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Rare earths and other trace elements in minerals from skarn assemblages, Hillside iron oxide–copper–gold deposit, Yorke Peninsula, South Australia

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ABSTRACT

The Hillside Cu–(Au) deposit, Yorke Peninsula, South Australia, is a recently-discovered ore system within the 1.6 Ga World-class Olympic iron oxide–copper–gold (IOCG) Province. The deposit is characterized by a skarn-style alteration zone. Analyses of feldspar, calcite, skarn minerals (garnet, pyroxene, clinozoisite and actinolite) and accessories (titanite, apatite and allanite), and grain-scale element mapping by laser-ablation inductively-coupled plasma mass spectrometry are used to assess the distributions of rare earth element (REE), incompatible and ore-forming elements in host rocks, prograde and retrograde skarn.

Garnet is a major repository of HREE, especially in prograde skarn, whereas LREE-enriched clinozoisite is the principal REE-host in retrograde skarn. REE distribution patterns define a pronounced partitioning of elements among the dominant coexisting minerals. Compositional variation between assemblages, and also within individual grains, defines an evolution from early feldspar–pyroxene skarn through main-stage calcic skarn to the ore-stage. A switch from a prograde, HREE-dominant signature to a LREE-enriched signature is observed in both retrograde and distal skarn. Zr-in-titanite geothermometry supports transition from magmatic to hydrothermal, skarn-forming processes at temperatures of ~660 °C; the initiation of ore-stage is about 100 °C lower. Understanding REE distributions in all minerals within a complex, multistage ore system assists the development of vectoring tools that use trace element chemistry in exploration for similar IOCG deposits beneath regolith cover across the Olympic Province. Titanite and apatite show particular promise because of their characteristically distinct REE patterns in magmatic and hydrothermal stages, trace element responses to redox changes, and their widespread abundance throughout different lithologies in the area.

1. Introduction

Hypogene alteration in iron oxide–copper–gold (IOCG) systems is characterized in terms of a sequence of paragenetic mineral assemblages that result from fluid–rock interaction at scales ranging from regional to district to deposit. The Mesoproterozoic Olympic Province, South Australia, hosts a large number of World-class IOCG deposits (Skirrow et al., 2007; Hayward and Skirrow, 2010). Although host rocks vary, these deposits can be broadly divided into two types: giant sericite-altered, hematite-dominant IOCG systems (typified by Olympic Dam and Prominent Hill); and a group of deposits of comparable age in which both hematite and magnetite are present and which are associated with a marked skarn-like alteration signature that could represent a deeper style of mineralization. Hillside, the subject of the present study, is within this latter group.

Since the bedrock of the Olympic Province has a negligible surface expression and lies under a thick cover sequence, there is considerable motivation to identify and understand the geochemical footprints of these ore systems and to develop vectoring tools that can be applied in exploration. Rare Earth Elements (REE) are abundant in most if not all IOCG systems (Hitzman, 2000; Williams et al., 2005), and although the elements are not extracted, the Olympic Province is one of the largest REE concentrations on Earth. The changing distribution of REE in a given mineral across the region is thus one potential guide to mineralization.

Research is focused on minerals which are ubiquitous in IOCG systems and their enclosing alteration envelopes, and which have been demonstrated to incorporate ppm-level concentrations of REE that can be quantified by analytical techniques such as laser-ablation inductively-coupled plasma mass spectroscopy (LA-ICP-MS). In order

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to apply such tools, however, there is a need to understand REE distributions in all minerals within a given ore system, and the role which their partitioning among coexisting minerals plays during the lifespan of that system. Only then can the distribution patterns in selected minerals be considered as predictive tools for identification of proximal/distal or mineralized/non-mineralized relationships.

Similar approaches have been made to quantify REE deportment in granites (Bea, 1996; Gromet and Silver, 1983) but the work reported here represents the first attempt at building an integrated, holistic model of REE distribution in an IOCG-skarn system. We use changes in these elements within skarn minerals and accessories to monitor the evolution of alteration of the Hillside IOCG deposit, Yorke Peninsula, South Australia (Conor et al., 2010: Fig. 1). At Hillside, the alteration reflects a spatial–temporal development of ore zones rooted within skarn alteration. The lead idea is that the trace element endowment in IOCG systems can be constrained and used for geochemical fingerprinting in a range of exploration templates. Results have general application to IOCG systems and could also be extended to other mineral systems assuming that geological processes involved can be constrained both spatially and temporally.

2. Background

2.1. The Olympic IOCG Province

The Olympic IOCG Province is the world's most richly-endowed IOCG ore province. It includes the super-giant Olympic Dam deposit, Prominent Hill, Carrapateena, Punt Hill, and other prospects (Hayward

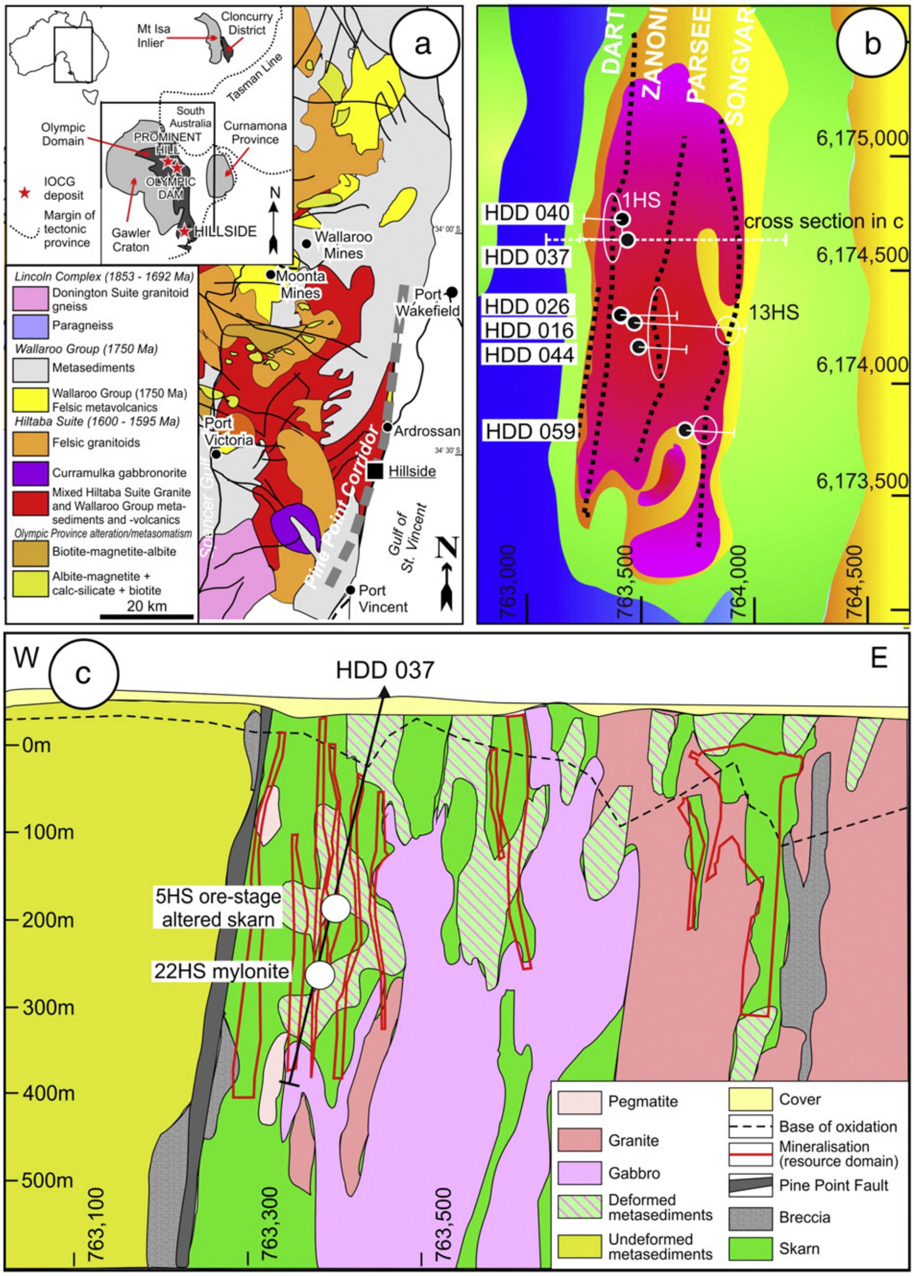

Fig. 1. (a) Geological sketch map of the northern part of the Yorke Peninsula showing Hillside and the Olympic Province. Inset shows the location of the Gawler Craton and other Australian IOCG-bearing provinces mentioned in the text (simplified after Conor et al., 2010). (b) Location of sampled drillholes projected onto the residual magnetic anomaly defining the Hillside deposit. Areas covered by sampling (Zanoni and Parsee orebodies) are circled. Locations of anomalously REY-rich sample (1HS) and sample 13HS from Songvaar are shown. (c) Schematic W–E cross-section (4600N transect, drillhole HDD037), showing typical position of skarn and orebodies relative to intrusives and host rocks. Panels (b) and (c) are simplified after company reports (www.rexminerals.com.au/).