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Genesis of Neoproterozoic Au-bearing volcanogenic sulfides and quartz veins in the Ar Rjum goldfield, Saudi Arabia

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ABSTRACT

The Ar Rjum goldfield is an example of late Neoproterozoic Au mineralization that is hosted by submarine arc assemblage and syn-anorogenic intrusive rocks. Apart from ancient workings, recent exploration in the goldfield defined three main targets along 3 km N–S corridor (Um Na'am, Ghazal and Wasema), and indicated that Wasema alone hosts 11.8 Mt @ 2.5 g/t Au. The majority of gold and sulfide mineralization is confined to diorite, where gold content increases with shearing, pyrite–sericite–carbonate alteration and development stockworks of quartz–carbonate–pyrite veins and stringers. Generally, the concentration of gold increases in the diorite samples that experienced variable degrees of hydrothermal alterations near local shear zones. Anomalous gold content (up to 11.76 g/t) in some metachert is the result of the remobilization of volcanogenic lattice-bound (refractory) Au into free Au due to post-metamorphic hydrothermal alterations. The chemistry of pyrite from the mineralized veins and stringers indicates considerable amounts of gold that reaches ~0.3 wt.%. Chlorite that co-exists with pyrite in the hydrothermally altered metavolcanics is mostly sheridanite with up to ~25 wt.% FeO^t and minor amounts of ripidolite. Chlorite geothermometry suggests that two temperature ranges affecting the area. The first temperature range (290–334 °C) is consistent with regional greenschist facies metamorphism, and the second (306–355 °C) is interpreted to be related to recrystallization-submarine hydrothermal alteration related to the gold mineralization. Stable isotope ($\delta^{34}S$, $\delta^{18}O$ and $\delta^{13}C$) data suggest an original volcanogenic arc signature that has been slightly modified by low-grade metamorphism, and finally by the late interaction of hydrothermal fluids. Ore evolution model for the Ar Rjum goldfield includes seafloor sulfide alteration, several deformation episodes and intrusive effects, and in this context the ore resulted from the reduction of seawater sulfates. The gold-rich veins interpreted as orogenic lode deposits are confined to localized shear zones in a syn-orogenic diorite.

1. Introduction

The Ar Rjum goldfield (Fig. 1) is a ~7 × 9 km mineralized area in western Saudi Arabia and represents a peculiar example of Neoproterozoic volcanogenic gold-bearing pyrite in addition to gold associated with pyrite in quartz veins along shear zones cutting syn-tectonic dioritic intrusions and syn- to late-tectonic granitic intrusions. The area includes several gold prospects in addition to a zinc–copper prospect. The Ma'aden Mining Company has discovered gold mineralization in outcrops and drill holes over a strike length of 1.2 km in one of the five target areas and a resource of 11.8 Mt with an average grade of 2.5 g/t gold has been estimated. The company is carrying a detailed exploration program to define the extension of the potentially mineralized zones both vertically and horizontally in the prospect area.

Sulfide-rich metavolcanics and volcanic massive sulfide (VMS) deposits are located in arc-related successions and the remainders are hosted by ophiolitic successions in what are interpreted to be present in back-arc rifts or rifted marginal basins (Franklin et al., 1999). The VMS deposits are major sources of gold and other valuable metals that are formed by different genetic processes (Hannington and Scott, 1989; Hannington et al., 1999; Huston, 1999). The characteristics of any VMS type vary from one to another according to the tectonic setting, particularly the ones that are formed orogenically where quartz veining, metamorphism and deformation are major events (Franklin et al., 1999; Lydon, 1988). These deposits are located in a variety of submarine volcanic terranes from mafic bimodal through felsic bimodal to bimodal siliciclastic. Their host successions are commonly underlain by coeval sub-volcanic intrusions and sill-dyke complexes, which are typically metamorphosed to greenschist and lower amphibolite facies in greenstone belts of various ages (e.g. Dubé et al., 2007). In the sulfide-rich metavolcanics and VMS deposits, hydrothermal activity and associated sulfidation and gold mineralization take place during deformation and metamorphism, or sometimes after metamorphism (e.g. Groves et al., 2000; Hagemann and Cassidy, 2000). In contrast, Chang et al. (2008) used some isotopic data to conclude that sulfidation and associated

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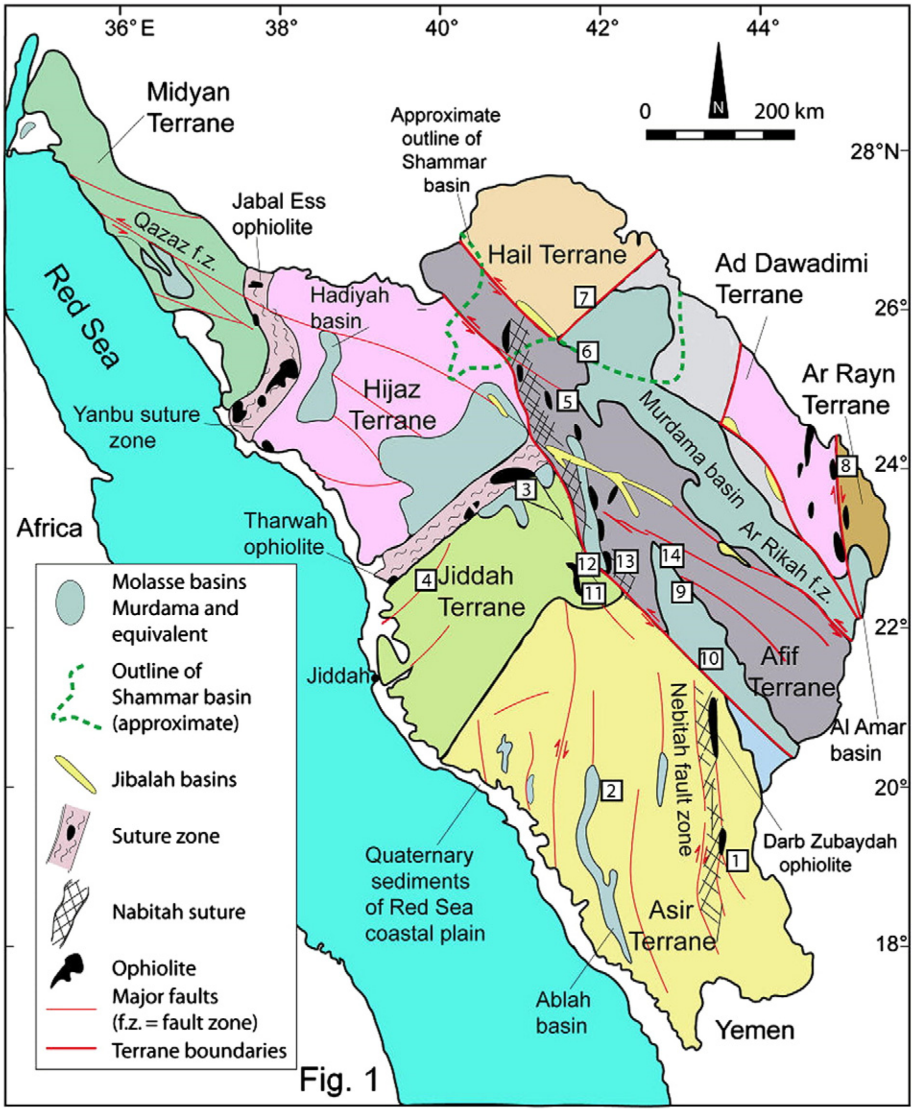

Fig. 1. General geological map of the Arabian Shield showing location of the Ar Rjum goldfield, major tectonostratigraphic terranes, ophiolite belts, sutures, fault zones, post-accretionary basins of western Saudi Arabia (from Nehlig et al., 2002 with modifications by Johnson and Woldehaimanot, 2003; Stern and Johnson, 2010). Numbers represent locations of the major gold deposits as follows: 1) Hamdah, 2) Al Hajar and Jadmah, 3) Mahd ad Dhahab, 4) Jabal Shayban, 5) Humaymah, 6) Bulghah, 7) Sukhaybarat, 8) Al Amar, 9) Ad Duwayhi, 10) Um Matierah, 11) Ar Rjum, 12) Ash Shakhtaliya, 13) Zalm and 14) Bi'r Tawilah (including Jabal Ghadarah, Al Mansourah and Masarah).

gold mineralization is an early event in the history of basin rather than during metamorphism and deformation. At this early stage in the evolution of a basin, seawater was an active crustal fluid undergoing sulfate reduction. Although it is generally believed that most gold in orogenic and epithermal deposits are transported as bisulfide complexes, the source of sulfur has been equivocal for the last three decades (e.g. Stefansson and Seward, 2004; Williams-Jones et al., 2009). Orogenic Au-deposits in many arc terranes are generally localized where extensional tectonics are coeval with widespread magmatism (Goldfarb et al., 1997).

This paper presents the first published research on the stable isotope geochemistry of the mineralized zones in the Ar Rjum goldfield of Saudi Arabia. It provides a context of geology, mineralogy, and mineral chemistry, and focuses on reconnaissance-level collection of stable ($\delta^{34}S$, $\delta^{18}O$ and $\delta^{13}C$) isotope analyses of gold mineralization within the goldfield. This study aims to use the stable isotopes and mineral chemistry of pyrite and chlorite to elucidate the source of gold and sulfur in fluids associated with deposition of gold in the goldfield, and place this in the context of clear and better understanding of the source of gold and the role that seawater played in mineralizing fluids.

2. Regional geology and gold mineralization in Saudi Arabia

The crust in the Arabian Shield developed during transpressive suturing between East and West Gondwana that culminated ~550 Ma (Johnson and Kattan, 2001). It formed through a prolonged history of the accretion of interoceanic island arcs along sutures now marked by ophiolites (Al Saleh et al., 1998; Bakor et al., 1976; Gass, 1981; Johnson, 1998; Kröner, 1985; Pallister et al., 1987; Quick, 1991; Stoeser and Camp, 1985; Vail, 1985). The accretions episodically took place between 900 and 550 Ma ago during the closure of the Mozambique Ocean (Stern, 1994). Accretion may have included an oceanic plateau formed at the head of an upwelling mantle plume (Stein and Goldstein, 1996).

The Arabian Shield in Saudi Arabia is slightly metamorphosed (except for some areas of gneissic rocks) and constitutes one of the best-preserved and well exposed Neoproterozoic assemblages developed during the accretion of volcanic arcs. The shield is overlain to the east, north, and south by a thick succession of Phanerozoic sedimentary rocks, and is bound to the west by the Red Sea that now separates the Arabian and Nubian Shields in western Arabian Peninsula and NE