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The Protogine Zone. Geology and mobility during the last 1.5 Ga

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September 1992

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GEOLOGY AND MOBILITY DURING THE LAST 1.5 Ga

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The Protogine Zone.

Geology and mobility during the last 1.5 Ga

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CONTENTS

ABSTRACT

This report treats the Protogine Zone (PZ) as the western boundary of the Southeastern Megablock (SEM), and summarizes scientific aspects of different geological and geophysical functions of the zone. A systematic inventory and a technical description of shear zones and faults in the type area of the "Schistosity Zone" ("Förskiffringszonen") are presented. The report then reviews observed and inferred activity of the zone during the last 1500 million years. This calendar includes at least eight different periods of compression or extension, tilting, uplift, magmatism etc. along the zone, in harmony with the common experience that old zones of weakness in the crust seldom heal. The network of major structures of southern Sweden is described, and the function of the PZ within this network is discussed with particular attention to east-west running lineaments within the SEM, like the Nömmen-Oskarshamn and Hörnebo-Högsby fault and shear zones. Future work should inter alia investigate if these two zones are connected with the PZ, and if movements along the PZ can reactivate the zones. A bibliography comprising c. 100 titles is included as an appendix.

SUMMARY

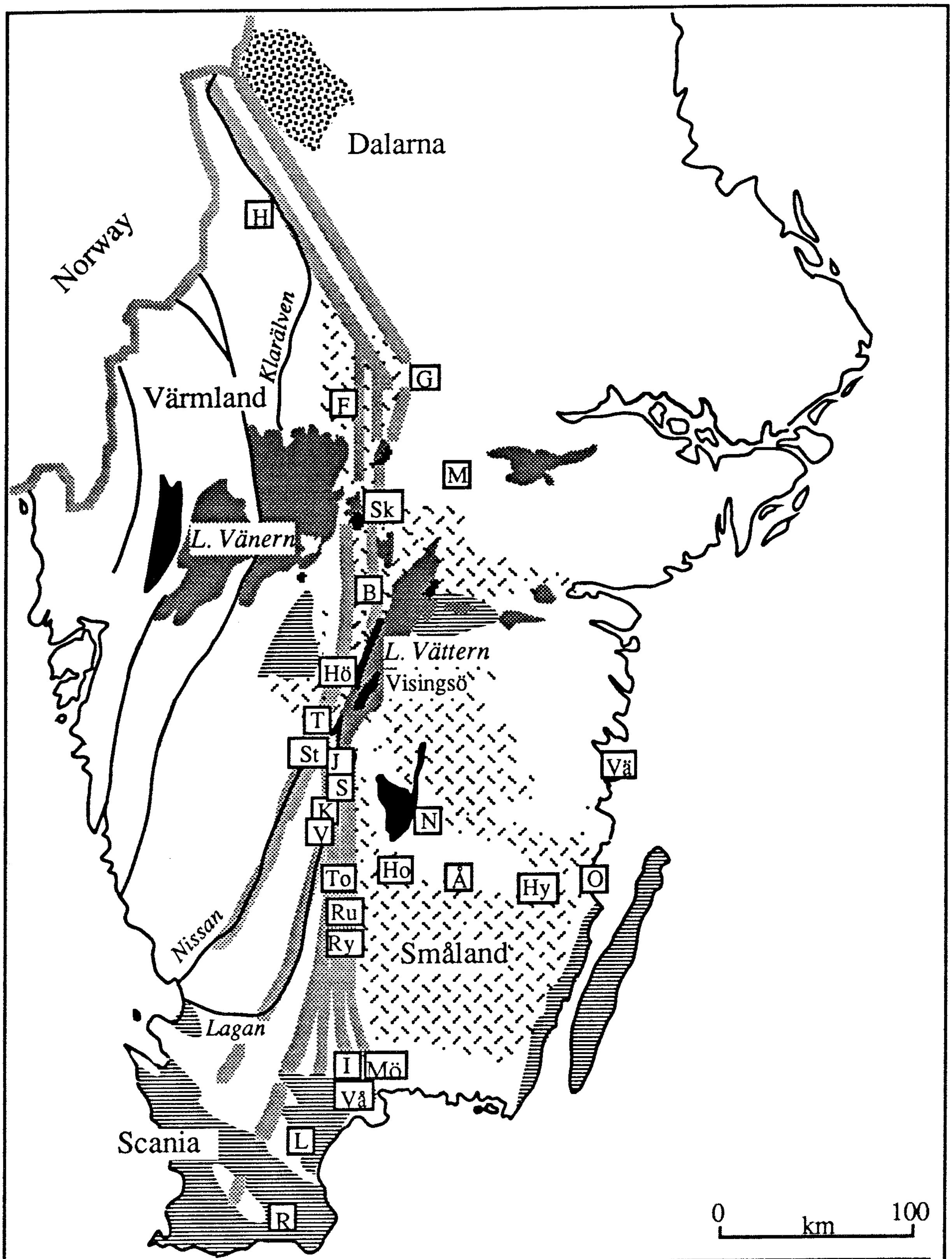
The Protogine Zone (PZ) is tretated here as the western margin of the Southeastern Megablock (SEM). The PZ has a complex structure with a long tectonic history. In addition to being a system of NNW, N-S and NNE trending deformation zones, it is the site of magmatic intrusions, metamorphic breaks, hydrothermal mineralizations and is characterized by geophysical anomalies such as a gravity low and aeromagnetic breaks and lows. The evidence of repeated deformation over a period of more than 1000 Ma is in marked contrast to the history of the adjacent granite region of eastern Småland (i . e. the SEM).

In the type area of the "Schistosity Zone", typical structures include a foliation (the "schistosity") striking c. N-S and dipping steeply to the west and a conspicuous stretching lineation defined by quartz and feldspar plunging steeply towards WSW. The sense of net regional displacement is inconclusive, both as regard vertical and horizontal movements. The geometry of small-scale faults is not uniform and does not comply with trends and dips of foliations and mylonite zones. Ductile and brittle structures are often intimately associated and ductile structures also pass gradually into brittle ones suggesting continuous deformation during uplift.

Three generations of mafic dyke swarms of remarkably similar, specific composition indicate repeated E-W tension along the PZ at c. 1500, 1200 and 900 Ma. Syenitic and granitic rocks intruded along the zone in connection with the 1200 Ma event. The typical PZ foliation as seen in the field and described in Chapter 3 of the report probably formed during uplift of the gneiss complex of SW Sweden following deep crustal (>35 km) metamorphism of the gneisses c. 915 Ma ago. Deformation continued under more shallow and thus brittle conditions as the Vättern Basin opened from c. 850 Ma. The following deformation was essentially related to uplift and resulted in regional tilting of blocks and local faulting. The PZ was most probably affected and reactivated in connection with the large deformational events during which the Caledonian, Hercynian and Alpine mountain belts formed. These events strongly affected the southwestern margin of the shield and must have triggered movements along the PZ. Faulting occurred during deglaciation at least locally. Since such evidence requires considerable detailed and systematic mapping in order to be demonstrated, it may be much more frequent than is known so far and may be directly measurable with modern satellite techniques. Historical seismicity and the pattern of the relative uplift suggest that the PZ may be a significant zone of ongoing movement. Horizontal displacement may be significant even if vertical scarps and throws have not been detected. Future work should inter alia investigate, if east-west running lineaments within the SEM like the Nömmen-Oskarshamn fault zone are connected with the PZ, and if movements along the PZ can reactivate these zones.

ACKNOWLEDGEMENTS

The Protogine Zone has been a popular subject of discussion at our department during the last two decades, and we acknowledge many stimulating and constructive talks with our colleagues. Discussions with participants on national and international field excursions along the PZ have also increased and refined our knowledge. The systematic study of structures presented in Chapter 3 was carried out mainly by Dr. Joseph Hull. Prof. David G. Gee and Dr. Carl-Henric Wahlgren kindly read an early version of the manuscript and contributed valuable information and critizism. Mrs. Christin Andréasson made the illustrations.



B	Bölet	J	Jönköping	Ru	Lake Rusken	Vä	Västervik
F	Filipstad	K	Klevabergen	Ry	Lake Rymmen	Vå	Västanå
G	Grythyttan	L	Linderöd Horst	S	Spexeryd	Å	Åseda
H	Hålsjöberg	M	Lake Möckeln	Sk	Lake Skagern	Patterns: cf. Fig. 2	
Hy	Högsby	Mö	River Mörrumsån	St	Lake Stråken		
Ho	Hörnebo	N	Lake Nömmen	T	River Tidan		
Hö	Hökensås	O	Oskarshamn	To	Tofteryd		
I	Lake Immeln	R	Romele Horst	V	Vaggeryd		

Figure 1: Index map of geographical names

1 INTRODUCTION

The background of this report is the increasing evidence that the bedrock of eastern Småland belongs to the most stable in the country and as such is potentially suitable for a repository of Sweden´s toxic waste. The relatively stable Southeastern Megablock (SEM) is delimited to the west by the Protogine Zone (PZ), a system of defomation zones for which there is a variety of evidence for movement over the last 1000 Ma.

It is well-known that old zones of weakness in the Earth´s crust often are reactivated during younger deformational events. For instance, the ongoing transform faulting in the Red Sea reactivates Pan-African (c. 500 Ma old) faults in the Arabian Shield, as evidenced by microseimic activity along these faults. With regard to the stability of the SEM, the ideal function of the PZ would be that the regional stress is localized to the zone and released within it. Possible faults extending eastwards across the megablock could deviate and transfer movements from the PZ. Therefore, the relations between the PZ and east-west trending fracture zones of southeastern Sweden are important subjects for future investigation.

The PZ is a composite feature and this report provides a review of the various geological and geophysical characteristics of the zone (*Chapter 2*), followed by a structural study across the zone in its type area (*Chapter 3*). The published evidence of mobility along the zone is summarized in *Chapter 4*. Possible relations between the PZ and other major structures of southern Sweden are discussed in *Chapter 5*. A comprehensive bibliography of specific subjects is provided as an appendix.

2 GEOLOGY OF THE PROTOGINE ZONE (PZ)

2.1 DEFINITIONS

Geological maps of Sweden (a. o. Magnusson et al. 1958) describe the PZ as an approximately N-S trending zone of strong schistosity and *a boundary between two bedrock provinces of different age* (Fig. 2-3). To the east is the belt of 1.75-1.5 Ga old Småland-Värmland granitoids and volcanics (SVG) with remnants of Svecofennian (> 1.8 Ga) supracrustal rocks and intrusions. To the west of the zone occurs the gneiss complex of southwest Sweden (SGC) which underwent strong deformation and metamorphism mainly in Sveconorwegian time (1.25 - 0.9 Ga). The N-S trending zone of strong deformation ("Förskiffringszonen") that has also been used as a criterion to define the PZ does not coincide precisely with the lithological boundary. Mapping by the Geological Survey of Sweden to the west of Lake Vättern has demonstrated that granitoids of the SVG *can be*

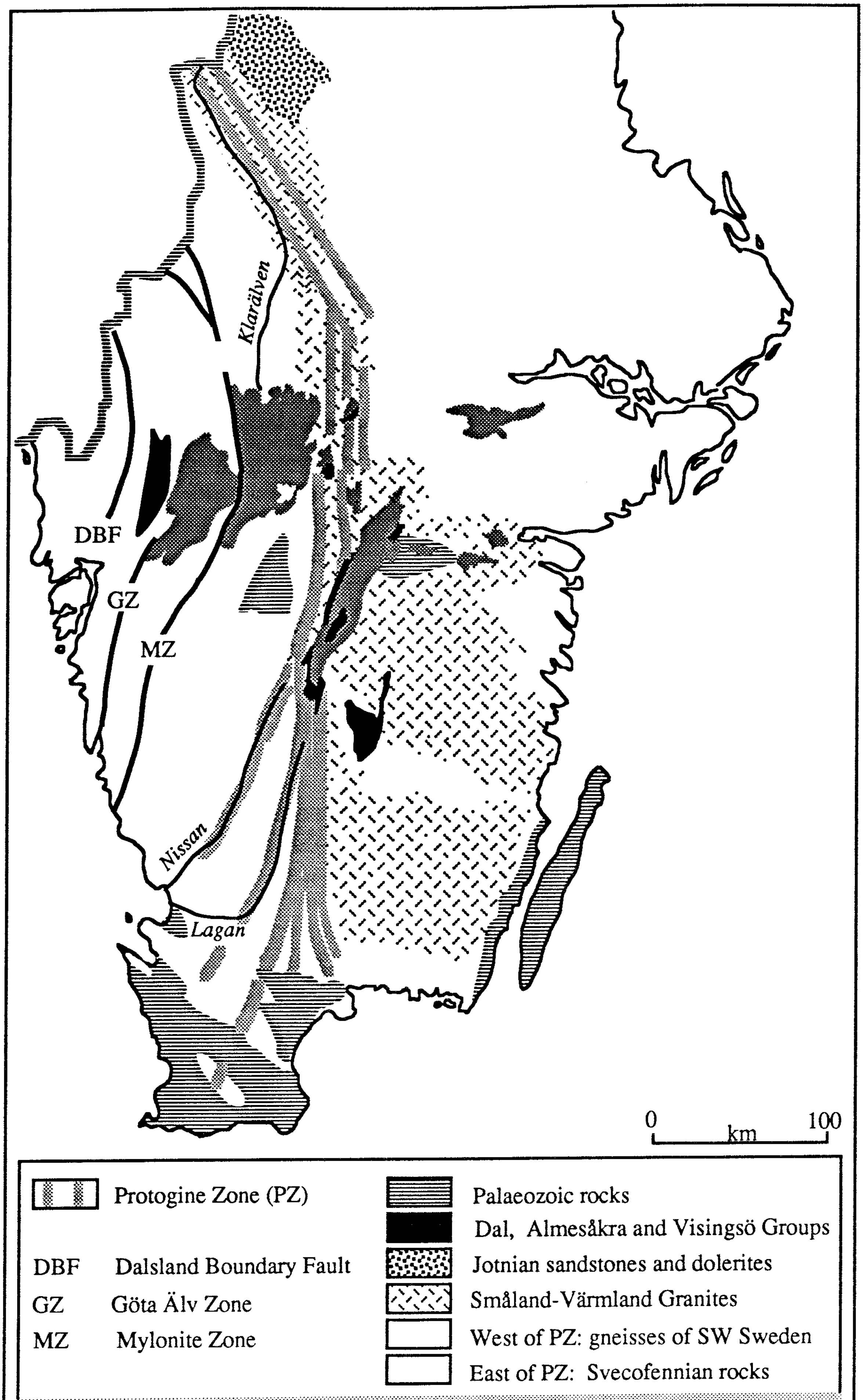


Figure 2: Major bedrock provinces

traced across the PZ (Gorbatschev 1971; Lundegårdh 1977; Larsson et al. 1986; Wahlgren and Rönnlund 1988). Andréasson and Rodhe (1990) demonstrated, that the lithological PZ and the tectonic PZ south of Lake Vättern only locally coincide in the field.

In this report, the Protogine Zone is defined as a zone of intense deformation which runs from Scania in the south northwards between Lake Vättern and Lake Vänern and along the upper reaches of the Klarälven River into Norway. The term is used in its widest sense and irrespective of age of deformation. This is done with regard to the task, and because of frequent evidence that old fractures in the crust frequently regenerate.

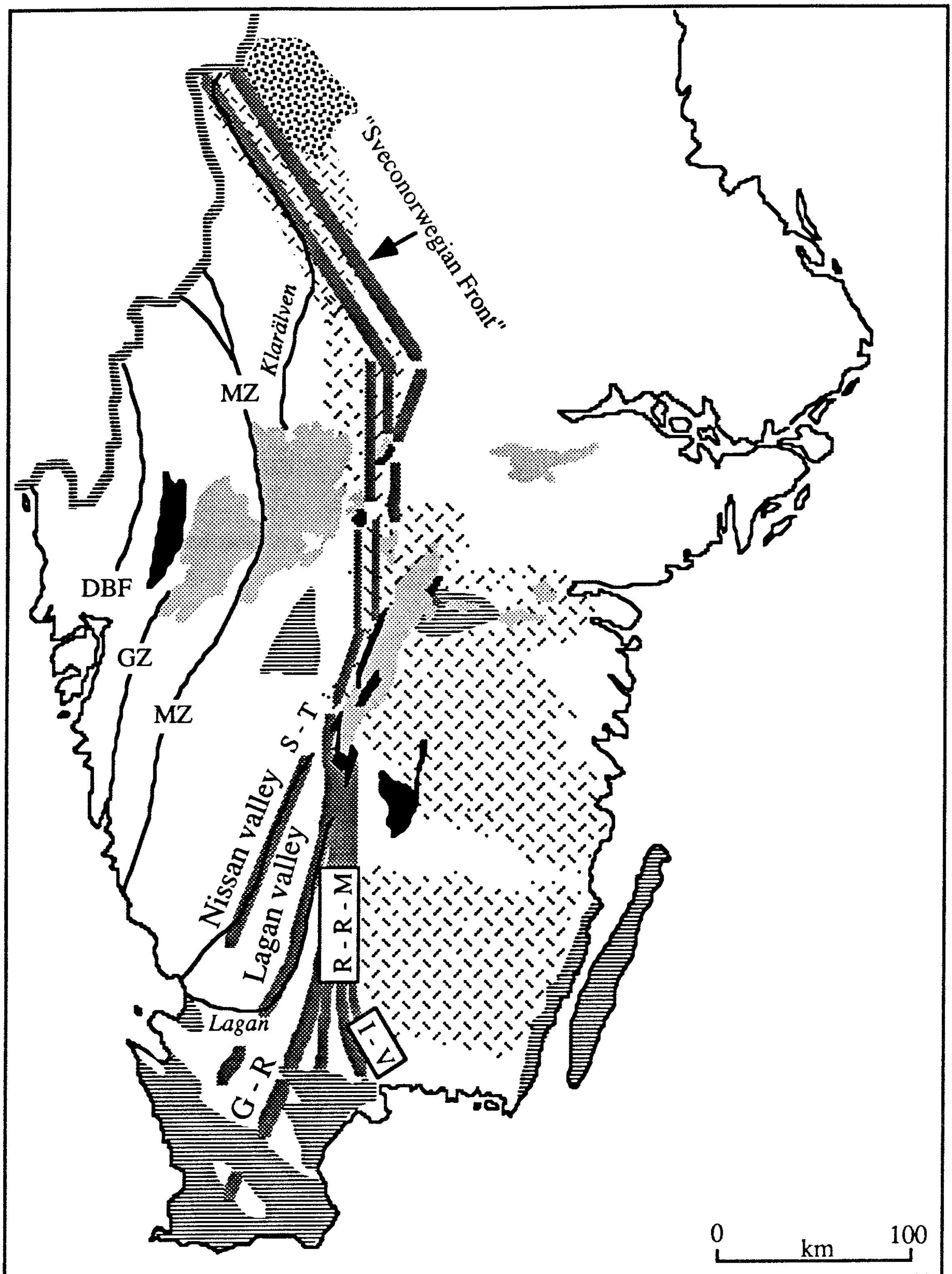
In the type area south of Lake Vättern, the zone is *a 20-30 km wide belt of anastomosing, steep shear zones striking NNW, N-S and NNE.* Each shear zone is normally less than 100 m wide; it passes laterally into undeformed granite. Similar descriptions have been given for the zone in Scania (Kornfält *in* Kornfält et al. 1978; Wikman *in* Wikman et al. 1983); west of Lake Vättern (Johansson *in* Westergård et al. 1926) and east of Lake Vänern (Wahlgren & Stephens 1990); however, in the latter area, zones are less steep. Geological and aeromagnetic patterns indicate that PZ structures extend into Bergslagen at least as far as the Grythytte Field (Fig. 1, 3; Wahlgren & Stephens 1990) .

Structures identical to those in the type area of the tectonic PZ south of Lake Vättern with regard to intensity and style of deformation and metamorphic grade can be observed along several lineaments further west like the Nissan and Lagan valleys (Fig. 3). This report suggests that these lineaments can be regarded as splays of the main PZ. Moreover, it has been known for a long time that PZ structures occur on the Romele and Linderöd Horsts in Scania, and also along Lake Immeln in eastern Scania. Thus, as defined in this report, the PZ is *a system of deformation zones* rather than a single zone.

Both ductile and brittle structures are observed along the discrete shear zones. To the former belong *foliations, lineations and their mylonitic equivalents* . The most conspicuous lineation is a steeply pitching, strong stretching lineation defined by quartz and feldspar. Brittle structures include *breccias, slickensides and slickensidelines.* Metre-wide zones of *gouge and clay* occur along several topographically marked fault scarps like, for instance, the boundary faults of the Lagan valley (Tofteryd).

While regional scale off-set of rock units is very rare, kinematic indicators abound (Andréasson and Rodhe 1990). In general they indicate *dip-slip movements*; only very locally have strike-slip movements been proved.

A systematic study of structures within the PZ type area is reported in Chapter 3.



S - T Stråken - Tidan river-lake system
R - R Rusken - Rymmen - Möckeln lake system
G - R Glimåkra - Romele branch
I - V Immeln - Västanå branch

Figure 3: The Protogine Zone and its branches

2.2 THE PZ AS A GEOLOGICAL LINE OR BOUNDARY

2.2.1 The aligned intrusions

There is a conspicuous alignment of intrusive rocks of different ages along the PZ. Mafic dyke swarms of three generations (1.5, 1.2 and 0.9 Ga; Johansson and Johansson 1990; Welin et al. 1980; Johansson 1988) run approximately parallel to the zone (Fig. 4). The dykes occupy NNW, N-S and NNE trending fractures. All three groups represent extensional crustal stress regimes (Solyom et al. 1983, 1984; Johansson and Johansson 1990; Morthorst et al. 1983). Syenitic, monzonitic and granitic rocks occur as elongated intrusions of varying size all along the PZ (Fig. 4). The largest intrusion ("Vaggeryd Syenite") is 60 km long and some 10 km as widest. The margins of the intrusions are almost always foliated by PZ deformation. Ages between c. 1120-1220 Ma have been obtained for these syenitic and granitic intrusions along the PZ (Klingspor 1976; Patchett 1978; Solyom, pers. commun. 1989 in Johansson 1991; Johansson 1991; Jarl 1990; Hansen & Lindh 1991).

2.2.2 The aligned hydrothermal mineralizations

Manganese-barium mineralizations of Red Sea type occur in brittle fractures parallel to the PZ fractures at Bölet and Spexeryd (Figs. 5, 1). They formed in breccias and brittle structures, but have locally been ductilely deformed afterwards. The Al_2SiO_5-TiO_2-rare alumina phosphate mineralizations at Hålsjöberg, Hökensås and Västanå (Figs. 5, 1) occur in metavolcanic and metasedimentary rocks and granites reworked by deformation zones parallel to the PZ (Andréasson and Stanfors 1988; Ek & Nysten 1990; Rodhe and Andréasson 1992). The importance of the mineralizations in this context lies in that they indicate regional events of extension and shearing along the PZ (Andréasson et al. 1987); moreover they demonstrate that hot water solutions circulated along PZ fractures, contributing to the ductility of the strain during deformation and probably also to the oxidation of magnetite, causing magnetic lows referred to by Henkel (in Kornfält et al. 1978).

2.2.3 The metamorphic break

The gneisses to the west of the main branch of the PZ crystallized at intermediate to high pressure while the rocks to the east of the zone are either low-P, high-T rocks or are only weakly metamorphosed to unmetamorphosed (Fig. 6). This marked break in metamorphic grade across the boundary between the two bedrock provinces in southern Sweden has been known since long but the exact location and timing of the break is still unclear.

A linked feature is the break in K-Ar ages across the zone, with ages

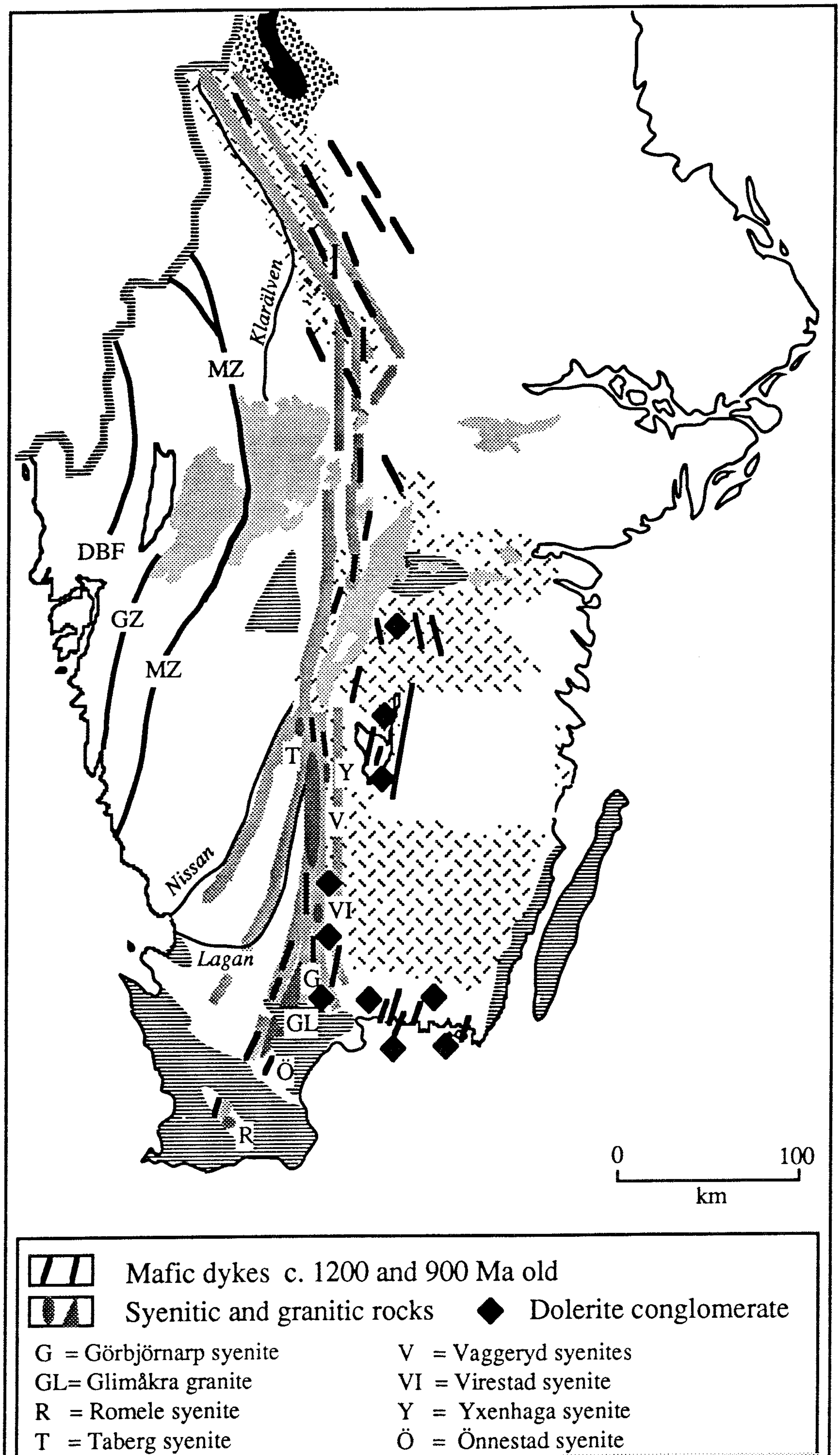


Figure 4: Intrusions along the PZ

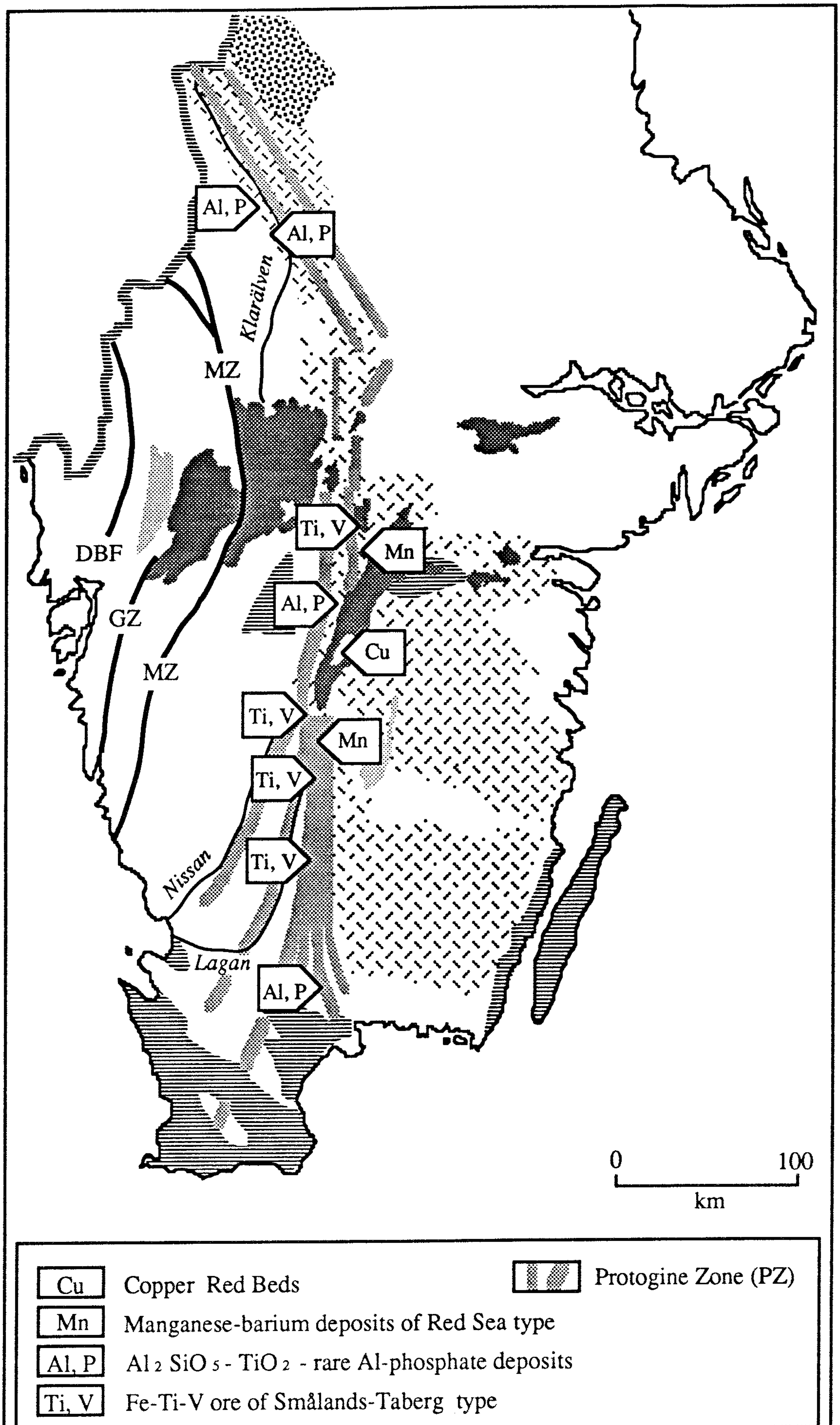
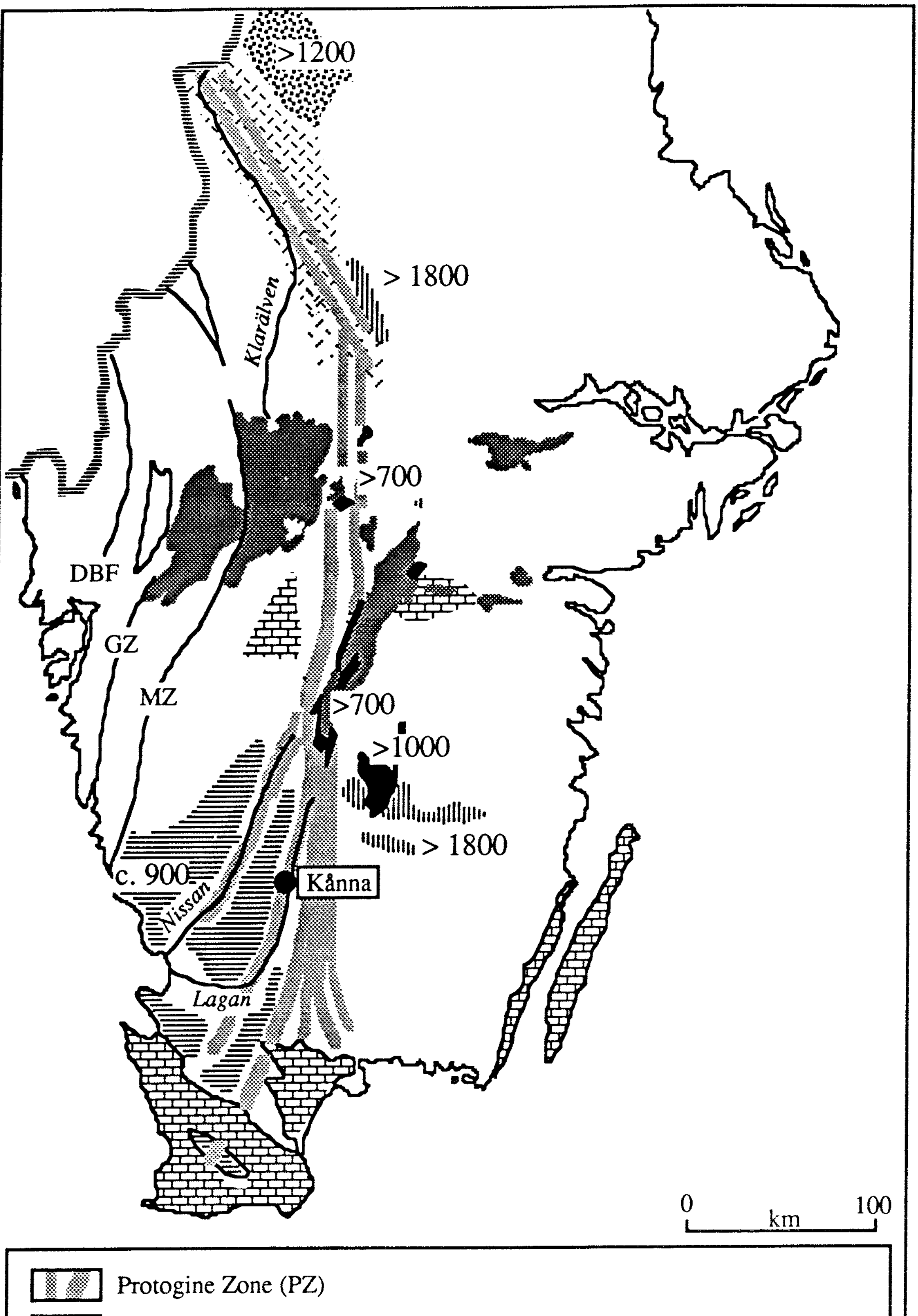


Figure 5: Mineralizations along the PZ



Protogine Zone (PZ)

Unmetamorphosed (Visingsö, Almesåkra) or very low grade (Jotnian)

Low-pressure, high-temperature (Svecofennian metasedimentary rocks)

High-pressure (Southwest Swedish Granulite Region)

c. 900 Age in Ma of metamorphism (or formation, if unmetamorphosed)

Figure 6: Metamorphism of selected units

<1000 Ma apparently restricted to the SGC. This has been taken to indicate Sveconorwegian uplift of the western block (a. o. Welin and Blomqvist 1966). Systematic Ar-Ar-dating across the zone is in progress (L-G. Jarl, Riksmuseet, Stockholm). According to Bylund (1981), the PZ may represent an eastern limit of Sveconorwegian regeneration of palaeomagnetism.

The pervasive regional foliations *within the PZ* ("protoginförskiffringen") are typically defined by mineral assemblages of epidote-amphibolite facies grade. Foliated mafic dykes may carry hornblende and garnet. The mineralized mica schists at Västanå, Hökensås and Hålsjöberg carry complex assemblages indicative of a polyphase low- to high-grade metamorphic evolution which, however, appears to be restricted to the mineralized zones.

2.3 GEOPHYSICAL ANOMALIES

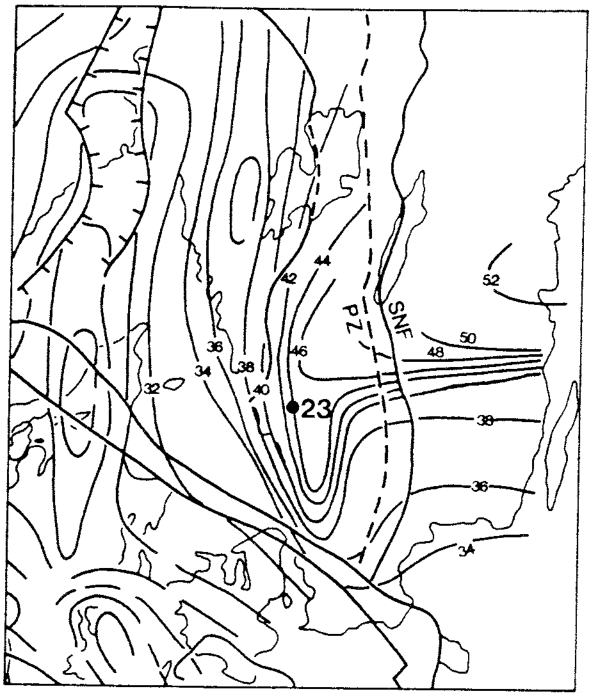
Several geophysical features run parallel to, or are bounded by, the lithological PZ. Again, there is no complete coincidence with the tectonic PZ. For instance, the tectonic PZ in Scania overlaps areas with contrasting geophysical characters (Henkel *in* Wikman et al. 1983).

2.3.1 Moho

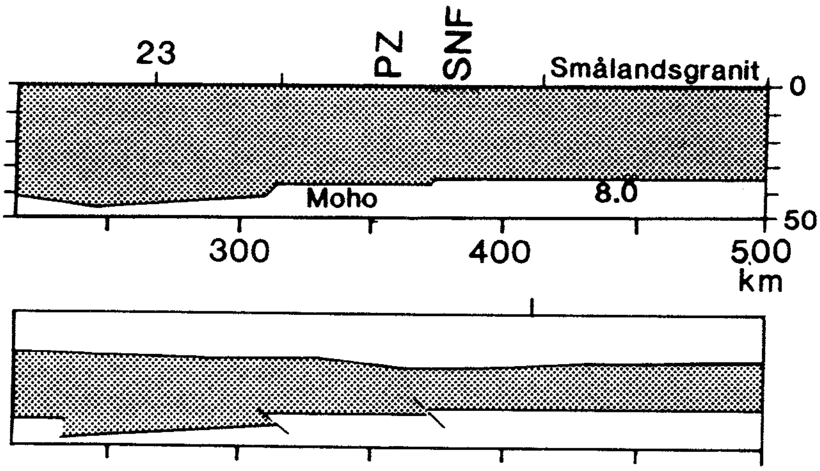
Moho *contour* maps show a marked N-S trending ridge to the west of the PZ (Fig. 7a; Thybo et al. 1989). The EUGENO-S *refraction seismic* profile between Karlskrona and Gothenburg shows two breaks in the Moho beneath Shotpoint 23 (Fig. 7b) which have been interpreted as the roots of Sveconorwegian listric thrusts. The EGT *reflexion seismic* profile across the PZ north of Lake Vättern (Dahl-Jensen et al. 1991) found shallow reflectors possibly corresponding to the changing dip of PZ foliation east of Lake Vänern (cf. 3.4). The deep reflectors which had been interpreted to represent Sveconorwegian listric thrusts could not be traced to the Earth´s surface or connected with the inferred thrust front ("Sveconorwegian Front"; Berthelsen 1988; cf. Fig. 3). The reflections terminate against a blank, vertical wall at the boundary to the Småland Granites. The authors concluded that considerable vertical movements, with westerly downthrow, must have occurred along the wall after the inferred overthrusting.

2.3.2 Bouguer anomaly patterns

These show a gravity low along the PZ (Fig. 8; Wideland 1970) which has been interpreted as an evidence of crustal thickening (Gorbatschev 1980; Thybo et al. 1989) or the opposite (Mörner 1977). Stephansson (1978) emphasized the importance of the trench and also the break in anomaly patterns along the zone as an expression of "a major, deep-seated structure".



7a



7b

7a: Moho contours of southern Sweden
From Thybo et al. (1989).
7b: Jumps in the Moho beneath Shotpoint 23 (location: cf. Fig. 7a).
From EUGENO-S Working Group (1988).

PZ = Protogine Zone
SNF = Sveconorwegian Front

Figure 7: Moho contours and relief

Evidence from rift zones indicates that gravity lows may be due to intrusions of low-density rocks along the rift. Of potential interest in this context is that the zone has been described as a continuation of the Oberrhein-Altmark zone of high heat flow (Hurtig and Schlosser 1973 referred to in Mörner 1977).

2.3.3 Aeromagnetic patterns

Aeromagnetic anomalies show bands and linear strips of low magnetic anomalies caused by steeply dipping oxidation zones (Henkel *in* Kornfält and Bergström 1983). Some mafic dykes and syenite bodies have negative inclination remanent magnetization. In Värmland, the PZ separates blocks with distinctly different local aeromagnetic patterns (Henkel and Eriksson 1987). These authors also inferred <100 km long sinistral displacement of the aeromagnetic patterns of the Småland-Värmland Granites along the northern PZ (Filipstad-Västervik zone; cf. Chapter 5).

2.3.4 Palaeomagnetism.

Palaeopoles obtained from mafic dykes along the zone all fall in the Sveconorwegian loop which is a segment of the Fennoscandian apparent polar wandering path between 200-250° E and 50° S - 20° N (Bylund 1981; Patchett and Bylund 1977; Stearn and Piper 1984). The size of the loop suggests rapid apparent polar wandering and plate movements within a short time period (200 Ma).

2.3.5 Seismicity

Stephansson (1978) pointed at the "casual connection between the geological structures and the earthquake occurrence". The main branch of the PZ is located to the east and away from the zone of high seismicity of southern Sweden; however, the Nissan-Stråken-Tidan branch defines the eastern boundary of the Halland-Vänern-Gävle-Gulf of Bothnia-Tornedalen seismic zone (Fig. 9; Båth 1978, 1983; Slunga 1981, 1982; Wahlström 1988). According to Noponen (1977), the PZ coincides with a line separating positive and negative values of the relative residual of teleseismic P-waves.

2.4 THE ZONE AS A MORPHOTECTONIC FEATURE

2.4.1 The aligned palaeo-depressions

The so called "dolerite conglomerates" e. g. dolerites containing numerous pebbles-boulders of quartzite, porphyry and granite are associated with the 900 Ma dyke generation (above) testify to very shallow crustal levels of some outcrops along the PZ at the time of intrusion of the dykes *and ever since*. The "conglomerates" occur from the coast of Blekinge in the south to

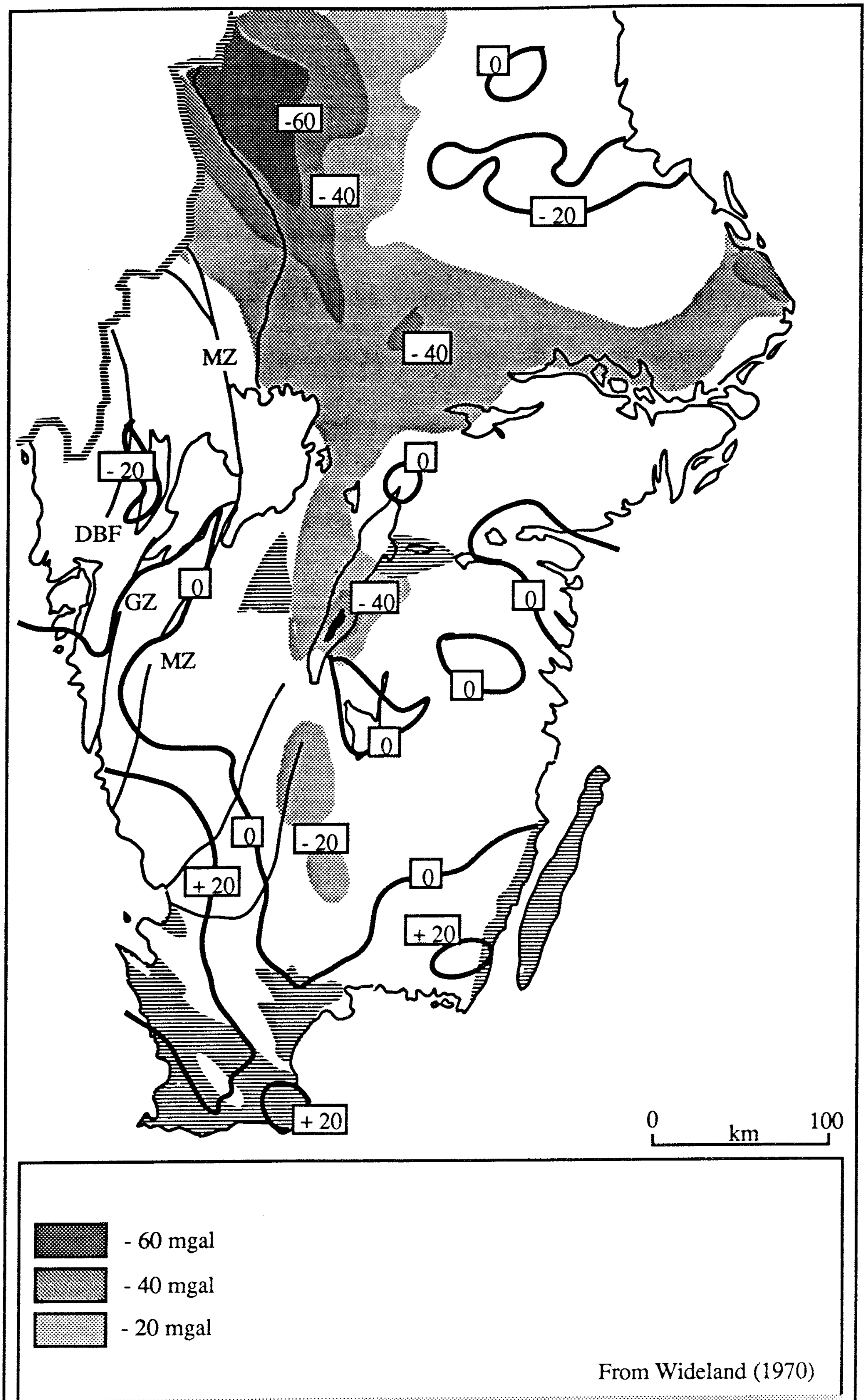


Figure 8: Bouger anomaly patterns in southern Sweden

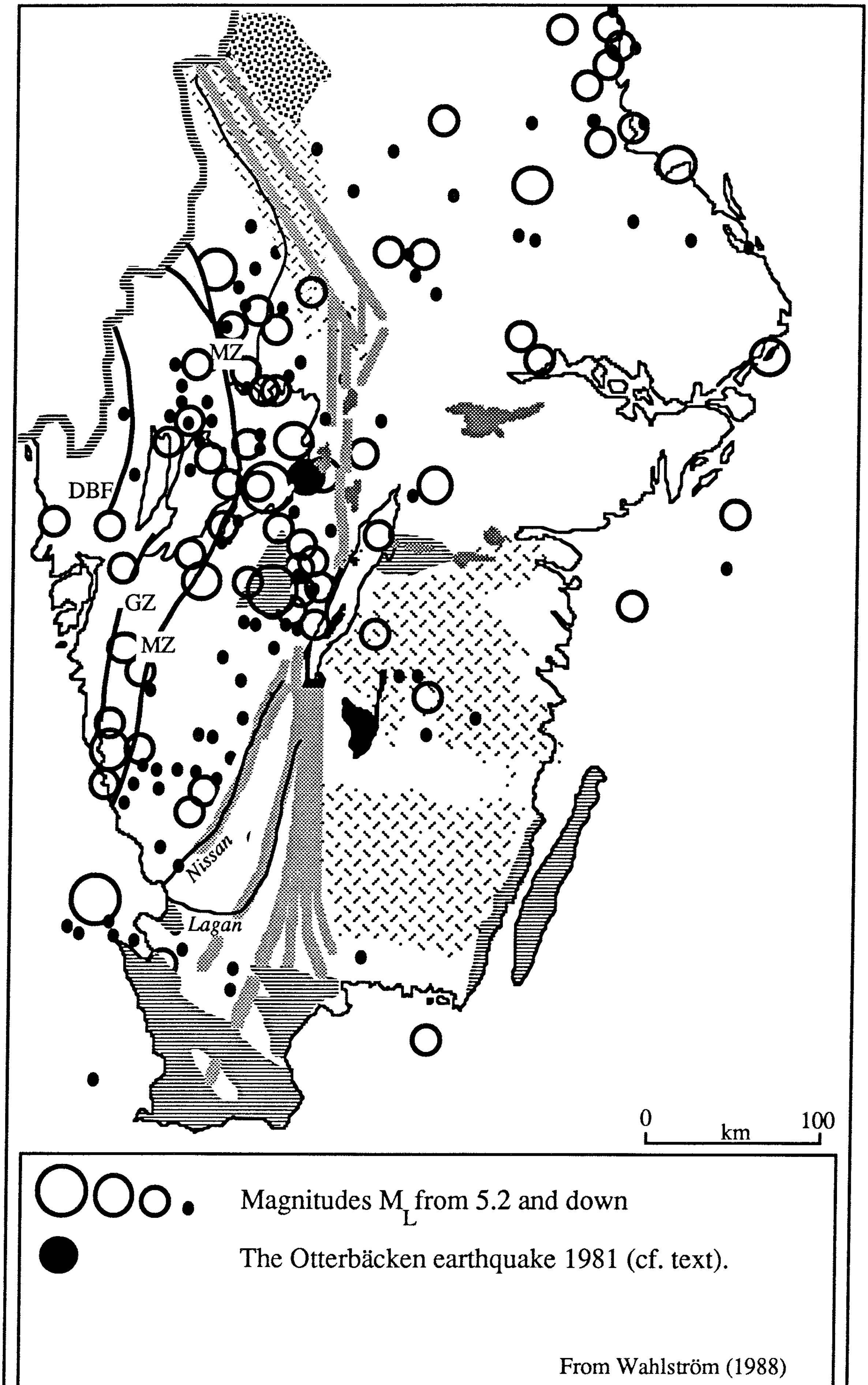
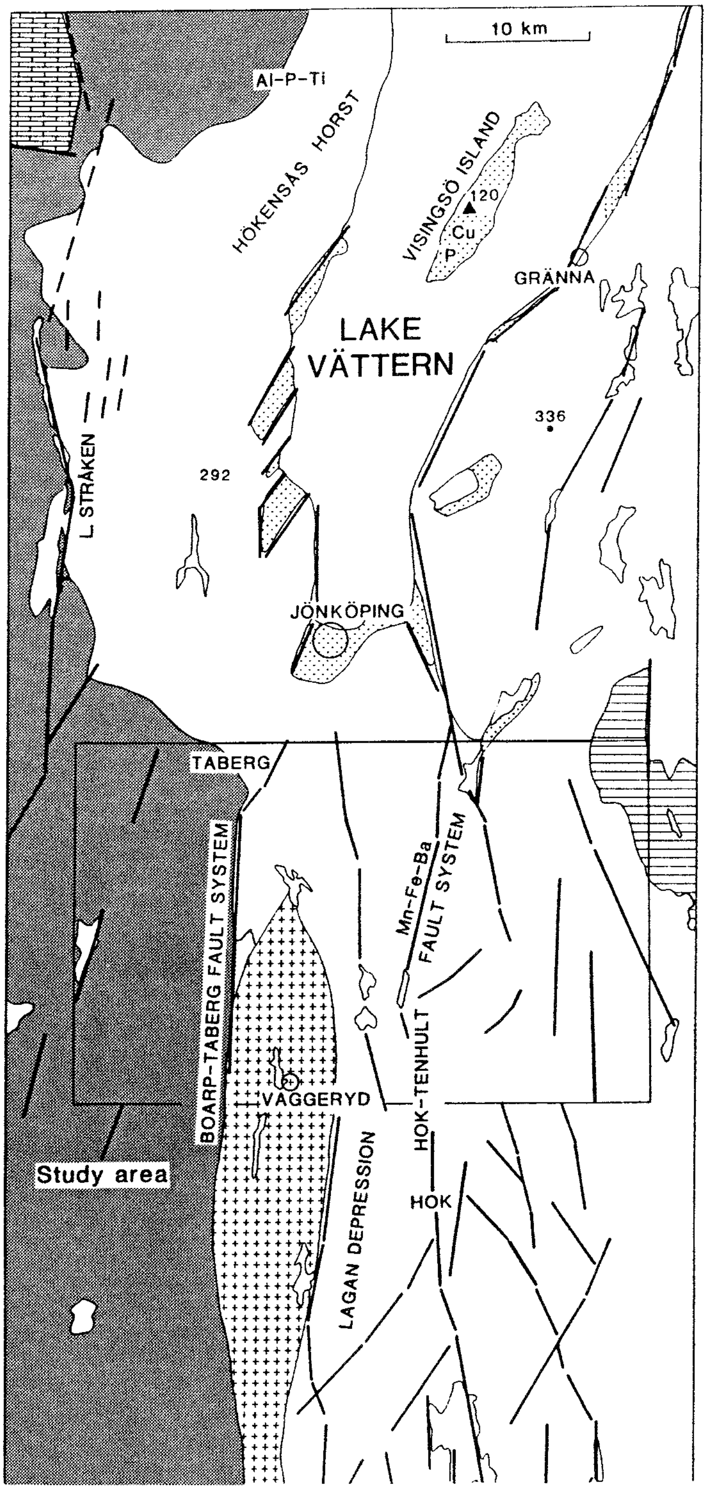
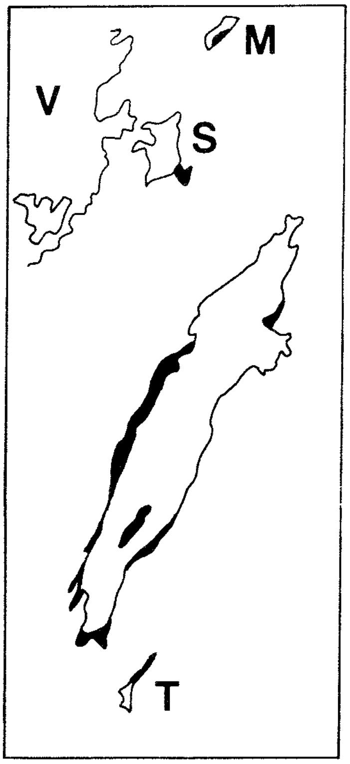


Figure 9: Seismicity of southern Sweden 1963-1985





Visingsö Group

V Lake Vänern
S Lake Skagern
M Lake Möckeln
T Lake Tenhultasjön

PZ deformation zones and faults of Lake Vättern
Palaeozoic
Occurrences of the Visingsö Group
Almesåkra Group
Vaggeryd syenites
Gneisses of SW Sweden
Mn-Fe-Ba; Cu, P: Mineralizations

Figure 10: Visingsö Group. Fault pattern south of Lake Vättern

Lake Vättern in the north (Fig. 4).

Rafts of sandstone occur within the PZ at Klevabergen (N Vaggeryd; Jansson 1988). Sedimentary rocks of the Visingsö Group occur from Lake Tenhultasjön in the south to Lakes Skagern and Möckeln (135 and 165 km N Jönköping; Fig. 10) in the north, suggesting 185 km of fault-bounded preservation of the group along the PZ.

2.4.2 Ongoing subsidence

Lake Vänern represents a considerable (300x150 km) depression. Based on interpretations of aeromagnetic, seismicity and land rise data, Henkel and Eriksson (1991) suggested that ongoing dextral strike-slip along the PZ and the Tornquist Tectonic Zone (5.4) causes a tectonic mega-lens ("Vänern deformation lens") to subside. The strike-slip is related to ongoing transform faulting in the North Sea.

A similar kinematic interpretation of Lake Vänern though with opposite sense of strike-slip was made by Talbot and Slunga (1989); cf. section 5.2.

2.4.3 The break in regional rock block patterns along the PZ

Using a. o. digital terrain modelling Tirén and Beckholmen (1989, 1990) were able to demonstrate an interesting difference between block patterns of southwestern and southeastern Sweden. The boundary between the domains runs approximately along the PZ (c. 10 km east of the lithological boundary). While blocks in the west are more lensoidal, those in the east are more orthogonal. The authors concluded that the patterns reflect penetrative shear in the west, "while southeastern Sweden appears less distorted".

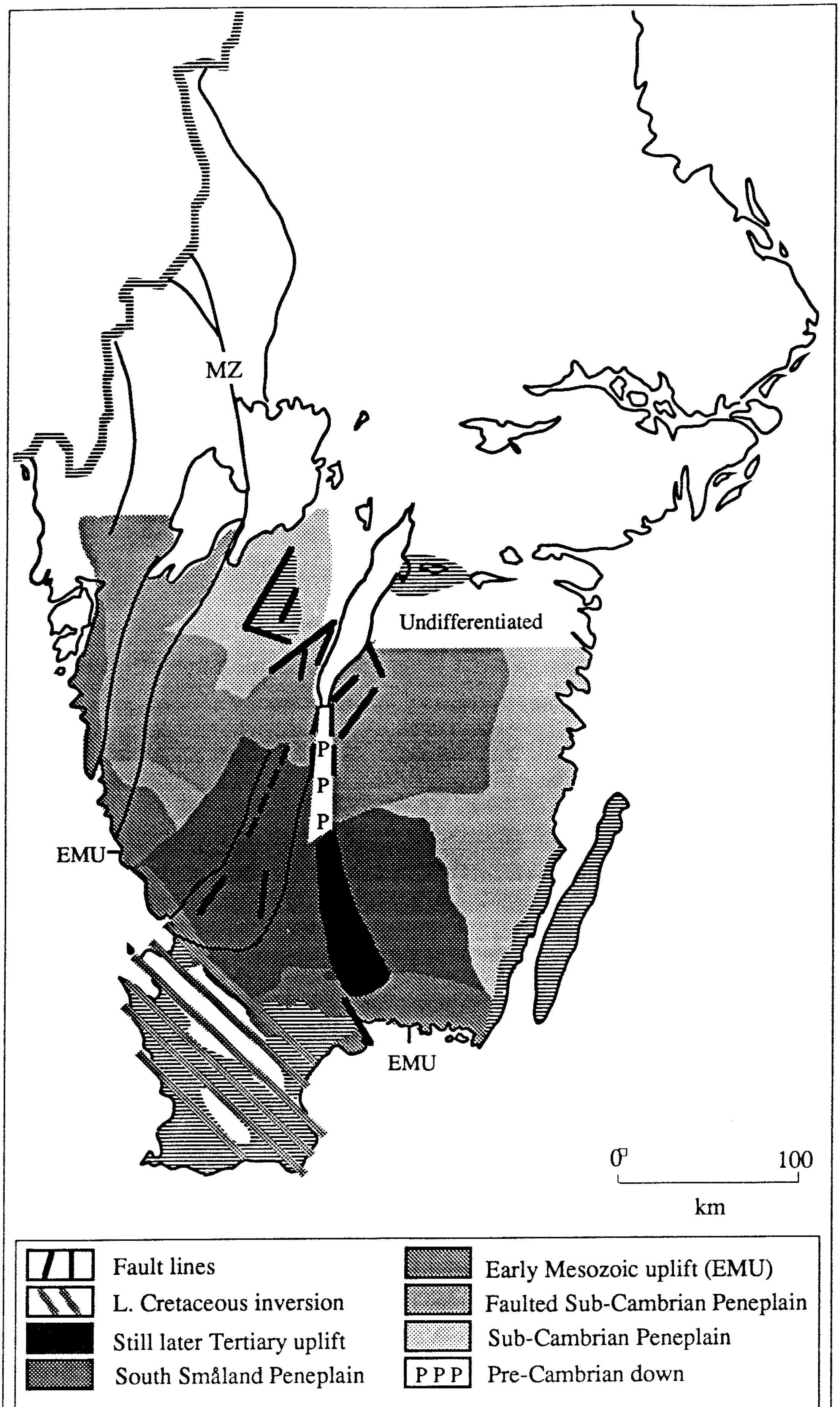
2.4.4 Tilted and broken peneplains

Denudation surfaces are sensitive indicators of regional scale movements and faulting (Lidmar-Bergström 1988; 1991; Lidmar-Bergström et al. 1991). The PZ crosses several such surfaces (Fig. 11), from north to south: the sub-Cambrian Peneplain including "the 200 m level", the South Småland Peneplain (SSP) and the sub-Cretaceous and sub-Jurassic etch-surfaces (Lidmar-Bergström 1988).

Movements along Lake Vättern and other NNE-SSW trending lineaments have broken the sub-Cambrian peneplain into a northwestern and an southeastern part. However, studies of the sub-Cambrian Peneplain in the SEM (Lidmar-Bergström 1991; her Fig. 3) provide no evidence of significant vertical displacement.

2.4.5 Features of the PZ landscape

Many topographically marked linear features of southern Sweden follow deformation zones with typical PZ foliations and structures. Such features



From Lidmar-Bergström (1988, 1991) and Ahlin (1987; faults W Lake Vättern)

Fig. 11. Morphotectonics

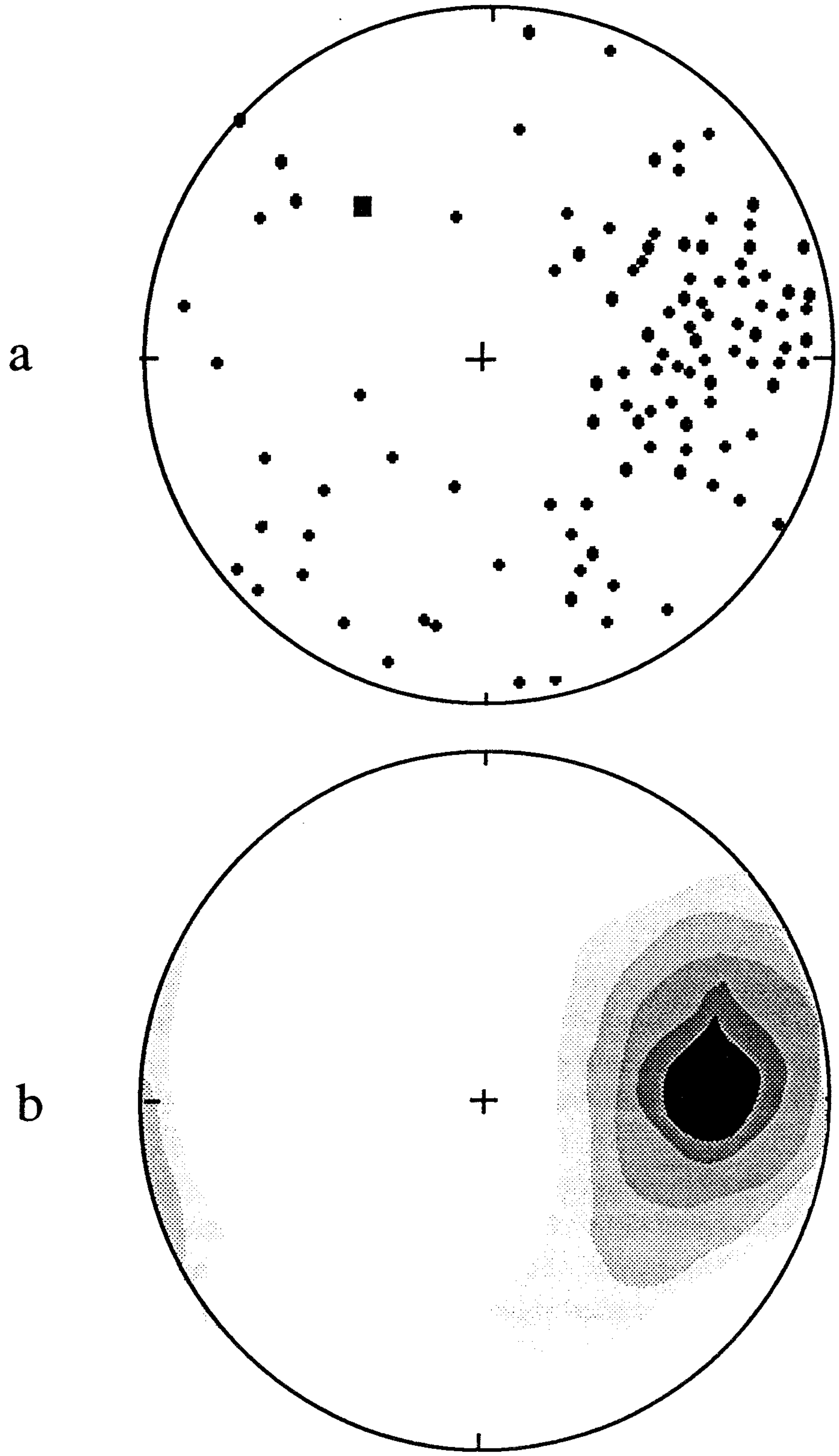
include long river valleys (Klarälven, Lagan), horst-graben (Hökensås-Vättern) and lake-river systems (Tidan-Stråken-Nissan; Rusken-Rymmen-Möckeln). Clearly, erosion has been greatest in the deformation zones.

Also on a more local scale, the trends of individual valleys in valley systems, like the NNW, N-S and NNE trends of valleys in the Hokadalen-Tenhult system, coincide closely with trends of PZ foliations (Andréasson and Rodhe 1990). The valleys are often bounded by distinct steep fault scarps. For instance, the western wall of the Lagan valley is at Skillingaryd a marked scarp in foliated syenite; the eastern wall is at Tofteryd (Fig. 1) a several metres wide zone of foliated and crushed rock, and gouge. It is seldom possible to demonstrate or deny the existence of recent movement along these zones but more work should be done to clarify this.

3 PZ STRUCTURES IN THE "SCHISTOSITY ZONE" TYPE AREA

The type area of the "Schistosity Zone" (Swedish: "Förskiffringszonen") as shown on the Geological Map of Sweden (Magnusson et al. 1958; 1960) was chosen as the area for systematic study (Fig. 10). It is an area of excellent exposure, with a bedrock predominantly of Småland Granite intruded by mafic dykes. Both these rock types were undeformed prior to development of the PZ structures as defined in this report and described below. The progressive development of the PZ deformation from massive granite to phyllonitic schist and eventually mylonite can be observed in many places in the study area (Andréasson et al. 1990). Therefore, both intensity and style of deformation vary considerably over short distances. There is often a complete gradation from massive rocks via tectonites with discernible fabrics to mylonites. Ductile and brittle deformation is often intimately associated along one and the same zone of deformation, and ductile fabrics may pass gradually into brittle fabrics (Andréasson and Rodhe 1990).

This chapter first describes *tectonites of moderate strain* i. e. rocks where foliations and lineations of tectonic and metamorphic origin are still discernable. *Tectonites of high strain,* i. e. rocks with mylonitic fabrics, are then treated. Finally, characteristic *faults* are described. While the relations and geometries described in this chapter are probably characteristic for the whole length of the PZ, the values of strikes and dips are, of course, valid for the study area only.



N = 107
Count area = .078
Contour interval = 1.5
■ fanning axis

Eigenvectors in *Fig. 12a:*			
plunge	31°	28°	46°
towards	88°	196°	320°
value	10.0	3.9	2.2

Figure 12: Stereographic projections of foliation of tectonites of moderate strain

3.1 TECTONITES OF MODERATE STRAIN

3.1.1 Fabric description

Fabrics of tectonic and/or metamorphic origin are defined by 1) the preferred orientation of platy or elongate minerals (*mineral fabric*) or 2) by oblong minerals or mineral aggregates formed during recrystallizaton or destructive deformation (*shape fabric*). 3) *Gneissosity* , formed by reorientation of primary inhomogeneities, is less important, since most rocks in the study area were homogeneous prior to deformation. With regard to style, most tectonites contain both a foliaton and a lineation (*LS-tectonites*).

3.1.2 Fabric geometry

Fig. 12 shows a stereographic plot of poles of *foliations*. The point maximum corresponds to a foliation striking N-S and dipping ≈ 60° to the west. The maximum is rather broad, confirming frequent field observations that the PZ foliation anastomoses in both horizontal and vertical directions. The weak girdle defined by the Z-axes indicates that there is a fanning of the foliation about an axis plunging ≈ 50° towards 320°. In order to find out if the fanning is real or represents two subsets of foliations, the poles were arbritarily edited and the eigenvectors were recalculated. As evident from Fig. 13, the girdle is still there and the eigenvalues are the same, suggesting that the fanning of foliation is real.

Fig. 14 shows a well defined point maximum for *lineations* (mineral and stretching lineations). The eigenvector plunges 64° towards 264°.

3.2 TECTONITES OF HIGH STRAIN

3.2.1 Fabric description

Planar elements include deformation zone boundaries, mylonitic foliation (S-fabric), C-fabric, and an extension crenulation cleavage (C´-fabric), cf. Fig. 20. S-fabrics are usually defined by quartz blades and mica, C-fabrics vary from cleavages to tight and thin, distinct bands of ultramylonitic character.

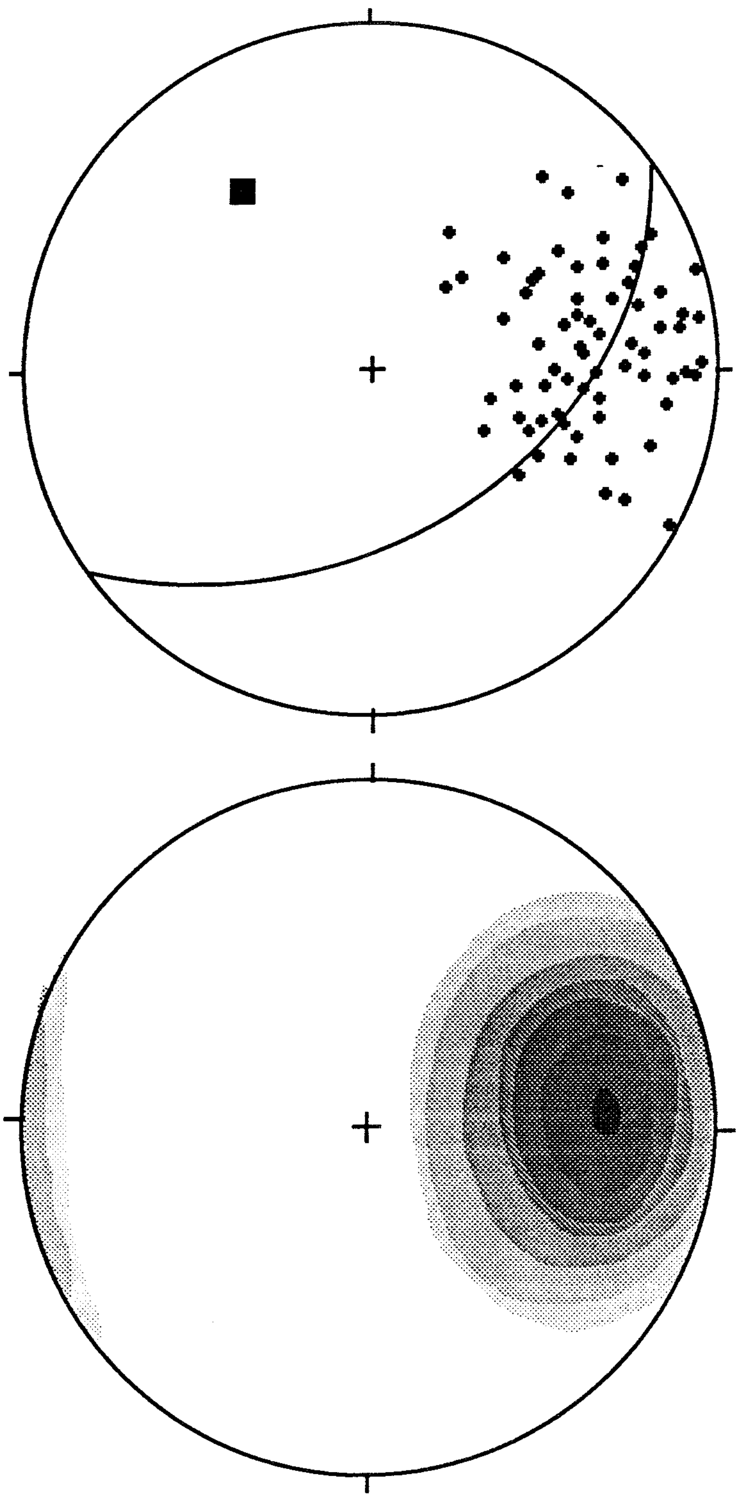
Linear elements include a conspicuous strong *stretching lineation* defined by feldspar and quartz pencils. It formed prior to CS-fabrics (Andréasson and Rodhe 1990; their Fig. 6).

3.2.2 Fabric geometry

Poles to deformation zone boundaries and mylonitic foliations show a well defined but girdled maximum (Fig. 15), indicating that the foliations fan about an axis plunging ≈ 60° towards 264°. The maximum corresponds to a strike ≈N-S and dip 60-70° towards the west.

a

b



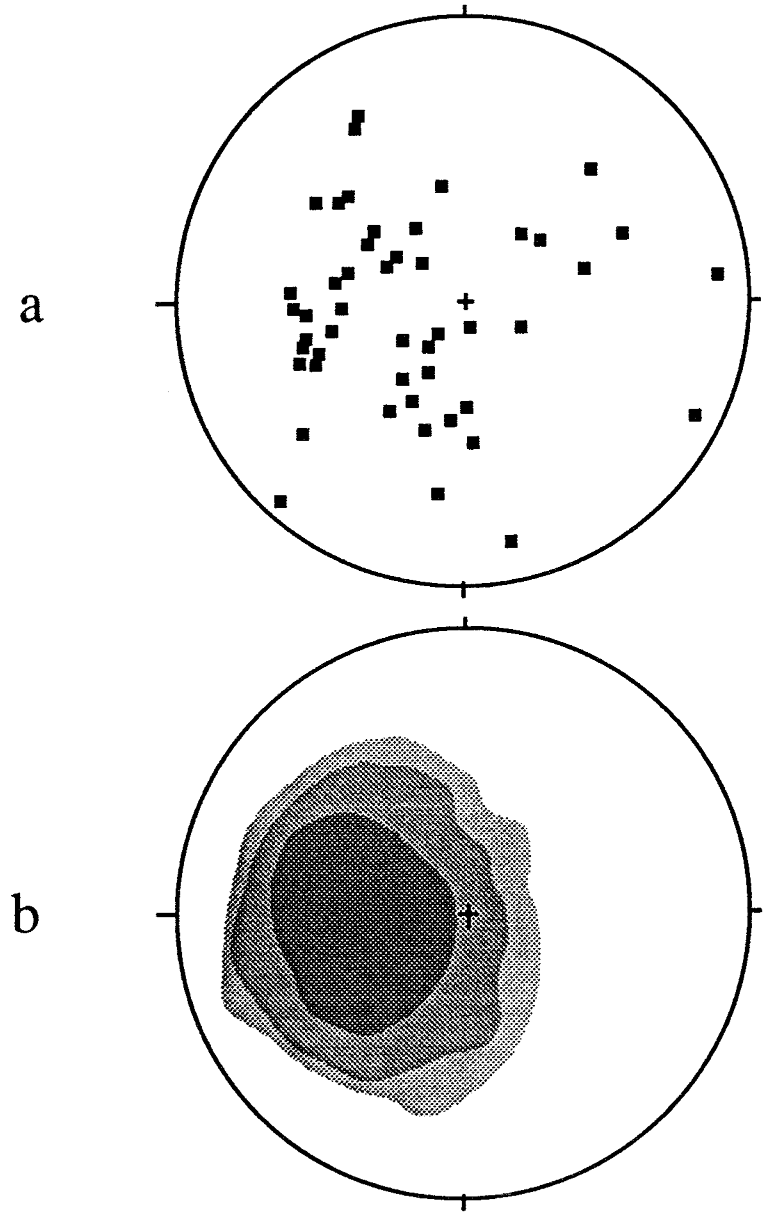
Count area = .114
Contour interval = 1.5

■ Axis of fanning

Eigenvectors in Fig. 13a:

plunge	33°	35°	38°
towards	84°	196°	324°
value	10.0	0.98	0.91

Figure 13: Foliation of tectonites of moderate strain; recalculated

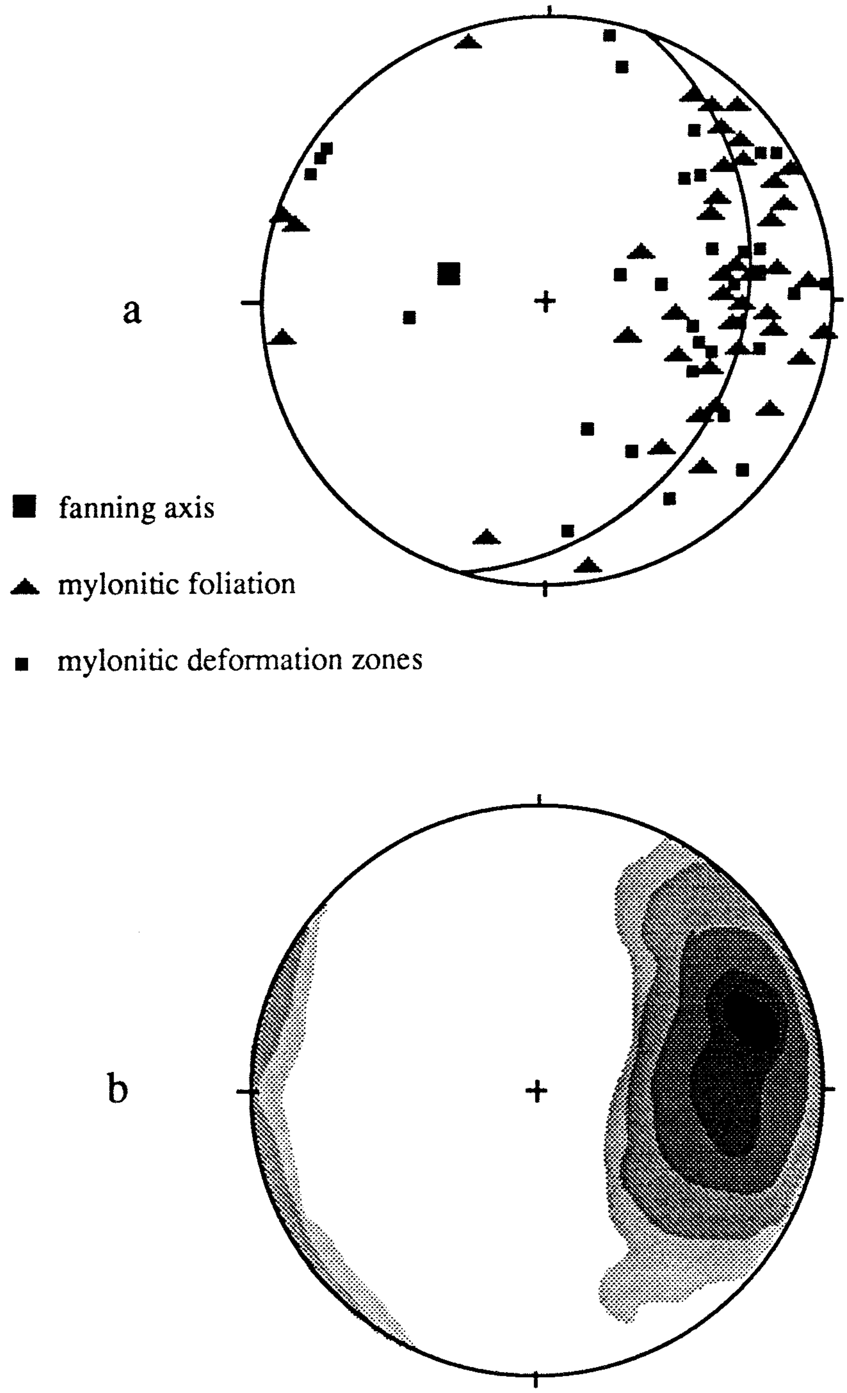


N = 53
Count area = .145
Contour interval = 1.5
■ mineral lineation

Eigenvectors in Fig. 14a:

plunge	64°	24°	9°
towards	264°	106°	12°
value	10.0	2.33	2.32

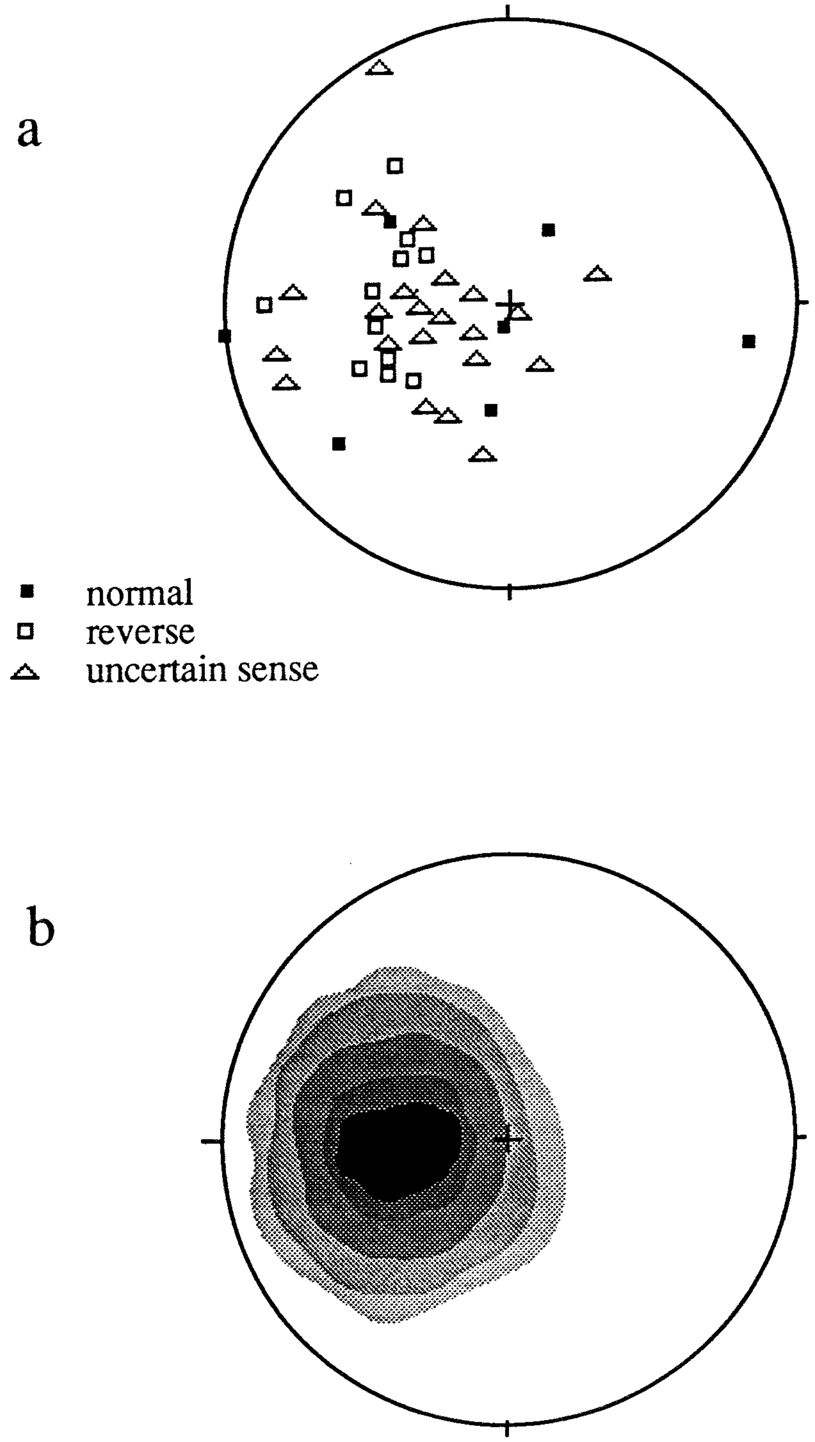
Figure 14: Stereographic projections of *lineations* of tectonites of moderate strain



N = 79
Count area = .102
Contour interval = 1.5

Eigenvectors in Fig. 15a:			
plunge	28°	8°	61°
towards	86°	181°	286°
value	10.0	3.42	1.31

Figure 15: Stereographic projections of mylonitic foliation and deformation zones

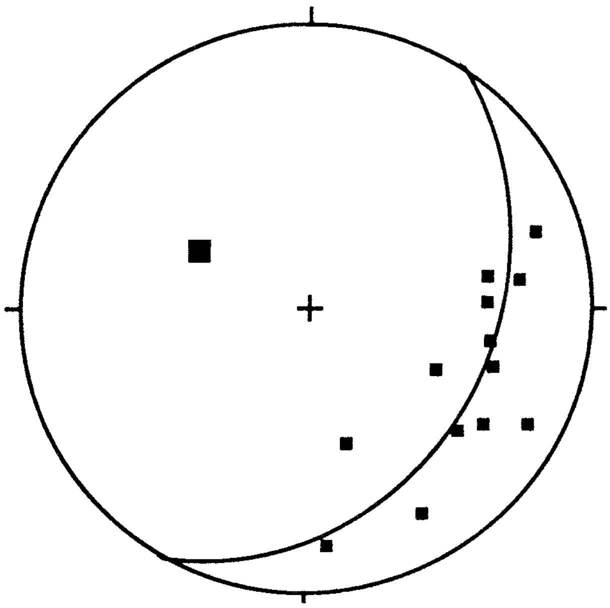


N = 50
Count area = .153
Contour interval = 1.5

Eigenvectors in Fig. 16a:

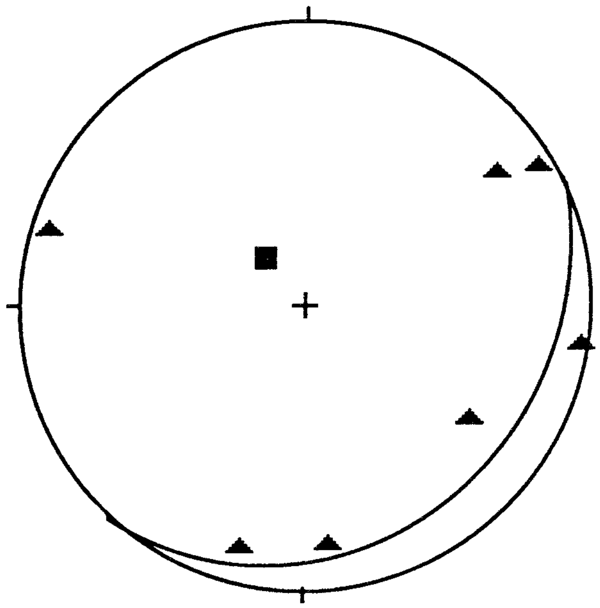
plunge	57°	31°	8°
towards	266°	104°	9°
value	10.0	1.84	1.26

Figure 16: Stereographic projection of mylonitic lineation



a

N = 13



b

N = 7

Eigenvectors in Fig. 17a:

plunge	35°	3°	55°
towards	111°	203°	298°
value	10.0	2.23	0.40

Eigenvectors in Fig. 17b:

plunge	9°	15°	72°
towards	81°	173°	320°
value	10.0	7.12	0.74

Figure 17: Stereographic projections of normal (b) and reverse (a) movement planes

Mylonitic lineations give a well defined point maximum corresponding to an eigenlineation plunging 57° towards 266° (Fig. 16).

3.2.3 Sense of movement

Kinematic indicators include a. o. C-S fabrics, broken and displaced feldspars, feldspars with asymmetric tails and σ-type rotated feldspars and garnets. Of twenty outcrops investigated, 13 give reverse and 7 normal sense of movement; the latter being much more scattered than the former (Fig. 17). Based on reconnaissance work across the PZ, Andréasson and Rodhe (1990; their Table 1) concluded that normal movements dominated.

Marker lines or horizons for determination of *offset directions* of mega-scale movements are not found within the study area. To the west of the study area (Bratteborg), en echelon structures of a mafic dyke indicate dextral strike slip along the PZ (Rodhe, unpublished results).

3.3 FAULTS

3.3.1 Regional scale faults

Major faults of this study area belong to the Hok-Tenhult fault system defined by steep, normal faults with NNW, N-S, NNE and NE trends. This system is the southward extension of the eastern wall of the Vättern basin (Fig. 10). As mentioned above, the faults coincide with ductile deformation zones. Fault breccias frequently carry clasts of foliated or mylonitic granite. No systematic study of regional scale faults within the study area was undertaken.

3.3.2 Slickensides

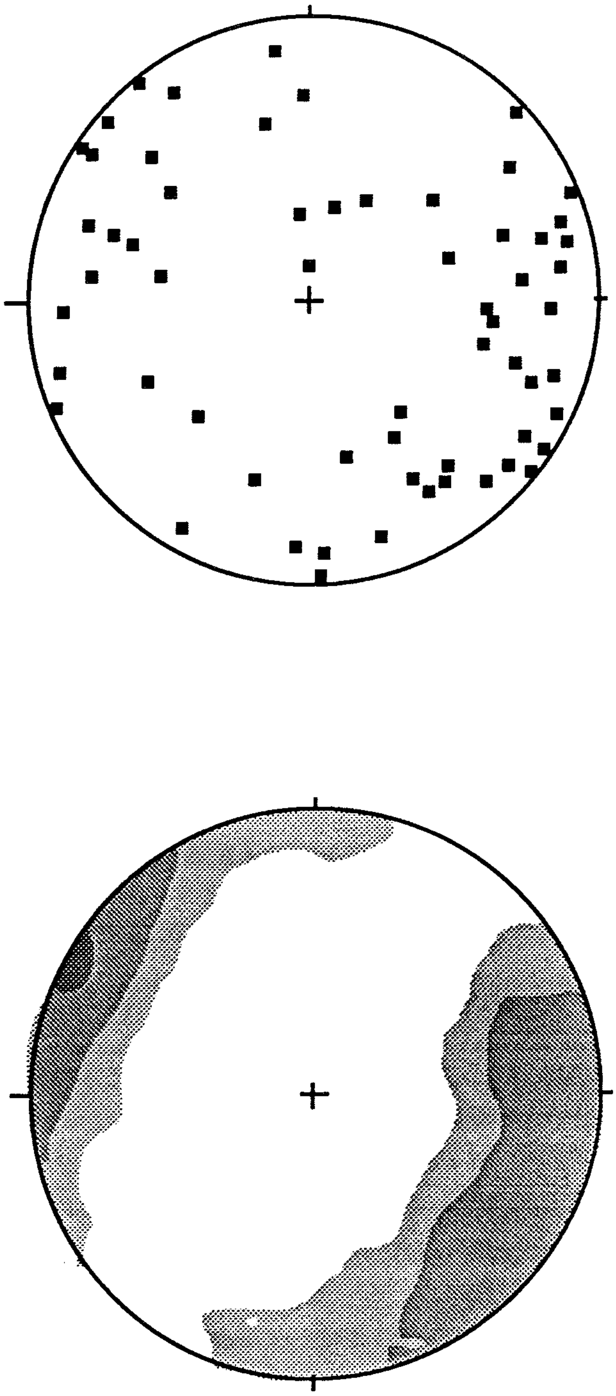
Red and black staining by Fe- and Mn-oxides characterize slickensides of one population of faults in the study area and along Lake Vättern. This population was selected for a systematic study of geometry. Slickenlines are defined by linear corrugations.

As evident from Fig. 18, poles to slickensides scatter considerably. A weak maximum corresponds to a strike 027° and dip ≈ 80° towards W. The slickensides fan about an axis plunging 80° towards 260°. Slickenlines (Fig. 19) define a girdle indicating a variation of displacement from dip slip to strike slip. However, two weak point maxima demonstrate a dominating oblique slip along the faults, plunging 51° towards 219° and 39° towards 39° respectively.

Fig. 19a also shows with different symbols the sense of dip slip, where it could be determined from markings on the slickensides; the distribution between normal and reverse sense of displacement is about fifty-fifty.

a

b

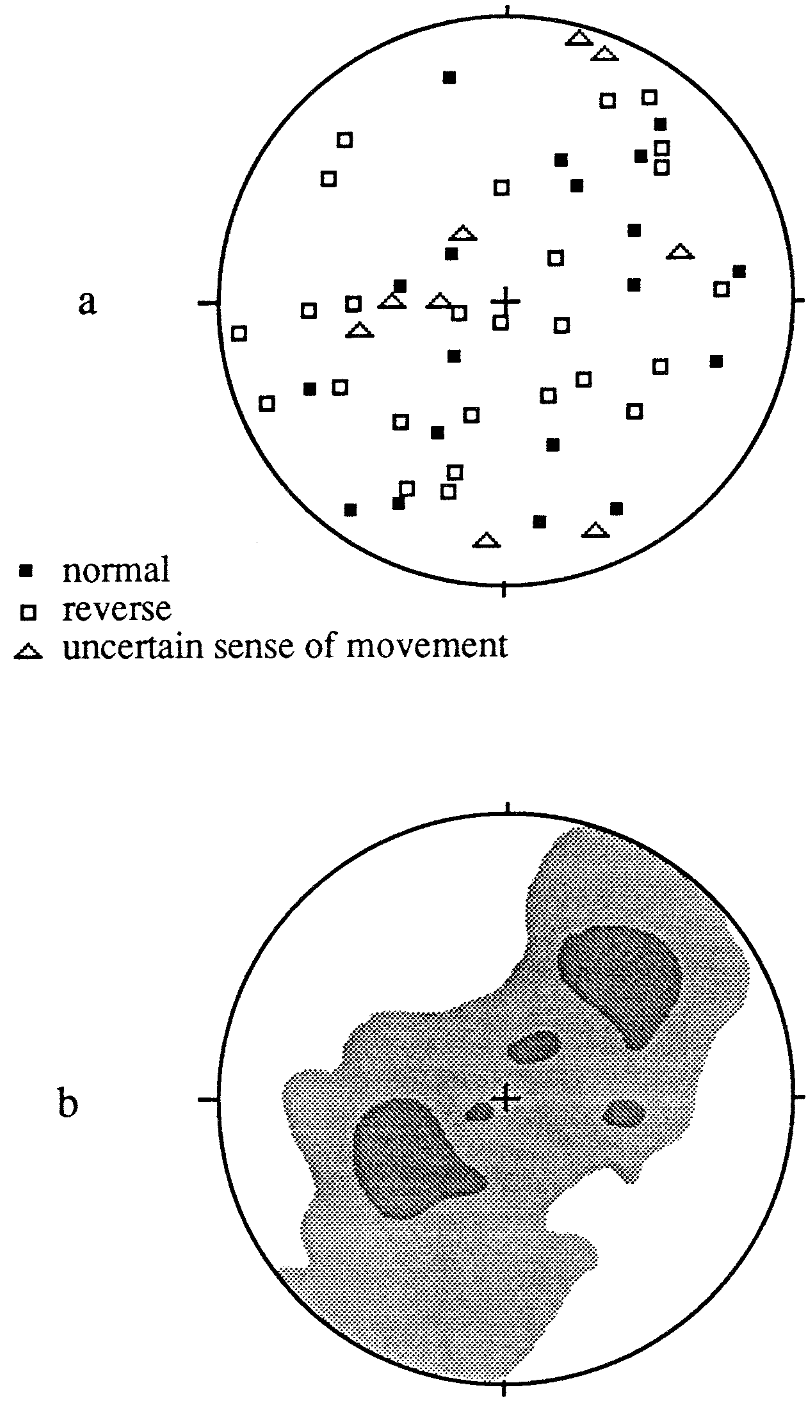


N = 70
Count area = .114
Contour interval = 1.5

Eigenvectors in Fig. 18a:

plunge	8°	7°	79°
towards	117°	26°	256°
value	10.0	5.6	3.3

Figure 18: Stereographic projections of slickensides of small-scale faults

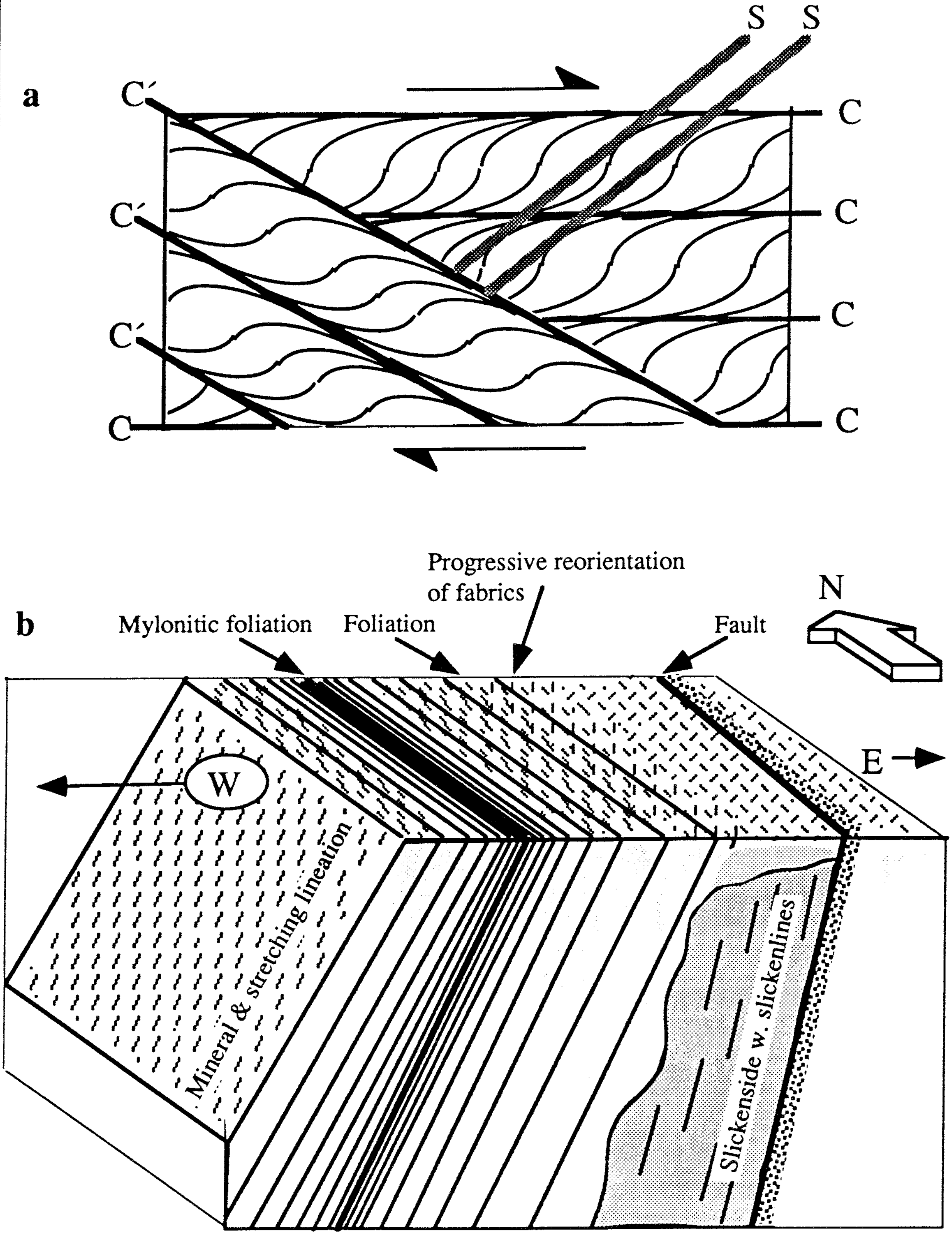


N = 56
Count area = .138
Contour interval = 1.5

Eigenvectors in Fig. 19a:

plunge	77°	12°	6°
towards	195°	41°	310°
value	10.0	8.6	4.9

Figure 19: Stereographic projections of slickenlines of small-scale faults



a : Definition of s-, c- and c′-fabrics, and their relations to sense of movement

b : Block diagram showing the various fabrics presented in the stereographic projections of Figs. 12-19.

Figure 20: Summary of structures in the PZ type area

3.4 SUMMARY OF STRUCTURES IN THE TYPE AREA

Fig. 20 summarizes the various structures in the type area of the PZ south of Lake Vättern. The fabric of moderate strain tectonites is very uniform within the study area. Foliations strike N-S and dip moderately-steeply to the west. Lineations pitch steeply down the dip of foliations. Mylonitic foliations and zones strike NNE and dip towards the west. Lineations plunge as moderate strain lineations. Sense of movement along the mylonite zones is both normal and reverse. Moderate and high strain tectonites and regional scale faults largely coincide, confirming other evidences of a continuous development, or regeneration. There is on the other hand no (and need not be any) coincidence between these tectonic elements and the investigated population of small-scale faults. The implication of the varying geometry and shear sense of hematite-stained slickensides is poorly understood on the basis of data recorded in this study and more work is needed. The detailed study of foliation poles confirms the overall anastomosing pattern of PZ deformation zones on local (Andréasson and Rodhe 1990) and regional scales (Fig. 10).

Foliation point maxima are less well defined in areas to the east and west of the study area (Andréasson and Rodhe 1990; their Fig. 3). Hjern (1958) compiled foliations from an area to the south. His results are very similar to those reported here. Wahlgren and Stephens (1990, 1991; cf. also Wahlgren & Rönnlund 1988) described the PZ east of Lake Vänern as an at least 25 km wide belt of 50-100 m thick ansatomosing shear zones with 2-3 km spacing, trending NNW, N-S, NNE and NE. The sense of displacement in this area is constantly western-block-up. The zones have steep to gentle easterly dips in the western part and westerly moderate to steep dips in the eastern part of the zone, resulting in both normal and reverse movements. In the western part the deformation is semi-penetrative to penetrative. The early deformation along the zones was ductile and the younger brittle. Thus, with the exception of the fanning of the shear deformation and the constant sense of displacement, the PZ north of Lake Vättern appears similar to the PZ south of the lake.

4 MOBILITY OF THE PZ AND RELATED FAULTS DURING THE LAST 1.5 Ga

The calendar of activity along the PZ presented below is based on published evidence and our own results and conclusions. The inventory includes geological features of all scales, from movements affecting the bedrock over the whole of southern Sweden during, for instance, orogenic uplift, to observations of local adjustment of single small blocks along a fault scarp.

4.1 PRE-SVECONORWEGIAN (>1.0 GA) REPEATED TENSION AND INTRUSION

As an orogenic and lithological feature, *the PZ was established* prior to, or latest in connection with the emplacement of the Småland-Värmland Granites, the youngest of which is c. 1660 Ma old (Jarl 1988).

The c. 1475 Ma old mafic dykes swarm now occurring as deformed lenses and sheets along the PZ in Värmland demonstrate an event of *tension* in the crust.

Renewed *rifting* and *extensive intrusive activity* along the whole length of the PZ is evidenced by the emplacement of the c. 1200 Ma old mafic dyke swarm and the possibly associated Fe-Ti ores and anorthosite-mangerite-charnockite-granite suite, including the Vaggeryd, Görbjörnarp, Önnestad-Glimåkra syenites and granites and the Smålands Taberg ore (Klingspor 1976; Patchett 1978; Johansson 1988; Solyom and Hansen 1988; Jarl 1988; Johansson & Johansson 1988, 1990). Deposition of the Almesåkra Group and Klevabergen sandstone could belong to this event of rifting and basin formation beginning the Sveconorwegian orogenic cycle.

4.2 SVECONORWEGIAN COLLISION, COMPRESSION AND THRUSTING

The Sveconorwegian orogeny is generally described as a collisional event with crustal thickening and extensive *eastward overthrusting*. *Small-scale folding, tilting and imbrication* of sandstones in Dalarna (Fig. 1) along the so-called Sveconorwegian Front (Berthelsen 1988) may be related to this overthrusting. Sedimentary rocks occurring within and immediately to the east of the PZ deformation zones, such as the Almesåkra Group remained unmetamorphosed; however, small-scale reverse faulting of the Almesåkra Group could be related to this compression.

The collision is assumed to have caused crustal thickening and granulite facies metamorphism, which recent dating has shown to be as young as c. 915 Ma (Johansson et al. 1991; Johansson & Kullerud, submitted). Granite intrusion occurred in the west (Bohus Granite) and along deformation zones in Värmland-Dalsland.

4.3 POST-SVECONORWEGIAN UPLIFT

The crustal thickening and c. 915 Ma old granulite facies metamorphism of the gneisses to the west of the PZ must have been followed by *extensive crustal uplift and ductile-brittle deformation* along the eastern margin of the gneiss complex i.e. along the PZ. We regard the ductile-brittle deformation along the PZ as described in Chapter 3, i. e. the PZ foliation sensu stricto ("Protoginförskiffringen") as related essentially to this event.

If the Vättern Basin is a pull-apart basin related to combined translational and tensional crustal movements, it could have started to form at this stage.

4.4 LATEST RIPHEAN-VENDIAN (C. 0.9-0.59 Ga) TENSION, BASIN FORMATION, DEPOSITION AND DYKING

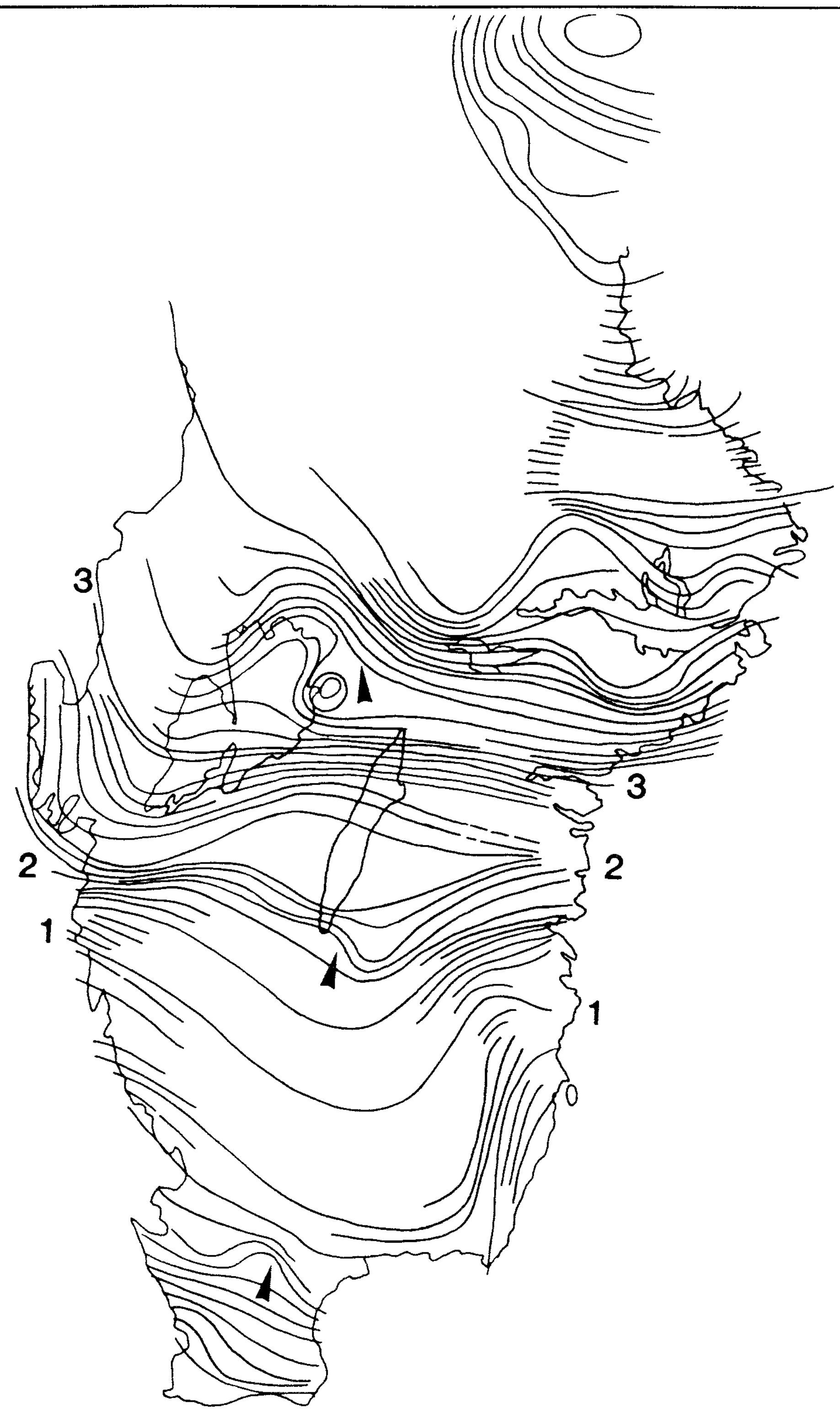
This time interval was a period of abortive continental break-up and rift basin formation all over the Baltic Shield including its western margin. Deposition of the Visingsö Group sediments in the Vättern basin, beginning c. 850 Ma ago (Vidal 1979) must have been preceeded by *tension* along the PZ. Deposition of the group occurred during faulting (Vidal and Bylund 1981). Visingsö Group strata have been raised to steep angles at Omberg a. o. places; however, this deformation is not necessarily synsedimentary but could be Palaeozoic.

Rift facies mafic dykes intruding along the PZ have been dated as young as c. 850 Ma (Johansson and Johansson 1990). The narrow trench extending southwards from Lake Vättern on the *morphotectonic* map (Fig. 11) is interpreted as pre-Cambrian in age (Lidmar-Bergström 1991).

4.5 EARLY PALAEOZOIC TILTING AND FAULTING; COLLISION IN THE WEST

Studies of the sub-Cambrian denudation surface (Ahlin 1987) suggest that *E-W extension* caused early Phanerozoic dip-slip faults with displacements on the order of 30-50m; these faults follow closely c. N-S trending zones of strong PZ foliation like the Tidan-Stråken lineament and the Hökenås horst (Fig. 1). The Nissan-Vättern lineament, here considered a branch of the PZ, *breaks* the sub-Cambrian but not the sub-Mesozoic *peneplain* (Lidmar-Bergström 1988).

The Late Silurian-Early Devonian collision and accretion of the Scandinavian-Danish-Polish *Caledonides* is likely to have affected southern Sweden and reactivated the PZ; geological and geophysical evidences for this have still to be presented.



Highest shorelines. Bends along the PZ marked by arrows.

From Mörner (1977)

Figure 21: Present relative uplift

4.6. PERMIAN RIFTING

The Permian rifting and formation of the Oslo Graben must have affected SW Sweden. The Mn-Ba deposits on PZ fractures at Spexeryd and Bölet were previously interpreted as being *Permian mineralizations* associated with the formation of the Oslo Rift, a possibility which still cannot be excluded. In Scania, lateral movements along the Tornquist lineament are related to this stress regime in Late Carboniferous-Early Permian time. Mafic dykes and increased heat flow accompanied the tectonic movements.

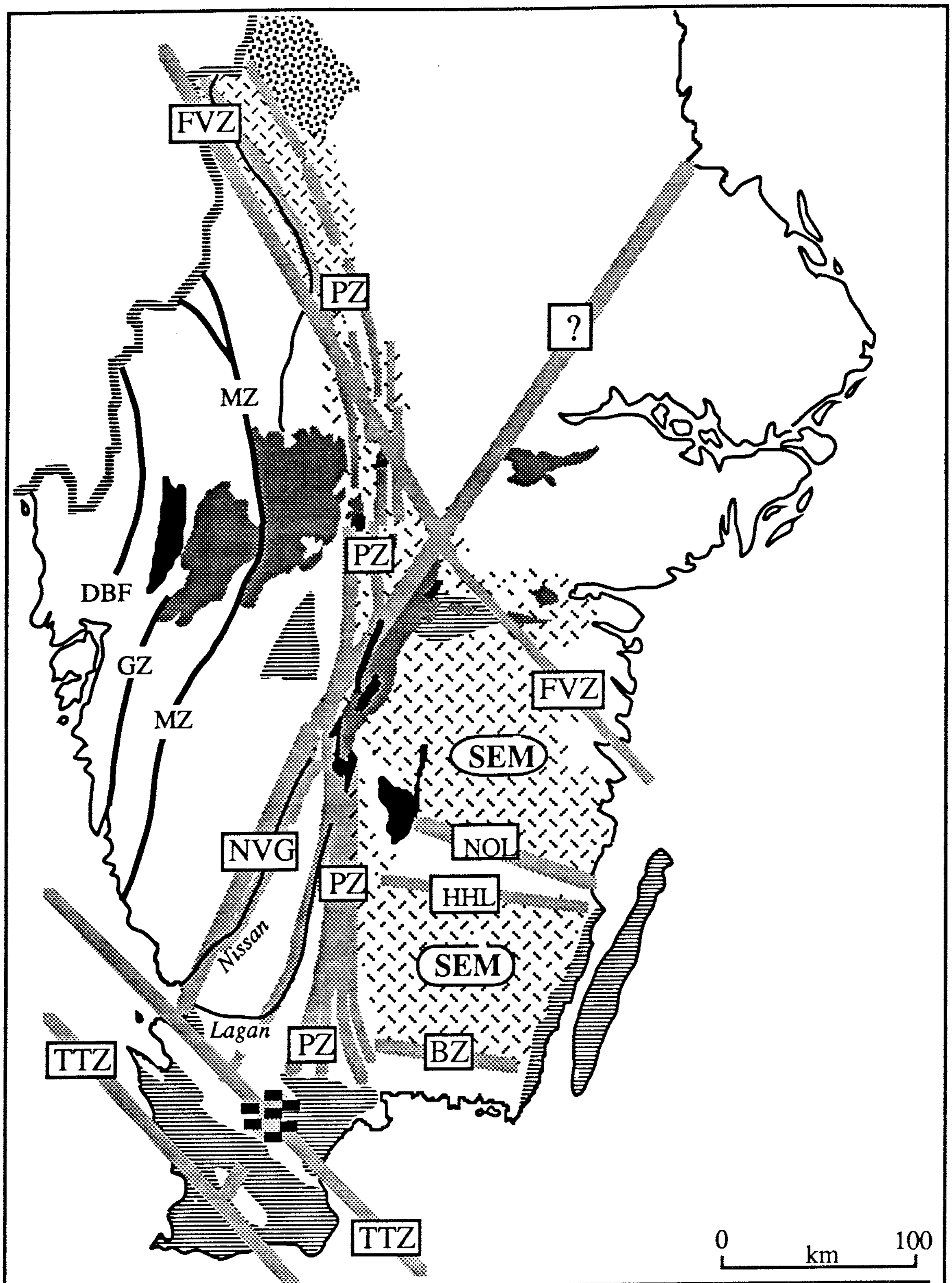
4.7 MESOZOIC UPLIFT AND BLOCK MOVEMENTS ALONG THE SOUTHWEST BORDER OF THE SHIELD

In southwestern Sweden, Mesozoic strata rest directly upon the eroded Precambrian basement requiring several hundred metres of early Mesozoic *regional uplift* and erosion (Lidmar-Bergström 1991). Triassic-Jurassic tensional block movements accompanied by volcanism were followed by Late Cretaceous inversion along the Tornquist Tectonic Zone.

4.8 TERTIARY-RECENT UPLIFT, FAULTING AND SHORE-LINE DISPLACEMENT

Late Tertiary to Recent uplift of the South Småland Peneplain of Early to Middle Tertiary age affected areas shown in Fig. 11. The southwest extension of the Lagadalen valley faulted the peneplain. In the Vättern area, the rise of the South Vättern Dome including the break in the sub-Cambrian Peneplain must have occurred later than latest Cretaceous-early Tertiary.

Several *Quaternary faults* within the PZ have been reported largely based on highest-shoreline data (Fig. 21; Mörner 1977). Breaks in the uplift pattern are considered to be evidence for postglacial faulting. Some of the evidence is ambiguous, the Mörrumsån case is an exception. Late Glacial (≈10 900 BP) dip slip displacement of c. 5 m along a high-angle lithological boundary in the Mörrumsån valley (Fig. 1) has been demonstrated on the basis of *displacement of the highest-shoreline* (Lagerlund and Björk 1979; Mörner et al. 1981; Björkman and Trädgård 1982). Since such evidence requires considerable detailed and systematic mapping in order to be demonstrated, it may be much more frequent than is known so far. Numerous normal faults occuring in diamictons at the southern end of Lake Vättern are all interpreted to be of glaciotectonic or depositional origin (Waldemarsson 1986). However, Mörner (1978a) mentioned acoustic-seismic evidence of vertical dislocations of 10-20 m in glacial clays in Lake



Protogine Zone (PZ)

SEM	Southeastern Megablock
DBF	Dalsland Boundary Fault
GZ	Göta Älv Zone
MZ	Mylonite Zone
FVZ	Filipstad-Västervik Zone
NVG	Nissan-Vättern-Gävle Zone
TTZ	Tornquist Tectonic Zone
NOL	Nömmen-Oskarshamn lineament
HHL	Hörnebo-Högsby lineament
BZ	Blekinge Zone

Volcanoes

Figure 22: Major tectonic zones of southern Sweden

Vättern prior to deposition of postglacial sediments.

4.9 RECENT SEISMICITY

The zone of seismicity of southern Sweden crosses the PZ and several "large" historical earthquakes have occurred within or close to the zone. The intensity map of the earthquake in October 1904 (Svedmark 1908) shows a distinct eastern boundary defined by early Palaeozoic faults (Ahlin 1987) to the south and southeast of Lake Vänern. Focal mechansim solutions for the Otterbäcken earthquake (Fig. 9) indicate an oblique-slip thrust movement with a WNW trending pressure axis (Wahlström 1988; cf. also Slunga 1981, 1982 for other earthquakes).

Interpretations of strike-slip deformation along the PZ based on seismic data are mentioned in sections 2.3.3 and 5.2.

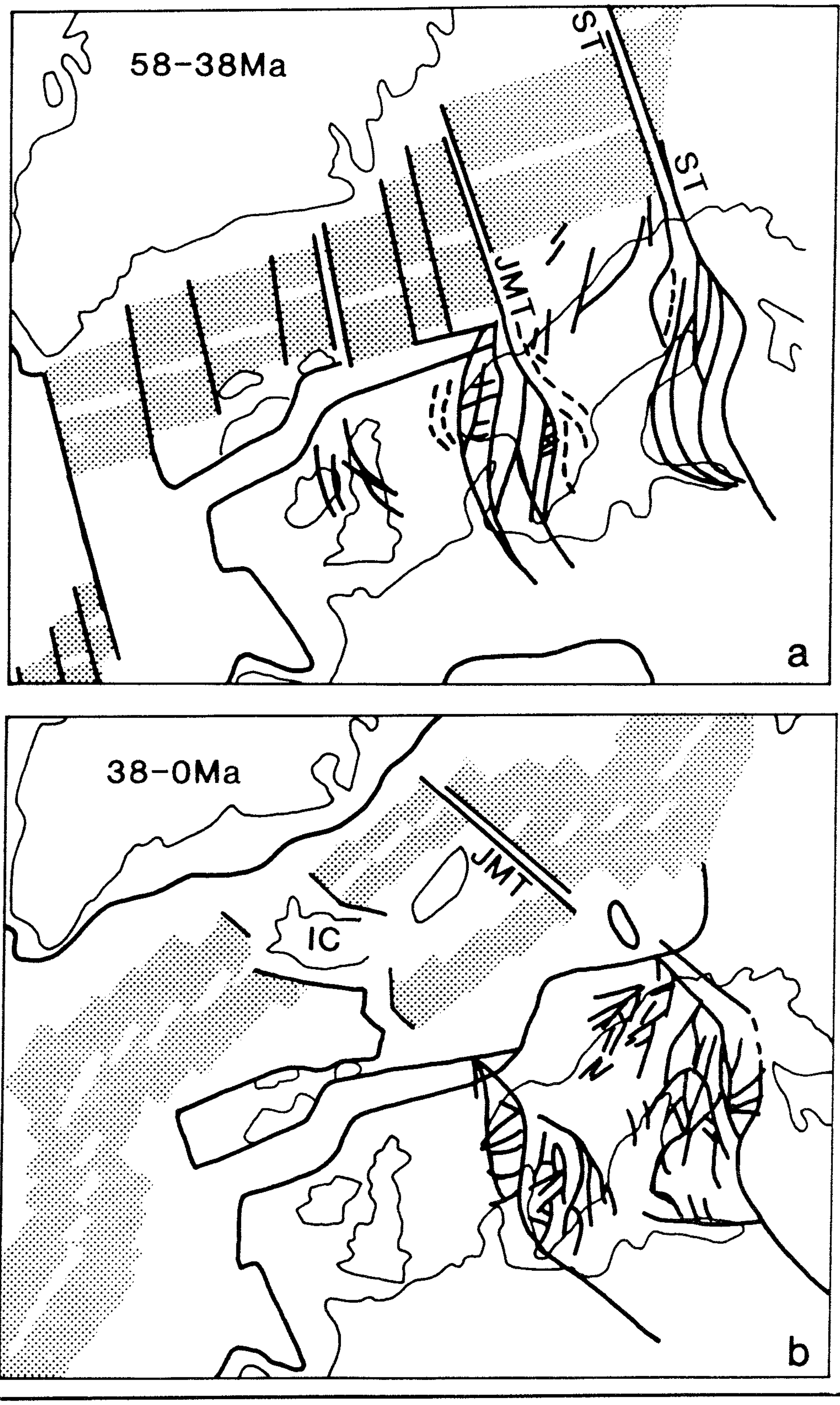
5 THE PZ IN RELATION TO OTHER MAJOR STRUCTURES OF SOUTHERN SWEDEN

Southern Sweden is a network of large fracture zones (Fig. 10). The movements along some of these zones resulted in conspicuous tectonic features; for others tectonic activity has been inferred from displaced geophysical anomalies. The nature of their interrelations is poorly known. Thus, although it is very obvious that the PZ has been cut and faulted by the TTZ, there are, to our knowledge, no descriptions of structures and deformation at their intersection.

5.1 THE MYLONITE ZONE (MZ) AND THE LINEAMENTS OF LAKE VÄNERN

Several models describe the MZ and PZ as thrusts formed during Sveconorwegian-Grenvillian collision, and a tectonic affinity between the two structures is accordingly implied. However, there are important differences between the MZ and the PZ with regard to mechanical properties, the former being much more recrystallized and healed.

On the other hand, studies of the bottom topography of Lake Vänern (Håkansson et al. 1978) suggest that the fractures of the eastern part of the lake run parallel to the boundary faults of the Vättern basin and it appears as if the two large lakes of southern Sweden may partly share the same fracture system (Andréasson et al. 1987). Mineralizations on some of the Värmland



a : Between 58-38 Ma ago, Fennoscandian strike-slip duplexes were related to the Senja (ST) and Jan Mayen (JMT) transform faults
b : After a change in the spreading pattern at 38 Ma, major strike-slip in Fennoscandia is related to the JMT and the Island transform fault (IC).

Figure 23: Relation of strike-slip duplexes shown in Fig. 24 to transform faults in the North Sea
After Talbot and Slunga (1989; their Fig. 7)

and Dalsland fractures (Johansson 1984) could have the same age and geotectonic cause as the PZ mineralizations.

5.2 THE FILIPSTAD-VÄSTERVIK ZONE (FVZ) AND THE VÄNERN STRIKE-SLIP DUPLEX

The FVZ is a conspicuous topographic feature in the Västervik-Loftahammar area and along the upper reach of River Klarälven (where it coincides with the PZ). In between these areas, it is less obvious. Based on seismic evidence Eriksson and Henkel (1983; cf. also Henkel and Eriksson 1987) considered the zone to be connected with the Jan Mayen fault and thus linked with ongoing transform faulting. The same authors inferred a < 100 km sinistral post-Caledonian displacement of the PZ along the FVZ, based on the mis-match of the magnetic anomaly pattern of the Småland-Värmland Granite belt.

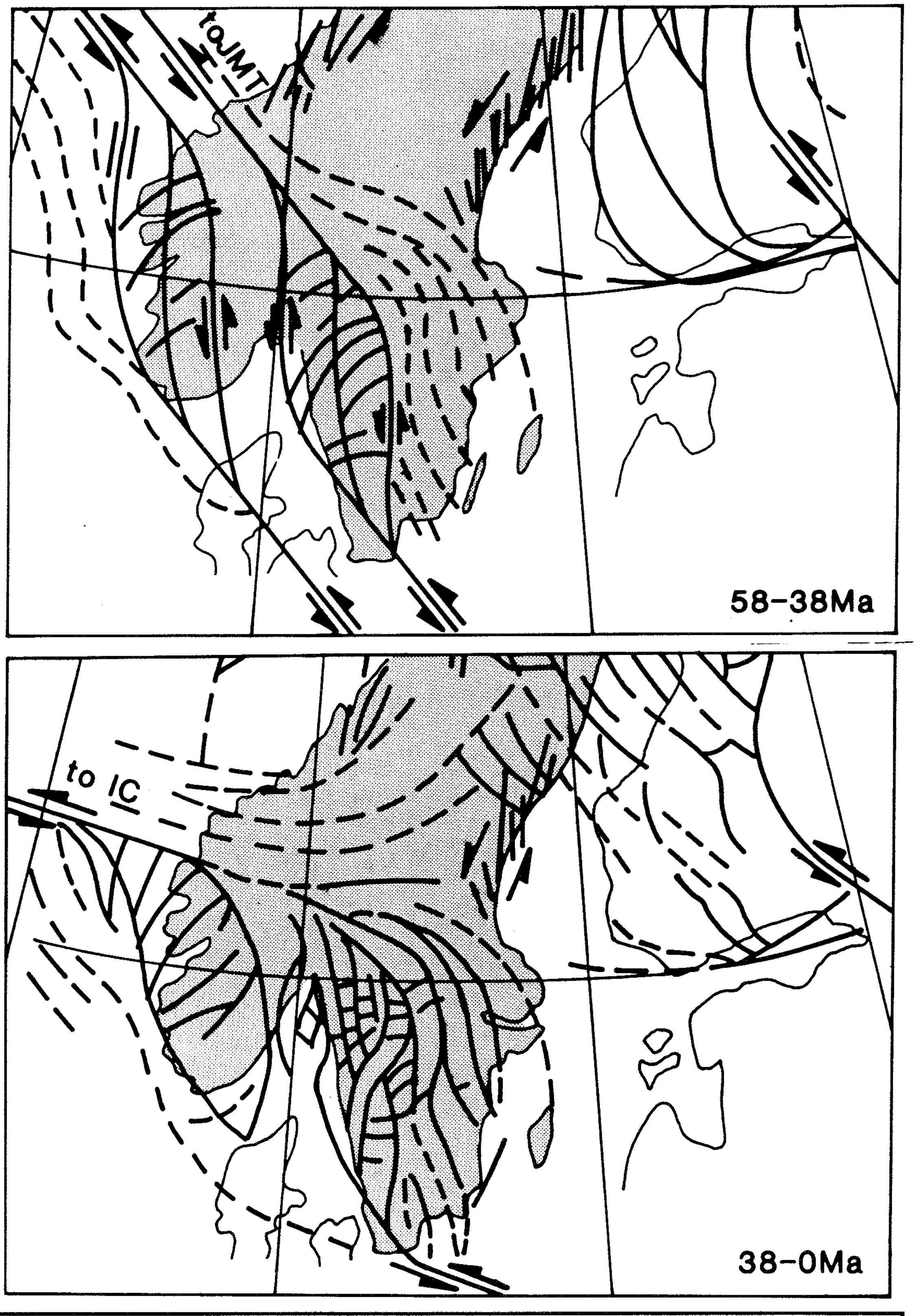
Using fault plane solutions for two hundred earthquakes in southern Sweden during 1980-84, Talbot and Slunga (1989) identified a strike-slip lens of active fault zones in southwestern Sweden (Fig. 24; cf. also Henkel & Eriksson 1991). The strike-slip is attributed to the transform faulting in the North Sea during the last 58 Ma (Fig. 23).

5.3 THE NISSAN-VÄTTERN-GÄVLE ZONE (NGZ)

A zone called the "Varberg-Vättern-Gävle fracture zone" has been described in several publications (a. o. Henkel and Eriksson 1987), obviously thought to be somehow related to the seismically active zone of Sweden (cf. 2.3.5). Between Vättern and Gävle the zone is less obvious as a tectonic feature. The Nissan-Vättern part of the zone is here considered a branch of the PZ (Fig. 3), defining also the eastern boundary of the zone of Recent seismicity.

5.4 THE TORNQUIST TECTONIC ZONE (TTZ)

Much is written about this zone , which defines the border zone between the Danish-Polish Trough and the Fennoscandian Shield, running from the Black Sea in the southeast to the Viking Graben in the northwest. The c. 70 km wide zone is a complex system of six large horsts and associated grabens; very extensive strike-slip faulting along the zone has also been suggested. Field and aeromagnetic observations suggest that thousands of dolerite dykes of Permo-Carboniferous age intruded along the zone.



Upper figure: pattern fitting plate kinematics between 58 and 38Ma
Lower figure: pattern related to plate kinematics during the last 38Ma

JMT Jan Mayen transform fault
IC Iceland

Figure 24: Kinematic patterns of historically active faults in S Sweden according to Talbot and Slunga (1989)

Active in Late Carboniferous -Early Permian, Jurassic-Early Triassic and Late Cretaceous-Early Tertiary, the TTZ may have formed already in Early Palaeozoic time.

The structural relations between the TTZ and the PZ are poorly known. It is notable, that the only occurrence of late volcanism in Scandinavia, the c. 100 volcanoes of Carboniferous-Jurassic age, occurred at the intersection of TTZ and PZ fractures.

5.5 THE BLEKINGE ZONE (BZ)

An E-W trending tectonic zone has been inferred to delimit the Småland Granite from the gneisses of Blekinge. The zone was recently thought to be connected with a jump in the Moho (Guggisberg & Berthelsen 1987) and uplift of the southern block. In the field, a zone of intense shearing of the bedrock can be seen (Kornfält & Bergström 1991); however, the Småland Granites cross the zone (K.-A. Kornfält, Lund; personal communication 1991). The boundary is cut by c. 1400 Ma old granites.

5.6 EAST-WEST TRENDING TECTONIC ZONES IN THE SOUTH-EASTERN MEGABLOCK (NOL; HHL)

The belt of Svecofennian supracrustal and intrusive rocks across Småland between Vetlanda and Oskarshamn (white in Fig. 2) is bounded to the north and south by systems of fault and shear zones, here referred to as the Nömmen-Oskarshamn (NOL) and the Hörnebo-Högsby (HHL) lineaments. The NOL is very marked on aeromagnetic maps and relief maps (Persson 1989; Kornfält & Larsson 1987; their Pl. 3-4). Sinistral strike slip is suggested by large scale tension gashes occupied by dolerite dykes, as seen on the aeromagnetic map Vetlanda (Persson 1989; his Fig. 6). In the field, it is a very distinct boundary betwen high- and low-grade metamorphic rocks, suggesting crustal relief (Andréasson et al. in prep.). Sundblad (in Andréasson et al. 1990) inferred that shear zones of this lineament controlled the gold mineralization at Ädelfors. The fault is overlain by Almesåkra Group (<1200 Ma old) deposits with intruding dolerites.

The Hörnebo-Högsby lineament has been suggested to be the surface expression of a 10 km vertical displacement in the Moho beneath Småland (cf. also the E-W wall of Moho contours in Fig. 7), as deduced from the FENNOLORA deep seimic refraction profile ("Åseda Zone" of Guggisberg and Berthelsen 1987). Mylonitization was locally so intense that the rock can be used as roofing slate (Hörnebo quarry). A detailed description of the mylonite zone (Nyatorp Shear Zone) was recently published by Skjernaa (1992).

6 SUMMARY AND CONCLUSIONS

The Protogine Zone is a complex structure with a long tectonic history. In addition to being an anastomosing system of NNW, N-S and NNE trending deformation zones, it is the site of magmatic intrusions, metamorphic breaks, hydrothermal mineralizations and is characterized by geophysical anomalies such as a gravity low, aeromagnetic breaks and lows, and possibly increased heat flow. The evidence of repeated deformation over a period of more than 1000 Ma is in marked contrast to the history of the adjacent granite region of eastern Småland (the SEM).

In the type area of the "Schistosity Zone", typical structures include a foliation (the "schistosity") striking c. N-S and dipping steeply to the west; a conspicuous stretching lineation defined by quartz and feldspar plunging steeply towards WSW, raking down the dip of the foliation. The sense of net regional displacement is inconclusive both as regard vertical and horizontal movements. The geometry of small-scale faults is much less uniform and does not comply with trends and dips of foliations and mylonite zones. Ductile and brittle structures are often intimately associated and ductile structures also pass gradually into brittle ones suggesting continuous deformation during uplift.

Three generations of mafic dyke swarms of remarkably similar magmatectonic signature indicate repeated E-W tension along the PZ at c. 1500, 1200 and 900 Ma. Syenitic and granitic rocks intruded along the zone in connection with the 1200 Ma event. The typical PZ foliation as seen in the field and described in Chapter 3 probably formed during uplift of the gneiss complex of SW Sweden following deep crustal (>35 km) metamorphism of the gneisses c. 915 Ma ago. Deformation continued under more shallow and thus brittle conditions as the Vättern Basin opened from c. 850 Ma.

The following deformation was essentially related to uplift and resulted in regional tilting of blocks and local faulting. The PZ was most probably affected and reactivated in connection with the large deformational events during which the Caledonian, Hercynian and Alpine mountain belts formed. These events strongly affected the southwestern margin of the shield and must have triggered movements along the PZ.

Faulting occurred during deglaciation at least locally. Since such evidence requires considerable detailed and systematic mapping in order to be demonstrated, it may be much more frequent than is known so far and may be directly measurable with modern satellite techniques. Historical seismicity and the pattern of the relative uplift suggest that the PZ may be a significant zone of ongoing movement. Horizontal displacement may be significant even if vertical scarps and throws have not been detected.

7 SUGGESTED WORK

7.1 IS THERE ANY CONNECTION BETWEEN THE PZ AND THE NOL?

This study concludes that a closer analysis of the SEM and particularly the E-W trending fracture systems that delimit the block is required. The NOL is a prominent and potential link between the PZ and the Oskarshamn area and its extension into the PZ, if any, should be investigated. The area to the east of the present study area (Hok-Tomtabacken and eastwards) is well exposed and suitable. A second traverse could run from the typical N-S trending PZ structures at Lake Rusken to the very intense, E-W trending mylonite zone at Hörnebo, which has a continuation eastwards via Åseda and Högsby to the coast.

7.2 QUANTITATIVE INVESTIGATIONS OF FAULTS

Attempts should be made to date fault gouge in marked topographic scarps along the PZ as in the Lagan valley (e. g. at Tofteryd).

Stress tensor analysis of faults in the Vättern area should be made and compared to seismically determined fault plane solutions.

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8 APPENDIX: BIBLIOGRAPHY OF SPECIFIC SUBJECTS

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