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AGNES RODHE

DEPOSITIONAL ENVIRONMENTS AND LITHOSTRATIGRAPHY OF THE MIDDLE PROTEROZOIC ALMESÅKRA GROUP SOUTHERN SWEDEN

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ABSTRACT

Rodhe, Agnes, 1987: Depositional environments and lithostratigraphy of the Middle Proterozoic Almesåkra Group, southern Sweden. Sveriges geologiska undersökning, Ser. Ca, No. 69, pp. 1—80. Uppsala 1987.

The Middle Proterozoic Almesåkra Group was deposited upon a predominantly granitoid Early Proterozoic basement in southern Sweden, southeast of Lake Vättern. Approximately 1000 Ma ago the sedimentary sequence was intruded by concordant dolerites. Five formations have been distinguished in the Almesåkra Group, here named from base upwards: the Marbäck Formation, the Nässjö Formation, the Forserum Formation, the Branteberg Formation and the Storekvarn Formation. The Marbäck Formation underlies the Nässjö Formation in eastern areas where it locally separates the latter from the basement. The Nässjö Formation is overlain in the north by the Branteberg Formation, in the southwest by the Storekvarn Formation. Erosional and angular unconformities separate the Nässjö Formation from the two overlying formations and probably from the underlying Marbäck Formation. In the northwestern part of the Almesåkra Group, the Storekvarn Formation probably overlies the Branteberg Formation conformably, but a lateral transition is also possible. The Forserum Formation overlies the basement in the westernmost areas and is probably coeval with part of the Nässjö Formation.

Owing to extensive cover by dolerite sills and Quaternary deposits, and also to complex faulting, no further stratigraphic subdivision of the Almesåkra Group has been possible. The thickness of the group is estimated to c. 1200 m.

The main lithology of the Almesåkra Group is feldspathic arenitic sandstone. Argillites and conglomerates are relatively subordinate. A number of depositional sedimentary facies and facies associations have been distinguished chiefly by sedimentary structures and textures.

The Marbäck Formation (probably not exceeding 50 m) comprises grey quartzitic sandstones, often brecciated, and red quartz arenites, mostly well-preserved. The red quartz arenite lithofacies is interpreted as having been laid down in a shallow-water, in part aeolian desert, environment. The Nässjö Formation (at most c. 1000 m thick) represents a fluviatile-lacustrine, possibly deltaic environment, characterized by laminated argil-

lites, fine-grained sandstones and, locally, by conglomerate-bearing sandstones. A fluviatile association of sandstone and conglomerate dominates the Forserum Formation (c. 300 m thick). Palaeocurrents in the Nässjö and Forserum Formations flowed mainly northwestwards.

The Branteberg Formation (c. 150—200 m thick) represents a distal alluvial fan environment characterized by basal coarse conglomerates interbedded with fine conglomerates and thin argillites. This association passes gradually upwards into trough cross-stratified sandstones. Palaeocurrents in the Branteberg Formation flowed in westerly and locally in southerly directions. The Storekvarn Formation (at least c. 200 m thick) consists predominantly of grey quartzitic sandstone. The sandstone is locally interbedded with conglomerates indicating a fluviatile depositional environment. As in the Nässjö and Forserum Formations, palaeocurrents in the Storekvarn Formation flowed northwestwards.

The compositions of the sandstones and their variational trends indicate that granitic rocks were dominant initially in the source areas of the Branteberg Formation, whereas metavolcanic rocks dominated those of the Nässjö Formation. The clast compositions of most conglomerates in the Almesåkra Group indicate that the source areas also comprised unmetamorphosed sedimentary rocks; fragments of the latter are also present in the sandstones of particularly the Nässjö Formation.

The main diagenetic minerals of the Almesåkra medium-grained sandstones are quartz, hematite and calcite; minor K-feldspar cement occurs widely. A relatively large average pre-cement porosity in the quartz-cemented Storekvarn sandstones suggests that most of the cementation of these beds had been completed beneath an overburden of less than 500 m.

The present distribution of the Almesåkra Group is largely controlled by faulting. Major high-angle faults are mainly oriented N—S, NE—SW and NW—SE. Dips of bedding are usually gentle to moderate except where close to fault zones. Folds in the sedimentary rocks and dolerites are commonly open and upright except near faults and/or in argillite-dominated units. Movements on the faults appear generally to have been normal; however, both reverse and strike-slip faults have been observed. Locally, in association with the NE-trending faults, there is evidence of thrusting.

INTRODUCTION

Historical background. — The Almesåkra Group is a sequence of Middle Proterozoic fluvial sedimentary rocks deposited on the crystalline basement to the southeast of Lake Vättern in southern Sweden. The basement consists predominantly of the so-called Småland-Värmland belt of granitoids (Gorbatschev 1980). Grey or red sandstone and argillites together with conglomerates are the most important components of the Almesåkra sequence. The sedimentary rocks have been contact-metamorphosed by dolerite intrusions but are otherwise unmetamorphosed.

Precambrian sedimentary rocks of similar continental type occur widely in Scandinavia and are generally intruded by dolerite. They are post-orogenic in relation to the Svecokarelian orogeny. This crust-forming event terminated c. 1750 Ma ago. The intrusion of mafic sills followed by subsidence along faults has contributed to the preservation of the sedimentary cover which together with the dolerites has been termed the Jotnian system or complex (Lundegårdh 1964, Lundqvist 1979, Sederholm 1897).

The time of the Jotnian sedimentation is bracketed between a lower limit of 1600 Ma (Gorbatschev and Gaál 1986) and the time of the intrusion of the dolerites. The Rb-Sr ages of the dolerites are between 850 and 1000 Ma in southern Sweden and between 1000 and 1250 Ma in central Sweden (Patchett 1978).

Jotnian complexes in Sweden have been described by Asklund (1934 and 1939, Gävle sandstone), Gorbatschev (1967, Gävle sandstone), Gorbatschev and Kint (1961, Mälar sandstone), Hjelmqvist (1966, Dala sandstone), Olivecrona (1920, Dala sandstone), Sobral (1913, Nordingrå sandstone) and Lundegårdh (1967, Gävle and Dala sandstones). Comprehensive but partly obsolete reviews of the Jotnian have been written by von Eckermann (1937) and Magnusson *et al.* (1963).

The Almesåkra Group has been regarded as the southernmost remnant of Jotnian sedimentary rocks in the Fennoscandian Shield. Almesåkra rocks are tectonically more disturbed and richer in argillites than other Jotnian sequences. As such the group appears to have an exceptional position in the Jotnian. These differences as well as the age and regional distribution of Almesåkra sedimentation have been discussed for a long time.

The earliest description of Almesåkra sedimentary rocks, based on field observations, was published by Nathorst (1879) who believed the ''sparagmites'' south of Lake Vättern to be Cambrian. Nathorst's main interest was in recognizing ancient weathering in basement rocks underlying sedimentary deposits. He considered that intense weathering of the peneplaned basement had preceded the deposition of the Lower Cambrian basal sandstones laid down during a period of marine transgression in Scandinavia. This hypothesis was supported, so he thought, by the composition of some Almesåkra conglomerates. Nathorst's views influenced later interpretations of the Almesåkra conglomerates and of the Jotnian rocks in general.

Around 1870 reconnaissance mapping of southern Sweden by the Geological Survey of Sweden started and maps to a scale of 1:200000 were published between 1877 och 1892. These maps which show the main rock outcrops as well as various Quaternary deposits are still the main source of information on the bedrock in this part of Sweden. Stolpe (1892), whose map included most of the southern part of the Almesåkra region, suggested that the argillitic sandstones found here belonged to the basal part of the Almesåkra sequence. He also noted their arkosic character and suggested that they had been derived from weathered crystalline basement. Later, Hedström (in Munthe and Gavelin 1907; 1917) and Gavelin (1912) mapped the remaining parts of the Almesåkra Group on the scale of 1:50000.

According to Hedström (1907, 1917) the sedimentary rocks that rest directly on the basement appear always to be ''quartzites''. However, in some parts of the area he was puzzled to find coarse arkosic sandstones close to the basement, but believed that they rested on unexposed subjacent ''quartzites'' (Hedström 1917). When mapping the sandstones farthest to the west, Hedström (1907) studied a folded part of the sequence and made a rough sketch of the section. He stated, however, that the lack of continuous exposure and the abundance of faults precluded all but local evaluation of the bedding attitudes. Hedström (1917) distinguished between ''quartzite'', apparently lacking clastic texture, and various kinds of ''quartzitic sandstones'' which displayed such texture. In the latter he found a matrix or cement between the detrital grains and varying amounts of ''sericitic'' or ''kaolinized'' feldspars.

The early geologists, whose main concern was with the dolerites, discovered rounded quartzitic xenoliths in several dolerite dykes to the east of the Almesåkra Group. Eichstädt (1885) examined the composition and texture of these xenoliths which he was able to correlate with the quartzitic pebbles found in the Almesåkra conglomerates. A discussion by many influential Scandinavian geologists followed upon Eichstädt's work (1885) concerning the origin of these xenolith-bearing dykes. Attention was drawn to the general problems of the Almesåkra Group (cf. Geologiska Föreningen, Stockholm, 1885; see also Sederholm 1927, Magnusson *et al.* 1963, Berg-Lembke 1970, and others). An important inference from the discoveries was the idea of a wider occurrence of Jotnian sedimentation to the east of the Almesåkra Group. The discovery of similar xenolithic dykes also along the southeastern coast of Sweden (Blomberg 1900, cf. Wiklander 1974), one of which carries abundant sandstone xenoliths, suggested that the Almesåkra Group had once covered all of southeastern Sweden.

Another point of discussion was the near absence of conglomerate fragments and conglomerate matrix in the xenolithic dolerites. This was taken by Eichstädt (1885) and others to signify that the Almesåkra conglomerates had either been disintegrated or were poorly consolidated at the time of dolerite intrusion. The latter hypothesis became the accepted one. The short time lapse inferred between sedimentation and the emplacement of the dolerites led to the opinion that the Almesåkra rocks were younger than other Jotnian sandstones (cf. Lundqvist 1979). However, Hedström (in Högbom *et al.* 1910) maintained that the dolerites could have been intruded into consolidated conglomerates, the magma digesting most of the ''gritty loose, brittle'' conglomerate matrix while entraining the quartzitic clasts.

Eichstädt (1885) had found that the pebbles of the Almesåkra conglomerates were jointed and faulted similarly to the xenoliths in the dolerites, which led attention to the tectonic aspects of the Almesåkra Group. Gavelin (1931) made important observations concerning faulting and folding in the argillitic sequences previously mapped by Stolpe (1892). He discovered a remarkable instance of thrusting of granitic basement rocks over sandstone and suggested that the direction of the thrusting was from the west.

Later, Martin (1939) studied the deformation of the Almesåkra rocks and their basement as part of a large-scale, probably rotational deformation of the whole of southern Sweden. He suggested that the rocks in question had been thrust from the northeast. In the late 1960's Gorbatschev and Vessby concentrated their fieldwork on sedimentological and structural aspects. The discovery of several small basement inliers and of previously unknown red arkosic sandstone were among the results which remained unpublished, some of them, however, referred to in a brief survey of the Jotnian (Gorbatschev and Collini 1978).

Various attempts have been made to subdivide the Jotnian ''period'' and correlate the Jotnian rocks. Sederholm (1927) suggested that the lowermost part of the sedimentary sequence was formed during a Jatulian (Early Proterozoic) period of sedimentation. This proposal, which presumed an unconformity within the Almesåkra Group, was rejected by certain Swedish geologists (Asklund 1927, see also Högbom 1909). Based on observations of minor erosional discordances in the westernmost conglomerate-bearing sandstones, Gavelin (1931) inferred the existence of an unconformity below these conglomerates which he considered to be uppermost in the sequence. He believed that the predominance of quartzitic clasts in the conglomerates was due to their intraformational character, i.e. the tectonic disturbance of the Almesåkra Group was thought to be largely syn-sedimentary and pre-intrusive. In his authoritative treatise on Swedish geology, Magnusson (in Magnusson *et al.* 1963) presents a general ''stratigraphy'' of the Almesåkra sedimentary sequence (referred to as a formation) based largely on Gavelin's (1931) work. Koark (1970) presented a summary of these relationships. Gavelin's tectonic and stratigraphic conclusions were based, as he himself points out, on a rather brief study of some parts of the sequence. Nevertheless, they contributed to the general opinion that the Almesåkra Group had been intruded by dolerites during a very early stage of consolidation. Later, Gorbatschev and Collini (1978) apparently presumed but did not explicitly propose a discordance between the southwesternmost quartzitic and the underlying argillitic sandstones.

Aims of the present study. — The purpose of this study is to provide an interpretation of the depositional facies and palaeo-environments of the Almesåkra sedimentary sequence, and to present a lithostratigraphy for the Almesåkra Group. These objectives required detailed remapping and the use of modern quantitative field methods. A more detailed stratigraphic subdivision of the Almesåkra Group was not possible, owing to the low degree of exposure, the complexity of faulting and the cover of dolerite sills.

Estimating the mineral composition of the detritus of the different lithofacies has served to distinguish source areas and to suggest distribution patterns for the sediments. For all petrographic work standard optical methods were mainly used. X-ray diffraction was employed in some cases.

THE STRATIGRAPHY OF THE ALMESÅKRA GROUP

GENERAL ASPECTS

Geological setting. — The sedimentary rocks of the Almesåkra Group occur southeast of Lake Vättern (Fig. 1, Fig. 2). The area is located about 30 km east of the Protogine Zone, a belt of steep shear zones that traverses southern Sweden. The Protogine Zone separates the predominantly Gothian rocks (1800—1500 Ma) in the gneiss domain of southwestern Scandinavia from the Svecokarelian Orogen (c. 2000—1750 Ma) in the east. The basement rocks beneath the Almesåkra Group comprise mainly granitoids and related acid prophyries of the Early Proterozoic Trans-scandinavian Granite-Porphyry Belt formed in the western boundary zone of the Svecokarelian Orogen 1800—1650 Ma ago (Gorbatschev 1980, Gorbatschev and Gaál 1986). Minor belts of Svecokarelian meta-supracrustal basement rocks trending WNW—ESE also occur; in a few places, the Almesåkra Group sediments rest directly on these units.

Outcrops of the Almesåkra sedimentary sequence occur in a narrow tongue — the Ralången area — running northwards to the approach of Tranås and the roughly triangular Spexhult area extending southwards from around Nässjö (Fig. 1). The latter area includes the downfaulted Forserum subarea in the northwest and extends as far as Lake Älmeshult to the northeast. The Forserum subarea is delimited to the east by a fault that exposes the basement, and to the southeast by dolerite.

The Ralången and Spexhult areas together comprise an area of c. 300 km², roughly 100 km² of which are occupied by dolerites intruded into the Almesåkra Group and its basement approximately 1000 Ma ago (Patchett 1978). The dolerite intrusions usually occur as sills. Later tectonic events, mainly high-angle faulting, have tilted and locally folded the sills and the sedimentary sequences.

The dolerite is of continental-tholeiitic composition (Solyom *et al.* 1984). It is related compositionally to a number of 850—1000 Ma old dolerite dykes which trend NNE, N and NNW, parallel to the border-zone between the Trans-scandinavian Granite-Prophyry Belt and the Southwest Scandinavian Domain (Gorbatschev and Gaál 1986, Solyom *et al.* 1984). One large dyke can be traced for at least 20 km along the eastern boundary of the Almesåkra Group. It is probably the main feeder dyke of the eastern Almesåkra dolerite sills.

In this study, the Almesåkra Group is subdivided into five formations, the Marbäck Formation, the Nässjö For-

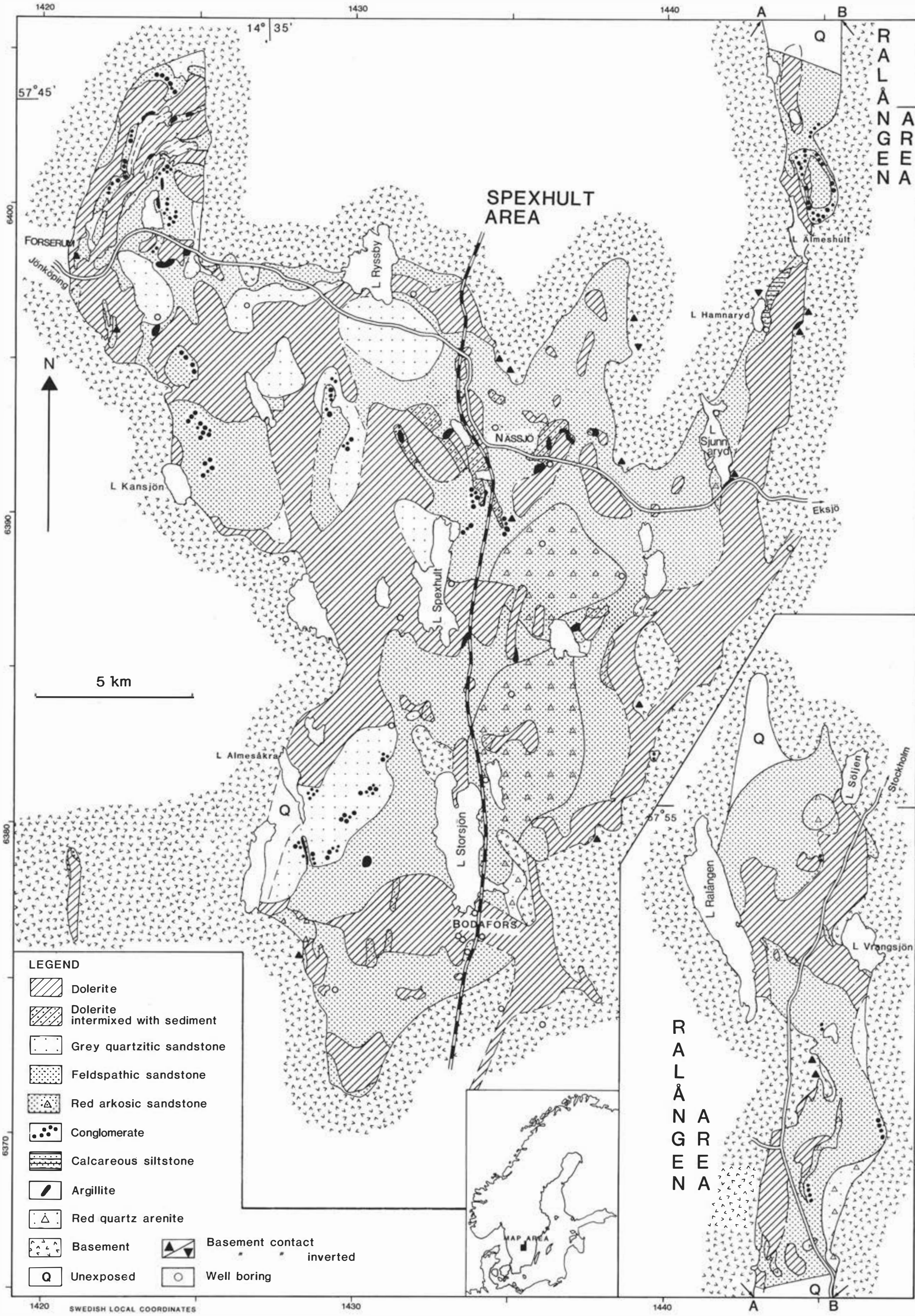


Fig. 1. Lithology of the dolerite-intruded Almesåkra Group. Swedish National Grid numbers are shown in the margins.

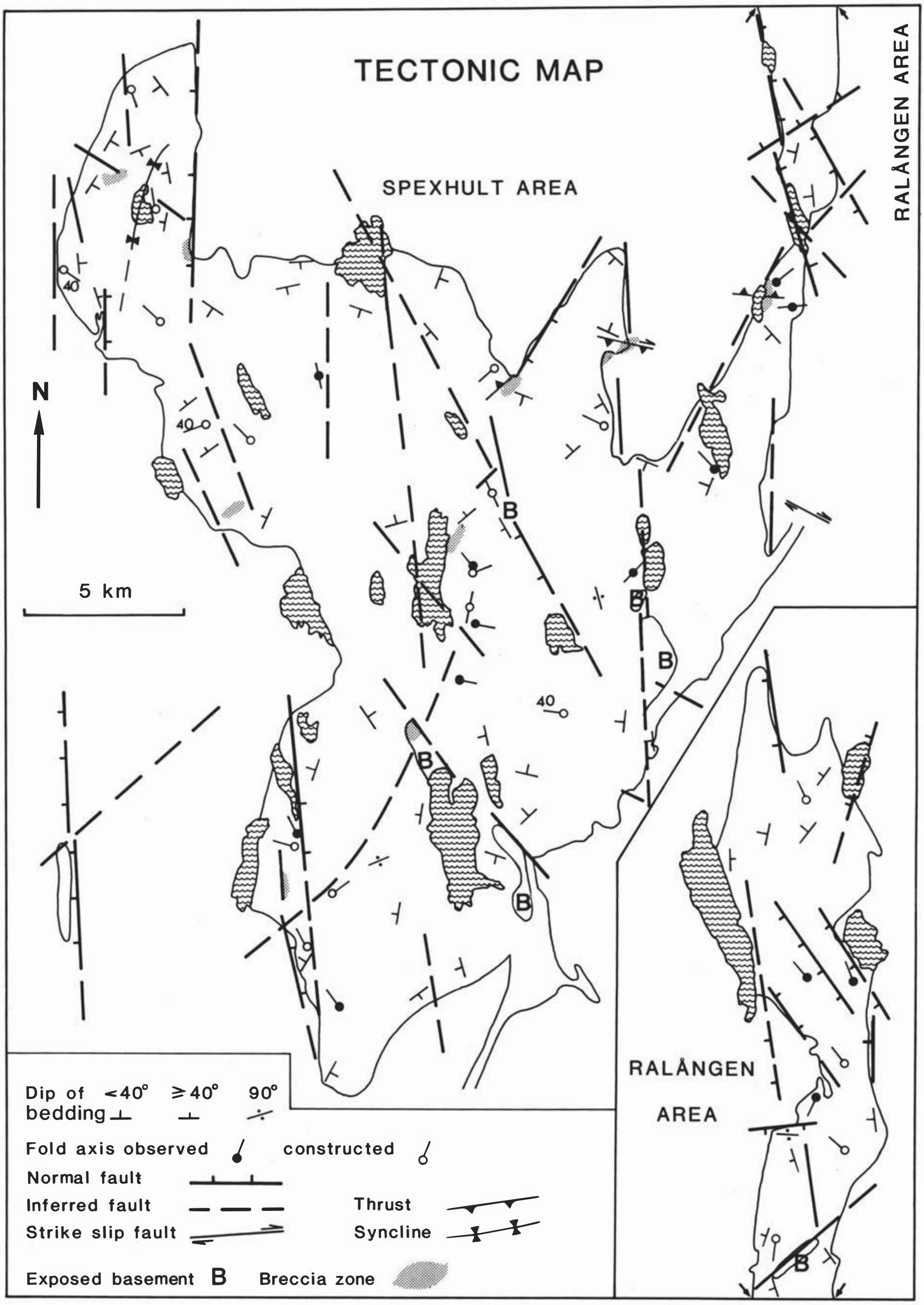


Fig. 2. Tectonic map of the Spexhult and Ralången areas.

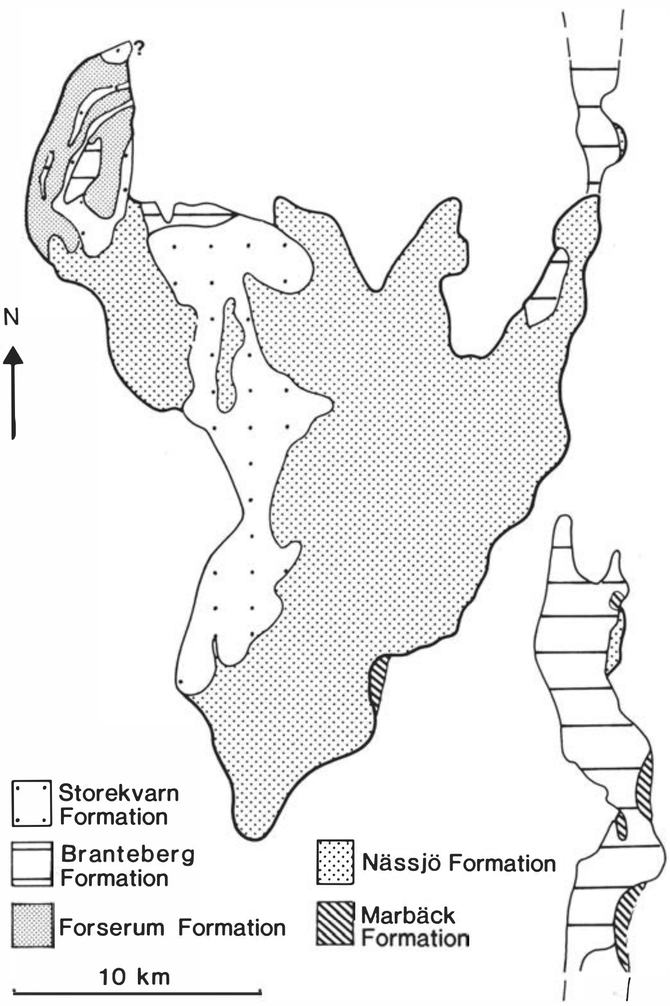


Fig. 3. Map showing the general occurrence areas of the formations of the Almesåkra Group. The dolerites have been omitted for clarity.

mation, the Branteberg Formation, the Storekvarn Formation and the Forserum Formation. The Marbäck Formation underlies the Nässjö Formation locally in the east, it is exposed in a few outcrops only. The Nässjö Formation is overlain by, and separated by unconformities from, the Branteberg Formation in the north, the Storekvarn Formation in the west. The Nässjö Formation is exposed predominantly in the Spexhult area, the Branteberg Formation mainly in the Ralången area and the Storekvarn Formation only in the Spexhult area. The Forserum Formation occupies most of the Forserum subarea in the northwestern part of the Spexhult area (Fig. 1).

The Forserum Formation is overlain by deposits closely resembling those of the Branteberg and Storekvarn Formations. This suggests that the Forserum Formation is coeval with the Nässjö Formation or with some parts of it.

The relatively quartz-rich compositions of the sandstones of the Branteberg Formation suggest that they may grade into the similarly quartz-rich sandstone of the Storekvarn Formation in the southwest (cf. Fig. 60c and p. 73). In some parts of the Spexhult area, stratigraphic relationships between the Branteberg and Storekvarn Formations suggest that the Storekvarn Formation may overlie the Branteberg Formation. The possibility of a tectonic contact cannot, however, be excluded.

The field distribution of the different formations of the Almesåkra Group is shown schematically in Fig. 3. The location of the stratigraphic sections and the areas mapped in detail are given in Fig. 4. Descriptions of the individual formations are given below.

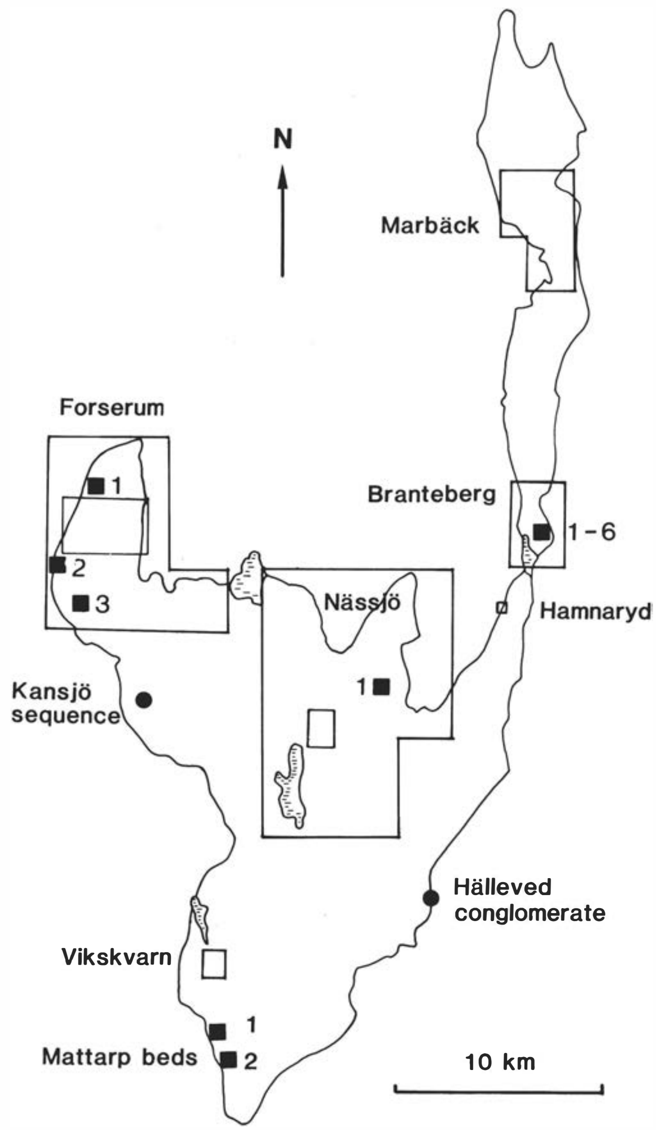


Fig. 4. Location of detailed maps (outlines) and specific localities (dots); solid squares denote the location of the sections shown in Figs. 39, 40, 46 and 50.

THE MARBÄCK FORMATION

The Marbäck Formation comprises red quartz arenites and greyish quartzitic sandstones, all found close to or resting upon the basement. The outcrops are small and occur scattered along the eastern boundaries of the Ralången and Spexhult areas (Fig. 3). The red quartz arenites occur also as large accumulations of local blocks at the boundary with the basement northernmost in the central part of the Ralången area. Beds of greyish, quartzitic sandstone or quartzite rest upon the basement or occur close to faults at the narrow junction between the central and northernmost parts of the Ralången area. They underlie the local sandstones of the Branteberg Formation. Contrasting to the red quartz arenites, which are generally well-preserved, the greyish quartzites are commonly brecciated and allow little textural assessment.

Similar grey quartzitic sandstones are also exposed close to the basement in the northernmost parts of the Ralången area and the Forserum subarea; at least those in the Ralången area probably belong to the Marbäck Formation. The thickness of the Marbäck Formation probably does not exceed 50 m; the type area is the central part of the Ralången area.

In conjunction with palaeocurrent directions (cf. Fig. 55), the predominance of quartzitic pebbles in almost all Almesåkra conglomerates (cf. Fig. 28) suggests that extensive older sedimentary source rocks were once present to the east of the Almesåkra Group. Sedimentary lithic grains, occurring particularly in sandstones of the Nässjö Formation, and the composition of the conglomerate clasts indicate that the older sedimentary source rocks contained beds of red and greyish, fine- to medium-grained quartzitic sandstones, hematitic mudstone and red quartz arenite. Chert clasts in some conglomerates can possibly also have been derived from the older cover. The Marbäck Formation may well be a remnant of an older sedimentary sequence that, in part, comprised the source rocks of the Nässjö and Branteberg Formations.

THE NÄSSJÖ FORMATION

The Nässjö Formation is exposed mainly in the eastern part of the Spexhult area and also in its westernmost part, south-southeast of the Forserum subarea (Fig. 1). Numerous outcrops of argillite, fine-grained sandstone and medium-grained sandstone with coarse conglomerate beds occur in the area surrounding Nässjö. This area (Fig. 5) is the type area of the Nässjö Formation. Type sections are given on p. 36.

In the southwestern part of the Spexhult area, south of Lake Almesåkra (= the Vikskvarn-Storekvarn subarea), an argillitic unit of the Nässjö Formation underlies a unit of the Storekvarn Formation. Both are exposed intermittently along a fault scarp. In the Ralången area sandstones of the Nässjö Formation outcrop mainly along fault scarps beneath basal conglomerates of the Branteberg Formation.

The unconformable contact of the Nässjö Formation on the basement is exposed at several places in the type area and along the eastern and southern boundaries of the Almesåkra Group (Fig. 1).

The basal deposits of the Nässjö Formation consist predominantly of fine-grained, greyish or reddish feldspathic sandstone thinly interbedded with laminated mudstone. Thin beds of gravelly sandstone occur locally; coarse conglomerate is basal in one occurrence only. In some places the basal sandstones rest on sedimentary breccias derived from the local basement rocks (Fig. 6). There is a gradual transition from the breccias into overlying sandstone. Beds of granitoid debris (Fig. 7) decreasing upwards in thickness can be seen in a few small outcrops. Remnants of the lowermost Nässjö sequence can be studied also in local accumulations of blocks and boulders.

The basal deposits of the Nässjö Formation are usually overlain by red arkosic sandstone, but in the Nässjö subarea there are also beds of argillite and fine-grained feldspathic sandstone several metres thick. Reddish medium-grained sandstone with coarse conglomerate beds is locally intercalated with the argillite beds in a tilted sequence occurring to the south of Nässjö (Figs. 5, 11). The different lithofacies of the Nässjö Formation can be traced intermittently in the field. There is, however, pronounced lateral variation in their relative abundances.

The red arkosic sandstone dominates the area south-southeast of Nässjö (Fig. 1); it contains very little gravel and almost no argillite. The thickness of this sandstone probably exceeds 100 m in the northern part of this area where the dips are gentle (Fig. 2). Red argillites interbedded with feldspathic, mostly fine-grained, greyish, reddish or buff sandstones (the argillite/fine-grained sandstone association, cf. p. 34) can be traced southwestwards from Nässjö. This association is also present in drilled water wells beneath dolerite sills (cf. Fig. 15). Samples from many wells in the Spexhult area suggest that the dolerite has mainly been intruded along argillitic beds of the Nässjö Formation.

In the Vikskvarn-Storekvarn subarea, red argillite dominates the 20—30 m thick rock sequence exposed here. The argillite is interbedded with very fine-grained feldspathic sandstone, the sandstone beds vary considerably

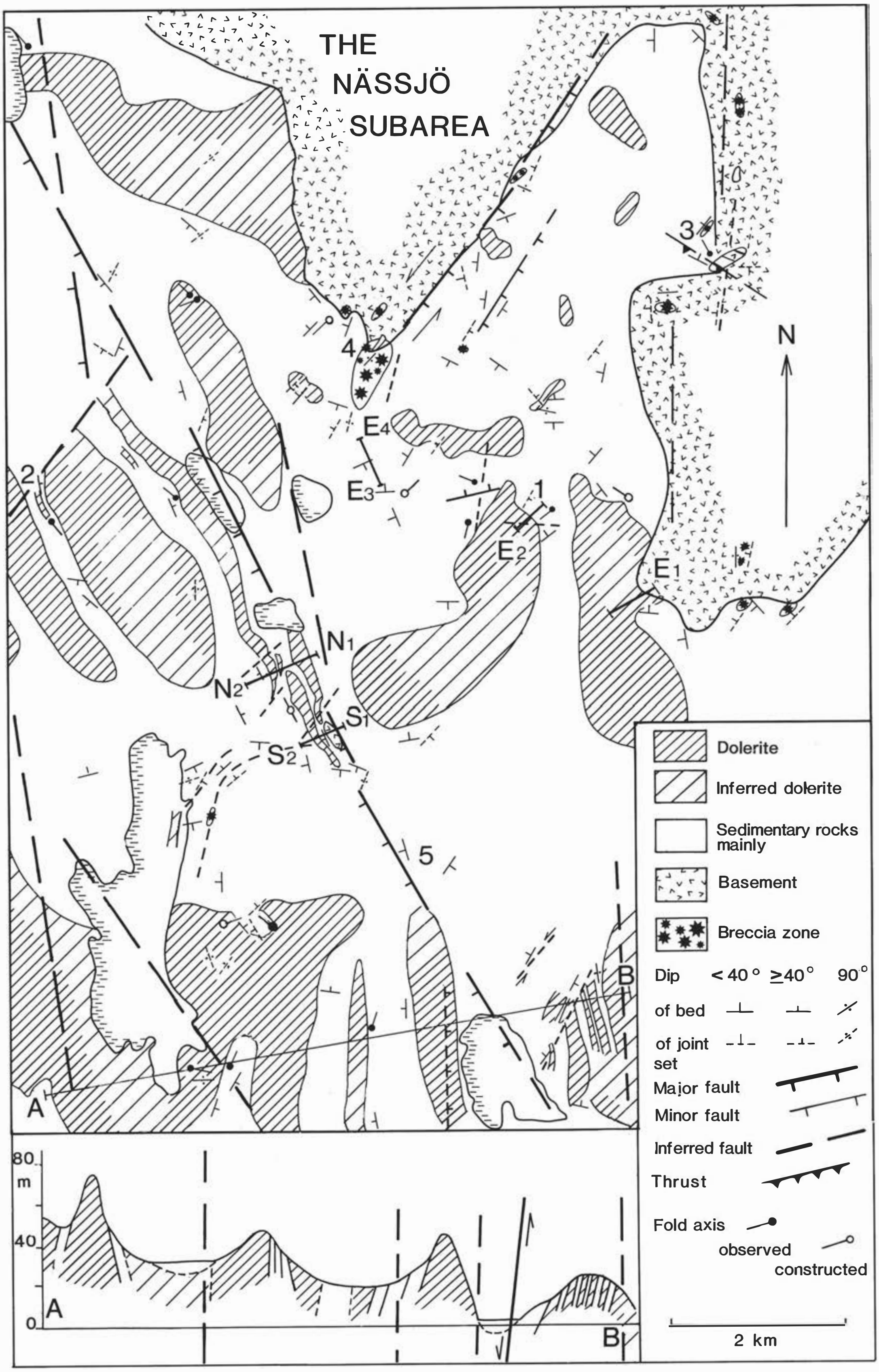


Fig. 5. Geological map of the Nässjö subarea. Numbers denote outcrops referred to in the text. N1—N2, S1—S2, E1—E2 and E3—E4 indicate the location of the sections shown in Fig. 11.

Fig. 6. Basal sedimentary breccia of the Nässjö Formation with angular to subrounded fragments of local granitoid basement in a muddy matrix. Hammer 0.4 m. Outcrop at E1 in Fig. 5.

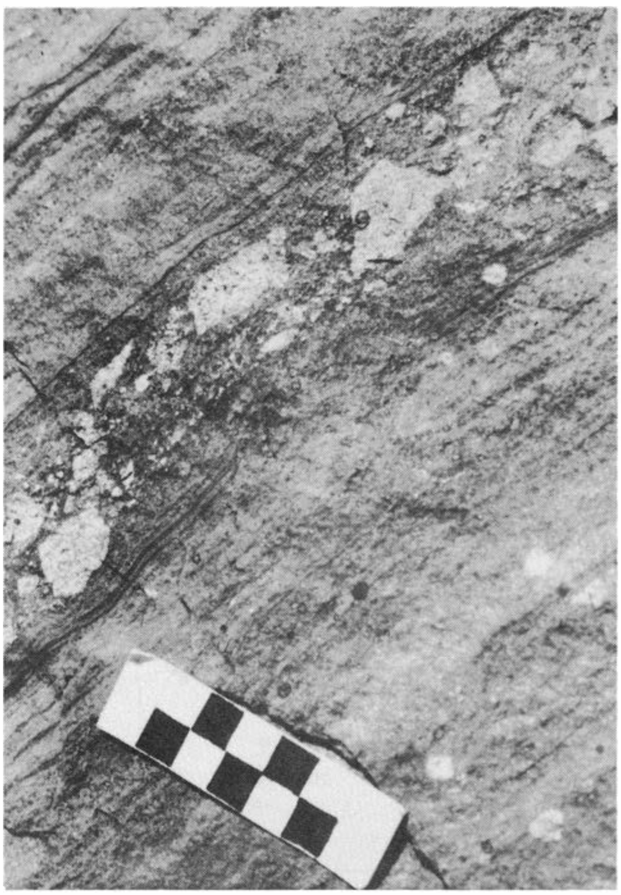


Fig. 7. Layer of granitoid debris in argillite/fine-grained sandstone. The lamination below the breccia layer is disrupted by a waterexpulsion structure. Scale in centimetres. Local boulder at E1 in Fig. 5.

in thickness. The uppermost beds are medium-grained sandstone and contain thin layers of fine conglomerate. The whole sequence is much disturbed by faulting and no vertical sections could be described in detail (Fig. 8).

To the west of Bodafors, exposures of the argillite/fine-grained sandstone association occur along the faulted southwestern basement boundary of the Almesåkra Group. These beds are relatively poor in argillite and grade into overlying red arkosic sandstone. The sequence, which is designated the Mattarp beds (Fig. 4), rests conformably on a layer of polymictic, granite-bearing sedimentary breccia which overlies the regolithic basement rocks. The basal unconformity is exposed only in the northernmost part of the section shown in Fig. 40. Thin beds and laminae of clay-pebble breccia occur at more or less regular intervals in the lowermost 10 m of the Mattarp beds. The whole sequence is gently folded and less than 50 m thick.

Medium-grained sandstone with conglomerate beds extends from south of Nässjö in a westerly direction. In a few outcrops, conglomerate is seen to rest on argillite (Figs. 9, 10), or to be otherwise associated with argillite beds. In the westernmost part of the Nässjö Formation, south-southeast of Forserum, a sequence of reddish feldspathic sandstone containing thick conglomerate beds but very little argillite is designated the Kansjö sequence (Fig. 4). It dips towards the northwest (cf. Fig. 2) and appears to be younging in this direction. The Kansjö sequence is probably at least 500 m thick. A fault zone separates it from folded sandstones of the Nässjö Formation further to the east.

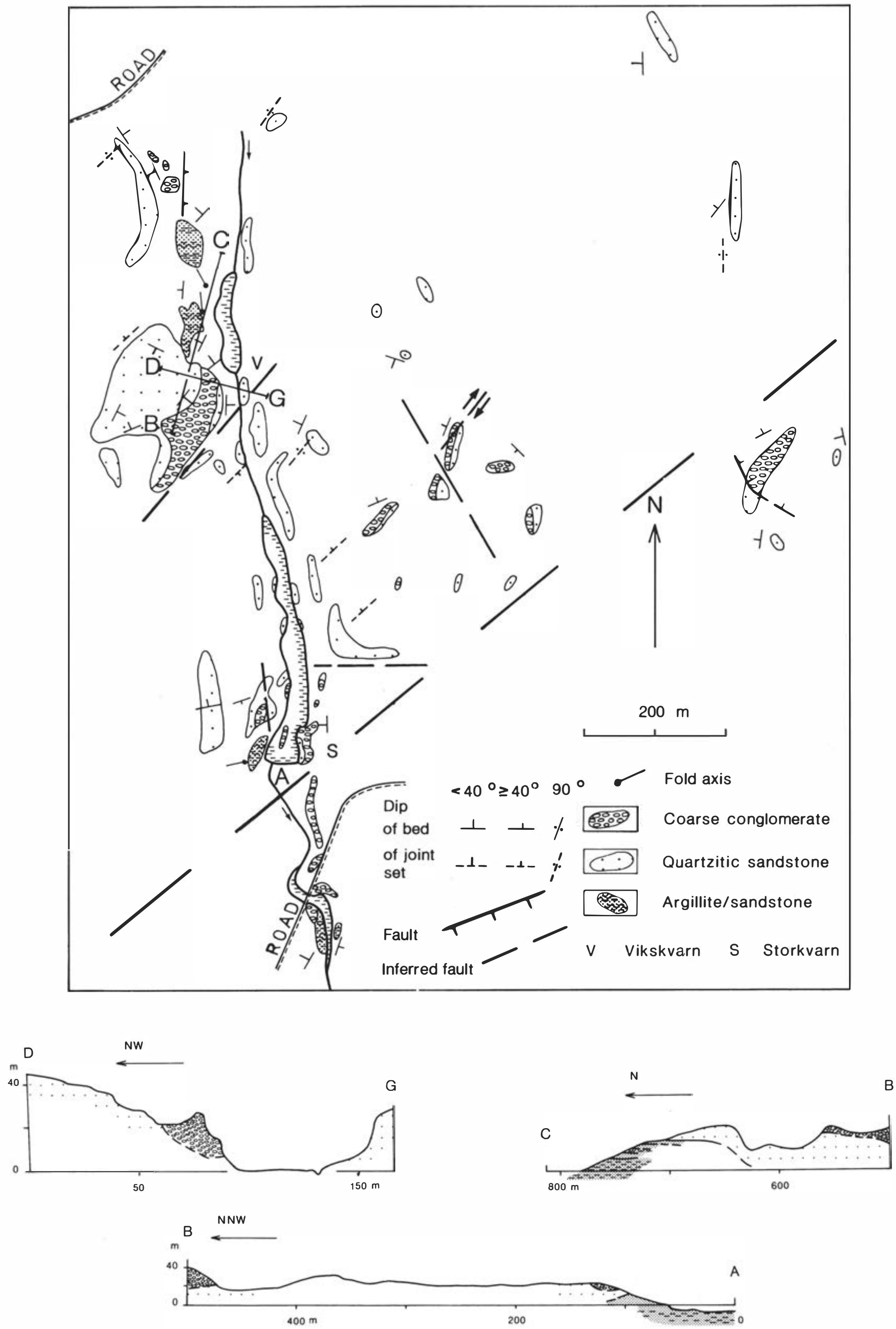


Fig. 8. Outcrop map of the Vikskvarn-Storekvarn subarea showing the surroundings of the N-trending fault zone to the south of L. Almesåkra (cf. Figs. 1 and 4).

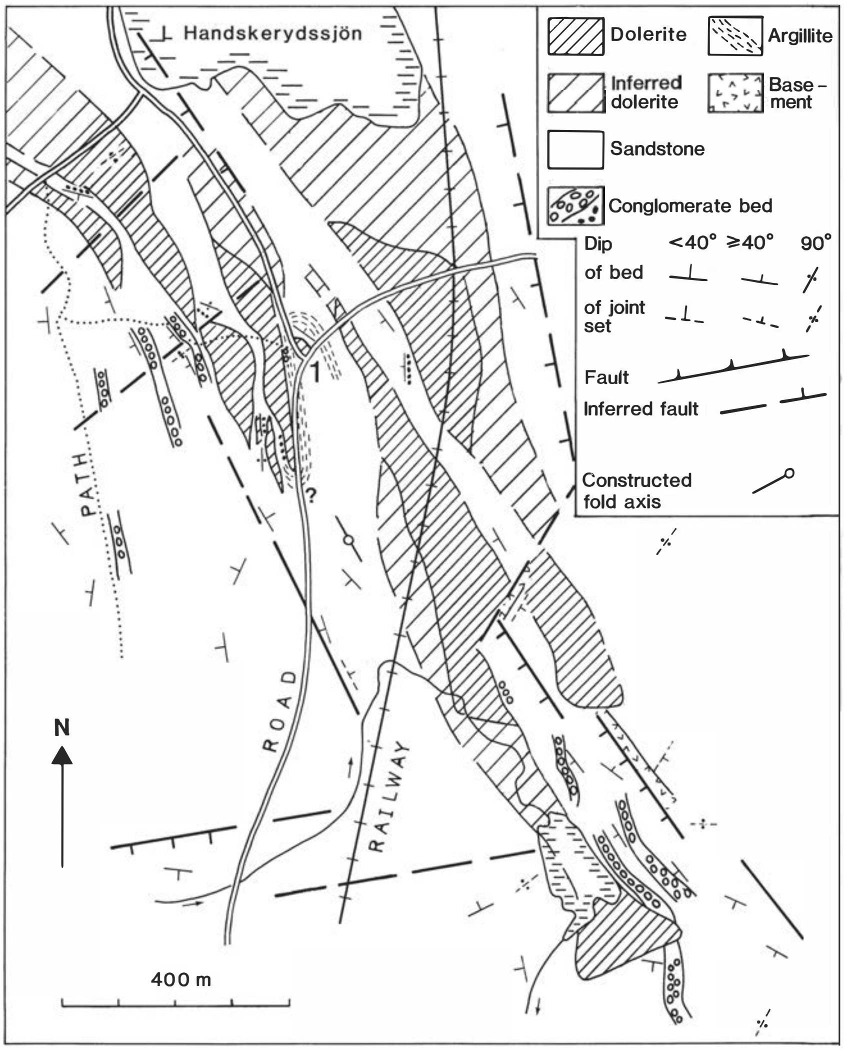


Fig. 9. Map of the area c. 3 km SSW of Nässjö indicated in Fig. 4. The digit 1 denotes the outcrop shown in Fig. 10.

In the Ralången area, most outcrops of the Nässjö Formation are found in the north. Here the feldspathic sandstone is fine-grained and contains some argillite and also beds of clay-pebble breccia. In the south, in the Branteberg subarea, the sandstone is fairly mature both compositionally and texturally.

It is difficult to estimate the overall thickness of the Nässjö Formation. Many important sections are almost completely covered and may be dolerite-intruded (Fig. 11) or tectonically repeated. In the Nässjö subarea, the upper part of the formation consists mainly of feldspathic sandstone which is estimated to be at least 60 m thick just north of the town. Minimum thickness estimates in this subarea vary between 300 and 400 m; the total (composite) thickness of the formation is probably 900—1000 m. In the Ralången area the general configuration of the lowermost argillitic sandstone units suggest that the Nässjö Formation is not more than a few hundred metres thick.

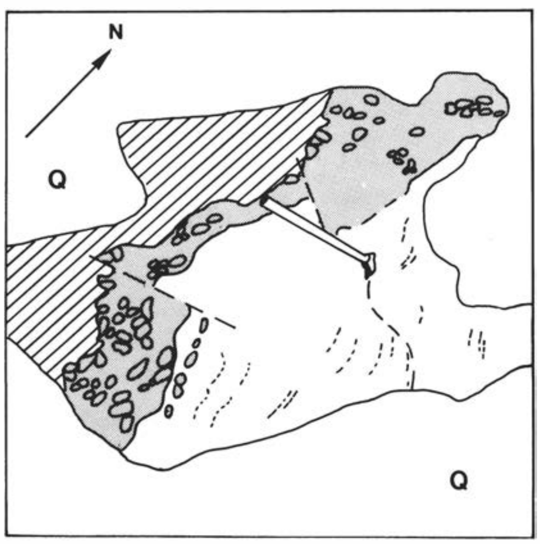


Fig. 10. A faulted bed of coarse conglomerate (grey) overlying laminated argillite (white) along a subvertical intrusive contact with dolerite (ruled). Hammer 0.4 m. Q denotes Quaternary cover. Drawing from a photograph. Outcrop 1 in Fig. 9.

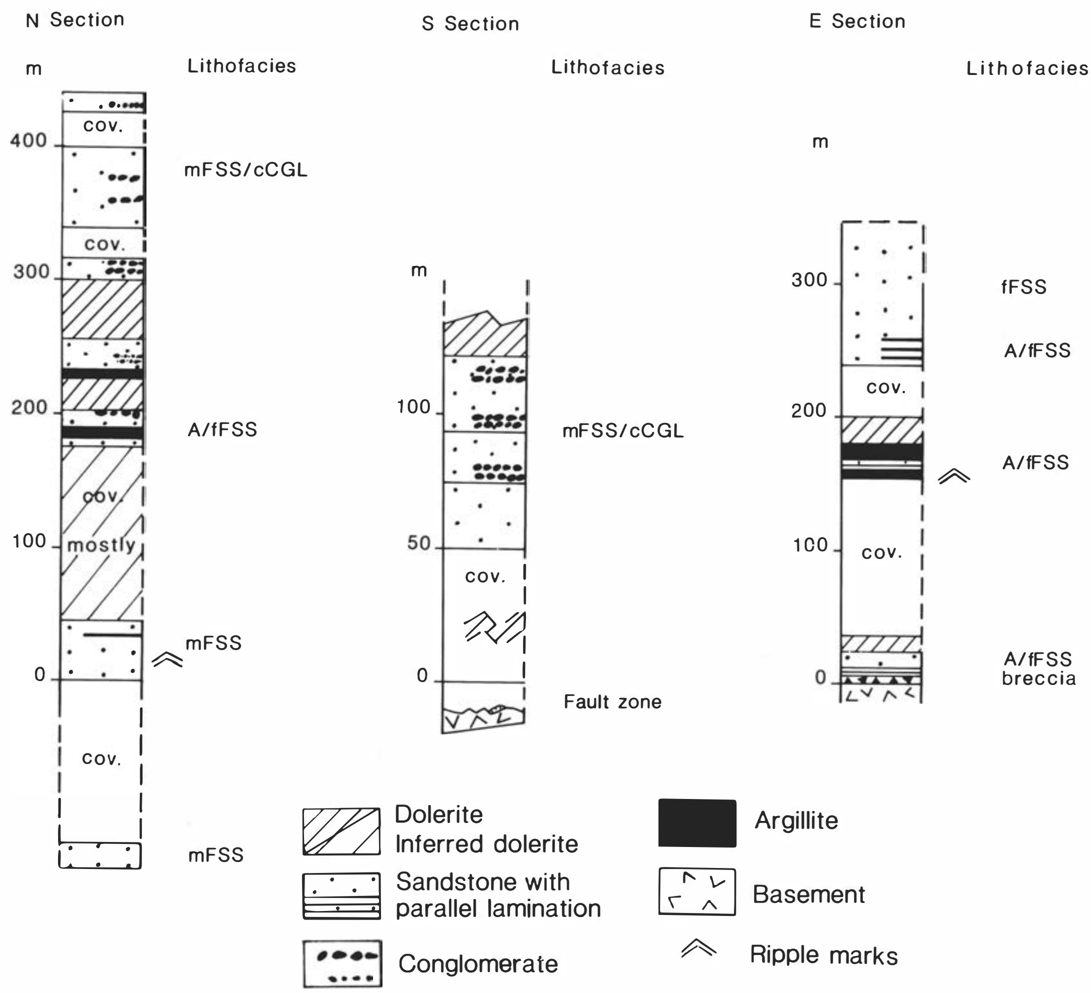


Fig. 11. Generalized sections showing the sequence of lithofacies in the Nässjö subarea at N1—N2, S1—S2, E1—E2 and E3—E4 in Fig. 5. Symbols: A/fFSS = association of argillite and fine-grained feldspathic sandstone, mFSS = medium-grained feldspathic sandstone, cCGL = coarse conglomerate; cov. denotes soil cover.

THE BRANTEBERG FORMATION

The Branteberg Formation dominates the Ralången area where coarse and fine conglomerates crop out mainly in its southernmost part, the Branteberg subarea. The unconformity between the Branteberg Formation and the Nässjö Formation is exposed here. Coarse conglomerates with impersistent thin beds of red mudstone rest almost horizontally on a medium-grained, poorly stratified, W-dipping Nässjö sandstone unit probably not exceeding some tens of metres in thickness (Fig. 12). In the southernmost part of the Branteberg subarea, the Branteberg Formation apparently overlaps on to the basement. A remnant of the formation is found further to the south, in the narrow subsided basin between Lake Hamnaryd and Lake Sjunnaryd in the Spexhult area (Fig. 3). A second, more extensive remnant of the Branteberg Formation in the Spexhult area occurs to the east of the Forserum subarea (cf. Fig. 14) along the northern boundary with the basement. The lowermost beds exposed here consist of trough cross-stratified, fine-gravelly, coarse to medium-grained sandstone while the uppermost beds are medium-grained grey sandstone. Southerly dips suggest that this unit is overlain by a quartzitic sandstone of the Storekvarn Formation. Neither the lower nor the upper contacts are exposed.

A number of sections above the interformational unconformity in the Branteberg subarea were studied in detail; type sections are shown on p. 44. The basal Branteberg association of coarse polymodal conglomerates with interbedded fine conglomerates and subordinate mudstones gradually passes upwards into cross-stratified, medium-grained sandstone with subordinate fine conglomerate. This association displays large-scale trough cross-strata. It can be recognized throughout most of the Ralången area and is also found in the two isolated occurrences in the

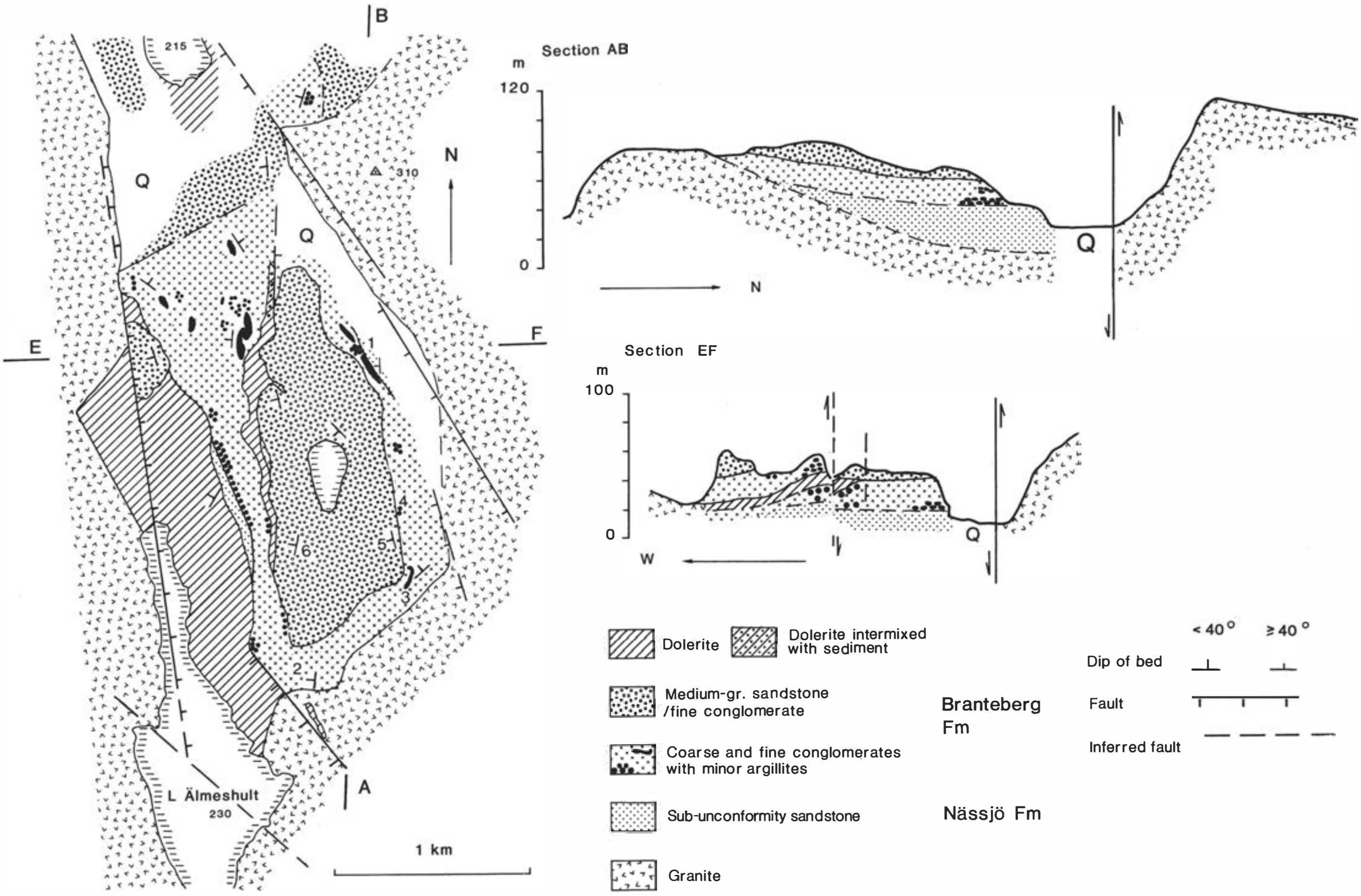


Fig. 12. Geological map of the Branteberg subarea. The large digits refer to the outcrops in which the observations recorded in Fig. 50 were made. The small numerals in the lakes and in the granite area denote height above sea level in metres. The ''dolerite intermixed with sediment''-sign in the north-central part of the area denotes an outcrop of a xenolithic dolerite sill. The dolerite has been intruded into coarse conglomerate beds with local argillites and carries abundant quartzitic cobbles. The cobbles have apparently been derived from the conglomerate beds owing to mobilization of their matrix (cf. profile section E—F). Q denotes Quaternary cover.

Spexhult area described above. Some coarse conglomerates outcrop in the northernmost part of the Ralången area where numerous finds of conglomerate blocks indicate a formerly more extensive occurrence. While retaining its typical structures, the cross-stratified sandstone becomes more fine-grained upwards; in the Ralången area the entire sequence becomes more fine-grained northwards. In the northernmost part of this area, beds of red subarkosic sandstone occur in the folded upper units near Lake Ralången while thin beds of fine-grained sandstone with abundant ripple marks are found at several stratigraphic levels (Fig. 13).

Gently NW-dipping beds of red fine-grained, arkosic sandstone appear to be the uppermost unit of the Branteberg Formation in the northernmost part of the Ralången area near Lake Söljen. In the central part of the Ralången area, south of Marbäck, thin similar arkosic sandstone beds occur in the faulted and tilted Branteberg Formation sequence. The beds dip westwards at gentle to steep angles (see Fig. 2). A polygonal pattern on a bedding surface suggests a former mudstone bed in the sandstone. These mudcracks indicate a ''right-way-up'' position of the beds. To the northwest of these beds a greyish sandstone/ fine conglomerate sequence contains a unit, at most 10 m thick, of interbedded mudstones and coarse conglomerates. Apart from these mudstones and those described from the Branteberg subarea (cf. p. 15), virtually no mudstones are exposed in the Branteberg Formation in the Ralången area.

The Branteberg Formation in the Branteberg subarea is estimated to be 130 m thick. In the central Ralången area a conservative estimate is 80 m; in the larger of the two remnants of the formation in the Spexhult area the maximum thickness is 200 m.

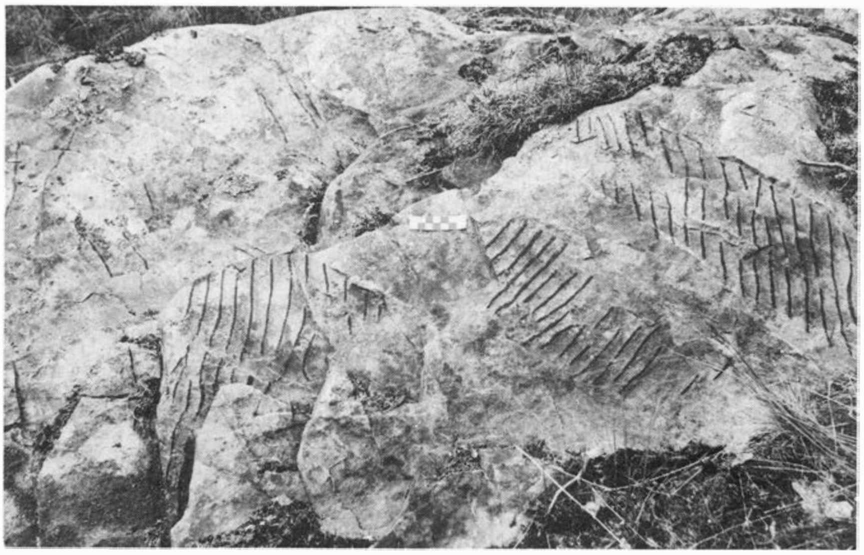


Fig. 13. Ripple marks in thin-bedded fine-grained sandstone. Trains of wave ripple marks with varying crest orientations and wave-lengths on several bedding surfaces in the Branteberg Formation. Scale in centimetres. The ripple crests have been marked with black on the rock. Outcrop 2, Fig. 24.

THE STOREKVARN FORMATION

The Storekvarn Formation dominates the western part of the Spexhult area (Fig. 1). Apart from local conglomerate beds it is lithologically homogeneous, the sandstone being everywhere a medium-grained feldspar-poor subarkose or quartz arenite. Its colour ranges from greyish to white or greyish-pink. Parallel or discordant lamination due to varying proportions of feldspar occurs sparsely and is the only sedimentary structure observed. Beds of coarse conglomerate occur almost only in the Vikskvarn-Storekvarn subarea, which is the type area, and in adjoining terrains to the east (Figs. 8, 1). The bedding attitudes vary, though the gentle to moderate dips are mostly westerly. Minor faults with varying trends can be observed. Minor outcrops of the same lithofacies with similar, apparently irregular bedding attitudes run in a belt dominated by dolerites extending north from Lake Almesåkra towards Nässjö and Forserum. The delimitation of this belt toward the east is probably governed by N-trending faulting which has caused subsidence of the western block along a line from Lake Ryssby to Lake Storsjön (cf. Fig. 2). Estimates of minimum thickness of the sandstone in this belt range from 60 to 200 m.

THE BRANTEBERG AND STOREKVARN FORMATIONS IN THE FORSERUM SUBAREA

In the centre of the Forserum subarea (Fig. 14), sandstones belonging to the Branteberg and probably also to the Storekvarn Formation are recognized. The stratigraphic relationships are obscured by complex faulting with unknown amounts of vertical and lateral displacement (cf. discussion p. 73 and Fig. 16). A closely folded, partially eroded sequence of interbedded fine conglomerate and argillitic, fine-grained sandstone to siltstone surrounding Lake Lättarp apparently overlies the Forserum Formation. This sequence is assigned to the Branteberg Formation. Trough cross-stratification is observed here, and the coarse beds have the same immature composition as the fine conglomerates occurring in the Branteberg Formation in the Branteberg subarea (cf. p. 29). The quartzitic sandstone units exposed in this part of the Forserum subarea probably overlie the folded argillitic sandstone/fine conglomerate sequence and belong to the Storekvarn Formation. However, the stratigraphic relationship is ambiguous and the interpretation depends on whether some of the quartzitic units are regarded as belonging to the Forserum Formation (cf. Fig. 19 and discussion p. 73). In the southern part of the Forserum subarea, samples from a boring indicate that a quartzitic sandstone overlies beds of yellowish sandstone interlaminated with red siltstone (Fig. 15, well No. 1). This sandstone probably belongs to the Branteberg Formation.

THE FORSERUM FORMATION

The Forserum Formation can be studied best in the western and northern parts of the Forserum subarea where it occupies most of the western fold limb of the Lättarp syncline. Part of the formation is exposed here between two dolerite sills. It can be traced southwards in outcrops as far as Forserum where the sandstones dip eastwards and rest on faulted basement rocks.

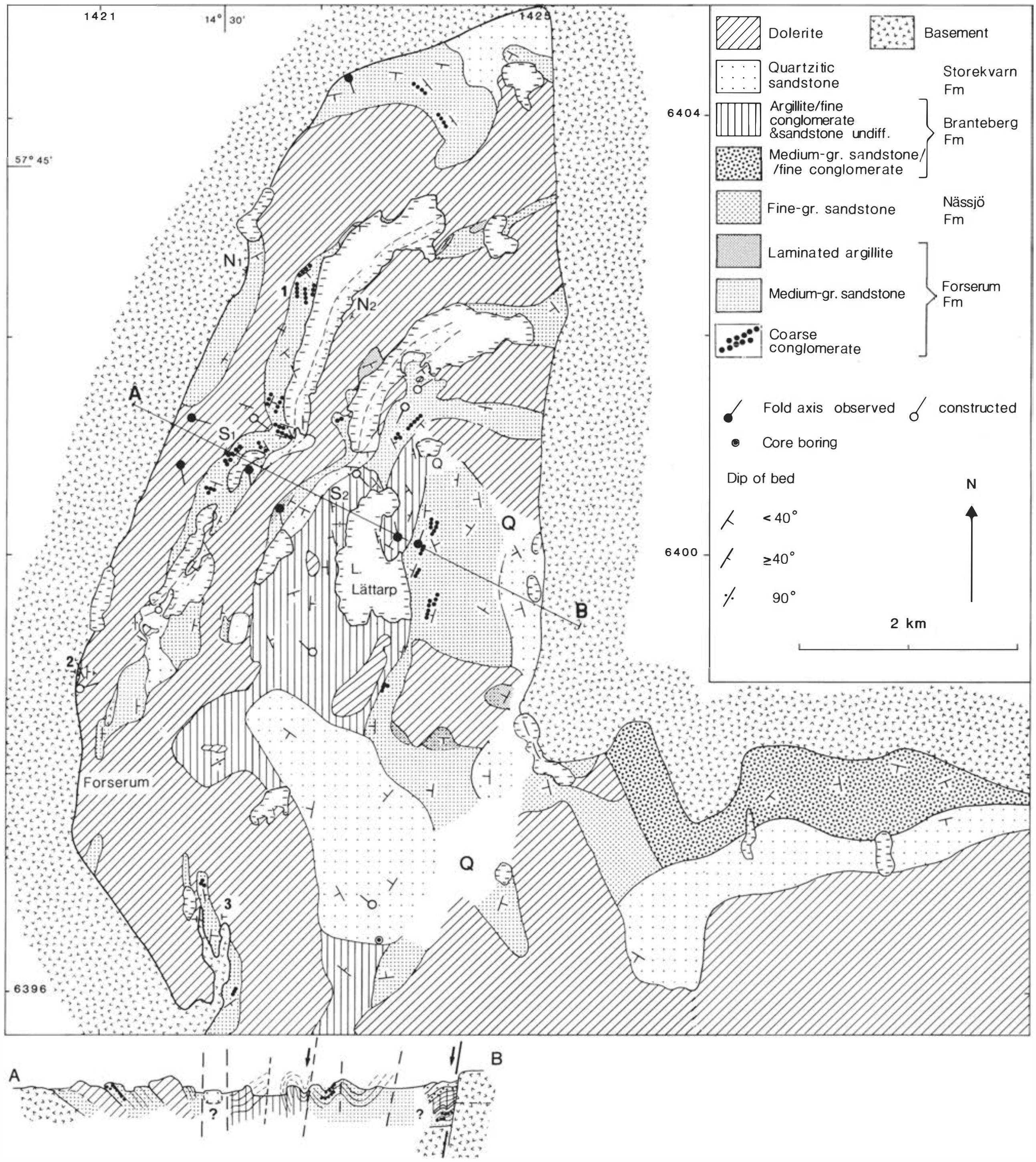


Fig. 14. Geological map of the Forserum subarea and adjacent areas to the east. N1—N2 and S1—S2 indicate the location of the sections shown in Fig. 19. The digits denote the outcrops in which the observations recorded in Fig. 46 were made. Q denotes Quaternary cover.

To the east and north of Lake Lättarp there are several exposures of the formation. East of the lake reddish conglomerate-bearing sandstones are locally folded and occur between two NS-trending faults. In the north, outcrops of sandstone and, locally, mudstone occur in several crescent-shaped belts between dolerite exposures (Fig. 14). The mudstones are parallel-laminated and calcareous, and have been intruded by the subjacent dolerite. The contact between this part of the Forserum Formation and the Branteberg Formation to its south appears to be controlled by strike-slip faults (Fig. 16).

The sandstones of the Forserum Formation are predo-

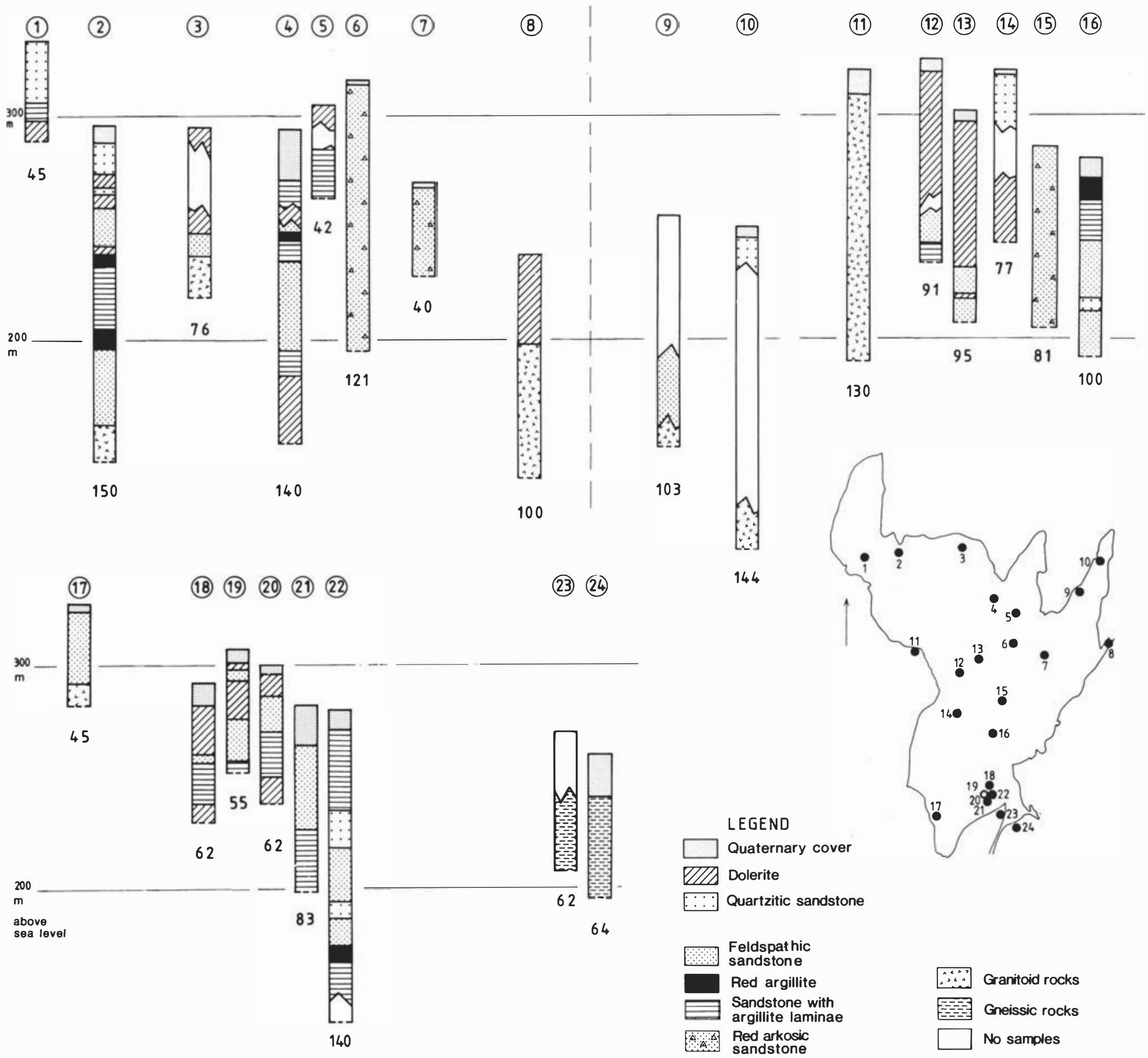


Fig. 15. Lithostratigraphy of the Almesåkra rocks as shown by well borings indicated in the inset map. The numbers below the columns indicate the depths of the wells in metres. The heights above sea level of the sites are marked by horizontal lines. Most wells were sampled at vertical intervals of 5 or 10 m.

minantly medium-grained. They are subarkosic in composition with few opaques and rock fragments (cf. Table 3). In the west, the sandstones are mostly greyish. In the lowermost outcrops along the northwestern boundary with the basement, the sandstone is reddish and largely massive. It is generally poor in feldspar except for some thin, coarse-grained layers. Most of the Forserum Formation overlying the basal beds is a quartz-rich sandstone with feldspars enriched in laminae which are conspicuous in weathered outcrops (Fig. 17). Beds of bimodal coarse conglomerate occur at several stratigraphic levels and tend to be associated with massive sandstone.

In the upper part of the Forserum Formation, the conglomerate beds are often overlain by thin beds of fine-grained, silty sandstone. Polygonal patterns of small sandstone dykes (Fig. 18) suggest a former mudstone cover. Many exposures display ripple-marked bedding surfaces. Some of these beds are associated with thin conglomerates and have poorly preserved symmetrical ripple marks with wavelengths of up to 0.2 m.

In the faulted eastern exposures, the sandstone is reddish and mostly unlaminated. Feldspar lamination resembling that in the west occurs in a few upper beds. The interbedded conglomerates are similar in particle compo-

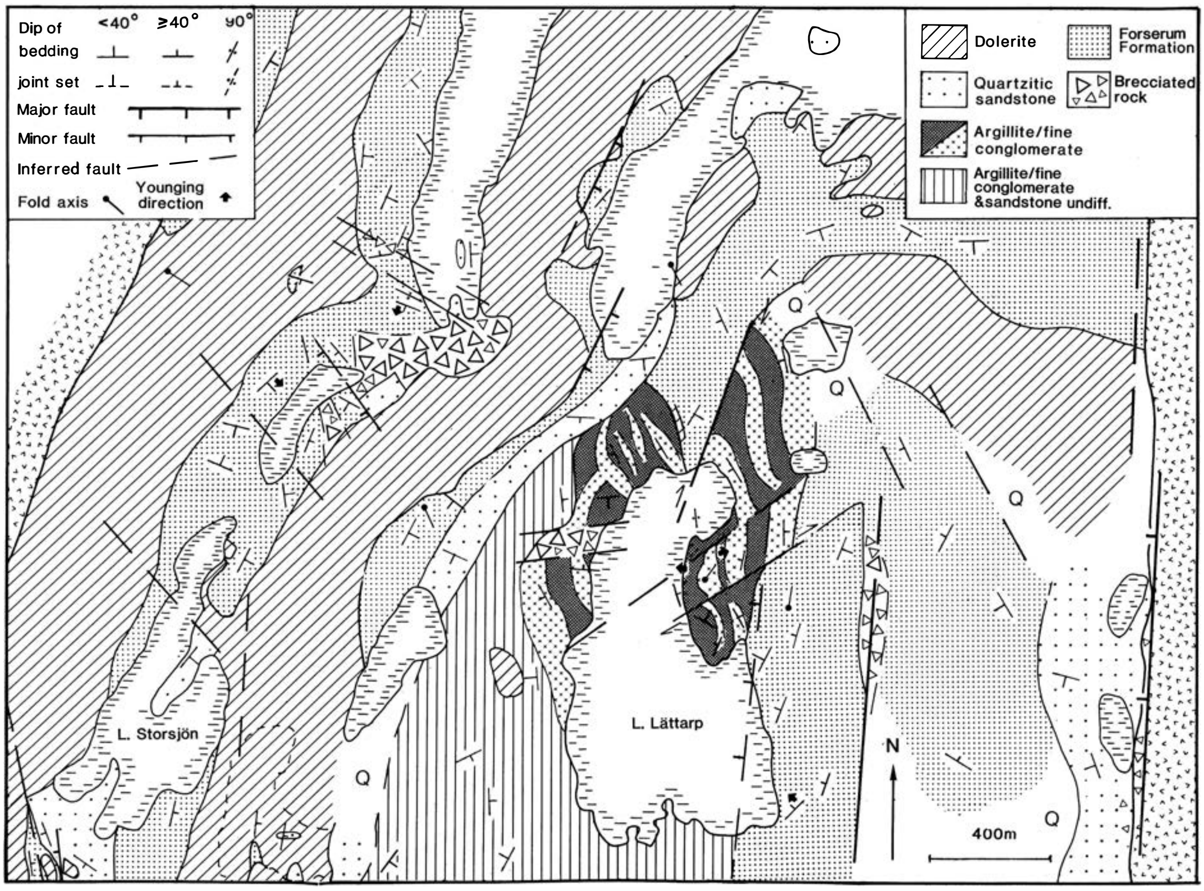


Fig. 16. Detailed map of the central part of the Forserum subarea. Q denotes Quaternary cover. Quarry in the dolerite is marked to the east of L. Storsjön.

sition to those in the west, but the particles tend to be smaller (cf. Fig. 28). A few ripple marks on a W-dipping bedding surface with remains of overlying siltstone indicate that younging is towards the west.

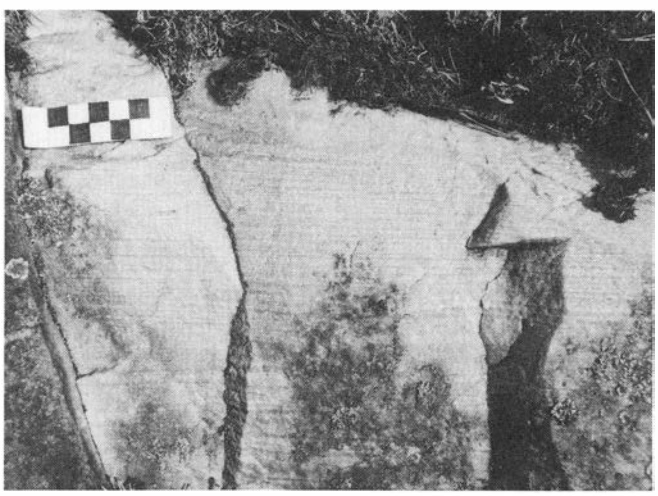


Fig. 17. Parallel lamination in sandstone of the Forserum Formation defined by feldspar concentration. Scale in centimetres. Outcrop in sequence Forserum 1, Figs. 14 and 46.

The Forserum Formation is at least 300 m thick. The two generalized sections in Fig. 19 show sequences from the western limb of the Lättarp syncline. Sections showing additional details including soft-sediment deformation are given in Fig. 46. The sections Forserum 1 and 2 are type sections of the Forserum Formation.

The mudstones of the Forserum Formation are thin, less than one metre in thickness, and restricted to the upper parts of the sequence. Virtually all mudstones have been intruded by dolerite. The field distribution suggests that the two main dolerite intrusions occurred along mudstone horizons. Calcite appears to have been a common cementing mineral in the upper mudstones. It has now mostly been replaced by contact-metamorphic calc-silicate minerals, e.g. wollastonite (cf. Rodhe 1985). In a quarry in the uppermost dolerite sill, a greyish-white, parallel-laminated, highly calcareous 0.5 m thick mudstone bed was exposed after blasting. This bed, which was later destroyed, was uppermost in a 10 m thick, E-dipping sandstone unit intruded by dolerite (Fig. 16).

The depositional facies (cf. p. 41) indicate that the For-

Fig. 18. Relict polygonal pattern of mud cracks filled with sandstone ''dykes''. Surface in thin-bedded silty sandstone partly covering conglomerate bed in the Forserum Formation. Pen 15 cm. The ''dykes'' have been marked with black on the rock. Outcrop at S1 in Fig. 14.

serum Formation probably represents a sand-dominated fluvial sequence. It tends to become more fine-grained upwards. The proportion of mudstone appears to be lower than in the Nässjö Formation in the central Spexhult area. In composition and inferred depositional facies, the conglomerates of the Forserum Formation resemble those of the Nässjö Formation. The palaeocurrent directions agree with those inferred from outcrops of the Nässjö Formation conglomerates in the Kansjö sequence (cf. Fig. 55). These features and deposition on the basement suggest that the Forserum Formation is a lateral equivalent of part of the Nässjö Formation.

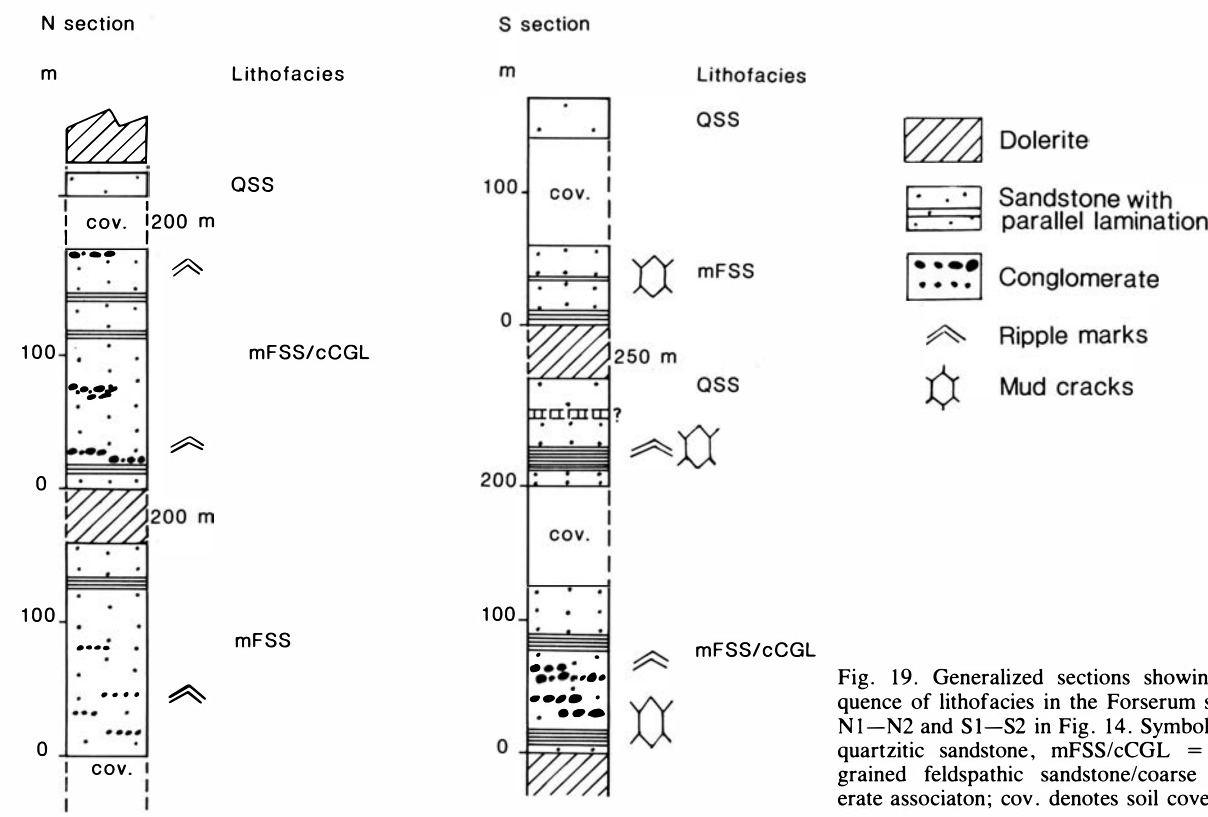


Fig. 19. Generalized sections showing the sequence of lithofacies in the Forserum subarea at N1—N2 and S1—S2 in Fig. 14. Symbols: QSS = quartzitic sandstone, mFSS/cCGL = medium-grained feldspathic sandstone/coarse conglomerate associaton; cov. denotes soil cover.

THE TECTONIC SETTING OF THE ALMESÅKRA GROUP

GENERAL ASPECTS

Regional faults control the exposure areas of the Almesåkra Group and the distribution of basement inliers within it (Fig. 1). South and east of Lake Vättern, the Baltic Shield is largely characterized by lineaments trending approximately N (Fig. 20). Such trends are also typical of the belt of steeply dipping shear zones composing the Protogine Zone which separates the Precambrian domains of southeastern and southwestern Sweden. A presumably Late Proterozoic graben structure of similar orientation exists in the Vättern basin (Axberg and Wadstein 1979, cf. Wikman *et al.* 1982).

The Protogine Zone has been variously interpreted, as a Sveconorwegian frontal thrust following the trends of older faults (Berthelsen 1980, Falkum and Petersen 1980), as a Proterozoic suture resulting from continent collision (Eriksson and Henkel 1983), and as a repeatedly reactivated intracratonic, Early or Middle Proterozoic fault zone separating a reworked Svecokarelian continental margin from the main body of the Svecokarelian orogen (Gorbatschev 1980). Several authors (Magnusson 1960, Welin and Blomqvist 1966, Patchett and Bylund 1977) have explained late faulting along the Protogine Zone as a consequence of uplift of southwest Sweden c. 1000 Ma ago (cf. also Baer 1981). Other workers (Solyom *et al.* 1984, cf. Kumpulainen and Nystuen 1985) have suggested that this faulting was caused by continental rifting during Late Proterozoic development of the Iapetus or a pre-Iapetus Ocean.

Apart from N-trending lineaments, the Protogine Zone also displays lineaments of other orientations. Immediately south of Lake Vättern, such lineaments mostly trend NE and ENE, but there is also a set striking NW (Fig. 20). Several large faults trending NE and N occur in the area between the Almesåkra Group and the Protogine Zone. Further to the east and southeast of Lake Vättern, lineaments trending NW are dominant. Faults with this orientation occur mainly in the northeastern part of the Almesåkra Group. Apart from the N-trending faults, the Almesåkra Group appears to be situated in a zone of transition from mostly NE-trending faulting in the west to mostly NW-trending faulting in the east.

STRUCTURES OF THE ALMESÅKRA GROUP

The principal tectonic elements observed in the area studied here are summarized in Fig. 2. The indicated fold axes, plunging gently when not specified, have been derived from folds, seen in the field, or constructed from measurements of bedding in sedimentary rocks. Included locally in the latter are contactparallel planar surfaces in the sill. These constructed fold axes are based on data recorded in areas generally less than 1 km². The map also shows representative bedding attitudes.

One major, tectonically deformed zone of the Almesåkra Group passes southwards through the Nässjö subarea to

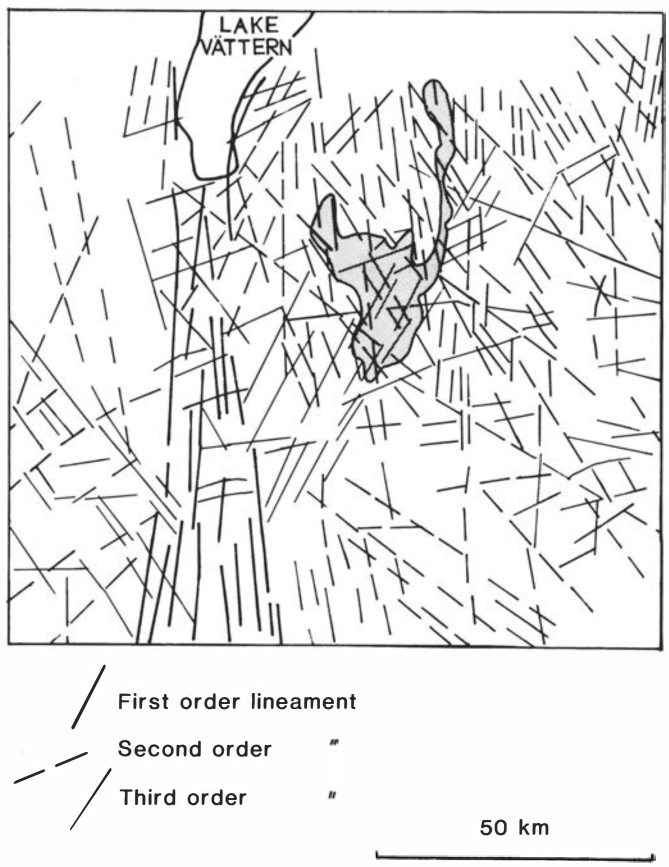


Fig. 20. Lineament map of the area SE of L. Vättern (after Röshoff 1979). The occurrence area of the Almesåkra Group is shown in outline.

Fig. 21. Asymmetric folds in argillite. Hammer head 15 cm. Outcrop c. 100 m W of Storekvarn, Fig. 8. Photo by O. Häggbom.

Bodafors. Another main zone of similar orientation influences most of the rocks of the Forserum subarea and, passing southwards through the Kansjö sequence, connects with the faulted rocks south of Lake Almesåkra. Between and to the east of these zones, the bedding dips are generally gentle and folds are relatively scarce. Only the area around Marbäck in the north is an exception.

FOLDS AND FAULTS

In the tectonically most deformed zones, folds are relatively common. When best exposed and observable over a few tens of metres, they are either upright and open or, as in argillites, asymmetric and of flexure type (Fig. 21). In the argillite/sandstone association, there was generally strong, more or less plastic deformation of the argillite simultaneous with brittle deformation of the sandstone (Fig. 22). In a large number of cases, mostly concerning small-scale flexure folds (dimension <0.5 m) in argillitic rocks, the folds have clearly been caused by slip along steeply to moderately inclined faults. These minor faults are predominantly high-angle, sometimes clearly normal, and parallel to the regional fault trends. The fold axes recorded in such outcrops are generally subparallel to the local faults, their plunges are usually gentle.

When plotted and contoured on an equal area net, the total fold axis distribution defines a diffuse girdle, its centre roughly at N80W/30W (Fig. 23A). A similar distribution is seen in a contoured plot of the observed fold axes (Fig. 23B). The plots show that the greatest concentration of fold axes plunges gently to NW—NNW. Subordinate concentrations are oriented NE—SW and E—W.

The trends of observed high-angle faults have a polymodal distribution (Fig 23C) whith a clear maximum to the N—NE. Another well-defined maximum at N35W suggests that faults of this trend are related to the folding in the occurrence areas of the Almesåkra Group.

FOLDING AND FAULTING IN SOME PARTICULAR AREAS

High-angle faults. — In one relatively well-exposed small area south of Nässjö, a set of NW-trending normal faults has exposed the basement and caused steep to moderate dips to SW in a dolerite-intruded sandstone/conglomerate sequence (Fig. 9). A subhorizontal fold axis, constructed from the local bedding attitudes, trends N30 °W parallel to the faults; virtually no folds are exposed, however.

Folding along a NW-trending axis is obvious in the Marbäck subarea (Fig. 24). Here, two similarly NW-trending, normal faults with subsidence between them of the local Branteberg sandstone sequence, can be inferred. In a subordinate anticline within the subsided units, the largest single fold seen in the Almesåkra Group is exposed, its wavelength c. 200 m, its amplitude <10 m (Fig. 24, outcrop 1).

Major folds with other trends occur in the Forserum subarea. Largest by far (c. 3 km across) is the Lättarp syncline, its axis trending NNE. The western fold limb dips gently ESE, the eastern one is truncated by a set of

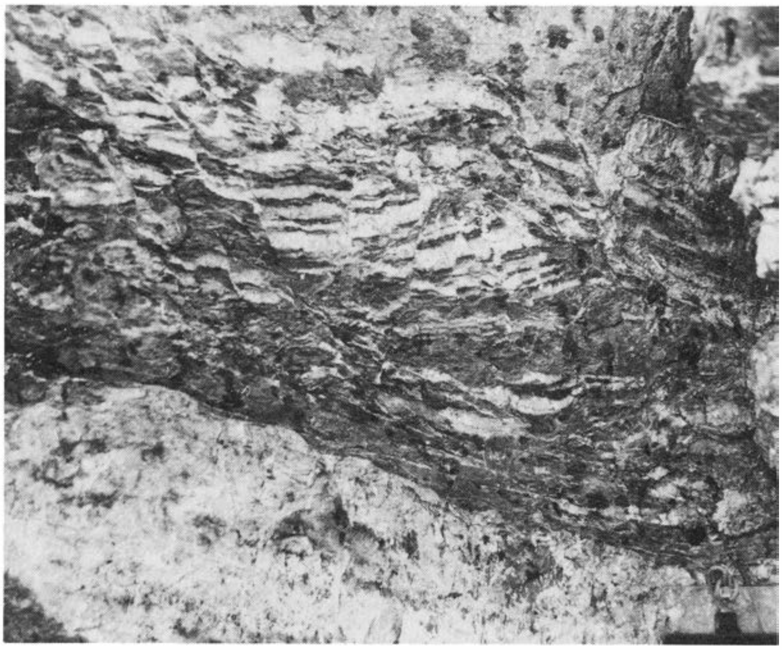


Fig. 22. Small-scale faulting in an argillite bed overlying sandstone in an open syncline. Compass 10 cm. Road cutting in faulted and gently folded beds of the Nässjö Formation c. 1 km W of locality 1 in Fig. 5.

steep N-trending normal faults (Fig 14). Several lithologic and structural discordances in the central part of the Lättarp syncline (Fig. 16) have probably been caused by strike-slip along NE- to N-trending minor faults accommodating compressive E—W stresses.

In the Lättarp syncline, east of Lake Lättarp, folding on N-trending axes is observed in argillitic sandstones/fine conglomerates of the Branteberg Formation (Fig. 14). Close folds, slightly overturned to the west, with a wavelength of c. 250 m, and amplitude of c. 60 m, are inferred from bedding attitudes, younging directions and several parasitic minor folds (Fig. 25). A pronounced subvertical cleavage in the argillite is probably an axial plane structure related to this folding. It is parallel to the dominating set of N-trending faults east of the lake and also to a synform observed in underlying Forserum sandstone. A fold axis constructed from bedding attitudes in the main outcrops strikes N, suggesting a close relationship between folding and faulting.

Thrusting and strike-slip faulting in the northern part of the Spexhult area. — Together with the N-trending faults, a set trending NE obviously controls the Almesåkra rocks and their contact with basement in the area between Nässjö and Lake Älmeshult (Fig. 2). The regional extent of this NE-striking set is indicated by its presence in basement rocks to the southwest of the Almesåkra Group and in the Ralången area to the northeast, where the faults cut Branteberg Formation rocks and basement (Fig. 12). Tectonic disturbance, such as close jointing and zones of brecciation trending N20°—60°E, occurs widely in the Almesåkra rocks as well as in the surrounding basement. A strike-slip component is evident on high-angle NE-trending faults, particularly in the Nässjö subarea, as inferred from low-angle slickenside striations on numerous surfaces and also from minor offsets of sedimentary or tectonic structures (Figs. 5, 8). In a few cases the displacements are dextral on NE-trending structures; in most, no sense of the movement can be inferred. Several instances of minor thrusting or reverse faulting on varying EW- to NE-striking, gently S-dipping surfaces in basement and cover rocks occur in the concerned area, the thrusting direction inferred to be towards the east. The uplift of basement blocks to the northwest of the NE-trending faults could have caused much of the brecciation in the area. Altogether, many features suggest that these NE-trending faults have experienced strike-slip movements during at least part of their existence (cf. Reading 1978).

The most obvious thrust is found along the eastern shore of Lake Hamnaryd (Gavelin 1931). A slice of brecciated granite, at least 3 m thick, overlies a sandstone/argillite unit of the Nässjö Formation along the lake (Fig. 26, cf. Table 5). The contact is virtually horizontal; the sandstone beds are almost undeformed beneath most of the contact. Argillite layers occur along parts of the contact and are also found as crushed remnants on several N-dipping surfaces in the lowermost part of the granite breccia. Several small thrusts in the sandstone, and slickenside striations in granite and sandstone dipping moderately to gently N, indicate that the latest thrust movements were directed

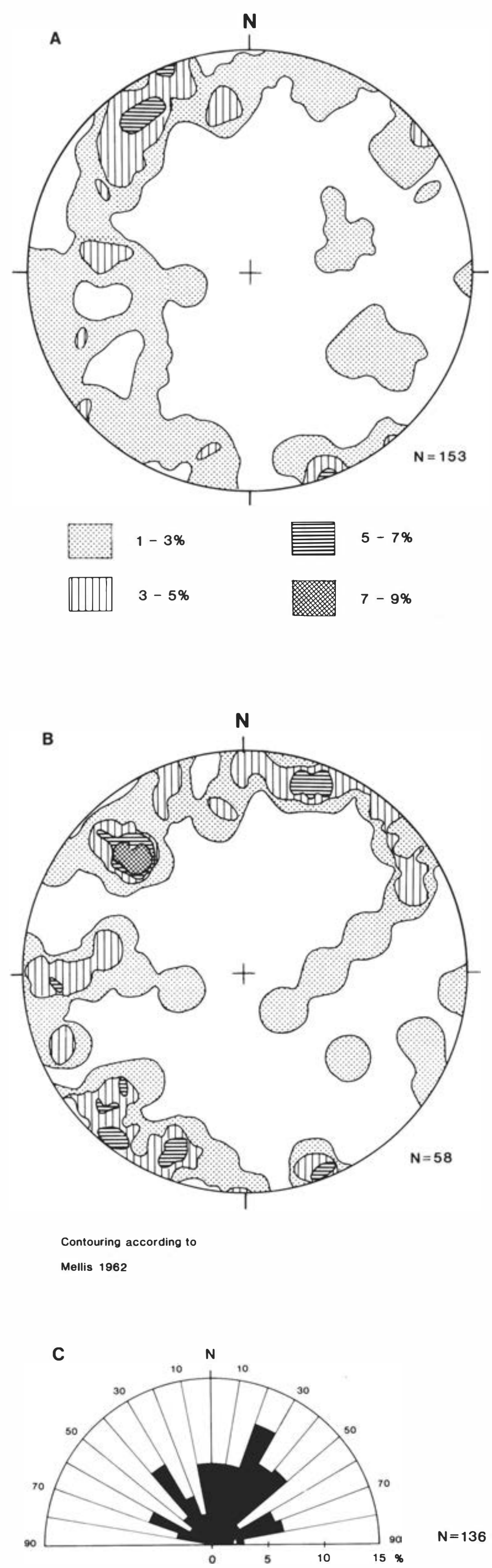


Fig. 23. Folding and faulting in the Almesåkra rocks. A: Observed or constructed fold axes. B: Observed fold axes. C: Trends of observed fault surfaces and planar breccia zones.

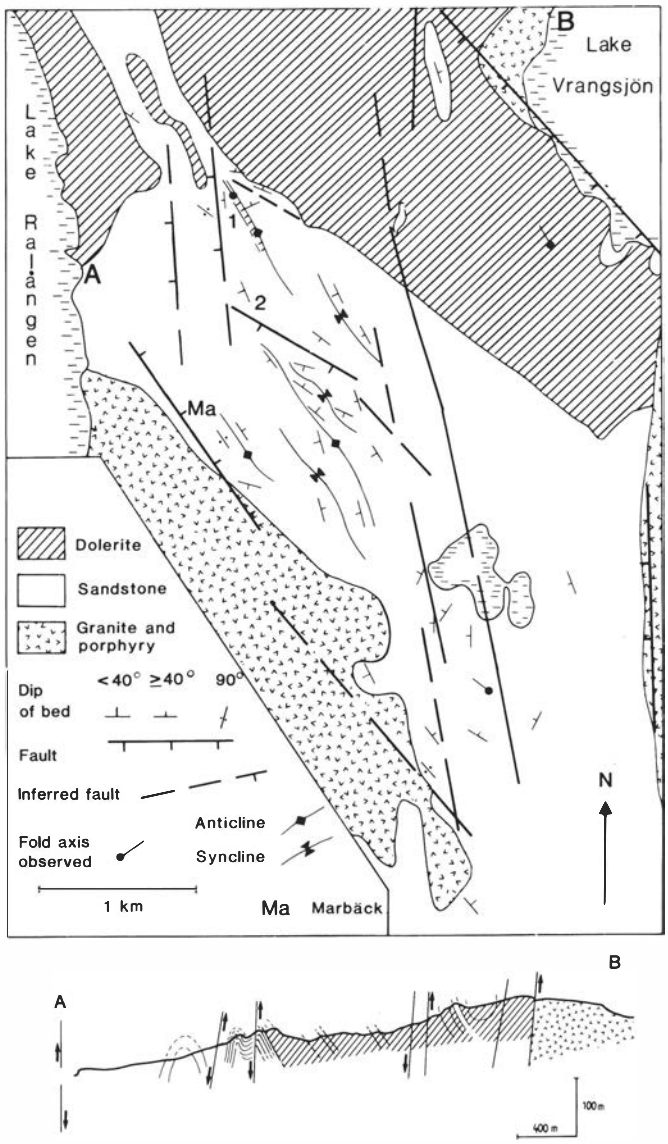


Fig. 24. Geological map of the Marbäck subarea. Digits 1 and 2 indicate outcrops mentioned in the text.

southwards (Fig. 26:1). The imbricate, northwards dipping structure of large granite and sandstone lenses seen in sections south of the main outcrop also support the conclusion that the latest compressional stress was orientated about N—S. Stress of this orientation is indicated also by folding in the dolerite of this area (Fig. 2). The argillites have obviously facilitated the thrust movements. Folding in the argillite, seen below the thrust, appears to have been caused by drag along a normal, NE-trending, steeply N-dipping fault in the sandstone. This fault does not cut the overthrust granite (Fig. 26). Several other minor faults trending about NE, dipping mostly NW, some of them cutting the thrust, indicate that faulting of this orientation has occurred repeatedly.

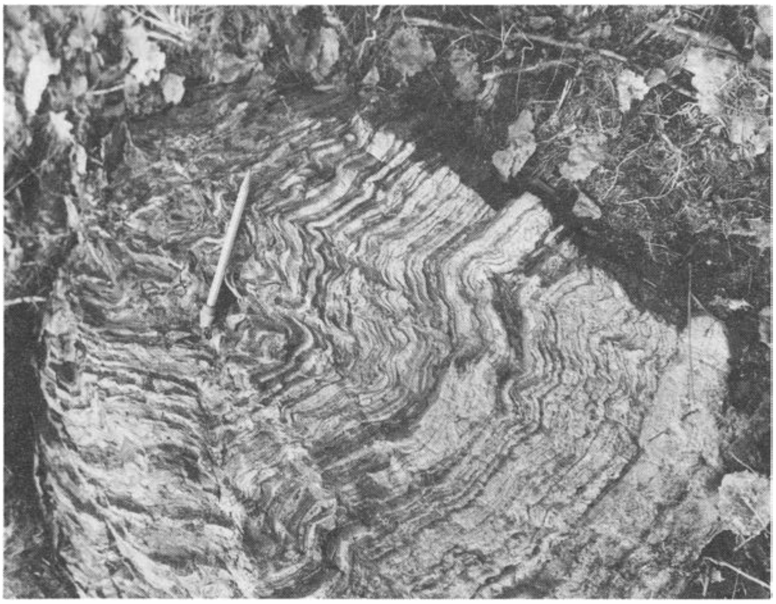


Fig. 25. Crenulation cleavage in argillite and fine-grained calcite-cemented sandstone in folded Branteberg beds. Pen 15 cm. Outcrop on the peninsula in L. Lättarp, Fig. 16.

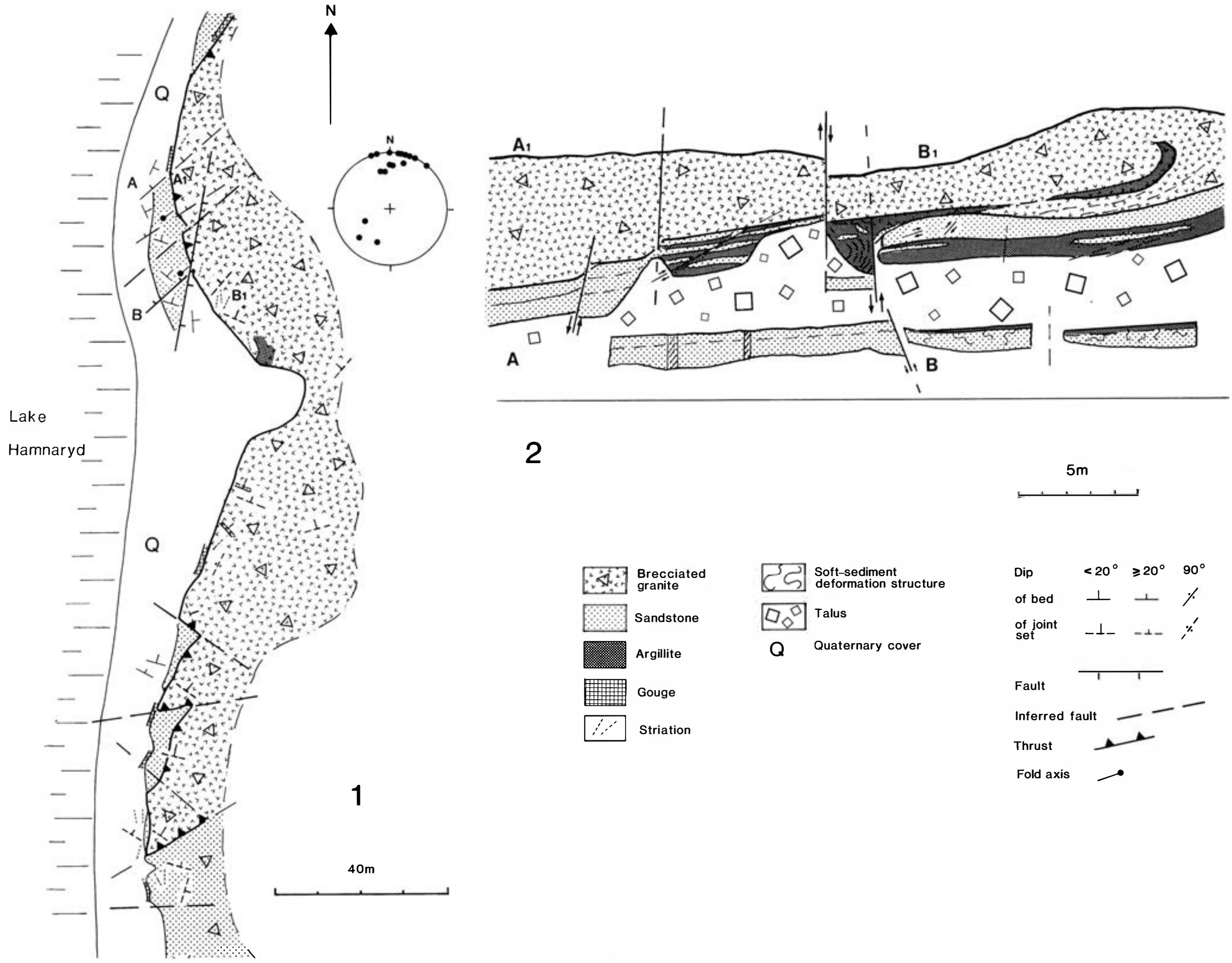


Fig. 26. 1. Map showing outcrops E of L. Hamnaryd. The π-diagram shows the attitudes of striations recorded on gently to moderately inclined slickenside surfaces mainly in the granite breccia. 2. Composite vertical section of the area between A—A1 and B—B1 in Fig. 26. 1. This sketch represents a vertical cliff face in granite breccia and subjacent argillite/fine-grained sandstone with recent talus and outcrops of lower sandstone beds.

THE DEPOSITIONAL ENVIRONMENTS OF THE ALMESÅKRA GROUP

INTRODUCTION

In the stratigraphical description (pp. 6—21) a number of lithological units or lithofacies which dominate different parts of the Nässjö and Branteberg Formations were distinguished and briefly characterized; they are summarized in Table 1. Twelve depositional facies or associations of such facies have been identified on the basis of texture, sedimentary structures, composition and rock colour. In the following text these facies and their associations are described, and interpreted as to the depositional process. Trends in the sequence of the facies are noted and the probable depositional environments defined (cf. Collinson 1968, Reading 1978). Post-depositional features such as soft-sediment deformation and cementing properties are considered briefly and interpreted when distinctive for a certain facies. The mineral compositions of the different lithofacies are treated in greater detail in the Petrography section (p. 52).

TABLE 1. Lithofacies of the Almesåkra Group.

Facies	Abbreviation	Main characteristics
Conglomerate, coarse	cCGL	Coarse conglomerate, pebble to cobble grades.
Conglomerate, fine	fCGL	Fine conglomerate, granule to fine pebble grades.
Feldspathic sandstone medium-grained	mFSS	Medium-grained subarkosic sandstone, mainly grey.
Red quartz arenite	RQA	Medium-grained quartz arenite with hematite-pigmented quartz grains.
Argillite	A	Mudstone, mainly silty claystone or clayey siltstone, red or grey, low-metamorphic.
Feldspathic sandstone fine-grained	fFSS	Fine-grained feldspathic sandstone, grey, buff or reddish.
Red arkosic sandstone	RFSS	Medium- to fine-grained arkose or feldspar-rich subarkose, high in lithic grains and opaques.
Quartzitic sandstone	QSS	Medium-grained subarkose very low in feldspar, or quartz arenite, grey, white or reddish.

TERMINOLOGY AND METHODS

When not otherwise specified, bed and lamina thickness is defined according to Ingram (1954) as modified by Campbell (1967) and used by Reineck and Singh (1973). This classification (Table 2) was found to be adequate for the argillite as well as the sandstone/fine conglomerate associations. Lamination type is described in greater detail according to the terminology used by Reineck and Singh (1980).

Terms for particle size follow the Wentworth scale. The Phi scale is used in most distribution diagrams and profiles. The parameters of the size distributions have been derived and classified according to Folk (1974).

The Maximum Particle Size (MPS) for conglomerates is the average of the size of the ten largest particles, estimated according to Bluck (1967) from apparent long axes in sample squares. The estimates of average roundness and composition of the particles are based on studies of at least 20 random particles in each square. The true size distribution of the particles could be determined on some bedding planes (cf. p. 29). For particles larger than 3—4 cm with length/width $\geqq 1.5$, the preferred orientation of the apparent long axes on the bedding surface was recorded. The imbrication of the particles was determined from the distribution of the dips of apparent long axes in some vertical sections (cf. Nilsen 1968).

Sandstone colours in outcrops are given in terms of the Rock-colour chart (Geol. Soc. Am. 1970).

TABLE 2. Bedding terminology used.

Beds cm		Laminae cm	
100	very thick	30	very thick
30	thick	10	thick
10	medium	3	medium
1	thin	1	thin
	very thin		very thin

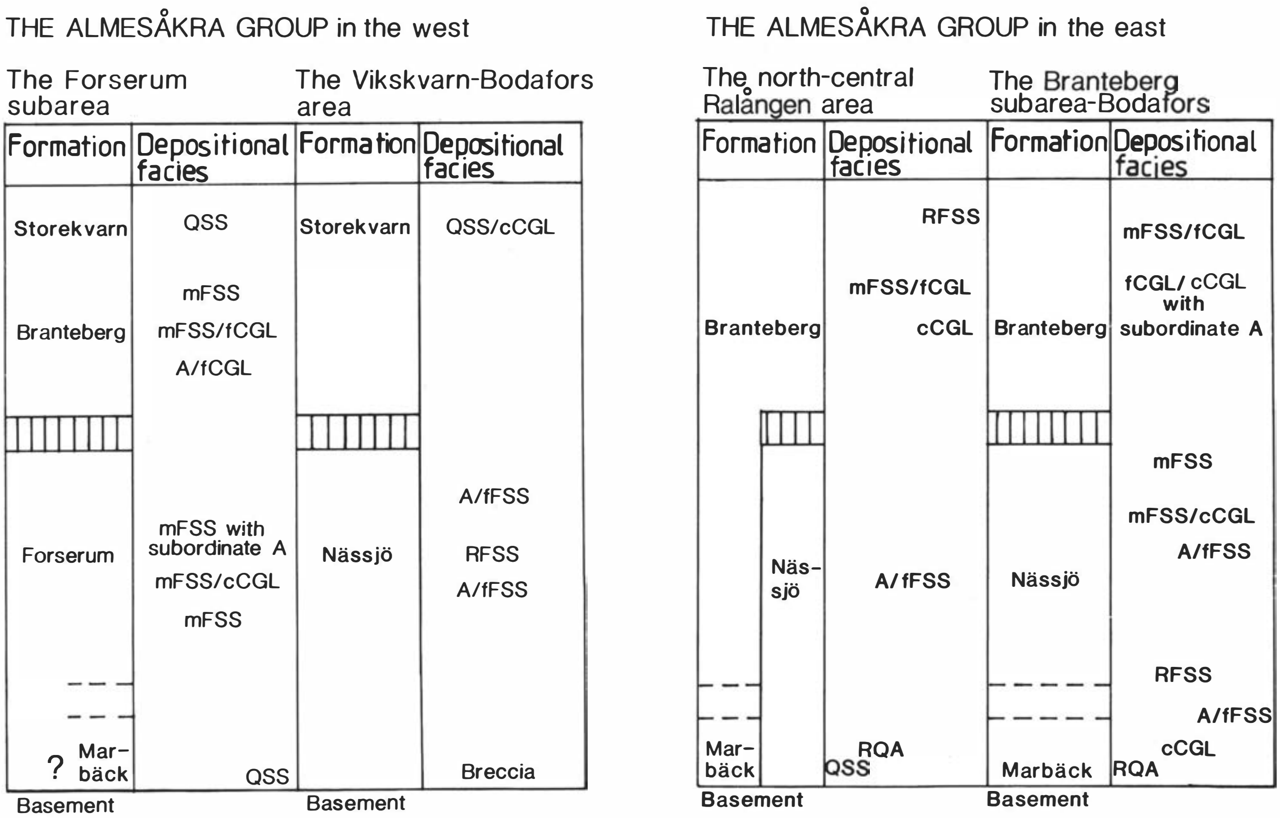


Fig. 27. The formations of the Almesåkra Group and the main sequence of depositional sedimentary facies as found in the western and eastern parts of the field respectively. Facies abbreviations as in Table 1.

THE DEPOSITIONAL FACIES AND THEIR STRATIGRAPHIC DISTRIBUTION

The *argillite facies* and the *argillite/fine-grained sandstone association* dominate in the lower parts of the Nässjö Formation in most of the Spexhult area and in the northernmost part of the Ralången area (Fig. 3). In the eastern part of the Spexhult area, the Nässjö Formation appears to consist mainly of the *red arkosic sandstone lithofacies.* This sandstone probably rests on basal conglomerates and immature sandstones found as remnants along part of the eastern boundary with basement which is now largely covered by dolerite sills (cf. p. 70).

Reddish, *medium-grained sandstones associated with coarse conglomerates* are superposed on and partly interfinger with the argillitic association of the Nässjö Formation. These rocks occur mainly in the northern and northwestern parts of the Spexhult area. In the area south of Nässjö, the stratigraphic relationship between the medium-grained sandstone/coarse conglomerate association and the red arkosic sandstone is not clear (cf. Figs. 5, 9). In the uppermost parts of the Nässjö Formation, medium-grained feldspathic sandstones are generally the prevalent rocks.

In the Branteberg Formation, above the unconformity separating it from the Nässjö Formation, the *fine and coarse conglomerate/argillite association* is predominant. Upwards, this association passes gradually into the *medium-grained feldspathic sandstone/fine conglomerate association* which dominates the upper levels of the Branteberg Formation. In the central and northernmost Ralången area, there are also minor intercalations of red arkosic sandstone differing in specularite content and mode of hematite cementing from the corresponding lithofacies in the Nässjö Formation.

In the Storekvarn Formation the *grey quartzitic sandstone lithofacies* is prevalent. In the Vikskvarn-Storekvarn subarea, coarse conglomerates occur interbedded with the quartzitic sandstones.

The Forserum Formation consists in its basal northern parts mainly of medium-grained sandstone, while the medium-grained sandstone/coarse conglomerate association dominates the formation elsewhere. Thin argillite units occur in the upper parts of the formation.

The Marbäck Formation consists mainly of a *red quartz arenite lithofacies* but also of grey quartzitic sandstones.

DEPOSITIONAL SEDIMENTARY FACIES

As stated above, conglomerate and medium-grained feldspathic sandstone represent depositional facies widely encountered in the Almesåkra Group.

THE CONGLOMERATES

Description. — The particles (clasts) occurring in the Almesåkra conglomerates range from granule- to boulder-size. A rough subdivision, based on the predominance of two size groups, is made between *fine conglomerates* which have granule to fine pebble modes (3 to 6 mm), and *coarse conglomerates* which are dominated by pebbles or cobbles and contain occasional boulders. The fine conglomerates are poorly or very poorly sorted; the coarse conglomerates are mostly poorly sorted (Table 4). The conglomerates are generally well consolidated, indurated usually by quartz cement.

The fine conglomerates are very immature in composition. Granitoid lithic fragments and feldspars dominate over quartz grains. The matrix is generally sandy and polymodal; the conglomerates are mostly clast-supported (cf. Harms *et al.* 1982). In the principal occurrences, the beds are thick and the stratification is indistinct.

The coarse conglomerates consist mainly of quartzitic sedimentary particles (Fig. 28). Clasts deriving from the crystalline basement are dominant or appreciable only in a few cases. The matrix ranges from silty or muddy sand to sandy fine gravel. The coarse conglomerates are clast-supported. The beds generally range from 0.1 m to 2 m in thickness but may occasionally be several metres thick (cf. Fig. 47). Stratification is generally indistinct but can be seen locally in thick beds. Low-angle cross-stratification occurs in some units interlayered with fine conglomerate. In units interlayered with sandstone, stratification in the conglomerates is sometimes marked by impersistent thin layers of sand or fine gravel.

The apparent long axes of the particles generally exhibit a preferred orientation (cf. Fig. 55) best developed where the particles are the size of cobbles. Imbrication of the pebbles can be seen locally (cf. Fig. 57). Grading is uncommon, but some thick beds may exhibit weak normal or inverse-to-normal grading.

The particles are generally subrounded to rounded. Large cobbles and boulders are mostly well rounded. In a number of localities, all three dimensions of these can be observed on weathered bedding surfaces and it is apparent that most particles are prolate whereas oblate forms occur sparsely.

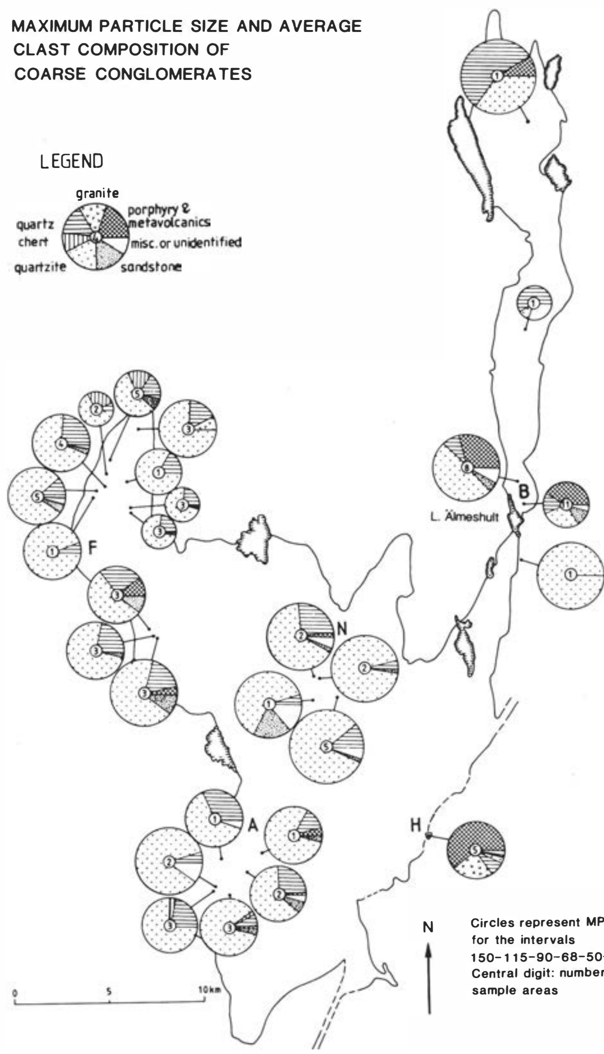


Fig. 28. Average clast composition and maximum particle size (MPS) of coarse conglomerates and other fragment rocks in the Almesåkra Group as recorded in 85 sample squares. A = Almesåkra church, B = Branteberg subarea, F = Forserum, H = Hälleved, N = Nässjö. The clast composition of the rock to the south of L. Älmeshult (100% quartzite clasts) is anomalous. This rock is a xenolithic dolerite with abundant inclusions of well-rounded quartzite cobbles and pebbles. The dolerite is a dyke exposed along a N-trending fault separating the Almesåkra sedimentary rocks from red Småland granites.

Interpretation. The clast-supported framework indicates that the conglomerate beds were deposited from running water. Where the clasts display preferred orientation, they are interpreted to have been rolling on the bed with their long axes oriented more or less transversely to the direction of flow (Rust 1979, Harms *et al.* 1982; cf. Palaeocurrents p. 50).

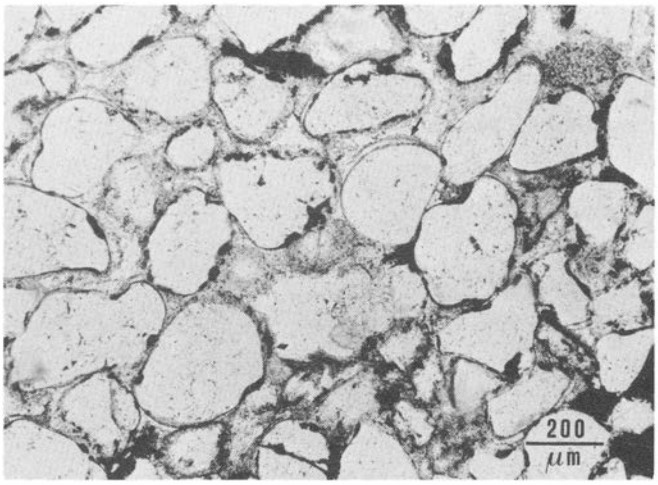


Fig. 29. Red quartz arenite derived from older, now eroded, sedimentary sequence E of the Almesåkra Group. Note subangular to well-rounded quartz grains and a few feldspar pseudomorphs (dusty grains). The pores are filled with authigenic quartz and sericitic-hematitic pseudomatrix. Hematite pigment defines the outlines of the detrital grains; several pitted quartz grains have hematite infillings. Some of the detrital quartz grains are partly surrounded by syntaxial quartz cement with a thin second layer of hematite pigment (arrow) indicating derivation from older sandstone. Plain light. Red quartz arenite clast in the Hälleved conglomerate, Fig. 4.

THE MEDIUM-GRAINED FELDSPATHIC SANDSTONES

Description. — Medium-grained feldspathic sandstones are the most widely occurring sedimentary rocks in the Almesåkra Group. They are moderately well to poorly sorted subarkoses of variable feldspar content. Lithic grains and opaques are commonly subordinate (cf. Fig. 60). Cementation is predominantly by quartz, the quartz cement varying between roughly 10% and 35% of the total rock (group averages, see Table 3). In the Forserum and Nässjö Formations, the medium-grained sandstones are often associated with beds of coarse conglomerate (cf. p. 41). In the Branteberg Formation they occur thinly interlayered with fine conglomerates (cf. p. 47).

Interpretation. — Interpretations of the depositional environments of these sandstones are given in the interpretations of these two main associations.

DEPOSITIONAL SEDIMENTARY FACIES OF THE MARBÄCK FORMATION

THE RED QUARTZ ARENITE

Description. — The red quartz arenite is a medium-grained sandstone. As with the grey quartzitic sandstones there are few indications of the conditions of sedimentation. Average compositions are shown in Table 3. In most samples, the whole-rock content of detrital feldspar does not exceed 5%. The feldspar is usually strongly altered and often converted to sericite and hematite. The content of lithic grains is low; metavolcanic and sedimentary lithic grains predominate (cf. Fig. 61b). Grain size and roundness are easy to assess because of hematite rims on the grains (Fig. 29). The size distributions are unimodal and tend to be symmetrical (cf. Fig. 65), and the sandstone is well-sorted to moderately sorted. Most grains are rounded or subrounded (cf. Fig. 66); the roundness increases with grain size (cf. Fig. 72e). Many quartz grains have few inclusions and a relict high-quartz habit is occasionally seen in equant grains. Embayments or shallow pits are fairly common on the grains; they are filled with hematite or hematitic clay (Fig. 29).

Quartz is the main authigenic mineral. Hematite pigment, however, is the earliest cement and generally coats the detrital grains. On some quartz grains iron-oxide and thin silica coatings alternate (Fig. 29). Euhedral quartz overgrowths on the quartz grains are common in some samples. Outside such overgrowths the pore space is filled by later quartz cement and/or sericitic ''matrix'' and hematite. A low relict porosity is sometimes present (cf. Table 3a). In some samples hematite coatings of varying thickness on the grains define laminae in the sandstone. These coatings are probably late-diagenetic since they are absent at the grain contacts (cf. p. 63).

The most common sedimentary structure is a thin interlayering of medium- and fine-grained sandstone, best seen in the northernmost occurrence in the Ralången area. Indistinct, very thin laminae of dark red, silty clay or silt occur sparsely, as do thick laminae of coarse sand with rounded granules of quartz and red porphyry. Some low-angle cross-lamination can be observed. There are also a few small-scale ripple marks with wave-lengths of less than 2 cm as well as mud cracks and small mudstone clasts (Fig. 30).

Interpretation. — The sedimentary structures and the occurrence of mudcracked mudstone and mudstone clasts suggest a shallow-water environment with subordinate mud accretion and episodic exposure to air.

Hematite pigment on detritus grains covered by later quartz cement indicates early diagenetic formation of the hematite (cf. Turner 1980, Dott 1983). The alternation of thin authigenic hematite and quartz on some grains and the euhedral early quartz overgrowths are features characteristic of many desert sands and sandstones (cf. Glennie

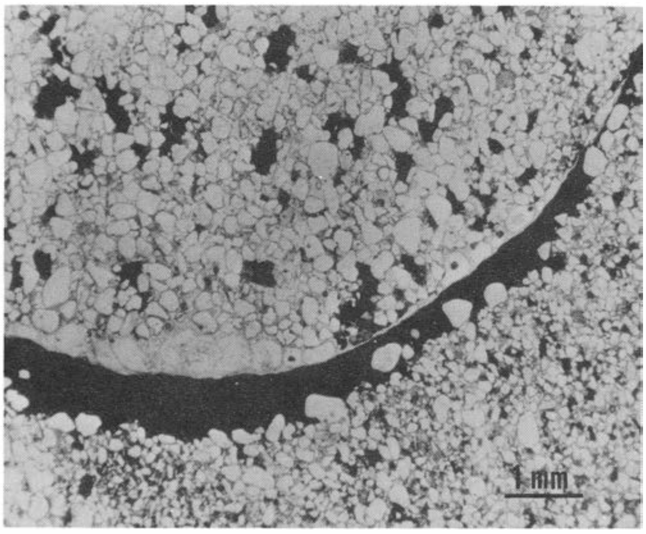


Fig. 30. Curved clay-pebble (claystone ripped-up-clast) in fine-grained and medium-grained red quartz arenite of the Marbäck Formation. Plain light. Sample from boulder in the N. Ralången area, Fig. 1.

1970, Waugh 1970, Folk 1976). A warm climate is suggested by the relatively rapid formation of hematite indicated by multicoated grains; the forming of hematite from precursor iron minerals is promoted by high temperatures (Walker 1967). Modern analogues suggest that the euhedral quartz cement was formed by precipitation during the evaporation of silica-rich solutions derived from saline ground waters. Such solutions are capable of dissolving fine silica dust produced by the abrasion of quartz during aeolian transport (Kessler 1978). The relatively common, well-rounded medium to coarse sand grains (cf. Figs. 29, 31) also suggest an aeolian mode of transport, some of the pits on the grains being possibly of impact-saltation origin (cf. Kuenen 1960). However, because much of the quartz detritus in these rocks probably derives from quartz phenocrysts in porphyry source rocks, these features are inconclusive. On the other hand, for medium to fine sand grains which are subrounded or subangular and display several small pits (up to 4 pits on each grain have been recorded, cf. Fig. 29), an origin of the pitting from magmatic resorption embayments appears improbable. The frequency of the pits and the prevailing occurrence of hematite or hematitic clay fills within them suggest that they result from corrosion by alkaline solutions and, possibly, some exposure to weathering in soil profiles (cf. discussion in Chaudhuri 1977, see also Crook 1968). According to Walker (1979) such hematite-pigmented fine sand grains with hematitic clay fills are the reddest components in many sands of present deserts. They have preserved their hematitic cover, which is due to iron-oxide bearing clay particles in the desert dust, because fine sand grains do not become abraded in aeolian transport.

Summing up: the detritus compositions of the red quartz arenites (see Table 3a) indicate either source rocks low in feldspar, and/or the extensive destruction of the feldspars during weathering and transport. The low proportion of unaltered feldspar grains favours the latter possibilities. These sandstones were probably laid down mainly in shallow water, possibly in ephemeral rivers or lakes. Local accumulation on aeolian dunes in an arid or semi-arid desert environment is probable.

The occurrence of euhedral quartz overgrowths on grains in the red arkosic sandstones of the lowermost part of the Nässjö Formation (cf. p. 63) as well as the apatite cementation found locally (see p. 68) suggest that similar environments may have prevailed during the earliest time of deposition of the Nässjö Formation.

DEPOSITIONAL SEDIMENTARY FACIES OF THE NÄSSJÖ FORMATION

The argillite facies, the argillite/fine-grained sandstone association, the red arkosic sandstone facies and the medium-grained feldspathic sandstone/coarse conglomerate association dominate the sedimentary sequences of the Nässjö Formation.

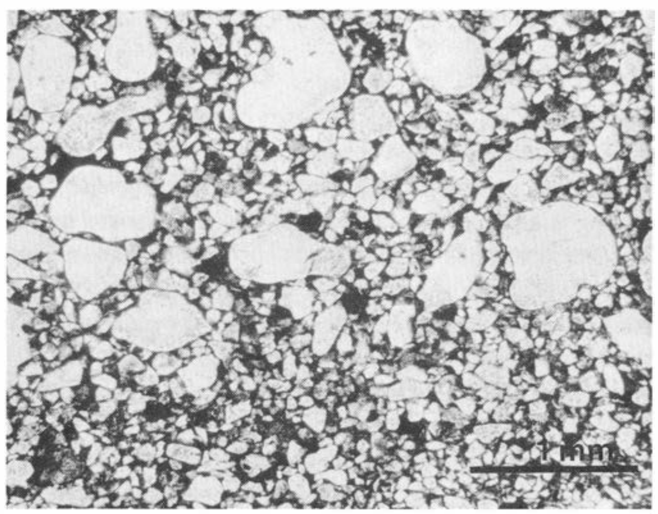


Fig. 31. Bimodal grain-size distribution in a sample of reddish subarkosic sandstone of the argillite/fine-grained sandstone association in the Nässjö Formation. Rounded and subangular grains in sparse muddy hematitic matrix. The large rounded grains probably derive from the older sandstone cover. Plain light. Base of SE sequence, Nässjö 1 in Fig. 5.

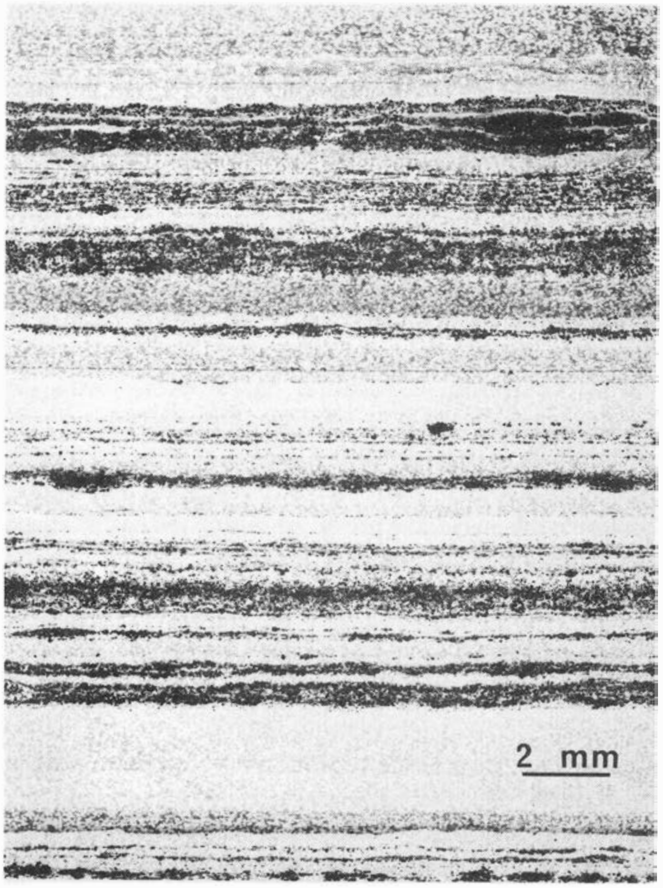


Fig. 32. Even, parallel lamination in argillite. Negative print from thin section; black laminae are siltstone, white laminae hematitic claystone. Argillite from the upper part of the SE sequence, Nässjö 1, in Fig. 5.

THE ARGILLITE

Description. — The argillite facies consists predominantly of silty claystone and siltstone. The rocks of this facies are almost invariably laminated, occasionally also containing laminae of very fine-grained sandstone and hematitic wackestone. The siltstone is composed of quartz and sericitic feldspar in a sericitic or hematitic matrix. Zircons, micas and opaque oxide grains are the main accessories. The claystone consists mainly of illite with variable amounts of chlorite. The chemical composition is described elsewhere (Rodhe 1985).

Lamination is mostly thin and discontinuous but may also be even and parallel or wavy to lenticular (Figs. 32, 33). Thick claystone laminae are often graded. The grain size decreases upwards whereas the content of hematitic clay increases. The parallel lamination sometimes shows a rhythmic trend.

Wavy to slightly lenticular layering is prominent in several thick argillite units, and flaser bedding can be identified locally. Flat sandy siltstone or sandstone lensoids can sometimes be observed in lenticular bedded sequences (Fig. 34). Lenticular siltstone and claystone laminae occasionally reveal internal micro-structures such as cross-lamination, wavy lamination in ''bundles'' (Fig. 35) or minute mud flasers, all typical of wavy flaser lamination (Reineck and Singh 1980). Flaser bedding with ''simple flasers'' has also been observed locally on weathered rock surfaces (Fig. 36).

Mud cracks (shrinkage cracks) of a polygonal, irregular, random orthogonal type are common. The polygons range up to 0.2 m across. Two or three generations of cracks can often be observed on the same bedding plane. Seen in cross-section, the mud cracks are mostly shallow and roughly U-shaped. Ptygmatically folded fine-sand or silt wedges infilling mud cracks can occasionally be observed (cf. Fig. 34). Thin sandstone ''dykes'' very often fill the cracks (cf. p. 21, Fig. 18). Thin beds or laminae

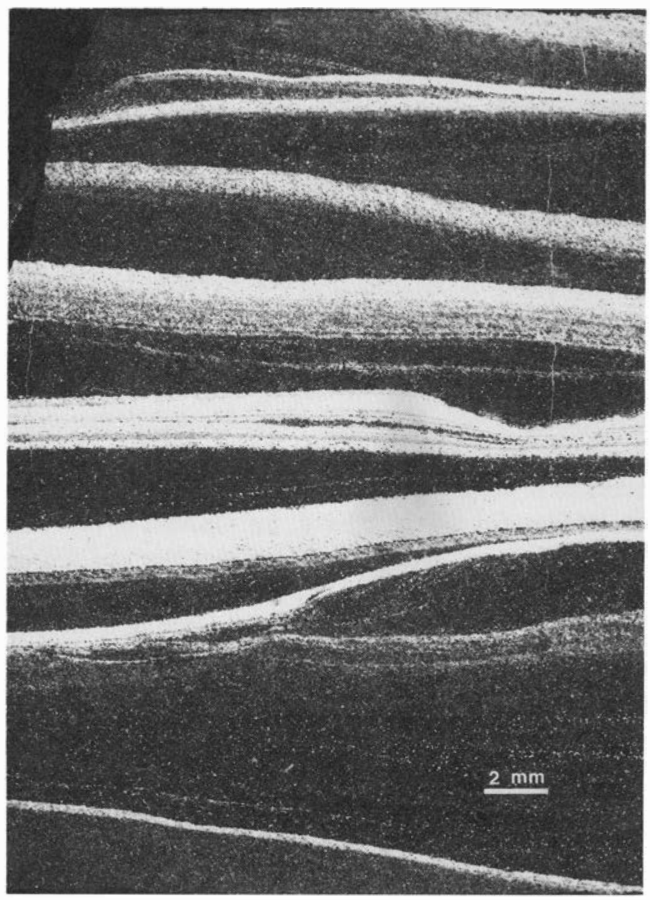


Fig. 33. Ripple lamination in wavy-lenticular bedded argillite. Negative print from thin section; black laminae are siltstone, white laminae hematitic claystone. Note bifurcation of mud flasers (arrow) and grading in claystone laminae. Sample from road cutting in the easternmost argillite outcrop of the Forserum subarea, Fig. 14.

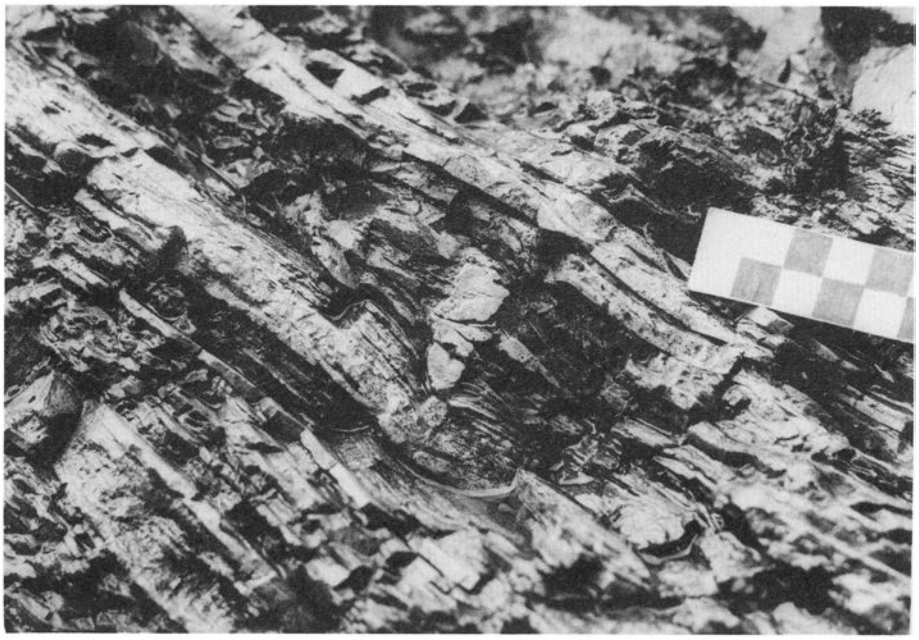


Fig. 34. Lenticular bedding in argillite with sandstone lenses (lower left). A ptygmatically folded wedge of fine-grained sandstone or, possibly a pillar indicating water expulsion is oblique to the bedding (lower centre). Scale in centimetres. Outcrop in the NW sequence b, Nässjö 1, in Fig. 5.

of clay-pebble breccia are sometimes associated with the argillites and can, in places, be seen to have been derived from a subjacent claystone layer. These breccias are mostly monomictic. The length of the clasts ranges from a few millimetres to 10 cm and the matrix varies from silty clay to coarse sand (Fig. 37). The breccia layers sometimes occur repeatedly at irregular intervals in a sandstone/argillite sequence (cf. Fig. 40, Mattarp 1).

Interpretation. — Evenly parallel-laminated mud indicates deposition by settling in still water (Pettijohn 1975, Allen 1982). Each graded lamina may represent deposition from a suspension cloud of silt- and clay-size material supplied by a pulse of current. This kind of sharply defined persistent lamination indicates a low degree of flocculation of the clay minerals because of low electrolyte content in fresh or brackish water (Reineck and Singh 1973, Blatt *et al.* 1980). Such lamination is most likely to be preserved in Precambrian sediments and possibly also in later sediments that were deposited in low-oxygenated basins and lacked bioturbation (Potter *et al.* 1980). This suggests that the depositional environment was lacustrine or lagoonal.

Wavy-lenticular layering and flaser layering are exam-

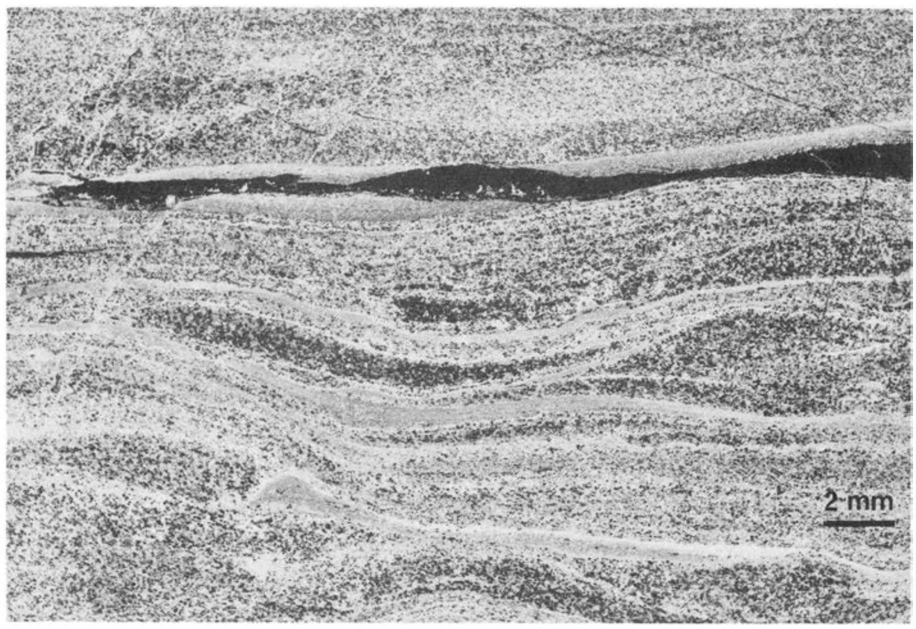


Fig. 35. Lenticular micro-structure in argillite with incipient ripples and mud flasers. Negative print from thin section; dark layers are siltstone, white and greyish layers mudstone, black "layer" is hole in mudstone. Argillite from the uppermost part of the SE sequence, Nässjö 1, in Fig. 5.

Fig. 36. Weathered outcrop in fine-grained sandstone with mud flasers. Scale in centimetres. Lowermost part of the sequence Forseum 3a in Fig. 46.

ples of ''ripple bedding'' in a two-component system (Reineck and Singh 1980). Formation of current or oscillation ripples in the coarse member alternates with erosion and, during episodes of quiescence, with mud fallout. This kind of layering, particularly when occurring in thick units, is typical of deposition on intertidal flats. It has also been reported from deltaic or lacustrine environments characterized by strong variation in sediment supply (Reineck and Singh 1973).

In the Almesåkra Group the components are mostly sandy silt and clay, occasionally fine sand and clay. Ripples formed by predominantly oscillatory flow are suggested by the type of lamination seen in some siltstone lenses (cf. Fig. 35).

The wacke-stone layers are interpreted as re-deposited sand and mud; the grain size is strongly bimodal. Upwards, these layers generally grade into argillite or sandstone while the lower boundaries are sharply defined. These features are most easily explained by deposition from currents of more than average energy with capacity to erode mud deposited during preceding periods of low-water.

Red hematitic mudstone indicates deposition in oxidizing environments (Turner 1980). Mudcracks, that are clearly V-shaped and sand-filled and indicate that dewatering occurred by exposure to air, are scarce in the Almesåkra argillites. This may be because mud laminae are mostly thin or because soft-sediment deformation is very common (cf. Fig. 44 and p. 35). The complete and regular development of two generations of mud cracks seen on many bedding surfaces suggests, however, that the cracks were caused by desiccation (Plummer and Gostin 1981, Allen 1982).

The clay-pebble breccias are common in the argillite/fine-grained sandstone association described below. Such breccia beds are ubiquitous in ancient alluvial sequences of interbedded mudstone and sandstone (McKee 1954, Allen 1962, Pettijohn 1975). They are also common in deltaic sequences (Taylor 1963) and have been reported from tidal flats (Reineck and Singh 1980). Their presence indicates that the currents were periodically strong enough to erode mud-cracked layers. The oblong and angular ''ripped-up-clasts'' have clearly been transported over short distances only. Rhythmically occurring intraformational breccias or conglomerates of this type have been reported from a number of ancient continental deposits. Although individual layers are thin and contribute little to the total thickness of sedimentary sequences, such beds are often very frequent. Thus, there are 6 to 8 beds of clay-pebble breccia to each 100 m of sandstone in parts of the lower Old Red Sandstone described by Allen (1962). In the basal Mattarp beds west of Bodafors, there are on average one breccia layer to each metre of the host sandstone (Fig. 40).

THE ARGILLITE/FINE-GRAINED FELDSPATHIC SANDSTONE ASSOCIATION

Description. — The sandstone of the argillite/fine-grained sandstone association is grey, reddish or buff in outcrops. The composition is arkosic to subarkosic, the matrix content is usually below 15%. Most of the feldspar is altered, mainly to sericite. The average contents of lithic and o-

Fig. 37. Clay-pebble breccia in sandstone. Scale in centimetres. Polished hand specimen from an outcrop c. 3 km S of locality Mattarp 2 in Fig. 4.

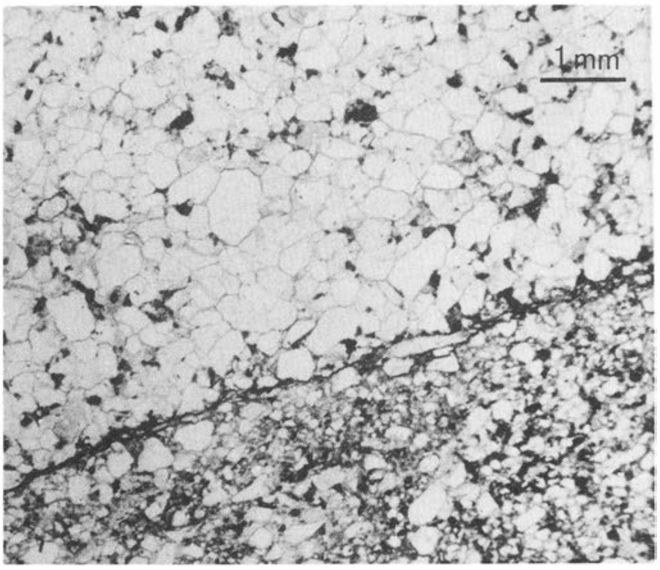


Fig. 38. Well-defined lamination in medium-grained quartz-rich and fine-grained sericitic sandstone of the Nässjö Formation. Plain light. Sample from outcrop c. 2 km N of locality 1 in the Nässjö subarea, Fig. 5.

paque grains are much lower than in the red arkosic sandstones but higher than in the medium-grained sandstones of the Branteberg Formation (Table 3).

Quartz usually dominates among the authigenic minerals, especially in relatively coarse layers consisting mainly of detrital quartz grains. Silty to very fine-grained sandy laminae contain much sericite mostly derived from altered feldspar (Fig. 38). The matrix here is largely a pseudomatrix (Dickinson 1970). Authigenic epidote and chlorite minerals tend to dominate in some laminae or thin beds. Hematitic mud occurs in pores between the sand grains or in laminae or thin beds of red wacke-stone. An alternation of colour bands ranging from dark grey (N4) to pale olive-grey (5Y 6/1—4/1) or pale red (R 6/2) is thus produced, seen particularly well on weathered surfaces. A highly calcareous variety of the argillite/fine-grained sandstone association occurs in a small area at Lake Hamnaryd (Fig. 1) enclosing formerly well-known ''limestone'' quarries. This sandstone variety contains the largest single concentration of authigenic calcite found in the Almesåkra Group (cf. Petrography p. 67).

Several sequences in the Spexhult area (Figs. 39, 40) exemplify the thin bedding and variable lithology generally found in this association. In the composite section of Fig. 39, which comprises at most 25 m of typical beds of argillite/fine-grained sandstone, sandstone beds occur at irregular intervals. They are mostly fine-grained or very fine-grained and irregularly laminated by silt or silty clay. Where argillites dominate they occur in units up to 20 m thick with subordinate sandstone beds of variable thickness and lateral persistence. In some argillite units there is a more or less evident trend of coarsening upwards. Silty layers become thicker and/or tend to be more frequent. In the sandstones, no systematic variation in grain size or bed thickness can usually be observed.

Parallel lamination is predominant in the basal deposits of the Nässjö Formation (Figs. 40, 41). It is the most common sedimentary structure observed in the sandstones of the argillite/fine-grained sandstone association. Laminae of mudstone or very fine-grained sandstone occur singly or in groups at irregular intervals. Mostly in the medium-grained sandstone a few cross-stratified beds have been observed (Figs. 39, 40). The cross-strata are of the trough type, the sets being mostly solitary and at most 0.2 m thick (Fig. 39).

The lower contacts of sandstone beds against argillite or argillite-dominated units are sharp. They are mostly planar and the downward bounding surfaces lack channeling features. The transition upwards from sandstone or sandstone-dominated beds into argillite is mostly abrupt, but gradual transitions are seen in the upper part of the southeastern profile (Fig. 39). Because of the soft-sediment deformation structures commonly found in beds of this association, the character of the facies transitions is generally difficult to assess.

In some sandstone beds, lensoid structures can be seen in cross-section. They range from a few centimetres to 2 m in width and differ from the surrounding sandstone by their colour and often by slightly coarser grain sizes. In the largest observed lensoid structure there is an internal lamination which is concave upward and roughly conformable to the shape of the lens. Very small-scale cross-lamination can be seen locally.

Small-scale ripple marks with wave-lengths less than 0.1 m occur on bedding surfaces in most exposures of the association. They are regular and straight- to somewhat curving-crested, that is ''two-dimensional'' (Harms *et al.* 1982), and commonly have rounded crests (Fig. 42). In vertical profile transverse to the crests, the ripple marks are symmetrical or slightly asymmetrical and represent a combined-flow type of oscillation ripples (wave ripples). Ripple marks of the same type are found on mud-coated surfaces and may be associated with mud cracks.

Soft-sediment deformation is common in this association. Thin beds of sandstone laminated with mudstone often display mud-cracked surfaces with infillings of sandy material up to a few centimetres wide (Figs. 43, 18). The mode of infilling, whether by hydrostatic injection of sand or by sedimentation from above cannot always be determined. In some cases, however, a faint side-parallel

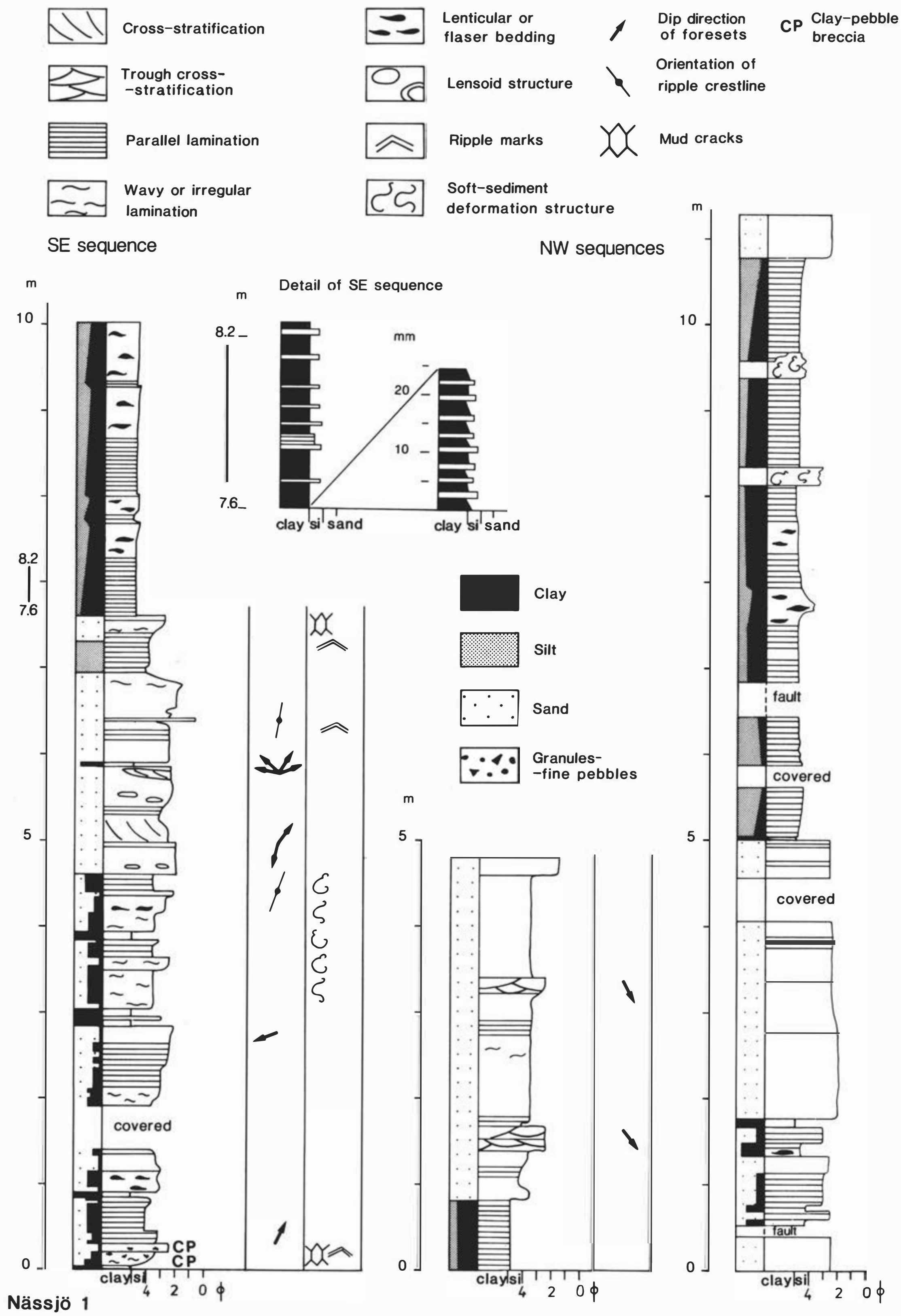


Fig. 39. Type sections through argillite and fine-grained sandstone of the Nässjö Formation at locality 1, Fig. 5. Lithology is shown to the left, grain size and structures to the right. The observations were made in two outcrops, c. 50 m apart, in a NW-trending fault scarp facing north and topped by a dolerite sill. The beds dip gently mainly NW. The NW sequences are displaced relative to the SE sequence by a minor fault trending E—W. The two NW sequences are separated by unconformably intruding dolerite. The average grain size of the sandstone is shown in Phi units at the base of each section. The grain size was estimated by hand lens, the observations verified in several representative thin sections.

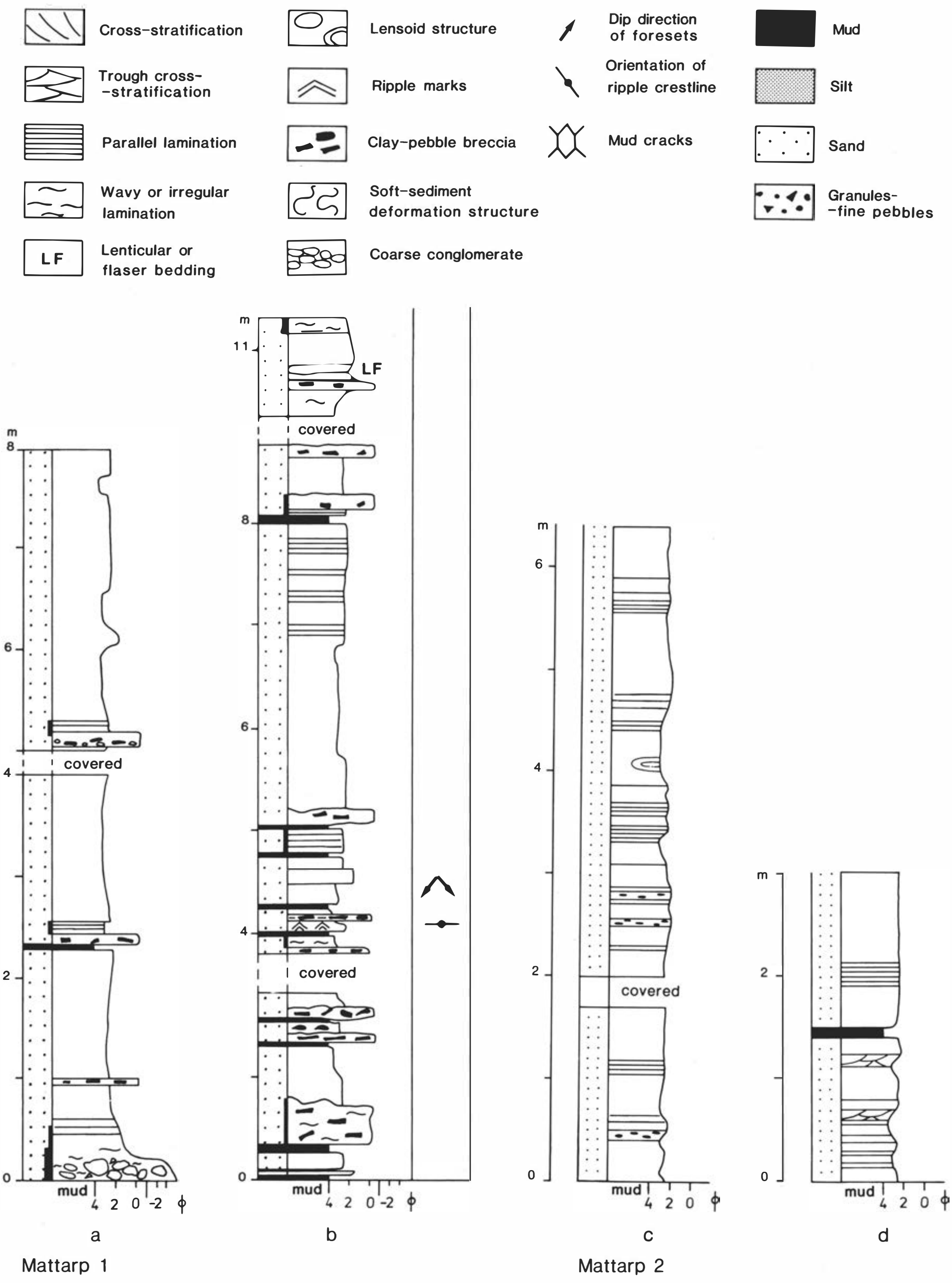


Fig. 40. Sections through fine-grained sandstone interlaminated with argillite and containing clay-pebble breccias in the virtually horizontal Mattarps beds (see Fig. 4). The sequences Mattarp 1a and b lie c. 50 m apart in a west-facing fault wall topped by dolerite. The basal conglomerate-breccia is exposed beneath sequence a and is inferred beneath sequence b. The sequences Mattarp 2c and d are exposed on a hillside 1.6 km SSE of Mattarp 1. The base of the sequence Mattarp 2d lies at a stratigraphic level about 15 m above the top of sequence 2c. The sandstone at Mattarp 2 belongs mainly to the red arkosic sandstone facies. A dolerite sill crops out further up the hillside. At both localities bedding is horizontal to gently dipping with variable strike. Average grain size and directional structures are shown as in Fig. 39.

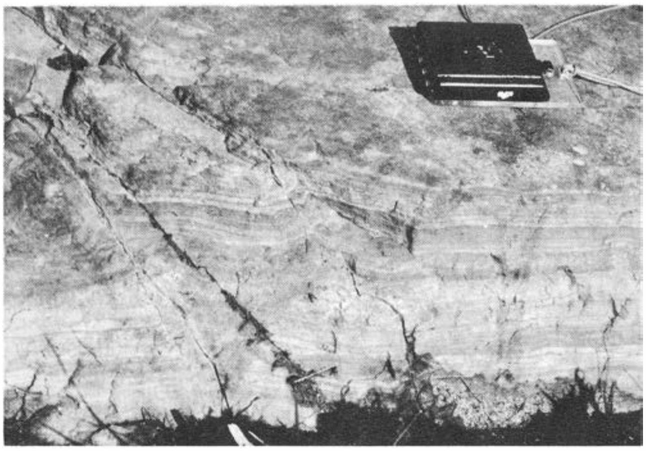


Fig. 41. Parallel lamination in argillite bed overlying granitoid basement. Part of the basement can be seen below the compass which is 10 cm long. Outcrop on the SSE shore of L. Sjunnaryd, Fig. 1.

lamination of the sand-filled mud cracks suggests injection of the sand by laminar flow (Fig. 43). In cross-sections small irregular sand bodies may be seen to protrude from these injected dykes or from deformed sandy layers (Fig. 44).

The soft-sediment deformed structures have complex three-dimensional shapes. Most are seen as steeply inclined zones of faintly structured sand which are discordant to lamination and resemble the pillars of type B of Lowe (1975). The pillars, of variable height, are commonly less than one centimetre wide. They may be larger locally and numerous. In some beds (e.g. at Lake Hamnaryd, cf. Fig. 26), the pillars are more or less funnel-shaped and may exceed 0.2 m in height.

Interpretation. — The range of grain size and many characteristics of the interlayering of the argillite and the fine-grained sandstone show that this association can be interpreted as belonging to the top stratum of a flood or delta plain or possibly to a tidal-flat environment. The rapid shifts of flow conditions and the shallow water depths, which can be inferred from such features as thin layering, the erosion of mud layers, small-scale ripple marks and the presence of hematitic mudstone, exist in all these environments (Allen 1964, Reineck and Singh 1973, Allen 1982).

Parallel-laminated sandstone beds are a prominent feature of the association. They indicate deposition on plane beds, probably under rapid flow conditions approaching the upper flow regime. This conclusion is supported by the observation that trough cross-stratification tends to occur only in beds which are somewhat coarser than average (cf. Harms *et al.* 1982). The cross-stratified beds indicate deposition on dunes (megaripples) at lower velocities of flow.

The ripple marks indicate shallow water and a dominant oscillatory component of the flow. The rounded crests suggest that the ripples were formed at high flow velocities (Harms *et al.* 1982). Ripple marks of this type prevail in the Almesåkra fine- to medium-grained sandstones (see Fig. 13) but are best exposed in beds of the Forserum Formation and the upper part of the Branteberg Formation. Additional aspects are considered in the section on palaeocurrents (p. 51).

Thinly interlayered muds and sands which may be ripple-laminated are sometimes referred to as a ''turbidite-like association'' (Allen 1982). They are produced by river systems during periodic flooding of interchannel areas by overbank flow or by ''crevassing'', e.g. splitting of the channel bank (Doeglas 1962, McKee *et al.* 1967, Reineck and Singh 1973). Sedimentation in channels of deltas strongly influenced by tides and storms produces a similar form of interlayering (Reineck and Singh 1973).

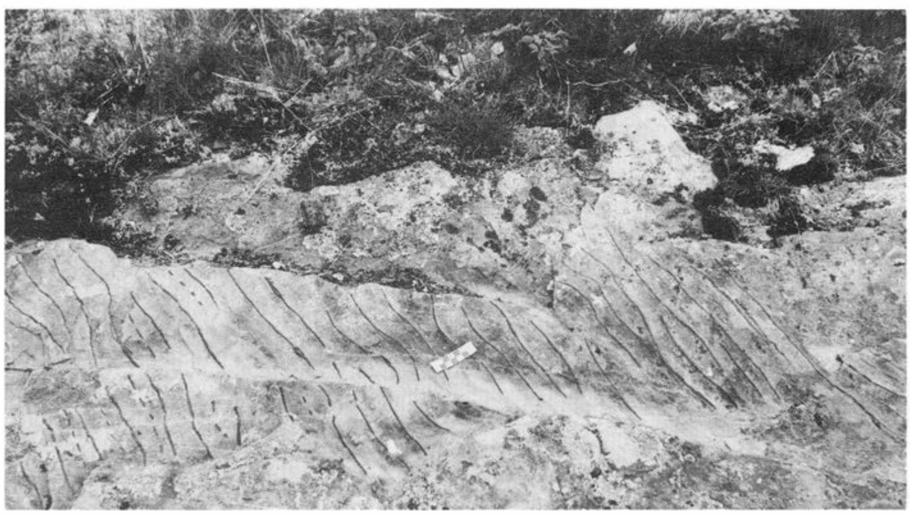


Fig. 42. Train of ''two-dimensional'' ripple marks with regular, slightly curving crests. The ripple crests are marked with black lines; black dotted lines at left denote secondary crests. Scale in centimetres. Outcrop 2 in the Marbäck subarea, Fig. 24.

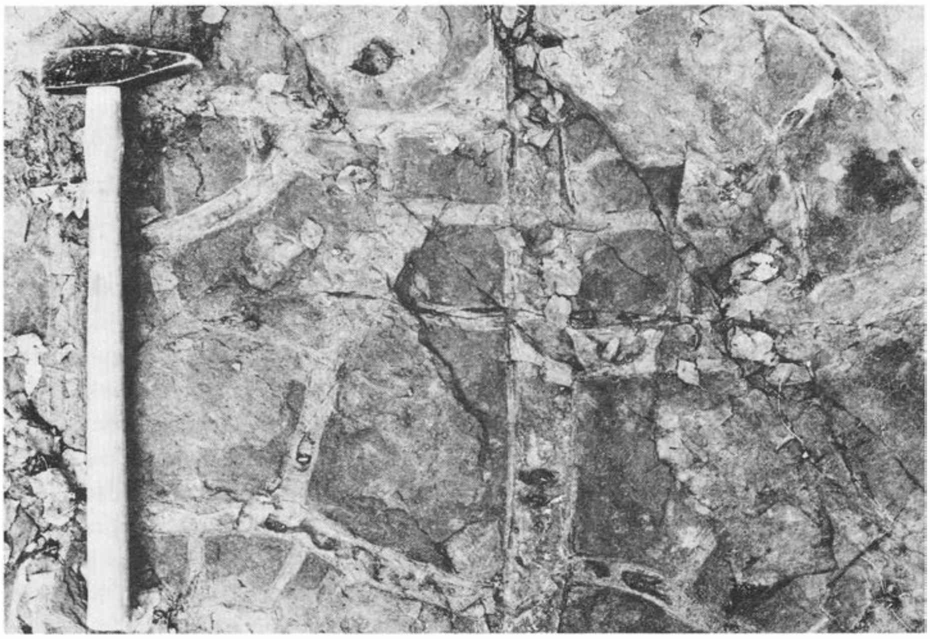


Fig. 43. Partly oriented orthogonal mud-crack pattern in argillite at the base of the Nässjö Formation. Lamination seen in the sandstone filling the cracks is parallel to the edges of mudstone polygons suggesting that the sand has been injected by laminar flow from below. Hammer 0.4 m. Outcrop on the SSE shore of L. Sjunnaryd, Fig. 1.

The lensoid structures observed in some beds and the tendency for the grain size to increase upwards (Fig. 39) give additional indications regarding the mode of deposition. The lensoids are interpreted as cross-sections of minor channel-fills. In the largest structure observed, conditions seem to have been in accordance with those in submerged channels (Reineck and Singh 1973). The tendency of the lower contacts of the sandstone beds to be sharp, and the channeling features, suggest that part of the sandstone could have originated by crevassing of a river bank (Elliott 1974).

Upward increase in thickness and frequency of silty-sandy laminae is common in silty clays deposited in fluvial-lacustrine environments. Upward coarsening of this type is produced when fluvial materials fill in a depression in a plain, e.g. by an advancing small delta (Coleman 1966, Kelling 1968, Oomkens 1970). Similar sequences are reported from ancient deltaic-lacustrine sequences (Taylor 1963) and also from intermontane tectonically controlled basins (Bryhni 1978, Pollard *et al.* 1982). In the top strata of some environments of this kind, e.g. in the Carboniferous and Cretaceous, red mudstones (McBride 1974, Turner 1980) are as common as in the Almesåkra Group.

The argillite/fine-grained sandstone association probably represents various flood plain — lacustrine or possibly deltaic deposits. Support for the former, more proximal, model may be found in the close field association between argillite beds and sandstones with interbedded coarse conglomerates which are clearly of a fluvial type (cf. p. 10 and Fig. 9).

The majority of the sand dykes, filling mud cracks in argillitic sandstones of the Nässjö Formation, are probably caused by the injection of fluidized sand. The various pillars and deformed sand layers are interpreted as water escape structures (Lowe 1975, Allen 1982), that is, caused by fluidization and water expulsion. The pillars represent fluidized sand that has moved discordantly upwards in columns and sheets. Soft-sediment deformation of this kind is penecontemporaneous with early compaction and deposition. It occurs in sediments of coarse silt to gravel grades but is commonest in silts and fine sands (Dionne and Shilts 1974, Lowe and Lo Piccolo 1974). It has been

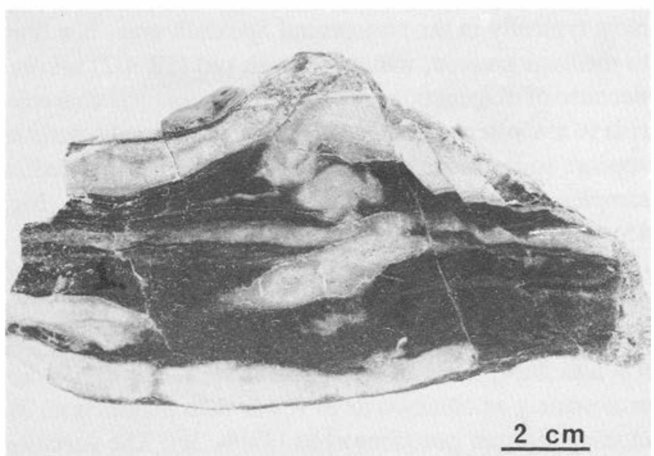


Fig. 44. Water-expulsion structures in argillite/fine-grained sandstone. An irregular sand body has disrupted the layering and partly extruded as a "sill" along the bedding surface above. Polished hand specimen from the lower part of the SE sequence, Nässjö 1, in Fig. 5. Photo by S. Stridsberg.

reported widely from waterlaid sequences of rapid accumulation that promotes loose packing (Allen 1982). The frequency and scale of pillar structures are believed to be positively correlated with the accumulation rate of the overburden. In heterolithic sediments, ''loading compaction'', that is, compaction by the rapid advance of superposed sand beds on to piles of interlayered cohesive and non-cohesive materials, may be sufficient to trigger off local fluidization (Lowe 1975). Sands deformed in the soft-sediment stage, and injection structures, have often been reported from distal alluvial fan environments (Laming 1966).

Injected sand dykes and sills, often of large scale, are also reported to form as a consequence of earthquakes. Cyclic disturbance initiates the collapse of cohesionless sediments which are fluidized and then driven upwards by density inversion or inclination of the depositional area (Hayashi 1966, Hesse and Reading 1978, Bryhni 1978).

The water escape structures in the Almesåkra argillitic sequences are clearly larger (up to 0.3 m) and more frequent in the Nässjö Formation of the Nässjö-Lake Hamnaryd area than in other lithologically and depositionally comparable units in the western part of the Spexhult area. In the Branteberg sequence in the Forserum subarea, pillars are infrequent and at most a few centimetres high. Along with loading compaction, tectonic events may have caused much of the soft-sediment deformation. This is supported by the lack of slumping features in this facies association (cf. Allen 1982).

THE RED ARKOSIC SANDSTONE

Description. — The red arkosic sandstone, occurring most typically in the east-central Spexhult area, is a fine- to medium-grained, mainly greyish red (5R 4/2) arkose. Because of diagenetic modification, the textural characteristics are often difficult to assess. The sandy detritus appears to be moderately sorted. In most of the studied samples the grains are subangular to subrounded (Fig. 45).

This sandstone is rich in lithic grains and opaques and occasionally verges on a lithic arenite (cf. Fig. 60a). The whole-rock content of feldspar detritus ranges between 9% and 26%, the average being 20%. K-feldspar is approximately as common as or lower than plagioclase, including feldspar pseudomorphs (Table 3c). The variation of feldspar types is wider than is usually observed in the Almesåkra feldspathic sandstones. Finely structured patch- and string-perthitic grains, which are almost wholly restricted to this lithofacies, are commoner than coarse-perthitic types. Accessory minerals include epidote and titanite which are uncommon or lacking in other facies. Micas are more frequent than in other sandstones of this grade and may amount to 1—2%.

The colour of the sandstone is due to hematite which is largely present as numerous grains of specularite and pseudomorphs after mafic minerals and rock fragments. The average content of coarse hematite is nearly 4% (cf. Table 3c). Authigenic clay minerals are commonly the first cement coating the detrital grains. Authigenic quartz is low as compared with other non-argillitic sandstones.

Most of the outcrops in the poorly exposed areas display massive beds of medium thickness and beds with parallel lamination defined by fine sand or silt that is often rich in opaques. Laminae of silty claystone may occur exceptionally. The lamination is generally not sharply defined. The laminae are mostly persistent, they are even and parallel, often occurring in groups. There is sometimes a thin interbedding of medium-grained sandstone with fine-grained sandstone. Sets of large-scale trough cross-stratification up to 0.3 m in thickness are observed in a few outcrops. Some cross-strata display soft-sediment deformation structures such as overturned cross-bedding. The cross-stratified sets alternate with thin beds with parallel lamination.

Ripple marks of the same type as those in the argillite/sandstone association have been found mostly in boulders and blocks. Coarse layers, e.g. thick laminae containing granules and small pebbles, occur exceptionally. Red clay chips, at most a few centimetres across and often rounded, are found locally on bedding surfaces or scattered in the sandstone. Thin (1—5 cm) beds of clay-pebble breccia occur in a few exposures of this sandstone where it is transitional into the argillite/sandstone association (Fig. 40:2).

Interpretation. — The grouped sets of cross-strata indicate deposition on dunes. The restricted textural range of most of the lithofacies and the paucity of structures other than parallel lamination indicate a shallow-water environment. The scarcity of mudstone layers shows that flow conditions were less variable than during the deposition of the argillite/sandstone association (cf. Harms *et al.* 1982).

The large-scale trough cross-stratification which alternates with parallel lamination in part of the red arkosic sandstone suggests that the parallel-laminated beds were deposited under flow conditions of the upper regime. The same general interpretation also applies to other parts of this facies lacking association between parallel-laminated and cross-stratified beds and other diagnostic features. Persistent, not sharply defined parallel lamination in rela-

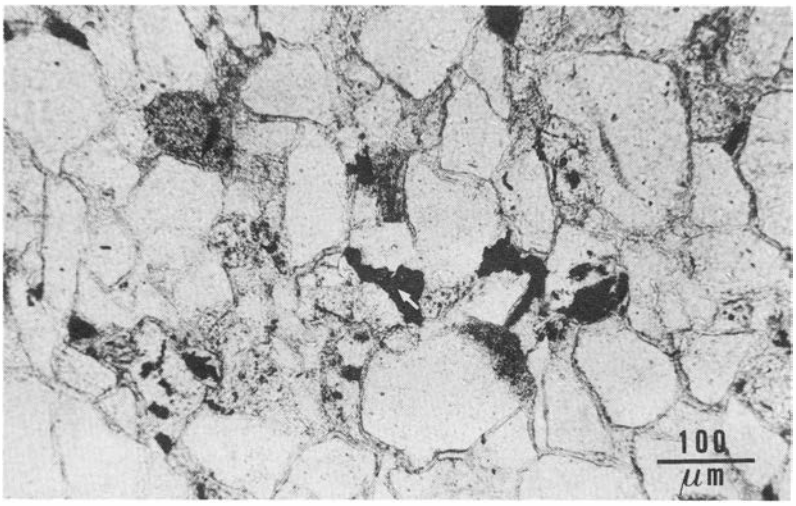


Fig. 45. Texture and cementation in red arkosic sandstone of the Nässjö Formation. Quartz cement fills pores between grains coated with clay minerals. Note poor roundness and scattered specularite grains and hematitized biotites, one of which (white arrow) is replaced by titanite. Plain light. Sample from outcrop N of Bodafors, Fig. 1.

tively fine-grained sands has been reported from sands in numerous present-day rivers, e.g. from the ''horizontally laminated'' flood deposits produced by rapid, strong shallow flows (McKee *et al.* 1967) and also from tidally influenced sands.

The overturned cross-beds are believed to indicate that strong drag was exerted on previously deposited, waterlogged strata when the flow increased after a temporary slack or low-water interlude (Allen and Banks 1972). Similar phenomena have been reported also from distal parts of alluvial fans where ground-water rises towards the surface thus increasing the hydrostatic pressure on soft sandy sediments (see Pettijohn *et al.* 1973, Dott and Doe 1980).

The medium—grained feldspathic sandstone/coarse conglomerate association

Description. — The conglomerates of this association are clast-supported. They are bimodal, displaying pebble- to cobble-sized clasts in a matrix which is generally a moderately sorted sand. The beds usually have sharp lower and upper contacts. There is sometimes a gradual transition from a conglomerate bed into sandstone with scattered pebbles. Individual conglomerate beds cannot be traced for more than a few metres in any direction. Often they wedge out laterally and merge gradually into sandstone. On bedding surfaces, clusters of large particles sometimes suggest remnants of local channels. The conglomerate matrix is not as well sorted as the associated sandstone and is generally also more immature in composition.

The associated sandstones are often massive. Lamination of several types occurs mainly in sandstones of the Forserum Formation. It is defined by variation of the feldspar content. The lamina sets are mostly 0.1—0.2 m thick. Separate sets seen in various sections may persist laterally for a few metres. The sets of sub-parallel or very low-angle discordant laminae do not appear to truncate each other as do similar sets observed in the wave-generated ''swash'' lamination of beach sands (cf. Reading 1978, Thompson 1937). In most sections, the type of bedding described alternates with medium to thick beds with even parallel lamination (Figs. 18, 46) and occasionally with indistinctly cross-laminated thin beds of the same lithology and grain size. Distorted and compressed bundles of laminae in a few beds indicate soft-sediment deformation (Fig. 46:1).

Units of the medium-grained sandstone/coarse conglomerate association can locally be estimated to have thicknesses of about 100 m (cf. Figs. 10, 18). Sandstone clearly dominates over conglomerate. The conglomerate beds are mostly less than 0.3—0.4 m thick and occur in groups in most sections.

The bed thickness distributions for coarse conglomerates are shown in Fig. 47. In the ''sandy'' conglomerates as well as in the ''fine-gravelly'' ones, most beds are thin or medium-thick. This may be because about one third of the beds were observed in eroded outcrops where they presumably do not display their maximum thickness.

The distributions of maximum particle size (MPS) are similar in the two associations (Fig. 47). Both tend to be bimodal and skewed towards finer sizes. When bed thickness is plotted against MPS there is pronounced overlap between conglomerates belonging to the fine and coarse conglomerate/argillite association and those belonging to the medium-grained sandstone/coarse conglomerate association (Fig. 48). There is little or no correlation between MPS and bed thickness except for small MPS and thin beds.

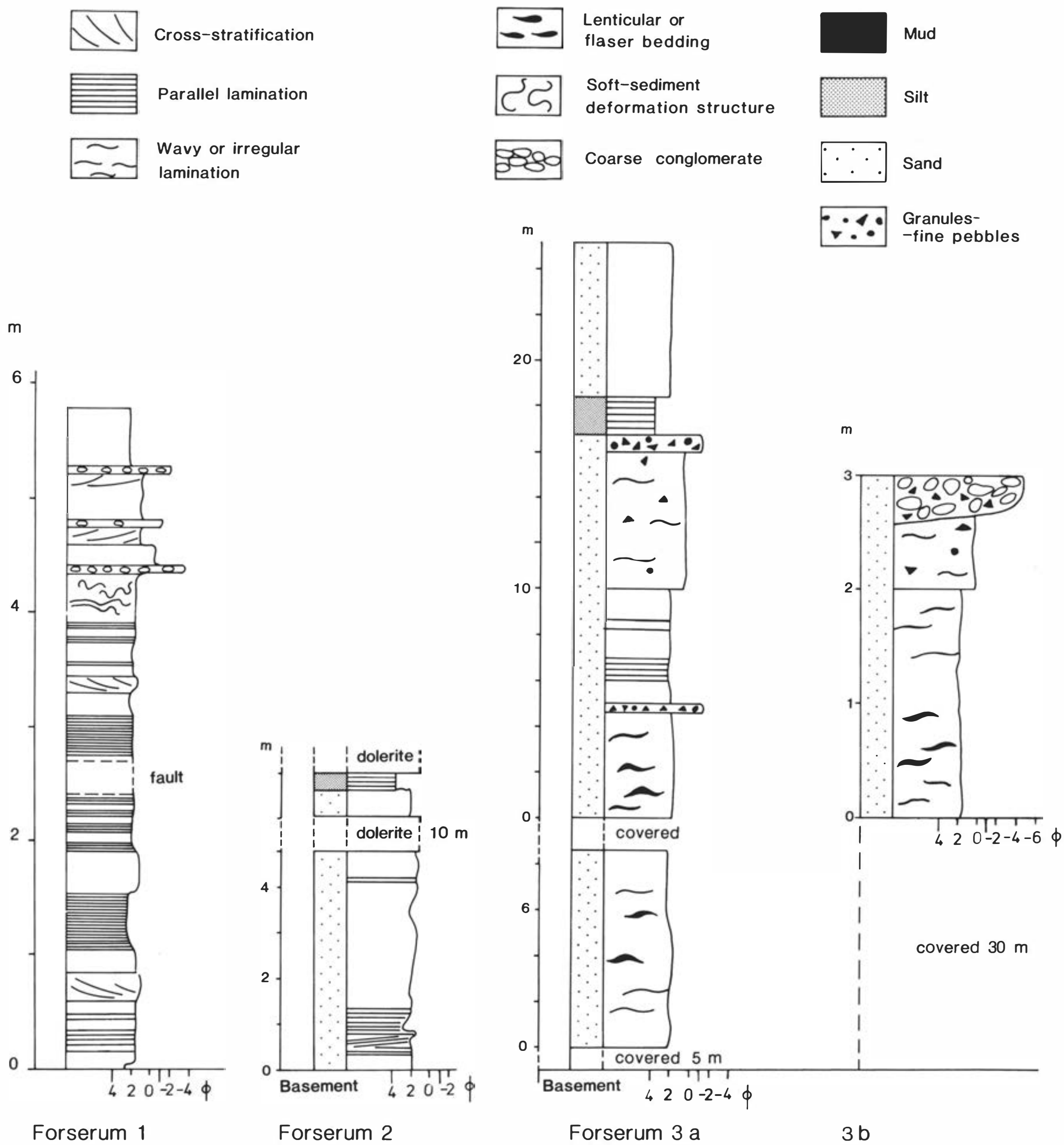


Fig. 46. Sections through the Forserum Formation. The observations were made in the outcrops denoted by digits in Fig. 14. The sequence Forserum 2 was observed at Forserum in steeply east-dipping beds overlying faulted basement rocks and intruded by dolerite. The sequences Forserum 3a and 3b were observed in steeply to gently dipping beds on a small horst of basement c. 2 km S of Forserum. Average grain size shown as in Fig. 39. Sequences Forserum 1 and 2 are type sections of the Forserum Formation.

Interpretation. — The interbedded sandstones and coarse conglomerates represent fluvial deposits, probably mainly lag deposits of various channels. This is suggested by the predominance of thin bedding in the conglomerates, the poorly defined stratification and sharp contacts with sandstone, as well as by the poor sorting (Fig. 49 and Table 4) and the local channelling features (cf. p. 41 and see Harms *et al.* 1982). Little or no correlation between MPS and bed thickness is to be expected in coarse lags of sandy river channels or in the gravels of braided streams (Bluck 1967). Both environments are characterized by considerable reworking of older deposits. The thickness

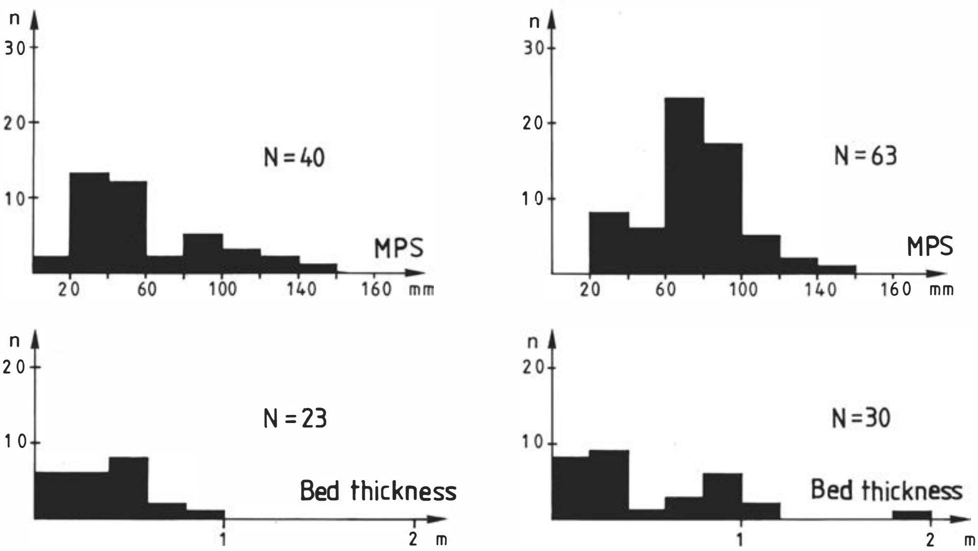


Fig. 47. Distribution of maximum particle size (MPS) and bed thickness of conglomerates of the fine and coarse conglomerate/ argillite association (left) and of coarse conglomerates of the medium-grained sandstone/coarse conglomerate association (right).

of eroded and redeposited beds bears little or no relationship to the competence of the initially depositing flow. Therefore, there is also little correlation with the size of the largest deposited particles.

The low-angle discordant and parallel lamination seen in many sandstones of this association points to deposition by flows of the ''upper flow regime''. The main reasons for this interpretation are the close association in the field with beds displaying even, parallel lamination and the occurrence of cross-bedded units in the sequences (cf. interpretation of parallel lamination in the fine-grained sandstones on p. 38 and Harms *et al.* 1982).

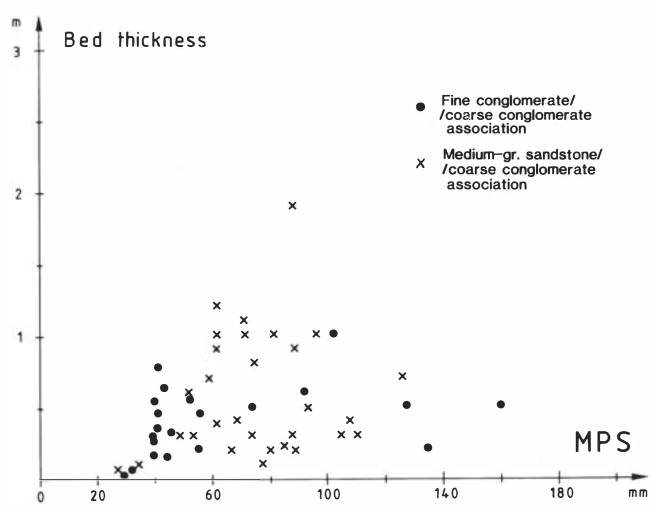


Fig. 48. Bed thickness plotted against maximum particle size in coarse conglomerates of the Almesåkra Group.

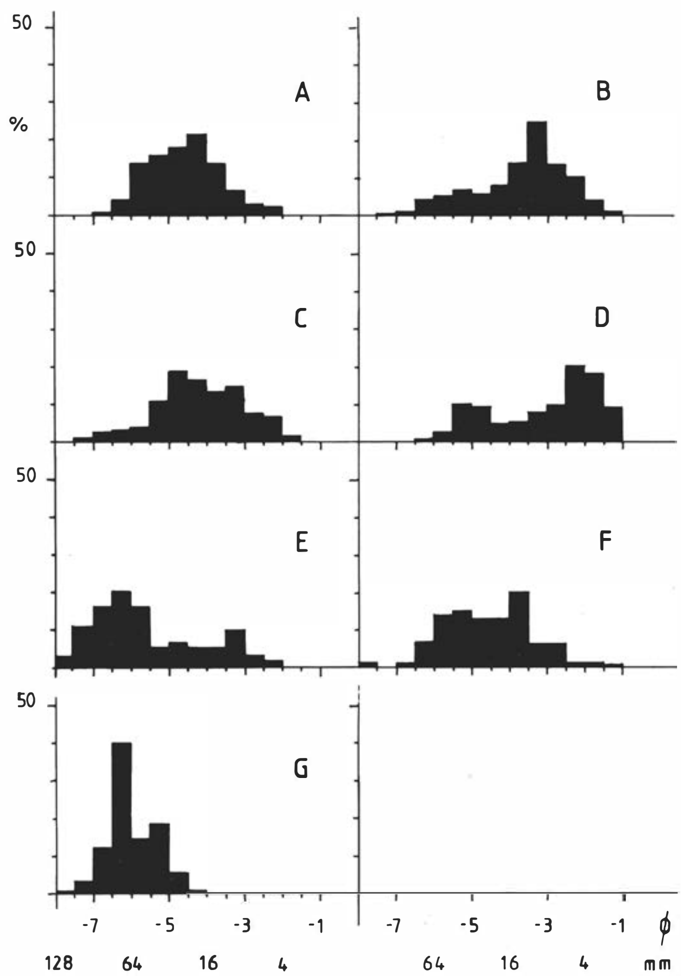


Fig. 49. Particle size distributions of coarse conglomerates. A, C, E: Nässjö Formation, B: Forserum Formation, D: Branteberg Formation, F: Storekvarn Formation. The distribution of 79 MPS values is shown in diagram G.

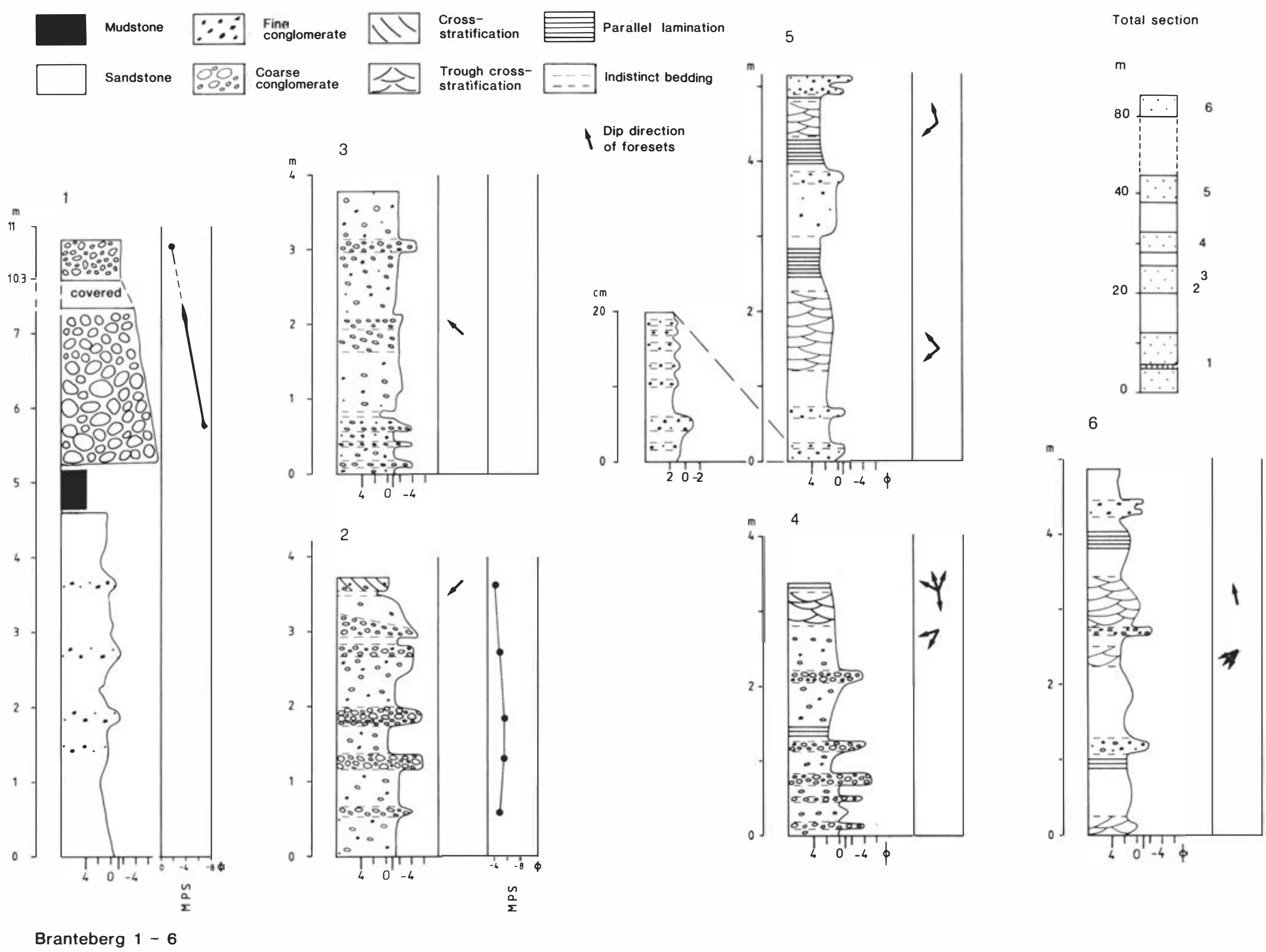


Fig. 50. Type sections through the conglomerates and sandstones of the Branteberg Formation overlying the unconformity over the Nässjö Formation. The observations were made in the outcrops denoted by digits in Fig. 12. Upper right: sketch showing the stratigraphic order of the sequences 1—6 shown in the sections, with approximate height levels in metres. The base of the sandstone of the Nässjö Formation in section No. 1 is taken as the 0 m-level. Average grain size and directional structures are shown as in Fig. 39. The argillite bed overlying the unconformity between the Nässjö and Branteberg Formations in sequence No. 1 is not seen in outcrop but is inferred from numerous cobble-sized angular clasts found at this level.

DEPOSITIONAL SEDIMENTARY FACIES OF THE BRANTEBERG FORMATION

The fine and coarse conglomerate/argillite and the medium-grained feldspathic sandstone/fine conglomerate associations dominate the Branteberg Formation sequence.

THE FINE AND COARSE CONGLOMERATE/ARGILLITE ASSOCIATION

Description. — The texture and typical interlayering of this association are shown in Fig. 50, which represents sequences studied in the Branteberg subarea.

Stratification is planar or inclined at very low angles (Fig. 51). It is defined mainly by the interbedding of coarse and fine conglomerates (Fig. 50). Less well-defined stratification in the fine conglomerate beds is indicated by small-scale interlayering between sandy gravel (gravel mode at 4—5 mm) and granules mixed with subordinate coarse sand (gravel mode at 2—3 mm). The beds of fine conglomerate contain numerous large pebbles and cobbles which occur scattered or in thin layers and patchy accumulations (Figs. 50, 52). The coarse conglomerates are polymodal with poorly sorted, coarse-sandy granular matrix. The beds have predominantly gradational contacts.

In units with high contents of sand, the beds sometimes display sets of cross-strata (Fig. 52) which may be grouped. The sets have variably curved, erosional lower and

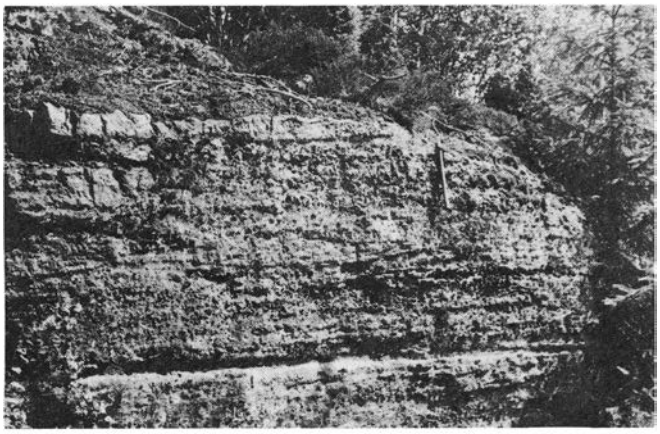


Fig. 51. Planar stratification in beds of fine and coarse conglomerate of the Branteberg Formation. Hammer 0.5 m. Outcrop No. 2 in the Branteberg subarea, Fig. 12.

upper contacts; they persist laterally for at most a few metres. The thickness of the sets ranges from 5 to 30 cm, which is similar to that of the sets in the cross-stratified overlying sandstones (cf. p. 46). An upward decrease in set thickness and average grain size is observed in some of the sections (Figs. 50:4,6).

The proportion of coarse gravel estimated in the sections varies between 40% and 60%. The distribution of maximum particle size (MPS, cf. p. 27) is bimodal with the strongest mode at 3—5 cm and the other at 9—11 cm (cf. Fig. 47). The correlation between MPS and bed thickness is poor (cf. Fig. 48).

Red (10 R 4/2) or grey (N 4), massive or parallel-laminated siltstone is a minor component of the association. The siltstone occasionally grades into claystone or very fine-grained sandstone. These layers range in thickness from about 5 mm to 5 cm. They are often observed in shallow depressions on conglomerate bedding surfaces just covering the pebbles. Exceptionally, a persistent unit of this type may reach a thickness of 0.8 m.

In deposits of a similar association in the Forserum subarea, where very few beds of coarse conglomerate are exposed, the fine conglomerates occur in thick beds. Red clayey siltstone and fine-grained sandstone are major components (cf. p. 17). Cross-stratification of the trough type on various scales can be observed in the interbedded sandstones and fine conglomerates. Small-scale sedimentary structures include mud cracks, load structures and ripple marks.

Interpretation. — The high gravel content of this association indicates that it was laid down by a transport system of considerable flow strength. Most features suggest deposition from flows of fluctuating velocity and high sediment charge.

The coarse conglomerate beds indicate predominant tractional transport by being clast-supported and displaying preferred orientation of the long axes of the pebbles. The very poorly sorted fine conglomerate beds lack preferred orientation of the particles. This indicates that the detritus was predominantly transported in suspension. The gradational contacts between the beds suggest fluctuating flow and the grain sizes of framework and matrix in the coarse conglomerates suggest largely simultaneous deposition of bed load and suspended load (cf. Harms *et al.* 1982). These features indicate subaqueous transport on a slope at high sediment charge. A depositional en-

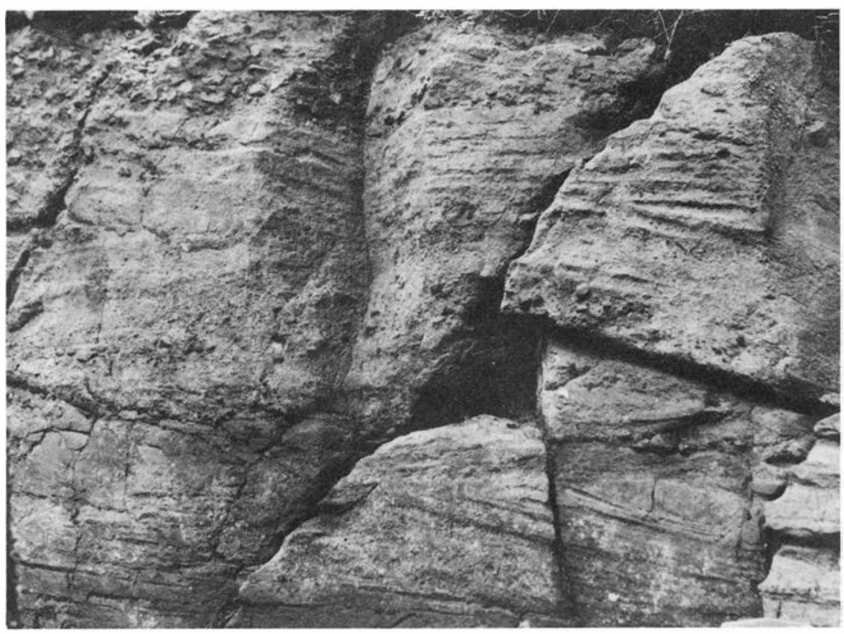


Fig. 52. Large-scale trough cross-stratification in sandy fine and coarse conglomerates of the Branteberg Formation. Note lenticular bed of coarse conglomerate (centre) and part of second bed (above). Hammer head, lower right, 14 cm. Outcrop No. 4 in the Branteberg subarea, Fig. 12.

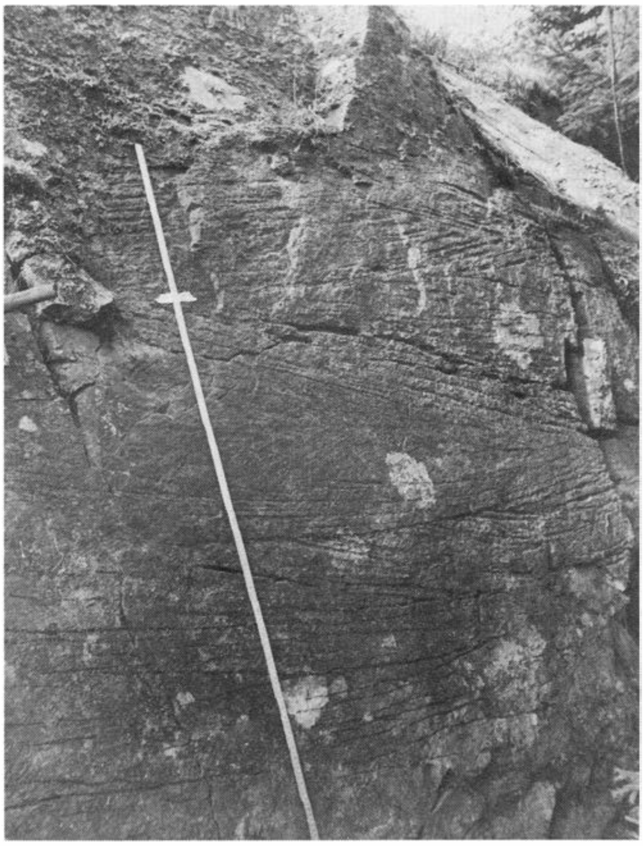


Fig. 53. Sets of large-scale trough cross-strata in the medium-grained sandstone/fine conglomerate association. The traces of foresets have been filled in with black on the rock. Carpenters rule c. 2 m. Outcrop No. 5 in the Branteberg subarea, Fig. 12.

vironment of lower alluvial fan type, that is, of pebbly braided rivers is indicated (Walker 1975b, Boothroyd and Nummedal 1978, Harms *et al.* 1982).

The type of stratification closely resembles that reported from various types of gravelly bars forming in the upper reaches of modern pebbly and low-sinuosity rivers or on glacial outwash plains (the ''braided flows'' of Rust 1972b, cf. also Gustavsson 1974, Smith 1974, Hein and Walker 1977). Such bars are ephemeral bed forms. They may be either transverse or elongated downstream and migrate in this direction. Gravel bars often develop on remnants of older lag by the deposition of the coarsest bed load from shallow, rapid flows (Leopold and Wolman 1957, Eynon and Walker 1974). They are characteristic of pebbly braided rivers with highly variable discharge and abundant supply of coarse debris (Williams and Rust 1969, Miall 1977). The process of bar building from diffuse gravel sheets moving only at maximum flow results in a crude horizontal stratification. Cross-bedded gravels tend to occur at lower rates of discharge and have finer gravel modes (Hein and Walker 1977). In the sequences 2 and 3 shown in Fig. 50, planar or very low-angle stratification is observed in thin coarse beds. There is also an occasional low-angle cross-stratification. These features suggest the preservation of superposed migrating gravelly bars (Smith 1974).

In some sections (see Fig. 50), cross-stratified sandy beds are observed. They resemble units which have often been described as interlayering various massive or crudely bedded gravels. They are believed to represent temporary bar margins or minor channel-fills or both (Miall 1977, Harms *et al.* 1982). The occurrence of interlayered siltstone or mudstone in the conglomerates agrees with this interpretation. In most descriptions of the deposits of present-day, pebbly braided rivers, a thinly bedded fine-grained facies has been noted. Massive and laminated, up to a few centimetres thick mud-and-silt drapes or laminated fine sand, silt and mud, may form layers in restricted undisturbed areas such as abandoned stream channels or sheltered spots on small beaches downstream of the bars (Rust 1972b, Gustavsson 1974, Miall 1977, Reading 1978).

In the Branteberg subarea, the facies sequence overlying the unconformity between the Branteberg and Nässjö Formations (cf. p. 15) can be traced stratigraphically upwards for almost 100 m. The gravelly and sandy facies are closely related. The transitions between gravel- and sand-dominated beds are usually gradual and symmetrical (cf. Selley 1969, Harms *et al.* 1982).

THE MEDIUM-GRAINED FELDSPATHIC SANDSTONE/FINE CONGLOMERATE ASSOCIATION

Description. — For this association the variations in grain size, gravel content, thickness of beds and type of stratification have been recorded in a number of vertical sections (see Figs. 50, 53).

The prevalent sedimentary structure is a large-scale trough cross-stratification occurring in cosets. Erosional surfaces are slightly curved or almost planar. Cross-strata are upward-concave and more or less tangential to the lower boundaries of the sets (Fig. 53). The sets are typically 15—20 cm thick, but may range up to about 30 cm. The sets persist laterally for at most a few metres. The dips of cross-strata are 15° to 20° in tectonically undisturbed units and the strata range in thickness from a few millimetres to about 2 cm. They are defined by grain-size variation, e.g. medium sand alternating with coarse sand which may be rich in granules and pebbles (Fig. 50). As seen in most sections, the cross-stratification resembles the ''low-angle planar cross-stratification'' described by High and Picard (1974), which is distinct from the ''high-angle avalanche-front type'' of these authors. When clearly developed, the cross-stratification is of the π-type in Allen's scheme (Allen 1963, Fig. 4) which is the ''three-dimensional'' end member in Allen's later (1982) system of bed form dimensionality.

The cross-stratified units alternate with medium to thin sandstone beds which are massive or display parallel lamination. A few very thin sandstone beds may be fine-grained. Fine conglomerates, e.g. single or grouped parallel laminae or thin beds of granules and pebbles, occur between the cross-stratified beds. They are texturally and compositionally indistinguishable from the coarsest-grained foreset laminae in these beds. In the field, this association exhibits transitional relationships with the conglomerate/argillite association described above (p. 44f.).

Interpretation. — The alternation between large-scale trough cross-stratified units and parallel-laminated or massive sandstone beds indicates deposition by flows alternating between the ''lower'' and ''upper flow regimes'' (Harms *et al.* 1982). The trough cross-stratification was generated by the downstream migration of dunes. Dunes are ''three-dimensional'' large ripples, i.e. with curving and irregularly spaced crest lines. They are more variable in height than the ''two-dimensional'' ripples described above (cf. p. 35). The parallel-laminated sandstone beds indicate deposition on plane surfaces.

Subaqueous dunes deposited in fairly shallow troughs up to a few metres in length seem to have been the dominating bed form of the cross-stratified sands. According to many students of modern deposits of this kind, there is a tendency for ''two-dimensional'', tabular cross-stratified large ripples to represent lower average flow velocities than do more ''three-dimensional'' types (Harms *et al.* 1982). On the other hand, some grain-size effects recorded in the literature indicate that dunes forming in coarse sands and fine gravels have smaller amplitudes and also tend to be less ''three-dimensional'' than those forming in finer deposits (Allen 1982, Rust 1972b).

The thin, granular and gravelly coarse beds occurring between the cross-stratified units probably reflect fluctuations in depth of water or in bed-load composition rather than major changes in flow regime (Collinson 1970). Deposits of this kind are commonly encountered in sandy fluviatile environments ranging from point-bars in high-sinuosity rivers to various bars built between channels in low-sinuosity braided streams. Dunes are well known also from tidally influenced estuaries, coasts and shallow marine platforms; their general scale increases with the scale of flow (Allen 1982).

The facies sequence. — The gradual transition from coarse conglomerates to cross-stratified sandstones described above probably indicates a shift from more proximal to more distal alluvial fan environments. Support for this interpretation is found in the general continuity of the sequence of facies and bed forms. Additional support comes from various studies of present-day rivers which show that sand-dominated bars tend to increase in frequency downstream in pebbly braided rivers, whereas gravel bars tend simultaneously to decrease (Smith 1970, Miall 1977, Rust 1979).

The westerly palaeocurrent directions (cf. p. 49), the large initial content of fine granitoid debris, and the progressive decrease in this debris *versus* other components (cf. p. 70), suggest that, in addition to derivation from uplands east of the Almesåkra Group, the Branteberg Formation was derived from fault scarps in which the granitoid basement was exposed. The proximal-distal evolution of the sequence was probably caused by a successive lowering of relief in the east; gentler depositional slopes caused finer detritus to be laid down. At the same time granitoid sediment sources became subordinate to upland source areas which appear to have consisted largely of older sedimentary cover and porphyries. An alternative explanation could be lateral shifts and consequent gradual abandonment of stream channels on the proximal fan(s). This model appears less probable because of the wide extent of essentially similar sequences north of Branteberg in the Ralången area.

The relative thinness and the upwards decreasing grain sizes in the Branteberg Formation suggest that the deposition of the alluvial fan was caused by a single episode of faulting rather than by repeated displacements characterizing strike-slip faults (cf. Heward 1978). Thus, the marginal faults which controlled the deposition of the Branteberg Formation in the Ralången area were probably regional vertical faults.

In the northern Ralången area and also in the minor occurrences of the Spexhult area, cross-stratified sandstones are prevalent and coarse conglomerates are few. This indicates a general change of the depositional environments from relatively proximal, pebbly braided rivers to more distal, sandy rivers.

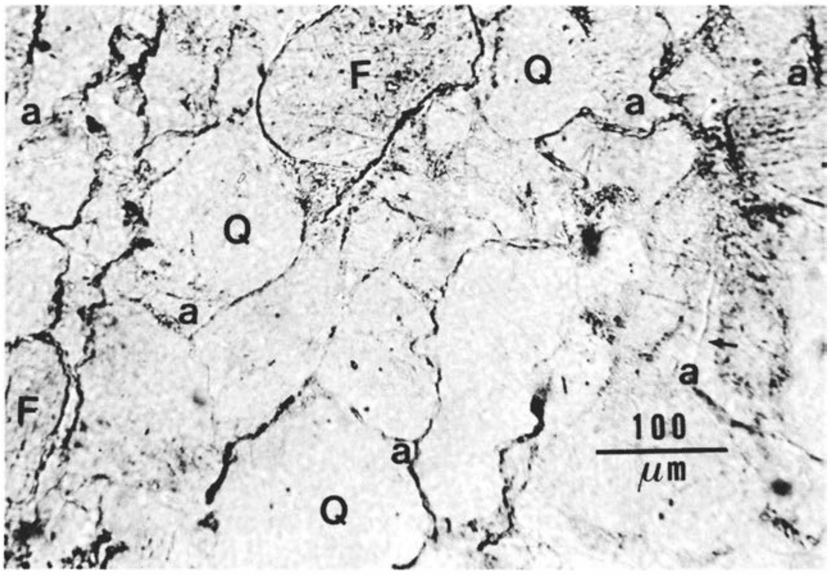


Fig. 54. Texture and typical cementation of the quartzitic sandstone lithofacies, Storekvarn Formation. Q and F denote rounded quartz and feldspar grains, a denotes authigenic quartz. Note local thin sericite rims and one straight cement-to-cement contact (arrow). Most grain-to-grain contacts are long or tangential, a few are sutured. Plain light. Sample from an outcrop in the N. Spexhult area, Fig. 1.

DEPOSITIONAL SEDIMENTARY FACIES OF THE STOREKVARN FORMATION

THE GREY QUARTZITIC SANDSTONE

Description. — The quartzitic sandstone is commonly a greyish subarkose with a low feldspar content (Table 3). Pure white or pink quartz-arenitic types occur in several outcrops. The detritus is a well-sorted to moderately sorted medium-grained sand with rounded to well-rounded grains (Fig. 54). Authigenic quartz occurs everywhere as syntaxial overgrowths extending into and generally completely filling the pore space (Fig. 54). The detrital quartz grains can usually be distinguished by rims of ''dust'', fine hematite pigment or, occasionally, by thin discontinuous sericite coatings. This distinction is only partly possible in the purest white quartzitic sandstones and in samples from tectonically disturbed strata. The feldspar is mainly K-feldspar (cf. Fig. 63a), mostly microcline. In most of the quartzitic sandstones, overgrowths of authigenic K-feldspar occur on the feldspar grains and may occupy up to 1% of the total rock volume.

In most outcrops, the sandstone is massive. In places, poorly defined laminae rich in feldspar represent an element of sedimentary structure. The feldspar laminae may sometimes be grouped, sub-parallel or discordant. Interbedding with siltstone or mudstone is notably absent. The small outcrops and the very common close jointing limit structural observations. Local, incongruently high bedding dips suggest the presence of some type of cross-bedding. In one subarea, interlayering coarse conglomerates occur. The lower contacts of the conglomerate beds are planar or slightly upward concave erosional surfaces. The conglomerates are roughly of the same composition and average particle size as those found in exposures of the sandstone/coarse conglomerate association of the Nässjö and Forserum Formations.

Interpretation. — The quartzitic sandstones are interbedded with coarse conglomerates of a type and depositional facies resembling closely that of the conglomerates occurring in the sandstone/coarse conglomerate association described above (p. 41). This suggests that the quartzitic sandstones were also laid down in a fluvial environment (cf. p. 42). Petrographic characteristics of the quartzitic sandstones and of the sandstones of the Branteberg Formation considered relevant to this are given below (p. 71). The rest of the interpretation is therefore referred to p. 73.

PALAEOCURRENTS

PALAEOCURRENTS IN THE NÄSSJÖ AND FORSERUM FORMATIONS

In the case of the red arkosic and the argillite-associated fine-grained sandstones of the Nässjö Formation, indications of paleoflow direction are inconclusive. Observations have been made in several outcrops in the Spexhult area, most of them in the Nässjö subarea. Vectors were derived from foresets in cross-stratified beds of different sizes; only a few are based on observed trough axis directions. The rose diagram is bimodal, suggesting that streams flowed towards the south and northeast (Fig. 56). Ripple crest orientations in the same lithofacies indicate that oscillatory wave train movements trended mainly NW—SE. The preferred orientations of particles on bedding surfaces in the sandstone/coarse conglomerate association are more informative (Fig. 55). The long-axis distributions tend to be unimodal, the modes oriented approximately NE—SW. In a few cases imbrication indicates transport towards the northwest.

A northwesterly direction of transport is also inferred for the gravels of the Forserum Formation. The axial modes of particles are similar to those in the Nässjö Formation, and imbrication indicates flow towards the northwest. Most of the foreset azimuths in the associated sandstones were recorded from scattered instances of small-scale cross-stratification (cf. p. 41). The crest orientations for oscillation and combined-flow ripple marks show a polymodal distribution.

PALAEOCURRENTS IN THE BRANTEBERG FORMATION

In the Branteberg subarea transport was from east to west, as shown by the orientation of foresets mainly in the cross-stratified sandstones but also in the conglomerates (Figs. 55, 56). The spread in directions is large which is hardly surprising. Flow directions, obtained from foreset azimuths in cross-stratified alluvial sediments of this type, have a large variance (see e.g. Dott 1973, High and Picard 1974, Miall 1974). In present-day rivers, the mean vector derived from the dip directions of foreset laminae in cross-

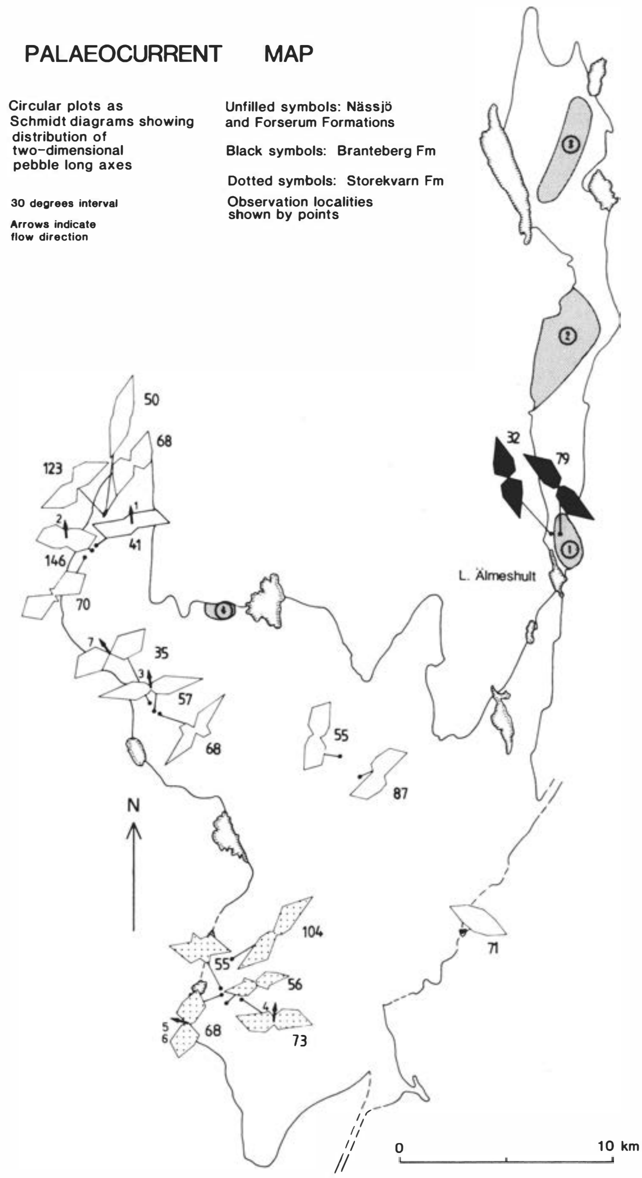


Fig. 55. Palaeocurrent indications in coarse conglomerates of the Almesåkra Group. Large numerals indicate the number of pebble long-axis orientations recorded at each locality. Small numerals indicate the localities where imbrication direction could be assessed (see Fig. 57). Shaded areas with digits in circles are observation areas for cross-bedding dip directions in the Branteberg Formation, the distributions shown in Fig. 56.

stratified sand may be regarded as closely approximating the local direction of flow (Smith 1972). In the sandstone of the Branteberg subarea (Fig. 12), the azimuth readings

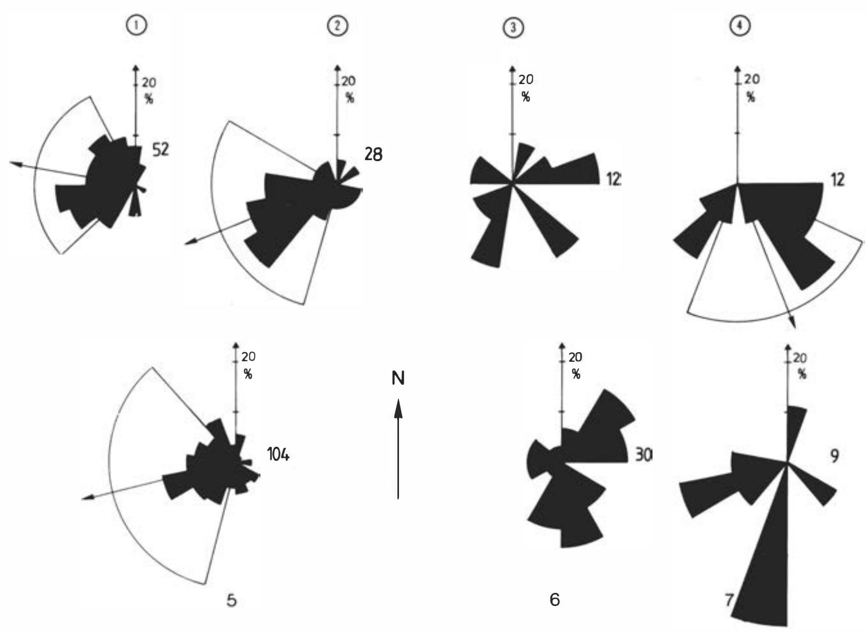


Fig. 56. Circular plots showing distributions of foreset dip directions of large-scale cross-beds in the Branteberg Formation corresponding to the observation areas in Fig. 55 (1 through 4), the total Branteberg Formation (5), and of mainly small-scale cross-beds in the Nässjö Formation (6) and the Forserum Formation (7). The numerals at each plot indicate the number of observations. Sector width is 20°; mean vectors and angular deviations were calculated according to Curray 1956.

are clustered, and distributed across rather than along the inferred flow direction. This suggests the occurrence of many channels; therefore, the sampling may be unrepresentative. Later, variable low-angle (<10°) tectonic tilting of the units can also be inferred. Since the attitude of regional bedding could not always be determined exactly, no correction was attempted.

In the central part of the Ralången area, the direction of transport was to the southwest (Fig. 56). Only a few readings were obtained from scattered outcrops in the northernmost part of the Ralången area. The detritus appears to have been transported mainly southwards but also eastwards. Similar transport directions were obtained from the cross-bedded sandstones of the Branteberg Formation adjoining the Forserum subarea to the east.

Palaeocurrent directions are also indicated by conglomerate fabrics which can be studied on bedding surfaces. In the Branteberg subarea, the long axes of the conglomerate particles tend to have unimodal distributions oriented NNW—SSE, as seen best in prolate cobbles. Assuming

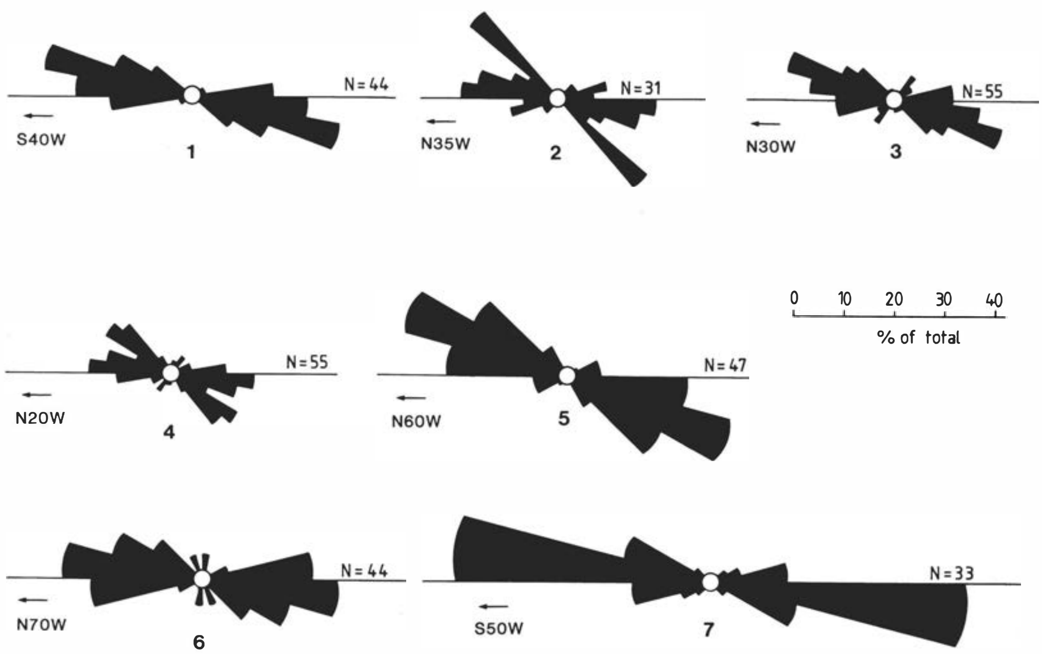


Fig. 57. Imbrication directions of conglomerate pebbles as seen in the field in sections normal to the bedding plane. The diagrams show the distribution of apparent long axis dips as related to the trace of the bedding plane (horizontal lines). The numerals refer to observation localities (1 through 7) indicated in Fig. 55. Sector width 10° or 15°.

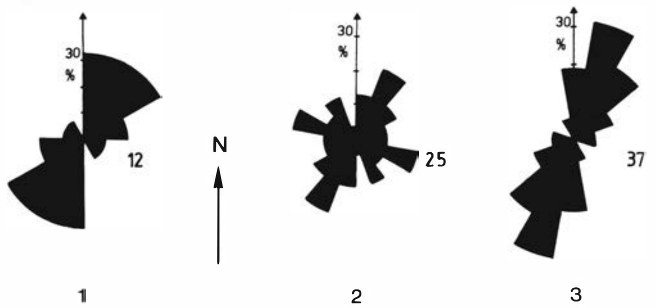


Fig. 58. Distributions of ripple mark crest orientations in the Nässjö Formation (1), the Forserum Formation (2) and the Branteberg Formation (3). The numerals indicate the number of observations.

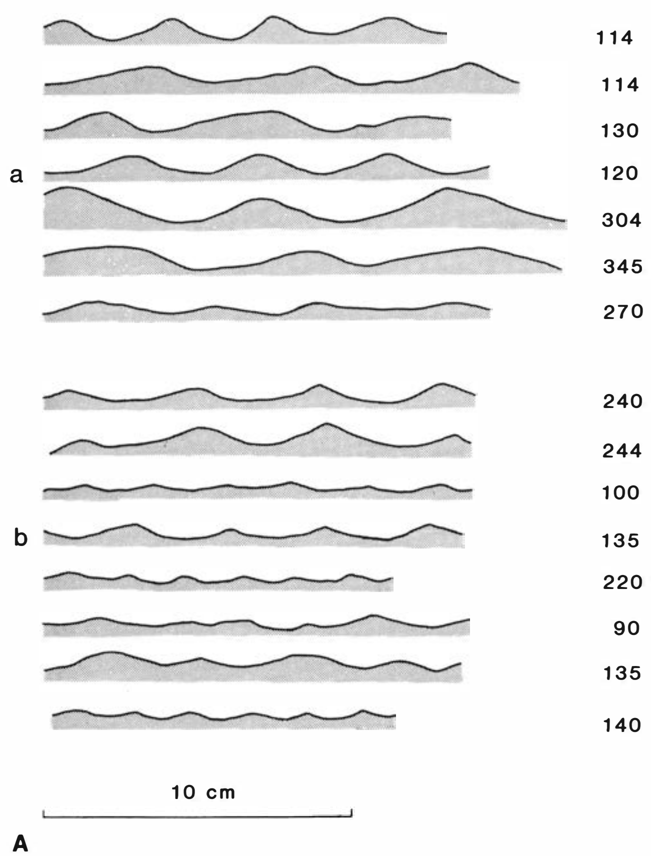
that most of these have their long axes oriented transverse to the direction of flow (cf. Harms *et al.* 1982, Johansson 1965), this agrees with the mean direction of flow recorded from the cross-strata. The local palaeoflow in the gravel-transporting system was thus towards the west and southwest.

Bedding surfaces with ripple marks are fairly common in the upper, relatively fine-grained sandstones of the Branteberg Formation in the Ralången area (cf. Fig. 13). The preferred orientations of the crestlines tend to cluster between N—S and NE—SW (Fig. 58). A few ripple marks have been noted in the lowermost units of the Branteberg Formation, none in the Storekvarn Formation.

As in the Nässjö and Forserum Formations, almost all ripple marks represent ripples of a combined-flow type (cf. p. 35). They are small-scale and generally slightly asymmetrical (Fig. 59A). Form indices plotted in Tanner's (1967) diagram indicate that they are mostly wave ripples of variable asymmetry. Only a few plot in the field of overlap with current ripples (Fig. 59B). The ripples represent oscillatory and oscillation-related movement of water (Allen 1979). Application of Allen's diagrams (1979) relating ripple form parameters and sediment grain sizes to the range of possible oscillation periods shows that these are well below a limiting value for shallow water. The wave ripples are therefore interpreted as due to wave trains in shallow water moving in the direction of decreasing water depth.

Small wave-generated ripples with wave-lengths of less than 8 cm are common along the banks of some present-day streams. They are believed to result from secondary wave trains moving away from the channel and refracted towards the shore at an oblique angle to the main flow (Gustavsson 1974, cf. also Donaldson 1967, Williams and Rust 1969).

Fairly prominent sinuosity, observed in one highly asymmetrical wave train in the Branteberg Formation, indicates current ripples (Reineck and Singh 1973). The orientation of most steep crest faces suggests that the wave



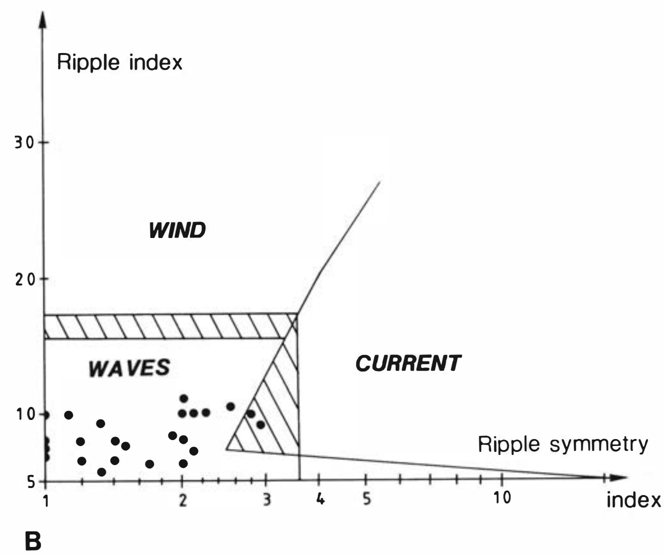


Fig. 59. A: Profiles of representative ripple marks in the Forserum Formation (a), in the Branteberg Formation (b). Numbers to the right indicate the trends of the profiles in degrees from north. The ripple marks were analysed with a profile comb. B: Ripple index plotted against ripple symmetry index. Overlap fields are ruled.

trains were usually moving towards the east and southeast in the northernmost part of the Ralången area. The only current ripple observation suggests a similar direction.

No palaeocurrent analysis was attempted in the argillite/fine conglomerate association of the folded sequence in the central Forserum subarea. The sedimentary structures are generally small in scale and very variable as to direction sense; also the beds dip steeply and the nature of the tectonic disturbance is uncertain (cf. Fig. 16).

PALAEOCURRENTS IN THE STOREKVARN FORMATION

In the conglomerates of the Storekvarn Formation in the Vikskvarn-Storekvarn subarea, the preferred orientation of pebble long axes varies between E—W and NNE—SSW (Fig. 55). Imbrication of the particles indicates northerly to westerly transport directions (Fig. 57).

SUMMARIZED CONCLUSIONS

There are few definite indications of palaeoflow direction in the Nässjö Formation and the Forserum Formation; in the sandy facies they are largely inconclusive. The preferred particle orientation in the coarse conglomerates in the northern part of the Spexhult area suggests that the gravels were transported by streams flowing towards the northwest.

In the Branteberg Formation palaeoflow indications are abundant but variable, and seem in part to be related to the local palaeoslope. Flow directions toward the west predominate. They were observed in all measured outcrops; the grand vector mean is 256° (cf. Fig. 56).

In the Storekvarn Formation, coarse conglomerates are the only indicators of palaeoflow direction and suggest that, in the southwestern part of the Spexhult area, streams flowed towards the west or northwest.

PETROGRAPHY

The main purpose of this section is to consider sandstone petrography in order to assess the provenance of the detritus, its maturity and the character of the authigenic minerals.

METHODS

The whole-rock compositions of the sandstones were estimated by point counting 600 or more points in representative samples with reasonably well recognizable minerals (v. der Plas and Tobi 1965). In Table 3 the results are given as averages for groups. Grouping is largely according to localities. Detritus compositions are illustrated in triangular diagrams, separate diagrams also showing the composition of lithic fractions (Figs. 60, 61, 62). The relative contents of K-feldspar and plagioclase including feldspar pseudomorphs are given in Fig. 63. The parameters for detritus and lithic compositions are defined according to Okada (1971); chert grains are classified as rock fragments. The definitions are given in Fig. 60 (caption).

A number of ''stability indices'' (see Table 3 for definitions) have been calculated for the groups of sandstone (cf. Mack 1981, Blatt *et al.* 1980). The Polycrystalline Quartz Index is bimodally distributed reflecting predominantly a grain-size effect, high values being characteristic of the coarse sandstones and fine conglomerates of the Almesåkra Group (cf. Table 3). The Lithic Index and possibly the Perthitic Feldspar Index are of greater interest as source rock and/or maturity indices. The Lithic Index demonstrates the significant differences which exist between rocks of the same lithofacies and similar grain size (Table 3c, columns 12, 13, 16). The Perthitic Feldspar Index is usually variable within the groups. It differentiates between sandstones of the red arkosic lithofacies and other fine- to medium-grained sandstones in the Nässjö Formation (Table 3, columns 15, 6, 7).

The grain-size distributions in a number of sandstones were estimated in samples with clearly defined grains by measuring the apparent long axes of a minimum of 200 grains randomly chosen on a grid. Measurements of poorly defined grains were rejected, which probably introduces a bias because the contours of small grains are often blurred. The results were converted to 1/2 Phi classes, and distribution parameters were derived graphically from log-probability curves (Folk 1974). The ''mean

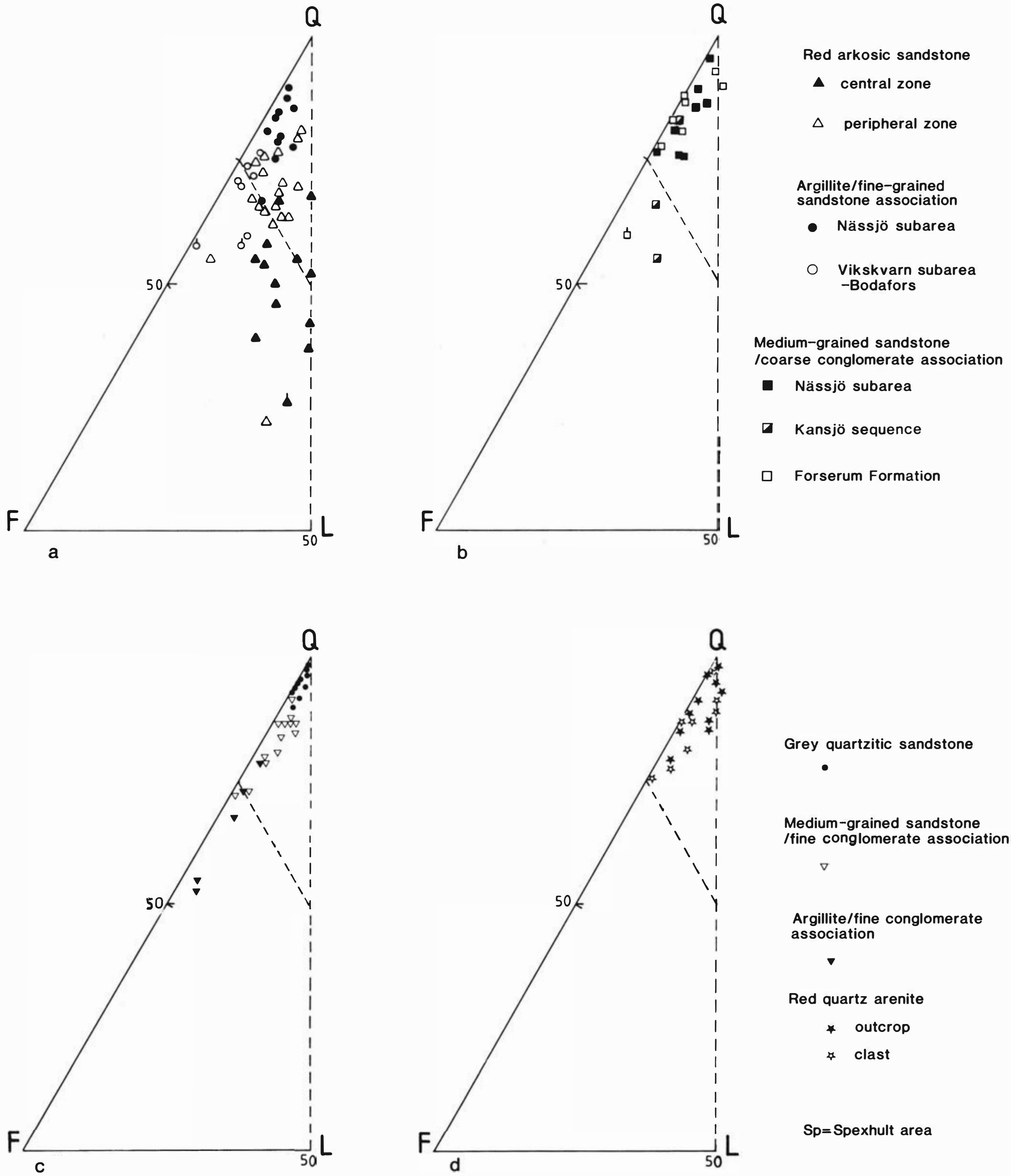


Fig. 60. Detritus compositions of medium- to fine-grained sandstones of the Nässjö Formation (a), the Nässjö Formation and the Forserum Formation (b), the Storekvarn Formation and the Branteberg Formation (c), and the red quartz arenites of the Marbäck Formation and the older sedimentary sequence as represented by conglomerate clasts (d). Q = monocrystalline and polycrystalline quartz, F = K+P = K-feldspar and plagioclase with feldspar pseudomorphs, L = all lithic grains including cherty grains and heavy minerals. Spiked symbols denote exceptional, very fine-grained or fine-grained samples.

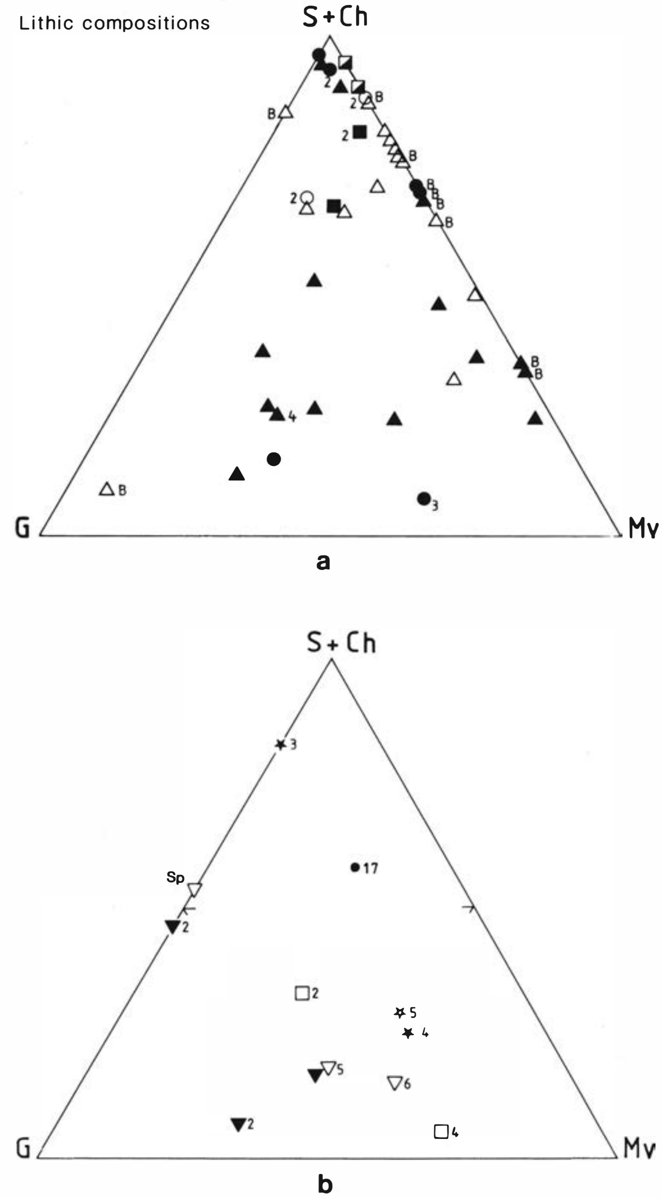


Fig. 61. Compositions of the lithic fractions of sandstones of the Nässjö Formation (a), the Storekvarn and Branteberg Formations, the Forserum Formation and the red quartz arenites (b). S+Ch = sedimentary grains and cherty grains, Mv = metavolcanic grains, G = granitoid grains including heavy minerals. B denotes samples from units or beds resting on the basement. Numerals at points indicate the number of thin sections that were averaged in the estimate. Symbols as in Fig. 60.

grain-size'' estimated in this manner can be shown to represent most accurately the mean true intermediate axis of the grains (Kellerhals *et al.* 1975). The estimated ''average grain-size'', when given numerically in Table 3, is the arithmetic mean determined on the apparent long axes of about 100 randomly chosen grains in each thin section (cf. K̂ukal 1980).

Roundness was estimated by visual comparison according to Powers (1953). In thin sections, this was done only for grain sizes between 0.13 and 0.56 mm. In some cases of well-defined grain boundaries in sandstones, the roundness distribution was determined from at least 200 grains in each thin section. The results were converted to the ϱ (rho) scale according to Folk (1974). Size and roundness distributions are shown as histograms (Figs. 65, 66). The parameters of the grain-size distributions are presented in Table 4.

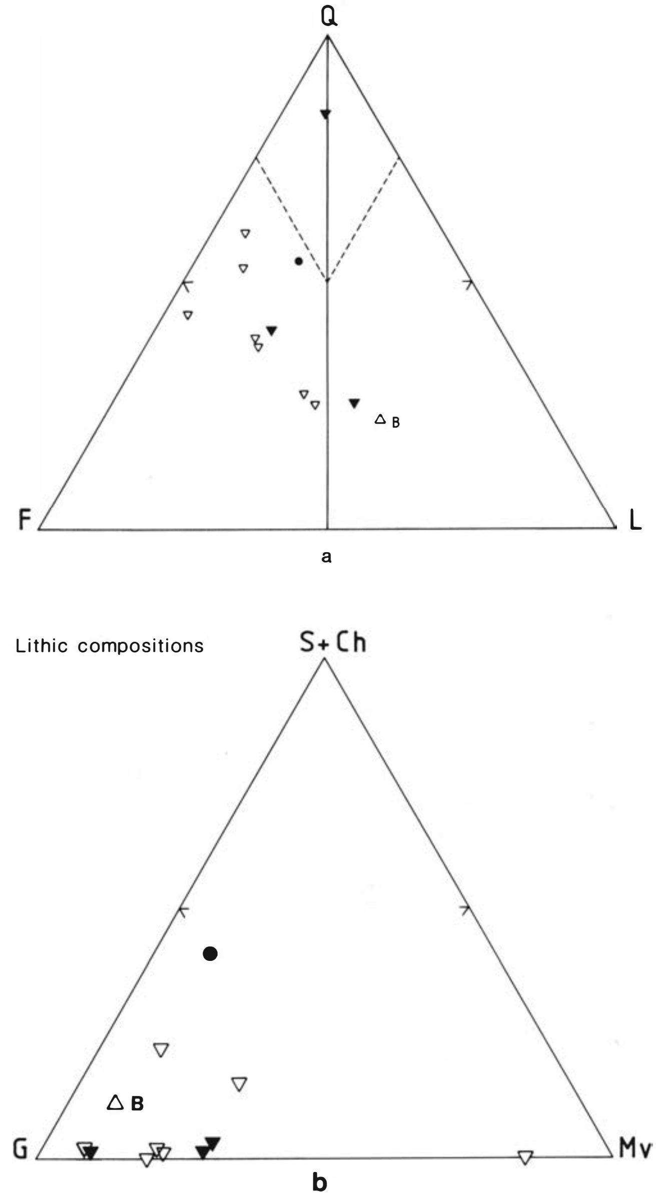


Fig. 62. Detritus compositions (a) and lithic compositions (b) of coarse sandstones — conglomerate matrices of the Nässjö and Branteberg Formations. Symbols as in Fig. 60.

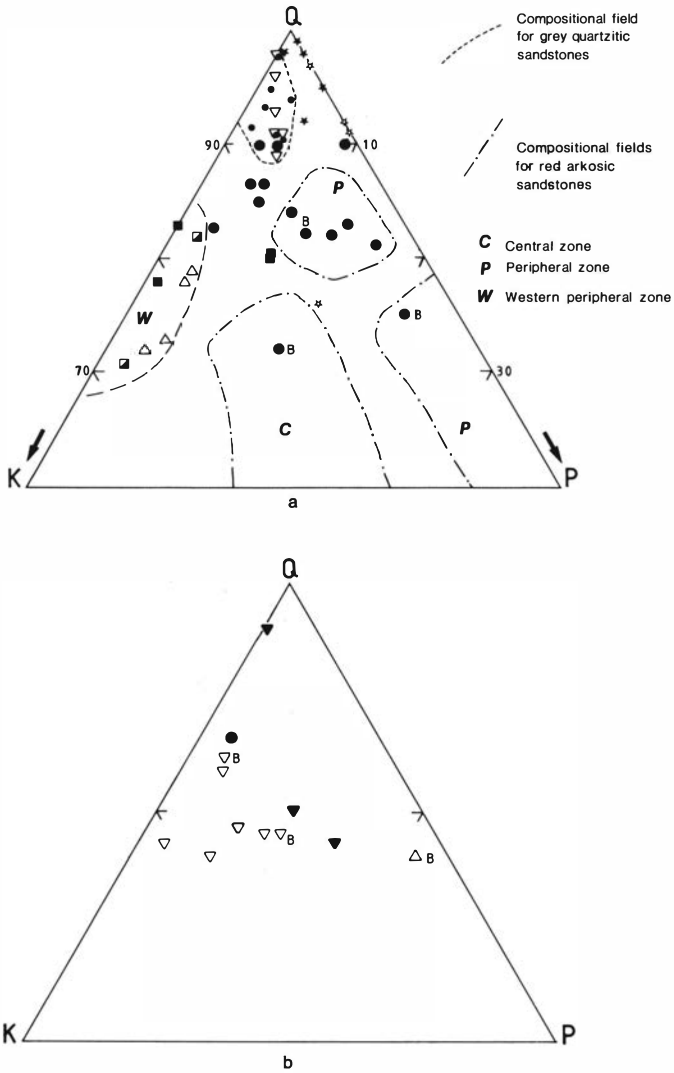


Fig. 63. Relative contents of quartz detritus (Q), K-feldspar (K) and plagioclase with feldspar pseudomorphs (P) in medium-grained sandstones (a), and coarse sandstones — conglomerate matrices (b) of the Almesåkra Group. Symbols as in Fig. 60. Individual feldspar compositions of the red arkosic sandstones are shown in Fig. 63a only for samples from the western peripheral zone (WP in Fig. 70). For samples from zone C and remaining parts of zone P the compositional fields are indicated. The ''peripheral red arkosic sandstone'' composition point marked with B at right in Fig. 63b represents a sample of very coarse sandstone — conglomerate matrix from a bed in the Hälleved conglomerate (Figs. 4 and 70).

THE MAIN DETRITAL COMPONENTS

Monocrystalline quartz is the major component of all sandstones except the very coarse ones. In coarse sandstones and the matrix of fine conglomerates, polycrystalline grains may exceed 50% of the quartz detritus, they are usually below 5% in the medium-grained sandstones (Table 3). The quartz is predominantly of the common, ''plutonic'' type (Folk 1974). Microlites, vacuoles and bubble trains are abundant in some of the grains. Brownish vein quartz comprises at most a few per cent of the detrital quartz. Comparatively ''clean'' quartz is fairly common, particularly in the red quartz arenites. Here, the quartz grains are often well-rounded and display features suggesting derivation from porphyry phenocrysts.

Polycrystalline quartz usually forms composite grains made up of a few quartz crystals with widely differing orientations and unsutured boundaries. Meta-quartzite and ''stretched metamorphic'' quartz grains (Folk 1974) are scarce except in some strata derived from metasupracrustal basement. There are chert grains in most of the sandstones though few or none in the feldspathic sandstones of the Branteberg Formation. In the sandstones of the Nässjö Formation they average 20% of the lithic debris.

In each thin section there are usually a few quartz grains with deformation lamellae. Sometimes such grains comprise between 10% and 20% of the detrital quartz as in some samples of stratified, red quartz arenite.

The feldspar is dominantly potassic and often belongs to a patch-perthitic type. Cross-hatched or twinned microcline is subordinate in most facies. Plagioclase is rare being most frequent in the fine conglomerates and in the red arkosic sandstone. In most sandstones, plagioclase and feldspar pseudomorphs amount to no more than a few per cent (Table 3). Degree and type of feldspar alteration is variable. Fresh and altered grains coexist in a random manner indicating that the alteration is probably not the result of diagenetic alteration or outcrop weathering. Plagioclases are generally much more altered than K-feldspars. Sericitic alteration is by far the commonest mode of alteration in all feldspars of all units. Brownish turbid alteration (Folk 1974) is, however, appreciable in feldspars of the Branteberg Formation. Estimates of detritus compositions show that the ratio of K-feldspar to plagioclase plus feldspar pseudomorphs is a distinguishing characteristic for the lithofacies in the Nässjö Formation (Fig. 63).

The lithic grains can be subdivided into *granitoid*, *sedimentary*, *metavolcanic*, *cherty* and *tectonite* types (Dickinson 1970). Lithic grain content provides a main compositional distinction between the Nässjö and Branteberg Formations (Fig. 60). The frequency of various types of lithic grains in the sandstones of different outcrop areas appears to be source-controlled (cf. Fig. 61).

The granitoid grains are composed of feldspar and quartz, sometimes with the addition of micas, chlorite and iron oxides. In the red arkosic sandstone, they are generally finer and contain more oxides than those of the other lithofacies.

The sedimentary lithic grains are mainly fragments of

TABLE 3. Modal compositions of sandstones of the Almesåkra Group. A + sign in a column denotes a component observed, but not counted, in one or more of the thin sections. A number in brackets indicates that the component in question was counted and averaged for this number of thin sections.

The Polycrystalline Quartz Index, PQI = $\frac{\text{polycrystalline quartz grains}}{\text{detrital quartz}} \times 100$

The Lithic Index, LI = $\frac{\text{lithic grains}}{\text{detrital quartz + feldspar}} \times 100$

The Perthitic Feldspar Index, PFI = $\frac{\text{perthitic feldspar grains}}{\text{detrital feldspar}} \times 100$

The Volcanic Quartz Index, VQI = $\frac{\text{volcanic quartz grains}}{\text{detrital quartz}} \times 100$

The VQI estimates the proportion of embayed or pitted quartz grains in the quartz detritus.

TABLE 3a. Average modal compositions (vol. %) of red quartz arenites of the Marbäck Formation and the older sedimentary cover (conglomerate clasts).

Composition	1. Ralängen area		2. Spexhult area		3. Conglomerate clasts		4. Conglomerate clasts	
	n = 5		n = 4		n = 6		n = 2	
Detrital	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Quartz	63	3.7	64	5.3	57	5.6	50	7.8
K-feldspar	2.1	2.8	1.5	2.9			7.6	1.6
Plagioclase and feldspar pseudomorphs	1.2	1.0	2.1	2.0	4.9	3.1	5.9	1.5
Rock fragments	1.0	0.9	0.6	0.3	1.7	1.6	1.4	0.9
Muscovite	+				+		0.2 (1)	
Biotite								
Epidote								
Zircon	+		+				+	
Apatite					+			
Matrix (sericitic)					6.6	7.5	13 (1)	
Authigenic								
Quartz	27	2.3	26	7.8	24	8.3	24	3.5
K-feldspar			0.6 (1)		0.5 (1)			
Sericite	1.7	0.9	3.7	2.6	5.4 (1)		7.2 (1)	
Hematite	2.9	1.5	1.2	1.1	2.6	3.8	1.7	0.9
Opaque grains incl. hematite pseudomorphs	0.7	0.7	0.2	0.3	0.1 (1)			
Epidote								
Chlorite	C.3 (1)				1.3 (1)			
Calcite					0.3 (2)			
Other cements					6.1 (1)			
Porosity	0.4	0.5						
LI	2.5	1.8	1.4	0.5	2.8	2.5	2.0	1.4
PQI			1.6(3)	1.3				
VQI	7	5	12 (3)	8	11 (3)	11	3 (2)	3
Average grain-size					fine to medium-gr.		medium-gr.	
range (mm)	0.2 - 0.5		0.3 - 0.5					

hematitic or sericitic very fine-grained sandstone and siltstone. Occasional sedimentary quartz grains with rounded quartz overgrowths (Fig. 29) are also found. Apatite-cemented sandstone fragments have been observed in a few samples (cf. p. 66).

There are several kinds of metavolcanic lithic grains. These include quartz-feldspar mosaics, devitrified glass, micrographic and granophyric intergrowths, as well as other fragments of volcanic rocks such as microquartz with oxides and small micas. Felty-textured, mafic grains probably derived from dolerites are uncommon.

It is difficult to distinguish between chert grains of metavolcanic origin and sedimentary chert (cf. Wolf 1970, Potter 1978). Most of the cherty grains, in particular those

TABLE 3 b. Average modal compositions (vo. %) of feldspathic sandstones of the Nässjö Formation. Columns, 5, 6, 8, 9 represent samples from medium-grained sandstones.

Composition	5. Spexhult area basal beds n = 4		6. Nässjö subarea n = 6		7. Nässjö subarea n = 5		8. Nässjö subarea upper beds n = 7		9. Vikskvarn sub-area n = 4		10. Vikskvarn sub-area upper-most beds n = 3		11. Branteberg subarea sub-unconformity sandstone n = 4	
Detrital	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Quartz	50	4.7	56	5.0	57	7.4	61	6.4	44	7.2	57	6.1	62	6.8
K-feldspar	7.7	4.1	5.9	6.3	9.1	3.1	6.1	1.0	9.9	6.8	12	2.3	3.1	1.1
Plagioclase and feldspar pseudomorphs	7.9	3.7	7.2	2.4	3.3	2.8	3.0	1.0	11	6.8	7.6	6.0	3.3	1.5
Rock fragments	4.4	2.9	3.6	1.9	2.2	1.4	1.6	1.1	2.0	1.8	2.7	0.1	1.4	1.2
Muscovite	+		0.2 (1)		0.3 (3)	0.2	+		0.6 (2)		+			
Biotite	+		+				+		+					
Epidote	0.9 (1)													
Zircon	+		+		+		+		+		+		+	
Apatite	+		+				+							
Titanite	+													
Matrix (sericitic chloritic hematitic)	12 (3)	2.6	11	6.0	1.1	1.3	1.1	1.4	8.9	4.1	11	3.9		
Authigenic														
Quartz	15	6.4	11	4.8	21	9.8	21	7.1	17	8.2	9.3	5.0	21	12
K-feldspar	0.3 (1)		0.6 (1)		1.1 (2)	0.1	0.2 (1)		6.3 (1)					
Sericite					3.6	2.8	4.9	2.3					5.9	2.6
Hematite	0.2	0.3	1.2	1.3	1.1	0.7	0.2	0.4	0.5 (1)		0.9	1.2	1.7	2.1
Opaque grains incl. hematite pseudomorphs	1.4	1.2	0.6 (2)				0.2	0.2	0.8	1.1	0.9	1.1		
Epidote	1.0 (1)		5.3 (1)								0.8 (1)			
Chlorite	0.8	1.0	2.2 (5)	2.1			0.4 (1)		0.5 (1)					
Calcite									8.9 (1)					
Titanite			0.1 (1)											
LI	7.2	4.8	5.1	2.6	3.1	1.9	2.4	1.8	3.4	3.3	3.6	0.6	2.1	2.1
PQI			1.2 (4)	1.2									1.8 (3)	2.0
PFI			0.4 (4)	0.7										
VQI													0.3	0,6
Average grain-size range (mm)	fine-gr.		0.1 - 0.3		medium-gr.		0.2 - 0.3		0.1 - 0.2		medium-gr.		0.30 - 0.45	

containing micas and hematite dust, are probably derived from porphyries. The presence of large chert clasts in the quartzite-dominated conglomerates of the western Spexhult area would appear to indicate the occurrence of chert beds in the sedimentary source rocks of the Almesåkra Group. There is, however, no correlation between the occurrence of cherty lithic grains and sedimentary rock fragments.

Tectonite fragments, mostly cataclastic quartz grains, occur rarely. Lithic grains of uncertain derivation make up less than 10% of the total lithic fraction.

The lithic grain content is related to grain size (cf. Blatt *et al.* 1980), as seen in the sandstones of the Branteberg and Storekvarn Formations which have a low content of lithic grains (Fig. 64). This is less obvious in the Nässjö Formation where the average lithic grain content is about four times greater and the range in grain size is more restricted. In the Nässjö and Branteberg Formations, granitoid fragments always dominate in the coarse to granular sandstones. They are subordinate in the medium-grained sandstones (Table 3). A paucity of granitoid lithic grains is conspicuous in some basal units of the Nässjö Formation and also in the sandstone/coarse conglomerate association of the Kansjö sequence. In most of the red arkosic sandstones of the central Spexhult area, chert or metavolcanic fragments or both dominate over sedimentary fragments (Fig. 61).

The commonest detrital accessory minerals are micas,

TABLE 3c. Average modal compositions (vol. %) of red arkosic sandstones of the Nässjö Formation. Columns 17, 18 represents samples from beds of the proximal red arkosic sandstone lithofacies overlying the Hälleved conglomerate.

Composition	12. Spexhult area zone C n = 12		13. Spexhult area zone P n = 14		14. Total of columns 12 and 13 n = 26		15. Spexhult area zone C n = 1	16. W Spexhult area zone WP n = 7		17. Spexhult area zone H n = 1	18. Spexhult zone H n = 1
Detrital	mean	s.d.	mean	s.d.	mean	s.d.		mean	s.d.		
Quartz	39	7.5	50	7.9	45	9.4	17	49	3.9	15	15
K - feldspar	9.0	3.9	6.8	3.7	7.8	3.9	13	15	4.4	2.4	1.0
Plagioclase and feldspar pseudomorphs	13	3.4	8.7	2.8	10	3.6	13	1.8	0.8	20	30
Rock fragments	13	3.9	5.8	2.0	9.0	4.6	9.0	3.7	2.7	36	20
Muscovite	1.2(4)	1.1					3.5	+		0.3	3.3
Biotite			+				4.7	+		0.8	0.6
Epidote	1 (2)	0	+				+			0.6	0.5
Zircon	+		+				+	+			+
Apatite	+		+					+		+	
Titanite	+		+					+			+
Chlorite											
Matrix	2.4	2.4	3.7	2.8	3.1	2.7	2	3.0 (3)	2.6	15	20
Authigenic											
Quartz	9.5	4.3	14	3.5	12	4.4	8.1	23	9.9	+	+
K-feldspar	1 (2)	0	1 (2)	0	1 (4)	0		0.9	0.8		
Sericite	6.7	3.1	6.0	2.6	6.3	2.8	10	3.8	3.9		
Hematite	1.5	1.7	1.3	1.5	1.4	1.6	14	1.0	1.2	1.7	0.8
Opaque grains incl. hematite pseudomorphs	4.4	1.9	2.8	1.0	3.5	1.7	3.7			5.8	8.1
Epidote	1.7(8)	1.2	1.0(2)	0	1.5(10)	1.1	1.4			0.3	
Chlorite	1 (4)		1.2(2)	0.4							
Calcite											
Titanite	+		+		+						
LI	21	7	9	3	15	8	21	6	4	97	43
PQI	2 (9)	1	1 (8)	1				1 (5)	1	65	65
PFI	15 (11)	10	15 (9)	18	15 (20)	14		5 (6)	5		
Average grain-size range (mm)	0.2 - 0.4		0.2 - 0.4		0.2 - 0.4		0.17	fine to medium-gr.		very coarse	0.41

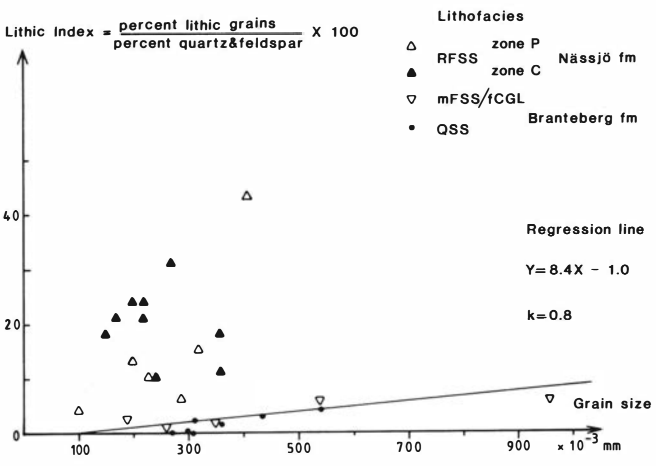


Fig. 64. The proportion of lithic grains in the detritus of fine- to coarse-grained sandstones plotted against average grain size. Lithofacies abbreviations as in Table 1.

opaques, epidote, zircon and apatite. Tourmaline has been observed in a few samples as small, green rounded grains up to 0.2 mm across and strongly pleochroic. Biotite mostly occurs in fine-grained sandstones where often concentrated in micaceous laminae. It is commonly altered to hematite. Muscovite is found as scattered grains. Like biotite, apatite and opaques, muscovite is commonest in the red arkosic sandstone of the Nässjö Formation; it is uncommon or lacking in the medium-grained sandstones of the Branteberg and Storekvarn Formations. Apatite occurs as rounded, slightly elongated grains up to 0.1 mm across.

Most of the opaque oxide grains are hematite, occurring singly or as heavy-mineral laminae; they may amount to several per cent of the total rock in the red arkosic sandstones (cf. p. 40). The specularite amounts at most to 1—2

TABLE 3d. Average modal compositions (vol. %) of sandstones of the Forserum Formation.

Composition	19. W Forserum subarea n = 6		20. E Forserum subarea n = 1	21. E Forserum subarea n = 1
Detrital	mean	s.d.		
Quartz	49	8.1	50	75
K-feldspar	7.4	6.0	13	1.7
Plagioclase and feldspar pseudomorphs	2.3	2.6	0.6	1.1
Rock fragments	1.0	0.8	0.5	2.6
Muscovite	+		+	
Biotite				
Epidote				
Zircon	+		+	
Apatite				
Titanite				
Matrix				
Authigenic				
Quartz	34	5.9	31	14
K-feldspar	1.9	3.0	1.5	0.3
Sericite	1.8	2.1	0.3	
Hematite	1.0	0.8	3.5	4.6
Opaque grains incl. hematite pseudomorphs			0.3	0.1
Epidote				
Chlorite				
Calcite				
Titanite				
Other cements				
LI	2	1	1	3
PQI				
PFI				
Average grain-size range (mm)	0.3 - 0.4		fine-gr.	0.43

TABLE 3e. Average modal compositions (vol. %) of sandstones of the Branteberg Formation. Columns 24, 25, 26 represent individual sandstones of varying grain size and cementing properties. Column 31 represents red arkosic sandstones in the upper part of the Branteberg Formation.

Composition	22. Central Forserum subarea n = 2		23. Central Forserum subarea n = 2		24. Central Forserum subarea n = 1
Detrital	mean	s.d.	mean	s.d.	
Quartz	45	4	28	9	38
K-feldspar	8	2	13	4	5
Plagioclase and feldspar pseudomorphs	7	2	18	2	24
Rock fragments	1	0	26	14	2
Muscovite					+
Biotite			+		
Epidote					
Zircon	+				
Apatite					+
Titanite			+		
Tourmaline					+
Matrix			16	1	21
Authigenic					
Quartz	31	1			
K-feldspar	1	0			
Sericite	7	0	1 (1)		
Hematite	1	1			1
Opaque grains incl. hematite pseudomorphs					
Epidote					
Chlorite					
Calcite					8
Titanite					1
Other cements					2
LI	2	0	'49	35	2.5
PQI			18	17	
PFI			26	25	
Average grain-size range (mm)	0.2 - 0.4		1.0 - 1.3		v. fine-gr.

per cent in other sandstones of the Nässjö Formation; it is very rare in the Branteberg and Forserum Formations (Table 3). The opaques seem to have been derived largely from oxide pseudomorphs after other minerals and from lithic grains. Epidote occurs as rounded, single or composite grains often together with opaque grains. Authigenic epidote is associated with detrital epidote.

In the sandstones and siltstones of the Nässjö Formation, zircons are usually metamict, equant and rounded. Hematitic alteration is common in red beds. In the feldspathic sandstones of the Branteberg Formation, the zircons tend to be elongated and fresh, and are sometimes subhedral and zoned. Grain size ranges up to c. 300 μm, c. 100 μm being the commonest size. Overgrowths occur rarely, sometimes being of euhedral shape, occasionally, however, being patchy or abraded suggesting a multicyclic history.

Small amounts of titanite occur widely in the Nässjö Formation. Most grains are 20 to 50 μm across, rounded and pale brownish in colour. However, in samples from the lowermost units, a few rounded titanite grains have diameters up to 200 μm.

THE CONGLOMERATE PARTICLES

In roughly 70% of all sampled beds of coarse conglomerate, the particles are predominantly ''quartzite'' (cf. Fig.

TABLE 3e, cont.

Composition	25. Central Forserum subarea n = 1	26. Central Forserum subarea n = 1	27. Branteberg subarea and N Spexhult area n = 6 mean	s.d.	28. Branteterg subarea and N Spexhult area n = 7 mean	s.d.	29. N Ralången area n = 5 mean	s.d.	30. N Ralången area fine beds n = 2 mean	s.d.	31. Ralången area n = 3 mean	s.d.
Detrital												
Quartz	38	73	30	9	54	7	59	4	48	2	35	2
K-feldspar	9	8	23	2	6.4	3.5	4.5	2.5	8.4	3.7	16	6
Plagioclase and feldspar pseudomorphs	22	1	11	5.6	2.3	1.2	3.8	1.4	4.3	2.3	14	3
Rock fragments	3	5	15	10	1.3	0.8	1.9	1.4	2.1	0.7	3.6	3.5
Muscovite	1	+	+				+		+		+	
Biotite												
Epidote	+											
Zircon			+		+		+		+		+	
Apatite	1		+				+		+			
Titanite												
Tourmaline												
Matrix		4	12	7								
Authigenic												
Quartz	7	10	5.4	4.2	32	7	27	5	32	12	22	2
K-feldspar		1			0.5	0.9						
Sericite	6				1.6	1.6	3.5	1.8	5.7	4.7	8.4	0.7
Hematite	8				0.8	0.4	0.9	1.4	0.7	0.4	3.5	1.5
Opaque grains incl. hematite pseudomorphs	2		0.3	0.2			0.2	0.2			1.6	1.9
Epidote			1.7	3.8								
Chlorite												
Calcite											1.2 (1)	
Titanite												
Other cements	2				4.0 (2)							
LI	4.5	7	26	20	2.3	1.2			3.7	1.6	6.0	6.4
PQI		14	35	29	2.3	1.5(3)	1.7	1.2	1 (1)			
PFI		4	51	32 (5)	8.0	5.5(4)	11	19	5.7	6.1		
Average grain-size range (mm)	v. fine-gr.	coarse pebbly	1.0 - 1.6-		0.26 - 0.54		0.30 - 0.54		0.2		fine-gr.	

28). A clastic texture can easily be recognized in most of these. A small proportion of the quartzitic clasts are very fine-grained and appear to consist of recrystallized sedimentary quartzite, some of them showing a slightly micaceous, foliated, completely recrystallized texture in thin sections. Other sedimentary particles studied in thin sections include fine- to medium-grained feldspathic sandstones (''sandstone'' in Fig. 28). Many of these particles belong to conglomerates of the Nässjö and Branteberg Formations along the eastern boundary of the Almesåkra Group. The particles consist of arenites low in feldspar and are mostly red-coloured, cemented by hematite and quartz. The colouring is caused mainly by pigmentary hematite coating the quartz grains. This is a mode of hematite occurrence characteristic of the red quartz arenite lithofacies recognized in the Marbäck Formation.

Most feldspars are converted to sericite. In composition (Fig. 60d, Table 3a) and texture (Figs. 65, 66) as well as in diagenetic characters, these particles thus closely resemble the red quartz arenite facies (cf. p. 21). More detailed study of the clasts shows that the early-diagenetic hematite pigment is overgrown by authigenic quartz (Fig. 52). Because both the colouring by hematite and the quartz cementation reflect diagenesis in the source rocks, at least some millions of years must have elapsed between the formation of these rocks and the deposition of the red clasts in the Almesåkra sequences (cf. Turner 1980). Both single-grain strain and aggregate strain (seen from deformation lamellae and undulatory extinction of the quartz) are less common in these clasts than in the red quartz arenites of the Marbäck Formation. This suggests, that the older sedimentary sequence from which the clasts were

TABLE 3f. Average modal compositions of grey quartzitic sandstones of the Storekvarn Formation.

Composition	32. N Spexhult area n = 6		33. North-central Spexhult area n = 6		34. SW Spexhult area n = 5		35. Forserum subarea n = 6	
Detrital	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
Quartz	64	5.5	61	3	60	2	56	2.3
K-feldspar	2.3	1.3	2.5 (5)	1.3	2.3 (4)	0.5	1.4	1.5
Plagioclase and feldspar pseudomorphs	1.9	0.7	0.6	0.4	1.2	1.0	1.5	0.8
Rock fragments	0.8	0.8	0.2	0.2	0.5	0.5	0.2	0.2
Zircon	+		+		+		+	
Muscovite, Biotite, Epidote, Apatite, Titanite, Chlorite	not identified							
Matrix			0.7 (1)					
Authigenic								
Quartz	28	7.9	34	4	35	3	39	3.3
K-feldspar			0.4	0.4	0.3 (1)		0.2	0.3
Sericite	2.8	1.7	0.9	1.1	0.9	0.8	0.4	0.7
Hematite	0.3	0.4	0.4	0.4	0.2 (1)			
Opaque grains incl. hematite pseudomorphs					0.7 (1)			
Epidote					2.5 (1)			
LI	1.2	1.3	0.3	0.3	0.9	0.7	0.3	0.4
PQI			0.5	0.6	0.3 (4)	0.3		
PFI			0.5	1.2				
Average grain-size range (mm)	0.3 - 0.5		0.3 - 0.5		medium-gr.		medium-gr.	

derived had source rocks, that had suffered little tectonic or overburden stress. The stress affecting the red sandstone of the Marbäck Formation probably occurred later than the erosion of the older sedimentary sequence of which this formation is supposed to be a remnant (cf. p. 10).

The porphyry particles are predominantly microcrystalline and carry small quartz and feldspar phenocrysts. Some porphyries are coarse-grained and granophyric. A few are eutaxitic suggesting derivation from ignimbritic lavas (Hjelmqvist 1955). The quartz phenocrysts often have a modified bipyramidal habit sometimes with corrosion embayments. The porphyry matrix is dominated by microcrystalline quartz and small feldspars, with varying amounts of mica and oxides. Local bands and schlieren of clear macroquartz are common. The occasional spotted appearance of the matrix suggests devitrification. Lithic grains displaying this texture occur in many of the sandstones of the Nässjö Formation. The various metavolcanic lithic grains were probably derived from different kinds of Småland porphyries, that are now exposed in the surrounding basement (Persson 1973, Hjelmqvist 1982).

Granitoid particles are notably lacking in most of the coarse conglomerates of the Almesåkra Group (cf. Fig. 28). They occur, however, in some conglomerate beds of the Forserum Formation and also in the Hälleved conglomerate inferred to be basal in the Nässjö Formation (cf. p. 70 and Fig. 4). In this conglomerate most particles consist of mafic and other metavolcanic and metasedimentary rocks, and were probably derived mainly from a belt of Early Proterozoic meta-supracrustals in the basement extending from east to west of the Almesåkra Group (cf. Röshoff 1975). In the granitoid particles, the feldspars are strongly sericitized while the mafic minerals are converted to hematite (Table 5). Some of the metavolcanic clasts are fine-grained and rich in fresh K-feldspar grains of a

TABLE 4a. Parameters of the particle size distributions shown as histograms in Fig, 49.

Sample	A	B	C	D	E	F	G
$\phi(50)$	-6.0	-4.6	-5.0	-2.5	-4.1	-4.6	-6.0
$M_z\phi$	-5.6	-4.6	-4.8	-2.5	-4.1	-4.6	-6.0
M_z mm	48	25	28	8	17	25	64
$\sigma_I\ \phi$	1.5	1.0	1.2	1.4	1.2	1.1	0.72
$Sk_I\ \phi$	0.41	0.04	0.27	-0.46	-0.05	0.07	-0.04
K_G	0.94	0.90	1.1	0.75	1.0	0.90	0.96

TABLE 4b. (A—D). Parameters of the grain-size distributions shown as histograms in Fig. 65.

A.

Sample no.	1	2	3	4	5	6	7	8	9
$\phi(50)$	2.3	2.4	2.2	1.5	1.8	2.2	1.3	1.3	-0.72
$M_z\ \phi$	2.3	2.8	2.2	1.7	1.8	2.3	1.3	1.3	-0.72
M_z mm	0.20	0.14	0.22	0.31	0.29	0.20	0.40	0.40	1.7
$\sigma_I\ \phi$	0.96	0.58	0.73	0.82	0.69	0.86	0.52	0.47	0.55
$Sk_I\ \phi$	-0.01	0.22	0.14	0.35	0.07	0.08	-0.22	-0.09	0.03
K_G	1.0	1.0	0.99	1.1	1.1	0.99	0.99	1.0	1.1

B.

Sample no.	1	2	3	4
$\phi(50)$	1.9	1.5	2.1	1.6
$M_z\ \phi$	1.9	1.6	2.1	1.7
M_z mm	0.27	0.33	0.24	0.31
$\sigma_I\ \phi$	0.70	0.78	0.52	0.59
$Sk_I\ \phi$	-0.09	0.29	0.12	0.25
K_G	1.1	0.95	1.1	0.91

C.

Sample no.	1	2	3	4	5
$\phi(50)$	1.6	1.5	2.2	0.50	2.3
$M_z\ \phi$	1.5	1.2	2.3	0.63	2.3
M_z mm	0.35	0.44	0.20	0.66	0.20
$\sigma_I\ \phi$	0.96	1.1	1.0	1.4	0.49
$Sk_I\ \phi$	-0.16	-0.39	0.18	0.18	-0.21
K_G	1.1	1.1	0.70	1.3	1.4

D.

Sample no.	1	2	3	4	5
$\phi(50)$	1.6	1.9	1.8	1.2	1.6
$M_z\ \phi$	1.7	1.9	1.8	1.3	1.7
M_z mm	0.31	0.27	0.29	0.40	0.31
$\sigma_I\ \phi$	0.49	0.53	0.58	0.66	0.69
$Sk_I\ \phi$	0.37	-0.07	0	0.28	0.13
K_G	1.2	0.99	0.92	1.3	0.92

very finely structured perthitic variety, a type that is fairly common also in parts of the red arkosic sandstone of the Spexhult area (cf. p. 40).

The granitoid particles in the Forserum conglomerates appear to have lost most of their plagioclase and ferromagnesian minerals by weathering. They differ from possible source rocks in the basement to the east of the Almesåkra Group (cf. Palaeocurrents) in their high content of twinned microcline (Table 5).

Chert clasts are observed only in conglomerates of the Vikskvarn-Storekvarn subarea and locally in those of the Forserum Formation and are generally pebble-sized but range up to boulder size. In the Forserum Formation, chert pebbles are common in some beds and appear to be derived from silicified mudstone. They are light yellowish-grey and not translucent. The microcrystalline quartz texture is poorly defined and crystal size varies between 5 and 30 μm. Numerous sand-sized aggregates of opaque matter, small areas of sericitic alteration (feldspar ''ghosts'') and aggregate polarization in the chert suggest an origin of the chert by replacement. In the Vikskvarn-Storekvarn subarea, chert particles are brownish, slightly translucent and consist of chalcedony breccia. Many of the fragments comprise well-developed spherulites set in a matrix of microcrystalline quartz. This chert is very pure and the chalcedony is of the common, optically length-fast variety.

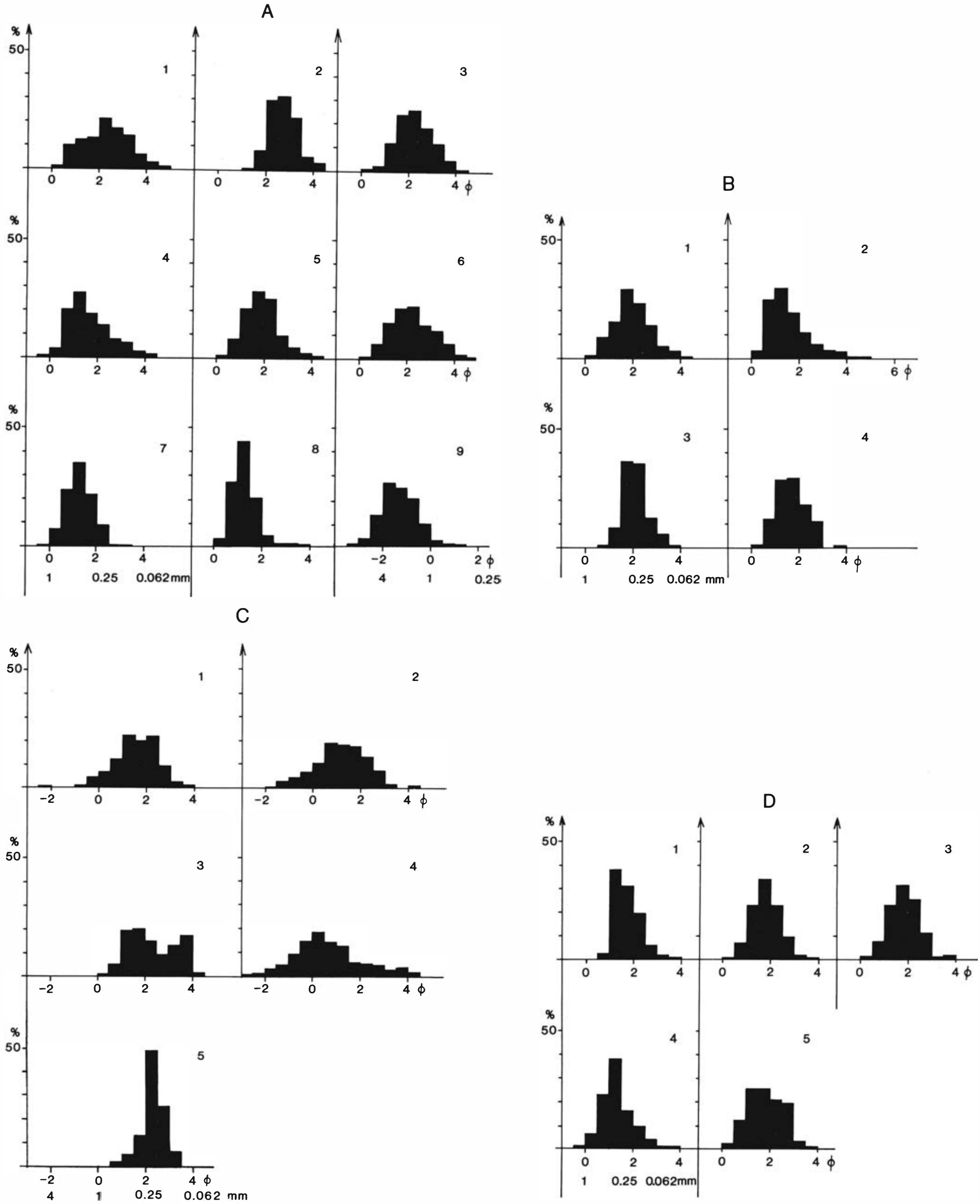


Fig. 65. Grain-size distributions of sandstones. Nässjö and Forserum Formations (A), red quartz arenite of Marbäck Formation and conglomerate clasts (B), Branteberg Formation (C) and Storekvarn Formation (D). The roundness distributions of several of these samples are shown with numbers in Fig. 66.

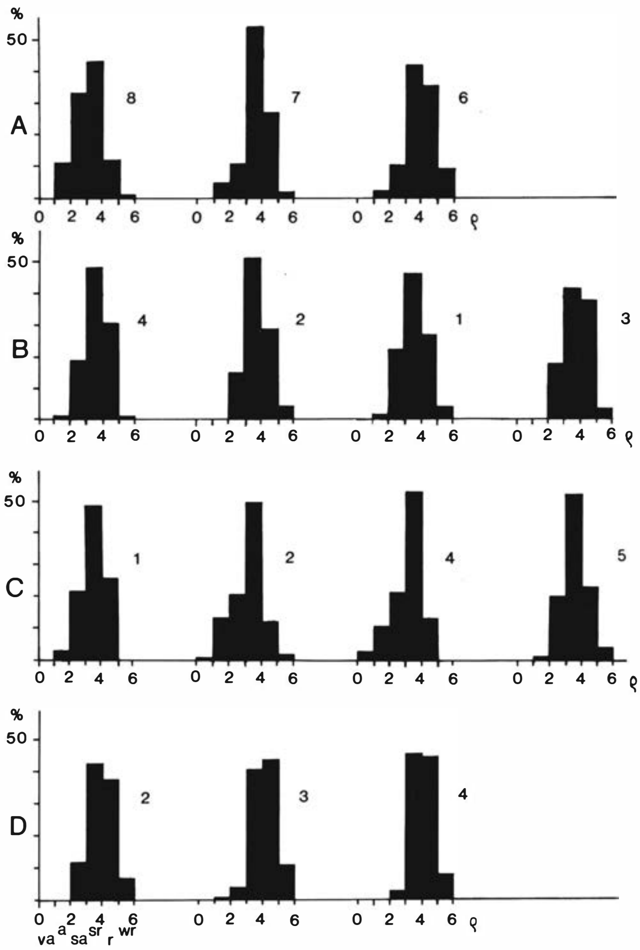


Fig. 66. Distribution of grain roundness in sandstone samples with well-defined grain outlines. Nässjö formation (A), red quartz arenite (B), Branteberg Formation (C), Storekvarn Formation (D). The sample numbers are the same as in Fig. 65.

AUTHIGENIC MINERALS

The major authigenic components of the sandstones of the Almesåkra Group are quartz, hematite and clay minerals. Calcite, K-feldspar, epidote and chlorite are relatively minor cements but may be abundant locally. Titanite and zircon occur subordinately. Authigenic apatite is found in a few outcrops.

Prehnite has been observed close to a dolerite contact in one calcite-cemented sandstone bed of the Forserum Formation. Other contact-metamorphic features include slight recrystallization of the feldspars and quartz and abundant formation of authigenic chlorite, epidote and titanite. There are also instances of hybridization and mobilization of the intruded sandstones.

Quartz cement. — The content of authigenic quartz in the medium-grained, subarkosic and quartzitic sandstones (mostly Storekvarn and Branteberg Formations) ranges up to 44% of the total rock and averages more than 30% (Table 3). There is virtually no uncemented pore space and no clear evidence of more than one stage of cementation. The other cements make up on average less than 5%. The contacts between adjacent overgrowths are generally simple or slightly crenulated. They may be straight (cf. Fig. 54) and exhibit a triple point.

Curves showing porosity reduction with depth for quartz sandstones of comparable grain size and purity indicate that the quartzitic Almesåkra sandstones cannot have been buried at a depth of more than 1000 m before cementation stopped compaction (Füchtbauer and Müller 1977). For most of the grey quartzitic sandstones of the Storekvarn Formation with an apparent pre-cement porosity of more than 35%, cementation must have been completed under less than 500 m of overburden.

Some of the authigenic quartz in these quartzitic sandstones was probably derived from pressure solution. In several samples, there are thin horizons with sutured grain-to-grain contacts. They often exhibit thin sericitic seams. However, most of the authigenic quartz was presumably derived from the transformation of clay minerals and decomposing feldspars in underlying argillitic units of the Nässjö Formation. Signs of early-diagenetic upward water expulsion are very common in beds of this association (cf. p. 35f). The smallest amounts of quartz cement in the quartzitic sandstones of the Storekvarn Formation occur in the sandstones close to the northern erosional boundary of the Spexhult area having no subjacent argillitic beds (Table 3f, cf. Fig. 1).

In the less sorted feldspathic and hematitic sandstones with a sericitic matrix (mostly Nässjö Formation), quartz cement is less predominant, but usually forms more than 50% of the total cement. In the red arkosic sandstones, authigenic quartz occurs in several ways and belongs to different generations. It may be difficult to distinguish from quartz detritus or quartz replacements. Some early precipitation of quartz cement can be seen as euhedral quartz overgrowths. However, most of the authigenic quartz is relatively late and occurs as localized, anhedral outgrowths on detrital grains having discontinuous coatings of other cements (cf. Heald and Larese 1974). Quartz can also be seen to replace feldspar, growing inwards from the grain boundaries and gradually transforming the feldspar into a granular mass of small, anhedral quartz grains. A relict feldspar habit with twinning can occasionally be seen in the replacing quartz (cf. Wallace 1976).

Authigenic hematite. — Early-diagenetic hematite pigment coats the detrital grains in most samples of the red quartz arenite. Grains with hematite-pigmented rims oc-

TABLE 5. Modal analyses (vol. %) of some granitoid rocks from the basement area surrounding the Almesåkra deposits.

Analysis	1	2	3	4	5	6	7	8	9	10
Quartz	33	40	26	24	18	22	29	17	50 X	32
K-feldspar unspecified									10	
K-feldspar perthitic	44	33	21	15	5	9.5	9.3	15		3.4
K-feldspar microcline			2.3			5.3	1.0	28	30	
Plagioclase	21	22	46	44	60	55	53	37	1	50
Biotite/Chlorite	2.2		3.3	12	13	5.2	5.7	0.5	7 XX	0.6
Muscovite		1.8								0.9
Epidote	0.2	0.5	1.3		1.6	0.9	0.7	0.3		0.2
Titanite	0.2	+		0.8	1.0	0.2	+			
Opaque	0.8	2.3	0.2	4.3	0.6	0.9	1.2	2.4	1	14
Apatite	+		+	+	+	0.2	0.2	+	+	+
Zircon	+	+		+	+	+		+		
Fluorite		0.6								
Calcite					0.6					

X) includes some chert (1 %) and poikilitic quartz in K-feldspar (2 %).
XX) includes muscovite and epidote.

1 = red medium-gr. granite, quarry 4 km N of Nässjö, 2 = red fine-gr. granite, outcrop 1 km E of the Branteberg subarea, 3 = greyish red fine-gr. granite, outcrop 0.1 km S of the Branteberg subarea, 4 = grey fine-gr. granitoid, railway cutting 1.8 km E of L. Sjunnaryd, 5 = grey fine-gr. granitoid, railway cutting 3.6 km E of L. Sjunnaryd, 6 = grey fine-gr. granitoid, outcrop 1 km NE of L. Hamnaryd, 7 = greyish fine-gr. granite, from thrust along L. Hamnaryd, 8 = reddish medium-gr. granite, outcrop 4.4 km NNE of Forserum, 9 = grey granite clast (350 points counted), conglomerate in the Forserum sandstone 2.7 km N of L. Storsjön in the Forserum subarea,10 = greyish granitoid clast, the Hälleved conglomerate.

cur sparsely in sandstones of the Nässjö and Branteberg Formations and rarely in the quartzitic sandstones of the Storekvarn Formation. The hematite pigment of such grains is sometimes overgrown by later quartz cement which has been rounded indicating derivation from older sandstones (Fig. 29).

Diagenetic hematite lining pores or coating grains in the form of black rims of hematitic matter is seen locally in the sandstone of the two red lithofacies and in some sandstones of the argillite/fine-grained sandstone association. In these cases, a later introduction of hematite or some precursor iron compound is inferred from the localized mode of occurrence. This type of authigenic hematite, which is often concentrated in laminae, is absent at most grain-to-grain contacts (cf. discussion in Glennie *et al.* 1978).

In the red arkosic sandstones most of the hematite appears to be late-diagenetic. The variable degree of hematite replacement in various incipient pseudomorphs suggests, however, some pre-depositional oxidization (Turner 1974). In many samples of this lithofacies, a late-diagenetic transfer of iron is indicated by the dissolution of part of the hematitized biotites. Such grains are surrounded by a more or less tightly fitting reddish-brown halo (Fig. 67). Similar haloes have been described by Walker (1967) and Turner (1980) who believe that they were caused by oxygenated pore waters leaching iron out of the biotite lattice (cf. discussion in Turner 1980, Walker *et al.* 1978). This phenomenon has previously not been described from Precambrian red beds. Another example of diagenetic reddening is the occurrence of small, roughly circular areas up to a few millimetres across, which are predominantly cemented by hematite. Hematitic aggregates occur centrally in some of these domains, suggesting the former presence of siderite cement (cf. Pettijohn 1975).

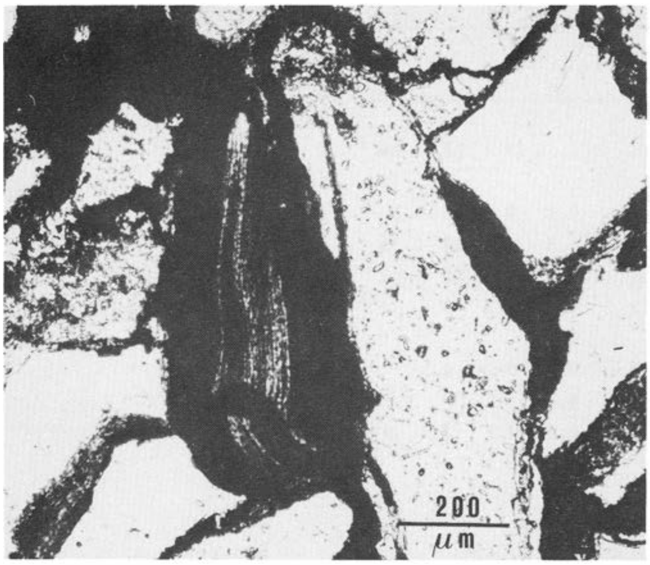


Fig. 67. Partly leached hematitized biotite grain with black iron-rich halo in red arkosic sandstone of the Nässjö Formation. Plain light. Sample from the top of outcrop No. 5 in the Nässjö subarea, Fig. 5.

Authigenic clay minerals. — Authigenic clay minerals coating detrital grains in tangential array are best developed in the feldspathic sandstones of the Nässjö Formation, particularly in the red arkosic sandstones. In samples from tectonically undisturbed sections, such rims are typically 5 to 10 μm thick and light greenish to colourless. Maximum interference colour is yellowish (c. 0.01). They are probably made up of illite (cf. Wilson *et al.* 1977). The coatings on each grain are usually discontinuous and equally well developed on grains of different minerals (cf. Fig. 45). Clay minerals coating detrital grains in this manner are probably early-diagenetic (Füchtbauer and Müller 1977).

In the quartzitic sandstones of the Storekvarn Formation and generally in the subarkosic sandstones, clay mineral coatings occur only locally. The rims are usually discontinuous and thin (cf. Fig. 54). In the red quartz arenite, authigenic clay minerals are mostly found in the matrix. They appear to be mainly sericite, occasionally occurring in laminae alternating with laminae of hematite-cemented sandstone. Pore-filling sericite ''matrix'' is common in the feldspathic sandstones of the argillite/fine-grained sandstone association; a derivation from feldspar pseudomorphs is often suggested by remnant cleavage or small remains of unaltered grains.

Authigenic K-feldspar. — K-feldspar usually forms less than 3% of the total cement + matrix, but locally ranges up to 15% (Table 3). It occurs typically as thin overgrowths on detrital K-feldspars, usually in medium-grained, quartz-cemented sandstones. It is poorly developed or absent in fine-grained sandstones containing much sericite. The best-developed overgrowths exhibit perfect rhombohedral sections (Fig. 68). More often, the overgrowths are incomplete and show ''hack-saw'' projections with preferential growth in some directions. Grain enlargement by authigenic growth ranges up to 50%.

The detrital cores consist of microcline, perthitic K-feldspar and occasionally plagioclase. The feldspar overgrowths may or may not be optically continuous with the core. Twinning is occasionally seen to extend into the overgrowths. These are generally similar in colour to the core. Clear, unstained cement on turbid cores is exceptional, whereas very turbid cement is often seen coating feldspars particularly in the Branteberg sandstones. Such K-feldspar cement has been interpreted as signifying early-diagenetic authigenic K-feldspar which has incorporated traces of primary matrix (Carozzi 1960). In the quartzitic sandstones of the Storekvarn Formation and in several medium-grained subarkosic sandstones of the Nässjö Formation, the precipitation of K-feldspar and quartz cements appears to have been more or less contemporaneous.

Authigenic growth of K-feldspar is regarded as a feature of shallow-burial diagenesis in sandstones (Blatt *et al.* 1980) and has been reported from many areas and epochs ranging down to the late Precambrian. In some Paleozoic formations of North America, K-feldspar cement may form up to 40% of the total rock; its abundance is suggested to be the result of uncommon availability of detrital feldspar on the continental shelf and in possible tephra layers (Buyce and Friedmann 1975). In the Jotnian (Proterozoic) sandstones of Sweden, authigenic K-feldspar oc-

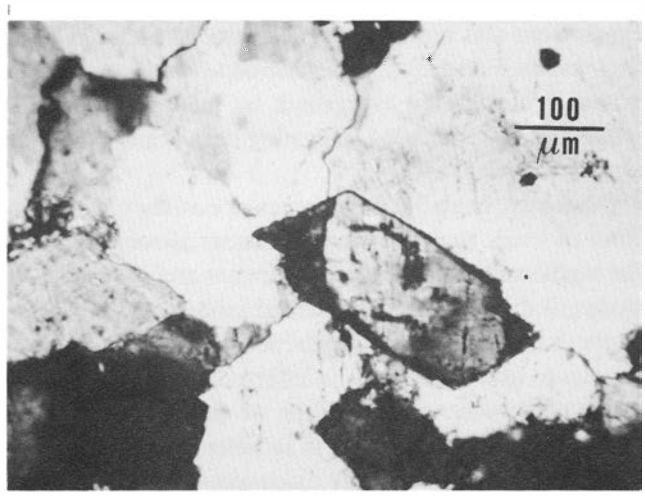


Fig. 68. Rounded detrital K-feldspar grain (grey) with authigenic K-feldspar (black). Note rhombohedral shape of the latter. Crossed nicols. Fine-grained feldspathic sandstone of the Nässjö Formation in the Vikskvarn-Storekvarn subarea, Fig. 8.

curs to about the same extent as in the Almesåkra sandstones (Gorbatschev and Kint 1961, Gorbatschev 1967).

Füchtbauer (1974) found that K-feldspar is the first cement in feldspathic fluviatile deposits. He demonstrated the influence of the depositional environment on the types and order of formation of the different cements. Walker *et al.* (1978) showed that the formation of authigenic K-feldspar in first-cycle desert alluvium was preceded by intrastratal dissolution of unstable minerals.

The small amounts of authigenic K-feldspar present in the Almesåkra sandstones were precipitated from alkaline pore solutions sufficiently high in potassium (cf. Walker 1976). The relatively abundant K-feldspar cement in some subarkosic sandstones has probably derived its prominent constituents from underlying arkosic or argillitic beds rich in unstable detritus. One of these sandstone beds containing much authigenic K-feldspar is found directly overlying a thick sequence of the argillite/fine-grained sandstone association; another overlies a siltstone and mudstone bed in the Forserum Formation.

Calcite cement. — Microcrystalline sparry calcite occurs as a discontinuous cement in some silty fine-grained sandstones of the Nässjö Formation. It is commonest in the lowermost deposits at the eastern and southern boundaries with the basement. Calcite cement is also prominent in fragments of medium-grained sandstone derived from wells drilled at Bodafors. In the argillite/fine conglomerate association of the Forserum subarea, coarse sparry calcite cement is prominent in a few strongly jointed beds; in one small outcrop, calcite forms up to one third of the rock. In some associated fine-grained sericitic sandstones, calcite cement may locally exceed the amount of quartz cement (Table 3). The calcite commonly replaces detrital feldspar grains, sometimes also quartz cement, and it is thus relatively late.

Outside the Forserum subarea, calcite occurs as a major cement only in the calcareous argillite at Hamnaryd (Fig. 1) where it forms sub-parallel undulating laminae, 1 to 15 mm thick, separated by laminae of red, hematitic, clayey siltstone or silty, sericitic feldspathic sandstone (Fig. 69). This calcite is a medium- to coarse-grained, anhedral spar, mostly seen as somewhat elongated grains (Folk 1974). Predominantly bedding-parallel twinning obscures the grain boundaries. In most of the thick, calcite-cemented laminae, floating grains of corroded quartz occur scattered or in groups; occasionally, there are also quartz grains rimmed by hematite, and small opaque grains. A few feldspar grains have been recognized among these "ghosts" by remnant cleavage. In the silty sericitic sandstone, the clay mineral coatings seem to have

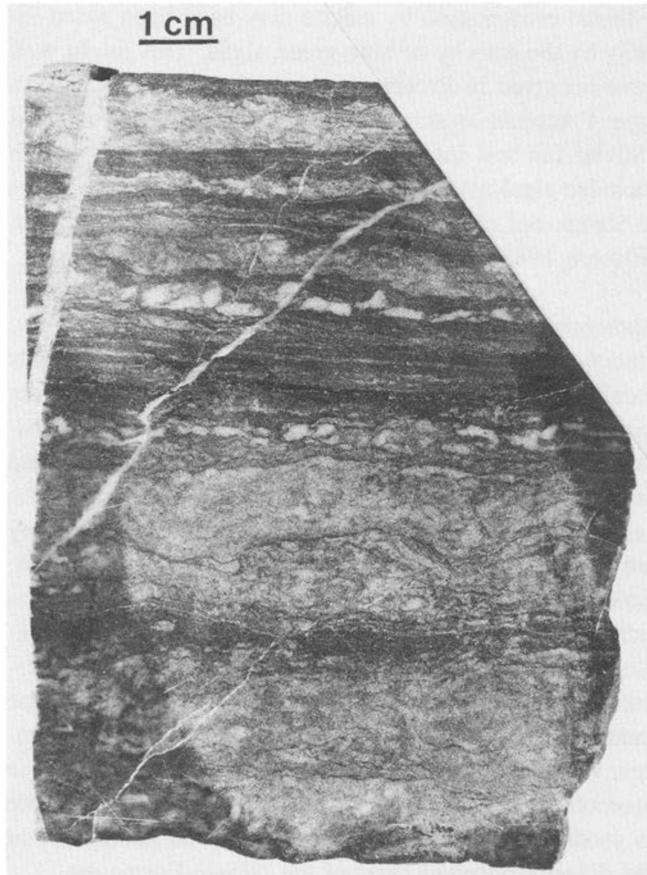


Fig. 69. Polished hand specimen showing calcite (white or light grey) replacing fine-grained sandstone laminated with argillite (dark grey). Note laminae with nodular calcite and the enterolithic habit of the calcite. Limestone quarry in the Nässjö Formation c. 200 m E of L. Hamnaryd, Fig. 1. Photo by S. Stridsberg.

protected the feldspars from being replaced by calcite. Much of the authigenic calcite thus appears to have formed by replacing framework grains which were unstable relative to the carbonate.

Carbonate cementation involving volume expansion and rearrangement of the sandstone framework is a common diagenetic process and is not easily placed in time. It is often associated with replacement of detrital silicate minerals, mainly quartz and feldspar but not of muscovite. An advanced degree of replacement indicates a slow process involving precipitation from dilute solutions allowing time for the dissolution of pre-existing phases (Dapples 1971).

In some parts of the calcareous argillite there is less evidence of replacement, and microspar dominates. Locally, well-defined calcite laminae exhibit a nodular or enterolithic habit suggesting that the calcite has replaced nodular anhydrite (Fig. 69). No signs of gypsum or anhydrite crystal shapes or moulds can, however, be seen in the strained calcite fabric.

Initial cementation by calcite may have been aided locally by the activity of blue-green algae. This might well have occurred in Proterozoic deposits of the Almesåkra type. Precambrian stromatolites have been described from alluvial fan and inferred lacustrine environments which included algal-mat deposits, for instance coating boulders in abandoned channels of an inferred braided river plain (Elmore 1983).

Authigenic epidote and chlorite minerals. — Authigenic epidote minerals apparently replacing plagioclase occur locally in the sandstones and may be appreciable in the matrix of some conglomerates of the Branteberg Formation. Epidote minerals are common in the basal laminated sandstones of the Nässjö Formation and generally in the argillite/fine-grained sandstone association where they are locally abundant and may colour whole beds green. Epidote mainly occurs as a pore-filling cement in quartz-rich laminae. In places euhedral epidote replaces authigenic calcite. Epidote-cemented sandy laminae often alternate with less permeable hematitic or chloritic-sericitic muddy laminae. In some cases, the dolerite intrusions appear to have played a part. Higher temperatures may have promoted a reaction between calcite cement and hematite to produce epidote, which may explain its abundance in the dolerite-intruded parts of the Nässjö Formation.

Chlorite mineral cements are usually negligible in the medium-grained sandstones of the Almesåkra Group (Table 3), but in the fine-grained sandstones of the argillitic association, pale green, slightly pleochroic chlorite is relatively common. It often replaces feldspar grains and can also be seen as small spherulitic flakes in the pore space, probably formed from interstitial clay grade materials. Rarely, chlorite occurs as chloritized biotite grains. In laminae which are slightly coarser than average, authigenic chlorite, like epidote, may locally be prominent. In these cases, as with the chlorite cement occurring in some beds of fine gravelstone, the chlorite may average 1 or 2 per cent of the total rock, ranging up to several per cent (cf. Table 3). Chlorite is believed to form at relatively high diagenetic temperatures in sediments when sufficient iron is available (Füchtbauer and Müller 1977).

The preferential development of authigenic chlorite in the Almesåkra fine-grained sandstones, as compared to the medium-grained ones, probably reflects both a difference in depositional facies and the local influence from the dolerites which have often been intruded into argillitic beds. The growth of authigenic chlorite in sandy laminae could be an indication of iron-rich solutions having had access, thus suggesting incomplete cementation of the sandstone. In clearly contact-metamorphosed Almesåkra sandstones, chlorite is abundant, coarse-grained and of a deep green colour.

Authigenic apatite. — Authigenic apatite occurs as a pore-filling cement together with hematite in a few sandstone beds in the sandstone/coarse conglomerate association of the lower part of the Nässjö Formation. By their dark red colour and corroded surface, the apatite-cemented parts of the rock, at most a few metres across in outcrop, contrast strongly with the surrounding pale red, quartz-cemented sandstone which weathers smoothly. The apatite cementation cuts across bedding; it also occurs locally in small pockets in otherwise quartz-cemented sandstone. Fragments of apatite-cemented sandstone are found in some Nässjö and Branteberg sandstones. This indicates that apatite cementation may have been common in the Marbäck Formation or the older sedimentary sequence.

The apatite forms a crypto- to micro-crystalline cement. It is stained to varying degrees by hematite and fills the pore space completely. In large pores, hexagonal stubby prismatic crystals, up to 100 μm long, and with very low-order interference colours, make up a random meshwork generally enclosing hematite or hematitic clay minerals. The apatite appears to be late-diagenetic. It replaces quartz, and most of the quartz grains are slightly corroded. The detritus composition of the sandstone cemented by apatite is virtually identical with that of the sandstone cemented by quartz.

The identification of the pore-filling mineral as apatite has been confirmed by X-ray diffraction. The apatite is probably a variety of fluor-apatite. The separation of the (004) and (410) peaks in the diffractogram (cf. Gulbrandsen 1970) indicates that little carbonate is present in the apatite.

Phosphate cements, mainly comprising varieties of carbonate-apatite, are common in phosphoritic marine sandstones that are rich in organic matter (Notholt 1980). In Precambrian deposits of this kind the cementing phosphate mineral is generally an F-apatite that is low in carbonate (Lucas *et al.* 1980). Diagenetic phosphatization of clay minerals with attendant formation of apatite is known to occur under specific slightly alkaline conditions (Altschuler 1973). Apatite occurrences of this type are commonly associated with marine phosphorites. Cementation by apatite is met with also in continental sequences, for instance in lacustrine deposits. Layers rich in organic matter are generally associated with the apatite, but this is not always so. In the Helikian Thelon Formation of Canada, approximately 1600 Ma old, pervasive late-diagenetic cementation by phosphate minerals including apatite of a type similar to that in the Almesåkra sandstones has been observed (Miller 1983). The Thelon Formation, a sandstone/conglomerate sequence interpreted as being fluviatile-lacustrine, has no deposits rich in organic matter. It has been suggested that the phosphate mineralization is associated with formation of phosphates in saline lakes of a playa-evaporite environment. The variable concentration of phosphorus in Recent lakes of this type has been explained by changes in bacterial activity (Friedman *et al.* 1976). Apatite cement in sandstone has also been reported from the lower part of the Upper Proterozoic Visingsö Group in southern Sweden where the phosphorus source is believed to have been inorganic (Morad 1983).

Authigenic titanium minerals. — Authigenic titanium minerals, mainly titanite, are common in the opaque-rich, red arkosic sandstones of the Nässjö Formation. They are not found in the red sandstones of the Branteberg Formation.

Titanite generally forms anhedral crystals 5 to 20 μm across or finely granular aggregates mostly 20 to 50 μm across, often associated with leucoxene. Titanite sometimes appears to replace detrital biotite (Fig. 45). The titanite of granular aggregates replaces alteration products of ferromagnesian minerals and appears in turn to be replaced by hematite. Highly birefringent small crystals occurring in such aggregates are probably anatase.

Authigenic titanite is generally believed to form in lithic sedimentary rocks of prehnite-pumpellyite metamorphic grade (cf. Bishop 1972). It has also been shown to form diagenetically at temperatures of about 100 °C in volcanic arenites containing some detrital hornblende (Merino 1975).

In the Almesåkra rocks, the sources of titanium probably include detrital biotite; hematitized or partially leached biotites (cf. p. 65) are often observed together with the authigenic titanite. Another source may be detrital titanite which occurs as large grains in the fine conglomerate which is basal in the red arkosic sandstone.

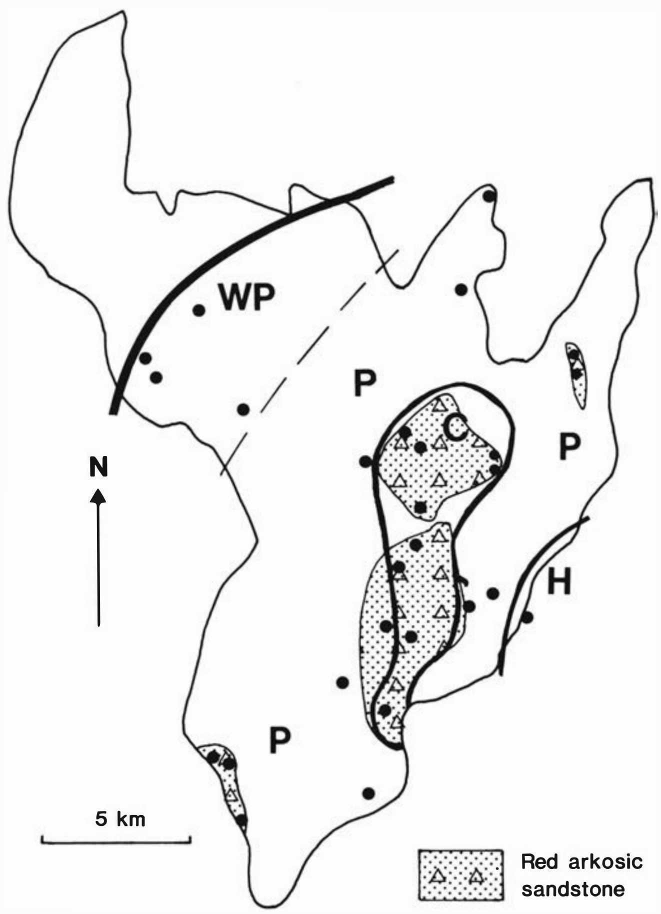


Fig. 70. Zoning of compositions of the red arkosic sandstones of the Nässjö Formation in the Spexhult area. The zoning reflects different values of the ratio lithics and opaques/detrital quartz and feldspar ×100. In the peripheral zone H this value is c. 60, in the central zone C 20 to 50, in the peripheral zones P and WP 4 to 15. Black dots denote sampling localities.

COMPOSITIONAL TRENDS AND PROBABLE SOURCE ROCKS

The diagrams showing the compositions of medium-grained sandstones demonstrate obvious differences in the contents of feldspar and lithic grains between the feldspar-poor sandstones of the Branteberg and Storekvarn Formations and the red arkosic sandstones of the Nässjö Formation (Fig. 60). There are analogous differences in the contents of opaque grains and plagioclase feldspar detritus (cf. Table 3 and Fig. 60). In addition, sedimentary and cherty lithics tend to be low in the Branteberg Formation, but high in the Nässjö Formation (Fig. 61). These differences clearly indicate different source rocks.

A rough zoning of the composition of the red arkosic sandstones is found in the Spexhult area. The zoning becomes more pronounced when the opaque oxide grain (specularite) content is taken into account. In an elongate central zone (zone C in Fig. 70) the ratio of lithics and opaques to detrital quartz and feldspar is high while it is lower in a large peripheral zone (zone P in Fig. 70). The variation of this ratio is probably due to the occurrence of stratigraphically lower units of the red arkosic lithofacies in the peripheral zone and of higher ones in the central zone. The lower stratigraphic position of the peripheral zone is confirmed by bedding attitudes at least in some localities (see Fig. 2). It should be noted that the ratio in question is low for all other comparable sandstones of the Nässjö Formation (cf. Fig. 70, caption).

The diagram for lithic compositions (Fig. 61) shows that granitoid lithic grains are, with few exceptions, fairly common only in samples of the red arkosic sandstone in the central zone of Fig. 70. Like other medium- to fine-grained sandstones in the Nässjö Formation, red arkosic sandstones in the peripheral zone tend to have lithic fractions dominated by metavolcanic and sedimentary grains. This dominance is strongest for "peripheral" sandstones resting on the basement (Fig. 61). One of these basal peripheral sandstones is, however, exceptional by being high in granitoid lithics (Fig. 61). This sandstone is arkosic and verges compositionally on a lithic wackestone. It occurs as interbeds in the Hälleved conglomerate which rests on metasupracrustal basement in a marginal zone to the east (zone H in Fig. 70, cf. p. 61). As with the other sandstones discussed here, the difference in lithic composition is not a grain-size effect since the sandstone is medium-grained (cf. Odum *et al.* 1976, Blatt *et al.* 1980).

The immature marginal sandstone, and the associated coarse conglomerate beds which are rich in granitoid and metasupracrustal particles (cf. Fig. 28), are probably remnants of an eastern proximal facies of the red arkosic sandstone of the Nässjö Formation. This eastern facies and the red arkosic sandstone share features such as high contents of unstable lithic and opaque grains, presence of detrital epidote grains and dominance of plagioclase over potassic feldspar (see Table 3). These features are unusual in other sandstones of the Nässjö Formation. The Lithic Indices of the proximal and distal red arkosic sandstones fall into the same field when plotted against grain size (Fig. 64). The sources of the proximal facies included granodioritic, granitic and metasupracrustal rocks now exposed to the east and southeast of the Almesåkra Group. Older sedimentary cover rocks were subordinate sources.

From the trends in composition and grain size, a general transport of detritus to the west can be inferred. However, northwesterly transport directions are suggested by the occurrence in the uppermost red arkosic sandstone beds (zone C, north part, Fig. 70) of a specific type of K-feldspar (cf. p. 40) and of granitoid lithics which were probably derived from sources to the southeast. These directions of transport agree with the palaeoflow directions obtained from the conglomerate beds of the Nässjö Formation (cf. Fig. 55), but not with indications from trough cross-stratification in some red arkosic sandstone beds (cf. p. 49 and Fig 56:6).

Red arkosic sandstones in the western peripheral zone have more sedimentary and cherty rock fragments than the rocks in the central zone (Fig. 61). Moreover, in the western sequence which includes red feldspathic sandstones belonging to the sandstone/coarse conglomerate association (the Kansjö sequence), the K-feldspar/plagioclase ratios tend to be much higher than elsewhere (Fig. 63). This suggests other source areas richer in sedimentary and poorer in granitoid components, or a higher-energy depositional environment, or both. A higher-energy environment is also suggested by a relatively higher content of (quartzitic) conglomerates in the western sequence. For long transport distances there is a reduction with transport length of feldspar and unstable lithic grains in medium-grained sands. This holds for high-gradient rivers (Suttner and Basu 1981, cf. also Pollack 1961), the greatest reduction in unstable components being achieved in the transition from proximal to non-proximal wadi—braided river environments (Mack 1978).

In the Branteberg subarea, a grey sandstone of the Nässjö Formation beneath the unconformity with the Branteberg Formation resembles the red quartz arenite lithofacies in its textural maturity, the occurrence of "volcanic" quartz grains and the intensity of feldspar alteration (Table 3). However, it differs in the average composition of its lithic detritus, the fewer embayed "volcanic" quartz grains and the absence of hematite grain coatings (Table 3).

The detritus compositions of the sandstones of the Branteberg and Forserum Formations resemble that of the red quartz arenite of the Marbäck Formation in low contents of feldspar and lithic grains (Figs. 60 c, d). Unlike those of the red quartz arenite, the feldspars of the former sandstones, however, are all dominated by K-feldspar (Fig. 63, Table 3).

The feldspathic sandstones of the Branteberg Formation have been studied in samples from the type sections. The samples include granular, sandy matrices of conglomerate beds. The immature composition of the lowermost of the conglomerate beds and the almost complete dominance of granitic and metavolcanic lithic grains in them are illustrated in Fig. 62. In samples from the upper conglomerate beds there are more K-feldspar grains than plagioclase and perthitic grains. The plagioclase largely occurs within the lithic fragments which are similar in composition to the neighbouring red Småland granite. Much of the sericitic (and hematitic) matrix in this fraction of the conglomerates is probably a pseudomatrix derived from altered plagioclase and perthitic K-feldspar. Several characteristics thus indicate that the detritus was derived from a granite source. The palaeocurrent directions at Branteberg and the low content of opaques in the detritus suggest that an adjoining leucocratic granite complex to the east or related rocks were major contributors (cf. Table 5).

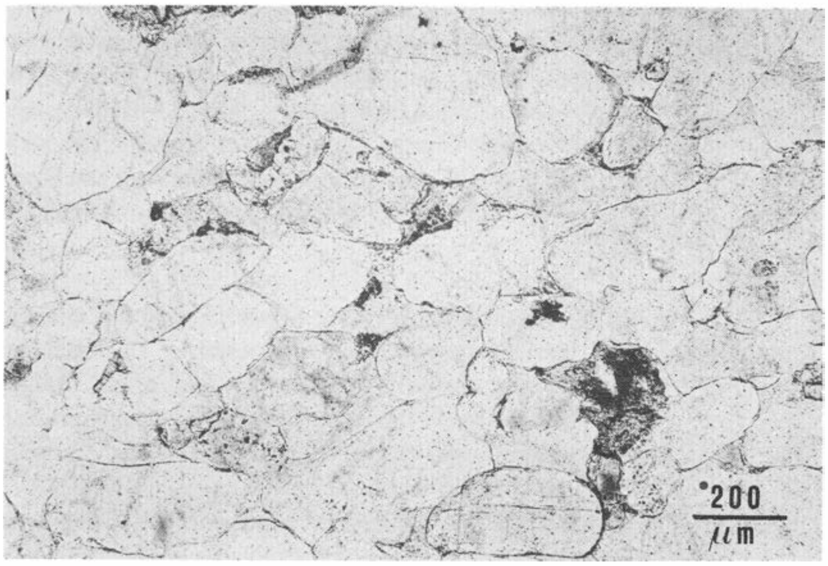


Fig. 71. Medium-grained subarkosic sandstone of the Branteberg Formation. Note subrounded to well-rounded quartz and feldspar grains delimited by "dust" rims or hematite pigment, and some quartz cement. Plain light. Sample from the uppermost beds in the Branteberg subarea, Fig. 12.

Dominance of granitic debris in the granule—fine pebble modes and near absence of it in the coarse modes is typical of the Branteberg conglomerates. Several explanations can be suggested for this feature which seemingly contradicts other indications of rather short transport distances, such as poor sorting and roundness, and the persistence of unstable composite grains in the debris. Severe weathering in the source areas has been suggested, supported in this case by the strong sericitic alteration of most feldspars in the basal conglomerate beds (Hedström 1917, cf. also Bradley 1970). Sericitic alteration of detrital feldspars derived from plutonic rocks is, however, largely a pre-erosional feature not by itself indicating an origin from weathered sections (cf. Weaver and Pollard 1973, see also James *et al.* 1981). A "millstone effect" caused by the high proportion of ultradurable quartzite and porphyry particles in the Branteberg gravels appears more likely: the less durable granitoid fragments were probably rapidly comminuted in the streams (cf. Abbott and Peterson 1978). The higher proportion of granitoid particles in the Hälleved conglomerate of zone H (cf. p. 61) may also be due to this effect: quartzitic clasts are few in these beds and most other particles were derived from moderately durable foliated rocks.

A study of the medium-grained sandstones overlying the conglomerates in the Branteberg sections and elsewhere in the Ralången area shows that the unstable components of the coarse facies have almost disappeared (Fig. 71). Perthitic and altered K-feldspar is much reduced, and instead there is twinned and untwinned microcline of a type extremely rare in the fine conglomerates. Large, scattered turbid grains of perthitic K-feldspar still indicate contribution from the granitic source. As far as can be judged from the lithic compositions of these and other sandstones in the Ralången area, the diluting sources appear to have been mainly feldspathic sandstones and metavolcanic rocks (Fig. 61b).

The sandstone of the Branteberg Formation in the Spexhult area resembles those in the Ralången area in composition. The lithic composition, however, indicates a more prominent sedimentary source (Fig. 61). Together with the local palaeocurrent directions (cf. p. 49) this suggests that Småland granites, now exposed to the north, and the sedimentary rocks that once probably covered the adjacent basement, have been the dominant sources of detritus. In the fine conglomerate rocks of the Forserum subarea (cf. p. 45), granitoid fragments are roughly as common as in the occurrences at Branteberg (Fig. 61). A few fragments are tectonites and some, containing zoned plagioclase, came from granodioritic rocks.

A number of textural inversions can be observed in the sandstones of the Branteberg Formation. The grain-size distributions tend to be bimodal (Fig. 65), in part because of polymodal feldspar grain sizes. The average size of the feldspars tends to be as large as that of the quartz grains and roundness decreases with increase in grain size (Fig. 72). These features are anomalous in mono-source feldspathic sands but typical of feldspathic sands of mixed provenance derived, for instance, from older mature sandstones and immature arkosic debris (Folk 1974).

The quartzitic sandstones of the Storekvarn Formation are homogeneous in composition and the lithic grain content is extremely low (Table 3). Many lithological characteristics suggest that these sandstones are multicyclic (cf. p. 73).

In the western, dolerite-intruded parts of the Forserum

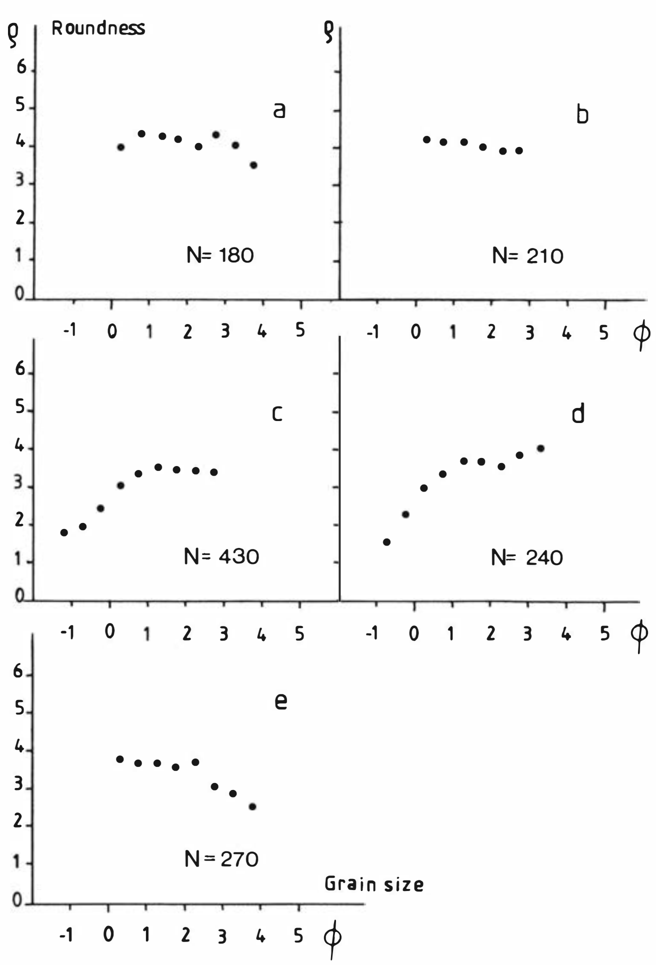


Fig. 72. Grain roundness as a function of grain size in sandstone of the Storekvarn Formation (a and b), the Branteberg Formation (c and d), the red quartz arenite (e). Note that the roundness/size relationship in a, b and e are normal, whereas roundness increases with decreasing grain size in c and d.

Formation, metavolcanic and granitoid fragments dominate over sedimentary ones. In samples from the reddish, eastern part of the Forserum Formation, sedimentary lithics are, however, clearly more common than in the western sandstone and are mostly fragments of hematite-cemented siltstones. Muddy hematitic pore-fillings, not found in the western beds, are common.

SOME QUESTIONABLE STRATIGRAPHIC RELATIONSHIPS AND CORRELATIONS

The limited extent of outcrops and their often sporadic character makes the exact nature of the stratigraphic relationships of the formations of the Almesåkra Group difficult to determine precisely. These problems, the nature of the unconformity between the Nässjö and Storekvarn Formations, the stratigraphic positions of isolated occurrences of the quartzitic sandstone in the Forserum subarea, and the correlation of the Forserum Formation with the rest of the Almesåkra Group, are discussed below. The stratigraphic relationships between the Storekvarn and Branteberg Formations have been described above (pp. 15, 17).

The relationship between the Nässjö Formation and the Storekvarn Formation. — As exposed in the Ralången area, the unconformity between the Nässjö and Branteberg Formations clearly denotes the westward spreading of alluvial fans over eroded argillitic and other sandstones of the Nässjö Formation.

In the Vikskvarn-Storekvarn subarea 25 km to the south of the Branteberg subarea, a presumably erosional unconformity records an abrupt change from the low-energy environment of the flood or delta plain that existed during the sedimentation of this part of the Nässjö Formation. It was replaced by a higher-energy environment marked by the deposition of quartz-rich Storekvarn sands and local coarse gravels.

In the Spexhult area, taken as a whole, the general lithology of the Storekvarn quartzitic sandstones and, especially, their homogeneity over a comparatively large region indicate that an overall shift of environment had occurred after the deposition of the Nässjö muds.

Was this a major shift in the environment marked by a marine transgression accompanied by the deposition of beach and shallow-marine sediments in this southern part of the area of Almesåkra sedimentation? The majority of previous students were convinced of the marine origin of most, if not all, of the Almesåkra sedimentary sequence. Recently, suggestions of rifting in the neighbouring Protogine Zone between 850 and 1000 Ma ago (Solyom *et al.* 1984) have directed attention towards this question.

Mature, often massive quartz-arenitic sandstones of wide extent (''blanket sandstones'') are common in the Upper Proterozoic and Cambrian (Reading 1978, Pettijohn *et al.* 1972). Apart from cases such as the Lower Cambrian of Scandinavia, where sedimentary structures and/or evidence from fossils indicate shallow-marine or beach depositional environments, their modes of deposition are largely uncertain. Modern analogues are lacking; at present quartz arenite sands appear to be forming predominantly by the erosion of older mature sandstones (Potter 1978). Fluvial sands now being laid down on all the continents are seldom compositionally mature even in the lower reaches of the rivers (Potter 1978, cf. also Suttner *et al.* 1981). Exceptions to this rule are explained either by downstream enhanced maturity of the sands, due mainly to dilution by quartz-rich tributaries, or by an overall compositional maturity, which is uncommon and due to deep weathering in all source areas (Franzinelli and Potter 1983, cf. also Harms 1979, Dott 1983).

The coarse conglomerates interbedding the Storekvarn quartzitic sandstones in the Vikskvarn-Storekvarn subarea are poorly sorted and display virtually no grading nor pebble segregation (cf. Clifton 1973, see also pp. 29, 48): they do not indicate any reworking by waves on a beach. A general characteristic of these quartzitic sandstones is the total absence of siltstone and mudstone layers or mud drapes such as occur in heterolithic facies of shallow marine deposits (Reading 1978). Detrital micas are also absent. Together with the lithological homogeneity of the sandstones this suggests a large degree of reworking, probably combined with episodic aeolian transport. Next to transport on beaches, aeolian transport is the mechanism most conducive to textural maturity in sands.

Depositional models of this kind have been suggested for several ancient quartz arenites (Donaldson 1967, Folk 1968, Chaudhuri 1977, cf. also Ross 1983). Strongly bimodal grain-size distributions and the absence of a fine sand fraction as well as bimodal grain roundness distributions are considered to indicate at least intermittent aeolian transport. In the case of the Storekvarn quartzitic sandstones, however, such textural traits appear to be lacking (cf. Figs. 65, 66). The absence of fine-grained, angular quartz materials in the pores of ancient arenites can, however, very well be a diagenetic effect. Small angular quartz grains and splinters commonly form by attrition in deserts. They are easily subjected to dissolution and reprecipitation (Heald and Renton 1966).

Because of features contradicting a beach origin and because of the absence of criteria characteristic of a shallow marine sandstone facies (except that of textural maturity), the quartzitic sandstones of the Storekvarn Formation are considered to have been formed from sands deposited mainly by fluvial processes and being widely reworked in interchannel areas by intermittent aeolian transport. Probably the main source-rocks consisted of low-lithic and feldspar-poor sands of the Branteberg Formation. The outcrop pattern of the quartzitic sandstones in the Spexhult area is consistent with westward and southward transport directions, similar to those actually recorded in the Branteberg Formation in the Ralången area. The relationships between the lithologies of the Branteberg and Storekvarn Formations are compatible with a gradual reworking of the less mature eastern sediments to produce the more mature western ones.

The stratigraphic correlation of isolated units of quartzitic sandstone in the Forserum subarea and the tectonic evolution of the Lättarp syncline. — As described above (p. 17), the Forserum subarea contains several isolated occurrences of quartzitic sandstone. These rocks are compositionally similar to most of the medium-grained sandstones of the Forserum Formation (cf. Fig. 60). Moreover, the general configuration of the rocks in the Lättarp syncline suggests their correlation with the Forserum sandstone. However, the following factors render this correlation doubtful: 1) In the eastern part of the Forserum subarea, some of the quartzitic units in question occur close to the remnants of the Branteberg Formation and also close to presumably overlying beds of the Storekvarn Formation (Fig. 14). This spatial association suggests that the quartzitic units of the eastern part of the Forserum subarea, which are downfaulted relative to the basement, belong to the Storekvarn Formation. 2) In the central part of the Forserum subarea, several of the problematic quartzitic units are exposed between the minor lakes and the dolerite outcrops to the west and north of Lake Lättarp (Fig. 16). Some of these units might belong to the Forserum Formation on the evidence of conformable bedding attitudes. However, the majority does not conform with the regional synclinal pattern, and appears to be controlled by faults. This suggests that the quartzitic sandstones in question overlie the Forserum Formation discordantly. The conclusion is reinforced by observations made in the dolerite quarry to the west of Lake Lättarp (Fig. 16). In this exposure, now largely destroyed, an intrusive contact between the dolerite and sandstone of the Forserum Formation was observed, whereas a tectonic contact between the dolerite and the quartzitic sandstone appeared probable.

On the evidence of these field relationships, and the lithological homogeneity of the problematic quartzitic sandstones in the Forserum subarea (cf. Table 3), which contrasts with the upward increasing occurrence of fine-grained feldspar-rich layers and thin mudstone beds in the undisputed Forserum Formation sequence, these two sandstones appear to be stratigraphically unrelated. The quartzitic sandstones (except those of the northernmost part of the Forserum subarea, where a reference to the Marbäck Formation appears possible), are interpreted as relics of the Storekvarn Formation. It is probable that the latter originally covered much of the Spexhult area including the Forserum subarea. This cover of Storekvarn rocks could have been broken up and partially eroded during the post-intrusive compressional folding of the Lättarp syncline. In the eastern part of the syncline this early folding may have been accentuated by later downwarping against the set of N-striking faults described on p. 24. The subsided heterolithic sequence of Forserum, Branteberg and Storekvarn sedimentary rocks was then confined between an unyielding granite foot-wall to the east and the relatively rigid, dolerite-intruded Forserum sandstone to the west.

The relationship between the Forserum Formation and the rest of the Almesåkra Group. — The unconformity probably existing between the Forserum Formation and overlying units of the Branteberg Formation (cf. p. 17) is largely covered by recent deposits and complicated by faulting (Fig. 16). However, on the eastern shore of Lake Lättarp the abrupt upward change in facies can be studied. Relatively mature, reddish Forserum sandstones with coarse conglomerate beds are overlain by a Branteberg association of compositionally and texturally very immature fine conglomerates with argillites and fine-grained sandstones. This association is believed to have been laid down as an alluvial fan spreading southwards and westwards, as indicated by a decrease of the fine conglomerate fraction and by a general fining of the grain size in those directions.

In the remnant Branteberg Formation to the east of the fault zone, cross-strata and axial directions of troughs indicate palaeocurrents flowing mainly southwards (Fig. 56). No coarse conglomerate beds are exposed here, nor are they found in the basal faulted beds of the formation in the Lättarp syncline. Such beds, if present, may very well have been preferentially eroded in the tectonically disturbed Forserum area. The relatively high incidence of argillites suggests, however, a more distal alluvial fan environment for these occurrences of the Branteberg Formation.

Statistically the average composition of the detritus in the Forserum Formation does not differ significantly from that of the sandstones of the Branteberg Formation; both were probably derived from similar source rocks. However, the presence of many sedimentary lithic grains in the eastern part of the Forserum Formation supports a relationship between the eastern Forserum sandstones and the sandstone/coarse conglomerate sequence of the Nässjö Formation, the Kansjö sequence, exposed in the western Spexhult area (cf. p. 70). That the Forserum Formation is probably coeval with this part of the Nässjö Formation is also suggested by the close field association to the south of Lake Lättarp between small exposures of reddish, conglomerate-bearing Forserum sandstones and fairly thick argillites of the argillite/fine-grained sandstone association (Fig. 14). To the south of Forserum, typical Nässjö Formation fine-grained sandstone beds with mud flasers and thin conglomerate beds occur directly on the basement (Fig. 46). A transitional or interfingering relationship between the Forserum Formation and at least part of the Nässjö Formation thus appears probable in the southernmost part of the Forserum subarea.

SYNOPSIS AND CONCLUSIONS

The Middle Proterozoic Almesåkra Group consists of five formations (see Fig. 3). In the east, below the Nässjö Formation, the Marbäck Formation comprises isolated erosion remnants resting on the basement. The Nässjö Formation is overlain in the north (in the Ralången area) by the Branteberg Formation and in the west (in the western Spexhult area) by the Storekvarn Formation. The Storekvarn Formation may overlie the Branteberg Formation in the west. In the westernmost occurrences of the Almesåkra Group, the Forserum Formation overlies the basement; it is probably coeval with a part of the Nässjö Formation.

The Nässjö Formation is exposed mainly in the eastern part of the Spexhult area, the Branteberg Formation mainly in the Ralången area. The Nässjö Formation probably attains a composite thickness of 900—1000 m, the Branteberg Formation is att least 130 m thick. The Storekvarn Formation is at least 200 m and the Forserum Formation is approximately 300 m thick.

The sedimentary rocks of the Almesåkra Group are composed largely of feldspathic arenites. Conglomerates and argillites are subordinate and make up approximately 15% and 10% respectively of the sequence. Conglomerates occur in all of the formations, argillites predominantly in the Nässjö Formation. Twelve depositional facies or associations of such facies have been distinguished, described and interpreted. Based on the interpretations of the various depositional facies, on the palaeocurrent patterns, and on the detritus composition of the sandstones, a general picture of the palaeoenvironments of the Almesåkra Group can be presented.

The sediments of the Nässjö Formation were deposited in an environment characterized by initial low-energy conditions. Fine-grained sands and muds settled upon exposed basement rocks and on remnants of an older sedimentary cover; also, upon local accumulations of weathering debris. In the north-central part of the Spexhult area, a west-trending belt of feldspathic sandstones with numerous conglomerate beds (the medium-grained sandstone/ coarse conglomerate association) indicates the presence of a sand-dominated river system which transported feldspathic sands and predominantly quartzitic coarse gravels in westerly to northwesterly directions.

A portion of these deposits probably constitutes the Forserum Formation in the northwest. To the north and south of these rivers, laminated silts and clays (the argillite facies) and laminated muds interbedded with mostly fine-grained sands (the argillite/fine-grained sandstone association) accumulated over fairly wide regions. They were probably deposited on episodically inundated flood plains associated with the river channels and presumably also in lakes. The red arkosic, fine- to medium-grained sandstones (the red arkosic sandstone lithofacies) of the basal parts of the Nässjö Formation in the east and extreme south of the Spexhult area were probably laid down at roughly the same time by another river system. This system derived its detritus, which was comparatively rich in specularite grains and rock fragments, from metavolcanic and granitoid source areas in the east and southeast. These sources contained fewer quartzitic sandstones of the older cover than those of the north-central drainage system. Detritus from a granodiorite source became prominent with time. The proximal facies of the red arkosic sandstones in the marginal Hälleved zone rests on locally derived conglomerates which probably represent part of the basal deposits of the southeastern river system.

Later, coarse and fine gravels with local thin muds (the fine and coarse conglomerate/argillite association of the Branteberg Formation) and, on top of these, cross-stratified fine-gravelly sands (the medium-grained sandstone/fine conglomerate association) were laid down in several alluvial fans at the foot of west-facing scarps of regional faults which occurred in an area extending westwards at least as far as Forserum. The fans spread out over eroded and probably tilted Nässjö and Forserum sandstones. In places, crystalline basement and sandstones of the older cover appear to have formed part of the substratum. The detritus was largely transported in pebbly braided streams. It had been derived from mixed eastern sources made up of older sedimentary cover and crystalline rocks. The trends of detritus variation suggest that initial granitic debris, derived from the fault scarps, was gradually replaced by sands comprising detritus mainly from metavolcanic and older cover sources.

The transition from the upward-fining alluvial sequence of the Branteberg Formation to the relatively mature quartz-rich sands of the Storekvarn Formation (the grey quartzitic sandstone lithofacies) is believed to have been effected largely by the reworking of the feldspar-poor sands of the former sequence. Fluvial transport was probably the main reworking mechanism at least in the southwestern part of the Spexhult area. Conglomerates or gravels of the Nässjö Formation may have been exposed here in fault scarps and become eroded. The lithological homogeneity of the quartzitic sandstones in comparatively wide areas to the west suggests a stable depositional environment such as, for instance, downfaulted plains. The textural maturity of the multicyclic sands was probably promoted by wind transport and deposition on more or less ephemeral aeolian dunes in interchannel areas.

Shallow-water conditions and, probably in part, aeolian transport are suggested by certain structural and textural characteristics of the red beds of the Marbäck Formation (the red quartz arenite lithofacies). The modes of hematite and quartz cementation in this formation further suggest that the palaeoclimate was arid or semi-arid, and warm. The preserved euhedral overgrowths on quartz grains in the Nässjö red arkosic sandstones indicate that similar climates probably prevailed also during the deposition of at least the lowermost part of the Nässjö Formation.

As above-mentioned, compositional variation and persistent palaeocurrent directions indicate that the sediments of the Almesåkra Group were laid down in basins or on plains by streams draining uplands located mainly to the east and southeast. In contrast, the characteristics of the Almesåkra sediments do not indicate any influx of detritus from possible highlands in the area to the west of the Protogine Zone which were affected by the Sveconorwegian — Grenvillian orogeny 1250—900 Ma ago.

When the dolerite magma intruded c. 1000 Ma ago (Patchett 1978), the sediments of the Almesåkra Group were consolidated but not cemented completely (cf. Rodhe 1985). A minimum time lapse of some millions of years between the consolidation of the red beds of the older sandstone cover and the deposition of the conglomerates of the Nässjö and Branteberg Formations is suggested by the modes of hematite and quartz cementation in red sandstone clasts found in the conglomerates. Similar red quartz arenites are exposed today only in outcrops of the Marbäck Formation.

Several remnants of fine-grained dolerite-intruded sandstones, presumably belonging to the Nässjö Formation, are found to the west of the present occurrence area of the Almesåkra Group (cf. Fig. 1). Together with the observations of xenolithic dolerite dykes several tens of kilometres further south (cf. p. 5), this supports Eichstädt's (1885) and Magnusson's (1963) conclusions regarding the one-time presence of a very extensive Jotnian sedimentary cover in southern Sweden. This Jotnian cover derived part of its detritus from more ancient, unmetamorphosed sedimentary sources.

The authigenic mineralogy of the Almesåkra sandstones and the very low-metamorphic grade of the argillites suggest moderate depths of burial of the Almesåkra Group.

Brittle tectonics characterize the deformation of the Almesåkra sedimentary sequences with intruding sills. The intensity of tectonic disturbance does not on the whole decrease from the west to the east of the occurrence area as has been suggested by earlier observers (cf. Gavelin 1931, Martin 1939).

The folding style as observed in a limited number of large-scale structures is upright and, with one exception, open. A majority of the folds, large or small, can be related to movements along high-angle faults belonging to the regional system. The fold axes form a diffuse girdle pattern when plotted on an equal area net. The axial trends tend to cluster at NW—NNW, but also at NE and W; the plunges are gentle and preferentially westerly.

The dips of the bedding in sandstones are usually gentle except near fault zones. Argillite-dominated units in such zones are generally much more deformed than the associated sandstones, the deformation still being largely brittle.

Major high-angle faults mainly trend N, NE and NW to NNW. Movements on the faults appear generally to have been normal; however, reverse faulting and thrusting has been observed locally in association with the NE-trending regional faults. The latter have probably acted as strike-slip faults during part of their existence. No conclusive proof of appreciable lateral displacements along them has, however, been found.

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REFERENCES

GFF = Geologiska Föreningens i Stockholm Förhandlingar
SGU = Sveriges geologiska undersökning

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Errata

page: column	line	printed	should be
Geochemistry and clay mineralogy of argillites in the Late Proterozoic Almesåkra group, south Sweden			
175:2	16	sills exceeding	sills locally exceeding
182:1	44	microline	microcline
Depositional environments and lithostratigraphy of the Middle Proterozoic Almesåkra Group, southern Sweden			
title-page		ALMESÅKRA GROUP SOUTHERN SWEDEN	ALMESÅKRA GROUP, SOUTHERN SWEDEN
1		ALMESÅKRA GROUP SOUTHERN SWEDEN	ALMESÅKRA GROUP, SOUTHERN SWEDEN
4:1	35	Svecokarelian	Svecofennian
6:1	32	Svecokarelian	Svecofennian
6:1	34	Svecokarelian	Svecofennian
22:1	18	Svecokarelian	Svecofennian
22:1	19	Svecokarelian	Svecofennian
23:1	15	(Fig. 22)	delete
23:1	19	high-angle,	high-angle (Fig. 22),
27 in Table 2		Laminae cm	Laminae mm
30:2	29	p. 63	p. 65
52:2	30	columns 15,6,7	columns 14, 6, 7
54 text to Fig. 61	7	as in Fig. 60.	as in Fig. 60. Filled triangle with numeral 4 represents average lithic composition of sandstone in Table 3 b, col. 11. Sp = Spexhult area.
56:1	5	cf. p.66	cf. p. 68
58:1 in Fig. 64		Nässjö fm	Nässjö Fm
		Branteberg fm	Branteberg & Storekvarn Fm
60:2	4	(cf. p. 21)	(cf. p. 30)
60:2	7	52).	29).
70:2	22	Table 3	Table 3b
70:2	25	Table 3	Table 3b and Fig. 61, caption
70:2	32	Table 3	Table 3a and 3d, 3e

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