

EuroCarb Finland Workshop 14 - 20 September 2001

Introduction

Welcome to the second workshop of the EuroCarb network on mantle carbon and carbon cycling. EuroCarb is a European Science Foundation Network, and as such, aims to stimulate communication and debate between scientists in order to facilitate new links and ideas. This workshop will concentrate on economic deposits associated with mantle carbon and with one carbonatite being mined for apatite, one recently considered for niobium and phosphate, the proximity to the Kola Peninsula mines, and the recent discovery of diamondiferous kimberlites, Finland seems an ideal location for a European workshop on this subject. Activities are centred around field visits and we have one full day for discussion, plus the possibility of a couple of evening sessions, and some long coach journeys. The group contains people considering the fundamental geochemical issues of mantle carbon, as well as experts on the more applied aspects of mantle carbon rocks and we hope there will be some healthy debate and cross-fertilization of ideas.

The first issue will be mantle carbon itself as an economic deposit, in the form of diamond. We will have a chance to see kimberlite drill core, and maybe sample some for further research. The relationship between mantle carbon and carbonate in carbonatites and kimberlites is a perennial problem and one we might consider further on the bus. Perhaps you would like to answer the following questions, which we will pick up again later in the discussion session.

What is the relationship between carbonatites and kimberlites? Is there a continuous series of rock types between kimberlites and carbonatites?

The Saturday itinerary concentrates on a visit to the ca. 2500 Ma Siilijärvi carbonatite. There is a chance to see the apatite mine and we can consider how the lithosphere has evolved in this area. Siilijärvi is much older than the ca. 380 Ma Kola Alkaline Province (KAP) and is one of a several older carbonatites in Finland, Kola, and Karelia. The timing and relationship of magmatism involving mantle carbon in this region is considered in two of the workshop abstracts and can be picked up in the discussion sessions. There will also be an opportunity during this workshop to learn more about the activities of SVEKALAPKO, part of the European Science Foundation

Europrobe programme that has been studying the Archaean and Palaeoproterozoic evolution of the Baltic (Fennoscandian) Shield. Maybe for the bus on the way to Suomussalmi we can prepare for more consideration of ore deposits by considering the following two questions.

What are the key controls on the crystallization of niobium minerals, REE minerals, and apatite in carbonatites?

How much, when, and where do carbonatites interact with their wall rocks?

We have one full day for discussion sessions, including the display of poster material, on the Sunday. The programme is divided into three sessions, each will start with short talks and will then continue in open discussion, guided by a team of two chair people. The aim is for lively and informal discussion. There will be no detailed record of the discussion (so you can try out your craziest ideas) but the chair people will make notes to help pull out the main points and facilitate the compilation of a workshop report.

The final Finnish locality is the Sokli carbonatite complex, composed mainly of carbonatite together with a magnetite, mica, apatite rock locally called phoscorite. This will be the first introduction to the phoscoritic rocks and their relationship to carbonatites – cumulate or separate melt? The main exposures at Sokli are of weathered material and these will highlight the role of weathering in forming ore deposits associated with carbonatites.

For those making the extension to Russia, a long drive will take us back close to Sokli into the mining town of Kovdor. In the Iron Quarry we will be treated to spectacular exposure of phoscorite and carbonatite. Kovdor has almost everything: economic deposits of magnetite, apatite, baddeleyite, phlogopite, and vermiculite, excellent exposure of cross-cutting relationships and rock textures, pegmatites, hydrothermal alteration/weathering, rare minerals.... It should be a memorable last field day

If you enjoy this workshop, the next EuroCarb events will be workshops in Italy, 7-10 June 2002 and the Canary Islands in 2003. There will also be a session on “Recycling of volatile elements through the mantle” at the International Mineralogical Association conference, 1-6 September 2002. Watch the web site for further details.

www.nhm.ac.uk/hosted_sites/eurocarb

Frances Wall, Seppo Gehör,
EuroCarb co-ordinating committee

Programme

Friday 14 September

Travel to Loppi drill core archives to view Finnish kimberlite rocks in drill core. Permission has been obtained for 'light sampling'. It is not possible to see these rocks in field exposures. Possible short discussion session. Overnight at the Hotel Sandels, near Siilinjärvi.

Saturday 15 September

Visit the open pit mine at Siilijärvi, near Kuopio, to study a 2500 Ma carbonatite worked for apatite and various by-products by Kemira Chemicals Oy. Travel to the Scandic Hotel Kiannon kuohut, Suomussalmi. Possible evening discussion session.

Sunday 16 September

Discussion meeting with poster session and oral presentations at Suomussalmi, 9.00 am - 4.00 pm, then departure to travel north to Savukoski village, by coach. Two nights in the Samperin Savotta Hotel.

Monday 17 September

Visit the Sokli carbonatite complex, near Tulppio, part of the Kola Alkaline Province. Overnight at Savukoski, Samperin Savotta Hotel.

Tuesday 18 September

Extension to Kovdor, Kola Peninsula, Russia, travelling by coach and crossing to Russia at Salla. Two nights at the Hotel Ujut, Kovdor.

Wednesday 19 September

Visit to Kovdor open pit mine and surrounding localities. (Overnight at Hotel Ujut, Kovdor.)

Thursday 20 September

Return to Rovaniemi airport in Finland, via the Salla road border. There are good connections from here to Helsinki. We will not arrive until about 19.00 pm. There is a sleeper train from Rovaniemi to Helsinki, the departure time is 21.15, and two evening flights to Helsinki at 21.30 and 22.10.

Note about rock samples

Please note there are strict – and rather variable - customs regulations for the carriage of rock samples out of Russia. We can leave rocks collected in Finland at the Salla border point and collect them on our return. In Kovdor, a customs officer will inspect the material that has been collected in Russia and issue official customs documentation. However, there is still a risk that the Russian border customs officials may not allow the rock samples through! Back in Finland, you can pack and post rock samples from the Post Office in Rovaniemi.

Provisional timetable for discussion session on Sunday 16 September 2001

If people are keen, we might take the first two talks on Saturday evening.

Posters are on display from Elena Balaganskaya, Jose Gaspar, Stefan Klemme, Ruslan Liferovich, Vikki Niku-Paavola, Masha Sitnikova, Frances Wall, Terry Williams and their co-authors.

9.00 – 10.30 Mantle processes - fundamental controls on element enrichment and the relationship between kimberlites and carbonatites

Chair: Alan Woolley and Hilary Downes

10 minute talks by: Juha Karhu
Alan Cooper
Stefan Klemme

11.00 – 12.30 Crustal evolution and interaction of carbonatites, concentrating particularly on the formation of ore deposits.

Chair: Bernhard Bühn and Terry Williams

10 minute talks by: Bernhard Bühn
Dick Hagni

13.30 – 15.00 Exploration, exploitation and environmental issues associated with mantle carbon ore deposits.

Chair: Frances Wall and Heikki Vartiainen

10 minute talks by: Andrei Bulakh
Tony Mariano
Pete Siegfried
Natalya Krasnova

16.00 depart to Savukoski

Abstracts

Two magmatic events from the one mantle source in formation of Seblyavr massif: rule or exception for Kola Alkaline Carbonatite Province?

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The Seblyavr massif of the Kola Alkaline Carbonatite Province (KACP) consists largely of clinopyroxenites, as well as ijolites, phoscorites and carbonatites, dated at 376 – 410 Ma. Petrography, mineralogy, geochemistry, and Sr-Nd isotope systematics has been studied in 15 samples. There are two types of phoscorites, stage I which can be classified as ore diopsidite and stage II and III phoscorites which belong to the olivine series of phoscoritic rocks. Seblyavr rocks have high concentrations of Ba, Sr, Nb, Ta and LREE, high Zr/Hf (7-80) and show trace element distribution patterns largely related to mineralogical control. They display LREE-enriched REE patterns with (La/Yb)_N ratios mostly ranging from 38 to 189, although there is an extreme (La/Yb)_N value of 1659. In the rocks and minerals studied concentrations of trapped mantle ³He vary from 9x10⁻¹² to 8.4x10⁻¹⁰ cc/g with ⁴He/³He from 0.15x10⁶ to 2.66x10⁶, due to the contribution of a lower mantle plume component. ⁸⁷Sr/⁸⁶Sr and epsilon_{Nd} for whole rock samples, calculated at 380 Ma, vary from 0.7031 to 0.7034 and +4.9 to +7.5 respectively.

We conclude that: (i) the melts parental for Seblyavr intrusion were derived from a depleted upper mantle source, metasomatized by the action of a lower mantle plume; (ii) the Seblyavr intrusion is evidence for the existence in the metasomatized subcontinental mantle of a long lived melt source which produced at least 2 discrete portions of magmas varying in composition: a) rich in Fe, Ti and P carbonate-bearing silicate melt, from which the clinopyroxenites and stage I phoscorites and carbonatites of Seblyavr were formed; and b) Mg-Ca carbonatite melt rich in Fe, P and S, from which II-IV stages phoscorite-carbonatites originated.

When compared with results from other authors, the two-event magmatic history of Seblyavr complex formation looks rather like a rule for generation of Kola Proterozoic alkaline and ultramafic-alkaline rocks with carbonatite complexes.

Nature of orthomagmatic, carbonatitic fluids precipitating REE, Sr-rich fluorite, and element fractionation during fluid/rock interaction

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An H₂O–CO₂ fluid is trapped in fluid inclusions in quartz of the immediate wall rocks of the Cretaceous, carbonatite-related Okorusu fluorite deposit, Namibia. The bulk fluid composition was determined at 21 wt.% Na₂O, 8 wt.% K₂O, 5.5 wt.% CaO, 3 wt.% F, 10.8 wt.% Cl, and REE, Ba and Sr each in the percentage range. The low ratio Ca/alkalis, the remarkable F content, and a closely carbonatitic ⁸⁷Sr/⁸⁶Sr ratio are solid indications that the inclusion population represents an orthomagmatic fluid that deposited fluorite by reaction with crustal limestone. Sr and Pb isotopes determined for the extracted fluid and for all stages of mineral precipitation indicate a 1:1 reaction of limestone with orthomagmatic fluid for early fluorite (f=0.5), and a higher ratio limestone/fluid up to f=0.8 for late calcites. Consistent Sr isotopes within primary fluorite profiles suggest a constant and continuous limestone/fluid reaction, which allows an investigation into the element distribution between the fluid and fluorite.

Phoscorite-carbonatite deposits of Russia, the history of prospecting works and their economic mineralization

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In Russia, carbonatites were discovered first on the Turiy Peninsula in the Kola region in the 1920s as veins and dykes in fenites. Today, carbonatite complexes are known in many parts of Russia. The main provinces are: a) the Kola Peninsula and Karelia, b) the Maimecha-Kotuy region, c) Aldan in Siberia, d) The Sette-Daban range in the Far East, e) the Sayan Mountains.

In the 1940-1960s prospecting of phoscorite-carbonatites complexes were usually directed towards one main raw material (e.g. ores of Fe, Nb, Ta, or phlogopite). Since about 1970 the main target has been apatite, but at the same time a variety of raw materials was sought at every prospect (for example, at Kovdor, Sebl-yavr, Vuori-yarvy, Turiy mys etc.).

Except the Murmansk district and Karelia, all the phoscorites and carbonatites are situated in areas remote from economic centres of Russia. As a result, the Kovdor massif is the only currently productive deposit in Russia. A brief history of its exploitation is as follows:

1932 – discovery of iron ore,

1962 – beginning of industrial extracting of iron ore,

1965 - beginning of exploitation of vermiculite and phlogopite,

1975 – first production of industrial apatite concentrate,

1976 – first production of industrial baddeleyite concentrate.

Some examples of typical difficulties and mistakes of prospecting works will be given in the conclusion of this talk. One of them is the Seligdar apatite deposit in Siberia. It had been prospected as a phoscorite-carbonatite complex, but it is formed by Precambrian metasomatized calcifires.

Nepheline syenite and carbonatite from the Transantarctic Mountains of southern Victoria Land

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The Transantarctic Mountains have developed on the site of the Ross Orogen, the lower Paleozoic suture between the East Antarctic craton and the accreted collage of terranes which make up West Antarctica. In southern Victoria Land, the Dry Valleys calc-alkaline and alkali-calcic province has been dated at 530-488 Ma, but is replaced along strike to the south by the Koettlitz Glacier Alkaline Province (KGAP) which contains A-type granitoids, alkaline gabbro and diorite, and nepheline syenites and carbonatites. High precision U-Pb dating indicates intrusion between 551 and 535 Ma.

Nepheline syenites are miaskitic, and, in the largest body (5-6 km²), range in composition from cumulate alkali pyroxenite to ijolite and syenite. Elsewhere the syenites form small intrusions (600m x 150 m) and thin dykes cutting country rock and earlier intrusives. A syenite at Radian Ridge is cut by a zoned carbonatite dyke that contains calcite-biotite-fluorite-kspar-zircon. Carbonatite dykes elsewhere carry apatite, fluorite, rare allanite and graphite and barrel-shaped euhedra of biotite. Syenite and carbonatite also occur as composite intrusions, with coarsely granular calcite-biotite carbonatite occurring in the core of a zoned dike.

Carbonates from carbonatites and syenites exhibit an overlapping range of oxygen and carbon isotope ratios ($\delta^{18}\text{O}$ +13 to +17 per mil, $\delta^{13}\text{C}$ +1.0 to -2.5 per mil). However, these ratios are consistently depleted relative to carbonate in country rock marbles ($\delta^{18}\text{O}$ +17 to +23 per mil and $\delta^{13}\text{C}$ -2 to +3.5 per mil respectively). Carbonatites and syenites have overlapping ranges of initial $^{143}\text{Nd}/^{144}\text{Nd}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ (0.511917 to 0.512378 and 0.705938 to 0.706870 respectively). Carbonatites and syenites have parallel, LREE-enriched patterns with small, negative Eu anomalies ($\text{Eu}/\text{Eu}^* < 1$). Carbonatites are enriched in terms of absolute concentrations relative to syenites, with La_N values approaching 10^3 .

Although carbonatites and syenites occur in areas where the country rock is rich in carbonate-metasediment, the geochemistry of the magmas is compatible with mantle derivation. Associated intrusive rocks of the KGAP (A-type granites, alkaline gabbros) also have a typically within-plate character, suggesting a pre-orogenic or early-orogenic episode of extensional, or conceivably transtensional, tectonic magmatism that predates the main Ross Orogeny convergence.

Late-Stage Carbonatites, Fluorite Replacement Ores, and the Alteration of Pyrrhotite in the Open Pit Fluorspar Mines at Okorusu, North-Central Namibia

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Precambrian Damara Series metasedimentary rocks were intruded and pervasively fenitized by a 5 km diam. ring complex of late Cretaceous (126.6 Ma) alkaline igneous silicate rocks (nepheline syenite, foyaite, tinguaita, etc.) and fine-grained calcite carbonatite at Okorusu, Namibia. Late stage coarse-grained pyroxene and pegmatitic carbonates that traverse the fenites consist of abundant calcite, salite pyroxene, titaniferous magnetite, locally abundant pyrrhotite, and minor chalcopyrite. These late-stage carbonatites are preferentially replaced by fluorite, and they form a major factor in the control for the emplacement of the fluorite orebodies. Large euhedral pyrrhotite crystals in the late-stage carbonatites have been altered during a late magmatic-hydrothermal stage to fine-grained marcasite crystals elongate parallel to the (0001) of the pyrrhotite, and subsequently to a mosaic of fine-grained pyrite cubes intergrown with secondary magnetite and hematite. Within the fluorite orebodies, pyrrhotite, salite, and magnetite of the replaced carbonatites were further altered to goethite pseudomorphs.

Radiometric ages and isotope systematics of some Finnish carbonatites

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Carbonatite magmatism in Finland spans from late Archean to Devonian in age. The Siilinjärvi Carbonatite Complex has yielded a late Archean U-Pb age of 2609 ± 6 Ma (Geological Survey of Finland, unpublished data, Lukkarinen et al., in prep.). The Laivajoki and Kortejärvi carbonatite intrusions in northern Finland are Paleoproterozoic and show scattered U-Pb systematics in zircons. This is, at least partly, related to later metamorphic formation of zircon from primary baddeleyite. The crystallization age of the intrusions is about 2.0 Ga, but several younger zircon generations are present as well. The $\delta^{13}\text{C}$ values of these and the Devonian Sokli Carbonatite show relatively little variation, all falling in the range from -2.7 to -4.9 ‰. Surprisingly, the $\delta^{13}\text{C}$ values of carbonate in the Neoproterozoic kimberlite pipes also fall in the same range (Peltonen et al., 2000) suggesting a homogeneous source of carbon for the carbonatite and alkaline magmatism within the Archean Karelian craton. Nd isotope compositions, however, show more variation. The ϵ_{Nd} values for the Archean Siilinjärvi Carbonatite plot close to the chondritic growth curve, but the Paleoproterozoic Laivajoki and Kortejärvi carbonatites have a depleted Nd isotope signature, with distinctively positive ϵ_{Nd} at +1 to +3. Even higher ϵ_{Nd} values have been reported for the Devonian Sokli Carbonatite (Kramm, 1993).

Some new partition coefficients between apatite and carbonatite melts

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To more fully establish a basis for quantifying the role of apatite in trace-element fractionation processes, hitherto unknown partition coefficients for a variety of trace elements (Li, Be, B, Cs, Rb, Ba, Th, U, Nb, Ta, La, Ce, Sr, Pr, Hf, Zr, Sm, Gd, Y, Lu, and Pb) have been measured between fluorapatite, chlorapatite, and hydroxylapatite and carbonatite melt, respectively.

Apatites were equilibrated experimentally with carbonatite melts at 1 GPa and 1250°C, and run products were analysed for trace elements with secondary ion mass spectrometry and with Laser Ablation ICP-MS. Calculated partition coefficients ($D_{\text{apatite/carbonatite melt}}$) indicate incompatibility of most analysed trace elements. Rare earth element partition coefficients show a convex-upward pattern, indicating that apatite prefers the middle rare earth elements relative to the lighter rare earth elements and heavier rare earth elements, respectively.

Comparison of partition coefficients determined in this study with previous results in silicate systems reveals a strong influence of melt chemistry on partition coefficients with decreasing partition coefficients ($D_{\text{apatite/melt}}$) with decreasing silica-content of melts, and increasing calcium and phosphorus in melts, respectively.

The Devonian timing of magmatism in the Paleozoic Kola Alkaline Province (KAP), and the problem of selective resolution of magmatic processes within single alkaline complexes.

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All KAP plutonic magmatism occurred during Devonian times. Rb-Sr isochrons suggest a period of magma injection and cooling between 380 Ma and 360 Ma. Within this time span the different alkaline complexes are characterised by distinct ages, with Sokli close to the lower and Kovdor close to the upper limit of the span, as shown by Rb-Sr isotope investigations of minerals. The temporal resolution of the sequence of injections within the complexes, which needs a rapid cooling of the selective magma batches as well as a high precision age dating technique is not sufficiently solved so far.

Different age dating methods present the problem of concordance which can be discussed in terms of isotope exchange dynamics. U-Pb ages seem to be slightly higher than Rb-Sr data, yet, for Kovdor, are within the limits of error of the compared methods.

Recent Rb-Sr age determinations on alkaline dyke rocks in the region of KAP suggest a tremendous enlargement of the period of Phanerozoic alkaline activity to a span of 450 Ma. The isotopic equilibration between the suggested isochronous phases has to be discussed.

Utilisation of Kovdor phlogopite tailings as a raw material for complex potassium fertilizers.

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Utilisation of the tailings accumulated at the Kovdor Mining Companies undoubtedly has tremendous importance for their future development. The tailings at the Phlogopite mine contain about 99% of mica, while the overdressing of phoscorite-carbonatite ores results in the production of apatite concentrate and forsterite-carbonate (calcite + dolomite) loose tailings. In addition, near the phoscorite open-pit prospecting has shown the presence of an apatite-francolite deposit with about 100 millions tons of phosphorous ores similar to those of the Sokli massif. So, on the basis of these Kovdor raw materials it is possible to create a new type of phosphorous-potassium-calcium fertiliser with a long "life span".

Results of experiments on the use of mica as a source of potassium in the manufacture of fertiliser were published first in 1911 by A. Stolgan in a work entitled "About ability of K-bearing silicates to give back potassium in exchange for other bases". The principal possibility to use mica and carbonates as a K-Mg-Ca-fertiliser was proved recently by Kemira Agro Oy, which produces the complex "Kemira biotitti" fertiliser using by-product phlogopite at the Siilinjärvi carbonatite deposit (Finland).

Our field experiments, involving barley (cv."Potra"), potatoes (cv."Nevskiy") and Kovdor phlogopite and calcite support the recommendation that these minerals can be used as an effective fertiliser for sod-podzolic soils. An increase in phlogopite content invariably results in increasing levels of K in the plant, and augmentation of the crop. Most effective is the combination of mica and calcite. In comparison with the well-known soluble potassium fertilisers, phlogopite does not dissolve completely, but turns to vermiculite with progressive extraction of K. This transformation further improves the fertility of the soil. In summary, the use of mica-based potassium fertilisers will have a prolonged positive effect on the fertility of soils, without causing any adverse environmental impact.

A new set of field experiments started this year with the main task of determining the complex influence on the plants of using fine-grained francolite, in addition to phlogopite and calcite, as a natural source of phosphorous. This is an additional step to work out a new type of long-acting complex fertiliser enriching the soil with the necessary elements – K, Ca, Mg, P, in a form that is not washed away quickly (i.e. leached) by surface water. It is expected that the complex mica-carbonate-phosphorous fertiliser will fulfil the requirements of such a fertiliser. There is a plentiful supply of the raw material saved in the tailings of the Kovdor Mining Companies.

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Hydrothermal processes in carbonatites and phoscorites of the Kola Alkaline Province: Mineralogy, Geochemistry and some implications.

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During their final evolution under crustal conditions, silicate-carbonate magmas released abundant carbothermal fluid, which separated into CO₂-gaseous and hydrous phases. Having intruded into the consolidated crust, the carbonatite stocks generally had no way to lose the fluid. Thus the fluid had to impregnate the parental structure. The carbonatites and phoscorites had therefore often undergone autometasomatism followed by intense local hydrothermal alterations. The hydrothermal processes resulted both in late generations and in collapse of carbonatite minerals including conventional geochronometers like zircon, baddeleyite, phlogopite. Thus hydrothermal alterations by CO₂-rich fluid, if any, would inevitably have distorted the original features of any rock, obtained through a monomineral approach.

Although the exotic oxysalts composing the carbonatite-related hydrothermal assemblages may not be common as rock-forming minerals, their very co-existence is a challenge to our understanding of equilibrium geochemical processes. The redistribution of some HFSE elements such as Sc, Zr and Nb caused new types of mineralization of these elements.

Collinsite in hydrothermal assemblages related to carbonatites in the Kovdor massif, NW Russia

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Several generations of collinsite were formed during hydrothermal alteration of phoscorites and dolomite carbonatite in the Kovdor alkaline-ultramafic massif, NW Russia. The collinsite in this locality shows isomorphic substitution of Sr for Ca at the A crystallographic site, which is atypical both for this species and for the entire fairfieldite group. The Sr content reaches 0.74 atoms per formula unit and shows an inverse correlation with Ca. Sr is found to account for no more than 37% of the total occupancy of the A site, a proportion that fits the Lewis acidity of interstitial cations, a value of 0.25 valence units (assuming a disordered distribution of Sr), which in turn matches the Lewis basicity of the collinsite structural unit, the chain [Mg(PO₄)₂(H₂O)₂]. The collinsite-bearing assemblages were formed by juvenile hydrothermal solutions derived from phoscorites and carbonatites that had been cooling in a tectonically active environment. Textural evidences and strontium isotopic characteristics show the assemblages to be superimposed upon the host rocks and coincident with cataclasis of the dolomite carbonatite and selective leaching of

its primary minerals. The Sr isotopic composition of collinsite and the associated hydrothermal phosphates shows no significant contribution of crustal component. Being confined to faults, the orthomagmatic hydrothermal solutions migrated upward and were not mixed with ground waters or crustal fluids in tectonic channels prior to deposition of the collinsite-bearing assemblages. The active fluid-rock interaction below 270°C under wide variations in pH - Eh parameters, $f(O_2)$, $f(S_2)$, and relatively low $f(CO_2)$ did not homogenize the isotope composition of Sr between the solutions and affected carbonate rock.

World Class Carbonatites for Niobium from Araxá, Brazil; Bastnaesite from Mianning, China; and Ta-pyrochlore from Blue River, British Columbia

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This presentation will include discussions on the mineralogy and petrology of mineralized rocks from carbonatite complexes that are almost unique as major sources of niobium from Araxá in Minas Gerais, Brazil; bastnaesite in the carbonatite veins of the Mianning area in Sichuan, China and Ta-bearing pyrochlore from the carbonatite veins of the Blue River area in British Columbia.

For Araxá discussions will be confined mainly to the fresh un-weathered carbonatite with high-grade pyrochlore mineralization.

The Mainning occurrence will be presented as the best known mineralization of bastnaesite in the world and the case of which high grade concentrates can be made.

In Blue River accessory pyrochlore occurring in all of the carbonatite bodies contains anomalous Ta relative to pyrochlore from most carbonatites. Drilling from one localized area of the Verity carbonatite of Blue River has revealed the presence of at least 3 million tons with 196 grams/ton of Ta_2O_5 , 645 grams/ton of Nb_2O_5 and 3.2 wt.% P_2O_5 .

Yttrium and HREE-rich carbonatite veins of Lofdal, Damaraland, Namibia

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A swarm of carbonatite veins occurring on the Bergville and Lofdal farms just northwest of Khorixas in the Kunene Region of Namibia assume a NE-SW trend and are mostly dark brown to almost brick-red in color. Despite the strong ferruginous appearance, the veins are predominantly calcite carbonatites with associated ferric iron oxides. Some of the veins are > 5 meters in width

with lengths of several hundred meters, and some were found to contain as high as 2 wt.% xenotime. Contrary to most carbonatites all of the analyzed rocks showed a dominance of HREE and anomalous values of Y. Associated minerals with xenotime are thorite, apatite, monazite, fluorite and parisite.

Cathodoluminescence was found to be an effective tool for identification of the xenotime. The associated apatite gave CL emission spectra with Sm>Dy but also showing a pronounced Eu³⁺ and Tb³⁺ emission.

Hydrothermal horizontal layered rocks with monazite and apatite mineralizations in Catalão I Complex, Brazil.

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The Catalão I Complex is composed of phlogopitites, carbonatites, pyroxenites, and phoscorites. The Complex hosts important apatite and niobium economic deposits associated with large monazite and anatase mineralizations. A monazite mineralization associated with hydrothermal horizontal layered rocks occurs at the central part of intrusion. This monazite mineralization comprises an area of about 1 km² and 30 m thick. The hydrothermal layered rocks comprise: apatite and secondary ilmenite as main constituents of the lower layers; monazite, ilmenite, quartz, and apatite in the middle layers and ilmenite, quartz, and clay in the upper layers. The monazite layers can reach up to 30 cm thick. A swarm of vertical late veining, composed of monazite, crosscuts the layered rocks and the host carbonatitic wall rocks. Several semi-circular conduits, about 1 meter in diameter, filled by breccia composed of fragments from the wall rocks can be found.

Geophysical responses of carbonatites – the use of geophysical methods in their exploration.

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Carbonatites, as well as associated alkaline intrusive rocks, have very specific chemistry due, in large part, to their restricted mantle related origin. Many of the elements which are concentrated within carbonatite melts are susceptible to geophysical detection methods, most notably by magnetic and radiometric surveys. Both these surveys are cost effectively carried out from an airborne base and large areas can be rapidly covered.

Magnetics - The presence /or absence of magnetic minerals (usually magnetite) in rocks produces an apparent magnetic susceptibility of the rock which can be measured. This can be carried out qualitatively in the field with a compass or magnet or quantitatively with a magnetic susceptibility instrument such as the Kappameter. Many carbonatites have very high magnetic susceptibilities which can be used effectively for their exploration.

Radiometrics - As carbonatites are enriched in high field strength elements including U and Th, they often form radiometric anomalies. Using ternary plots of the major radiogenic elements (K, U, Th) the ratio can be determined and plotted as an apparent colour. High Th relative to U and a low potassium count would characterise the carbonatite signature. Often there will be a nearby potassium anomaly, the result of related fenitization.

Niobium deposits in weathered carbonatite: an example at Sokli, northern Finland

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The Sokli carbonatite complex in northern Finland (67°50', 29°20') has recently been the subject of an EU BRITE-EURAM-sponsored project to develop it as a niobium deposit in order to supply a European specialist market. Apatite would probably be produced as a by-product together with the Nb ore mineral, pyrochlore. The main rock types at Sokli are calcite carbonatite and apatite-mica-magnetite rock, locally called phoscorite. Pyrochlore is most concentrated in the phoscorite. Almost all Nb mines are currently working weathered carbonatite (e.g. Araxá and Catalão, Brazil; Lueshe, D.R. Congo) and weathered material at Sokli, which is more than 80 m deep in places and preserved under glacial deposits, was the main subject of this study. The style of weathering, as defined by whole-rock chemistry, especially Sr/(Ca+Sr) ratios and Si/Al ratios, is similar to the apatite-rich levels of African lateritic carbonatite weathering. Pyrochlore also behaves similarly to pyrochlore in lateritic deposits in that Ca and Na are leached and partially exchanged for Ba and Sr. Th and U are retained in pyrochlore under the moderate degrees of weathering at Sokli.

U-Th-Pb- elemental and isotopic distribution of pyrochlore minerals from the Sokli carbonatite complex, N-Finland

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Pyrochlore, ideally $(Ca,Na)_2(Nb_2O_6)(OH,F)$, is a relatively common accessory mineral in many rock-types including carbonatites. In the Sokli carbonatite, N. Finland, pyrochlore concentrates to

economically-important amounts, where it forms the ore mineral for niobium. A large number and variety of cations can be accommodated in the pyrochlore structure, including actinide elements (uranium and thorium). During radioactive decay of the unstable isotopes of the actinide elements, the pyrochlore structure can become partially or totally metamict. This will render the mineral susceptible to further chemical alteration.

In this work the influences of metamictisation, hydrothermal alteration and weathering on the U-Th-Pb- isotopic distribution and the crystallographic order within single pyrochlore crystals and crystal domains should be quantified and correlated. It will reveal conclusions to the retention of pyrochlore group minerals for actinides in differently ordered crystal lattices and different chemical compositions. This will show the possibility to use pyrochlore minerals for age determination of carbonatite crystallisation and subsequent alteration stages.

Nb- and Zr-bearing minerals from Sokli, Finland.

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The Sokli carbonatite complex contains a range of Nb- and Zr-bearing accessory minerals, including **zirconolite**, **baddeleyite**, and **pyrochlore** in the calcite carbonatite and phoscorite phases. Here, we describe the mineralogical, textural and compositional variations observed in **zirconolite** [ideally $\text{CaZrTi}_2\text{O}_7$, with up to 23% Nb_2O_5], **baddeleyite** [ideally ZrO_2 , with up to 6% Nb_2O_5] and fresh **pyrochlore** [ideally $(\text{Ca},\text{Na})_2\text{Nb}_2\text{O}_6(\text{OH},\text{F})$].

Zirconolite has a relatively small compositional range, but displays some degree of secondary alteration and replacement by a Ba-rich phase. Baddeleyite often shows spectacular zonation and twinning, and displays post-magmatic corrosion and replacement features. Pyrochlore displays significant compositional variation during evolution of the Sokli carbonatite from early high-Ta, high-U pyrochlore, to late variants depleted in these elements.