Tectonophysics 618 (2014) 102–106

Contents lists available at ScienceDirect

Tectonophysics

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

Pop-down tectonics, fluid channelling and ore deposits within ancient hot orogens

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ARTICLE INFO

Article history:
Received 26 July 2013
Received in revised form 17 January 2014
Accepted 26 January 2014
Available online 30 January 2014

Keywords:
Tectonics
Crustal shortening
Weak lithosphere
Fluid transfers
Ore deposits
Ancient cratons

ABSTRACT

Many Archaean and Paleoproterozoic deformation zones, often rich in ore resources, show particular structural patterns in particular marked by regional vertical stretch. These zones are not restricted to greenstone-bearing Archaean domains that may have suffered gravity-driven sagduction of heavy supra-crustals, as extensively discussed since the last twenties. Structures are actually best explained by pop-down tectonics of upper-crustal units within an underlying weak crust submitted to horizontal regional shortening. Here we present three complementary examples from two Archaean greenstone belts (Abitibi sub-Province, Quebec, and Murchison belt, South Africa) and one greenstone-lacking Paleoproterozoic belt (Thompson belt, Manitoba). In the three examples, ore is concentrated along steeply dipping deformation zones, rich in syntectonic deposits and marked by substantial sub-vertical crustal stretch. On the other hand, the three regions show differences in age, in metamorphic grade (from sub-greenschist facies to upper amphibolite facies), in metal contents (gold, antimony, nickel), in metal sources, transfers and concentration histories. Our compared analysis emphasizes that pop-down tectonics associated with horizontal shortening of weak lithospheres may account for observed geometric patterns and provide a new and promising frame for the analysis of relationships between structural patterns and ore concentrations within old cratons.

1. Introduction

Tectonics that structured Precambrian cratons is a major ongoing debate in Earth sciences. This relates to academic reasons linked to long-lasting and still debated controversies about the modes of lithospheric deformations through geological times (Burg and Ford, 1997; Chardon et al., 2009; Choukroune et al., 1995; Ganne et al., 2011; Gapais et al., 2009; Hamilton, 2003; Windley, 1995), and to economic ones, Precambrian cratons being particularly rich in ore concentrations.

Archaean and Paleoproterozoic cratons have remarkable structural specificities (Chardon et al., 2009; Choukroune et al., 1995; Gapais et al., 2009). In particular, strains marked by steeply dipping fabrics often bearing steeply plunging stretching lineations are widespread, from low grade upper crust to deeper granulitic and partial melting conditions (Bouhallier et al., 1995; Cagnard et al., 2006a, 2007; Chardon et al., 2002, 2008, 2009; Choukroune et al., 1995; Chown et al., 1992; Fueten and Robin, 1989; Gapais et al., 2008; Goscombe, 1991; Hudleston et al., 1988; Jaguin et al., 2012; Lonka et al., 1998). These regions contain deformation bands that show large strains despite lack of major metamorphic jumps (Bleeker, 1990; Chown et al., 1992; Gapais et al., 2005; Jaguin et al., 2012; Powell et al., 1995; Vearncombe et al., 1992), and some are marked by important ore concentrations (Bleeker, 1990; Böhm et al., 2007; Chardon et al., 2002; Dubé and Gosselin, 2007; Gapais et al., 2005; Jaguin et al., 2012; Lin and Beakhouse, 2013; Vearncombe et al., 1992). Recent analogue experiments and field surveys have argued that vertical tectonics, marked by downward motion of upper-crustal rocks within a weak ductile underlying crust was a major mode of shortening of hot lithospheres (Cagnard et al., 2006a, 2006b; Chardon et al., 2009 and refs. therein; Gapais et al., 2009).

In this paper, we compare three orogenic sub-provinces marked by different metal contents: the Southernmost Abitibi greenstone belt (Abitibi Sub-Province, Quebec) (Au), the Antimony line within the Murchison greenstone belt (South Africa) (Sb), and the Thompson Nickel belt (Canada) (Ni). Beside their different metal contents, the areas range from Archaean (Abitibi and Murchison belts) to Paleoproterozoic in age (Thompson belt). They further show different metamorphic grades, sub-greenschist facies to greenschist facies in southernmost Abitibi (Powell et al., 1995), greenschist facies along the Antimony line in the Murchison belt (Vearncombe et al., 1992), upper-amphibolite facies, up to partial melting and granulitic conditions, in the Thompson belt (Bleeker, 1990; Zwanzig et al., 2007 and refs. therein).

Our paper emphasizes that pop-down tectonics marked by downward motions of fault-bounded upper crustal blocks was common during horizontal compression of weak continental lithospheres and may have been a first-order factor accounting for channelled fluid transfers and concentrations of ore deposits in ancient deformation belts.

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0040-1951/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2014.01.027

2. Geology, structure, and ore deposits

At the map scale, the three examples show two first-order characteristics (Figs. 1 and 2). First, foliations are mainly steeply dipping, strike parallel to the belt (locally disturbed by syn-kinematic intrusions), and bear widespread steeply plunging lineations attesting to sub-vertical stretch; second, ore deposits are concentrated within or around belt-parallel alignments of supra-crustals (sediments or volcanics) and along narrow deformation zones parallel to the belts (Böhm et al., 2007; Chown et al., 1992; Dubé and Gosselin, 2007; Gapais et al., 2005; Jaguin et al., 2012; Vearncombe et al., 1992).

In the southernmost Quebec Abitibi sub-Province, major gold deposits mark the E–W striking steeply dipping Cadillac deformation zone that separates the Abitibi greenstone belt from the Pontiac domain to the South (Fig. 1a). Other E–W striking deformation zones also marked out by supra-crustals and gold deposits occur within the belt to the North (Fig. 1a) (Dubé and Gosselin, 2007). Evidence for vertical stretch components is widespread throughout the region (Chown et al., 1992; Dubé and Gosselin, 2007) (Fig. 2a, b) where kinematics involved dominant top-to-the-South motions in an overall transpressive context (Chown et al., 1992). However, metamorphic and structural data attest to limited syn-transpression offsets along the Cadillac zone (Chown et al., 1992; Dubé and Gosselin, 2007; Powell et al., 1995). Gold concentrations are also observed along NW–SE striking zones recognised as late dextral strike-slip zones that offset lithologies to a maximum extent of the order of 10th of km (Chown et al., 1992; Dubé and Gosselin, 2007) (Fig. 1a). Gold is concentrated in quartz-carbonate ± tourmaline veins (Dubé and Gosselin, 2007; Tremblay, 2001).

In the Murchison belt, sub-vertical fabrics bearing steeply plunging stretching lineations affect the entire belt, ore deposits being concentrated in quartz-carbonate veins along the so-called Antimony line (Vearncombe et al., 1992) (Figs. 1b and 2c, d). At the regional scale,

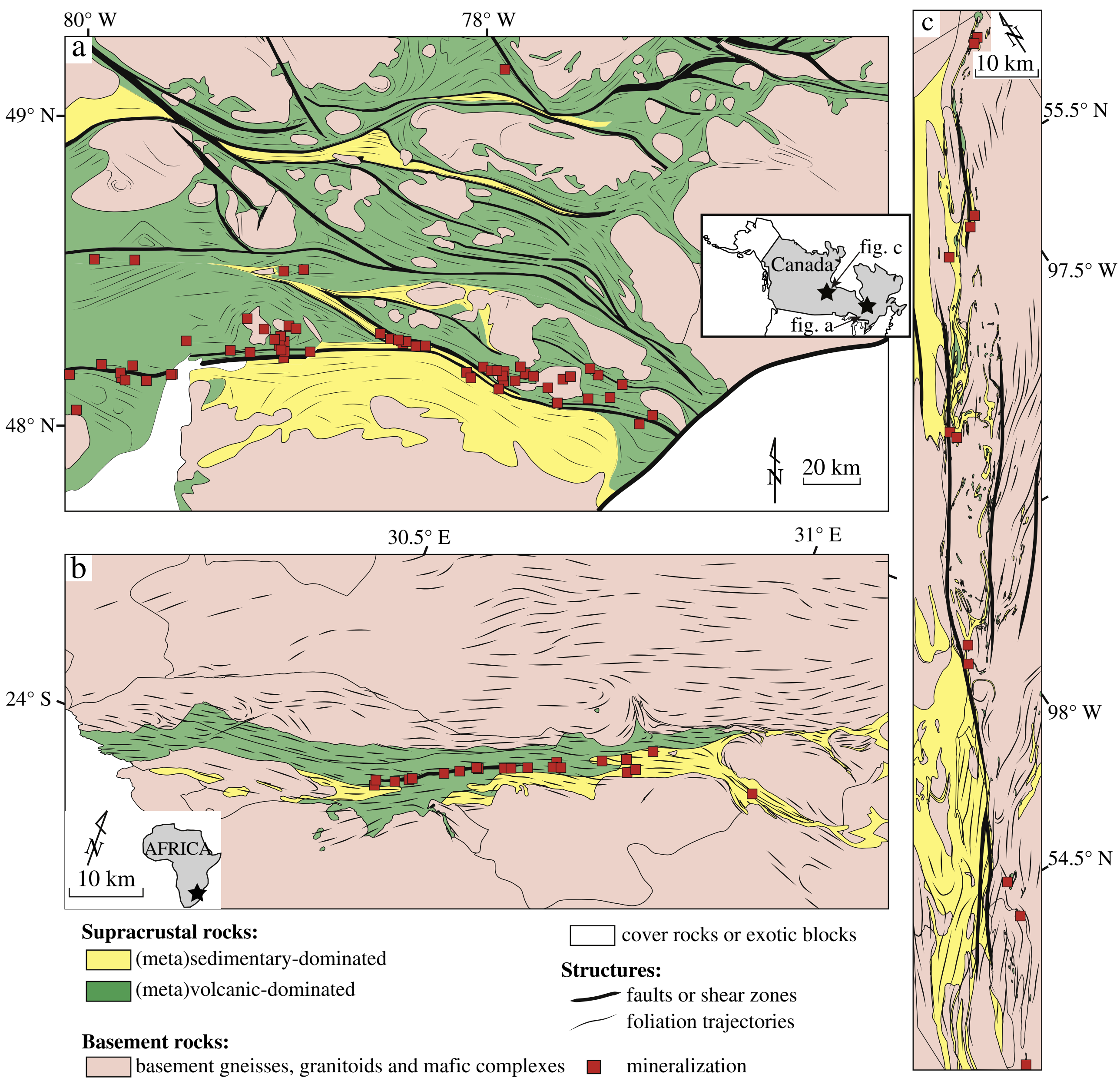

Fig. 1. Simplified geological and structural maps of studied areas. (a) Southern Abitibi sub-Province (Quebec) (Au), (b) Murchison belt (South Africa) (Sb), (c) Thompson belt (Manitoba) (Ni). Maps show main zones of supra-crustal deposits, fault zones, ore deposit locations, and simplified foliation trajectories.
Modified after Chown et al. (1992), Gapais et al. (2005), Böhm et al. (2007), Dubé and Gosselin (2007) and Jaguin et al. (2012).