SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 711 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 69 NR 3

LENNART SAMUELSSON

PALAEOZOIC FISSURE FILLINGS AND TECTONISM OF THE GÖTEBORG AREA, SOUTHWESTERN SWEDEN

STOCKHOLM 1975

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 711 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 69 NR 3

LENNART SAMUELSSON

PALAEOZOIC FISSURE FILLINGS AND TECTONISM OF THE GÖTEBORG AREA, SOUTHWESTERN SWEDEN

STOCKHOLM 1975

ISBN 91-7158-071-9

Kartan är ur sekretessynpunkt godkänd för spridning i statens lantmäteriverk 1974-10-03.

CONTENTS

ABSTRACT

Different kinds of fissure fillings in more than 100 dikes from the Göteborg area are tabulated and described. A supposed Cambrian basal arkose from the Lake Mjörn area is treated in connection with accompanying arkosic dikes. Fissures with bituminous shale and asphaltite are also described as well as clay veins. The emplacement of the dike material is assumed to have taken place by injection of unconsolidated sediments. The formation of the Cambrian breccia at Kungälv is reinterpreted. The significance of the present observations on the Palaeozoic history of the area is discussed and a tentative tabulation of some events is given.

1. INTRODUCTION

This investigation is the result of a continuous collection of observations concerning clastic dikes since the discovery of Cambrian rocks in two rather broad fissures at Kungälv (Samuelsson 1967, Martinsson 1968). The main part of the material has been collected during mapping of the Geological Survey quadrangle maps Göteborg SO and Kungsbacka NO. Some observations outside the mapping area are also included.

The bedrock of the well-exposed area is dominated by a diversity of high grade metamorphic rocks (Sandegren and Johansson 1932, Lundegårdh 1958). The regional metamorphism seems to have terminated with the formation of pegmatitic dikes radiometrically dated to about 930 m.y. (Welin and Blomqvist 1964, p. 33). Dolerite dikes orientated WNW—ESE are 800—900 m.y. old according to a recent paleomagnetic investigation (Abrahamsen, 1974).

Palaeozoic rocks outcrop 40 km to the north and northeast of the area. They may also be expected in a possible southward continuation of the Oslo graben some tens of kilometres to the northwest. Ramberg (1972, p. 43) from geophysical data finds this N—S extension of the Oslo rift through Skagerrak and Kattegatt less probable than a NNE—SSW extension to the area northwest of Jutland (see also Sorgenfrei 1969, p. 188). However, the early Permian dikes of the Swedish Skagerrak coast indicate the existence of the Oslo plutons rather close to the coast line 50 km NNW of Göteborg (Samuelsson 1971). This interesting contradiction between geophysical and petrographical evidence is, however, beyond the scope of the present investigation.

Information and material for this study has been provided by fil.kand. S. Ahlin, fil.kand. H. Bernhardsson, fil.kand. T. Lundgren, fil.stud. P.-O. Martinsson, fil.mag. S. Nordblom, Dr. K. Palmqvist and Dr. B. Ronge. Prof. A. Martinsson critically read the manuscript and is taking over the collected material for further treatment at the Department of Palaeobiology, Uppsala. The illustrations were prepared by Mrs. M. Jonsson (drawings) and Mr. E. Yngvesson (photos). The text has been corrected by Dr. P. H. Lundegårdh and Mrs. C. Wilson. Mrs. L. Hillén has typed the manuscript. To all I express my sincere thanks.

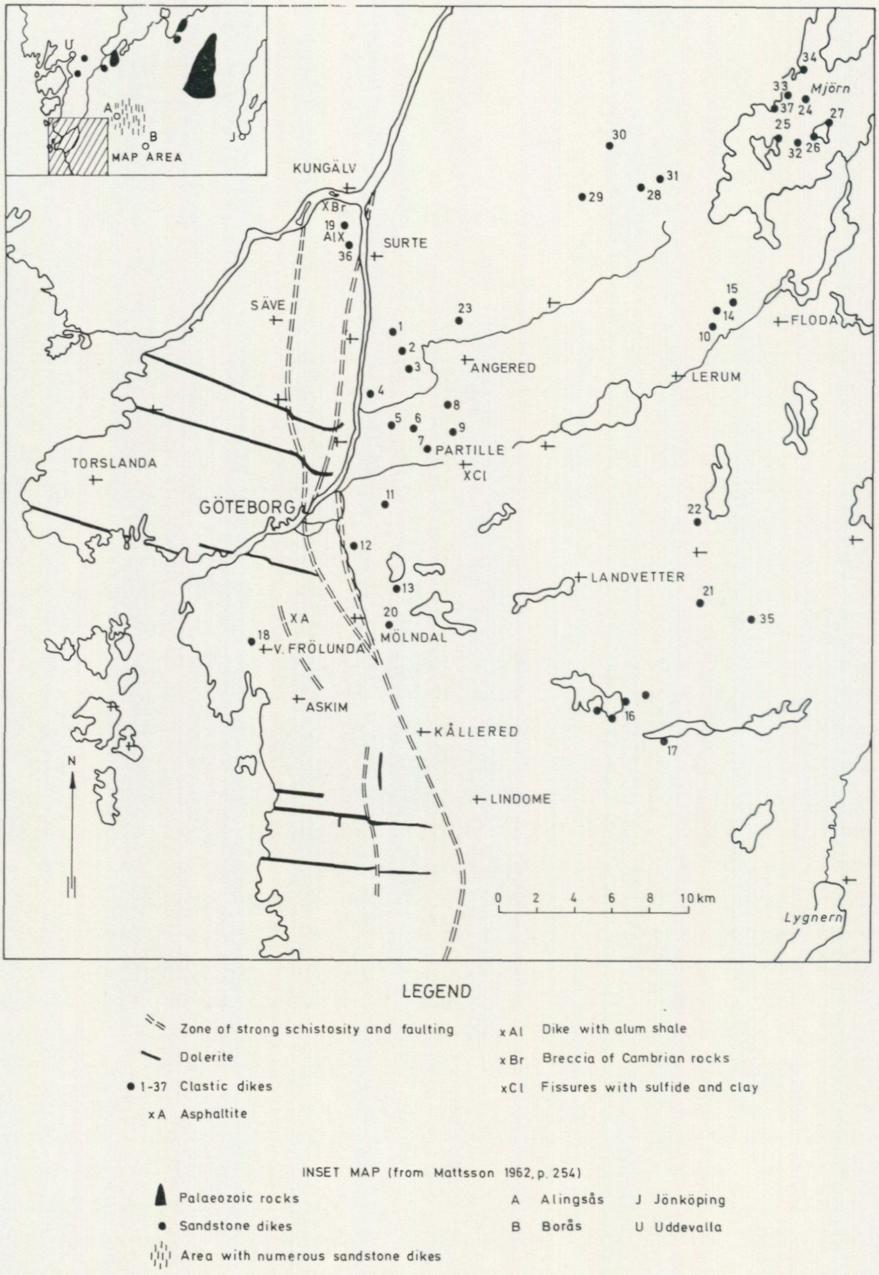

Fig. 1. Map of the Palaeozoic dikes in the Göteborg region. (*Cf*. Table 1.) The dolerites are older (800—900 m.y.). The river Göta zone of strong schistosity and faulting has not been marked.

2. CLASTIC DIKES AND BASAL ARKOSE

2.1. GENERAL FEATURES

Clastic dikes are found scattered over almost the whole area (Fig. 1). They are most easily observed in road cuttings and tunnels or on the exposed bedrock of lake shores. It must also be noted that the area systematically mapped in this connection is situated east of a line through Kungälv and Mölndal. It is consequently not possible to make any statements from the dike distribution presented in Fig. 1.

The clastic dikes are steeply dipping, tabular bodies. They are mostly composed of sand- or siltstone but arkose, shale and arenaceous limestone are found in a few dikes. According to the nature of the outcrop it is usually not possible to follow a dike for more than a few metres. In one instance (Table 1, no. 17), however, it seems possible to trace a dike in several outcrops along a distance

Fig. 2. Sandstone dike at Oryddal (Table 1, no. 14).

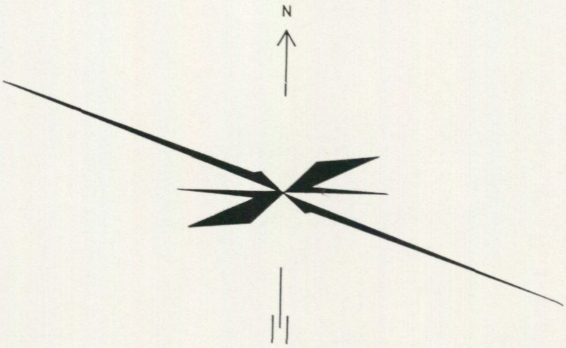

Fig. 3. The orientation of 131 clastic dikes.

of 900 m. The dikes are usually less than five centimetres thick with a maximum of 40 cm (Table 1, no. 4). Dike no. 36 (Table 1) is wider but excluded in this connection (see below).

Clastic dikes have been found at different altitudes up to 130 m a.s.l. Two small occurrences on the lake shore (58 m a.s.l. *cf.* below) of horizontally stratified arkose connected with a vertical arkose dike (Table 1, no. 25) imply that the pre-arkosic surface in detail was at least of the same relief intensity as the present one. Reservations must be made for possible post-arkosic movements along the Kungälv—Göteborg—Mölndal—Kungsbacka line.

The dikes have been observed in tunnels at a depth of about 50 m below the bedrock surface. They have been traced in vertical road cuttings of about 10 m with unchanged thickness (Table 1, no. 2). More than 100 individual dikes have been found. They are restricted to 37 localities and consequently appear in swarms at some localities, one of which is discussed below. The orientations of the dikes are usually WNW—ESE (Table 1 and Fig. 3).

The sandstone dikes at Hjällbo (Table 1, no. 4) are mentioned in a previous paper (Samuelsson 1967, p. 457). The geology and tectonic history of this outcrop has later been studied by Bergman and Åkesson (1969, unpublished paper). Their observations are summarized in Fig. 4, which is published with their kind permission. This outcrop was made available when the area was prepared for construction works. Consequently there is not much left to be seen today.

The youngest Precambrian rocks at this locality are pegmatitic dikes orientated WNW—ESE and with vertical dips. The pattern of tectonic displacement of the pegmatitic dikes is rather puzzling and it seems likely that these dikes were emplaced on several occasions. The opening of the pegmatitic dikes was connected with repeated strike-slip faulting along NNE—SSW trending lines. The main character of the movements during this period of formation of pegmatitic dikes is right lateral. This means that the western block moved northwards. The age of the pegmatites is not less than 900 m.y. (*cf.* above p. 5).

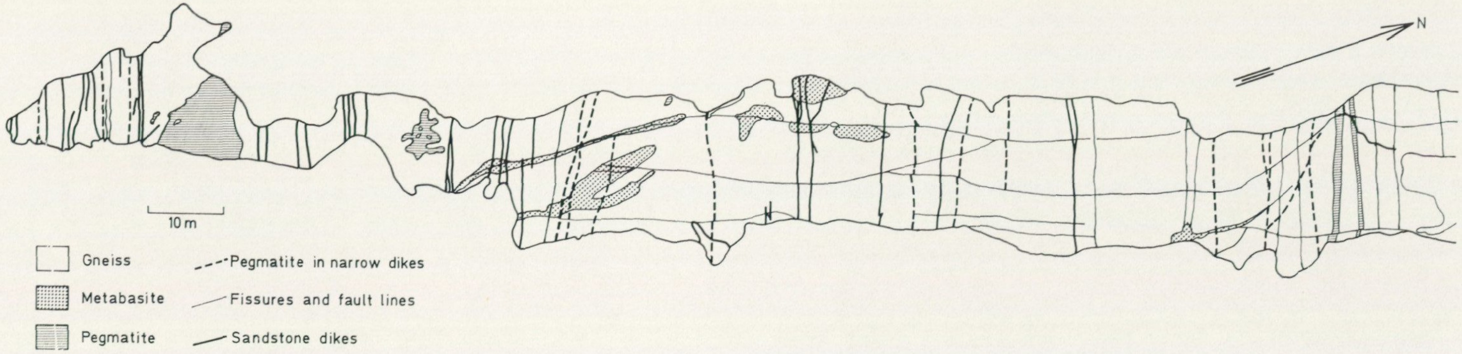

Fig. 4. Map of the outcrop at Hjällbo, northern Göteborg (Table 1, no. 4), by Bergman and Åkesson (1969).

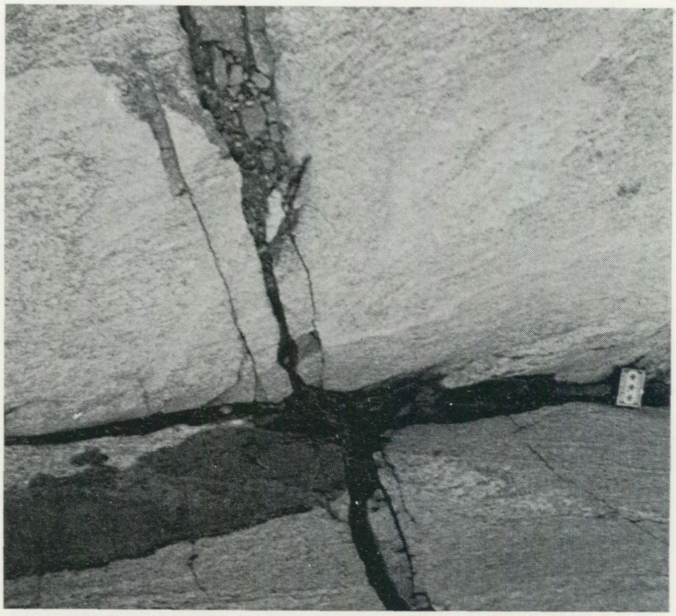

Fig. 5. Left lateral fault (5 cm) across a sandstone dike at Hjällbo, northern Göteborg (Table 1, no. 4).

The next episode to be recorded by this outcrop is again an opening of WNW—ESE fissures with emplacement of clastic material. In some places the clastic dikes have later been faulted by a left lateral movement along NNE—SSW trending lines. Fracturing of the dike material, when crossed by the faults, indicates that this southward movement of the western block occurred after the consolidation of the clastic dikes (Fig. 5).

The occurrences of basal arkose mentioned above were observed on islands in Lake Mjörn in the northeastern part of the area. No. 25 (Table 1) at Sunnerö is the most interesting of them. It is found on the shore and nearby are several clastic dikes. The arkose is only 1—5 cm thick. The weathered bedrock consists of acid gneiss with the foliation dipping 10—20° towards the west. There are two small patches of arkose at a distance of 2 m apart and a third occurrence about 50 m to the northwest. The sheets of arcose are subhorizontal and together they cover an area of only one square metre (Fig. 6). However, signs of weathering of the same kind as that connected with the arkose are found scattered in the surrounding bedrock. The outcrops of arkose are discordant on the foliation of the gneiss. This, together with the observed weathering of the bedrock, indicates that the present bedrock-surface is roughly consistent with the surface on which the arkose was formed. However, some morphological details have been added by among others, the Quaternary glaciations. The net results of this must have been a smoothing of the prearkosic surface.

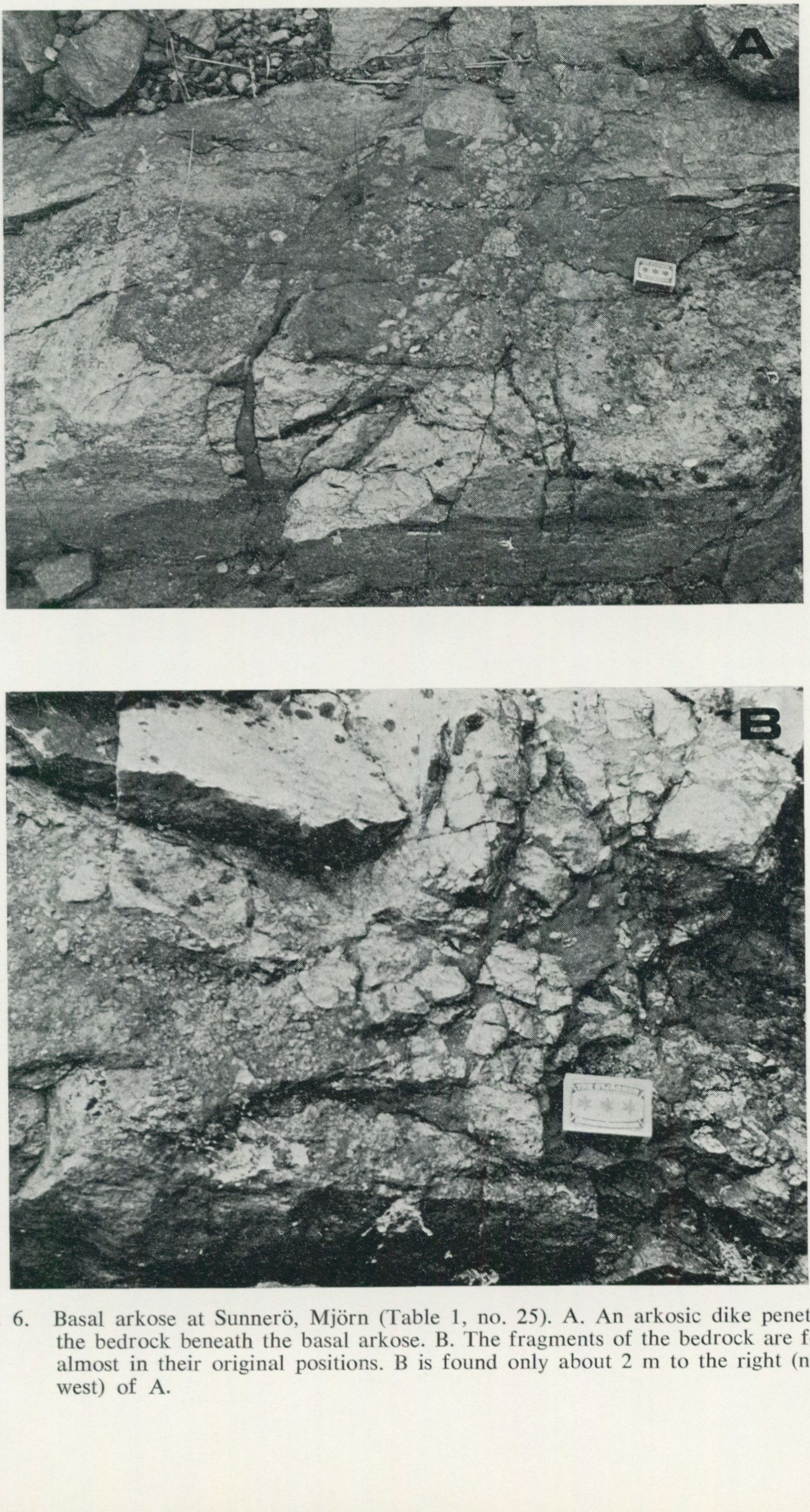

Fig. 6. Basal arkose at Sunnerö, Mjörn (Table 1, no. 25). A. An arkosic dike penetrates the bedrock beneath the basal arkose. B. The fragments of the bedrock are found almost in their original positions. B is found only about 2 m to the right (northwest) of A.

One of the clastic dikes traverses the bedrock on which the arkose is deposited (Fig. 6). The dike is composed of the same kind of material as the matrix of the horizontally bedded arkose. Neither in the field nor in thin section can it be observed that the clastic dike cuts the arkosic layer.

The most prominent difference between the dike material and the arkosic layer is the almost complete absence of rock fragments larger than 5 mm in the dike. This is also valid for the other dikes at this locality. Rock fragments are very numerous in the arkosic layer (Fig. 6 B). Only in locally very distinct parts of some dikes an inflow of rock fragments can be observed. Most of the dikes of the Lake Mjörn area consist of a redbrown arkose. However, on the shore SE of Sjövik (Table 1, no. 37) two dikes of grey sandstone are found only about 200 m to the north of and at the same altitude as another two dikes with the ususal redbrown arkose.

2.2. LITHOLOGY

Macroscopically different types of clastic dikes have been studied under the microscope (Table 2). Only 500—600 points were counted in each thin section. The clastic dikes of Tables 1 and 2 can be treated in four groups, although transitional forms, especially between groups 1 and 2, are rather common.

1. Dikes with sand- and siltstone sometimes arkosic constitute the majority of the dikes.
2. Clay rich dikes nos. 4, 16.
3. Dikes with bituminous shale nos. 19, 35, 36.
4. Limestone dike of locality no. 4.

2.2.1. Sandstone dikes

A conspicuous feature of many of these dikes is a splitting up of the material into two grain-size groups. One with mostly angular or only slightly rounded grains and an average diameter of 0.05—0.1 mm, and a second group with larger frequently rounded grains 0.3—0.6 mm in diameter (Fig. 7). Another notable feature is the existence of minute clay balls sometimes rounded and sometimes flattened. The overall high content of a clayish matrix is noteworthy. Pressure solution along grain contacts is thus not very common (*cf.* Gorbatschev 1967, p. 25). In dike no. 14 (Tables 1 and 2), where the matrix comprises only 1 precent by vol. pressure solution and secondary growth of quartz is conspicuous. The same is also valid for a sample of a sandstone dike at Vargön about 1 km from the outcropping Lower Cambrian sandstone. The latter sample was collected by Mr. Nordblom, Nol. Its composition is presented in Table 2.

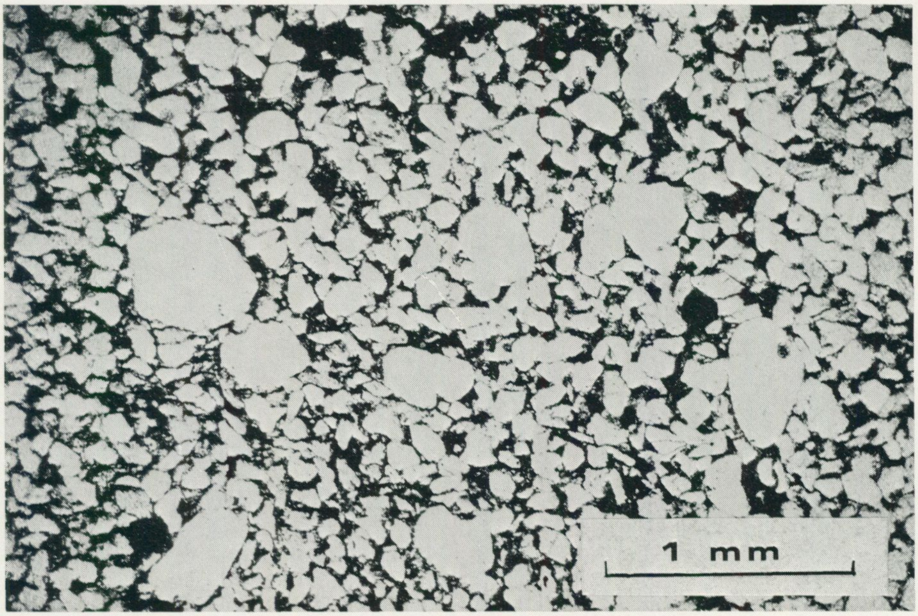

Fig. 7. Bimodal grain-size distribution (Table 1, no. 5). 1 nic.

Quartz is the most common mineral (*cf.* Table 2). The quartz grains are less frequently undulous than in the bedrock of the region. Overgrowth of quartz in crystallographic continuity with detrital quartz grains has sometimes been observed.

Feldspars and micas comprise usually only a few percent. They are of the same types as recorded from the country rocks. The opaques are dominated by magnetite and pyrite. Both are rather common in the surroundings. However, the pyrite of the dikes seems to be mostly authigenic.

The calcite found in a few dikes is distinctly later than the emplacement of the dike material. Glauconite is observed as sparse distinct grains in some slides.

2.2.2. Dikes rich in clay-sized particles (sometimes bituminous)

40 percent by volume of dike no. 4 a (Table 2) is made up of clay-sized material. The main mineral is quartz with a great variation in grain size. Most quartz grains are angular and of rather small diameter (0.1 mm). However, there are a few percent larger (about 0.6 mm) conspicuously well rounded quartz grains. Slender crystals of rutile are frequent in these grains. These larger quartz grains are often broken.

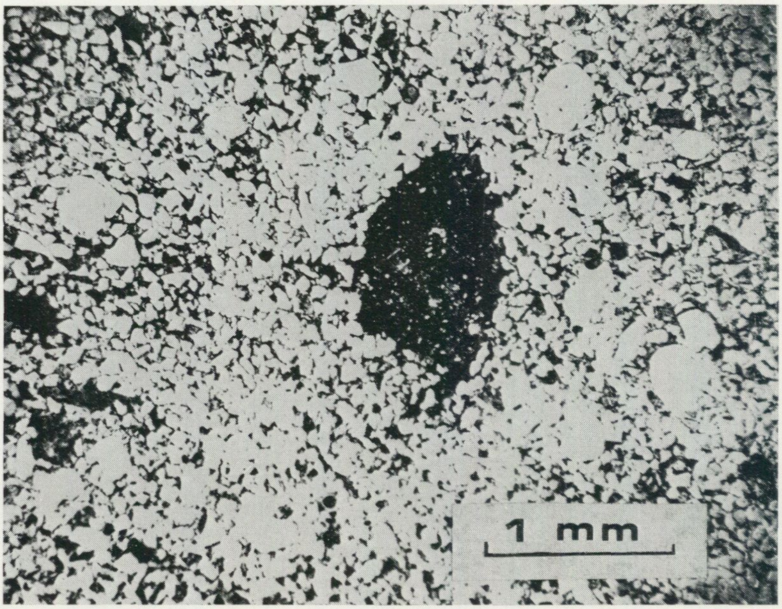

Fig. 8. Clay ball with bituminous matrix (Table 1, no. 16). 1 nic.

Feldspar grains are rather common and they usually contain secondary minerals. Glauconite is a genetically notable mineral.

The alum shale dike (Table 1, no. 19) is a typical representative of dikes with a bituminous matrix. A closer examination of this type of dike is given in the next section. However, it is necessary to stress that about 40 percent by volume of this dike is made up of quartz grains in a fine-grained bituminous matrix. Rounded "clay balls", which are composed of quartz grains in a non-bituminous and very fine-grained matrix, are found in this dike. This is important because a macroscopically rather normal "sandstone" dike (Table 1, no. 16) contains "clay balls", which are composed of small quartz grains in a bituminous and very fine-grained matrix (Fig. 8). A dike at locality no. 35 (Fig. 12) also contains pieces of bituminous claystone (see next section).

Despite the macroscopic and field similarities between the average "sandstone" dikes and dike no. 16 the latter differs also in the high content of both "clay balls" and fine-grained matrix. The content of opaques is also rather high.

2.2.3. Fissures with bituminous shale

As mentioned in the introduction, brecciated Cambrian rocks have been previously described from fissures 1.5 km W of the Fortress of Bohus, Kungälv

(Samuelsson 1967, Martinsson 1968). It is of some interest for this section to note that black bituminous shale (alum shale) made up an important part of the material.

Approximately 1 km SE of the locality previously mentioned a small (0—10 cm wide) fissure containing a black rather homogeneous material is situated in a road-cutting through intensely fractured Precambrian rocks (Fig. 9). Its approximate extension is WNW—ESE. Due to Quaternary deposits it can only be observed in the road-cutting. It penetrates more than 5 m downwards from the bedrock surface. It also contains many angular fragments from the wall rock. The dike itself is slightly fractured parallel to the dike walls. It cuts the most frequent slickenside direction which is NNE—SSW with a rather steep westerly

Fig. 9. Fissure with alum shales. The bedrock is strongly fractured (Table 1, no. 19).

dip. One of these fractures cuts the black dike. Consequently there must have been movements even after the deposition of the black shale.

The black fissure filling is very fine-grained and without any macroscopic structures. When put into a fire it glows and gives off a sulphuric odour, as the alum shale from the previously mentioned breccia. According to a negative test with diluted HCl it does not contain any appreciable amount of calcite.

From a tunnel 1.3 km south of the locality mentioned above another fissure (Table 1, no. 36) with black, homogeneous and bituminous shale has been observed (Tom Lundgren, Geotechnical Institute of Sweden, Stockholm, personal communication). The strike of this fissure is about N70°W and the dip is vertical. The fissure is 0.2—2 m across. This dike was observed in a tunnel at two localities 250 m apart at a dept of about 30 and 50 m below the bedrock surface.

At locality no. 35 (Table 1) several ordinary sandstone dikes have been observed. One of these contains bituminous shaly material at several places along the 5 m long outcrop of the dike. The bituminous material has an irregular appearance, however, small pieces do occur as xenoliths in the sandstone. Some of the black xenoliths (1 mm to 15 cm in length) seem to have been plastically deformed during the emplacement of the dike material.

2.2.4. Limestone dike

Fissures containing calcite are a common feature in different kinds of geological environment. Usually they have been formed by precipitation from aqueous solutions. Anyway it must appear very hazardous to treat this kind of fissure filling in connection with clastic dikes. However, at locality no. 4, where a larger number of sandstone dikes occur (see p. 8), there is a limestone dike with some indications of a clastic origin.

The dike is orientated WNW—ESE with a vertical dip. It is about 2—3 cm wide and was observed in a tunnel about 10 m below the bedrock surface. A thin section (Fig. 10, Table 2, no. 4b) reveals that the main part of the dike is made up by calcite with a good deal of quartz, some feldspar grains, and biotite. The calcite is found as coarse grains in almost monomineralic veins and as smaller granoblastic grains contaminated with rather large well rounded quartz grains and a few angular grains of feldspar, biotite, and muscovite.

The genesis of this dike is difficult to interpret. However, it seems reasonable to assume that the monomineralic coarse-grained calcitic parts of the dike were formed by precipitation of calcite from solutions introducted at a late state or by complete recrystallization of pre-existing calcite. The rest of the dike was probably formed in one of two ways. Either the clastic quartz grains comprise remnants of a pre-existing sand-filled dike, which, due to the lack of sandstone

Fig. 10. Dike with veins consisting almost entirely of calcite (A) and calcite with rounded quartz grains (B). Table 1, no. 4. 1 nic.

pieces, was contaminated with calcite before the consolidation of the dike material, or the quartz grains and the calcite were emplaced in the dike contemporaneously. As the quartz grains of the limestone dike are larger as compared to the "average sandstone dike" and because the Middle Cambrian limestone found in the breccia at Kungälv (*cf.* p. 32) contains arenaceous layers with well rounded quartz grains, the latter of the proposed modes of formation seems to be the most probable.

2.3. MODE OF FORMATION

There are different ways for the emplacement of the clastic material in the dikes. In the first hand it has been a sedimentation into a pre-existing open fissure. In the second hand the emplacement of the sand and the opening of the fissure could have been momentary and synchronous. In the latter case the opening of the fissure might have been preceded by a joint.

In the first case the dikes are expected to be rather shallow, with more or less weathered walls, and to have a conglomeratic to arkosic sediment (Fig. 11 A).

The second alternative requires the existence of sediments on the fissured bedrock. At least some parts of this sedimentary column, not necessarily the

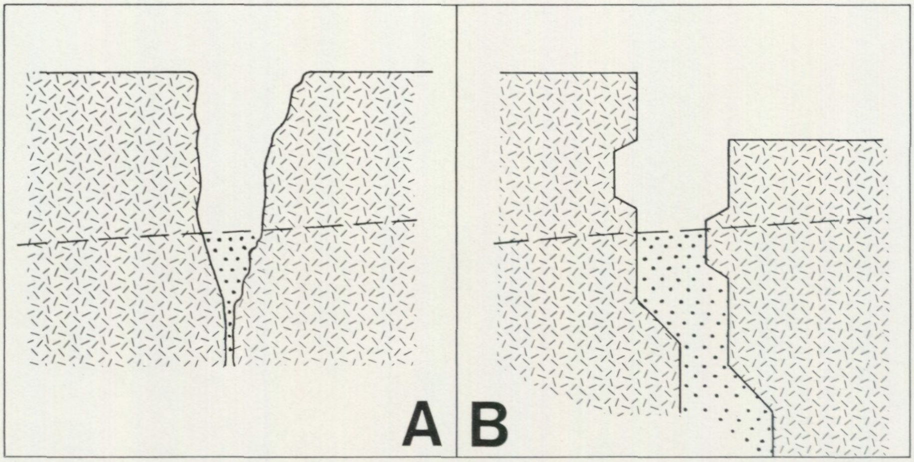

Fig. 11. The fundamental difference of appearance (and depth) between a sandstone dike in a weathered fissure cleaned by erosion (A) and a dike in a tectonically opened fissure (B). The dashed line shows a later erosion level. From Mattsson 1962, Fig. 120.

basal parts, must have consisted of unconsolidated material. The appearence of the dikes should be that of Fig. 11 B. The dikes can be expected to extend to considerable depths. The dike walls are either unweathered or, in the case of the fissure being preceded by a joint, weathered to some degree, or mineralized.

Hjelmqvist (1939) describes a sandstone dike in marble. The marble is of Svecofennian age (1 800—2 000 m.y.) and the sandstone dike is of supposed Cambrian age. The dike has been formed by the replacement of dissolved calcite with clastic grains of quartz and silica precipitated from water solution. Replacement of this kind has not been observed in the Göteborg area. Thus this third mode of dike formation is not applicable to the Göteborg dikes.

Mattsson (1962) gives an extensive record of the distribution and formation of sandstone dikes in the southern part of Sweden. Lindström (1968) describes "funnel grabens" occurring in the sedimentary cover as a consequence of the opening of basement fissures accompanied by synchronous injection of sandy material. The latter study also allows some considerations concerning the chronology of sandstone dike formation and the consolidation of the sediments.

Harms (1965, p. 992) describes sandstone dikes from Colorado formed by simultaneous fissuring and injection of sand. He stresses the importance of the orientation of quartz grains and rock fragments in the dikes. He found that their long axes parallel the dip directions of dike walls and concluded: "The grain orientation definitely precludes filling by gravity fall of individual grains into an open fissure". It has in places been shown that pieces of more or less consolidated parts of the overlying sedimentary column occur in the clastic

Fig. 12. Sandstone dike containing a wedge of the wall rock (Table 1, no. 35). (A) shows the field appearance (the match is 4.5 cm). (B) is a sketch of the same occurrence. For discussion see the text.

dike matrix (*cf.* Harms 1965, p. 993, Lindström 1968, p. 1148, Mattsson 1962, Taf. XII b).

For the formation of the majority of the clastic dikes in the Göteborg area the following observations seem to be valid.

a. The dikes are ususally bordered by unweathered and matching wall rock surfaces. A good example is shown in Fig. 12. The gneiss wedge has a very thin termination and all surfaces are unweathered. At the lower end the wedge is separated from its downward continuation by a thin seam of sandstone. The surfaces of the upper and lower fragment are strictly matching. This is also the case for the wedge and the walls of the dike. Obviously the lower fragment had time to fall just 1 cm before it was fixed in the sand. This means that the opening of the fissure and the emplacement of the sand were synchronous. A similar relationship between wall rock, wedge and sandstone is seen in Fig. 13. Here it can also be observed that rock fragments in the lower part of the picture have their longest axes parallel to the dip of the dike (vertical). If these fragments were emplaced by gravity fall into an open fissure their axes ought to be horizontal (*cf.* Harms *loc.cit.*). Analogous observations were also made in some additional dikes (particularly at the southern shore of lake Östersjön, Table 1, no. 16).

b. The alum shale dike (Table 1, no. 19) traverses an intensly factured bedrock. The main part of this fracturing is older than the alum shale dike. It is considered impossible that open fissures of the dimensions of the dike can have existed without an immediate infilling of pieces from the dike walls. Some scattered wall rock pieces are actually found in the dike but on the whole the fissure is filled with shale. It should be noticed that dike no. 36 was observed at a depth of 50 m below the bedrock surface. Consequently it must be assumed that the bituminous mud was injected at the moment of fissuring.

c. The small rounded pebbles consisting of quartz grains in a clayish matrix (Fig. 9) are likewise consistent with the existence of a sediment cover at the time of emplacement of the dike material.

d. The dike covered by arkose (Table 1, no. 25) indicates a close connection between the dike material and the horizontally bedded arkose. Examination of the rock fragments in the layered arkose confirm that they came from the local bedrock. In places it can be seen that they have moved less than 1 cm. They thus comprise the bottom of the arkose. As they are the oldest components in the sedimentary column it is reasonable to assume that they gathered in depressions in the topography. If the dike fissures existed at that time they would have been filled with fragments as they are wide enough for most of the pieces. In consequence most of the dike fissures in the Lake Mjörn area were formed after the deposition of the arkose. According to the close proximity of arkose

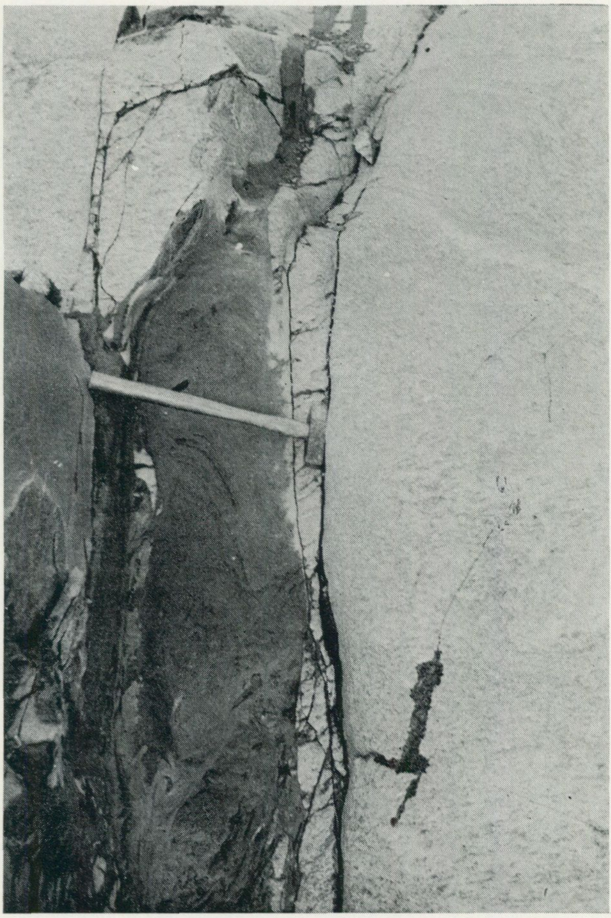

Fig. 13. Broad sandstone dike at Hjällbo, northern Göteborg (Table 1, no. 4). The lower part of the dike contains fragments separated from the wall rock and showing vertical long axes.

dikes and sandstone dikes at locality no. 37 (Table 1) it is plausible that some pure sand was also deposited at the time of fissuring. The opening of the dike-fissures caused a synchronous injection of the most fine-grained parts of the arkose. In areas were the arkosic layer was absent or consolidated enough for fissures to penetrate, pure sand was injected. However, the possibility that the dikes with grey sandstone represent a separate, younger episode of fissuring and infilling can not be denied.

To complete the picture of the Mjörn area it is necessary to mention that there are some occurrences of arkose rich in rock fragments (*e. g.* the basal arkose type) with a dike-like appearance. These dikes are very short and shallow (Fig.

Fig. 14. Shallow fissure filled with arkose of the basal type. The central parts of the base of the fissure protrude through the arkose in the lower left corner (Table 1, no. 24, Torsholmen). The rule is 20 cm.

14), although their depth cannot always be determined. However, in one case the surface beneath the arkose was observed and there was no continuation of clastic material downwards. In another case where the arkose depression was bounded by two fissures with traceable continuation on the bedrock outside, no sandstone or fine-grained arkose was found in the continuations of the fissures.

It is thus necessary to consider two kinds of fissure fillings in the Mjörn area. The oldest one was formed by sedimentary infilling of shallow open fissures cleaned by erosion and the younger one was formed by fissuring of the bedrock beneath a cover of unconsolidated sediments. The latter mode of formation seems valid for the majority of the dikes of the Göteborg region.

2.4. SOURCE OF DIKE MATERIAL

The mineralogy and grain shapes of the material within the dikes indicate that it was mainly derived from sedimentary sources. Provided that the injection mode of emplacement is correct, the dike material could be derived from any sedimentary formation younger than the Sveconorwegian pegmatites (930 m.y.). However, the only known sedimentary formation in the neighbourhood is the Cambrian to lower Silurian deposits of Västergötland. As previously mentioned there is also the possibility of both older and younger sediments and volcanic rocks west of the coastline. The observations made at the arkose locality (Table 1, no. 25) indicate that the dike material in the Mjörn area is derived mainly from the basal arkose. There is so far no fossil evidence of the age of this arkose. However, from the regional geology and the prominence of the sub-Cambrian peneplain it is probable that the arkose is of Lower Cambrian age (*cf.* Magnusson-Lundqvist-Regnell 1963, Rudberg 1970). As the arkose dikes must have been formed before the consolidation of the bedded arkose they cannot be much younger than the latter.

Among the clastic dikes described some are obviously of younger age. The alum shale dikes, for example, are at the oldest of Upper Cambrian age (Martinsson 1974, p. 226). It should also be noted that the majority of the clastic dikes of the area have a lithology different from the dikes of the Mjörn area. However, they may still belong to the same event of fissure opening. The prerequisite would be that there was no arkose on the fissuring bedrock or the fissures tapped layers of sand and silt higher up in the column. The latter case is demonstrated by Lindström (1967, p. 1151).

As seen from the discussion above there is so far very little really substantial evidence for a correct stratigraphic correlation of the material in the clastic dikes. Some observations seem to be inconsistent with each other. It is obvious that some kind of dating of the material is highly desirable. According to the somewhat depressing experiences by Welin-Lundström-Åberg (1972), the fission track method has not been considered very promising. Although no definite proof of a fossil content has occurred during the present study is seems reasonable to expect microfossils, which could be concentrated by means of modern techniques. The collected material will be treated in this respect at the Department of Palaeobiology, University of Uppsala. They are hereby continuing the previous study of Palaeozoic rocks of the Göteborg area by Martinsson (1968).

Awaiting the results of this time-consuming investigation the present knowledge concerning the sources of the dike material can be summarized as follows.

a. Within the investigated region there is evidence of dike formation contemporaneous with or slightly younger than the formation of a basal arkose on a weathered bedrock surface. According to the regional geology this basal arkose is probably of Lower Cambrian age.

b. The dikes with black, bituminous shale (Table 1, nos. 19 and 36) derived their material from Upper Cambrian strata. The occurrence of Upper Cambrian alum shale 1.5 km to the northwest of these dikes has been established by the fossil record (Martinsson 1968). These facts indicate a fissure opening in the Upper Cambrian or slightly later. The observations of bituminous xenoliths in two sandstone dikes (Table 1, nos. 16 and 35) indicates that some sandstone dikes might have been formed in connection with the fissure opening mentioned. The sand and silt of these dikes might be Upper Cambrian or somewhat younger.

3. ASPHALTITE

Two pegmatites from Högsbo, southwestern part of Göteborg (Fig. 1), have previously been described by Sundius (1950, 1952), Brotzen (1959) and other investigators. The southern pegmatite is the smallest with a width of about 10 m and an E—W extension of about 75 m. The western part of this pegmatite is traversed by an irregular fissure striking N20°E and with a steep westerly dip. In connection with this fissure small druses have been formed in the pegmatite.

The pegmatite and druse minerals have been fractured due to later movements in the druse-rich zone. A clay mineralization of the feldspar close to the fissure has developed in connection with, or later than this fracturing.

Along the fissure down to at least 2 m below the present bedrock surface, small (about 0.5 cm^3) black spots and drops of a bituminous material are found (Fig. 15). This material is combustible and soluble in toluol. It is brittle with a conchoidal fracturing. It can be regarded as asphaltite in the sense of Welin (1966, p. 510). The asphaltite is found in small druses along the fissure. It fills up the spaces between the quartz and feldspar crystals. The surfaces of the asphaltite have to some degree been contaminated with dust from the altered feldspar. The same dust, however, is also found between the asphaltite and the crystals on which it is fixed. It is thus probable that the asphaltite arrived in its present position contemporaneously with the alteration of the feldspars.

Organic mineraloids in hydrothermal veins crossing a pegmatite at Besmer Mine, Canada, have been treated by Mueller (1972, p. 43). This paper mainly deals with the genesis of thucholites and their transformation to other organic compounds. Mueller (p. 47) has found some indications that ”Thucholites from pegmatites, or from high-temperature hydrothermal veins from Canada, Sweden, Isle of Man, etc., are radiogenic condensates of the ascending juvenile magmatic carbon-containing gases”. Grip and Ödman (1944) also suggest a formation of thucholite by replacement of a pre-existing uranium mineral.

Although the general geological setting at the Besmer Mine and the Högsbo bituminous occurrences are to some degree similar, there are some important differences. The chemistry of the Högsbo asphaltite has not been investigated in any detail. However, simple tests with a scintillator counter and autoradiogram do not reveal any radiation. There is thus no reason to believe that thucholite is

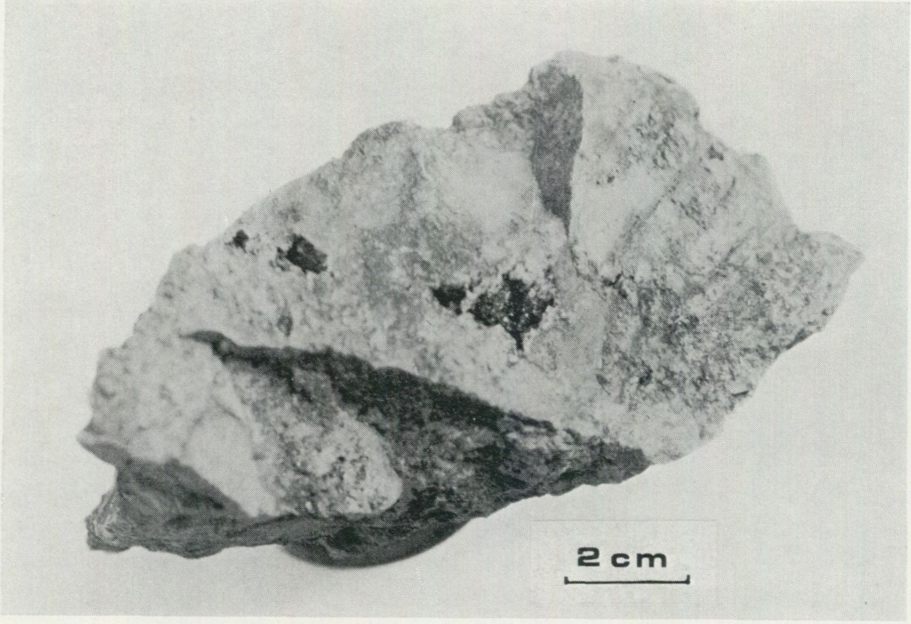

Fig. 15. Asphaltite from the small pegmatite quarry at Högsbo, southwestern Göteborg. Photo E. Yngvesson.

present. Radioactive minerals are rather common in the neighbouring larger pegmatite at Högsbo. However, there is no report of thucholite (Brotzen 1959). There is thus no obvious evidence that the Högsbo material has been formed as radiogenic condensates in connection with hydrothermal processes.

Asphaltite and thucholite in the Precambrian bedrock of Sweden have been studied by Welin (1966, p. 509) among others. A well illustrated description is given by Lundegårdh (1967, p. 114). Welin's detailed investigation led him to the conclusion that: "the carbonaceous matter has been transported by ground water streaming in fractures in the Precambrian bedrock and deposited down to a dept of several hundred metres. This organic material had a composition which varied within certain limits but is essentially represented by asphaltite. The carbonaceous matter is of plant or animal origin and consists of many different organic compounds . . . It is also shown that the organic compounds which constitute the thucholite probably have been subordinated constituents of the organic material." Lundegårdh (1967, p. 122) is also of the opinion that the asphaltite came oozing down the fractures on repeated occasions.

Thorslund has given an interesting description of an asphaltite occurrence in Johansson, Sundius and Westergård (1943, p. 86). Thorslund observed several gas vents vertically penetrating the Upper Cambrian bituminous alum shale at Kinnekulle. The escape of the gas was explosive and caused thermal alteration and brecciation of the shale. An abundance of asphaltite bodies and drops were found in the vents and its close surroundings but not outside the area. The explosions are assumed to be connected with the intrusion of large doleritic sills. Remnants of these are now found on top of the Palaeozoic rocks in that area. Of interest is the observation of some fissures filled with material, which can be shown to come from higher stratigraphic levels. In places the fissure fillings are rather claylike. The fractures have variable width (max. 0.9 m). An extension of at least 1.5 km for one of the fractures is estimated. The fractures and the gas vents are presumed to have been formed at the same time (*op. cit.* p. 89).

Returning to the asphaltite occurrence at Högsbo it seems possible to apply the following hypothesis for its formation. In a late stage of crystallization the pegmatite body was tectonically disturbed and a transversal fracture was developed within it (*cf.* Brotzen 1959, p. 26). Along this fracture the latest crystallization took place in druses. The age of this crystallization is about 930 m.y. or slightly younger (Welin and Blomqvist, 1964). After the Upper Cambrian deposition of bituminous alum shale on the bedrock surface above, the fracture was again active. After, or simultaneous with this activation of the fissure, the alum shale was heated and asphaltite oozed down the fissure. This was probably contemporaneous with the occurrence of hot water in the fissure causing the alteration of the feldspars. Concerning the age of the asphaltite at Högsbo it is of importance to note the connection between Permian igneous activity and occurrences of coal blends in the Oslo area (Dons 1956).

4. CLAY VEINS

Clay veins are frequently observed in tunnels, road cuttings, etc. in the Göteborg region. Here only a few occurrences and aspects will be treated as they seem to contribute to the tectonic history of the region.

The clay veins of the area show a diversity of orientations. There is, however, some preference to WNW—ESE with steep or vertical dips (*cf.* Lundgren and Scherman 1973, p. 41). This direction coincides with the orientation of most of the sandstone dikes. The same direction is also displayed by the dolerites (Fig. 1) and less distinctly by the pegmatites.

There are many examples of clay veins associated with sandstone dikes and showing the same orientation, such as at Hjällbo (Table 1, no. 4), Kortedala (Table 1, no. 5), Rösered (Table 1, no. 2) *etc.* In some of these cases it has been observed that the formation of the clay veins is younger than the emplacement of the sandstone of the dikes.

Thus a steep sandstone dike at Kortedala, measuring 4 cm across, is accompanied by a clay vein (0—1 cm across) along its northern margin. In places the fissure where the clay is found runs parallel to the sandstone dike 1—2 cm north of the contact. The same thing has also been observed in other localities. At Rösered part of the sandstone in a dike has been broken into pieces, which are surrounded by a clay film. The latter is in contact with a clay vein running between the sandstone and the wall rock. A clay vein 0.2—0.3 m across is situated south of Kungälv (Table 1, no. 19). The wall rock, a red potassic gneiss, has been altered to clay. In the clay are found rather large (1 dm^3) pieces of a grey siltstone. These observations show that the clay formed after the diagenesis of the clastic dikes.

In the breccia at Kungälv, which contained Upper Cambrian rocks among others, it was demonstrated that clay alteration occurred along WNW—ESE fissures. The latter had developed after the diagenesis of the breccia. They traverse the breccia and the wall rock (Samuelsson 1967, Fig. 2). In consequence it can be deduced that the fissuring represents a tectonic event postdating the Upper Cambrian. The clay formation might be of the same age, or younger.

Occasionally it is observed that the clay mineralization (alteration) is not restricted to distinct fissures. Thus at Kortedala (Fig. 16) the alterations go

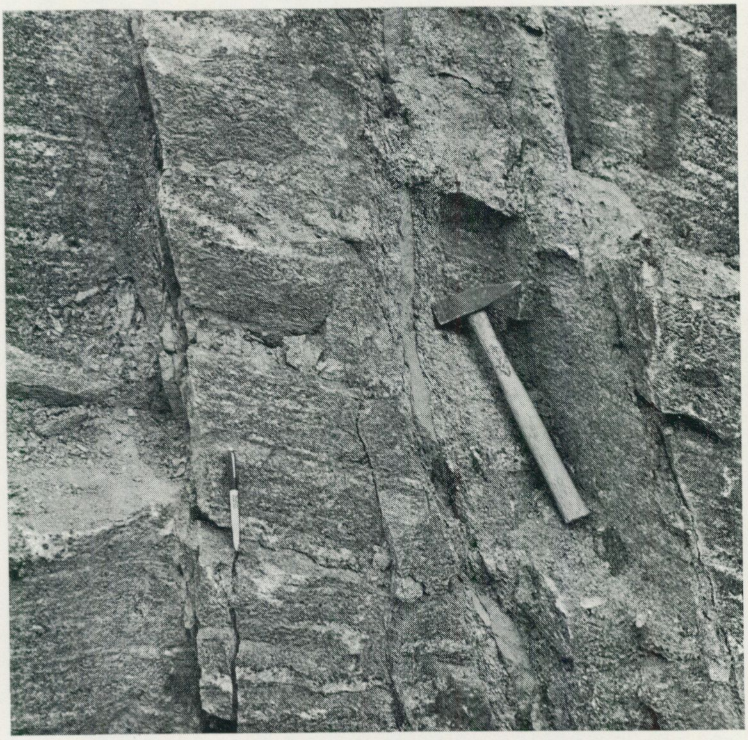

Fig. 16. Sandstone dikes with younger clay veins (Table 1, no. 5).

deep into the wall rock of the fissures. In a tram tunnel some 20 m below the bedrock surface a disseminated clay alteration has affected several tens of square metres. The bedrock has been divided into more or less altered blocks cemented by small calcite veins giving the impression of a criss-cross breccia. The calcite veins and the alteration of the bedrock seem to have been caused by the same geological event, which has included a fracturing of the rock.

Calcite is also found locally in the WNW—ESE vertical clay veins. It is sometimes found to be older and sometimes younger than the clay minerals. In general, however, there seems to be some genetic relationship between the calcite and the clay veins.

The clay veins are found at all depths in the tunnels (maximum observed depth about 100 m below the bedrock surface). The width of a certain dike is sometimes approximately the same on the glaciated bedrock surface as in the tunnels some tens of metres below.

The mineralogy of the veins is complex, montmorillonites usually being present. Lundgren and Scherman (1973) present an exhaustive record of clay veins and their tectonic environments in tunnels from the area between Göteborg and Kungälv.

The general appearance of the clay veins, as well as the mineralogy, indicates that they have been formed by hydrothermal processes rather than by superficial weathering (*cf.* Saether 1964, p. 423, von Eckermann 1954, Lundgren and Scherman 1973, p. 60).

Considering the fact, however, that the present bedrock surface seems to be consistent with the sub-Cambrian bedrock surface, a considerable degree of supergene weathering in fissures should be expected. It was observed that the breccia at Kungälv was attached to the unaffected bedrock in northeast by a thin seam of pyrite. A similar occurrence of pyrite has also been found 300 m south of the church of Partille (Fig. 1, Cl). Several parallel and vertical fissures (WNW—ESE) have a central seam of pyrite surrounded by partially altered bedrock. This clay alteration has also affected the bedrock between the fissures. When exposed to weathering owing to road construction, the whole rock-side changed to a clayey gravel within a few years. Small gypsum needles are observed in material from the fissures. It seems reasonable to ascribe this alteration to weathering by supergene water with dissolved material from an alum shale layer above the bedrock.

5. COMMENTS OF THE TECTONIC HISTORY OF THE CAMBRIAN BRECCIA AT KUNGÄLV

Martinsson (1968) was able to establish important facts about the stratigraphic position of some components of the breccia at Kungälv. The oldest fossiliferous rock, recorded up to now, is Middle Cambrian light grey limestone. This limestone contains arenaceous layers with well rounded quartz grains as well as angular rock pieces (Samuelsson 1967, Fig. 5). An even lighter grey limestone with conspiciously weathered surfaces is also of Middle Cambrian age. Martinsson assumes this rock to be somewhat younger than the former (*op.cit.*p.150). No light grey limestone of Upper Cambrian age is reported, however. Alum shales and black limestone were deposited on the weathered surface of the Middle

Fig. 17. A breccia of Precambrian rocks in a matrix of Middle Cambrian arenaceous limestone is cut by a fissure containing upper Cambrian bituminous material. From the Cambrian breccia at Kungälv. Photo E. Yngvesson.

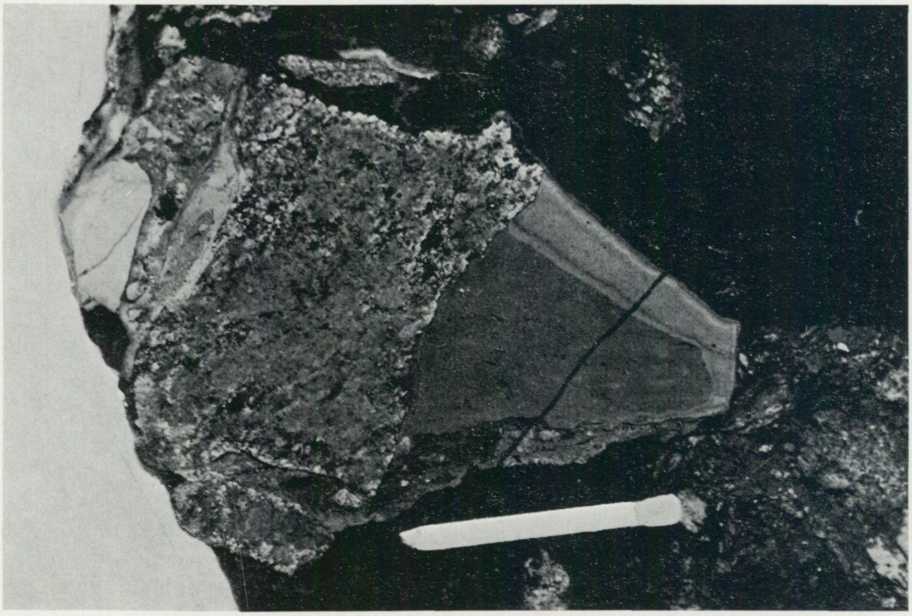

Fig. 18. A fragment consisting of Precambrian gneiss and Middle Cambrian limestone is enclosed in Upper Cambrian black shales. Note the weathered rim of the fragment. The Cambrian breccia at Kungälv. The match is 4 cm. Pohto E. Yngvesson.

Cambrian limestone. During this deposition pieces of the Middle Cambrian limestone dropped into the black mud (Martinsson 1968, Fig. 11). Fragments of the Precambrian rocks were deposited in the same way. In the light of these facts it is necessary to lay stress on certain information concerning the breccia.

a. The excavated material contained a boulder made up mainly of angular fragments of Precambrian rocks in a matrix consisting of grains of sand and gravel cemented by calcite (Samuelsson 1967, Fig. 6). Fig. 17 shows a polished slab of this part of the breccia with angular fragments of Precambrian rocks in a matrix of arenaceous limestone with rather coarse, rounded grains of quartz and fragments of fossils. The limestone also occurs as more or less discrete fragments. The matrix in the narrower "channels" between the fragments is less rich in coarse quartz grains and fossil fragments. Continuous transitions between this fine grained limestone and the arenaceous type can be observed. The limestone in the matrix and in the pieces is of the Middle Cambrian type (Martinsson 1968, p. 148). The impression is that the Middle Cambrian limestone was partly consolidated when this part of the breccia was formed. Notable is also the existence of pieces of the early breccia just mentioned as discrete fragments in the breccia at Kungälv (Fig. 18). It can be observed that these fragments have a weathered zone, which predates their deposition in the present breccia.

Fig. 19. The Cambrian breccia at Kungälv, part of the north-western wall of the shaft. To the right of the knife is a stinkstone concretion which dips 35° from the horizontal plane.

Figs. 17 and 18 also show that the described part of the breccia was later cut by fissures, which now contain a black bituminous material of Upper Cambrian type (Martinsson 1968, p. 150). These black fissures cut the fresh Precambrian fragments right across. The breccia was thus completely consolidated at their formation. It was observed that these black fissures were cut by later fissures filled with calcite. It is thus obvious that the breccia at Kungälv was formed by several discrete tectonic events. The first observable one occurred in the Middle Cambrian or slightly later and the second in the Upper Cambrian or slightly later. The third set of cross-cutting fissures is even younger.

b. No strict stratigraphic order could be observed in the breccia. Boulders of light grey limestone (Middle Cambrian) were found both at the top and at the bottom of the cleft. They were surrounded by black limestone and alum shales. There were more and larger limestone boulders along the NE wall of the cleft, as illustrated by Samuelsson (1967, Fig. 5).

c. Concretions of stinkstone have been dispersed in the breccia. Some have remained unbroken and some have been divided into irregular pieces. One whole concretion is seen in Fig. 19. It has a maximum diameter of about 30 cm. It is noteworthy that it does not lie in its original horizontal position. One half piece of a stinkstone with about 1 m maximum diameter was found in the excavated material above the cleft.

d. The black limestone and alum shale material did not display any macroscopic evidence of original shale cleavage (*cf.* Martinsson 1968, p. 150). In the stinkstone concretions, however, bedding is occasionally observed.

e. It was found that after the diagenesis of the different components of the breccia, new fissures developed parallel to the SW wall. Both the wall rock and the breccia have been cut by such fissures. Their formation was accompanied by clay mineralization both in the Precambrian wall rock and in the breccia.

The steep walls of the cleft as well as the angular fragments of limestone and Precambrian rocks indicate that the cleft was formed by normal faulting rather than by complete removal of the Precambrian rocks in a zone bounded by fissures. The existence of a breccia consisting only of Middle Cambrian and Precambrian fragments and its deformation after diagenesis, as well as the strong deformation of the stinkstone concretions of Upper Cambrian age indicate two episodes of faulting. The first episode occurred after the diagenesis of the Middle Cambrian limestone but before the Upper Cambrian deposition (Fig. 20 b). Erosion removed most of the limestone south of the fault so that Upper Cambrian black shales were deposited directly on the Precambrian rocks in this area (Fig. 20 c). The occurrences of black shales in dikes (p. 14) and asphaltite (p. 25) makes the relative uplift of the southern block more probable than an uplift of the northern block. It is possible that some parts of the limestone breccia were removed during this period of erosion. Weathering around some of the limestone blocks was noted by Samuelsson (1967, p. 455). A weathered unconformity between the Middle Cambrian limestone and the bituminous Upper Cambrian is also demonstrated by Martinsson (1968, Fig. 11).

The erosion was followed by a transgression and sedimentation of Upper Cambrian black shales and limestone contaminated by fragments of the Precambrian and Middle Cambrian rocks. It can be expected that the Upper Cambrian black mud was deposited also in between the limestone blocks of the previously formed breccia.

After the deposition of the Upper Cambrian and the development of stinkstone concretions, faulting along the WNW—ESE fissures again occurred. This time the result was a relative uplift of the northern block. At the same time Upper Cambrian material and some Middle Cambrian sediments were mixed and "squeezed" into the cleft, which now definitely was formed (Fig. 20 d).

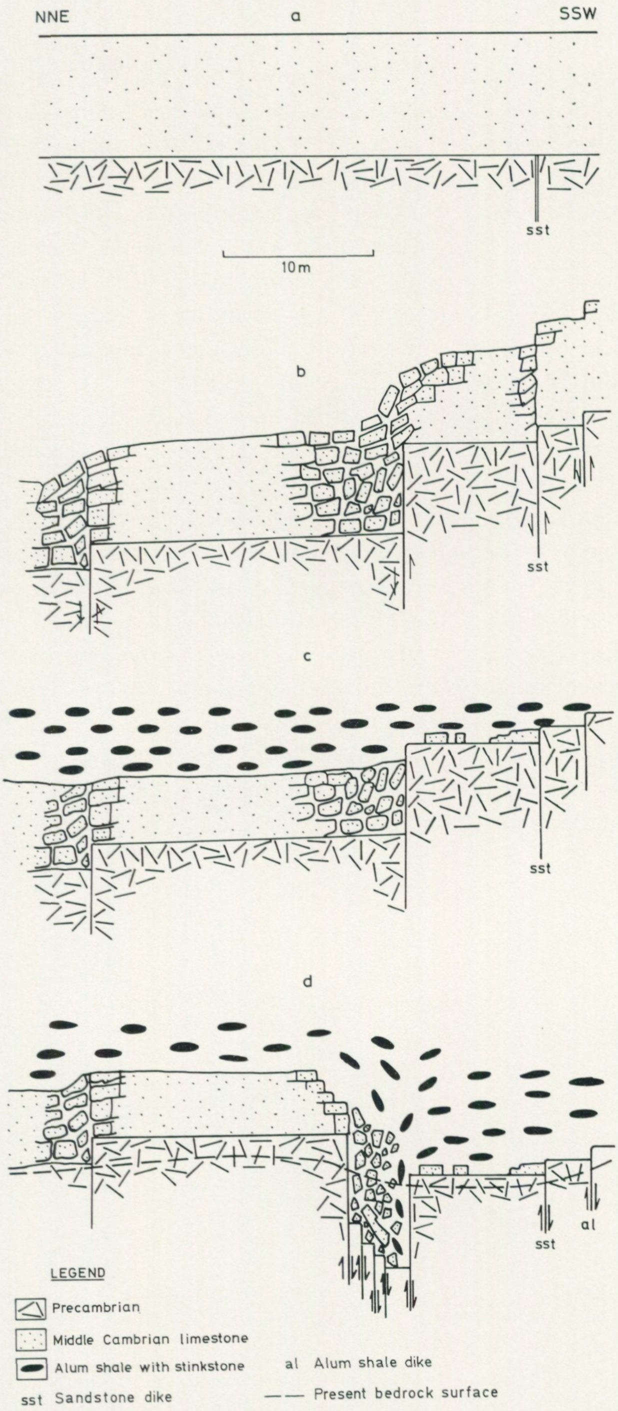

Fig. 20. Sketch of different stages in the development of the Cambrian breccia at Kungälv. (a) Middle Cambrian, (b) late Middle Cambrian to early Upper Cambrian, (c) Upper Cambrian, (d) late Upper Cambrian or slightly later.

According to the observation by Martinsson (1968, p. 150) that the shales of the breccia lack signs of deformation, and the observed ability of the shales to penetrate into open fissures (*cf.* above p. 14 and 33), it is assumed that the faulting occurred before the Upper Cambrian was completely consolidated. This problem includes the question of the rate of stinkstone formation. From the Cambrian at Kinnekulle some observations indicate that the stinkstone was formed before the consolidation of the shales (Johansson, Sundius and Westergård, 1943, p. 37). Martinsson (1974, p. 253) is of the same opinion. The events affecting the breccia concluded with the formation of clay in distinct fissures along the SW wall after the diagenesis of the whole breccia.

This somewhat hypothetical sequence of events is based entirely on the analysis of the breccia, with the exception of the statement that the southern block was uplifted before the northern.

This inerpretation differs from Samuelsson (1967, p. 456) in the conception of the emplacement of the breccia during two different tectonic episodes. Martinsson (1968, p. 148) assumes a feature that pre-formed the present breccia-filled crevice at the time of the Middle Cambrian transgression and that the Middle and Upper Cambrian rocks were deposited in this depression. Martinsson's general conclusions concerning the depositional environments during the Middle and Upper Cambrian transgressions are quite compatible with the present model of breccia formation. A bedrock topography of at least the present roughness is also indicated by the occurrences of bottom arkose (p. 10) and the wide distribution of sandstone dikes.

6. SUMMARY

The Precambrian basement of the Göteborg region contains fissures with arkose sandstone, siltstone, alum shales, asphaltite and clay. The interpretation of the occurrences indicates the Palaeozoic sequence of events listed in Table 3.

The Middle and Upper Cambrian deposits are established according to the fossil records (Martinsson 1968). The chronology of the other events are tentative. It is based on comparison with data from other areas.

The WNW—ESE clay veins are interpreted as hydrothermal products of igneous activity of post-Cambrian age. The asphaltite occurrence is supposed to have been formed in this connection. Mulder (1971) has given a radiometric age of 282 ± 5 m.y. for the nearby doleritic sills of Västergötland. Dike rocks belonging to the Permian of the Oslo graben are recorded 45 km NW of Göteborg (Samuelsson 1971). According to the asphaltite formation it can be assumed that the Upper Cambrian and possibly also younger deposits covered the area in Upper Carboniferous to Permian times. The breccia at Kungälv and the alum shale dikes south of it indicate that the present land surface is not very different from the sub-Middle Cambrian land surface. The latter is, according to the occurrences of *in situ* arkose, the clastic dikes and the general geomorphological features, probably consistent with the sub-Cambrian surface. The present observations also indicate that this western part of the Baltic shield was subjected to tensional stress in a general NNE—SSW orientation during several periods of the Palaeozoic.

REFERENCES

GFF=Geologiska Föreningens i Stockholm Förhandlingar

SGU=Sveriges geologiska undersökning, Stockholm

ABRAHAMSEN, N., 1974: The paleomagnetic age of the WNW.-striking dikes around Gothenburg, Sweden. — GFF 96, p. 163—170.

BERGMAN, G., and ÅKESSON, J-Å., 1969: Geologiskt detaljkartering av ett begränsat område i Hjällbo. Unpubl. paper. — Dept. of Geol. Univ. of Göteborg.

BROTZEN, O., 1959: Outline of Mineralization in Zoned Granitic Pegmatites. — GFF 81, p. 1—98.

DONS, J. A., 1956: Coal blend and uraniferous hydrocarbons in Norway. — Norsk. Geol. Tidsskr. 36, p. 249—266.

ECKERMANN, H. von, 1954: Montmorillonitbildning i Bergeforsens gnejsgranit. — GFF 76.

GRIP, E., and ÖDMAN, O. H., 1944: On thucholite and natural gas from Boliden. — SGU C 464.

GORBATSCHEV, R., 1967: Petrology of Jotnian rocks in the Gävle area. — SGU C 621.

HARMS, J. C., 1965: Sandstone dikes, Southern Front Range, Colorado. — Geol. Soc. America Bull., v. 76, p. 981—1001.

HJELMQVIST, S., 1939: En kambrisk sandstensgång i St. Malms s:n, Södermanland. — GFF 61, p. 209—217.

JOHANSSON, S., SUNDIUS, N., and WESTERGÅRD, A. H., 1943: Beskrivning till Kartbladet Lidköping. — SGU Aa 182.

LINDSTRÖM, M., 1967: "Funnel Grabens" and Early Paleozoic Tectonism in South Sweden. — Geol. Soc. America Bull., v. 78, p. 1137—1154.

LUNDEGÅRDH, P. H., 1958: Göteborgstraktens berggrund. — SGU C 553.

— 1967: Petrology of the Gävleborg County in Central Sweden. — SGU Ba 22.

LUNDGREN, T., and SCHERMAN, S., 1973: Lerzoner i berganläggningar. Lerförekomster i Göteborgsområdets berggrund — ovan — och underjordsstudier. — Stat.Geot.Inst. Rapport 71—63/U46. Stencil.

MAGNUSSON, N. H., LUNDQVIST, G., and REGNELL, C., 1963: Sveriges geologi. 4th ed. — Stockholm.

MARTINSSON, A., 1968: Cambrian palaeontology of Fennoscandian basement fissures. — Lethaia, v. 1, p. 137—155. Oslo.

— 1974: The Cambrian of Norden. — Lower Palaeozoic Rocks of the world. Vol. 2 Ed. Holland, C. H., John Wiley & Sons.

MATTSSON, Å., 1962: Morphologische Studien in Südschweden und auf Bornholm über die Nichtglaziale Formenwelt der Felsenskulptur. — Lund Studies in Geography, Ser. A. Physical Geography, No. 20. Lund.

MUELLER, G., 1972: Organic Microspheres From Hydrothermal Veins at the Besmer Mine, Brit, Ontario, Canada. — Intern. Geol. Congress. Section 1, p. 43—49. Montreal.

MULDER, F. G., 1971: Paleomagnetic research in some parts of central and southern Sweden. — SGU C 653.

RAMBERG, I. B., 1971: Oslofeltets dypstruktur og utstrekning. — Nytt fra Oslofeltgruppen, 1970, No. 2. p. 29—47.

RUDBERG, S., 1970: The sub-Cambrian peneplain in Sweden and its slope gradient. — Annals of Geomorphology, Supplementband 9, p. 157—167. Stuttgart.

SAETHER, E., 1964: Clay veins in rocks in Norway. — Norsk Geol. Tidskrift, v. 44 p. 385—429.

SAMUELSSON, L., 1967: Breccia av paleozoiska bergarter 1.5 km väster om Bohus fästning, Kungälv. — GFF 89, p. 448—459.
— 1971: The relationship between Permain dikes of dolerite and rhomb porphyry along the Swedish Skagerrak Coast. — SGU C 663.
SANDEGREN, R., and JOHANSSON, H. E., 1931: Beskrivning till kartbladet Göteborg. — SGU Aa 173.
SORGENFREI, T., 1969: Geological Perspectives in the North Sea Area. — Bull. Geol. Soc. Denmark. Vol. 19, Part 2.
SUNDIUS, N., 1950: Mineral från Högsbo fältspatbrott vid Göteborg. — GFF 72, p. 473.
— 1952: Kvarts, fältspat och glimmer samt förekomster därav i Sverige. — SGU C 520.
WELIN, E., 1965: The occurrence of asphaltite and thucholite in the Precambrian bedrock of Sweden. — GFF 87, p. 509—526.
WELIN, E., and BLOMQVIST, G., 1964: Age measurements on radioactive minerals from Sweden. — GFF 86, p. 33—50.
WELIN, E., LUNDSTRÖM, I., and ÅBERG, G., 1972: Fission track studies of hornblende, biotite and phlogopite from Sweden. — Bull. Geol. Soc. Finland 44, p. 35—46.

TABLE 1. Sandstone dikes and related fissure fillings (see also Fig. 1)

No.	Locality	Latitude N	Longitude E	Strike	Dip	Width, cm	Appearance
1.	Western bridge-abutment, Gårdsten, N. Göteborg	57°48’09”	12°02’00”	E—W	vertical	1—3	Brownish-grey sandstone
2.	Road cut, Rösered, N. Göteborg	57°47’20”	12°02’30”	N75°W	,,	3—5	Grey, fractured, fine-grained sandstone
3.	Road cut, Hammarkullen, N. Göteborg	57°46’44”	12°02’42”	NNW—ESE	,,	1	Grey, arkosic sandstone
4.	Entrance to tram tunnel, Hjällbo, N. Göteborg	57°46’28”	12°01’40”	av.N70°W	,,	0.1—40	Light grey to greyish brown sandstone occasionally arkosic. 37 dikes
5.	Entrance to tram tunnel, Kortedala, N. Göteborg	57°45’39”	12°02’39”	N70°W	,,	1—10	Light grey to yellow sandstone. 6 dikes some with later clay veins. One yellow dike in N—S orientation
6.	N. Bergsjön, NE. Göteborg	57°45’42”	12°03’47”	E—W	,,	1	Brownish-grey, arkosic sandstone
7.	S. Bergsjön, NE. Göteborg	57°44’50”	12°04’40”	N60°E	,,	1—20	Greyish-brown sandstone. 4 dikes
8.	E Långevattnet, NE. Göteborg	57°46’30”	12°05’33”	E—W	,,	1	Grey sandstone
9.	SW Surketjärn, N. Partille	57°45’33”	12°05’30”	E—W	,,	1—2	Grey sandstone
10.	Oryd, W. Floda	57°48’06”	12°19’27”	N40—80°E	,,	1—2	Grey. 2 outcrops, probably of the same dike
11.	Björkekärr, E. Göteborg	57°42’45”	12°02’30”	N70°W	,,	1—3	3 dikes brownish-grey sandstone
12.	At highway E6, E. Göteborg	57°41’42”	12°00’00”	E—W	,,	1—3	Arkosic material with carbonaceous matrix
13.	At highway 40, S St. Delsjön	57°40’36”	12°03’21”	N70°W	,,	1	Grey sandstone
14.	Oryddal, W. Floda	57°48’37”	12°19’42”	N60°W	85°SSW	4—5	Grey, recrystallized sandstone
15.	Uddared, W. Floda	57°48’23”	12°20’55”	N60°E	vertical	1	Grey sandstone
16.	Östersjön, E. Lindome. The majority of the dikes are found at Hovgårdsvik	57°37’55”	12°14’06”	N70—90°E	,,	0.5—11	Grey, arkosic sandstone, more than 20 dikes
17.	Road cuttings, S Yttre Ingsjön	57°36’20”	12°15’45”	E—W	,,	1—5	Brownish grey sandstone. One dike more than 900 m. 4 outcrops
18.	Road cuttings, Va. Frölunda church	57°38’58”	11°55’20”	E—W	,,	1—2	Several dikes. Grey and brown, arkosic sandstone

19. Road cuttings, S. Kungälv	57°51’05”	12°00’09”	N70°W	vertical	0—30	One dike with pieces of sandstone in a clay vein. One dike with alum shale
20. 100 m W of S. Långvattnet, E. Mölndal	57°38’58”	12°03’15”	N35°E	„	1.5	Brown, arkosic sandstone
21. Summer cottage, 2 km SSW of Härryda church	57°40’30”	12°19’24”	N60°E	„	1	Grey sandstone. Irregular strike
22. 400 m SW of Härsjödamm	57°42’29”	12°19’03”	N65°E	„	1—3	Grey sandstone attached to vertical wall
23. Geråsen, 3.8 km W of Bergum church	57°48’36”	12°06’36”	N75°W	„	1	Grey sandstone
24. Långholmen, Mjörn	57°54’45”	12°24’30”	N55—80°W	„	1—3	Brown arkosic, 11 dikes including 4 with basal arkose
25. Sunnerö, Mjörn	57°53’24”	12°22’48”	N60—80°W	„	1—3	Brown arkosic. Several dikes, occurrence of basal arkose
26. Bokö, SW. shore, Mjörn	57°53’24”	12°25’10”	E—W	„	2	Brown arkosic
27. Bokö, NE. shore, Mjörn	57°53’43”	12°25’31”	N65°W	85°S	2	Brown arkosic. Basal arkose
28. 1.3 km SW of Gräskärr, St. Lövsjön	57°52’10”	12°13’12”	N45°E	vertical	1—4	4 dikes. Grey sandstone
29. 600 m E of Holmesjön, Vättlefjäll	57°51’30”	12°11’33”	N65°W	„	1—2	2 dikes. Grey sandstone
30. 200 m N of Göksjön, Alefjäll	57°52’59”	12°12’30”	N50°E	„	1	Grey sandstone
31. 100 m SW of Lilla Lövsjön, Alefjäll	57°52’30”	12°16’00”	N70°W	85°S	1—3	2 dikes. In the same fracture zone. Grey sandstone
32. Höga Ekholmen, Mjörn	57°53’15”	12°24’30”	N70°W	vertical	1—2	4 dikes. Brown arkose
33. Kvarnholmen, Mjörn	57°54’43”	12°23’43”	N70°W	„	0.5	Greyish-brown arkosic sandstone
34. Måsskär, Mjörn	57°55’20”	12°24’12”	N70°W	„	1—3	Brown arkose
35. Road cuttings, 150 m W of Grundasjön	57°39’23”	12°22’40”	N55—90°E	„	1—3	10 dikes. Grey sandstone
36. In tunnel, Rösbo, 1.3 km NW of Surte church	57°50’22”	11°59’55”	N75°W	„	20—200	Alum shale
37. At the shore of Lake Mjörn, Sjövik	57°54’40”	12°23’00”	N70°W	„	0.5—2	2 arkose dikes and 2 sandstone dikes

TABLE 2. Mineral content (volume percent) of some clastic dikes (only 500—600 points counted)

+ = Present in amounts less than one percent

No. of locality *cf.* Table 1	Rock type	Quartz	Potash feldspar	Plagio-clase	Biotite + Muscovite	Calcite	Glauco-nite	Opaque	Clay balls	Matrix
4 a	Greyish brown, clay-rich sandstone	54	3	+	+		+	1		40
4 b	Light grey, arenaceous limestone	23	5	1	2	69				+
5	Grey, fine-grained sandstone	75	2	+		8		+	1	14
7	Greyish brown sandstone	79	1	+	+				+	20
14	Grey sandstone	95	2	1	1			+		1
16	Dark, bituminous sandstone	66	1	2	+			3	5	23
17	Grey sandstone	94	2	+	+		+	+	+	4
19	Bituminous shale	40							3	57
25 a	Basal arkose, horizontal layer	57	9	18	2			+		14
25 b	Brown arkosic dike	57	10	6	1			4		22
Vargön (*cf.* p. 12)	Grey sandstone	85	4			4	1	1		5

TABLE 3. Tentative tabulation of the Palaeozoic in the Göteborg area

Time	Regime	Tectonism	Fissure fillings
Carbon-Perm		Faulting and volcanism in the Oslo region. Igneous dikes and sills N Göteborg	Clay veins, asphaltite
	Mainly deposition?		
Upper Cambrian	Deposition of alum shale	Block faulting and WNW—ESE tension fissures	Alum shale dikes. Final emplacement of the breccia at Kungälv with Upper Cambrian, Middle Cambrian and Precambrian rocks
	Erosion of Middle Cambrian deposits	Block faulting	Breccia with Middle Cambrian and Precambrian rocks at Kungälv
Middle Cambrian	Deposition of grey limestone		
	Erosion of Lower Cambrian deposits		
Lower Cambrian	Deposition of sand and silt	WNW—ESE tension fissures	Injection of sand and silt
	Erosion of Precambrian rocks		
Late Sveconorwegian (800—900 m.y.)	Plutonic	WNW—ESE tension fissures	Dolerite
Late Sveconorwegian (=Dalslandian, 930 m.y.)	Plutonic	WNW—ESE tension fissures	Pegmatite

PRISKLASS D

Distribution

LiberTryck

FACK, 162 10 VÄLLINGBY 1

ISBN 91-7158-071-9

Laholm 1975 · Trydells Boktryckeri AB