Precambrian Research 291 (2017) 220–235

Contents lists available at ScienceDirect

Precambrian Research

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

Dating shear zones with plastically deformed titanite: New insights into the orogenic evolution of the Sudbury impact structure (Ontario, Canada)

Konstantinos Papapavlou [a,*], James R. Darling [a], Craig D. Storey [a], Peter C. Lightfoot [b], Desmond E. Moser [c], Stephanie Lasalle [a]

[a] *School of Earth and Environmental Sciences, University of Portsmouth, Portsmouth PO1 3QL, UK*
[b] *Harquail School of Earth Sciences, Laurentian University, Sudbury, Ontario P3E 2C6, Canada*
[c] *Department of Earth Sciences, University of Western Ontario, London, Ontario N6A 5B7, Canada*

ARTICLE INFO

Article history:
Received 12 August 2016
Revised 29 December 2016
Accepted 8 January 2017
Available online 09 January 2017

Keywords:
Shear Zones
Titanite
Mineralization
Sudbury impact structure
Orogeny

ABSTRACT

The Sudbury structure is a mineralized impact crater that hosts different families of ore-controlling shear zones with poorly known orogenic affinities. Discriminating whether these deformation events relate to the 1.85 Ga crater modification stage or later regional tectonism, that collapsed the impact structure, is important both for crustal and mineral exploration studies. We have combined underground mapping with isotopic and microstructural analysis of titanite and host minerals in a benchmark ore-controlling mylonitic shear zone of the mining camp, the Six Shaft Shear Zone from the Creighton Mine. Three growth stages of chemically and microstructurally-characterised titanite grains were identified related with the pre-, syn and late deformation stages. *In-situ* U-Pb age dating of the syndeformational grains demonstrates that a shearing event took place at 1645 ± 54 Ma during the Mazatzalian–Labradorian orogeny (1.7–1.6 Ga). This event led to the plastic deformation and local-scale remobilization of primary Ni-Cu-PGE sulphides in Creighton Mine (Sudbury, South Range). The adopted novel petrochronological approach can reveal the age significance of syn-deformational processes and holds promise for the untangling of complex syn-orogenic processes in Precambrian terranes globally.

1. Introduction

High-strain mylonitic shear zones control the location, geometry, and metal tenor of a range of ore-deposits in many mining camps around the world (McQueen, 1987; Phillips et al., 1987; Cook et al., 1993; Blenkinsop, 2004; Duuring et al., 2007). The world-class polymetallic Ni-Cu-PGE Sudbury mining camp (Ontario, Canada) is not an exception. The structural architecture of this camp is controlled by a crustal-scale network of greenschist to amphibolite facies shear zones, collectively termed as the South Range Shear Zone (Shanks and Schwerdtner, 1991). The timing of operation and the orogenic affinity of the structures that define this system of shear zones remains unclear (Bailey et al., 2004). Better age constraints on their operation will provide new insights on the tectonothermal events that induced the orogenic deformation of the crater and remobilization of some of the magmatic sulphide ore bodies to satellite positions. In this regard, the concept of petrochronology has emerged as a novel means to understand the chronologic significance and constrain the rates of metamorphic and deformational processes in polyphase deformed terranes globally.

Petrochronology is the linkage of isotopic ages with microstructural, geochemical, and/or thermobarometric constraints from the same or adjacent intra-grain domains of accessory phases. Constraining the timing of deformation remains a challenging endeavour but U-Th-Pb-bearing accessory phases have revealed, in several cases, a great potential to resolve the timing of deformation and fluid flow events in mylonitic shear zones (Parrish et al., 1988; Storey et al., 2004; Clark et al., 2005; Mahan et al., 2006; Cenki-Tok et al., 2014). In this contribution, we focus on a uniquely exposed mylonitic shear zone from the Creighton Mine (Fig. 1) that is spatially related with magmatic and remobilized Ni-Cu-PGE sulphide ore bodies. The main aims of this study are to: (a) bracket the timing of operation and the orogenic affinity of the shear zone, by adopting a petrochronologic approach using the accessory phase titanite and (b) characterise in detail this ore-controlling deformation zone and the mineralization that it hosts with new field,

* Corresponding author.
E-mail address: konstantinos.papapavlou@port.ac.uk (K. Papapavlou).

http://dx.doi.org/10.1016/j.precamres.2017.01.007
0301-9268/

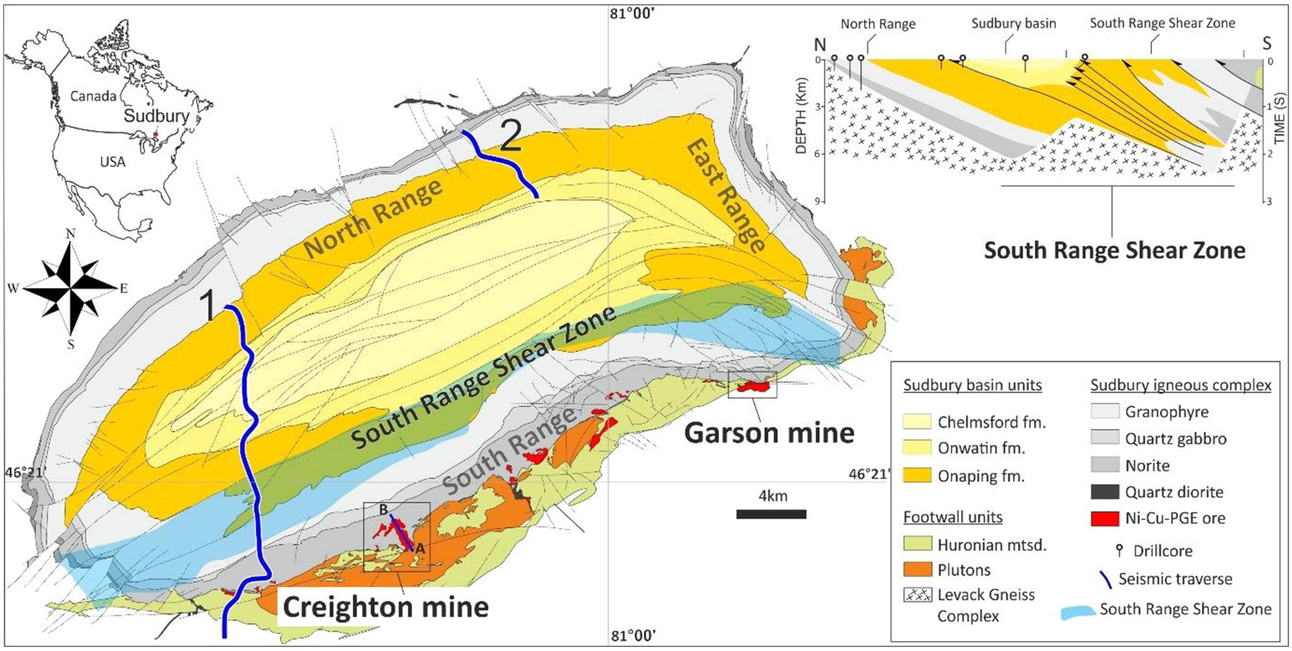

Fig. 1. Simplified geological map of the Sudbury impact structure and composite North-South seismic cross section along the traverses 1 and 2 that are depicted with blue jagged lines (map modified from Ames et al. (2008) and cross section from Adam et al. (2000)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

kinematic, mineral-chemical, and quantitative microstructural data (electron backscatter diffraction; EBSD).

2. The Sudbury impact structure

2.1. Geological setting and styles of mineralization

The 1.85 Ga Sudbury impact structure is a unique example of an ore-bearing terrestrial impact crater that underwent multiple orogenic events that extensively modified its structural architecture and metallogenic potential (Krogh et al., 1982; Riller, 2005). It is located at the junction of three Precambrian orogenic provinces (Superior, Grenville and Southern provinces), and is traditionally divided into the North, East, and South Ranges (Fig. 1). The three major impact-related lithostratigraphic units of the Sudbury structure are: (a) the pseudotachylitic Sudbury Breccia (Spray, 1998; Rousell et al., 2003), (b) the Sudbury igneous complex (SIC) or Main Mass (Lightfoot et al., 1997), and (c) the elliptical Sudbury Basin (Pye et al., 1984 and references therein). In the South Range, Paleoproterozoic metamorphosed volcano-sedimentary rocks of the Huronian Supergroup form the footwall of the SIC (Card et al., 1984). In the North and East Ranges, the footwall of the SIC contains the 2.71 Ga Levack Gneiss Complex which consists of amphibolite to granulite facies tonalitic gneisses (Card, 1990; Ames and Farrow, 2007). Four main types of sulphide mineralization are recorded in the Sudbury mining camp (Lightfoot et al., 1997; Mukwakwami et al., 2012). The dominant type comprises contact-style Ni-Cu-PGE sulphide ore bodies that accommodate more than 50% of the Sudbury ores (Lightfoot and Doherty, 2001). These are characterised by massive and disseminated sulphide ore bodies that settled gravitationally as immiscible liquids from a voluminous supra-liquidus silicate melt to thermally eroded embayments at the bottom of the SIC (Barnes and Lightfoot, 2005). The Offset-style deposits constitute the second major style of mineralization. These deposits are hosted within inclusion-bearing quartz diorite dykes (i.e. Offset Dykes) that exhibit pinch and swell geometry and thin away from the SIC (Lightfoot and Farrow, 2002). The third major ore-bearing environment comprises Cu-Ni-PGE footwall-style deposits that are hosted mainly within the Sudbury breccia (South Range) and the Archean gneiss complex (North Range) (Ames and Farrow, 2007). The fourth type is associated with mylonitic shear zones that host, displace and remobilize high metal tenor contact and footwall-style ore bodies and is exemplified mainly by deposits in Garson, Thayer Lindsley, Falconbridge and Creighton Mines (Bailey et al., 2006; Gibson et al., 2010; Mukwakwami et al., 2012).

2.1.1. Structural and metamorphic evolution of the South Range

The main deformation system of the South Range is the South Range Shear Zone that comprises a moderately dipping array of top-to-the-north ductile and brittle-ductile structures that transect the SIC and the southern footwall of the Sudbury Structure (Shanks and Schwerdtner, 1991). Quantitative thermobarometric constraints and mineral-chemical analyses of amphiboles place the peak metamorphic conditions, and the operation of the South Range Shear Zone, within the epidote-amphibolite facies stability field (T = 550°–600 °C, P = 4–5 kbar) (Thomson et al., 1985; Fleet et al., 1987; Mukwakwami et al., 2014). The western segment of the South Range Shear Zone comprises ENE- trending, top-to-the-NW thrusts whereas the eastern exhibits a map-scale switch in the orientation of the structural grain with development of WNW-trending structures (Fig. 1). These two structural domains are characterised by distinct kinematics (Santimano and Riller, 2012). A kinematic domain dominated by thrusting in the western part of the complex and a domain of dextral transpression in the eastern part (Riller et al., 1999). Generally, the following processes have been proposed that influenced the deformation pattern of the South Range during and/or after the impact event: (a) the formation of syn-impact fractures (Siddorn and Hamm, 2006), (b) the mechanical weakening of the crust by the impact event (Riller et al., 2010), (c) the orogenic buckling of the Sudbury Igneous Complex in a flexural – slip mode (Mukwakwami et al., 2012), and (d) a tri-shear fault – propagation folding of the crater units (Lenauer and Riller, 2012).