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Alteration-weakening leading to localized deformation in a damage aureole adjacent to a dormant shear zone

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ABSTRACT

Deformation adjacent to faults and shear zones is traditionally thought to correlate with slip. Inherited structures may control damage geometry, localizing fluid flow and deformation in a damage aureole around structures, even after displacement has ceased. In this paper we document a post-shearing anastomosing foliation and fracture network that developed to one side of the Mesoarchean Marmion Shear Zone. This fracture network hosts the low-grade, disseminated Hammond Reef gold deposit. The shear zone juxtaposed a greenstone belt against tonalite gneiss and was locked by an intrusion that was emplaced during the final stages of suturing. After cessation of activity, fluids channeled along fault- and intrusion-related fractures led to the pervasive sericitization of feldspars. Foliated zones resulted from flattening in the weaker sericite-rich tonalite during progressive alteration without any change in the regional NW-SE shortening direction. The anastomosing pattern may have been inherited from an earlier ductile fabric, but sericite alteration and flattening fabrics all formed post-shearing. Thus, the apparent foliated fracture network adjacent to the Marmion Shear Zone is a second-order effect of shear-related damage, distinct in time from shear activity, adjacent to an effectively dormant shear zone. This phenomenon has implications for understanding the relative timing of fault zone activity, alteration and (in this case) gold mineralization related to long-term fault zone permeability.

1. Introduction

Zones of deformation, fluid flow and alteration are commonly observed around major faults and shear zones. In brittle faults, the development of fractured damage zones is attributed to off-fault fracturing associated with fault growth, rupture propagation and stress concentrations caused by geometric heterogeneities in fault systems (Shipton and Cowie, 2003; Mitchell and Faulkner, 2009; Savage and Brodsky, 2011; Johri et al., 2014). In ductile shear zones, strain gradients in the deformation fabrics are related to strain localization around the high-strain core (Coward, 1976; Ramsay, 1980; Mohanty and Ramsay, 1994; Fusseis et al., 2006; Carreras et al., 2010). Major shear zones are known to have a long history of multi-phase deformation, and many studied faults record an evolution from ductile deformation at depth, to later brittle deformation near the surface (Holdsworth et al., 2001; Rutter et al., 2001; Bezerra et al., 2014; Salomon et al., 2015). The deformation zones around faults or shear zones reflect inherited fabrics developed throughout the life of these structures. The fabric development and alteration associated with early deformation may control subsequent structural and geochemical evolution. In this paper, we use the term ‘damage aureole’ to describe a zone of concentrated deformation fabrics and alteration adjacent to a major fault or shear zone, which cannot be described by only brittle fracturing around a fault (c.f. ‘damage zone’ Cowie and Shipton, 1998; Childs et al., 2009; Savage and Brodsky, 2011). Once established, these damage aureoles may act as loci for fluid flow and further deformation, even after activity on the shear zone that formed them has ceased. Therefore, juxtaposition of different periods of deformation can obscure the spacial and temporal link between fault cores and damage aureoles.

In the traditional view, damage zones represent deformation gradients around faults/shear zones and are expressed by distributed small offset fracturing (“damage”) during progressive slip along principal slip surfaces (Chester and Logan, 1986; Chester and Chester, 1998; Gudmundsson et al., 2001; Sibson, 2003; Kim et al., 2004). Fractured damage zones typically show a gradually decreasing fracture density away from the fault core (Chester and Logan, 1986; Rawling et al., 2001; Shipton and Cowie, 2003;

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Faulkner et al., 2003, 2010; Mitchell and Faulkner, 2009; Savage and Brodsky, 2011). Fault zones and their associated wall-rock damage aureoles influence fluid flow through the crust and allow for deep crustal fluids to move to shallower depths (Sibson et al., 1988; Sibson, 1992; Kennedy et al., 1997; Cox, 2002; Kulongoski et al., 2013). Fluid flow is controlled by permeability contrasts leading to fluid conduits or barriers, and can be localized or distributed in and around fault zones (Caine et al., 1996; Faulkner et al., 2010). Fluid flow through fault zones is often recorded as hydrothermal alteration of the fault core and wall rock (Goddard and Evans, 1995; Clark et al., 2005; Caine et al., 2010; Morton et al., 2012; Arancibia et al., 2014). Concentrated flow of a fluid through fault zones may also lead to the formation of economic ore deposits within the fault core and the surrounding damage aureoles (Vearncombe, 1998; Piessens et al., 2002; Sibson, 2001; Micklethwaite, 2009; Moir et al., 2013).

We present map-scale and microstructural observations of a damage aureole adjacent to the trace of an inferred terrane-bounding shear zone, whose core has been obscured by the intrusion of a granodiorite pluton. The Marmion Shear Zone (MSZ) lies along the western margin of the tonalite – granodiorite Marmion gneiss terrane in the Superior Province in western Ontario (Fig. 1). The shear zone separates the 3.00 Ga Marmion gneiss from the 3.00 to 2.93 Ga Finlayson Lake greenstone belt (Stone, 2008a, 2010). The Diversion Stock granodiorite intruded along the shear zone and plays an important role in identifying and separating the subtleties of the deformation history and cross-cutting structural fabrics. The damage aureole is developed within the Marmion gneiss, and to a lesser extent, within the Diversion Stock, and hosts the disseminated, low-grade Hammond Reef gold deposit. The damage aureole consists of a fractured and altered zone along the entire length of the terrane boundary with localized foliation zones mapped by Stone (2008a) as a regional anastomosing pattern parallel to the western margin of the Marmion gneiss (Fig. 2). In the course of a study of the Hammond Reef gold deposit, we discovered a disparity in timing, kinematics, and conditions of deformation between motion on the Marmion Shear Zone and deformation that formed the anastomosing foliated zone adjacent to the terrane boundary. In this paper we relate the observed deformation fabrics in the tonalite – granodiorite rocks to the regional deformation history and describe and discuss the origin of anastomosing foliation in order to explain the seemingly paradoxical relationship between the damage aureole and the Marmion Shear Zone.

2. Geological setting

The Superior Province of North America is composed of Archean tonalite-trondhjemite-granodiorite (TTG) and greenstone belt terranes. Our study area is located within the south-central portion of the Wabigoon subprovince, which lies immediately to the north of the Quetico subprovince, across the Quetico fault (Fig. 1). The Wabigoon subprovince is a mainly Mesoarchean crustal block that has been subdivided into greenstone belt- and TTG-dominated terranes (the Marmion, Winnipeg River, eastern Wabigoon and western Wabigoon terranes; see Davis and Jackson, 1988; Tomlinson et al., 2003; Percival, 2007). The onset of deformation in the south-central Wabigoon subprovince has been dated at around 2.92 Ga, based on the youngest igneous ages found in greenstone belt terranes (Tomlinson et al., 2003, 2004; Percival, 2007). Younger, east-west trending terrane boundaries across the Superior Province record a progressive north to south amalgamation of subprovinces between 2.72 and 2.68 Ga (Corfu and Stott, 1986; Polat and Kerrich, 2001; Percival et al., 2006; Percival, 2007). The southern margin of the Wabigoon subprovince is the ~2.70 Ga Quetico fault, which records dextral transpression during accretion of the Quetico and Wawa subprovinces from the south

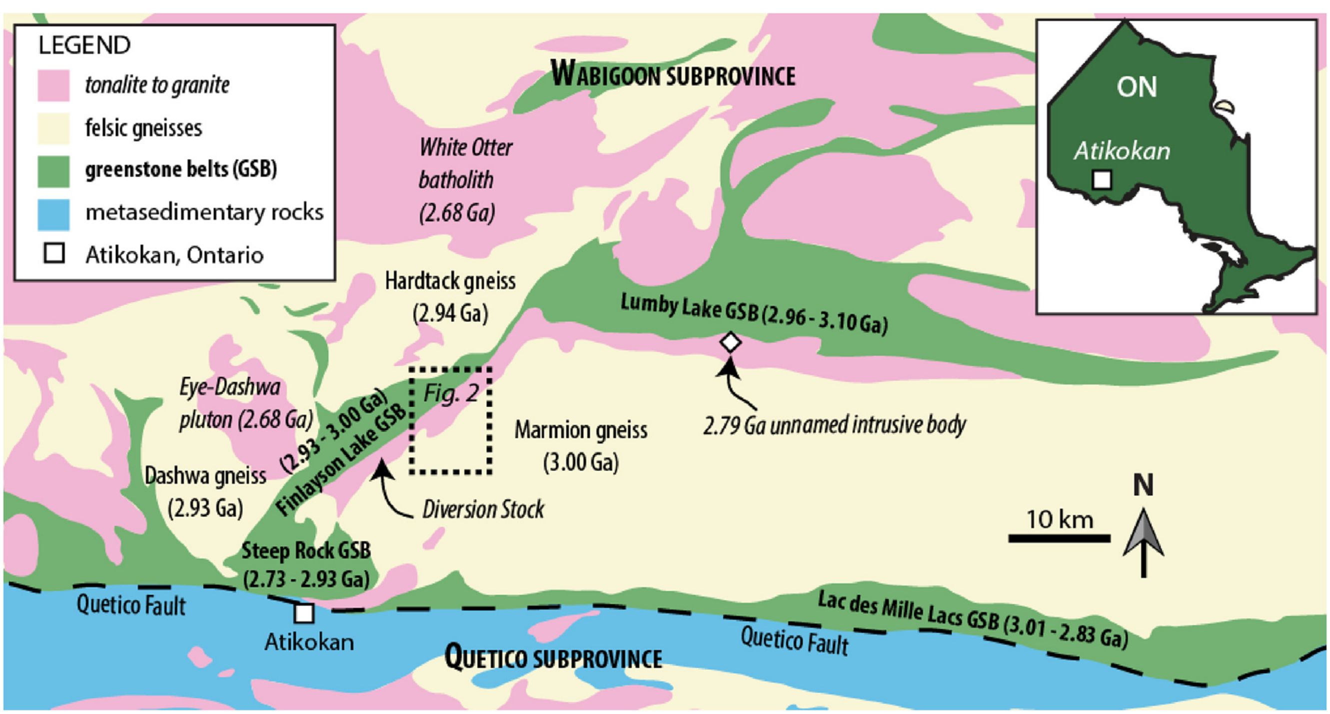

Fig. 1. A simplified regional geological map of the south-central Wabigoon subprovince showing the ages of the Archean tonalite-trodhjemite-granodiorite (TTG) and greenstone belt terranes (modified from Stone, 2008a). The eastern boundary of the Finlayson Lake greenstone belt with the Marmion gneiss is thought to be a tectonic contact called the Marmion Shear Zone, and was intruded by the Diversion Stock. The east-west trending dextral Quetico fault to the south separates the Wabigoon subprovince (north) from the Quetico subprovince (south). Location of U-Pb age for boundary intrusive between Marmion gneiss and Lumby Lake greenstone belt is shown (diamond, Buse et al., 2010). Inset map: Outline of Ontario, Canada with location of Atikokan shown.