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# A possible relationship between augen gneisses and postorogenic granites in S.E. Sweden

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**Abstract**—Augen gneisses occur east of the postorogenic Småland granites in south-eastern Sweden. These augen gneisses are generally folded conformably with the surrounding rocks but in several areas they seem to pass transitionally into the otherwise cross-cutting postorogenic granites. The augen gneisses in the Finspång area are suggested to be caps or down-pointing flukes of the postorogenic granites in a structure similar to one of Ramberg's (1967) centrifuged model experiments. Several factors suggest that these granites intruded as congealing magmas. The proposed evolutionary model has some features in common with the balloon tectonic model (Ramsay 1981). However, rather than the magma expanding an outer skin around a simple balloon-like structure, the concept is extended to include the magmatic inflation and distortion of the cap resulting also in down pointing, folded fluke structures.

If the proposed relationship can be established, it follows that extensive metamorphism and deformation took place in southeast Sweden as a marginal effect of the intrusion of the Småland granites.

## INTRODUCTION

ALONG the eastern margin of the Småland belt of postorogenic Svecokarelian granites (with ages 1750–1690 Ma), there occur several smaller massifs of augen gneiss, named Loftahammar, Hälla, Finspång, etc. (Fig. 1). Whether these augen gneisses belong to the postorogenic granites or to the oldest Svecokarelian plutonics (generally orthogneisses, age 1900–1840 Ma) has been the subject of debate in the past (see below). They are generally foliated, although isotropic parts are present locally. The contacts and internal foliations of the massifs are generally folded in harmony with the fold pattern of the surrounding Svecokarelian rocks which are dominated by ortho- and paragneisses. Discordant contacts towards older structures within the supracrustal rocks have been identified around the Finspång augen gneiss. To a limited extent the massifs are migmatized. Within the Loftahammar augen gneiss some basic dykes have been found, but otherwise such dykes are absent or rare.

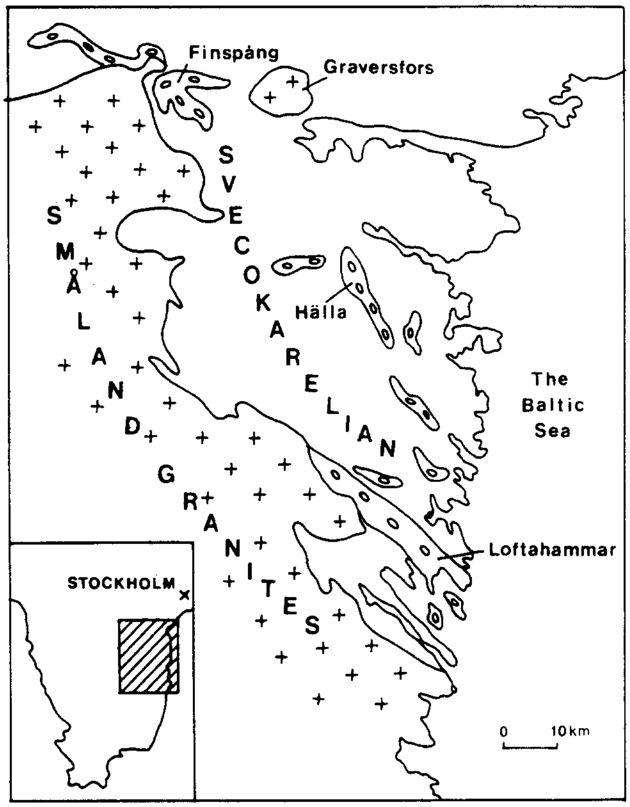


Fig. 1. Position of the granitic massifs described in the text.

## HISTORY

The discussion about the granites and augen gneisses started with a debate between Holmquist (1905a, b) and Gavelin (1905, 1910) on the age relationships between the different rocks on the Loftahammar map-sheet (made by Gavelin). Holmquist regarded the Loftahammar augen gneiss as contemporaneous with the Småland granites and he also suggested that some of the amphibolite dykes could be remnants of the older mafic volcanics north of the massif. Gavelin's (1905, 1910) arguments for an older age of the Loftahammar augen gneiss were mainly structural, but he also interpreted a noritic gabbro within the massif as younger than the augen gneiss, a relationship not identified for the Småland granites.

Asklund (1921) believed that the augen gneisses of the northern part of the area shown in Fig. 1, were related to the younger Småland granites. At that time these rocks were referred to the Gothian orogenic cycle, which was believed to be separate from, and younger than, the Svecofennian orogeny. When radiometric data became available in the 1960s the concept of separate Gothian, Svecofennian and Karelian orogenies was abandoned, and the term Svecokarelian was introduced to cover the plutonism, deformations and metamorphism which took place in time-span 1900–1800 Ma (approx.). Asklund (1921) related the deformation of the augen-gneisses to a process which he called 'the coastal-zone folding', not active further to the west. Sundius (1928a) followed Asklund in mapping these rocks as Gothian, although in the map description he pointed out their structural relationship to the oldest Svecofennian plutonics (age 1900–1850 Ma). Somewhat later (Sundius 1928b) he took the firm standpoint that the augen gneisses belonged to the oldest plutonics and also emphasized that he had been unable to identify Asklund's 'coastal-zone folding'.

Magnusson (1957, 1960) followed Asklund in mapping these rocks as Gothian. However, he apparently did not recognize Asklund's 'coastal-zone folding' but explained the Svecofennian fold pattern of, i.e. the Finspång massif, by assuming that magma of the Småland granites had been soaking through an older folded bedrock. What is presently seen in the augen gneisses should then be ghost structures.

Westra *et al.* (1969) recognized similarities between the Loftahammar augen gneiss and the Småland granites, and concluded that since the Loftahammar augen gneiss was folded with the surrounding rocks, the Småland granites should be older than major Svecokarelian deformation.

Wikström (1974) noted that the structure west of the Graversfors granite (described below) was superimposed on the Svecokarelian structures in that area.

## RADIOMETRIC DATING

Radiometric dating of the augen gneisses in question has been limited to the Loftahammar augen gneiss. Rb/Sr whole rock isochrons have given 1660 ± 35 Ma (Priem & Bakker 1973) and 1620 ± 40 Ma (Åberg 1978). These values are the recalculated ages given by Welin (1979). U/Pb determinations of zircons have given an episodic-lead-loss age of 1845 Ma (Åberg 1978).

While Priem & Bakker (1973) related their Rb/Sr age to a main deformation and metamorphic event of the Loftahammar augen gneiss (emplaced somewhat more than 100 Ma earlier), Åberg (1978) regarded the zircon age as the time of the intrusion and the Rb/Sr-age to result from resetting as a consequence of the intrusion of the Småland granites.

For comparison it can be mentioned that the post-orogenic Graversfors granite (Åberg & Wikström 1982) yields a Rb/Sr whole rock isochron of 1692 ± 7 Ma and a U/Pb discordia age of $1971^{+51}_{-43}$ Ma where the Rb/Sr age is interpreted as the time of intrusion.

## THE FINSPÅNG AUGEN GNEISS

With the start of mapping in 1980 on the Finspång map-sheets (situated in the upper left corner of Fig. 1), the question again arose of how to separate the Småland granites from the oldest Svecokarelian plutonics in the field. The older concept of the Småland granites in some areas having gradational transitions into the augen gneisses can be verified, yet there is discordance with the folded Svecokarelian rocks in other areas.

By conventional structural methods, at least two, more or less contemporaneous fold phases can be distinguished within the Finspång augen gneiss. This gneiss is in part migmatized, a phenomenon in general not recognized among the postorogenic granites. A photograph of this rock type is given in Fig. 2.

Within the Finspång massif one can distinguish two areas with no or little sign of deformation (Fig. 3). If this massif belonged to the oldest plutonics one could imagine that it has lost its structures in these areas as a contact metamorphic effect of the adjacent postorogenic granite. This is a type of process described by Lundqvist (1973). However, going from the massive into the gneissic parts of the massif, one can see how a second generation of feldspar megacrysts has grown in the latter, in part affected by the deformation but with continuous transitions into oblique orientations. In the weakly deformed parts this second generation is also weakly developed. This is a recrystallization which appears to have been promoted by kinetic energy. As a consequence the massive parts rather than being homogenized versions of older augen gneisses are more likely to be areas which have escaped deformation.

## THE GRAVERSFORS GRANITE

Before going further into the structural position of the Finspång massif some work on the nearby Graversfors granite (Wikström *et al.* 1980) will be summarized.

This granite (Fig. 4) was shown to have a diapiric mushroom structure (Fig. 5) with a gravity high over the massif (mass excess). The granite is now somewhat heavier (mean value 2702 $kg/m^{-3}$, $N$ = 54) than the predominating surrounding orthogneisses (mean value 2675 $kg/m^{-3}$, $N$ = 153) and the paragneisses in the south (mean value 2697 $kg/m^{-3}$, $N$ = 105). Plagioclase mantling of K-feldspar megacrysts, which sometimes give monoclinic X-ray patterns, is common and local varieties contain orthopyroxene and accessory fayalite.

As can be seen in Fig. 3, the western contact is characterized by conformable structures. The antiform to the west of the granite with a gentle plunge towards the northeast is oblique to the older Svecokarelian structural pattern with linear elements plunging towards ESE and E. This antiform is believed to be caused by and situated below a northwestward protruding cap of the Graversfors granite (Fig. 3). By contrast the eastern contact is highly discordant, with dykes of the granite penetrating the country rocks in a radiating pattern.

A magmatic type of intrusion for the granite was proposed and the argument for this can be summarized as follows.

(i) The high density of the present granite suggests that it could not have risen buoyantly in the solid state.

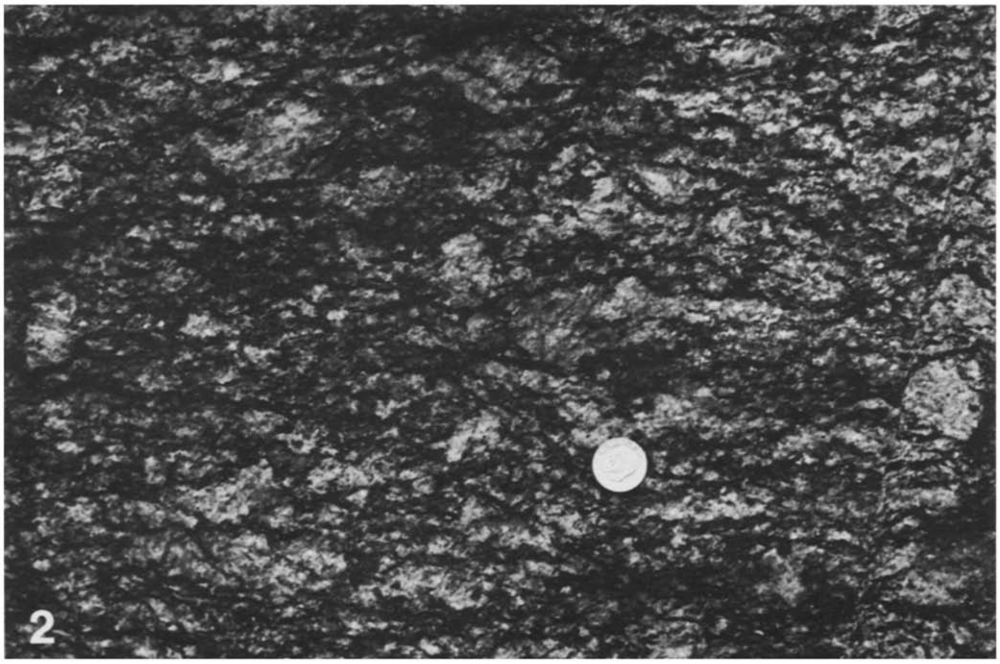


Fig. 2. Strongly deformed Finspång augen gneiss. The diameter of the coin is 25 mm.

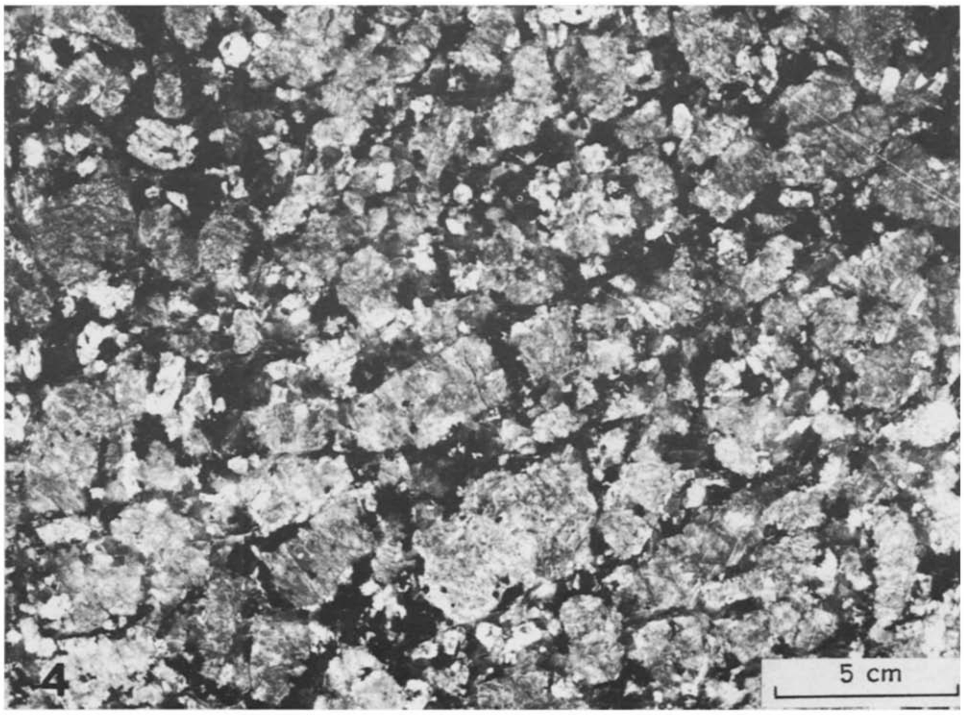


Fig. 4. The Graversfors granite.

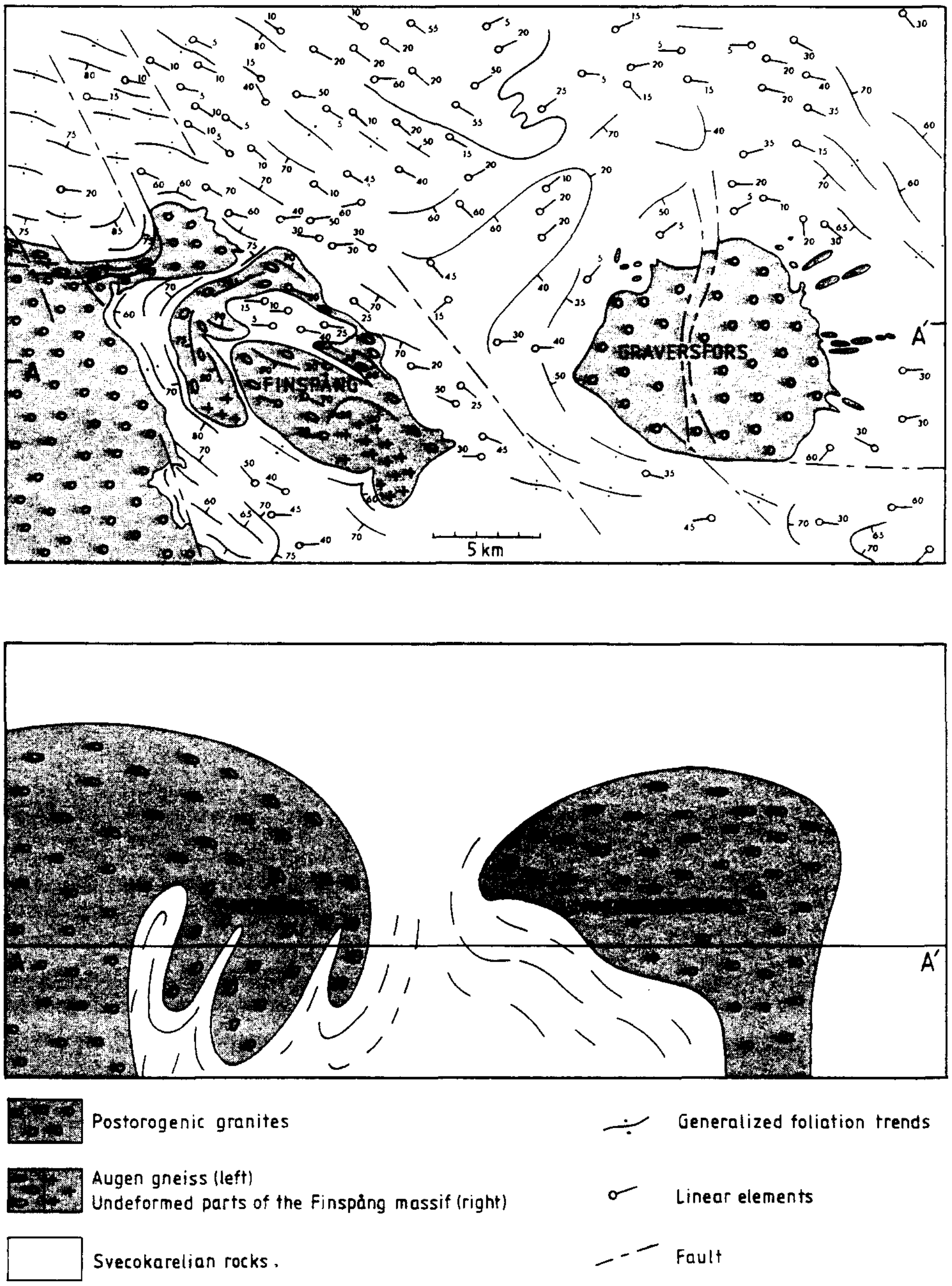


Fig. 3. Structures in surrounding the Graversfors and Finspång massifs (above) and a proposed cross-section (below).

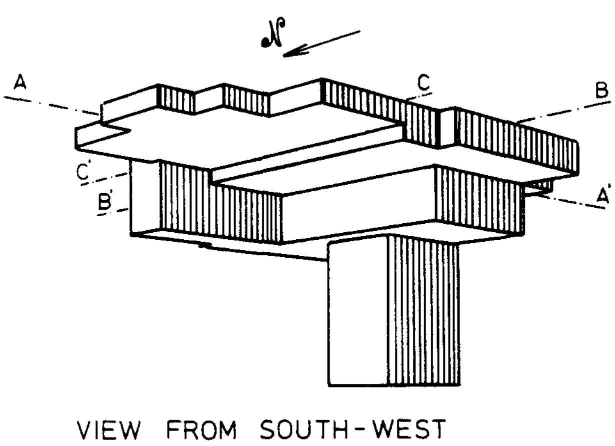


Fig. 5. A structural model of the Graversfors granite based on gravimetrical data. Calculation made by Aaro & Lagmansson (in Wikström *et al.* 1980).

The argument that the crystallized granite could have received its buoyancy at deeper levels is difficult to combine with the points below.

A high-temperature magma with the average composition of the Graversfors granite would have had a density in the order of 2400–2500 $kg/m^{-3}$ (calculated according to Bottinga & Weill 1970). This is assumed to have been less than the density of its country rocks at that time and to account for its buoyant rise as a melt to its present level.

(ii) The nature of the eastern contact with narrow dykes of the granite filling a fracture pattern in the country rocks, speaks more in favour of a magmatic than a solid type of intrusion.

(iii) The K-feldspars along the eastern contact and within the dykes show typically 'blurred' X-ray patterns when measuring the triclinicity. This is commonly interpreted as a sign of disequilibrium during crystallization. A solid type of intrusion would probably have taken place under such a long time that thermal equilibrium should have been achieved. No differences in texture between the eastern and western parts of the granite have been found.

## MODEL ANALOGUES AND CONCLUSIONS

Model experiments (e.g. Ramberg 1967) show that for the development of fold structures in the country rocks of the dimensions depicted in Fig. 3, the viscosity contrast between a diapir of Graversfors type and its country rocks cannot have been very large when it formed. A maximum difference of $10^3$ poises has been calculated.

The following factors are intuitively believed to have contributed to the necessary reduction of the effective viscosity in the country rocks.

(1) Partial melting. Some migmatitic mobilizates are linked to the northeast-plunging structure west of the Graversfors granite.

(2) Strain-softening due to the nearby rising and expanding magma body.

(3) Folding during amphibolite facies conditions, possibly under conditions of high water vapour pressure.

Returning now to the structural position of the Finspång augen gneiss; one of Ramberg's (1967) model experiments is believed to give a partial picture of the situation. Figure 6 shows a diapir with the marginal parts of the cap infolded conformably into the surrounding rocks while the central trunk cuts them discordantly. The corresponding structure assumed for the Finspång massif is shown in the profile of Fig. 3, although the dimensions of the trunk are not the same. Preliminary data from a gravimetric investigation supports the given model in principle (S. Aaro pers. comm. 1982), although available data do not permit a detailed calculation. The granite west of the Finspång massif is similar to the Graversfors type. It can be noted that structures outside this granite seem to be somewhat affected by the intrusion.

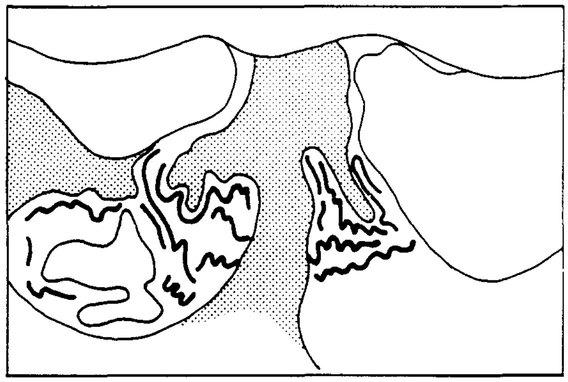

Fig. 6. Diapir structure (redrawn from Ramberg 1967, fig. 41), which shows the marginal parts of the cap folded conformably with the surrounding material, while the trunk has discordant contacts.

In a larger perspective (cf. Fig. 1) other intrusive mechanisms than those so far discussed seem to have played a role. The Småland granites belong to a coherent belt of granites which are postorogenic in relation to what is generally supposed to be Svecokarelian folding. In southern Sweden the granite belt has a width of about 100 km, and can be followed towards the NNW for a distance of about 700 km where it disappears beneath the Caledonides. Transitions into subvolcanic types can be found and acid volcanics are typically associated with the belt. The overall trend of the belt, as well as different internal contacts, suggest that lineaments and different kinds of fracturing have been essential for the localization of the intrusives.

The structures so far described in this paper are related to an isolated massif (Graversfors) and the contact zone of the belt and have not so far been recognized further to the west. The Graversfors granite shows that radically different contact relationships can be found within a short distance. A model in which these field observations can be developed further, is the so called 'balloon tectonic model' (Ramsay 1981), where an earlier crystallized part of a magma chamber expands like the skin of a balloon when new magma is intruded into it. In principle this idea could be extended to the behaviour of the cap of a diapir which can also be inflated and distorted by further supplies of magma.

The picture thus arrived at, is that the granites of the area have intruded as magmas in partly diapiric-like fashion. The augen gneisses are early crystallized 'skins' of the granites, which later on have been deformed and metamorphosed by the somewhat younger intrusions, rising up much the same path.

If this relationship can be sustained, it follows that a major deformation and a related metamorphic event occurred, as a consequence of the intrusion of the Småland granites. However, the separation of these structures from those of the Svecokarelian may not always be recognizable in the field and so far, no distinguishing criteria have been recognized on the outcrop scale. Lineations plunging towards the E or ESE, which are typical for the youngest major Svecokarelian deformation event, can be followed northwards along the Baltic coast for some 900 km. These structures are probably unrelated to the type of deformation outlined here.

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