Petrology of the Salmagora Ultramafic-Alkaline-Carbonatite-Complex (UACC), Kola Alkaline Province, NW Russia

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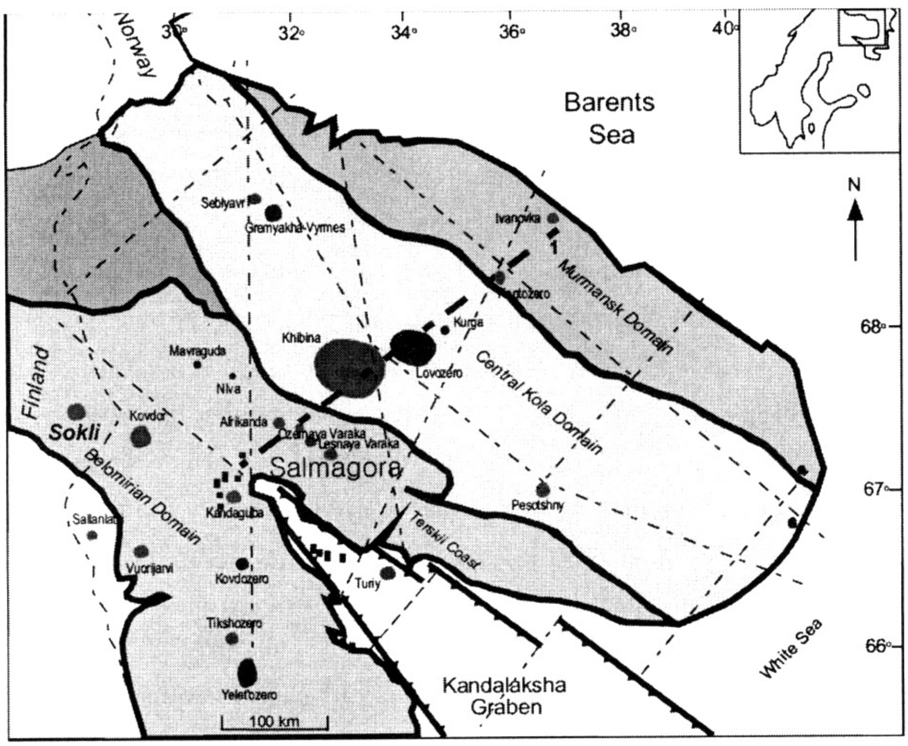
ABSTRACT

The Salmagora complex, located in the southern part of the Kola Peninsula, NW Russia, consists of the sequence of rocks (dunite - pyroxenite - melilitolite - melteigite - ijolite - urtite - carbonatite) that show a concentric inward zoning. Occurrences and petrographic features of all alkaline rock facies in the complex suggest that the fractional crystallization accompanying a physical accumulation was the major magmatic process responsible for the formation of various rock series and the concentric zonation. The highest Al content in magnetites is found in the dunite magnetite, which implies that the dunite was crystallized firstly in the highest temperature condition from the Salmagora ultramafic-alkaline magma system. The Al content of magnetite continuously decreases toward the later-stage magnetites. This is consistent with the assumption that all Salmagora rock units may represent a continuum of ultramafic-alkaline magma system with time.

Keywords : Salmagora complex, Ultramafic-alkaline-carbonatite-complex (UACC), Kola Alkaline Province, fractionation, accumulation

Introduction

The Kola Alkaline Province (KAP), located between ~66-70°N and ~30-42°E in the northwestern Russia, bounded by the White Sea and Kandalaksha Graben to the south, and the Barents Sea to the north, is underlain by Archaean gneisses and granite-gneisses (Fig. 1). It contains about 25 Paleozoic alkaline complexes whose emplacement was largely controlled by pre-existing, reactivated, lithospheric fractures including the Kontozero Graben and Kandalaksha Deep Fracture Zone (Kogarko et al., 1995). The alkaline complexes range from 1 to 40 km in diameter, and from dunite-pyroxenite to ijolite-carbonatite in composition. Most complexes consist of sub-vertical pipes and stocks, commonly containing ring dikes or cone sheet intrusions. Geochronological studies suggest that the KAP was formed during the Upper Devonian (360-380 Ma; Kramm et al., 1993; Amelin and Zaitsev, 2002).



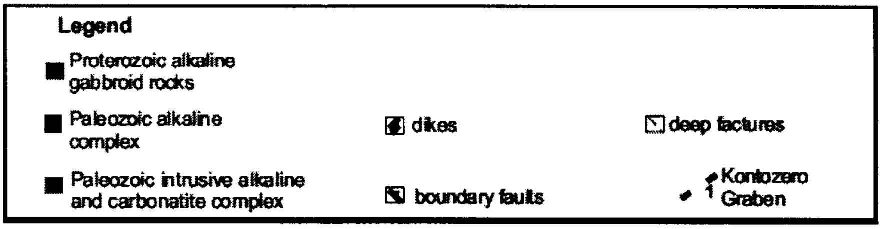


Fig. 1. Map of the Kola Alkaline Province showing the locations of the Proterozoic and Paleozoic alkaline intrusions (Modifeid from Bell et al., 1996).

The poorly exposed Salmagora complex (26 km2 at the surface) located in the southern part of the Kola Peninsula is hosted by Archaean gneiss, and consists of a series of concentric ultramafic, alkaline and carbonatitic rocks. It was discovered in 1949 and subsequently studied for 15 years (Kukharenko et al., 1965). The age of the Salmagora intrusion was estimated to be 375 Ma using the U-He method for garnet from ijolite (Kukharenko et al., 1965). This is consistent with many age determinations (360-380 Ma) obtained by Kramm et al (1993) for other Paleozoic alkaline complexes in the KAP. New data on the geology of the intrusion and associated mineralization have been obtained from recent drilling to explore the apatite and perovskite ores. As a result, a revised geological map of the Salmagora complex (Fig. 2) has been made by Korobeinikov et al. (1998). However, their work was mainly concentrated on the copper-sulphide mineralization, and the occurrence and genetic relation among the rock facies are still poorly understood. In this paper, we present systematic mineralogical and whole-rock geochemical data to understand the characteristics and genesis of the Salmagora complex.

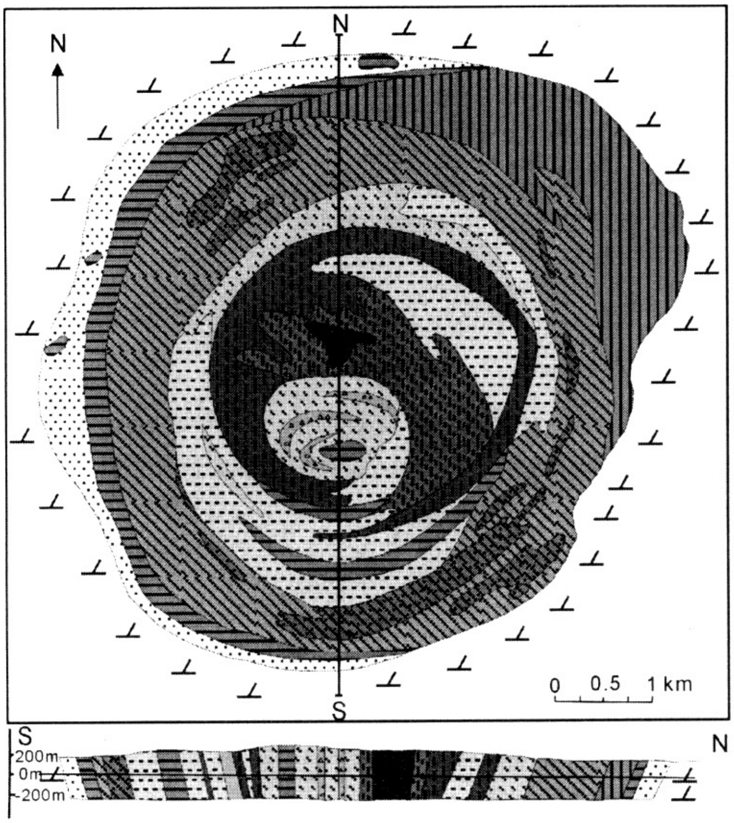


Fig. 2. Geologic map and cross-section of the Salmagora complex (Korobeinikov et al., 1998).

Carbonatite

Sulfide-, Ap-rich Melteigite

Coarse-grained Ijolite and Urtite

Fine, medium-grained Ijolite

Melteigite

Melilitolite

Pyroxenite

Pyroxene Peridotite (Werhlite)

Dunite

Pv-, Mt-rich Dunite

Fenite

Gneiss

Petrography of the Salamagora complex

We observed 140 thin sections from 14 drill holes (up to 350 m) of the Salmagora complex, and the representative 36 sections have been intensively observed under microscope and counted for modal analysis (2,000 counts per section, Table 1). Mineral chemistries of major and accessory minerals were obtained from 52 thin sections by electron probe macro-analyzes (CAMECA SX 50) at Korea Basic Science Institute. The nomenclature of the Salmagora rocks has been revised according to the IUGS classification of igneous rocks (Le Maitre, 1989), and the melilitolite classification of Dunworth and Bell (1998).

Table. 1. Modal mineralogy of the typical rock types of the Salmagora complex (sample number means core number-depth in meter scale).

Sample	11-9	11-22	31-5	31-3	10-9	33-22	10-10	10-2	15-3
Grain size	coarse	fine	medium	coarse	fine	coarse	fine	coarse	fine
Rock type	Dunite		Pyroxenite		Ultra-melilitolite		Melteigite	Ijolite	
Olivine	83.5	69.6							
Pyroxene			71.3	81.1	3.4		57.2	58.2	45.2
Nepheline			0.1				11.2	30.8	38.2
Phlogopite		0.8	2.9	1	3.3	1.8	17.8	2	2.7
Magnetite	12.7	27.7	12	0.3	8.5	0.7	11.5	2.9	11.6
Melilite				11.9	82.5	83.4			
Garnet			12.4					0.4	
Sphene			1.1	3.3					2.2
Perovskite	3.7	1.9			2.1	0.1	2.1	5.5	
Apatite									
Calcite						6.7			
Sulfide									
Sericite						7.2			

Dunite forming a ring dike between pyroxenite and melilitolite-ijolite is fine- to coarse-grained rock consisting of modal olivine (50-90 vol%; Fo85-90), titaniferrous magnetite (10-25%), perovskite (1-5 vol%), augite (0-2 vol%) and phlogopite (0-5 vol%), Apatite, chromite, spinel and amphibole occur as accessory mineral phases.

Pyroxenite is fine- to coarse-grained rock occurring at the outermost zone in the western part of the complex, and at discontinuous zones within melilitolite in the inner part of the complex. Pyroxenite is composed mainly of augite and aegirine-augite (40-90 vol%) with subordinate olivine (0-27 vol%), phlogopite (1-28 vol%), magnetite (1-15 vol%). melilite (0-10 vol%), garnet (0-12 vol%), sphene (0-7 vol%) and calcite (0-7 vol%).

Perovskite and amphibole occur as accessory mineral phases. Two types of magnetites are distinduished; titaniferous magnetite (7-17 wt% of TiO_2) and pure magnetite (0-1 wt% of TiO_2).

Ultra-melilitolite (melilite>65%) and melilitolite are medium- to coarse-grained rocks consisting mainly of varying amounts of melilite, clinopyroxene (augite, diopside and aegirine-augite) and phlogopite. Melilitolites of the Salmagora complex have similar compositions of typical 'tujaite' (10 < melilite < 65%, most abundant defining mineral < 10% is nepheline; Dunworth and Bell, 1998).

Ijolite and melteigite (and a little urtite) occupying the central part of the complex are fine- to coarse-grained rocks that consist mainly of clinopyroxene and nepheline with variable amouts of magnetite. They contain veins formed by magnetite or calcite with aegirine, mica and sulfide. The coarse-grained melteigite contains sub-economic copper-sulphide minerals and is characterized by the densest system of such veins (Korobeinikov et al., 1998).

Carbonatite occurs as a stockwork of veins cross-cutting the ijolite-melteigite rock series. The carbonatite veins are composed of calcite with lesser amounts of ankerite, diopside and aegirine-augite, phlogopite, apatite, magnetite, perovskite, pyrrhotite, chalcopyrite and accessory zircon.

Magnetite compostion as a tracer of evolution

The chemical composition of titaniferrous magnetite (or spinel) can be used as a tracer of evolution indicating various conditions related to the formation and differentiation of the Salmagora complex, because magnetite is ubiquitously present in all rock facies and shows very wide compositional range (Fig. 3). The Al content is one of the most important values in distinguishing magnetite and spinel compositions from different groups of rock facies. The Al content and Fe^{2+}# (defined as $100Fe^{2+}/(Fe^{2+}+Mg)$) are inversely correlated in all rock facies. The magnetite in the dunite contain the highest proportions of spinel (up to 0.6 Alapfu) and the lowest Fe^{2+}#, and thus easily distinguished from the other varieties. The compositions of magnetites from the pyroxenite and melilitolite mostly overlap in Fe^{2+}# and Al space, suggesting a possibility of their close petrogenetic relationship.

Magnetites from the melteigite and ijolite have higher Fe2+# and lower Al content than those from the pyroxenite and melilitolite.

Considering higher formation temperature of spinel among oxide group minerals, the Al content of oxide minerals is likely to be related to the magmatic differentiation. And thus we could presume the intrusive sequence based on the Al content of magnetite in a given rock facies. In the case of Salmagora complex, the dunite seems to have been formed firstly in the highest temperature condition, and melteigite-ijolite group formed in the lowest temperature. Though the magnetite compositions of carbonatite are not shown in Fig. 3, the occurrence of carbonatite which crops out as lots of veinlets cutting melteigite-ijolite group in the central part indicates that carbonatite should be the final product in the Salmagora complex whether they were formed by mineral fractionation or liquid immiscibility.

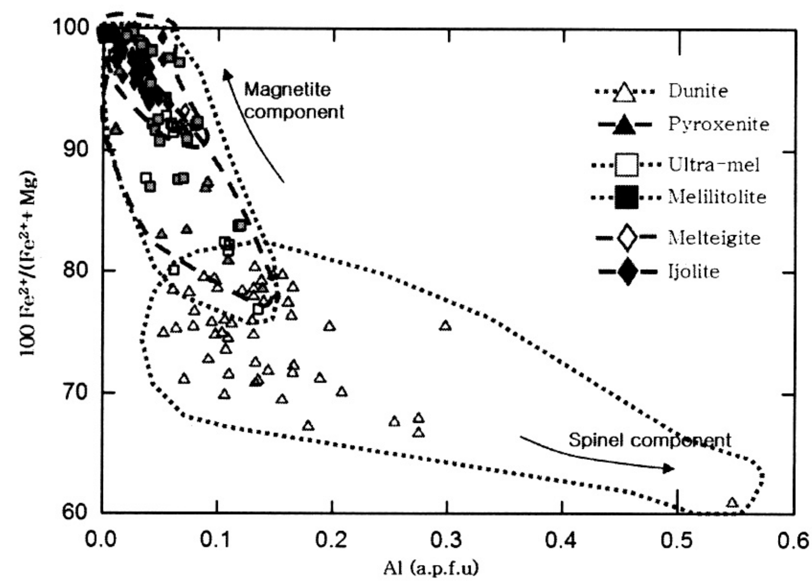


Fig. 3. Fe-Ti oxide compositions from the Salmagora rocks. (a.p.f.u = atoms per formula units, cation = 3)

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