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Nature of Carbonatite Complexes of the Kola-Karelia Province in Arctic Region: Special Emphasis on Mineral Potential

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ABSTRACT. In recent years many new occurrences of carbonatite complexes have come to light to such an extent that they can no longer be considered rare in igneous rock families. The carbonatite complexes of the Kola-Karelia province in Arctic region include a great diversity of rock types, but they are genetically associated with valuable economic minerals. The occurrence, petrologic feature, and associated mineralization of the representative carbonatite complexes in the Kola-Karelia province, together with general characteristics of carbonatites, are reviewed for better understanding about the nature of carbonatite complexes.

Key Words: Alkaline Complexes, carbonatites, Arctic region, mineral potential

Introduction

Carbonatite is an igneous rock containing at least 50% modal abundance of carbonate minerals (Streckeison 1980). Carbonatite-bearing ultramafic alkaline complexes generally exhibit chaotic field relations because of explosive magmatism, metasomatic alteration and high activity of volatiles. Carbonatites probably originate in the upper mantle and, along with related alkaline rocks, are characterized by geochemical enrichments in Ba, Nb, REEs, Sr, Ta, Th, U, and Zr. In view of the current interest in Y and HREEs for superconductors and permanent magnets, the natural enrichment of these elements in carbonatites should be of interest to exploration geologists.

Among more than 300 carbonatite occurrences, there are many petrologically and economically famous carbonatite-bearing ultramafic alkaline complexes (hereafter "carbonatite complexes") in Arctic region, particularly in the Kola-Karelia province of the eastern Baltic Shield. More than thirty alkaline complexes are known in the Kola-Karelia province, and fourteen of them contain carbonatites and phoscorites (Kramm *et al.* 1993). Carbonatite complexes in the Kola-Karelia province (Kukharenko *et al.* 1965) are usually concentrically zoned, pipe-like intrusions in which ultramafic rocks (olivinite or clinopyroxenite) occupy the central parts of the complexes and melilitolites with foidolites surround the former.

The first author had a chance to visit the representative carbonatite complexes in the Kola-Karelia province from June to July 1999 with British, French, and Russian geologists, and could get many valuable data and information of them. In this paper, we will review the occurrence, petrologic feature, and economic mineralization of the representative carbonatite complexes in the Kola-Karelia province, together with general characteristics of carbonatites, for better understanding about the nature of carbon-

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Table 1. Summary of principal characteristics and classification scheme of carbonatites.

Characteristics	Classifications
Rock association	**I-extrusive carbonatites**
nephelines, ijolites, nepheline syenites	natrocarbonatite : nyerereite-gregoryite-calcite
ijolite-melteigite-urtite series	pyroclastic carbonatite
okaites, melilites, pyroxenites	tuffaceous carbonatite
fenites (metasyenites)	**II- intrusive carbonatites**
Mineralogy	
major minerals : calcite, dolomite, ankerite, rarely siderite	**Mineralogical Classification**
accessory minerals : pyrochlore, phlogopite, magnetite, Na-pyroxene strontianite, synchisite, parisite, bastneasite monazite, burbankite, allanite, barytine	coarse-grained carbonatites — sövite : calcite; beforsite : dolomite
Chemistry	fine-grained carbonatites — alvikite : calcite; rauhaugite : dolomite; ferrocarbonatite : Fe-calcite or ankerite
enrichment in Sr, Ba, Zr, Nb, Th, U, REE	
Isotopic composition	
$(^{87}Sr/^{86}Sr)_I<0.704$	
$\delta^{13}C = -1 \sim -9‰$ relative to PDB	**Chemical Classification**
$\delta^{18}C = +6 \sim +12‰$ relative to SMOW	calciocarbonatites : $CaO > 80\%$
Sequence of abundant cations	magnesiocarbonatites : $MgO > FeO+Fe_2O_3+MnO$
$Ca > Mg > Fe+Mn$	ferrocarbonatites : $FeO+Fe_2O_3+MnO > MgO$
Physical property of magma	
viscosity : $0.01 \sim 0.1$ Pa at >500°C	
density : $2.2 \sim 2.8$ g/cm^3	
fusion point : ~ 450°C	

atite complexes.

Definition and Classification

Until the middle of the last century, it was generally accepted that carbonatites are formed by sedimentary processes via calcareous and dolomitic mobilization in the continental crust. This idea has been abandoned by the evidence of their specific chemical composition of high enrichment in alkalis, P, Ti, and Sr.

The primary minerals of carbonatite are calcite, dolomite, and possibly ferrous carbonate (ankerite). The accessory minerals are pyrochlore, apatite, magnetite, phlogopite, and strontium and/or rare earth carbonates (e.g., strontianite, bastnaesite, synchisite, and parisite); in some cases, however, apatite and pyrochlore comprise major constituent. The principal characteristics of the carbonatites are summarized in Table 1.

The carbonatites are defined as igneous carbonate rocks with more than 50% modal carbonate minerals (Streckeison 1980; Le Bas 1987). Since the carbonatites are mostly composed of coarse-grained rocks, their classification should be performed on the basis of modal analysis according to the recommendations of the IUGS Subcommision (Table 1). Common presence of complex intergrowths, however, makes it difficult to classify using only modal analysis data. For these reasons, some classification schemes were suggested on the basis of chemical composition of carbonatites (Woolley 1982; Woolley and Kempe 1989; Table 1).

Spatial and Temporal Distribution of Carbonatite

About 330 carbonatite occurrences are known

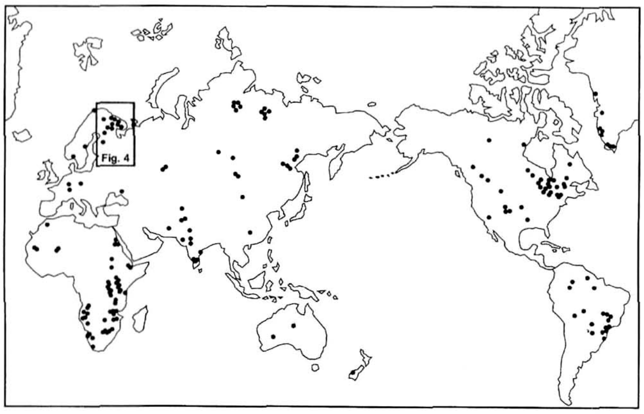

Fig. 1. Spatial distribution of carbonatite complexes in the world.

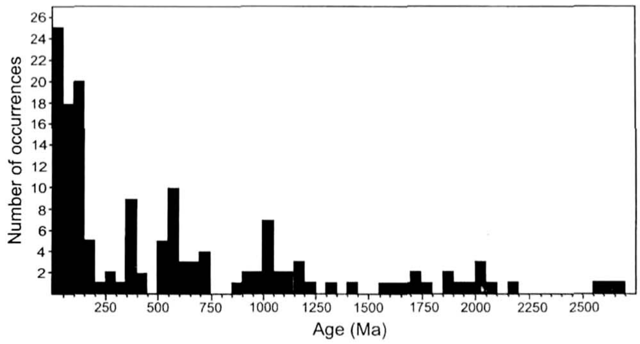

Fig. 2. A frequency distribution diagram of carbonatite dates in the world (after Woolley 1989).

worldwide till now (Fig. 1). It has been generally accepted that carbonatites are characteristic of the central parts of anorogenic continental areas, but the increase of their occurrences indicates that many carbonatites can be linked with orogenic activity. The fact that some carbonatites occur close to plate margins also suggests their distribution is clearly related to plate movement (Garson 1984).

Approximately half of the known carbonatites occur in Africa, with the majority concentrated in or close to the East African Rift occupied a broad zone trending southwards from Kenya through Mozambique into South Africa. There is a lesser, but significant concentration, along the southwest African coast. These concentrations are commonly associated with major faults which may define rifts.

In South America, the large concentration of carbonatites is well known from the southern Brazil for many years, but recently several ones discovered on the northern part of the Amazon Basin. This Amazon Group constitutes a major province in South America.

Carbonatites are also widely distributed throughout North America. Although most occur in the southern part of the Canadian Shield, some are scattered over the whole Precambrian craton and along the central and southern Cordillera. Carbonatite bodies recently discovered on the western coast of Greenland are characterized by wide range of formation age regardless of their limited distribution.

Northern Europe is another relatively small crustal segment in which carbonatites yield a broad spectrum of formation age. The Kola province in northern Finland and the Kola Peninsula of Russia comprise a major part of the northern European alkaline provinces. More than 50 carbonatite occurrences are known within the former USSR. They are grouped into several provinces; namely, Kola, Ukraine, Maimecha-Kotui, Olenek, Aldan, and Sayan-Tuva provinces.

There are several carbonatite provinces in Indian continent. About 20 carbonatites are known in the Eastern Ghats and Tamil Nadu provinces of southern India. The Amba Dongar carbonatites lie in the central part of the Deccan volcanic province, and Peshawar Plain carbonatites are distributed in the northern Pakistan and Afghanistan. Some carbonatites are also known from Australia, New Zealand, China, Iran, Turkey, and Yemen.

Figure 2 shows the summary of age dating results (mostly by K-Ar method) for the well known carbonatites. Although K-Ar dates are probably minimum limits for carbonatite activity, it is apparent that the ages fall into groups, which generally correspond to major orogenic and tectonic events. The middle Proterozoic group corresponds to the Hudsonian and Svecokarelian orogenies of North America and Europe, respectively. A broad, major, later Proterozoic event corresponds to the Grenville orogeny. The peak between 750 Ma and 500 Ma is related to early Caledonian orogeny from northern Europe, North America, and Africa. A major period of carbonatite activity starting 200 Ma is probably associated with the breakup of Pangaea.

Although there are still many carbonatites to be dated, the age dating information from Figure 2 reflects that the gradual increase in the number of carbonatite occurrences with time is undoubtedly real. In addition, it implies that the conditions necessary for the production of carbonatite were not only established by the late Archean, but have become increasingly widespread with time (Woolley 1989). In an alternative interpretation, the observed trend may be viewed as an artifact of preservation, because the probability of preservation decreases exponentially with increasing age of the crustal segments (Veizer *et al.* 1992). The secular trend for carbonatites since at least 1.8 Ga, the time that continental crust attained its near-modern extent (Taylor and McLennan 1985; Condie 1989), is compatible with a stead-state process of carbonatite generation and destruction that has a half-life of about 445 my. The most acceptable model for the temporal distribution of carbonatites involves a combination of orogenic activity and erosional dispersal (Veizer e*t al.* 1992).

Nature of Economic Mineralization

Carbonatite displays geochemical enrichments in Ba, Nb, REEs, Sr, Ta, Th, U, and Zr. Some of the best known or potential ore deposits for Cu, Nb, REEs, fluorite, phosphate, and vermiculite are associated with carbonatites (Mariano 1989).

A distinctive aspect of carbonatites is the anomalously high REE contents. In general, the total REE content in sedimentary carbonates rarely exceeds 200 ppm, but that in carbonatites ranges from 500 to >10,000 ppm (Eby 1975; Möller *et al.* 1980). The major carbonate minerals in all carbonatites contain anomalous quantities of REEs. Therefore, calcite and dolomite in carbonatites are potential sources for REEs during hydrothermal and weathering processes. Discrete REE minerals also occur in carbonatites, and apatite can also be a major source of REEs. A genetic classification of REE deposits associated with carbonatites is as follows:

(1) primary mineralization from carbonatite melts (bastnaesite and parisite — Mountain Pass, USA),

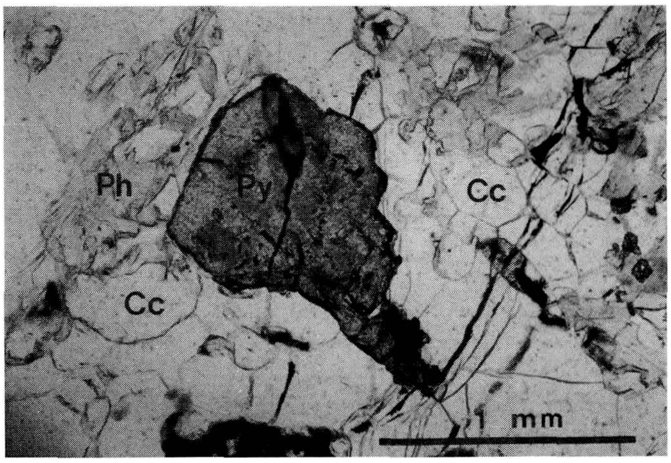

Fig. 3. Photomicrograph (under open polar) showing pyrochlore in calcite carbonatite, Sokli complex, Finland. Py=pyrochlore, Ph=phlogopite, Cc=calcite.

(2) hydrothermal mineralization (bastnaesite and monazite — Bayan Obo, China; Wigu Hill, Tanzania; Karonge, Burundi), and

(3) supergene mineralization developed in carbonatite-derived laterites (Araxá and Catalão I, Brazil; Cerro Impacto, Venezuela; Mrima, Kenya; Mt. Weld, Australia).

Carbonatites and associated alkaline rocks constitute the world's largest source of Nb. The presence of Nb minerals or enrichment in Nb is a good criterion for carbonatite identification. Pyrochlore is the only mineral mined for Nb in carbonatites (Fig. 3). Pyrochlore commonly occurs as disseminated minerals in carbonatites, but primary pyrochlore also occurs in veins cutting earlier carbonatite. At least four kinds of Nb mineral can occur in sufficient quantities to affect the Nb content of carbonatites. They include ferrocolumbite, fersmite, niocalite, and wöhlerite.

On a world level, the monetary value of phosphates is greater than any other commodity derived from carbonatite deposits. Apatite deposits in carbonatites have a higher phosphate content than marine phosphorite deposits. Primary apatite is probably the most widespread accessory mineral in early- and intermediate-stage carbonatites and associated alkaline rocks. In some carbonatites, such as glimmerites, ijolites, pyroxenites, and silicocarbonatites, the apatite content can exceed 50 vol.% and is called as an igneous phosphorite.

Kola-Karelia Province in Arctic Region

The Kola-Karelia alkaline province is situated in the eastern part of the Baltic Shield and occupies the Kola Peninsula and northern part of Karelia (Fig. 4). The alkaline and alkaline-ultramafic magmatisms were most intense in the Middle Paleozoic (370-340 Ma), and occur as intrusives, dikes, and diatreme forms. More than thirty alkaline complexes are known in this province, and fourteen of them contain carbonatites and phoscorites (Kramm *et al.* 1993). Most of them are related to reactivation of much older, deep-seated faults formed within the Baltic Shield, especially the northeast-trending Kontozero graben and the northwest-trending Kandalaksha graben. One of the interesting features that distinguish the Kola province from many other provinces of alkaline affinity is the abundance of ultramafic (pyroxenite, olivinite) and melilite-bearing plutonic rocks.

The Kola-Karelia complexes include a great variety of rock types ranging from early ultramafic rocks, foidolites, melilitolites and nepheline syenites, to carbonatites and phoscorites as well as a number of economic deposits, such as apatite, baddelytite, magnetite, phlogopite, and vermiculite (Kovdor), apatite (Khibina), and loparite (Lovozero).

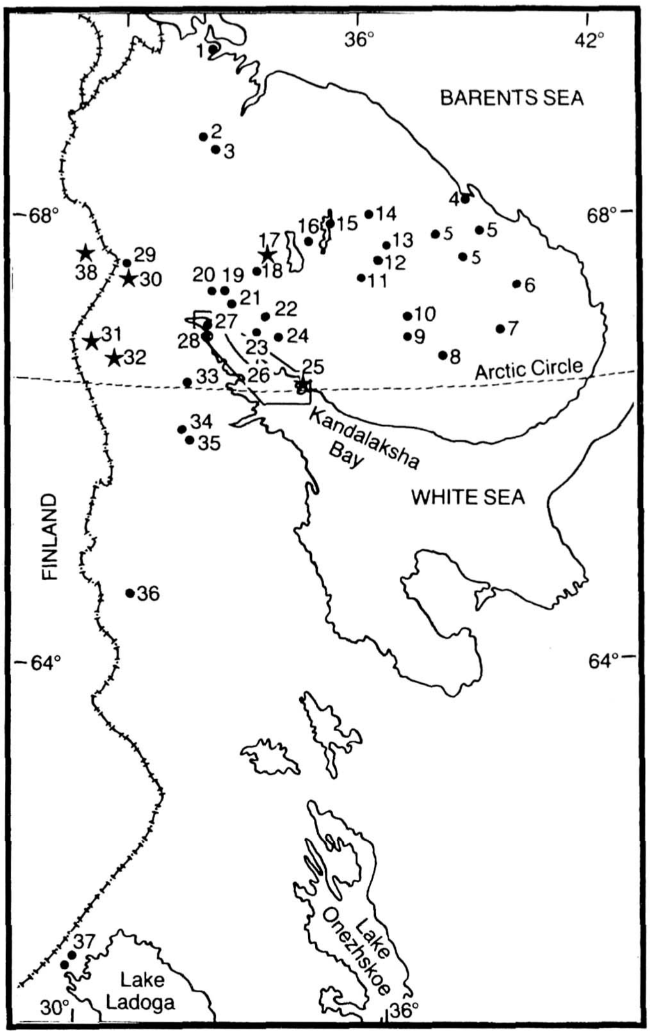

Fig. 4. Distribution of alkaline igneous rocks and carbonatites in the Kola-Karelia province (after Kogarko *et al.* 1995). 1, Chagvedaiv; 2, Seblyavr; 3, Gremyakha-Vyrmes; 4, Ivanovskii; 5, Nizyavrskii, Iokan'skii and Koyutyngskii; 6, Pachinskii; 7, Ponoiskii; 8, Strel'ninskii and Purnachskii; 9, Pesochnyi; 10, Lavrent'evskii; 11, White Tundra; 12, Sakhariokskii; 13, Western Keiv; 14, Kontozerskii; 15, Kurginskii; 16, Lovozero; 17, Khibina; 18, Soustova; 19, Ozernaya Varaka; 20, Afrikanda; 21, Lesnaya Varaka; 22, Salmagorskii; 23, Ogorodnyi; 24, Kanozerskii; 25, Turiy Peninsula; 26, Kandalakshskii dikes; 27, Elovyi Island; 28, Kandagubskii; 29, Mavragubskii; 30, Kovdor; 31, Sallanlatvi; 32, Vuoriyarvi; 33, Kovdozerskii; 34, Tikshozerskii; 35, Elet'ozerskii; 36, Kostomukshskii dike complex; 37, Elisenvaarskii; 38, Sokli. (★, representative carbonatite complexes reviewed in this paper).

Sokli complex

The Sokli carbonatite complex in the eastern Finland was discovered by airborne geophysical survey carried out by the Mining and Steel Company of Rautaruukki Oy. The complex is not directly associated with any alkaline complex, and is rather rare type of carbonatite complexes. The carbonatite body occurs as an oval shape on the map (Fig. 5) and covers an area of about 20 km^2. Topographically it forms a depression surrounded by hills of fenite aureole.

The complex is divided into five geological units (Vartiainen and Paarma 1979): (1) magmatic core, (2) horseshoe-shaped metacarbonatite area, (3) metaphoscorite zone, (4) collar-like transition zone, and (5) fenite aureole. Gravimetric interpretation, together with geological data, indicates the complex is cone-shaped and plunges southward (Fig. 5). The southern part of the fenite aureole is more intensely fenitized, and carbonatite dikes and veins are more numerous than on the northern side.

Exploration has been focused on weathered phosphorus ores. The complicated pyrochlore and

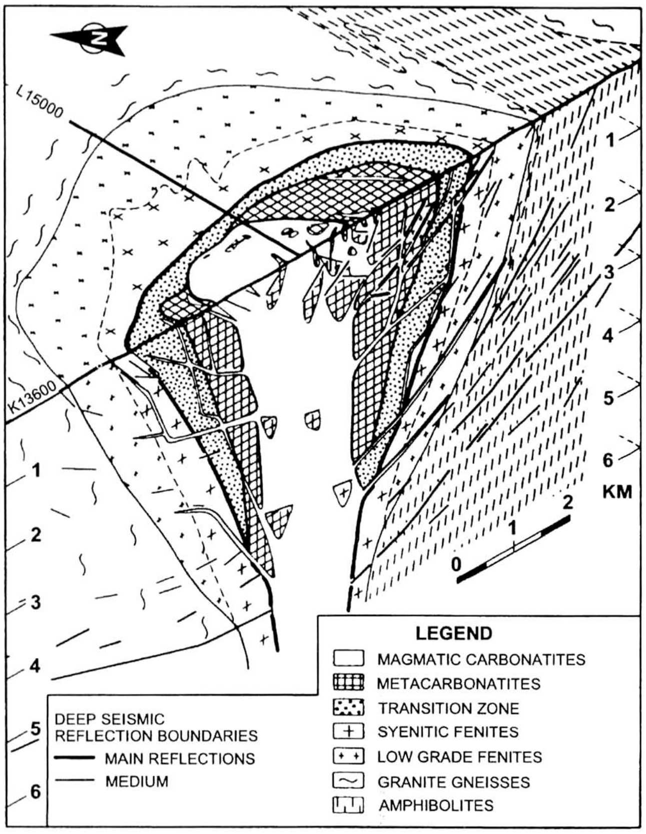

Fig. 5. Schematic cross section of the Sokli carbonatite complex (after Vartiainen and Paarma 1979).

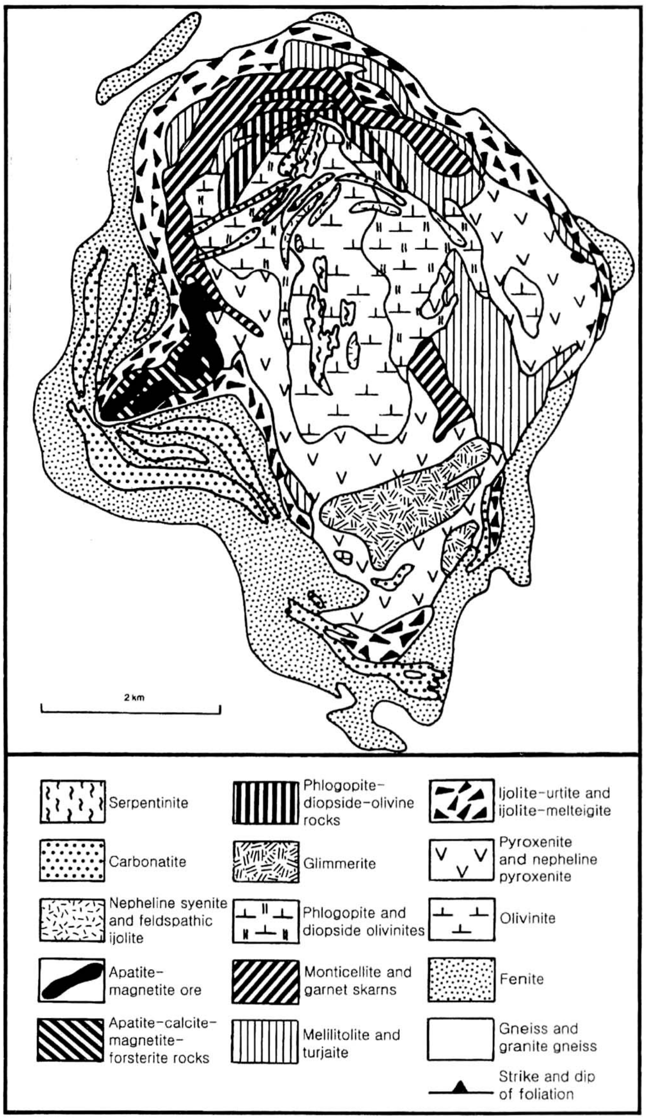

Fig. 6. Geologic map of the Kovdor complex (after Kukharenko *et al.* 1965).

apatite-magnetite mineralizations occur in the deeper part of the massif. The most important prospect explored in the Sokli complex is an apatite-francolite regolith in the western and eastern part of the massif. Francolite is secondary carbonate fluorapatite. The average thickness of the deposit is 25 m with maximum of 72 m. Reserves are believed to be 80 to 100 million tons. The U-Ta-pyrochlore mineralization is related only to early-stage magmatic carbonatites (Fig. 3), but Th-pyrochlore mineralization seems to be related to hydrothermal activity.

Kovdor complex

The Kovdor complex has a drop-like shape in plane and its distributed area is about 55 km^2. It is related to an east-west fracture system and intrudes granite gneisses of Archean age. The complex is a composite, multiphase intrusion with a concentric zonal structure (Fig. 6). The following rock suites have been mapped from the oldest to the youngest: (1) ultramafic rocks (olivinites and pyroxenites), (2) alkaline rocks of an ijolite-melteigite series, (3) melilite rocks, (4) a complex of apatite phoscorite rocks and magnetite ores, (5) carbonatites, and (6) nepheline syenites. Olivinites are located in the central part, and pyroxenites envelop the olivinite body in the central part and western side. Both two rocks are mostly phlogopitized and amphibolized. Phlogopite mined for industrial purpose mostly comes from these rocks, and its individual crystal may reach several meters in diameter.

The youngest suite of rocks includes carbonatite and phoscorite. The latter term is used in Kovdor for a group of forsterite-, calcite-, and phlogopite-bearing apatite-magnetite rocks of cumulative ori-

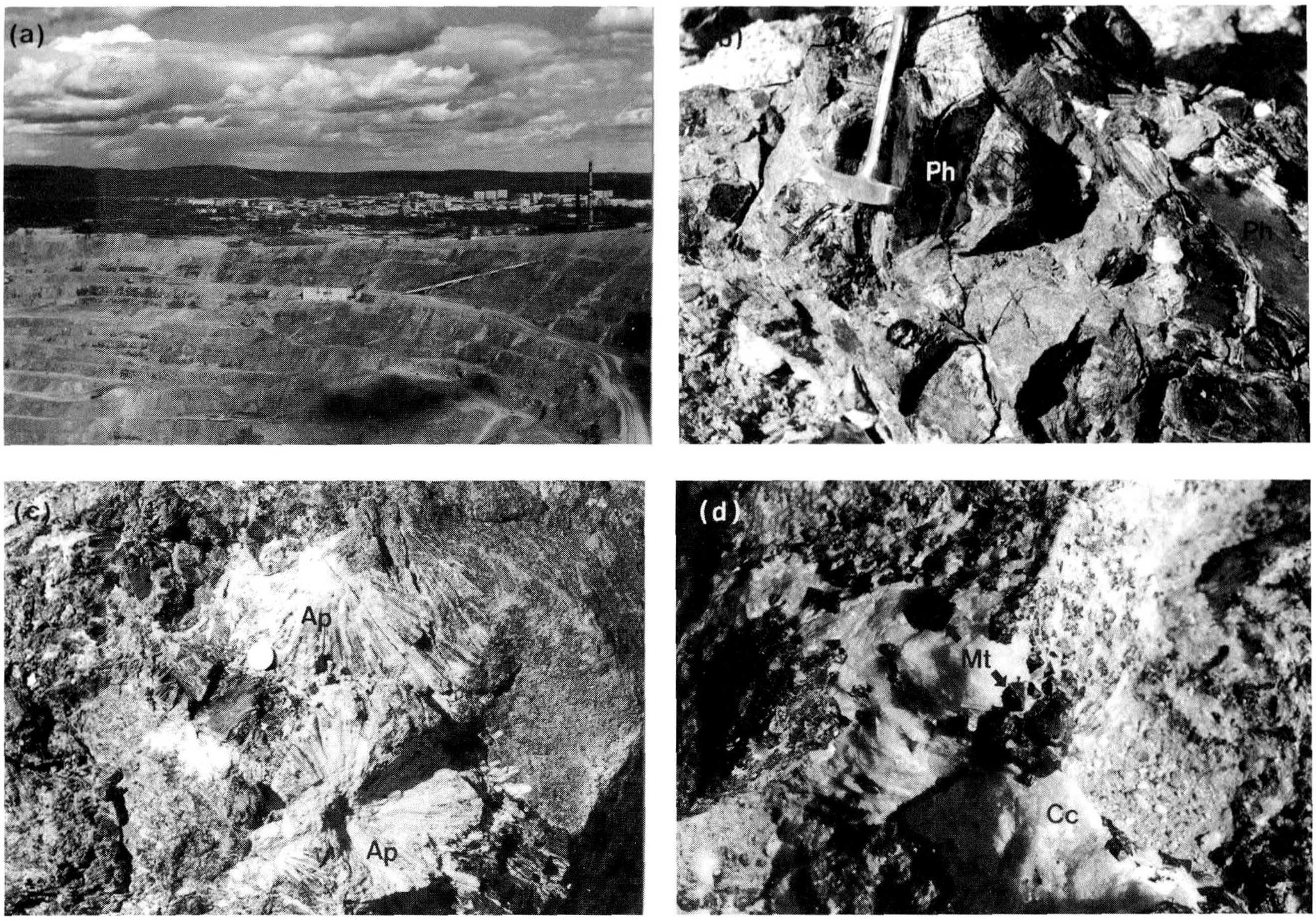

Fig. 7. (a) Photographic view of the Kovdor iron quarry, processing plant, and town Kovdor, (b) phlogopite ores in olivinite host, (c) apatite ores in olivinite host, (d) magnetite ores in calcite vein. Ph=phlogopite, Ap=apatite, Mt=magnetite, Cc=calcite.

gin. Carbonatites and phoscorites form a vertical stock on the contact between pyroxenites and ijolites in the southwestern part of the complex. Several types of carbonatite are recorded and include early diopside-, nepheline-, and forsterite-bearing calcite carbonatite and late-stage dolomite carbonatite.

The stock is currently mined for magnetite, apatite, phlogopite, vermiculite, and baddeleyite (Fig. 7), and has been mapped and studied in great detail (Krasnova and Kopylova 1988). The phlogopite and vermiculite deposits were discovered in 1960 and 1962 when the iron ore commenced from an open pit. An experimental plant for the extraction of apatite and baddeleyite was built in 1964. In that year 100 million tons of iron ore were extracted, and increased to 260 million tons in 1989. Apatite occurs as apatite-forsterite and apatite-forsterite-magnetite rocks, and is produced about 700,000 tons per year as a by-product of magnetite ore (Gorbunov *et al.* 1981). Apatite is widely developed in the strongly weathered upper zone of mine which produce francolite and vermiculite. More information about mineralization can be referred from Ivanyuk and Yakovenchuk (1997).

Khibina (Khibiny) complex

The Khibina alkaline complex, occupying 1,327 km^2, is the second largest one only after the Guli complex in size (Fig. 8). The complex is emplaced into Archean granite gneisses and Proterozoic volcanic-sedimentary rocks along steep outer contacts, which have been traced to a depth of 7 km by geophysical investigation. Galakhov (1975) distinguished several zones in this complex, which correspond to distinct ring and conical intrusions formed by successive phases of intrusion. Eight zones are existed from the periphery to the center: (1) alkaline syenite and nepheline syenite (0.3 km thick); (2) and (3) massive

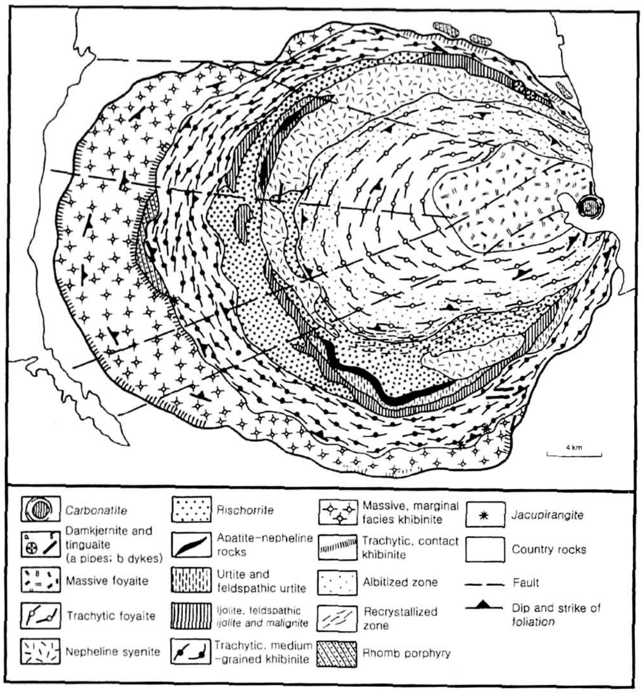

Fig. 8. Geologic map of the Khibina complex (after Zak *et al.* 1972).

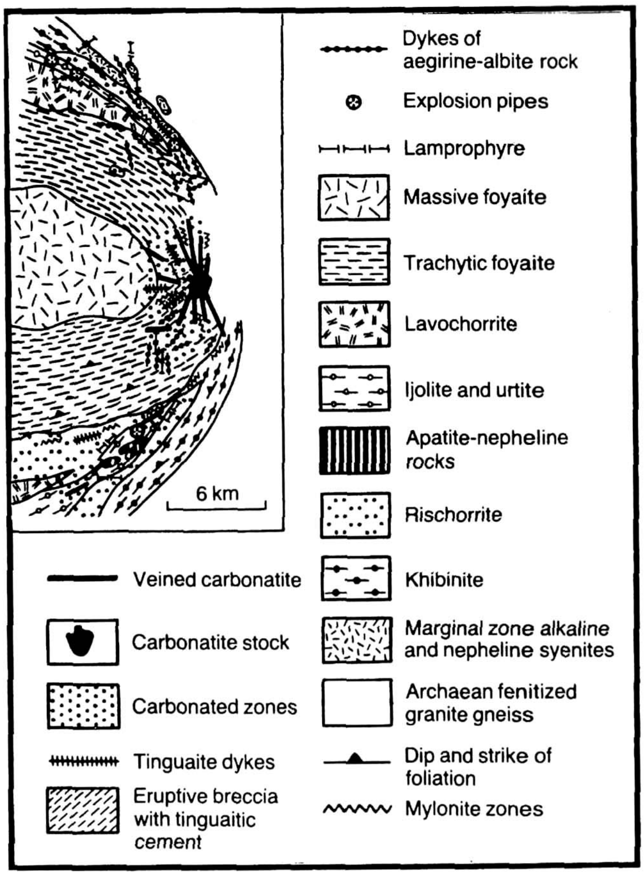

Fig. 9. Carbonatite center at the eastern end of the Khibina complex (after Dudkin *et al.* 1984).

and trachytic khibinites (about 5.5 km thick); (4) rischorrite (biotite-nepheline syenite)-ijolite-urtite-apatite-nepheline-rocks (2 - 3 km); (5) melteigite, ijolite, and urtite; (6) and (7) heterogeneous nepheline syenite and foyaite (3.5 - 4 km); (8) carbonatite.

In the eastern part, carbonatite stockwork with a diameter of about 800 m (Fig. 9) lies at the focus of the multiple layered complexes near the bodies of rischorrite and urtite. The carbonatite is considered to be younger than the principal layered units of the complex. The carbonatite stock displays complicated structure. Multi-stage carbonatite breccias are cut by a stockwork of carbonatites that extend through the central part of the stock. There are a number of formational stages among the carbonatites including (1) biotite-, aegirine-biotite-, and albite-calcite carbonatite, (2) manganiferous calcite-ankerite and siderite carbonatites, and (3) manganiferous siderite and ankerite carbonatites with significant natrolite and dawsonite (Dudkin 1991). The carbonatites are characterized by predominance of Na over K and high contents of Sr, Ba, Mn, F, S, and REEs. More than 80 minerals have been identified in the carbonatites and associated rocks.

The largest igneous apatite deposit in the world is located in the ijolite-urtite part (zone 5) of the complex (Ivanova 1963). The apatite-rich rocks have been classified into three groups, such as pre-ore, ore, and post-ore. The principal phosphate-ore deposits are found in group two where the apatite-rich rocks occur in the hanging wall of an ijolite-urtite intrusion. The resources have been reported to total 4,000 million tons averaging 15% P_2O_5 (Ilyin 1989). Prospect began in 1929 and five mines are still in production both underground and surface mining. Among them, central open pit accounts for half of production.

Turiy Peninsula complex

The alkaline complex of the Turiy Peninsula consists of several subvolcanic intrusions and associated dikes and veins. The four main intrusive bodies include the Central Complex (28 km^2), the Southern Complex (13 km^2), the Eastern Complex (10 km^2), and the Kuznavolok Complex (1.3 km^2) (Fig. 10). The Central Complex is the largest one and consists

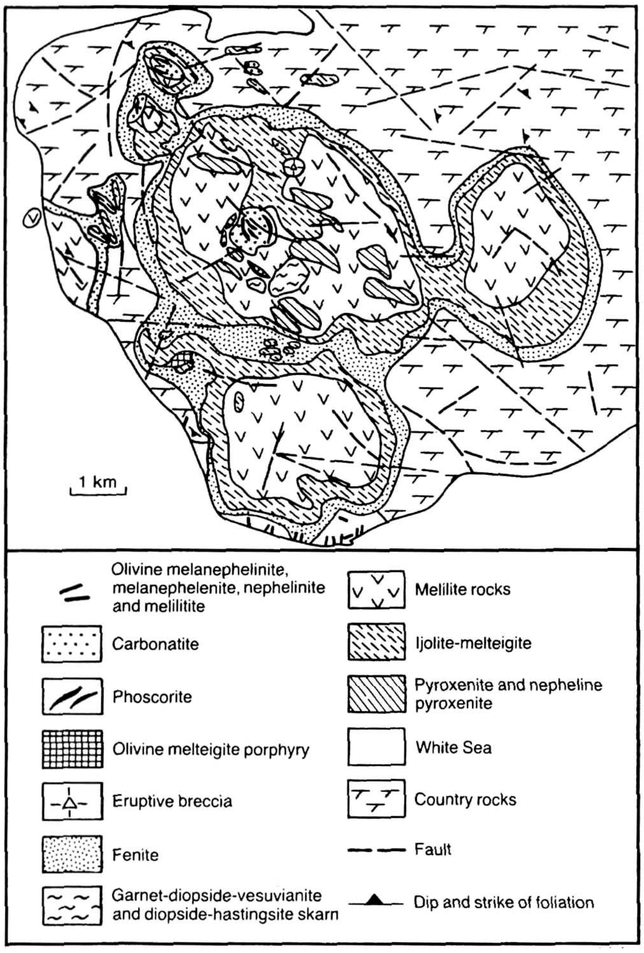

Fig. 10. Geologic map of the alkaline complex of the Turiy Peninsula (after Bulakh and Ivannikov 1984).

of many intrusive bodies of complex form. The intrusions are composed, from the oldest to the youngest rocks, of (1) ultramafic rocks (olivinite and clinopyroxenite), (2) feldpathoidal mafic rocks (melteigite, ijolite, and ijolite-urtite), (3) melilite-bearing rocks, (4) eruptive breccia of ijolite porphyry, (5) phoscorite and carbonatite, and (6) dike rocks. The complicated zonal structure of intrusions indicates that initial single intrusive bodies were subsequently transformed into confocal intrusions with central stocks of carbonatite and phoscorite.

Carbonatites are divided into calcite, calcite-dolomite, and dolomite varieties with ore phoscorite. The calcite carbonatites can be further divided into forsterite-, phlogopite-, biotite-, diopside-, aegirine-, melilite-, and monticellite-bearing varieties. Two varieties of calcite-dolomite carbonatite occur; one consisting mainly of carbonate minerals, and the other containing amphibole, phlogopite, and magnetite as well as carbonate minerals. The dolomite carbonatite contains phlogopite, magnetite, and apatite. Vertical pipe-like body of carbonatite and phoscorite, consisting of intersecting veins of carbonatite with relics of altered ultramafic, melilite-bearing, and other alkaline rocks, is distributed in the inner part of the Central Complex.

Phoscorite, or so called "ore rock", is enriched in magnetite and contains apatite (5 to 60%) and calcite (10 to 50%). Both carbonatite and phoscorite are associated with Nb, Ta, Zr, and REE mineralization, with pyrochlore concentrating high field strength elements (HFSE), and apatite and calcite enriched in REE (Bell *et al.*, 1996).

Sallanlatvi (Sallanlatvinskii) complex

The complex is a concentrically zoned intrusion occupying about 9 km^2. It comprises three major zones, which decrease in age from the periphery towards the center and are composed respectively of melteigite, urtite-ijolite, and carbonatite (Fig. 11). The width of the peripheral zone varies from 100-200 m in the north to 600-800 m in the west. The melteigites are fine-grained and characterized by a fluidal layered structure, which dips towards the center of the complex. These rocks are gradually replaced by banded ijolites with nests and vein-like bodies of urtites.

Carbonatites make up the central part of the massif and also display a zonal structure. The narrower outer ring is composed of a series of closely spaced, steeply-dipping veins and irregular, possibly lens-shaped bodies of calcite carbonatite with relics of silicate rocks which have been much replaced by mica. The central part of the carbonatite zone is composed of dolomite-ankerite or dolomite-siderite carbonatites. Calcite carbonatites also form independent veins in the ijolite-urtite and ijolite-melteigite zone of the massif. The calcite carbonatites of the ring-shaped zone and veins contain 75-80% calcite together with natrolite, cancrinite, phlogopite, aegirine-diopside, and secondary chlorite. The dolomite-ankerite carbonatites include dolomite, rhodochrosite, and barite in the weathered crust. They are also enriched in hematite.

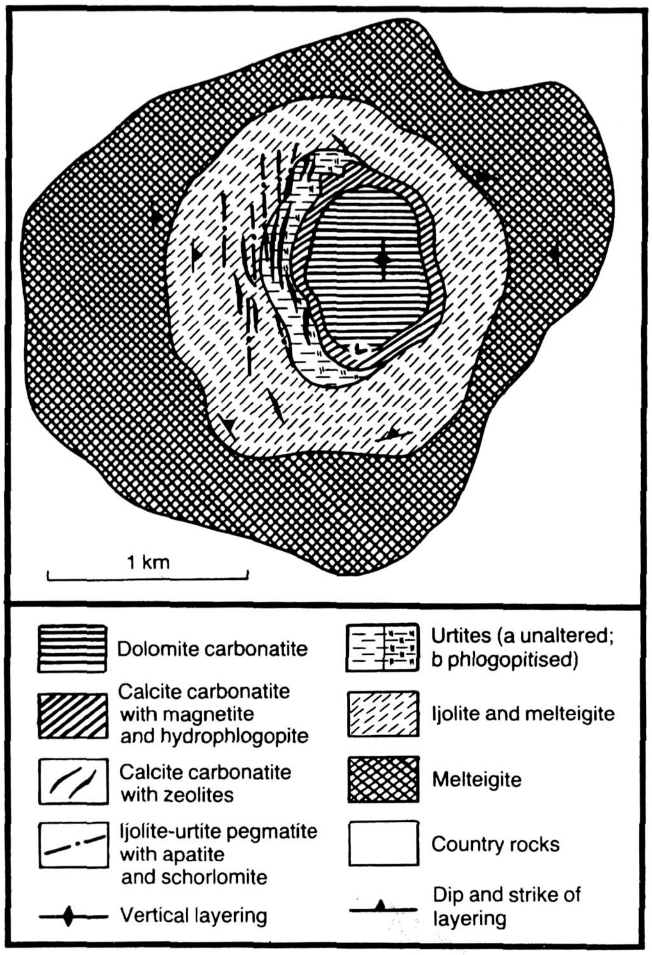

Fig. 11. Geologic map of the Sallanlatvi complex (after Kukharenko *et al.* 1965).

Apatite, barite, and rare earth minerals are concentrated in the weathered crust. Apatite ore in the ijolites and urtites reaches 10-15%. Titanomagnetite is concentrated up to 9% in the pyroxenites (Kukharenko *et al.* 1965).

Vuoriyarvi complex

This complex occurs within the Archean gneisses and migmatites. The intrusion (about 20 km^2) displays an elliptical shape and a concentrically zoned structure (Fig. 12). The central and largest part (12 km^2) is composed of clinopyroxenites containing individual blocks and lenses of olivinite and olivine-pyroxene rocks. The peripheral zone is made up of melteigites and ijolites with schorlomite. A stockwork of phoscorites, which contain calcite and dolomite, is situated in the eastern part of the massif.

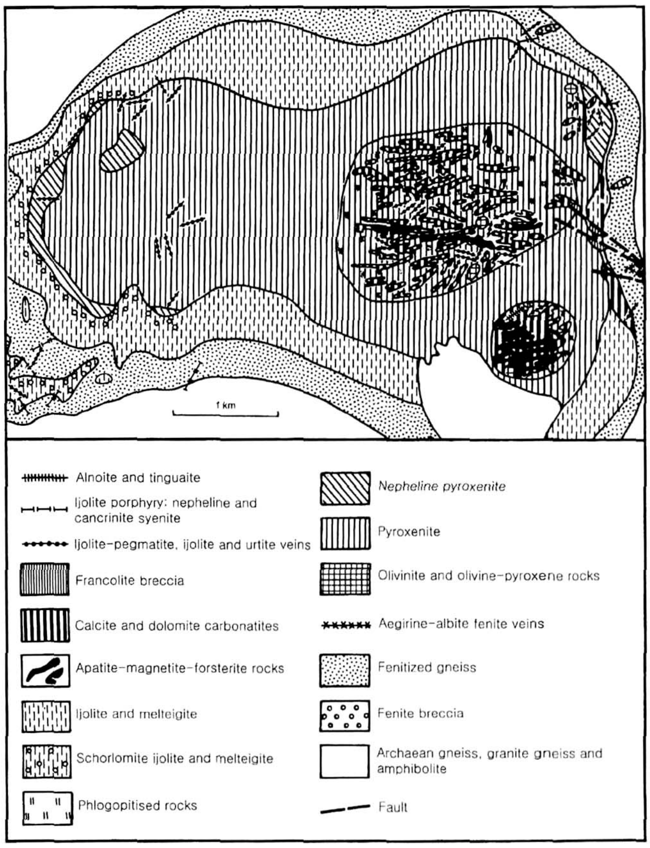

Fig. 12. Geologic map of the Vuoriyarvi complex (after Kukharenko *et al.* 1965).

Carbonatites are widely distributed through the complex, mainly as sheets and veins, but subordinately as a stock-like body towards the eastern margin. They are spatially and genetically associated with magnetite-forsterite-apatite rocks (phoscorites), which form a series of thick bodies elongated along an east-west direction. Early and late carbonatites have been distinguished (Kapustin 1976), and the former comprises about 90% of the carbonatites.

Both apatite phoscorites and carbonatites contain a suite of rare earth and other accessory minerals. Forsterite-magnetite, apatite-magnetite, and calcite-magnetite ores with subordinate minerals including baddeleyite, tetraferriphlogopite, pyrrhotite, melilite, and diopside are developed in the complex.

Summary

Apart from their geologic interest, the carbonatite complexes are of major economic importance. The carbonatite complexes of the Kola-Karelia province in Arctic region include a great diversity of rock types, but they are always associated with valuable economic mineralizations. They are significant repositories of certain metals, indeed the only source of some of them, including Nb, REEs, Cu, V, U, Th, phosphate, vermiculite, bauxite, and raw materials for the manufacture of ceramics. Thus, the economic potential of these rocks is now widely appreciated.

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