SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 747 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 72 NR 9

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RB/SR AGES OF PRECAMBRIAN DOLERITES AND SYENITES IN SOUTHERN AND CENTRAL SWEDEN

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SUMMARY

P. Jonathan Patchett: Rb/Sr ages of Precambrian dolerites and syenites in southern and central Sweden. Manuscript received 1977-05-05, revised 1978-01-16.

17 dolerite dykes and sills and a syenite intrusion from central and southern Sweden have been dated by Rb/Sr methods. The intrusions penetrate Svecofennian crust thermally unaffected since 1 600 m.y., and emplacement ages lie between 1 600 and 800 m.y. Dolerite ages are obtained by mineral isochrons and whole-rock-biotite pairs from dolerite samples, and by mineral isochrons from samples of remelted country-rock granite. The isochrons depend upon a series of feldspar density fractions, but for a reliable emplacement age, all minerals should be concordant, and two or more independent ages should agree at 2σ. The decay constant $\lambda^{87}Rb = 1.42 \times 10^{-11}$ yr^{-1} is used

Four periods of dolerite intrusion are defined. E—W trending dykes, the Breven-Hällefors system, were emplaced in the area west of Stockholm in central Sweden at c. 1 530 m.y. based on mineral data, and the NNE-trending Tuna dykes of central Sweden were intruded at c. 1 370 m.y., based on a whole-rock study. Widespread dolerite sills, chiefly of alkali-olivine type, were emplaced in northern central Sweden at c. 1 220 m.y., and extensive dykes parallel to the Sveconorwegian (Dalstandian) tectonic zones in central and southern Sweden were intruded during c. 1 000—850 m.y. before present, both these episodes being defined by mineral data. The Vaggeryd syenite of southern Sweden gives a whole-rock line of 1 130 m.y., probably reflecting the time of intrusion.

Later disturbance of isotopic systems has been recorded in the Vaggeryd syenite, where micas give c. 900 m.y. cooling ages following Sveconorwegian schistosity zone deformation, and in the E—W dyke system, where certain minerals and whole-rocks were disturbed at least 200 m.y. after intrusion, and possibly at c. 900 m.y. Mineral ages from granite country rocks in southern Sweden, however, demonstrate that Sveconorwegian heating did not usually significantly affect Rb/Sr mineral systems outside the tectonic zones, and that mineral ages of dolerites in this region are to be taken as defining the time of intrusion rather than some regional thermal event.

The c. 1 530 and c. 1 370 m.y. intrusive episodes seem to be relatively isolated in time and space. The c. 1 220 m.y. dolerites can be shown to correlate with similar occurrences in Finland and probably Greenland; they may correspond to widespread fracturing of the continents of the North Atlantic region at this time. Major tectonic events are also probably reflected by the 1 000—850 m.y. dolerites, which have been explained as due to craton fracture during the final tectonic stages (possibly post-orogenic uplift) in the adjacent Sveconorwegian orogenic belt.

Appendices give locality information and analytical data for all samples analysed from Sweden for geochronological and geochemical purposes.

INTRODUCTION

The development of the Svecofennian crustal region in Sweden has been reviewed by Lundegårdh (1967, 1971), Welin (1970), and others. The main tectonic events apparently took place 1 900—1 750 m.y. ago, while ages of post-orogenic plutonic and volcanic rocks are as young as 1 520 m.y. in northern Sweden (Welin et al., 1971; Gulson, 1972). Almost all the Svecofennian region can however, be considered as essentially stable crust from c. 1 600 m.y. onwards, and it is in this tectonic environment that most if not all of the igneous events of this study took place.

The Svecofennian crust was affected by various events after the close of the Svecofennian tectogenesis and the intrusion of the post-Svecofennian anatectic magmas. The first of these was emplacement of cross-cutting granite and syenite intrusions, and it is possible that the granites and syenites of northern Sweden at c. 1 520 m.y. fall into this category. Other occurrences more clearly of this

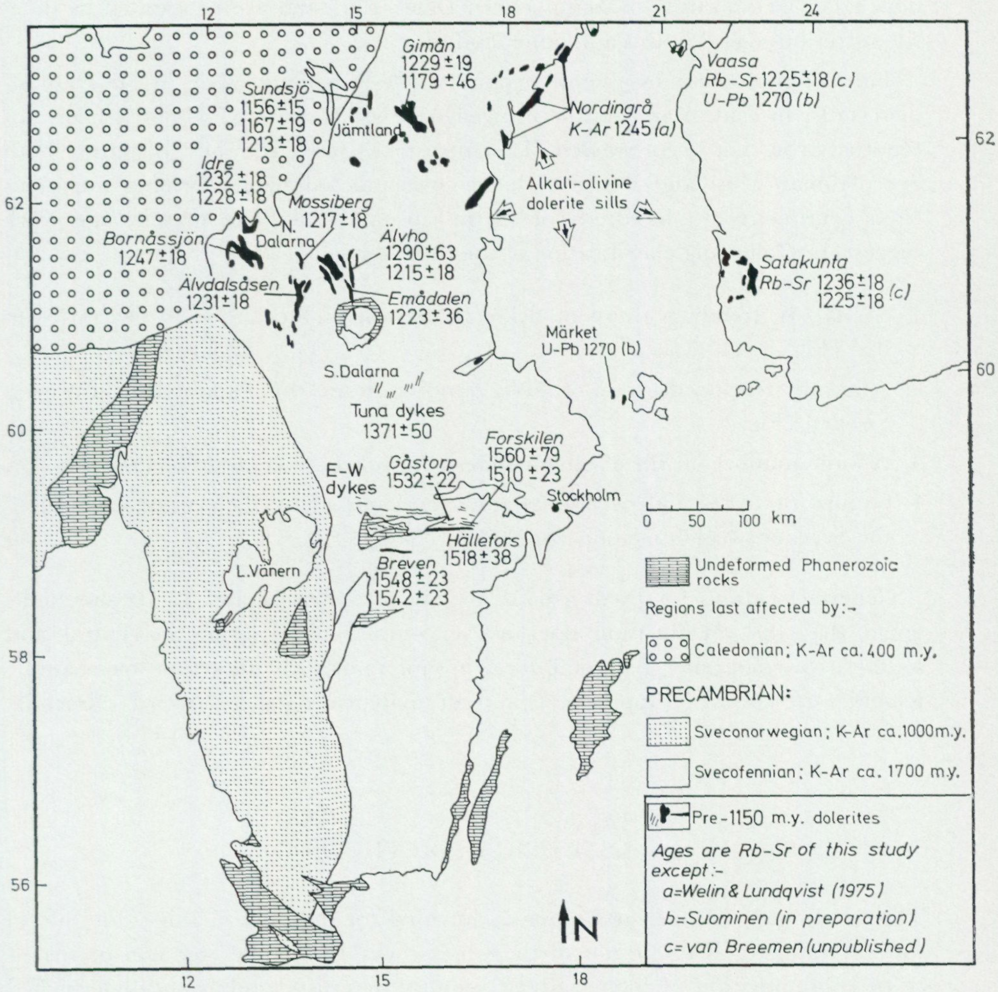

Fig. 1. Distribution of pre-1 150 m.y. dolerites in central Sweden, showing the age results of this and other studies.

group are the Karlshamn granites of southeastern Sweden at 1 455 m.y. (Welin and Blomqvist, 1966; U/Pb determination, not recalculated), and the gabbro, granite and syenite plutons of the Ragunda-Nordingrå region of northern central Sweden with ages between 1 600 and 1 320 m.y. (Welin and Lundqvist, 1975).

Deposition of continental sediments, chiefly sandstones and shales, also took place, and these now appear as isolated remnants of a cover lying on the Svecofennian crust. In the Nordingrå region of northern central Sweden, the sandstones are bracketed within the interval 1 385—1 245 m.y. (Welin and Lundqvist, 1975), but elsewhere there is little age control on deposition, except that almost all formations are essentially undeformed (though affected by the Sveconorwegian tectonization in southwestern Dalecarlia) and are penetrated by dolerite intrusions dated in this and other studies.

The dolerites occur over most regions of pre-Sveconorwegian, or pre-Dalslandian, crust in central and southern Sweden (Figs. 1 and 13), while they are not reported from northern Sweden. The intrusions, dykes and sills, penetrate both Svecofennian crust and the overlying continental sediments, forming intrusions from centimetres to hundreds of metres in thickness. The present age work suggests the following classification of the dolerites:

1. An E—W trending group of dykes lying west of Stockholm in central Sweden (Fig. 1).
2. A locally developed group of NNE trending dykes, the Tuna dykes, in central Sweden (Fig. 1).
3. A large number of sills of olivine dolerite in northern central Sweden (Fig. 1).
4. Groups of dykes and occasional sills characterised by their trend parallel to the Sveconorwegian tectonic zones (Fig. 13).

General locations for these groups are given in Figs. 1 and 13. It should be noted that the classification does not encompass all dolerites in central and southern Sweden, and that some local groups remain of uncertain age. Sample localities are shown in appendix 1, and all analytical data are given in appendix 2.

ANALYTICAL METHODS

The whole-rock isochron technique is not used for dolerites in this study due to the low range of Rb/Sr ratios of the whole-rocks and to the common occurrence of contamination of higher Rb/Sr samples by crustal radiogenically-enriched Sr, leading to upwardly-biased whole-rock ages (Patchett and van Breemen, unpublished paper). Single-sample mineral methods were used for dolerites, and these comprise three approaches:

1. Mineral lines from dolerite samples.
2. Whole-rock-biotite pairs from dolerite samples.
3. Mineral lines from samples of country rock remelted at contacts with dolerite, and therefore last recrystallised at the time of dolerite intrusion.

The Vaggeryd syenite and the Tuna dykes however, with larger ranges of whole-rock Rb/Sr ratios, were studied by the whole-rock method.

Mineral separations for the Vaggeryd syenite and the granite country rocks were performed by standard techniques, but for the dolerites a small size fraction was taken (45—84μ) and special techniques applied. Apatite and clinopyroxene were separated in the usual way and the feldspars were sunk as fractions of progressively decreasing density in tetrabromoethane diluted with acetone: each stage in the separation was left until no further grains sank, the sink run off at the base of the funnel and more acetone added and mixed to allow the next lightest fraction to settle. Each separate was then cleaned in a magnetic separator (to remove composite grains) and the result was a series of feldspar separates numbered F1 onwards in order of decreasing density, and usually increasing Rb/Sr ratio. The fine size fraction minimises compositional overlap between successive density fractions, and any alkali feldspar or interstitial granophyre is concentrated in the lighter separates. The feldspar analyses (4—7 in number) generate the isochron, and clinopyroxene, apatite and the whole-rock can usually only marginally affect the age obtained. Only where clinopyroxene and, if analysed, apatite are concordant with the feldspar data, however, can any confidence be placed in the mineral line age.

Crushed whole-rock and uncrushed mineral samples were subjected to an HF-$HClO_4$ or an HF-HNO_3 dissolution in pre-spiked PTFE beakers and ion-exchanged in glass columns containing Bio-Rad 50W-X8 200—400 mesh resin. Analytical blanks were less than 8 ng Rb and 4 ng Sr; these are non-significant at the Rb and Sr levels of all analysed samples except for some clinopyroxenes, where blank errors exceeded overall analytical uncertainties on isotope ratios and the $^{87}Rb/^{86}Sr$ ratio has consequently been corrected by up to 2 % to allow for Rb blank.

Mass analysis of Rb and Sr fractions was carried out on a modified AEI-GEC MS-12 solid-source mass spectrometer with a 30.5 cm radius and 90° sector using a Faraday cup and Cary 401 vibrating-reed electrometer. The Sr fractions of samples from dolerites (with the exception of biotites) were run for 10 sets of 10 scans of the Sr peaks in most cases, and ^{85}Rb was continuously monitored throughout the runs, the ^{87}Sr peak being corrected for any inferred ^{87}Rb present. The 10 data sets yield a 1σ error on $^{87}Sr/^{86}Sr$ of between 0.00002 and

0.00015, generally 0.00004—0.00010, and this accuracy is adequate for the range of isotope ratios in the samples studied. The value for the Eimer and Amend $SrCO_3$ standard was 0.70804 ± 0.00012 (2σ), based on 16 analyses made by J. Hutchinson over the general period of study.

Regression calculations were performed by the method of York (1969) using $\lambda\ {}^{87}Rb = 1.42 \times 10^{-11}\ yr^{1}$. This decay constant is now fixed by international convention (Steiger and Jäger, 1977) and is used for all ages reported or quoted in this paper. The results listed by Patchett and Bylund (1977) were based on $\lambda\ {}^{87}Rb = 1.39 \times 10^{-11}\ yr^{-1}$, and should be reduced by 2.11 % to correspond to the accepted decay constant.

An estimated uncertainty of 0.7 % (1σ) on ${}^{87}Rb/{}^{86}Sr$ is assigned to all samples, based on previous replicate analyses. An estimated uncertainty of 0.04 % (1σ) is assigned to the ${}^{87}Sr/{}^{86}Sr$ ratios of samples from granites and syenites, as well as to dolerite biotites. For the dolerite mineral lines, the mean in-run 1σ error on ${}^{87}Sr/{}^{86}Sr$ of all the points on the line was calculated as a percentage and used for the regression treatment: generally this value was less than 0.015 %. Since the 1σ uncertainties are used for regression, in-run errors are given in the tables of appendix 2 at the 1σ level. All final age and initial ratio errors are given at the 2σ level.

Repeat analyses given in Appendix 2 very often show positively correlated deviations in ${}^{87}Rb/{}^{86}Sr$ and ${}^{87}Sr/{}^{86}Sr$ ("isochron shifts") in excess of analytical uncertainties. In the case of mineral analyses this is clearly due to inhomoge-

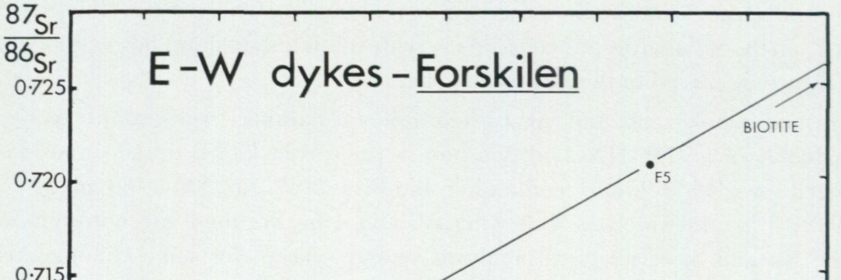

Fig. 2. Mineral line and whole-rock-biotite age from olivine dolerite of the Forskilen dyke, E—W system. For location see Fig. 1.

neity of granular sample, and this explanation must also apply to some of the whole-rock duplicate analyses, suggesting that in some cases grinding of whole-rock powders was inadequate. The adopted analytical uncertainties of 0.7 % on $^{87}Rb/^{86}Sr$ and 0.04 % on $^{87}Sr/^{86}Sr$ are based on a much larger population of replicate analyses than are reported in this study.

The value of MSWD (or SUMS/[n-2]) for each regressed line is presented; this quantity is in practice equivalent to the MSWD of McIntyre et al. (1966) and is unity when observed scatter of points about the best-fit line corresponds to that expected from analytical uncertainty. For values of MSWD of less than unity the observed scatter of points is smaller than that expected from analytical error, and where MSWD exceeds unity an additional, possibly geological component in scatter of points is indicated. Brooks et al. (1972) have suggested an MSWD value of c. 2.5 as defining the upper limit (in a laboratory where the analytical uncertainty is quite well known) for which data can be considered as constituting an isochron in the statistical sense. Many of the mineral lines of this study which have MSWD greater than 2.5 are nevertheless interpreted as giving reliable ages, since they are confirmed by other results; these are discussed in the appropriate sections.

Most considerations relating to initial ratios of dolerites and their minerals are not discussed in this paper (Patchett and van Breemen, unpublished paper). However, one conclusion relevant to the age study is that it is possible to pro-

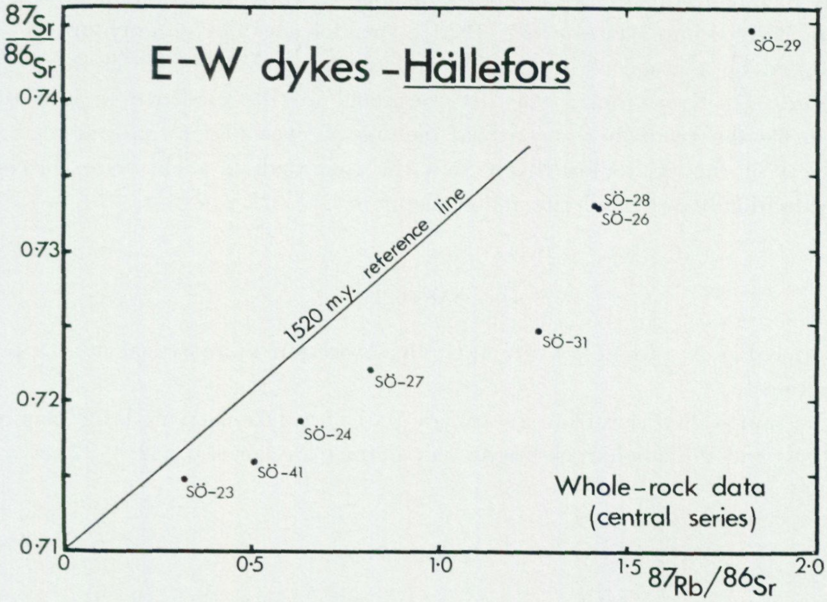

Fig. 3. Scattered pattern of whole-rock analyses from basic rocks of the Hällefors dyke, E—W system. For location see Fig. 1.

duce upwardly-biased mineral line ages by addition of radiogenically-enriched Sr to the dolerite during crystallisation, because in this way the latest-crystallising, higher Rb/Sr feldspars become contaminated with ^{87}Sr relative to the lower Rb/Sr feldspars. Therefore in a case where two mineral lines from dolerites do not agree at 2σ, the younger result is usually preferred.

EAST—WEST DYKES OF CENTRAL SWEDEN

The E—W dyke system of central Sweden is exposed over an area at least 120 km (E—W) by 60 km (N—S) lying to the west of Stockholm (Fig. 1), and intrudes Svecofennian gneisses and granites. The group consist of two giant dykes and a variety of smaller dykes.

The smaller dykes of the system (appendix 1) are olivine-bearing and olivine--free dolerites, and include many dykes carrying plagioclase phenocrysts and occasional anorthosite xenoliths (Gorbatschev, 1961)· Two of these dykes were selected for study, a 20 m olivine dolerite from Forskilen, and a 2 m plagioclase-phyric dyke from Gåstorp. The Hällefors giant dyke consists of a marginal olivine dolerite facies intruded by a central facies porphyritic in pyroxene and feldspar (Krokström, 1936). Gorbatschev (1961) has drawn comparisons between the rock types present in the Hällefors dyke and in the smaller dykes. The Breven giant dyke (appendix 1) consists of a western portion made up entirely of olivine dolerite and an eastern portion where a roughly central granophyre body occurs (Krokström, 1932); the dolerite and granophyre are often separated by a range of intermediate rocks. These could be differentiates from dolerite, but Krokström (1936) reinterpreted all the evidence to indicate an origin for the granophyre by partial melting of Svecofennian crustal rocks, and in view of this it is more likely that the intermediate rocks were formed by hybridisation between dolerite and granophyre.

GÅSTORP

Location Fig. 1; sample locality appendix 1, section 1; analytical data appendix 2, section 1.

The sample SÖ-54 is from an aphyric part of a dyke carrying large plagioclase crystals, and the whole-rock-biotite pair defines an age of 1 532 ± 22 m.y.

FORSKILEN

Location Fig. 1; sample localities appendix 1, section 1, analytical data appendix 2, section 1; isochron diagram Fig. 2.

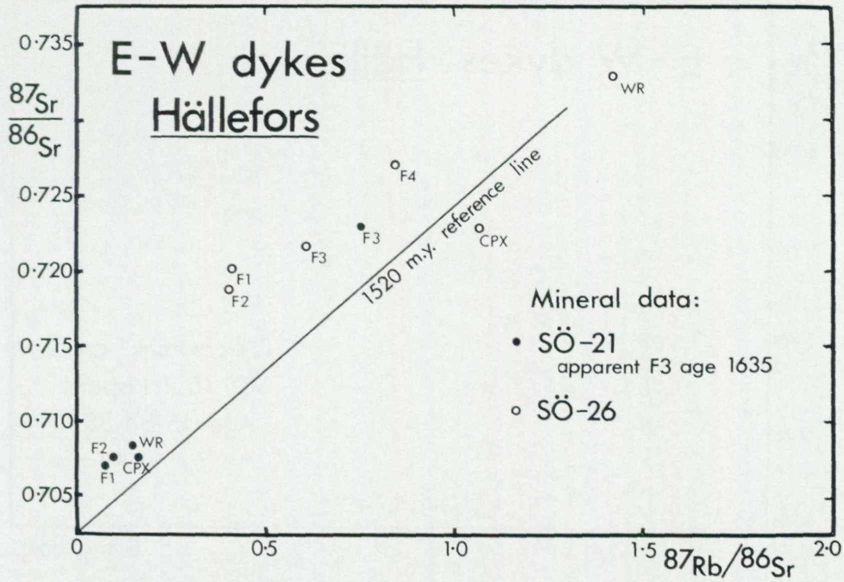

Fig. 4. Scattered pattern of mineral analyses from basic rocks of the Hällefors dyke, E—W system. For location see Fig. 1.

The olivine dolerite sample SÖ-49 was separated into clinopyroxnene and several feldspar fractions, and the analyses define a best-fit line of 1 560 ± 79 m.y. (Fig. 2). The value 7.02 for MSWD indicates scatter of the mineral data beyond the analytical uncertainty, but the age obtained is confirmed by a whole-rock-biotite pair from the same sample, which gives an age of 1 510 ± 23 m.y. Accordingly, the age of intrusion of the Forskilen dyke is inferred to be c. 1 530 m.y., in agreement with the result from Gåstorp.

HÄLLEFORS

Location Fig. 1; sample localities appendix 1, section 2; analytical data appendix 2, section 2; isochron diagrams Figs. 3—5.

Whole-rock data for fresh samples of the porphyritic central series of the Hällefors dyke define a scatter on an isochron diagram (Fig. 3). Minerals separated from a central series sample (SÖ-26) and a marginal series sample (SÖ-21) are also discordant (Fig. 4). The lightest feldspar fraction of SÖ-21 defines an apparent age of 1 635 m.y., but the clinopyroxene from this sample lies considerably below the line. Since it can be shown from other results (Patchett and van Breemen, unpublished paper) that feldspar lines can be biased upward due to contamination with radiogenically enriched Sr during crystallisation, and that one indication of this might be given by the clinopyroxene (unaffected by the

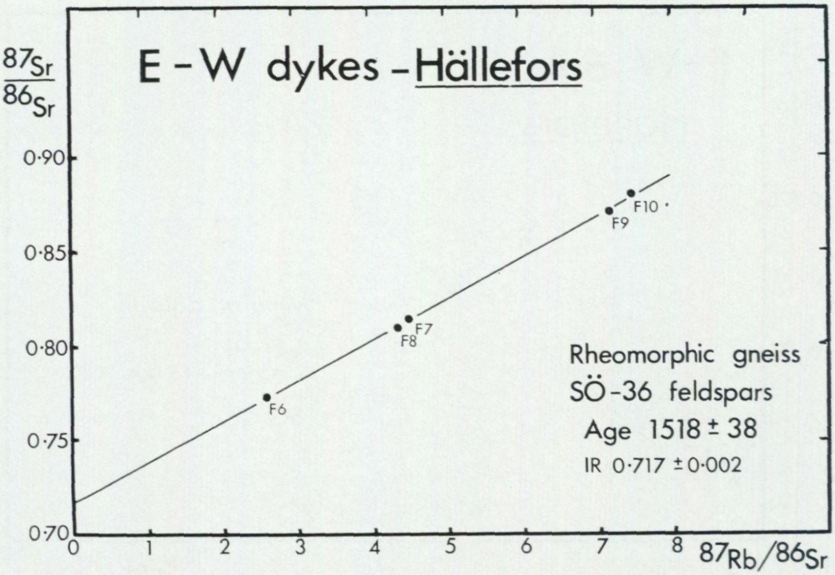

Fig. 5. Mineral (feldspar) line from a 6 cm rheomorphic granophyre vein at the contact of olivine dolerite with Svecofennian gneiss: Hällefors dyke, E—W system. For location see Fig. 1.

contamination) lying below the feldspar line, the 1 635 m.y. age is to be regarded with scepticism. Mineral separation of SÖ-26, the central series sample, was complicated by the fact that all feldspars with Rb/Sr greater than that of the whole-rock apparently had magnetic inclusions and were consequently discarded during cleaning of the feldspar fractions on a magnetic separator. Nevertheless a confused pattern is apparent in the isotopic analyses (Fig. 4): the feldspars and whole-rock are very poorly aligned along a c. 900 m.y. trend with an initial ^{87}Sr/^{86}Sr ratio of c. 0.715, and the clinopyroxene lies well below this vague line.

Neither the whole-rock nor the mineral data from the basic rocks of Hällefors can be interpreted as giving an intrusive age, and for this reason a 6 cm rheomorphic vein derived from country-rock gneiss at the contact with olivine dolerite was separated into feldspar fractions. The sample (SÖ-36) is a fine-grained granophyric rock hybridised to some extent with the dolerite magma, and in order to eliminate feldspars which originate in the dolerite, only the five lightest (most potassic) fractions out of ten were analysed. The five-point line derived has an age of 1 518 ± 38 m.y. (Fig. 5) with MSWD = 1.74, suggesting an isochron relationship. The initial ^{87}Sr/^{86}Sr ratio, 0.717 ± 0.002, is consistent with this rheomorph having been derived from rocks with a considerable pre-1 520 m.y. crustal history. The age defined by this mineral line agrees with the results from the smaller dykes of the E—W system, and the Hällefors dyke is therefore also interpreted as having been emplaced at c. 1 530 m.y.

The scattering of whole-rock analyses from the Hällefors dyke can readily be related to the extensive propylitic alteration which these rocks have suffered; this may have taken place at the time of dyke emplacement or at any later time. The whole-rock SÖ-31 (Fig. 3) has an initial $^{87}Sr/^{86}Sr$ ratio of less than 0.7 at 1 530 m.y., and since the lowest possible terrestrial $^{87}Sr/^{86}Sr$ at this time is c. 0.701 (see Faure and Powell, 1972 p. 26), then the present isotopic composition of SÖ-31 must have been acquired at a time considerably later than 1 530 m.y. In order to have a "possible" initial ratio of greater than 0.701, SÖ-31 cannot have been upon its present isotopic evolution for longer than c. 1 300 m.y. before present. It is possible that the actual age of this event is suggested by the feldspars of SÖ-26, which are crudely aligned along a c. 900 m.y. trend. The extensive thermal events in southwestern Sweden around this time form a ready cause for mild isotopic disturbance in the area of the E—W dykes, especially since it is shown below that the Breven dyke has also suffered such a disturbance, and that dykes of 1 000—900 m.y. age are present in the general area.

BREVEN

Location Fig. 1; sample localities appendix 1, section 3; analytical data appendix 2, section 3; isochron diagrams Figs. 6 and 7.

Whole-rock and mineral samples from the Breven dyke also define a complicated picture. Six whole-rock samples of the central granophyre give a line of

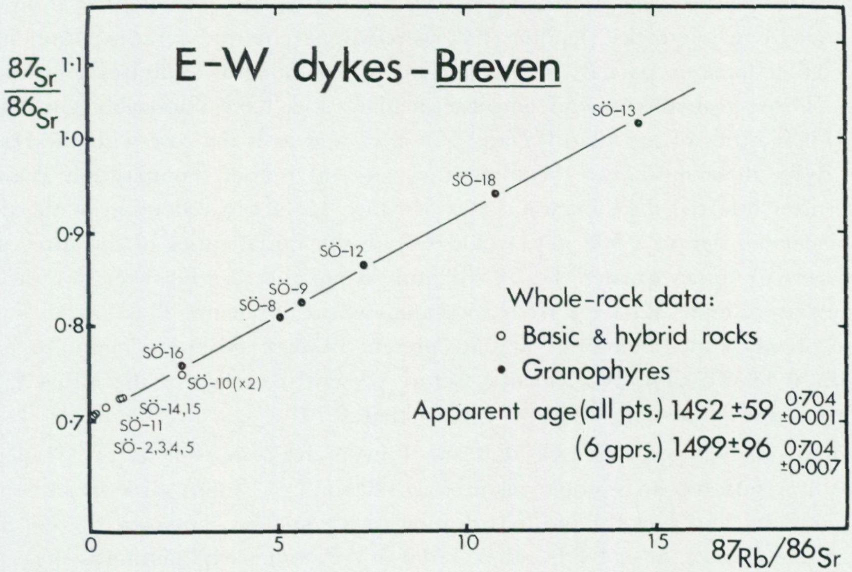

Fig. 6. Apparent age defined by whole-rock dolerites and granophyres of the Breven dyke, E—W system. For location see Fig. 1.

1 499 ± 96 m.y., while inclusion of basic and intermediate samples leads to a 1 492 ± 59 m.y. result (see Fig. 6). MSWD values are 26·94 and 36.60 respectively and indicate significant discordance outside analytical error.

Whole-rock-biotite pairs from two samples of the unaltered olivine dolerite in the western portion of the dyke (SÖ-3 and 4), where the granophyre is absent, define ages of 1 548 ± 23 and 1 542 ± 23 m.y. These results agree with those from the other dykes of the E—W system, and the Breven dyke is taken to have been intruded at this time.

Feldspar-quartz fractions separated from four granophyres define six-point lines which vary in age between 1 392 and 1 485 m.y. (Fig. 7). The extremes of these mineral ages do not overlap at 2σ, and if all ages are taken at face value, then the Breven dyke was formed by at least three entirely separate intrusive events, on of dolerite at c. 1 545 m.y. and two of granophyre at c. 1 470 and c. 1 390 m.y. Since however, the Breven granophyre seems to be a coherent magmatic unit emplaced in a single intrusive event, alternative explanations for the differing mineral line ages must be sought. No systematic relationship between apparent age and either of grain-size or geographical position exists, but if the granophyre is assumed to be 1 545 m.y. in age, as given by the dolerite biotites, and initial ratios calculated accordingly, then the apparent initial ratios of the four samples are arranged in the same order as their apparent mineral line age. The lower the apparent age, the lower the initial $^{87}Sr/^{86}Sr$ at 1 545 m.y.

This relationship suggests that a mild event of a thermal or hydrothermal nature long after dyke emplacement could have caused loss of ^{87}Sr from the granophyre whole-rocks (leading to lowered apparent initial ratios), and have effected a total or partial re-equilibration of the mineral separates to younger ages. Three granophyres and one intermediate rock have impossibly low initial $^{87}Sr/^{86}Sr$ ratios of less than 0.7 at 1 545 m.y., and as is the case with the Hällefors dyke, these must have acquired their present isotopic composition at some time after inferred dyke intrusion at 1 545 m.y. In fact, a reduction of the dyke emplacement age to 1 500 m.y. would restore the initial ratios of the three granophyres to values greater than 0.701; this is not the case however, for the intermediate sample SÖ-10, a fresh rock analysed in duplicate. This has an initial ratio of 0.694 at 1 545 m.y., and its present isotopic evolution ought to have begun at least as late as 1 350 m.y. before present in order for the initial $^{87}Sr/^{86}Sr$ to have a "possible" value of greater than 0.701.

There is therefore evidence that the Breven dyke, as well as the Hällefors dyke, has suffered an isotopic disturbance 200 m.y. or more after its intrusion. The mineral line ages for the four granophyres could be explained by two phases of disturbance, at c. 1 470 and c. 1 390 m.y. Another explanation is suggested by the mineral separation procedure for these mineral lines. The separates F1

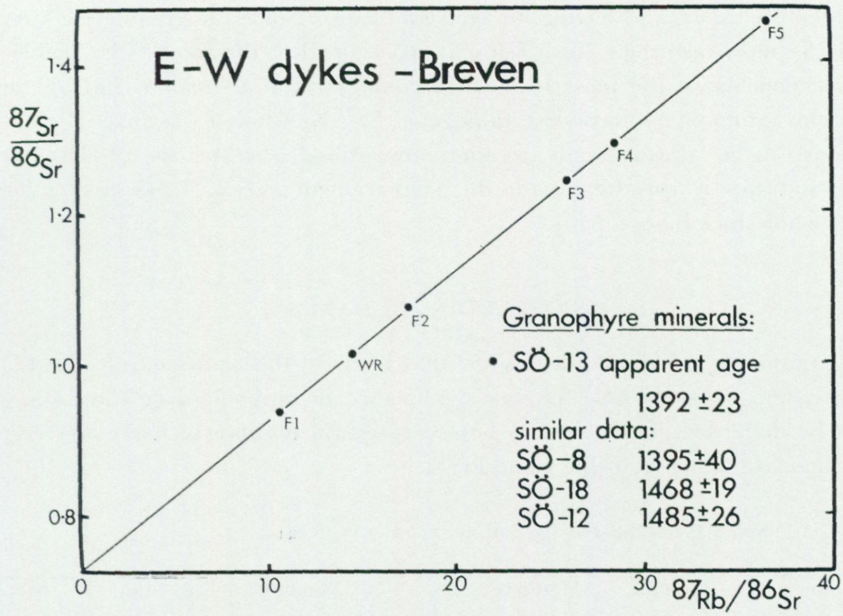

Fig. 7. Anomalous mineral lines for quartz-alkali feldspar density fractions from Breven granophyres, E—W dyke system. For location see Fig. 1.

to F5 (see Fig. 7 and appendix 1, section 3) are a series of density fractions of grains 45—84μ in diameter ground from granophyres consisting mainly of albite, quartz and granophyric intergrowths on a scale usually *finer* than 45μ. This size disparity means that there will be many composite grains of quartz and alkali feldspar in the 45—84μ sample, and the density of these will vary over a range which includes that of albite. Consequently the separates F1 to F5 are related to each other by an increasing proportion of alkali feldspar to other constituents, and any trend on an isochron diagram will be controlled by the alkali feldspar. If in addition the alkali feldspar has suffered an isotopic disturbance long after crystallisation of the granophyre, then the technique would yield a range of mineral line ages, varying with the degree of disturbance of

TABLE 1. Initial ratios at 1 545 m.y. and apparent mineral line ages for Breven granophyres

Sample	Mineral age m.y.	MSWD	$(^{87}Sr/^{86}Sr)_0$
SÖ-13	1 392 ± 23	1.21	0.691 ± 0.005
SÖ-8	1 395 ± 40	7.24	0.696 ± 0.002
SÖ-18	1 468 ± 19	0.86	0.701 ± 0.004
SÖ-12	1 485 ± 26	4.58	0.707 ± 0.003

the alkali feldspar, and having no age significance. Since the granophyre samples with the most disturbed alkali feldspar have also lost the most ^{87}Sr (Table 1), this scheme seems the most likely to account for the anomalous mineral lines.

If the granophyres have lost radiogenic Sr, the whole-rock lines of c. 1 500 m.y. are to be regarded only as minimum estimates of the age of dyke intrusion, and this is consistent with the emplacement age of 1 545 m.y. inferred from whole-rock-biotite pairs.

CONCLUDING REMARKS

The arguments presented above show that many of the analyses from the E—W dyke system probably have no age significance in terms of dyke intrusion, and must be discarded. There remain however, several results which are convergent, and these are shown in Table 2 and Fig. 1.

TABLE 2. Summary of reliable age data for the E—W dykes

Intrusion	Sample	Method	Number of points	Age m.y.	MSWD
Gåstorp	SÖ-54	WR-biotite	2	1 532 ± 22	—
Forskilen	SÖ-49	dolerite minerals	7	1 560 ± 79	7.02
Forskilen	SÖ-49	WR-biotite	2	1 510 ± 23	—
Hällefors	SÖ-36	rheomorph minerals	5	1 518 ± 38	1.74
Breven	SÖ-3	WR-biotite	2	1 548 ± 23	—
Breven	SÖ-4	WR-biotite	2	1 542 ± 23	—

The general agreement of the results with a c. 1 530 m.y. age suggests that the dyke swarm was emplaced at this time; age differences within the range 1 560—1 510 m.y. are undetectable by present techniques· The fact that several results give the inferred age of intrusion, while others show isotopic disturbance at a much later time, suggests that this disturbance was very localised in its effects: a hydrothermal event might have this characteristic, but the isotopic data do not shed any direct light upon the nature of the processes involved.

TUNA DYKES OF CENTRAL SWEDEN

Lecation Fig. 1; sample localities appendix 1, section 4; analytical data appendix 2, section 4; isochron diagram Fig. 8.

In southern Dalarna, central Sweden, occurs a well-defined swarm of dykes, trending NNE and mapped over an area of c. 50 km dimensions (Hjelmqvist, 1966). This swarm known as the Tuna dykes, includes aphyric dolerite, plagioclase-phyric dolerite, porphyritic intermediate rocks and a range of alkali feld-

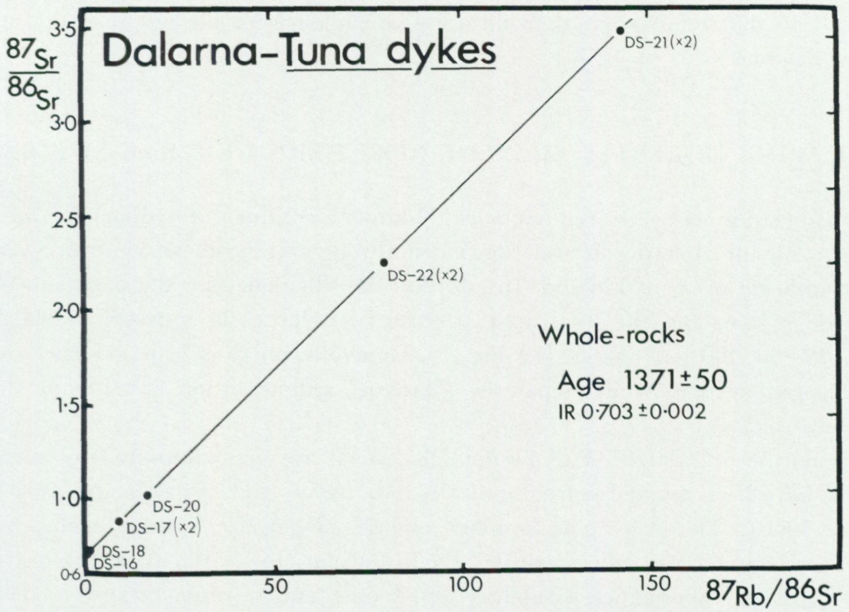

Fig. 8. Whole-rock line for dolerites, a trachytic rock and quartz porphyries from the Tuna dykes, southern Dalarna. All samples are from different dykes. For location see Fig. 1.

spar-quartz porphyries. The dykes are individually less than 20 m in width, but may occur in dense swarms, composite dykes being also common.

Samples from two localities are analysed: the three with lowest Rb/Sr ratios (Fig. 8) are from a locality where basic and intermediate rocks occur, and the three with highest Rb/Sr ratios are from a locality where mainly alkali feldspar-quartz porphyries are exposed. In view of the small number of samples used, three of the analyses were duplicated and their position on the isochron diagram confirmed. The line obtained (Fig. 8) has an age of 1 371 ± 50 m.y., an initial ^{87}Sr/^{86}Sr ratio of 0.703 ± 0.002 and MSWD = 23.9. This value indicates discordance of the data points from the best-fit line beyond analytical uncertainty, but Fig. 8 shows that the age depends to a large extent on the very high Rb/Sr samples DS-21 and DS-22. Since these are fresh, essentially unaltered samples, which have been analysed in duplicate, and would each in isolation define a 1 370 m.y. age, then in the absence of contradictory evidence the Tuna dykes must be supposed to have been intruded at this time.

Whether the porphyries are derived by differentiation from the dolerites or have some other origin does not affect the age interpretation, since the range of Rb/Sr (and hence ^{87}Sr/^{86}Sr) ratios on the line is very high, making any variation in initial ^{87}Sr/^{86}Sr between samples insignificant. The initial ratio of the line, 0.703 ± 0.002, is defined mainly by the two dolerites DS-16 and

DS-18, so that the isotopic data do not give evidence for the origin of the more felsic magmas.

OLIVINE DOLERITE SILLS OF NORTHERN CENTRAL SWEDEN

An association between remnants of "Jotnian" continental sediments and intrusive olivine dolerites is well described throughout northern central Sweden and adjacent areas of Finland. In addition the sills penetrate the basement over a wide region, and the total area affected by dolerite sill intrusion is 500 km (E—W) by 400 km (N—S; see Fig. 1). Generally, there is little evidence as to the length of time which separates "Jotnian" sedimentation and olivine dolerite intrusion.

In northern Dalarna (Fig. 1) the sills, which are up to hundreds of metres thick, have been divided petrographically into "Åsby" and "Särna" types (Hjelmqvist, 1966). The Åsby type contains olivine, plagioclase, clinopyroxene, opaques, apatite, biotite and interstitial alkali feldspar; the Särna type differs from this in its low abundance of apatite and biotite and in often lacking an alkali feldspar phase. Major element analysis of typical samples shows that the Åsby variety has distinctly higher TiO_2, Na_2O, K_2O, P_2O_5 and Fe/Mg ratio for the same SiO_2 content as compared to the Särna dolerite. The Särna type is confined to the westernmost parts of Dalarna (e.g. Idre and Bornåssjön, Fig. 1), and all other occurrences in Dalarna are of the Åsby type. Petrographic and chemical data for sills in the Los-Hamra area (Lundqvist, 1968), included in the "northern Dalarna" of this study, show that these are of the Åsby type. This may apply also to the Nordingrå region (Lundqvist and Samuelsson, 1973; Fig. 1), some dolerites of the Gävle region (lying c. 100 km east of the area of the Tuna dykes, Fig. 1; Gorbatschev, 1967), and to the Finnish occurrences (Sederholm, 1934; Kahma, 1951). The sills and occasional dykes of Härjedalen and Jämtland (Fig. 1) contain olivine, plagioclase, clinopyroxene, opaques, apatite, biotite and interstitial alkali feldspar, and are thus at least on mineralogical grounds to be compared to the Åsby dolerites of Dalarna. No layering was observed by the author in any of the intrusions sampled, but in the Nordingrå region Lundqvist and Samuelsson (1973) and Larson (1973) have described rhythmic layering in well-exposed sills. By implication this may also be present in more poorly exposed intrusions inland.

Over the entire region of northern central Sweden there is a tendency for the development of "monzonitic dolerites" and "monzonites": these are related to dolerite by increase of the alkali feldspar content and introduction of significant quartz, the most felsic monzonites being granophyres of subgranitic composition (e.g. Lundqvist, 1968). In minor occurrences these rocks are often marginal to the dolerite bodies and are probably produced by hybridisation of basic

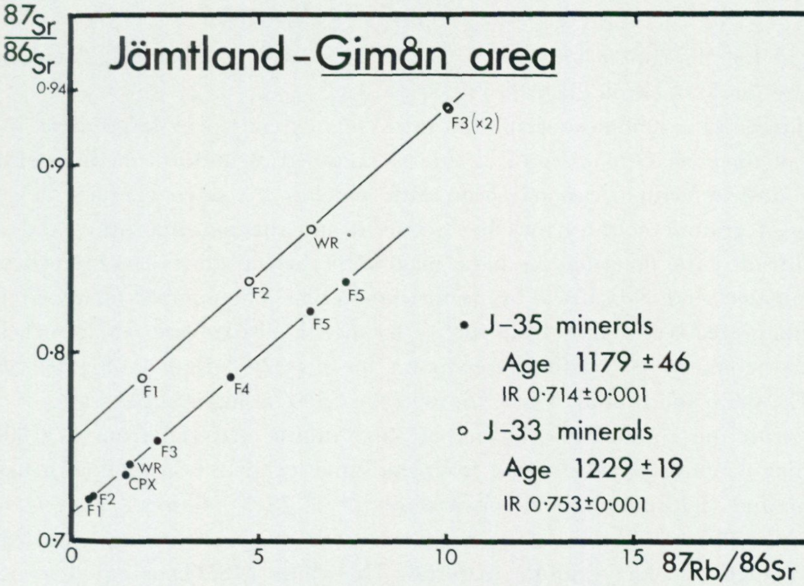

Fig. 9. Mineral lines for a granitic rheomorph and a related hybridised dolerite from a large olivine dolerite sill in the Gimån area, Jämtland. For location see Fig. 1.

magma with country rock (e.g. Hjelmqvist, 1966, p. 150), but in other cases extensive areas of monzonite occur and may even constitute a central facies of the sills (e.g. Lundqvist, 1968).

The main dolerite intrusions, chiefly sills, of the north-central region of Sweden and adjacent areas of Finland (Fig. 1) thus consist of a dominant alkali-olivine dolerite (Åsby and related types) associated with a subordinate olivine dolerite poorer in TiO_2, Na_2O, K_2O and P_2O_5 (Särna type). In Dalarna the two varieties do not occur in the same areas and the Särna type is confined to the western parts, while most occurrences over the rest of northern central Sweden have been compared to the Åsby type, though no attempt has been made to petrographically classify the dolerites outside Dalarna. The present age work on the Bunkris dyke in Dalarna, together with mapping work in Härjedalen and Jämtland by Lundegårdh and Gorbatschev, does however suggest the presence of one or more groups of dolerites different in both petrography and age (being probably older) than the olivine dolerite sills of Åsby and Särna type. Apart from Bunkris, which did not yield a conclusive age result, these intrusions were not covered by this study.

The olivine dolerites, however, were sampled at many localities in Dalarna and Jämtland. In Dalarna the country rock can be late-Svecofennian acid volcanics or the overlying "Jotnian" Dala Sandstone Formation, and in Jämtland country rocks are mainly Svecofennian gneisses and granites.

GIMÅN

Location Fig. 1; sample localities appendix 1, section 5; analytical data appendix 2, section 5; isochron diagram Fig. 9.

In Jämtland a complex of sill-like intrusions extends over large areas in the region of the river Gimån; most of this is composed of uniform medium-grained olivine dolerite with occasional pegmatitic patches. At some contacts however, melting of granitic country rock has occurred and rheomorphic dykes and veins have intruded the dolerite; the basic magma at such localities has often become contaminated and hybridised by granitic material. The samples analysed from the Gimån area were taken from such a locality· Feldspars and whole-rock from granitic rheomorph J-33 define a four-point line of 1 229 ± 19 m.y. (Fig. 9), where MSWD = 0.67 and initial $^{87}Sr/^{86}Sr = 0.753$. Such a high initial ratio is consistent with the considerable history of this granitic material from c. 1 800 to 1 230 m.y. Contaminated dolerite from the same locality, J-35, defines a best-fit mineral line (feldspars and clinopyroxene) of 1 179 ± 46 m.y. (Fig. 9), with initial $^{87}Sr/^{86}Sr = 0.714 \pm 0.001$, consistent with this rock having been heavily contaminated by older granitic material. The value MSWD is equal to 12.82, and if clinopyroxene is omitted from the regression then the age is unchanged at 1 176 ± 14 m.y., but MSWD is reduced to 1.19. This relationship indicates that clinopyroxene is slightly discordant with the other points on the line; since

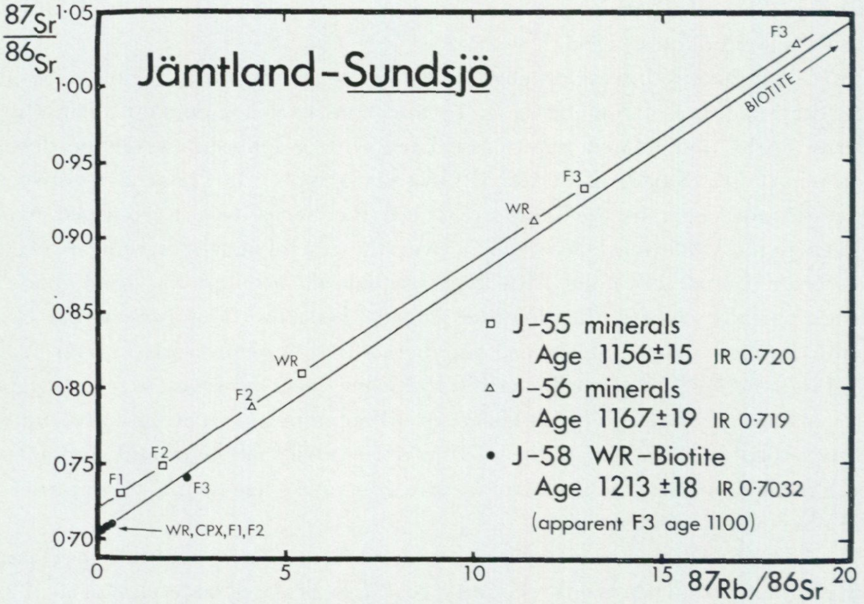

Fig. 10. Superimposed mineral lines for two granitic rheomorphs together with a whole-rock-biotite age from a large olivine dolerite dyke at Sundsjö, Jämtland. For location see Fig. 1.

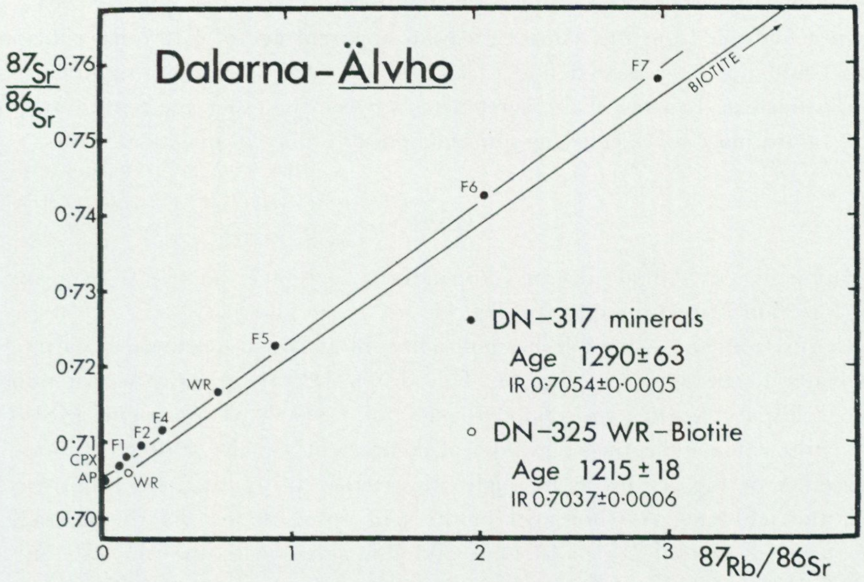

Fig. 11. Mineral line and whole-rock-biotite age for dolerites of the Älvho olivine dolerite-monzonite sill, northern Dalarna. For location see Fig. 1.

however, its inclusion does not alter the age and gives what is probably a more realistic error, and because the result agrees at 2σ with that from J-33, the clinopyroxene is retained in the regression.

SUNDSJÖ

Location Fig. 1; sample localities appendix 1, section 6; analytical data appendix 2, section 6; isochron diagram Fig. 10.

To the west and north-west of the Gimån area various petrographically similar dolerite bodies of more restricted extent occur; one of these is a probable dyke c. 250 m in width at Sundsjö (appendix 1). The dyke is cut and slightly hybridised by a 50 cm rheomorphic dyke of granite, and two samples of this were separated into feldspar fractions for mineral analysis. J-55 defines a four-point line of 1 156 ± 15 m.y., and J-56 a three-point line of 1 167 ± 19 m.y. (Fig. 10); in both cases MSWD is less than unity, 0.12 and 0.83 respectively. This can be explained by fortuitously good alignments of small numbers of data points; therefore the true age errors are likely to be larger than the regression results suggest. The rheomorphic samples have high initial $^{87}Sr/^{86}Sr$ ratios (c. 0.72), consistent with their pre-1 200 m.y. isotopic history since the Svecofennian episode at 1 900—1 750 m.y. The whole-rock-biotite pair from olivine dolerite J-58 of the Sundsjö dyke gives 1 213 ± 18 m.y., in general agreement with the ages from the rheomorph and with the results from the Gimån area. The lightest feldspar from this sample gives an apparent age of 1 100 m.y.; this analysis could not be repeated due to lack of material so that its significance, if any, is unclear. In view of the agreement between the other age results, an 1 100 m.y. figure must be rejected as spurious, possibly due to analytical error.

ÄLVHO

Location Fig. 1; sample localities appendix 1, section 7; analytical data appendix 2, section 7; isochron diagram Fig. 11.

Results from the Åsby dolerite-monzonite sill at Älvho, northern Dalarna (see appendix 1) are shown in Fig. 11. The sample DN-317 gives a best-fit mineral line (feldspars, apatite and clinopyroxene) of 1 290 ± 63 m.y., with MSWD= 22.7; this value indicates a "geological component" in the scatter of points, by inspection of Fig. 11 involving slight discordance of apatite and clinopyroxene with the feldspars. A whole-rock-biotite pair from olivine dolerite DN-325 of the same sill gives 1 215 ± 18 m.y., and this agrees with the mineral line age of DN-317.

EMÅDALEN

Location Fig. 1; sample localities appendix 1, section 8; analytical data appendix 2, section 8; isochron diagram Fig. 12.

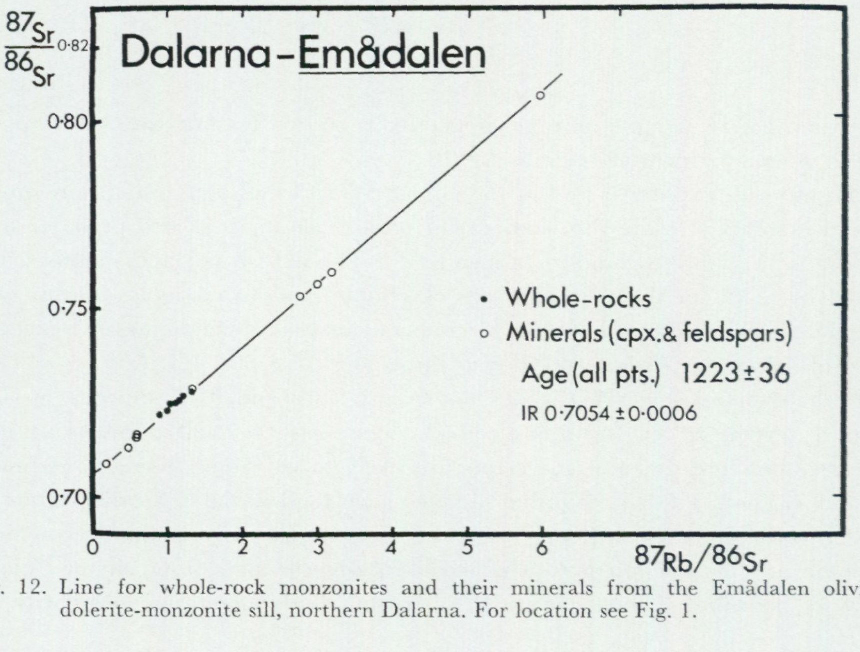

Fig. 12. Line for whole-rock monzonites and their minerals from the Emådalen olivine dolerite-monzonite sill, northern Dalarna. For location see Fig. 1.

To the south of Älvho, the comparable sill of Emådalen also consists of dolerite and monzonite; at Emådalen itself (see appendix 1), monzonite is a homogeneous medium-grained rock developed over at least 100 m measured across the trend of the sill, though whether it has a marginal or an internal position is not clear. Whole-rock and mineral samples from eight of these monzonites, a total of 17 points, are concordant with a single isochron of 1 223 ± 36 m.y. (Fig. 12), where MSWD = 1.80.

ÄLVDALSÅSEN

Location Fig. 1; sample localities appendix 1, section 9; analytical data appendix 2, section 9.

Åsby type olivine dolerite DN-51 from Älvdalsåsen, northern Dalarna, yields a whole-rock-biotite age of 1 231 ± 18 m.y.

MOSSIBERG

Location Fig. 1; sample localities appendix 1, section 10; analytical data appendix 2, section 10.

Åsby type olivine dolerite DN-74 from Mossiberg, northern Dalarna, yields a whole-rock-biotite age of 1 217 ± 18 m.y.

IDRE

Location Fig. 1; sample localities appendix 1, section 11; analytical data appendix 2, section 11.

Särna type olivine dolerite from Idre, north-western Dalarna, was dated by whole-rock-biotite pairs at 1 228 ± 18 m.y. (sample DN-21) and 1 232 ± 18 m.y. (biotite of DN-17, from the same quarry, joined to the whole-rock analysis DN-21).

BORNÅSSJÖN

Location Fig. 1; sample locality appendix 1, section 12; analytical data appendix 2, section 12.

Särna type olivine dolerite from Bornåssjön, north-western Dalarna, defines a whole-rock-biotite age of 1 247 ± 18 m.y.

CONCLUDING REMARKS

The results from the olivine dolerite sills of northern central Sweden are summarised in Table 3 and illustrated in Fig. 1.

If all ages, by whatever method, are given equal weight, then the mean age is 1 218 ± 68 m.y., where the error is 2σ of the distribution of the 13 results. Welin and Lundqvist (1975) obtained a K/Ar "isochron" of 1 245 m.y. (two biotites independently gave this age) for dolerite sills in the Nordingrå region (Fig. 1). Kouvo (1976) reported a U/Pb zircon discordia upper intercept at 1 270 m.y. for olivine dolerite from Märket in the islands between Finland and Sweden (Fig. 1; Suominen, in preparation). New Rb/Sr biotite ages from Vaasa in Finland (Fig. 1) give a mean of 1 225 ± 18 m.y., while results of 1 236 ± 18 and 1 225 ± 18 m.y. are obtained from two sills in the Satakunta region of Finland (Fig. 1; van Breemen, unpublished data). Zircons from Vaasa agree with the Rb/Sr biotites ages, giving a discordia upper intercept of 1 270 m.y. (Suominen, in preparation). All these results are in agreement with the mean based on the ages of this study.

TABLE 3. Summary of age data for the olivine dolerite sills

Intrusion	Sample	Method	Number of points	Age m.y.	MSWD
Gimån	J-33	rheomorph minerals	4	1 229 ± 19	0.67
Gimån	J-35	dolerite minerals	8	1 179 ± 46	12.82
Sundsjö	J-55	rheomorph minerals	4	1 156 ± 15	0.12
Sundsjö	J-56	rheomorph minerals	3	1 167 ± 19	0.83
Sundsjö	J-58	WR-biotite	2	1 213 ± 18	—
Älvho	DN-317	dolerite minerals	9	1 290 ± 63	22.66
Älvho	DN-325	WR-biotite	2	1 215 ± 18	—
Emådalen		WRs + minerals	17	1 223 ± 36	1.80
Älvdalsåsen	DN-51	WR-biotite	2	1 231 ± 18	—
Mossiberg	DN-74	WR-biotite	2	1 217 ± 18	—
Idre	DN-17	WR-biotite	2	1 232 ± 18	—
Idre	DN-21	WR-biotite	2	1 228 ± 18	—
Bornåssjön	71-15	WR-biotite	2	1 247 ± 18	—

The close agreement of all whole-rock-biotite pairs with a c. 1 220 m.y. figure (see Table 3) suggests that in dolerite intrusions unaffected by later tectonic/thermal events this method of dating yields the most consistent results. In view of the agreement of ages, the isotopic data suggest either a single or a series of closely spaced magmatic events to explain the dolerite intrusions, though it must be emphasised that age differences of less than 18 m.y. would be undetectable even by biotite determinations. A point worthy of note is that the two zircon ages from Finland both agree at 1 270 m.y. (Suominen, in preparation), possibly slightly older than the Rb/Sr results, though there is overall agreement within errors. The evidence therefore indicates a major alkali-olivine dolerite igneous province in northern central Sweden and adjacent areas of Finland at 1 220 ± 25 m.y. before present, this being the distribution of the whole-rock-biotite pairs, believed to provide the most accurate and consistent estimates of the emplacement ages of the dykes from Rb/Sr data.

DYKES PARALLEL TO THE SVECONORWEGIAN TECTONIC ZONES

The dykes (and in one area sills) of this group are shown in Fig. 13. They are grouped together primarily on the basis of the age work, but their orientation is at once a strong unifying feature. In the literature they are treated region by region, and indeed petrographic characteristics do vary from one part of the "swarm" to another. Since many parts of central and southern Sweden are not covered by detailed mapping, the distribution of these dolerites may actually be more continuous than Fig. 13 suggests.

The most southerly of the groups of dolerites studied occurs in the province

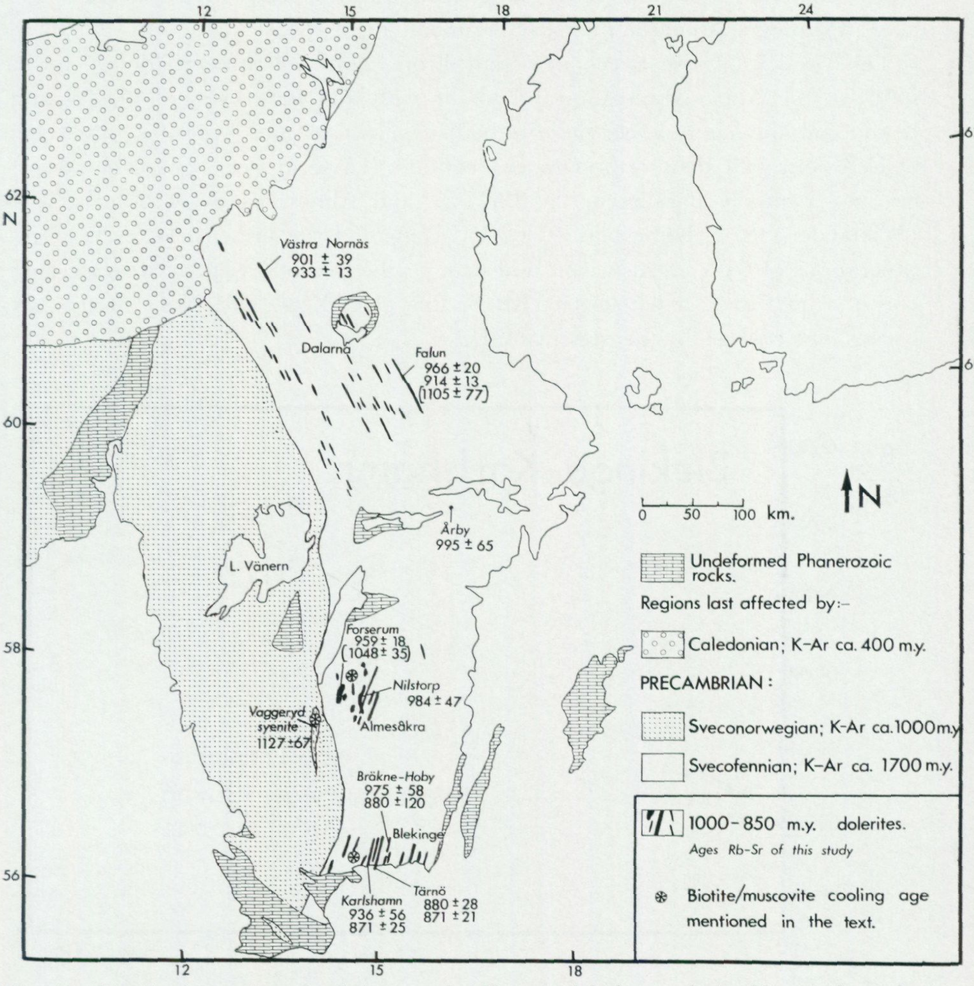

Fig. 13. Distribution and ages of the post-1 150 m.y. dolerites and the Vaggeryd syenite of central and southern Sweden.

of Blekinge (Fig. 13), trending NNE and mapped over a width of c. 90 km. The dykes cut the Karlshamn granite group and consist of olivine, orthopyroxene, clinopyroxene, plagioclase, apatite, opaques and sometimes biotite, and contain rare plagioclase megacrysts and sandstone xenoliths. In the Tärnö dyke (see appendix 1), xenolithic sandstone can account for a large percentage of the volume.

In the Almesåkra region (Fig. 13 and appendix 1) the metasediments and granites are penetrated by long NNE-trending dykes, with a NNW trend developed to a lesser extent. The Almesåkra Formation sediments which overlie the Svecofennian rocks and consist of conglomerate, sandstone, shale and rare limestone, are intruded by large sills of dolerite sometimes over 20 m thick. The typical mineralogy of these rocks comprises orthopyroxene, clinopyroxene, plagioclase, opaques, apatite and interstitial granophyre.

The portion of the Sveconorwegian Front Zone (Schistosity Zone) to the south of the Almesåkra region and to the west and north-west of the Blekinge region contains many linear dolerite bodies, known as the ”hyperites” after their black colour and their orthopyroxene content. These are not shown in Fig. 13, but lie essentially parallel to the Blekinge and Almesåkra dykes. Recent work (Wiklander, 1974; Klingspor, 1976) has suggested the presence of at least two generations of basic intrusives in and near to the Sveconorwegian orogenic zone, one of which gives a whole-rock Rb/Sr line of c. 1 600 m.y. None of the ”hyperites” are covered by the present study.

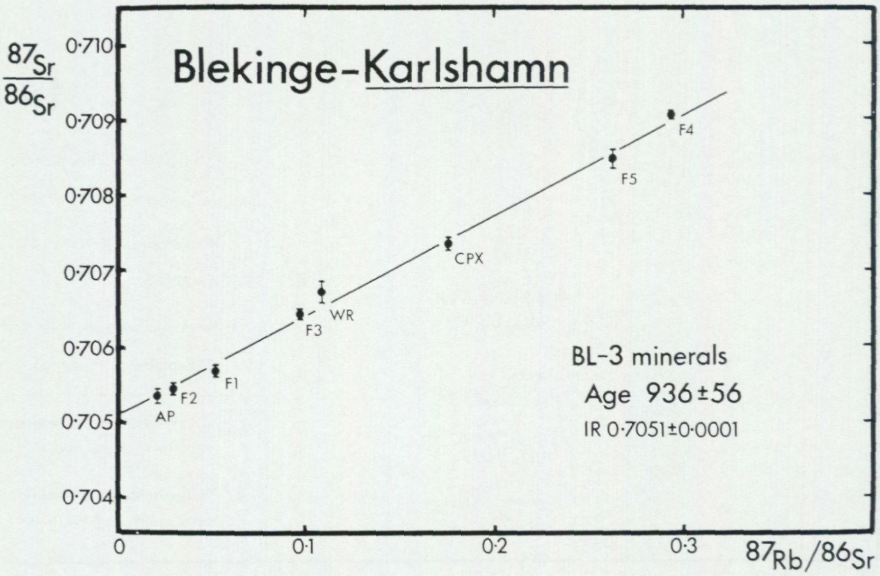

Fig. 14. Mineral line for olivine-hypersthene dolerite BL-3 from the Karlshamn dyke, Blekinge. For location see Fig. 13.

In the area between Blekinge and Almesåkra in the south, and Stockholm in the north there are numerous small dykes, mostly trending between NW and NE (Asklund, 1923). They have previously been classed as uralite-, bronzite- and olivine-dolerites (Törnebohm, 1877; Eichstädt, 1882). These dykes were not included in the present study. However, west of Stockholm a dolerite has been sampled which gives results in contrast to the E—W dyke system of the region. This occurrence is at Årby (Fig. 13), where the rock consists of serpentinised olivine, together with clinopyroxene, plagioclase, opaques and apatite. There is only a single outcrop, but neighbouring exposures indicate that the trend of the dyke must be between NW and NE rather than E—W. It is not clear how many of the dykes in the region west of Stockholm should be grouped with the Årby dolerite, which is identified primarily by its Rb/Sr age. Lundegårdh et al. (1971) record a NNW trend for a plagioclase-phyric dolerite, a type common in the older east-west system (Gorbatschev, 1961), and this would suggest that a NW or NNW trend is no evidence that a dyke does not belong to the older set.

The dolerite dykes of the Stockholm area (Stålhös, 1969), which lie c. 100 km east of the Årby dyke, but are not shown in Fig. 13, have a dominant NNW trend associated with a minor NNE trend. These dykes are not covered by this study.

In southern Dalarna a swarm of NNW-trending olivine dolerite dykes occurs over a width of some 70 km (Hjelmqvist, 1966; Fig. 13); these dykes have been

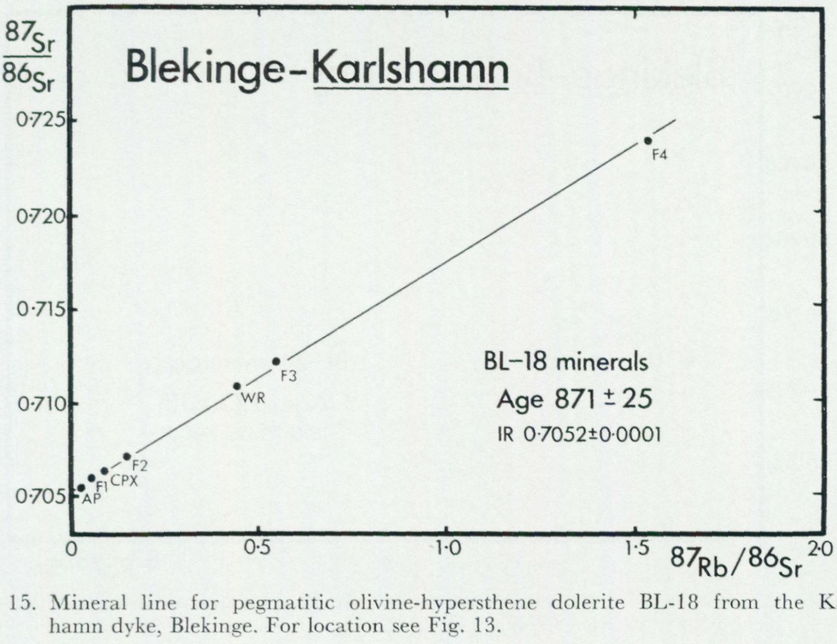

Fig. 15. Mineral line for pegmatitic olivine-hypersthene dolerite BL-18 from the Karlshamn dyke, Blekinge. For location see Fig. 13.

referred to the group ”Åsby dolerite”, and hence by implication correlated with the large sills of this type in northern Dalarna. They consist of olivine (often altered), clinopyroxene, plagioclase, rare apatite, opaques, biotite and often interstitial granophyre. The NNW dykes differ structurally from the thick sills of northern Dalarna, which have an age of c. 1 220 m.y.

In southwestern Dalarna and the neighbouring province of Värmland to the west and southwest occur olivine-free orthopyroxene-bearing dolerites with a NNW trend (Hjelmqvist, 1966).

Certain NNW-trending dykes cut the Dala Sandstone Formation in northwestern Dalarna, some of which have widths greater than 100 m and are studied here. The dyke at Västra Nornäs is a clean dolerite composed of serpentinised olivine, clinopyroxene, plagioclase, opaques, apatite, biotite and interstitial granophyre. The other dyke studied is mapped as having a parallel trend to that at Västra Nornäs, and as cutting the Dala Sandstone (see appendix 1); it is however, a rather strongly altered dolerite with considerable sericite, amphibole and chlorite.

Worthy of mention also, however, are the ”hyperites” which lie wholly within the gneiss-granites and gneisses traversed by numerous Sveconorwegian tectonic zones in the region of Lake Vänern northwards; they are not shown in Fig. 13. These are black hypersthene-bearing olivine dolerites intruded as dykes and sills, probably immediately after the Svecofennian tectogenesis (Lundegårdh, 1977, and unpublished investigations).

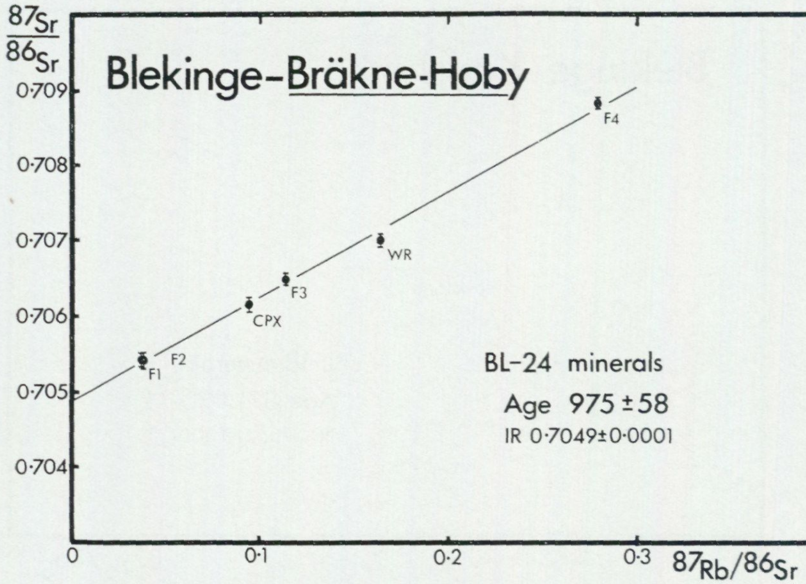

Fig. 16. Mineral line for olivine-hypersthene dolerite BL-24 from the Bräkne-Hoby dyke, Blekinge. For location see Fig. 13.

Important fracture directions in the Svecofennian crust are often oriented parallel to the dolerite dykes. In the region to the west of Stockholm faults trend NW (Stålhös, 1969; Gorbatschev, 1961) or NNW (Bergdahl, 1943; Stålhös, 1969; Lundegårdh et al., 1972; Gorbatschev, 1972), and in southern Dalarna an important fracture direction is NNW, with faults also of this orientation in northern Dalarna (Hjelmqvist, 1966).

The known extent of dykes parallel to the Sveconorwegian tectonic zones is thus some 600 km measured in a north-south direction, by a maximum of 150 km measured across the strike.

KARLSHAMN

Location Fig. 13; sample localities appendix 1, section 13; analytical data appendix 2, section 13; isochron diagrams Figs. 14 and 15.

The c. 250 m Karlshamn dyke is the most westerly of the three studied in the Blekinge region of southern Sweden (see Fig. 13 and appendix 1), and intrudes Svecofennian gneisses at the sampled localities. Minerals from average centre dolerite BL-3 and pegmatitic dolerite BL-18 give best-fit lines of 936 ± 56 m.y. (Fig. 14) and 871 ± 25 m.y. (Fig. 15) respectively. MSWD values are discussed in the concluding part of this section. The ages overlap at 2σ, and since clinopyroxene and apatite are concordant with the feldspars in both cases, then a considerable degree of confidence is to be placed in the results.

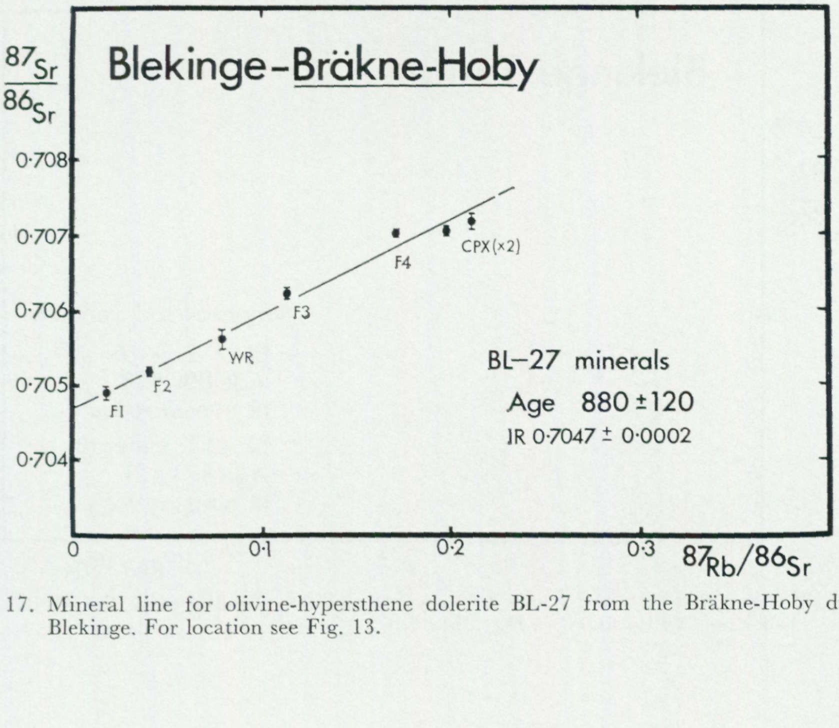

Fig. 17. Mineral line for olivine-hypersthene dolerite BL-27 from the Bräkne-Hoby dyke, Blekinge. For location see Fig. 13.

BRÄKNE—HOBY

Location Fig. 13; sample localities appendix 1, section 14; analytical data appendix 2, section 14; isochron diagrams Figs. 16 and 17.

The dyke 2 km east of Bräkne—Hoby intrudes Karlshamn granite and the analysed samples BL-24 and BL-27 are average dolerites from the centre of the dyke. The range of Rb/Sr ratios of the minerals is low (0—0.1) and the errors on the best-fit lines consequently rather high. The clinopyroxene analysis of BL-27 was repeated and the two analyses have an "isochron relationship" to one another (due to inhomogeneity of granular sample); the mean is used for regression treatment. The ages obtained are 975 ± 58 m.y. (sample BL-24, Fig. 16) and 880 ± 120 m.y. (sample BL-27, Fig. 17). These are in general agreement with the Karlshamn results, though a close comparison is not possible. MSWD values are discussed in the concluding part of this section.

TÄRNÖ

Location Fig. 13; sample localities appendix 1, section 15; analytical data appendix 2, section 15; isochron diagram Fig. 18.

The c. 50 m Tärnö dyke is the central of the three studied in Blekinge (see appendix 1), intrudes granite and consists of an intimate mixture of fine dolerite and arkosic sandstone, despite the fact that no such sediment is exposed in

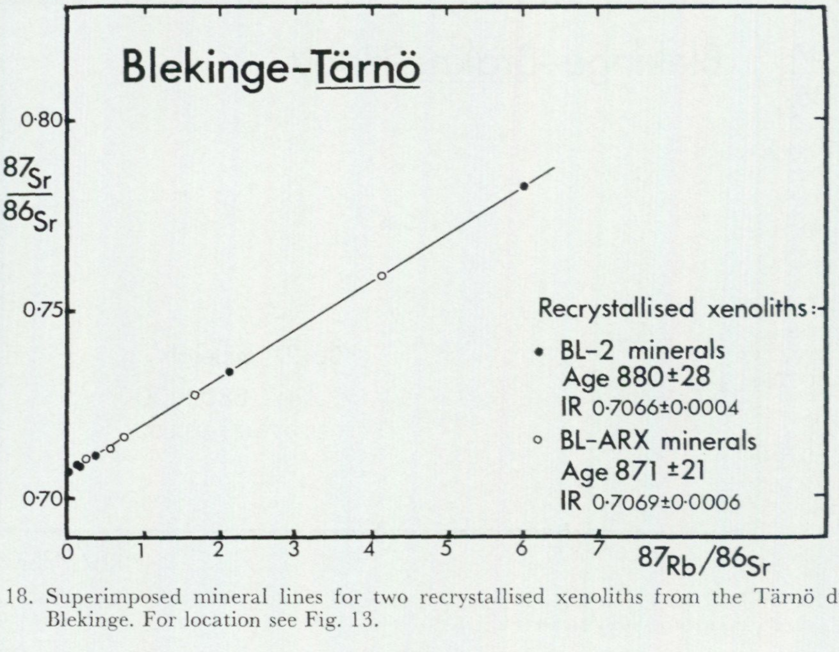

Fig. 18. Superimposed mineral lines for two recrystallised xenoliths from the Tärnö dyke, Blekinge. For location see Fig. 13.

Blekinge at the present erosion level (compare Wiklander, 1974). The arkosic sandstone has often been disrupted into pieces or even individual grains rather easily by the dolerite magma, but the dyke also contains well-indurated xenoliths which must have been carried in the magma for a longer time; they are totally recrystallised to medium- or coarse-grained rocks consisting of quartz, feldspars, epidote, hornblende, sphene and opaques. Two of these (BL-3 and BL-ARX) were separated into mineral fractions and they generate isochrons with identical ages of 871 ± 21 and 880 ± 28 m.y. (Fig. 18). If the xenoliths are presumed to have last recrystallised at the time of intrusion of the dolerite, then the mineral isochrons can be taken as defining an emplacement age for the dyke; this inferred age agrees with the result from Karlshamn.

FORSERUM

Location Fig. 13; sample localities appendix 1, section 16; analytical data appendix 2, section 16; isochron diagram Fig. 19.

The thick sill at Forserum in the Almesåkra region (see appendix 1) intrudes Svecofennian metasediments and the overlying Almesåkra Formation; the analysed samples are both from the interior of the sill. AL-6 defines a mineral best--fit line of 959 ± 18 m.y. (Fig. 19), which includes clinopyroxene; apatite, however, lying some distance below the line; this analysis could not be repeated so that its significance is not clear. AL-12 defines a mineral best-fit line of 1 048

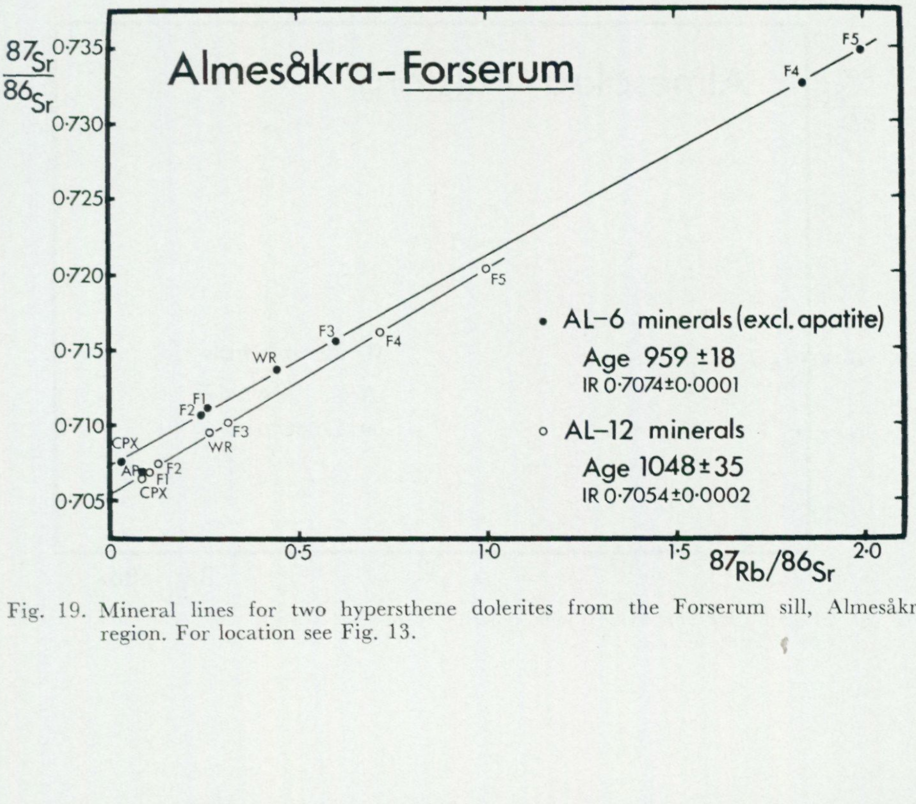

Fig. 19. Mineral lines for two hypersthene dolerites from the Forserum sill, Almesåkra region. For location see Fig. 13.

± 35 m.y. (Fig. 19). Allowing for the possibility of radiogenically enriched Sr entering the crystallising system and causing later crystallised, higher Rb/Sr feldspars to be contaminated leading to an upwardly-biased mineral line age (Patchett and van Breemen, unpublished paper), it is clear that the younger result of 959 ± 18 m.y. should form a closer approximation to the intrusive age of the sill. This inference is applied in this study whenever two mineral lines from the same body do not agree at 2σ.

NILSTORP

Location Fig. 13; sample localities appendix 1, section 17; analytical data appendix 2, section 17; isochron diagram Fig. 20.

The sill of comparable size at Nilstorp intrudes Almesåkra Formation sediments at the sampled locality (see appendix 1). The sample AL-22 is an interior medium-grained dolerite and the mineral line of 984 ± 47 m.y. (Fig. 20), which includes clinopyroxene and apatite, is in good agreement with the result from Forserum. MSWD values are discussed in the concluding part of this section.

ÅRBY

Location Fig. 13; sample locality appendix 1, section 18; analytical data appendix 2, section 18; isochron diagram Fig. 21.

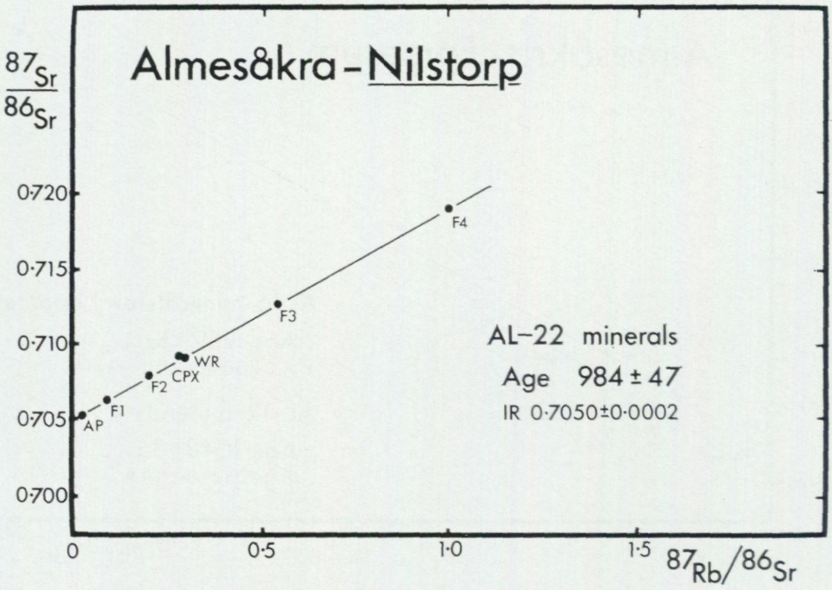

Fig. 20. Mineral line for hypersthene dolerite from the Nilstorp sill, Almesåkra region. For location see Fig. 13.

The Årby dyke is probably c. 10 m wide and may trend NW, the sample being from a single exposure. The country rocks are Svecofennian gneisses and gneiss-granites. The mineral best-fit line from SÖ-50 includes clinopyroxene and defines an age of 995 ± 65 m.y. (Fig. 21). The MSWD value is discussed in the concluding part of this section.

FALUN

Location Fig. 13; sample localities appendix 1, section 19; analytical data appendix 2, section 19; isochron diagram Fig. 22.

The NNW olivine dolerite dykes of southern Dalarna were covered by a study of the most easterly of the group, a 50 m dyke running for over 50 km from Falun southwards (see appendix 1). A sample from 30 km SSE of Falun (DS-9) defines a mineral isochron which includes clinopyroxene of 966 ± 20 m.y. (Fig. 22). A petrographically very similar sample DS-31 from near Falun gives a mineral best-fit line of 1 105 ± 77 m.y. (Fig. 22). These ages do not agree at 2σ, and by the principle explained in connection with the Hällefors dyke and the Forserum sill, the younger result should be preferred. Support for this interpretation comes from the fact that the whole-rock-biotite pair of DS-31 gives 914 ± 13 m.y., agreeing more closely with the 966 ± 20 m.y. age than with the 1 105 ± 77 m.y. result from DS-31. An intrusive age of c. 930 m.y. is therefore indicated for the Falun dyke.

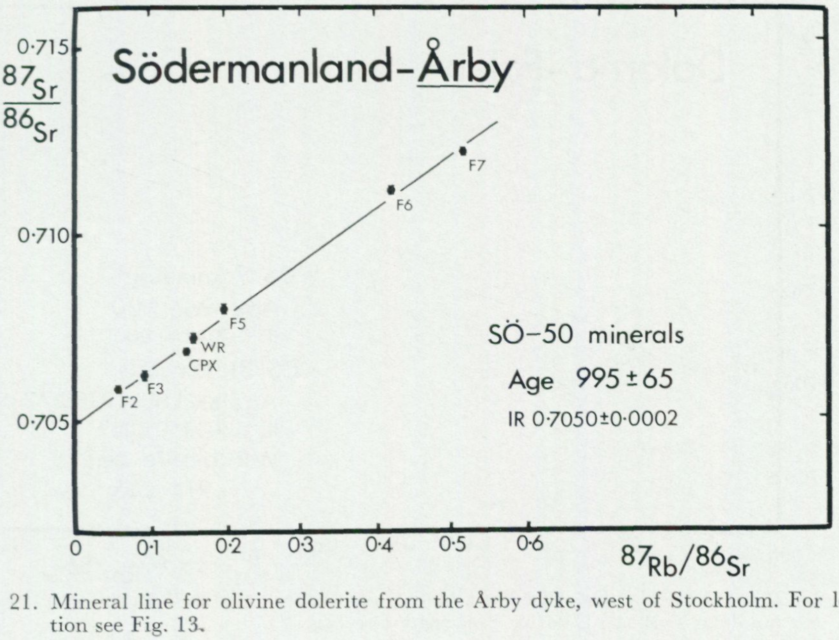

Fig. 21. Mineral line for olivine dolerite from the Årby dyke, west of Stockholm. For location see Fig. 13.

VÄSTRA NORNÄS

Location Fig. 13; sample locality appendix 1, section 20; analytical data appendix 2, section 20; isochron diagram Fig. 23.

Dolerite D75-26 from a large dyke near Västra Nornäs, intruding the Dala Sandstone Formation in northern Dalarna (see appendix 1), defines a mineral best-fit line of 901 ± 39 m.y. (Fig. 23), while the whole-rock-biotite pair from the same sample gives 933 ± 13 m.y. The agreement between mineral line and biotite ages is good evidence that the c. 920 m.y. age is that of dyke intrusion.

BUNKRIS

Location appendix 1; sample localities appendix 1, section 21; analytical data appendix 2, section 21; isochron diagram Fig. 24.

A large dyke at Bunkris, northern Dalarna, mapped as lying parallel to that at Västra Nornäs, apparently intrudes post-Svecofennian acid volcanics and the overlying Dala Sandstone Formation. Two altered dolerites give feldspar lines of 1 516 ± 62 and 1 546 ± 84 m.y. (Fig. 24), but clinopyroxene in both cases lies considerably below the line and consequently little confidence is to be placed in the results. Initial $^{87}Sr/^{86}Sr$ ratios of the lines are as high as 0.710 and suggest substantial addition of radiogenically enriched Sr to the dyke; if some of this was added during crystallisation then anomalously old ages could have

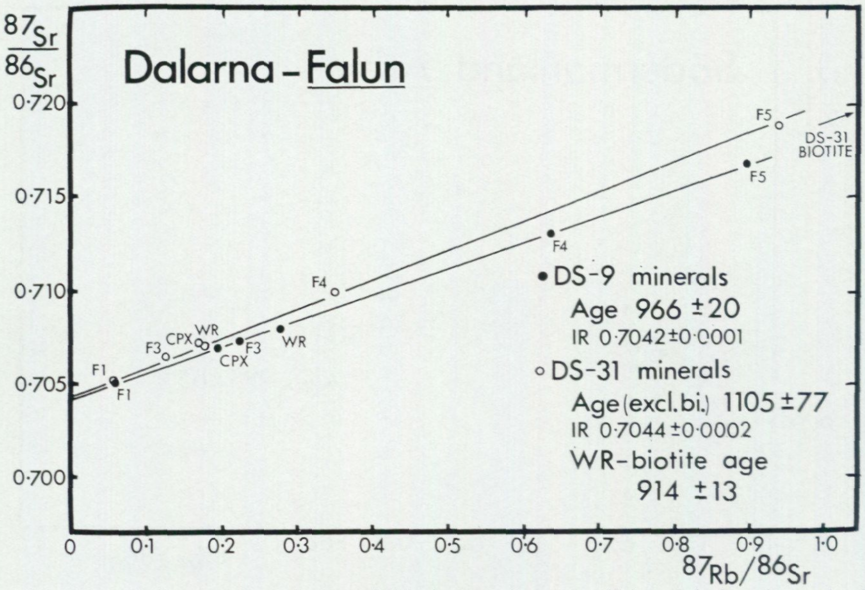

Fig. 22. Mineral lines and a whole-rock-biotite age for two olivine dolerites from the Falun dyke, southern Dalarna. For location see Fig. 13.

been produced. Clinopyroxene was among the earliest phases to crystallise in these rocks, and so the fact that it has a lower initial ^{87}Sr/^{86}Sr ratio than the feldspars does suggest contamination during crystallisation.

Since the dyke is mapped as lying parallel to Västra Nornäs, it would under normal circumstances be assigned a similar age. The results however, despite the likelihood of contamination during crystallisation, may indicate an age as old as 1 530 m.y. for the Bunkris dyke. Because of this uncertainty, the intrusion is not shown on either Fig. 1 or 13. If the Bunkris dyke did indeed cut the Dala Sandstone Formation, as suggested by the mapping (Hjelmqvist, 1966), and its age were as old as 1 530 m.y., then the sediments would be somewhat older than hitherto assumed, a possibility which is not considered likely (compare the Nordingrå Sandstone, Welin and Lundqvist, 1975).

CONCLUDING REMARKS

Age data from the dykes (and the two sills) parallel to the Sveconorwegian tectonic zones, omitting only the data from Bunkris, are summarised in Table 4 and illustrated in Fig. 13.

Some of the mineral lines have MSWD less than c. 2.5 and should therefore be regarded as isochrons in the strict statistical sense, but the majority of MSWD values fall between 2.5 and 8. This may suggest a degree of geological scatter in the points regressed, but it is equally possible that the method of calculation

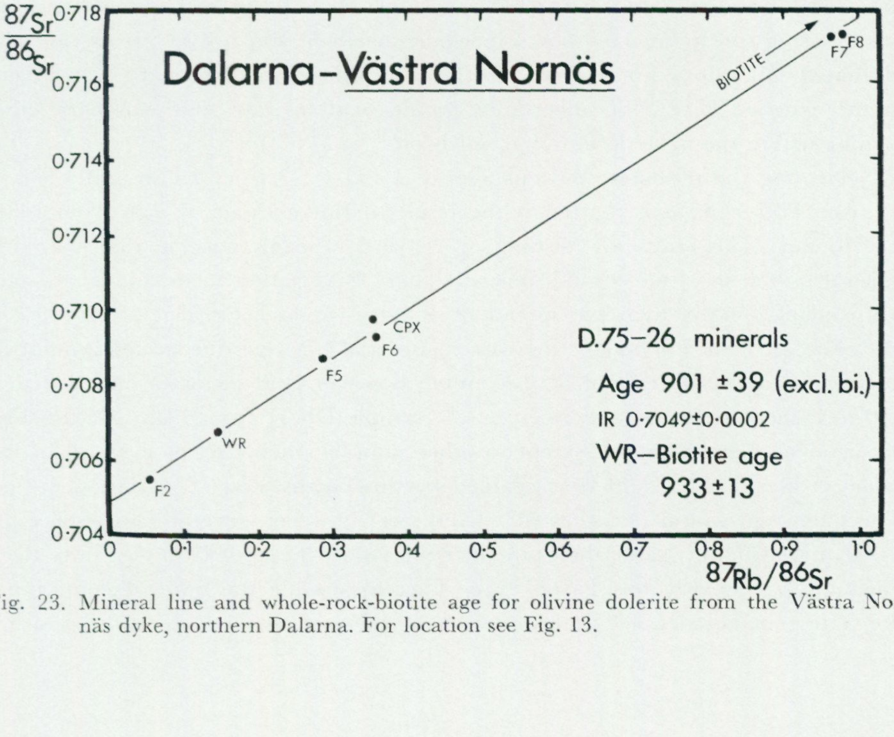

Fig. 23. Mineral line and whole-rock-biotite age for olivine dolerite from the Västra Nornäs dyke, northern Dalarna. For location see Fig. 13.

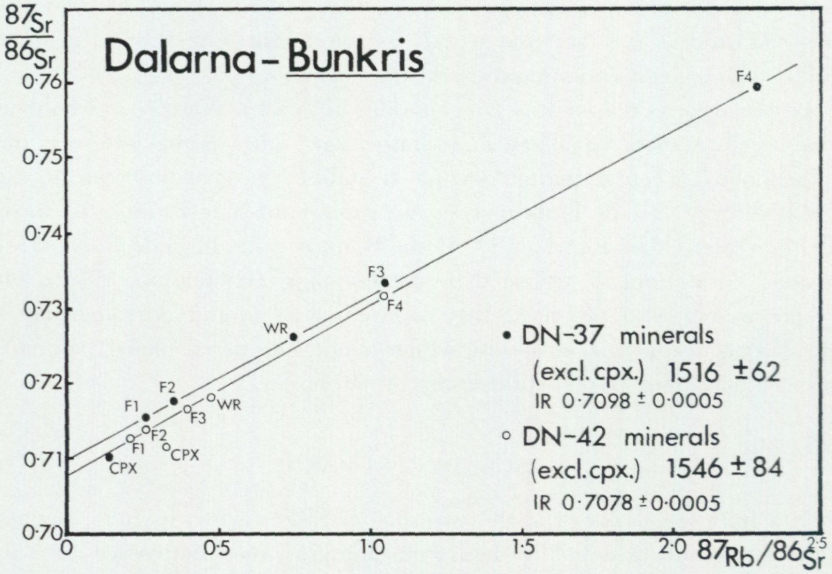

Fig. 24. Feldspar lines for two dolerites of the Bunkris dyke, northern Dalarna. Note the position of the clinopyroxenes lying below the lines. See text for discussion of the age of this dyke. For location see appendix 1.

of ^{87}Sr/^{86}Sr uncertainties (which are the main source of error for low-Rb/Sr data) yields an estimated error that is too low. It is possible that the true analytical error for these data lies somewhere between the in-run errors and the estimated laboratory uncertainty of 0.04 %; quite a small upward adjustment in the assigned ^{87}Sr/^{86}Sr uncertainty would lead to most of the mineral lines coming within the strict definition of isochron.

Neglecting the probably spurious ages of 1 105 ± 77 from Falun and 1 048 ± 35 from Forserum, it is clear that the results define a range of ages from 1 000 to 870 m.y. The limits are distinct at 2σ, and it seems possible that within a general c. 950 m.y. age for the dolerites there is variation in detail. If the ages were taken literally then the spread of activity would be from c. 1 000 to 870 m.y.; the effect of anomalous increase in mineral line age due to contamination during crystallisation cannot be discounted however, and seems to have led to a 150 m.y. increase in the age given by the sample DS-31 from Falun. If this had occurred to a more limited extent in other samples, then part or even all of the range of age results could be explained by this means, and no variation in emplacement age would be necessary. There are, however, several results between 1 000 and 930 m.y., and these are in contrast to the c. 900 m.y. results from Blekinge, particularly the Tärnö dyke. Therefore while the mineral contamination effect makes detailed interpretation of the age patterns difficult, it seems

TABLE 4. Summary of age data for dykes parallel to the margin of the Sveconorwegian orogenic belt

Intrusion	Sample	Method	Number of points	Age m.y.	MSWD
Karlshamn	BL-3	dolerite minerals	8	936 ± 56	2.07
Karlshamn	BL-18	dolerite minerals	7	871 ± 25	3.72
Tärnö	BL-2	xenolith minerals	5	880 ± 28	2.22
Tärnö	BL-ARK	xenolith minerals	4	871 ± 21	2.22
Bräkne-Hoby	BL-24	dolerite minerals	6	975 ± 58	1.85
Bräkne-Hoby	BL-27	dolerite minerals	6	880 ± 120	4.41
Forserum	AL-6	dolerite minerals	7	959 ± 18	2.89
Forserum	AL-12	dolerite minerals	7	1 048 ± 35	4.71
Nilstorp	AL-22	dolerite minerals	7	984 ± 47	7.56
Årby	SÖ-50	dolerite minerals	7	995 ± 65	5.43
Falun	DS-9	dolerite minerals	6	966 ± 20	1.06
Falun	DS-31	dolerite minerals	6	1 105 ± 77	7.34
Falun	DS-31	WR-biotite	2	914 ± 13	—
V. Nornäs	D75-26	dolerite minerals	7	901 ± 39	6.25
V. Nornäs	D75-26	WR-biotite	2	933 ± 13	—

likely that the dykes parallel to the Sveconorwegian tectonic zones represent a spread of intrusive ages from 1 000 to 850 m.y.

VAGGERYD SYENITE OF SOUTHERN SWEDEN

Location Fig. 13; sample localities appendix 1, section 22; analytical data appendix 2, section 22; isochron diagram Fig. 25.

The Vaggeryd syenite occurs within the Sveconorwegian tectonic zone of southern Sweden. The syenite body forms an intrusion in gneiss-granites and gneisses affected by Sveconorwegian metamorphism to the west and schistose granite probably of Svecofennian age (Åberg, 1972) to the east (Quensel, 1960). The body has dimensions of 12 km (E—W) by 60 km (N—S) and is thus elongated parallel to the tectonic zone. The syenite, quartz-bearing in marginal areas and sometimes peralkaline in its interior, is itself strongly deformed along zones of shearing. Metamorphic muscovite, biotite, epidote and garnet have formed in the most deformed rocks; zones of strong deformation can however be separated by lenses of almost undeformed syenite on a scale of hundreds of metres or kilometres.

Samples have been taken from the northern part of the body, and the localities are found in appendix 1. Most of the collected rocks have rather low Rb/Sr ratios (less than 1.0), only the peralkaline syenites yielding higher points. In view of the scanty number of analyses at high Rb/Sr, three of these were duplicated and their position confirmed.

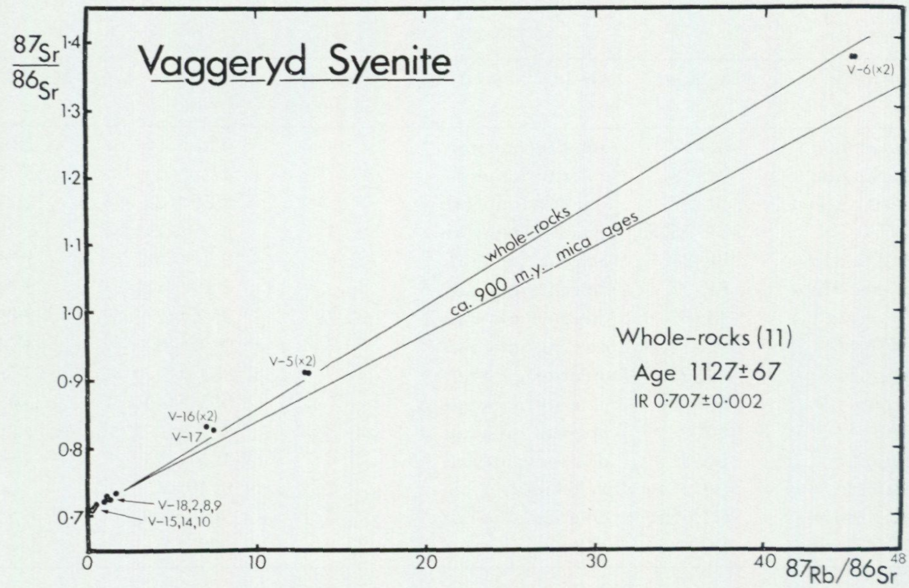

Fig. 25. Whole-rock line for the Vaggeryd syenite of southern Sweden. The mica ages are diagrammatically represented. For location see Fig. 13.

The whole-rock age obtained, 1 127 ± 67 m.y. (Fig. 25), has an MSWD value of 53.3, indicating that the scatter of points contains a considerable geological component. This is clearly to be found in redistribution of Rb and Sr during the metamorphism which has affected the syenite. The further possibility, that the 1 130 m.y. result is itself a metamorphic age, cannot be ruled out. Since, however, the line is defined by both deformed and essentially undeformed samples (e.g. V-5), the age is considered to be an approximation to the time of emplacement of the body. The result should be compared to a more precise age of 1 184 ± 38 m.y. for smaller syenite bodies lying near the thrust zone c. 100 km to the south of the Vaggeryd syenite (Klingspor, 1976).

The initial $^{87}Sr/^{86}Sr$ ratio, 0.707 ± 0.002 is too imprecise to allow any conclusions regarding the ultimate origin of the syenite.

Ages of whole-rock-biotite and whole-rock-muscovite pairs from deformed syenites are shown in Table 5. The micas became closed systems to Rb and Sr

TABLE 5. Ages of metamorphic micas (in m.y.) from the Vaggeryd syenite

Sample	WR-muscovite	WR-biotite
V-2	928 ± 13	875 ± 13
V-8	—	858 ± 13
V-10	914 ± 13	904 ±13

migration at c. 900 m.y., and since the samples were selected for their content of metamorphic minerals, the results should be regarded as metamorphic ages. If the Vaggeryd syenite was deformed and metamorphosed at a relatively shallow level, then the mica ages could be close to the actual age of metamorphism, but it is more likely that they represent the time at which the rocks cooled through the relevant Rb and Sr blocking temperatures; thus the metamorphism would have taken place at some time prior to the age defined by the micas. The fact that the muscovites (isotopic closure c. 500°C, Jäger, 1973) give slightly older results than the biotites (isotopic closure c. 300°C, Jäger, 1973) lends support to this view.

MINERAL AGE STUDIES ON GRANITE COUNTRY ROCKS OF SOUTHERN SWEDEN

Sample localities appendix 1, section 23; analytical data appendix 2, section 23.

Because the age results presented here for the dolerites are based on various types of mineral data, it is necessary to establish that the ages obtained are those of intrusion and not some regional thermal event. The almost completely undeformed nature of the dolerites might be considered evidence enough, but in the central and northern regions of study several K/Ar ages of c. 1 700 m.y. (Magnusson, 1960) indicate that the country rock has not been thermally affected since Svecofennian time. In particular, the fact that dolerites from Idre in Dalarna, lying 5 km from exposed Caledonian thrust-sheets and possibly once covered by these, yield Rb/Sr biotite ages of c. 1 230 m.y., demonstrates a lack of 500—400 m.y. thermal effects in northern central Sweden, at least above a temperature of c. 300°C (Jäger, 1973). The uncertainty over the ages of thermal events in southern Sweden, however, prompted a mineral age study of country rocks in the Almesåkra and Blekinge regions (Växjö and Spinkamåla granites respectively).

Coarse white Växjö granite F-3 from the Almesåkra region, lying 11 km to the north-east of Forserum, gives whole-rock-biotite ages of 1 614 ± 24 and 1 625 ± 24 m.y. (two analyses), and the whole-rock-orthoclase pair gives 1 573 ± 97 m.y. These ages, which must be younger than the intrusion age of the granite (and therefore consistent with Welin et al., 1966, and Åberg, 1972), show that this portion of crust has not been thermally affected since late-Svecofennian time.

Spinkamåla granite SPG-1 from 13 km west of the Karlshamn dyke in Blekinge is of similar grain-size to the dolerite samples used for dating. The whole-rock-biotite pair from this sample gives 1 364 ± 23 and 1 352 ± 23 m.y. (two analyses), and the whole-rock-microcline pair gives 1 169 ± 68 m.y. The Spinkamåla granite is considered to belong to the Karlshamn group of granites, emplaced at c. 1 450 m.y. (Welin and Blomqvist, 1966), and a cooling age of 1 360 m.y. might thus be considered reasonable for this body. K/Ar ages from similar granites on Bornholm to the south of Blekinge also suggest this cooling age (Larsen, 1971). On the other hand, the age of the microcline does indicate some open-system behaviour as late as 1 170 m.y.; this could be related to Sveconorwegian events in south-western Sweden. The granite sample is in any case much closer to the Sveconorwegian tectonic zone than the dolerite dykes, and since it does not show mineral ages as young as 900 m.y., or give evidence of an isotopic disturbance sufficient to reset all minerals after granite cooling at c. 1 360 m.y., then the 900 m.y. dolerite ages from Blekinge can be interpreted as representing the time of intrusion.

DISCUSSION

The 1 560—1 510 m.y. age for the E—W dyke system corresponds to other events in Sweden. Intrusion of post-tectonic granites and syenites took place in northern Sweden at c. 1 520 m.y. (Welin et al., 1971; Gulson, 1972), and in central Sweden to the immediate north and north-east of the E—W dyke region, Welin (1963) has dated a period of mineralisation by U/Pb at 1 585 m.y. (Welin, personal communication 1976). In southern Sweden, the alkaline complex of Norra Kärr has been dated at 1 547 ± 62 m.y. by the Rb/Sr whole-rock method (Blaxland, 1977). The correlation with mineralisation in the same area is probably significant; the mineralisation could have been associated with the fracturing and heating of the Svecofennian basement connected with the magmatic activity which gave rise to the E—W dyke system. Therefore the dykes of c. 1 530 m.y. can be related to anorogenic igneous and hydrothermal events in northern, central and southern Sweden, and may be part of widespread fracturing and magmatism at this time, though on the evidence of the present study such an event would not have encompassed very extensive activity.

The c. 1 370 m.y. Tuna dykes of central Sweden can also be related to other igneous events. In northern central Sweden the Ragunda and Nordingrå syenites and granites were emplaced between 1 450 and 1 300 m.y. (Welin and Lundqvist, 1975), and in southern Sweden the Karlshamn group of granites were intruded at c. 1 450 m.y. (Welin and Blomqvist, 1966). In the Sveconorwegian tectonic belt, Skiöld (1976) has dated two small granite bodies by Rb/Sr whole--rock at c. 1 370 m.y. Therefore the age of the Tuna dykes corresponds in a general way to those of igneous events in other parts of Sweden. The relationships between all these events are however rather vaguely defined, and it is possible that they are all tectonically and magmatically independent.

In contrast to the restricted locals of the 1 530 and 1 370 m.y. dykes, the olivine dolerite sills of 1 220 m.y. were emplaced over a large region of northern central Sweden and adjacent areas of Finland (Fig. 1). This it at once suggestive that the sills do not represent some isolated event, but must be part of larger--scale tectonic/magmatic processes. In Fennoscandia, the only ages comparable to those of the dolerites come from the Sveconorwegian tectonic belt. In southwestern Sweden, Gorbatschev and Welin (1975) and Welin and Gorbatschev (1976) have dated granite plutons at 1 214 ± 30 and 1 224 ± 50 m.y. Metamorphic results of 1 200 m.y. or slightly later have been reported from southern Norway by among others O'Nions and Baadsgaard (1971) and Versteeve (1974). These comparisons may suggest that the 1 220 m.y. dolerites were related to orogenic events in the neighbouring Sveconorwegian tectonic belt (compare Lundqvist and Samuelsson, 1973). It is also possible that the c. 1 220 m.y. basaltic events took place during a tensional tectonic phase, and this alternative has been favoured by several reviewers (Burke and Dewey, 1973; Baer, 1976; Poorter, 1976), either with respect to the events in Scandinavia or their possible correlatives in Greenland-Canada. Whether the basic magmatism was associated with Grenville-Sveconorwegian (Dalslandian) orogenic events or with pre- or intra-Grenville continental separation depends critically upon the exact nature and duration of the orogenic processes. Since this is not yet satisfactorily established, it is not possible at this stage to distinguish between these alternative explanations for 1 220 m.y. basic magmatism in the North Atlantic region.

The 1 000—850 m.y. dykes of central and southern Sweden run essentially parallel to most of the 600 km length of the Sveconorwegian tectonic belt. This has been interpreted by Patchett and Bylund (1977) as indicating tensional stress in the Svecofennian crust at right angles to the tectonic zones; the fact that the Sveconorwegian tectonic belt was probably undergoing postorogenic uplift at this time, as given by K/Ar ages, suggests that this could have caused upwarping and tensional fracture of the Svecofennian region, resulting in dyke emplacement. The 1 000—850 m.y. dykes do not have equivalents in Greenland or Canada, and fracturing of the pre-Grenville crust parallel to the tectonic zones is restricted to Sweden.

Of the four episodes of dolerite intrusion recognised therefore, two (1 220 and 1 000—850 m.y.) seem to be related to major tectonic processes. This suggests that fracture and basic magmatism in "stable" Scandinavia from 1 600 to 800 m.y. is at least partly an expression of tectonic events taking place in adjacent non-stable regions.

The present study makes some contribution to knowledge of the age of the continental sediments which overlie the Svecofennian crust, but does not clearly bracket their deposition. The Dala Sandstone Formation is cut by sills of 1 220 m.y.; it is not clear whether this formation must also be pre-1 530 m.y., the age of the Bunkris dyke, which apparently also intersects the sediments, being uncertain. The age of the Tärnö dyke (c. 870 m.y.) provides evidence for weakly cemented sediments in southern Sweden at the time (A. Rodhe, personal communication, 1976). The Almesåkra Formation is intruded by dolerites of c. 970 m.y., and incorporation of pebbles into the magmas ("diabase conglomerates") may suggest that some sedimentation preceded dolerite intrusion by only a short time. Thus the age work does not resolve the problem of correlation of the continental sediments, but it is possible that those in southern Sweden (Almesåkra and Blekinge) are wholly younger than those to the north, which must be pre-1 220 m.y. (see also Welin and Lundqvist, 1975).

The present work also has some bearing on the origin of more evolved rocks associated with dolerites. Small veins, especially near the contacts, have been supposed to represent rheomorphic melts of country rock (e.g. Krokström, 1936), and this is confirmed by the high initial $^{87}Sr/^{86}Sr$ ratios yielded by these rocks when used for dating (see Hällefors, Gimån, Sundsjö sections). Three larger occurrences of more evolved rocks have been studied. The Breven granophyre has been affected by a mild post-intrusive isotopic disturbance, and it is therefore not possible to interpret the initial ratios in terms of magma origin. "Monzonites" at Emådalen, northern Dalarna, yield initial $^{87}Sr/^{86}Sr$ ratios of 0.7050—0.7065, similar to dolerites from the same sill (0.7045 and 0.7056 for two samples): this correspondence does not allow the monzonites to be derived by melting or large-scale assimilation of country rock unless this was of similar age to the sill (1 220 m.y.). Since all country rocks in the area as exposed today are > 1 600 m.y. in age, it may be concluded that the Emådalen monzonites were derived largely by differentiation from dolerite, though some limited assimilation of older crustal rock is allowed by the initial ratios. Similar monzonites in the neighbouring sill of Älvho have initial ratios up to 0.7124, as against 0.7040 etc. for dolerites, and in this case more extensive contamination from older rocks seems to have taken place. It is in fact possible, though not necessary, for the monzonites of Älvho to have been derived by partial melting of older crustal rocks.

The monzonites of Älvho and Emådalen are very similar in lithology and mode of occurrence (Hjelmqvist, 1966; Lundqvist, 1968). The results from the two bodies suggest that the more evolved rocks were derived by a combination of differentiation and contamination processes, though differentiation is likely to have predominated in the case of Emådalen, and at Älvho considerable contamination seems to have occurred. In a general way this conclusion is in accordance with geological evidence from monzonites and granites associated with dolerites at these and other localities in Dalarna (Hjelmqvist, 1961, 1966).

Anomalous initial Sr isotopic ratios are also observed in less evolved rocks. For example, plotting of the seven whole-rock analyses from the Forserum sill (appendix 2, section 16) will show that they define an apparent regression line of c. 1 300 m.y., viz. 300 m.y. or so older than the age of the dolerite intrusion as inferred from mineral data. Support for the mineral isochrons as magmatic ages is given by the tectonically unaffected condition of the samples, and by undisturbed mineral results from nearby Svecofennian country rocks (see above). It must be supposed that the highest Rb/Sr samples from Forserum have raised initial ^{87}Sr/^{86}Sr values, leading to upward bias in regression age. Broadly, bulk assimilation of crustal rock, assimilation of partial melts of crustal rock, or crustal-rock contamination via a late-magmatic fluid phase could all lead to such a Rb/Sr-initial ^{87}Sr/^{86}Sr correlation, and the author has no data which could distinguish between these processes.

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APPENDIX 1: SAMPLE LOCALITIES

Sample localities are presented here for each intrusion in the same order in which they are mentioned in the text. The section numbers of this appendix correspond to those of appendix 2; i.e. for samples with localities in section 1.1, the analytical data are given in section 2.1 etc. Map references correspond to the Swedish national grid. The letter S denotes that a thin-section of the sample was studied.

1.1 GÅSTORP, BÄLGVIKEN AND FORSKILEN DYKES

SÖ-49 S	Medium olivine dolerite at centre of 20 m dyke. Natural exposure 50 m W of Forskilen, 10 G Eskilstuna SO, 15414/65683.
SÖ-53 S	Plagioclase-phyric dolerite of 3 m dyke. Railway cutting, Bälgviken, 10 G Eskilstuna SO, 15373/65650.
SÖ-54 S	Fine dolerite, associated with dolerite carrying plagioclase megacrysts and anorthosite xenoliths in a 3 m dyke. Natural exposure 200 m SW of Gåstorp, 10 G Eskilstuna SO, 15302/65712.

1.2 HÄLLEFORS DYKE

SÖ-21	S	Medium-coarse olivine dolerite of southern marginal series. Roadcut SW of Hälleforsnäs, 10 G Eskilstuna SO, 15381/65580.
SÖ-23	S	Medium-coarse laminated 'porphyrite'; plagioclase and pyroxene phenocrysts in a dark groundmass, intrudes marginal series. SW of Hälleforsnäs, 10 G Eskilstuna SO, 15382/65580.
SÖ-24	S	Coarse porphyrite, unlaminated. As SÖ-23.
SÖ-26	S	Fine-medium porphyrite with reddened feldspars. Roadcut SW of Hälleforsnäs, 10 G Eskilstuna SO, 15383/65583.
SÖ-27	S	As SÖ-26, 50 m further NE.
SÖ-28	S	As SÖ-27, 100 m further NE.
SÖ-29	S	Medium porphyrite with reddened feldspars. Roadcut 200 m NE of SÖ-28.
SÖ-31	S	Fine porphyrite with reddened feldspars. Roadcut SE of Hälleforsnäs, 10 G Eskilstuna SO, 15413/65577.
SÖ-36		Fine granophyre of 6 cm rheomorphic vein at contact between fine dolerite of southern marginal series and country rock gneiss. Sample contains small pieces of dolerite chill. Roadcut SE of Hälleforsnäs, 10 G Eskilstuna SO, 15421/65570.
SÖ-41	S	Coarse laminated porphyrite. Quarry S of Svalboviken, 10 G Eskilstuna SO, 15306/65603.

1.3 BREVEN DYKE

SÖ-2		Coarse olivine dolerite, near western end of dyke. Roadcut, 9 F Finspång NV, 14686/65396.
SÖ-3	S	As SÖ-2. Roadcut, 9 F Finspång NV, 14686/65397.
SÖ-4	S	As SÖ-3.
SÖ-5		Coarse olivine dolerite, serpentinised and chloritised. Roadcut, Bottorp, 9 F Finspång NO, 14768/65399.
SÖ-8		Coarse granophyre. Natural exposure W of Högsätter, 9 F Finspång NO, 14783/65395.
SÖ-9		Coarse granophyre, with incipient weathering. Natural exposure W of Högsätter, 9 F Finspång NO, 14782/65395.
SÖ-10	S	Coarse dolerite hybridised by granophyre. Natural exposure W of Högsätter, 9 F Finspång NO, 14781/65395.
SÖ-11		As SÖ-10. Natural exposure, 9 F Finspång NO, 14781/65396.
SÖ-12	S	Coarse granophyre. Natural exposure W of Johannisberg, 9 F Finspång NO, 14855/65368.
SÖ-13	S	Fine granophyre, vein cutting SÖ-12.
SÖ-14	S	Coarse dolerite-granophyre hybrid. Roadcut W of Johannisberg, 9 F Finspång NO, 14856/65370.
SÖ-15		Coarse dolerite, rusty. Natural exposure at eastern end of dyke near Eriksberg, 9 F Finspång NO, 14921/65358.
SÖ-16		Medium granophyre. Natural exposure 15 m W of SÖ-15.
SÖ-18		Fine granophyre, vein cutting medium granophyre 2 m from SÖ-16.

1.4 TUNA DYKES

DS-16	Porphyritic dolerite: phenocrysts of plagioclase in an ophitic groundmass. Centre of a 7 m dyke at Halvarsgårdar, 12 F Ludvika NO, 14771/66986.
DS-17 S	Porphyritic intermediate rock: phenocrysts of alkali feldspar and hornblende in a trachytic groundmass. Centre of a 5 m dyke 10 m from DS-16.
DS-18	Aphyric dolerite. Centre of a 5 m dyke 100 m E of DS-17.
DS-20 S	Quartz—K-feldspar porphyry, somewhat reddened. Centre of a 3 m dyke, natural exposure 1 km N of Österby, 12 F Ludvika NO, 14931/66998.
DS-21 S	Quartz—K-feldspar porphyry, somewhat reddened. Centre of a 7 m dyke 25 m E of DS-20.
DS-22	Quartz—K-feldspar porphyry, reddened. Centre of a 6 m dyke 15 m E of DS-21.

1.5 GIMÅN AREA SILLS

J-4	Fine olivine dolerite 1.5 m from contact with granite. Roadcut, 18 G Håsjö SV, 15119/69598.
J-12	Medium olivine dolerite. Roadcut, 18 G Håsjö SV, 15155/69565.
J-18 S	Medium olivine dolerite. Roadcut, 18 G Håsjö SV, 15178/69563.
J-19	Medium olivine dolerite. Roadcut, 18 G Håsjö SV, 15060/69623.
J-25	Medium olivine dolerite. Roadcut, 18 G Håsjö SV, 15044/69672.
J-29 S	Pegmatitic dolerite. Roadcut, 18 G Håsjö SV, 15045/69657.
J-33	Medium granophyric rock near contact of olivine dolerite with granite, occurrence suggests rheomorphic origin. Roadcut, 18 G Håsjö SV, 15019/69658.
J-34 S	Medium dolerite with red feldspars, hybrid between dolerite and rheomorph. As J-33.
J-35 S	As J-34.
J-36	Fine olivine dolerite 2 m from contact. 18 G Håsjö SV, 15017/69656.
J-41	Pegmatitic dolerite. 18 G Håsjö SV, 15019/69749.

1.6 SUNDSJÖ DYKE

J-55 S	Medium-coarse rheomorphic granite of 50 cm dyke cutting olivine dolerite. Roadcut on highway E 75 2 km S of Sundsjö, 18 F Bräcke NV, 14678/69819.
J-56 S	Fine-medium rheomorphic granite. As J-55.
J-58 S	Coarse olivine dolerite. Centre of dyke at same locality.

1.7 ÄLVHO SILL

DN-315 S	Medium-coarse olivine dolerite. Riverbed exposure at Älvho, 15 E Älvho SO, 14427/68207.
DN-316	Medium olivine dolerite. 4 m W of DN-315.
DN-317 S	Medium-coarse dolerite with slightly reddened feldspars. 4 m NW of DN-315.
DN-323	Medium-coarse monzonite. Slightly weathered roadcut 500 m W of hill Pilkalampinoppi, 61.6°N, 14.7°E, 108 Storejen, 14425/68312.[1]
DN-324	Medium-coarse monzonite. Slightly weathered roadcut 1 km S of hill Siikamäki, 61.5°N, 14.7°E, 108 Storejen, 14426/68257.[1]
DN-325 S	Medium-coarse olivine dolerite, near eastern margin of sill. Roadcut 1.2 km S of hill Siikamäki, see DN-324.
DN-326	Medium-coarse monzonite. Natural exposure on western flank of hill Siikamäki, see DN-324.
DN-327 S	As DN-326.
DN-328	As DN-326.

1.8 EMÅDALEN SILL

DN-301 to DN-312	Medium-coarse monzonites, from a large homogeneous body either within or marginal to olivine dolerite. Samples are spread at regular intervals along the river Ämån and along a roadcut at Emådalen, 15 E Älvho SO, 14419/68009.
DN-329 S	Medium-coarse olivine dolerite. Roadcut 400 m S of the river Ämån at Emådalen, see DN-301.
DN-330 S	Fine-medium olivine dolerite with interstitial granophyre, 1 m from contact with acid volcanics. Roadcut 500 m S of the river Ämån at Emådalen, see DN-301.

1.9 ÄLVDALSÅSEN SILL

DN-51 S	Medium olivine dolerite. 1 500 m S of river Österdalälven, in stream Ugsiån; 2 km S of Älvdalsåsen, 14 E Mora NV, 13920/67969.
DN-56	Medium olivine dolerite. 200 m S of Österdalälven, in stream Ugsiån, see DN-51.
DN-60	Fine biotite-rich olivine dolerite cutting coarse. 150 m S of Österdalälven, see DN-51.
DN-64 S	Coarse olivine dolerite. 140 m S of Österdalälven, see DN-51.
DN-67	Extremely coarse olivine dolerite developed for c. 100 m S from Österdalälven, see DN-51.

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[1] Approximate coordinates extrapolated on older topographic map from the modern topographic map-sheets 14 D SÄLEN NV and 15 E ÄLVHO SO.

1.10 MOSSIBERG SILL

DN-69 S	Medium olivine dolerite. Roadcut on northern lakeshore at Mossiberg, 61.5°N, 13.9°E, 107 Älvdalsåsen, 13941/68301.[1]
DN-71 S	Fine olivine dolerite rich in biotite, associated with rheomorphic granite veins. Northern lakeshore at Mossiberg, natural exposure close to contact, see DN-69.
DN-74 S	Coarse olivine dolerite. Roadcut at lakeshore 50 m W of DN-69.
DN-78	Coarse olivine dolerite. Natural exposure at NW corner of lake at Mossiberg, probably near contact, see DN-69.

1.11 IDRE SILL

DN-17	Olivine dolerite. Quarry at foot of hill Vålåberget on north side of lake Idresjön, 5 km SE of Idre, 81 Idre, 13377/68607.[1]
DN-21	As DN-17.
DN-24	Olivine dolerite, serpentinised. Natural cliff exposure on S side of lake Idresjön, 5 km SE of Idre, 81 Idre, 13377/68607.[1]
DN-30 S	Olivine dolerite, serpentinised. 50 m W of DN-24.
DN-31 S	Olivine dolerite, serpentinised. 20 m W of DN-30.

1.12 BORNÅSSJÖN SILL

71-15 S	Olivine dolerite. Roadcut 500 m S of lake Bornåssjön, 61.5°N, 13.0°E, 107 Älvdalsåsen, 13544/68294.[1]

1.13 KARLSHAMN DYKE

BL-3 S	Medium-coarse olivine-hypersthene dolerite. Centre of dyke in quarry, 1.5 km S of Karlshamn, 3 E Karlshamn NO, 14408/62251.
BL-7	Medium dolerite, 6 cm from eastern contact with granite. Roadcut across entire 250 m width of dyke 1 km S of Karlshamn, 3 E Karlshamn NO, 14410/62257.
BL-8	Medium dolerite with reddened feldspars, indicating contamination. 4 cm from contact, 6 cm along strike from BL-7.
BL-9	Fine-medium dolerite 0—2 cm from contact hybridised by melted granite. Adjacent to BL-8.
BL-10	Medium dolerite 1 m from eastern contact. Same traverse as BL-8 and 9.
BL-15	Medium-coarse olivine-hypersthene dolerite. Interior sample, 50 m from western contact, roadcut, 3 E Karlshamn NO, 14409/62257.
BL-18	Pegmatitic patch, feldspar-rich with prominent needles of clinopyroxene. Interior of dyke 20 m from western contact, roadcut, 3 E Karlshamn NO, 14409/62257.

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[1] Approximate coordinates extrapolated on older topographic map from the modern topographic map-sheets 14 D SÄLEN NV and 15 E ÄLVHO SO.

1.14 BRÄKNE-HOBY AND PARALLEL DYKES

BL-24 S	Medium-coarse olivine-hypersthene dolerite. Centre of dyke in quarry 5 km NE of Bräkne-Hoby, 3 F Karlskrona SV/NV, 14609/62371.
BL-27 S	Medium-coarse olivine-hypersthene dolerite. Centre of dyke 15 m S of BL-24.
BL-31	Two-phase fine dolerite. Loose block in quarry, 3 F Karlskrona SV/NV, 14609/62370.
BL-32	Pegmatitic dolerite with turbid plagioclase. Loose block in same quarry as BL-31.
BL-35	Fine dolerite. 1 m dyke cutting granite, part of a swarm in line with the 50 m dyke of the quarry 6 km to the N. Dyke carries xenoliths/xenocrysts of granite and K-feldspar. Roadcut S of Bräkne-Hoby, 3 F Karlskrona SV/NV, 14583/62276.
BL-36	Fine dolerite. 20 cm from contact of 6 m dyke in the same traverse as BL-35, 3 F Karlskrona SV/NV, 14584/62275.
BL-40 S	Fine dolerite. Centre of the 6 m dyke of BL-36.

1.15 TÄRNÖ DYKE

BL-1	Fine dolerite contaminated with c. 50 % fine, loose arkosic sand. Centre of 50 m dyke on highest point of the island Tärnö, 7 km SE of Karlshamn, 3 E Karlshamn SO, 14487/62219.
BL-2 S	Totally recrystallised xenolith consisting of quartz, alkali feldspar and epidote. Centre of dyke on northern coast of Tärnö, 1.5 km N of BL-1.
BL-ARX S	As BL-2, from Tärnö. Sample on loan, no detailed locality available.

1.16 FORSERUM SILL

AL-2	Fine dolerite, chill against quartzite of Almesåkra Formation. Quarry 2 km NE of Forserum, 6 E Nässjö NV, 14221/63994.
AL-6 S	Medium hypersthene dolerite, interior of sill. Quarry, as AL-2.
AL-7 S	As AL-6.
AL-10 S	Coarse hypersthene dolerite of interior of sill, with interstitial red granophyre. Quarry, as AL-2.
AL-12 S	Medium hypersthene dolerite, interior of sill. Quarry, as AL-2.
AL-15 S	Pegmatitic dolerite with sericitised plagioclase and interstitial red granophyre. Quarry, as AL-2.
AL-17 S	As AL-15.

1.17 NILSTORP SILL

AL-21	Medium hypersthene dolerite. Small quarry on highway 33 Nässjö—Eksjö, 6 E Nässjö NV, 14426/63910.
AL-22 S	Medium hypersthene dolerite. 4 m from AL-21.
AL-29	Fine dolerite 20 cm from contact with siltstone of the Almesåkra Formation. Roadcut 800 m W of the small quarry, 500 m E of farm Nilstorp, 6 E Nässjö NV, 14419/63910.

1.18 ÅRBY DYKE

SÖ-50 S	Medium olivine dolerite, serpentinised. Centre of a 5 m outcrop of a dyke trending between NW and NE in railway cutting 900 m S of Årby hållplats, 10 G Eskilstuna SO, 15372/65724.

1.19 FALUN DYKE

DS-1 S	Fine dolerite of 1 m satellitic dyke 15 m NE of the main dyke. Roadcut, Bispberg, 12 F Ludvika NO, 14997/66948.
DS-2	Medium olivine dolerite of main dyke at Bispberg, nearest exposed to western contact. See DS-1.
DS-9 S	Medium olivine dolerite, centre of main dyke at Bispberg. See DS-1.
DS-29	Medium olivine dolerite, approximately central. Natural exposure on eastern shore of lake St. Vällan, 2 km W of Falun, 13 F Falun SO, 14876/67196.
DS-31 S	Medium olivine dolerite, approximately central. 10 m across strike from DS-29.

1.20 VÄSTRA NORNÄS DYKE

D75-26 S	Olivine dolerite. Centre of dyke running 2 km W of Västra Nornäs, 61.4°N, 13.1°E, 107 Älvdalsåsen, 13611/68144.[1]

1.21 BUNKRIS DYKE

DN-37 S	Dolerite with blades of clinopyroxene, possibly phenocrysts, and reddened and sericitised feldspars. Centre of c. 500 m dyke, roadcut at Bunkris, 61.4°N, 13.4°E, 107 Älvdalsåsen, 13749/68152.[1]
DN-42 S	Dolerite, feldspars only slightly reddened. 40 m S of DN-37.

1.22 VAGGERYD SYENITE

V-2 S	Strongly schistose coarse quartz-rich syenite with considerable muscovite, biotite and epidote. Roadcut 16 km N of Vaggeryd at Röshult, 6 D Gislaved NO, 13971/63910.
V-5	Igneous-textured coarse syenite, mainly K-feldspar, black amphibole and quartz. Roadcut 8 km N of Vaggeryd, 1 km NW of Krängsberg, 6 E Nässjö NV, 14102/63846.
V-6 S	Fine-medium schistose syenite, mainly K-feldspar, black amphibole and quartz. Roadcut 7 km N of Vaggeryd, 500 m SW of Krängsberg, 6 E Nässjö NV, 14016/63837.

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[1] Approximate coordinates extrapolated on older topographic map from the modern topographic map-sheets 14 D SÄLEN NV and 15 E ÄLVHO SO.

V-8	S	Igneous-textured medium-coarse syenite with a weak directional fabric. Roadcut 2 km SSE of Vaggeryd, 6 E Nässjö SV, 14012/63742.
V-9		More feldspathic facies of V-8 locality.
V-10		Strongly schistose syenite, very similar to V-2. Roadcut 6 km E of Vaggeryd, 6 E Nässjö SV, 14056/63748.
V-14	S	Mafic syenite within feldspathic syenite, mainly hornblende and plagioclase. Roadcut 3 km E of Vaggeryd, 6 E Nässjö NV, 14033/63752.
V-15		As V-14.
V-16		Strongly schistose syenite, similar to V-2. Roadcut 2 km E of Vaggeryd, 6 E Nässjö NV, 14027/63754.
V-17		As V-16.
V-18	S	Igneous-textured syenite, massive, mainly perthite. Roadcut 1 km E of Vaggeryd, 6 E Nässjö NV, 14014/63756.

1.23 COUNTRY ROCKS FROM SOUTHERN SWEDEN

F-3	S	Coarse grey Växjö granite. Roadcut near Järsnäs, 11 km NE of Forserum, 7 E Jönköping SO, 14261/64065.
SPG-1	S	Medium Spinkamåla granite. Quarry W of Ugglesjön, 14 km NW of Karlshamn, 3 E Karlshamn NO, 14295/62346.

APPENDIX 2: ANALYTICAL DATA

Rb/Sr analytical data are presented here for each intrusion in the order in which they first appear in the text. Section numbers correspond to those of appendix 1.

Analytical errors indicated for $^{87}Sr/^{86}Sr$ are at the 1σ level; where no error is shown, an assigned 1σ error of 0.04 % is used.

Repeated analyses are indicated by *; where appropriate, means of duplicates are used for interpretation purposes.

Sample code

AB = albite
AP = apatite
BI = biotite
CPX = clinopyroxene
EP = epidote
F = feldspar
HB = hornblende
MCL = microcline
MUSC = muscovite
OR = orthoclase
SPH = sphene
WR = whole-rock

2.1 GÅSTORP, BÄLGVIKEN AND FORSKILEN DYKES

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
SÖ-49	Dolerite	WR	18.7	260.2	0.2081	0.70822 ± 9
Do.		F1	18.0	464.4	0.1124	0.70591 ± 7
Do.		F2	25.7	431.7	0.1720	0.70767 ± 6
Do.		F3	30.7	414.8	0.2138	0.70858 ± 6
Do.		F4	39.2	382.5	0.2966	0.71037 ± 7
Do.		F5	75.8	286.8	0.7662	0.72090 ± 7
Do.		CPX	0.6	23.9	0.0668	0.70543 ± 7
Do.		BI	230.1	58.5	11.6454	0.95619
SÖ-53	Dolerite	WR	40.8	237.6	0.4976	0.71546 ± 12
SÖ-54	Dolerite	WR*	20.3	214.7	0.2740	0.71015 ± 6
Do.		WR*	20.9	215.2	0.2811	0.71008 ± 5
Do.		BI	409.1	12.8	115.8990	3.25270

2.2 HÄLLEFORS DYKE

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
SÖ-21	Dolerite	WR	16.9	323.4	0.1511	0.70828 ± 7
Do.		F1	12.5	472.3	0.0765	0.70706 ± 4
Do.		F2	16.0	475.7	0.0975	0.70751 ± 4
Do.		F3	106.2	406.0	0.7580	0.72283 ± 8
Do.		CPX	1.4	24.9	0.1627	0.70751 ± 6
SÖ-23	Porph. dolerite	WR	36.0	324.6	0.3212	0.71484
SÖ-24	Porph. dolerite	WR	39.9	182.7	0.6326	0.71870 ± 4
SÖ-26	Porph. dolerite	WR	73.5	150.7	1.4155	0.73302 ± 10
Do.		F1	64.5	454.4	0.4113	0.72008 ± 3
Do.		F2	58.8	424.0	0.4018	0.71870 ± 3
Do.		F3	66.4	315.1	0.6104	0.72153 ± 5
Do.		F4	85.7	304.0	0.8458	0.72703 ± 4
Do.		CPX	11.5	31.3	1.0677	0.72280 ± 6
SÖ-27	Porph. dolerite	WR	59.5	211.1	0.8171	0.72210 ± 8
SÖ-28	Porph. dolerite	WR	89.7	184.6	1.4099	0.73311 ± 3
SÖ-29	Porph. dolerite	WR	78.3	124.5	1.8271	0.74477 ± 7
SÖ-31	Porph. dolerite	WR	79.9	183.5	1.2622	0.72470 ± 4
SÖ-36	Melted granite	F6	72.3	82.3	2.5597	0.77282
Do.		F7	137.7	90.2	4.4645	0.81396
Do.		F8	132.3	89.5	4.3175	0.80986
Do.		F9	235.7	97.4	7.1127	0.87075
Do.		F10	252.9	100.4	7.4139	0.88015
SÖ-41	Porph. dolerite	WR	35.7	203.3	0.5088	0.71574 ± 3

2.3 BREVEN DYKE

Sample	Rock type	Mate-rial	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
SÖ-2	Dolerite	WR	10.9	259.3	0.1212	0.70576
SÖ-3	Dolerite	WR	5.9	260.5	0.0656	0.70480
Do.		F7	150.1	651.1	0.6682	0.72379 ± 1
Do.		BI	374.6	35.6	32.5527	1.42646
SÖ-4	Dolerite	WR	6.8	267.1	0.0737	0.70561 ± 3
Do.		F1	5.3	443.7	0.0346	0.70459 ± 9
Do.		F5	6.1	454.2	0.0388	0.70501 ± 9
Do.		F6*	18.8	469.2	0.1159	0.70723 ± 10
Do.		F6*	20.3	472.0	0.1243	0.70738 ± 3
Do.		F7	114.4	696.1	0.4762	0.71988 ± 5
Do.		CPX	1.7	10.6	0.4625	0.71353 ± 18
Do.		BI	371.4	35.0	32.8865	1.43197
SÖ-5	Dolerite	WR	14.9	268.7	0.1600	0.70706
SÖ-8	Granophyre	WR	111.0	63.8	5.0859	0.80860
Do.		F1	29.7	43.8	1.9677	0.75005
Do.		F2	43.9	38.0	3.3602	0.77879
Do.		F3	107.0	38.6	8.1586	0.87579
Do.		F4	164.0	36.5	13.3401	0.97869
Do.		F5	209.9	32.1	19.6484	1.10392
SÖ-9	Granophyre	WR	116.8	61.0	5.6013	0.82227
SÖ-10	Hybrid dol.	WR*	89.1	106.1	2.4385	0.74808
Do.		WR*	90.1	108.2	2.4145	0.74777
SÖ-11	Hybrid dol.	WR	30.0	200.0	0.4337	0.71470
SÖ-12	Granophyre	WR	195.0	78.8	7.2712	0.86864
Do.		F1	85.9	48.0	5.2424	0.83018
Do.		F2	157.5	38.1	12.2724	0.97934
Do.		F3	336.8	42.0	24.3766	1.23178
Do.		EP	19.8	1550.9	0.0369	0.71697
Do.		HB	230.5	26.1	26.9277	1.23964
SÖ-13	Granophyre	WR	161.1	32.9	14.5774	1.01501
Do.		F1	88.8	24.7	10.6511	0.93812
Do.		F2	105.4	18.0	17.5280	1.07586
Do.		F3	150.2	17.6	25.9805	1.24485
Do.		F4	160.2	17.1	28.5824	1.29414
Do.		F5	215.5	18.3	36.6435	1.45574
SÖ-14	Hybrid dol.	WR	43.2	140.3	0.8930	0.72347
SÖ-15	Dolerite	WR	52.0	181.6	0.8297	0.72273
SÖ-16	Granophyre	WR	112.2	130.5	2.4985	0.75878
SÖ-18	Granophyre	WR*	174.5	47.8	10.8098	0.93985
Do.		WR*	174.2	47.9	10.7625	0.94005
Do.		F1	35.2	26.3	3.9045	0.79663
Do.		F2	58.0	24.3	7.0148	0.86319
Do.		F3	89.8	31.7	8.3469	0.89109
Do.		F4	244.6	50.0	14.6046	1.02335
Do.		F5	326.9	54.7	17.9350	1.09236

2.4 TUNA DYKES

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
DS-16	Dolerite	WR	27.5	566.7	0.1405	0.70615
DS-17	"Trachyte"	WR*	184.3	63.8	8.5049	0.87978
Do.		WR*	184.5	64.1	8.4709	0.88071
DS-18	Porph. dolerite	WR	43.3	455.6	0.2749	0.70841
DS-20	Qz-porphyry	WR	257.6	47.3	16.2237	1.01198
DS-21	Qz-porphyry	WR*	295.4	7.6	142.6810	3.47919
Do.		WR*	297.0	7.6	143.1550	3.47085
DS-22	Qz-porphyry	WR*	290.0	12.2	78.9671	2.23765
Do.		WR*	290.0	12.1	79.7054	2.25405

2.5 GIMÅN AREA SILLS

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
J-4	Dolerite	WR	16.5	315.4	0.1511	0.70569 ± 11
J-12	Dolerite	WR	14.3	319.0	0.1293	0.70518 ± 4
J-18	Dolerite	WR	10.4	335.8	0.0892	0.70432 ± 6
J-19	Dolerite	WR	8.3	303.7	0.0788	0.70428 ± 4
J-25	Dolerite	WR	10.8	337.8	0.0924	0.70441 ± 5
J-29	Dolerite pegm.	WR	6.9	207.1	0.0958	0.70542 ± 8
J-33	Melted granite	WR	254.1	116.6	6.4017	0.86535
Do.		F1	68.8	106.7	1.8818	0.78638
Do.		F2	179.4	110.4	4.7623	0.83773
Do.		F3*	438.1	129.0	10.0399	0.93093
Do.		F3*	439.9	129.1	10.0715	0.92995
J-34	Hybrid dol.	WR	126.5	233.9	1.5702	0.74100 ± 7
J-35	Hybrid dol.	WR	119.7	225.3	1.5416	0.74064 ± 2
Do.		F1	67.1	419.9	0.4627	0.72256 ± 8
Do.		F2	68.5	351.2	0.5653	0.72379 ± 7
Do.		F3	181.6	232.1	2.2740	0.75357 ± 9
Do.		F4	280.8	192.3	4.2583	0.78676 ± 20
Do.		F5*	359.3	143.5	7.3335	0.83730 ± 8
Do.		F5*	338.7	154.8	6.3994	0.82188
Do.		CPX	7.8	15.7	1.4387	0.73575
J-36	Dolerite	WR	16.0	310.2	0.1493	0.70557 ± 7
J-41	Dolerite pegm.	WR	8.6	244.9	0.1016	0.70530 ± 4

2.6 SUNDSJÖ DYKE

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
J-55	Melted granite	WR	105.7	57.2	5.4033	0.80987
Do.		F1	15.1	69.6	0.6285	0.73057
Do.		F2	38.8	64.7	1.7419	0.74897
Do.		F3	226.9	52.0	12.8961	0.93316
J-56	Melted granite	WR	113.5	28.9	11.5724	0.91163
Do.		F2	38.4	27.4	4.0840	0.78762
Do.		F3	210.3	33.9	18.5096	1.02971
J-58	Dolerite	WR	15.5	319.1	0.1405	0.70564 ± 20
Do.		F1	5.6	518.7	0.0312	0.70371 ± 4
Do.		F2	43.3	474.0	0.2642	0.70774 ± 10
Do.		F3	222.1	267.2	2.4123	0.74118
Do.		CPX	1.3	26.5	0.1407	0.70563 ± 5
Do.		BI	489.6	22.6	70.0857	1.92065

2.7 ÄLVHO SILL

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
DN-315	Dolerite	WR*	32.0	371.7	0.2488	0.70914
Do.		WR*	34.5	375.5	0.2659	0.71024
DN-316	Dolerite	WR	20.4	316.4	0.1863	0.70723
DN-317	Dolerite	WR	63.8	302.2	0.6117	0.71688
Do.		F1	35.7	839.8	0.1231	0.70808 ± 5
Do.		F2	42.3	588.8	0.2079	0.70963
Do.		F4	56.8	516.5	0.3185	0.71168 ± 5
Do.		F5	121.1	384.4	0.9132	0.72274 ± 4
Do.		F6	178.2	255.0	2.0286	0.74280
Do.		F7	219.7	215.9	2.9582	0.75804 ± 5
Do.		AP	1.3	359.3	0.0104	0.70484 ± 6
Do.		CPX	1.1	34.1	0.0910	0.70690
DN-323	Monzonite	WR	133.4	214.8	1.8030	0.73978
DN-324	Monzonite	WR	156.7	173.9	2.6187	0.75438
DN-325	Dolerite	WR	20.1	414.0	0.1405	0.70617 ± 6
Do.		BI	492.0	23.8	66.6938	1.86438
DN-326	Monzonite	WR	161.2	195.6	2.3941	0.75311
DN-327	Monzonite	WR*	157.3	210.6	2.1698	0.74985
Do.		WR*	156.3	205.3	2.2116	0.75149
DN-328	Monzonite	WR	160.8	206.0	2.2692	0.75220

2.8 EMÅDALEN SILL

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
DN-301	Monzonite	WR	103.7	259.4	1.1580	0.72539
DN-302	Monzonite	WR	104.0	261.0	1.1546	0.72556
DN-303	Monzonite	WR	96.1	266.7	1.0445	0.72467
DN-304	Monzonite	WR	94.3	277.1	0.9859	0.72285
Do.		F1	90.1	438.2	0.5955	0.71648
Do.		F2	215.1	209.0	2.9919	0.75657
Do.		CPX	2.0	32.7	0.1802	0.70854 ± 5
DN-305	Monzonite	WR	90.3	292.5	0.8949	0.72140
DN-306	Monzonite	WR*	107.1	235.7	1.3167	0.72779
Do.		WR*	107.7	235.9	1.3236	0.72783
Do.		F1	77.6	393.7	0.5705	0.71544
Do.		F2	134.7	296.7	1.3163	0.72898
Do.		F3	231.4	113.5	5.9555	0.80610
Do.		CPX	4.5	27.4	0.4727	0.71276
DN-310	Monzonite	WR	106.4	256.3	1.2027	0.72654
Do.		F2	195.8	206.0	2.7622	0.75300
DN-311	Monzonite	F2	205.8	187.2	3.1968	0.75963
DN-312	Monzonite	WR	101.2	264.2	1.1098	0.72501
DN-329	Dolerite	WR	32.5	431.4	0.2178	0.70836
DN-330	Dolerite	WR	39.0	292.3	0.3862	0.71287

2.9 ÄLVDALSÅSEN SILL

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
DN-51	Dolerite	WR	41.3	635.3	0.1880	0.70938 ± 8
Do.		BI	405.8	25.6	49.8434	1.58542
DN-56	Dolerite	WR	23.0	555.5	0.1196	0.70562 ± 5
DN-60	Dolerite	WR	32.5	438.7	0.2142	0.70807 ± 4
DN-64	Dolerite	WR	28.9	666.8	0.1252	0.70678 ± 6
DN-67	Dolerite pegm.	WR	31.9	675.6	0.1368	0.70827 ± 4

2.10 MOSSIBERG SILL

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
DN-69	Dolerite	WR	11.1	618.2	0.0521	0.70409 ± 5
DN-71	Dolerite	WR	19.5	572.1	0.0984	0.70524 ± 5
DN-74	Dolerite	WR	17.9	633.9	0.0814	0.70448 ± 6
Do.		BI	307.1	56.7	16.0849	0.98333
DN-78	Dolerite	WR	30.1	590.2	0.1474	0.70608 ± 7

2.11 IDRE SILL

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
DN-17	Dolerite	BI	398.3	45.9	26.2324	1.16654
DN-21	Dolerite	WR	7.7	306.8	0.0725	0.70462 ± 10
Do.		F1	8.4	527.4	0.0461	0.70416 ± 10
Do.		F2	4.1	521.6	0.0227	0.70373 ± 4
Do.		F3	3.6	504.0	0.0204	0.70376 ± 5
Do.		F5	5.5	475.5	0.0337	0.70399 ± 8
Do.		CPX	1.1	35.2	0.0918	0.70520 ± 10
Do.		BI	488.0	41.0	36.5710	1.34661
DN-24	Dolerite	WR	11.2	322.6	0.1004	0.70563 ± 9
DN-30	Dolerite	WR	7.3	318.0	0.0663	0.70514 ± 6
DN-31	Dolerite	WR	19.8	356.4	0.1604	0.70766 ± 8
Do.		F1	36.8	572.9	0.1857	0.70772 ± 7
Do.		F3	7.7	384.9	0.0580	0.70557 ± 5
Do.		F4	5.1	311.3	0.0472	0.70578 ± 3
Do.		F5	5.1	317.3	0.0463	0.70583 ± 3
Do.		CPX	0.8	32.0	0.0681	0.70535 ± 28
Do.		CPX+10%EP*	0.8	227.9	0.0096	0.70898 ± 7
Do.		CPX+10%EP*	0.7	237.9	0.0088	0.70920 ± 6

2.12 BORNÅSSJÖN SILL

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
71-15	Dolerite	WR	10.1	314.5	0.0926	0.70527 ± 10
Do.		BI	166.8	41.4	11.8833	0.91600

2.13 KARLSHAMN DYKE

Sample	Rock type	Material	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
BL-3	Dolerite	WR	16.0	427.8	0.1081	0.70673 ± 13
Do.		F1	15.3	869.2	0.0511	0.70570 ± 6
Do.		F2	8.9	892.9	0.0287	0.70545 ± 7
Do.		F3	28.6	857.5	0.0965	0.70645 ± 4
Do.		F4	79.9	787.0	0.2938	0.70908 ± 5
Do.		F5	72.8	803.0	0.2624	0.70850 ± 11
Do.		AP	4.0	542.1	0.0215	0.70536 ± 8
Do.		CPX	3.4	55.6	0.1749	0.70737 ± 7
BL-7	Dolerite	WR	34.3	443.9	0.2237	0.70893 ± 6
BL-8	Hybrid dol.	WR	133.8	379.3	1.0220	0.72682 ± 6
BL-9	Hybrid dol.	WR	135.9	292.2	1.3489	0.73354 ± 4
BL-10	Dolerite	WR	25.1	451.9	0.1604	0.70754 ± 6
BL-15	Dolerite	WR	19.6	439.0	0.1292	0.70703 ± 4
BL-18	Dolerite pegm.	WR	55.8	361.6	0.4464	0.71091 ± 6
Do.		F1	15.3	752.4	0.0588	0.70601 ± 4
Do.		F2	35.4	673.1	0.1523	0.70721 ± 3
Do.		F3	92.3	487.1	0.5483	0.71222 ± 8
Do.		F4	170.0	320.8	1.5356	0.72403 ± 4
Do.		AP	3.5	338.2	0.0302	0.70547 ± 15
Do.		CPX	1.1	32.7	0.0970	0.70635 ± 4

2.14 BRÄKNE-HOBY AND PARALLEL DYKES

Sample	Rock type	Material	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
BL-24	Dolerite	WR	16.0	282.5	0.1641	0.70701 ± 5
Do.		F1	7.9	585.9	0.0392	0.70541 ± 7
Do.		F2	8.1	593.8	0.0393	0.70544 ± 4
Do.		F3	20.9	530.8	0.1140	0.70648 ± 5
Do.		F4	41.6	431.0	0.2792	0.70882 ± 5
Do.		CPX	0.8	25.7	0.0957	0.70616 ± 7
BL-27	Dolerite	WR	9.5	347.5	0.0792	0.70562 ± 10
Do.		F1	4.0	654.6	0.0178	0.70491 ± 7
Do.		F2	8.9	634.0	0.0406	0.70520 ± 3
Do.		F3	22.9	585.6	0.1132	0.70623 ± 6
Do.		F4	33.0	557.5	0.1713	0.70703 ± 4
Do.		CPX*	1.3	18.0	0.2116	0.70719 ± 9
Do.		CPX*	1.2	18.1	0.1978	0.70706 ± 5
BL-31	Dolerite	WR	63.5	622.2	0.2953	0.70849 ± 3
BL-32	Dolerite pegm.	WR	27.9	478.3	0.1691	0.70743 ± 9
BL-35	Dolerite	WR	43.4	495.5	0.2537	0.70830 ± 6
BL-36	Dolerite	WR	25.8	612.4	0.1220	0.70616 ± 7
BL-40	Dolerite	WR	29.4	624.7	0.1364	0.70650 ± 5

2.15 TÄRNÖ DYKE

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
BL-1	Hybrid dol.	WR	62.7	395.5	0.4592	0.71454 ± 3
BL-2	Xenolith	WR	116.3	1722.3	0.1953	0.70848
Do.		F1	39.0	288.8	0.3912	0.71119
Do.		F2	91.2	124.0	2.1332	0.73348
Do.		F3	259.1	125.3	6.0274	0.78236
Do.		EP	3.8	11870.3	0.0009	0.70705
Do.		SPH	5.8	103.5	0.1630	0.70891
BL-ARX	Xenolith	WR	78.2	382.6	0.5918	0.71384
Do.		F1	41.2	157.0	0.7595	0.71621
Do.		F2	108.3	185.9	1.6894	0.72788
Do.		F3	253.4	177.6	4.1473	0.75875
Do.		SPH	7.4	80.1	0.2689	0.71082

2.16 FORSERUM SILL

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
AL-2	Dolerite	WR	17.4	548.1	0.0916	0.70663 ± 10
AL-6	Dolerite	WR	54.3	355.9	0.4415	0.71355 ± 5
Do.		F1	71.1	798.8	0.2578	0.71109 ± 7
Do.		F2	61.4	731.6	0.2427	0.71070 ± 9
Do.		F3	90.4	438.2	0.5970	0.71547 ± 3
Do.		F4	156.8	247.2	1.8391	0.73254 ± 3
Do.		F5	165.2	240.6	1.9924	0.73476 ± 6
Do.		AP	14.9	503.8	0.0857	0.70682 ± 3
Do.		CPX	1.5	137.4	0.0310	0.70776 ± 3
AL-7	Dolerite	WR	25.3	430.0	0.1704	0.70779 ± 3
AL-10	Dolerite	WR	66.1	307.0	0.6238	0.71559 ± 8
AL-12	Dolerite	WR	35.4	392.7	0.2609	0.70951 ± 8
Do.		F1	28.2	790.1	0.1034	0.70685 ± 2
Do.		F2	32.6	738.8	0.1276	0.70745 ± 8
Do.		F3	59.3	554.7	0.3095	0.71009 ± 8
Do.		F4	100.1	403.6	0.7185	0.71615 ± 4
Do.		F5	120.9	351.3	0.9973	0.72074 ± 5
Do.		CPX	1.0	33.4	0.0842	0.70654 ± 6
AL-15	Dolerite	WR	51.0	368.2	0.4009	0.71309 ± 8
AL-17	Dolerite	WR	37.1	322.8	0.3326	0.71150 ± 8

2.17 NILSTORP SILL

Sample	Rock type	Material	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
AL-21	Dolerite	WR	39.8	514.6	0.2239	0.70816 ± 9
AL-22	Dolerite	WR	49.9	482.1	0.2992	0.70909 ± 3
Do.		F1	31.7	991.6	0.0926	0.70627 ± 4
Do.		F2	58.4	831.1	0.2033	0.70793 ± 4
Do.		F3	114.4	607.4	0.5454	0.71268 ± 5
Do.		F4	161.1	467.2	0.9989	0.71901 ± 3
Do.		AP	6.1	692.0	0.0255	0.70523 ± 3
Do.		CPX	4.8	49.1	0.2818	0.70921 ± 9
AL-29	Dolerite	WR	25.3	537.9	0.1362	0.70659 ± 4

2.18 ÅRBY DYKE

Sample	Rock type	Material	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
SO-50	Dolerite	WR	30.6	558.9	0.1584	0.70721 ± 10
Do.		F2	20.4	1029.4	0.0573	0.70585 ± 7
Do.		F3	29.0	906.8	0.0926	0.70622 ± 8
Do.		F5	47.0	685.9	0.1984	0.70798 ± 10
Do.		F6	69.7	477.6	0.4221	0.71114 ± 5
Do.		F7	79.8	445.8	0.5179	0.71214 ± 6
Do.		CPX	4.0	76.8	0.1491	0.70686 ± 7

2.19 FALUN DYKE

Sample	Rock type	Material	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
DS-1	Dolerite	WR	20.6	523.8	0.1136	0.70557 ± 7
DS-2	Dolerite	WR	33.5	548.2	0.1769	0.70667 ± 4
DS-9	Dolerite	WR	45.1	469.5	0.2781	0.70793 ± 9
Do.		F1	19.6	923.7	0.0614	0.70513 ± 10
Do.		F3	49.8	642.4	0.2245	0.70731 ± 6
Do.		F4	76.0	343.8	0.6396	0.71302 ± 2
Do.		F5	88.5	284.6	0.9006	0.71671 ± 13
Do.		CPX	4.9	70.2	0.1999	0.70693 ± 4
DS-29	Dolerite	WR	33.7	534.9	0.1825	0.70727 ± 3
DS-31	Dolerite	WR	32.9	532.4	0.1788	0.70702 ± 6
Do.		F1	18.1	933.6	0.0560	0.70514 ± 4
Do.		F3	31.2	708.4	0.1273	0.70645 ± 4
Do.		F4	60.6	498.7	0.3515	0.70994 ± 5
Do.		F5	96.1	295.3	0.9425	0.71872 ± 9
Do.		CPX	3.2	55.0	0.1703	0.70729 ± 10
Do.		BI	638.6	12.3	185.7540	3.13210

2.20 VÄSTRA NORNÄS DYKE

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
D75-26	Dolerite	WR	27.7	546.7	0.1467	0.70672 ± 5
Do.		F2	18.4	948.7	0.0562	0.70549 ± 8
Do.		F5	51.6	520.9	0.2865	0.70872 ± 8
Do.		F6	59.1	478.1	0.3577	0.70927 ± 10
Do.		F7	99.1	298.1	0.9630	0.71728 ± 5
Do.		F8	98.6	292.0	0.9778	0.71733 ± 6
Do.		CPX	2.2	18.0	0.3534	0.70973 ± 5
Do.		BI	526.6	16.3	106.1220	2.11941

2.21 BUNKRIS DYKE

Sample	Rock type	Material	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
DN-37	Dolerite	WR	69.7	268.0	0.7543	0.72584 ± 13
Do.		F1	57.1	630.5	0.2621	0.71527 ± 4
Do.		F2	66.9	556.2	0.3481	0.71748 ± 8
Do.		F3	130.5	362.3	1.0444	0.73305 ± 8
Do.		F4	201.1	255.8	2.2857	0.75882 ± 5
Do.		CPX	1.0	21.0	0.1354	0.70984 ± 14
DN-42	Dolerite	WR	46.4	281.2	0.4777	0.71795 ± 6
Do.		F1	44.5	618.8	0.2082	0.71254 ± 8
Do.		F2	51.6	582.2	0.2568	0.71346 ± 5
Do.		F3	69.6	516.2	0.3906	0.71644 ± 6
Do.		F4	138.1	378.2	1.0589	0.73161 ± 6
Do.		CPX	2.5	21.9	0.3299	0.71138 ± 13

2.22 VAGGERYD SYENITE

Sample	Rock type	Mate-rial	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
V-2	Syenite	WR	91.8	489.5	0.5433	0.71633
Do.		MUSC	245.6	54.6	13.2340	0.88466
Do.		BI	431.2	23.2	57.5954	1.42941
V-5	Syenite	WR*	114.0	26.1	12.9124	0.91321
Do.		WR*	115.9	26.0	13.1728	0.91283
V-6	Syenite	WR*	257.9	17.6	45.2645	1.37728
Do.		WR*	258.5	17.7	45.0589	1.37762
V-8	Syenite	WR	46.2	100.2	1.3363	0.72778
Do.		BI	192.6	9.1	65.7502	1.51796
V-9	Syenite	WR	61.3	105.3	1.6897	0.73482
V-10	Syenite	WR	146.2	338.5	1.2527	0.73116
Do.		MUSC	454.1	35.4	38.9782	1.22457
Do.		BI	824.1	28.6	93.2640	1.91886
V-14	Syenite	WR	34.6	325.1	0.3082	0.71102
V-15	Syenite	WR	34.0	342.2	0.2876	0.71196
V-16	Syenite	WR*	44.6	18.4	7.1137	0.83419
Do.		WR*	44.4	18.4	7.0682	0.83026
V-17	Syenite	WR	41.4	16.2	7.4742	0.82865
V-18	Syenite	WR	50.5	130.2	1.1242	0.72357

2.23 COUNTRY ROCKS FROM SOUTHERN SWEDEN

Sample	Rock type	Mate-rial	Rb ppm	Sr ppm	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr
SPG-1	Granite	WR	252.8	245.6	2.9946	0.76586
Do.		AB	106.5	198.4	1.5585	0.74146
Do.		MCL	523.5	231.6	6.6156	0.82518
Do.		BI*	699.9	81.4	26.1083	1.21762
Do.		BI*	688.2	85.7	24.2931	1.17857
F-3	Granite	WR	145.4	533.3	0.7900	0.72308
Do.		OR	275.9	524.6	1.5265	0.73972
Do.		BI*	697.4	32.3	72.8096	2.39260
Do.		BI*	682.7	29.3	79.6339	2.56348

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