

The late Svecofennian granite–migmatite zone of southern Finland—a belt of transpressive deformation and granite emplacement

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ABSTRACT

The late Svecofennian granite–migmatite (LSGM) zone in southwestern Finland is a ~100 km wide and 500 km long belt transecting the southern Svecofennides from WSW to ENE. It was formed in an area of thin pillow lavas, volcanoclastic sediments and limestones. The area is interpreted as having been an early basin of crustal extension which was the locus of an inherited zone of weakness in the Proterozoic crust. Early recumbent folding was followed by crustal thickening and intrusions of ~1.89–1.88 Ga old plutonics.

The LSGM-zone is characterized by 1.84–1.83 Ga old rhomboidal sheets of late Svecofennian microcline granite and is bounded by ductile shears. Amongst the two major phases of deformation defined in the LSGM-zone, the earlier one (D1) affected only the supracrustals and the 1.89–1.88 Ga old early plutonics. In contrast, the later phase (D2) also deformed the late Svecofennian migmatites and granites. D1 represents a complex and long-lasting deformation event which included overturning and thrusting of the Svecofennian strata.

D2 comprised ENE–WSW directed drag accompanied by NNW–SSE compression. The Svecofennian crust was thickened further and anatectic microcline granites intruded along thrusts. The rhomboidal outline of the late Svecofennian granite sheets indicates a sense of movement in agreement with measured dextral strike-slip in the shears delimiting the LSGM-zone. Imbricated feldspar megacrysts in the granites indicate thrusting towards the west during the stage of granitic magmatism. The gently dipping early Svecofennian gneisses and the late granite sheets were folded into upright F2 folds with gently plunging axes. Locally, the F2 axial surfaces were intruded by late Svecofennian granite mobilisates.

1. Introduction

The Svecofennian domain of Finland and Sweden (Fig. 1, inset) is a large crustal segment of ~2.0–1.8 Ga age, consisting of calc-alkaline plutons and metavolcanic rocks with interspersed metagreywackes and metapelites. Plutonism commenced during the calc-alkaline volcanism and granitoids occupy most of the crustal volume. The oldest known zircons found in metagreywackes are 2.1 Ga old (Huhma, 1990), but no source rocks of that age have been found. Most of the early granitoids have ages of 1.89–1.88 Ga (Huhma,

1986; Patchett and Kouvo, 1986). They represent an episode of massive formation of continental crust and comprise I-type rocks ranging from diorites through dominant tonalites and granodiorites to red microcline-rich granites (Front and Nurmi, 1987; Gaál and Gorbatshev, 1987).

In southern Finland, the 2.0–1.8 Ga old crust was intruded by a second generation of granites. These late Svecofennian, S-type granites have ages of ~1.84–1.83 Ga (Huhma, 1986; Vaasjoki and Sakko, 1988; Suominen, 1991). They form a 500 km long and 100 km wide belt of intrusions (Fig. 1) and are associated with high-grade metamorphism and extensive migmatites which have been described by Seder-

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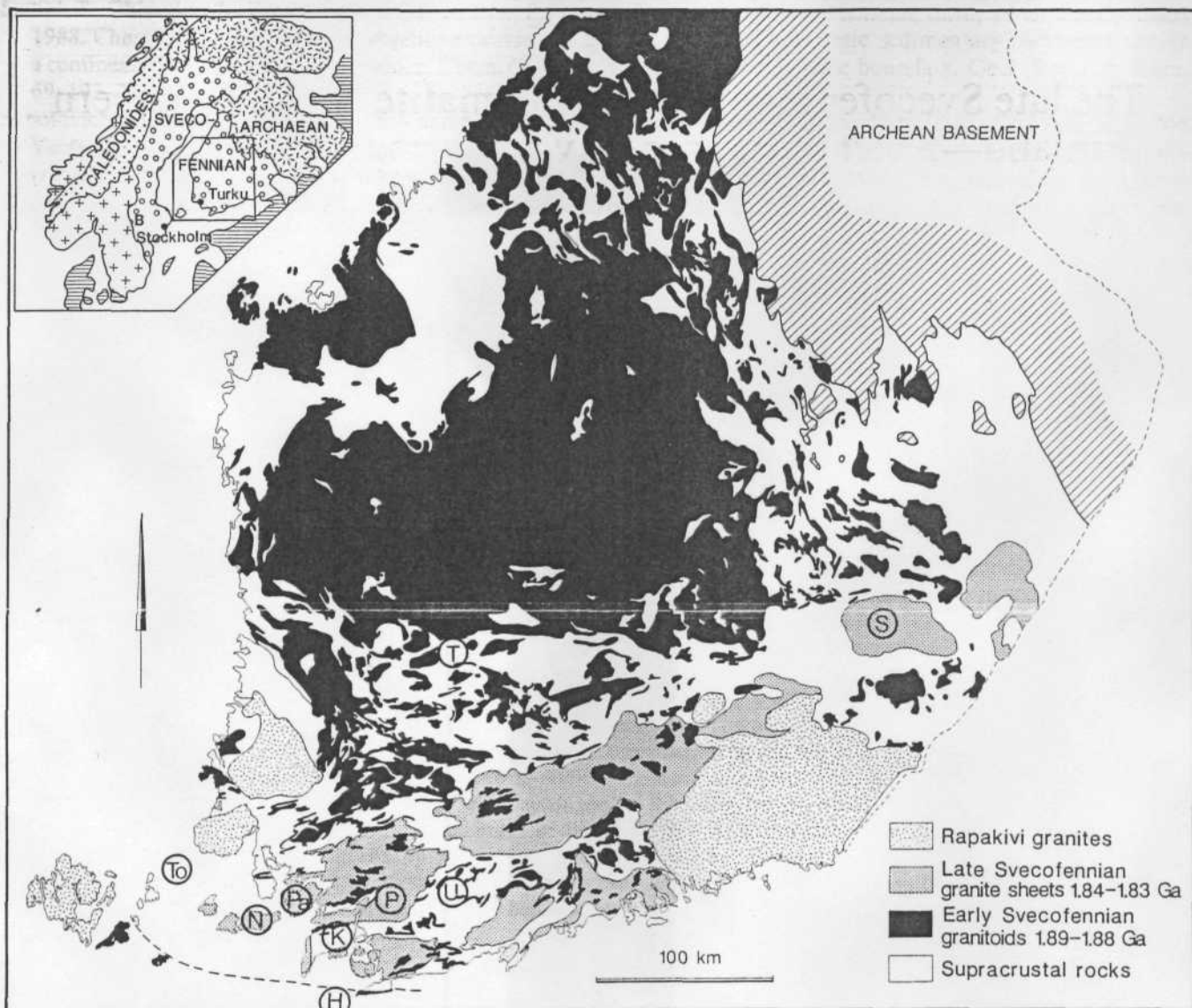


Fig. 1. The Svecofennian rocks of southern Finland (after Simonen, 1980). The zone of late Svecofennian 1.84–1.83 Ga old granites and migmatites (LSGM) transects the earlier crust. S=Sulkava, T=Tampere, U=West Uusimaa, Mustio and Orinjärvi, P=Perniö, K=Kemiö, H=Hanko, Pa=Pargas, N=Nagu, To=Torsholma.

holm (1926), Hoggood et al. (1976), Edelman and Jaanus-Järkkälä (1983), Hoggood et al. (1983), Korsman et al. (1984), and others.

There has been a tendency to describe the Svecofennian geology of Finland on the basis of detailed studies in only a few key areas (e.g. Simonen, 1960). This is a legacy of J.J. Sederholms excellent pioneer papers from the beginning of the century. His strong influence on geological thinking has subsequently led to overly generalized inferences about stratigraphy and deformation. At present, new U–Pb

datings and numerous new geophysical and geological data facilitate a different approach where distinct structural and stratigraphic units within the large Svecofennian domain can be distinguished.

The aim of this paper is to give an overview of the late Svecofennian granite–migmatite zone of southern Finland, the LSGM-zone, as a distinct structural unit. We have tentatively defined two main phases of deformation (D1 and D2) separated by a time lapse of some 50 Ma as shown by their relationships to radi-

ometrically dated granitoid intrusions. Phase D1 comprises deformational episodes mostly preceding the intrusion of the 1.89–1.88 Ga old granitoids, but also includes episodes during and soon after these intrusions. In contrast, phase D2 also affects the 1.84–1.83 Ga old granites. We made no attempts to distinguish between different episodes of deformational phase D1. Thus, S1 designates all the dominant subhorizontal schistositities formed during the D1 events. D2 is confined to the LSGM-zone and must not be confused with deformation phases in other parts of the Svecofennian domain. Later deformations (D3 etc.) as described in the literature (e.g. Schreurs and Westra, 1986) are not discussed in this paper. Our conclusions are based on observations made in the western part of the LSGM-zone.

2. The late Svecofennian granite-migmatite (LSGM) zone of southern Finland

2.1. Age determinations and geographical extent

Although rather few U–Pb zircon age determinations are available, the results are consistent: the migmatites and granites forming the LSGM-zone have ages of ~1.84–1.83 Ga. Age determinations on the migmatites of the Sulkaava area (1833 ± 16 Ma; Korsman et al., 1984), the Hanko granite (1830 ± 10 Ma; Huhma, 1986), the Nagu granite (1842 ± 31 Ma; Suominen, 1991) and the Kumlinge granite in the southwestern archipelago (1840 ± 4 Ma; Suominen, 1991) all plot within this period (Figs. 1 and 2A). Suominen (1991) also reports three new U–Pb ages from the LSGM granites in the Perniö area (1829 ± 14 ; 1840 ± 8 ; 1829 ± 14 Ma) and one from Kemiö (1840 ± 8 Ma). Undeformed post-orogenic dykes and intrusions with ages of ~1.80 Ga have been reported from different parts of the LSGM-zone (Nykänen, 1983, 1988; Korsman et al., 1984; Vaasjoki and Sakko, 1988). A

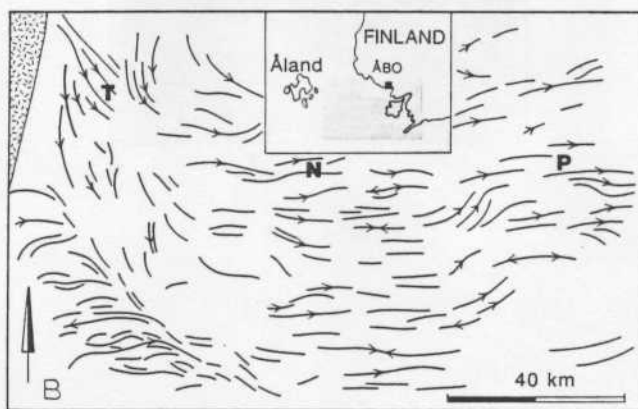
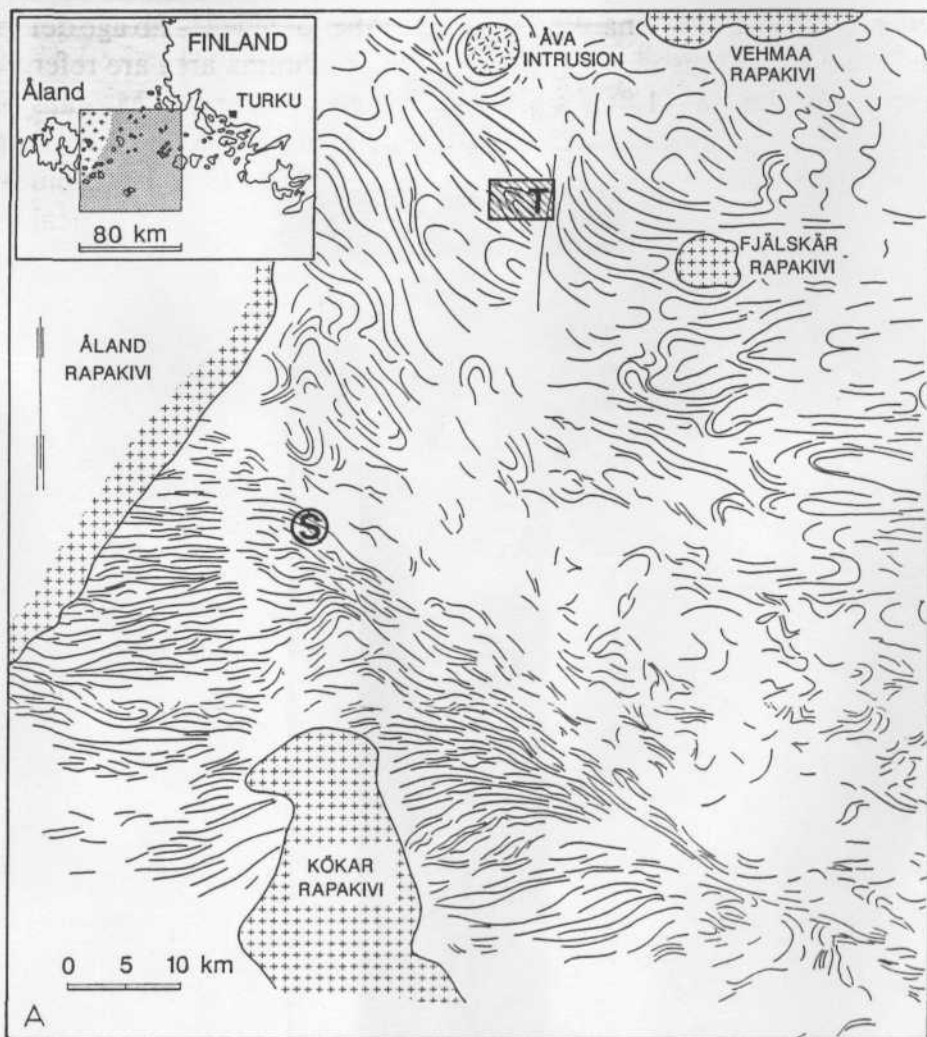
number of new U–Pb age determinations from the Torsholma area are referred to as personal communications by M. Vaasjoki, 1991.

The red microcline granites along the southern margin of the large plutonic complex in central Finland are chemically similar to those of the LSGM-zone, but are older and belong to the same age group as the predominant 1.89–1.88 Ga old granodiorites and tonalites (Huhma, 1986; Patchett and Kouvo, 1986). In fact, no 1.84–1.83 Ga granite ages have been recorded in the Finnish part of the Svecofennian domain outside the LSGM-zone (M. Vaasjoki, pers. commun., 1991).

The LSGM-zone of late Svecofennian granite massifs extends to the shore of the Gulf of Finland in the south. Its southwestern part is separated from the realm of massive early Svecofennian granites by a steeply dipping regional shear zone with a considerable strike-slip component (Fig. 2 in this paper, and Ehlers and Lindroos, 1990a). South of this marked shear zone, all granitic rocks belong to the 1.89–1.88 Ga age group (Suominen, 1987, 1991).

Maps based on numerous drillings through the Palaeozoic cover of northern Estonia into its Precambrian basement show no extensive granite and migmatite occurrences (Puura et al., 1983). This is in accordance with earlier descriptions of the islands in the southern part of the Gulf of Finland (Ramsay, 1891). Furthermore, published geological maps and descriptions indicate that the early Svecofennian granitoids within the LSGM-zone are more deformed than those in the 1.89–1.88 Ga old granitoid massifs of the central Finnish early Svecofennian granitoid complex.

From the data now available we can delineate approximately the boundaries of a roughly 500 km long and 100 km wide zone of repeated strong deformation and high-grade metamorphism accompanied by extensive migmatitization and intrusions of late Svecofennian granites along the southern coast of Finland (Fig. 1).



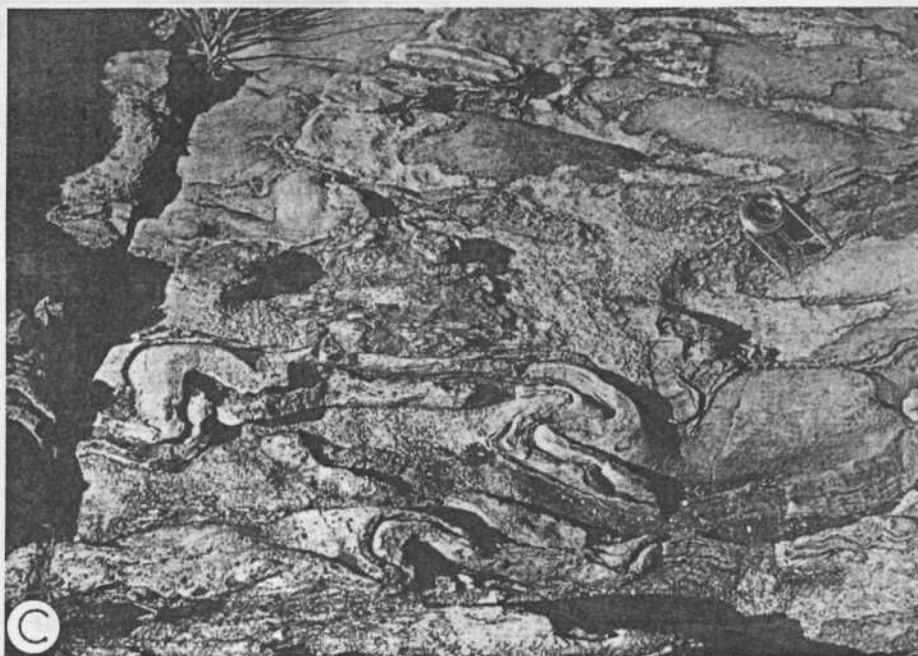


Fig. 2. (A) Schistosity trends as traced from geological map sheets covering 7000 km² of the southwestern archipelago of Finland. The area is well exposed and the trends in this map (from Ehlers and Lindroos, 1990a) are based on measured field observations. A steeply dipping shear zone transects the area in a NW direction. The LSGM-zone with characteristic dome- and basin-structures in gently dipping migmatitic supracrustal rocks is northeast of the shear zone. On the southwestern side, the steep schistosity in the 1.89–1.88 Ga old granitoids is deflected by dextral movement. The localization of Fig. 5 (Torsholma area) is indicated. *S*=Sottunga area. (B) Gently dipping stretching lineations and mineral lineations in the LSGM-zone. The lines on the map are drawn along the general trend of the dominant subhorizontal lineations. Plunge directions (20° or less) are indicated with arrows. The contact to the Åland rapakivi granite complex and the shear zone in the western part of the map are the same as those in (A). *T*=Torsholma, *N*=Nagu, *P*=Perniö. (C) Sheath folds in a thin marble with quartz-feldspar layers indicate subhorizontal shearing. Direction of movement is towards the NW (towards the camera). The locality is situated within the area of gently dipping domes and basins northeast of the strike-slip shear in (A).

2.2. General structural features

The Proterozoic rocks within the LSGM-zone have a number of characteristic lithological and structural features. Geographically, the LSGM-zone overlaps a roughly 100 km wide zone of volcanic and sedimentary, basin-type, shallow marine lithologies consisting of thin sequences of basaltic pillowed lavas covered by thin marbles and iron formations. North of the LSGM-zone, the volcanic rocks consist of much thicker volcanoclastic sequences, and pillow lavas and associated marbles are absent.

The lithological layering of the oldest supracrustals with a strong transposed schistosity (*S*1) is subhorizontal (Fig. 2A) and roughly parallel to the presently exposed peneplain.

This dominant *S*1 event forms the axial-plane surfaces of early overturned folds which reach a size in the order of several kilometres (Fig. 3). Some of these structures have been mapped in detail (e.g. Bleeker and Westra, 1987).

The early 1.89 Ga old granitoids (gneissose granites) form sill-like intrusions along the previously formed *S*1 axial-plane schistositities (Fig. 4B). These rocks are often strongly schistose and lineated due to continuing subhorizontal deformational movements.

The 1.84–1.83 Ga old microcline granites were emplaced as sheets conformable with the gently dipping *S*1 axial-plane schistosity and also roughly in conformity with the previously deformed 1.89 Ga old sills of gneissose granite. In the Perniö area (Figs. 1 and 2B), abundant

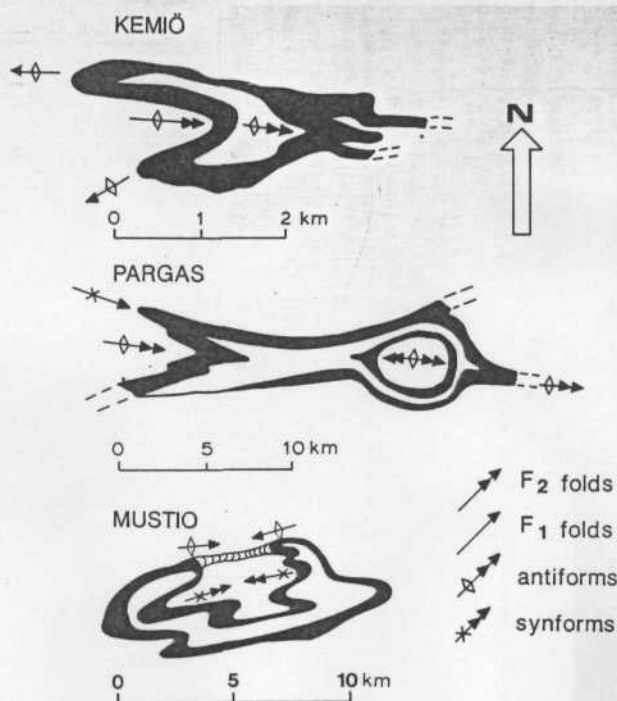


Fig. 3. Large-scale folds as shown by mapped structures in the early Svecofennian volcanic rocks of the LSGM-zone. The representation of the Kemiö and Mustio areas are from Scheurs and Westra (1986) while the map of the Pargas area is based on mapping by Ehlers.

thin slabs of early Svecofennian metasediments and volcanics assume the typically crescent-shaped forms often surrounding small hills, thus demonstrating their subhorizontal positions in the granite. The microcline granites are partly porphyritic and have marked subhorizontal schistosity and a mineral lineation formed by the rotation and imbrication of microcline megacrysts (Fig. 6). A small valley close to the village of Kemiö cuts through the southern contact of one of the granite sheets and exposes the lower contact against the underlying mica schists. The schist and the subhorizontal lower part of the granite sheet are strongly stretched in an east-west direction and schistose. This indicates a long history of repeated deformation and intrusions along the

initially formed subhorizontal axial-plane schistosity (S1).

All these deformed lithologies, the microcline granites included, have been folded into E-W-trending open folds (F2) with gently plunging axes and steep axial planes (S2B) forming the interference patterns of Fig. 2A. The open F2 folding is the main cause of the prominent overall E-W structural trend of the LSGM-zone.

Stretching lineations and the axes of small, tight F1-folds within the S1 schistosity have the same direction and are roughly parallel to the subsequent open F2-folds. They are all horizontal or dip gently towards the east (Fig. 2B). The linear structures in Fig. 2B are thus a combined result of one or several overlapping deformation events which affect both the 1.89–1.88 Ga old granitoids and the 1.84–1.83 Ga old granites.

The late Svecofennian granites occur mainly in two different structural settings (cf. Eskola, 1914). They are found as: (1) large gently dipping sheets of porphyritic microcline granite emplaced along S1 schistositities; and (2) small discordant massifs and dykes of microcline-rich granite, which often form intrusive breccias with the surrounding deformed and veined gneisses; small ballooning intrusions occur (Ehlers, 1978; Edelman, 1979; Ehlers and Bergman, 1984). The granites of this type show only a steep E-W schistosity trending parallel to the axial surface S2B (Fig. 4D). A recent U-Pb zircon age of 1840 ± 4 Ma (Suominen, 1991) obtained from a small, discordantly intruding microcline granite in the southwestern archipelago (Kumlänge), shows that that rock belongs to the same age group as the granite sheets regardless of the structural difference.

A possible explanation of the difference in structural style between the various late Svecofennian microcline granites is their tectonic position in relation to large contemporaneous crustal shears. The granite sheets were emplaced in a mid-crustal zone of high metamorphism and shearing. They are localized in do-

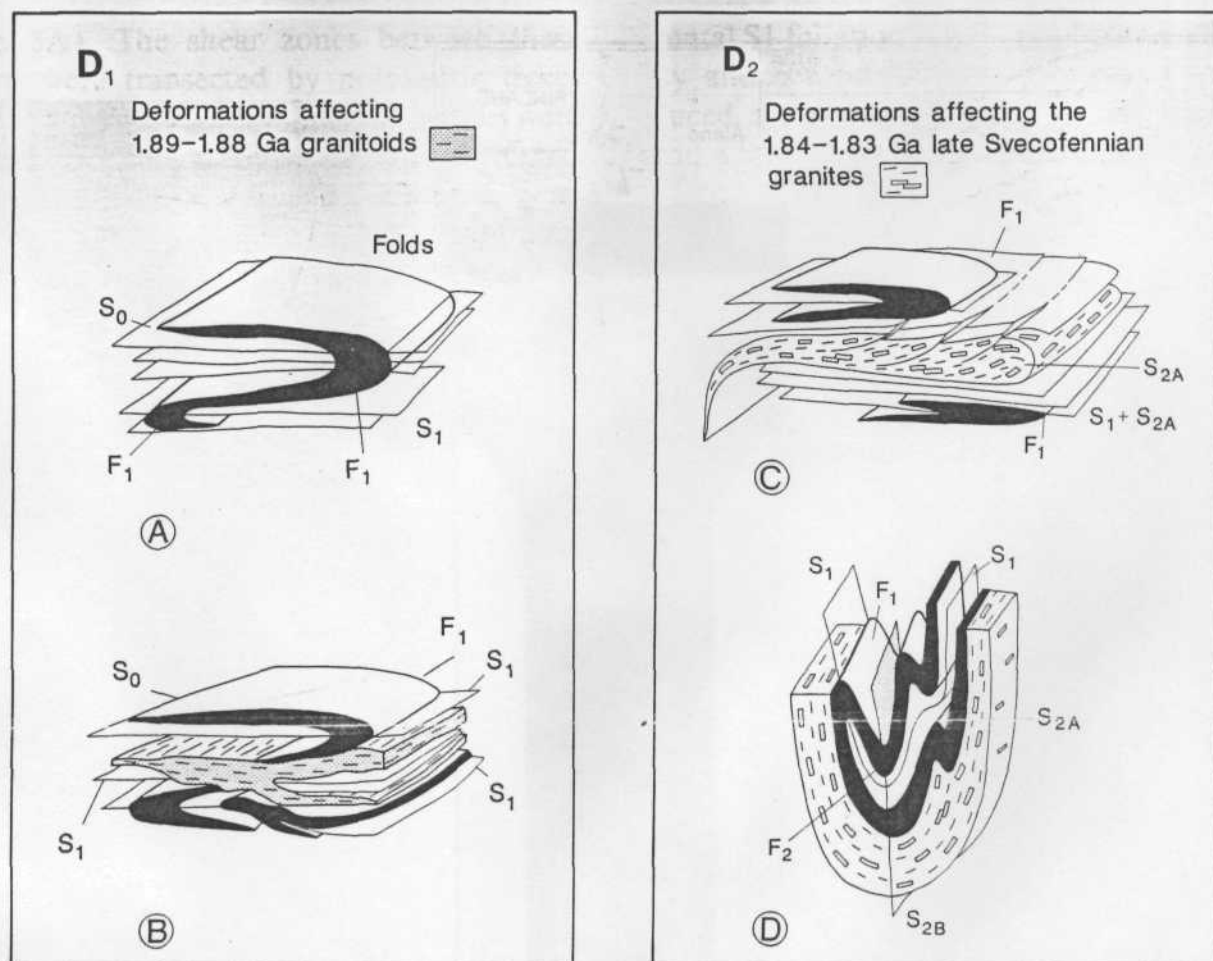


Fig. 4. Simplified sketch of the main deformational episodes within the LSGM-zone. The D1 phase involves all deformations affecting the supracrustal sequence and the 1.89–1.88 Ga old early Svecofennian granitoids. The D2 also affects the 1.84–1.83 Ga old microcline granites. The D2 phase reactivated early S1 schistositities. Early granitoid sills have been omitted in (C) and (D).

mains of sub-horizontal tectonic mobility which served as channels and sites of emplacement for granitic partial melts.

The less deformed, discordant, smaller and regionally more insignificant intrusions represent small balloons or dykes of granitic magma which had escaped from areas of intensive movements and penetrated surrounding portions of the crust. They are non-porphyrific and some of them give the impression of almost being post-orogenic. However, the U–Pb zircon ages demonstrate that all “late Svecofennian” granites within the LSGM-zone belong to the same 1.84–1.83 Ga age bracket although they have been emplaced in structurally different settings.

2.3. Ductile shears in the southwestern part of the LSGM-zone

The southwestern margin of the LSGM-zone is bounded by steep ductile shears with a substantial strike-slip component. Some of these shear zones are well exposed (Fig. 2A). Within the granitic and migmatitic areas, horizontal and gently dipping ductile shears exert a strong influence on the structures (Fig. 5A).

Fig. 2A shows the steep, regional, zone of mylonites and ductile shears that postdate and deform the 1.89–1.88 Ga old granodiorites on their southwestern side. This shear zone extends some 150 km eastwards and has an esti-

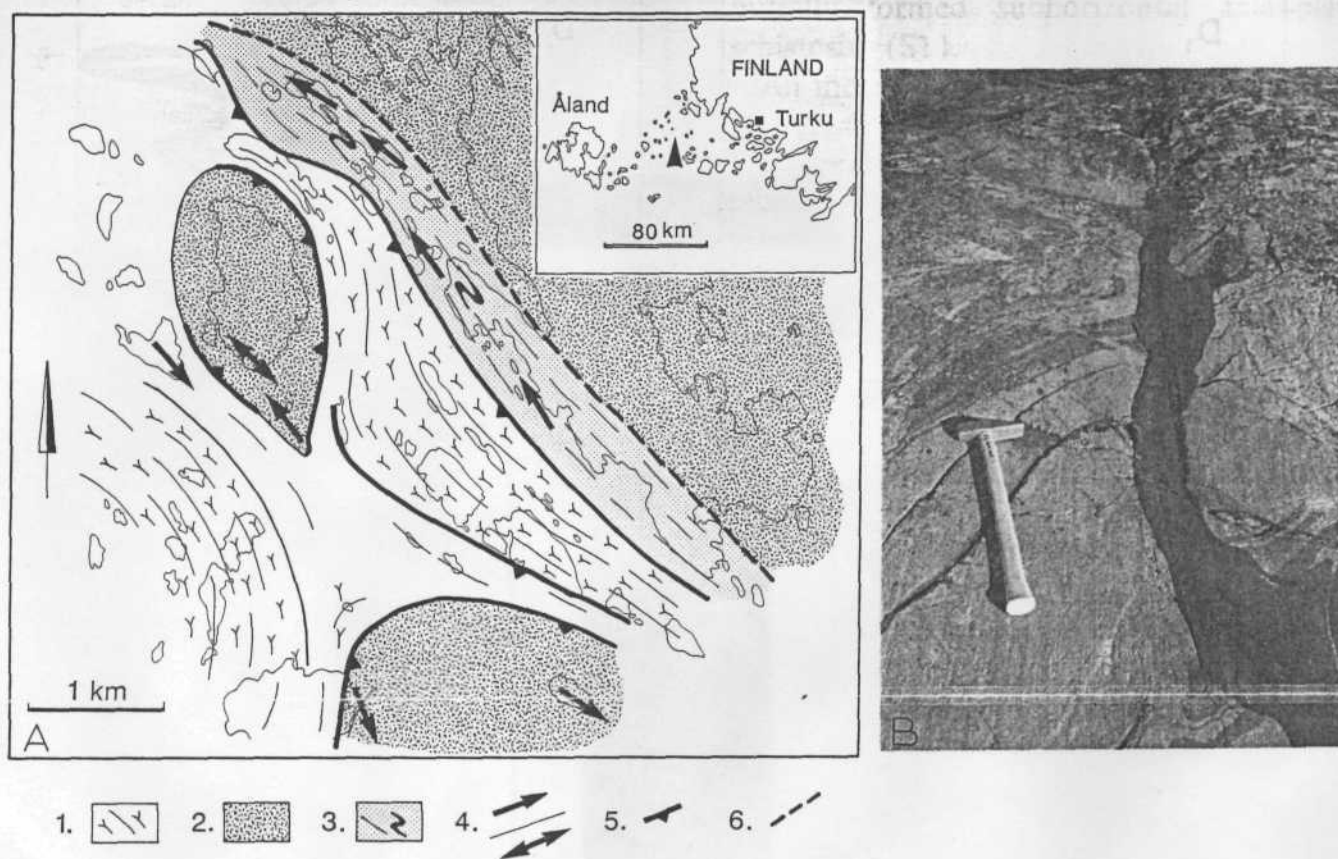


Fig. 5. (A) Structural geology of the Torsholma area (see Figs. 1 and 2 for localization). Slabs of rock with a strong subhorizontal stretching lineation dip gently towards the southwest. A small thrust-bound slab of strongly deformed granulite facies granitoids intersected by numerous thin alkali basaltic amphibolitic dykes is tectonically emplaced between the supracrustals and early granitoids of western Torsholma. A small subhorizontal allochthonous sheet of amphibolite can be seen in the northwestern corner of the map. 1=early granitoids with strike of schistosity; 2=amphibolite; 3=granulite facies granitoids with strong deformation and folded amphibolitic dykes; 4=subhorizontal/horizontal stretching lineations (direction of plunge is indicated); 5=tectonic contact with direction of gentle dip indicated; 6=inferred tectonic contact. (B) Folded dyke of metabasalt intersecting the strongly deformed granulite facies granitoids (symbol 3 in A). The metabasaltic dykes are confined to a rock slab of high-grade metamorphism.

mated dextral strike-slip component of more than 20 km. Northeast of this zone there are migmatitic supracrustal rocks with subhorizontal schistosity refolded into open folds by F2. This has produced an interference pattern which gives the area the characteristic structural style of the LSGM-zone (Figs. 2A and 3).

In the Sottunga area (Fig. 2A), this shear zone is intersected by dykes of late Svecofenian fine-grained granite which postdate the shears and only show weak E-W schistosity (Edelman, 1979) corresponding to the S2B of Fig. 4D. This indicates that this large strike-slip zone is of an earlier date than the S2B de-

formation as shown by the E-W schistosity in the granite dykes.

The Torsholma area (Figs. 2A, 5A) serves as an illustration of the structures within the southwestern part of the LSGM-zone. Fig. 5A shows that this area consists of thin subhorizontal slabs of rock, separated by ductile shears. The slabs dip gently towards the southwest. One of the rock slabs has a mineralogy indicating granulite-facies metamorphism in contrast to the surrounding amphibolite-facies rocks. A marked subhorizontal stretching lineation parallel to the axes of small folds indicates strong displacement of the different sheets of rock

(Fig. 5A). The shear zones between these sheets were transected by pegmatitic dykes showing no deformation. The pegmatites were tentatively dated and yielded a U-Pb monazite age close to 1.80 Ga (M. Vaasjoki, pers. commun., 1991), which provides a minimum age for the shearing in the Torsholma area.

2.4. High-grade metamorphism

In Torsholma (Fig. 5A), a thin slab of strongly deformed granulite-facies gneiss (1.89 Ga; M. Vaasjoki, pers. commun., 1991) is cut by folded amphibolite dykes and only slightly deformed 1.7 Ga old dykes of granodiorite. None of the dyke intrusions show traces of granulite-facies metamorphism. In the Orijärvi area (Fig. 1), the peak of metamorphism postdates the main phase of thrusting and stacking (D1) of the supracrustal rocks (Väisänen, 1988).

In the West Uusimaa area (Fig. 1), low pressure granulite facies rocks (3–5 kbar) with temperatures of up to 800°C, occur within domains of low pressure amphibolite facies rocks. The granulite-facies metamorphism cuts across tectonic and lithological contacts, and represents a local thermal dome that overprinted the late Svecofennian microcline granites (Schreurs and Westra, 1986).

The high-grade metamorphism in the Torsholma area is older than the 1.87 Ga old dykes intersecting and discordantly overthrusting the high-grade slab (Fig. 5A). Thus the LSGM-zone must be considered to be a site of repeated metamorphic episodes of different ages.

5. Structural interpretation

5.1. D1 deformation affecting the 1.89–1.88 Ga old granitoids

The early phases of D1 generated macroscopic recumbent F1 folds overturned towards the west and northwest, for instance in Kemiö and Pargas (Fig. 3). The dominant, subhor-

zontal S1 foliation is a F1 axial-plane schistosity and controlled local thrusting that produced a repetition of supracrustal sequences and a local thickening of the crust. The zones of most intense thrusting and transposition are confined to thin marble layers which are often all but completely sheared out (van Staal and Williams, 1983) and have acted as regional surfaces of decollement.

The early intrusions of granitoids belonging to the 1.89–1.88 Ga age group intruded as sills along these mostly subhorizontal S1 surfaces. The D1 phase deformed the supracrustal sequence and partly also the sills of early synvolcanic granitoids. It provides a rough estimate of the extent of the early deformation. In the Torsholma area (Fig. 5), the strongly deformed tonalitic gneisses of 1.89 Ga age are cut by discordant dykes of 1.87 Ga old granodiorites (M. Vaasjoki, pers. commun., 1991). These dykes are only slightly deformed and thus indicate that the most intensive stage of D1 was (at least locally) over by that time.

5.2. D2 affecting the 1.84–1.83 Ga old granites

The LSGM-zone comprises rhomb-shaped sheets of porphyritic granite. Two areas in one of the granite sheets have been studied in greater detail (Fig. 1); these are the porphyritic granites in Nagu (Edelman, 1972) and Perniö (Eskola, 1914; Selonen and Ehlers, 1990). Edelman described the foliated Nagu granite that features a compositional banding which surrounds and conformably underlies a gently F2-folded amphibolite synform. The foliation was formed by the rotation of microcline megacrysts which are aligned into a linear structure that can be observed on the planes of schistosity. The rotated megacrysts are sometimes bent and squeezed against each other.

Imbrication or tiling of feldspars has been observed and measured in the Perniö granite (Figs. 6A and 6B). Nearly 70% of the measured tilings ($n=228$) indicate westward ro-

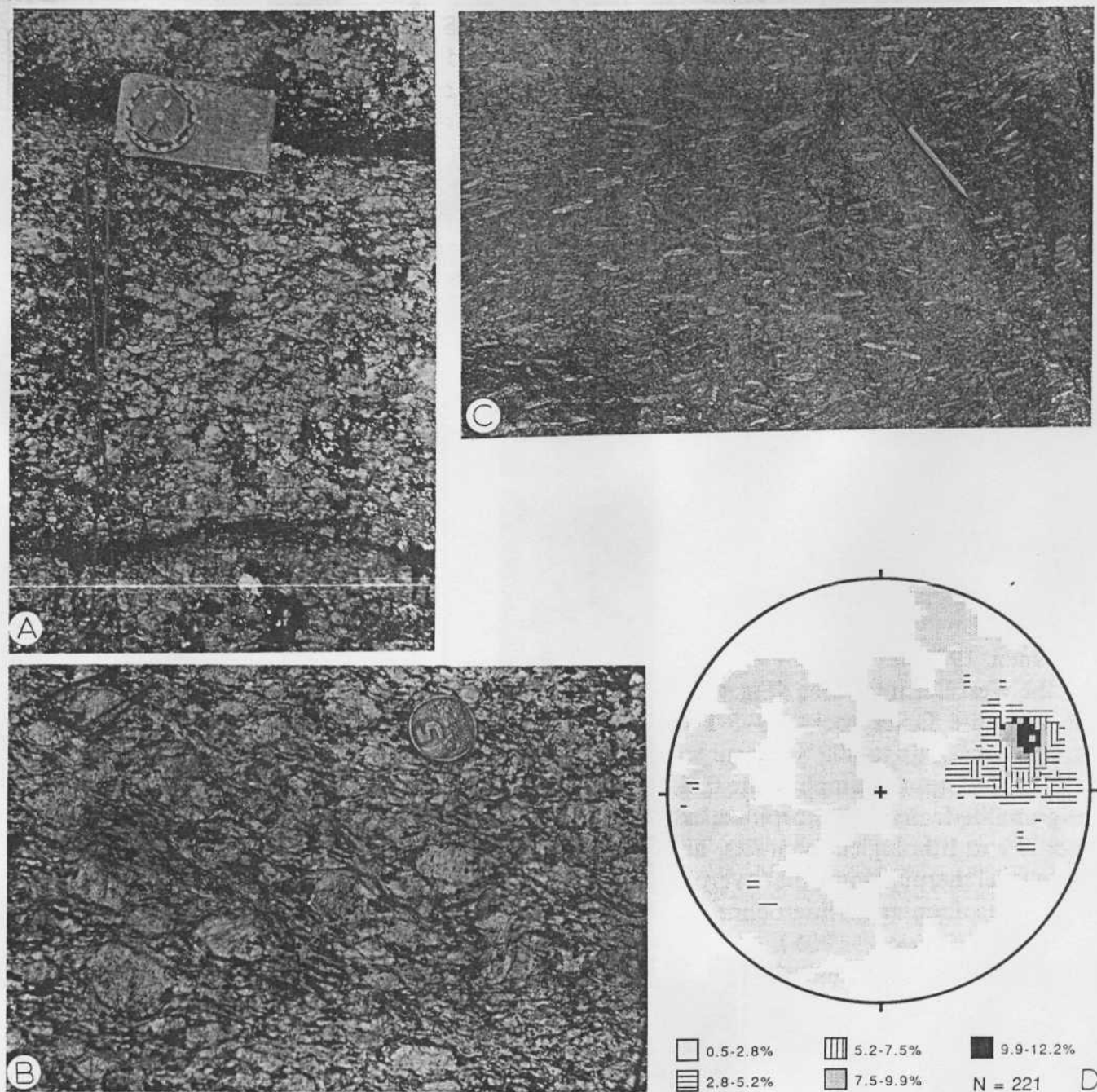


Fig. 6. Imbrication (tiling) of microcline feldspars in the 1.84–1.83 Ga old granites. (A) Imbrication of megacrysts in a vertical outcrop in the Perniö granite. The direction of movement is top towards the west. (B) Rotated and deformed microclines in the southern part of the Perniö granite. Note the partly cataclastic deformation. (C) Parallel arrangement of microcline megacrysts in the Nagu granite. (D) The linear structures in the Perniö area in a stereographic projection (lower hemisphere equal area plot).

tation (Fig. 6A). The sense of rotation is consistent throughout the granite sheet. The imbricated megacrysts are aligned in a regionally consistent E–W lineation (Fig. 6D). Zones of cataclastic deformation also occur. This in-

dicates that the movements continued until the consolidation of the granites.

The imbrication of megacrysts is considered to indicate non-coaxial magmatic flow and rotation of crystals in a viscous matrix in re-

sponse to tectonic stresses. In sections perpendicular to the planar structure and parallel to the linear structure formed by the rotation of the feldspar megacrysts in deformed porphyritic rocks, the imbrication shows either clockwise or anticlockwise rotation (Den Tex, 1969; Blumenfeld and Bouchez, 1988; Paterson et al., 1989).

We consider the banding and the foliation in the granites to be an indication of shearing (Fig. 4C, S2A) along planes parallel to the previously formed subhorizontal lithological layering with transposed S1 schistosity. The imbrication of the feldspars indicates that movement of the upper sides towards the west occurred along subhorizontal shear zones at the time of the emplacement of the granites.

Together with the surrounding, structurally transposed supracrustal successions, the foliated (S2A) granite sheets have been folded into open F2 folds with steep S2B axial planes (Fig. 4D). Granitic melts occasionally also intruded along the F2 axial planes.

6. Discussion

The D1 phase affected the Svecofennian crust and produced different styles of folding in different areas (cf. the Tampere area in Nironen, 1989). Along the southern coast of Finland, the D1 phase created early recumbent folds overturned towards the west. This deformation stacked the thin shallow-marine supracrustal rocks and was followed by intrusion of synvolcanic early granitoid sheets. The earliest episodes of high-grade metamorphism were synchronous with this phase of deformation.

The second phase of deformation, D2, culminated about 1.84–1.83 Ga ago along the previously formed zones of D1 shearing. These subhorizontal zones were the sites of accumulation of anatectic melts and controlled the emplacement of 1.84–1.83 Ga old S-type microcline granites. The D2A deformation is identified by imbrication of microcline megacrysts in the granite sheets to form a schistosity

(S2A) parallel to the earlier D1 surfaces of thrusting (Fig. 4, S1 + S2A), but the thrusting seems to have continued also for some time after the consolidation of the granite sheets. This can be seen as a strong shearing and extension of the lower contacts of the granite sheets. The granite sheets were folded into E–W striking open folds with upright axial planes (S2B) and gently dipping fold axes. Kinematically, the S2A and the S2B could belong to the same phase of deformation even though they are separate geometrically. This could be the case, e.g., in the formation of large sheath folds. Strike-slip zones as important sites of local granite magmatism have been reviewed by Fyfe (1987) and examples of granite control by strike-slip have been published from the Alpine fault of New Zealand (Allis, 1981) and from the Armorican Massif (Brown et al., 1990, and others).

Examples of localization of strike-parallel movements to areas of inherited fault structures have been described by Vauchez and Nicolas (1991). One reason for the localization of the intense deformation of the LSGM-zone to this particular part of the Svecofennian domain could perhaps be found in its Palaeoproterozoic volcanic history. The volcanic sequences indicate subaqueous basins floored by basaltic pillowed lavas and covered by thin chemical sediments comprising marbles and iron formations. The chemical signature of the basaltic lavas suggests extensional rifting basins (Ehlers et al., 1986). Volcanic rift basins with shallow-water type thin-bedded lithologies could more easily be sites of strong tectonic movements than neighbouring, much thicker volcanic sequences in the area north of the LSGM-zone where the rocks, richer in volcanoclastics and coarse conglomerates, indicate a different volcanic surrounding. Marbles and thin pillow lavas all but disappear (Ehlers and Lindroos, 1990b). The chemical signature of the basaltic lavas north of the LSGM-zone is that of continental-margin magmatism (Kähkönen et al., 1989).

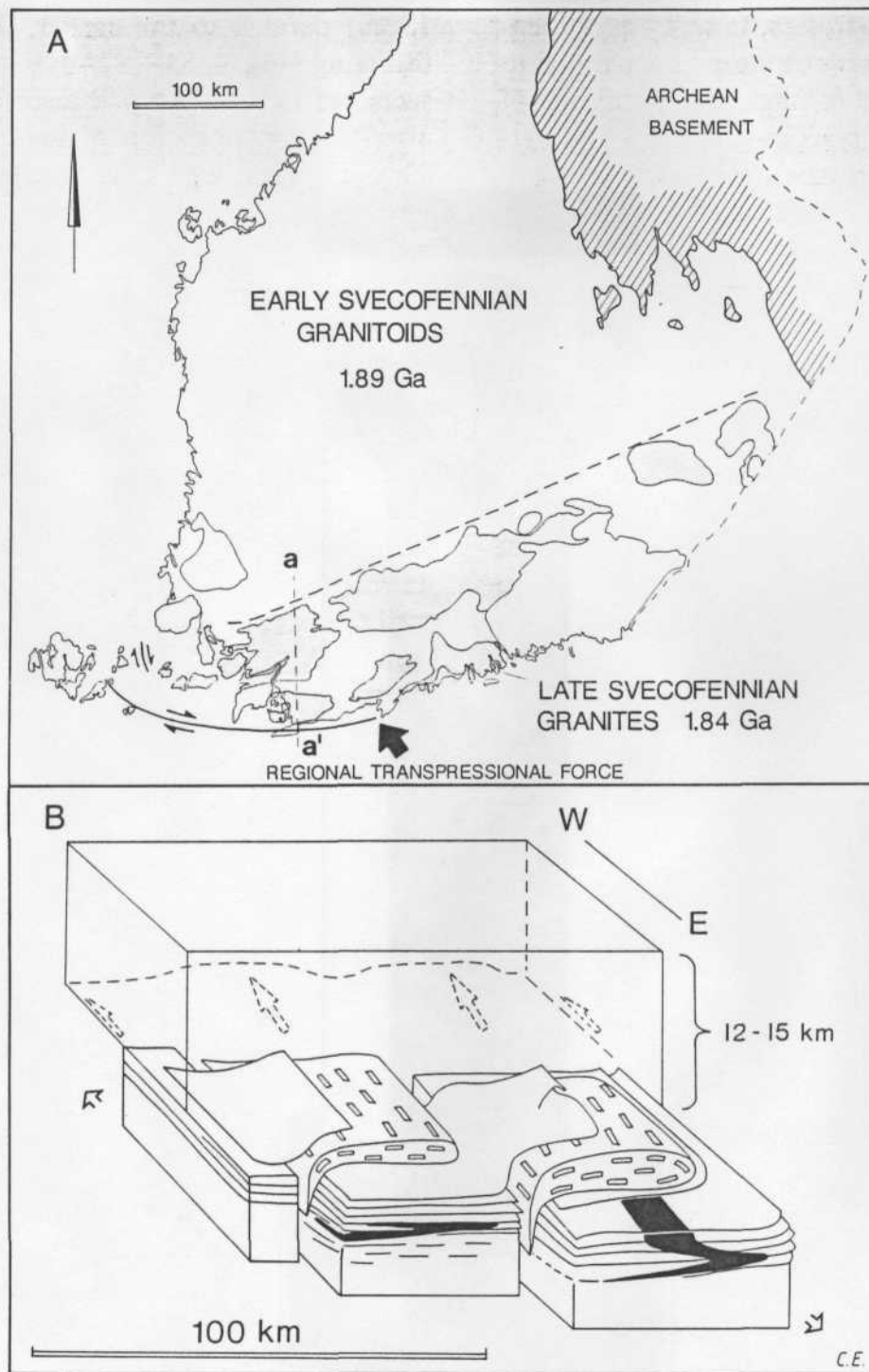


Fig. 7. (A) The LSGM-zone in southern Finland is bordered by ductile shears. The southwestern end of the zone curves towards the northwest along a steep shear zone with a dextral component of horizontal movement. The direction of compression from the southeast is indicated. The sense of movement is interpreted from published geological maps and outcrops. Symbols *a-a'* mark the site of the cross-section in (B). (B) Interpretation of a north-south cross-section through the LSGM-zone as indicated in (A). The granite sheets were emplaced within a transpressional zone of strike-slip shears and horizontal shears in the middle crust. An almost horizontal stretching lineation in the granites and westward imbrication of microcline megacrysts indicate horizontal movements of the "roof" towards the west. The later D2 phase that folded the granite sheets around open E-W fold axes is omitted from this figure as have been early Svecofennian granitoids. The depth of emplacement of the granitic sheets in this figure has been estimated from *P/T* estimates (Schreurs and Westra, 1986).

D1 overturning of early folds is not restricted to the subsequent LSGM-zone alone, but the thin lithologies of the Palaeoproterozoic rift basin appear to have been more susceptible to recumbent folds than the thicker supracrustal sequences to the north of this zone. These differences in structural style presumably initiated the early strike-slip deformation which accompanied recumbent folding within the zone of thinned crust. Recumbent structures such as those in Fig. 3 mostly affected specific rock slabs separated from the surrounding area by steep shears.

The juxtaposition of high-grade metamorphic subhorizontal sheets of rock with sheets of lower metamorphic grade and the different histories of dyke intrusion in these sheets are features indicating considerable horizontal stacking of rock slabs before the emplacement of the microcline granites of the LSGM-zone. The anatexis and emplacement of S-type granites seem to have occurred at crustal depths of 12–15 km (Fig. 7B).

The southwestern side of the LSGM-zone is delimited by a steep strike-slip zone that deformed 1.89–1.88 Ga old granitoids in a dextral sense of movement (Figs. 2A and 7A). The same sense of movement can also be seen in smaller strike-slip shears within the LSGM-zone (Fig. 7A). The northern margin of the LSGM-zone is defined by a lithological boundary (Fig. 7A, dashed line) which has been interpreted as representing a major dextral shear zone (Gaál, 1990), but the interpretation of the sense of movement along this zone is speculative. Dextral movement, however, is in harmony with the symmetry of the rhomb-shaped granite sheets. The LSGM-zone curves towards the NW (Fig. 7A). This could be related to the dextral sense of shearing which, if the movements had been stronger on the southern side of the zone, could accommodate the extra displacement by bending the zone towards the NW. Such bending of the LSGM-zone towards the NW could possibly also explain why no granites of 1.84–1.83 Ga age are found in the

Svecofennian terrain of the Stockholm area in Sweden (Patchett et al., 1987), which is situated due west of the LSGM-zone (Fig. 1, inset).

We conclude that the LSGM-zone is a structurally distinct tectonic unit of strong deformation coupled with high-grade metamorphism and intrusion of 1.84–1.83 Ga old granite sheets along subhorizontal ductile shears. The zone is located in an Palaeoproterozoic extensional basin, presumably acting as an inherited zone of weakness in the crust.

Dextral strike-slip movement coupled with sub-horizontal ductile shears and E–W open folding can be explained by transpression-type deformation (Fig. 7A) of Palaeoproterozoic terranes along a zone of inherent weakness in the Palaeoproterozoic crust.

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