



Review

Fenites associated with carbonatite complexes: A review

H.A.L. Elliott^{a,*}, F. Wall^a, A.R. Chakhmouradian^b, P.R. Siegfried^c, S. Dahlgren^d, S. Weatherley^e,
A.A. Finch^f, M.A.W. Marks^g, E. Dowman^h, E. Deadyⁱ

^a Camborne School of Mines, University of Exeter, Penryn Campus, Cornwall TR10 9FE, UK

^b Department of Geological Sciences, University of Manitoba, 125 Dysart Road, Winnipeg, Manitoba R3T 2N2, Canada

^c GeoAfrica, P.O. Box 24218, Windhoek, Namibia

^d Telemark, Fylkeshuset, Postboks 2163, 3103 Tønsberg, Norway

^e Geological Survey of Denmark and Greenland, Øster Voldgade 10, DK-1350 København K, Denmark

^f School of Earth and Environmental Sciences, University of St Andrews, Irvine Building, St Andrews, Fife KY16 9AL, UK

^g Universität Tübingen, FB Geowissenschaftern, Wilhelmstrasse 56, D-72074 Tübingen, Germany

^h Kingston University, Penrhyn Road, Kingston upon Thames, Surrey KT1 2EE, UK

ⁱ British Geological Survey, The Lyell Centre, Edinburgh EH14 4AP, UK



ARTICLE INFO

Keywords:

Fenite
Carbonatite
Metasomatism
REE
Niobium

ABSTRACT

Carbonatites and alkaline-silicate rocks are the most important sources of rare earth elements (REE) and niobium (Nb), both of which are metals imperative to technological advancement and associated with high risks of supply interruption. Cooling and crystallizing carbonatitic and alkaline melts expel multiple pulses of alkali-rich aqueous fluids which metasomatize the surrounding country rocks, forming fenites during a process called fenitization. These alkalis and volatiles are original constituents of the magma that are not recorded in the carbonatite rock, and therefore fenites should not be dismissed during the description of a carbonatite system. This paper reviews the existing literature, focusing on 17 worldwide carbonatite complexes whose attributes are used to discuss the main features and processes of fenitization. Although many attempts have been made in the literature to categorize and name fenites, it is recommended that the IUGS metamorphic nomenclature be used to describe predominant mineralogy and textures. Complexing anions greatly enhance the solubility of REE and Nb in these fenitizing fluids, mobilizing them into the surrounding country rock, and precipitating REE- and Nb-enriched micro-mineral assemblages. As such, fenites have significant potential to be used as an exploration tool to find mineralized intrusions in a similar way alteration patterns are used in other ore systems, such as porphyry copper deposits. Strong trends have been identified between the presence of more complex veining textures, mineralogy and brecciation in fenites with intermediate stage Nb-enriched and later stage REE-enriched magmas. However, compiling this evidence has also highlighted large gaps in the literature relating to fenitization. These need to be addressed before fenite can be used as a comprehensive and effective exploration tool.

1. Introduction

Carbonatites and alkaline-silicate (hereafter referred to as alkaline) rocks are the most important sources of rare earth elements (REE) and niobium (Nb) (Wall, 2014; Goodenough et al., 2016), both high profile raw materials critical to technological advancement. Intrusions of both carbonatite and alkaline rocks are typically found in close spatial relationship with aureoles of high temperature metasomatically altered country rock, termed fenites. These alteration aureoles have great potential as exploration indicators. However, the vast majority of prior research has been focused on the intrusions themselves, with little attention paid to the potential for alteration to inform exploration. This

contribution seeks to explore that potential by reviewing the current knowledge of fenite types, formation and relationship to economic mineralization.

The process of alteration (fenitization) is generally viewed to result from multiple pulses of alkali-rich fluid expelled from cooling and crystallizing carbonatitic or alkaline melt (Morogan, 1994; Le Bas, 2008). Fenites are typically composed of, and characterized by, K-feldspar, albite, alkali pyroxenes and/or alkali amphiboles (Zharikov et al., 2007). However, mineral assemblages are highly variable and dependent on a number of parameters such as protolith mineralogy, permeability and structure, in addition to fluid composition, temperature and pressure (Dawson, 1964; Heinrich, 1966; Le Bas, 1987; Platt,

* Corresponding author.

E-mail address: h.elliott@exeter.ac.uk (H.A.L. Elliott).

1996). The secondary mineral assemblages associated with fenitization are often visible in hand sample, whereas other effects such as the formation of turbidity in feldspars (e.g. Woolley, 1969; Heinrich and Moore, 1969; Vartiainen and Woolley, 1976; Garson et al., 1984; Kresten and Morogan, 1986; Morogan and Woolley, 1988; Williams-Jones and Palmer, 2002; Le Bas, 2008) or the modification of primary mafic phases can be more subtle and only visible via optical microscopy. Vein networks often develop early on in the fenitization process, facilitating the passage of fluids expelled from the melt through fractures and joints in the country rock, to form the outer fenite aureole (Woolley, 1969). The scale of fenitization varies greatly from centimeters to several kilometers from the intrusive contact. Fenites are often associated with hydraulic fracturing and brecciation, exhibiting both temporal, spatial, mineralogical and chemical variations, resulting in both horizontal and vertical zoning.

Fluids derived from cooling alkaline magmas or carbonatite intrusions transport high quantities of alkalis and volatiles. These were originally constituents of the magma that are not retained in the carbonatite rock, therefore descriptions of intrusions are incomplete without also characterizing their associated fenite. Fenitizing fluids emanating from evolved and subsequently enriched magmas, form REE and Nb micro-mineral assemblages in the country rock (Elliott et al., 2016; Dowman et al., 2017). These can provide information regarding their source magma and any associated mineral deposits, effectively acting as exploration indicators. Fenites are vertically and horizontally extensive, forming 3D aureoles around these intrusions and are therefore likely to be identified at a variety of different erosion levels, even where source intrusions are not necessarily exposed. However, resource exploration has predominantly focused on intrusive units in alkaline and carbonatite complexes as these are the primary sources and hosts of REE and Nb deposits (Wall, 2014; Goodenough et al., 2016). There is a distinct lack of emphasis in the literature regarding fenites, with only a few recent publications appreciating the importance of fenitizing fluids with regard to element mobility within the system (e.g. Arzamastev et al., 2011; Al Ani and Sarapää, 2013; Trofanenko et al., 2014; Dowman et al., 2017). As such, our comprehension of the relationship between intrusions, fluids and country rock is relatively restricted. This is in complete contrast to other ore systems, such as porphyry copper deposits, where alteration patterns and zones are a standard exploration tool (e.g. Hedenquist et al., 1998; Sillitoe, 2010).

This paper is the product of an expert council workshop as part of the HiTech AlkCarb project, funded by the Horizon 2020 Research and Innovation Programme of the European Union. This project brings together a variety of multi-disciplinary academic and industrial partners from around the world to develop new geomodels to explore for ‘high technology elements’ in alkaline rocks and carbonatites. Although the locations of many alkaline and carbonatite complexes are well known (e.g. Woolley and Kjarsgaard, 2008), these exploration models are required in order to better target unexposed economic deposits. Fenite enrichment is not typically sufficient to warrant exploitation; however, these rocks do have the potential to be used in the future as exploration tools to target critical metal resources.

1.1. Rare earth elements and critical metals

New technologies are utilizing an increasingly diverse array of elements in their manufacture. Amongst these are a sub-group of ‘critical metals’ (European Commission, 2017a, b), so defined as they are economically important metals with a significant risk of supply disruption. Carbonatite and alkaline rock-related deposits dominate the supply of REE and Nb, in addition to being sources of phosphate, fluorite, copper, titanium, platinum group elements and dimension stone. Alkaline and ultramafic rocks also provide vermiculite, nepheline and are potential sources of scandium and tantalum (e.g. Woolley and Kjarsgaard, 2008; Wall, 2014; Mitchell, 2015; Goodenough et al., 2016).

The term rare earth elements (REE) is used in this manuscript to represent the lanthanide series elements lanthanum (La) to lutetium (Lu), plus scandium (Sc) and yttrium (Y). Although the division between light and heavy rare earth elements is variably defined, the European Commission (2014) subdivides these into light REE (LREE) consisting of La-Sm, and the heavy REE (HREE) consisting of Eu-Lu including Y. These metals have advantageous paramagnetic, mechanical and spectral properties (Gupta and Krishnamurthy, 2005; British Geological Survey, 2011; Wall, 2014), making them useful in a wide range of industrial processes.

The vast majority of REE production occurs in China (> 95%) (British Geological Survey, 2017; European Commission, 2017a), with only three other major mining operations globally. These consist of a weathered carbonatite at Mt Weld, W. Australia (e.g. Hoatson et al., 2011; Pirajno, 2015); a nepheline syenite at Lovozero, Kola Peninsula, Russia (e.g. Kogarko et al., 2010; Arzamastev et al., 2011; Wall, 2014); and as a by-product of Ti exploitation from mineral sand at Orissa, India (e.g. Gupta and Krishnamurthy, 2005; British Geological Survey, 2011). Currently Nb production is dominated by the carbonatite-related laterite deposits at Araxá and Catalão II, Brazil (e.g. Mitchell, 2015); carbonatite at St Honoré, Canada (Mitchell, 2015); and the nepheline syenite at Lovozero, Russia (Linnen et al., 2014). However, prospective deposits for both REE and Nb exist worldwide (see Fig. 1). Therefore, to develop a reliable and sustainable supply of these critical metals, complexes and deposits within politically stable countries must be explored and developed. Fenites do not contain exploitable quantities of critical metals, but do have great potential to be used as an exploration tool. Of the commodities listed above, only fluorite, vermiculite, phosphate and dimension stone have previously been mined from fenite.

1.2. Classification

Fenites are described as a metasomatic family by the IUGS (Zharikov et al., 2007), formed at high temperatures and characterized by a certain suite of minerals, but no attempt for further subdivision or more detailed nomenclature has been made by the IUGS. Fenite terms originally used by Brögger (1921) to describe the Fen type locality, Norway are listed in the IUGS classification of igneous rocks (Le Maitre et al., 2002). However, names such as tveitåsite and ringite are local, specific to Fen, and not commonly used elsewhere. Within fenites and their associated intrusive rocks, other forms of localized metasomatic processes are also observed, for example: autometasomatism in the peripheral parts of intrusions, contact metasomatism at the intrusion-country rock interface, and near-vein metasomatism forming symmetrical zonation on either side of a vein (Zharikov et al., 2007).

The classic definition of the term fenitization by Brögger (1921), involves the removal of silica from the protolith. However, during the metasomatism of undersaturated igneous rocks (e.g. Nurlybaev, 1973; Viladkar, 2015) there is no loss of silica, and often some gain relative to the protolith. As such, Bardina and Popov (1994) argued that fenitization is marked by an increase in alkali content ($\text{Na}_2\text{O} + \text{K}_2\text{O}$), irrespective of silica content or mobility.

Many endeavours have been made in the literature to subdivide fenites further into categories, dating back to von Eckermann (1948). For example, Kresten (1988) classified fenites as contact, aureole or veined depending on their spatial relationship to the source intrusion; Verwoerd (1966) first attempted to use the ratio of Na and K to classify fenites as sodic, potassic or intermediate, terms still used widely in the literature; and Morogan (1994) used a continuous scale of fenitization intensity to classify fenites as low, medium or high-grade. Russian literature names rocks that retain some of the original texture or protolith mineralogy, using the modifier “fenitized” added before the protolith name (e.g. Arzamastev et al., 2011; Kozlov and Arzamastev, 2015). Additionally, the prefix “apo-” is used to indicate the nature of this protolith following the recommendations of the IUGS for metamorphic

Download English Version:

<https://daneshyari.com/en/article/8909832>

Download Persian Version:

<https://daneshyari.com/article/8909832>

[Daneshyari.com](https://daneshyari.com)