The sandstone dyke swarm of Vang, Bornholm (Denmark)

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A very well exposed sandstone dyke swarm in the basement of Bornholm (Vang and Hammer granite) has been discovered recently north of Vang. It strikes 120° to 125° on average. Individual dykes are up to 23 cm thick. The fillings consist of pale, greyish to brownish, fine-grained to medium-grained quartz sandstone. It has a grain-supported structure, and the porespace is filled with argillaceous-limonitic material and carbonate (dolomite) cement. The opening and filling of the fissures were caused by normal extension movements in NNE–SSW direction in several steps, probably during the early Cambrian. The overlying Balka sands were implosively sucked down into the fissure vacuums caused by the sudden opening. The downwards moving of the water saturated sediments led to a loss of material above and to the creation of funnel structures. Tapering down ring structures in the Hardeberga sandstone at the east coast of Scania (Sweden) are interpreted as such funnel structures.

Key words: Bornholm, Tornquist Ocean, Lower Cambrian, extension tectonics, sedimentary dyke swarm, sandstone, funnel structure.

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Several outcrops of sandstone dykes in the basement of Bornholm have been described by Ussing (1899), Milthers (1930), Mattson (1962) and Katzung (1996). The best exposed dykes up to now are those of Listed on the Gule Hald peninsula, northeastern Bornholm (Fig. 1). Bruun-Petersen (1975) characterizes the fillings of the dykes as greyish to brownish and green, medium-grained to coarse-grained, non-bedded sandstone with chlorite matrix; an early Cambrian origin is supposed. Structural surveys of a small dyke in the Vang granite of northwest Bornholm indicate N–S extensional forces probably in connection with the opening of the Tornquist Ocean between Baltica and Peri-Gondwana (Katzung 1996). In summer of 1996 a conspicuous sandstone dyke swarm was discovered north of Vang during field work with the students Michaela Aehnelt and Dorothea Frieling. A set of dykes which are up to 23 cm thick occurs in the Vang granite and to a limited extent in the Hammer granite. They have been studied in detail, so that direction and degree of extension could be determined and the filling mechanism interpreted.

Situation

The basement of the island of Bornholm consists mainly of gneisses and granite intrusions. At the north-western edge, the partly foliated Vang granite (intrusion age is about 1.4 Ga) is bordered to the north by the slightly younger Hammer granite. Just south of the intrusion contact between these granites, a set of WNW–ESE striking sandstone dykes are exposed on nearly N–S oriented walls of an old quarry north of Vang, 200–250 m northwest of the Vester Borregård farm (Fig. 1).

The lower part of the quarry is hidden by bushes and trees and the bottom is partly filled with water. At the upper levels and on the humps (rounded by glaciers during the Pleistocene) nearby, the clearly outlined, brownish coloured clastic dykes can easily be distinguished from the greyish Vang granite with its reddish aplitic and pegmatitic dykes and veins (Figs 2, 3 and 4).

Fig. 1. Locality map. Two sandstone dyke swarms exist in the basement of northern Bornholm: Listed and Vang. The sandstone dyke swarm north of Vang cuts the Vang and the Hammer granite. The position of the swarm is indicated by short black lines.

Fig. 2. Sandstone dyke swarm north of Vang. The photo shows a view of the nearly N-S oriented wall of a very old quarry (uppermost level I) and cliffs.

Fig. 3. Drawing of Fig. 2. The sandstone dykes cutting the Vang granite are numbered beginning from the south.

Fig. 4. The photos show a closer view of a few sandstone dykes to demonstrate that they differ in thickness and orientation.

a) The dyke I/11 on the right side is one of the thick dykes, which can reach up to 23 cm thickness. Note that a granite band is included. On the left side thinner dykes occur which branch off and join together again downwards. A drawing of this photo is given in Fig. 5d. The knife is about 8 cm long.

b) The dyke I/22 turns from vertical to nearly horizontal direction indicating the rotation of granite blocks between opening fissures during extensional movements. The length of the hammer head is about 18 cm.

Description of the sandstone dyke swarm

Structural features

The outcrop can be divided into three parts representing the former levels of the quarry. The levels are situated not only below each other but are also displaced towards the north with increasing depth, thus offering a view of the more northern dykes exposed at the lower levels. Beginning in the south and at the uppermost (first) level northwards as well as downwards to the third level of the quarry, the dykes will be listed (Table 1) and only significant features are described in detail and documented by photographs and drawings as follows.

The first level is about 41 m in length and up to 5 m

high. The first two sandstone dykes (I/1 and I/2) occur 12.60 m north of the southern edge. They strike $113-114^{\circ}$ and generally dip $80-89^{\circ}$ north. Both are about 1 cm thick. The southern one thins out downwards into a curved tip where the other one opens.

Several fissures and joints mm up to 2 cm thick and filled with sandy material are visible further north. They occur either individually or as sets. Often they are related to brecciated shear zones.

Dyke I/10 which is 18–20 cm thick, cuts the Vang granite and a pegmatite body. It strikes 114° and dips 87° northwards. The host rock at its southern margin is intensively brecciated due to older shear processes. Riedel shears indicate subvertical movements (Fig. 5a). In this zone a thinner dyke I/10a branches off.

Fig. 5. The drawings summarize features of the sandstone dykes. The key is given in Fig. 3. The knife is about 8 cm long. a) The host rock between the southern margin of dyke I/10 and the branching dyke I/10a is intensively brecciated indicating an older shear zone. The dyke I/10 itself is affected by epigenetic tectonic movements. Thus bands of sandstone are separated by light quartz filled fissures. b) Granite 'xenoliths' occur within dyke I/11. Pieces of Vang granite fell into the gap or were carried away by the inflow of clastic material into the joint during the opening. c) A thin, nearly horizontal oriented dyke (I/V) connects two vertical dykes. Note that the thickness decreases when dyke II/4 splits off. d) The thick dyke I/11 contains a granite band which was separated from the host rock when two fissures opened, and were filled with sediment. On the left side a thinner dyke branches off into two segments which join together again downwards forming a parallelogram shaped structure, see also Fig. 4a). e) An aplitic lens cut by the clastic dyke II/2 shows no evident vertical movement.

Features inside dyke I/10 point to epigenetic tectonic movements. Sheets of brownish sandstone are separated by light quartz-filled fissures. The shear direction can be determined following the dyke on top of the cliffs. Here, the dyke is not evenly separated into several sandstone bands, but diagonal orientation and sigmoidal bending of the fissure fillings indicate sinistral movements.

Another thick dyke (I/11) is exposed only 40 cm further north. It generally strikes 128° and dips 85° – 89° to the north. At the top, it is 23 cm thick but downwards its thickness decreases to 16 cm. In the middle part, the bordering walls jump 3 cm northwards at an offset (Fig. 5b). Below, a shear zone at the northern

margin is visible. There also occur granite 'xenoliths' within the clastic dyke. Pieces of the Vang granite fell into the joint and were carried away by the downwards moving sedimentary material during the opening. Further down, the main dyke (I/11) splits up into a thick segment and a thin segment which run parallel and come together after a short distance. They include a 2 cm thick granite band of about 20 cm in length (Figs 4a and 5d, on the right).

North of dyke I/11, several thinner dykes are visible. Two of these dykes (I/12 and I/13) show similar features to the first two dykes. They also end in two tips that open up in opposite directions. The southern one (I/12) additionally splits up downwards into two

dyke #	distance [m]	striking	dipping	thickness [cm]	remarks
I/1	12.60	113	89 N	1	ends in a curved tip downwards
I/2		114	80 N	1	opens as I/1 ends downwards
I/3				0.1	in a shear zone
I/4				0.5	curved
I/5	15.00			0.3-0.5	in a shear zone
I/6				0.5	
I/7		122	89 N	2	in a shear zone together with I/6 and I/8
I/8				0.6	
I/9	16.30			0.5	
I/10	16.45	114	87 N	15-20-18	the southern margin is part of a shear zone dyke itself is sheared into sheets dyke I/10a branching off at the southern margin is 3 cm thick bordering walls jump 3 cm to the north at an offset
I/11	17.05	128	85 N	23-16	pieces of granite ('xenoliths') and a granite band occur dyke I/11a at southern margin (119° and 85 N), ends in a tip dyke I/11b at the northern margin (2-3 mm thin)
I/12	17.60	128 120 110	89 N 85 N 89 N	2-3	opens downwards; splits and joins (parallelogram-shaped structure) the very thin dyke I/12a branches off at the northern margin ends in a tip downwards as I/12 opens (in this part, it is situated together with I/12 in a shear zone)
I/13		107	83 N	3	curved shape
I/14		103	85 N	0.2	
I/15		(102)	(70 N)	0.1	
I/16				0.1	
I/17				0.1	
I/18	18.60	120	89 N	11-12-10-14	dyke thins out at an offset in the uppermost part (only 0.5 cm thick)
I/19	20.70	120	83 N		granite lenses and bands in the lower part
I/20	21.05	108	85 N	0.5	ends upwards and downwards in tips
		127	80 N	10	continues downwards as dyke I/2
		122	89 S		
		128	89 S		
		110	80 S		
I/21		123	89 N	0.5	
		135	83 N		
		137	87 N		
I/22				1-2	curved shape, partly horizontal oriented
I/23				1	ends upwards in a tip
I/24	26.15	(115)	(85 S)	20-16	granite lenses and bands in the lower part
I/25	35.00			0.2	in a shear zone
I/26	38.75	(110)	(84 N)	0.5	in a shear zone
I/27	39.75	135	85 N	1	continues downwards as dykes II/8 and III/1 in a shear zone
II/1	21.20	(106)	(74 S)	1	
II/2	21.55	(122)	(86 N)	9	upper part jumps 1.5 cm northwards at an offset dyke II/2a branches off downwards from above the offset an aplite lens which is cut by the dyke indicates no vertical movements during opening
II/3	24.40	(110)	(72 S)	0.4	in a shear zone
II/4	26.85	121	85 S	2-3-4	
II/5				0.4-0.2	horizontal oriented
II/6 a	27.70	(122, 135)	(71 N, 61 N)	3-2	it connects dykes II/4 and II/6a
II/6 b		(130)	(62 N)	0.8	dyke splits off upwards into 5 segments
II/6 c		(124)	(54 N)	0.5	
II/6 d				2	
II/6 e		(140)	(64 N)	3	
II/6		127	75 N	8	granite lenses in the middle part
II/7	28.20	(120)	(88 N)	8	upper parts jumps northwards at two offsets (1.5 cm each time) aplite band at both sides indicates no vertical movements
II/8 = III/1	39.20	(120)	(86 S)	0.7-1	continuation of dyke I/26
III/2	47.50	136	86 N	12-14	
III/3	47.75	(105)	(58 S)	0.15	within a curved shear zone
IV/1	-			9	'quartzitic' (partly secondary quartz-cemented)
IV/2	-			0.8	'quartzitic'
IV/3	-	145	86 N	10-12-10	dyke IV/3a which is 2 cm thick branches off at the southern margin granite lens close to the southern margin host rock is intensively fractured
IV/4	-			18	this dyke occurs 5.30 north of dyke IV/1

Table 1. Features of the sandstone dykes north of Vang. The dykes cutting the Vang granite in an old quarry are numbered in accordance to the level (I, II or III) on which they are exposed. The distance is given as the length between the southern edge (level I) of the quarry and the individual dyke. The dykes that cut the Hammer granite are numbered with IV. Estimated values are put in parentheses.

segments which are connected again further down forming a parallelogram-shaped structure (Figs 4a and 5d, on the left).

Dyke I/18 has undulate margins, thus the values of the strike vary between 108° and 120°. It dips between 83° and 85° to the north, and its thickness varies from 10 to 14 cm.

Between this dyke and the next thick one (I/20) which is to be seen 2.35 m further north, a big pegmatite body occurs which has a fine-grained red marginal zone and a coarse-grained interior consisting of quartz and feldspar megacrysts. Dyke I/20 is 10 cm thick and its striking varies between 122° and 128°. It dips slightly southwards (80–89°) in the upper part; in the lower part it is vertical oriented.

Five metres further north, dyke I/24 occurs which is 20 cm thick at maximum, but the thickness decreases downwards to 16 cm where the dyke carries several granite lenses or bands. Sixty centimetres south of dyke I/24 a curious, 2–3 cm thick dyke (I/22) of about 30 cm length is exposed which turns from vertical to nearly horizontal direction (Fig. 4b), a phenomenon that might indicate the rotation of granite blocks between opening fissures during the extensional movements.

Some thin fissures filled with clastic material and partly framed by shear zones are exposed south of the northern edge of the first level (not seen in Fig. 2). One of them (II/26) is also exposed at the second (II/8) and at the third level (III/1) of the quarry.

All the shear zones indicate a subvertical movement of the northern block relatively to the southern one, before the fissures have been opened and filled with sand.

The second level is about 18 m long and 1.80 m high. Beginning from the south dyke II/1 occurs after 70 cm. This dyke is 1 cm thick. It strikes nearly 106° and dips 74° to the south (Fig. 5e, on the right).

Dyke II/2 is exposed about 30 cm to the north. This dyke is 7 to 9 cm thick and proves to be the continuation of dyke I/20 from the first level. The upper part jumps 1.5 cm northwards at an offset. Below this offset, a reddish aplitic lens is separated by the clastic dyke showing no evident vertical movement (Fig. 5e, centre). At the northern bordering wall, a subsidiary dyke (II/2a) branches off downwards from above the offset (Fig. 5c, on the left).

Dykes II/4 and II/6a are connected by a thin dyke (II/5) which is oriented horizontal (Fig. 5c). Dyke II/6 splits upwards into 5 thinner dykes (II/6a to e) within a 23 cm wide shear zone. The thickness of these branching dykes ranges between 0.5 and 3 cm.

The third level is about 2.50 m high. There are only three dykes visible. An oriented sample was taken from the thickest dyke (III/2) which is described in detail below. Just north of this dyke, a curved shear zone attracts attention by its weathering-away and protruding fissure filling of clastic materials in the centre. The fissure (III/3) is only 1.5 mm thin. It strikes about

105° and dips 58° to the south in the middle part. No other clastic dykes are found further north.

Following the strike direction of this broad sandstone dyke swarm westwards to the coast of Bornholm another outcrop was found 100 to 150 m south of the Pissebæk waterfall. The area at the cliffs just east of the beach path between Vang and the waterfall is rather poorly exposed due to overgrowth by plants and trees which cover the rock. Nevertheless, four dykes are exposed which cut the Hammer granite here. One of them (dyke IV/4) reaches up to 18 cm thickness indicating that at this deeper level the extension still reaches remarkable values. Taking into consideration that the difference of the altitude between the two outcrops where the clastic dykes were found is about 50 m, it can be said that the opening of the joints was not only limited close to the present surface. Two of the dykes (IV/1 and IV/2) seem to be affected by later tectonic movements. The clastic filling looks rather quartzitic which may due to secondary compression processes.

Fillings

The fillings of the clastic dykes consist mainly of pale, greyish to brownish, fine-grained to medium-grained sandstone. Due to weathering, the marginal parts as well as parts close to fissures or cracks within are mostly darker. Sometimes thin dark lines occur representing either shear planes or more or less vertical oriented pressure-solution seams. These younger tectonic planes were partly opened and filled with white quartz which sometimes occur as crystals in open gash fractures.

The fillings of the dykes have been examined, and different types can be described. The common filling is represented by dyke III/2 from which a sample was taken perpendicular to the strike direction. The dyke, which cuts the Vang granite, has a significant zonation: on both sides a 4.5 cm thick inhomogeneous, fine-grained to medium-grained stripe appears, whereas the 5 cm thick inner part is rather homogeneous and more coarsely grained. The thin section (Fig. 6a) shows bands in the outer parts that differ in the grain size of the clastic components. Some bands are more fine-grained, whereas in the other ones the medium-sized grains dominate. They are oriented parallel to the bordering wall of the dyke as well as intensively curved with bulges up and down like irregular folds. These flow structures were generated when the opening fissures were filled with sand.

The sandstone has a grain-supported structure. The main components are quartz grains (85 to 90%). Subordinate grains of microcline, perthite, titanium-bearing ore (leucoxene) and plagioclase are visible. Between the grains a few mica flakes occur which might be of primary (detrital) origin. Round zircons are con-

Fig. 6. Photos showing the texture and components of the dyke fillings. a) Thin section (PPL) of dyke III/3. The southern contact is just on the right side. Bands running parallel to the contact can be distinguished in which either fine-sized or medium-sized grains dominate, indicating that the opening processes took place in several steps. On the left, the material is rather homogeneous representing the more coarsely grained inner part of the dyke (about 5 cm thick, but only 1 cm is shown here). The dark lines indicate younger shear zones or pressure-solution seams. The length of the long side amounts to nearly 5.5 cm. b) Detail view (XPL) of the filling components from the same dyke. The sandstone has a grain-supported structure. Quartz grains, partly with deformation bands (on the left side), dominate (85 to 90%). Microcline (on the right side), perthite, ore and plagioclase occur to a less amount. The porespace (25 to 30%) is filled with argillaceous-limonitic material and carbonate (dolomite) cement. The grains are round-shaped to slab-shaped. At their contacts the grains are deformed due to pressure solution (concavo-convex contacts). The length of the long side amounts to nearly 2.5 mm.

spicuous by their higher refraction and coloured interferences. The porespace (25 to 30%) is filled with argillaceous-limonitic material and carbonate (dolomite) cement (Fig. 6b).

Most of the grains are round-shaped to slab-shaped so that the longest diameter is oriented parallel to the dyke margins (Fig. 6a). At their contacts the grains are deformed due to pressure solution. Thus they show concavo-convex rims (Fig. 6b).

The dominating quartzes occur either as monocrystalline grains, which are of magmatic origin, or as polycrystalline grains. The latter ones are made up of quartz crystals in different orientations. They must have been affected by previous deformation processes indicating that they belonged to metamorphic rocks of the basement. Some grains show optical microstructures like undulose extinction and deformation bands

caused by dislocation glide, whereas other neighbouring ones exhibit features of dislocation creep: formation of subgrains and subgrain rotation associated with limited grain boundary migration. The crystals within a few composite quartz grains show not only sutured boundaries but they are also elongated in a preferred direction. These grains are called sheared quartz or stretched metamorphic quartz in accordance to Adams et al. (1991).

Some zones in which the grains are intensively brecciated to fine crystal fragments showing sharp edges are marked by dark lines (Fig. 6a, on the left). They are about 1 to 2 mm wide. Within these brecciated zones the amount of the argillaceous-limonitic material, which sometimes outline pressure-solution planes, is larger. They are considered as post-diagenetic shear zones.

Fig. 7. Schmidt-net lower hemisphere. Squares – poles of dykes belonging to the sandstone dyke swarm north of Vang; 24 measured values are used. The arrows indicate the direction of extension (s_3).

The inner part of the dyke is characterized by rather round grains (Fig. 6a, on the left). The material is well-sorted. Medium-sized quartz grains dominate which show similar features like the grains in the outer part of the clastic dyke described above.

The filling of dyke I/18 differs from that of dyke III/2. The rock shows subparallel light bands which are outlined by more or less disseminated limonitic material. The sandstone is partly well cemented by secondary (authigenic) quartz (15 to 20%) which has overgrown the original grains. The overgrowths grew in optical continuity with the grains. Therefore, the overgrowths and the cores show uniform interference colours. The surfaces of the detrital grains are marked by thin brownish, limonitic rims, and the quartz cement looks turbid due to fine dispersed opaques which represent residues of the previously existing matrix. Other parts of the porespace are cemented by limonitic material (up to 15%). Only minor space is still filled with argillaceous matrix. The amount of the limonitic cement changes laterally. It is concentrated in certain bands, so that a stripe-shaped structure is formed.

Another type of fillings is represented by dyke IV/3a that cuts the Hammer granite south of the Pissebæk waterfall. The sandstone is of greenish grey colour. The argillaceous-limonitic and chloritic matrix exceeds in discrete parts of the dyke more than 50%, and the amount of carbonate cement is rather less. Deformation features like pressure solution hardly occur due to the reduced number of grain contacts. The thin section shows both the clastic filling and the

surrounding host rock. The crystals of the granite which are situated close to the contacts are deformed. They are elongated and partly sheared. It is not possible to predict if these processes are pre- or syngenetic to the formation of the clastic dyke.

One sample was taken from one of the more 'quartzitic' dykes (IV/1) which also cuts the Hammer granite. At the first glance the filling seems to consist of a homogeneous fine-grained sandstone but under the microscope it has similar composition like the other dykes. The grains are oriented in bands subparallel to the dyke margins. The sandstone is partly cemented like it is described from dyke I/18. In other parts it still has a high amount of argillaceous matrix, but no limonitic or chloritic material occurs like in dyke IV/3a which is situated very close.

No fossils or other unequivocal age criteria have been observed in all thin sections.

Space origin, direction and degree of extension

Summarizing all the features of the dykes mentioned above, it can be said that (1) all the dykes strike from 100° to 140° with a maximum at 120°–125° and (2) they are mostly oriented subvertical, dipping more to the north, less to the south. That means they are characterized by strongly preferred orientation, despite the variety of attitudes of the preexisting joints. Thus, the space origin for these sedimentary dykes resulted without any doubt from a regional tensional tectonism. The same interpretation of similar situations was given for example from Stanton (1981) for the Mendip region, SW England, Vera et al. (1984) for the Subbetic Ranges, S Spain, Blendinger (1986) for the Middle Triassic platform of the Dolomites, N Italy, and Schlische & Ackermann (1995) for columnarly jointed basalts.

The horizontal extension occurred in NNE–SSW to NE–SW direction (Fig. 7). No features of lateral or vertical movements along the dykes related to the opening processes have been found. Especially the aplitic lenses or bands occurring in the Vang and Hammer granite and cut by the clastic dykes show no evident vertical movements. Only a few dykes are inclined to 50° in both directions using older cataclastic shear zones during disintegration of the rigid crust by extension forces. Dyke II/6 splits off into 5 segments within such a shear zone which strikes about 130° and dips 62° north.

In general, it seems to be quite common that the dykes follow older shear zones with their strike direction, representing presumable zones of weakness in the Vang granite. In most cases the tendency of a minor uplift of the northern block against the southern one during former shearing can be assumed by the orientation of riedel shears.

From the study of the fillings of the clastic dykes, it

Fig. 8. The so called 'Præstens Badekar' is a tapering down ring structure which is situated in the Hardeberga sandstone which is a time equivalent of the Balka sandstone. It is exposed at the eastern coast of Scania (Sweden), near Vik, and can be interpreted as a funnel structure which developed in the unconsolidated horizontal Hardeberga beds. Immediately opening of extensional fissures and joints in the basement created a vacuum below covering water which exerted suction on the overlying sediments. The water saturated sediments were implosively sucked down or so to speak slurped into the open fissures and cracks. a) In the middle part of the funnel structure the beds are clined towards the centre below which a gap filled with sedimentary material is supposed. b) At the southern edge of 'Præstens Badekar' a concentric joint system is developed (on the left side) which indicate the ring shape of the funnel structure.

is obvious that the extension processes were not restricted to one single event. Lateral changes of the structure and composition (e.g. homogeneity or lamination and filling, the size of the grains) show that the opening of the joints was a multi-stage process.

Considering the folded laminations within the dykes and the appearance of a few thin horizontal or curved dykes, it can be said that the sandy material intruded into the fissures and joints under subaquatic conditions. Following Bruun-Petersen (1975), and taking into consideration the composition of the fillings (85% quartz, no rock fragments), the time during the sedimentation of Balka sand fits best.

Taking into consideration the tectonic evolution of

the southern border of Baltica in Ordovician and Silurian times, which points to plate tectonic stages from ocean floor spreading to orogenic overthrusting (Katzung et al. 1993, 1997; Giese et al. 1994; Beier et al. 1997 and others), the extension may be related to the opening of the Tornquist Ocean as has been stated formerly (Katzung 1996).

The total degree of extension can be determined for the study area (levels I, II, III). The exposed length of all three levels is about 50 m and the total thickness of all dykes is about 1 m. Thus the degree of extension amounts to 2%.

Features of some sandstone dykes moreover indicate younger post-diagenetic tectonic movements ei-

ther along the contacts of the dykes to the granite or within the dyke itself. In particular, the thicker dykes are broken off along fissures into single bands. Sometimes the fissures are filled with white quartz which was formed during the circulation of SiO_2 -containing solutions within the fissures and joints. These younger tectonic movements are due to left-lateral shear processes in which the transpression forces were approximately NE-SW oriented.

Filling mechanism

There are two ways of sedimentary infill into sedimentary rocks as well as into magmatic and metamorphic ones, either from below or from above. Only the latter way is possible for the sandstone dykes in the crystalline basement near Vang. It will be emphasized by the petrographical correspondence of the sandy material with the Balka sandstone which overlies the crystalline rocks, assuming that the Nexø sandstone is primarily missing on northern Bornholm.

The mechanism of the filling can be recognized from distinct features of the fillings itself and the regional situation when the fissures in the basement opened and extended (see Smart et al. 1988). In this respect it must be considered that sedimentary dykes of this type and age are not restricted on Bornholm. They are widespread through southern Scandinavia (see Gavelin 1909, Tanner 1911, Hjelmqvist 1939, Martinson 1957, Mattson 1959, 1962, Greiling et al. 1988).

The fillings of the sandstone dykes near Vang and also on the Gula Hald peninsula show no horizontal bedding indicating normal sedimentation in preexisting open fissures or gaps. Stripes and bands of fine-grained and medium-grained sand parallel to the dyke margins occur, which are sometimes irregularly bended and folded. These indicate flowage or slumping of clastic material which was water saturated.

The same parallel zonations of fissure fillings are reported from sedimentary dykes in the Carboniferous limestone of southwest England by Robinson (1956) and Duff et al. (1986). They suggest injections of unconsolidated sediment from the sea floor following the sudden opening of the fissures below. Injections of soft sediments overlying the fissure-bearing unit are also described by Castellarin (1965), Jeanbourquin (1985), Lehner (1991), Winterer et al. (1991), Schlische & Ackermann (1995).

We assume that the basement was covered with unconsolidated Balka sand, when the fissures opened. Therefore, the downwards moving of clastic sediments should lead to a loss of material above. Thus, indications of material loss must exist within the Balka sandstone. Up to now, they are not known from Bornholm. However, they occur in the Hardeberga sandstone in southern Sweden, a time equivalent of the Balka sandstone. Tapering down ring structures of different size are to be seen at the east coast of Scania (Lindström

Fig. 9. Schematic cross section: The sudden opening of fissures and cracks in the basement created a vacuum which led to an implosively sucking down of the overlying water saturated sediments. This process might be a possible reason for the development of funnel structures in the unconsolidated Hardeberga beds.

1967, Hamberg 1994). The most impressive one is the so called 'Præstens Badekar' near Vik (Fig. 8). The large structure is accompanied by smaller ones.

In our opinion, these are funnel structures which developed in the unconsolidated horizontal Hardeberga beds. Immediately opening of extensional fissures and joints in the basement created a vacuum below covering water which exerted suction on the overlying sediments. The water saturated sediments were implosively sucked down or so to speak slurped into the open fissures and cracks (Fig. 9). Pieces of the crystalline rocks split off and fell into the gaps or were carried away by the inflow of the clastic material.

Comment

The very old quarry north of Vang, 200–250 m northwest of the Vester Borregård farm is an important outcrop in the basement of Bornholm. Therefore, we propose to protect this outcrop as a 'geotope'. For this reason, we have taken only a few samples from inconspicuous places for our studies.

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Dansk sammendrag

En velblottet gangsværm af sandsten er fundet i Vang og Hammer graniten ved Vang på Bornholm. Gangsværmen stryger 120°–125°. De enkelte gange er op til 23 cm tykke og består af lys, grålig til brunlig, fin-kornet til mellemkornet kvartssandsten. Porerum i sandstenen er udfyldt med et leret-limonitisk materiale og med karbonat (dolomit) cement. Åbning og indfyldning af spalterne blev forårsaget af flere faser med extensionsbevægelser (NNØ-SSV retning) sandsynligvis i tidlig Kambrium. Det overlejrende Balka sand blev suget ned i spalterne ved deres dannelse. Den nedadgående bevægelse af det vandmættede sediment førte til dannelse af tragtede strukturer. Lignende strukturer er kendt fra Hardeberga sandstenen ved Skånes østkyst.

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