Lead-Zinc hydrothermal mineralization in the Pechenga Area, Kola Peninsula, Russia

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The Early Proterozoic Pechenga supracrustal belt in the western part of the Kola Peninsula, Russia, contains hydrothermal Pb-Zn mineralizations, occurring as veins or sulphide dissemina- tions along hydrothermally altered tectonic zones. These occurrences are confined mainly to the metasedimentary Productive Zone of the Pechenga supracrustal belt. Their lead isotopic composi- tions are similar to those of Early Proterozoic mantle-derived mafic rocks, such as the gabbro- wehrlite intrusions of the Pechenga Complex, that contain Cu-Ni sulphide ores. The lead-isotopic composition of the Pb-Zn mineralization is distinctly less radiogenic than that of base-metal veins from Archaean rocks bordering the Pechenga supracrustal belt.

Fluid inclusions in quartz from the Pb-Zn mineralizations of Pechenga yield lower temperatures and higher CO_2 contents than those in the hydrothermally mobilized Cu-Ni mineralizations. It is suggested that the hydrothermal solutions which produced the Pb-Zn mineralizations in the Pechenga area could be of Late Proterozoic — Early Palaeozoic age, and that metasedimentary rocks enriched in sedimentary iron-sulphides may have played the role of a 'geochemical barrier', where dissol- ved metals were precipitated.

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Introduction

The Early Proterozoic Pechenga supracrustal belt is situated in the northwestern part of Kola Peninsula, Russia, close to the border with Norway (Fig.1). Within this area there are localised economic deposits of Cu-Ni sulphide ores (Gorbunov et al. 1985) and small occurren- ces of various types of ore-mineralization, inc- luding Cu and Pb-Zn veins, gold veins and magnetite-bearing quartzites. These minerali- zations, although uneconomic, are critical for understanding the nature and diversity of the ore-forming processes in the Pechenga area. One of the most interesting types of ore- mineralization is that of hydrothermal Pb-Zn veins, which often occur together with Cu-Ni sulphide ores (Abzalov et al. 1988). The gene- tic relationship between these two kinds of ores, however, is not clear. In order to evalua- te their relationship it was particularly impor- tant to compare the lead sources for the Pb- Zn mineralization and Cu-Ni sulphide ores.

In this paper we present new data on mine- ral chemistry, fluid inclusions and lead-isotope compositions, with the aim of clarifying the genetic features of the Pb-Zn mineralization in the Pechenga belt.

Regional Geology

The Pechenga belt is composed of Lower Proterozoic sedimentary and volcanic rocks (Fig.1) which rest unconformably upon Archae- an basement. The supracrustal Pechenga Complex has been divided into the Pechenga and South-Pechenga series (Zagorodny et al. 1964, Predovsky et al. 1974). The Pechenga series, situated to the north of the Poritash Fault, is subdivided (Zagorodny et al. 1964) into four megacycles, known as the Ahmalahti, Kuetsjarvi, Kolasjoki and Pilgujarvi suites, which generally dip at 30-60° to the south. Each of this suites begins with a sedimentary unit and passes up into a volcanic pile. The sedimentary rocks of the lower suites are re- presented predominantly by coarse-grained clastic sediments and carbonates; these are replaced in the uppermost Pilgujarvi suite by carbonaceous clastic sediments, pelites and tuffites enriched in sedimentary iron sulphi- des. The sedimentary sulphides occur as lami- nated beds and disseminations (Balabonin 1984, Melezhik et al. 1988).

The volcanic rocks of the Pechenga series are represented mainly by mafic lithologies (Fig.1). In the lower suites andesites and alkali
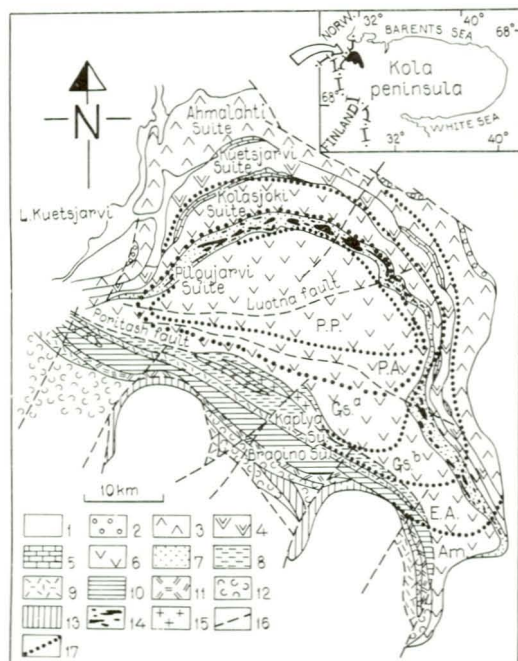
Fig.1. Geological map of the Pechenga area, after Zagorodny et al.(1964), Predovsky et al. (1974), Hanski & Smolkin (1989). Metamorphic zones after Petrov et al.(1986), modified by the authors. 1, Archaean gneisses; 2-15, Proterozoic Pechenga Complex: 2, conglomerates; 3, andesites and basalts; 4, trachybasalts, trachyandesites; 5, quartzites, dolomites; 6, basalts, picrites; 7, Productive Zone: sandstones, silt-stones, pelites and tuffs, with abundant sulphides and carbonaceous matter (gabbro-diabases, intruding the Productive Zone not shown); 8, phyllites, dolomites; 9, basalts; 10, psammites, siltstones; 11, picritic tuffs and tuffites, basalts; 12, andesites, dacites; 13, basalts, andesites, dacites; 14, Ni-bearing gabbro-wehrlite intrusions; 15, extrusive andesitic porphyrites; 16, faults; 17, boundaries of metamorphic facies and subfacies: P.P.- prehnite-pumpellite, P.A.- prehnite-actinolite, Gs-greenschist (a - muscovite-chlorite and b - biotite-chlorite subfacies), E.A.-epidote-amphibolite, Am.- amphibolite.

basalts are abundant with minor felsic volcanites, whereas the upper volcanic suites contain minor picrites (Predovsky et al. 1974, Hanski & Smolkin 1989).

The South-Pechenga series, comprising the Bragino and Kaplya suites, is situated south of the Poritash Fault and is composed of volcanites interlayered with clastic sedimentary rocks, tuffites and quartzites (Zagorodny et al. 1964). The volcanic rocks vary in composition from basalts and picrites to andesites and rhyolites. The youngest occurrences are porphyritic andesites, extruded along the Poritash Fault Zone.

The age of the rocks of the Pechenga supracrustal belt ranges from c.2.4 Ga to c.1.81 Ga. The lower age boundary is an emplacement age for a layered gabbro-norite intrusion on Mt.Generalskaya, situated in the Archaean basement and overlain by rocks of the Pechenga belt (Bakushkin et al. 1990). The upper age boundary is provided by a U-Pb zircon age for the Litsa-Araguba granites (Pushkarev et al. 1978). Regional metamorphism in the Pechenga belt varied from prehnite-pumpellite facies in the central part of the structure (Fig.1) to amphibolite facies on the flanks (Petrov et al. 1986).

The supracrustal rocks are cut by gabbro-diabase intrusions and differentiated mafic-ultramafic sills of the gabbro-wehrlite association (Hanski 1986) bearing Cu-Ni sulphide ores. The age of the gabbro-wehrlite intrusions and comagmatic picrites of the Pilgujarvi suite has been determined by different methods (Hanski et al. 1990) and is c.1.99 Ga.

Metamorphism led to intensive serpentinization and talc-carbonate alteration of the ultramafic rocks. Metamorphosed intrusions contain numerous hydrothermal veins of varying compositions. Carbonate and talc-carbonate veins are more or less ubiquitous whereas serpentine and rodingite veins are rather less common (Smolkin & Abzalov 1990). Rodingite veins have been dated by the Pb-Pb whole-rock method (Pushkarev et al. 1985) and gave an age 1.81 ± 0.03 Ga for the metamorphic alteration of the Ni-bearing intrusions.

Most of the ore-bearing intrusions and associated Cu-Ni deposits are confined to sedimentary units of the Pilgujarvi suite (Fig.1), the so-called Productive Zone (Gorbunov et al. 1985). The majority of the Cu-Ni deposits are located in one small area, in the part of the Productive Zone situated to the northwest of the Luotna Fault (Figs.1 & 2). This area (Fig.2) is known (Gorbunov 1968) as the Pechenga ore-field.

The Cu-Ni deposits contain three principal types of ores: (1) high-grade massive and breccia ores, situated in the basal parts of the massifs and along tectonic zones;(2) disseminated ores within gabbro-wehrlite massifs; (3) hydrothermal veins with Cu-Ni sulphides occurring in the wall-rocks.

The primary magmatic textural and chemical features of the Cu-Ni ores are preserved in the weakly altered massifs (Kochnev-Pervukhov 1978, Distler et al. 1989) but are gradual-
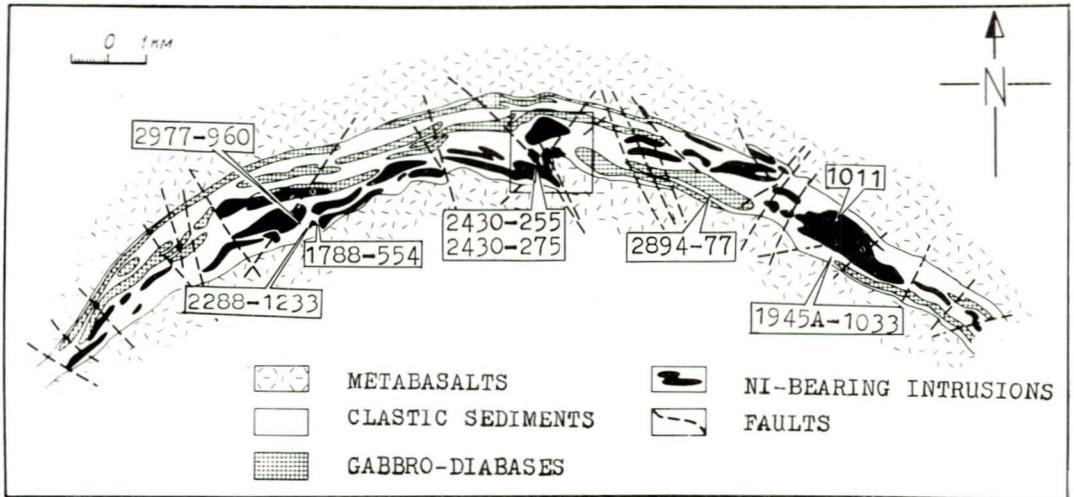
Fig.2. Geological map of the Pechenga ore field (see text) and location of sampled occurrences of Pb-Zn mineralization. The boxed area is that of Fig.3.

ly obliterated with increasing degrees of meta-morphic alteration, owing to intensive redistri-bution of sulphides.Thus, genetically, Cu-Ni ores can be subdivided into primary magmatic and metamorphic types (Makarov et al. 1974, Kochnev-Pervukhov 1978).

A typical kind of metamorphic Cu-Ni minerali-zation is that of hydrothermal quartz-car-bonate veins that contain Cu-Ni-Fe sulphides with minor galena, sphalerite, argentopent-landite, altaite, hessite, cobaltite and gold (Ab-zalov & Polezhaeva 1987, Abzalov 1991, Ego-rov et al. 1991). The veins occur in the tectoni-sed footwalls of gabbro-wehrlite massifs and along fault zones. The age of metamorphic mobilization of the Cu-Ni ores, determined by a sulphide lead-isotope study, is c.1.83 Ga (Abzalov et al. 1991).

In addition to the veins with Cu-Ni mineraliza-tion there are numerous metamorphic quartz and carbonate veins; these are either barren or carry minor pyrite and pyrrhotite (Abzalov & Ikorsky 1991). Rather less common is the hydrothermal Pb-Zn mineralization, observed (Abzalov et al. 1988) in drillcores and in the underground nickel mines of the Pechenga ore-field. Besides this mineralization there are numerous veins containing base-metals which occur in Archaean rocks outside the Pechenga area. They are mainly found along the coast of the Barents Sea (Sundblad et al. 1989, Fedotova 1990).

Geological setting and composi-tion of the Pb-Zn mineralization

The Pb-Zn mineralization is located predomi-nantly within the Productive Zone and mostly confined to tectonised contacts of gabbro-wehrlite massifs (Fig.2 & 3; Table 1). Spatial-ly, these occurrences are generally associated with strata enriched in sedimentary iron sulphi-des (Fig.3), but there are also examples loca-ted in magmatic rocks (Table 1).

Pb-Zn mineralization occurs as veins or metasomatic sulphide disseminations along hydrothermally altered tectonic zones. The veins are composed mainly of quartz with carbonates and K-feldspar and contain sulphi-des as irregularly distributed disseminations. Locally, massive sulphide veinlets occur (Fig. 4A), and yield stockwork-like mineralized zo-nes. The thicknesses of individual veins and of the mineralized zones vary from millimetres (Fig 4A) to a few metres. The contents of lead and zinc are normally each about 1 wt% (Tab-le 2).

The principal ore minerals are sphalerite and galena. Pyrrhotite is nearly always present and locally constitutes an important part of the sulphide volume (Fig. 4B,D). The ratios of the-se minerals are extremely variable and the ores range from pure sphalerite ores to gale-na-dominated varieties. The ore mineral as-semblages also include pyrite, chalcopyrite,

Table 1. Some characteristic features of the sampled occurrences of Pb-Zn hydrothermal mineralization in the Pechenga area.

Geological setting, host rocks	Modes of occurrence	Ore-minerals	Gangue	Sample no.
Gabbro-wehrlite intrusive massif	Vein	Gn,* Sph,* Po, Alt, Hs, Ilm, Tt	Q,* Carb, Kfp	1011
Clastic metasedimentary rocks in the exocontacts of gabbro-wehrlite massifs	Net of veinlets Disseminations	Sph,* Gn, Alt, Cp, Tt Sph,* Gn,* Po,* Pn, Cp, Alt, Cb, Ilm, Tt, Ru	Q,* Carb Q,* Carb	2430-255 2977-960, 2288-1233, 1788-554
Tectonised fine-grained clastic metasedimentary rocks	Disseminations	Sph,* Po,* Py,* Asp, Cp, Gs, Tt	Carb,* Q*	1945A-1033, 2430-275
Mafic tuffs	Disseminations	Po,* Sph,* Cp, Ilm, Tt	Carb,* Q	2894-77

* - major minerals. Alt - altaite, Asp-arsenopyrite, Cb-cobaltite, Cp-chalcopyrite, Gn-galena, Gs-gersdorfite, Hs-hessite, Ilm-ilmenite, Pn-pentlandite, Po-pyrrhotite, Ru-rutile, Sph-sphalerite, Tt-titanite, Carb-carbonates, Q-quartz, Kfp-microcline.

Table 2. Contents of ore-forming major and trace elements in the samples of Pb-Zn mineralization, Pechenga ore field.

Sample numbers	1011	2288 1233	2430 255	1945A 1033
Pb.wt$^\circ$o	1.5	1.15	0.003	0.004
Zn.wt$^\circ$o	1.5	1.05	1.13	0.95
Ag.ppm	4.3	1.4	1.8	0.8
Mo.ppm	n.d.	5.5	9.5	5.5
Cu.ppm	40	651	1100	420
Ni.ppm	17	493	160	190
Co.ppm	n.d.	113	85	64

All elements determined by emission spectral analysis. n.d. - not detected.

pentlandite, altaite, hessite, gersdorfite, cobaltite, arsenopyrite, rutile, ilmenite and titanite (Table 1). All these minerals usually occur as accessory phases and some of them as inclusions in the major minerals (Fig.4C). There are exceptions, however, including a mineralization where arsenopyrite and pyrite are the major phases along with sphalerite. It is noteworthy that pentlandite and tellurides have been found in the near vicinity of mafic-ultramafic bodies, whereas arsenopyrite and other arsenic minerals tend to occur more abundantly in the tectonised carbonaceous schist occurrences.

A microprobe study of the ore minerals has revealed a wide range of trace elements; and the contents of some indicate various distinct types of ore parageneses (Figs.5 & 6). Galenas from the Pb-Zn mineralization, for example, differ distinctly from those of the Cu-Ni ores in terms of lower contents of selenium (Fig.5). Differences in sphalerite composition, however, are small (Fig.6) although sphalerites of the Pb-Zn mineralization tend to be less ferrous than the sphalerites of the Cu-Ni ores and clearly differ from the sphalerites which occur in serpentine veins (Fig.6).

Fluid-inclusion study

Fluid inclusions are abundant in the quartz of different hydrothermal veins occurring in the Pechenga ore-field (Abzalov & Ikorsky 1991). Sizes of inclusions normally range from a few microns to 20-30 µm. The shapes are generally equant, commonly rounded, and more seldom elongated.

The distribution of the inclusions within the quartz crystals is usually irregular. Most of such inclusions are primary or, probably, pseudosecondary in accordance with the classification of Roedder (1984). Exceptionally, groups of inclusions can be observed in the form of chains which follow cracks in the quartz grains; these show great variation in size and shape. These inclusions are obviously secondary (Roedder 1984), and we have tried to exclude such samples from further investigations.

Observed inclusions mostly are trapped water solutions and at room temperature contain two phases, vapour and liquid. In the quartz of the Pb-Zn mineralization, single-phase inclusions of liquid CO_2 have also been found. The melting temperature of the CO_2 inclusions was close to -56° C. These inclusions homogenised in the temperature interval from 10° to 19° C (Fig.7).

During heating experiments the two-phase inclusions homogenised to liquid. Homogenisation temperatures of inclusions in quartz from Pb-Zn mineralization are shown in Fig.7, and compared with those from the Cu-Ni hydrothermal mineralization. Despite a strong scatter of the data, homogenisation temperatures of inclusions in quartz of the Pb-Zn mineralization (98°-274° C) are clearly lower than in the case of the Cu-Ni mineralization (122°-349° C).

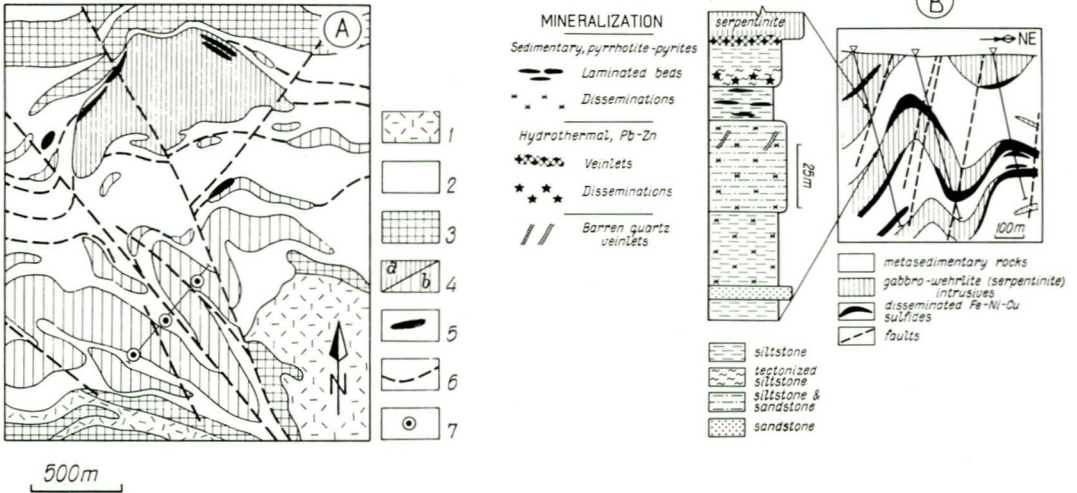The composition of gases entrapped in quartz was analysed by the gas-chromatograp-

Fig.3. (A) Geological map of the Souker area (boxed area in Fig.2). 1, basalts; 2, sandstones, siltstones, pelites and tuffites; 3, gabbro-diabases; 4, gabbro-wehrlites (a - ore-bearing, b-weakly mineralized); 5, Cu-Ni sulphide ores; 6, faults; 7, drillholes. (B) Geological section along the line shown in Fig.3A, illustrating the geological setting of the Pb-Zn mineralization.
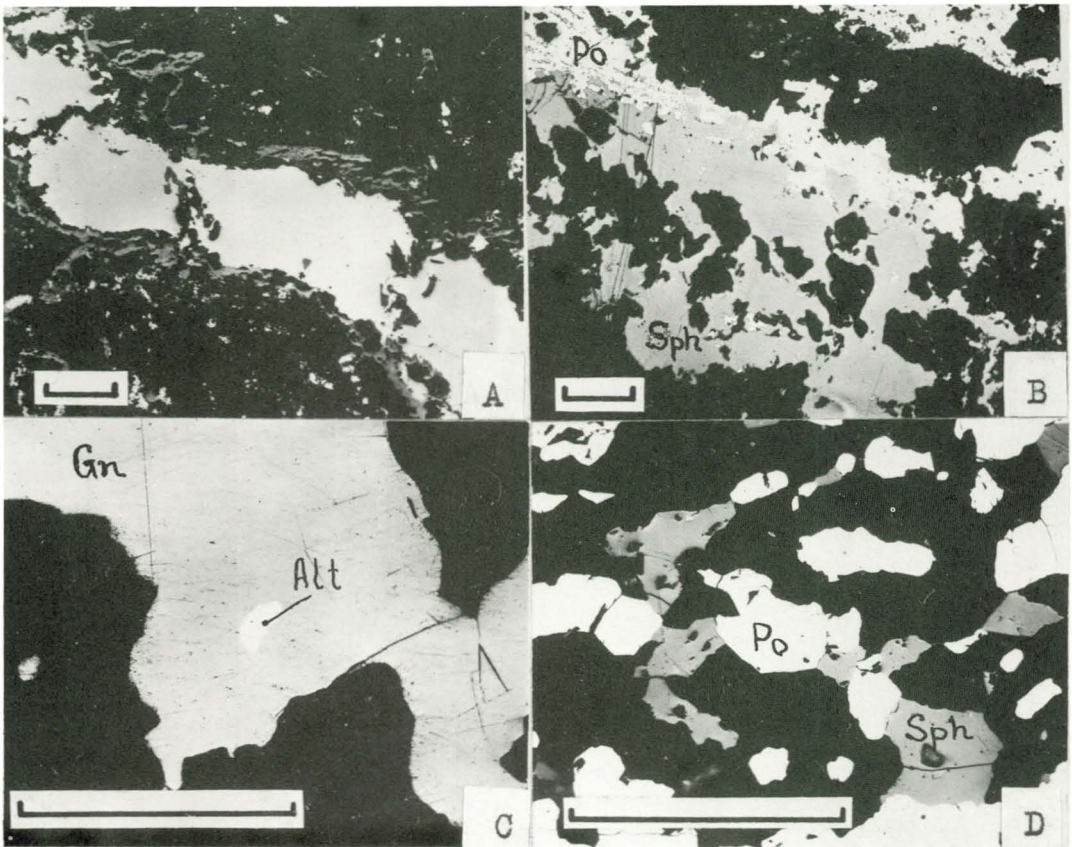

Fig.4. (A) Sphalerite veinlet occurring in the exocontact of an ultramafic body; (B) Dissemination of sphalerite (Sph) in carbonaceous siltstones, with replacement contacts between sphalerite and pyrrhotite (Po); (C) Dissemination of galena (Gn) with enclosed altaite (Alt) in quartz vein; (D) Equigranular pyrrhotite (Po) and sphalerite (Sph) disseminations in siltstone. Polished sections, reflected light. Black in all photos is gangue. Scale bar - 0.25 mm.

hic method and confirms the differences betwe-
en the Pb-Zn and Cu-Ni hydrothermal occurren-
ces. The former is characterised by a much
higher content of CO_2 in quartz. The ratio
CO_2: CH_4 is also higher for the Pb-Zn minerali-
zation (Fig.8). Barren veins situated in metase-
dimentary rocks of the Productive Zone show
a highly variable content of CO_2 in quartz and
CO_2: CH_4 ratio (Fig.8). Nevertheless, the con-
tent of CO_2 in barren quartz is lower than in
the quartz of the Pb-Zn mineralization.

Lead-isotope systematics

In order to determine the source of the ore-
forming metals the lead-isotope composition
has been studied in various minerals (galena,
sphalerite, pyrite, pyrrhotite) of the Pb-Zn hyd-
rothermal mineralization.

The lead-isotopic composition of these sulp-
hides varies widely (Table 3). Galena and spha-
lerite show the least evolved isotopic composi-
tion whereas the iron sulphides are characteri-
sed by a more radiogenic isotopic composi-
tion. Analyses of successive acid leachings
of pyrrhotites and sphalerite reveal their slight
isotopic heterogeneity (Table 3).

Galena and sphalerite plot on the $^{207}Pb/^{204}Pb$
vs. $^{206}Pb/^{204}Pb$ diagram (Fig.9) close to the lo-
wer-crust evolution curve (Zartman & Doe
1981). However, these samples do not show
any enrichment of thorogenic lead (Fig.9),
which is a typical feature of lower-crust leads
(Zartman & Doe 1981). Analysed samples of
Pb-Zn mineralization along with sedimentary
sulphides from the rocks of the Productive
Zone plot in a linear array on the isotopic
diagram (Fig.10). A regression line (Fig.10)
computed from all data points (Table 3) has

Discussion

From the fluid inclusion study data it follows
that the Pb-Zn mineralization is radically diffe-
rent from the hydrothermal veins containing
Cu-Ni sulphides in having a higher temperatu-
re of the fluid-inclusion homogenization, a high
content of CO_2 in quartz and a higher CO_2:CH_4
ratio. Although this ratio is rather sensitive to
host rock composition we cannot explain the
observed differences (Figs.7 & 8) merely by
fluid-rock interaction because the host lithologi-
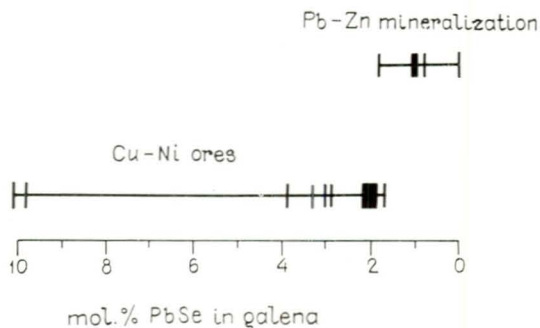es are similar for the Cu-Ni veins from the

Fig.5. Mol.% PbSe in galena from the Pb-Zn mineralization
and Cu-Ni ores. Data sources: Yakovleva et al. (1983) and
present work. Mineral analyses performed on a MS-46
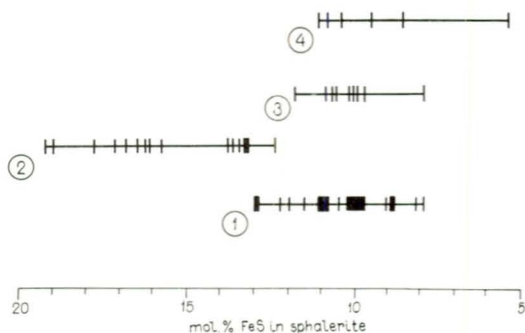'Cameca' microprobe (Kravchenko-Berezhnoy et al. 1976).

Fig.6. Mol.% FeS in sphalerite from different types of mine-
ralization and ores in the Pechenga area. 1, Cu-Ni ores
(Yakovleva et al. 1983); 2, serpentine veins (Smolkin &
Abzalov 1990); 3, sedimentary pyrrhotite-pyrite mineraliza-
tion in the rocks of the Productive Zone (Balabonin,1984);
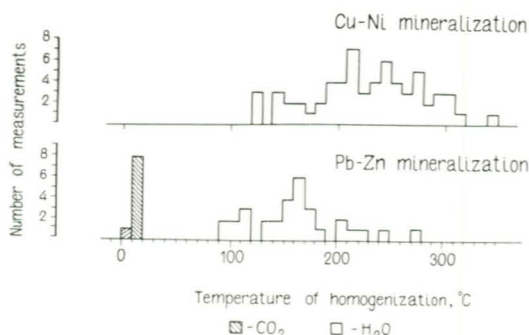4, Pb-Zn hydrothermal mineralization (present work).

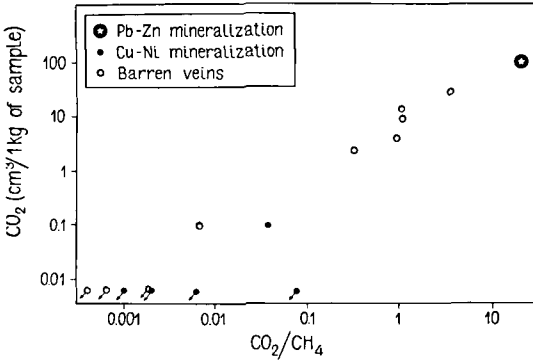Fig.7. Homogenization temperatures of the fluid inclusions
in hydrothermal quartz.

Fig.8. CO_2 vs.CO_2/CH_4 diagram for gases entrapped in hydrothermal quartz. The gas contents were determined by the gas-chromatographic method (Ikorsky & Stepanova 1990). Symbols with arrows indicate upper limits.

tectonised footwalls of gabbro-wehrlite massifs and for the analysed Pb-Zn occurrence (sample 1011). These differences accord well with regular discrepancies in galena and sphalerite composition and apparently could be interpreted in terms of primary differences between Pb-Zn-bearing solutions and those which precipitated the Cu-Ni sulphides.

The isotopic composition of lead in galena and sphalerite, particularly its non-evolved character and low $^{207}Pb/^{204}Pb$ value, is indicative of the absence of an Archaean crustal lead component and apparently reflects the mantle character of the source. Similar isotopic compositions evaluated as mantle leads have been reported from the sulphide ores of the Skellefte field (Vaasjoki & Vivallo 1990) and the Outukumpu area (Vaasjoki 1981).

The sedimentary pyrrhotite-pyrite mineralizations in the Productive Zone are abnormally enriched in radiogenic isotopes (Fig.10), with values of $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ of 20.84-32.26 and 16.02-17.56, respectively (Pushkarev et al. 1985). Consequently, the sulphide-bearing metasedimentary rocks could not have been the direct source of lead for the Pb-Zn mineralization. It is remarkable that accessory galena, occurring in the sulphide-bearing carbonaceous rocks in association with the sedimentary iron-sulphides, also has a radiogenic isotopic lead composition (Figs.9 & 10).

Thus, mafic and ultramafic rocks, namely the igneous rocks of the gabbro-wehrlite association which are widespread in the Pechenga area, could be a local metal source for the
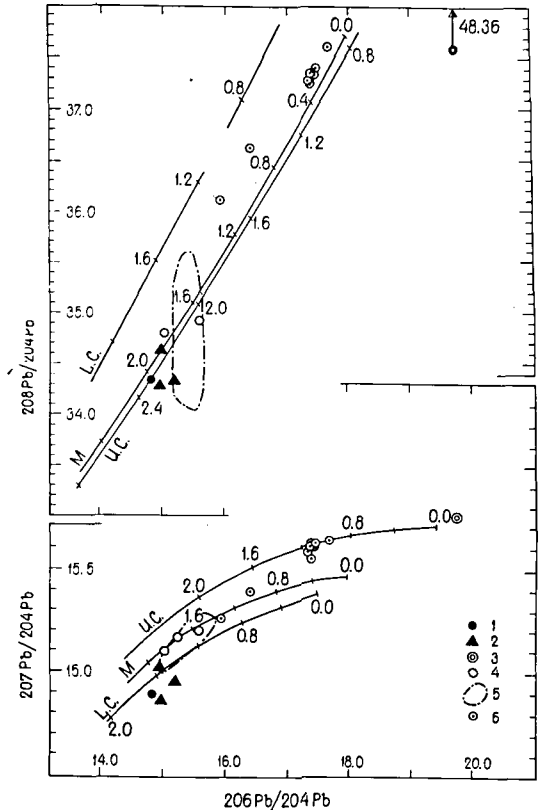

Fig.9. Lead-isotope composition of galena and sphalerite of the Pechenga Pb-Zn mineralization compared with other types of ores. 1-2, Pb-Zn mineralization in the Pechenga area (1-galena, 2-sphalerite); 3, galena associated with sulphide-bearing carbonaceous metasedimentary rocks; rocks; 4, galena from carbonate veins in serpentinites; 5, massive and brecciated Cu-Ni ores; 6, galena of base-metal veins from the Barents Sea coast. Data sources: 1 & 2, present work; 3-5, Pushkarev et al. (1985); 6, Chernyshev & Kazansky (1978). Model curves (version 2) of Zartman & Doe (1981): M - mantle, L.C. - lower crust, U.C. - upper crust; figures denote billion years.

Pb-Zn mineralization in the area. Slight differences in the $^{207}Pb/^{204}Pb$ ratio between the Pb-Zn mineralization sulphides and the Cu-Ni ores (Fig.9) may reflect possible heterogeneities in the isotopic ratios of the Pechenga mafic-ultramafic rocks.

Veins of base-metals situated in the Archaean block outside the Pechenga belt are characterised by a distinctly different type of ore metal source (Chernyshev & Kazansky 1978, Sundblad et al. 1989). Firstly, they reveal the influence of a source with upper crustal isotopic signatures (Fig.9), which most probably

Fig.10. $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ diagram of data for the Pb-Zn mineralization sulphides (filled symbols) and sedimentary sulphide mineralization in the rocks of the Productive Zone (open symbols). Evolution curve after Stacey & Kramers (1975), figures - billion years.

- iron sulphides
- galena, sphalerite
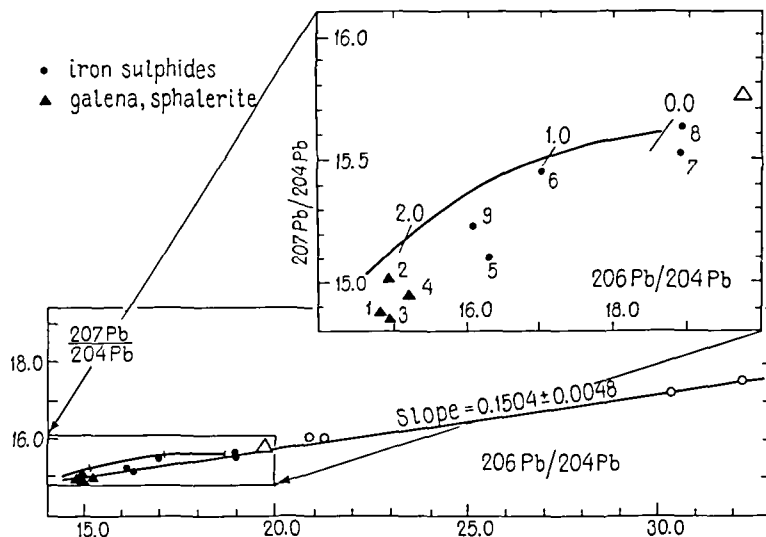
can be attributed to Archaean gneisses. Another lead contributed to these deposits is less radiogenic and shows features of a possible mantle source (Fig.9); alternatively, as it follows the trend of the base-metal veins composition on a $^{208}Pb/^{204}Pb$ -$^{206}Pb/^{204}Pb$ diagram (Fig.9) the influence of a lower crust component could be suggested. Thus, Pb-Zn mineralization in the Pechenga area and the base-metal occurrences in the Archaean basement are characterised by completely different sources of ore metals.

More problematic is the timing of Pb-Zn mineralization in the Pechenga belt. We consider the linear array of the Pb-Zn mineralization samples, along with sedimentary sulphides from the rocks of the Productive Zone in the $^{206}Pb/^{204}Pb$ -$^{207}Pb/^{204}Pb$ diagram (Fig. 10), to represent a mixing line for leads derived from two separate sources. Scatter around the mixing line and isotopic heterogeneity of the sphalerite and pyrrhotite samples could be the result of heterogeneity of the sources. Consequently, in this case evaluation of the age would be rather tentative.

The linear array includes isotopic data from galenas and sphalerites and hence in order to evaluate a model age for the formation of the Pb-Zn mineralization (t_2) the age of the lead source (t_1) should be known (Doe & Stacey 1974). Using the date of c.1.8 Ga for the metamorphic alteration of the gabbro-wehrlites (Pushkarev et al. 1985, Abzalov et al. 1991)

as the age of the lead source, the Pb-Zn mineralization age would be c.1.0 Ga. Providing that the source of the ore metals has an age of around 1.98-2.0 Ga, which is more favorable since it corresponds to the actual emplacement age of the gabbro-wehrlite intrusions (Hanski et al. 1990), then the age of the Pb-Zn mineralization would be close to 0.5-0.6 Ga. Alternatively, if we assume an Early Proterozoic age for the Pb-Zn mineralization we nevertheless also have to suggest that a Late Proterozoic-Early Paleozoic mineralization event affected primary mineral associations, partially disturbed their Pb isotopic ratios and resulted in the formation of the new generation of galena. A process like this has been advocated (Bjorlykke et al. 1990) for the Early Proterozoic Bidjovagge gold-copper deposit where U-Pb systems in primary sulphides were disturbed in Early Palaeozoic time. However, this scenario seems less probable for the Pb-Zn mineralization in the Pechenga belt since it doesn't explain the regular differences (Figs. 5-8) in temperature and chemical characteristics of the lead- and zinc-bearing hydrotherms as well as major mineral compositions in comparison with the metamorphic Cu-Ni sulphides.

The reported results have thus clearly indicated a Late Proterozoic or even Early Palaeozoic mineralization event in the Pechenga belt and enable us to attribute the formation of the Pb-Zn mineralization to this period.

The spatial association of Pb-Zn mineraliza-

Table 3. Lead-isotope composition of sulphides from hydrothermal Pb-Zn mineralization (analyses 1-9) and sedimentary sulphide mineralization in carbonaceous rocks of the Productive Zone (analyses 10-14).

N	Sample No	Mineral	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$
1	1011	galena[T]	14.87 ± 0.03	14.89 ± 0.01	34.35 ± 0.03
2	1011	sphalerite[F]	15.00 ± 0.05	15.03 ± 0.08	34.64 ± 0.22
3	1011	sphalerite[R]	15.01 ± 0.07	14.86 ± 0.10	34.29 ± 0.21
4	2288/1233	sphalerite[T]	15.24 ± 0.01	14.96 ± 0.02	34.33 ± 0.08
5	2430/275	pyrrhotite[F]	16.33 ± 0.04	15.11 ± 0.03	34.49 ± 0.06
6	2430/275	pyrrhotite[R]	17.05 ± 0.08	15.45 ± 0.07	35.23 ± 0.22
7	1788/554	pyrrhotite[F]	18.95 ± 0.04	15.53 ± 0.02	34.96 ± 0.04
8	1788/554	pyrrhotite[R]	18.97 ± 0.03	15.63 ± 0.04	36.14 ± 0.10
9	1945A/1033	pyrite[T]	16.13 ± 0.02	15.24 ± 0.03	34.74 ± 0.06
10	335/2*	iron-sulph[F?].	32.26 ± 0.20	17.56 ± 0.098	34.07 ± 0.80
11	335/3*	iron-sulph[R].	30.38 ± 0.10	17.25 ± 0.05	35.55 ± 0.45
12	338/1*	iron-sulph[F].	20.84 ± 0.04	16.02 ± 0.03	33.67 ± 0.20
13	338/6*	iron-sulph[R].	21.83 ± 0.008	16.02 ± 0.007	35.29 ± 0.87
14	353*	galena[T]	19.80 ± 0.02	15.76 ± 0.01	42.07 ± 0.90

* - analyses from Pushkarev et al. (1985). T-total sample, F-first leaching, R-residue. Pyrrhotite fraction 2430/275 contains sphalerite inclusions.

Analytical techniques. Galena, pyrite and one sphalerite sample were dissolved in HNO_3. Pyrrhotites and the other sphalerite were at first selectively dissolved in 4N HCL (first leaching) and the residue was then completely dissolved in concentrated HNO_3.

Solutions were dried and further purified by using an ion-exchange column with anionite (Pushkarev et al. 1978) in HCL form, which yield $PbCl_2$ of high purity. The procedure has been repeated twice. Purified lead was placed on a Re filament, together with a solution of silica gel and H_3PO_4. The blanks for the total analytical procedure were near 10 ng.

The isotopic analyses were carried out on a single-collector mass-spectrometer MI-1201T, at operating temperature 1200°C. 500 measurements were made on each sample; the resulting error limit was $\leq$ 0.3% at a 2σ confidence level. As lead standard, SRM981 was used; the fractionation factor was near 0.05%.

tion with the sulphide-bearing metasedimentary rocks of the Productive Zone (Fig.3B) and the observed replacement contacts between sphalerite and pyrrhotite (Fig.4B) indicate that such rocks may have acted as a geochemical barrier where dissolved lead and zinc would have precipitated from the hydrothermal solutions.

Thus, carbonaceous rocks enriched in sedimentary sulphides could have acted as a trap for lead and zinc, derived locally from mafic-ultramafic rocks and transported by hydrothermal solutions probably in Late Proterozoic - Early Paleozoic time.

Summary and conclusion

1. The lead of Pb-Zn mineralization occurring in the Pechenga belt reflects a mantle character of the source and in contrast to base-metal veins situated in the Archaean basement does not show any involvement of Archaean lead sources.

2. Ore-metals were derived locally during interaction of hydrothermal solutions with the country or wall rocks. The most probable source rocks of the lead are the mafic-ultramafic intrusions of the Pechenga gabbro-wehrlite association, which have a similar lead isotopic composition as the Pb-Zn mineralization.

3. The age of mineralization, defined from a linear trend of data points on the $^{207}Pb/^{204}Pb$ -$^{206}Pb/^{204}Pb$ diagram (Fig.10), is probably Late Proterozoic to Early Palaeozoic.

4. Hydrothermal solutions which gave rise to the Pb-Zn mineralizations were characterised by low temperatures and differ from other types of hydrothermal occurrences within the Pechenga ore-field in having had high contents of CO_2.

5. Metasedimentary rocks enriched in sedimentary iron-sulphides may have played the role of 'geochemical barriers' and led to the precipitation of lead and zinc, derived locally from mafic-ultramafic rocks and transported by hydrothermal solutions.

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