THE AGE OF THE FERROPICRITIC VOLCANICS AND COMAGMATIC Ni-BEARING INTRUSIONS AT PECHENGA, KOLA PENINSULA, U.S.S.R.

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Sm-Nd, Pb-Pb and U-Pb isotopic results are presented for samples from the Pilgujärvi Suite of the Pechenga Series. Whole rock samples and clinopyroxenes of ferropicritic volcanics yield a Sm-Nd isochron age of 1990 ± 66 Ma with ε_{Nd} $+1.6 \pm 0.4$. This age is also supported by the Pb-Pb data on ferropicrites, although the Pb isotopic system was partly disturbed by secondary processes. One 90% concordant U-Pb zircon analysis from a felsic metasediment indicates a minimum age of 1970 Ma for the deposition.

Our isotopic results along with previous geochemical data support the view that the ferropicritic volcanics and the Ni-bearing gabbro- wehrlite intrusions are coeval and have similar source characteristics. The calculated ε_{Nd} (1990 Ma) value of +1.6 suggests that the Pechenga ferropicrites previously had had a long-term depleted mantle source that experiended an enrichment event about 200 Ma before the melt extraction occurred. Comparison with the previously presented Sm-Nd data from northern Finland, Sweden and Norway reveals differences in initial Nd isotopic ratios, which suggests a prolonged geochemical heterogeneity in the early Proterozoic subcontinental mantle below the Baltic Shield.

Key words: metavolcanic rocks, picrite, intrusions, absolute age, Sm/Nd, U/Pb, Pb/Pb, Proterozoic, Pechenga, Kola Peninsula, USSR.

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Introduction

Differentiated gabbro-clinopyroxenite-wehrlite intrusions are widely developed in the so-called »productive» tuffogene-sedimentary unit of the lower Proterozoic Pechenga (Petsamo) structure. The Pechenga Ni-Cu sulfide deposits are spatially and genetically related to these intrusions. According to Predovskii et al. (1974), the intrusions are comagmatic with picritic volcanic rocks of the younger South Pechenga Zone and hence there appears to be a considerable time gap between the emplacement of the intrusions and the deposition of the host sedimentary rocks. Such a view is in accord with the opinion of Gorbunov (1968) that the emplacement of the intrusions took place during the initial stages of folding of the area. In contrast, on the basis of geological, geochemical, and mineralogical investigations, Smolkin (1977, 1985) proposed a comagmatic relationship of the nickel-bearing intrusions and picritic volcanics of the Pechenga Series (North Pechenga

Zone) and suggested that the emplacement of the intrusions occurred in the late stage of picritic volcanism after pronounced loss of volatiles of the magma. Consequently, the nickel-bearing intrusions and picritic volcanics were assigned to a single volcano-plutonic association. Relatively recently, a similar association has also been discovered and investigated in the central part of the Imandra-Varzuga structure (Smolkin and Dain 1985). Recent geochemical studies strongly support the close genetic relationship between the gabbro-wehrlite intrusions and ferropicritic volcanics (Hanski and Smolkin, 1989). Isotopic data based mainly on whole rock Pb-Pb analyses have so far been inadequate to discriminate between the two views on the genetic relationship between the picritic volcanics and ore-bearing intrusions mentioned above.

To produce a precise age determination using the Sm-Nd method, the samples must fulfill three pre-requisites: they should be genetically related (have the same initial isotopic composition), have a sufficient compositional variation in parent/daughter ratios, and have been closed systems since crystallization for the elements considered. If primary magmatic minerals are unavailable, it may be difficult to find whole rock samples of basic/ultrabasic volcanics with sufficiently large variation in Sm/Nd ratios (see Gruau et al. 1990). Ferropicritic volcanics at Pechenga are good candidates for Sm-Nd dating since they occur as strongly differentiated flows with rock types ranging from olivine-rich cumulates at the base through clinopyroxenites in the middle part to quench-textured gabbroic rocks in the upper part (Smolkin et al., 1987). Furthermore, clinopyroxene is in most samples partially or wholly preserved and can be separated for isotopic analyses.

We present in this article Sm-Nd and Pb-Pb isotopic results of whole rock and pyroxene samples of ferropicritic volcanics and pyroxene and apatite separates from one Ni-bearing intrusion. In addition, we have analysed U-Pb isotopic composition of one zircon sample from a felsic metasediment spatially associated with ferropicritic volcanics.

Regional geology

The lower Proterozoic Pechenga structure comprises two zones: the Northern Zone and the Southern Zone which are separated by the major Poritash fault (Fig. 1). These zones are composed of rocks belonging to the Pechenga and South Pechenga Series, respectively. Rocks of the Pechenga Series have been penetrated by the Kola Superdeep Hole where their thickness reaches 6842 m (Kozlovsky 1987). They lie on an Archean basement with zircon ages of 2620—2640 Ma (Kozlovsky 1987) and also cover the Mt. Generalskaya differentiated gabbro-norite intrusion which has a Sm-Nd age of 2453 ± 42 Ma (Bakushkin *et al.*, in press). The Pechenga Series is subdivided into four suites (Ahmalahti, Kuetsjärvi, Kolasjoki and Pilgujärvi) each of which begins with sedimentary rocks and ends with a thicker pile of volcanic rocks (Fig. 1).

The sedimentary rocks are dominated by coarse clastic sediments and carbonates in the lower part of the section while phyllites and tuffites deposited in a deeper water environment prevail in the upper sedimentary units. The volcanic rocks change from andesites through alkalic basalts to tholeiitic basalts and minor picrites when going upwards in the section of the Pechenga Series.

The South Pechenga Series is composed of strongly deformed metasediments and metavolcanics. The latter vary in composition from picrites and tholeiitic basalts to andesites and rhyolites. The volcanism of this zone was terminated by the extrusion of porphyritic andesites at Poritash.

The upper age boundary for the formation of the Pechenga structure is provided by the emplacement age of the Litsa-Araguba granites. Pushkarev *et al.* (1978) report a U-Pb age of 1810 ± 50 Ma for zircons from these granites

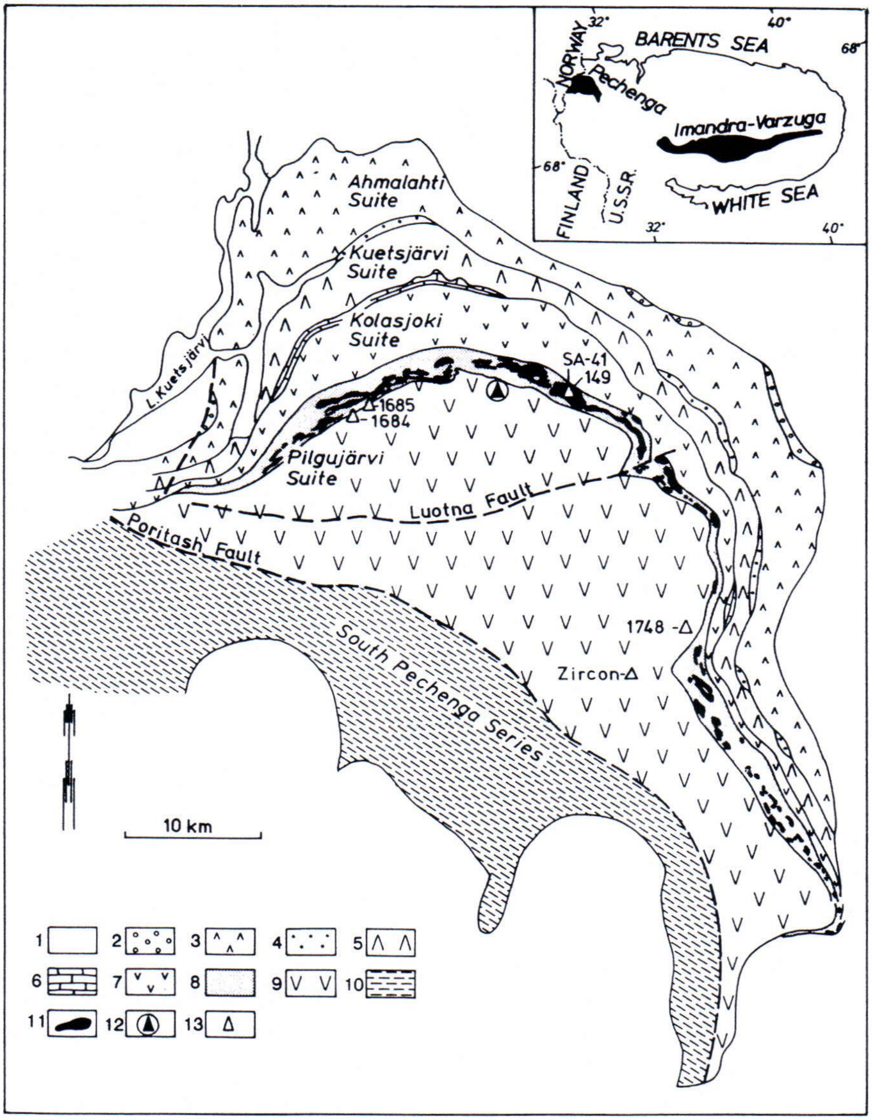

Fig. 1. Geological map of the Pechenga area simplified from Hanski and Smolkin (1989). Legend: 1, granitoids, migmatites, amphibolites; 2, 3, sedimentary and volcanic rocks of the Ahmalahti Suite; 4, 5, sedimentary and volcanic rocks of the Kuetsjärvi Suite; 6, 7, sedimentary and metavolcanic rocks of the Kolasjoki Suite; 8, 9, sedimentary and volcanic rocks of the Pilgujärvi Suite; 10, South Pechenga Series; 11, gabbro-wehrlite intrusions; 12, site of superdeep drilling; 13, sampling site of this work.

which (with respect to their composition and structural position) correspond to porphyritic granites in the Lake Inari area in northern Finland (Meriläinen 1976).

One of the most interesting features of the Pechenga area is the presence of iron-rich picritic volcanics which Hanski and Smolkin (1989) called ferropicrites. They have been found at five stratigraphic levels: in the lower part of the Kolasjoki Suite, in the middle part of the »productive» unit together with Ni-bearing intrusions, and in the lower, middle, and upper parts of the overlying volcanic unit of the Pilgujärvi Suite where they are intercalated with tholeiitic volcanic rocks. Ferropicritic volcanics occur as tuffs (mostly of hyaloclastic nature), lava-breccias, pillow lavas, massive lavas, and thick, layered lava flows. The relative proportions of different modes of occurrence vary from level to level but a diminution of the amount of tuffs upwards in the section can be observed as a general trend. Ferropicritic volcanics of the fourth and, to a less degree, of the fifth level are associated with massive, rhytmically layered and brecciated tufosilitsites with turbidite-like structured beds.

About one quarter of the exposed area of the tuffogene-sedimentary unit of the Pilgujärvi Suite is occupied by gabbro-wehrlite intrusions which occur as relatively thin, often differentiated phacolith-like bodies with a maximum thickness of 500 m. The intrusions and related Ni-Cu sulfide deposits have been studied by Finnish and by Russian geologists (e.g. Väyrynen 1938, Gorbunov 1968, Zak *et al.* 1987).

Previous age determinations

Previous datings of the Pechenga rocks have been made utilizing Rb-Sr, K-Ar, and Pb-Pb systems. Core samples of the Kola superdeep hole penetrating the Pechenga Series have been extensively analysed for K-Ar isotopes by E.K. Gerling and his coworkers (e.g. Kozlovsky 1987). The ages of minerals and rocks do not correlate with depth in the section and mostly vary within wide limits between 800—2100 Ma. Figures as high as 3000—13000 Ma were obtained for some samples from the lower part of the Pechenga Series due to excess of argon (Gerling *et al.* 1982). The K-Ar system has obviously been disturbed during metamorphism of the Pechenga rocks and cannot be used to date the time of deposition of the supracrustal rocks. Gorokhov et al. (1982) made the same conclusion regarding the Rb-Sr isotope analyses of phyllites from the Pilgujärvi Suite. They considered the age of 1650 ± 75 Ma to represent the time of metamorphism. Skufin *et al.* (1986) obtained a Rb-Sr whole rock age of 2150 ± 125 Ma for mugearitic-trachytic volcanics from the Kuetsjärvi Suite and regarded this figure as the time of volcanic eruptions.

The Pechenga nickel-copper deposits and their host intrusions have been intensively studied using Pb-isotopes. Early analyses of pyrrhotite from nickel-copper ores together with model-age estimates were given by Vinogradov *et al.* (1959). Pushkarev *et al.* (1985) determined an age of 1810 ± 80 Ma for a garnet-diopside-vesuvianite vein cutting the ore-bearing Pilgujärvi intrusion. Pushkarev *et al.* (1988) have recently published 82 Pb-isotope analyses of various samples from the Pechenga ore field including sulfide ores and whole rock samples from intrusions, pyrite ores from sedimentary country rocks, and whole rock samples of ferropicritic volcanic rocks. Taking the whole data set of metaperidotites and metagabbros, an age of 1920 ± 100 Ma is reported. The scattered ferropicrite analyses provide an age estimate close to 2 Ga.

Sample description

The location of the sampling sites is shown in Fig. 1. The ferropicritic samples were taken from the third level which denotes the beginning of the thickest ferropicrite-tholeiitic basalt cycle.

Samples 1748/10 and 1748/9 are from the upper part and sample 1748/6 from the middle part of a layered flow outcropping near the Lake Lammas in the eastern part of the Northern Zone. Sample 1748/10 is composed mainly of clinopyroxene and magnetite. The prismatic pyroxene grains (now replaced by amphibole) are randomly oriented but magnetite grains form parallel bands. Sample 1748/9 is fine-grained rock composed almost totally of amphibole. It has a quench texture with pseudomorphs of narrow pyroxene needles indicating rapid crystallization from liquid. Sample 1748/6 is a pyroxene cumulate with well-preserved euhedral clinopyroxene grains in a matrix composed of kaersutite needles, leucoxene pseudomorphs after skeletal magnetite, and serpentine.

Samples 1684 and 1684/1 are from the lower part, 1684/4 from the middle part, and 1684/5 from the upper part of a 24-m-thick, layered flow in the Kotselvaara area. The first two samples are olivine cumulates in which olivine has totally been replaced by talc and chlorite but intervening, prismatic clinopyroxene is partially preserved. Sample 1684/4 is clinopyroxene cumulate and analogous to sample 1748/6 from the Lammas flow described above. Clinopyroxene separates were analysed from samples 1684/4 and 1684/5.

Samples 1685a-G and 1685a-M represent respectively a globule and its matrix from the upper part of a layered flow in the Kaula area. They probably belong to the same flow as the 1684 sample series. The size of the globules vary from 2 to 18 mm and they comprise 20—30% of the volume of the rock (Smolkin *et al.* 1987). The matrix is composed of zoned, often skeletal clinopyroxene needles and prisms in a chlorite-albite-orthoclase groundmass. The globules contain similar clinopyroxene grains in an albite-rich groundmass. Both the globules and matrix are characterized by the presence of kaersutite needles and leucoxene pseudomorphs after skeletal ilmenite grains.

Clinopyroxene separate SA-41 was analysed from pyroxene cumulate (plagiopyroxenite) from the middle part of the Pilgujärvi intrusion. Fluorapatite (3.05% F) (sample 149) was separated from a lower gabbro-pegmatite segregation in the same intrusion. Detailed information on the petrography and mineralogy of the Pilgujärvi intrusion can be found in Smolkin (1977).

One zircon separate (sample 1) was analysed from a coarse-clastic tufosilitsite lying in the middle part of the volcanic unit of the Pilgujärvi Suite near Lake Ostrovnoe. The stratigraphic position of this metasediment is about 0.5 km from the lower contact of the volcanic unit. The zircon sample is composed of transparent, pale-pink, short-columnar zircons with well-developed pyramide faces. Studies using a microprobe have revealed their complicated inner structure which resembles a microbreccia. The fragment-like type is represented by low-Ca zircon and the cementing one by high-Ca zircon which is relatively depleted in Zr. Judging from their interrelation, they are both magmatic, high-temperature varieties, but because of their mutual impregnation, their isotopic composition could not be separately analysed. The rock also contains another, clearly different zircon generation. These zircons are rounded and turbid and yield an Archean age (2700 ± 90 Ma; Smolkin, unpublished data).

Results

The isotopic data produced at the Geological Survey of Finland (GSF) are given in Tables 1—3. The analytical techniques have been described elsewhere (Huhma 1986, Vaasjoki 1989).

Table 1. U-Pb results for zircon from tufosilitsite at Pechenga.

Sample	Size (mg)	^{238}U (ppm)	Measured			Ratios & ages (Ma)*		
			$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb^{+}$	$^{208}Pb/^{204}Pb^{+}$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
1$	1.5	421	964	0.1337	0.2238	0.3165 1772	5.276 1865	0.1210 1970 ± 5

+ Corrected for blank (Pb = 0.5 ng, U = 0.2 ng).

* Corrected for blank and initial common lead estimated from the whole rock data and least radiogenic sulfides ($^{206}Pb/^{204}Pb$ = 15.0, $^{207}Pb/^{204}Pb$ = 15.0, $^{208}Pb/^{204}Pb$ = 34.2; Pushkarev et al., 1988).

$ Zircons are transparent, pale pink and broken fragments.

Table 2. Pb isotopic results from Pechenga.

Sample	Pb (ppm)	U (ppm)	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
1684/1	0.76	0.25	20.639	15.930	43.507
1684/5	1.42	0.38	22.404	15.954	43.033
1685a-G	11.83	1.35	17.984	15.470	37.859
1685a-M	5.58	1.57	21.002	15.813	40.854
1748/9	6.26	0.52	17.158	15.359	36.926
1748/10	1.72	0.84	33.693	17.346	55.081
149 (apatite)			37.41	17.88	54.81

Errors in measured ratios are 0.15 %.

Table 3. Sm-Nd results from Pechenga.

Sample	$	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$*	$^{143}Nd/^{144}Nd$+
1684	wr	3.81	18.67	0.1234	0.511746 ± 26
1684/1	wr	3.09	13.72	0.1362	0.511896 ± 52
1684/4	cpx	3.12	9.58	0.1968	0.512713 ± 26
1684/5	wr	4.50	19.81	0.1373	0.511950 ± 21
1684/5	cpx	2.99	9.23	0.1962	0.512715 ± 30
1748/9	wr	6.89	31.84	0.1309	0.511862 ± 25
1748/6	wr	4.65	18.73	0.1502	0.512124 ± 21
SA-41	cpx	4.65	14.06	0.2001	0.512787 ± 40
149	apatite	296.00	1322.00	0.1353	0.511947 ± 24

* Error is 0.4 %. The concentrations were determined from liquid aliquots.

\+ Ratios normalized to $^{146}Nd/^{144}Nd = 0.7219$. Reported errors are $20\sigma_m$.

$ wr = whole rock, cpx = clinopyroxene.

U-Pb

Only one, 90% concordant analysis on transparent zircon from tufosilitsite is available at the moment. It has a 207Pb/206Pb-age of 1970 ± 5 Ma (Table 1). Providing that the zircon comes from a single magmatic population, this is a minimum age for the zircon.

Pb-Pb

Using only the analyses made at GSF, the six picritic samples and one apatite from the Pilgujärvi intrusion give an age of 1982 ± 110 Ma (MSWD = 48). Excluding the analysis of sample 1684/1, which is an olivine cumulate that is extensively serpentinized and hence chemically somewhat disturbed, the age becomes 2004 ± 55 Ma (MSWD = 12, Fig 2). Without apatite and 1684/1, the figure is 1955 ± 43 Ma. The data plot below average global lead evolution curves, and thus the initial Pb-isotopic composition must have had a relatively low $^{207}Pb/^{204}Pb$ ratio when compared with the coeval average terrestrial lead (Fig. 2). This means that for a long period before the extrusion, lead isotopic evolution took place in a reservoir which had U/Pb ratio lower than the global average. This reservoir can be characterized by $\mu(^{238}U/^{204}Pb)$ which has been

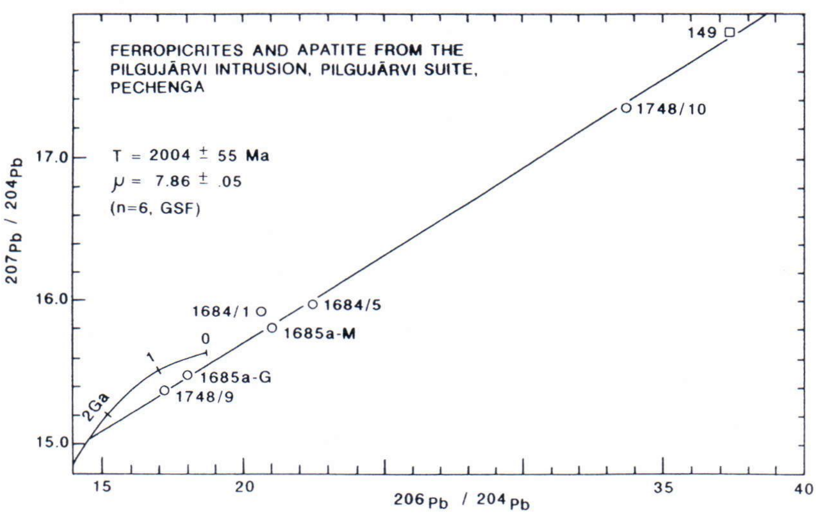

Fig. 2. $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ diagram for ferropicritic whole rocks samples (circles) and apatite separate (square) from the Pilgujärvi intrusion. Excluding one altered picrite sample (1684/1), the regression line defines an age of 2004 ± 55 Ma (2 , MSWD = 12). The initial ratio (μ) shown for the chord represents a single stage evolution from the Canyon Diablo lead. The average terrestrial growth curve after Stacey and Kramers (1975) is shown for comparison.

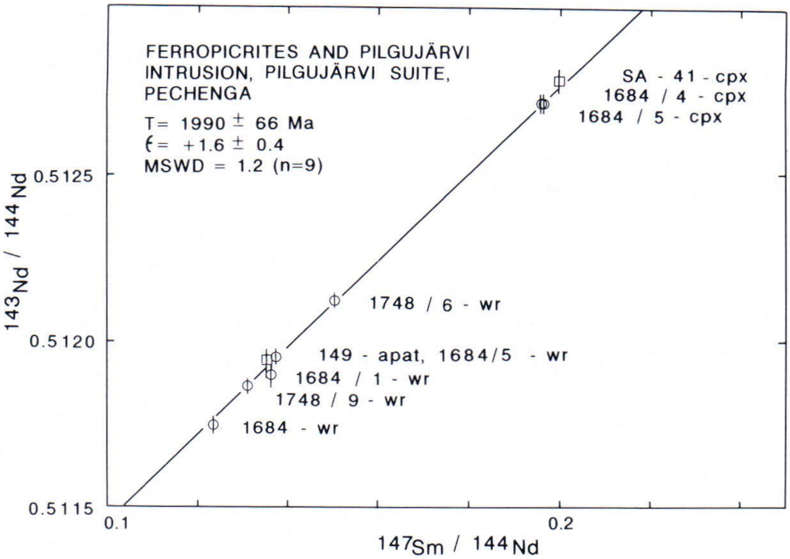

Fig. 3. Nd isochron diagram. Whole rocks (wr) of and clinopyroxenes (cpx) from Pechenga ferropicrites (circles), and fluorapatite and clinopyroxene from the Pilgujärvi intrusion (squares) define an age of 1990 ± 66 Ma (2σ MSWD = 1.2). The initial ε_{Nd} value is + 1.6 ± 0.4. The vertical lines in the symbols represent 2σ errors.

calculated from the Canyon Diablo lead using a single stage evolution and $T_0 = 4570$ Ma. Our isotopic analyses yield a μ value of 7.86, whereas a μ value of 7.75 can be calculated on the basis of data given by Pushkarev *et al.* (1988).

Sm-Nd

The Sm-Nd data on five ferropicrites and two clinopyroxene fractions define an age of 1990 ± 66 Ma with an initial ε_{Nd} value of + 1.6 ± 0.4 (Table 3 and Fig. 3). The result would be exactly the same if analyses on clinopyroxene and apatite fractions from the Pilgujärvi intrusion were included.

Discussion

The Pb isotopic data analysed at the Geological Institute in Apatity (GI) provide ages similar to our results (Pushkarev et al. 1988). Eight ferropicritic samples from the lower part of the volcanic unit of the Pilgujärvi Suite yield Pb-Pb age of 2032 ± 85 Ma. Pushkarev et al. (1988) also included in their calculation two samples from the »productive unit» representing a tuff and a layered flow and two pillow lava samples from the Tominga Series in the Imandra-Varzuga Zone, and obtained a younger age of 1995 ± 80 Ma. The justification of including the Tominga samples is based on their similarity in stratigraphic position and geochemical composition to those of volcanics of the Pilgujärvi Suite (Smolkin and Dain 1985). Hanski and Smolkin (1989) showed that the Tominga picrites are similar in chemical composition (including REE) to the Pechenga ferropicrites and clearly differ from picrites of the South Pechenga Series and the Umba Suite in their MgO-FeO-Al_2O_3 relations. Although any meaningful age cannot be calculated on the basis of the two Tominga samples, their isotopic composition is compatible with a common origin for both the Pechenga and Tominga ferropicrites.

Lead isotopic data for ferropicritic samples from both GSF and GI show scatter in excess of experimental error most probably caused by secondary processes following eruption. This makes the method less reliable for dating. Furthermore, some data points have been ambiguously rejected in order to obtain reasonable errors. Nevertheless, all three methods used during this study (the U-Pb zircon, Pb-Pb and Sm-Nd) yield reasonable consistent ages of about 1970—2000 Ma which are considered to define the time of extrusion of the ferropicrites. The younger zircon population in tufosilitsites is probably derived from the upper part of a ferropicritic pillow lava or layered flow. This inference is based on the observations of zones of submarine weathering (halmyrolysis) in ferropicrites and the similarity of REE characteristics (excluding Eu) of ferropicrites and tufosilitsites.

Pushkarev *et al.* (1988) report Pb isotopic analyses on 32 whole rock samples from the Pechenga gabbro-wehrlite intrusions. On the basis of the whole data set, they have calculated an age of 1920 ± 100 Ma. Excluding the three most radiogenic (anomalous) data points and including our analysis of the Pilgujärvi apatite (Table 2), an age of 1970 ± 70 Ma can be calculated. The figure for the Pilgujärvi intrusion solely would be 1979 ± 114 Ma (four whole rocks and our apatite sample). Seven analyses on the Kierdzhipori intrusion yield 1963 ± 52 Ma (two analyses excluded), whereas Pilgujärvi and Kierdzhipori data combined would give 2001 ± 77 Ma. Thus both Sm-Nd and Pb-Pb isotopic data suggest that the gabbro-wehrlite intrusions and the ferropicrites are coeval within analytical error.

Based on major and trace element geochemistry, Hanski and Smolkin (1989) have demonstrated that the parental magma of the Ni-bearing intrusions is similar to ferropicrite. This is compatible with the Sm-Nd isotopic results, since the initial ε_{Nd} values for the picrites and intrusions are the same within analytical error (Fig. 3). The Pb isotopic data on the intrusions provide a source value slightly higher compared to the picrites. This could be due to the addition of radiogenic crustal lead e.g. by fluids during the cooling of intrusions. However considering the scatter of the data, it is difficult to state anything definite about the origin of Pb in the intrusions. The Pb isotopic data do not contradict the view of a common origin for the ferropicritic volcanics and the gabbro-wehrlite intrusions.

In this connection, it is interesting to note that Gorbunov *et al.* (1989) have recently reported a new finding of a 3.2-m-thick ferropicritic flow with a massive, 0.45-m-thick Ni-Cu sulfide ore deposit at its base. This discovery provides strong evidence for the operation of ore forming processes during the ferropicritic volcanism. However, studies on the contact relations by one of us (V.F.S.) suggest that in this case we are dealing with a shallow level sill rather than a lava flow.

The Pechenga ferropicrites form a geochemically distinct, primitive magma type. They are characterized by high total iron content exceeding 14% (calculated as FeO), low Al_2O_3/TiO_2, and strong LREE enrichment (Hanski and Smolkin, 1989). These features are considered to be inherited from the mantle source region which was enriched in iron and LREE (Hanski 1989). The isotopic results provide further constraints to the origin of these rocks. The whole rock Pb isochron passes through the most primitive sulfide Pb isotopic composition ($^{207}Pb/^{204}Pb = 15.0$, $^{207}Pb/^{204}Pb = 15.0$, Pushkarev et al. 1988) and gives an initial Pb isotopic composition which has a relatively low $^{207}Pb/^{204}Pb$ ratio compared with the average for terrestrial lead at 2 Ga (Fig. 2). The initial Pb ratio is very close to the mantle ratios derived from the plumbotectonics model by Zartman and Doe (1981). Strongly contrasting to the slighly older Runkaus basalts from the Peräpohja area, northern Finland (Huhma *et al.* 1990), these results suggest that the ferropicrites were not contaminated by old radiogenic crustal lead. Neither is there any sign of contamination in the major or trace element chemistry of the ferropicrites. Thus the initial ε_{Nd} (1990) value of $+1.6$ should represent Nd isotopic composition of the mantle source. This suggests that at some stage the source had an evolution in a LREE depleted environment. However by the time of extrusion, the source was already strongly enriched in LREE. The data may give some constraints for the timing of this enrichment. Since the ferropicrites are high-MgO magmas produced by a relatively high-degree of melting in which garnet was probably not a residual phase (Hanski 1989), their Sm/Nd ratio is close to that of their source region. One can thus calculate the TDM model ages for the enriched samples, which in this case are c. 2.2 Ga. Providing that no fractionation of Sm/Nd took place in the source between 2.2 and 2.0 Ga, the 2.2 Ga age corresponds to the time when the source of the ferropicrites would have had a Nd isotopic composition equivalent to the model depleted mantle as expressed by DePaolo (1981).

In regional stratigraphic correlation schemes, the Kolasjoki Suite belongs to the Upper Jatulian (e.g. Zagorodnyi 1980). The overlying Pilgujärvi Suite has traditionally been correlated with the Suisaarian formations in southern Karelia (e.g. Svetov 1976), one reason being the presence of picritic volcanics in both units. Later, after the combination of the Zhaonezhye and Suisaarian into the Ludicovian (Kratts *et al.* 1984), the Pilgujärvi Suite has been assigned to the Ludicovian (e.g. Predovskii *et al.*, 1987). Our isotopic results are compatible with the suggestion made by Meriläinen and Sokolov (1981) that the upper age limit of the Jatulian rocks is about 2000 Ma. In contrast, there is a discrepancy with the following statement by Zagorodny et al. (1986): »the zircons from albite diabase dykes which serve as feeders of Zhaonezhye and possibly Suisarian volcanites are dated at 2100—2200 Ma».

It is interesting to compare the Sm-Nd isotopic data from Pechenga with published isotopic results from other greenstone belts in northern Norway, Sweden and Finland. Krill *et al.* (1985) have shown that the Archean age for the Karasjok greenstone belt suggested by some authors was incorrect and published a Sm-Nd whole rock age of 2085 ± 85 Ma for 8 komatiite samples (ε_{Nd} +4.1) from the Bakkilvarri Formation. Although the samples have a good fit to the regression line, the precision of the age is somewhat doubtful. This is because the samples used in the isochron construction form two populations: the one has high MgO (23—27%), low TiO_2 (0.5—0.7%), and is LREE-depleted whereas the other is lower in MgO (16—18%) and enriched in TiO_2 (1.2—1.8%) and other incompatible elements (LREE-enriched). These two types of komatiites can not be related to each other by low-pressure crystal fractionation and the possibility of their derivation from multiple sources can not be ruled out.

The Jatulian tholeiitic volcanics of the Jouttiaapa Formation from the Peräpohja schist belt in Finland appear to be slightly older than the Pechenga ferropicrites. Huhma *et al.* (1990) have obtained an age of 2090 ± 70 Ma and an initial ε_{Nd} value of $+4.2 \pm 0.5$ for these volcanics. This figure together with the above mentioned Nd values for the Karasjok komatiites and the +3.6 value reported by Skiöld and Cliff (1984) for greenstones in the Kiruna area clearly show that the source region of the Pechenga ferropicrites (ε_{Nd} $+1.6 \pm 0.4$) was different (less depleted) than the mantle from which the komatiites in northern Norway and tholeiites in the Kiruna and Peräpohja area were derived. This gives evidence that during the early Proterozoic there existed geochemically distinct subcontinental mantle reservoirs, which remained unmixed for a long period of time (<200 Ma).

Magmatic activity on the cratonic terrain at c. 2.0 Ga is further corroborated by U-Pb zircon ages on felsic porphyries and diabases in central Finnish Lapland (Hiltunen 1982, Kouvo 1984) which might imply more widespread coeval volcanism there. Also some gabbros c. 100 km west of Pechenga are temporally close to ferropicrites (about 1.95 Ga, U-Pb zircon, Meriläinen 1976). This calc-alkaline magmatism within the Archaean craton of the Baltic Shield (Barbey *et al.* 1984) seem to have occurred after the »rift-related» ferropicritic volcanism at Pechenga.

On the southwestern margin of this craton, the Jormua and Outokumpu ophiolites seem to be roughly coeval with the Pechenga ferropicrites and Ni-bearing intrusions. Gabbros associated with these ophiolites yield a U-Pb zircon age of ca. 1.96 Ga (Kontinen, 1987; Huhma, 1986). Lead isotopes provide another interesting similarity. The isotopic composition of Outokumpu galena (Vaasjoki 1981) can be very close to the initial lead isotopic composition inferred for the Pechenga ferropicrites. Geochemically ferropicrites and ophiolites are, however, strictly unrelated. Furthermore, although the tholeiitic basalts of the Pilgujärvi Suite have REE characteristics resembling those of MORB, they are much more iron-rich than MORB and differ markedly in this respect from the basalts of the Jormua ophiolite complex (Kremenetsky and Ovchinnikov 1986, Kontinen, 1987).

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