Tectonophysics 631 (2014) 130–145

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Rheological conditions for emplacement of Ural–Alaskan-type ultramafic complexes

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ARTICLE INFO

Article history:
Received 4 October 2013
Received in revised form 29 January 2014
Accepted 2 February 2014
Available online 10 February 2014

Keywords:
Ural–Alaskan complexes
Dunite core geometry
Magma ascent mechanisms
Platinum-group elements
Numerical modelling
Softening

ABSTRACT

Ural–Alaskan- (or Alaskan-) type complexes correspond to a particular class of ultramafic intrusions that attract particular attention due to their deep mantle origin and their platinum-group element (PGE) mineralization. When defined as massifs of dunite–clinopyroxenite, only forty-six complexes are reported in the literature. These large-scale dunite pipe-like structures are rarely isolated and they even can appear in clusters. To better understand genesis of these relatively young (<460 Ma) complexes, a worldwide compilation has been built, and three categories have been defined: single circular or elliptical bodies, twin bodies with similar shapes, and dismembered dunite bodies. PGE enrichment in Alaskan-type complexes is highest for the second category, where twin bodies are interpreted as horizontal sections of Y-shaped dunite pipes. To constrain mechanical properties of the lithosphere allowing emplacement of the Alaskan-type complexes, the forceful diapiric ascent hypothesis is investigated through numerical thermo-mechanical models. One hundred high resolution experiments accounting for realistic phase changes and softening mechanisms have been performed. The experiments show that with no rheological softening of the host rock and in case of a relatively weak ductile lower crust, the uprising magma tends to spread laterally without reaching the surface. To account for the forceful ascent of deep magmas, it is hence necessary to assume a strong lower crust rheology and strong local softening mechanisms. Besides reproducing the clustered distribution of the weakness zones representing magma pathways, these latter experiments reproduce large-scale pipe-like (cylindrical) structures, Y-shaped and funnel-shaped bodies, and laterally-shifted structures. Interestingly, zones of highest strain rates are located at the bottom parts of the inclined edges of Y-shaped and funnel-shaped bodies. The restricted age range of Alaskan-type complexes (<460 Ma) would mean that prior to this time, the lower crust was less resistant due to the hotter geotherm, prohibiting the possibility of "Alaskan-type magmatism".

1. Introduction

Alaskan-type (or Ural–Alaskan-type) complexes represent a group of ultramafic bodies where orthopyroxene is generally absent, and can thus be described as dunite–clinopyroxenite massifs. They have been originally defined as intrusions of olivine-rich lithologies (considered as mantle-derived material) with a concentrically zoned distribution, evolving from a dunite core to a clinopyroxenite rim, with gabbros or diorites at the margins (Taylor, 1967). The size of Alaskan-type complexes ranges from a few to hundreds of km^2, with one exception, the Guli massif, reaching 2000 km^2. In map view, they present circular or elliptical geometries, and can appear as isolated bodies or accompanied by a twin body of similar size, each of them being separated by a few kilometres. At a larger scale (hundreds of kilometres), several Alaskan-type bodies can be gathered in clusters, like in the Urals or in south-eastern Alaska (Fig. 1). Although ultramafic rocks of various typologies can be found in many places on Earth, Alaskan-type complexes are very scarce since only 46 complexes can really fit the above definition of a dunite core surrounded by a clinopyroxenite rim (Table 1). Twelve other ultramafic bodies were classified in the past as Alaskan-type complexes but they do not include a dunite core, and hence they are not listed in Table 1 (e.g. Turn Mountain, Salt Chuck and Sukkwan Island ultramafic bodies in SE Alaska, Himmelberg and Loney, 1995). There is also no evidence for a dunite core in the so-called Alaskan-type complexes of Gnat Lake or Menard Creek ultramafic bodies in British Columbia (Nixon et al., 1997). Similarly, although Pettigrew and Hattori (2006) suggested that the Neo-Archean ultramafic intrusions in the Quetico subprovince, Canada, correspond to Alaskan-type complexes, it appears that their cores are made of wehrlite (less than 90% of olivine) and not of dunite. Nevertheless, even if the listed number of Alaskan-type complexes depends on their definition and on the interpretation of geological maps, their scarcity is noteworthily evident. Besides their scarcity, dunite–clinopyroxenite massifs show another

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0040-1951/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2014.02.002

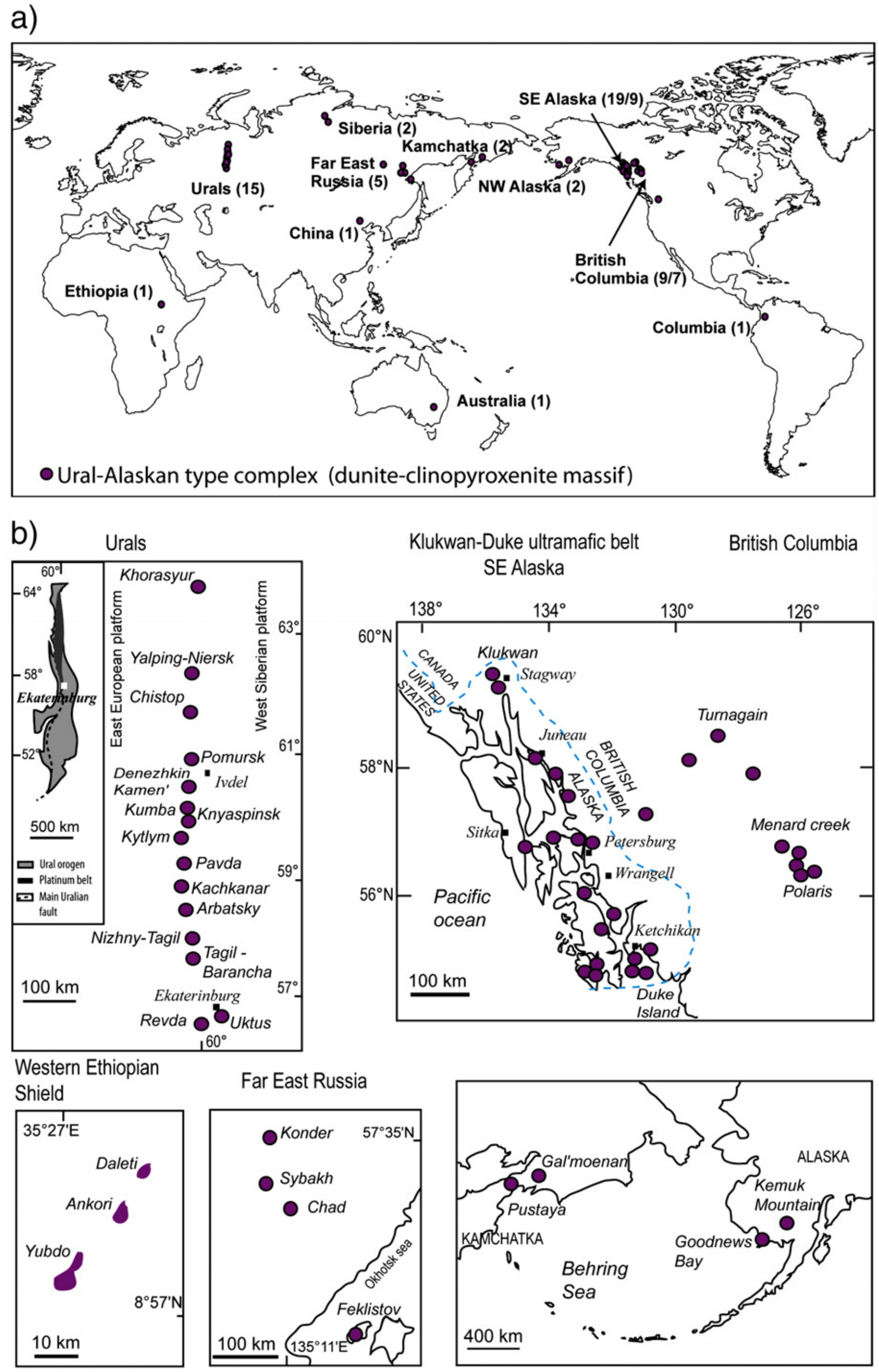

Fig. 1. a) World-wide distribution of Alaskan-type complexes, as defined by previous studies (first number in parentheses); second number in parentheses refers to our definition (one or two dunite core(s) surrounded by clinopyroxenites); b) zoom on particular areas, where clusters of Alaskan complexes have been described. At the small-scale of the bottom left figure (Yubdo area, Ethiopia), individual massifs separated by a few kilometres can be defined.

intriguing feature, dealing with their ages: Alaskan-type complexes were emplaced during a small part of the Earth history, from 460 to 20 Ma.

Ultramafic bodies and Alaskan-type complexes in particular, have been studied for a long time because of their associated mineralization in platinum-group elements (PGE) (Johan, 2002). Platinum-group elements, which refer to six metals (osmium, iridium, ruthenium, rhodium, platinum and palladium), have become essential to modern industry and are now classified as “strategic” metals. Among these elements, two of them, iridium and platinum, are particularly present in Alaskan-type bodies, and it appears that the price of these two metals has been continuously increasing for the last decade. However, the number of exploited PGE ore deposits is largely limited to South Africa (Bushveld complex) and Russia (Noril'sk intrusion). In addition, the principal source of PGE in Alaskan-type complexes is placer deposit and not primary mineralization. This partly explains that there are only few studies dedicated to the emplacement mechanisms of Alaskan-type complexes which could help understand the conditions of PGE mineralization.

Platinum “nuggets” have been discovered and exploited within placers spatially associated with Alaskan-type bodies (e.g. Barkov et al., 2005; Malitch et al., 2002; Slansky et al., 1991; Tolstykh et al., 2000). Placers remain an important source for PGE production in Russia, after the Ni–Cu sulphide ores of Noril'sk-type intrusions