Available online at www.sciencedirect.com

SCIENCE DIRECT®

Lithos 83 (2005) 371–393

LITHOS

www.elsevier.com/locate/lithos

Emplacement processes and cooling history of layered cyclic unit II-7 from the Lovozero alkaline massif (Kola Peninsula, Russia)

Olivier Féménias[a,*], Nicolas Coussaert[b], Stéphane Brassinnes[a], Daniel Demaiffe[a]

[a]*Laboratoire de Géochimie Isotopique et Géodynamique Chimique, DSTE, Université Libre de Bruxelles (CP 160/02), 50, av. Roosevelt, B-1050 Bruxelles, Belgium*

[b]*Unité de Minéralogie et Géochimie, Musée Royal de l'Afrique Centrale, B-3080 Tervuren, Belgium*

Received 9 January 2004; accepted 18 February 2005
Available online 25 April 2005

Abstract

The Lovozero alkaline massif (Kola Peninsula, Russia) is composed of three major units. The central unit (80% of the volume) comprises numerous well developed layers composed, from bottom to roof, of an urtite–juvite–foyaite–lujavrite continuous lithological sequence (ijolite–foid-bearing alkali feldspar syenite in IUGS nomenclature). The mode of emplacement of the massif and the mechanism of formation of the layering are still under debate. Petrological, mineralogical (two stages of crystallisation) and structural evidence from the detailed analysis of one of these layers (unit II-7) is interpreted in terms of both mechanical (magmatic to sub-solidus, non-coaxial deformation) and thermal differentiation operating on a crystal-laden (alkali feldspar, high *T* nepheline, aegirine-augite) material of foyaitic composition. Textural and mineralogical data suggest that a sheet of foiditic magma intruded into solidified earlier units of the Lovozero layered sequence and acquired a sill-like structure on cooling.

Keywords: Lovozero alkaline massif; Unit II-7; Layered rocks; Sill; Agpaitic syenites

1. Introduction

Since the pioneering work of Wager and co-workers on the Skaergaard intrusion (Wager and Deer, 1939; Wager and Brown, 1968), the origin of layering, and more particularly of cyclic layering, has been hotly debated and many mechanisms have been proposed (see review books edited by Parsons, 1987 and Cawthorn, 1996). Most of the proposed mechanisms concern ultramafic–mafic layered intrusions (i.e. Skaergaard, Bushveld, Stillwater…) that involve classical mineral phases (olivine, ortho- and clino-pyroxene, plagioclase, oxides…). Highly differentiated alkaline to peralkaline layered intrusions are much less common and are characterised by a specific mineralogy (alkali feldspar, foids, sodic clinopyroxene and/or amphibole, with rare accessory minerals of unusual composition…). The Lovozero (Kola Pen-

* Corresponding author. Tel.: +32 2 6502254; fax: +32 2 6502226.
E-mail address: ofemenia@ulb.ac.be (O. Féménias).

0024-4937/$ - see front matter
doi:10.1016/j.lithos.2005.03.012

insula, Russia; i.e. Gerasimovsky et al., 1966) and Ilimaussaq (Greenland; Larsen and Sorensen, 1987) intrusions are the type-examples of such layered alkaline complexes.

In many papers related to layered intrusions, there are almost no structural nor micro-fabric data published on the layered rocks. However, recent studies in France have developed a micro-fabric approach on both the kinematic analysis of magmatic rocks (Nicolas, 1992; Bouchez et al., 1992) and the experimental aspects of shape fabrics and orientation (Fernandez et al., 1983; Ildefonse and Fernandez, 1988; Ildefonse et al., 1992; Arbaret et al., 1996, 2001).

The Lovozero massif constitutes an exceptional opportunity to study the mode of emplacement and the crystallisation history of an agpaitic magma. Agpaitic alkaline rocks are rare nepheline syenites characterised by high (>1.2) molar (Na+K)/Al ratio and by the presence of complex Zr- and Ti-silicate minerals (Sørensen, 1997). This paper is focused on one cyclic unit (called the "rhythm II-7") from the well-layered stratiform central part of the Lovozero massif. Detailed petrological, mineralogical and micro-fabric data were obtained on this cyclic unit to better constrain the crystallisation and cooling history, as well as the development of the layering and of the magmatic fabric within the various lithologies of the cyclic unit ("rhythm") II-7.

2. Geological setting and structure of the Lovozero massif

The alkaline Lovozero massif is, together with the nearby Khibina (i.e. Kogarko et al., 1995) and the Ilimaussaq layered complex of Greenland (Larsen and Sorensen, 1987), one of the world's largest occurrences of agpaitic nepheline syenite intrusions. It intruded into the Archean to Paleoproterozoic Central Kola Composite Terrane (Kogarko et al., 1995) (Fig. 1a) and was emplaced at 370 ± 7 Ma (whole rock Rb–Sr isochron, Kramm and Kogarko, 1994). Khibina and Lovozero massifs were emplaced in the Proterozoic basement essentially composed of Central Kola trondhjemite–tonalite–granodiorite (TTG) series and various biotite-, hornblende- and pyroxene-gneisses, migmatites and amphibolites of the "basement complex".

The general geology, mineralogy and geochemistry of Lovozero have been extensively described by Vlasov et al. (1959), Gerasimovsky et al. (1966), Arzamastsev (1994, 1995), Khomyakov (1995) and Pekov (2000). Previous studies and reports (i.e. Kogarko et al., 1995; Arzamastsev et al., 2000 and references below) describe Lovozero as a multi-intrusion complex, interpreted as an asymmetric, stratiform and laccolith-like body. Exposed over a 650 km^2 area between the Umbozero and Lovozero lakes (Fig. 1b), the Lovozero complex is composed of three major intrusive phases:

1) The first phase (macro-unit I on Fig. 1b) is composed of poikilitic feldspathoid (nepheline, sodalite and nosean) syenites representing less than 5% of the total volume. This macro-unit constitutes the lower part of the massif, as recognised by drilling, and also tabular sheet-like bodies in the layered central unit. The field relations of these bodies are debatable (Osokin, 1980): for example, do they represent elongated macro-xenoliths or do they belong to the layering? Magmatic breccia containing xenoliths of syenite of this first phase have been observed at the base of the second major phase.
2) The second phase (macro-unit II on Fig. 1b) is a well-layered differentiated complex that consists of numerous units (Atamanov et al., 1961 or Gerasimovsky et al., 1966) (Fig. 2a). Arzamastsev (1994) has described a schematic idealised cyclic unit: it consists of an *urtite–juvite–foyaite–lujavrite* continuous series (Fig. 2b). Not all of the layered units are complete; the most complete ones generally occur in the upper part of the layered sequence whereas, in the central and lower parts, lujavritic and foyaitic layers predominate while urtites are generally lacking. According to the IUGS classification (Le Maitre, 2002), these rocks should be named ijolite for urtite, foid syenite for foyaite and foid-bearing alkali feldspar syenite for lujavrite. The layered units have been grouped in 5 series (Atamanov et al., 1961) on the basis of marker horizons (mainly urtite) rich in apatite and/or loparite, from the upper series I to the lower series V that has been reached by drilling at a depth of 1700 m (Fig. 2a). The number of units in each series is