Available online at www.sciencedirect.com
ScienceDirect
Lithos 95 (2007) 19–42
LITHOS
www.elsevier.com/locate/lithos

Accessory and rock forming minerals monitoring the evolution of zoned mafic–ultramafic complexes in the Central Ural Mountains

J. Krause [a,b,*], G.E. Brügmann [b], E.V. Pushkarev [c]

[a] Institut für Geowissenschaften, Universität Mainz, Becherweg 21, D-55099 Mainz, Germany
[b] Max-Planck-Institut für Chemie, Becherweg 27, D-55020 Mainz, Germany
[c] Institute of Geology and Geochemistry, Russ. Acad. Sciences, 620151 Ekaterinburg, Russia

Received 5 December 2005; accepted 15 July 2006
Available online 4 October 2006

Abstract

This study describes major and trace element compositions of accessory and rock forming minerals from three Uralian–Alaskan-type complexes in the Ural Mountains (Kytlym, Svetley Bor, Nizhnii Tagil) for the purpose of constraining the origin, evolution and composition of their parental melts. The mafic–ultramafic complexes in the Urals are aligned along a narrow, 900 km long belt. They consist of a central dunite body grading outward into clinopyroxenite and gabbro lithologies. Several of these dunite bodies have chromitites with platinum group element mineralization.

High Fo contents in olivine (Fo 92–93) and high Cr/(Cr+Al) in spinel (0.67–0.84) suggest a MgO-rich (>15 wt.%) and Al_2O_3-poor ultramafic parental magma. During its early stages the magma crystallized dominantly olivine, spinel and clinopyroxene forming cumulates of dunite, wehrlite and clinopyroxenite. This stage is monitored by a common decrease in the MgO content in olivine (Fo 93–86) and the Cr/(Cr+Al) value of coexisting accessory chromite (0.81–0.70). Subsequently, at subsolidus conditions, the chromite equilibrated with the surrounding silicates producing Fe-rich spinel while Al-rich spinel exsolved chromian picotite and chromian titanomagnetite. This generated the wide compositional ranges typical for spinel from Uralian–Alaskan-type complexes world wide.

Laser ablation analyses (LA-ICPMS) reveal that clinopyroxene from dunites and clinopyroxenite from all three complexes have similar REE patterns with an enrichment of LREE (0.5–5.2 prim. mantle) and other highly incompatible elements (U, Th, Ba, Rb) relative to the HREE (0.25–2.0 prim. mantle). This large concentration range implies the extensive crystallization of olivine and clinopyroxene together with spinel from a continuously replenished, tapped and crystallizing magma chamber. Final crystallization of the melt in the pore spaces of the cooling cumulate pile explains the large variation in REE concentrations on the scale of a thin section, the REE-rich rims on zoned clinopyroxene phenocrysts (e.g. $La_{Rim}/La_{Core} \sim 2$), and the formation of interstitial clinopyroxene with similar REE enrichment.

Trace element patterns of the parental melt inferred from clinopyroxene analyses show negative anomalies for Ti, Zr, Hf, and a positive anomaly for Sr. These imply a subduction related geotectonic setting for the Uralian zoned mafic–ultramafic complexes. Ankaramites share many petrological and geochemical features with these complexes and could represent the parental melts of this class of mafic–ultramafic intrusions.

Diopside from chromitites and cross cutting diopside veins in dunite has similar trace element patterns with LREE/HREE ratios (e.g. La/Lu=5–60) much higher than those in diopside from all other lithologies. We suggest that the chromitites formed at high

* Corresponding author. Institut für Geowissenschaften, Universität Mainz, Becherweg 21, D-55099 Mainz, Germany. Fax: +49 6131 371051.
E-mail address: krause@mpch-mainz.mpg.de (J. Krause).

doi:10.1016/j.lithos.2006.07.018

temperatures (800–900 °C) during the waning stages of solidification as a result of the interaction of an incompatible element-rich melt or fluid with the dunite cumulates.

Keywords: Uralian–Alaskan-type complex; Ural Mountains; Spinel; Chromitite; Parental melt; Ankaramites

1. Introduction

Uralian–Alaskan-type zoned mafic–ultramafic complexes are a class of intrusions which are distinct with regard to their tectonic setting, internal structure and petrology (Taylor and Noble, 1960; Noble and Taylor, 1960; Himmelberg et al., 1986; Himmelberg and Loney, 1995). The complexes are known from convergent margin settings, for example the Ural Mountains (Noble and Taylor, 1960; Taylor, 1967), the Cordillera of Alaska and British Columbia (Findlay, 1969; Clark, 1980; Himmelberg et al., 1986; Nixon et al., 1990; Himmelberg and Loney, 1995), and on Northern Kamchatka, Russia (Batanova and Astrakhantsev, 1992; Batanova and Astrakhantsev, 1994). The intrusions are distributed along narrow belts often several hundreds of kilometres long. Their classical distinctive geologic and petrographic feature is a zonal distribution of mafic and ultramafic rocks. Often a central dunite body grades outward into wehrlite, clinopyroxenite and gabbroic lithologies. Many of these complexes host a mineralization of platinum group minerals (PGM) locally of economic importance.

In the Ural Mountains 15 Uralian–Alaskan-type mafic–ultramafic complexes define a linear belt along the 60-th meridian, which is about 900 km long (Fig. 1a). Due to the occurrence of economic platinum deposits associated with these complexes this chain is called the "Ural platinum belt" (UPB). This is a narrow belt in the middle and southern part of the Tagil–Magnitogorsk zone consisting of island arc related volcanic rocks and plutons in tectonic contact with ophiolite fragments and different types of mafic to ultramafic intrusive complexes.

For the Uralian–Alaskan-type complexes of the UPB important geological and geochemical features such as the age and mechanism of emplacement or the composition and evolution of their parental melts are poorly understood. In addition the origin of the chromitites, sources for PGM placer deposits, is not well known.

The composition of minerals, rock forming and accessory phases, is controlled by parameters such as pressure, temperature and the composition of the parental magma. This is why the chemical composition of minerals, such as chromian spinel, give important information regarding the degree of partial melting in the mantle or the evolution of mantle melts during their rise to the surface (e.g. Hill and Roeder, 1974; Sack and Ghiorso, 1991a,b; Van der Veen and Maaskant, 1995). The compositional variations of chromian spinel can be further used to discriminate among different tectonic settings (e.g. Irvine, 1967; Roeder, 1994; Cookenboo et al., 1997; Zhou et al., 1997; Lee, 1999; Barnes and Roeder, 2001). However, one has to keep in mind that the composition of chromian spinel can be easily re-equilibrated at subsolidus conditions.

Trace element concentrations, for example those of the REE, play a key role in monitoring the fractionation of silicate melts. In particular in cumulate rocks, where there is no direct access to the melt composition, the trace element distribution in minerals provides powerful clues to the origin and evolution of the parental melts. For example, melt compositions can be calculated with experimentally determined mineral–melt partition coefficients and calculated trace element patterns can be compared with those of natural samples from different tectonic environments (e.g. McKenzie and O'Nions, 1991; Hart and Dunn, 1993; Ionov et al., 1997; Bédard, 2001; Ionov et al., 2002).

In this study we present new major and trace element data from rocks and minerals from three Uralian–Alaskan-type complexes in the middle and southern Urals. The comparison of the chemical composition of olivine and chromian spinel from the Urals with data from other localities indicates that they are unique intrusions having a characteristic spinel chemistry. Laser-ICPMS analyses of trace element concentrations in clinopyroxene are used to calculate the melt composition. The mineral compositions monitor the evolution of the parental magmas and decipher differences between the complexes. The data also show that ankaramites could be the parental magmas of Uralian–Alaskan-type complexes.

2. Samples and analytical methods

2.1. Sample description

For this study dunites, chromitites, wehrlites, clinopyroxenites, hornblendites and gabbros were sampled from three Uralian–Alaskan-type complexes of the UPB.