefore the soft sediment has been gradually transformed into indurated cherty rock.

Amorphous silica of sponge spicules which did not go into solution changed gradually to chalcedony; axial canals of the majority of these spicules have been filled with a brownish chalcedony similar to that of the groundmass and probably representing the same generation of silica. Earlier, some spicules had their axial canals filled with glauconite, while the canals of some others were later filled with carbonates. Recrystallization of calcareous fossils was probably in progress at the same time.

Selective replacement of calcareous fossils by silica and selective calcification of siliceous sponge spicules were presumably later diagenetic processes. These processes of selective replacement were pH- and alkalinity-controlled similarly to that of the earlier reversal carbonate-silica precipitation discussed above. It is not clear why such a selective silicification of calcareous fossils occurs commonly in nature. A connection between the silicification process in fossils and some particular environment has been reported (e. g. NEWELL et al. 1953) and many authors have suggested that certain types of fossils may be quite sensitive to silicification. As shown by data summarized by DAPPLES (1967, table II) bryozoans, brachiopods

and also corals exhibit the most marked tendency towards silica-replacement. Of siliceous fossil remains, sponge spicules are perhaps those most easily converted to carbonate. In conclusion, the hypothetical view of the author is that the silicification of brachiopods and bryozoans and calcification of siliceous sponge spicules observed in the Permian cherty rocks of Spitsbergen are closely related processes constituting a closed system.

Dolomitization and local precipitation of siderite, more or less advanced in these cherty rocks, are regarded as relatively late processes subsequent to the silicification. The dolomitization is manifested in scattered individual euhedral crystals of dolomite or groups of rhombic crystals of this mineral.

The diagenetic reorganization of silica and carbonates seems to be more advanced in cherts of the Sørkapp area where sponge spicules are often calcified and the cement, as well as other originally calcareous fossil remains, silicified.

Cherty rocks of Permian age are widespread in central Spitsbergen, and their occurrence has been reported in many papers. Somewhat more detailed descriptions of these rocks are to be found in the publications of HOEL and ORWIN (1937) and WINSNES (1966). The petrology of these cherty rocks from central Spitsbergen is poorly documented, but in their general character they are similar to the cherts of southern Spitsbergen. Moreover, HINDE (1888) recorded the occurrence of sponge spicules in a specimen of Brachiopod Cherts from Grønfjorden (at the eastern side of Isfjorden). White cherts present at the top of the Brachiopod Cherts on Templet in eastern Isfjorden and not recorded in southern Spitsbergen, consist almost exclusively of siliceous sponge spicules (HINDE 1888). It is thus possible that the Permian cherts of the whole of Spitsbergen have a common origin, and that everywhere sponges were the main agent precipitating silica. Certain petrological differences exist, however, even between the Sørkapp and Bellsund areas, so that a final opinion on the probable genetical uniformity of these Spitsbergen cherts must await supplementary investigations.

Comparisons with some cherts from other regions

Cherts, layered or nodular, derived from an accumulation of siliceous sponge spicules, have been reported by several authors from geological sequences of different age. Probably the ones most closely related to the cherts from Spitsbergen are those from the Permian Phosphoria Formation, widespread over large areas of the western United States.

The Rex Chert is a distinct and important lithostratigraphical unit of the Phosphoria Formation, and its petrology in some sections in Utah, Wyoming and Idaho has been investigated by KELLER (1941) who established that authigenic silica, terrigenous quartz, and carbonates are the main components of rocks constituting this chert unit. Depending on the quantitative ratios between these constituents, cherts, limestones with cherts, arenaceous cherts, and cherty quartzites may be differentiated. These rocks are usually dark grey or black in colour. A phosphate addition is quite common. KELLER (1941) has also noted the frequent

occurrence of siliceous sponge spicules, but calcareous spicules are scarce: particles of trepastome bryozoans occur only rarely. The Rex Chert is thought of by KELLER (1941) as primary, and inorganic in the main, with probably considerable diagenetic replacement of carbonates. Simultaneous precipitation of silica and carbonates is also taken into account in KELLER's (1941) interpretation.

CRESSMAN (1955) described cherts occurring in the Phosphoria Formation in SW Montana. Siliceous sponge spicules are present in these dark grey layered rocks; some beds consist almost entirely of siliceous sponge spicules. Many of the spicules (hexactinal in form) are replaced by apatite. Other fossil remains are rare. Glauconitic sandstones (up to 5% of glauconite) are associated with the cherts. CRESSMAN (1955, p. 25) regards these cherts "...to have resulted in large part from the accumulation and partial diagenetic reorganization of sponge spicules and other siliceous organisms...". Similar, dark, bedded cherts, locally rich in sponge spicules and carbonaceous matter, have been described by SHELDON (1957, 1963) from NW and W Wyoming.

Generally, the Rex Chert and other chert-rich members of the Phosphoria Formation, e.g. Tosi Chert and Lower Chert (MCKELVEY et al. 1959, SHELDON 1963) show lithological and petrological similarities to the Permian cherts of Spitsbergen. More recently (MCKELVEY et al. 1959), Rex Chert and other, less prominent cherty horizons of the Phosphoria Formation, have been thought to originate from accumulations of siliceous sponge spicules in a marine environment similar to that in which the Brachiopod Cherts and their petrological equivalents from Spitsbergen are thought by the present author to be deposited. In both these regions silica precipitated by sponges has been subsequently rearranged after burial.

Some similarities between Upper Tokrossøya Beds from the Sørkapp area and rocks of the Park-City Formation (MCKELVEY et al. 1959) are also manifest. The latter formation (occurring in Utah and interdigitating with the Phosphoria) consists of sandy carbonate rocks, often bioclastic, grading into sandstones and containing a fauna of brachiopods and bryozoans. These fossils are often replaced by phosphates. In Spitsbergen evidence of the replacement of sponges by phosphates has been recorded only in Hornsund by BIRKENMAJER (1964).

The Spitsbergen Permian rocks described in the present paper may also be compared with Permian deposits of the Delaware Basin (W Texas and S New Mexico), bordered by the famous Capitan reef (NEWELL et al. 1953). Besides sandstones, the Delaware Basin contains black or dark grey bituminous and sandy limestones. These limestones, especially common in the Bone Spring Formation of Leonardian age, include up to 30% of sponge spicules. Many of the spicules, originally composed of silica, have been replaced by calcite. It is supposed (Newell et al. 1953) that the spicules are not essentially autochthonous but have been transported from the basin margins by turbidity currents. Nodular and lenticular cherts are common in these basin limestones and the origin of these cherts is thought (NEWELL et al. 1953) to be connected with the occurrence of the sponge spicules. Closer to the reefs (i. e. towards the margin of the basin) the limestones contain large quantities of worn and broken brachiopods, bryozoans, and other fossils constituting the reefs.

The interpretation of sedimentary environment and of the diagenesis of the Delaware Basin sediments given by NEWELL et al. (1953) is quite similar to that advocated by the present author for the cherty rocks of Spitsbergen. Consequently, the geological setting of the Spitsbergen cherty rocks may be conjecturally regarded as analogous to that of the Delaware Basin.

The Permian Fantasque Formation occurring in Canada in the south-western district of Mackenzie and in north-eastern British Columbia (KINDLE 1944, HARKER 1961, 1963, BAMBER et al. 1968) consists of cherts similar to those of Spitsbergen. These cherts are bedded, grey, brownish-grey or dark-grey to black and, as reported by BAMBER et al. (1968), contain abundant sponge spicules.

Lithological and petrological similarities also exist between the investigated cherty rocks from Spitsbergen and sediments of Lower Permian age occurring in Preuralia (Cisuralia) — the classical area of the occurrence of beds of the Permian system. It would seem that in particular the Irghina beds of Lower Permian age are lithologically similar to cherty rocks from Spitsbergen. In an area between the towns Kuzino and Perm (TOLSTIKHINA 1937) north of the Ufa Plateau, the Irghina beds are represented by limestones, which are strongly silicified and often dolomitized, containing abundant skeleton fragments of siliceous sponges. A rich fauna of bryozoans and crinoids is also present, while in some horizons fusulinids are common. The thickness of the Irghina beds, not known exactly, may be considered as being between 25 and 280 m (TOLSTIKHINA 1937, pp. 46, 47).

In the area from Chussovaya to Solikamsk (GORSKY 1937) the Irghina beds are from 250–270 m in thickness and consist of limestones with chert nodules and layers. The latter are present more especially in the upper part of the Irghina beds. According to GORSKY (1937), “The source of the silica are remains of sponges, whose spicules are abounding in the limestones” (p. 77). Besides sponges, foraminifers, bryozoans, hydroid crusts, brachiopods and crinoids are present.

As shown by MASLOV (1950), limestones comprising sponge spicules, cherts and spongiolites are common in the Permian of the Ufa Plateau. The limestones consist essentially of remains of brachiopods, bryozoans and foraminifers and contain a considerable amount of siliceous sponge spicules. The spongiolites consist mainly of minute siliceous sponge spicules (0.02 mm in diameter, 0.2–0.5 mm in length) cemented by carbonates. In both the limestones and the spongiolites the spicules are either partly or completely calcified. In particular stratigraphical horizons, on the other hand, cherts occur either as irregular concentrations of silica with diffuse outlines or as well-defined lenses. In some horizons cherts are present in excess of carbonates. That siliceous sponge spicules probably contribute to the formation of well defined lenses of cherts has been suggested by MASLOV (1950) and, in general, they are considered to be the main source of silica in the formation of all types of Permian cherts from the Ufa Plateau.

Closely related lithologically to the Permian cherts of Spitsbergen are some Carboniferous cherty rocks of the British Isles. These rocks have been investigated mainly by HINDE (1887), SARGENT (1921, 1923, 1929), and more recently by HEY (1955). HINDE (1888) mentioned that a specimen of bluish chert from Akseløya examined by him is, “. . . precisely similar in appearance and character to the cherty rocks of the Yoredale Series in Yorkshire, and could not be distinguished

from them" (p. 244). Siliceous and calcareous sponge spicules are common in these rocks; other organic debris, e. g. spines of productids and crinoid stems are also present. HINDE (1887) and later CAYEUX (1929) were of the opinion that the silica of these cherts had been precipitated by sponges and introduced into the sediment mainly in form of sponge spicules. This process was subsequently followed by the diagenetic reorganization of silica. SARGENT (1921, 1923, 1929) did not accept that sponges contributed to the origin of cherts and HEY (1955) agreed with this opinion. Cherts from Derbyshire (SARGENT 1921, 1929), North Flintshire (SARGENT 1923) and the Yoredales (SARGENT 1929) are thought to have been primary sediments of inorganic origin. Silica "...resulting from decomposition of granitic rocks would probably come down in the form of colloidal alkaline silicates". (SARGENT 1923, p. 181.)

HEY (1955), describing cherty rocks from the Crow Series in Yorkshire, emphasised the different stages in the preservation of sponge spicules, a similar feature to that observed by the present author in the Permian cherty rocks of Spitsbergen. The spicules present in cherts of the Crow Series, now consisting of silica and/or carbonates, were thought by HEY (1955) to have originally been calcareous. Such an opinion had also earlier been held by SARGENT (1929) who interpreted the calcitic spicules present in Yoredale cherts as belonging to *Calci-spongia*, probably to *Peronella Zittel*.

The presence of sponge spicules in the Carboniferous cherts from the British Isles, together with the experimental evidence that silica does not precipitate directly (chemically) from the sea water (KRAUSKOPF 1959), argues for an organic origin for these rocks as HINDE (1887) and CAYEUX (1929) suggested. Calcareous sponge spicules present in these rocks could be pseudomorphs after siliceous spicules, as with those from the Permian cherts of Spitsbergen.

Conclusions

Permian Brachiopod Cherts and their lithostratigraphical equivalents in southern Spitsbergen consist of impure cherts, siltstones and carbonate rocks. Different kinds of sandstones are also present in the Sørkapp area. The dark, indurated, impure cherts are the most interesting rocks in these associations. They consist of several components, in particular authigenic silica, carbonates, terrigenous quartz, and fossil remains. Among the fossil remains the most common and characteristic of these rocks are minute spicules of siliceous sponges. These spicules are simple in shape, smooth and are thought to belong to sponges other than lithistids, which are preserved "in situ". Glauconite and carbonaceous matter are the typical accessory constituents of the cherts. In addition to the impure cherts pure spiculites have been recorded.

The rocks described in the present paper originated in an epicontinental marine environment and, especially in the Sørkapp area, record a period of regression of the sea. Parent sediments of the cherty rocks were muds rich in siliceous sponge spicules, which were deposited in depressions on the outer shelf in poorly aerated,

stagnant waters. Fragments of a benthonic fauna other than sponges were only occasionally brought into this environment and locally form well defined lenses of calcarenites. In the gradually shallowing water (profiles in the Sørkapp area) carbonate and arenaceous sediments were deposited including typical littoral and beach sediments.

Complicated processes of diagenetic reorganization are responsible for the cherty rocks as they appear today. The most important of these processes was reversal silica-carbonate replacement with ascendant silica-precipitation.

At an early stage of diagenesis, some of the opaline sponge spicules were dissolved and silica-saturated solutions formed in the pores of the fresh sediment, while a coeval precipitation of carbonates was also in progress. Silica was then precipitated in voids within the sediment and carbonates went into solution. These alternating processes could have been repeated many times. At a later stage of diagenesis, siliceous sponge spicules which had avoided solution in the earlier stages were replaced by carbonates and, conversely, calcareous fossil remains were silicified. Thus, it can be stated that the siliceous sponge spicules were the source of silica in the formation of these particular cherty rocks.

Cherts and associated rocks from southern Spitsbergen (and presumably of Spitsbergen in general) show similarities to certain other Permian marine successions, e. g. the Phosphoria Formation, a part of the basin sediments associated with the Capitan reef, and some beds of the classical Permian of Cisuralia. In all these sedimentary associations various natural resources of economic value are present, e. g. phosphates, metallic ores and petroleum, a fact which should attract the attention of future investigators of the Brachiopod Cherts in Spitsbergen.

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Part II

Sponges and problematic fossil-bodies from Permian cherty rocks in Spitsbergen

Abstract

Haplistion arcticus (DUNIKOWSKI 1884), *Haplistion macroporus* (DUNIKOWSKI 1884), and two new species, *Haplistion elongatus* and *Haplistion festningensis* are described. *H. arcticus* and *H. macroporus* have previously been described from Spitsbergen by DUNIKOWSKI (1884) as *Pemmatites arcticus* and *Pemmatites arcticus* var. *macropora*.

Scheiia tuberosa TSCHERNYSCHEW & STEPANOW, 1916 not known from Spitsbergen before is also described in the present paper.

Brief descriptions then follow of some problematic fossil-bodies; these appear to consist mainly of sponge spicules.

Introduction

On studying the petrology of the Brachiopod Cherts (Permian) of Spitsbergen, the present author (A. SIEDLECKA, Part I, this vol.) established that sponges were an important contributory factor in their formation. A general knowledge of the sponge fauna preserved in Brachiopod Cherts therefore became a topic closely connected with the above-mentioned petrological study, and important in any consideration of sedimentary and diagenetic processes. This interesting connection between the sponges, their activity and the origin of beds in which they are preserved, later directed the present author's attention towards an investigation of the sponges in the Brachiopod Cherts.

The collection of fossils described below comprises 54 sponges and 13 problematic fossil-bodies. This is a unique collection of sponges gathered in Spitsbergen by different investigators during the period of the last 60 years or more, and has never been described. The fossils were collected from Tokrossøya Beds in the Sørkapp area, from Brachiopod Cherty Limestone in Hornsund, and from Brachiopod Cherts in the Bellsund, Isfjorden and Kongsfjorden areas (see Fig. 1). The collection includes: (1) 11 specimens from Sørkappøya and (2) Øyrlandet (Sørkapp area) gathered by S. SIEDLECKI in 1962 on a Polish Spitsbergen Expedition and in 1964 on an expedition organized by Norsk Polarinstitut; (3) 3 specimens from Treskelen and Hyrnefjellet (Hornsund) collected by S. CZARNIECKI in 1960 on the Polish Spitsbergen Expedition; (4) 8 specimens from Reinodden (Bellsund)

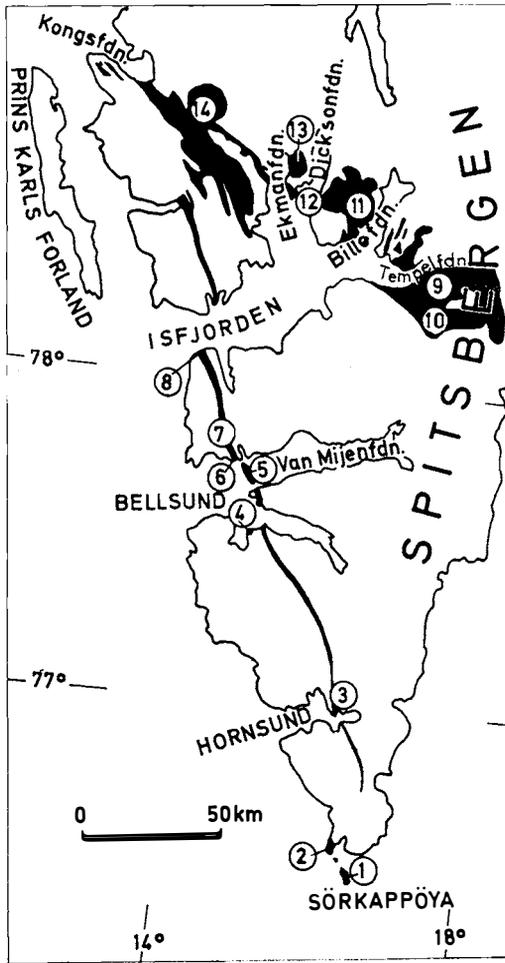


Fig. 1. Localities cited in text:

1. Sörkappöya
2. Öyrlandet
3. Treskelen and Hyrnefjellet
4. Reinodden
5. Akseløya
6. Sundodden
7. Summit 731 west of Fridtjofbreen
8. Festningen
9. Stensjøfjellet (Anderssonfjellet)
10. Rejmyrefjell
11. inner part of the valley W of Skansen
12. Kap Wijk
13. Kapitolfjellet
14. Dronningfjellet

gathered by T. WINSNES in 1950; (5) 20 specimens from Akseløya and (6) Sundodden (Bellsund) collected by S. SIEDLECKI in 1965 on Norsk Polarinstittutt's expedition; (7) 3 specimens from summit 731 W of Fridtjofbreen (Van Mijenfjorden), gathered by OLSEN during HOEL's and STAXRUD's Spitsbergen Expedition, 1913; (8) 6 specimens from Festningen (Isfjorden); (9) 1 specimen from Stensiøfjellet (old name — Anderssonfjellet), inner Sassendalen (Tempelfjorden) collected by T. WINSNES in 1949; (10) 2 specimens from Rejmyrefjell (Tempelfjorden) gathered by T. WINSNES in 1949; (11) 1 specimen from a valley W of Skansen (Billefjorden) collected by T. WINSNES in 1948; (12) 1 specimen from Kap Wijk (between Dicksonfjorden and Billefjorden) collected by the 1959 Norwegian Spitsbergen Expedition; (13) 3 specimens from Kapitolfjellet (Ekmanfjorden) gathered by A. HEINTZ in 1964; (14) 8 specimens from Dronningfjellet (Kongsfjorden), collected by O. HOLTEDAHL in 1910. The localities are shown in Fig. 1. All sponges are strongly silicified and recrystallized and the spicules have mostly been destroyed. Because of silicification the sponge skeletons could be studied only in thin sections.

The collection is housed in the Palaeontological Museum, Oslo, Norway.

Previous investigations

Previous investigations of Late Palaeozoic sponges from Svalbard have been carried out by DUNIKOWSKI (1884) and by HINDE (1888). Palaeontological material described by these authors was collected in 1882 during NATHORST's and DE GEER's expedition, from the following beds and localities:¹ (1) Brachiopod Cherts on Akseløya and Eholmen (Eders-Insel) in Bellsund; (2) Cyatophyllum Limestone at Tempelfjorden and Gipshuken (inner part of Isfjorden) and, (3) "Kohlen- und Pflanzenführende Ursasandstein" on Midterhuken in Bellsund. The stratigraphy of the last-mentioned locality is probably wrongly reported (DUNIKOWSKI 1884); the bed in which a sponge has been found is now thought to be a transgressive clastic deposit corresponding in age to Cyatophyllum Limestone, not to Lower Carboniferous.

DUNIKOWSKI (1884), on the basis of the above-mentioned collection, described a new genus *Pemmatites*, and the species: *P. arcticus*, *P. arcticus* var. *macropora* and *P. arcticus* var. *latituba*. Taking into account the internal structure of *Pemmatites* and the shape of its preserved spicules DUNIKOWSKI (1884) assigned it to the Monactinellidae. Later, HINDE (1888) re-examined this collection and concluded that translucent siliceous fibres considered by DUNIKOWSKI (1884) as canals are spicule tracts consisting of lithistid spicules, and the canals, which were mistaken by DUNIKOWSKI (1884) for skeletal fibres, are filled by matrix including randomly oriented, smooth monaxons. On account of this emendation, HINDE (1888) assigned the genus *Pemmatites* to the suborder Lithistida, family Rhizomorina.

Several species of *Pemmatites* have been described from Ural and Timan (TSCHERNYSCHEW 1899) and from Timor (GERTH 1929). Recently FINKS (1960), after studying Late Palaeozoic sponges from the Texas region, concluded that genera: *Haplistion* YOUNG & YOUNG, 1877, *Rhaphidhistia* CARTER, 1878, *Pemmatites* DUNIKOWSKI, 1884, and *Pseudopemmatites* R. H. KING, 1943 (= *Monarcho-pemmatites* DE LAUBENFELS, 1947) should be considered as one genus *Haplistion*.

The collection of sponges from Svalbard described by DUNIKOWSKI (1884) and by HINDE (1888) was originally housed in the Naturhistoriska Riksmuseet in Stockholm; in 1926 it was lent to GERTH in Leiden, then to SCHWINDEWOLF in Berlin, and was later most probably lost during World War II. Another collection of Permian sponges, including *Pemmatites arcticus*, *Pemmatites macroporus* and others, is that from Ural and Timan, described by TSCHERNYSCHEW (1899). This collection is housed in TSCHERNYSCHEW's Central Museum of Geology and Surveying, Leningrad (CNIGR), as collection No. 317. The present author has unfortunately not been able to study this latter collection; the following descriptions of recently gathered sponge fauna are therefore based only on published data.

¹ Data after DUNIKOWSKI (1884).

Systematic descriptions

The systematic positions of the genera *Haplistion* and *Scheiia* adopted here are those given by FINKS (1960, pp. 87 and 97).

Class DEMOSPONGEA SOLLAS, 1875

Order Lithistida SCHMIDT, 1870

Suborder Rhizomorina ZITTEL, 1878

Family Haplistiidae DE LAUBENFELS, 1955 (emend. FINKS 1960, p. 87)

Genus *Haplistion* YOUNG & YOUNG, 1877.

Haplistion YOUNG & YOUNG, 1877, p. 428; HINDE, 1888a, p. 147; FINKS, 1960, p. 87.

Rhaphidhistia CARTER, 1878, p. 140.

Pemmatites DUNIKOWSKI, 1884, p. 13; HINDE, 1888, p. 249; TSCHERNYSCHEW, 1899, p. 6.

Pseudopemmatites R. H. KING, 1943, p. 12 (= *Monarchopemmatites* DE LAUBENFELS, 1947, p. 187).

Four different genera, *Haplistion*, *Rhaphidhistia*, *Pemmatites*, and *Monarchopemmatites* have recently been considered by FINKS (1960) as representing one genus only. FINKS (1960) preserved for the genus the name *Haplistion* because this designation was introduced earlier than any other. This same author also introduced a new diagnosis and description of the genus *Haplistion*. Properties of *Haplistion* taken into account by FINKS (1960) in descriptions of species were as follows: "(1) body form, (2) dimensions of the mesh spaces, (3) thickness of the spicule tracts, and (4) the form of the larger canals, if present" (FINKS 1960, p. 87). On the basis of thickness of the tracts several previously described species of *Haplistion* were divided into two groups and five subgroups. The diagnostic properties listed by FINKS (1960) are taken into account in the following descriptions.

Unfortunately, the specimens of *Haplistion* described below are for the most part very poorly preserved. The skeleton pattern is usually not destroyed, but the internal structure of the skeleton fibres in most of the examined specimens is nearly completely obscured. The skeleton fibres now consist of microcrystalline or fibrous chalcedony with few spicules preserved. These spicules either consist of chalcedony or, more commonly, are calcified. Despite the poor state of preservation of the sponges, most of them could be assigned to two different species known previously from Spitsbergen. Two others have been described as new species although the author is fully aware that this establishment is uncertain because of little available and poor material. In addition, some incomplete specimens with a deformed body and internal structure have been described as *Haplistiidae incertae sedis*.

Haplistion arcticus (DUNIKOWSKI 1884)

Plate I, figs. 1–7, Plate III, fig. 3, Plate IV, figs. 1, 2, 4, 7, 8, 9, 10, 11, text-Fig. 2.

Pemmatites arcticus DUNIKOWSKI, 1884, p. 14, pl. I, figs. 3, 10; pl. II, figs. 3, 4; emend. HINDE, 1888.

Haplistion arcticum (DUNIKOWSKI 1884) emend. FINKS, 1960, p. 88.

Material and megascopic description: Thirty-nine specimens, three of them not complete (numbers: A4897, A26147, A26426, A26474, A26475, A27119, A27845, A28457, A28482, A28498, A28499a, A28501, A28505, A28506, A28519, A28521, A28522, A28525, A28559, A28680, A28827, A30340, A30348, A30349, A31245, A33201, A33202, A33203, A33204, A33205, A33206, A33207, A33208, A33209, A33210, A33221, A33222, A33217, A33218).

The form of the sponge may be: (1) ellipsoidal, flattened with a round or irregular depression (c. 15–30 mm in diameter) in the top part (Plate I, figs. 2, 3); (2) ellipsoidal, slightly flattened without any depression on the top surface; (3) subdiscoidal, with a relatively thin and sharp margin (Plate I, fig. 4); (4) subconical (only one specimen, see Plate III, fig. 3). All these varieties, seen from the side, are shown on Fig. 2. The particular specimens are quite different in size; the largest specimen measures 130 × 110 × 50 mm, the smallest — 30 × 30 × 20 mm; usually the longest diameter is c. 40–80 mm, the short diameter — c. 30–70 mm, height — c. 25–50 mm. There are no indications of a point of attachment on the underside. Surfaces are covered by small rugae, these being the projecting ends of radial fibres (spicule tracts) (Plate I, figs. 2, 3, 7). The surface of the depression occurring in some individuals is usually smooth, without rugae (Plate I, fig. 2). The sponges are compact, grey to black in colour and consist mainly of silica. Seen in the transverse and longitudinal sections, the skeleton consists of: (1) radial fibres running from a point of origin to the surface, and (2) transverse fibres running transverse to the radial fibres and forming concentric ellipsoids parallel to the external form of the fossil-body (Plate I, figs. 1, 5, 6, Plate III, fig. 3). The transverse fibres are less regularly arranged and they do not always connect the adjacent radial tracts; some of them appear as stubby processes situated at the same or different levels in adjacent radial fibres. The fibres consist of dense, translucent, bluish silica. The skeletal net is usually more regularly developed near the surface of the sponge. The point of origin of the radial tracts is commonly situated eccentrically and exactly under the dimple occurring on the upper surface of some of the individuals. No central cloaca has been observed; the above-mentioned depression occurring on upper surfaces of some specimens perhaps represents an apical cloaca.

Microscopic examination: Radial and transverse fibres are c. 0.5–1 mm in thickness and consist of colourless chalcedony, often spherulitic. The radial fibres are usually somewhat thicker than the transverse ones, an average thickness of radial fibres is c. 0.9 mm, average thickness of transverse tracts — c. 0.5 mm. Spicules

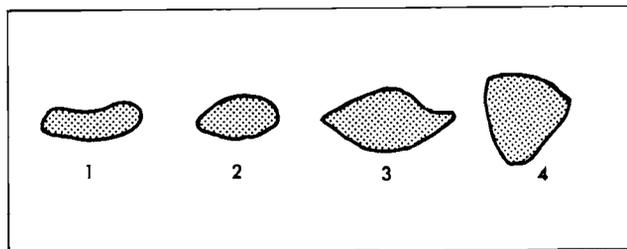


Fig. 2. Typical shapes of body of *H. arcticus* seen from the side; description in text.

are usually not visible; in some places, however, within compact chalcedony poorly preserved rhizoclonal structures may be observed, these commonly being calcified. The rhizoclonal structures are c. 0.04–0.06 mm in diameter and c. 0.4–0.8 mm in length. They are straight, elongated, obtuse at their ends and have short, stubby or warty lateral processes (see Plate IV, figs. 1, 2, and 4–11).

Spaces between skeletal fibres are c. 1–2.5 mm (seldom 0.5–2.5 mm) in size and are filled by a dark, fine-crystalline mixture of carbonates, silica, terrigenous quartz grains and sponge spicules. The latter are smooth monaxons c. 0.03–0.06 mm in diameter and consist of chalcedony or carbonates. These spicules are broken, the length of particles reaching up to 1 mm. In addition, an admixture of carbonaceous and other matter, e. g. small foraminifera, occurs within the material filling the spaces.

Measurements of the above-described specimens of *Haplistion arcticus* agree with corresponding data reported by DUNIKOWSKI (1884), HINDE (1888), TSCHERNYSCHEW (1899), and FINKS (1960).

Diagnosis: (1) ellipsoidal, flattened shape with or without a dimple (?apical cloaca) on the top surface; (2) skeleton consisting of radial and transverse fibres, c. 0.5–1 mm in thickness. The radial fibres are usually more regular and may be twice as thick as the transverse ones; (3) spaces between the fibres are mostly 1–2 mm in size.

Haplistion macroporus (DUNIKOWSKI 1884).

Plate 2, figs. 4, 6.

Pemmatites arcticus var. *macropora* DUNIKOWSKI 1884, p. 15, pl. II, figs. 1, 2, 5.

Pemmatites macropora DUNIK., emend. HINDE, 1888, p. 249–250, pl. VIII, figs. 1–4.

Pemmatites macroporus DUNIKOWSKI, TSCHERNYSCHEW, 1899, p. 15–17, pl. II, figs. 7–10, pl. III, fig. 3, pl. IV, figs. 3–4.

Haplistion macropora (DUNIKOWSKI 1884) emend. FINKS, 1960, p. 88.

Material and megascopic description: Three specimens, one of them incomplete (A31244, A33211, A33212).

Spheroidal sponges, flattened, without a point of attachment. Sizes of particular specimens are: 77 × 48 mm, 75 × 60 mm and 85 × 72 × 48 mm. Surfaces of sponges are hispid covered by small projecting rugae and joined together by short ribs in an irregular net (Plate II, fig. 6). Sponges are compact, dark grey in colour and consist mainly of silica.

The skeleton, seen in transverse and longitudinal sections, consists of relatively thick (c. 1.5–2 mm) radial fibres and usually thin (mainly c. 0.5 mm), less regularly arranged transverse fibres (Plate II, fig. 4). The fibres radiate from an eccentrically situated point. Spaces between the fibres are usually about 2 mm, sometimes reaching up to 4 mm.

Microscopic examination: Skeletal fibres consist of dense, colourless chalcedony. Spicules of rhizoclone type, c. 0.06 mm in diameter and c. 0.5–0.8 mm in length, are seldom observed. The rhizoclonal structures, elongated, obtuse at their ends, and with

stubby processes, either consist of chalcedony or are replaced by carbonates. Within some better preserved fibres closely-packed rhizoclones appear to be arranged parallel to the long axis of the fibre, the rhizoclones having many interlocking processes.

Canals are filled by a mixture of carbonates, silica, and carbonaceous matter. Carbonates form anhedral crystals or, sometimes, rhombs about 0.5–1.5 mm in size. Simple, smooth, usually broken monaxons (?oxeas) c. 0.03 mm in diameter are recognizable within the silica filling the canals.

Diagnosis: 1) spheroidal or sub-spheroidal shape; no central or apical cloaca; 3) skeleton consists of radial fibres c. 0.5–2 mm thick and c. 2 mm (max. 4 mm) apart, and of less regularly arranged transverse fibres c. 0.5 mm thick; 4) the fibres are composed of straight, obtusely terminated rhizoclones with stubby lateral processes. The rhizoclones are c. 0.06 mm thick and c. 0.5–0.8 mm long.

Discussion: The specimens described above as *Haplistion macroporus* differ somewhat from each other. Skeletal fibres of the specimen A33212 are more variable in thickness than those of specimens A31244 and A33211. The above described individuals are strongly silicified and differences between them may be considered partly as individual variability and partly as a result of diagenetic reorganization. In spite of some dimensional differences between the holotype of *Haplistion (Pematites) macroporus* and the present specimens, the latter are considered as *Haplistion macroporus* because (1) their properties are much closer to *Haplistion (Pematites) macroporus* than to other species of the genus *Haplistion* and, (2) the poor material and its poor state of preservation precludes the precise observations necessary in the description of a new species.

Haplistion elongatus, new species.

Plate II, figs. 1, 2, 3; Plate IV, figs. 5, 6, text Fig. 3.

Material and megascopic description: One incomplete specimen (A33220) from the upper part of the Brachiopod Cherts on Akseløya, Bellsund, Spitsbergen.

Elongated, sub-cylindrical, somewhat flattened sponge (Plate II, fig. 1, 2), measuring 150 × 53 × 36 mm; it thins gradually towards one of the ends, the dimensions of which are 33 × 28 mm. The exterior surface of the sponge is covered by rugae c. 0.5–1.5 mm in diameter (Plate II, fig. 2). In some places the rugae are joined together forming an irregular net.

Skeletal fibres, visible in transverse section, are usually c. 1.5–2 mm in thickness, and consist of dense, somewhat bluish translucent silica. Spaces (1–2 mm in size) between the fibres are filled by a dark grey mixture of silica and carbonates. In transverse section fibres seem to be irregularly arranged, somewhat curved and branched. No central cloaca is visible. A radial arrangement of fibres is visible in longitudinal section (Plate II, fig. 3). This arrangement gradually becomes parallel towards the narrower end of the sponge, which was probably originally attached to the sea-bottom (scheme of arrangement of radial fibres — see text fig. 3). Radial

fibres are connected by relatively closely spaced transverse fibres which are 1–2 mm in diameter. Generally, relatively thick and closely spaced fibres form the compact skeleton of this particular sponge.

Microscopic examination: Skeletal fibres consist of colourless chalcedony, often spherulitic. Traces of spicules have been sporadically observed. Straight rhizoclones are present, c. 0.05 mm in diameter and c. 0.5 mm in length, with stubby lateral processes (Plate IV, figs. 5, 6). These rhizoclones are in analogous size and shape to those of *H. arcticus* and *H. macroporus*. The rhizoclones are calcified. Canals between the skeleton fibres are filled with a fine-crystalline mixture of carbonates, silica and carbonaceous matter, and one little foraminifer has been observed. Within this mixture broken, smooth monaxones (?oxeas) frequently occur. These monaxones either consist of silica or are replaced by carbonates and are 0.01, 0.03, 0.05 mm in diameter.

Diagnosis: 1) elongated sub-cylindrical shape, somewhat thinner at one end; 2) presumed point of attachment at the narrower side; 3) no central cloaca; 4) radial and transverse skeletal fibres, c. 1–2 mm in thickness, consisting of straight rhizoclones with stubby and warty lateral processes.

Discussion: In this species the dimensions and arrangement of skeletal fibres as well as the shape of the few preserved rhizoclones are similar to those observed in *H. arcticus* and *H. macroporus*. Because of these features the above-described

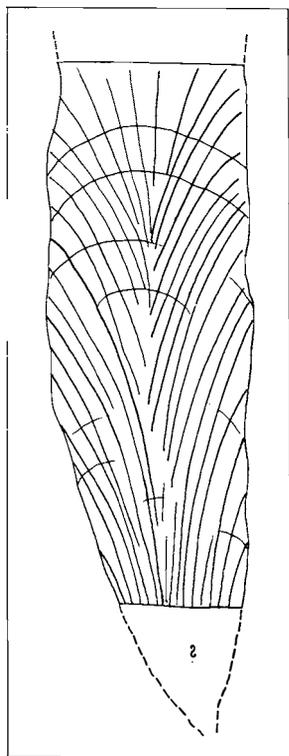


Fig. 3. Scheme of arrangement of the radial spicule tracts in *H. elongatus*, c. $\frac{1}{2}$ natural size.

sponge has been assigned to *Haplistion*; the shape of the sponge and the presence of a probable point of attachment are the reasons for the creation of the new species.

The holotype, P.M.O. A33220, is housed in the Palaeontological Museum, Oslo.

Haplistion festningensis, new species.

Plate III, figs. 1, 2, 4, 5.

Material and megascopic description: Three incomplete specimens (A4598, A4617, A4693) from a section at Festningen, outer Isfjorden, Spitsbergen. On one of the specimens (A4598) a label indicates that it was collected from Fossil horizon 12. This information presumably refers to the description of the section at Festningen by HOEL and ORVIN (1937) and indicates that the sponge was found in a bed of light-grey limestone rich in corals and brachiopods. This limestone was regarded by HOEL and ORVIN (1937) as "Schwagerina-Kalk", marking the boundary between Carboniferous and Permian. On recent evidence this bed should be regarded as an intercalation within the Brachiopod Cherts, situated near the middle of this unit. The two other specimens (A4617 and A4693) were presumably found in the same or superjacent bed of fossiliferous limestone but no information is available.

The three specimens are light grey in colour and consist partly of silica and partly of carbonates. They seem to be somewhat elongated in shape. Their surfaces are uneven and covered by irregular, sub-rounded dimples, mainly c. 2–3 mm in size which appear to be openings of canals. Skeleton fibres are visible in transverse sections, these being relatively thick (1.5–4 mm) and often branching out and changing thickness quite rapidly. Generally they are arranged subparallel, slightly radiating, and are situated rather close to each other. Because of the irregular character of the fibres the spaces between them vary in size and shape (Plate III, figs. 1, 4).

Microscopic examination: The skeleton fibres consist of rhizoclones which though perfectly preserved have mostly been replaced by calcite. Spaces between the spicules are filled by chalcedony. The rhizoclones have straight (sometimes slightly curved) shafts with many stubby, short lateral processes (Plate III, figs. 2, 5). These processes are often more numerous on one side of the spicule. The spicules are usually enlarged at their ends, flattened or notched, or terminated by knobs. They may also be furcate at one or both ends. The rhizoclones reach c. 0.03 mm in diameter and about 0.25–0.4 mm in length. The spicules are usually interlocked at their ends and in many places are so crowded and intermingled that it is extremely difficult to establish the shape and length of any individual spicule. While they are generally arranged parallel to the direction of the fibres, many spicules transversing this direction have also been observed. In addition to the described rhizoclones a few smooth monaxons have been recorded.

Irregularly shaped spaces between the skeleton fibres are filled by carbonates including fragments of bryozoans and crinoids. Glauconite is also present.

Diagnosis: 1) branching, thick (1.5–4 mm) skeletal fibres; 2) the fibres consist of slender rhizoclonal, c. 0.03 mm in diameter and up to 0.4 mm in length. The rhizoclonal have stubby lateral processes and are frequently enlarged and furcated at their ends.

Discussion: In shape, size and arrangement of rhizoclonal this species is close to that of *Pemmatites conscipatus* HINDE, 1896, but the body-shape and the arrangement of skeletal fibres constitute an important difference. The structure of the skeletal fibres of *Pemmatites latituba* DUNIKOWSKI 1884, as described by HINDE (1888) also makes this species similar to the *Haplistion festningensis*. The possibility of *P. latituba* and *H. festningensis* representing the same species must not be overlooked but, because of the sketchy description and erroneous interpretation of the skeleton construction of *P. latituba* given by DUNIKOWSKI (1884), this would be hard to establish. Besides, *P. latituba* was found in somewhat older (Cyathophyllum Lms.) beds. Still more prominent is the similarity between *H. festningensis* and *Pemmatites n. sp. cf. latitubo* TSCHERNYSCHEW 1899, which has been found also in Permian (Artinskian) beds. An examination of these two forms side by side could, quite possibly, lead to their being regarded as the same species.

The holotype, No. P.M.O. A4617, is housed in the Palaeontological Museum, Oslo.

Haplistiidae incertae sedis.

Seven poorly preserved specimens, some incomplete, have been assigned to this family. They exhibit skeletal nets consisting of radial and transverse fibres in which some calcified rhizoclonal have been observed. Differences between these specimens are seen in dimensions of skeletal nets, in body-shapes and in general state of preservation. Based on this differentiation, and in order to facilitate their description, they have been divided into A, B, C and D groups of specimens or individual specimens.

A. Three individuals (A28499b, A33213, A33214), flattened, of irregular, presumably lobate (A33213 and A33214) or subdiscoidal (A28499b) shape. The largest specimen is c. 150 mm in diameter and c. 40 mm in thickness, the smallest c. 80 mm × 55 mm × 28 mm. Surfaces of those sponges are hispid, covered by rugae c. 1–1.5 mm in diameter and c. 1–2 mm apart. In some places the rugae are joined together irregularly; they represent the projecting ends of skeletal fibres. In transverse sections a central cloaca is visible surrounded by curved and branched skeleton fibres consisting of dense, bluish translucent silica. Traces of the primary arrangement of the skeleton fibres are visible in some places with both radial and transverse tracts sometimes distinguishable. These are approximately 0.5–1 mm in thickness, although they have frequently been enlarged during recrystallization and their contours obliterated. The fibres consist of spherulitic and fibrous chalcedony and, in part, of carbonates. Within the fibres a few calcified rhizoclonal have been recorded. The rhizoclonal are c. 0.04 mm in diameter and up to 0.4 mm in length. They are straight with short, stubby lateral processes like those in

species of *Haplistion* described in the present paper. Spaces between the skeletal fibres are filled with a fine-crystalline mixture of carbonates, clay minerals, chalcedony and carbonaceous matter. Small terrigenous quartz grains and glauconite are also scattered throughout this material. Smooth monaxons, c. 0.025–0.08 mm in diameter are common here; they are usually broken and consist of chalcedony, often with the axial canal filled by glauconite.

Discussion: On account of the architecture and dimensions of the skeletal net and as so few calcified rhizoclonal structures have been recorded, the specimen may possibly be compared with the genus *Haplistion*.

B. One incomplete specimen (A33224). Two slender, cylindrical, somewhat flattened branches belonging presumably to one ramose individual. The larger, slightly curved branch is 15 mm × 25 mm thick and c. 140 mm long, the smaller, somewhat conical, is 9 mm × 17 mm thick and c. 50 mm in length. On the surface of the sponge light projecting skeletal fibres c. 0.8 mm in diameter are visible, these being connected with each other by c. 0.5 mm thick transverse fibres; the meshes of this net-like structure are c. 0.5–1 mm in diameter.

An arrangement of the radial fibres, subparallel in the centre and radiating out at the sides, is visible in a longitudinal section. The transverse fibres are perpendicular to the radial ones and, especially near the surface of the sponge, are relatively regularly arranged. Some of them do not connect with the adjacent radial fibres, in this case appearing as stubby processes situated on the latter. The fibres consist of chalcedony and include concentrations of carbonates. Some of these concentrations appear as calcified rhizoclonal structures c. 0.03–0.05 mm thick and c. 0.3 mm in length. The spaces between the fibres are filled by a mixture of carbonates, clay minerals, authigenic chalcedony and carbonaceous matter. Quite commonly small, smooth, usually broken monaxons are present; these are sometimes calcified.

Discussion: Dimensions and spacing of the fibres resemble those of *H. arcticus*; the body-shape, however, is dissimilar. The body-shape as well as the arrangement of the fibres is close to that of *H. elongatus*, but the dimensions and spacing of the skeletal fibres are different. The few extremely poorly preserved, calcified rhizoclonal structures are analogous in shape and size to those of *H. arcticus*, *H. macroporus*, and *H. elongatus*.

C. One irregular fragment (A31246), c. 35 mm × 20 mm × 17 mm. Skeletal fibres, where preserved, consist of chalcedony; in other cases, however, they are weathered out and a system of holes depicts their shape, size and arrangement. Among the preserved fibres both radial and transverse tracts may be differentiated; the radial fibres are c. 0.6–1 mm thick and c. 1.2–1.5 mm apart. The transverse fibres are somewhat thinner, situated at different levels on adjacent radial fibres and c. 1.5 mm apart. Spaces between the skeletal fibres are filled by a rusty-yellow marly rock.

In the arrangement and dimensions of the skeletal fibres the specimen is similar to *Haplistion arcticus*.

D. Two specimens, A4885 and A4891, 6 cm and 9 cm in size, one discoidal and the other with discoidal centre and foliate, irregular edges. On the surfaces of these specimens small (<1 mm) depressions filled by rusty iron-oxides and/or carbonates are visible, these being traces after weathered skeletal fibres. They are sometimes joined together in a kind of net. In some places a radial arrangement of these "fibres" is perceptible.

In a thin section of one of these specimens (A4885) sporadically interlocking rhizoclonal, reminiscent of those of *Haplistion*, were observed within isolated calcified fragments of the skeleton. Scattered smooth monaxons are present in a dark-grey siliceous filling of the spaces between the "fibres".

Suborder Eutaxi cladina RAUFF, 1893.

Family Hindiidae RAUFF, 1893 (Hindiadae, nom. correct. FINKS, 1960).

Genus *Scheiia* TSCHERNYSCHEW and STEPANOV, 1916.

Species *Scheiia tuberosa* TSCHERNYSCHEW and STEPANOV, 1916.

Plate II, figs. 5, 7, 8; Plate IV, fig. 3, text Fig. 4.

Scheiia tuberosa TSCHERNYSCHEW and STEPANOV, 1916, text figs. 1-4, pl. I, figs. 1-7, pl. II, figs. 1-4; FINKS, 1960, p. 98, pl. 32, figs. 1-7, pl. 33, figs. 1, 7.

Hindia permica GERTH, 1929, p. 6, pl. CCXIX, figs. 3, 3a, 4, pl. CCXXIV, fig. 2.

Hindia permica var. *bitaumiensis* GERTH, 1929, p. 7, pl. CCXIX, figs. 2, 2a, pl. CCXXIV, fig. 3.

Hindia wanneri GERTH, 1929, p. 7, pl. CCXIX, figs. 1, 1a, 1b, pl. CCXXIV, fig. 1.

?*Hindia pumila* HINDE, 1888, p. 157, pl. 5, figs. 8, 8a-f.

Material and megascopic description: One specimen (A33219) from the Brachiopod Cherts on Akseløya, Bellsund, Spitsbergen.

Subglobular, somewhat flattened sponge 5 cm × 5 cm × 3 cm in size (Plate II, figs. 7, 8). No point of attachment. On the weathered part of the surface of the sponge a delicate, net-like structure can be seen, this partly radially arranged from an eccentrically situated point on the underside. Small, irregularly arranged dimples also occur on this same surface. These dimples, probably representing ostia, are about 1 mm apart and c. 0.3–0.5 mm in diameter.

Radial fibres, running from the centre of the sponge towards its surface, are visible in transverse section. The fibres are c. 0.2–0.5 mm thick and appear as tuberculate rods or linearly arranged tubercles (Plate II, fig. 5). Bluish dense silica constitutes the fibres and dark grey silica fills the canals. The spaces between the fibres are c. 0.3–0.5 mm. The fibres are joined together transversely, though somewhat irregularly. The described skeletal structure is visible near the surface of the sponge. Towards the centre it has been destroyed by recrystallization of silica.

Microscopic examination: In thin-section a fibre structure consisting of dicranoclonal is visible, the shapes and arrangement of which is typical of the Hindiidae (Plate IV, fig. 3, text fig. 4). Distal surfaces of the dicranoclonal observed in thin-section are denticulate (Plate IV, fig. 3, a); this feature suggests presence of tubercles

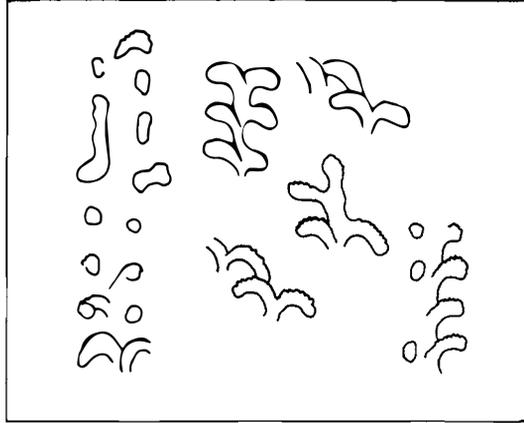


Fig. 4. Fragments of preserved skeleton structure of *Scheiia tuberosa*; c. 35 times natural size.

on these surfaces. In spite of poor preservation, the construction of the fibres and morphology of the dicranoclones seem to be analogous to that of *Scheiia tuberosa*. It was not possible, however, to study the morphology and sizes of spicules in detail.

Diagnosis: 1) subglobular shape; 2) radially arranged dicranoclones distal surfaces of which are covered with tubercles.

Discussion: The various features of this specimen conform with those of *Scheiia tuberosa* described by TSCHERNYSCHEW (TSCHERNYSCHEW and STEPANOV 1916) as well as with the diagnosis and description given recently by FINKS (1960, p. 98). The shape and size of the above-described *S. tuberosa* is also similar to that of *Hindia wanneri* GERTH (GERTH 1929, p. 7), although the thickness and construction of the fibres is much closer to that of *Hindia permica* GERTH (GERTH 1929). Dimensions of the skeletal fibres in these various specimens of *Hindia* and *Scheiia tuberosa* are as follows:

- 0.14–0.53 mm *S. tuberosa* described by TSCHERNYSCHEW (TSCHERNYSCHEW and STEPANOV 1916); c. 0.3 mm measured on his pl. II, Figs. 1 and 2;
- 0.2–0.5 mm *S. tuberosa* described in the present paper;
- 0.15 mm *Hindia wanneri* described by GERTH (1929); measured on his pl. CCXXIV, Fig. 1;
- 0.3 mm *Hindia permica* described by GERTH (1929); measured on his pl. CCXXIV, Fig. 2.

Problematic fossil-bodies (?sponges)

Plate V, figs. 1–6, text fig. 5.

Introductory note. S. SIEDLECKI (personal communication) observed these problematic bodies, presumably of organic origin, in the Permian cherty rocks of Bellsund and Sørkapp Land. They are especially common in Lower Tokrossøya Beds in the northern part of Øyrlandsodden. In this locality within some thick

cherty layers numerous, often closely packed subcylindrical, subconical and branched forms appear, situated with their long axes generally perpendicular to the bedding planes and “attached” on the bottom surface of any one bed. Some of them are curved, inclined or oriented parallel to bedding planes. Broader ends of the conical forms are pointed towards the top surface of the bed. Where individuals are branched, the branches are also directed upwards. Generally, all occurrences of these problematic individuals appear as colonies of benthonic organisms growing on the sea floor. The individuals are not strongly cemented with the surrounding cherty rock, tending to weather out from it rather easily. At Øyrlandsodden many of these ‘fossils’, weathered out from the disintegrating rocks, lie on the ground surface adjacent to the outcrop.

Material and megascopic description: Thirteen (Nos. A33215, A33216, A33223, A33225, A33226, A33227, A33228, A33229, A33230, A33231, A33232, A33242, A33243) silicified whole individuals and fragments. Most of them were collected by S. SIEDLECKI in 1964 at Øyrlandsodden (8 specimens) and Sørkappøya (3 specimens), though two specimens were found by the same investigator in 1965 in Bellsund at Sundodden.

Conical, cylindrical, and subcylindrical forms prevail; one specimen (A33226) is subspheroidal and somewhat flattened, and another (A33228) branched. Individuals are usually large, reaching up to 200 mm in height and 130 mm in diameter. All specimens are compact and dark grey in colour and some show parallel horizontal lines on their exterior surface, reminiscent of growth stages occurring e.g. in some corals or stromatoliths. Generally however, exterior surfaces do not exhibit conspicuous features and are similar to surfaces of the surrounding cherty rocks. In transverse sections concentric or curved lines are often visible, shown schematically in Fig. 5. No other structures could be observed megascopically.

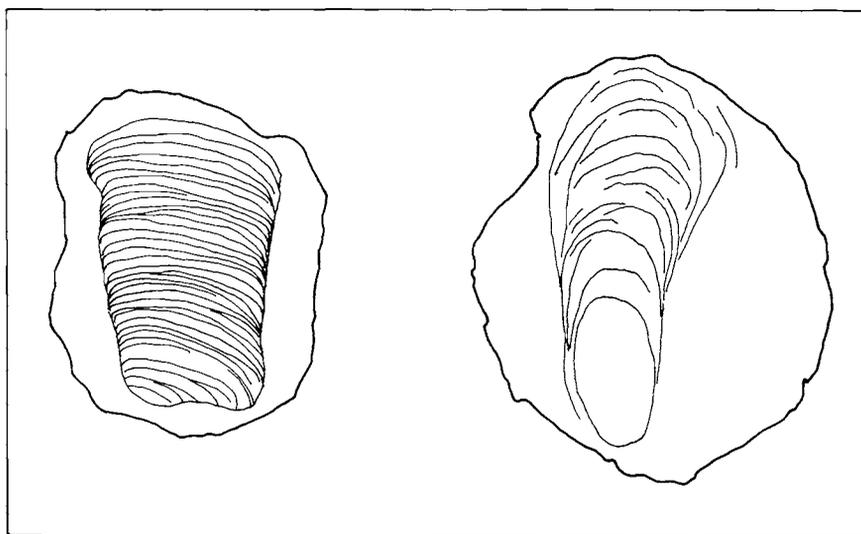


Fig. 5. Problematic fossil-bodies; structure seen in a transverse section. Natural size. To the left specimen No. A33216, to the right specimen No. A33215.

Microscopic examination: The main constituents observed under the microscope are sponge spicules. They occur both outside and within the area of concentric lines shown on Fig. 5, and are randomly oriented. The spicules are smooth, rod-shaped or somewhat curved, and most of them probably represent monaxons. These spicules consist of chalcedony, the better preserved examples displaying an axial canal filled with chalcedony or glauconite; a few spicules are entirely calcified. Dimensions of the spicules are: c. 0.03–0.08 mm in diameter and c. 1–1.5 mm in length. In addition to the sponge spicules terrigenous quartz grains c. 0.1 mm in size occur quite often, together with scattered carbonate rhombs and glauconite. Iron-oxides, as well as carbonaceous matter, are also present. All these constituents are closely packed and cemented by authigenic silica.

General remarks

Numerous species of the genera *Haplistion* and *Scheiia* have been described from different localities in the world, from marine Carboniferous and Permian strata, but their importance in stratigraphy seems to be rather doubtful. Species of *Haplistion* have been described from Great Britain, United States (New Mexico, Texas, Montana), Soviet Union (Ural and Timan), Timor and Spitsbergen. *Scheiia tuberosa* has been found in Canada (King Oscar's Land), United States (Glass Mts., Guadalupe Mts.), Ireland, Timor, and recently in Spitsbergen. The above-mentioned species of *Haplistion* and *Scheiia* occur either in (1) biocalcarenites connected with some kinds of reefs, or in (2) dark, bituminous, often spiculitic limestones and in dark, impure spiculitic cherts. The Permian cherts of Spitsbergen, where the above described sponge fauna has been found, include large amounts of siliceous sponge spicules. These spicules are mostly smooth monaxons which have been derived from sponges other than the lithistids; complete specimens of these sponges are not preserved. The monaxons present in the cherts are analogous to those constituting the problematic fossil-bodies.

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PLATES I-V

PLATE I

- 1-7. *Haplistion arcticus* (DUNIKOWSKI). 1 – horizontal section, fragment, c. $1\frac{1}{3}$ nat. size, P.M.O. A33202; 2, 3 – view of the top surface with a characteristic depression, and side view of the same specimen; P.M.O. A33204, c. $\frac{3}{4}$ nat. size; 4 – side view, P.M.O. A33208, c. $\frac{3}{5}$ nat. size; 5 – vertical section of specimen P.M.O. A33208, nat. size; 6 – horizontal section, P.M.O. A33206, c. $\frac{1}{1}$ nat. size; 7 – top view of specimen P.M.O. A33206, c. $\frac{1}{2}$ nat. size.

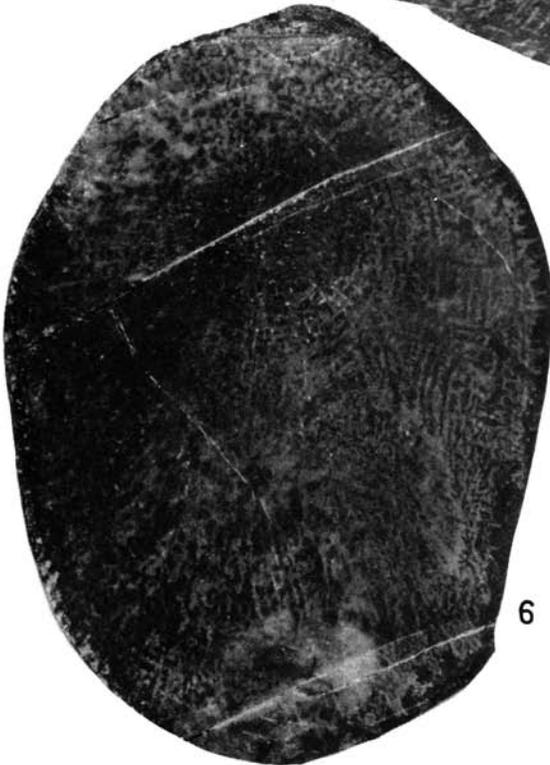
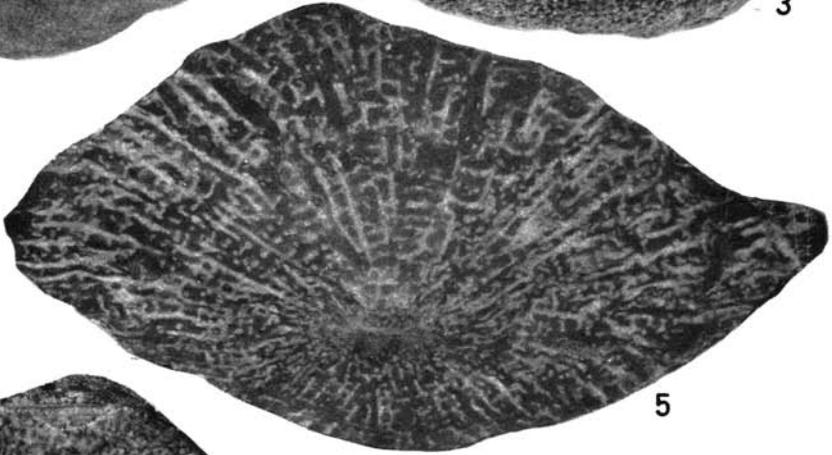
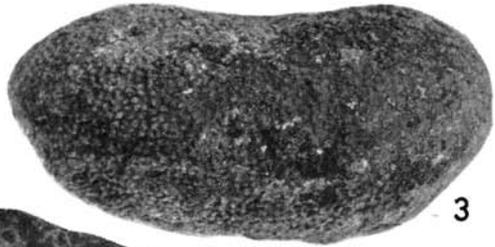
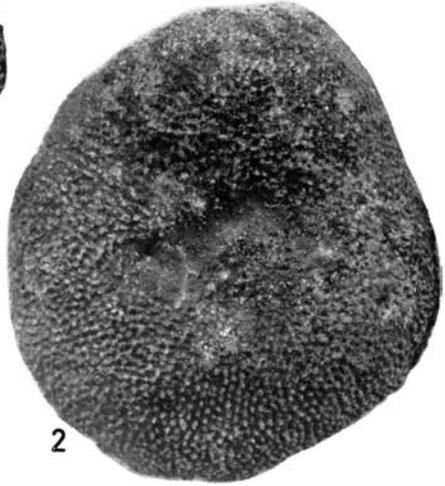
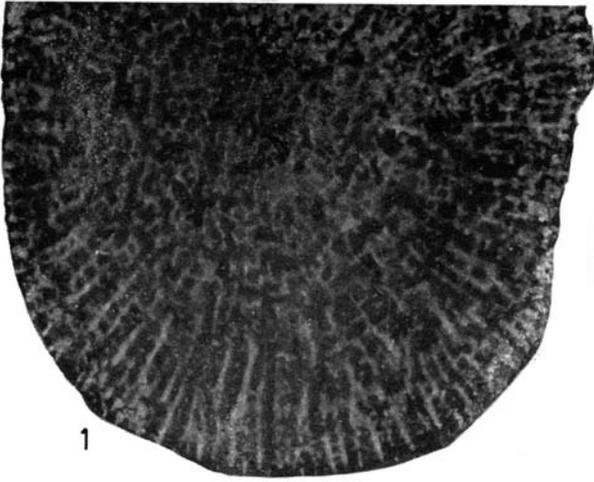


PLATE II

- 1, 2, 3. Holotype of *Haplistion elongatus* new species, P.M.O. A33220. 1 – view of transversal section, c. $\frac{3}{4}$ nat. size; 2 – side view, c. $\frac{3}{4}$ nat. size; 3 – longitudinal section, fragment, c. 1.2 nat. size.
- 4, 6. *Haplistion macroporus* (DUNIKOWSKI), P.M.O. A33211; 4 – vertical section, c. 1.2 nat. size; 6 – top view, c. $\frac{3}{4}$ nat. size.
- 5, 7, 8. *Scheiia tuberosa* TSCHERNYSHEW and STEPANOV, P.M.O. A33219; 5 – vertical section, c. 2 times nat. size; 7 – top view, c. $\frac{4}{5}$ nat. size; 8 – side view, c. $\frac{4}{5}$ nat. size.

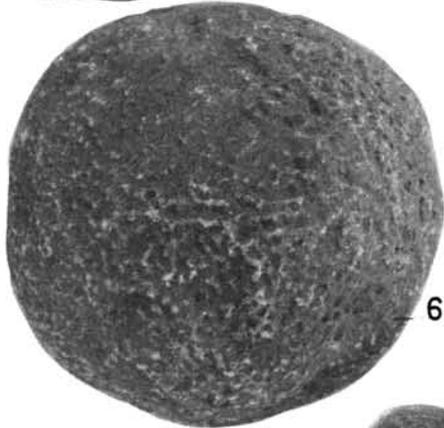
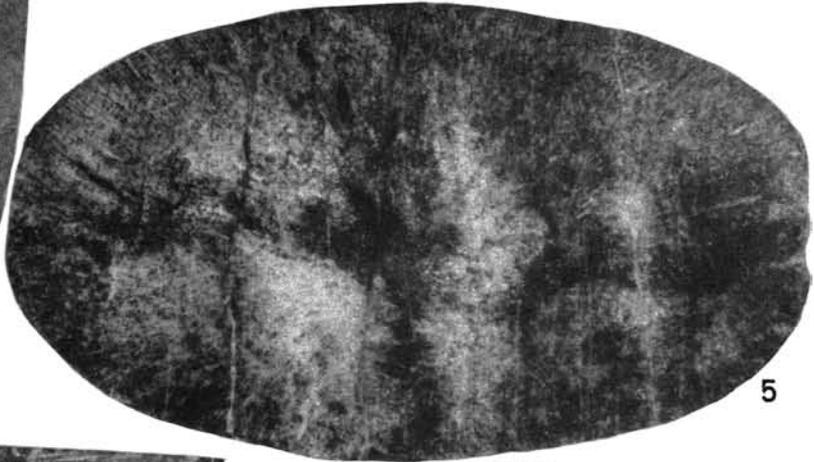
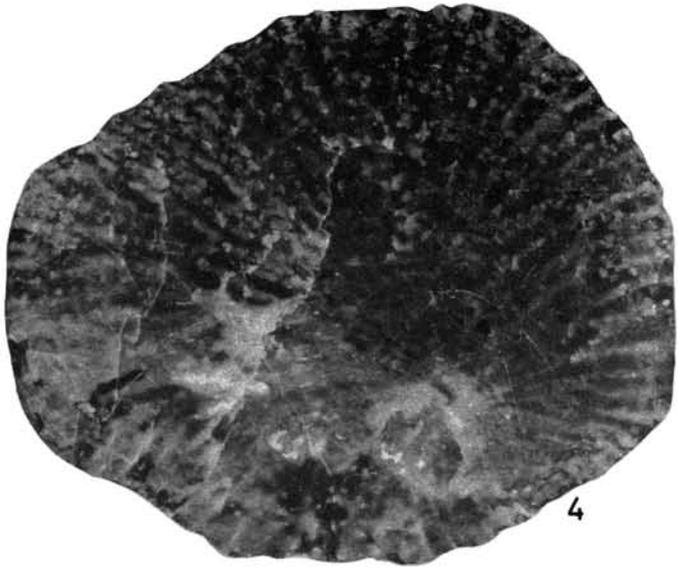


PLATE III

1. 2. Holotype of *Haplistion festningensis* new species, P.M.O. A4617. 1 – longitudinal section, c. 1½ nat. size; 2 – thin section of the same specimen, showing rhizoclonal constituting the skeletal fibres; enlarged 31.2 times.
3. *Haplistion ?arcticus* with subconical body-shape, P.M.O. A28505, vertical section, c. 4/5 nat. size.
- 4, 5. *Haplistion festningensis* new species, P.M.O. A4693; 4 – longitudinal section, c. 2 times nat. size; 5 – thin section of the same specimen showing rhizoclonal constituting the skeletal fibres; enlarged 31.2 times.

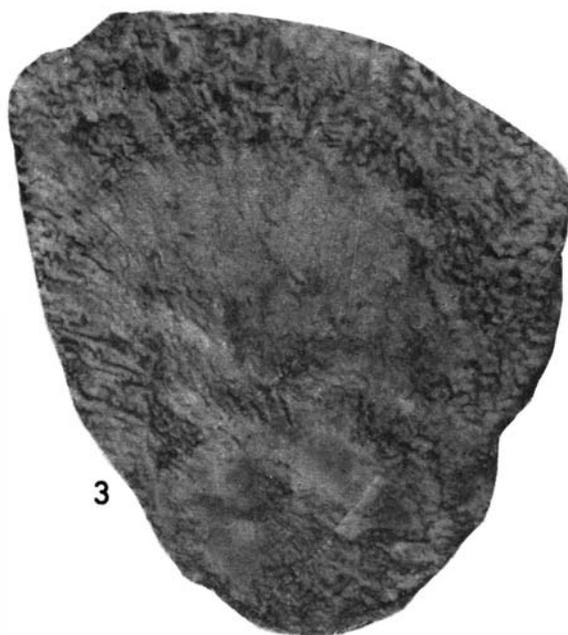
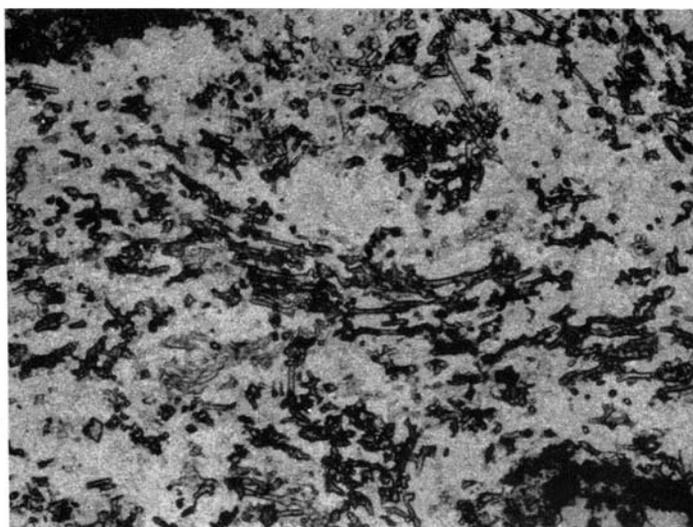
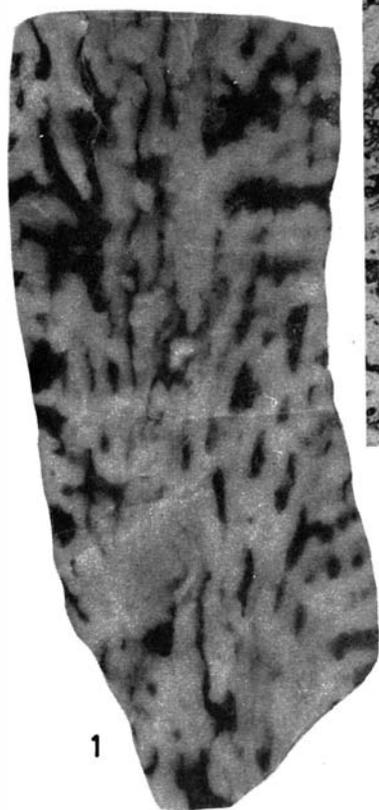
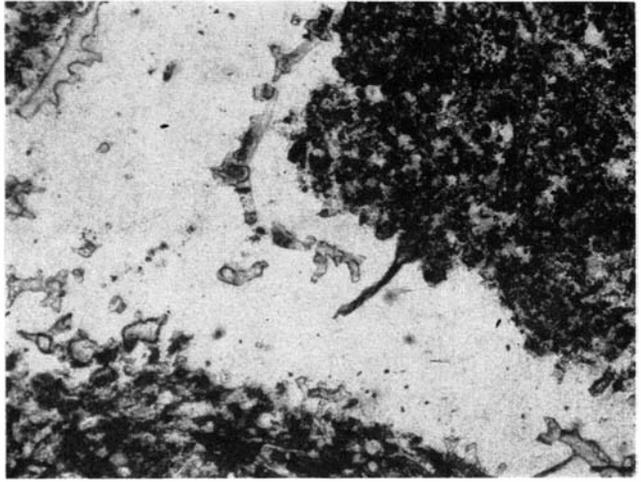


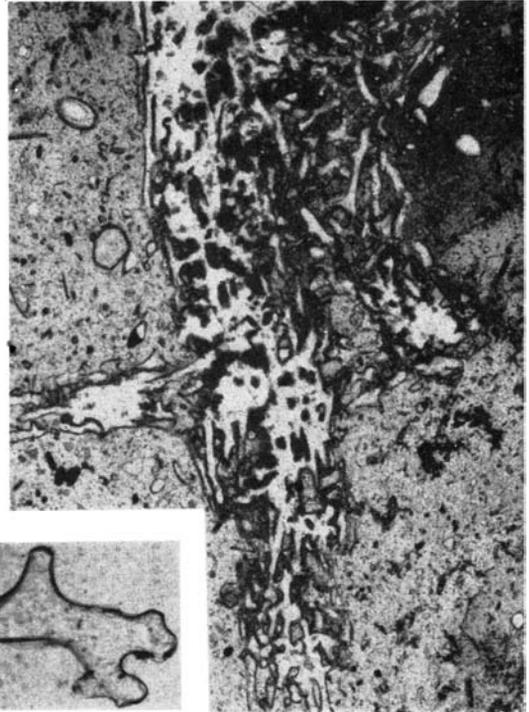
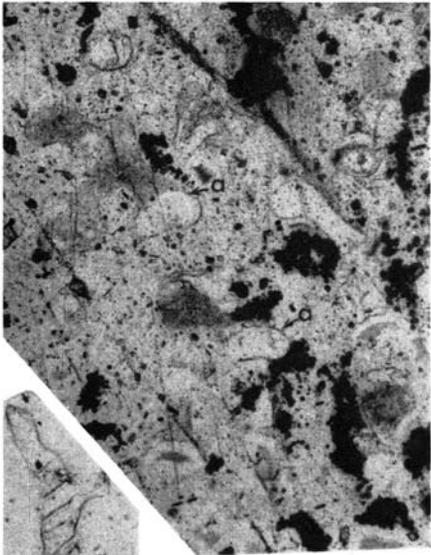
PLATE IV

1. Fragment of a skeletal fibre of *Haplistion arcticus* (DUNIKOWSKI) with preserved calcified rhizoclonal, P.M.O. A33205, enlarged 50 times.
2. Enlarged fragment of skeleton of *Haplistion arcticus* (DUNIKOWSKI) with preserved calcified rhizoclonal, P.M.O. A33217 enlarged 50 times.
3. Fragment of skeleton of *Scheiia tuberosa* TSCHERNYSCHEW and STEPANOV, P.M.O. A33219, enlarged 50 times.
4. Radial and transversal fibres of *Haplistion arcticus* (DUNIKOWSKI) consisting of interlocked rhizoclonal; P.M.O. A4897, enlarged 31.2 times.
- 5,6. Calcified rhizoclonal of *Haplistion elongatus* new species, P.M.O. A33220, enlarged 125 times.
- 7,9. Calcified rhizoclonal of *Haplistion ?arcticus* P.M.O. A28505, enlarged 125 times.
8. Rhizoclonal of *Haplistion arcticus* (DUNIKOWSKI), P.M.O. A33218, enlarged 50 times.
10. Fragment of skeletal fibre of *Haplistion arcticus* (DUNIKOWSKI) with parallelly arranged rhizoclonal, P.M.O. A30340, enlarged 50 times.
11. Preserved fragments of rhizoclonal of *Haplistion arcticus* (DUNIKOWSKI), P.M.O. A33217, enlarged 125 times.



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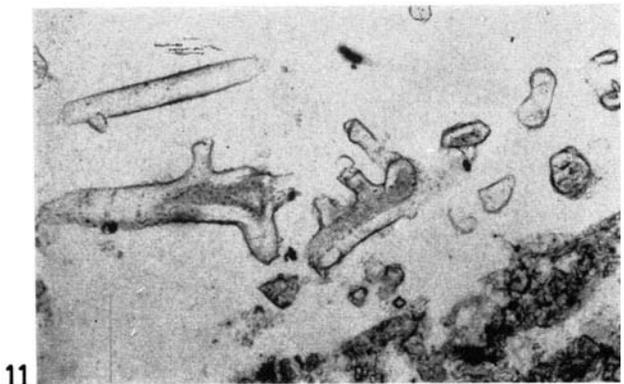
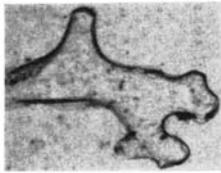


PLATE V

- 1-6. Problematic fossil-bodies (?sponges). 1 - branched individual, P.M.O. A33228, nat. size; 2 - cylindrical individual, P.M.O. A33216, c. $\frac{2}{3}$ nat. size; 3, 4 - fragments of probably branched individual, P.M.O. A33225, nat. size; 5 - thin section of specimen P.M.O. A33215: chalcedony smooth monaxons and terrigenous quartz grains are visible; enlarged 50 times, crossed nicols; 6 - thin section of specimen P.M.O. A33216 showing smooth monaxons of which this problematic fossil-body essentially consists; enlarged 50 times, parallel nicols.

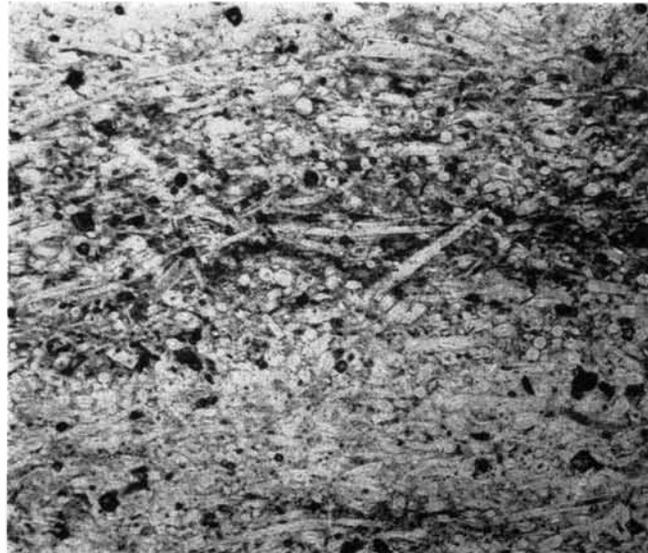
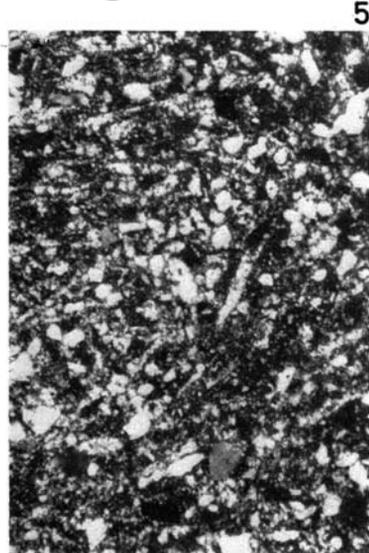
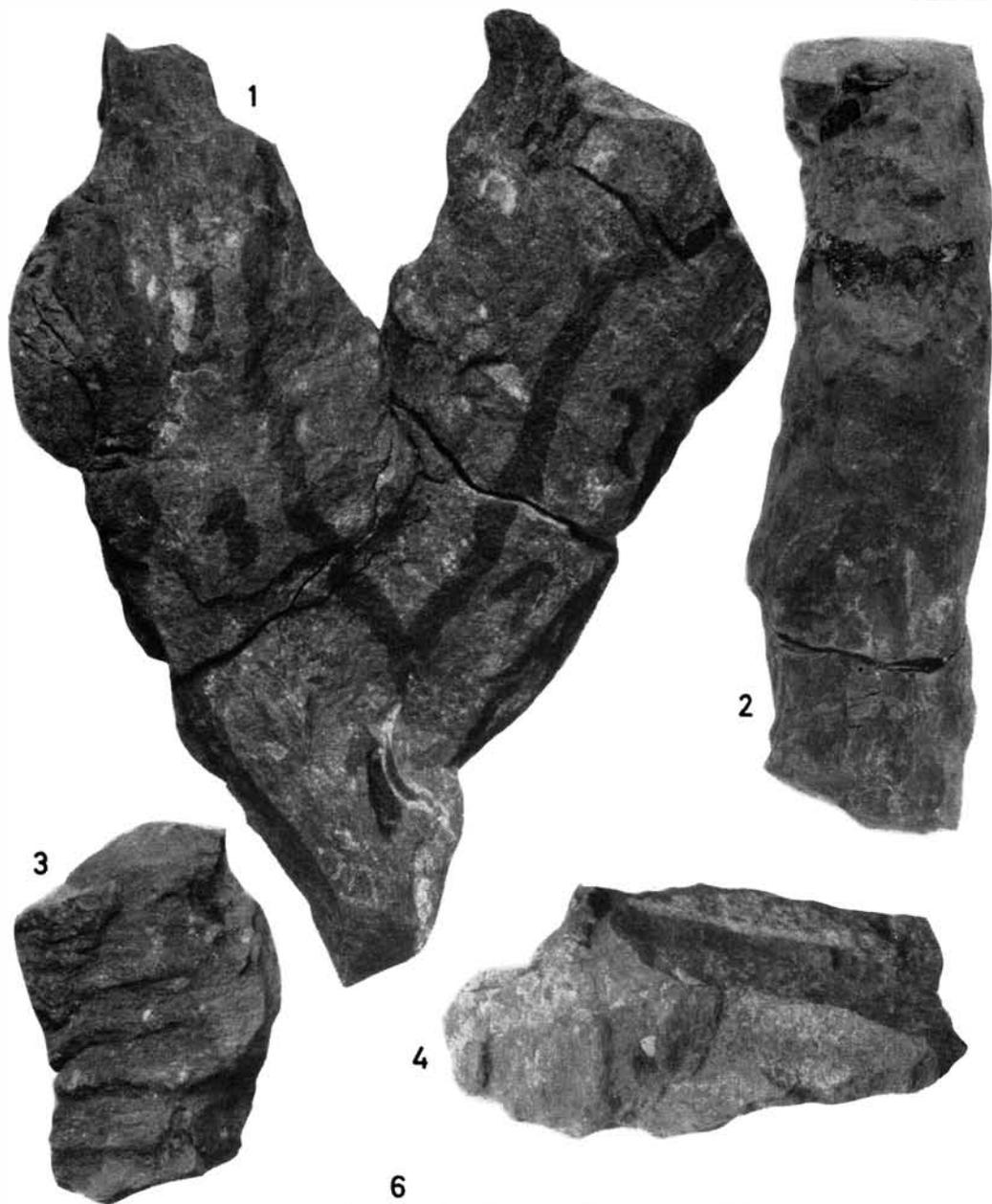


Fig. 3. Geological columns of Permian cherty rocks in southern Spitsbergen (the Sørkapp, Hornsund and Bellsund areas): 1 - spiculites; 2 - arenaceous, calcareous spiculites; 3 - arenaceous, calcareous spiculitic cherts; 4 - arenaceous, cherty limestones; 5 - fossiliferous, calcareous sandstones and siltstones; 6 - carbonate-cemented quartz sandstones; 7 - silica-cemented quartz sandstones; 8 - brachiopods; 9 - bryozoans; 10 - pectenids; 11 - sponges; 12 - *Helicoprion*; 13 - floral detritus; 14 - symbol of profiles on maps (figs. 2, 26); 15 - numbers of thin-sections, in parentheses numbers of beds; 16 - Upper Tokrossøya Beds; 17 - Lower Tokrossøya Beds.

A.W. BRØGGERS BOKTRYKKERI A/S - OSLO