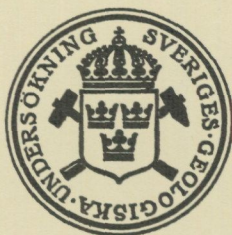


SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 780 AVHANDLINGAR OCH UPPSATSER ARSBOK 75 NR 1

ANDERS LINDH, ZOLTAN SOLYOM  
AND  
INGRID JOHANSSON

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CHEMICAL HOMOGENEITY  
AMONG BASIC HYPABYSSALS  
ALONG THE SCANDINAVIAN PROTOGINE ZONE



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## ABSTRACT

Lindh, A., Solyom, Z., and Johansson, I., 1980-04-01, revised 1981-01-15: The question of chemical homogeneity among basic hypabyssals along the Scandinavian Protogine Zone. Sveriges geologiska undersökning, Ser. C, No. 780, pp. 1—36. Uppsala 1981.

Along a broad tectonic zone in southern Sweden known as the Protogine Zone and in general also as the 'Gothian Front' two suites of mafic hypabyssal intrusions occur, one in the east and one in the west thought to have intruded in connection with the formation of the 'Front'. Applying multivariate cluster analysis, step-wise discrimination analysis, and principal component analysis, chemical analyses of the western suite have been divided in two groups. Furthermore, t test statistics revealed that the means for  $TiO_2$ ,  $Al_2O_3$ ,  $MgO$ ,  $Na_2O$ ,  $K_2O$ , and  $P_2O_5$  are different at the 0.999 significance level. The chemical clustering displays a geographic clustering with a homogeneous northern and a heterogeneous southern population. This speaks against a common origin of the rocks and casts doubts on hypotheses suggesting that the rocks have been intruded in connection with a plate-tectonic process. If this is true there are at present no volcanics known to have accompanied any possible continental collision or subduction zone involving the 'Gothian Front'.

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## INTRODUCTION

In an effort to apply actualistic plate-tectonic approaches to the evolution of the earth many search for sutures in shield areas. Some have confined these approaches to the last billion of years, others to all the crustal history. South-western Sweden and adjacent parts of Norway seem to be a suitable region for testing

today's concept of earth development. The region is characterized by long-recognized lithologic discontinuities (e.g. Magnusson 1963; Lundegårdh 1974) and more or less pronounced zones of strongly deformed rocks. In the absence of sufficient geochronological data recent hypotheses attempt to explain the gross features within the frame-work of actualistic plate-tectonic models (e.g. Zeck and Malling 1976; Burke et al. 1977; Berthelsen 1977, 1980). Among the precepts of those hypotheses is the now widely discussed connection of the North-American 'Grenville Front' to a Scandinavian 'Gothian Front', the southern part of which has since long been known as the Protogine Zone.

Zeck and Malling (1976) attempted to explain the recorded features applying a plate-tectonic model. Supporting evidence is found in a suggestion of a 50 km broad zone of crustal shortening and the occurrence of metavolcanics of poorly known composition belonging to the so-called Dal group of supracrustals (general Grenville age). They also refer to paleomagnetic results that are not consistent with the polar wandering curve for stable Europe. However, according to Bylund (oral communication) the paleomagnetic results obtained are rather inconclusive even if inconsistent with those from the central part of the Baltic Shield. Burke et al. (1977) suggest a similar model based on literature data reported by Magnusson (1965) and Zeck and Malling (1976).

Berthelsen (1977) presented a complicated picture with several obducted crustal slabs. The presented evidence is mainly based on the recognition of regionally occurring shear zones, lithologic discontinuities, and measured fold axes. In a later contribution (Berthelsen 1980) he thoroughly reconsiders this hypothesis, and it reappears in a basically revised form though on the whole still being based on the same evidence complemented mainly with a few recent age determinations.

Patchett et al. (1978) favour large-scale horizontal movements including continental rotation in Grenville time, but they do not suggest that subduction took place along a 'Gothian Front'. Supporting evidence is found in paleomagnetic results and age determinations of mafic dikes.

Gorbatshev (1980) reviews some of the most important field relations against the background of age determinations now available. He points out the existence of chemically identical and chronologically inseparable granitoids on both sides of the 'Front' (Filipstad granite group), and he concludes that whatever caused the development of the 'Front', no large scale horizontal movements including continental collisions or subductions were involved *later* than 1 650—1 700 million years before present. Lundegårdh (1977, 1980) also finds granites belonging to the Filipstad group on both sides of the 'Front'. Gorbatshev's conclusions are generally in accordance with those of Welin and Blomqvist (1966) as well as Patchett and Bylund (1977).

The present contribution forms part of an extensive geochemical survey of

Swedish dolerites. It is designed to present and discuss new chemical data on a suite of mafic dikes thought to be associated with the general development of the 'Front' in order to place constraints on possible models of the origin of the Scandinavian 'Gothian Front'.

## OUTLINE OF THE REGIONAL GEOLOGY

The region, the sample sites and the gross tectonic features of south-western Sweden are shown in Fig. 1. The part south of Lake Vänern is poorly known; with a few notable exceptions the only regional mapping was performed during the 19th century. More recent investigations are limited to detailed work in small areas, superficial surveys of greater regions and reinterpretations of the gross features in terms of current models. North of Lake Vänern intense field-work is in progress, so the present state of knowledge is here much better.

The Scandinavian part of the 'Grenville-Gothian Front' (incl. the Protogine Zone) is a belt of strongly schistose rocks which is very well defined in the south (Magnusson 1963) but less so in the north (Gorbatshev 1971). It is associated with mafic dikes. West of the Zone a suite of basic intrusions known as 'hyperites' occurs, and east of the Zone there is a suite of dikes that only recently were recognized to be semi-continuous along the whole 'Front'. The bordering part of the principal unit to the east of the Zone consists of 'early postorogenic' Svecokarelian granitoids. They have been dated by radioisotope methods and yield results around 1 650 Ma (Magnusson 1960; Welin et al. 1966; Röshoff 1975; Åberg 1978). In addition smaller but significant amounts of volcanics and clastic sediments occur. The principal unit to the west of the Protogine Zone is made up of a number of roughly north-south striking mega-units (Fig. 1). The easternmost of these is composed of gneissic granites and minor supracrustals among which lie relatively fresh volcanics (Gvein et al. 1974; Lundegårdh 1977). Some of these gneissic granites have been recognized as members of the Filipstad granite group (Lundegårdh 1977, 1980).

According to present knowledge, the mafic dikes east of the Protogine Zone were intruded about 1 000 million years ago (Patchett 1978), probably during an uplift of the crustal block to the west (Welin and Blomqvist 1966; Patchett and Bylund 1977). Earlier this suite was only recognized in southern Sweden, but now its existence along the whole 'Front' is confirmed (Patchett 1978). The chemical composition of these dikes will not be discussed in the present contribution. The 'hyperites' occur to the west of the Protogine Zone. South of Lake Vättern they are also found within the Zone and even within the granitic terrain immediately to the east. In the field they are recognized by dark feldspars which give the

rock an almost black appearance, and frequently they have a clearly visible subophitic texture.

The Mylonite Zone (Magnusson 1937; Lindh 1974) constitutes the next major tectonic discontinuity west of the Protogine Zone (Fig. 1). The *minimum* age of the Zone is about 1 000 Ma (Lindh and Kähr 1977). In the present context,

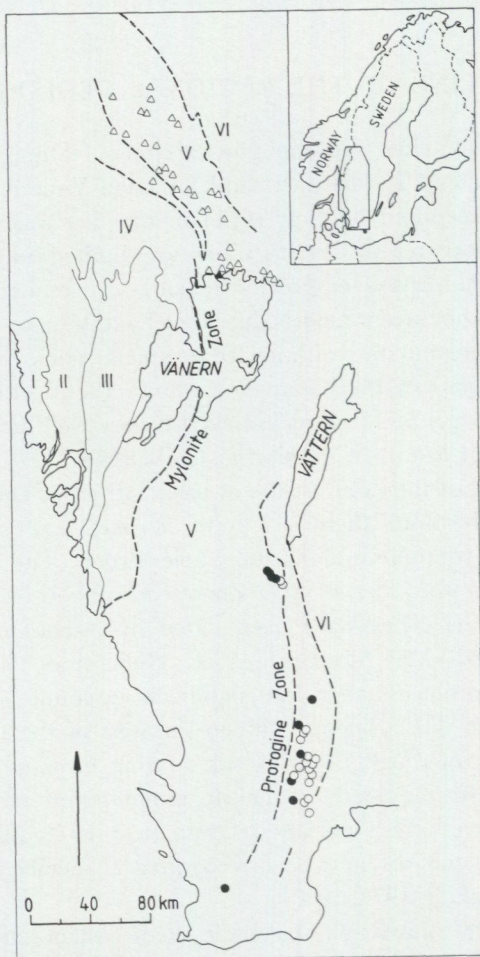


Fig. 1. Simplified map of south-western Sweden. Mega-units I — V make up the western principal unit and mega-unit VI is part of the Svecokarelian principal unit. I, Bohus granite (900—950 Ma); II, Stora Le-Marstrand group; III, Åmål mega-unit; IV, Western Pregothian mega-unit; V, Eastern Pregothian mega-unit; VI, Småland-Värmland granitoids.

Legend:

- |                 |                                       |
|-----------------|---------------------------------------|
| open circles:   | S-group samples south of Lake Vättern |
| solid circles:  | V-group samples south of Lake Vättern |
| open triangles: | V-group samples north of Lake Vänern  |
| solid triangle: | S-group sample north of Lake Vänern   |

its great importance lies in the fact that 'hyperites' are found up to and within the Zone north of Lake Vänern, but simultaneously it constitutes the extreme western limit for their occurrence. The continuation of the Zone through Lake Vänern is now confirmed (Håkansson et al. 1978; cf. Fig. 1); to the west of Lake Vättern no 'hyperites' are known in better mapped areas in the vicinity of the Mylonite Zone (Samuelsson 1978). Between the 'hyperites' and the Mylonite Zone there is a suite of irregularly formed metamorphosed mafic dikes and sills.

Lundegårdh (1974) explicitly states that 'hyperites' from the northern region — i.e. from the area north of Lake Vänern — are significantly older than those from the southern area — south of Lake Vättern. Otherwise the possible age homogeneity of the whole suite of 'hyperites' is rather vaguely expressed in older Swedish literature. A K-Ar dating has given an age of  $1516 \pm 50$  Ma (Priem et al. 1968) for the 'hyperites' in the area immediately north of Lake Vänern. The age is subject to errors arising both from the regional loss of argon at around 900 Ma and the recorded occurrence of excess argon in the K-poor 'hyperites'. Zircon dating of the 'hyperite suite' in this area has given an age of 1550 Ma (Welin et al. 1980), and this must be considered a reliable age for the pegmatitic fraction of the 'hyperites'. A considerable spread of ages for 'hyperites' south of Lake Vättern is recorded by Priem et al. (1968) and Klingspor (1976). These ages are partly lower, and the indicated spread might be due not only to partial degassing and differing amounts of excess argon, but also to a possible inhomogeneity of the sampled material (see below).

### 'HYPERITES' — PETROGRAPHY AND CHEMICAL COMPOSITION

The original magmatic texture of the 'hyperites' shows a variety of stages of preservation. The unaltered rock consists of olivine, pyroxene, biotite, plagioclase, apatite, and opaques — predominantly titanomagnetite. The olivine often has a thin corona of pyroxene frequently succeeded by a thin amphibole rim, and the pyroxene is sometimes slightly rimmed by amphibole.

On microtextural criteria the samples were divided into five groups:

- 1, unaltered magmatic textures — normally a slight corona formation is present;
- 2, slightly altered magmatic textures — the original mineralogy is normally preserved, olivine is altered, sometimes completely obliterated, and pyroxene is uralitized;
- 3, relics of magmatic textures — plagioclase has retained its subophitic texture in a completely altered aggregate of hornblende, biotite, and magnetite;
- 4, metamorphic disequilibrium textures — all phases have recrystallized but the mafic minerals are still very fine-grained with frequent hornblende — hornblende contacts indicating textural disequilibrium;
- 5, equilibrium metamorphic textures — all traces of an earlier magmatic texture is obliterated, grain contacts are clear-cut, and grain growth seems to have reached an equilibrium.

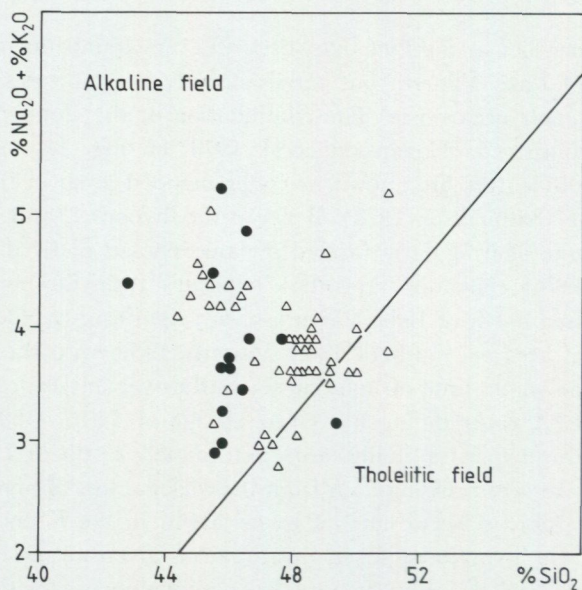


Fig. 2. Alkali versus silica plot for V-group samples. The line separating the tholeiitic field from the alkaline field is from MacDonald and Katsura (1964).

Legend:

open triangles: V-group samples north of Lake Vänern

solid circles: V-group samples south of Lake Vättern

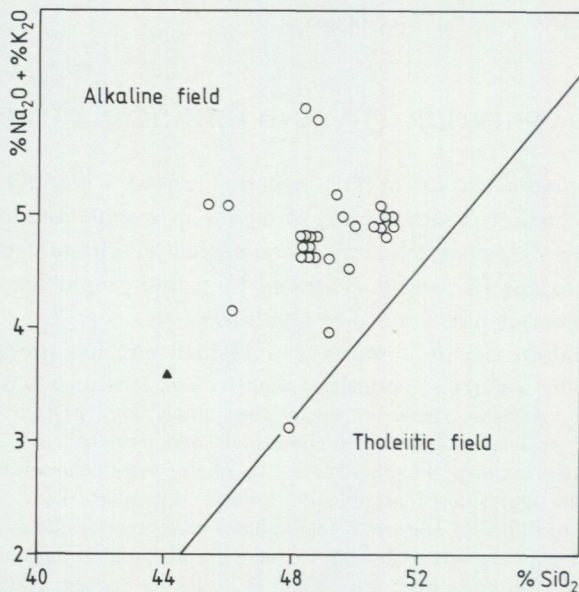


Fig. 3. Same plot as in Fig. 2 but for the S-samples.

Legend:

open circles: S-group samples south of Lake Vättern

solid triangle: S-group sample north of Lake Vänern

All chemical analyses used for this work are new and made by two of us (ZS and IJ). The analyses were performed in the following way. After crushing and homogenization  $\text{SiO}_2$ ,  $\text{TiO}_2$ ,  $\text{Al}_2\text{O}_3$ , total iron as  $\text{Fe}_2\text{O}_3$ , CaO and  $\text{K}_2\text{O}$  were determined by X-ray fluorescence techniques employing glass beads. The same method was applied for the determination of Rb, Sr, Zr and Y, though by means of powder pellets. Atomic absorption spectrometry was used for MgO, MnO and  $\text{Na}_2\text{O}$ . FeO was determined by potentiometric titration and  $\text{P}_2\text{O}_5$  by spectrophotometry. All results are referred to USGS standards. The results from the chemical analyses are reported in the appendix.

When plotted on the classical diagrams for Hawaiian basalts designed by MacDonald and Katsura (1964), the 'hyperites' were found to be titanium-rich olivine dolerites with an alkalic affinity — cf. Figs. 2 and 3.

Elliot (1973) studied 'hyperites' showing a similar microtexture as those in the present investigation, sampled in the area west of the Oslo rift. He compared rocks in different stages of alteration from one single outcrop. He recorded a consistent metasomatic alteration trend involving an increase in  $\text{Fe}_2\text{O}_3$ ,  $\text{K}_2\text{O}$ ,  $\text{P}_2\text{O}_5$ , and  $\text{H}_2\text{O}$  and a decrease in  $\text{SiO}_2$ , FeO, and CaO following the metamorphic reconstitution of the rock. Consequently, it is necessary to confirm that no chemical changes of significance for our methods accompanied the metamorphism (cf. textural criteria 1 to 5 above). A standard t-test (95 % significance) — with pooled variances when a null hypothesis of equal variances could not be rejected (F-test, 95 % significance) and with separate variances when rejected — was applied to test a null hypothesis of equal means irrespective of metamorphic alteration. No consistent differences other than an increase of volatiles could be confirmed due to the alteration. The apparent contradiction when compared to Elliot's results (1973) is one of scale; the regional sample variance is larger than the difference introduced by metasomatism.

## TREATMENT OF ANALYTICAL DATA AND RESULTS

For readers not familiar with multivariate statistics, we give in the following text references to Davis (1973) where an introduction to the various methods are given. For an exact description of the procedures, readers are referred to the manuals of the respective data program.

### GROUPING

The result of the preliminary test renders it possible to use all the material in search for a chemical grouping of the material in addition to the obvious geographical grouping (cf. the sample pattern in Fig. 1). For this purpose all the 90 new chemical analyses were run in a Q-mode cluster analysis. A Q-mode

analysis describes the interrelations between samples. The opposite would be an R-mode analysis, which describes the interrelations between the variables — in this case the element oxides. The elements of cluster analysis are described by, e.g., Davis (1973, pp. 456—473). Clustering is performed according to minimum Euclidian distances in an eleven dimensional space spanned by the oxides as basis vectors. The two nearest neighbours are successively amalgamated, the newly formed clusters are taken as new cases with their positions determined by the means of the original cases. The number of original cases in each cluster is applied as statistical weights in the successive amalgamation procedure.

This procedure resulted in dendograms showing a clustering into groups. There are two major groups and these nearly coincide with the geographical distribution of samples — cf. Fig. 1, where the chemical grouping is displayed as V- and S-groups. The definition of these groups is found below, but for all practical purposes it coincides with the result from the cluster analysis. The first of these two groups seems to be homogeneous. It is made up almost exclusively of samples found south of Lake Vättern and in addition one single sample from the area north of Lake Vänern (cf. the S-group in Fig. 1). The other group is less homogeneous. The dendograms (which are not shown here) indicate that this group is made up by three subgroups, and within it we find all samples but one from the area north of Lake Vänern as well as the remaining samples taken south of Lake Vättern (cf. Fig. 1: V-group samples). There is no correlation between the suggested subgroup pattern and the geographical distribution. From Fig. 1 it is suggested that the 'V-group samples' found south of Lake Vättern are concentrated in the north, near the lake. Furthermore, 'V-group samples' are absent in the eastern part of the Protogine Zone.

The material may be classified by a discrimination analysis. Different types of discrimination analyses are found. Davis (1973, pp. 442—456) describes the elements of this method. In the present case the material is grouped according to a grouping parameter, whereby group centres are defined. The other oxide entrances are added one at a time in descending order of discrimination power. After each step the original grouping is compared to the Mahalanobis distance to all centres.

The most important differences between these two statistical analyses are:

- 1, in the cluster analysis no user-introduced conditions are applied and all variables are treated as if they were of equal importance. In the version of discrimination analysis used in this investigation the user determines the number of groups and he also introduces one of the variables — the grouping variable — from which the groups are calculated. The groups are defined by introducing cut-points in the variation range of the grouping variable. The position of these cut-points are determined by and only by the user. The computer program compares the distance from the calculated group centres to each individual analysis, and in this way the goodness of the discrimination is tested.

- 2, in the cluster analysis all variables are introduced from the beginning; clustering is only a matter of distance between individual samples and a 'mean position' of already clustered samples. The step-wise discrimination analysis introduces one variable at a time in descending order of discrimination power.
- 3, the results from the cluster analysis are presented in the form of dendograms together with a numerical value giving the distance between separate clusters. The interpretation of the grouping as such is altogether a matter for the user. The results from the discrimination analysis are given as the probability for a sample to belong to the different groups, which, however, may be biased by the user's prejudices as described above. This probability is only dependent on the distance in space between the group centre and the analysis. The discriminant analysis only gives the probability for a given sample to belong to one of the groups defined by the user. There is no possibility for the statistic analysis to disclose outliers or further groups.

The discrimination analysis was applied with  $\text{TiO}_2$  and  $\text{P}_2\text{O}_5$  as grouping parameters. These oxides appeared to be the most group determining ones, when considering their range of variation in combination with only a small correlation with possible differentiation.  $\text{P}_2\text{O}_5$  appeared to be a very successful grouping parameter resulting in very few samples being erroneously classified after addition of all the relevant parameters, whereas  $\text{TiO}_2$  resulted in many erroneous classifications. The classification corresponds closely to the grouping obtained from the cluster analysis with the following differences:

- 1, most of the samples in the extreme south which on Fig. 1 are shown as V-samples (second group above) are suggested to belong to the first major group (Fig. 1: S-samples);
- 2, the only sample found north of Lake Vänern, which is not included among the V-samples in Fig. 1, should belong to the second major group (Fig. 1: V-samples);
- 3, on the other hand another three samples, in Fig. 1 shown as S-samples, from the southern part of south Sweden would be classified as belonging to the second group (V-samples in Fig. 1) instead of the first group (S-samples in Fig. 1).

$\text{TiO}_2$  was not a very successful grouping parameter since many samples were misclassified. The misclassifications were corrected for one sample at a time. However, corrections did not involve a correction of the group centres. Thus, the centres of the true groups are probably significantly different from those actually used in the classification procedure.

We suggest a division of the samples in two chemically distinct groups. This grouping is made primarily from the cluster analysis but the information from the discrimination analyses has to some extent been taken into account. The groups will in the following be referred to as V-groups (dominated by samples from the area north of lake Vänern) and S-groups (almost exclusively made up by samples from south of Lake Vättern). The difference between this grouping and the grouping obtained from only the cluster analysis is minor and rather subjective. This is why only one set of data has been diagrammatically displayed. Fig. 1 shows the close correspondence between the geographic and geochemical

Table 1

Three first eigenvectors from the principal component analysis of the whole material

Eigenvector	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>
% of total variance	37	19	13
SiO <sub>2</sub>	-0.1737	-0.4539	-0.1173
TiO <sub>2</sub>	-0.4189	0.1464	0.0231
Al <sub>2</sub> O <sub>3</sub>	0.2431	-0.2324	0.3998
Fe <sub>2</sub> O <sub>3</sub>	0.2543	0.3263	0.1478
FeO	-0.1396	0.4524	-0.2251
MnO	0.1067	0.5559	-0.1447
MgO	0.3516	-0.1864	-0.1776
CaO	0.3428	-0.0101	-0.2185
Na <sub>2</sub> O	-0.2661	0.0407	0.4882
K <sub>2</sub> O	-0.3534	0.0128	-0.1098
P <sub>2</sub> O <sub>5</sub>	-0.4009	0.0013	-0.0603

grouping. The major error in the chemical grouping is a possible overrepresentation of samples from the extreme south in the V-group (cf. point 1 in results from discrimination analyses). Thus, possible errors do not weaken the conclusion of a correlation between geographical location and chemical composition. We have tried to correlate the diverging samples with the degree of differentiation and with the metamorphic classification (groups 1—5, p. 7), but no such correlations have been possible to detect. The reason for this vague definition of the V- and S-groups is that we do not intend in any way to introduce errors that might give an exaggerated impression of geographically separated intrusion suites.

In addition to the two types of statistical studies already reported a principal component study was performed. Davis (1973, pp. 478—500) describes principal components. However, this is an R-mode analysis, and consequently designed to study the variation within one group and not the differences between groups. The method works with standardized input data, which makes it possible to achieve some sort of an intergroup characterization of material. The program (Blackith and Reyment 1971) calculates the linear correlation matrix, the eigenvalues of which are calculated and used as a new system of basis vectors. The method gives an empirical mathematical-statistical description of the variation with no *a*

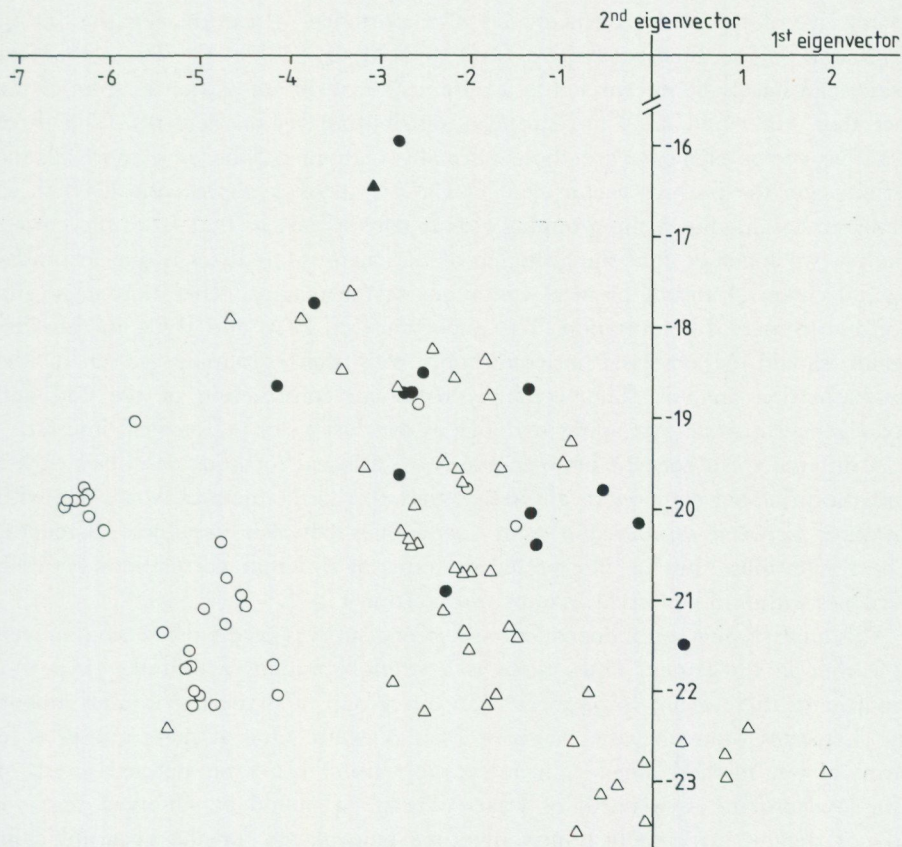


Fig. 4. Principal component analysis of all chemical analyses used for this work: Plot of the samples on the 1st and 2nd eigenvectors.

Legend:

- open circles: S-group samples south of Lake Vättern
- solid circles: V-group samples south of Lake Vättern
- open triangles: V-group samples north of Lake Vänern
- solid triangle: S-group sample north of Lake Vänern

*priori* petrological/geochemical interpretation possibilities. Possible sources of variation in the present material are a differentiation trend over a small silica interval and/or a heterogeneity of the samples.

As a start a principal component analysis was run where all chemical analyses of the 'hyperites' were included. Table 1 lists the resulting vectorial elements for the first three eigenvectors. A grouping of the data is found in plots only involving the 1st eigenvector (1st *versus* 2nd and 1st *versus* 3rd). Such a plot is displayed in Fig. 4, showing two groups of S-samples and an additional number of S-samples disposed within the more well-defined ellipse of V-samples. In the first eigen-

vector five of the eleven elements are of importance. These are negative  $\text{TiO}_2$ ,  $\text{K}_2\text{O}$  and  $\text{P}_2\text{O}_5$ , further positive  $\text{CaO}$  and  $\text{MgO}$  (Table 1). Thus, the first vector can hardly be interpreted as a pure vector of differentiation in spite of the fact that  $\text{MgO}$  and  $\text{K}_2\text{O}$  are strongly contributing vector elements. The three negative vector elements are those normally high in basalts of a more alkalic affinity and the positive vector element  $\text{CaO}$  is an oxide more typically high in tholeiitic basalts. Since the grouping closely corresponds to that from the cluster analysis we conclude that the grouping of the chemical analyses is due to fundamental chemical and/or physical conditions at the magma generation stage and not due to mere differentiation. The importance of  $\text{TiO}_2$  and  $\text{P}_2\text{O}_5$  in this first vector should be observed in connection with their grouping power in the discrimination analysis. The seemingly irrational construction of the 2nd and 3rd eigenvectors does not allow any obvious conclusions of petrological interest.

A difference in concept between the two statistical methods described earlier and the principal component analysis is that this latter method works not with distances between samples but with correlations between variables (R-mode). The results must thus be interpreted in terms of different correlations between variables within the different 'groups' displayed in Fig. 4.

This analysis gives an independent and strong support of the conclusion arrived at earlier in the paper. Thus, there is a strong grouping within the 'hyperite' group, and there seems to be more than one group of mafic hypabyssals among the 'hyperites' from the area south of Lake Vättern. One of these groups is in terms of our methods chemically inseparable from the better defined group of samples from the area north of Lake Vänern. It should be observed that we do not suggest any genetical nor any time equivalence for the geographically differently located samples in the V-group.

#### DIFFERENCES BETWEEN THE GROUPS

The two groups (the V- and S-groups) are made up of rocks which differ in metamorphic alteration. Thus, it is necessary to confirm that no differences in element means are introduced in any of the groups due to metasomatic alterations accompanying the metamorphism of the rock. The test was performed in the same way as earlier described, but at the 90 % significance level. The choice of such a low level of significance is governed by the fact that a rejection of a true null hypothesis does not introduce any false premises in the following discussion. In the S-group no consistent differences attributable to metasomatic effects could be found. In the V-group the unaltered samples were always richer in  $\text{MgO}$  and  $\text{CaO}$  than the other subgroups. These differences should not be ascribed to a metasomatic change (Elliot 1973) but depend on a too small and unrepresentative population of unaltered V-samples. Thus, we conclude that metasomatic effects

Table 2

High correlation coefficients  $r \geq 0.60$ . Values within paranthesis refer to the other group. Only absolute values larger than 0.40 are considered.

V-group			S-group		
TiO <sub>2</sub>	- FeO	+0.70 (+0.41)	SiO <sub>2</sub>	- MnO	-0.66
TiO <sub>2</sub>	- MgO	-0.72 (-0.57)	SiO <sub>2</sub>	- CaO	-0.77
TiO <sub>2</sub>	- CaO	-0.62	TiO <sub>2</sub>	- Fe <sub>2</sub> O <sub>3</sub>	-0.61
TiO <sub>2</sub>	- P <sub>2</sub> O <sub>5</sub>	+0.73 (+0.90)	TiO <sub>2</sub>	- P <sub>2</sub> O <sub>5</sub>	+0.90 (+0.73)
Al <sub>2</sub> O <sub>3</sub>	- MnO	-0.64	Al <sub>2</sub> O <sub>3</sub>	- FeO	-0.63
K <sub>2</sub> O	- P <sub>2</sub> O <sub>5</sub>	+0.61	Al <sub>2</sub> O <sub>3</sub>	- Na <sub>2</sub> O	+0.71
			Fe <sub>2</sub> O <sub>3</sub>	- P <sub>2</sub> O <sub>5</sub>	+0.60
			FeO	- CaO	+0.60 (-0.56!)
			FeO	- Na <sub>2</sub> O	-0.72
			MnO	- CaO	+0.65
			CaO	- Na <sub>2</sub> O	-0.74 (-0.48)

are negligible as compared to other effects in the type of model with which we work.

Separate principal component analyses were performed on the V- and S-groups. The analyses constitute closed arrays. Hence, a spurious negative correlation is inherent in the material. Table 2 lists those coefficients in the correlation matrixes with an absolute value larger than an arbitrary value of 0.60; in addition we give the correlation coefficient for the same pair in the other group if larger than 0.40. Otherwise it is considered insignificant. There are striking differences in the correlation pattern between the two groups. Only five of the element pairs showing high correlation in one of the groups have a corresponding correlation in the other group.

Table 3 lists the first three eigenvectors for the separate analysis of the V- and S-groups. In both cases the first eigenvector takes up somewhat less than half of the variation. The variation pattern revealed by these vectors is rather complex and cannot be explained in simple petrological terms. In the V-group Table 3 reveals that in the 1st eigenvector there is a positive correlation between iron oxides and alkali oxides (all values negative) and a negative one between magnesium oxide and alkali oxides (one value positive, two negative). Plotted in a traditional AFM plot (cf. Fig. 5) there should be a variation trend directed from

Table 3

Three first eigenvectors from the principal component analysis of the V- and S-groups.

Group Eigenvector	V			S		
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>
% of total variance	43	17	13	37	30	13
SiO <sub>2</sub>	0.202	-0.395	-0.524	0.389	-0.011	0.314
TiO <sub>2</sub>	-0.428	0.098	-0.072	0.042	0.528	-0.013
Al <sub>2</sub> O <sub>3</sub>	0.232	0.535	-0.181	0.272	-0.329	-0.036
Fe <sub>2</sub> O <sub>3</sub>	-0.226	-0.201	0.436	-0.127	-0.383	-0.256
FeO	-0.318	-0.160	0.059	-0.371	0.283	-0.006
MnO	-0.335	-0.199	0.341	-0.372	-0.150	-0.407
MgO	0.331	0.087	0.367	-0.255	-0.264	0.374
CaO	0.283	-0.356	0.293	-0.454	-0.100	0.045
Na <sub>2</sub> O	-0.260	0.379	-0.101	0.438	-0.144	-0.201
K <sub>2</sub> O	-0.246	-0.405	-0.377	0.129	0.006	-0.680
P <sub>2</sub> O <sub>5</sub>	-0.374	-0.019	-0.067	0.040	0.514	-0.156

the M corner towards both the F and A corners. The correlation displayed in Fig. 5 is blurred by other effects probably due to sample heterogeneity (the 1st eigenvector only makes up 43% of the total variation). In spite of this the 1st eigenvector is not a simple differentiation vector since the sign of SiO<sub>2</sub> is negative. The statistical load on this vector element is rather low indicating that SiO<sub>2</sub> does not contribute very much to the variation displayed by the 1st eigenvector. A very conspicuous contribution is a covariation of P<sub>2</sub>O<sub>5</sub> and TiO<sub>2</sub> with a sign opposite to that of MgO. The second and the third vectors make up smaller contributions to the variation and cannot be easily interpreted. One possible reason for the complex first eigenvector might be that the group is inhomogeneous. This is suggested by the extremely high contribution from the variables TiO<sub>2</sub> and P<sub>2</sub>O<sub>5</sub> which are strongly group-determining variables in the discrimination analysis. The high correlation is especially conspicuous when compared with that in the more homogeneous S-group. In this context it might also be recalled that the V-group is dominated by samples from the area north of Lake

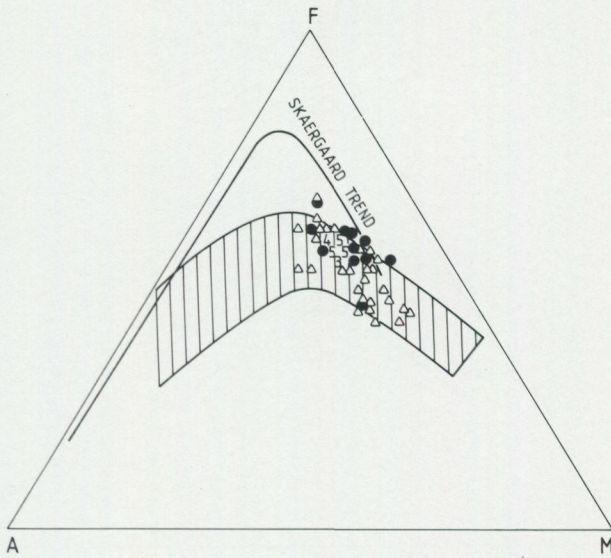


Fig. 5. AFM diagram for the V-group samples (total iron). The plotted curve refers to the Skaergaard trend (Wager and Deer 1939). The ruled area indicates the differentiation trend of the alkali olivine basalt series (Schwarzer and Rogers 1974).

Legend:

open triangles: V-group samples north of Lake Vänern

solid circles: V-group samples south of Lake Vättern

Numbers in the plot indicate overlapping plots.

Vänern, but a significant amount of samples from the area south of Lake Vättern is also found within this group. The diverging results in cluster, discrimination, and principal component analyses of the latter suggest that they actually do not belong to the true V-group, but to another still unidentified group.

The first vector in the S-group is more easily interpreted in terms of a more or less pure differentiation vector.  $\text{SiO}_2$ ,  $\text{Na}_2\text{O}$ , and  $\text{K}_2\text{O}$  are rather significant positive vector elements, while  $\text{FeO}$ ,  $\text{MgO}$ , and  $\text{CaO}$  are significant negative elements (Table 3). The resulting AFM plot (Fig. 6) consequently differs from that of the V-group. These principal component analyses result in different interpretations of the overall variation within the two groups. The AFM plots together with the vector elements in Table 3 for the V-group are suggestive of a trend obtainable for tholeiitic basalts, while no such suggestion can be found in the S-group. The only point significantly above the differentiation area for alkali basalts in Fig. 5 belongs to the single sample referred to the S-group north of Lake Vänern. This sample was allocated to different groups depending upon type of statistical analysis. The overall differentiation is rather small and inconclusive for the S-group, but the difference when compared to the V-group should

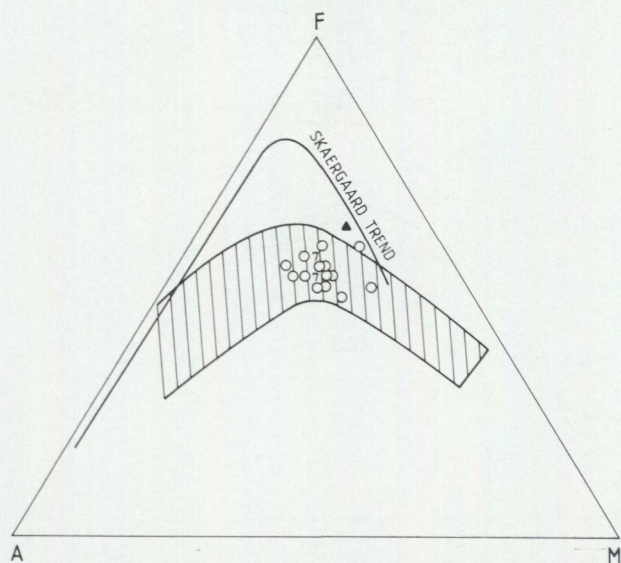


Fig. 6. Same type of diagram as in Fig. 5 but for the S-group samples.

Legend

- open circles: S-group samples south of Lake Vättern  
 solid triangle: S-group sample north of Lake Vänern

be observed. These interpretations are not entirely free from contradictions, since Fig. 2 is suggestive of an alkalic to transitional affinity for the whole suite of 'hyperites'.

The multivariate analyses do not tell us which elementary means are actually different. Strictly the samples are not normally distributed. Thus, to check the equality of the means between the groups some non-parametrical test should be adhered to instead of a standard *t* test. However, since the deviation from normality is small, we prefer the *t* test preceded by an *F* test at the same significance level to some more questionable model. The result of the *F* test determined whether the *t* test would be performed with pooled or separate variances. The test was performed at a higher significance level than the previous *t* tests, since an acceptance of a false null hypothesis of equal means does not introduce a false conclusion of element differences in the 'hyperite' group. We first tried the test at the 0.975 significance level and found that we had to reject the null hypothesis for all oxides except FeO. The test was rerun at the 0.999 significance level resulting in a rejection of the null hypothesis for the following entrances: TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, MgO, CaO, Na<sub>2</sub>O, K<sub>2</sub>O, and P<sub>2</sub>O<sub>5</sub>. We thus safely conclude that even

Table 4

Means, standard deviations and ranges for the elements.

oxide	V-group (n=61)			S-group (n=29)			tholeiitic basalt <sup>+</sup>		alkali basalt <sup>+</sup>	
	mean	s	range	mean	s	range	mean	s	mean	s
SiO <sub>2</sub>	47.11	1.71	42.68-50.87	48.67	1.73	43.93-50.95	49.34	0.54	47.41	3.08
TiO <sub>2</sub>	1.92	0.77	0.58- 3.66	3.72	0.96	1.28- 5.22	1.49	0.39	2.87	0.24
Al <sub>2</sub> O <sub>3</sub>	16.35	1.21	12.90-19.26	15.19	0.90	13.31-16.88	17.04	1.78	18.02	1.71
Fe <sub>2</sub> O <sub>3</sub>	2.52	0.72	1.03- 4.87	1.46	0.80	0.49- 3.65	1.99	0.65	4.17	1.16
FeO	10.52	1.84	6.33-14.29	10.61	0.92	8.77-12.96	6.82	1.50	5.80	1.17
MnO	0.20	0.03	0.14- 0.30	0.17	0.03	0.14- 0.27	0.17	0.03	0.16	0.03
MgO	6.77	1.44	4.12-10.88	5.34	0.89	4.27- 7.93	7.19	0.67	4.79	1.35
CaO	8.40	1.02	6.30-12.82	7.33	0.74	6.44- 9.76	11.72	0.69	8.65	0.91
Na <sub>2</sub> O	3.00	0.48	2.16- 4.23	3.42	0.35	2.53- 4.04	2.73	0.20	3.99	0.41
K <sub>2</sub> O	0.95	0.32	0.33- 1.85	1.53	0.35	0.64- 2.59	0.16	0.06	1.66	0.38
P <sub>2</sub> O <sub>5</sub>	0.35	0.20	0.20- 1.14	1.20	0.54	0.27- 2.00	0.16	0.05	0.92	0.22
Rb	27	13	10- 65	33	11	19- 76	10		33	
Sr	404	173	171-1057	584	100	219-664	130	25	815	375
Y	31	10	11- 56	40	8	29- 52	43	10	54	7
Zr	132	56	34- 294	238	67	105-331	95	35	333	48

<sup>+</sup> according to Engel et al. (1965)

s = standard deviation

Major elements in weight %, trace elements in ppm

if some doubts could be entertained against our sampling pattern, the former 'hyperite' group is not one single chemical group of basic hypabyssals, but there exist at least two chemically separable groups with different compositions as well as different variation trends. This statement does not carry any implications about an age homogeneity in any of the groups.

### TRACE ELEMENTS

Trace-element geochemistry of mafic extrusives has become a current method to discriminate between different chemical and/or tectonic environments. At present these models are at an empirical stage, and hitherto it has not been possible to formulate a well-founded theory to explain the recorded differences.

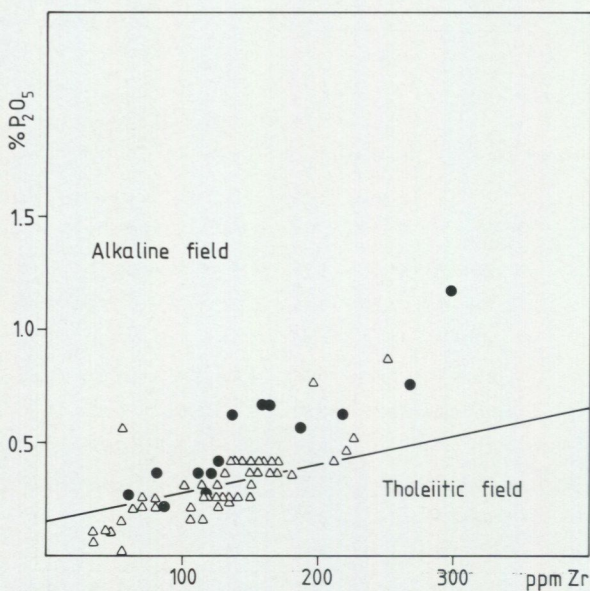


Fig. 7.  $P_2O_5$  versus Zr plot for the V-group samples. The line separating the tholeiitic and alkaline fields is from Winchester and Floyd (1976).

Legend:

- open triangles: V-group samples north of Lake Vänern  
 solid circles: V-group samples south of Lake Vättern

Consequently, we shall not discuss the trace-element data from the old hypabyssal rocks of this study in any of today's schemes for recently erupted mafic rocks. However, we may use some of our trace-element data to point out the differences between the groups and to show a general conformity with, but a divergence in detail, between major- and trace-element data. Table 4 gives the means and standard deviations for all our chemical analyses of the 'hyperites'. For comparison the averages for tholeiitic and alkali basalts as listed by Engel et al. (1965) are given. Figs. 7 and 8 reveal the S-group to be more or less totally situated in the alkaline field, when they are plotted in a  $P_2O_5$  versus Zr diagram (Floyd and Winchester 1975; Winchester and Floyd 1976), whilst the V-group appears more transitional in character. Similar results are obtained by plotting  $Zr/P_2O_5$  versus  $TiO_2$  or Sr versus Zr, though the overlap between the two groups is larger in these two plots. The results are not totally conclusive, since they point to same inconsistencies in the chemical character as compared to data from the principal component analyses and the AFM-plots in Figs. 5 and 6. These inconsistencies very hypothetically might depend upon a somewhat different temperature—pressure regime in the upper mantle of the Proterozoic Earth as compared with today's Earth.

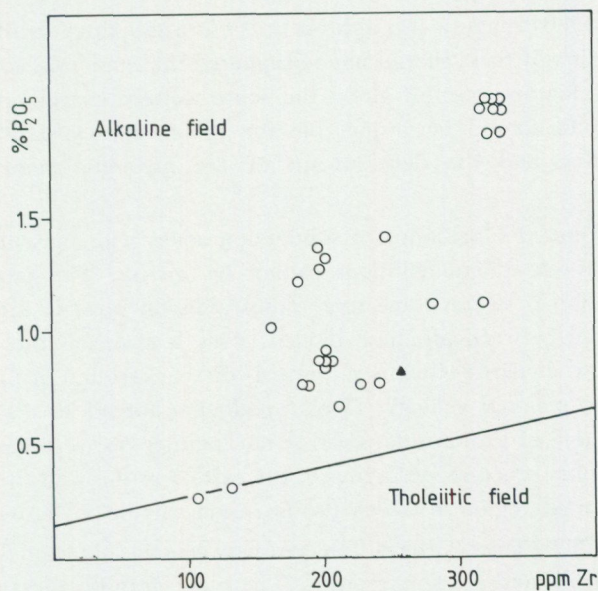


Fig. 8. Same plot as in Fig. 7 but for the S-samples.

Legend:

open circles: S-group samples south of Lake Vättern

solid triangle: S-group sample north of Lake Vänern

## DISCUSSION

One of the current topics of today's discussion of Earth development is the question: How far back in time can plate tectonic processes be followed? Plate tectonic processes are large-scale processes to be recognized only in connection with regional surveys. The following discussion is restricted to the Baltic Shield which is certainly not a large region, when discussing such processes. In the last years a large number of subduction zones has been proposed, sometimes suggested to have been followed by collisions between continents. Traces of these zones should be recognized on the present day surface of the earth. One such zone is the border line between the Svecokarelian and the Presvecokarelian rocks in the east (Hietanen 1975; Burke et al. 1977; Richard 1978; Lundqvist 1979), another the Protogine Zone (Burke et al. 1977; Berthelsen 1977, 1980), still others the Finnish Bay (Edelman and Jaanus 1980), the Skagerack and the south coast of Norway (Torske 1977), the Mylonite Zone, the 'Dalsland Boundary Fault' and the fault line delimiting the Dala Sandstones in western central Sweden (Berthelsen 1977, 1980), and finally a zone through western Norway (Falkum and Petersen 1980). Some lines may still be omitted from this survey.

Lundegårdh (1980) suggests two approaches of 'crustal plates' in the country of Värmland. The first of these should have originated the numerous foliation zones in the Filipstad-Hagfors granites along the south-western margin of the Baltic Shield. The second should be responsible for the initial Dalslandian (Sveconorwegian) folding and the development of the mylonite zones of western Värmland.

Obviously all quoted suggestions of subduction zones with or without accompanying continent—continent collisions cannot be correct. The purpose of the present contribution is to put some more constraints on possible models, not to try to discriminate between all these models. This is done on the basis of the presented results of 'hyperite' chemistry towards the background of the increasing knowledge of the regional geology. Here, we do not intend to discuss if plate tectonics were active in Proterozoic times or not, neither do we intend to discuss possible plate tectonic processes occurring in the east or in the west, but we intend to concentrate on the region in which the intrusions of the 'hyperites' occurred.

Lundegårdh (1980) stresses the differences between the older gneissic granites and the younger Filipstad-Hagfors granites. The older granitic rocks should have intruded about 1 770 Ma ago (Welin and Kähr 1980), i.e. should be coeval with the chemically different 'serogenic Svecokarelian granites'. The knowledge of the age relations within this group is, however, still rather fragmentary.

Observations by one of us (Lindh), by Gorbatshev (oral communications) and by Lundegårdh (1977, 1980) agree that granites identical to — or indistinguishable from — the Filipstad granite group occur within the region principally occupied by the older gneissic granites, i.e. to the west of the 'Gothian Front'. Furthermore, Lundegårdh (op. cit.) reports that the Filipstad-Hagfors granites are intrusive in the gneissic granites and probably underlie the latter. We consider these observations as evidence against the idea that the 'Gothian Front' incl. the Protogine Zone was developed as a result of a plate collision in Dalslandian (Sveconorwegian = Grenville) time, or at any time after the intrusion of the Filipstad-Hagfors granites, i. e. 1 655 Ma or later. (Compare Welin 1980.) If Lundegårdh's suggestion comes true that the Filipstad-Hagfors granites underlie the older suite, this only strengthens our views.

The interpretation involving a large-scale uplift of the western principal unit as responsible for the argon degassing, the remagnetization event, and the intrusion of the outer (eastern) girdle of dolerite dikes also seems reasonable (Welin and Blomqvist 1966; Patchett and Bylund 1977). However, the question whether the Protogine Zone and its northern continuation was formed during this uplift or at an earlier date still remains open. If formed during the uplift it cannot be a plate boundary, and probably none of the 'hyperite' groups is attributable to its formation. At least the Värmland 'hyperites' (the northern V-group) were

intruded much earlier — 1 550 Ma ago (Welin et al. 1980). However available radiometric dates are too inconclusive for a final answer.

More probably the Protogine Zone was formed in the time interval between the intrusion of the Filipstad-Hagfors granites and the degassing event. This hypothesis finds support in the intrusion of a syenite body at 1 210 Ma (Klingspor 1976). The intrusive pattern of this body is controlled by the already existing Zone. Noting that according to our interpretation the occurrence of Filipstad and allied granites on both sides of the 'Gothian Front' does not support the idea of a plate collision after the intrusion of these granites, i.e. if the 'Front' should constitute the suture. This also means that our opinion is at variance with that of Lundegårdh (1980). We do not see signs of any continent approaches during the time interval 1 650—900 Ma ago, though the evidence for both opinions are meagre. The intrusion of the 'hyperites' involves an element of tension, which according to Lundegårdh should have occurred between two periods of approaching crustal plates. At least, we cannot find any positive evidence supporting continent—continent approaches. If the 'hyperite' intrusions were caused by the same outburst of energy as the Protogine Zone, we would very tentatively suggest a process similar to the uplift causing argon degassing and remagnetization at a later date. To explain the recorded chemical and inferred age differences major movements and intrusions of 'hyperite' magma might have taken place in a two-stage or perhaps multistage process.

Finally there is a possibility that the 'Gothian Front' was formed before the intrusion of the Filipstad granite group. In such a case we do not find any convincing evidence against the possibility that plate tectonic processes were active. However, neither do we see any positive indication of such a process. Accepting an early formation of the 'Gothian Front', the later deformation of the granitoids should be due to repeated movements in the Zone. This could explain the generally different lithologies in western and eastern Sweden but not the contrasting history in middle and late Proterozoic times. Thus, if the 'Gothian Front' was formed as a result of a plate tectonic process, we do not find any volcanic rocks associated with it. Burke et al. (1977) probably refer to the 'hyperite dikes' when they mention basic volcanics in the 'Gothian Front' — Protogine Zone. Otherwise the 'hyperite' dikes seem to be neglected in recent plate-tectonic discussions of the region. Berthelsen (1980) tries to incorporate them into his model. However, the result of the age determination of the Värmland 'hyperites' by Welin et al. (1980) was unknown to him. Thus, he considered these rocks to have intruded much later than they really did. We also emphasize the tholeiitic nature of the 'hyperites', which according to today's concept of subduction zones would place them early in a magmatic evolution. They have, however, intruded into 200 Ma older granitoids which show a syenitic trend.

So far this discussion is centered on the assumption of having one set of 'hyperites' which are split into two groups. In older Swedish literature implicit support for this assumption is found only in the outcrop pattern of the 'hyperites' along a tectonic zone. Thus, the support is not very strong and abandoning the assumption renders other interpretations possible. There is an immediate suggestion in the pattern of outcrops that the dikes and sills from the area north of Lake Vänern would continue into the zone of metamorphosed and irregularly formed dikes and sills between the 'hyperites' south of Lake Vättern and the Mylonite Zone. The chemical composition and other characteristics of these rocks are, however, at present unknown. They will be the subject for further investigations in the near future. A continuation further to the west would be consistent with the rarity of V-group 'hyperites' in the extreme south and the fact that they are not found facing the Småland granitoids south of Lake Vättern, where only S-group 'hyperites' are found (cf. Fig. 1). A decoupling of the 'hyperites' north of Lake Vänern and probably also those unsampled ones found between Lakes Vänern and Vättern from the Protogine Zone offers better possibilities to explain the irregular first eigenvector of the V-group samples. This presently very hypothetical suggestion also involves a proposal that the geographically isolated V-group samples south of Lake Vättern (except possibly those found immediately southwest of the lake) is not connected to the geographically more homogeneous group north of Lake Vänern. Hence, these suggestions implicate that the V-group as defined is heterogeneous. Consequently, the first eigenvector in addition to carrying information of the differentiation of the rock suite also carries information of group heterogeneity — cf. the high statistical loads for  $P_2O_5$  and  $TiO_2$ . In this case it is an open question to what processes the intrusion of the V-group 'hyperites' might be connected. The Mylonite Zone marks a lithological break the significance of which has not been elucidated yet. It might have formed as a result of a plate tectonic process (cf. Berthelsen 1977) or by an uplift process similar to the process that occurred in the Protogine Zone about 1 000 million years ago (Welin and Blomqvist 1966; Patchett and Bylund 1977). In the latter case, the V-group 'hyperites' and their proposed continuation could be an earlier analogue to the outer girdle of mafic dikes to the east of the Protogine Zone and its northern continuation. However, before this hypothesis is pursued any further, the chemical characteristics of the proposed southern extension of the V-group 'hyperites' must be determined. At the present stage of knowledge, however, a linkage between the chemically well-defined S-group 'hyperites' and the Protogine Zone must be assumed.

A chemical classification and correlation of mafic dikes might seem to be a hazardous thing to undertake in view of the many variables involved: chemical and mineralogical composition of the source materials, depth and degree of partial melting, subsequent differentiation etc. The crucial point in the present

investigation is the close correspondance between the chemical and geographical grouping suggesting a regional difference in one or some of the above variables. Preliminary hitherto unpublished results from other Swedish dolerite dike systems also support the possibility to obtain a chemical correlation and classification.

### CONCLUSIONS

This study has shown that there exist at least two different groups of mafic hypabyssals in the former 'hyperite' group. This result supplemented with the discussion of field relations and isotopic dating casts serious doubts on plate-tectonic models applied to the region. In the absence of a conclusive theory for the evolution of both the Grenville and 'Gothian' Fronts, we will not make any statements of the justification of the linkage of the Grenville Front to any 'Gothian Front' in this paper.

### ACKNOWLEDGEMENTS

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## APPENDIX

## MAJOR AND SELECTED TRACE ELEMENTS IN ALL ANALYSED ROCKS

**H-group and H here correspond to S-group and S**

H-group	V14	H01KB	H01	H02	H03K	H04KME	H04ME	H05K	H05/1M	H06K	H06/7M	H08
Sample number												
SiO <sub>2</sub>	43.93	48.30	49.10	47.88	48.58	45.95	48.32	48.47	48.18	50.53	49.87	48.16
TiO <sub>2</sub>	3.73	4.94	3.63	2.19	4.87	5.18	5.22	3.77	3.79	3.48	3.83	2.57
Al <sub>2</sub> O <sub>3</sub>	13.91	14.54	13.31	14.41	14.48	14.82	14.45	16.03	15.85	15.07	16.02	16.76
Fe <sub>2</sub> O <sub>3</sub>	2.94	0.98	0.59	2.10	0.91	0.69	0.61	1.78	1.51	2.67	1.03	2.17
FeO	12.96	11.58	11.08	12.14	11.51	10.89	11.30	9.63	10.06	8.77	10.42	10.72
MnO	0.27	0.16	0.17	0.22	0.16	0.19	0.16	0.14	0.15	0.17	0.15	0.22
MgO	5.78	4.84	7.93	7.00	4.73	4.32	4.63	5.08	5.24	4.66	5.31	4.27
CaO	9.11	7.29	7.53	9.76	7.29	7.69	7.44	7.40	7.31	6.44	6.69	7.27
Na <sub>2</sub> O	2.61	3.40	2.83	2.53	3.37	2.92	3.21	3.57	3.68	3.77	3.78	4.04
K <sub>2</sub> O	1.12	1.58	1.31	0.64	1.64	1.39	1.64	1.21	1.30	1.51	1.30	2.20
P <sub>2</sub> O <sub>5</sub>	0.81	1.99	1.39	0.29	1.94	1.87	1.93	1.26	1.34	0.98	0.74	1.12
H <sub>2</sub> O <sup>-</sup>	0.09	0.10	0.06	0.01	0.08	0.22	0.09	0.14	0.14	0.11	0.17	0.07
LoI	2.13	0.67	0.95	1.29	0.67	3.57	0.91	1.47	1.15	1.36	0.87	0.84
Sum	99.39	100.37	99.88	100.46	100.23	99.70	99.91	99.95	99.70	99.52	100.18	100.41
Mn ppm	2074	1259	1313	1697	1256	1483	1277	1097	1140	1302	1156	1685
Rb	19	31	32	25	34	76	38	21	25	51	25	39
Sr	393	662	437	219	635	509	657	656	638	593	632	639
Y	43	51	47	35	51	48	47	35	34	41	29	52
Zr	257	323	246	129	326	321	331	193	197	158	185	314
Topographic map-sheet and coordinates in the Swedish net	10D Karlstad NV 13656/66830	3E Kar1shamn NV 14101/62499	3E Kar1shamn NV 14101/62499	3E Kar1shamn NV 14106/62497	3E Kar1shamn NV 14098/62492	4E Tingsryd SV 14105/62581	4E Tingsryd SV 14105/62581	4E Tingsryd SV 14040/62531	4E Tingsryd SV 14040/62531	4D Markaryd SO 13997/62566	4D Markaryd SO 13997/62566	4D Markaryd SO 13997/62554

H-group												
Sample number	H09K	H09	H09/5M	H11ME	H12K	H13K	H14/1M	H15K	H16B	H17K	H18	H19
SiO <sub>2</sub>	50.95	50.72	49.60	48.97	49.18	49.47	48.12	45.18	48.28	48.46	48.18	50.82
TiO <sub>2</sub>	3.37	3.24	3.95	3.76	2.86	2.87	4.87	2.78	4.90	4.85	4.92	3.07
Al <sub>2</sub> O <sub>3</sub>	14.46	15.75	15.20	15.99	16.47	16.88	14.26	15.34	14.51	14.68	14.43	15.46
Fe <sub>2</sub> O <sub>3</sub>	2.94	1.31	1.40	1.14	1.53	1.27	0.49	3.65	0.79	0.77	0.81	1.34
FeO	9.52	9.95	10.72	10.14	9.63	9.52	11.77	10.09	11.40	11.24	11.40	9.95
MnO	0.17	0.15	0.16	0.15	0.15	0.15	0.16	0.18	0.16	0.16	0.16	0.16
MgO	4.42	5.18	5.97	5.32	5.49	5.42	4.82	6.00	4.87	4.82	4.91	5.64
CaO	6.53	6.87	6.62	7.42	6.99	7.11	7.29	8.24	7.30	7.21	7.32	6.79
Na <sub>2</sub> O	3.49	3.69	3.49	3.57	3.62	3.71	3.35	3.65	3.29	3.28	3.26	3.53
K <sub>2</sub> O	1.56	1.48	1.24	1.26	1.77	1.49	1.67	1.60	1.62	1.61	1.58	1.48
P <sub>2</sub> O <sub>5</sub>	1.12	0.87	0.76	1.21	0.77	0.76	2.00	0.63	1.99	1.85	1.95	0.85
H <sub>2</sub> O <sup>-</sup>	0.03	0.08	0.08	0.09	0.10	0.13	0.12	0.13	0.10	0.11	0.08	0.10
LoI	1.31	0.87	0.93	1.08	1.55	1.61	0.63	2.30	0.68	0.70	0.65	0.89
Sum	99.87	100.15	100.12	100.10	100.11	100.39	99.55	99.77	99.89	99.74	99.65	100.08
Mn ppm	1331	1174	1250	1195	1158	1144	1256	1403	1236	1236	1236	1207
Rb	35	26	23	24	49	38	31	31	36	34	32	26
Sr	532	625	614	664	604	627	637	510	658	639	652	606
Y	45	35	31	30	33	32	51	39	51	48	48	35
Zr	281	206	184	178	241	226	327	212	321	330	314	196
Topographic map-sheet and coordinates in the Swedish net	4D Markaryd S0 13985/62524	4D Markaryd S0 13985/62524	4D Markaryd S0 13985/62524	3E Karlshamn NV 14022/62445	4E Tingsryd SV 14210/62504	4E Tingsryd SV 14220/62539	3E Karlshamn NV 14021/62310	3D Kristianstad NO 13966/62467	4E Tingsryd SV 14105/62567	3E Karlshamn NV 14017/62298	3E Karlshamn NV 14024/62264	4E Tingsryd NV 14052/62809

H-group					
Sample number	H20	H21	H22	H26	H27
SiO <sub>2</sub>	50.32	50.73	50.61	48.61	45.89
TiO <sub>2</sub>	3.50	3.35	3.36	3.85	1.28
Al <sub>2</sub> O <sub>3</sub>	15.46	15.91	15.80	14.14	16.06
Fe <sub>2</sub> O <sub>3</sub>	1.30	1.05	1.07	1.37	2.26
FeO	10.23	10.06	10.16	10.52	10.28
MnO	0.15	0.15	0.15	0.23	0.24
MgO	5.39	5.27	5.25	4.72	7.66
CaO	6.76	6.86	6.84	6.83	8.45
Na <sub>2</sub> O	3.61	3.69	3.68	3.48	3.15
K <sub>2</sub> O	1.48	1.51	1.41	2.59	2.12
P <sub>2</sub> O <sub>5</sub>	0.87	0.88	0.83	1.32	0.27
H <sub>2</sub> O <sup>-</sup>	0.08	0.07	0.12	0.06	0.04
LoI	0.82	0.92	0.78	1.82	1.89
Sum	99.97	100.45	100.06	99.54	99.59
Mn ppm	1184	1154	1175	1744	1832
Rb	28	27	28	34	38
Sr	622	630	624	508	506
Y	32	33	33	37	30
Zr	200	200	201	202	105
Topographic map-sheet and coordinates in the Swedish net	4E Tingsryd NV 14036/62772	4E Tingsryd NV 14024/62755	4E Tingsryd SV 14020/62741	6D Gislaved NO 1396/6380	6D Gislaved NO 13946/63815

## V-group

Sample number	V01	V02	V03	V04	V05	V06	V07	V08	V09	V10	V11	V12
SiO <sub>2</sub>	45.20	48.02	45.78	45.68	48.39	46.69	47.99	47.47	48.29	47.87	46.75	49.55
TiO <sub>2</sub>	3.33	1.70	2.35	2.28	1.82	2.07	0.96	0.86	1.74	1.35	0.63	1.65
Al <sub>2</sub> O <sub>3</sub>	16.36	15.86	17.36	17.32	15.72	16.60	18.83	18.94	15.94	17.73	18.02	15.55
Fe <sub>2</sub> O <sub>3</sub>	1.91	1.94	2.20	1.89	2.36	2.04	1.51	1.80	2.01	2.37	2.26	2.73
FeO	13.07	11.66	11.04	11.46	11.66	11.31	7.92	8.42	11.57	9.52	8.06	8.88
MnO	0.21	0.20	0.20	0.23	0.22	0.18	0.15	0.14	0.21	0.16	0.17	0.18
MgO	4.47	6.24	6.12	6.09	5.95	6.07	7.42	8.01	5.86	8.15	8.54	6.50
CaO	7.99	7.99	8.17	8.20	8.08	8.59	8.37	8.31	8.38	8.16	10.02	9.14
Na <sub>2</sub> O	4.23	2.75	3.78	3.70	2.69	2.92	3.16	3.14	2.78	2.78	2.57	2.84
K <sub>2</sub> O	0.93	1.18	0.74	0.60	1.29	0.91	0.86	0.59	0.95	0.79	0.44	0.82
P <sub>2</sub> O <sub>5</sub>	0.44	0.37	0.38	0.39	0.41	0.32	0.18	0.15	0.29	0.23	0.06	0.16
H <sub>2</sub> O <sup>-</sup>	0.06	0.06	0.05	0.05	0.06	0.06	0.09	0.08	0.05	0.06	0.08	0.06
LoI	1.56	1.72	1.95	1.79	1.69	1.68	2.42	1.79	1.58	1.05	1.90	1.63
Sum	99.76	99.69	100.12	99.68	100.34	99.44	99.86	99.70	99.65	100.22	99.50	99.69
Mn ppm	1626	1585	1512	1743	1741	1427	1130	1050	1596	1272	1331	1400
Rb	17	26	13	11	38	25	37	14	26	17	23	27
Sr	554	227	564	628	231	306	440	418	245	335	350	270
Y	36	37	28	28	37	31	17	15	40	22	19	32
Zr	218	151	134	140	160	113	65	56	152	81	34	115

Topographic map-sheet  
and coordinates in the  
Swedish net

10D Karlstad NO  
13990/65837

10E Karlskoga NV  
14011/65829

10E Karlskoga NV  
14032/65795

10E Karlskoga NV  
14032/65795

11D Munkfors NV  
13613/66278

11D Munkfors NV  
13515/66312

11C Arvika NO  
13404/66436

12C Torsby SO  
13305/66584

11D Munkfors NV  
13613/66278

11C Arvika NO  
13402/66451

11D Munkfors NV  
13504/66398

10D Karlstad NV  
13618/65863

V-group		V13	V15	V16	V18	V19	V20	V21	V24	V26	V28	V29	V30
Sample number													
SiO <sub>2</sub>		47.81	49.82	47.76	47.42	48.24	46.22	48.31	49.03	48.52	45.04	44.57	45.29
TiO <sub>2</sub>		1.89	1.24	2.03	0.58	1.72	2.86	0.90	1.12	1.70	2.69	2.96	2.19
Al <sub>2</sub> O <sub>3</sub>		16.28	16.12	16.41	15.61	15.98	15.78	16.40	17.28	16.05	16.10	16.44	16.92
Fe <sub>2</sub> O <sub>3</sub>		3.71	2.58	3.28	2.54	2.35	3.12	2.63	1.03	2.65	3.43	2.99	2.36
FeO		9.69	7.03	9.79	6.68	10.35	12.24	7.62	10.87	11.11	11.19	11.55	11.08
MnO		0.18	0.17	0.19	0.16	0.18	0.20	0.19	0.17	0.21	0.27	0.20	0.20
MgO		6.47	7.87	5.92	9.43	8.10	5.14	7.27	7.64	6.56	6.20	5.32	7.13
CaO		7.99	9.28	7.96	12.82	8.09	7.23	9.69	8.35	8.33	8.04	8.44	8.17
Na <sub>2</sub> O		2.90	2.26	2.97	2.16	2.68	3.21	2.48	2.62	2.67	3.83	3.64	3.71
K <sub>2</sub> O		1.06	1.44	1.08	0.64	1.00	1.17	1.43	1.00	1.03	0.72	0.72	0.80
P <sub>2</sub> O <sub>5</sub>		0.36	0.23	0.39	0.12	0.26	0.42	0.54	0.19	0.24	0.37	0.39	0.31
H <sub>2</sub> O <sup>-</sup>		0.15	0.10	0.11	0.06	0.06	0.08	0.09	0.06	0.07	0.08	0.49	0.10
LoI		1.74	1.35	1.60	1.30	1.00	1.82	2.13	0.73	0.95	1.77	2.07	1.88
Sum		100.23	99.49	99.49	99.52	100.01	99.49	99.68	100.09	100.09	99.73	99.78	100.14
Mn ppm		1427	1317	1467	1244	1408	1524	1459	1329	1611	2126	1564	1551
Rb		29	59	28	17	25	32	47	25	25	12	11	15
Sr		308	367	326	552	291	307	1057	256	236	498	506	574
Y		37	30	36	15	32	40	16	26	34	33	37	26
Zr		131	134	143	35	121	151	56	105	129	154	171	126
Topographic map-sheet and coordinates in the Swedish net		10D Karlstad NV 13733/66881	10D Karlstad NV 13677/65936	10D Karlstad NV 13675/66854	12C Torsby NV 13076/66795	12C Torsby NV 13236/66767	2015 II Kongsvinger 12983/66775	2015 I 1210/6700	11D Munkfors SV 1374/6619	12C Torsby NO 13401/66973	10E Karliskoga NV 14035/65796	10E Karliskoga NV 14035/65796	10E Karliskoga NV 14035/65796

## V-group

Sample number	V31	V32	V33	V34	V35	V36	V37	V38	V40	V41	V42	V43
SiO <sub>2</sub>	44.26	48.75	45.17	47.93	48.91	50.77	45.41	46.04	49.87	45.80	48.35	47.88
TiO <sub>2</sub>	2.63	1.87	2.81	1.63	1.34	1.57	1.79	2.32	0.82	1.84	3.09	1.23
Al <sub>2</sub> O <sub>3</sub>	16.49	17.48	16.17	16.21	15.58	16.23	16.56	14.56	14.33	15.77	12.90	19.26
Fe <sub>2</sub> O <sub>3</sub>	2.78	2.19	4.87	2.28	1.99	1.87	2.54	2.52	3.29	2.88	2.69	2.04
FeO	11.82	8.99	9.81	10.97	10.78	10.05	12.39	12.42	6.33	11.62	14.05	7.79
MnO	0.21	0.18	0.22	0.21	0.21	0.18	0.19	0.22	0.18	0.20	0.26	0.15
MgO	6.63	5.14	6.02	6.84	6.25	4.95	8.73	7.36	8.94	9.07	4.53	7.19
CaO	8.12	7.12	7.58	8.05	8.44	9.25	7.99	7.27	10.46	7.79	8.35	8.38
Na <sub>2</sub> O	3.48	3.93	3.56	2.66	2.78	2.90	2.40	3.57	2.90	2.75	2.63	3.06
K <sub>2</sub> O	0.69	0.92	0.69	1.06	1.03	0.96	0.75	0.73	1.25	0.72	1.47	0.65
P <sub>2</sub> O <sub>5</sub>	0.26	0.25	0.37	0.26	0.16	0.02	0.27	0.48	0.18	0.30	0.38	0.20
H <sub>2</sub> O <sup>-</sup>	0.18	0.20	0.16	0.11	0.13	0.11	0.11	0.38	0.10	0.10	0.05	0.12
LoI	1.92	2.54	2.03	1.72	1.93	1.21	1.11	2.11	1.24	1.09	1.02	1.98
Sum	99.47	99.56	99.46	99.93	99.53	100.07	100.24	99.98	99.89	99.93	99.77	99.93
Mn ppm	1662	1399	1706	1628	1657	1384	1453	1711	1401	1540	2023	1127
Rb	12	21	18	29	38	60	24	22	49	19	38	18
Sr	521	562	497	231	238	222	331	171	443	315	188	389
Y	25	25	33	34	33	31	25	41	25	26	53	22
Zr	116	152	163	135	104	54	127	227	72	101	210	80

Topographic map-sheet  
and coordinates in the  
Swedish net

10E Karliskoga NW  
14035/65796

10E Karliskoga NW  
14035/65796

10E Karliskoga NW  
14035/65796

10E Karliskoga NW  
14007/65831

11D Munkfors SO  
1376/6603

11D Munkfors SO  
1376/6603

6D Gislaved NO  
13885/63857

6D Gislaved NO  
13885/63859

11D Munkfors NW  
13551/66415

11D Munkfors NW  
13546/66412

11D Munkfors NW  
1352/6638

12C Torsby SO  
13402/66550

## V-group

Sample number	V44	V45	V46	V47	V48	V49	V50	V51	V52	V53	V54	H07
SiO <sub>2</sub>	50.87	48.23	47.22	48.48	47.06	47.60	49.07	48.63	46.43	44.86	48.02	46.21
TiO <sub>2</sub>	3.66	2.12	0.68	1.50	0.69	2.31	1.57	1.56	2.25	3.29	0.90	2.46
Al <sub>2</sub> O <sub>3</sub>	16.08	14.96	18.72	16.85	18.17	16.66	16.51	15.31	15.80	14.53	16.44	17.59
Fe <sub>2</sub> O <sub>3</sub>	1.80	2.28	1.46	2.37	1.57	3.17	2.21	3.82	3.21	3.24	2.44	2.60
FeO	8.68	12.53	8.94	10.13	9.25	9.77	10.40	8.46	10.76	11.93	7.79	11.33
MnO	0.15	0.22	0.14	0.19	0.15	0.20	0.19	0.30	0.22	0.26	0.18	0.19
MgO	4.40	5.79	10.20	6.14	10.88	4.84	6.55	6.82	6.27	5.52	8.02	5.87
CaO	6.30	8.21	8.45	8.00	8.20	8.21	8.20	8.63	8.03	8.40	10.72	7.36
Na <sub>2</sub> O	3.83	2.68	2.60	2.86	2.67	3.01	2.67	3.44	3.39	3.26	2.48	3.68
K <sub>2</sub> O	1.62	1.24	0.44	1.12	0.47	1.25	0.99	0.75	1.14	1.41	0.65	1.32
P <sub>2</sub> O <sub>5</sub>	0.76	0.34	0.12	0.26	0.12	0.39	0.20	0.35	0.41	0.86	0.26	0.63
H <sub>2</sub> O <sup>-</sup>	0.11	0.10	0.08	0.10	0.07	0.11	0.06	0.07	0.12	0.11	0.13	0.08
LoI	1.32	1.37	0.98	1.92	0.68	1.84	1.74	1.69	1.75	1.93	1.65	0.59
Sum	99.58	100.07	100.03	99.92	99.98	99.36	100.36	99.83	99.78	99.60	99.68	99.91
Mn ppm	1157	1737	1110	1483	1136	1512	1498	2337	1733	2048	1408	1462
Rb	38	32	10	34	11	34	26	35	33	30	15	21
Sr	667	221	360	280	353	330	238	413	356	573	521	784
Y	31	46	13	33	11	39	32	34	41	49	21	29
Zr	197	180	46	139	44	156	124	168	164	248	72	161

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Swedish net

12C Torsby NO  
13487/66440

13C Dalby SO  
1329/6703

12C Torsby NV  
13220/66958

12C Torsby NO  
13286/66753

12C Torsby NV  
13227/66955

12C Torsby SO  
13373/66622

13C Dalby SO  
1330/6713

11C Arvika NO  
13320/66385

10D Karlstad NV  
13682/66865

10D Karlstad NV  
13682/66865

10D Karlstad NO  
13823/66904

4D Markaryd SO  
13993/62566

## V-group

Sample number	H10	H23	H24	H25	H28	H29	H30	H31	H32	H33	H34	H35
SiO <sub>2</sub>	42.68	45.12	45.60	45.73	45.36	46.37	47.49	45.60	45.79	46.23	45.60	49.15
TiO <sub>2</sub>	3.27	2.84	2.34	2.42	2.23	0.89	2.91	1.41	2.04	1.67	1.37	1.94
Al <sub>2</sub> O <sub>3</sub>	15.32	17.68	15.53	15.61	15.02	16.26	15.21	16.95	17.36	18.14	16.30	14.33
Fe <sub>2</sub> O <sub>3</sub>	3.79	2.62	2.29	2.12	2.28	3.13	2.29	1.95	1.90	1.83	3.75	1.85
FeO	14.29	12.23	12.75	12.57	12.29	7.81	13.06	12.43	11.18	11.15	9.01	11.02
MnO	0.24	0.20	0.20	0.20	0.21	0.20	0.21	0.18	0.19	0.16	0.21	0.20
MgO	7.50	5.92	6.38	6.36	7.34	8.00	4.12	9.56	7.33	6.56	7.17	6.52
CaO	6.46	7.23	8.20	8.12	9.49	10.36	8.35	7.90	8.38	8.55	9.27	9.70
Na <sub>2</sub> O	3.24	3.53	2.60	2.76	2.32	2.70	2.71	2.34	3.10	2.98	2.99	2.24
K <sub>2</sub> O	1.29	1.11	1.12	1.04	0.63	1.31	1.31	0.67	0.59	0.56	0.33	0.91
P <sub>2</sub> O <sub>5</sub>	0.67	0.58	0.53	0.58	0.19	0.26	0.73	0.37	0.37	0.38	0.33	0.23
H <sub>2</sub> O <sup>-</sup>	0.06	0.07	0.05	0.05	0.06	0.07	0.09	0.04	0.10	0.05	0.07	0.08
LoI	0.72	0.84	2.07	2.21	2.13	2.18	1.17	0.87	1.71	1.84	3.58	1.61
Sum	99.53	99.97	99.66	99.77	99.55	99.54	99.65	100.27	100.04	100.10	99.98	99.78
Mn ppm	1839	1550	1559	1577	1633	1539	1647	1376	1458	1266	1595	1582
Rb	20	18	38	36	23	65	41	18	10	21	14	40
Sr	662	784	245	274	198	455	313	352	572	477	483	247
Y	26	22	42	44	24	24	56	22	25	25	28	29
Zr	159	137	185	216	87	62	265	109	121	126	78	117

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3D Kristianstad NO  
13966/62467

4D Markaryd NO  
13996/62799

5D Värnamo NO  
13977/6345

6E Nässjö SV  
1404/6354

6D Gislaved NO  
1392/6382

6D Gislaved NO  
1390/63845

6D Gislaved NO  
13893/63848

6D Gislaved NO  
13888/63855

6E Nässjö NV  
1401/6386

5E Växjö SV  
1409/6308

5E Växjö SV  
1408/6308

3D Kristianstad NO  
13933/62377

V-group	
Sample number	H36
SiO <sub>2</sub>	45.34
TiO <sub>2</sub>	3.13
Al <sub>2</sub> O <sub>3</sub>	15.02
Fe <sub>2</sub> O <sub>3</sub>	4.36
FeO	11.44
MnO	0.25
MgO	5.05
CaO	7.35
Na <sub>2</sub> O	3.56
K <sub>2</sub> O	1.85
P <sub>2</sub> O <sub>5</sub>	1.14
H <sub>2</sub> O <sup>-</sup>	0.11
LoI	1.22
Sum	99.82
Mn ppm	1915
Rb	41
Sr	557
Y	48
Zr	294

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2D Tome111a SV  
13512/61714

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