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Application of ASTER data for exploration of porphyry copper deposits: A case study of Daraloo–Sarmeshk area, southern part of the Kerman copper belt, Iran

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ABSTRACT

The Cenozoic Urumieh–Dokhtar Magmatic Belt (UDMB) of Iran is a major host to porphyry Cu ± Mo ± Au deposits (PCDs). Most known PCDs in the UDMB occur in the southern section of the belt, also known as the Kerman Copper Belt (KCB). Three major clusters of PCDs are distinguished in the KCB and include the Miduk, Sarcheshmeh and Daraloo clusters. The Daraloo and Sarmeshk deposits occur in a northwest–southeast-trending fault zone that is characterized by the presence of a narrow zone of alteration–mineralization that contains a series of Oligocene granitoids and Miocene porphyritic tonalite–granodiorite plutons that cut Eocene andesitic lava flows and pyroclastic rocks. Here we use various techniques, including different ratio images, minimum noise fraction, pixel purity index, and matched filter processing to process ASTER data (14 bands) and generate maps that portray the distribution of hydrothermal minerals (e.g., sericite, kaolinite, chlorite, epidote and carbonate) related to PCD alteration zones. In order to validate the ASTER data, follow-up ground proofing and related mineralogical work was done which, in all cases, proved to be positive. The results of this work have identified the regional distribution of hypogene alteration zones (i.e., phyllic, argillic, propylitic and silicic), in addition to areas of secondary Fe-oxide formation, which are coincident with known sites of PCDs. The regional distribution and extent of the alteration zones identified also highlighted the role of regional structures in focusing the mineralizing/altering fluids. These results demonstrate very convincingly that ASTER imagery that uses the appropriate techniques is reliable and robust in mapping out the extent of hydrothermal alteration and lithological units, and can be used for targeting hydrothermal ore deposits, particularly porphyry copper deposits where the alteration footprint is sizeable.

1. Introduction

Porphyry copper deposits (PCDs) presently provide most of the world's Cu, Mo, and Re, about 20% of the world's Au, and minor amounts of other metals such as Ag, Pd, Te, Se, Bi, Zn, and Pb (Sillitoe, 2010). These deposits typically develop at shallow crustal depths (<2–6 km from surface) and are associated with extensive hydrothermal alteration, typically zoned from an inner potassic assemblage, dominated by biotite and K-feldspar, which grades outward and upward into phyllic, argillic, and propylitic zones, respectively (e.g., Lowell and Guilbert, 1970; Mars, 2010, 2014; Mars and Rowan, 2006). The phyllic zone typically contains sericite and pyrite-rich rocks, the argillic zone consists of alunitic and kaolinitic rich-rocks, and the outer propylitic zone consists of a variable mineralogy of chlorite–epidote and calcite (e.g., Abrams and Brown, 1984; Hunt and Ashley, 1979; Lowell and Guilbert, 1970; Rowan and Mars, 2003; Seederoff et al., 2005; Spatz and Wilson, 1995). In addition, silicic alteration distinguished by the replacement of earlier alteration products and also primary igneous minerals by silica, and also by silica lithocaps and quartz veins, has been reported from the upper parts of many porphyry systems (e.g., Alimohammadi and Alirezaei, 2012; Ninomiya, 2003; Sillitoe, 1995; Titley, 1972; Tommaso and Rubinstein, 2007).

The potassic and phyllic alteration zones are closely associated with economic sulfide mineralization and, therefore, are considered as prime targets for PCD exploration. In particular, phyllic alteration can cover a large area and has served as an efficient tool in regional exploration for PCDs. This alteration typically overprints earlier potassic assemblages due to ingress of acidic to near-neutral fluids and is associated with the destruction of original magmatic minerals (e.g., plagioclase, K-feldspar), as well as secondary hydrothermal biotite and K-feldspar (e.g., Dilles and Einaudi, 1992; Reed, 1997; Singer et al., 2008; Sillitoe, 2010; Titley, 1972). The hypogene ore in these systems is characterized by the common occurrence of pyrite (<1–10%) and chalcopyrite (<1–3%) with subordinate bornite and molybdenite. Exhumation of PCDs

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results in their differential exposure at surface and more importantly also enhances oxidation of sulfides with the development of Fe oxides/hydroxides, jarosite (a hydrous K–Al sulfate) and production of acid alteration of earlier mineral assemblages. During this exhumation, Cu-bearing minerals can, at least partly, be leached and the Cu mobilized and re-precipitated to produce a supergene enriched blanket below the contemporaneous water table, and this leads to upgrading of the original hypogene ore.

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an advanced multispectral satellite imaging system that has created new opportunities for the mapping of geological structures and detecting certain alteration minerals or assemblages (e.g., Cudahy et al., 2008; Hewson et al., 2005; Mars and Rowan, 2006; Rowan and Mars, 2003; Rowan et al., 2003). ASTER is a cooperative effort between NASA and Japan's Ministry of Economic Trade and Industry (METI). The instrument was launched on board NASA's TERRA spacecraft in December 1999 and consists of three separate subsystems with a total of 14 bands: (1) the visible near infrared (VNIR) subsystem obtains optical images of three bands (0.52 to 0.86 μm), with a spatial resolution of 15 m; (2) the shortwave infrared (SWIR) subsystem scans optical images of six bands (1.60 to 2.43 μm), with a spatial resolution of 30 m; and (3) the thermal infrared (TIR) subsystem obtains optical images of five bands (8.12 to 11.65 μm) with a spatial resolution of 90 m (Fujisada, 1995). ASTER also has a backward-looking VNIR telescope with a resolution of 15 m which means that stereoscopic VNIR images can be acquired at 15 m resolution. The swath width is 60 km, but off-nadir pointing capability extends the total cross-track viewing of ASTER to 232 km (Fujisada, 1995).

The Cenozoic Urumieh–Dokhtar Magmatic Belt (UDMB) of Iran is an important metallogenic terrain for hosting porphyry Cu ± Mo ± Au deposits (Fig. 1; e.g., Alirezaei and Hassanpour, 2011; McInnes et al., 2005; Richards et al., 2012). The UDMB is a relatively narrow (50–80 km), linear belt dominated by calc-alkaline intrusive and extrusive rocks, and associated pyroclastic materials. The evolution of the UDMB is associated with the successive stages of closure of the Tethyan Ocean, including subduction during the Cretaceous–Oligocene, and continent–continent collision in the late Paleogene–Neogene (e.g., Agard et al., 2005; Allen et al., 2004; Berberian et al., 1982; Dercourt et al., 1986; McClay et al., 2004; Mohajjel et al., 2003; Ricou, 1994). Most of the known PCD systems are located in the southern section of the UDMB, also known as the Dehaj–Sardoieh belt or Kerman copper belt (Fig. 1). The National Iranian Copper Industries Company (NICICO) has conducted extensive exploration for PCDs in the UDMB, as well as other Cenozoic magmatic assemblages in Iran, since 2005. Processing satellite images has proven to be an effective tool in regional exploration for PCDs, including a variety of settings in Iran (e.g., Mars and Rowan, 2006; Mars, 2010; Pour et al., 2011; Ranjbar et al., 2004; Tangestani et al., 2008), examples of which include the following: (1) Ranjbar et al. (2004) identified iron oxides/hydroxides and hydroxyl-bearing minerals associated with hydrothermal and supergene alterations in PCD systems in the southern part

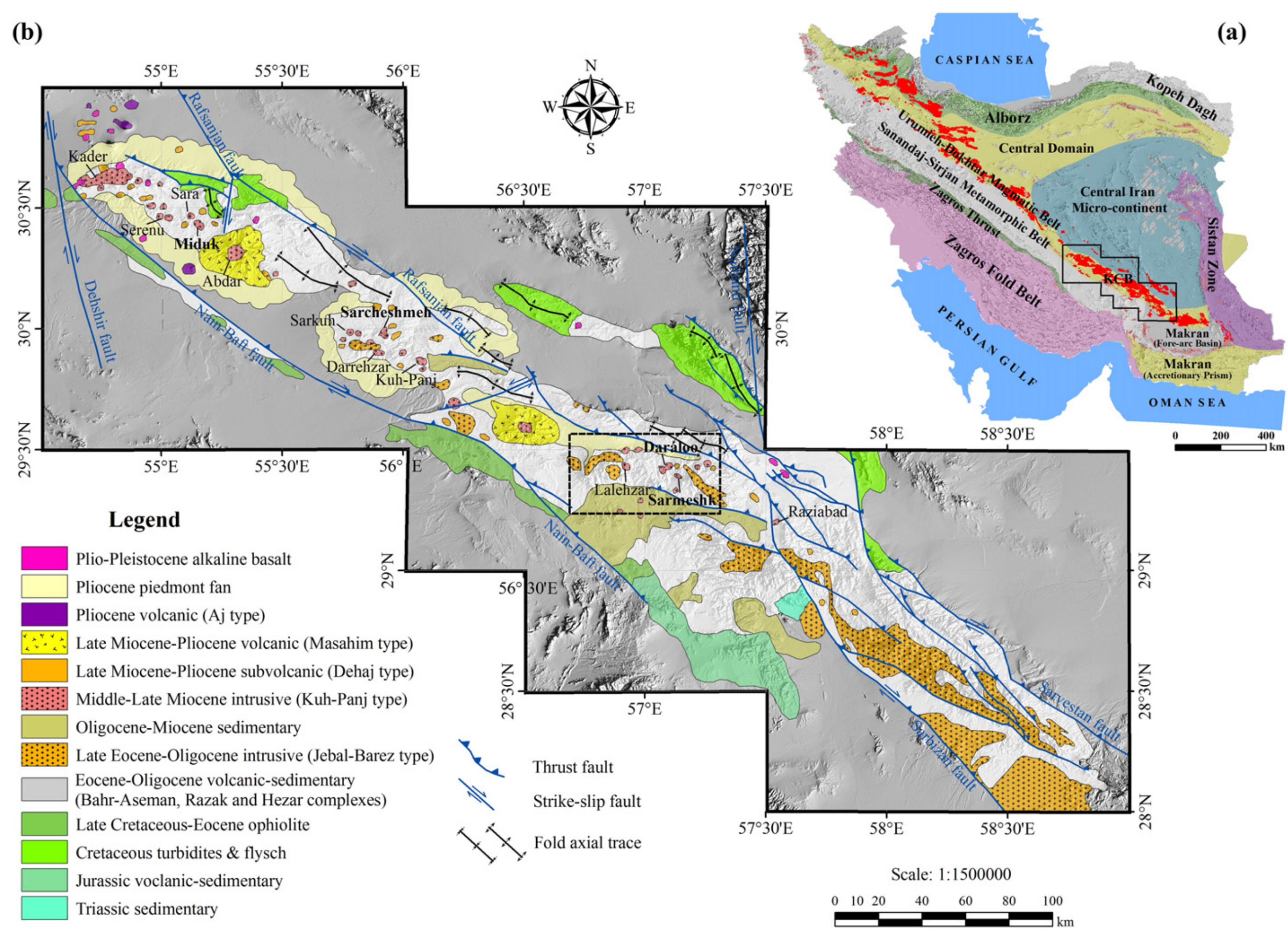

Fig. 1. (a) Major structural and geological subdivisions of Iran, after Stocklin (1968) and Nabavi (1976), which show the location of the Kerman Copper Belt (KCB) in the Urumieh–Dokhtar Magmatic Belt; (b) simplified litho-structural map of the KCB and location of three major porphyry Cu deposit clusters (Miduk, Sarcheshmeh and Daraloo) that are discussed in the text. Compiled from Dimitrijevic, 1973; Saric and Mijalkovic, 1973; Walker, 2006; Shafiei et al., 2009.