Chemical Geology 387 (2014) 144–156

Contents lists available at ScienceDirect

Chemical Geology

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

The Archean magmatic-hydrothermal system of Lac Shortt (Au-REE), Abitibi, Canada: Insights from carbonate fingerprinting

Olivier Nadeau [a,b,*], Ross Stevenson [a,b], Michel Jébrak [a]

[a] Université du Québec à Montréal, Montréal, Canada
[b] Geotop Research Centre in Geochemistry and Geodynamics, Montreal, Canada

ARTICLE INFO

Article history:
Received 3 March 2014
Received in revised form 15 August 2014
Accepted 19 August 2014
Available online 29 August 2014

Editor: K. Mezger

Keywords:
Gold and REE deposits
Mantle magmatism-hydrothermalism
Carbonatites
Syenites
Lamprophyres
Carbonate fingerprinting

ABSTRACT

Trace element and isotopic data from the Lac Shortt (Abitibi, Canada) gold and rare earth element (REE) deposit sheds light on the cogenetic association between alkali magmatism (syenites and lamprophyres), carbonatation (magmatic and carbothermal) and gold – REE mineralization. Magmatic and carbothermal carbonates from comagmatic lithologies from the Lac Shortt gold-REE deposit were analyzed for major, minor and trace elements concentrations as well as for their $^{87}Sr/^{86}Sr_0$, $\delta^{13}C$ and $\delta^{18}O$ isotopic ratios. Carbonates from Lac Shortt have $\delta^{13}C$ values ranging from −4.89 to 2.38 ‰ VPDB and $\delta^{18}O$ values ranging from 8.28 to 15.02. The lightest values are found in carbonate from the carbonatites and the heaviest values are associated with the ore-carbonates. Carbonates from the various lithologies lie between these two extremes. Initial $^{87}Sr/^{86}Sr$ ratios from the carbonates cluster tightly around 0.7013–0.7016, i.e., depleted Archean mantle signatures, although some have slightly more radiogenic values, from 0.7026 to 0.7029. The small variation in the strontium isotope ratios compared to the C and O isotopic values suggests that carbonate anions (CO_3^{2-}) were decoupled from the cations during hydrothermal alteration. Cations such as Sr^{2+} and Ca^{2+} in carbonates from the high grade ore and from magmatic and hydro-carbothermal carbonatite appear to originate from the Late-Archean, depleted mantle. Since gold is a cation and is strongly associated with carbonatite magmatism and associated carbo-hydrothermal carbonatation, we suggest gold too has a depleted mantle origin. The carbonates are enriched in mobile high field strength elements (HFS; Ba, Sr) elements, depleted in immobile HFS elements (Th, U, Ta, Nb, Zr, Ti) and have enriched- to slightly depleted REE patterns with flat to strong light-REE enrichments. These trace element concentrations support the fact that all the lithologies were comagmatic and that the ore itself was genetically related to these lithologies. Based on present day knowledge of Archean tectonics of Abitibi, post collision extension tectonics and mantle delamination, isotope geochronology, on the magmatic-hydrothermal system of Lac Shortt itself and on the present paper's carbonate fingerprinting, we propose that Lac Shortt calc-alkaline dioritic magmatism-hydrothermalism was followed by alkaline syenitic, and eventually carbonatitic magmatism-hydro-carbothermalism, and that gold and REE originated from the carbonatite magmatic-carbo-hydrothermal system and its mantle roots, which agrees with mass balance calculations. The depleted-mantle-rooted, carbonatite exsolved a hydro-carbothermal fluid enriched in REE and gold which fenitized and oxidized the syenite and out of which the gold and REE mineralization was deposited.

1. Introduction

Following Groves et al.'s (1998) classification of 'orogenic' gold deposits, Robert (2001) demonstrated that not all 'orogenic' gold deposits originate from orogeny and that there is at least one distinct class of non-orogenic magmatic-hydrothermal gold deposits in the Abitibi Archean greenstone belt. The magmatic-hydrothermal gold deposits of the Abitibi display disseminated as well as vein-hosted gold-sulfide mineralization, potassic (K feldspar, biotite or sericite) and carbonate alteration, and are associated with syenitic to monzonitic rocks and dikes. These deposits are often found in close association with post-orogenic Timiskaming-type conglomerates and are of Timiskaming age (2680–2672 Ma). The genesis of this class of deposit remains obscure and the present paper aimed at deciphering the origin of such mineralization by studying the Lac Shortt deposit, near Lebel-sur-Quévillon (Morasse, 1988; Prud'homme, 1990; See, 1994; Tilton and Bell, 1994; Brisson, 1998; Nadeau et al., 2012).

The Lac Shortt Au-REE deposit hosted 2.7 Mt of ore at an average of 4.6 g/t Au (total 12.4 tons Au; Brisson, 1998). The mineralization was associated with a complex suite of intrusions consisting of alkali gabbros, syenite, carbonatite and silicocarbonatite plugs and dykes, undifferentiated mafic and dioritic sills, and ultramafic, calc-alkaline and alkaline lamprophyres (Morasse, 1988; Prud'homme, 1990; Bourne and Bosse,

* Corresponding author.
E-mail address: onadeau@uottawa.ca (O. Nadeau).

http://dx.doi.org/10.1016/j.chemgeo.2014.08.021
0009-2541/

1991; See, 1994). The Lac Shortt deposit is both locally (Prud'homme, 1990) and regionally (Dolodau carbonatite; Bedard, 1988; Bedard and Chown, 1992) associated with coeval carbonatite magmatism. The syenite-lamprophyre-carbonatite-gold association at Lac Shortt provides a unique opportunity to study the role of the carbon-rich fluids associated with magmatic hydrothermal gold deposits of the Abitibi.

This paper presents new geochemical and isotopic ($\delta^{13}C$, $\delta^{18}O$ and $^{87}Sr/^{86}Sr$) data from carbonate minerals of the Lac Shortt carbonatite-lamprophyre-syenite-gold ore system that constrain both the petrogenesis of the magmatic system as well as the metallogenesis of the associated gold-REE deposit. At Lac Shortt, both magmatic and carbo-hydrothermal carbonates are present in carbonatites, silicocarbonatites, hornblendites, lamprophyres, mafic and dioritic sills, syenites and high and low grade ores. The geochemical and isotopic fingerprinting of carbonates from carbonatites, silicocarbonatites, mafic and dioritic sills, syenites and ores confirm that they have a common origin (Prud'homme, 1990) and sheds light on the ore-generating processes. Furthermore, the use of Sr isotopes as a proxy for solutes and C and O isotopes as proxies for solvents suggest that solutes present in these carbonates originated from the Late-Archean, sub-continental depleted mantle and that the solvents within the same crystals gradually equilibrated with the Archean crust during hydro-carbothermal alteration. Finally, as mineralization is intimately associated with carbonatization at Lac Shortt (Prud'homme, 1990; See, 1994; Brisson, 1998), the comparison of carbonates from Au ore and other lithologies suggest that gold was transported and deposited by mantle-derived, aqueous-carbonic fluids that exsolved from the carbonatite at emplacement depths and deeper.

2. Geological context

The Lac Shortt alkaline complex is located in the eastern Abitibi greenstone belt and is hosted by tholeiitic volcanic flows of the Wachigabau Formation and sediments of the Dalime formation (Brisson, 1998).The Lac Shortt deposit (Fig. 1) is embedded in ENE Lac Shortt fault, which is a secondary splay of the major Lamarck NE-SW shear zone (Brisson, 1998). Intrusions of the Lac Shortt alkaline complex were emplaced syn- to late-deformation within- and channelized by this shear zone. The alkaline complex contains the oldest carbonatite in Canada (2652 Ma; Morasse, 1988), undifferentiated mafic sills, massive and dike-like syenites and carbonatites, hornblendite dikes, diorite sills, calc-alkaline, alkaline and ultramafic lamprophyres (Bourne and Bosse, 1991) dikes and carbo-hydrothermal gold mineralization. The Lac Shortt fault zone contains blocs and clasts of carbonatites and syenites and the carbonatite contains syenite boudins.

2.1. Syenites

Fresh syenite contains K feldspar, albite, biotite, muscovite, dolomite, calcite, pyrite, magnetite, hematite, apatite and monazite (Morasse, 1988). Quartz, calcite and fluorite are present in veinlets. The altered syenite is mylonitized, oxidized to brick-red and contains ankerite, more abundant K feldspar and hematite, and is enriched in Au, Ba, Sr, Ca and CO_2 compared to the fresh syenite. The syenite dikes also contain sphalerite, galena, pyrrhotite, rutile and leucoxene, fluorite, barite, pyrochlore, cerianite ($[Ce^{4+},Th]O_2$), bastnaesite ($[Ce,La]CO_3F$), zircon, aikinite ($PbCuBiS_3$) (Morasse, 1988). The syenite has abnormally high levels of K_2O (up to 12 wt.%) and low levels of Na_2O (<1 wt.%), caused by metasomatism (Morasse, 1988). Zoned microcline is interpreted to result from potassic metasomatism. Calcite is observed in the syenite dikes as sheet-like structures interpreted to originate from the carbonatite. This is in agreement with the presence of pyrochlore, bastnaesite and monazite both in the carbonatite and the syenite and is corroborated by the existence of a hybrid carbonatite-syenite dike, having a core of red syenite injected and fragmented by calcite, an external envelope of carbonatite which appears to intrude the syenite, and a reaction texture at the contact between both units. This dike is interpreted to result from the intrusion of a syenite and subsequently by the injection of the carbonatite (Morasse, 1988). The

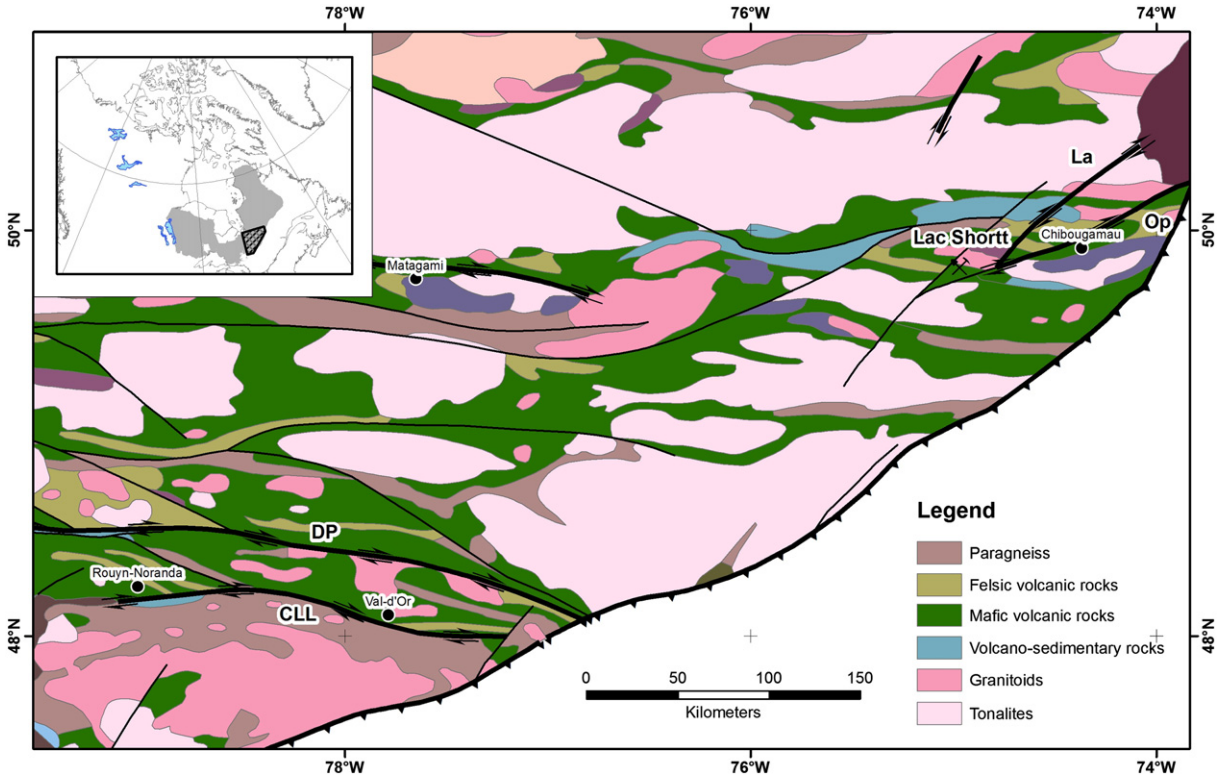

Fig. 1. Geological map of Abitibi. Lac Shortt is located in northeastern Abitibi, near the intersection of the Lamarck (La) and the Opawica (Op) regional faults. Rouyn and Val d'Or are shown between the Cadillac – Larder Lake (CLL) and the Destor Porcupine (DP) fault zones for reference. Southeastern Abitibi is in structural contact with the Province of Grenville (in white). The inset shows the localization of the map in the Archean Province of the Superior (in gray) and in North America.