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Crustal evolution of Fennoscandia—palaeomagnetic constraints

european egt geotraverse

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Abstract

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Palaeomagnetic poles from Fennoscandia, ranging in age from Archaean to Tertiary, are compiled and graded using a modified Briden–Duff classification scale. An new "filtering" technique is applied to select only the most reliable poles for analysis. The filtering takes into account the following information: (1) source block of rock unit, (2) age of rock, (3) age of magnetization component, (4) scatter of palaeomagnetic directions, (5) information from multicomponent analysis of natural remanent magnetization (NRM), (6) whether the pole considered belongs to a cluster or subcluster of poles, (7) magnetic polarity and (8) the author's original assignment of results.

Data are still insufficient for the drawing of separate Apparent Polar Wander Paths (APWP) for different blocks or cratons of Fennoscandia. Treating Fennoscandia as a single plate, a new APWP from Archaean to Permian is constructed. From the five previously drawn APWP loops (or "hairpins"), only one, the Jatulian loop (2200–2000 Ma), disappears in filtering. The loops during 1925–1700 Ma and during 1100–800 Ma ago are linked to Svecofennian and Sveconorwegian orogenies, respectively. Palaeomagnetic data support the concept that these orogenies took place episodically; three distinct orogenic pulses (early, middle and late) can be distinguished in the cluster plots of palaeopoles.

The drift history of Fennoscandia from Archaean to Permian is presented. During most of geological history, Fennoscandia has occupied low to moderate latitudes and undergone considerable latitudinal shifts and rotations. The Svecofennian and Sveconorwegian orogenies have different kinematic characteristics. During the Svecofennian orogeny, Fennoscandia drifted slowly while rotating a large amount in an anticlockwise sense. During the Sveconorwegian orogeny, it drifted rapidly and rotated first clockwise and then anticlockwise. The most striking feature in the drift velocity curves is, however, the pronounced maxima in the latitudinal drift and rotation rates (~ 9 cm/yr and ~ 0.8°/Ma, respectively) during the late Subjotnian–Jotnian anorogenic magmatism and rifting phase (~ 1450–1250 Ma ago), possibly reflecting the passage of Fennoscandia across a thermal upwelling (hotspot) at equatorial latitudes.

The use of palaeomagnetism in delineating and dating movements between blocks is demonstrated with three examples from the POLAR Profile area, the northernmost section of the European Geotraverse.

Introduction

The Fennoscandian Shield in northern Europe (Fig. 1) consists of different types of tectonic blocks, magmatic provinces and orogenic belts varying in age from Archaean to Tertiary (e.g., Bylund and Pesonen, 1987; Gorbatschev and Gaál, 1987; Gaál et al., this issue). It is generally held (e.g., Gaál, 1986) that the age of the rocks in Fennoscandia decreases from northeast to south-

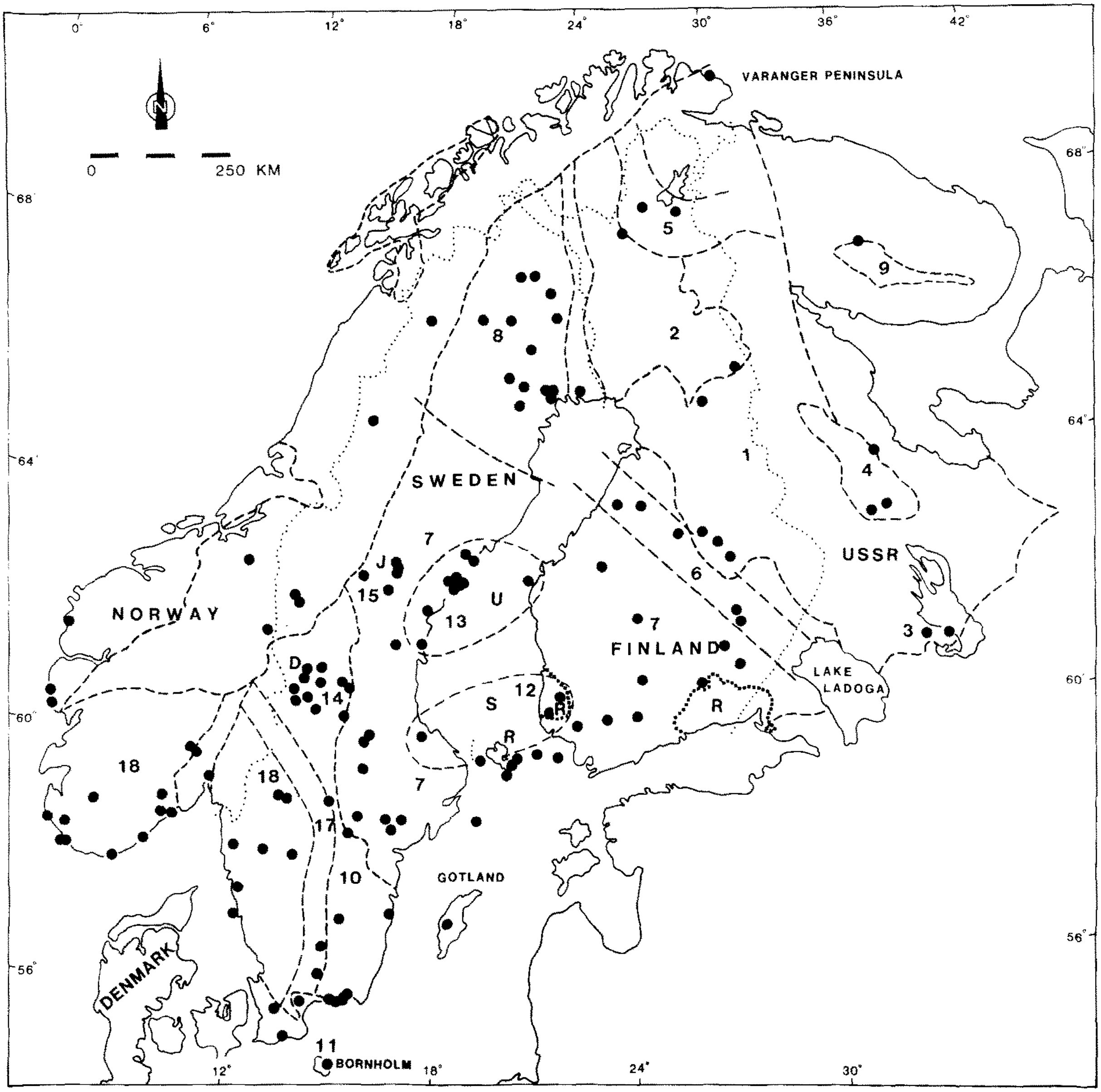

Fig. 1. The tectonomagmatic block division of Fennoscandia. The numbers and names of blocks are in Table 1 and follow the nomenclature used by Pesonen et al. (1989). Block 17 is the Protogine Zone. Letters *U*, *J*, *D* and *S* denote the four Central Scandinavian dolerite provinces of post-Jotnian age (see text).

west as a consequence of accretion of new crust from the southwest onto the pre-existing Archaean nucleus. The tectonic style and the kinematic processes associated with the accretion are, however, poorly understood. One possibility is that Fennoscandia has drifted as a single plate and collided occasionally with other continents, causing successive orogenies along its margins (e.g., see Pesonen and Neuvonen, 1981). Another possibility is that the mobile belts (e.g., Kröner, 1983) between the cratons are products of collisions of the once separated cratonic elements (e.g., Burke et al., 1976; Marker, 1985; Berthelsen and Marker, 1986a). A third possibility is that the mobile belts represent broad shear zones where transcurrent movements between adjacent blocks take place (e.g., Onstott and Hargraves, 1981; Berthelsen and Marker, 1986b).

In the northernmost part of Fennoscandia, geological and geophysical data have recently been collected along the seismic POLAR Profile which traverses the major tectonic units including the Archaean/Late Archaean cratons and the intervening Early Proterozoic belts (Gaál et al., this issue). Both vertical (e.g., Meriläinen, 1976; Silvennoinen, 1985; Gaál et al., this issue) and horizontal (Barbey et al., 1984; Marker, 1985; Berthelsen and Marker, 1986a) movements of crustal blocks in this area have been suggested, thus offering an ideal opportunity for tests using the palaeomagnetic approach. This is because all these tectonic models predict different amounts of relative movements between blocks or cratons and are therefore directly testable by palaeomagnetic measurements, since relative movements are indicated by differences in the Apparent Polar Wander Paths (APWP) of the blocks.

This paper has three parts. First, in order to place some constraints on the models to explain the tectonic evolution of Northern Fennoscandia (Gaál et al., this issue; Von Knorring and Lund, this issue) the drift history of Fennoscandia from Archaean to Permian (~ 2700–250 Ma) is presented in terms of palaeolatitudes and palaeorotations. Second, the latitudinal drift and rotational velocity curves for Fennoscandia are calculated in order to examine any correlation between orogenies, magmatism and plate kinematics (e.g., Baer, 1983; Jurdy and Gordon, 1984; Piper, 1987; Pesonen, 1988). Third, three examples of how palaeomagnetic data can be used to date magmatic and tectonic events are presented from the POLAR Profile area. In all these analyses it is crucial to use only the most reliable palaeomagnetic poles. Hence, a new grading scale was developed for the Fennoscandian palaeomagnetic database (Briden and Duff, 1981; Lähde and Pesonen, 1985; Pesonen et al., 1989) and is used as a "filter" to separate more reliable poles from less reliable poles.

Fennoscandian palaeomagnetic database

Lähde and Pesonen (1985) have compiled all the available palaeomagnetic data from Fennoscandia, ranging in age from Archaean to Tertiary, into a computer catalogue using the principles of Irving and McElhinny (e.g., see Irving and Hastie, 1975; McElhinny and Cowley, 1977). This catalogue, however, is not sufficiently rigorous with respect to the reliability classification of the poles. Therefore, the data (up to the end of 1987) have been graded using modified Briden and Duff (1981) reliability criteria. A detailed description of the new palaeomagnetic database and applied grading method is given elsewhere (Pesonen et al., 1989) and only the information relevant to the present paper is given here.

Block division of Fennoscandia

In this paper, Fennoscandia is divided into eighteen tectonomagmatic blocks (Fig. 1). This division is based on new geochronological data and on tectonic, structural and geophysical maps (Gorbatschev and Gaál, 1987; Gaál et al., this issue). The block names are listed in Table 1 and follow the nomenclature used by Pesonen et al. (1989). Each pole is assigned to a source region (tectonomagmatic block) with a structural age determined by radiometric age data, the majority of which are by U–Pb (Zr), by Rb–Sr or by K–Ar methods (e.g., the Archaean (~ 2.7 Ga) Karelian craton (block 1), the Svecofennian (~ 1.9–1.7 Ga) inlier in Central Karelia (block 4), and so on). Note that the Sveconorwegian Province (block 18) is considered, from a palaeomagnetic point of view, as Late Precambrian in age since the majority of Rb–Sr and K–Ar ages on rocks from this province reveal a Late Precambrian (Sveconorwegian) overprint around 1.1–0.8 Ga ago, rather than the original and much older crystallization (U–Pb) age of these rocks (see Skjiöld, 1976; Falkum and Petersen, 1980; Stearn and Piper, 1984). Because of the scarcity of data, rocks younger than ~ 670 Ma are grouped solely according to their time divisions into Late Precambrian, Cambrian, Ordovician, and so on (see Table 1).

Grading the poles

Each pole was graded into class A, B, C or D by means of a modified Briden and Duff (1981)

TABLE 1

Grand mean palaeomagnetic poles for Fennoscandia from Archaean to Permian

Pole	Block or magmatism (no./(entry name))	Time of magnetization	Estimated age	N	Plat.	Plon.	A_{95}
Archaean							
1	Karelian craton /1/ (A01)	Archaean	2680	1	64	313	–
Jatulian–Svecofennian							
2	Lapland Granulite Belt /5/(E01)	Early Svecofennian	1900	1	41	246	–
3	Central Sweden–South Finland block /7/(S02)	Early Svecofennian	1900	3	37	249	11.3
4	Jatulian/Svecofennian inlier in Karelia /4/(J02)	Early Svecofennian	1900	1	32	230	–
5	Raahe–Ladoga block /6/(S01)	Early Svecofennian	1880	5	42	235	4.9
6	North of Skellefteå block /8/(S03)	Early Svecofennian	1880	8	46	234	6.7
7	Central Lapland block in North Finland /2/(J01)	Middle Svecofennian	1850	1	47	234	–
8	Svecofennian inlier in Central Karelia /4/(J03)	Middle Svecofennian	1850	1	49	235	–
9	Svecofennian magmatism in Karelian craton /1/(A01)	Late Svecofennian	1800	3	49	220	21.2
10	Central Sweden–South Finland block /7/(S02)	Late Svecofennian	1780	2	53	206	–
11	Svecofennian magmatism, north of Skellefteå /8/(S03)	Late Svecofennian	1750	4	46	209	8.0
12	Central Sweden–South Finland block /7/(S02)	Late Svecofennian	1700	2	42	198	–
Subjotnian magmatic interval							
13	Subjotnian magmatism, South Finland /7/(B02)	Early Subjotnian	1620	3	16	187	6.8
14	Subjotnian overprints, north of Skellefteå /8/(S03)	Early Subjotnian	1570	2	22	194	–
15	Subjotnian magmatism, Central Sweden /7/(B03)	Early Subjotnian	1570	3	30	191	12.8
16	Subjotnian magmatism in TSGB, South Sweden /10/(B01)	Middle Subjotnian	1550	5	28	183	7.2
17	Subjotnian magmatism, South Finland /7/,/12/(B02)	Middle Subjotnian	1550	5	35	179	7.4
18	Subjotnian magmatism, south Central Sweden /7/(B03)	Middle Subjotnian	1415	6	34	151	8.6
19	Subjotnian magmatism, south Central Sweden /7/(B03)	Middle Subjotnian	1350	3	51	168	3.2
20	Subjotnian magmatism, Central Sweden /7/(B03)	Late Subjotnian	1320	1	16	194	–
Jotnian interval							
21	Jotnian sandstone in Finland /12/(G01)	Early Jotnian	1300	1	3	180	–
22	CSDG, Satakunta Complex /12/(G01)	(Post-) Jotnian	1260	3	3	154	8.8
23	CSDG, Dala Complex /14/(G03)	(Post-) Jotnian	1250	2	2	154	–
24	CSDG, Ulvö Complex /13/(G02)	(Post-) Jotnian	1250	9	−5	157	4.6
25	CSDG, Jämtland Complex /15/(G04)	(Post-) Jotnian	1250	1	−5	150	–
Sveconorwegian							
26	West of Protogine Zone /18/(P03)	Early Sveconorwegian	1100	5	−2	212	8.6
27	Laanila dyke swarm, North Finland/5/(G01)	Early Sveconorwegian	1000	1	−4	218	–
28	East of Protogine Zone /10/(P01)	Middle Sveconorwegian	950	2	−42	210	–
29	Within Protogine Zone /17/(P02)	Middle Sveconorwegian	950	4	−44	211	8.5
30	West of Protogine Zone /18/(P03)	Middle Sveconorwegian	950	19	−45	217	4.4
31	West of Protogine Zone /18/(P03)	Late Sveconorwegian	850	5	−25	231	5.5
32	West of Protogine Zone /18/(P03)	Late Sveconorwegian	850	5	−1	241	7.2
33	East of Protogine Zone /10/(P01)	Late Sveconorwegian	850	2	0	242	–
Late Precambrian–Palaeozoic							
34	Late Precambrian * (Q02)		640–550	3	−48	306	18.0
35	Devonian * (Q05)		406–360	5	18	152	11.0
36	Carboniferous * (Q06)		352–286	7	37	168	3.2
37	Permian * (Q07)		286–248	14	48	157	5.0

TABLE 1 (footnote)

Pole number refers to the Grand Mean Palaeomagnetic Poles (GMPs) in Fig. 7.
Block or magmatism (/No./(entry name)) denotes the geological block or magmatic province in Fig. 1 (see also Bylund and Pesonen, 1987). The entry names denotes the entry codes in the pole catalogue by Pesonen et al. (1989).
Time of magnetization is interpreted from the published age data and from the pole position on the APW curve in Fig. 7.
Estimated age is the interpreted age of the GMP (only approximate age given without error limits).
N is the number of poles used for the Grand Mean Pole calculations.
Plat. and Plon. are the position of the Grand Mean Palaeomagnetic Pole (latitude °N, longitude °E).
A_{95} is the half-angle of the 95% circle of confidence of the mean pole (calculated only when $N \geq 3$).
TSGB denotes the Trans-Scandinavian Granite–Porphyre Belt.
CSDG denotes the Central Scandinavian Dolerite Group.
* No block division is used.

grading scale. The following information is used in assessing a grade to each pole: (1) source area of the rock unit (i.e., tectonomagmatic block), (2) age (or range of ages) of the rocks, (3) results from the multicomponent analysis of demagnetization data of the rocks, (4) age (or range of ages) of magnetization component(s), (5) scatter of palaeomagnetic directions, (6) magnetic polarity, (7) whether the pole considered belongs to a cluster or subcluster of poles or is an "outlier", and (8) the author's assignment of their results. Our grading scheme is not as rigorous as that used by Briden and Duff, since only about 10% of the Fennoscandian poles would fulfill their class-A criteria and no more than about 30% their combined class A–B-criteria (see Pesonen et al., 1989).

In many cases, problems were encountered when it was necessary to make recalculations from original tables, and occasionally, even from figures. However, these recalculations were necessary in order to arrange all the published results into a comparable format in the database. Such recalculated data are difficult to grade. We are aware that there is no wholly objective way of grading the poles but we feel that the method we have used is effective and sufficient for the present purpose.

Effect of filtering on pole scatter

The first step in filtering the palaeomagnetic data was to eliminate the category-D poles from further analysis. A-, B- and C-poles were then plotted for each geological period. The C-poles were removed and a new plot with only A- and B-poles was obtained. Finally, only the A-poles were examined. Figure 2 presents a typical example of the effect of "filtering" on the scatter of poles. The data cover the Subjotnian poles in the 1650–1320-Ma age range. A dramatic decrease in scatter is noted when the D- and C-poles are omitted (compare Figs. 2a and b).

This phenomenon was observed throughout the Fennoscandian database (see further examples in Pesonen, 1989). By studying the reasons for this, we found that the D- and C-poles are often "outliers" due to large errors in remanence directions ($A_{95} > 25°$), due to incomplete demagnetization treatment, or due to problems in interpreting the age and/or local tectonic history of the rocks (see also Halls and Pesonen, 1982). We felt that the applied "filtering" technique is justified for drawing the APWP. On the other hand, we found that the best way to proceed, so as not to lose too much of the information in the database, was to also include the B-poles for final analysis. Figure 2c shows that the A-poles alone outline the shape of the Subjotnian polar wander loop (compare Fig. 2c with Fig. 7), but in many other cases essential parts of the APWP are lost if the A-poles alone are used.

Palaeomagnetic cluster plots

The APWPs were drawn using the following method. The A- and B-poles were first plotted without preselection on the source blocks and without details of radiometric or magnetization ages. In these plots (hereafter called cluster plots; e.g., Patchett et al., 1978) the poles are divided according to a crude age division of the Fenno-

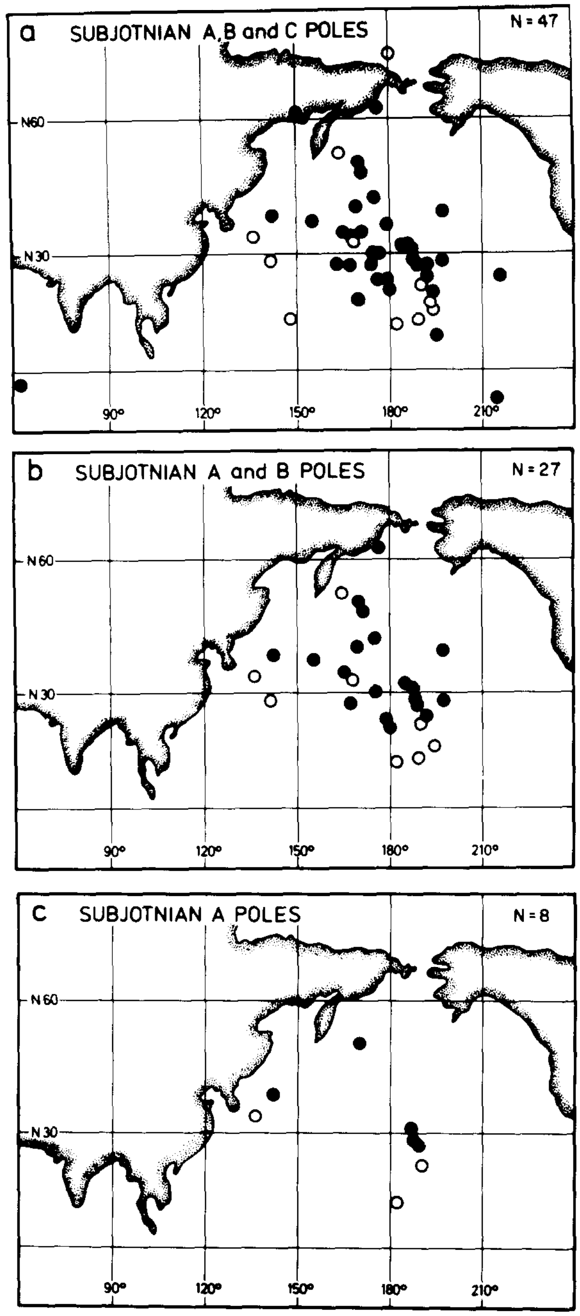

Fig. 2. Example of the effect of "filtering" (grading) on the scatter of palaeomagnetic poles. Subjotnian database (~ 1650–1320 Ma). The applied filter is a modified Briden–Duff scale (Briden and Duff, 1981), where class A is the most reliable, and so on (see Pesonen et al., 1989). Open symbol denotes reversed polarity of the pole and closed symbol denotes normal polarity. Note the decrease in scatter of poles when C-poles are omitted. Poles are listed in the Appendix.

scandian Shield (i.e., Archaean, Svecofennian, etc.; Table 1). Different symbols for poles were used to indicate the source blocks. The magnetic polarity (normal or reversed) of the pole is also indicated. The polarity choice is the same as that used by Pesonen and Neuvonen (1981), except for Late Precambrian and Cambrian poles (see Fig. 8 for explanation). The use of polarity data, although sometimes hampered by the existence of large gaps in the APWP, is an additional and independent constraint on correlation (e.g., Pesonen and Neuvonen, 1981; Piper, 1982; Bylund and Pesonen, 1987).

The purpose of the cluster plots was to test whether there is a correlation between the pole, or its polarity, and the source blocks, or whether the poles appear as tight groups (clusters), thus allowing the grand mean pole (GMP) to be calculated for each group. Examples of cluster plots are shown in Figs. 2–6 (see also Pesonen, 1989). Three main features can be observed. First, a few major clusters of poles can be recognized, for example the middle Svecofennian (1880–1800 Ma; Fig. 3) and the Jotnian (1300–1200 Ma; Fig. 4) clusters. Note that the polarity in these clusters is constant (normal in both cases) and that there are no apparent differences between poles derived from rocks of the same age but derived from separated blocks (e.g., the Jotnian blocks, Fig. 4). Second, distinct subclusters, e.g., the late Svecofennian

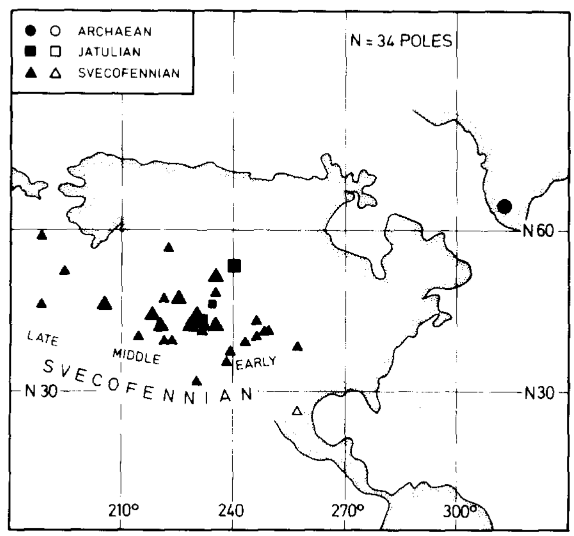

Fig. 3. Palaeomagnetic poles (class A–B) for Archaean–Jatulian–Svecofennian periods (~ 2700–1700 Ma). Large symbol denotes a class-A pole and small symbol denotes a class-B pole. The Svecofennian poles can be divided into late, middle and early Svecofennian clusters (see text). Data in Appendix.

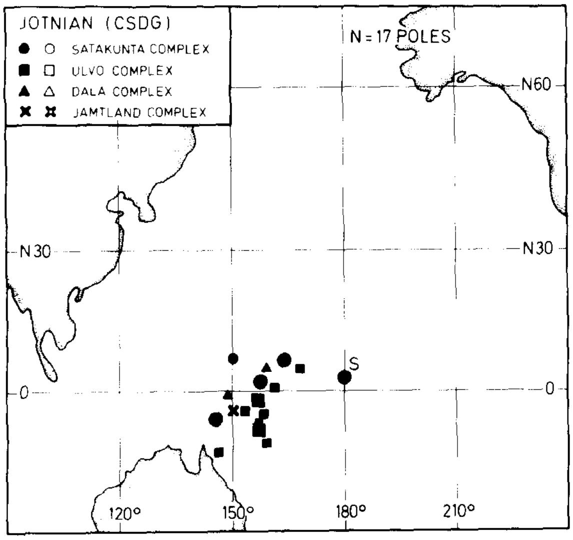

Fig. 4. Palaeomagnetic poles (class A–B) from the four Central Scandinavian dyke provinces (see Fig. 1) of post-Jotnian age (~ 1270–1200 Ma). *S* denotes the pole of the Satakunta sandstone (1350 Ma) cut by these dykes. See Figs. 2 and 3 for explanation and Appendix for data.

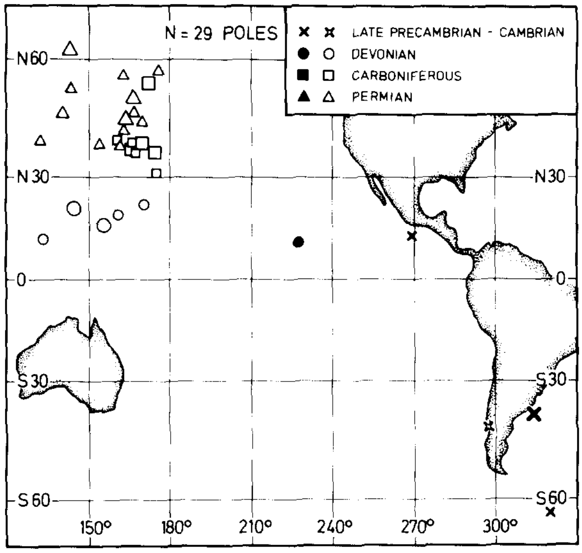

Fig. 6. Palaeomagnetic poles (class A–B) for Late Precambrian to Permian times (650–250 Ma). See Figs. 2 and 3 for explanation and Appendix for data.

subcluster (1750–1700 Ma; Fig. 3, left), can be identified. These subclusters are, in most cases, manifestations of later remagnetization events and can only be identified if multiple radiometric dating methods (U–Pb, Rb–Sr, Ar^{40}–Ar^{39}, etc.), and multicomponent analysis for $\overline{\text{NRM}}$, are applied

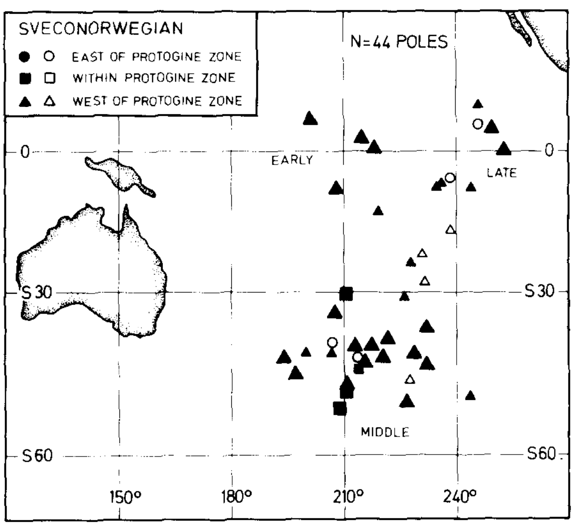

Fig. 5. Palaeomagnetic poles (class A–B) for Sveconorwegian times (~ 1100–800 Ma). The Sveconorwegian poles define three clusters which correlate with three phases of the Sveconorwegian orogeny (early, middle and late). See Figs. 2 and 3 for explanation and Appendix for data.

(Elming, 1985). Third, there are clear outliers (see Fig. 2a for examples).

The next step was to assign a magnetization age to each pole on the basis of age data, geological observations (stratigraphy and cross cuttings) and interpretations of magnetic overprints. With this approach we found that those subclusters which deviate from the major clusters usually include poles with aberrant magnetization directions or anomalously young ages. For example, the four poles on the left of Fig. 3 have magnetization ages of about 1780–1725 Ma based on the lowest Rb–Sr ages (Piper, 1980; Elming, 1985). They are derived from rocks of the northern Skellefteå block (block 8), which has suffered a late Svecofennian overprinting. Their average is used to define one of the Svecofennian mean poles (No. 11, Table 1), with an average age of ~ 1750 Ma.

Another example is from the Sveconorwegian database (Fig. 5). Three main clusters are identified: early, middle and late Sveconorwegian clusters. This division is based on study of the magnetization ages of the Sveconorwegian poles (Patchett et al., 1978; Bylund, 1981; Stearn and Piper, 1984) and on cross-cutting relationships of Sveconorwegian dykes (e.g., Bylund and Pesonen, 1987). As an example, all the four early Sveconorwegian poles come from the basement block (Bamble–

Rogaland block) in the west of the Protogine Zone (Fig. 1). These poles have uplift-related magnetization ages of about 1.1–1.0 Ga and are all of normal polarity (Hargraves and Fish, 1972; Poorter, 1972a, 1975; Stearn and Piper, 1984). In contrast, both polarities are present in the middle (980–900 Ma) and late Sveconorwegian (900–800 Ma) clusters (e.g., Stearn and Piper, 1984; Bylund and Pesonen, 1987).

The division of Sveconorwegian data into three successive clusters with a characteristic pattern of polarities (Bylund and Pesonen, 1987) probably reflects the episodic nature of the Sveconorwegian orogeny (Falkum and Petersen, 1980) in analogy with the coeval Grenvillian orogen of North America (Baer, 1983). This example also demonstrates the additional application of polarity in constructing the APWP.

In the case of younger (< 670 Ma) palaeomagnetic data, only Late Precambrian, Cambrian, Devonian, Carboniferous and Permian data passed the filtering. The cluster of these poles is shown in Fig. 6. Note that the reversed polarity dominates in the Fennoscandian Palaeozoic database; this is also the case in the corresponding Laurentian database (Piper, 1987). In Precambrian era, the normal polarity is dominant in both shields (Pesonen and Neuvonen, 1981).

Grand mean poles and the new APWP

Before the APWP for Fennoscandia was constructed, the feasibility of drawing separate APWPs for different blocks at successive time intervals was tested. For the Archaean era this test was not possible due to the lack of reliable poles from other than the Karelian craton (block I). This is a disappointing finding with regard to the testing of plate tectonic models for Fennoscandia during Archaean times (Barbey et al., 1984; Marker, 1985; Gaál et al., this issue). We did observe, however, that palaeopoles of similar ages but derived from separate Proterozoic blocks or magmatic terranes do not differ significantly from each other (e.g., see the Jotnian data in Fig. 4; and for further examples, see Pesonen, 1989), implying that no large-scale relative movements between blocks within Fennoscandia have taken place since the Early Proterozoic (Pesonen and Neuvonen, 1981). It should be emphasized, however, that the resolving power of the palaeomagnetic method is about 10° at most, so that relative lateral movements of less than ~ 1000 km cannot be detected palaeomagnetically (e.g., Irving, 1979). The only case where hints of possible block movements during Late Precambrian times can be recognized is the Sveconorwegian block (Pesonen, 1987). We will return to this example later.

The following method was applied for plotting the APWP for all Fennoscandia. First, we calculated Grand Mean Poles (GMPs) by averaging the A–B-poles in each cluster and subcluster. A total of 37 GMPs was identified. Some of these, however, are represented by only a single pole. For example, GMP No. 1 is defined by the pole of the Varpaisjärvi quartz diorite (Neuvonen et al., 1981), which currently is the only reliable Archaean pole from Fennoscandia (Fig. 7). The Archaean age of this pole (with grade A) is demonstrated by a U–Pb (Zr) age of ~ 2680 Ma and by a positive baked contact test (Neuvonen et al., 1981).

Table 1 summarizes the data on the GMPs. In Figs. 7 and 8 they are plotted with the 95% circles of confidence (A_{95}). The geochronological and stratigraphic information was used to calculate the age of each GMP (Table 1). The APWP was plotted by joining the GMPs in successive periods from the Archaean to Permian using the shortest distance method (Pesonen and Neuvonen, 1981). The width of the APW swathe is defined by the envelope of the confidence circles and is generally less than 20°. No weighting procedure accounting for the grade, or the number of poles in each GMP, was used.

Examination of Fig. 7 shows that from the five previously defined (Bylund and Pesonen, 1987) APW loops only the oldest, Jatulian loop (~ 2.2–2.0 Ga ago) disappears in the new "filtered" APWP. Figure 3 shows that the Jatulian poles do not differ significantly from the early Svecofennian poles and there is thus no reason to draw a separate Jatulian loop as suggested, for example, by Pesonen (1987). There are two possible explanations for this discrepancy: either the Jatulian rocks are strongly overprinted by the Svecofennian orogeny at ~ 1.9 Ga ago (Mertanen

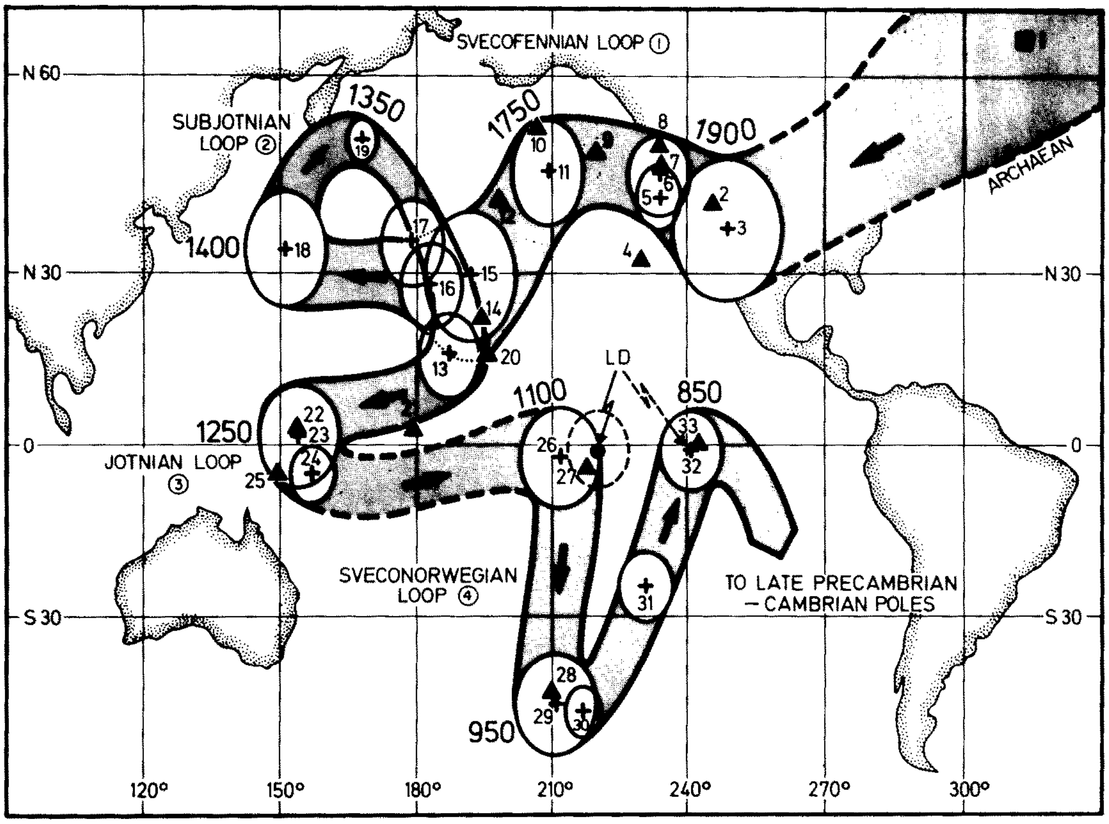

Fig. 7. Apparent Polar Wander Path (APWP) for Fennoscandia based on Grand Mean Palaeomagnetic Poles (GMP) as listed in Table 1. The A_{95} circles of confidences are shown in cases where three or more poles are available for the mean. Ages along the APWP represent mean values of radiometric ages. The two arrows from pole LD (Laanila dykes) to the APWP denote the two interpretations for this pole as discussed in example 2 (see text).

et al., 1987) or the rate of APW between Jatulian and early Svecofennian times was negligible (Neuvonen, 1975). Radiometric age data (Mertanen et al., 1987) and thermal demagnetization studies on Jatulian and early Svecofennian rocks (Piper, 1980; Elming, 1985; Mertanen et al., 1987) favour the first explanation.

The four other APW loops, the Svecofennian (1925–1700 Ma, loop 1), the Subjotnian (1650–1320 Ma, loop 2), the Jotnian (1300–1200 Ma, loop 3) and the Sveconorwegian (1100–800 Ma; loop 4) loops, pass the filtering (Fig. 7). The new Svecofennian loop is, however, considerably smoother than the previous one (e.g., Bylund and Pesonen, 1987). These loops probably reflect abrupt changes in the Euler geometries describing the relative motion of Fennoscandia during Precambrian and may also be manifestations of changes in the underlying mantle convection patterns (Arkani-Hamed et al., 1981; Piper, 1982; Baer, 1983). Loops 1 and 4 are anticlockwise and can be linked to the two major orogenies (Svecofennian and Sveconorwegian). Loop 3 is also anticlockwise and can be linked to the Jotnian rifting episode (~ 1.3–1.2 Ga ago), which is the first major rifting of continental crust of global extent as demonstrated by coeval rifting and igneous activity in Laurentia (Mackenzie and Gardar events; Pesonen and Neuvonen, 1981).

The most interesting feature in Fennoscandian APWP is the pronounced clockwise and self-closing loop 2 (Fig. 7). This loop can be linked to the Subjotnian anorogenic magmatic interval (1650–1320 Ma) when large amounts of Rapakivi granites and associated anorthosites and mafic dykes were intruded into the Central Fennoscandian Shield. The loop is well constrained by radiometric age and stratigraphic data on igneous and sedimentary rocks and by cross-cutting relationships of mafic dykes in Central Sweden and South Finland (Piper, 1979; Pesonen, 1979; Bylund and Pesonen, 1987). It is the most important kinematic feature in the Fennoscandian APWP and will be discussed in more detail below.

The geologically younger part of the APWP of Fennoscandia is shown in Fig. 8. Reliable poles are found only in the Late Precambrian, Cambrian, Devonian, Carboniferous and Permian data (see also Bylund, 1986; Bylund and Pesonen, 1987). The Late Precambrian–Permian APWP is expressed by a NW-trending swathe which makes a 90° change towards north at about Late Devonian times (360–380 Ma ago). This bend in the Palaeozoic APWP coincides in time with the hot-spot related alkaline magmatism in the Kola Peninsula (Zonenshain et al., 1985).

Drift history of Fennoscandia

The drift history of Fennoscandia was calculated from the APWPs in Figs. 7 and 8 using the following method. The paths were first divided into successive periods of about 30–100 m.y. The periods (Table 2) are not of equal length because of the uneven distribution of GMPs along the APWP. The Period Mean Poles (PMPs) are defined as the mid-points on the APWP for each period. If the APWP swathe is represented by many successive GMPs (e.g., the Svecofennian APW segment, Fig. 7), the PMPs roughly coincide with the GMPs. Seventeen successive periods with corresponding PMPs were selected (Table 2).

The position of Fennoscandia at different periods was calculated as follows. The city of Kajaani (64.1° N, 27.7° E) was selected as a reference city

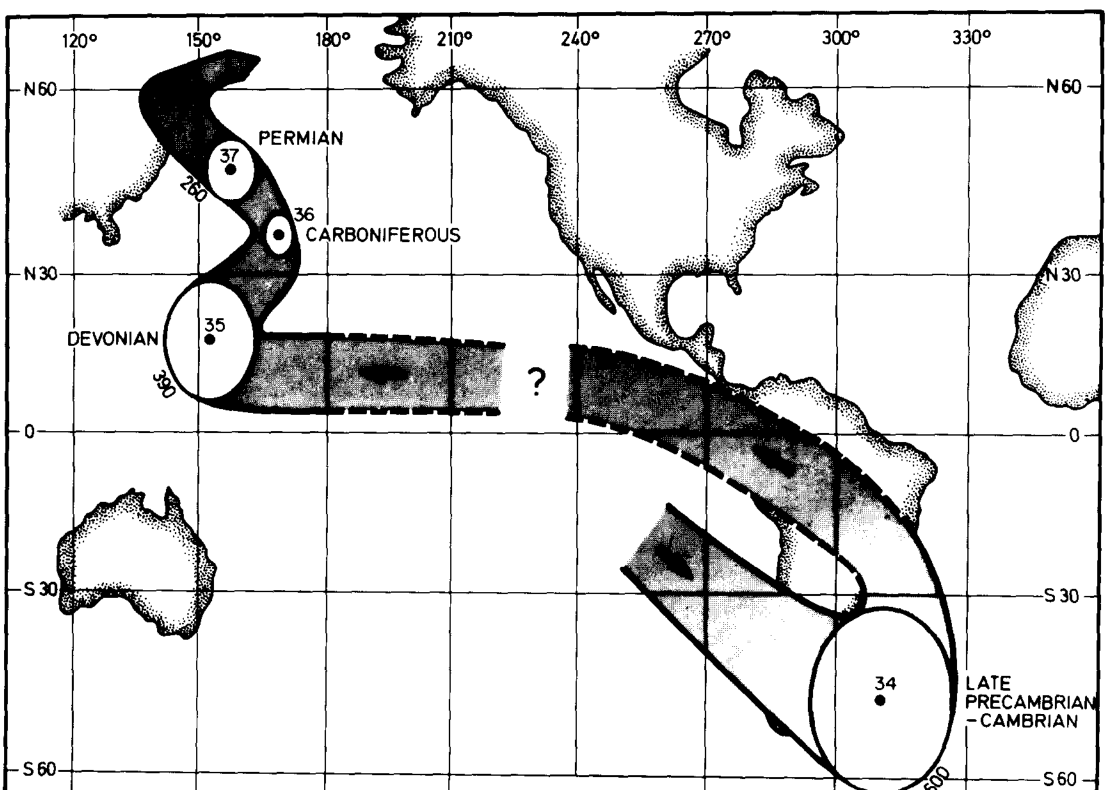

Fig. 8. APWP for Fennoscandia during Late Precambrian–Permian times (~ 650–250 Ma). The Late Precambrian–Cambrian pole (No. 34) has been plotted as a south pole (unlike the other poles) for plotting reasons. (If the north pole is chosen a more complex APW segment with a large gap between the Sveconorwegian (see Fig. 7) and Late Precambrian–Cambrian poles emerges.)

TABLE 2

Drift history of Fennoscandia from Archaean to Permian

Era	Age	D_{ref}	I_{ref}	Plat.	Plon.	λ	$\|d\lambda\|$	$\|d\lambda\|/dt$	θ	$d\theta$	$d\theta/dt$
Archaean	2680	304	73	64	313	59			−56		
							43	0.4		−22	−3
Early Svecofennian	1880	326	30	37	249	16			−34		
							6	2.1		−14	−46
Middle Svecofennian	1850	340	39	46	234	22			−20		
							2	0.2		−19	−19
Late Svecofennian	1750	359	37	46	209	20			−1		
							24	1.7		−18	−12
Early Subjotnian	1600	17	−8	21	190	−4			17		
							22	1.3		−30	−16
Middle Subjotnian	1415	47	33	34	151	18			47		
							11	2.4		20	43
Middle Subjotnian	1370	27	48	51	168	29			27		
							32	6.9		14	29
Late Subjotnian	1320	13	−6	22	194	−3			13		
							17	9.2		−17	83
Early Jotnian	1300	30	−36	3	180	−20			30		
							6	1.3		−25	51
Late Jotnian	1250	55	−27	1	155	−14			55		
							14	0.7		60	30
Early Sveconorwegian	1050	355	−47	2	212	−28			−5		
							42	3.0		2	2
Middle Sveconorwegian	950	353	−80	−44	211	−70			−7		
							49	3.8		30	30
Late Sveconorwegian	850	323	−38	0	242	−21			−37		
							58	3.2		−93	−47
Late Precambrian–Cambrian	650	236	−57	−48	306	37			56		
							34	1.2		5	2
Devonian	375	52	5	18	152	3			51		
							13	1.8		19	26
Carboniferous	300	32	30	37	168	16			32		
							13	2.6		−4	−8
Permian	250	36	48	48	157	29			36		

Age data (Ma) estimated from the calibrated APW curves of Figs. 7 and 8.

D_{ref} and I_{ref} (in degrees) are the reference declination and inclination, respectively, calculated from the Period Mean Poles (Plat. (°N), Plon. (°E) with respect to the reference city (Kajaani, 64.1°N, 27.7°E)

Plat. and Plon. are the estimated mean poles for each era (Period Mean Pole) (latitude °N, longitude °E) along the APW curve in Figs. 7 and 8.

λ = reference palaeolatitude (degrees).

$|d\lambda|$ = palaeolatitudinal drift during two successive time periods (in degrees).

$|d\lambda|/dt$ = corresponding drift velocity (cm/yr).

θ = amount of rotation (degrees) with respect to present orientation of Fennoscandia (+, anticlockwise; −, clockwise)

$d\theta$ = amount of rotation between two successive periods (degrees).

$d\theta/dt$ = corresponding rotation velocity (degrees/100 Ma).

(Pesonen and Neuvonen, 1981). Reference magnetization directions (D_{ref} and I_{ref}) were calculated from the PMPs using the method of Irving (1964, p. 186), and the palaeolatitude of Fennoscandia for each period was calculated from the I_{ref} values assuming an axial geocentric dipole field. This assumption is justified for the periods considered here (see also Bylund and Pesonen, 1987; Pesonen, 1987) The results of this calculation place Fennoscandia in the correct palaeolatitude at each period (Fig. 9).

The orientation of Fennoscandia at successive periods was calculated by subtracting D_{ref} values from the present axial geocentric dipole declination (360°); the rotation of Fennoscandia relative to its present orientation corresponds to this declination difference. The sense of rotation is defined by allowing a positive declination difference correspond to a clockwise rotation and a negative declination to an anticlockwise rotation. Table 2 summarizes the rotation parameters. The drift of Fennoscandia in terms of palaeolatitudes and various orientations is outlined in Fig. 9. In order to visualize Fennoscandia in different positions at successive periods, it has been shifted arbitrarily to the right.

From Fig. 9 it is evident that Fennoscandia has been located in a low to moderate latitudinal belt (~35°N–35°S) during most of its geological history. This startling finding is a crucial constraint on the models of tectonic evolution of Fennoscandia and in testing and constructing Proterozoic

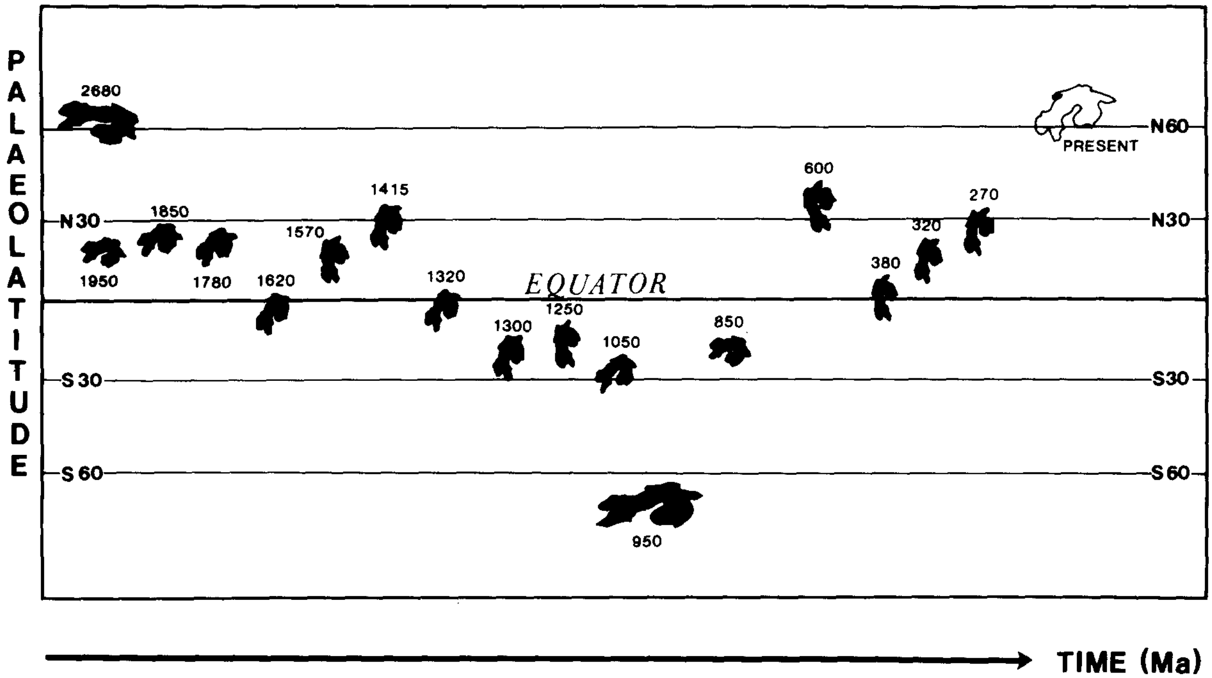

Fig. 9. The drift history of Fennoscandia from Archaean to Permian. Fennoscandia is plotted at correct palaeolatitudes and in correct orientations (with respect to its present orientation). To show up Fennoscandia at successive positions, it has been shifted arbitrarily to the right (longitudes are not shown as they cannot be determined by palaeomagnetic methods). The variation in size of Fennoscandia is due to the projection (Gall's). Lateral growth of Fennoscandia during orogenies (Svecofennian, Sveconorwegian and Caledonian) is not shown.

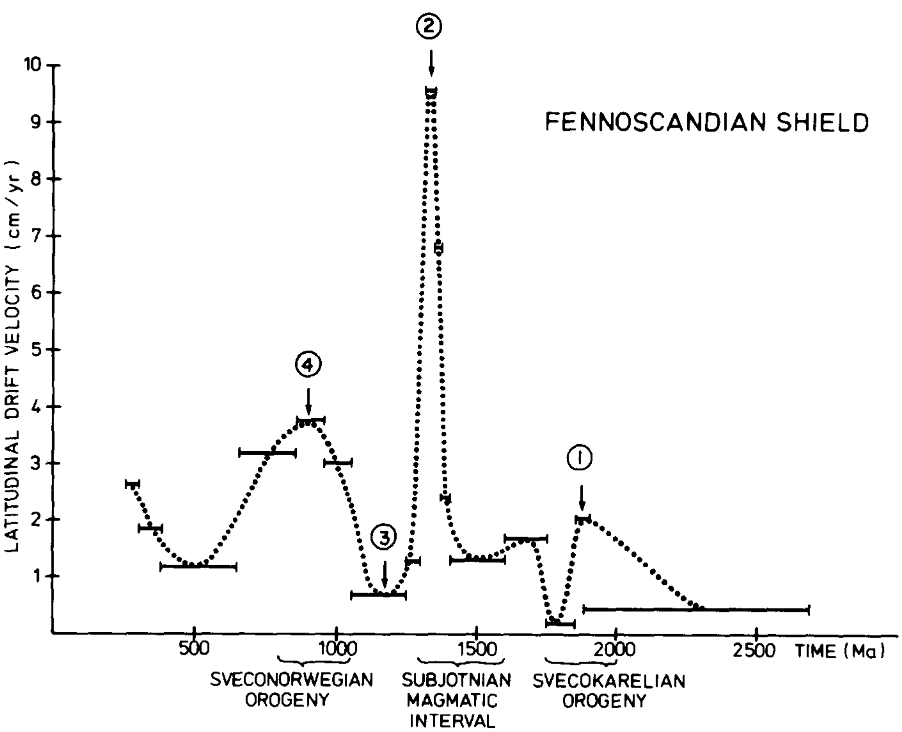

Fig. 10. Latitudinal drift velocity (cm/yr) of Fennoscandia from Archaean to Permian times (~ 2700–250 Ma). The horizontal bars correspond to periods shown in Table 2. The numbers correspond to apices of the four APW loops in Fig. 7 and are linked to major orogenies (*1*—Svecofennian; *4*—Sveconorwegian), to anorogenic magmatism (*2*—Subjotnian Rapakivi granites), or to a major rifting episode (*3*—Jotnian).

continental assemblages (supercontinents) (e.g., Piper, 1982). As an example, the palaeolatitudinal data suggest that in the early Jotnian period (~ 1350–1300 Ma ago) Fennoscandia was located at low latitudes (~ 5°S–15°S). Palaeoclimatological evidence reveals that the Jotnian red sandstone in Satakunta (~ 1.35 Ga), southern Finland, was deposited under warm or hot climatic conditions (Neuvonen, 1974) consistent with palaeolatitude data.

A similar argument also applies to older sediments in Fennoscandia. Figure 9 predicts a palaeolatitude of around 40°–50°N for the Early Proterozoic Jatulian period (~ 2.4–2.0 Ga ago). Moderately high palaeolatitude values (25°–55°) have been reported from Jatulian rocks (Neuvonen, 1975; Neuvonen et al., 1981) but, as pointed out previously, these data fail the filtering. If we assume, however, that this palaeolatitude estimate is roughly correct (see also Mertanen et al., 1987), the Jatulian clastic sediments should reveal palaeoclimatological evidence of high to moderate latitudes. In this context the discovery by Marmo and Ojakangas (1984) of Jatulian glaciogenic tillite formations in Finland is noteworthy, but it should be kept in mind that the existence of tillites does not necessarily imply high palaeolatitudes (e.g., see Nesbitt and Young, 1982; Embleton and Williams, 1986).

Drift velocities and plate kinematics

The palaeolatitudinal drift velocity of Fennoscandia was calculated from the successive positions of Fennoscandia at the various periods given in Table 2. The drift velocity across the palaeolatitudes (Fig. 10) represents the minimum velocity (Ullrich and Van der Voo, 1981). The rotational velocity curve (Fig. 11) was calculated from the successive orientations of Fennoscandia (Table 2).

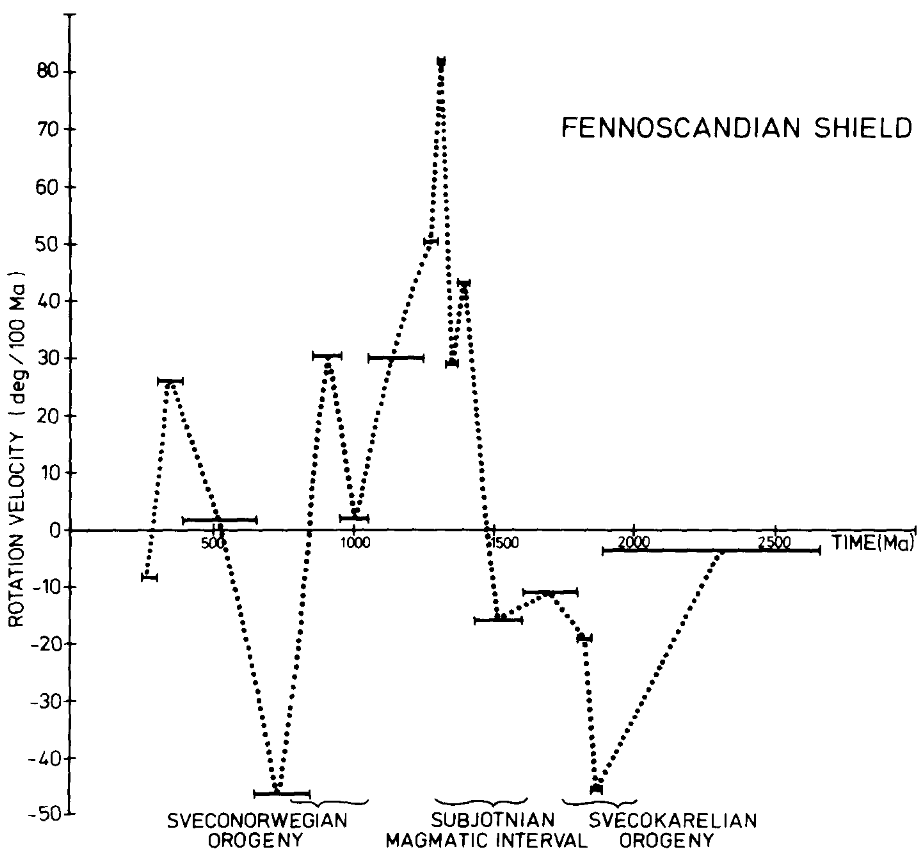

Fig. 11. Rotation velocity curve (°/100 Ma) of Fennoscandia from Archaean to Permian (~ 2700–250 Ma). Rotation is regarded positive when anticlockwise and negative when clockwise.

The average palaeolatitudinal drift velocity for Fennoscandia is ~ 2 cm/yr and the average rotation velocity around 0.3°/Ma. These results are compatible with those reported from other continents (e.g., Ullrich and Van der Voo, 1981; Zonenshain et al., 1985). In contrast to the Laurentian Shield (Irving, 1979), the latitudinal drift velocity of Fennoscandia during the Precambrian was not higher than during the Phanerozoic.

Orogenies and plate kinematics

It is evident from Figs. 10 and 11 that the Proterozoic orogenies in Fennoscandia are closely associated with high to moderate latitudinal drift and rotation rates and are thus periods characterized by high kinematic activity. Figures 10 and 11 reveal, however, slightly different kinematic signatures for the two orogenies. The older, Svecofennian orogeny, is characterized by an anticlockwise rotation, the maximum of which (~ 0.4°/Ma) occurs at the peak of the orogeny about 1880 Ma ago. The latitudinal drift rate at this time is only ~ 1.5 cm/yr. In contrast, the Sveconorwegian orogeny is associated with both anticlockwise and clockwise rotations, with peaks of 0.3°/Ma during the preceding anticlockwise rotation and 0.45°/Ma during the subsequent clockwise rotation, respectively. The cross-over point from anticlockwise to clockwise rotation occurs ~ 900 Ma ago. At this time, the latitudinal drift rate has its maximum value (~ 4 cm/yr), which is considerably higher than that during the Svecofennian orogeny.

Baer (1983) has shown that the Grenvillian orogeny in the Canadian Shield (~ 1.1–0.8 Ga ago), which is considered as coeval with the Sveconorwegian orogeny, can also be divided into clockwise and anticlockwise rotation phases in a fashion strikingly similar to that in the Sveconorwegian orogeny. The two orogenies have been previously correlated on the basis of geological and palaeomagnetic data (e.g., see Patchett et al., 1978; Pesonen and Neuvonen, 1981). The kinematic correlation between the two orogenies presented here strengthens the idea that the Grenville and Sveconorwegian Provinces represent dismembered elements of the once continuous orogenic belt. It is conceivable that the drastic changes in rotation curves represent changes in the Euler geometry describing the motion of the combined Fennoscandian–Laurentian continent during and slightly after the collision of Laurentia and Fennoscandia at about 1.1 Ga ago (Pesonen and Neuvonen, 1981). New palaeomagnetic data from the Grenville Province (Dunlop et al., 1985) give some support to the idea (e.g., Irving, 1979) that the Grenville Province moved like a "microcontinent" and collided with interior North America during the Grenvillian orogeny. A strikingly similar motion of the Sveconorwegian "microcontinent" relative to the interior Fennoscandia has recently been suggested by Pesonen et al. (1986). We return to this point later in example 2 from the POLAR Profile.

Anorogenic magmatism and plate kinematics

Figures 10 and 11 reveal that the most pronounced peak in drift and rotational velocities took place in late Subjotnian times at about 1.45–1.25 Ga ago, i.e., shortly before the onset of Jotnian rifting. The high drift rate during this interval is a consequence of the pronounced Subjotnian APW loop (Fig. 7; e.g., Pesonen, 1979; Piper, 1979; Pesonen and Neuvonen, 1981; Bylund, 1985). We note here that causes other than APW, such as errors in age data (Welin and Lundqvist, 1984), non-dipole geomagnetic field anomalies (Pesonen and Neuvonen, 1981; Pesonen et al., 1985a, b) and local tectonics could cause some of the Subjotnian poles to become aberrant, and ultimately to become responsible for the entire loop. This is, however, unlikely since the loop is defined by class-A poles (Fig. 2c). A similar peak at the same time (Elsonian) is also evident in the latitudinal drift velocity curve of the Laurentian Shield (Ullrich and Van der Voo, 1981).

Several explanations for the high velocities during the Subjotnian period can be offered. During this time Fennoscandia was drifting at nearly equatorial latitudes (Fig. 9) and thus with enhanced velocity, since plates near the equator appear to move faster than plates closer to the poles (e.g., Jurdy and Gordon, 1984). Another possibility is that Fennoscandia drifted independently as a single (small) plate across a thermal dome (mantle superswell; Hoffman, 1988) or across a local hot spot (Pesonen, 1989) during late Subjotnian times. Both of these factors (i.e., the size of the plate and the presence of a hot spot) may increase the drift velocity, since smaller plates tend to move faster than larger plates (e.g., Piper, 1987) and the movement of Fennoscandia across a thermal upwelling may be enhanced due to an increased mantle convection rate (Arkani-Hamed et al., 1981). In this context it is noteworthy that the peak in the drift rate at about 1450–1250 Ma ago coincides with one of the maximum values of mantle convection velocity for the Earth as suggested by Arkani-Hamed et al. (1981). However, this could simply be a coincidence in the light of the large number of parameters in the Arkani-Hamed et al. model.

Geological and geochronological data support the idea that Fennoscandia drifted across a thermal upwelling during Subjotnian times. This interval is characterized by large numbers of anorogenic Rapakivi granites, anorthosites and mafic dyke swarms along a belt which runs from Eastern Finland to Central Sweden. The ages of the Rapakivi granites and associated gabbro–anorthosites reveal a systematic decrease from about 1620 Ma (Wiborg massif) in the east to ~ 1350 Ma (Ragunda massif) in the west (e.g., Vaasjoki, 1977; Piper, 1979; Gorbatschev and Gaál, 1987), consistent with a passage of Fennoscandia across a thermal upwelling responsible for these intrusions. Westra and Schreurs (1985) have suggested that a series of thermal domes existed in this area during late Svecofennian times which acted as "precursors" for the subsequent Rapakivi granites.

The Subjotnian anorogenic belt in Fennoscandia also includes a number of mafic dyke swarms (Pesonen et al., 1985a; Bylund and Pesonen, 1987). The geochemistry of these dykes has not been examined in the light of the proposed thermal upwelling or hot-spot model (e.g., see De Boer and Snider, 1979), but the ages of these dykes decrease from east to west (e.g., Bylund and Pesonen, 1987), consistent with the thermal upwelling model. The Subjotnian magmatism terminated about 1.3 Ga ago and was succeeded by the Jotnian rifting episode at about 1.3–1.2 Ga ago. At that time Fennoscandia became closely connected to Laurentia (Patchett et al., 1978; Pesonen and Neuvonen, 1981) as demonstrated by coeval rifting and magmatic activity in North America (Mackenzie dykes), Greenland (Gardar dykes) and Fennoscandia (Jotnian dolerites). The palaeomagnetic poles and their polarities (all normal) of these ~ 1.25 Ga old dolerites from the two shields have been used to reconstruct the position of Fennoscandia with respect to Laurentia at this time (e.g., see Patchett et al., 1978; Gorbatschev and Gaál, 1987).

Palaeomagnetic examples from the polar profile

Figure 12 outlines the general geology of the POLAR Profile area in Northeastern Fennoscandia (see Gaál et al., this issue). Three case examples are presented in order to envisage different types of palaeomagnetic applications in solving some of the tectonic problems in this part of Fennoscandia.

Example 1: Dating synorogenic rocks by palaeomagnetism

The age, origin and tectonic history of the Lapland Granulite Belt (Fig. 12) are disputed. There is a concensus that it represents a slice of continental crust overthrusted to the south over the Archaean craton, but the mechanisms and time of the upthrusting are not precisely known (e.g., Meriläinen, 1976; Barbey et al., 1984; Kesola, 1986, pers. commun.; Gaál et al., this issue). The palaeomagnetic pole (AK; Fig. 13) of the Akujärvi quartz diorite from the eastern part of the Lapland Granulite Belt suggests a magnetization age of about 1900 Ma, consistent with the U–Pb (Zr) age of 1925 Ma (Pesonen and Neuvonen, 1981) on these rocks. The magnetization was probably acquired during slow cooling of the belt after the upthrusting and high-grade (granulite-facies) metamorphism, because this pole, and its predominantly normal polarity, are compatible with many other early Svecofennian (~ 1880 Ma) poles from South Finland and North Sweden (Figs. 3 and 13). The good match between early Svecofen-

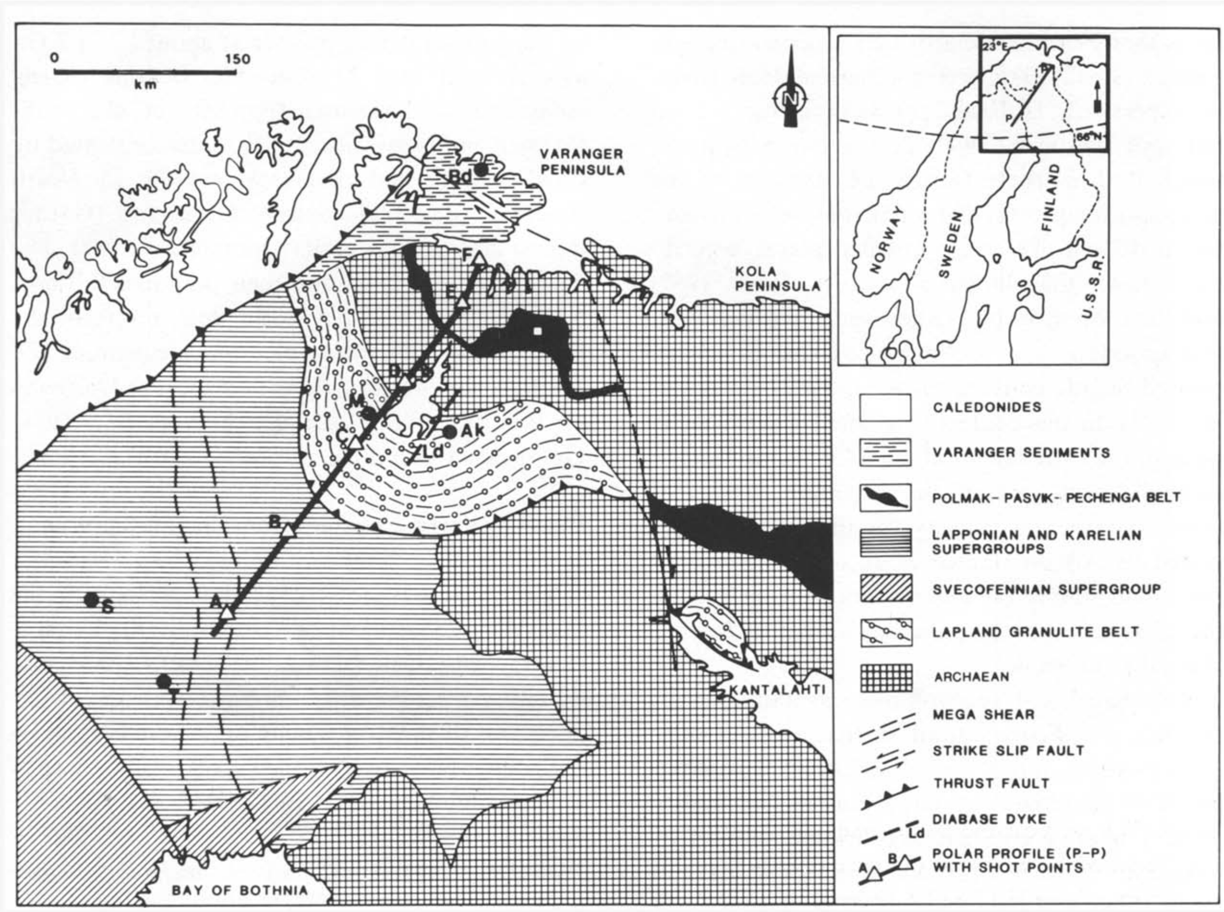

Fig. 12. Simplified geological map of the northeastern part of the Fennoscandian Shield showing the seismic POLAR Profile (with shotpoints A, B, C, D, E and F; see Von Knorring and Lund, this issue). Also shown are the sampling sites of the three palaeomagnetic case histories described in the text. Granulite belt sites (examples 1 and 3): *M*—Menesjärvi granulites; *Ak*—Akujärvi quartz diorite; *Ld*—Laanila dyke swarm. Svecofennian sites (example 1): *S*—Svappavaara gabbro; *T*—Tärendö gabbro. Varanger Peninsula sites (example 3): *Bd*—Båtsfjord dykes. The small open square is the site for the Kola Superdeep Hole. See Figs. 13 and 14 for palaeomagnetic data.

nian poles from the Lapland Granulite Belt and from other blocks outside of it (e.g., blocks 4, 7 and 8), suggests that no large-scale movements have taken place between these blocks *since* 1.9 Ga; however it does not preclude possible movements *before* 1.9 Ga (e.g., see Marker, 1985; Berthelsen and Marker, 1986a).

The second pole (M) from the middle part of the Lapland Granulite Belt comes from the Menesjärvi granulites (Papunen et al., 1977) and plots on the slightly younger part of the APW segment (Fig. 13). No radiometric age data are available from these sheared granulites, but the pole position suggests a middle Svecofennian age of ~ 1.85 Ga. The difference in the pole positions of the Akujärvi and Menesjärvi rocks probably reflects a metamorphism and subsequent cooling that occurred slightly later in the west (pole M) than in the east (pole AK) (see also Hörmann et al., 1980; Gaál et al., this issue). Another possibility is that the western part represents a slightly deeper exposure of the crust, and hence a younger uplift magnetization (Marker, 1985, pers. commun., 1987).

In Fig. 13 the high blocking temperature (HBT) palaeomagnetic poles of the synorogenic Svappavaara gabbro from Northern Sweden (1880–1725 Ma) are plotted onto the early Svecofennian–Archaean APW segment (Elming, 1985). The HBT poles trace this segment "backwards" in time from

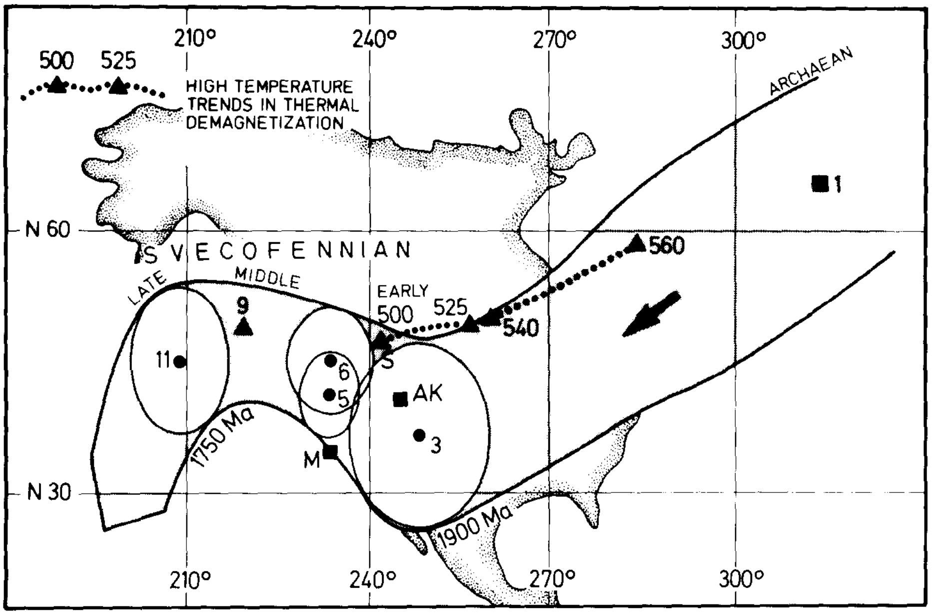

Fig. 13. Enlarged APW segment of Fig. 7 delineating the the poles of the Svecofennian orogen (1925–1700 Ma). Superimposed on this path is the trajectory (dotted line) of high blocking temperature (HBT) poles from the synorogenic Svappavaara gabbro from Northern Sweden (1880–1725 Ma; see Elming, 1985). *Ak*, *M* and *S*—palaeomagnetic poles (see Fig. 12 for elaboration).

the early Svecofennian towards the older part of the APWP. A possible palaeomagnetic interpretation (e.g., Morgan, 1976) of these data is that the trajectory of the HBT poles records the motion of Fennoscandia during prolonged cooling of the Svecofennian orogeny. An alternative interpretation is that the HBT directions reflect the presence of another (as yet unidentified) remanence component in these rocks, which has nearly the same blocking temperature spectrum as the Svecofennian component.

Example 2: Laanila dykes and the motion of Sveconorwegia relative to interior Fennoscandia

The Lapland Granulite Belt and the Archaean Inari craton are cut by ~ 1.0 Ga old Laanila dykes (Fig. 12). In Fig. 7 the Laanila pole (LD; Pesonen et al., 1986) has been plotted onto the Fennoscandian APWP. This pole is virtually coincident with the early Sveconorwegian poles (26) obtained from basement rocks of Southern Fennoscandia (e.g., Poorter, 1972a, 1975; Hargraves and Fish, 1972), implying that the Laanila dykes intruded comtemporaneously with the uplift and cooling of the Sveconorwegian block about 1.05–1.0 Ga ago. The tectonic implication of this result is that the Sveconorwegian Province has been an integral part of Fennoscandia since this time (e.g., Pesonen, 1989).

In the alternative interpretation (see Fig. 7), the Laanila pole is compared with poles obtained from dolerite dykes from east of the Protogine Zone (Fig. 1). These so-called "front-parallel" dykes have the same trend (NNE) and age (~ 980–900 Ma; Patchett, 1978) as the Laanila dykes. The difference in pole positions between the two swarms is about 20°. This difference may reflect microcontinental movement of the Sveconorwegian block 1.0–0.9 Ga ago before it was sutured onto Fennoscandia at about 0.9 Ga ago (Pesonen et al., 1986; Pesonen, 1989). This "plate tectonic" interpretation, involving some 700 km of lateral movement and ~ 15° of clockwise rotation of the Sveconorwegian microcontinent relative to interior Fennoscandia is, however, purely speculative as such a small relative motion between blocks is not resolvable within the error limits of the palaeomagnetic data. This scenario is, however, strikingly similar to that proposed for the motion of the Grenville Province relative to interior Laurentia at about the same time (see Dunlop et al., 1985).

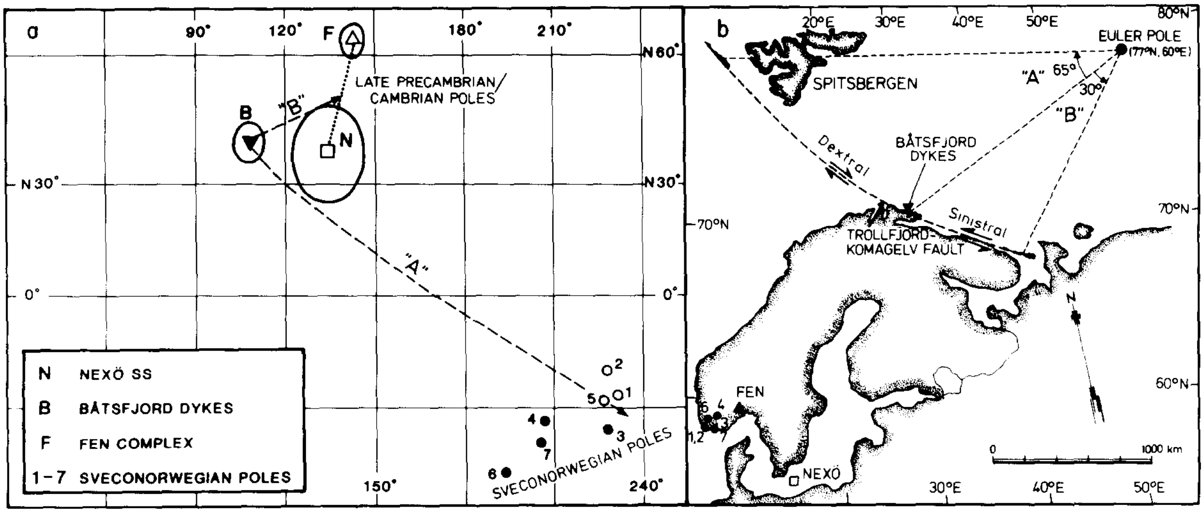

Fig. 14. Palaeomagnetic test of the proposed (Kjøde et al., 1978) strike-slip movement along the Trollfjord–Komagelv (T–K) fault in the Varanger Peninsula (b). In (a) two models are shown. Model "A" depicts the original concept of a dextral strike-slip fault by Kjøde et al. In this model the Båtsfjord dyke pole (*B*) is compared with Sveconorwegian (1, 2, 3, 4 and 6) and Torridonian (5) poles and it implies a considerable (~ 1000 km) dextral movement along the T–K fault of the northern (allochthonous) part of the Varanger Peninsula with respect to the southern part during Sveconorwegian–Devonian times. In model "B" (this paper) the Båtsfjord pole is compared with the Nexö sandstone (*N*) and Fen carbonatite (*F*) poles. This model implies a sinistral strike-slip movement along the T–K fault amounting to no more than 600 km during Late Precambrian–Devonian times.

Example 3: Movement along the Trollfjord–Komagelv fault

Kjøde et al. (1978) have proposed that considerable dextral strike-slip movement has taken place along the Trollfjord–Komagelv (T–K) fault in the Varanger Peninsula between Late Precambrian and Devonian times (Figs. 12 and 14). Their conclusion is based on a comparison of palaeomagnetic data from the Båtsfjord dykes (~ 640 Ma; Beckinsale et al., 1976; Kjøde et al., 1978) located on the *northern* side of the fault; with those of Sveconorwegian and Torridonian rocks on the *southern* side. The difference in pole position between these two data sets is about 65° (Fig. 14a) and, in order to match the poles, an extensive (> 1000 km) dextral movement along the T–K fault was proposed (model "A"). However, this comparison is not very meaningful as the majority (see Sundvoll (1987) for a possible exception) of the Sveconorwegian and Torridonian rocks (and poles) used in this comparison are more than 200 Ma older than the Båtsfjord dykes (Kjøde et al., 1978).

In model "B" (Fig. 14a) the pole of the Båtsfjord dykes (B) is compared with the poles of the Nexö sandstone (N) of Late Precambrian–Cambrian age (Prasad and Sharma, 1978) and of the Fen alkaline complex with an age of about 550 Ma (Poorter, 1972b; Storetvedt, 1973). The ages of these rocks are more comparable with that of the Båtsfjord dykes than are those from the Sveconorwegian–Torridonian rocks. The new comparison (model "B") reveals a small but significant difference between the Båtsfjord pole on the one hand and the Nexö or Fen poles on the other. This difference may be attributed to minor age differences and hence to APW. However, if this difference is to be interpreted in terms of transcurrent movements along the T–K fault, the motion may be sinistral rather than dextral, amounting to roughly 600 km at the most (Fig. 14b). At this stage we may conclude that there is clear geological (e.g., Johnson et al., 1978) and geochemical (Gaál et al., this issue) evidence that *some* lateral movement has taken place along the T–K fault, but the sense of the movement (dextral or sinistral) and its precise age and magnitude are still unknown (see also Abrahamsen, 1985).

Conclusions

In improving the geotectonic models for the POLAR Profile area of the northern segment of the European Geotraverse, the following conclusions derived from palaeomagnetic studies should be taken into account:

(1) There are insufficient palaeomagnetic data to distinguish whether the Early Proterozoic tectonic belts between the Archaean cratons in Northern Fennoscandia are products of plate tectonic or intracratonic processes.

(2) During most of geological history Fennoscandia has been located at moderate to low latitudes and occasionally collided with other continents causing orogenies at shield margins. The orogenies coincide with APW loops which reflect major changes in plate geometries.

(3) A pronounced peak in latitudinal drift velocity occurred during the late Subjotnian anorogenic interval (~ 1.4–1.3 Ga ago) when Fennoscandia drifted across a thermal upwelling or hot spot located near the palaeoequator.

(4) Palaeomagnetic data of the Lapland Granulite Belt suggest that the post-orogenic cooling in this belt took place during early Svecofennian times about 1.9 Ga ago.

(5) The pole of the Laanila dyke swarm suggests that the Sveconorwegian Province was already integrated with interior Fennoscandia during the intrusion of these dykes (~ 1.0 Ga ago). A small microcontinental movement and amalgamation of this province with interior Fennoscandia are plausible.

(6) The high blocking temperature palaeomagnetic directions of Svecofennian gabbros from Sweden define pole trajectories which may record movement of Fennoscandia during slow post-orogenic cooling.

(7) The strike-slip motion along the Trollfjord–Komagelv fault may be sinistral rather than dextral.

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Appendix

This Appendix lists all the individual grade A–B-palaeomagnetic poles (pole No., entry, Plat. (° N) and Plon. (° E)) used to calculate each Grand Mean Pole (GMP) of the Fennoscandian APWP (pole numbers 1–37 in Table 1 and in Figs. 7 and 8). The entry codes (underlined) follow the key system of the new palaeomagnetic database of Fennoscandia (see Pesonen et al., 1989). All the details, including statistical parameters and references for each pole, are also found in that publication.

Appendix

Pole No.	Entry	Plat.	Plon.	Entry	Plat.	Plon.	Entry	Plat.	Plon.
1	A01-001	64,	313						
2	E01-001	41,	246						
3	S02-022	26,	257	S02-024	40,	243	S02-027	44,	246
4	J02-010	32,	230						
5	S01-002	43,	232	S01-003	38,	239			
	S01-006	43,	235	S01-009	48,	225	S01-010	36,	238
6	S03-005	42,	248	S03-002	45,	230	S03-009	52,	235
	S03-011	43,	228	S03-020	39,	257	S03-022	57,	222
	S03-024	42,	231	S03-030	40,	221			
7	J01-001	47,	234						
8	J03-005	49,	235						
9	A01-002	48,	221	A01-003	42,	249	A01-006	47,	188
10	S02-016	59,	188	S02-021	45,	218			
11	S03-006	43,	220	S03-023	53,	194	S03-027	47,	205
	S03-033	41,	214						
12	S02-012	36,	201	S02-014	47,	195			
13	B02-004	13,	189	B02-006	12,	182	B02-009	22,	190
14	S03-014	21,	187	S03-031	23,	200			
15	B03-011	28,	197	B03-013	21,	180	B03-016	40,	197
16	B01-001	23,	179	B01-002	32,	185	B01-006	33,	168
	B01-009	27,	189	G05-003	24,	192			
17	B02-002	41,	169	B02-005	31,	187	B02-007	28,	188
	B02-011	43,	175	B02-020	30,	175			
18	B03-014	27,	167	B03-017	34,	136	B03-018	39,	142
	B03-020	28,	141	B03-021	38,	155	B03-023	35,	165
19	B03-001	49,	171	B03-002	53,	164	B03-003	51,	170
20	B03-005	16,	194						
21	G01-001	3,	180						
22	G01-003	2,	158	G01-005	7,	150	G01-006	−6,	146
23	G03-001	5,	159	G03-004	1,	149			
24	G02-002	−8,	157	G02-003	−13,	146	G02-004	−11,	159
	G02-005	5,	168	G02-006	−2,	157	G02-007	−5,	158
	G02-007	−4,	153	G02-009	1,	161	G02-010	−7,	157
25	G04-002	−5,	150						
26	P03-001	−13,	219	P03-020	3,	215	P03-032	7,	201
	P03-033	1,	218	P03-039	−8,	208			
27	E01-005	−4,	218						
28	P01-001	−43,	214	P01-002	−40,	207			
29	P02-001	−52,	209	P02-002	−45,	214	P02-003	−49,	211
	P02-004	−30,	211						
30	P03-002	−37,	232	P03-004	−44,	232	P03-005	−63,	208
	P03-006	−51,	227	P03-008	−43,	220	P03-009	−40,	221
	P03-011	−46,	197	P03-012	−41,	213	P03-014	−41,	217
	P03-015	−48,	211	P03-016	−44,	215	P03-018	−44,	214
	P03-028	−42,	200	P03-030	−43,	194	P03-017	−42,	229
	P03-031	−50,	244	P03-040	−42,	207	P03-041	−47,	228
	P03-043	−34,	208						
31	P03-003	−31,	226	P03-025	−17,	239	P03-026	−22,	231
	P03-025	−28,	232	P03-036	−24,	228			
32	P03-012	−8,	244	P03-019	−7,	236	P03-021	10,	246
	P03-021	0,	253	P03-024	5,	249			
33	P01-005	−6,	237	P01-011	6,	246			
34	Q02-002	38,	134	Q02-003	63,	142	Q02-007	41,	108
35	Q05-001	19,	160	Q05-002	16,	155	Q05-004	12,	133
	Q05-005	22,	170	Q05-007	21,	144			

Pole No.	Entry	Plat.	Plon.	Entry	Plat.	Plon.	Entry	Plat.	Plon.
36	Q06-001	40,	160	Q06-002	38,	166	Q06-003	39,	165
	Q06-004	38,	167	Q06-005	31,	174	Q06-006	37,	174
	Q06-007	39,	169						
37	Q07-002	43,	162	Q07-003	44,	161	Q07-004	47,	140
	Q07-005	39,	153	Q07-006	40,	132	Q07-007	53,	143
	Q07-008	39,	161	Q07-009	62,	143	Q07-011	45,	169
	Q07-012	47,	156	Q07-014	57,	175	Q07-015	56,	162
	Q07-016	51,	166	Q07-017	38,	166			

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