The Pre-Cambrian Sandstone of the Gotska Sandön Boring Core

By

Roland Gorbatschev

ABSTRACT.—The Pre-Cambrian sandstone unconformably underlies the Lower Cambrian sandstone of Gotska Sandön Island, Central Baltic, where it was penetrated by a deep boring which was not carried to the crystalline basement. The sandstone is predominantly a grey to greenish-grey kaoline-spotted rock with intercalations of purple sandstone, siltstone, and thin layers of mudstone. Compositionally the rock is intermediate between orthoquartzite and pelite, and contains a very limited association of heavy minerals. Horizontal bedding is distinct, there is rhythmic variation of grain size, and in some cases waning current type graded bedding. In cementation the sandstone ranges from hard quartzite to varieties with considerable amounts of clay matrix. Compaction and pressure solution in lithologically different types are described and discussed. The part played by clay in pressure solution varies during the different stages of the process. Authigenic sericite is found in pressolved areas, where it replaces microstylolitic quartz columns. The detritus is thought to be derived from a source area of plutonic rocks with considerable amounts of sediments. Conditions of sedimentation and the stratigraphic position are discussed. The sandstone is suggested to have been formed in an environment promoting more thorough chemical weathering and involving a slighter morphological relief than those of the Jotnian sedimentation period.

Contents

Introduction

In the summer of 1957 the basement of the Cambrian in the Central Baltic area was reached in a deep boring at Hamnudden, Gotska Sandön. According to THORSLUND (1958) the island of Gotska Sandön (for location see Fig. 20) is built up of thick Quaternary glacial and post-glacial deposits (73 m) resting on Ordovician Palæoporella Limestone. The Cambrian and Ordovician strata

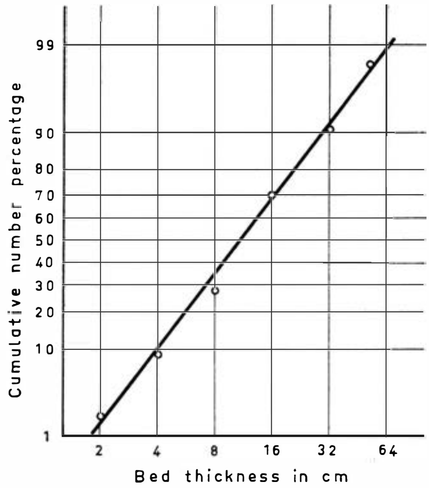

Fig. 1. Thickness distribution of bedding in the Gotska Sandön Pre-Cambrian sandstone.

have a total thickness of 159 m, and include Lower and Middle Ordovician limestones and Lower Cambrian sandstone. The Cambrian rests unconformably on Pre-Cambrian sandstones, nine metres of which (232.20–240.96 m depth) are included in the boring core. Since the boring was not continued to the crystalline basement the total thickness of these sediments and the nature of their substratum remain unknown.

The purpose of the present study is to elucidate the petrology of the Pre-Cambrian sandstone and to supply data which can be used for future correlations with other parts of the Baltic region.

ACKNOWLEDGMENTS.—The author is greatly indebted to Prof. P. Thorslund for permission to use the Gotska Sandön boring core. The interest in the investigation shown by Prof. E. Norin and Dr. V. Jaanusson is gratefully acknowledged. The author's thanks go also to Prof. O. Zdansky, Mr. G. Andersson, Mrs. A.-M. Ekström, Mrs. A. Kaljusaar, Mrs. Chr. Olsson, Mr. A. Sagerholm, and Mr. O. Wallner.

General lithology

The Gotska Sandön Pre-Cambrian consists predominantly of medium-grained, hard, grey to greenish- or yellowish-grey sandstone locally containing considerable amounts of clay matrix. In addition there occur pinkish to purple areas of sandstone stained by ore cement, fine-grained sandstones, siltstones, and thin intercalations of greenish sericitic mudstone. Quartz cement ranges from abundant (medium-grained quartzitic sandstones) to absent (pressolved siltstones). Horizontal bedding is well developed, the thickness of the individual beds varying between 2 and 53 cm. When grouped on a logarithmic scale, the thickness distribution yields a curve which is close to normal (Fig. 1). In many beds there is distinct rhythmic bedding or grading ranging from coarse basal sandstone layers, fractions of an inch thick, through quartz-cemented medium-grained sandstones and medium sandstones with sericite matrix to fine-grained sandstones, siltstones, and silty clay laminae. The bulk of each graded bed consists of macroscopically equigranular medium sandstones restricting the coarse and fine-grained layers to the bottom and topmost parts of the graded beds. The reduction in grain size is thus almost imperceptible in the central parts, but continues rapidly in the upper quarter of each bed. Some of the graded beds are incomplete, others have sharp limits between the constituent members, or show reversals in the trend. Nevertheless the general rhythmic character of the sediment is clearly perceptible, and is further confirmed by the systematical investigation of grain size variations in two graded beds. The grading is of a distinct waning current type, with silt and clay increasing rapidly in the top portions of the beds as contrasted to the more even distribution of the fine material in the turbidity type grading. Good cross-lamination implying rapid succession of 2–3 mm thick layers of medium-grained clean, and fine-grained clayey sandstones was found at only two levels, but on account of the small diameter (40 mm) of the core some of the possibly present cross-bedding may have escaped attention. Except for a strongly weathered rind immediately below the Cambrian sandstone, there is no recognizable change in Sub-Cambrian lithology throughout the core section obtained. The normal bedding dips at an angle of about 10 to 15 degrees to the "horizontal" of the core. This implies an unconformity of about as many degrees toward the overlying Cambrian sandstone. The deviation of the core from the perpendicular and the orientation of the core have not been ascertained. The contact toward the Cambrian is quite sharp. The cursorily investigated lowermost metres of the Cambrian consist of argillaceous quartz sandstone without feldspar and with rather poor sorting of the quartz detritus (pp. 23–24).

Petrography

MINERAL COMPOSITION.—The Gotska Sandön Pre-Cambrian sandstone consists of between 60 and 80 per cent detrital quartz plus feldspar pseudomorphs, 0–20 per cent secondary quartz cement, and varying amounts of argillaceous material (cf. Table 1). The content of detrital quartz is between 60 and 65 per cent by volume in the coarse and medium sandstones, 55 to 60 per cent in the fine-grained, and around 50 per cent in the very fine-grained sandstones and siltstones. Most grains consist of clear, straightly extinguishing, or slightly undulatory igneous-type quartz of the kind common in the Pre-Cambrian sediments of the Fennoscandian shield.

Composite grains include fine-grained or cryptocrystalline cherty material, fine-grained quartzite, and fine-grained argillaceous sandstone in addition to which there are compound grains consisting of several rounded quartz units

Table 1. Mineral composition of the Gotska Sandön sandstones (vol. per cent).

Macroscopial rock classification and specimen depth in cm (= sample no.)	Detrital quartz	Cement quartz	Quartzite and chert	Total quartz	Kaolinized and silicified pseudo-morphs, mainly after feldspar	Muscovite	Matrix (sericite, illite, kaolinite)	Detrital ores and leucoxene	Other heavies, mainly zircon	Pyrite	Ore cement	Total cement and matrix
23279 Quartzitic sandstone	67.8	14.0	0.7	82.5	6.9	0.2	10.4	0.0	0.0	—	—	24.4
23297 Quartzitic sandstone	65.3	21.6	0.3	87.2	8.2	0.2	4.1	0.2	0.0	—	0.1	25.8
23337 Quartzitic sandstone	67.1	15.1	0.2	82.4	9.3	0.1	8.1	0.0	0.0	—	0.1	23.2
23418 Quartzitic sandstone	65.4	17.9	0.7	84.0	7.0	0.1	8.7	0.1	0.0	—	0.0	26.6
23694 Quartzitic sandstone			0.4	77.6	8.2	—	13.9	0.1	0.0	—	0.2	
23747 Quartzitic sandstone			0.1	84.2	8.7	—	7.0	0.0	0.0	—	0.1	
23788 Quartzitic sandstone	61.5	17.2	0.1	78.8	7.7	0.6	12.8	0.0	0.1	—	—	30.0
23905 Quartzitic sandstone	64.0	20.3	0.0	84.3	8.6	0.3	6.5	0.2	0.0	—	0.1	26.9
23931 Quartzitic sandstone			0.1	82.4	11.2	0.3	6.0	0.1	0.0	0.0	—	
24076 Quartzitic sandstone	62.1	14.8	0.2	77.1	8.6	—	14.0	0.2	0.1	—	0.2	29.0
23350 Coarse sandstone	63.4	10.9	0.4	74.7	4.5	0.2	20.5	0.1	0.0	—	—	31.4
23847 Coarse sandstone	61.5	4.0	0.3	65.8	3.6	1.4	29.2	0.1	0.1	—	0.0	33.2
23947 Coarse sandstone	61.8	15.6	0.2	77.6	11.0	1.0	10.0	0.1	0.0	0.0	0.0	25.7
23379 Grey medium to coarse sandstone	66.3	7.4	0.1	73.8	3.0	0.2	22.8	0.2	0.0	—	0.0	30.2
23354 Greyish-green medium sandstone	59.2	12.8	0.2	72.2	6.8	—	20.5	0.0	0.0	—	—	33.3
23357 Greyish-green medium sandstone	67.6	9.4	0.4	77.4	4.2	0.0	18.2	0.0	0.0	—	0.1	27.7
23336 Grey fine to medium sandstone	66.5	10.2	0.1	76.8	6.4	0.0	16.4	0.4	0.0	—	—	26.6
23403 Grey fine to medium sandstone	63.9	12.3	0.1	76.3	6.7	0.3	16.5	0.2	0.0	—	—	28.8
23637 Greyish-green fine to medium sandstone	64.2	7.9	0.2	72.3	5.3	—	22.3	0.0	0.0	0.0	0.1	30.3
23987 Greyish-green fine to medium sandstone	59.9	10.9	0.3	70.6	8.2	0.6	19.9	0.1	0.1	—	0.0	30.8
23773 Greenish fine sandstone	57.3	10.0	0.1	67.4	9.4	0.6	22.3	0.2	0.0	—	0.1	32.4
23352 Silty sandstone	57.0	4.6	—	61.6	2.8	1.0	34.2	0.2	0.2	0.0	—	38.8
23886 Silty sandstone	57.7	7.4	0.1	65.2	8.4	0.8	25.2	0.0	0.0	—	0.4	33.0
24026 Very fine-grained sandstone	52.1	1.7	0.1	53.9	5.6	1.3	38.4	0.3	0.2	0.1	0.2	40.3
23330 Purple medium sandstone	63.7	8.6	0.1	72.4	7.2	0.1	18.2	0.7	0.1	—	1.3	26.9
23567 Red medium sandstone	60.1	17.3	0.2	77.6	10.3	0.3	10.2	0.4	0.1	—	1.1	28.6
23827 Pink quartzitic sandstone	62.1	18.2	0.3	80.6	9.9	0.1	8.7	0.0	0.0	—	0.7	27.6
23888 Purple fine sandstone	56.7	4.6	0.3	61.6	5.7	0.4	28.8	0.8	0.0	—	2.8	36.2
23896 Purple-greenish laminated fine sandstone	54.4	3.0	0.0	57.4	6.8	0.3	33.0	0.9	0.1	—	1.5	37.5
24053 Pink laminated medium sandstone	63.0	10.6	0.5	74.1	8.8	0.5	15.7	0.1	0.0	—	0.8	27.1
23104 Basal Cambrian sandstone	78.0	1.9	0.1	80.0	0.2	2.0	16.7	0.1	0.1	—	0.9	19.5

Fig. 2.

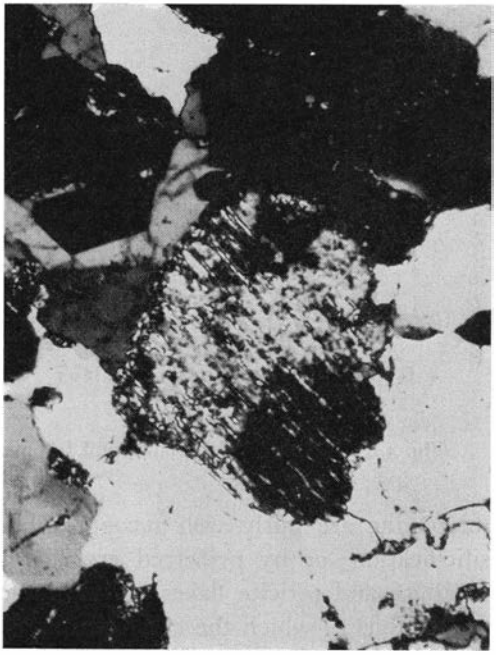

Fig. 3.

Fig. 2. Relict microcline twinning reproduced by selective silicification of a kaolinized feldspar psedomorph. Crossed nicols, ×41.

Fig. 3. Feldspar pseudomorph with sericite flakes arranged along original cleavage planes. Pseudomorph groundmass is kaolinite (light) and quartz (dark.). Crossed nicols, ×90.

cemented by quartz, or of quartz detritus with truncated rims of quartz cement. The chert appears to be both sedimentary and hydrothermal and often resembles the fragments of banded chalcedony veins common in the Jotnian sandstones. An origin from chalcedony veins is suggested by the admixture in the chert grains of minute chlorite flakes typical of the vein and amygdule cryptocrystalline quartz of the Jotnian Gävle sandstone and the Jotnian Gävle type dolerite.

No fragments of igneous rocks have been recognized, except for a few quartz grains with inclusions of sericite patches probably replacing originally present feldspar. A few mudstone or slate fragments appear in a coarse-grained basal layer of a graded bed which also contains small sandstone slivers.

Pseudomorphs after feldspar amount to between 3 and 11 per cent and consist of sericite, kaolinite, or both, giving the sandstone a characteristically spotted appearance. Some of the percentages of altered feldspar in Table 1 are maximum values, since in a number of thin sections considerable amounts of pseudomorph material were lost in the process of grinding and by way of compensation all voids in these slides have been taken to represent altered feldspar. None of the sections investigated was found to contain unaltered feldspar, but in some cases the original twinning structures of plagioclase and

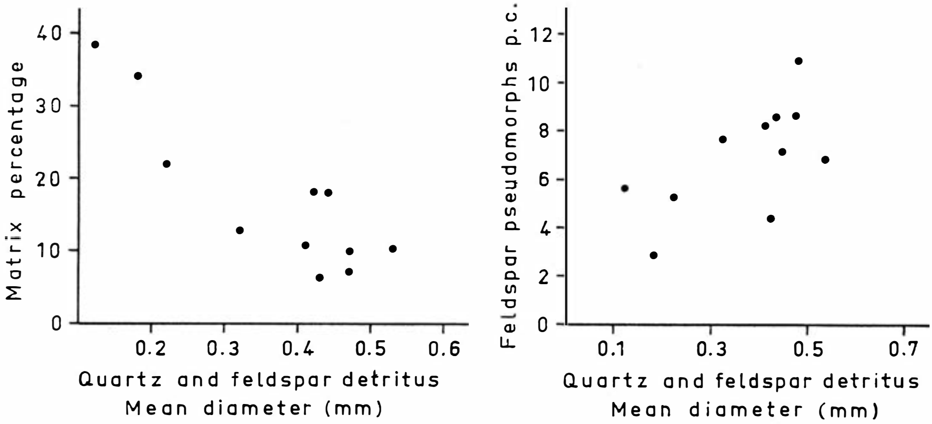

Fig. 4. Relations between matrix and feldspar pseudomorphs contents and mean size.

microcline are fairly well recognizable, having been preserved by selective silicification, or by preferred crystallographical orientation of the replacing kaolinite and sericite flakes (Figs. 2 and 3). The sericite belongs to several generations of which the early ones are clearly pre-depositional and comprise flakes arranged along the cleavages or twinning planes of the original mineral, or form irregular truncated clusters inside the pseudomorphs. Late sericite is demonstrated by the penetration of kaolinite pseudomorphous after feldspar by the sericite matrix. The presence of kaolinite was established both by X-ray and optical investigation. The mineral either forms aggregates of felty scales, or mosaics of fairly large, intricately intergrown grains. Since remains of kaolinite occur inside the cement quartz which replaces pseudomorphs after feldspar, the kaolinization must have preceded at least part of the silica cementation of the sandstone. However, it was not possible unambiguously to establish, whether all or part of the kaolinite was formed by weathering of the source rocks, by weathering during detritus transportation, or by post-depositional alteration of the feldspar. It may be suggested that some of the rounded feldspar pseudomorphs can hardly have survived the rigours of prolonged transportation if kaolinized as thoroughly as they are now. There appears to be no change in the proportions of kaolinite to sericite in the nine metres of obtained core, and since much quartz cementation preceded the deposition of the Lower Cambrian sandstone, nothing seems to prove that the feldspar was weathered *in situ* immediately prior to the Lower Cambrian transgression.

Apart from the continuous variation from quartzitic to argillaceous sandstone there is a fair correlation between matrix percentage and mean diameter, and a less good correlation between size and the content of feldspar pseudomorphs (Fig. 4). In addition to the colourless, white, or very faintly greenish feldspar pseudomorphs, there exist some few grains containing dirty green scaly flakes tentatively identified as chlorite. These flakes may be intergrown

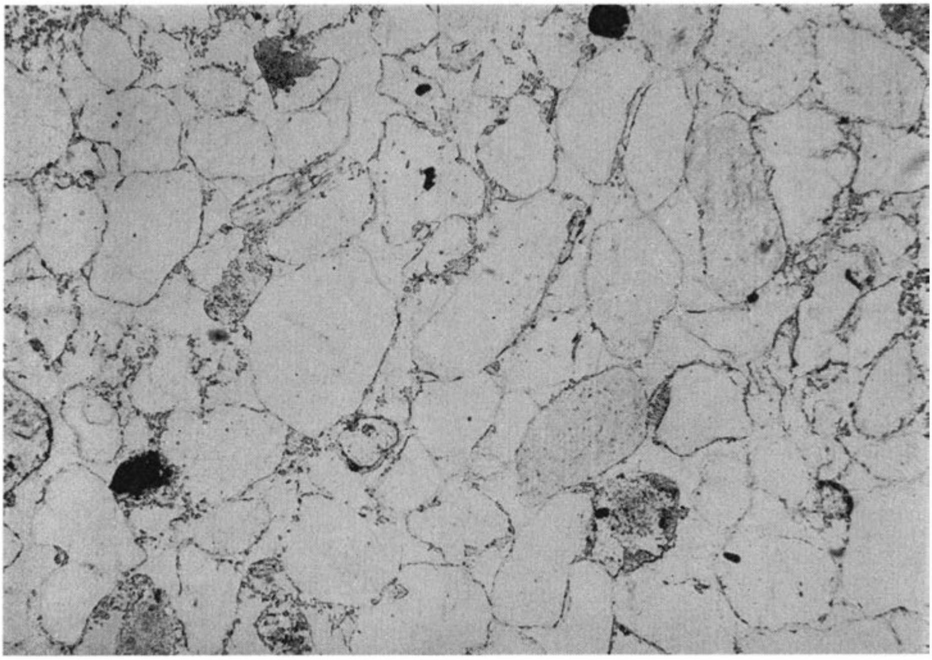

Fig. 5. Quartz-cemented (quartzitic) sandstone. Most detritus grains have narrow clay coatings. Plane-polarized light, × 43.

with kaolinite. Some of these pseudomorphs may represent altered ferromagnesian minerals or basic rock fragments, but no evidence revealing the details of their original character could be found.

The muscovite of the sandstone is partly detrital, but the bulk of this mineral is developed as large thin flakes formed from matrix sericite. Carbonates are entirely lacking in the Pre-Cambrian of Gotska Sandön.

Detrital heavy minerals belong to very few species. About three fourths of the grains are opaques, mainly magnetite with hematite coatings, leucoxenic ilmenite, and some detrital hematite. Non-opaque heavies are to more than 95 per cent zircon, the balance being brownish-green tourmaline, leucoxene, and a single grain of rutile. Of 400 counted zircon grains 43 were classified as well rounded, 135 were rounded to subrounded, 43 angular to subangular, 130 worn euhedral (approximately equivalent to subrounded), and 49 euhedral or broken euhedral. Some of the zircon grains have corrosion pits. Most of the angular grains belong to size grades smaller than 4 phi. Since there are many zircon grains included in detrital quartz, the fairly high percentage of euhedrals or broken euhedrals may be due to the release of these grains from protecting quartz not far from the site of deposition. Colour variations of the zircon are very slight, virtually all grains being faintly brownish grey. Ores and zircon are concentrated in the fine-grained sandstones and siltstones, and are there

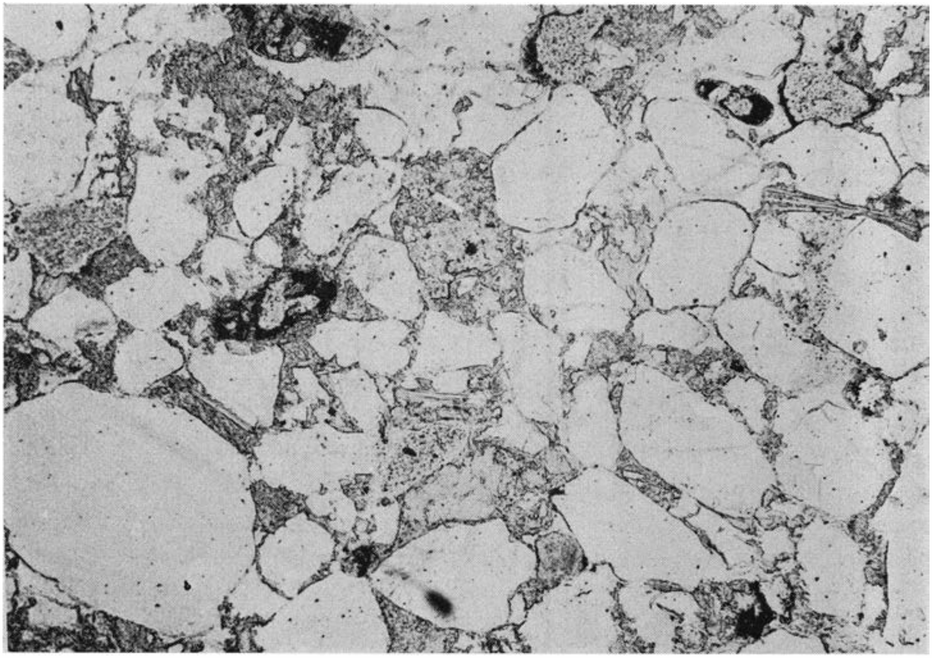

Fig. 6. Medium-grained sandstone with clay matrix and quartz cement. Some feldspar pseudomorphs have served as loci of iron oxide deposition. Plane-polarized light, × 44.

distinctly placered and often in good hydrostatic equilibrium with the quartz detritus. This mode of occurrence may depend on the size distribution of the heavy minerals in the source rocks. The original presence of some biotite is suggested by the occasionally very intricate intergrowths of muscovite and ore found in some parts of the rock otherwise free from opaque cement. In addition to this the investigated thin-sections contain several strongly bleached yellowish flakes of detrital biotite. Unaltered green biotite is found exclusively as minute flakes protected within grains of detrital quartz. In addition to the zircon mentioned above, the detrital quartz grains also contain epidote, sphene, amphibole, chlorite, ores, apatite, and calcite inclusions. In some of the very fine-grained sandstones and mudstones there are a few angular, probably authigenic, grains of pyrite. This mode of occurrence is presumably connected both with the depositional environment and the low permeability of these argillaceous rock types. The pyrite grains are usually surrounded by narrow rims of hematite or limonitic oxides of iron.

Sandstone matrix and shale are mainly sericite or illite with minor amounts of kaolinite. The clay in most thin sections appears to be thoroughly recrystallized, some of the newly formed flakes, especially in sandstones poor in matrix, being orientated with their long axes perpendicular to the surface of detrital quartz (Fig. 7).

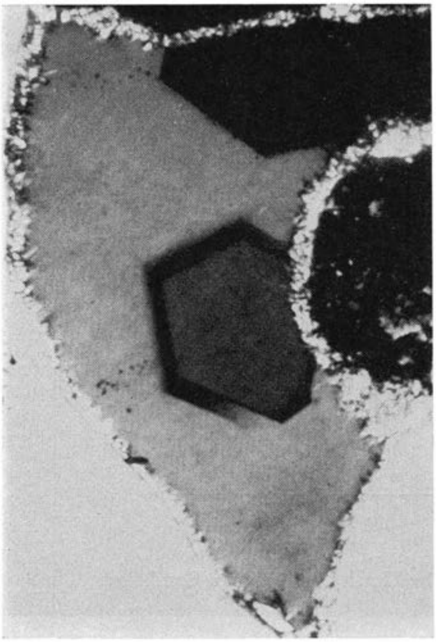

Fig. 7.

Fig. 8.

Fig. 7. Authigenic quartz crystal enclosed in massive quartz cement. Note sericite coatings on detritus grains. Crossed nicols, × 260.

Fig. 8. Euhedral outgrowths on detrital quartz. Crossed nicols, × 185.

The light-green colour of the matrix is largely responsible for the coloration of the rock. However, the colour of the sandstone changes to pinkish by an admixture of about 0.5 per cent by volume hematite cement. When the amount of ore cement is larger than about 1 per cent, the colour of the rock is purplish red. The green colour seems to be entirely due to illite and sericite, and there are no appreciable amounts of chlorite in the matrix, none being indicated either by optical or X-ray investigation. This is in good accordance with KELLER's (1953) and ROBB's (1949) findings as to the nature of the green-colouring agent in some sedimentary rocks.

Concerning the occurrence of clay minerals there is a general feeling that diagenesis is of considerable importance, and that kaolinite and montmorillonite in ancient sediments are apt to be replaced by illite and chlorite (GRIM, 1951, 1953, PETTIJOHN, 1957). This opinion, while certainly supported by numerous diagenesis investigations, is challenged by, amongst others, WEAVER (1956) who concludes that most of the clay minerals, at least as far as argillaceous rocks are concerned, are detrital in origin and only slightly changed in their depositional environment, which changes usually do not alter the basic lattice of the mineral. As WEAVER puts it: "Because kaolinite is more abundant

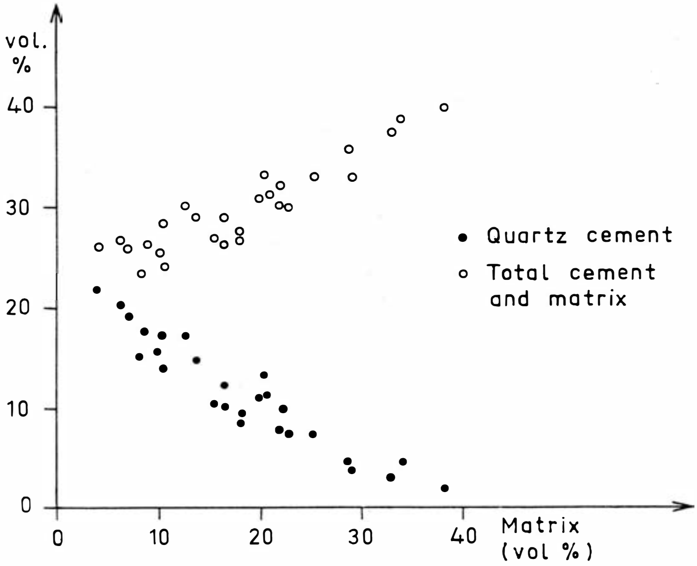

Fig. 9. Matrix and cement contents in the Gotska Sandön Pre-Cambrian.

in continental and near-shore sediments, a more reasonable explanation of the decrease in kaolinite (in ancient sediments) might be that these kaolinite-rich, border zone sediments are poorly represented in the older geological record."

In the Swedish Jotnian sediments kaolinite is known from the upper parts of the Dala Sandstone and also from parts of the Gävle and Mälar sandstone sequences. In the Gävle area kaolinite occurs in the possibly Post-Jotnian sandstone described by WESTERGÅRD (1939) from the Holmudden boring core and in a possibly equivalent sandstone from an excavation north of Gävle. In the Gävle sandstone proper kaolinite is found e.g. in the Tolvåbäcken sandstone which according to ASKLUND (1939) appears to belong to the central sandstone beds. At this locality kaolinite occurs both in the matrix and in kaolinized feldspars found side by side with unaltered microcline and plagioclase which indicates that the clay mineral was formed prior to detritus deposition. In the Mälar sandstone feldspar kaolinization is rather sporadic except in a tectonized pressolved quartzite, where it appears to have been produced by post-depositional alteration.

Quartz is the only abundant cement material in the Pre-Cambrian of Gotska Sandön. There are several generations of quartz cement the earliest of which consists of euhedral crystals coating the detrital quartz grains (Figs. 7 and 8). Where clay coatings are absent, the early cement prisms are in optical continuity with the detrital quartz grains. Otherwise, however, notably where clay coatings are prominent, there is no obvious relation in the optics of the cement prisms and any of the neighbouring grains visible in the thin section. The cement outgrowths occupying the same void are either enlargements of several

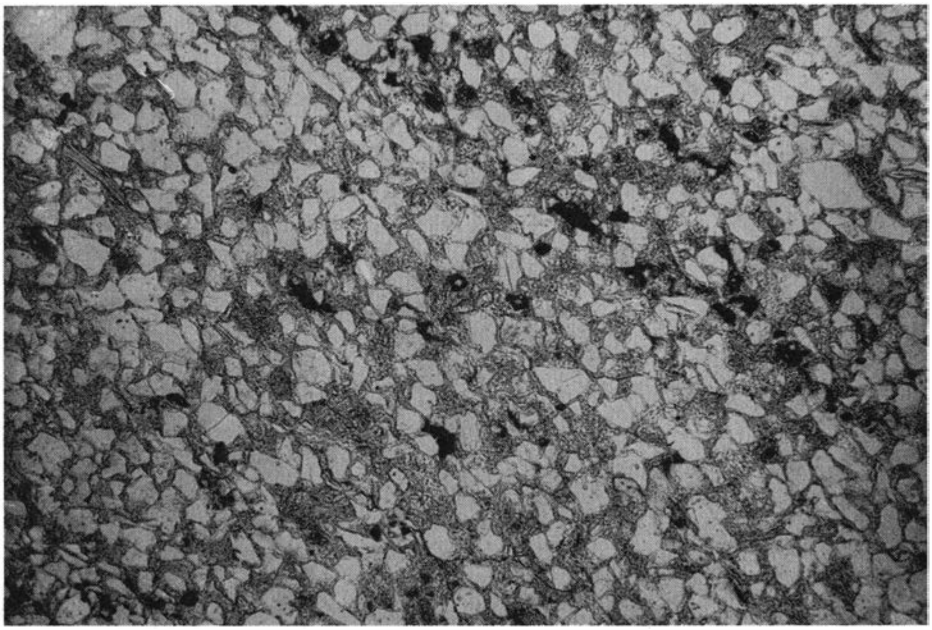

Fig. 10. Very fine-grained sandstone with placered ores and abundant matrix. Plane-polarized light, × 35.

surrounding grains or belong to one single grain in continuity with the cement of several cavities. Although no quantitative study has been made, it appears that some crystallographical orientations were favoured by quartz deposition. Since authigenic mica flakes occur between the detrital quartz and the overgrowths, the recrystallization of the clay matrix must have preceded most of the quartz cementation. Quartz cement also engulfs some of the recrystallized matrix clay. In beds affected by strong quartz pressure solution and showing little or no cement deposition secondary sericitic mica penetrates some of the detritus quartz to form curved pits reminding of myrmekite corrosion of plagioclase.

Quartz cement is most abundant in the lower and lower central parts of the individual beds. As appears from Fig. 9 there is a marked inverse relationship between the amounts of quartz cement and clay matrix respectively, which appears to be due mainly to the amount of pore space available for cementation (cf. p. 19), although permeability might have been of importance in controlling the time of cementation. This results in the early development of rigid textures in the lower parts poor in clay, and grain deformation, shattering, and pressure solution in the higher levels of each bed. Besides, as is shown by the relative amounts of microstylolitization, the properties of the pore liquid in clayey beds were decidedly unfavourable for silica deposition. In addition considerable amounts of silica were here abstracted by dissolution which accounts for

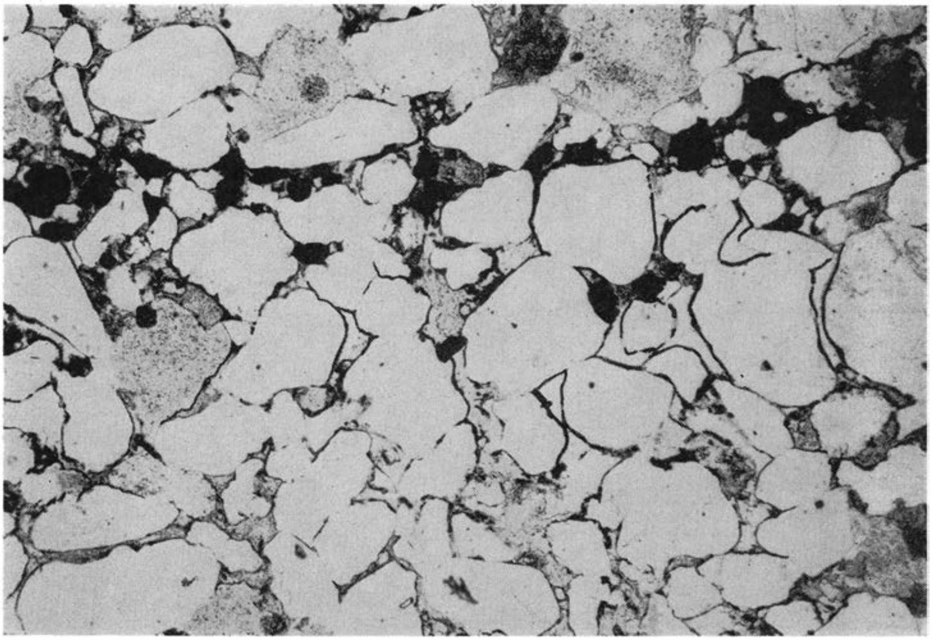

Fig. 11. Ore cement rims in the neighbourhood of a placered ore-zircon layer in medium-grained sandstone. Turbid grains are feldspar pseudomorphs, colourless cement is quartz. Plane-polarized light, × 36.

some, but definitely not the entire relative increase in total matrix and cement volume in the finer grained rocks. The abundant presence of angular fragments of quartz-cemented sandstone in the basal Lower Cambrian indicates that quartz cementation was reasonably complete at the time of the Cambrian transgression.

The only other cement mineral present is hematite found as thin coatings between detritus and cement quartz. Kaolinized feldspars have also served as loci of iron oxide deposition. Textures at the contacts between hematite cemented and hematite-free areas show that a period of reduction and dissolution of iron oxide followed upon the deposition of the hematite cement. However, relations in the uppermost part of the Pre-Cambrian, weathered prior to the deposition of the basal Lower Cambrian, indicate that the present distribution of iron-free and ore-cemented areas existed during the Cambrian pre-transgressional weathering. Usually the hematite cemented areas are closely associated with beds of placered detrital ores and zircon (Fig. 11), or else with predominantly fine-grained or silty sandstone containing a greater amount of detrital ores than usual (cf. Table 1). This suggests that the cement iron is of strictly local origin, and usually was displaced not more than a few centimetres. The alignment of detrital zircon with ore cement vitiates the argument that areas free of ore cement may have lost both detrital and cement ore by post-depositional dissolution.

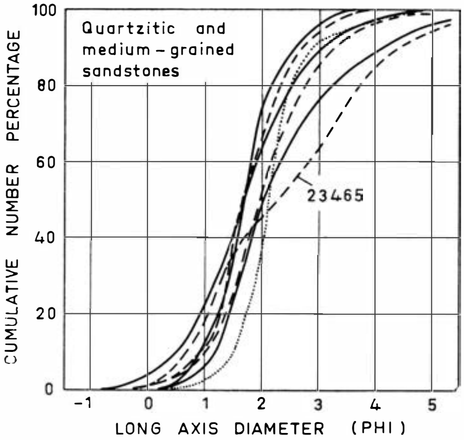

Fig. 12. Minus-matrix size distribution curves. Solid lines refer to Gotska Sandön quartzitic sandstones, broken lines to Gotska Sandön medium-grained sandstone, dotted line to Upper Gävle subarkose.

Beside the above matrix and cement the only other authigenic mineral is found in the shape of minute columnar crystals of moderate birefringence and rather high refraction indices (above 1.6). Sometimes these crystals form geniculated twins or incomplete hexagonal rings. The mineral is colourless, but often somewhat iron stained, and could not be identified positively. It occurs both in turbid dirty greenish pseudomorph clusters and as intergranular coatings projecting into the pore space subsequently occupied by quartz cement. The occurrence of the mineral is restricted to a few layers between 0.5 and 3 mm thick. Very tentatively the optical properties may be taken to suggest that the mineral is authigenic tourmaline.

Two partial chemical analyses of sandstone rather rich in clay show P_2O_5 contents of 0.10 and 0.17 per cent by weight corresponding to an apatite content of about 0.3 per cent, but no authigenic phosphates could be assured in the thin sections.

GRAIN SIZE.—The long axis diameters of feldspar pseudomorphs and quartz were measured on 200 grains per thin section, the results compiled in Table 2 giving the arithmetical mean and the standard deviation (both calculated from the first two moments according to KRUMBEIN, 1935), the Trask sorting coefficient, geometrical (phi) mean, phi standard deviation (derived from the cumulative curves according to INMAN (1952), which for the examined samples gives values that are on the average 0.08 lower than σ_φ calculated by conventional statistical procedure), phi median, and phi percentile deviation $((P_{90}—P_{10})/2$, GRIFFITHS, 1951, 1952). The medians range between 1.35 and 3.42 phi, most of them falling within a very narrow range between 1.6 and 2.0 phi. Most of the sandstone is thus medium-grained, the macroscopical classification of some

Table 2. Size distribution of detrital quartz and feldspar pseudomorphs (number frequency data).

Sample no.	Macroscopical rock classification	M_a (mm)	σ	So	M_φ	σ_φ	MD_φ	PD_φ
24026	Silstone	0.12	0.06	1.47	3.65	0.90	3.42	1.27
23352	Silty fine-grained sandstone	0.18	0.09	1.47	3.13	0.90	2.97	1.31
23637	Fine to medium-grained sandstone	0.22	0.12	1.42	2.81	0.87	2.72	1.42
23788	Quartzitic sandstone	0.32	0.15	1.61	2.33	0.97	2.00	1.46
23511	Medium sandstone	0.34	0.16	1.45	2.13	0.82	1.96	1.12
23465	Medium sandstone	0.35	0.25	2.28	2.46	1.48	2.28	1.85
23297	Quartzitic sandstone	0.41	0.15	1.35	1.81	0.66	1.74	0.95
23357	Medium sandstone	0.42	0.15	1.38	1.83	0.72	1.73	1.00
23905	Quartzitic sandstone	0.43	0.14	1.29	1.72	0.65	1.73	0.82
23330	Medium purple sandstone	0.44	0.20	1.33	1.75	0.69	1.62	0.89
23747	Quartzitic sandstone	0.47	0.31	1.55	1.73	1.00	1.67	1.29
23947	Coarse sandstone	0.47	0.32	1.85	1.85	1.25	1.81	1.53
23279	Quartzitic sandstone	0.53	0.33	1.60	1.60	1.02	1.54	1.29
23847	Coarse basal layer in graded bed	0.79	0.74	3.38	1.76	2.35	1.35	2.67
23104	Basal Lower Cambrian sandstone	0.18	0.28	2.44	3.88	1.95	3.86	2.45
	Upper Gävle sandstone	0.30	0.09	1.22	2.21	0.46	2.11	0.70

specimens as coarse being due to the admixture of coarse fractions which do not greatly depress the phi median as calculated on a number frequency basis, but the presence of which is apparent from the higher $PD\phi$ values. The poorly sorted medium-grained specimen No. 23465 is a finely cross-laminated sandstone and thus inhomogeneous. In the coarse basal layer, No. 23847, there is evidence of mixing of the coarser fractions with disturbed parts of a subjacent silty sandstone, resulting in poor sorting and prominently polymodal grain size distribution (Fig. 13). The average sorting of the quartz detritus in the Pre-Cambrian sandstone of Gotska Sandön is thus fairly good, but it should be stressed that the data of Table 2 do not account for the more or less prominent clay matrix which, at least in the upper and middle parts of each bed, is a primary constituent.

GRAIN ROUNDNESS.—Due to considerable pressure solution and masking of the detrital grain boundaries by cementation reasonably correct roundness data could be obtained only for a minority of the thin sections. Roundness was measured on 100 grains per thin section by visual comparison with POWERS' (1953) charts. The results given in Table 3 show a range of mean roundness values varying between 0.41 and 0.53. Well-rounded grains (roundness above 0.7) are rather scarce, seldom exceeding 4 per cent. The available data show no good correlation between mean grain size and roundness, which applies even to the coarsest rocks present. The mean roundness of detrital quartz in the Pre-Cambrian of Gotska Sandön is thus not very good. It is slightly poorer

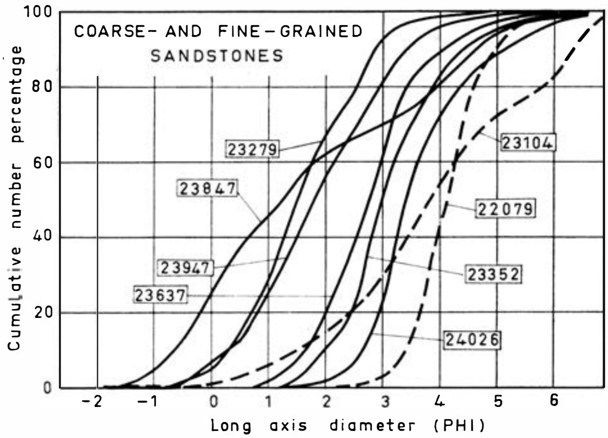

Fig. 13. Minus-matrix size distribution curves. Solid lines refer to Gotska Sandön Pre-Cambrian, broken lines to Gotska Sandön Lower Cambrian sandstones.

than the total average roundness in the Mälar Sandstone (GORBATSCHEV and KINT, 1961) and considerably lower than the roundness of the medium-grained Mälar Sandstone subarkoses (average roundness value 0.52) which, as regards composition and size of the sand-size detritus are closest to the common medium-grained and quartzitic sandstones of Gotska Sandön.

POST-DEPOSITIONAL TEXTURES.—Post-depositional modification of sedimentary texture in sandstones results in the elimination of porosity by compaction, pressure solution, cementation, and ultimately metamorphic alteration of the detrital grains. Whereas just deposited clean sands have porosities between 30 and 40 per cent by volume, compacted sandstones suffer mechanical reduction of pore space and alteration in type of the detritus-to-detritus grain boundaries. TAYLOR (1950) in a pioneer study examined the variations in number and type of contacts as depending on the depth of burial. She concluded that the number

Table 3. Roundness values of quartz detritus in the Gotska Sandön sandstone.

Sample number and rock classification		Mean roundness	Mean diameter (mm)
23352	Fine sandstone	0.43	0.18
23637	Fine to medium sandstone	0.50	0.22
23511	Medium sandstone	0.46	0.34
23297	Quartzitic sandstone	0.45	0.41
23905	Quartzitic sandstone	0.53	0.43
23330	Medium sandstone	0.44	0.44
23747	Quartzitic sandstone	0.49	0.47
23947	Coarse sandstone	0.48	0.47
23847	Coarse mode of coarse basal layer	0.44	1.1

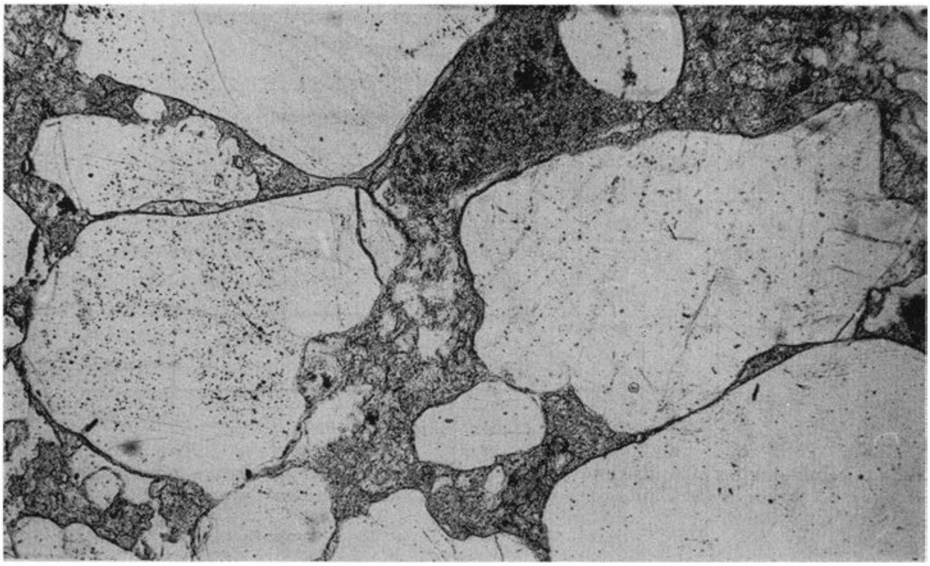

Fig. 14. Basal coarse layer in graded bed. Sorting is poor, matrix is abundant. Plane-polarized light, × 38.

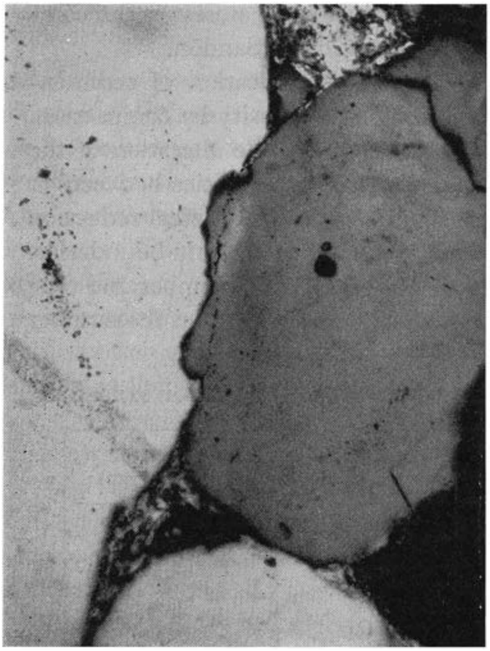

Fig. 15.

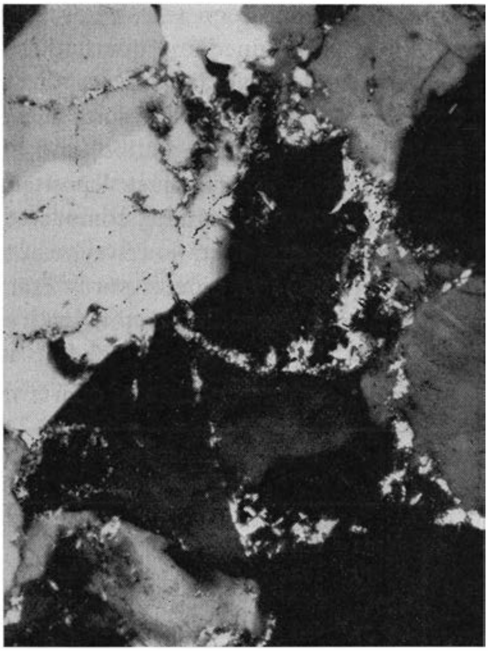

Fig. 16.

Fig. 15. Incipient recrystallization of quartz detritus-to-detritus contact. Row of dust particles marks original grain boundary. Crossed nicols, × 173.

Fig. 16. Considerably recrystallized area in quartzitic sandstone. Sericite rims mark original grain outlines. Crossed nicols, × 143.

Table 4. Contact relations of detrital quartz in the Gotska Sandön Pre-Cambrian sandstone.

Specimen number	Macroscopical rock classification	Type of contact (per cent)					Number of contacts per grain	Percentage clay matrix	Total cement percentage
		Tangential	Straight	Concavo-convex	Serrate	Microstylolitic			
23905	Quartzitic sandstone	27	43	25	4	1	2.20	6.5	20.4
23297	Quartzitic sandstone	30.5	40.5	25	4	0	2.47	4.1	21.7
23788	Quartzitic sandstone	30	37	31	2	0	2.73	12.8	17.2
23694	Quartzitic sandstone	24	37	20	16	3	2.91	13.9	ca 15[a]
23742	Quartzitic sandstone	20	37	30	13	0	3.45	7.0	ca 15[a]
23947	Coarse sandstone	14	33	26	22	5	2.75	10.0	15.6
23771	Medium sandstone	34	28	21	6.5	10.5	2.00	24	10.3
23330	Purple medium sandstone	29.5	36	26.5	7.5	0.5	2.55	18.2	9.9
23357	Medium sandstone	20	30	29	15	8	3.20	18.2	9.5
23353	Medium sandstone, pressolved layer	12	25	19	6	38	3.40	27	2.6
23637	Fine to medium sandstone	37	29	22.5	5.5	6	2.55	22.3	8.0
23773	Fine-grained sandstone	36	35	14	5	10	2.11	22.3	10.1
23888	Purple fine-grained clayey sandstone, pressolved	37	15	8	2	38	1.91	28.8	7.4

[a] In part masked by recrystallization.

of contacts per grain and the types of contacts due to pressure increase with depth. KAHN (1956), leaning on previously developed techniques (WINSAUER *et al.*, 1952, and others) codified and proposed the use of quantitative measures and statistical treatment in the description of detritus packing properties. During the last decade a large number of investigations have shed additional light on the properties of packing in arenaceous sediments, directing attention among other things to the importance of lithology in the process of sandstone compaction.

For the present study the types and number of contacts were determined in twenty thin sections. Representative results compiled in Table 4 also give data on packing density (sum of cement and matrix) and the type of material filling the interstices between detrital sand and silt. The measurements were made by counting the number per grain of detritus to detritus sand contacts and by recording the types of contacts for all grains passing the ocular crosshairs along short equally spaced lines drawn on the cover glass. 100–200 grains were counted per thin section. The classification of contact types is that employed by TAYLOR (1950), except that sutured contacts were subdivided into serrate and microstylolitic as shown in Fig. 17, and long contacts were replaced by straight. Since the investigation aimed at an evaluation of pore space reduction

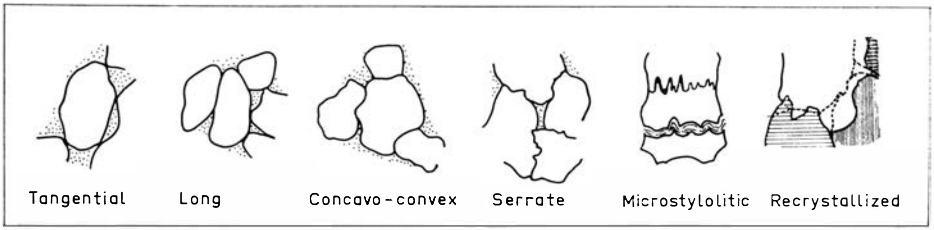

Fig. 17. Types of grain contacts.

by alteration of shape, recrystallized contacts were not classed separately. The data of Table 4 show a number of interesting details, but in general the relations between type and number of contacts are not of a simple nature. Evidently the lithology and particularly the amount and nature of matrix are of cardinal importance for the development of compaction and the type of pressure solution. It appears that smooth variation curves can be obtained only, if the petrological variables are kept reasonably constant by working with sections of essentially uniform lithology. Time and amount of cementation appear to have been important for the eventual development of contact types in the sandstones of Gotska Sandön. The conclusions suggested by the grain contact measurements are as follows:

The percentage of tangential contacts is inversely proportional to the number of contacts per grain;

There is an inverse relation between the number of tangential and serrate grain contacts;

Clay matrix counteracts tight-packing and hinders the development of straight contacts;

Clay promotes, but is not necessary for the interpenetration type pressure solution;

Clay matrix is a promoting but not a controlling factor in the development of microstylolites;

Further evidence suggests that the formation of limited, very strongly pressolved zones of the kind shown in Pl. II, is controlled by clay matrix, mainly by channelling the movement of intergranular liquids. No other systematic variation emerged from the data obtained. Provided such relations exist, the material was not sufficiently large to bring them out, or else differences in lithology mask the existing trends.

Mechanical shattering of grains at point-blank detritus contacts occurs both in argillaceous and in reasonably clean sandstones. Since the rock is now rigidly cemented by quartz, this must be a pre-cementation feature demonstrating that considerable overburden had accumulated before ensuing cementation and pressure solution were successful in the elimination of strong pressure maxima at tangential points of contact. Another pre-cementation effect of overburden load is the compaction of the sandstone by tight-packing of the detrital grains and by minor adjustment of detritus shape by initial pressure solution and attendant enlargment of the contact surfaces. The well-known inverse relation between the amounts of clay matrix and cement (KRYNINE, 1948, SIEVERS, 1959) is well developed in the Pre-Cambrian sandstone of Gotska Sandön (Fig. 9). Another important relation revealed by the data of Fig. 9 is the increase of the sum of cement and matrix with rising matrix contents. All the rocks recorded in this diagram contain some quartz cement, and from the ubiquitous occurrence of detritus interpenetration and pressure solution it must be concluded that the existent relations were produced mainly by lack of pore space available for cementation. However, in most rocks, except only some very fine-grained argillaceous sandstones, original intergranular space appears to have been sufficient for the accomodation of all or most of the co-deposited clay matrix. From the investigation of grain contact types and packing it emerges that the present co-variation of matrix and total intergranular space is due to the influence of clay on the detritus close-packing. The obvious explanation is that after some initial compaction clay produced a more even distribution of pressure, and by forming intergranular cushions prevented quartz-to-quartz contacts. In this way it counteracted mechanical interlocking, and hindered the development of straight grain contacts. This constitutes additional evidence for the assumption that cementation has taken place first after considerable time of burial. Once a great part of the tangential point-blank detritus contacts were eliminated by initial pressure solution and some cementation, additional quartz solution predominantly continued in sandstone with clay rims between the detrital sand grains. Typically the medium-grained sandstones rich in clay matrix have many microstylolitical grain contacts and deep interpenetration lobes in cases of concavo-convex contacts. This indicates that clay matrix promoted pressure solution and the development of microstylolites, although the distribution of the latter is not uniform, being distinctly aligned with zones parallel to the original bedding. It appears that most of the secondary quartz cement can be accounted for by the silica produced by detritus solution, but as no microscopically recognizable porosity remains anywhere in the rock, it is not clear whether significant differences in permeability existed between the different lithological types during any stage of cement deposition, and whether or not the quartz cementation was more or less contemporaneous in the different kinds of rock.

The part played by clay in post-depositional texture modification and in the development of solution textures has for about a decade been the subject of investigation and discussion. Recent work supplies evidence that interdetritus clay rims are a factor promoting (pressure-) solution of quartz and catalyzing the development of stylolitic seams and microstylolitic contacts (HEALD, 1955, 1956*a*, THOMSON, 1959, FOLK, 1960, and others). THOMSON (1959) suggested that the mechanism involved implies base exchange and degradation of illite resulting in increased K^+ concentration and attendant high pH in the intergranular solutions. Due especially to the work of HEALD the correlation between clay and pressure solution appears to be well established, but pressure solution and serrate or stylolitic contacts are not necessarily associated with clay (HEALD, 1956*b*).

Some investigators (SIEVER, 1959) have not noticed any relation between pressure solution and clay contents, or else a negative correlation between the amounts of clay and interpenetration (WALDSCHMIDT, 1941, GILBERT, 1949). Gilbert states that interlocking grain contacts in Californian Tertiary sands are typically associated with quartz cement, whereas clay-cemented sandstones have tightly packed but not interlocking grains. The type of clay has been suggested to be of importance in pressure solution, but as far as the present author is aware the effect of different clay types has not been investigated. In place of (load-)pressure the effects of structural deformation and of temperature have been proposed as factors controlling the formation of post-depositional solution textures (SIEVER, 1959). Although the importance of structural deformation is beyond discussion, many of the rocks with well developed solution textures have not been subject to significant tectonic deformation. The effect of temperature in promoting silica solubility is long since established (KRAUSKOPF, 1956), but cannot by itself account for the predominant orientation of the stylolitic columns at right angles to bedding.

As far as the Gotska Sandön is concerned, the somewhat controversial statements of literature reference can well be reconciled. Careful examination of the relations between solution and cementation indicates that post-depositional texture modification was a process operating through several different stages. At least as far as sandstones fairly rich in matrix are concerned, the cushioning effect of clay opposes its chemical catalyzation of pressure solution. The net result varies, among other things, with the completeness of compaction and cementation and possibly also with the permeability of the rock. Needless to say, temperature and the composition of pore solutions are other factors that may affect the role of clay matrix in sandstone diagenesis and trigger quartz solution.

Superimposed upon the general development of pressolved contacts there are several narrow zones of very strong quartz detritus dissolution (Pl. I, Fig. 2). The width of these zones varies between 1 and 4 mm, and their orientation is always strictly parallel to the bedding. Measurements of grain shape in strongly dissolved laminae and in moderately pressolved adjacent sandstone demonstrate a reduction in volume of quartz detritus amounting to as much as 70 per cent. Characteristically the zones of strong solution occur in sandstone with clay matrix and particularly at the boundary between argillaceous top and coarse basal sandstone layers. This localization strongly suggests that the main factor controlling the distribution in the lithological column of this type of quartz solution was the channelling effect of argillaceous layers inducing the development of restricted zones easily permeable by circulating intergranular waters. Probably the presence of clay promoted solution, but since fairly intact sandstone with abundant clay matrix borders on the narrow strongly dissolved zones, structure rather than lithology or pressure was the factor controlling the development of this type of quartz solution. Usually the laminar zones of dissolution carry no quartz cement. However, there are some exceptions, where the secondary quartz is corroded. This is important as demonstrating that laminar solution developed after the deposition of some cement in the sandstone. In thus appears that the formation of this type of solution texture is subsequent to the development of post-depositional textures in the bulk of the sandstone, and is due to the circulation along permeable layers of interstitial waters of high basicity and possibly of elevated temperature. The formation of laminar solution zones is consequently not an isochemical process. Quartz solution here produces two different types of corrosion structures. In cases of point-blank quartz to quartz contacts microstylolitical contacts will develop, while the type of structure produced in quartz grains bordered by thick matrix areas may be described as lobate corrosion. The latter type of solution implies the formation of broad, mostly shallow, concave pits in the corroded grains. As suggested above, the presence of waters of high pH rather than pressure is the triggering environment in producing strongly dissolved laminae. Nevertheless, all other things being equal, pressure is the factor controlling the location of corrosion lobes and the orientation of microstylolitical columns. In the lobate type of corrosion most large lobes correspond to neighbouring quartz grains (Pl. I, Fig. 2, and Pl. II, Fig. 1). Local pressure maxima thus affect the solubility of quartz resulting in lobate corrosion, where pressure concentrations are mitigated by the presence of thick matrix layers, and in microstylolites at detrital contacts with only thin interposed clay laminae.

Authigenic sericitic mica was found associated with microstylolites and corrosion lobes. In the corrosion lobes there are either large thin flakes or curved books outlining the lobe surface (Pl. I, Figs. 1 and 2), while some of the microstylolite quartz columns are partly or completely (Pl. II, Fig. 1) replaced by crenulated authigenic mica pseudomorphing the microstylolite columns. Experimental evidence shows that the solubility of silica is considerably lowered by the presence of $Al(OH)_3$, alumina reacting also with colloidal silica in water (ILER, 1955, GOTO, 1956). The type and environment of mica authigenesis in the sandstone of Gotska Sandön suggest that a process analogous to that proposed by MURRAY and GRAVENOR (1953), WHITE *et al.* (1956), and KRAUSKOPF (1956) for the formation of clay minerals from alumina and dissolved silica is operative in the (pressure) solution modification of sandstone texture. Actual observations advanced in support of clay authigenesis in connection with pressure solution are extremely few (KOPELIOVIČ, 1958), but it is interesting to note that muscovite, in contrast to feldspars, biotite, shale fragments, and other detrital minerals is unaffected or only weakly attacked by pressure solution (HEALD, 1955, 1956*b*, KOPELIOVIČ, 1958).

In the Gotska Sandön Pre-Cambrian the amount of matrix is sufficiently large to preclude any suggestion of a wholesale formation by authigenesis, and thus the interdependence between pressure solution and clay matrix is evident enough. However, in sandstones with little clay, "matrix" authigenesis during pressure solution implies a substantial danger of confusing cause and effect, when investigating the relations between matrix and pressure solution. Also the addition of authigenic to co-deposited clay may simulate a degradation process, when the clay of pressolved zones is compared with illite in unpressolved areas.

Incipient development of metaquartzite texture by recrystallization of quartz across the clay-rimmed or dust-marked detrital boundaries occurs in some of the quartzitic sandstones (Fig. 16). This crystallographical readjustment is still very weakly developed, and an investigation of petrofabrics would involve prohibiting amounts of work in preparing a number of thin sections sufficient to obtain statistically significant parameters.

From the universal absence of carbonates and unaltered biotite, and from the thorough kaolinization of feldspar as contrasted to the development of layers with strongly corroded quartz it would appear that acid and basic environments predominated alternatingly during the diagenetic period of the Pre-Cambrian sandstone of Gotska Sandön.

Since quartz cementation was well in progress prior to the Lower Cambrian transgression (cf. p. 12), and since most cementation was preceded by mechanical sandstone compaction, it is probable that considerable amounts of overburden were removed in Pre-Cambrian times. HEALD (1955) found notable pressure solution at a depth of only some thousand feet, while the sandstones studied by TAYLOR (1950) have no sutured contacts above 4535 feet. THOMSON (1959) mentions that quartz-cemented sandstones buried under 18,000 feet of superimposed strata still show tangential contacts. These data suggest that original lithology, environment, and time of cementation rather than depth of burial exert controlling influence on textural alterations. On application of the above data to the Pre-Cambrian sandstone of Gotska Sandön an overburden of at least a couple of thousand feet thickness appears to be a reasonable minimum guess.

The contact toward the Cambrian sandstone

The contact between the Lower Cambrian sandstone and its Pre-Cambrian counterpart is comparatively distinct, although no core was obtained for about 20 cm immediately below the actual contact line. Just above and for about 15 cm below the missing core portion the Pre-Cambrian sandstone is weathered and partly friable. Weathering predominantly attacked originally hematite-cemented layers, where the solid detritus-cement quartz texture is "blown up" by hydration and dissolution of the iron oxide. Layers poor in hematite

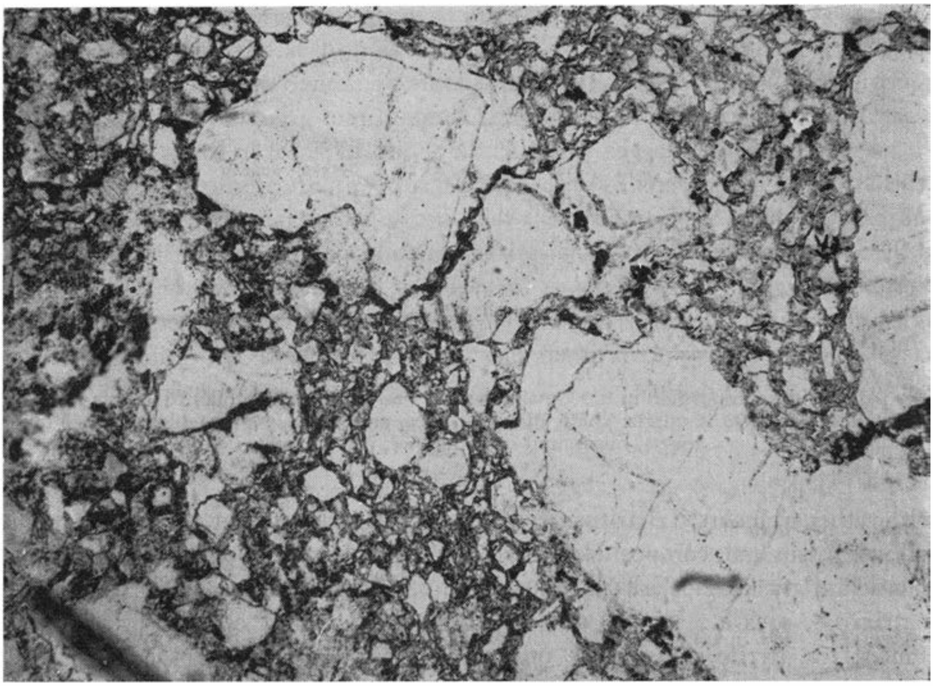

Fig. 18. Basal Lower Cambrian sandstone. Roundness and sorting are poor, truncated quartz cement rims are abundant. Plane-polarized light, × 50.

cement remain hard, although some disintegration is noticeable in beds rich in clay matrix.

The basal beds of the Lower Cambrian exhibit a gamut of quartz grain sizes ranging from pebbles to very fine silt embedded in sericite-kaolinite matrix. Sorting and roundness are poor (Figs. 13 and 18), angular sandstone fragments are very common, but feldspars or feldspar pseudomorphs are missing, all the kaolinized feldspars of the Pre-Cambrian sandstone having distintegrated into matrix kaolinite.

In the basal Lower Cambrian there occurs some incipient pressure solution and also some quartz cementation, but the amount of quartz cement is much lower than the clay matrix content. The basal layers of the Lower Cambrian have a total thickness of about 4 metres. This poorly sorted sandstone is interrupted by several layers of silty mudstone and for more than one meter above its base by beds of gravelly or conglomeratic sandstone, the pebbles consisting both of quartz, porphyry (Thorslund, 1958), and apparently Pre-Cambrian sandstone. At about 228.50 m depth the basal sandstone is succeeded by well-sorted, very fine-grained sandstone interbedded with clayey siltstone and mudstone, and in the lowermost parts (for instance at 227.10 m depth) by thin beds of poorly sorted sandstone of the basal type. The succeeding Lower Cambrian sandstone is an orthoquartzite or a subarkose rich in quartz, and

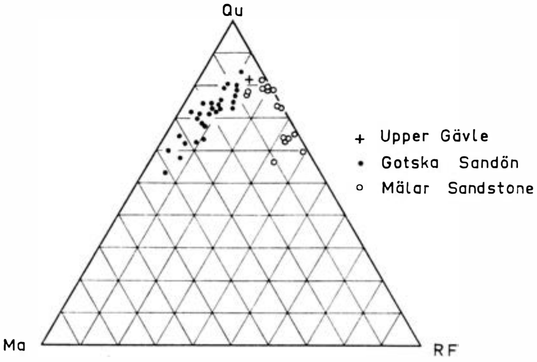

Fig. 19. Detritus composition in the Gotska Sandön Pre-Cambrian, Jotnian Mälar, and Upper Gävle sandstones. Qu is quartz, chert, quartzite, ores, and zircon, RF is feldspars, rock fragments, micas, and other heavies, Ma is matrix.

with rather well sorted detritus. A sample of the rock taken at 220.79 m has the following mineral composition (per cent by volume): Detrital quartz 66.5, microcline 3.7, plagioclase 2.4, muscovite 2.6, biotite and chlorite 1.0, sericite matrix 0.8, ores 0.2, zircon 0.1, tourmaline 0.1, quartz cement 17.1, calcite cement 1.2, pyrite cement 0.6, uncemented pore space (microscopical determination) 2.1. The phi median diameter is 4.11, phi standard deviation $((\phi_{84} - \phi_{16})/2)$ is 0.57.

Discussion of sedimentation and age

The complete lack of data on the lateral extent and facies variation of the Gotska Sandön Pre-Cambrian make the problem of its depositional environment an extremely knotty one. The characteristical features of the sandstone are rhythmic bedding, moderate grain roundness, rather good sorting of the sand-size detritus, the presence of a prominent clay mode, and a composition between orthoquartzite and argillite (Fig. 19) in what was PETTIJOHN's subgreywacke area previous to the modification of his terminology in the 1957 edition of "Sedimentary rocks". In comparison with its nearest Pre-Cambrian neighbours, the Jotnian sandstones of Central Sweden, the rock of Gotska Sandön has a more mature mineralogy and textural features suggesting a lower energy depositional environment. Mineralogical maturity in sandstones can be attained either by thorough chemical weathering and reworking of the débris, or by the passage of the detritus through several cycles of sedimentation. Sedimentary rocks in the source areas are indicated both for the Jotnian and Gotska Sandön sandstones, but since grain roundness is generally not very good in the Pre-Cambrian of Gotska Sandön it would appear that strong weathering, probably implying a warm humid climate, was the main factor controlling the lithology of this sediment. In the Jotnian sandstones, except for the conglomerates and gravels, all grains in the individual beds are about the same size, but there is great variation when comparing one bed to another. As far as the present section is considered to be representative, grain size variation in the Gotska Sandön is much smaller, the largest grain on record in a coarse basal bed having a long diameter just short of 4 mm. This indicates a less vigorous agent of transportation, which at the site of deposition was recurrently incapable of effecting good separation of sand and clay. The log normal distribution of bed thickness suggests that the type of sedimentation environment was constant throughout the time of deposition, but the rhythmic bedding indicates periodically recurrent changes of current strength of a type that might be expected in a shallow sedimentation basin off the mouth of a large river. Summing up, the compositional and textural properties of the Gotska Sandön Pre-Cambrian sandstone and the Jotnian sandstones of the Mälar and Gävle areas may be tabulated as follows:

	Jotnian	Gotska Sandön
Type of lithology:	subarkose and arkose (10–30 % feldspars)	argillaceous quartzite (3–11 % feldspars)
Matrix content:	predominantly low (0–10 %)	moderate to high (4–35 %)
Heavy minerals:	wide range	ores and zircon
Size range:	clay to boulders	clay to sand
Sorting of sand:	good	good
Roundness of sand:	good to moderate	moderate

From this it appears that sedimentation conditions during the deposition of the Pre-Cambrian of Gotska Sandön were different from those of the Jotnian as found in East Central Sweden, and involved among other things stronger chemical weathering and weaker morphological relief. It is thus suggested that the rock of Gotska Sandön cannot be a facies of the Jotnian Mälar, Gävle, and Satakunta sandstones. If the Gotska Sandön should still be referred to the Jotnian, it is probably not strictly contemporaneous with the other Jotnian rocks of Central Sweden and Southern Finland. It should, however, be remembered that Jotnian sedimentation is responsible for more than 2500 feet of strata, part of which are still not lithologically described. In two recent reviews of the Hoglandian-Jotnian POLKANOV (1956*a* and *b*) states that the detritus was strongly reworked and deposited in shallow basins with a "mobile aqueous medium (tides?)", the climatical conditions promoting extremely thorough weathering. Whereas POLKANOV's consideration of the effect of tides is similar to an idea of VON ECKERMANN (1937), his statement of very thorough weathering, while applicable to the Onega sandstones, is not quite adequate as far as the Swedish and Finnish Jotnian sediments are concerned (SIMONEN and KOUVO, 1955, GORBATSCHEV and KINT, 1961). While the Jotnian sandstones certainly are often more mature than indicated by their former classification as "arkoses", the concept of very thorough weathering is hardly supported by available lithological data. The term "quartzite" as used in most Scandinavian papers

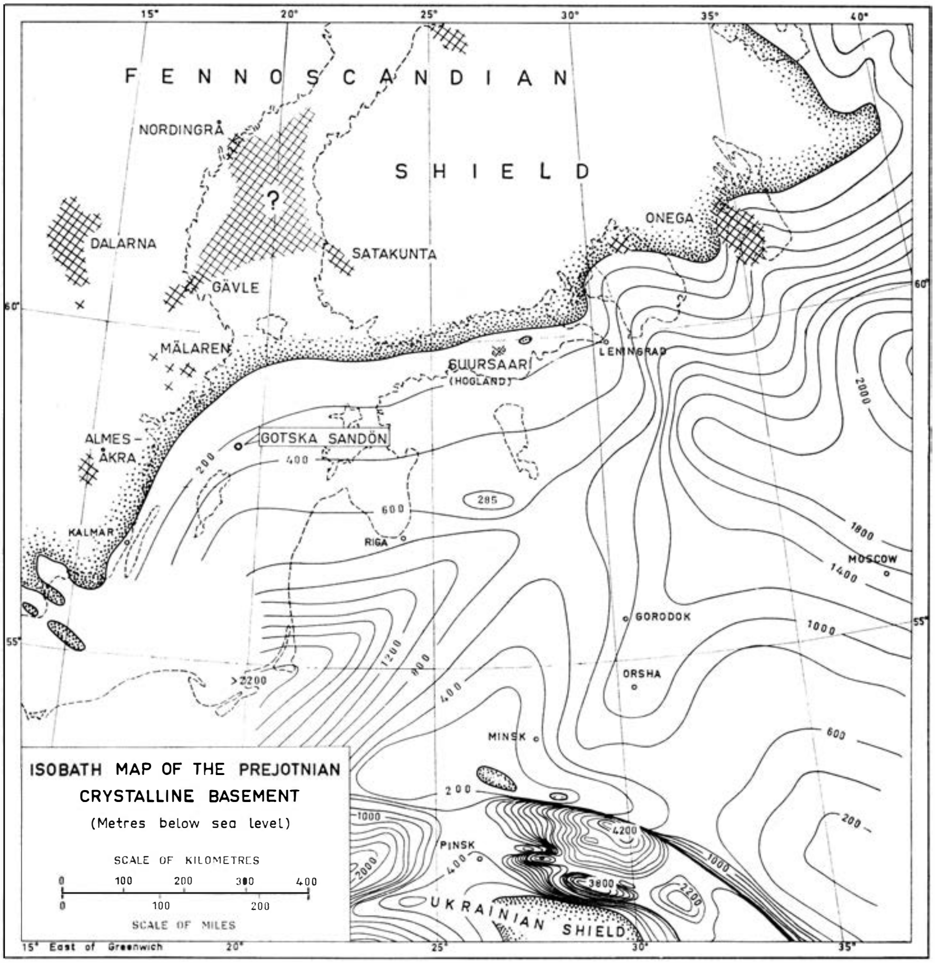

Fig. 20. Sketch map compiled from Aaloe *et al.* (1960), Bruns (1956), Gejsler (1956), Krivcov (1958), Machnač (1958), Martinsson (1958), and Zoričeva (1956). Cross-hatched areas are Jotnian sediments.

usually means "firmly quartz-cemented, glossy sandstone" and does not necessarily imply a mature orthoquartzitic lithology.

An age for the Pre-Cambrian of Gotska Sandön closely preceding the Lower Cambrian is precluded by the considerable diagenetic texture modification and, as it appears, Pre-Cambrian cementation of the sandstone, which demands that time be allowed for the accumulation and subsequent destruction of considerable amounts of Pre-Cambrian overburden. In looking for stratigraphical correlatives of the rock of Gotska Sandön attention is attracted by a kaoline-spotted sandstone described by Westergård (1939) from the Holmudden boring in the Gävle area (cf. Thorslund, 1958). According to Westergård this rock contains about 80 per cent quartz plus some feldspar and mica. Grain size is variable, being usually about 0.2 mm. The matrix consists of sericite, kaolinite, and carbonates. The sandstone rests between Lower Cambrian blue clay and Jotnian Gävle sandstone from which rocks it is separated by thin conglomerate beds. Unfortunately this part of Westergård's core is not available for examination, but a rock specimen from an allegedly similar stratigraphical position was obtained by courtesy of Mr. G. Englund, Gävle, from an excavation at Marielund just north of Gävle. This rock, described as "Upper Gävle" in Table 2 and Figs. 12 and 19, has the following mineral composition (per cent by volume): Quartz detritus 67.1, chert and quartzite 0.9, rock fragments 0.5, kaolinized feldspars 6.6, potash feldspar 2.4, plagioclase 1.2, zircon 0.1, chlorite 0.2, other heavies and mica 2.0, quartz cement 15.8, ore cement 0.5, kaolinite and sericite matrix 2.7. Both in composition and sorting this rock resembles rather the Jotnian Gävle sandstone than the Pre-Cambrian of Gotska Sandön.

Deep borings during the fifties and late forties have disclosed a number of sedimentary series on the Russian platform fringing the Fennoscandian shield in the south-east. Though some of them, particularly the Byelorussian series occurring in the Pinsk-Minsk-Gorodok-Orsha area (Fig. 20) and described by Machnač (1958, 1960), show lithological characteristics similar to the Pre-Cambrian of Gotska Sandön, it would be premature and purely speculative now to attempt correlations across the vast distances involved, the more so since radioactive datings are still scarce. Moreover, there is as yet a very considerable divergence of opinion concerning the age, stratigraphy, terminology, and mutual correlations of the sediments of the East European platform. It is, however, interesting to note that, as can be concluded from Fig. 20, the Karelidic belt can be morphologically traced over much of Central Russia and that, as is apparent from the sediment distribution on the Russian platform, the Fennoscandian and Ukrainian shields existed as detritus supplying areas for a long time before the onset of the Cambrian.

Addendum

The absolute age of the Gotska Sandön Pre-Cambrian sandstone has been determined by Prof. E. Gerling (A. A. Polkanov, personal communication) as follows:

Specimen	Depth in m	K g.g^{-1}	K^{40} g.g^{-1}	A^{40} g.g^{-1}	A^{40}/K^{40}	Age mill. yrs
1762	240.00–240.07	0.0472	$5.72 \cdot 10^{-6}$	$7.10 \cdot 10^{-7}$	0.124	1490
1763	233.55–233.70	0.0485	$5.92 \cdot 10^{-6}$	$7.68 \cdot 10^{-7}$	0.130	1540

The specimens selected for K/A age determination consist of recrystallized clay beds (1762), and of pressolved zones in sandstone (1763). Microscopic examination indicates that the mica is overwhelmingly authigenic or recrystallized. No unkaolinized detrital feldspars are present in either of the specimens.

The only potash silicates believed to be unaltered detrital, are a few flakes of bleached biotite and a minor amount of sericite formerly enclosed in feldspar. The amount of matrix sericite-muscovite appears to exceed that of biotite by a factor of at least 300.

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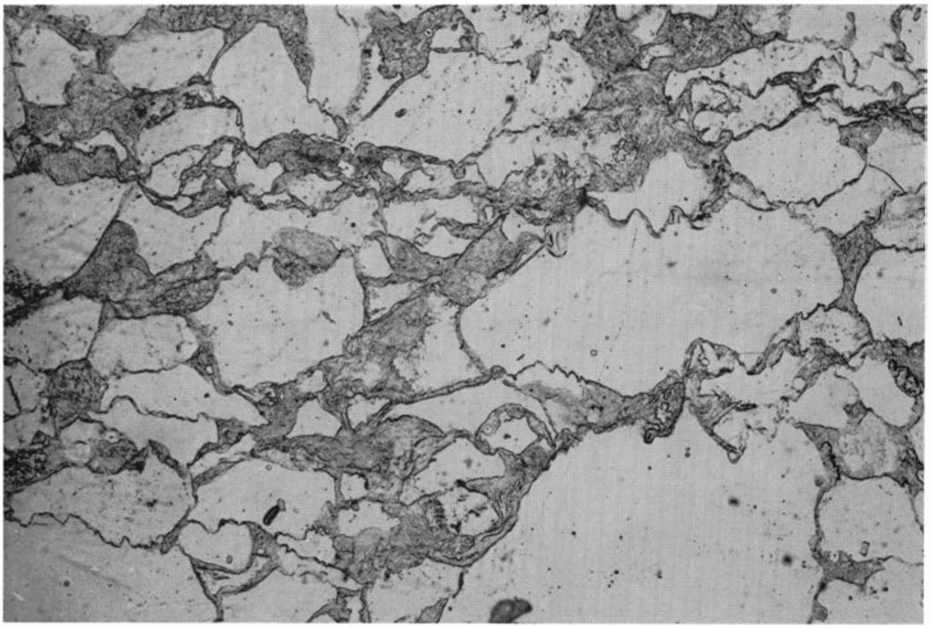
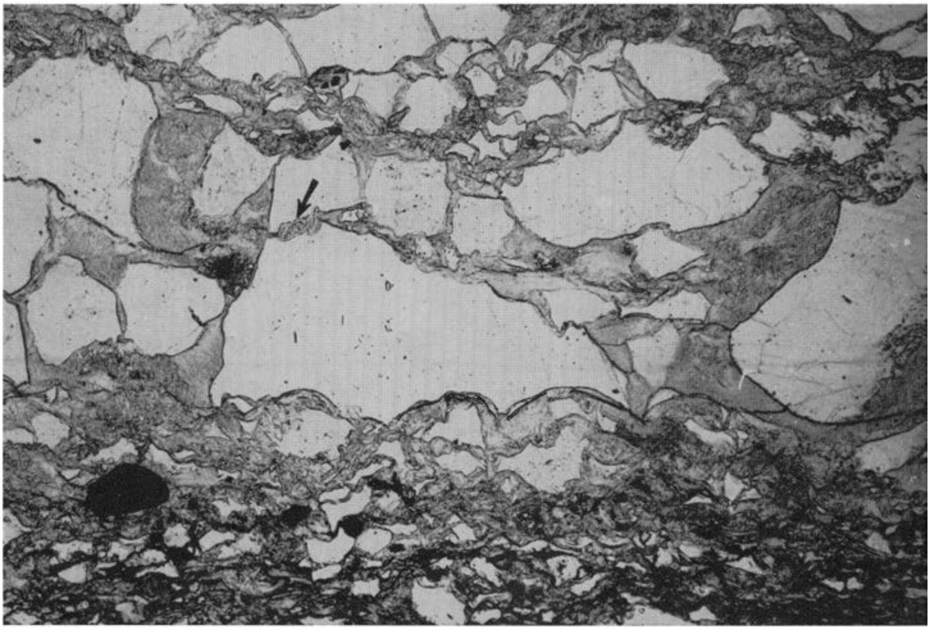
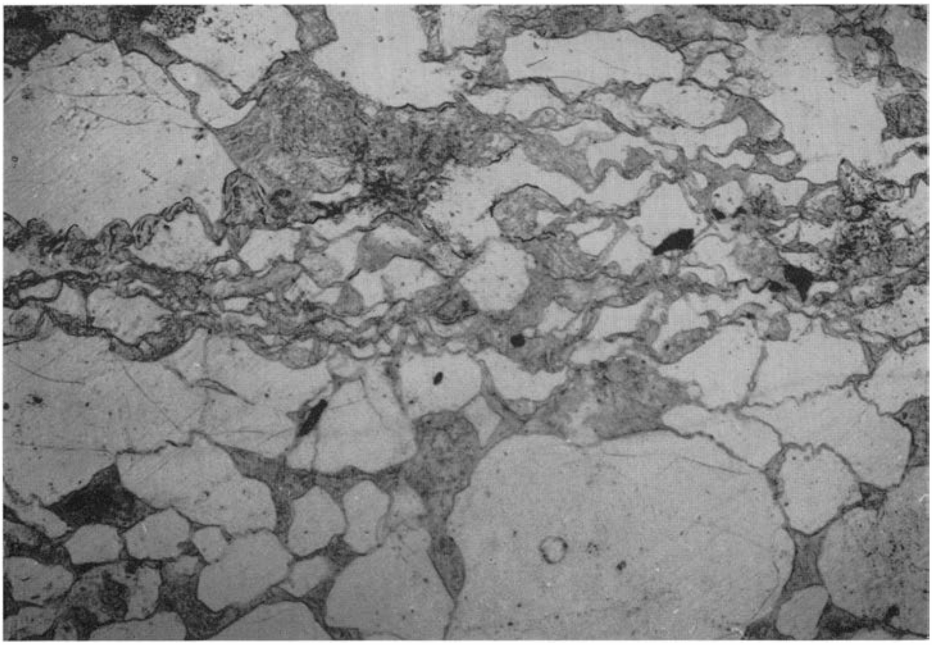


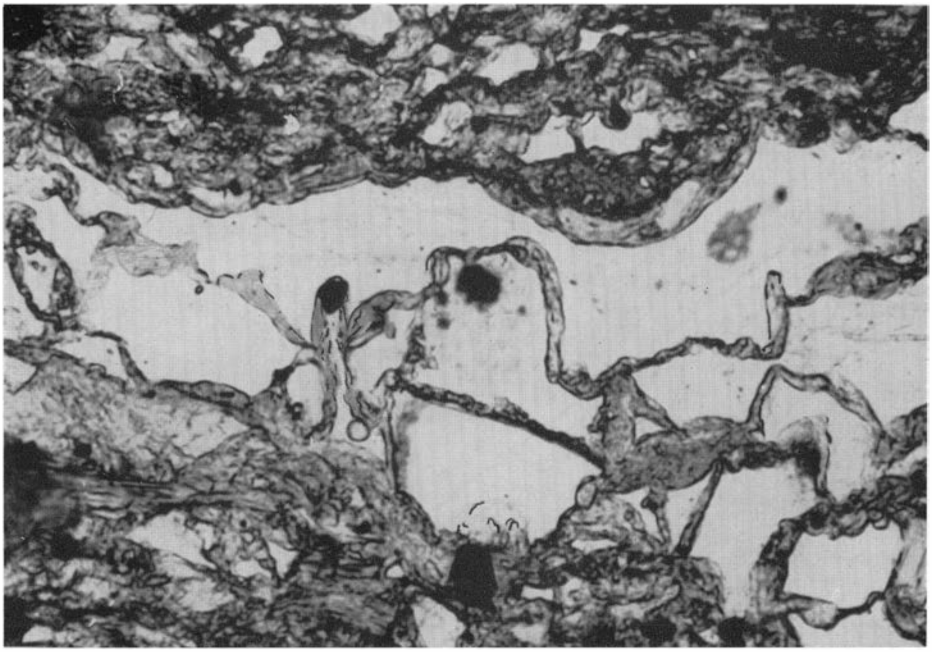
Pl. I, Fig. 1. Microstylolitic contacts in strongly pressolved, argillaceous, medium-grained sandstone. Plane-polarized light, × 56.



Pl. I, Fig. 2. Lobate corrosion type of quartz solution at the contact between coarse sandstone and argillitic siltstone. Arrow points at crenulated mica replacing a microstylolitic contact. Note the large flakes of authigenic mica outlining the corrosion lobes. Plane-polarized light, × 45.



Pl. II, Fig. 1. Thin layer with very strong solution in argillaceous sandstone. Plane-polarized light, × 42.



Pl. II, Fig. 2. Detrital ore grain capping a quartz column that penetrates strongly corroded quartz grains (left centre). Plane-polarized light, × 132.