Origin and correlation of the sandstone dykes at Listed, Bornholm (Denmark)

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The sandstone dykes at Listed consist of quartz sandstone with small amounts of feldspar and glauconite, and a chloritic matrix. The composition of some of the rock fragments found in one of the dykes is similar to that of the glauconitic Lower Cambrian Balka Sandstone, and others more closely resemble that of fine-grained beds in the overlying Lower Cambrian glauconitic siltstone, also known as the 'Green Shales'. The dyke sandstone itself has a composition resembling sandstone beds in the glauconitic siltstone. The sandstone in the dykes probably corresponds to the upper part of the glauconitic siltstone, i. e. the Wanneria? lundgreni & Holmia torelli Zone of the Scandinavian Lower Cambrian. The dykes were possibly formed either in fissures during earthquakes released before the overlying sediments were consolidated, or by slumping into existing fissures.

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Discussions concerning 'sandstone dykes' mostly centre on (1) the mechanism of intrusion, and (2) the stratigraphical relations of the rocks involved. Most authors, summarised by Shrock (1948), Potter & Pettijohn (1963) and Strauch (1966), deal with sandstone dykes (or 'clastic dykes') intruded into other sediments, while very few deal with sandstone dykes in basement rocks (Gavelin, 1909; Vitanage, 1954; Martinsson, 1956). Concerning the intrusion mechanism, two possibilities are open: either forceful intrusion of quicksand from below or above (a true 'sandstone dyke'), or simply gravitational filling of a fissure, grain by grain (a 'neptunian dyke' of Smith & Rast, 1958). The stratigraphical problems may be resolved in most instances of sandstone dykes in sediments, since the source beds commonly lie within the series concerned. On the other hand, in the case of fissure-fillings in basement rocks, where the sediment cover has been removed, correlation may present considerable problems.

The present paper discusses an example of fissure-fillings at Listed, about 2 km west of Svaneke on the northeastern corner of Bornholm, where some sub-parallel WNW-ESE trending sandstone dykes occur in the coarse-grained Svaneke Granite. East of Listed harbour, on the small point Gulehald, the sandstone dykes cut the 30 m wide doleritic Listed dyke (fig. 1). New field and petrographic data on these unfossiliferous sandstone dykes are presented, and their correlation with sedimentary rocks of similar lithology on Bornholm is discussed in the light of these and other characteristics.

Previous work

The sandstone dykes at Listed have been described and discussed by Jespersen (1865), Ussing (1899), Grönwall (1916), Hadding (1929), C. Poulsen (1960) and Mattson (1962). The sandstone in the dykes has commonly been described as a greyish-green to dark brownish-green quartz sandstone with a richly chloritic matrix (Ussing, 1899; Hadding, 1929; Mattson, 1962). The origin of the sandstone dykes has been ascribed either to slumping of a cover of sand (unconsolidated Balka Sandstone) into deep fissures opened in the underlying granite during earthquakes (Ussing, 1899), or to accumulation of sediment (again unconsolidated Balka Sandstone) in existing fissures, where it was protected from further sorting (Hadding, 1929). Isolated patches of

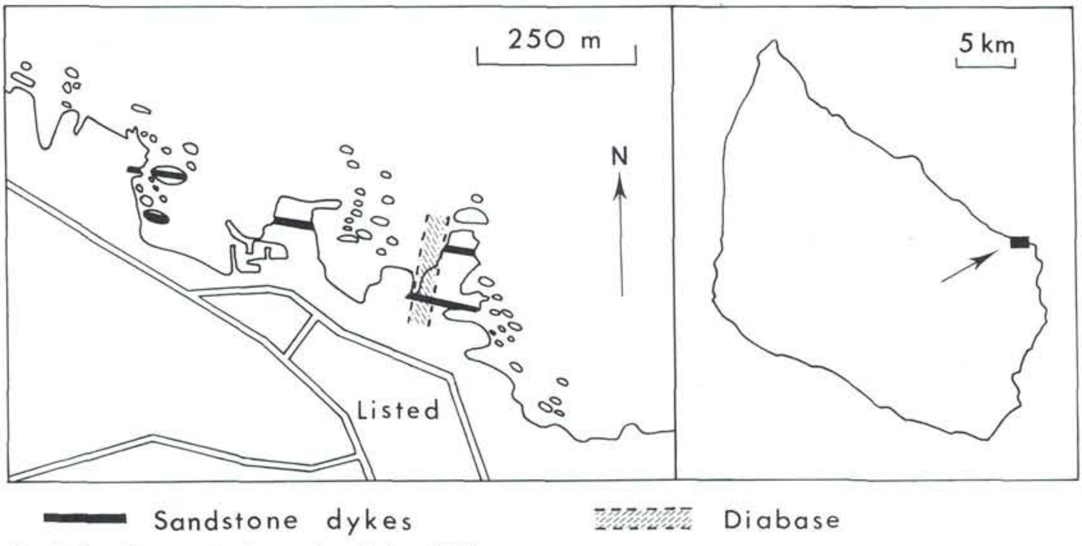

Fig. 1. Locality map (redrawn after Ussing, 1899).

a light grey pure quartz sandstone found by the latter in the green chloritic quartz sandstone, were interpreted as a second filling of the supposedly re-opened fissure. Stratigraphically the sandstone at Listed was correlated with the upper quartzitic part of the Lower Cambrian Nexø Sandstone (Grönwall, 1916); this part was later renamed Balka Sandstone by Hansen (1938). On the other hand a post-Silurian age was proposed by Mattson (1962). The doleritic Listed dyke has been described in detail by Jensen (1966). No radiometric age determinations have been carried out on this dyke.

Observations bearing on the emplacement of the dykes

No bedding is seen in the dyke sandstones. In one of the dykes west of Listed harbour, blocks of granite are seen floating in the sand,

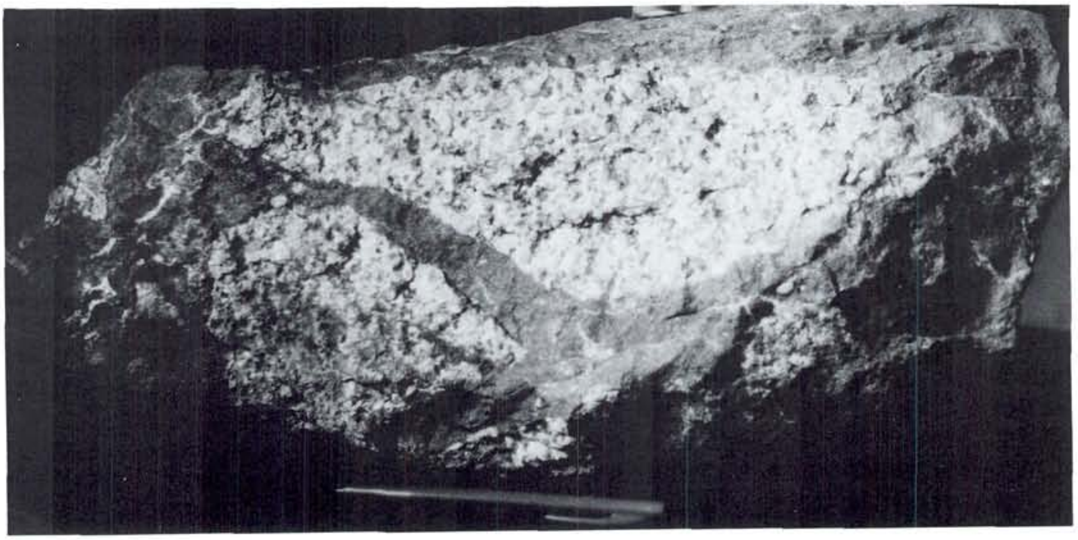

Fig. 2. Part of a "sandstone dyke" from Listed with granite blocks. The sandstone is grey and the granite spotted, light grey. Length of pencil 15 cm. (Sample in the Mineralogical Museum, Copenhagen).

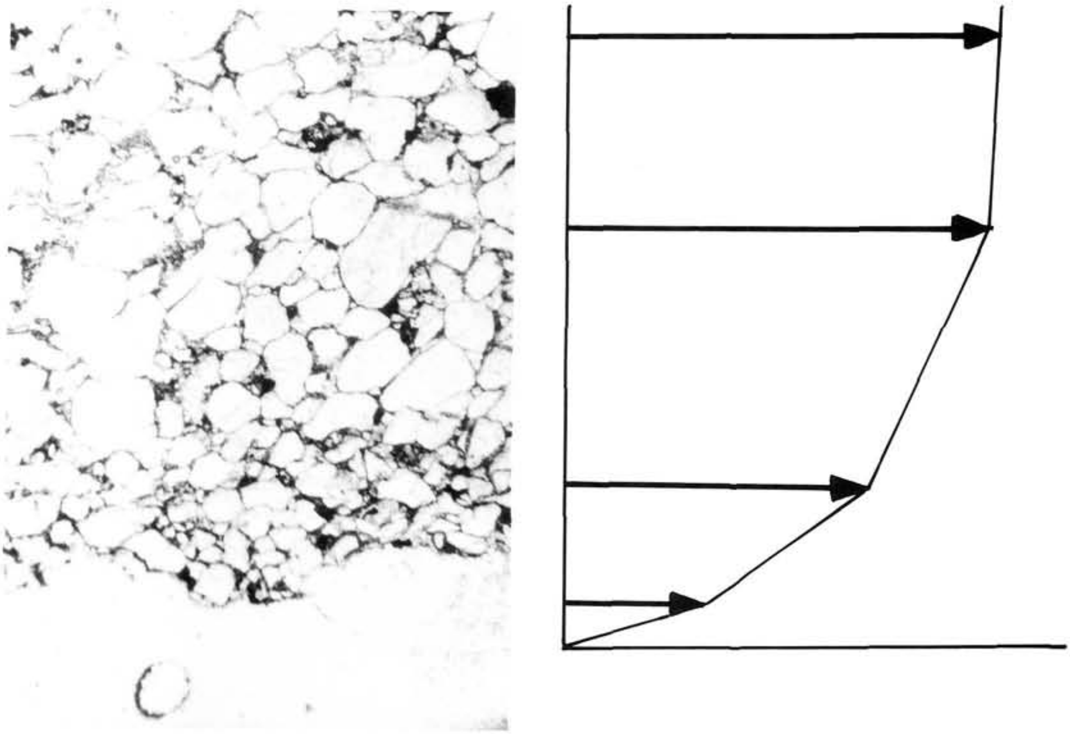

Fig. 3. Suggested velocity profile drawn next to photomicrograph of contact between granite (below) and sandstone fill (top). Sample MMH 1974.914, northeast of Listed harbour. Magnification as in fig. 4.

but still in almost original position, giving an impression of sandstone interfingering with granite (fig. 2). A thin section of a dyke sample with attached granite wall (MMH 1974.914) shows grading of the sediment (fig. 3), with the finer fraction closest to the granite wall. Similar grain size grading is mentioned by Strauch (1966) from dykes that have suddenly filled from above by intruding sediment, and suggest a velocity distribution of the intruding sand approximately as shown in the figure. It may be that water-saturated sand was forced into the dyke; due to friction the velocity along the walls was lower, and only fine-grained sediment was carried along here. But a similar grain size distribution possibly might also occur by filling of an existing, open fissure, e. g. by a slumping sediment. Only the lack of bedding indicates, that all the sandstone was deposited in the dyke at the same time.

Petrography

The following samples from the sandstone dykes have been investigated: (1) MMH 1974.912 collected by the writer in 1968, (2) MMH 1974.913 collected by H. C. Steiner in 1966; both are from the southernmost of the two dykes at Gulehald. Sample MMH 1974.914 collected by N. V. Ussing in 1898 has also been investigated. For comparison, thin sections of samples MMH 1974.916 and MMH 1974.917 from the Balka Sandstone, sample MMH 1974.915 from the Lower Cambrian 'Green Shales' (collected by F. Johnstrup in 1869), and other unregistered samples have been examined.

Under the binocular microscope sample MMH 1974.912 shows a dark greyish green sandstone with rounded, mostly clear quartz grains in the size interval 0.25–2.0 mm. Some of the quartz grains are turbid, others have brown or reddish brown inclusions. Two types of detrital micaceous grains occur: a colour-

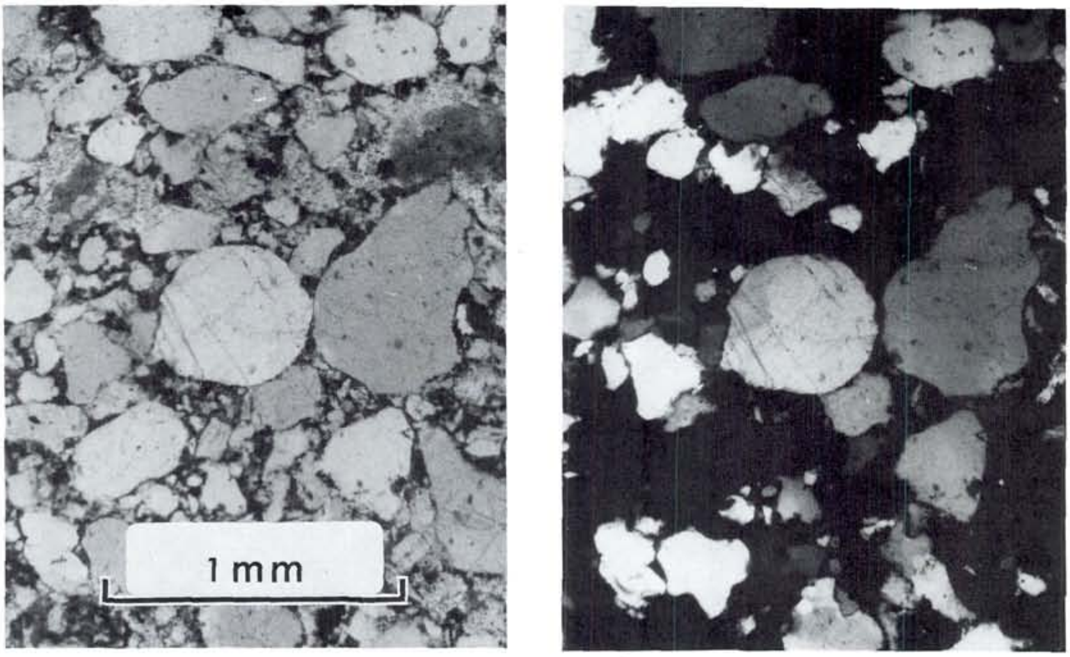

Fig. 4. MMH 1974.912. Photomicrographs of poorly sorted sandstone with matrix. Quartz grains dominate the sediment; in the uppermost part of figure two glauconite grains are seen. In figures 4–7 and 10, the photo on the left was taken with one nicol only, and that on the right with crossed nicols.

less rather brittle one, and a dark green rather soft one. The cement between the clastic grains contains a dark, yellow-green pigment. There are some irregular cavities in the rock around which there are small (< 1 mm) quartz crystals with well developed crystal faces. In other cavities the walls have coatings of a soft, green mineral, probably a phyllosilicate; such coatings are not found on the quartz crystals. Sample MMH 1974.913 is very similar to MMH 1974.912, only it is a little harder and lacks visible cavities. The colour of an unweathered fracture surface is 5 Y 4/2 olive gray (Munsell, 1954). In this sample one 15 × 5 mm angular inclusion and smaller, rounded inclusions of white quartz sandstone were found together with 6–7 mm well rounded inclusions of a dark green, fine-grained siltstone. The occurrence of these inclusions, which had not been recorded in the dykes by earlier

Table 1. Point counts of sandstones from Listed and of their inclusions. From 1000 to 1500 points were counted in each thin section. Error margin estimated after scheme in van der Plas & Tobi (1965). Values in volume per cent.

Sample	Quartz cement	Detrital quartz	Feldspars	Micas	Matrix	Glauconite
MMH 1974.912	10 ± 2	62 ± 3	2 ± 1	< 1	19 ± 2	1 ± 1
MMH 1974.913	14 ± 2	70 ± 2	1 ± 2	< 1	14 ± 2	1 ± 1
MMH 1974.913 (quartz sst. inclusion)	37 ± 3	58 ± 3	2 ± 1	< 1	2 ± 1	1 ± 1
MMH 1974.913 (siltstone inclusion)	22 ± 4	54 ± 5	1 ± 1	< 1	20 ± 4	3 ± 2
MMH 1974.914	5 ± 1	79 ± 2	2 ± 1	< 1	15 ± 2	< 1

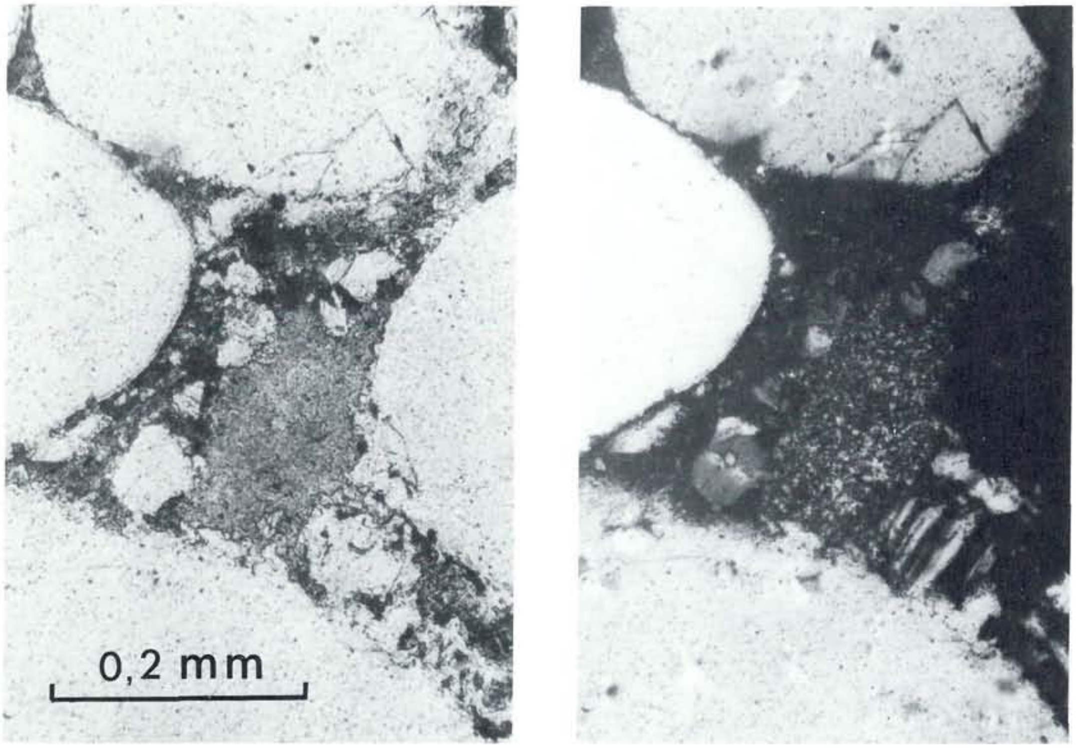

Fig. 5. MMH 1974.912. As fig. 4, under higher magnification, showing glauconite and plagioclase surrounded by matrix of quartz and chlorite. The remaining grains are all quartz.

workers, has an important bearing on the correlation of the dyke material.

In thin section sample MMH 1974.912 (fig. 4) is seen to consist mainly of quartz grains, partly large (0.5–2.0 mm), well rounded grains with undulate extinction and secondary overgrowths, partly small (0.05–0.5 mm) angular grains filling the pores between the larger ones (cf. Hadding, 1929). The small grains are surrounded by a fine-grained yellow-green to yellow-brown matrix. A few of the large quartz grains are composed of two or more interlocking individuals, others have inclusions of ferric oxides. There is a little feldspar in the sample, both rounded microclines and weathered turbid grains, probably of plagioclase. Scattered, strongly altered, yellowish mica grains are found, some with diffuse borders to the matrix. Scattered, well rounded light green glauconite grains also occur (fig. 5), under crossed nicols showing a non-orientated microcrystalline structure. Parts of the matrix have a similar appearance, but x-ray diffractometry on crushed material (table 2) revealed only chlorite in significant amounts. Zircon and rutile are the only heavy minerals present, but are very sparse. The percentages of the main components are given in table 1.

Sample MMH 1974.913 broadly resembles sample MMH 1974.912. There is less matrix, however, and the larger quartz grains reach 3 mm in size. The amount of quartz cement is larger than in sample MMH 1974.912.

Table 2. Reflection peaks on X-ray diffractogram of untreated, orientated specimen of sample MMH 1974.912 after crushing and suspension of the rock-flour.

d = 14,140 Å	(chlorite, 001)
d = 7,081 Å	(chlorite, 002)
d = 4,735 Å	(chlorite, 003)
d = 4,270 Å	(quartz)
d = 3,542 Å	(chlorite, 004)
d = 3,339 Å	(quartz)
d = 3,243 Å	(microcline)
d = 2,453 Å	(quartz)

The chlorite reflections correspond with those on ASTM card 7–78, thuringite, a high-ferrous, low-magnesian chlorite.

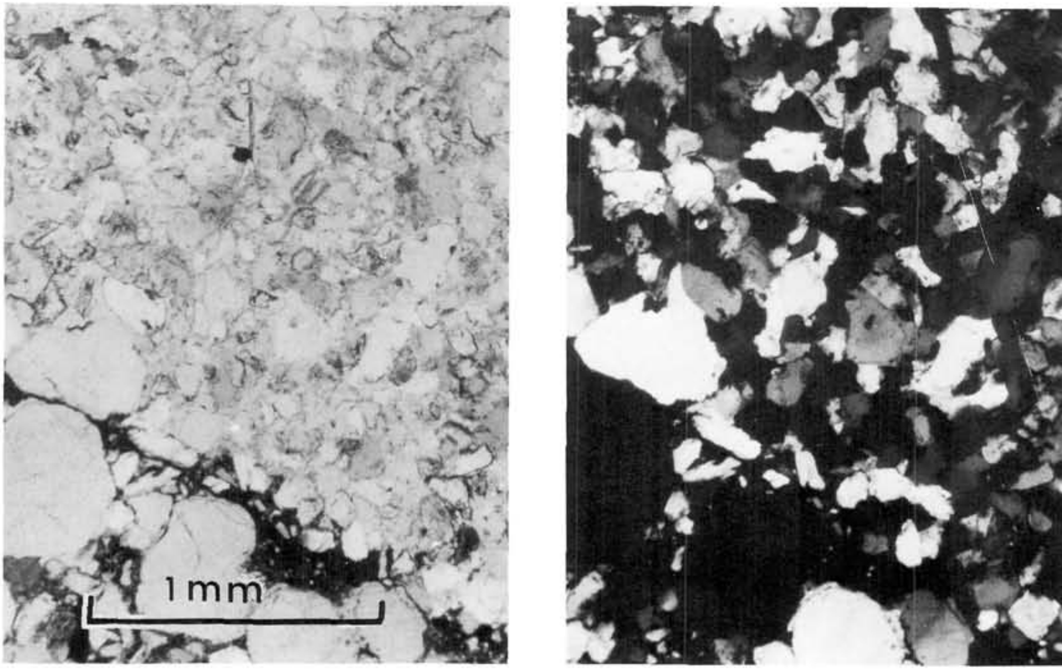

Fig. 6. MMH 1974.913. Photomicrographs of inclusion of quartz sandstone in the sandstone dyke. Lowermost in figure the transition to the matrix-rich dyke sandstone is marked by a concentration of matrix.

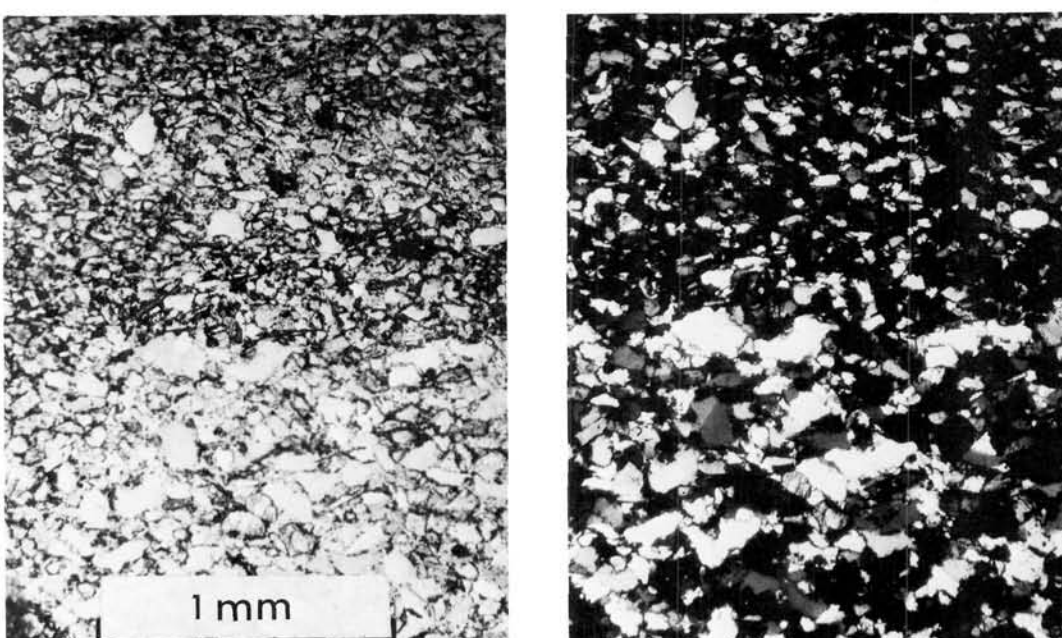

Fig. 7. MMH 1974.913. Photomicrographs of inclusion of siltstone, consisting of matrix-rich coarse-grained siltstone (upper part of photo) and matrix-poor fine-grained sandstone (lower part).

The quartz sandstone forming inclusions is a well sorted rock consisting largely of well rounded detrital quartz grains 0.1–0.3 mm in size that can be distinguished from the quartz cement only because their borders are marked by thin dust rings (fig. 6). Inferior amounts of feldspar and glauconite are present.

The inclusion of fine-grained sediment is composed of two parts: a rather well sorted sediment poor in matrix, and a rather poorly sorted sediment rich in matrix (fig. 7). The grain size of the former is 0.05–0.2 mm, which makes it a fine-grained sandstone; for the latter the grain size interval is 0.02–0.1 mm, corresponding to a coarse siltstone.

Point count data for the inclusions are given in table 1.

Possible correlations

No fossils have been found in the sandstone dykes at Listed. Biostratigraphical correlation is therefore excluded, and resort must be made to correlation on the basis of lithological similarities. In this context the occurrence of glauconite in the dyke is significant, particularly as this mineral has not been recorded in earlier descriptions of the dykes. (This is understandable, as the amount of glauconite is very small, and the colour of the rock is most probably derived from the chloritic matrix). Since glauconite has not been recorded from Precambrian sandstones in Bornholm and Scania, correlation with these will not be considered further. Both the Middle Cambrian Kal-

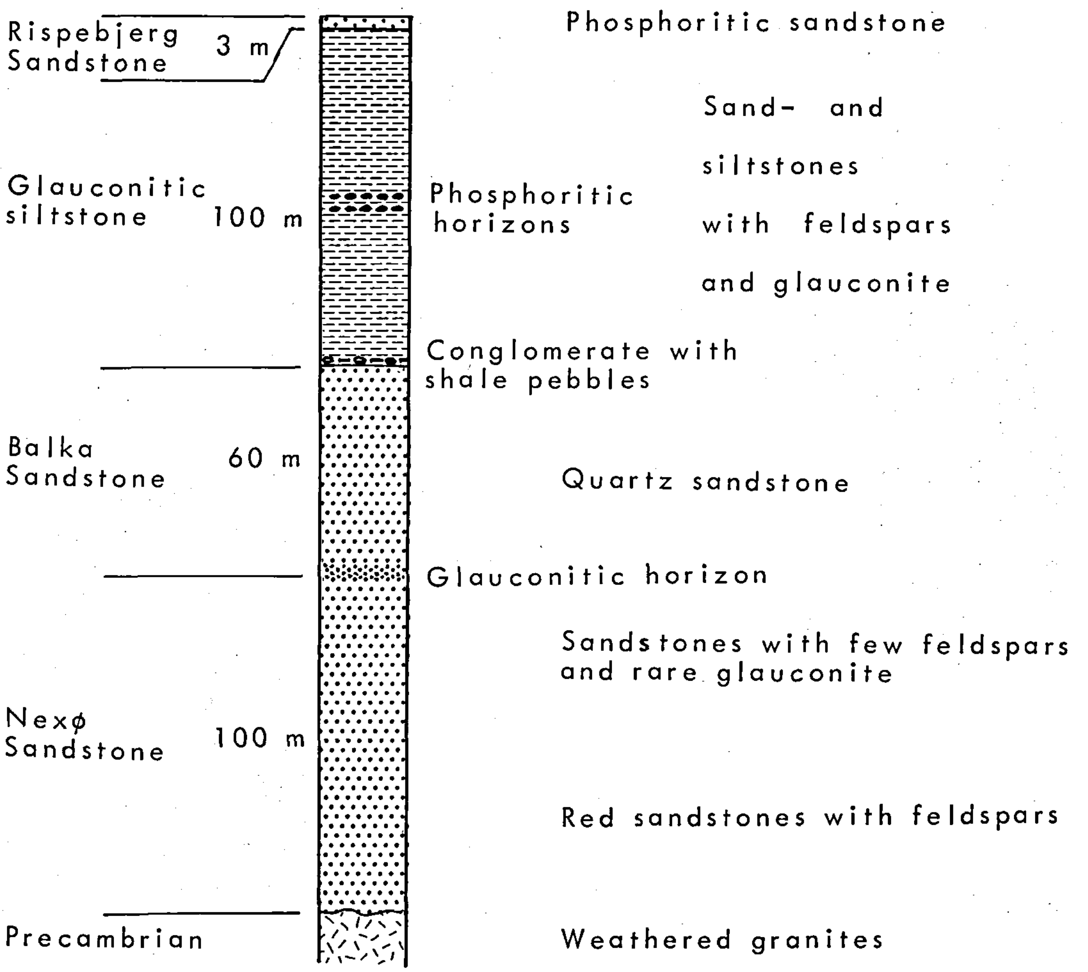

Fig. 8. Stratigraphical relations in the Lower Cambrian of Bornholm. Based on data from Bergström (1970, 1973); Gry (1960, 1962); Hansen (1936); Poulsen (1960,1967); Poulsen (1966); and new observations.

by Clay (V. Poulsen, 1966) and the basal conglomerate in the Middle Cenomanian Arnager Greensand (Ravn, 1925) contain evidence of formations, formerly present on Bornholm, but later eroded. The sandstone in the dykes at Listed could maybe be correlated with any of these disappeared formations, but comparison is of course impossible. Instead, the dyke sandstone will now be compared with the following existing glauconitic formations on Bornholm:

(1) The lowermost beds of the Lower Cambrian Balka Sandstone
(2) The Lower Cambrian glauconitic siltstone
(3) The Middle Cenomanian Arnager Greensand
(4) The Middle Senonian Bavnodde Greensand

The Lower Cambrian stratigraphy of Bornholm is summarised in fig. 8.

Lowermost beds of Balka Sandstone

Glauconite occurs in the uppermost part of the Nexø Sandstone and throughout the larger part of the overlying Balka Sandstone (Bruun-Petersen, 1971), but only in the lowermost beds of the Balka Sandstone is it abundant (Gry, 1962). Comparison with point count data from this part of the Balka Sandstone (sample MMH 1974.916) and from a black, fine-grained sandstone (sample MMH 1974.917) from a higher level of the Balka Sandstone shows that the Listed sandstone and the fine-grained Balka Sandstone have roughly the same content of matrix, and that the Listed sandstone and the glauconitic Balka

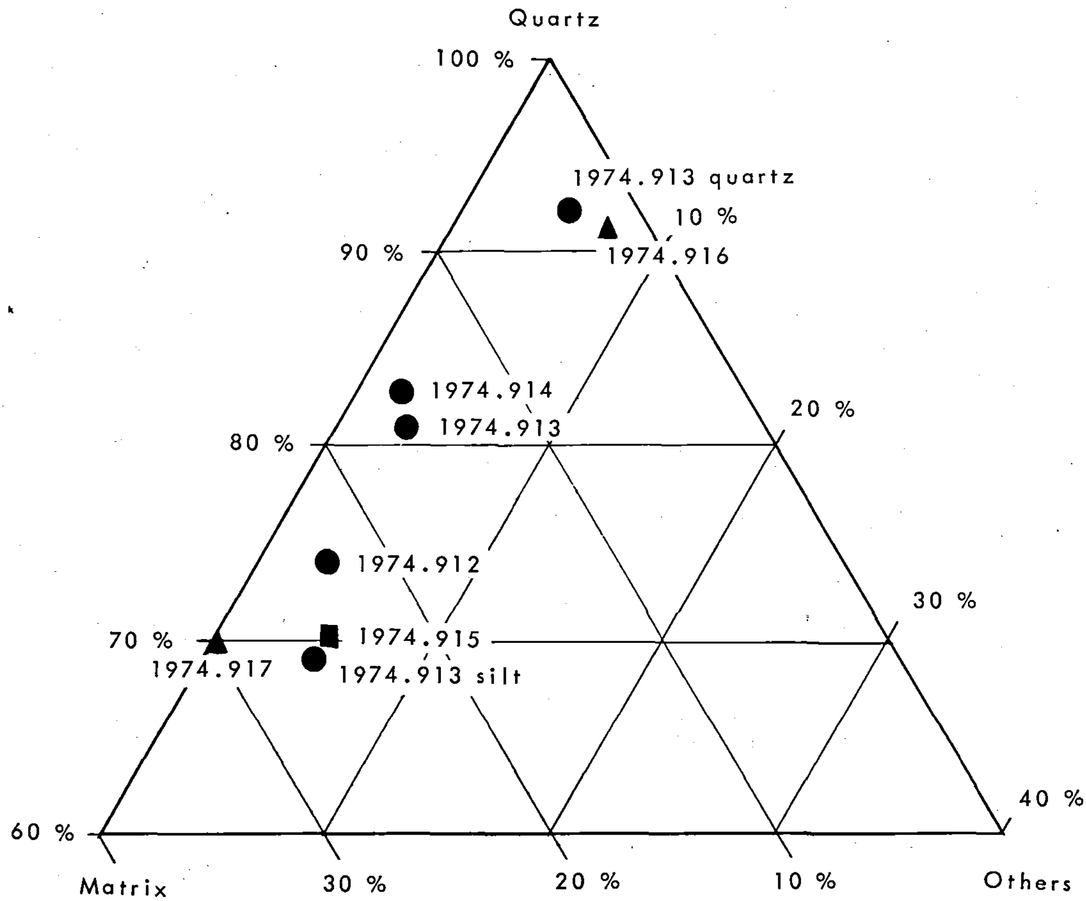

Fig. 9. Compositions of the sediments mentioned in the text. Data from tables 1 and 3. Cement omitted. 'Others' comprises feldspars, micas and glauconite. Samples MMH 1974.912–1974.914 are from the sandstone dykes; MMH 1974.916–1974.917 from the Balka Sandstone, and MMH 1974.915 from the glauconitic siltstone.

Table 3. Point counts of some sandstones from Bornholm. Volume per cent. Remarks as in table 1.

Sample	Quartz cement	Detrital quartz	Feldspars	Micas	Matrix	Glauconite
MMH 1974.916 Glauconitic Balka Sandst.	32 ± 2	62 ± 3	2 ± 1	1	1 ± 1	4 ± 1
MMH 1974.917 Fine-grained Balka Sandst.	16 ± 2	59 ± 3	0	1	25 ± 2	0
MMH 1974.915 Glauconitic Siltstone	70 ± 2		1 ± 1	3 ± 1	25 ± 2	1 ± 1

Sandstone have the same mineralogical composition of the detrital grains (table 3; fig. 9). However, the grain matrix ratio and grain size data from single samples of the Listed sandstone do not provide a reliable basis for correlation, since, as has been pointed out, the sediment was graded during intrusion into the fissure.

As mentioned previously, the inclusions found in sample MMH 1974.913 must also be taken into account. In tables 1 and 3 and in fig. 9 point count data for one of these quartz sandstone inclusions can be compared with data from the glauconitic Balka Sandstone. Great similarity in mineralogical composition is seen, and therefore the possibility that the inclusions represent clasts of lower Balka Sandstone must be considered. Balka Sandstone from higher levels has only very little glauconite and no feldspars and is thus unlikely to be the source of the quartz sandstone inclusion. Nor is the siltstone inclusion, which also contains a little feldspar, likely to have come from the higher levels of the Balka Sandstone. It might have been derived from the glauconitic, lowermost part of the Balka Sandstone, but there is another possible source, the glauconitic siltstone, which will now be considered.

Glauconitic siltstone

The glauconitic siltstone (Gry, 1960; also known as "Green Shales" – see Poulsen, 1967) comprises many varieties of siltstone and fine-grained sandstone composed of quartz, feldspars, and a variable content of chloritic matrix; some of the varieties also contain glauconite (Hansen, 1936). Very similar to the Listed sandstone is the 'Green Shale' type XII of Hansen (1936) of which there is a fine-grained variety (quartz grains 0.05–0.1 mm) and a coarse-grained variety (quartz grains 1.0–2.0 mm).

The glauconitic siltstone from Bornholm is correlated with the Scanian Norretorp Sandstone (Bergström, 1970; Lindström & Staude, 1971), which is a variegated glauconitic, phosphoritic and calcitic sandstone series with, at least in some horizons, a grain size distribution similar to that of the glauconitic siltstone and the sandstone at Listed (Hadding 1929, 1932). From both the lowermost beds of the glauconitic siltstone and the lowermost beds of the Norretorp Sandstone a quartz conglomerate with glauconite and pebbles of black shales is reported (Poulsen, 1966; Poulsen, 1967; Lindström & Staude, 1971). Possibly the clasts from the sandstone at Listed indicate a former extension of this conglomerate or at least are derived from a similar conglomerate.

A thin section from a grey, fine-grained sediment from the glauconitic siltstone at Grødbygård on the southern part of Bornholm (sample MMH 1974.915) shows a well sorted, coarse siltstone with a grain size about 0.05 mm (fig. 10; point count data in table 3). The quartz grains show pressure solution and the glauconite grains are light green. In spite of different degrees of diagenetic alteration, this random sample from the glaucon-

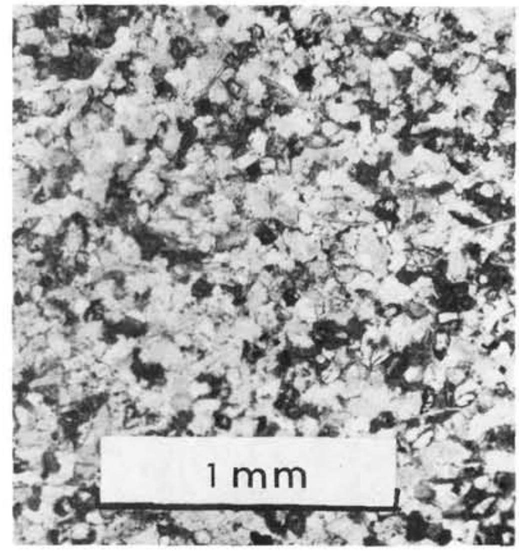

Fig. 10. Photomicrographs of sandstone from the glauconitic siltstone at Vestre Grødbygård, southern Bornholm. The rock consists of small quartz grains, some glauconite grains, and mica flakes. MMH 1974, 915.

itic siltstone and the fine-grained inclusion in the sandstone at Listed show great similarities in composition, and the two sediments therefore probably originated in the same geological situation and could well be correlatives.

Arnager Greensand and Bavnodde Greensand

The Middle Cenomanian Arnager Greensand is a clayey, grey sand with abundant glauconite (Grönwall, 1916; Ravn, 1916a; Rasmussen, 1967). At the bottom of the series two thin indurated beds are found (Ravn, 1916b). The approximate composition of the sand fraction from the Arnager Greensand is as follows: 48 % quartz, 36 % feldspars, and 16 % glauconite.

The Middle Senonian Bavnodde Greensand (Ravn, 1916a; 1921) is partly a greyish-green, sandy and carbonatic clay sediment with some hardened layers, partly a grey or green, indurated quartz sandstone (Grönwall, 1916; Ravn, 1921; Rasmussen, 1967). Thin sections of the latter show a feldspathic quartz sandstone cemented partly by opal, partly by chalcedony. Glauconite is present as lobate sand-sized grains. Neither of these Mesozoic sediments shows any strong resemblance to the sandstone from Listed, and correlation in both cases must be excluded.

Discussion

From the foregoing it may be concluded that the only possible existing correlatives of the Listed sandstone are the lowermost beds of the Balka Sandstone or some part of the glauconitic siltstone. The inclusions help to establish the maximum age of this sandstone, since they are not parts of a second generation of fissure filling, but clasts in the sediment which filled the fissure. The quartz sandstone and coarse siltstone inclusions appear to have been derived from the lower part of the Balka Sandstone and the glauconitic siltstone respectively, and it is therefore improbable that the sandstone in the dykes is an unsorted equivalent to the former. As the overall appearance of the sandstone at Listed is comparable to parts of the glauconitic siltstone, it is proposed that the sandstone in the dykes at Listed is to be correlated most likely with the glauconitic siltstone. This is referred to the zones of Wanneria? lundgreni and Holmia torelli (Poulsen, 1966; Bergström, 1973) of the Lower Cambrian, to which zones the sandstone dykes at Listed are therefore to be referred.

The sediment clasts found in the sandstone dykes may indicate the former presence of a quartz conglomerate similar to that from the lowermost glauconitic siltstone (Poulsen, 1967), but the presence in the dykes of clasts of a lithology similar to higher levels in the glauconitic siltstone, and lack of black shales indicates that the clasts in the Listed sandstone possibly are younger, and another possible explanation is proposed: The granite area at Listed lay in Lower Cambrian time under a shallow sea, where first a sediment equivalent to the basal parts of the Balka Sandstone was deposited, followed by equivalents to the oldest parts of the glauconitic siltstone (fig. 11.1). At a time when the middle part of the glauconitic siltstone was deposited, a regression took place in the Listed area (contemporary with deposition of phosphoritic nodules in the part of the basin now covered by southern Bornholm), and during the subsequent transgression (fig. 11.2) erosion and reworking of the hitherto deposited sediments took place, so that clasts from the older rocks were incorporated in new sediments (fig. 11.3) contemporary with the upper part of the glauconitic siltstone. Maybe during an earthquake, maybe due to other events, which took place before the sediments were consolidated, they were removed into newly opened fissures, or they slumped into existing fissures (fig. 11.4). The remaining sediment cover on the granite surface has been removed by later erosion. The lack of bedding, the grain-size grading along the dyke walls and the almost in-situ blocks of

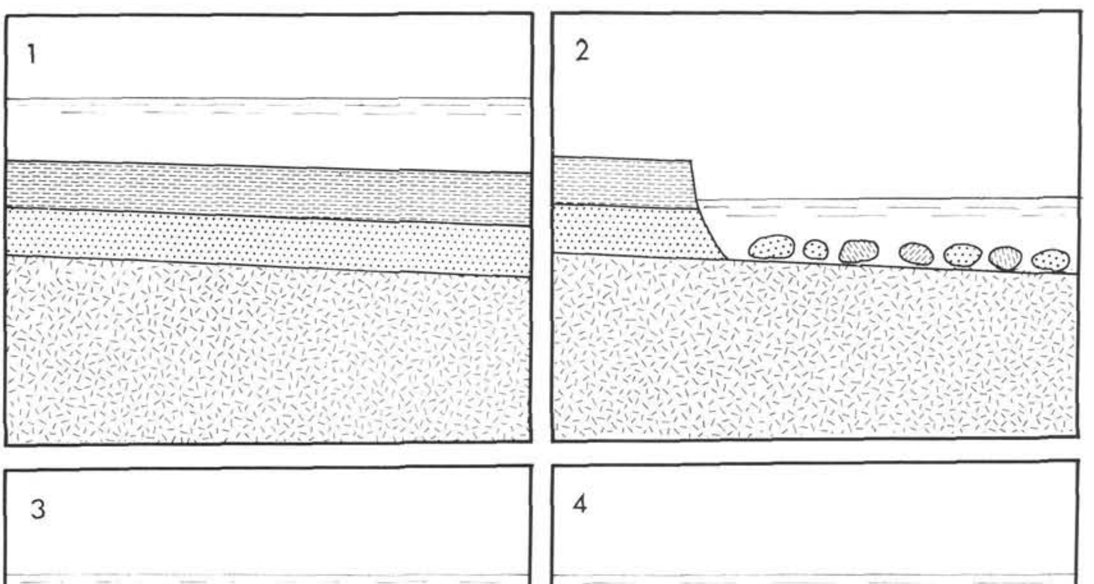

Fig. 11. Tentative reconstruction of events (not to scale). 1) Glauconitic Balka Sandstone and lower part of glauconitic siltstone is deposited. 2) Regression and erosion. 3) Transgression and incorporation of fragments of the older sedimentary rocks in the equivalent to upper part of the glauconitic siltstone. 4) Removal of deposit into fissure. 5) (not shown) Later erosion removes sediment cover and possibly the uppermost part of the granite.

granite show that the sandstone dykes have been formed rather suddenly. Maybe the accumulation hypothesis of Hadding (*1929*) comes closest to reality, if some sort of slumping is involved to bring the sediment into the fissures.

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Dansk sammendrag

Sandstenen i sedimentgangene ved Listed er en kvartssandsten med små mængder feldspat og glaukonit og med en matrix af klorit, der giver bjergarten dens mørkegrønne farve. I én af gangene er der fundet bjergartsfragmenter, hvoraf nogle ligner glaukonitholdig Balka Sandsten og andre ligner lag fra de Grønne Skifre. Selve gangsandstenen ligner i sin sammensætning sandede lag fra de Grønne Skifre. Der er stor sandsynlighed for, at sandstenen ved Listed kan korreleres med de Grønne Skifre. Gangene antages dannet således: I Listed-området blev i Nedre Kambrium først aflejret en glaukonitholdig Balka Sandsten og derefter sedimenter svarende til de Grønne Skifre. En kortvarig regression fandt sted samtidig med aflejringen af den fosforitiske midterste del af de Grønne Skifre på Sydbornholm, og ved den efterfølgende transgression omlejres resterne af de ældre sedimenter og indgår som bjergartsfragmenter i de yngre Grønne Skifre på Nordbornholm. Gangene blev dannet, enten ved at det uhærdnede sedimentdække udfyldte spalter, der blev dannet i forbindelse med jordskorpeuro, eller ved at uhærdnet sediment ved udskridning blev transporteret ned til eksisterende spalter i granitunderlaget.

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