

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 781 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 75 NR 2

ANDERS LINDH
EDITOR

CONTRIBUTIONS TO THE
PROTEROZOIC GEOLOGY
OF SOUTHERN VÄRMLAND
SOUTH-WESTERN SWEDEN



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THE FRYKSDALSHÖJDEN GNEISS A POSSIBLY EARLY PLUTONIC ROCK IN THE WESTERN PREGOTHIAN MEGA-UNIT

By ANDERS LINDH

ABSTRACT

Along the eastern edge of the Western Pregothian mega-unit an alkali-intermediate migmatite gneiss (the Fryksdalshöjden gneiss) occurs. It normally shows two generations of migmatite veins. It is interpreted as a plutonic rock. Chemical and field data both indicate that the Fryksdalshöjden gneiss and the Åmål-I granitoids are separate rock groups probably intruded at different times. Circumstantial evidence based on the number of discernible migmatite forming events, location in the mega-unit and mutual distribution of individual intrusions within the mega-unit suggests the Fryksdalshöjden gneiss to be the older rock. No conclusions regarding age relationships between the migmatite gneiss and metasediments presumably older than the Åmål-I granitoid suite can be presented.

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Anders Lindh. Avd. för Mineralogi och petrologi. Geologiska institutionen. Sölvegatan 13, S-223 62 Lund, Sweden. January 26, 1981.

INTRODUCTION

During the past decades opinions on the development in the south-western margin of the Baltic Shield has changed with changing models of continental growth and evolution. Recently a couple of between themselves incompatible models based on today's plate tectonic hypotheses have appeared (e. g. Zeck and Malling 1976; Burke et al. 1977; Torske 1977; Berthelsen 1977, 1980; Lundqvist 1979). A more or less successful adaption of these very different models is only possible if many relevant facts are unknown. Even if some features are consistent with certain ideas of modern approaches, the overall picture is in my opinion far too incomplete to allow conclusive models to be set up. Modern mapping free from prejudices of old concepts will with time allow such a model to grow out. Presently we work with a provisional division of south-western Sweden into mega-units. The current subdivision is displayed by Lindh et al. (1981, Fig. 1). The adoption of a consistently planned program for isotope dating has made invaluable contributions to the timing of events and put important constraints on possible models of development. Hitherto presented Rb-Sr whole rock isochrons are obtained from rocks of known plutonic origin and with well established field relations. Results from these studies have enabled the construction of a rather firm frame-work for the development for

the time following the intrusion of the calc-alkalic Åmål-I granitoids at around 1 650 Ma ago. Limited resources have not permitted attempts, necessarily more at a venture, for less well-defined rock groups. Hence, the deliberately biased sampling pattern has eliminated most possibly older rocks from being sampled. In the Western Pregothian mega-unit no successful dating project designed to unravel a possible history before the intrusion of these granitoids has consequently been presented. Nevertheless, available results must not be interpreted in terms of an exclusively post-Svecokarelian history of the marginal zone of the Baltic Shield. The intention with the present contribution is to draw attention to a sequence of sialic medium-grained rocks that presumably is older than the Åmål-I granitoids.

TRAITS OF THE GEOLOGICAL BACKGROUND

The earliest history of the marginal zone of the Baltic Shield is poorly known. We are still groping for a firm ground on which to base our discussions. The present progress report should be seen towards this background. North of the village of Kil, the Mylonite Zone separates the "Pregothian area" into two lithologically distinct mega-units (Magnusson 1937a; Lindh 1974; Lindh and Malmström 1980): the Eastern and Western Pregothian. In the Eastern Pregothian recently published isotope dating suggests a datable history before the intrusion of the age equivalents of the Åmål-I plutonics (Welin and Kähr 1980). Hence, the recorded part of the history is expanded well into Svecokarelian time, but still no pre-Svecokarelian event is dated. In the Western Pregothian mega-unit, to which the present contribution is devoted, the polymetamorphic nature of rocks complicates mapping. Definition of genetically coherent rock suits becomes difficult and interpretations of origins speculative; in many cases even fundamental subdivisions into plutonics and supracrustals are very uncertain.

In the Åmål mega-unit which is better preserved, supracrustals in the Åmål group are older than the provisional Åmål-I group of granitoids (see e. g. Gorbatshev 1977). Gorbatshev (1979) has put forward arguments to support an interpretation suggesting a primary sedimentary contact between these supracrustals and a granitic basement. The supracrustals include fragment-bearing rocks, among which are cobbles of an older granitic basement (Gorbatshev 1979).

In the Western Pregothian mega-unit rocks of supracrustal origin occur. Supracrustals can be followed along strike from better preserved areas in the Åmål tectonic mega-unit into the Western Pregothian, where eventually they are lost among more or less fine grained gneisses of unknown origin. In the east the two mega-units are separated by lineament structures including faults and overthrusts, but in the west no definable lines separating the two can be found.

The difference between them is only a difference in state of preservation. In many other cases recognition of supracrustals is more difficult. Wahlgren (1981) reports a conglomerate occurring as a xenolith in an Åmål-I granitoid. However, among the fragments also granitic cobbles occur, suggesting the former existence of a granitic basement to supracrustals that are unequivocally older than the Åmål-I granitoids. Mineralogical composition and grain size that is finer than normal speak in favour of a clastic origin for other rocks in the Western Pregothonian mega-unit. In many instances independent support is found in the distribution of individual rock units in long narrow bands. Mapping is in large areas principally a question of defining coherent rock suites. The interpretation of a suite so defined is in many cases more open. Well-defined even if not well interpretable rock associations are found north of Värmlandsnäs. The rock units are transected by numerous wrench faults (Wahlgren and Kähr 1977; Wahlgren 1979) making extrapolations doubtful. Northwards and southwards rocks gradually become more difficult to define and mapping again meets with severe difficulties.

The Åmål-I granitoids are spread over the entire mega-unit and should offer a comparatively well-dated and recognizable "stratigraphic level". They are often veined, sometimes beyond recognition. The greatest obstacle for their use as a relative age indicator is sheared-out contacts that almost always are parallel to the local foliation. The general pattern of lithology distribution and the general state of preservation are at least consistent with interpretations suggesting that the Åmål-I granitoids are intrusive into the metasupracrustals.

Foliation planes are folded into open folds resulting in low to moderate easterly and westerly dips. The wave-length of the folds is a couple of kilometres. On approaching the Mylonite Zone foliation planes are raised and their strike and dip are not discernible from those of the fluxion planes in the Mylonite Zone (for the area around the village of Kil, cf. Lindh and Malmström 1980). Rocks invariably dip steeply eastwards. We do not know the relation between original bedding and foliation. Thus, today's knowledge of tectonics does not help us in relative age determinations. In the absence of isotope datings, we must consequently rely on criteria from petrography, geochemistry and form and distribution of individual rock bodies for relative age estimates.

THE FRYKSDALSHÖJDEN GNEISS

The Fryksdalshöjden gneiss is a well defined migmatitic gneiss found in a couple of elongated massifs along the eastern edge of the Western Pregothonian mega-unit (Fig. 1). It occurs from the break in the Mylonite Zone at Kil (Lindh and Malmström 1980) to the eastern of the two lineaments forking out from Lake Mangen (Lindh 1980). The latter line abruptly cuts the Fryksdalshöjden

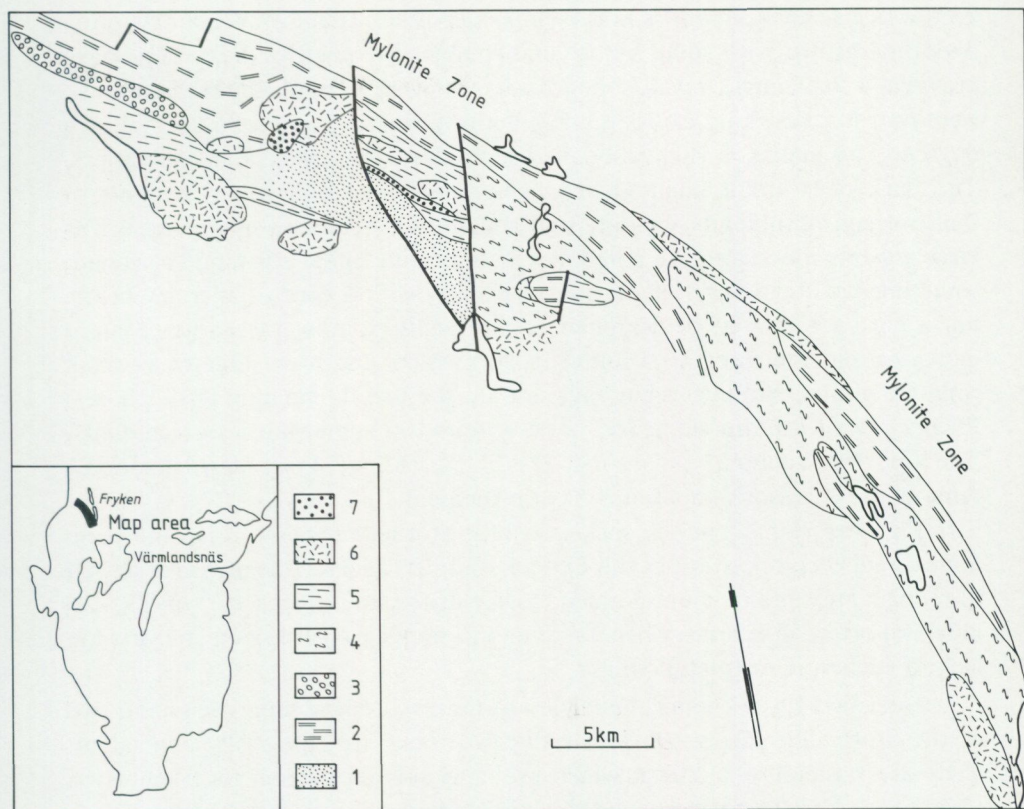


Fig. 1. Simplified sketch map of the Western Pregoethian mega-unit adjacent to the Mylonite Zone. Note the offsets of the southern border of the Zone.

Legend: 1, undifferentiated migmatite gneiss; 2, migmatite gneiss associated with the Fryksdalshöjden gneiss; 3, Storheden gneiss; 4, Fryksdalshöjden gneiss; 5, supracrustal gneisses; 6, Åmål-I granitoids; 7, younger microcline granites.

gneiss, and along strike it is replaced by a banded sequence of metasupracrustals. These supracrustals are in turn replaced by a more undefinable grey migmatite gneiss beyond the western of those two lineaments. Rocks interpreted as belonging to the Åmål-I sequence of granitoids occur both to the east of, to the west of and between these two lineaments. Obviously, their influence on the occurrence area of the Fryksdalshöjden gneiss is much more drastic.

The gneiss is a reddish grey to greyish red medium-grained rock. Occasionally the rock becomes somewhat greyer, which is caused by an increase in mafic minerals. The western massif (Fig. 1) is normally of this character. The rock has a more or less well-developed relic optamalitic texture; locally two generations of deformed megablasts are found. Migmatite veins of two generations are frequently recorded, the older one being rather diffuse. More seldom is even a third generation discernable, but this is more uncertain. The younger generation is conspicuously coarser than the "paleosome"; it is surrounded by

biotite-rich restites, and it is hornblende-sticholitic. The hornblende has often been intergrown with some biotite and sphene. Frequently, these veins have grown at a small angle towards the foliation or in the axial planes of older folds. Southwards, reworking caused by migmatite formation generally decreases in degree. The matrix is slightly banded with alternating dark and light layers. The dark ones are dominated by olive-green biotite and lesser amounts of bluish green hornblende, epidote and sphene. Occasionally sphene occurs as large crystals which also are noted macroscopically. Epidote is found as zoned, sometimes prismatic crystals, rather frequently with a core of allanite. In the north garnet seems to be confined to late veins, southwards garnet content increases and the mineral is found in all parts of the rock. Quartz as small rounded grains, and microcline euhedra are the two dominating felsic phases. Plagioclase of a more subhedral habit is found in somewhat lesser amounts. The anorthite content is around 22–24 % (Michél-Levy determination). Among the accessories apatite is most prominent.

In Fig. 1 appears a gneissic rock called the Storheden gneiss. It has the same mineralogical composition as the Fryksdalshöjden gneiss. It is also greyish red to reddish grey and medium-grained; coarse microcline augens are typical. The most important difference when compared to the Fryksdalshöjden gneiss is the lack of sticholitic migmatite veins.

Table 1 lists three chemical analyses of the Fryksdalshöjden gneiss and two of the Storheden gneiss. Obviously the two rocks are chemically equivalent. They are rather low in silica, which probably was the reason for Magnusson (1937b) to class the former as intermediate gneiss. The chemical composition, the mineralogical composition, the generally coarse appearance of the rock, and the form of individual massifs (cf. Fig. 1) are at least consistent with suggestions of a plutonic origin for the rock. If it is not plutonic unexplained differences between this rock and undisputable supracrustals arise. These differences pertain to a rather coarse texture *versus* a generally rather fine grain-size, individual bodies in form of elongated homogeneous ellipsoids *versus* long bands with significant compositional differences across but not along the strike, and a mineralogically feldspathic character *versus* a micaceous one.

South of the break in the Mylonite Zone at Kil migmatite gneisses occur which Magnusson (1933, 1937b) on earlier maps did not differentiate from the Fryksdalshöjden gneiss. Present field data are far from conclusive, but do not immediately suggest an identity between these rock types. Chemical analyses to back up a conclusive settling of this question are still lacking.

The Fryksdalshöjden gneiss occurs in close association with a more siliceous grey migmatite along the eastern border of the Western Pregothian mega-unit. The associated gneiss is not unique enough to allow an undisputable discrimination from other similar looking gneisses. North-west of the realm of the Fryksdalshöjden and Storheden gneisses, grey migmatitic gneisses occur,

TABLE 1. Chemical analyses of Fryksdalshöjden (Fg) and Storheden (Sg) gneisses. Coordinates in the Swedish National grid.

Analyst: Geochemical Division, Geol. Survey of Sweden.

Sample	S-AL 3336	S-AL3338	S-AL 3945	S-AL 5127	S-AL 5259
Top map	11C ARVIKA SO 66220/13450	11C ARVIKA SO 66228/13478	11C ARVIKA SO 66225/13470	11C ARVIKA NV 64432/13176	11C ARVIKA NV 66414/13190
rock	Fg	Fg	Fg	Sg	Sg
SiO ₂	67.5	67.5	66.0	65.9	68.7
TiO ₂	0.68	0.76	1.01	0.72	0.65
Al ₂ O ₃	14.6	14.6	14.7	14.2	14.4
Fe ₂ O ₃	1.4	1.6	1.8	1.2	1.3
FeO	2.6	2.6	3.4	3.1	2.4
MnO	0.10	0.09	0.12	0.11	0.10
MgO	1.20	1.24	1.64	1.3	1.03
CaO	3.1	3.2	3.5	2.9	2.8
Na ₂ O	3.4	3.5	3.0	3.4	3.3
K ₂ O	4.0	3.8	4.1	3.9	4.4
H ₂ O ⁺	0.5	0.7	1.2	1.1	0.3
P ₂ O ₅	0.16	0.20	0.29	0.23	0.20
Total	99.24	99.79	100.76	98.06	99.58

which may or may not be identical to the associated gneiss just mentioned. The only difference of importance is an intimate association with amphibolites and finer-grained siliceous types not recorded towards the south-east. Gneisses that cannot be told from these neither by the naked eye nor under the microscope occur rather widely spread in the Western Pregothian mega-unit; normally any classification beyond the rather banal one of a siliceous migmatitic gneiss is impossible.

DISCUSSION AND CONCLUSIONS

The earlier established model for the development of the Baltic Shield as it was outlined by e. g. Magnusson (1963), recognizes hardly any evolution in the south-western marginal zone. The two Pregothian mega-units were supposed to be an old Archean core to which later orogenic cycles had added newly

formed and partly reworked crust. No efforts were made to distinguish between different episodes in the Pregothian development. After the appearance of radiometric datings a different picture has emerged. A generally seen complex history of more or less continuous development during mid and late Proterozoic times is disclosed. The oldest part of this disclosed history is represented by the Åmål-I granitoids.

Differentiation in the field between Åmål-I granitoids and Fryksdalshöjden gneiss as well as equivalent rock types is never questioned. In spite of this unusually well-defined difference no interpretable criteria for an unequivocal age relation are found. The former shows a considerable range in composition from tonalite towards granodiorite not recorded in the latter group. Recent mapping indicates that the limited chemical variation does not result from biased sampling but reflects a homogeneous rock. When comparing rocks from both groups within the same silica range, mineralogical and chemical differences are obvious. In Åmål-I granitoids microcline is rather rare; much of the potassium is found in biotite. Plagioclase is consequently the dominating feldspar, in contrast to the Fryksdalshöjden gneiss. Sphene occurs abundantly in both rock types. However, it is more prominent in the Fryksdalshöjden and equivalent rocks. The proportion of mafic minerals is higher in the Åmål-I granitoid group.

Within the granitoid group TiO_2 shows an expected steady decrease with increasing SiO_2 . The limited number of chemical analyses in the other group and its limited SiO_2 -range do not permit suggestions of correlation between SiO_2 and TiO_2 ; the absolute content of TiO_2 is higher in the Fryksdalshöjden group (Fig. 2). Prominent linear relations between CaO and total iron as well as between CaO and MgO are present in the available lot of Åmål-I granitoid analyses. CaO contents in Fryksdalshöjden gneisses of similar MgO or total iron content are decidedly lower. On the other hand plots of alkali *versus* silica or any other index of differentiation do not reveal any correlations in the Åmål-I group, nor any significant differences between the two rock groups. Values within the Åmål-I group show a considerable scatter that conceals possible differences. It is beyond my appraisal to decide if scattering is purely due to inferior analytical precision or to a real scatter in the material.

The certain plutonic origin of the Åmål-I granitoids and the deep-seated intrusive character of the Fryksdalshöjden gneiss group justify exploitation of Niggli values for comparison purposes. Plots of Niggli's *k* *versus* Niggli's *si* reveal the more potassic character of the Fryksdalshöjden gneiss and of Niggli's *mg* *versus* Niggli's *si* the more magnesian character of the Åmål granitoids (Fig. 3). Results from the chemical analyses thus suggest a difference in character between the Åmål granitoid group and the Fryksdalshöjden gneiss and an identity between the latter and the Storheden gneiss. Chemical data and field interpretations consequently agree that the two groups are different.

Accepting the Fryksdalshöjden gneiss as plutonic, we are faced with two

plutonic sequences of different character. Earlier observations within both the marginal zone and the central parts of the Baltic Shield are not consistent with a suggestion of having two distinctly different plutonic sequences simultaneously intruded in the same area. This is certainly not evidence for different intrusive periods, but the chemical data at least support suggestions of age differences between the two rock suites.

Younger microcline granites that simultaneously are more siliceous than the Åmål-I granitoids occur. They are, however, only slightly migmatized which is a very important difference when compared with the Fryksdalshöjden gneiss. Consequently, a time equivalence between the younger microcline granites and the Fryksdalshöjden gneiss is completely precluded. A suggestion of a higher age of the Fryksdalshöjden rocks as compared to the Åmål-I granitoids would extend the plutonic history of the Western Pregothian in the same way as radiometric datings already have done in the Eastern Pregothian mega-unit. Important field observations are in accordance with this suggestion: The Fryksdalshöjden gneiss has at least two separate generations of migmatite veins and one or two generations of megablasts. The Åmål-I granitoids show normally only one discernible vein generation. (Occasionally two generations occur.) Åmål-I plutonic rocks occur, however, with unexposed contacts, as smaller intrusions within the Fryksdalshöjden gneisses. The Fryksdalshöjden gneisses are only exposed along the edge of the Western Pregothian mega-unit. Finally, the occurrence area of the Fryksdalshöjden gneiss is restricted by a lineament structure. The younger rock group according to this suggestion does not show a corresponding restriction in areal extension. This feature is more difficult to explain, since no other pieces of evidence are available suggesting an old age of the mentioned lineament structure; neither is there any suggestion of an explanation to the origin of the lineament.

Lundegårdh (oral communication, January 1981) suggests another possible rock with which the Fryksdalshöjden gneiss might be correlated. The older gneissic granitoids in the Eastern Pregothian have a chemical composition that is in part similar to the Fryksdalshöjden gneiss group (Table 1 and Lundegårdh 1981, Table 2). However, some important differences may be noted. The TiO_2 contents are more variable and normally lower in the older Eastern Pregothian granitoids than in the Fryksdalshöjden gneiss group. The TiO_2 contents are comparable with those of the Åmål-I suite. When comparing Niggli values between the two rock groups, we invariably find a higher value for al in the rocks described by Lundegårdh (38–47, mean 41) than in the Fryksdalshöjden rocks (35–38, mean 37) but a lower fm (15–23, mean 19; resp. 21–27, mean 23) and c (8–12, mean 9; resp. 14–15, mean 15). Consequently, in spite of similar Niggli's si values, Niggli's qz (quartz index) is much higher in the Fryksdalshöjden gneiss (79–103, mean 91) than in the Eastern Pregothian older granitoids (21–86, mean 39), clearly demonstrating a syenitic trend of the latter lacking in the former. Consequently it is not probable that the

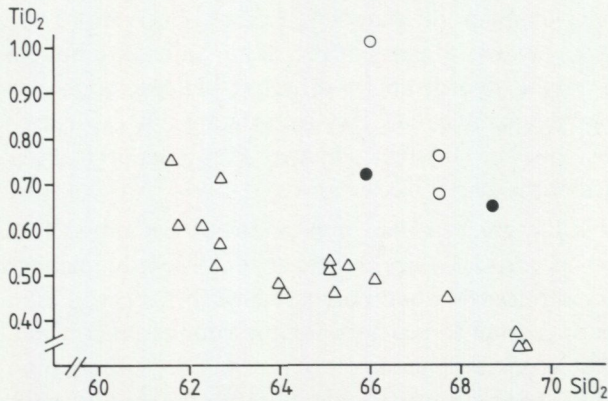


Fig. 2. Comparison between the Fryksdalshöjden–Storheden gneisses and Åmål-I granitoids from the Western Pregothonian mega-unit. Note the negative correlation between TiO_2 and SiO_2 in the Åmål-granitoids and the higher TiO_2 content in the other group. Legend: Triangles mean Åmål-I granitoids, open circles mean Fryksdalshöjden gneisses, solid circles mean Storheden gneisses.

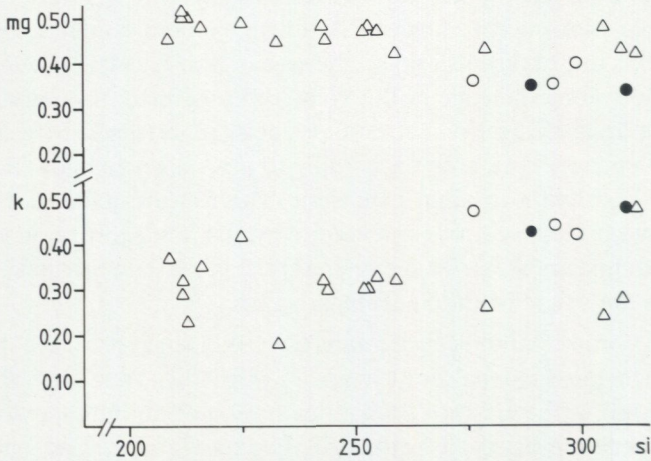


Fig. 3. Comparison between the Fryksdalshöjden–Storheden gneisses and Åmål-I granitoids from the Western Pregothonian mega-unit. The diagrams show plots of Niggli's si versus Niggli's k and Niggli's mg . Note the more potassic and the less magnesian character of the former group. Note also the greater scatter in the alkali analyses compared with that in the iron–magnesium analyses.

Legend: Triangles mean Åmål-I granitoids, open circles mean Fryksdalshöjden gneiss, solid circles mean Storheden gneiss.

Fryksdalshöjden gneiss would be a tectonically emplaced slice of the Eastern Pregothonian older granitoids. However, this is a suggestion of the utmost importance for the understanding of the history of the marginal zone of the Baltic Shield and it is worthwhile to discuss the matter more thoroughly at a later time, when more pertinent data are available. By stating that the rocks

are probably not identical, we do not imply any suggestions of equivalence or nonequivalence in age.

Circumstantial evidence suggests that the gneisses under discussion are metaplutonics and older than the Åmål-I group of granitoids. The next problem wanting a solution concerns their relation to the supracrustals. Neither here can any direct evidence be presented. There is only tectonic contacts between the Fryksdalshöjden gneiss and the metasupracrustals. The Storheden gneiss abuts on supracrustals to the south-west. If bedding were parallel to the now developed foliation this would suggest the metasupracrustals to underlie the Storheden gneiss. However, as mentioned earlier in this text the relation between bedding and foliation is not known.

The grey migmatite that is closely associated with the Fryksdalshöjden gneiss poses another problem. Assuming this gneiss to be an age equivalent to the Fryksdalshöjden gneiss we are faced with problems of equivalence with similar looking gneisses spread throughout the Western Pregothian mega-unit. If all these were identical in age and origin, plutonic rocks suggested to be older than the Åmål-I granitoids would not be confined to the edge of the mega-unit, nor would their area of occurrence be governed by lineament structures. If these assumptions, for the moment unsupported by evidence, would come true, the chain of circumstantial evidence presented here would be somewhat weakened.

The suggestion of an age relation between Åmål-I granitoids and Fryksdalshöjden gneiss as put forward in this contribution needs confirmation by isotope means. However, there certainly will be problems to obtain an unequivocal isotope dating due to the polymetamorphic nature of the Fryksdalshöjden gneiss.

CONCLUDING REMARKS

The discussion suggests that there exist exposed plutonic rocks intruded before the Åmål-I plutonics. Gorbatshev (1977; 1979) and Wahlgren (1981) have pointed to the occurrence of plutonic rocks that are older than the supracrustals of the Åmål group in the Åmål mega-unit and the Western Pregothian mega-unit respectively. To settle the question if these are time equivalents to the Fryksdalshöjden gneiss is beyond the scope of the present contribution. As a matter of fact an age relation between the Fryksdalshöjden gneiss and supracrustals occurring in the same area cannot presently be established. It may be noted that the plutonic character of the rock described by Gorbatshev (1979) is much better preserved than that of the Fryksdalshöjden gneiss. This might only reflect the better state of preservation found all over the Åmål tectonic mega-unit when compared with the Western Pregothian and may have no bearing at all on questions of age equivalence. Finally we note the siliceous and potassic character of the Fryksdalshöjden gneiss, in contrast with the calc-

alkalic Åmål-I group. This group of rocks is easily conceivable with a crustal generation stage, but all the same the more "mature" rocks seem to be older.

ACKNOWLEDGEMENTS

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A LATE GABBRO INTRUSION IN THE WESTERN PREGOTHIAN MEGA-UNIT

By ANDERS LINDH

ABSTRACT

Two bodies of gabbro have been found in the Western Pregothian mega-unit, western Värmland. They are mineralogically altered but olivine, pyroxenes and bytownitic plagioclase are retained. No isotope datings have been performed, but a comparison with the totally metamorphosed provisional calc-alkalic Åmål-I group of granitoids suggests the gabbro to be younger than this group. Textures of the gabbro and a siliceous xenolith speak against a tectonic emplacement of the gabbro. Future models for the evolution in the margin of the Baltic Shield must recognize the complexities introduced by a direct mantle involvement after intrusion and metamorphism of the calc-alkalic granitoids.

Lindh, A., 1981: A late gabbro intrusion in the Western Pregothian mega-unit. Sveriges geologiska undersökning, Ser. C, No. 781, pp. 15–23, Uppsala 1981.

Anders Lindh. Avd. för Mineralogi och petrologi, Geologiska institutionen, Sölvegatan 13, S-223 62 Lund, Sweden. January 26, 1981.

INTRODUCTION

Gorbatshev (1971) initiated a complete revision of our knowledge of lithologies and development in the south-western margin of the Baltic Shield, when presenting a progress report from a new mapping project. His results were totally inconsistent with established ideas. During the seventies increasing efforts have been directed towards a better understanding of the evolution. Isotope dating has enabled a construction of a rather firm frame-work from which a new model successively grows out. These datings are, however, still too few to allow a conclusive theory to be presented. Still we lack basic data for the supracrustal sequences, and all data for their basement. The shortcomings in our knowledge of the intrusive rocks, their chemical diversification and intrusive periods in time and space also create serious problems for our understanding. The present contribution points to the occurrence of gabbroic plutonism of for the moment unknown age within the Western Pregothian mega-unit. The division into mega-units of south-western Sweden as used in this contribution is outlined by Lindh et al. (1981, Fig. 1). Normally this type of plutonic activity is not met with in the area north of Lake Vänern. Comparisons with better known rock groups permit a discussion of its position in the time scale of evolution. For the moment the exact significance for future models of the tectonic and lithologic evolution of the area is left open to different approaches of interpretation.

DESCRIPTION OF THE GABBRO AND ITS SURROUNDINGS

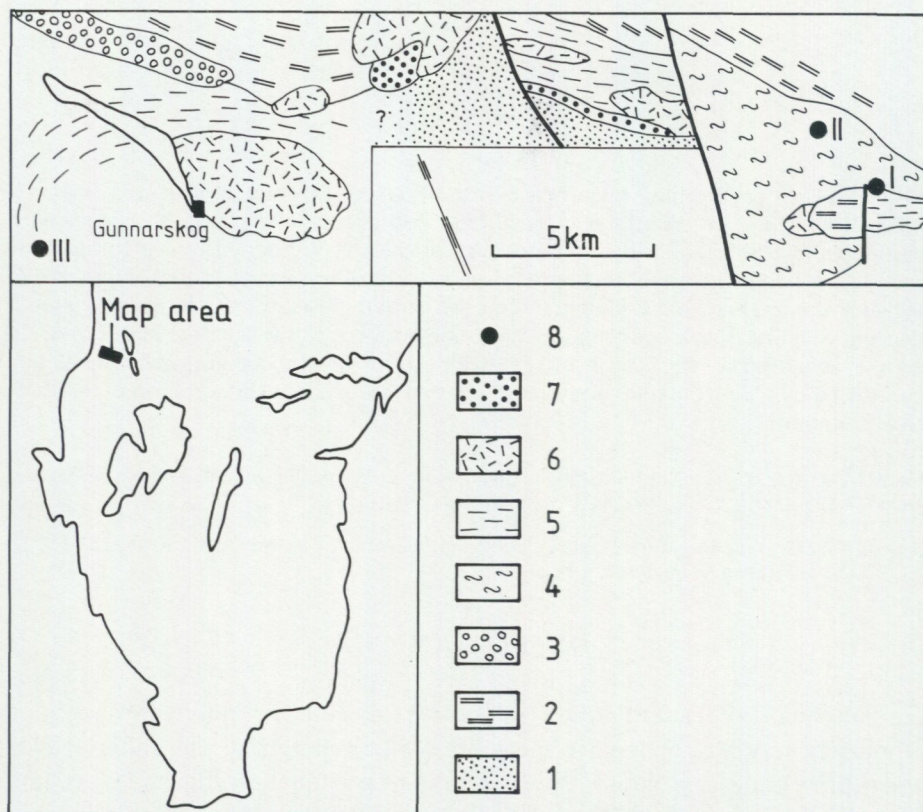


Fig. 1. Simplified sketch map showing the location of the two gabbro massifs I and II and the mafic-ultramafic body in Gunnarskog (III) mentioned in the text.

Legend: 1, undifferentiated migmatite gneiss, 2, migmatite gneiss associated with the Fryksdalshöjden gneiss (Lindh 1981), 3, Storheden gneiss (Lindh 1981), 4, Fryksdalshöjden gneiss (Lindh 1981), 5, supracrustal gneiss, 6, Åmål-I granitoids, 7, younger microcline granites, 8, gabbros and ultrabasites I-III.

The gabbro under consideration is found in an area situated above the highest sea level. Thus, very few outcrops are found; the gabbro itself crops out at only one single locality. To the north we find a migmatitic, rather siliceous reddish grey to greyish red rock showing a relic microcline-porphyroblastic texture – the Fryksdalshöjden gneiss – which according to Lindh (1981) belongs to the oldest rocks of the mega-unit. To the south the bedrock consists of a red rather fine-grained rock interlayered with mafic rocks. It might be a foliated granite as well as a metamorphosed supracrustal rock: an arkosic sediment or an acid volcanic rock. The gabbro occurs on the interpolated demarcation line between these two rock units, rather close to a small tectonic zone (Fig. 1). No relation

is claimed to exist between neither the rock contact nor the tectonic zone and the occurrence of the gabbro. In the general occurrence area more to the west at least one more gabbroic intrusion is found. It shows an exposed intrusive contact towards the Fryksdalshöjden gneiss which makes up the country rock. Here a penetrative foliation postdating the intrusion is found. The following description and discussion is mainly restricted to the first-mentioned intrusion.

The gabbro is a dark greenish, medium-grained, unfoliated rock. It is found in a more or less circular topographic depression that is supposed to be more or less coincident with the circumference of the gabbro. It consists of olivine interlaced with slightly curved joints filled with opaques, probably magnetite, and surrounded by a corona of magnesium-rich calcium-poor pyroxene in which sometimes a continuation of the joints can be traced. Augitic pyroxene occurs as individual grains always partly altered into a radiating pale greenish amphibole. Hypersthene showing schiller structure is rather frequent. It is normally surrounded by a very thin corona of a pale amphibole. Fig. 2 illustrates these textural traits. Plagioclase twinned according to the albite and pericline laws occurs as randomly orientated table-formed crystals. The Michél-Levy method indicates an anorthite content of about 75 mole per cent even if the number of suitably orientated crystals are too few to allow conclusive evidence. A microscopically zoning is ubiquitous. Very small amounts of biotite occur.

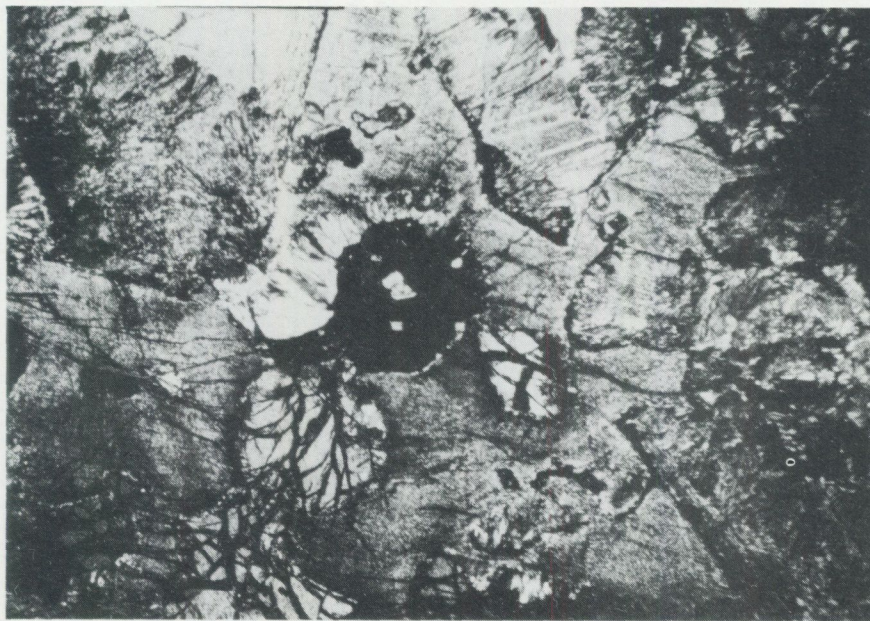


Fig. 2. Microtexture of gabbro. Four rounded olivine grains are set in an altered large pyroxene individual – probably poor in calcium – surrounded by plagioclase (two grains in upper part of picture) and completely unaltered pyroxene. Note alteration around olivine. Scale bar is 0,5 mm.

Table 1 gives a chemical analysis of the gabbro. It is olivine and hypersthene normative and its feldspar has a normative anorthite content of 79 mole per cent. It is low in K_2O and very high in MgO . The chemical composition is not sufficiently unique to allow an immediate correlation to any known group of plutonic rocks within the mega-unit.

A siliceous inclusion is found in the gabbro. Macroscopically it is a porphyroblastic fine-grained rock with foliation planes sweeping around the megablasts. Visually it resembles a mylonitic rock with fluxion texture. Microscopically the megablasts are polycrystalline but practically monomineralic made up of either plagioclase or microcline. The individual crystals are conspicuously equal in size and markedly (by a factor 3–4) coarser than the matrix crystals.

TABLE 1. Chemical analysis of gabbro in the Western Pregothonian mega-unit, per cent by weight. Coordinates in the Swedish National grid.

Analyst: Geochemical Division, Geol. Survey of Sweden.

Sample	S-AL 1398 11C ARVIKA NO
Top. map	66295/13388
SiO_2	44.6
TiO_2	0.14
Al_2O_3	17.5
Fe_2O_3	2.0
FeO	6.7
MnO	0.15
MgO	17.0
CaO	9.9
BaO	0.02
Na_2O	1.1
K_2O	0.3
CO_2	0.30
Total	99.71

They are bounded by unusually planar faces and when cut in thin sections show a preponderance of hexahedrals meeting in an exceptionally well-defined triple-junction texture. "Porphyroblasts" also exist made up of both microcline and plagioclase; in this case the two mineral phases are confined to different parts of the "megacryst" with a well-defined boundary between the two parts. Sometimes a polycrystalline rim of quartz is found near the border between the "megacryst" and matrix (Fig. 3). Occasionally similar quartz "megablasts" are found. The crystals making up these blasts are smaller and are arranged in a similar pattern as in the feldspar blasts but they do not show the same degree of perfection. The matrix is equigranular with a pronounced triple junction texture made up of quartz, perthitic microcline dominating over plagioclase, and smaller amounts of muscovite and biotite giving the rock a faint foliation. A rather high frequency of rational faces is noted, and occasionally feldspar grains are separated by thin quartz ribbons. An aggregation in trains of mineral grains of the same species showing neither morphological nor crystallographic orientation is noted. The aggregation explains why the foliation is macroscopically more distinct than microscopically.

The difference in texture between the gabbro and the siliceous xenolith is apparent. The gabbro has an altered magmatic texture with an incipient metamorphic overprinting, but the inclusion shows a nearly perfect metamorphic texture excepting the monomineralic but polycrystalline "megablasts".



Fig. 3. Microscopic picture of siliceous xenolith, crossed nicols. Microcline "megablast" showing triple junction texture (upper left) with thin quartz ribbons along the edge. Note equigranular grains in the triple junction texture in the matrix and the fine grain size in the matrix. Scale bar is 0,5 mm.

In spite of the described differences in foliation the two bodies of gabbro are supposed to be genetically associated. The evidence supporting this association is admittedly weak; they are both younger than the Fryksdalshöjden gneiss which, however, is proposed to belong to the very oldest rocks of the Western Pregothian mega-unit (Lindh 1981). If the gabbro bodies were not coeval, it would not influence the following discussion in any crucial way; it would, however, add in complexity to future models.

DISCUSSION AND CONCLUSIONS

In the Western Pregothian mega-unit the oldest mafic and partly ultramafic rocks have been mineralogically totally altered to amphibolites or hornblendites; no minerals like pyroxenes or olivines are ever preserved. Macroscopically they are often segregated into plagioclase-rich veins and more mafic "paleosomes". The gabbros discussed here with their geographically similar position cannot possibly have gone through the same geologic history.

Lindh and Malmström (1980) noted important differences in lithologies north and south of a break in the Mylonite Zone. To the differences listed by these authors we may add the occurrence of gabbroic bodies along the western border of the Zone on Värmlandsnäs. Such gabbros are unknown farther to the north; there is no obvious reason to suspect that these two isolated massifs would have anything to do with the Mylonite Zone.

No rock-forming processes have been observed in the time interval between the formation of the Fryksdalshöjden gneiss and the Åmål-I granitoids. One hypothetical exception might be the deposition of supracrustals on the Fryksdalshöjden gneiss. It is possible that the two gabbros are early differentiates of the Åmål-I granitoid suite. The chemical composition does not give unequivocal evidence for or against such a suggestion. The gap in the SiO_2 range between the gabbro and the series of granitoids is too large: hence an extrapolation from the granitoids to a gabbroid composition would encompass almost any gabbro. However, the mere lack of an identifiable line of chemical descent speaks against a common origin. The Åmål-I granitoids have been completely altered to foliated and often veined metamorphic rocks. Their minerals include plagioclase (appr. 25–30 mole per cent anorthite), quartz, biotite, microcline (sometimes subordinate), epidote and normally hornblende and/or garnet. No systematic measurements of the anorthite content have been performed considering the influence from different parageneses and other factors of importance (Lindh 1979). However, the suggested equilibrium between hornblende, epidote and oligoclase/andesine suggests a metamorphic grade somewhere in middle amphibolite facies. This is in palpable contrast to the probably bytownitic plagioclase in the gabbro. The plagioclase is not equilibrated to calcite, nor does it show any tendency to breakdown into albite-rich plagioclase and

epidote nor to any other decomposition product of anorthite. Another fact to be considered is the preservation of olivine in the gabbro. Olivine is normally not preserved in rocks occurring in the Western Pregothonian mega-unit. For example Wahlgren (1979) reported only minor amounts of olivine in the sole peridotite hitherto found in this mega-unit. It seems impossible that olivine would be metamorphic in origin since rather high pressures prevailed within the marginal zone of the shield. Conclusions on prevailing pressures are based on garnet compositions and on calcium distribution between garnet and plagioclase (unpublished results; Ahlin 1976; Gorbatshev, oral communication). Thus, the intrusion periods were probably separated from each other by a period of metamorphism.

In the Eastern Pregothonian mega-unit "hyperites" with a similar type of alteration and mineralogy occur. There are chemical differences. Seven major elements have deviations larger than 1σ from the mean of the V-group "hyperite" analyses (Lindh et al. 1981). Three of these are even outside the range of variation – TiO_2 and K_2O lower than and MgO extremely higher than any of the "hyperites" reported by these authors. Another important difference is the mode of occurrence – the "hyperites" occur as swarms of dikes and sills but the gabbro is found as two isolated massifs. Thus, there is no reason to believe in any connection between the "hyperites" and the gabbro and they consequently do not bridge the lithological and evolutionary gap between the two Pregothonian mega-units.

The xenolith described above cannot be easily identified. Texturally it is not similar to any other rock in the neighbourhood; it is obviously totally recrystallized. The texture of the felsic phases points towards contact metamorphic processes totally overprinting earlier textural features but for the occurrence of either phenocrysts or porphyroblasts. The formation of new aggregates of crystals of the same kind is energetically unfavourable (Flinn 1969; Vernon 1970) and thus improbable. The biotite fabric is presumably inherited from earlier regional metamorphic stages. Sieve textures or other positive indications of partial melting are lacking. A crystallization from a liquid of nearly eutectic composition should result in intergrowth of the different major phases. The rather high frequency of rational faces, the occurrence of quartz ribbons separating feldspar grains and occasional quartz rims around feldspar "megacrysts" are thus at least not inconsistent with crystallization from a liquid formed by partial melting due to the intrusion of the gabbro. If this is correct it follows that the texture was later totally equilibrated during the cooling stage. The vague indications of partial melting are consistent with an intrusive relation towards the country rock, and the total lack of indications of strain in both the gabbro and the xenolith speaks against an emplacement of the gabbro due to tectonic forces. An identification of the xenolith is at least presently impossible. The porphyroblastic Fryksdalshöjden gneiss is richer in iron and magnesium than the xenolith could possibly be.

For reasons discussed above we may be quite certain that the gabbro is younger than the provisional Åmål-I group. Possibly it may be a member of the provisional Åmål-II group. This group is poorly defined both in regard to its time of intrusion and its range of chemical composition (Gorbatshev 1975). Another alternative would be an age in the same range as the general Håstefjorden group (ca 1 200 Ma; Welin and Gorbatshev 1976), or, finally, it might represent a stage in development not recognized in hitherto dated granitoid groups. The two mentioned granite groups seem to have a rather alkalic affinity different from that of the analysed gabbro. If the gabbro were a time-equivalent to any of the two mentioned granitoid groups, it adds in chemical complexity to them and also invokes an element of direct mantle involvement in the otherwise principally crustal evolution after the Åmål-I intrusive period.

The possibility of a direct connection between the gabbros, the peridotite described by Wahlgren (1979) and the mafic to ultramafic body in Gunnarskog (Fig. 1) should not be overlooked. There is, however, a not easily resolved contrast between the magma intrusion of the gabbros as interpreted in this contribution and Wahlgren's interpretation based on a tectonic emplacement of the peridotite.

CONCLUDING REMARKS

The intrusion of the Åmål-I granitoids with their calc-alkaline character and low initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios indicate a mantle or near mantle interaction in crustal-forming processes. After their intrusion (1 650–1 700 Ma ago) the development in the Western Pregothian mega-unit was principally an ensialic crustal stabilizing process with intrusions of rather alkalic granitoids of a suggested crustal origin. These intrusions seem to increase in number and importance westwards and are perhaps peripheral signs of processes going on farther in the west (e. g. Telemark in Norway). However, gabbroic plutonism of mantle origin intervened of which these two bodies are examples. Two tensional stages have given rise to sparse basic dikes: dolerites (Wahlgren 1981) and younger lamprophyres (Wahlgren and Kähr 1977).

ACKNOWLEDGEMENTS

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THE RELATIONSHIP BETWEEN SOME HYPERITES, GRANITES AND GNEISSES IN SOUTHERN VÄRMLAND

By LARS MALMSTRÖM

ABSTRACT

In southern Värmland, black dolerites of the "hyperite" group are often found to be in contact with coarse, massive granites rather than with the "Pregothian" gneisses which make up most of the country rock. Occasionally these granites have clearly intruded into the marginal parts of the hyperite bodies and carry fragments of hyperite. A detailed study of the granite - hyperite relationships shows that the granite at the hyperite contacts should be interpreted as gneisses remobilized by the heat of the dolerite intrusions. Sometimes relics of specific inhomogenities in the ancient gneisses still remain in the granite. The remobilization has led to the development of new textures and the formation of garnet at the expense of the micas of the gneisses.

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Lars Malmström, Avd. för mineralogi och petrologi, Geologiska institutionen, Sölvegatan 13, S-223 62 Lund, Sweden. April 16, 1980.

INTRODUCTION

A broad belt of granitoid rocks known as the Småland-Värmland granites extends through south central Sweden. The northern part of this zone, the Värmland granitoids, has rendered two whole-rock Rb-Sr isochrons of $1\ 655 \pm 30$ Ma and $1\ 665 \pm 36$ Ma ($\lambda = 1.42 \cdot 10^{-11} \text{a}^{-1}$) for two somewhat different types of plutonics (Welin et al. 1977; recalculated by Welin 1979). To the west of the granitoid belt we find the "Eastern Pregothian" mega-unit and further to the west the "Western Pregothian" mega-unit. These mega-units are divided by the Mylonite Zone that former was thought to be continuous from the Caledonides to the Kattegatt (Magnusson 1937). However, it probably is split into two parts north of Lake Vänern (Lindh and Malmström 1980). The "Eastern Pregothian" mega-unit is essentially made up of gneissic granitoids of plutonic origin though supracrustal rocks also occur. Furthermore, intrusions of Värmland granitoids have been found (Lundegårdh 1977 and 1980). Dolerites of a group traditionally known as the hyperites (Törnebohm 1877), appear in a broad zone restricted to the "Eastern Pregothian" mega-unit. The hyperite zone is subparallel to the line separating the general occurrence area of the Värmland granitoids and the "Eastern Pregothian" gneisses. The hyperite intrusions have been involved in the latest folding that occurred in the "Eastern

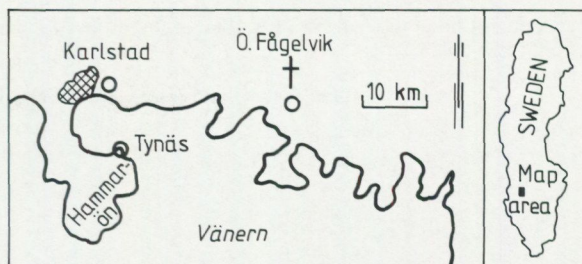


Fig. 1. Map showing the location of the three localities (open circles) with hyperite in close contact with a coarse-grained granite.

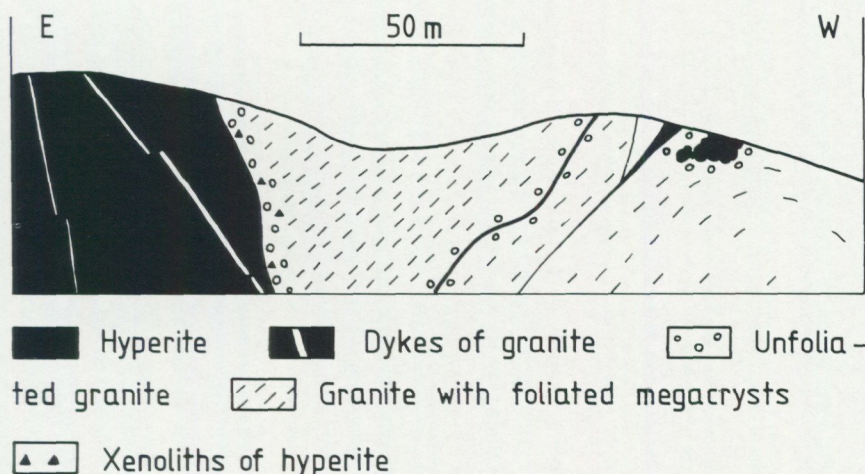


Fig. 2. Field-sketch of the locality (road-cut) east of Karlstad city, close to the church of Ö. Fågelvik. Vertical scale exaggerated.

Pregothian" mega-unit and they have also been affected by one of the late periods of zonal schistosity development which appear to be common for the two "Pregothian" mega-units (Gorbatshev 1971).

DESCRIPTION

At one locality (Fig. 1) to the east of Karlstad city, near Ö. Fågelvik church, a contact between a uralitized hyperite intrusion and a coarse-grained granite is exposed. The granite has brecciated the hyperite (cf. Lundegårdh 1977, Fig. 3). The total width of the granite and its transitional contact towards the regional granitic gneiss is about 100 m. The hyperite dyke cuts the schistosity of the granitic gneiss. It has a width of approximately 100 m and a length of around

TABLE 1. Chemical composition of the hyperite. Coordinates in the Swedish National grid. 10 D Karlstad NO: 659030/138225.

Analysts: Zoltan Solyom and Ingrid Johansson.

SiO ₂	48.02
TiO ₂	0.90
Al ₂ O ₃	16.44
Fe ₂ O ₃	2.44
FeO	7.79
MnO	0.18
MgO	8.02
CaO	10.72
Na ₂ O	2.48
K ₂ O	0.65
P ₂ O ₅	0.26
H ₂ O ⁺	0.13
H ₂ O ⁻	1.65
Total	99.68

1 000 m. Bulk chemical analysis (Table 1) shows it to be a normal Värmland hyperite (Lindh et al. 1981). Small cores of pyroxene, surrounded by a green mass of amphibole, have survived the uralitization, but olivine is totally obliterated. The original subophitic texture of the rock is defined by laths of plagioclase. The hyperite is cut by quartz veins and two granite dykes, around 0.5 m wide. The dyke granite consists mainly of myrmekite, quartz, microcline, and plagioclase. Late faulting with displacements up to 0.5 m can be demonstrated in these dykes. In the west the hyperite borders on the coarse-grained granite.

The contact between the hyperite and the granite is sharp, and there is no sign of a chilled margin in the hyperite. The granite, on the other hand, is foliated except for a 5 m wide zone close to the hyperite (Fig. 2). In this zone the granite has lost its foliation towards the hyperite, and a few garnets replacing biotite have been found. The coarse-grained appearance of the

granite is mainly due to augenlike assemblages of plagioclase, microcline and quartz. Lundegårdh (personal communication) reports that many microcline augens are mantled by oligoclase. This observation in an outcrop now covered by a highway made him interpret the granite as a Filipstad granite. The hyperite occurs as xenoliths in the granite (cf. Lundegårdh 1977, Fig. 3). In a later contribution (Welin et al. 1980) Lundegårdh has reinterpreted these and similar observations as reomorphic back veining of mobilized older granite. In addition, the granite carries fine-grained, more siliceous inclusions of two types, one dark grey (Fig. 3) and one red type. These inclusions are smaller than the hyperite xenoliths (Fig. 4), and they have been elongated parallel to the foliation of the granite. In the contact zone towards the regionally developed granitic gneiss and in the coarse-grained granite, except for the non-foliated zone, there are red, fine-grained, deformed sheets (Fig. 5). The sheets stand out clearly from the granite not only due to their colour but also due to their lack of augens. They also lack hornblende, which is another difference when compared with the granite. The field-sketch (Fig. 2) shows a dyke of hyperite in the granite which probably is a late apophysis from the slowly cooling hyperite body. In a zone a few meters wide around the dyke the granite shows no or only weak signs of foliation.

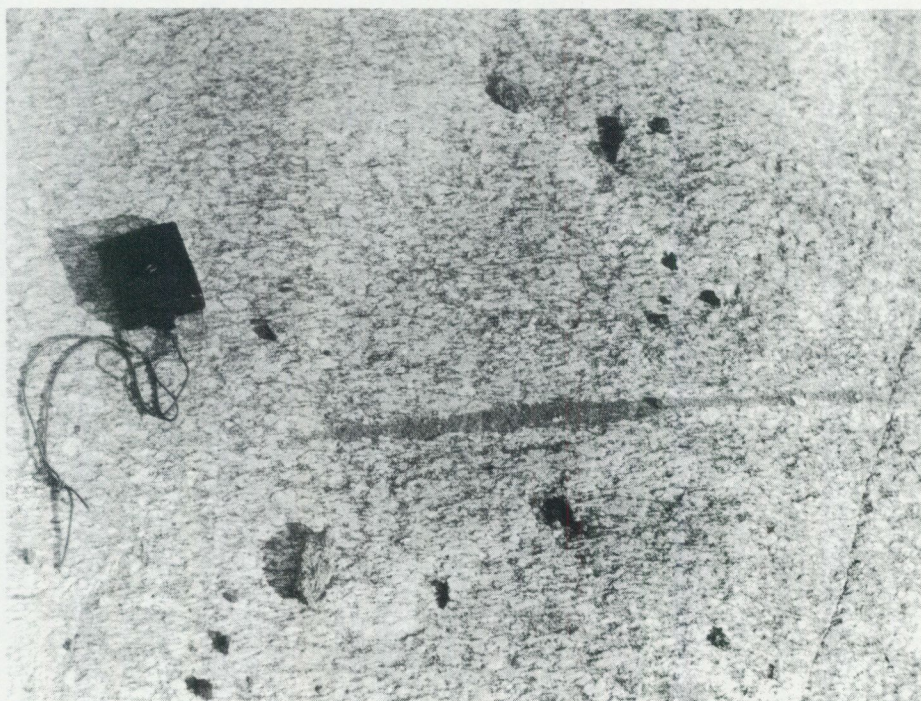


Fig. 3. Dark grey, fine-grained inclusion elongated parallel to the foliation of the granite.



Fig. 4. Xenoliths of hyperite in the granite. Photo P. H. Lundegårdh.

The contact between the granite and the granitic gneiss consists of a zone, where the size and number of augens in the granite gradually decrease and the rock becomes more foliated towards the gneiss, but here are also found 0.1 m wide bands of coarse-grained granite with the same amount of augens as closer to the hyperite body.

Two other localities have been observed showing hyperite in close contact with a coarse-grained granite, one immediately to the east of and the other to the south-east of Karlstad (Fig. 1). At the contact south-east of Karlstad, on the island of Hammarön, there are xenoliths of hyperite in a coarse-grained granite (Magnusson 1933). This granite, too, appears to have a transitional boundary towards a gneiss constituting the predominant rock at this locality. The coarse-grained granite immediately to the east of Karlstad seems to behave similarly though it is here more difficult to draw any conclusions owing to the lack of direct contacts.

DISCUSSION

The transitional boundary between the coarse-grained granite and the granitic gneiss, the sharp boundary towards the hyperite, the zones of granite around the hyperite which show no or only weak signs of foliation, and the discordant behaviour of the hyperite all indicate that the hyperite is younger than the

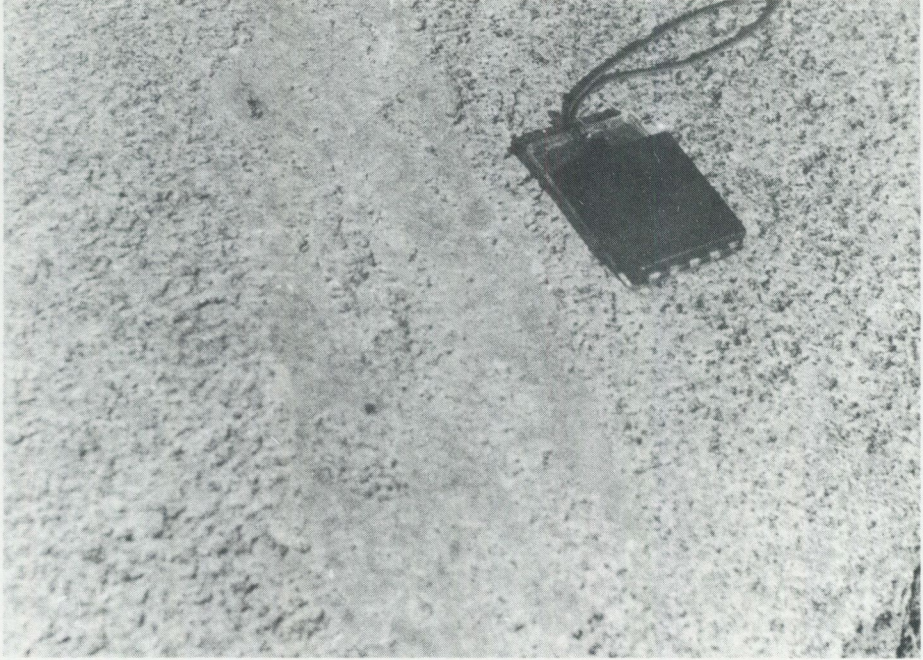


Fig. 5. Red, fine-grained, deformed sheet in the foliated part of the granite.

granitic gneiss. After the first completion of this manuscript isotope age determinations confirming these conclusions have appeared (Welin et al. 1980; Welin and Kähr 1980). During the intrusion the hyperite carried enough heat to affect some parts of the granitic gneiss, which were thus transformed into a coarse-grained granite. The red and grey elongated inclusions and the fine-grained sheets in the coarse-grained granite and in the transitional boundary zone probably are ancient inhomogeneities in the granitic gneiss. The sheets may be interpreted as former aplitic bands but it is impossible to say whether the elongated inclusions are earlier inclusions of supracrustal origin or something else. The absence of these inhomogeneities as well as of the foliation in the zone around the hyperite body suggests that the granite has been in a partially liquid state. In the western outermost part of the transitional zone occurs a hyperite (Fig. 2). At a first glance it looks like a xenolith but the coarse-grained granite around it indicates that the hyperite has carried enough heat to affect its surrounding which suggests that it most likely should be interpreted as an apophysis from the hyperite body. Its appearance is due to the effect of sectioning. The apophyses of hyperite in the coarse-grained granite and the lack of chilled margin in the hyperite all indicate that the hyperite and the granite are closely related in time. Because of the local character of this granite no regional conclusions regarding age relationships may be drawn from it.

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THE STORA BUSJÖN CONGLOMERATE an indication of granitoid basement in the gneiss complex of south-western Sweden

By CARL-HENRIC WAHLGREN

ABSTRACT

A polymict conglomerate is described from the gneiss complex of south-western Sweden. It occurs as xenoliths in a tonalitic gneiss which is supposed to be of Åmål-I age, i.e. c. 1 650 Ma old. The conglomerate has probably an age of about 2 000 Ma. The pebbles in the conglomerate indicate the existence of a granitic and supracrustal basement to the supracrustal gneisses in this part of south-western Sweden.

Wahlgren, C.-H., 1981: The Stora Busjön conglomerate – an indication of granitoid basement in the gneiss complex of south-western Sweden. *Sveriges geologiska undersökning, Ser. C, No. 781*, pp. 31–37, Uppsala 1981.

Carl-Henric Wahlgren, Geologiska institutionen, Avd. för mineralogi och petrologi, Sölvegatan 13, S-223 62 Lund, Sweden. April 14, 1980.

INTRODUCTION

The Western "Pregothian" mega-unit (Gorbatshev 1975) of south-western Sweden constitutes a complex, polymetamorphic gneiss-terrain. Due to strong reworking and deformation of the rocks, it is usually difficult to distinguish between rocks of supracrustal and plutonic origin. The Åmål tectonic mega-unit adjoins the Western "Pregothian" in the west. It is much less deformed and reworked, and is rich in easily identified supracrustals, comprising the Dal group, the Kappebo formation and the Åmål group (Gorbatshev 1977). In the "Pregothian" areas we can distinguish between little altered cover supracrustals, e. g. the Gräsmark and Östmark formations (Lundegårdh 1977, 1980) in the Eastern "Pregothian" mega-unit, and supracrustals forming integral parts of a strongly deformed and metamorphosed plutonic to supracrustal gneiss sequence. The supracrustals considered here belong to the latter type.

THE STORA BUSJÖN CONGLOMERATE

A conglomerate has recently been found in the Western "Pregothian" mega-unit (Fig. 1). It occurs as xenoliths, a decimetre to a metre in diameter, in a grey, metaplutonic tonalitic gneiss (Table 1). The conglomerate is polymict. Strong deformation has often deformed the pebbles and cobbles into lenses, but spherical or almost spherical balls also occur. They vary substantially in size having diameters between one and ten centimetres (Fig. 2). Medium-grained

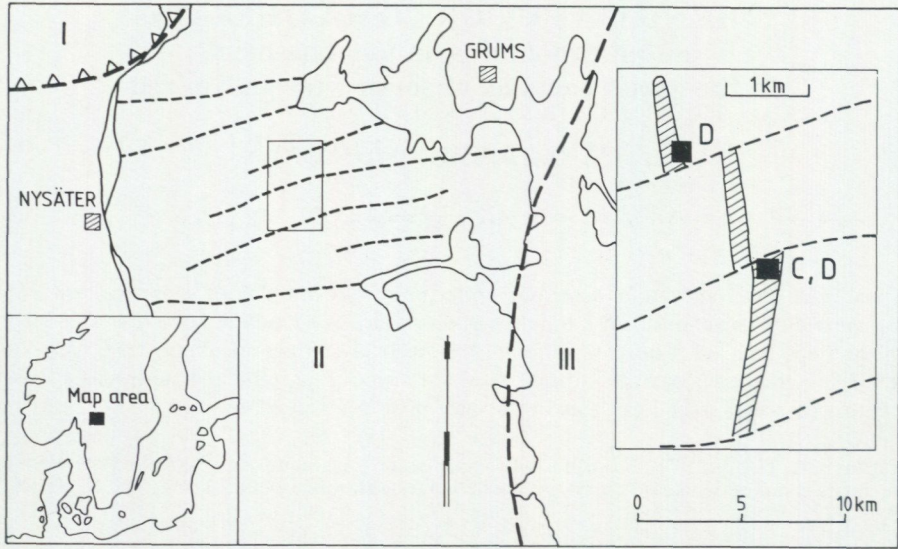


Fig. 1. Location map of the conglomerate (C) and the dolerites (D). Broken lines show wrench faults. The stout broken line in N-S shows the Mylonite Zone separating the Eastern "Pregothian" (III) and the Western "Pregothian" (II) blocks *sensu* Magnusson (1960). I is the Glaskogen Nappe according to Gorbatshev (1979b). The dashed area marks the occurrence of the tonalite.

grey to reddish grey granite and fine-grained, probably supracrustal, reddish and greyish rocks form the balls. Two fine-grained pebbles, one red and the other grey, have been studied under the microscope. The red pebble is mainly composed of quartz, biotite and muscovite with subordinate feldspar. This rock is probably a metasediment. The grey pebble is composed of quartz, plagioclase and mica (mainly biotite, but some muscovite also occurs). It is probably a metavolcanic. In the matrix, aggregates of quartz and quartz-dominated material are found as well, but their shape does not immediately suggest that they are pebbles of quartzite or vein quartz. Because the matrix is quartz-rich, such an origin is conceivable, but the quartz aggregates could also be segregation products developed either by regional metamorphism or contact metamorphism caused by the tonalitic magma. The conglomerate matrix is fine-grained, micaceous and mainly composed of quartz, biotite and muscovite with some feldspars. Due to strong deformation and reworking, it is sometimes difficult to distinguish between matrix and pebbles.

In the tonalite there are also numerous clearly supracrustal xenoliths of approximately the same composition as the matrix of the conglomerate. The lack of visible pebbles may depend on strong reworking leading to homogenization of the conglomerate. These xenoliths as well as the conglomerate xenoliths have often been partly assimilated by the tonalitic gneiss, which has resulted in diffuse contacts to the latter.

THE TONALITIC GNEISS AND OTHER SURROUNDING ROCKS

The tonalitic gneiss that encloses the xenoliths forms an elongated body 100 to 300 metres in width and 4.7 kilometres in length. It is transected by wrench-faults. (Fig. 1; Wahlgren and Kähr 1977; Wahlgren 1979; Lindh 1980), one of which delimits the body in the south. These faults are probably Sveconorwegian (Dalslandian; Wahlgren and Kähr 1977, Wahlgren 1979).

The tonalitic gneiss is medium- to coarse-grained, strongly deformed parts being more fine-grained. Folding and veining are faintly perceptible in some places. The tonalitic gneiss much resembles the c. 1 650 Ma granitoids of the provisional Åmål-I group (Table 1; Gorbatshev 1975). Granitoid gneisses of the same age in the Western "Pregothian" have been dated by Welin and Gorbatshev (1976).

The rock surrounding the tonalitic gneiss is a banded, sometimes migmatized gneiss, made up of felsic and mafic layers. The felsic bands shift between red and grey in colour. The frequency of mafic bands varies. Belts of augengneisses that are between 150 and 1 000 metres wide and can be traced for tens of kilometres occur to the west of the tonalitic gneiss. The contact between the tonalitic gneiss and the banded sequence is diffuse. The gradual transition most probably depends on post-intrusional deformation and reworking. One interpretation is that the tonalitic gneiss intruded into the banded sequence, which is supposed to be of supracrustal origin.

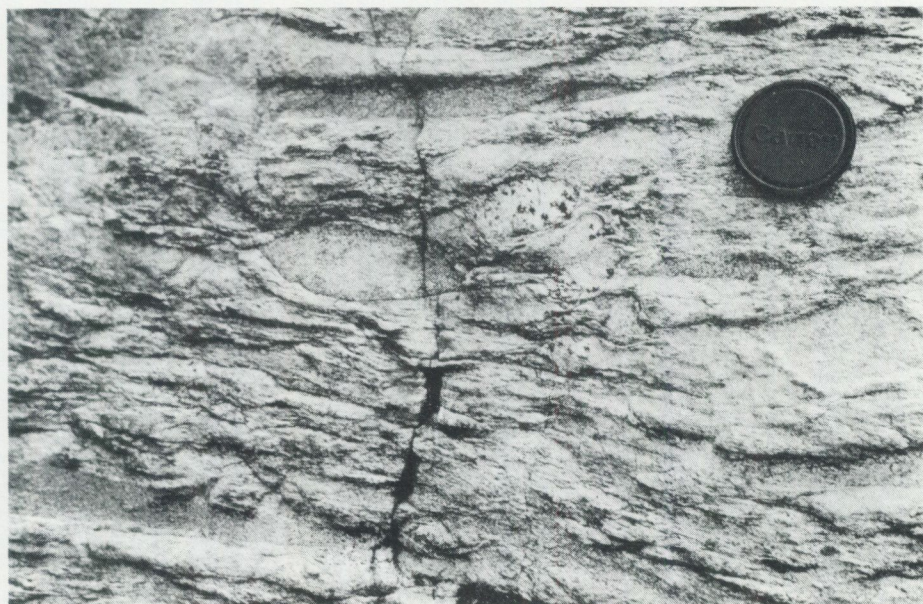


Fig. 2. The conglomerate with pebbles of different kind and size.

After its solidification, the tonalitic gneiss was intruded by dolerite dikes. The dikes are between one and nine metres wide. Apophyses occur in the surrounding tonalitic gneiss. They have been altered and often somewhat foliated. The best preserved parts still show a subophitic texture. In the north, there is another dolerite (Fig. 1) only found in an isolated outcrop — the adjacent outcrop westwards consists of the tonalitic gneiss. Thus, it is possible that also this dolerite has been intruded into the tonalitic gneiss.

TABLE 1. Chemical composition of the enclosing tonalite (1 459), a tonalite from the same area with a preliminary U-Pb age of 1 600 Ma (980 B) and one of the dolerite dikes (1 549).

Analysts: Geochemical Division, Geol. Survey of Sweden (1 459, 980 B),
Geochemical Laboratory, Institute of Geology, University of Lund (1 549).

Sample	1459	980 B	1549
Top. map	Ämål NO	Ämål NO	Ämål NO
	657895/	657805/	658025/
	13379	13467	13366
SiO ₂	58.60	58.10	51.79
TiO ₂	1.09	1.26	1.17
Al ₂ O ₃	17.10	17.10	15.97
Fe ₂ O ₃	3.40	2.70	2.73
FeO	4.70	5.70	6.98
MnO	0.19	0.19	0.19
CaO	6.20	6.50	8.72
MgO	2.70	2.70	6.59
Na ₂ O	3.20	2.60	2.55
K ₂ O	2.20	2.10	0.99
H ₂ O>105	1.50	1.20	1.63
H ₂ O<105	0.20	0.10	0.00
P ₂ O ₅	0.27	0.38	0.15
CO ₂	0.06	0.09	—
F	0.07	0.07	—
S	0.05	0.12	—
BaO	0.06	0.07	—
Sr	0.03	0.04	278 ppm
Rb	<u>0.01</u>	<u>0.01</u>	<u>29 ppm</u>
Total	101.63	101.03	99.46

Except the hyperites, dolerites are rare in the "Pregothian" mega-units in south-western Sweden. It is remarkable that the dolerites considered here only occur in, or in the absolute vicinity of the tonalitic gneiss.

DISCUSSION AND CONCLUSION

The present find of a conglomerate is the first unequivocal documentation of such a rock in the gneisses of the Western "Pregothian" mega-unit. A reason for the preservation of the conglomeratic structure may be the occurrence of the rock as xenoliths in the tonalitic gneiss, which probably protected the conglomerate from subsequent reworking and deformation. The strong deformation of the neighbouring supracrustals makes it difficult to tell whether these rocks are part of the same sequence as the rudite. In the Kedum mountains, c. six kilometres north-west of Vara, south of Lake Vänern, a fragment-bearing rock occurs in the Western "Pregothian" (Bo Ronge, Göteborg, pers. comm. 1980). However, this "conglomerate" is monomict and may be a recrystallized breccia or a rock belonging to one of the younger cover sequences (cf. above). Further investigation must precede a conclusive interpretation.

Clear evidence of a pre-existing basement of the Åmål supracrustals, and metasupracrustals in the "Pregothian" terrains has long been looked for by geologists working in this region. Gorbatshev (1979 a) has recently described a rock, which is suggested to represent a basement of the Åmål supracrustals. He also described granite balls from the Åmål conglomerates.

The strong reworking of the gneisses in the "Pregothian" terrains has been interpreted to suggest that they are older than and underlie the Svecofennian rocks in the east. Reference has been made to localities near Töreboda, Västergötland, where the gneisses appear to dip in below the Svecofennian rocks (Magnusson 1965), and to the Gillberga synform where they are said to be covered by Åmål supracrustals (Magnusson 1929). However, radiometric datings so far have failed to demonstrate pre-Svecofennian ages, rather suggesting that the "Pregothian" rocks are younger than or sometimes possibly coeval with the Svecofennian. The obtained ages are virtually identical to those of the granitoids in the Åmål tectonic mega-unit (Welin and Gorbatshev 1976; P.-O. Persson, Lund, and B. Hansen, Münster, pers. comm. 1980). Consequently, it is possible that the rocks in the Western "Pregothian" are mainly composed of reworked equivalents of rocks found in the Åmål tectonic mega-unit (e. g. Gorbatshev 1975). Still, it is possible that there are also pre-Åmål-I granitoids. Gorbatshev (1979 a) described the occurrence of tonalitic to granodioritic fragments in the Åmål supracrustals.

The pebbles in the conglomerate indicate the existence of a granitic and supracrustal basement below the supracrustals containing the conglomerate. The pebbles can probably not be very long-transported. Assuming that the tonalitic gneiss has an age similar to that of the Åmål-I granitoids, i.e. c. 1 650

Ma, the rocks in the conglomerate pebbles must be the oldest hitherto recorded rocks in the Western "Pregothian". The most interesting question is the age of the basement that supplied the pebbles of the conglomerate. The fine-grained, supracrustal, possibly metasedimentary pebbles represent an earlier cycle of erosion and deposition. Similar aspects apply if the supracrustal pebbles had been derived from metavolcanics. Thus, there is a fair possibility that the basement of the conglomerate, and some of the probable metasupracrustals in the Western "Pregothian" have an age of about 2 000 Ma or more. If this is correct, they may be coeval with Svecofennian supracrustals, which are supposed to be c. 2 000–2 200 Ma old. However, as long as there is no radiometric age for the tonalitic gneiss, we cannot exclude the possibility that the latter is older than the Åmål-I granitoids. However, an age of about 1 650 Ma is more likely for the tonalitic gneiss.

The possibility that the tonalitic gneisses are younger than c. 1 650 Ma is remote. Although the provisional Åmål-II group constitutes a very heterogeneous group of granitoids (Gorbatshev 1975) no tonalites have been reported. The Åmål-II plutonics mostly show more alkaline trends.

Coarse conglomerates containing pebbles of granitic plutonics do not form very far from continental crust, which suggest that such a crust existed in this area even before c. 1 700 Ma.

Quite apart from the problem of the age of the conglomerate and its basement, we find from the appearance of the conglomerate xenoliths that strong deformation had affected this part of south-western Sweden before the intrusion of the tonalitic gneiss.

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THE AGE OF THRUSTING OF THE GLASKOGEN NAPPE IN THE GILLBERGA SYNFORM

By CARL-HENRIC WAHLGREN, PER-OLOF PERSSON
AND BENT T. HANSEN

ABSTRACT

An attempt was made to determine the age of the thrusting of the Glaskogen Nappe with the Rb-Sr method. Microcline, whole-rock and biotite from a strongly lineated red granitic gneiss yield an isochron age of 962 ± 19 Ma. The obtained age is interpreted as the age of the thrust movement, or if it was a poly-stage process the last movement.

Wahlgren, C.-H., Persson, P.-O., and Hansen, B. T., 1981: The age of thrusting of the Glaskogen Nappe in the Gillberga synform. *Sveriges geologiska undersökning, Ser. C, No. 781*, pp. 38-43, Uppsala 1981.

Carl-Henric Wahlgren and Per-Olof Persson, Geologiska institutionen, Avd. för mineralogi och petrologi, Sölvegatan 13, S-223 62 Lund, Sweden, Bent T. Hansen, Institut für Mineralogie, Gievenbecker Weg 61, D-4400 Münster, Western Germany. April 16, 1980.

INTRODUCTION

The structural interpretation of the Gillberga synform has been discussed for a long time. Due to an alleged high content of muscovite in the underlying gneiss, Magnusson (1929) assumed that the supracrustals in the Gillberga synform were deposited on a weathered erosion surface (metapaleosol). In a re-interpretation, Zeck and Malling (1974) suggested that the Gillberga synform was made up of three great thrust sheets and that the alleged primary boundary between the "Pregothian" and "Gothian" rocks of earlier authors was wholly tectonic. In a later paper, Zeck and Malling (1976) suggested that the low-angle thrusting in the Gillberga area indicated the presence of a major global suture in south-western Sweden. During a recent re-investigation, Gorbatshev (1979) concluded that the three far-transported nappes of Zeck and Malling do not exist. However, he identified the remnant "klippe" of a thrust nappe (the Glaskogen Nappe; Fig. 1) in the northern part of the synform. The basis of this nappe is marked by a mylonite zone about ten metres thick. Minor mylonitic or strongly foliated thrust zones occur also within the nappe (Fig. 2). Zeck and Malling (1974, 1976) suggested that the thrust was Sveconorwegian (Dalslandian, Grenvillian).

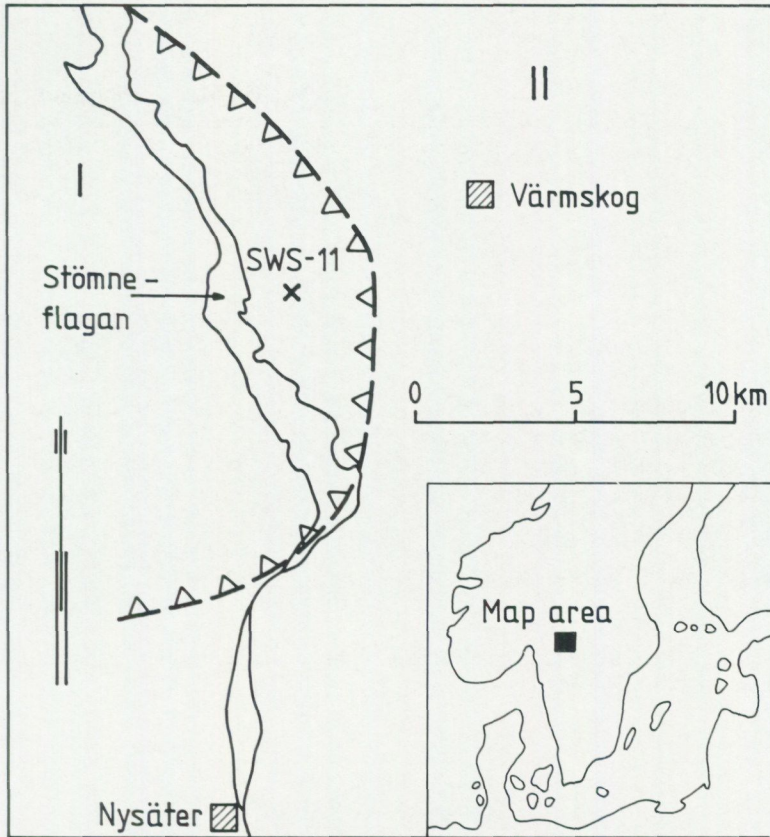


Fig. 1. Sketch map of the eastern part of the Glaskogen Nappe. SWS-11 marks the granitic gneiss. I is the Glaskogen Nappe and II is the "Pregothian" gneisses east of the nappe.

FIELD RELATIONSHIPS

The part of the Glaskogen Nappe that occupies the area east of Lake Stömne-flagan (Fig. 1) consists mainly of strongly lineated metaplutonic rocks which are mostly supposed to belong to the provisional Åmål-I group of granitoids (c. 1 650 Ma old; Gorbatshev 1975). They vary from gabbro to granite but tonalitic and granodioritic compositions are predominant. From the field observations it is obvious that the intense lineation of the rocks was developed during the thrusting of the Glaskogen Nappe. The local plunge is about 25° towards S 70° W. In order to date the thrusting event, biotite and microcline from a strongly lineated red granitic gneiss were separated for Rb and Sr analyses. The chemical composition of the granitic gneiss is shown in Table 1.

The rocks east of the Glaskogen Nappe consist of complex polymetamorphic gneisses.



Fig. 2. Strongly deformed and lineated rocks close to the eastern border of the nappe. Roadcutting about 1 km NNW of Björnö.

Rb-Sr ANALYSES

Method: Rb-Sr analyses were made by isotope dilution on 0.1 grams of the sample using standard techniques as described by, for instance, Blaxland et al. (1979). Mass-spectrometric analyses were performed at the *Zentral-laboratorium für Geochronologie* at the University of Münster using a NBS-type, twelve-inch, ninety-degree, solid-source mass spectrometer manufactured by Teledyne Energy Systems. It is equipped with a Cary-model 401 MR vibrating-reed electrometer, computer-controlled peak and attenuator-switching digital voltmeter, and further a Hewlett-Packard 9830 calculator.

Results: Concentrations and Rb-Sr isotopic data are shown in Table 2. They were calculated using the following constants: $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$, $^{84}\text{Sr}/^{86}\text{Sr} = 0.0572$, $^{85}\text{Rb}/^{87}\text{Rb} = 2.593$, $\lambda^{87}\text{Rb} = 1.42 \cdot 10^{-11}\text{y}^{-1}$ (Steiger and Jäger 1977). All errors are stated as 2σ . For 33 analyses of the NBS 987 Sr-standard during the period of this study a mean value of 0.710375 ± 0.000043 was obtained. Rb-Sr age and initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio were regressed by the least square method of York (1969). Fig. 3 shows the isochron plot obtained.

Interpretation: The Rb-Sr analyses on microcline, whole-rock sample and biotite from the granitic gneiss (SWS-11) yield an isochron age of 962 ± 19 Ma with an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.737 ± 0.001 . As the data points form an ideal

TABLE 1. Chemical composition of the granitic gneiss (SWS-11).

Analyst: Geochemical Division, Geol. Survey of Sweden.

Sample	SWS-11
Top. map	Åmål NO
	65939/ 13301
SiO ₂	70.80
TiO ₂	0.53
Al ₂ O ₃	12.70
Fe ₂ O ₃	1.20
FeO	3.60
MnO	0.10
CaO	1.90
MgO	0.32
Na ₂ O	3.40
K ₂ O	4.70
H ₂ O ⁺	0.50
H ₂ O ⁻	0.10
P ₂ O ₅	<u>0.09</u>
Total	99.94

TABLE 2. Rb-Sr analytical data of sample SWS-11.

Type of sample	Rb ppm	Sr ppm	⁸⁷ Rb/ ⁸⁶ Sr	⁸⁷ Sr/ ⁸⁶ Sr	Age in Ma ^a
Microcline	205	196	3.05	0.7789	
Whole-rock	154	122	3.68	0.7880	962 ± 19
Biotite	847	8.88	440	6.790	

^aEstimated errors (2σ) based on replicate analyses are ⁸⁷Rb/⁸⁶Sr = 2 %, ⁸⁷Sr/⁸⁶Sr = 0.05 %.

isochron (scatter = 6 Ma), the age is interpreted as the time of the last complete isotopic rehomogenization among the minerals. The high initial ratio suggests an isotopic redistribution within the minerals much later than the intrusion of the granite. The lineation in the granitic gneiss is perceptible due to a preferred orientation of feldspar, biotite and amphibole. There is nothing to indicate that the minerals had recrystallized and lost some of its radiogenic ^{87}Sr after the development of the lineation. It therefore appears reasonable to relate the obtained age to the time of deformation (thrusting).

This age falls within the established age interval (ca 850–1 050 Ma) of Ar degassing and partial disturbance of the Rb-Sr systems in south-western Sweden (Welin and Gorbatshev 1978). Of course it is possible that the thrusting was a polystage process operating during a considerable period of time. If this is the case the obtained age presumably dates the last translation of the Glaskogen Nappe while the early displacement must be almost impossible to date confidently. In contrast, a definite lower age limit of the thrusting can be obtained from the age of undeformed lamprophyre dikes (904 ± 13 Ma) described by Wahlgren and Kähr (1977). One of these dikes transects the contact between the Åmål supracrustals and the underlying "Pregothian" gneiss about one kilometre south-east of Nysäter. These lamprophyres are probably connected with numerous wrench-faults occurring in the area (Wahl-

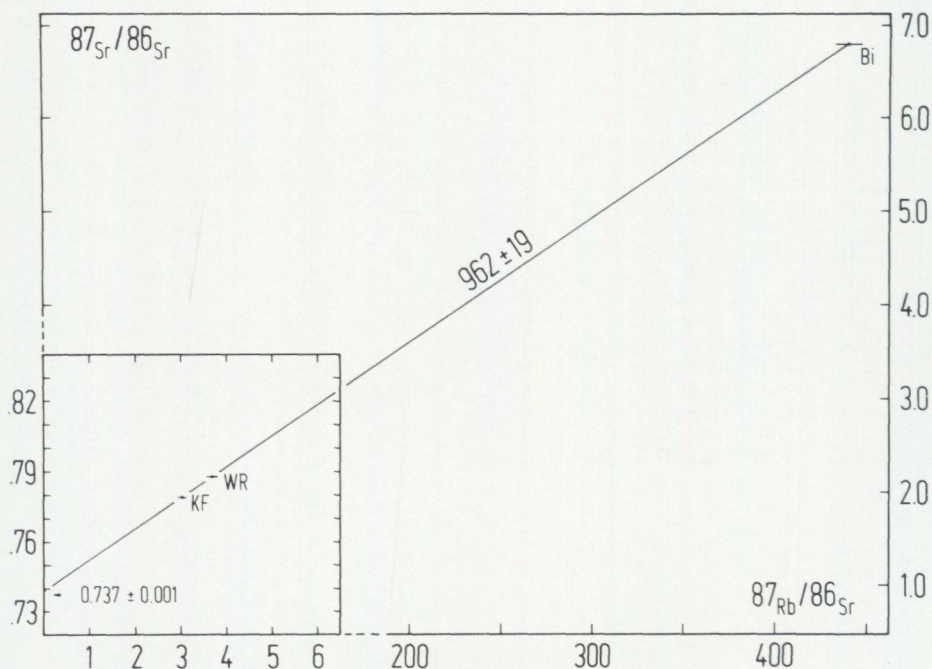


Fig. 3. Rb-Sr isochron plot of whole-rock and mineral data for sample SWS-11.

gren and Kähr 1977; Wahlgren 1979). Field observations suggest that these faults are synchronous with or later than the thrusting.

The age obtained and its interpretation are consistent with Zeck and Malling's (1974, 1976) suggestion of a Sveconorwegian (Dalslandian) age of the thrusting.

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We would like to thank Roland Gorbatshev (Lund) and Anders Lindh (Lund) for reading the manuscript critically and for making valuable improvements. We also want to thank Christine Ebner (Lund) who made the drafting work. This contribution forms part of a project with purpose to unravel the development of the south-western border of the Baltic Shield. The project is financially supported by the Swedish Natural Science Research Council (NFR, Grant No. 3559-106).

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