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Original paper

Distribution of base metals and the related elements in the stream-sediments around the Ahar area (NW Iran) and their implications

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ABSTRACT

The study area is located in the Ahar region, NW Iran. Volcanic rocks of Eocene cover major parts of the area, within which granitic-granodioritic intrusive bodies of Oligocene intruded and produced hydrothermal alterations and Cu-Au mineralization. This paper aims to explore anomalies of base metals and related elements across the region based on systematic sampling of stream sediments and using the secondary geochemical halos. In this regard, by taking into account factors such as stratigraphy, lithology, tectonics and the topologic center of the drainage system, 620 samples were taken from stream sediments and analyzed by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-OES) method.

All the distinguished anomalies correlate well with Oligocene granitic-granodioritic rocks and the related hydrothermal alterations occurred within the Eocene andesitic-basaltic volcanics, especially at the NE part of the quadrangle, as well as with alterations within trachy-andesitic and andesitic volcanics of Pliocene at the SE part of the quadrangle, where epithermal gold and Pb-Zn mineralization is found. Most of he studied elements also show moderate to strong anomalies over the Sonajil porphyry-type Cu mineralization. Copper, and to some extent Mo, as well as Pb, Zn, Sn, W, As and Sb are the best examples of this association. Bismuth has more limited anomalies across the region, showing correlation with the granitoid intrusion at the east of Ahar and the hydrothermal alterations within the Pliocene andesitic and basaltic rocks at SE of Ahar quadrangle which, considering the presence of epithermal gold and Pb-Zn veins in both areas, can be attributed to epithermal processes. However, anthropogenic pollutions are also found for As, Fe, V, Ti, Ni and Co downstream the urban and rural areas. In this regard, besides the Sonajil area, where porphyry-type Cu mineralization is discovered, the NE and SE parts of the quadrangle present promising areas for further investigations.

1. Introduction

Among the surface materials important for studying secondary geochemical halos, stream-sediments have a significant place in small-scale and medium-scale investigations (Levinson, 1980). Geochemical surveys using multi-element analysis on stream sediments are widely used to describe the geochemical characteristics of a watershed, to identify areas with anomalous concentrations of elements (Cohen et al., 1999) and to discover potential ore deposits. Chemical composition of stream sediments tells important details about the lithology of the watershed and the presence of ore deposits and pollution sources (Rantitsch, 2000). This method is particularly applicable for watersheds with moderate precipitation rate.

In this regard, stream sediments surveys remain the general geochemical methodology used in regional reconnaissance exploration (e.g. for Au) in areas where relief permits development of distinct drainage systems (Hale and Plant, 1994; Fletcher, 1997). Sampling of stream sediments has advantage over the rock or soil sampling, as the latter represents only a relatively small area close to the sample site, while stream sediments in any part of a drainage system represent weathering products of the rocks present in the upper parts of the system. Such investigations are especially efficient in areas covered by alluviums and/or greenfields with limited rock outcrops. In this research, systematic sampling and analysis of stream sediments and statistical analysis of the obtained data

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are used to discover the potential anomalies of elements and so, the mineralized zones and promising areas across the 1:100000 quadrangle of Ahar.

The 1:100000 geologic map of Ahar covers an area of 3074 km^2, being located at NW Iran between latitudes of 47° N and 47° 30′ N and longitudes of 38° E and 38° 30′ E (Figs. 1 and 2). Based on structural-sedimentary classifications of Iran, this area is part of the Alborz-Azarbaidjan zone (Nabavy, 1976) and Central Iranian domain (Alavi, 1991; Agha Nabaty, 2004). Most of the area is covered by Tertiary magmatic rocks, especially Eocene andesitic-basaltic rocks of Urumieh–Dokhtar volcano-plutonic belt of Iran (UDMA, Fig. 1), which is formed by the subduction of Neo-Tethyan oceanic crust beneath the Central Iranian plate (Berberian and King 1981). The Eocene volcanic rocks across the UDMA are referred to as subduction-related normal arc calc-alkaline magmatic products (e.g., Berberian et al., 1982; Shahabpour, 2007; Ghorbani and Bezenjani, 2011; Moritz et al., 2016), representing the peak of magmatic activity across it (e.g., Stocklin, 1974; Alavi, 2004). If we consider the late Eocene-Oligocene age for the collision between Arabian and Iranian plates (e.g., Allen and Armstrong, 2008; Dargahi et al., 2010; Aghazadeh et al., 2011; Castro et al., 2013), the Oligocene and younger volcanic and intrusive rocks in NW Iran will coincide with collisional to post-collisional stage (e.g., Sungun porphyry stock, Alavi et al., 2014; Kighal porphyry stock, Simmonds, 2013; Sonajil porphyry stock, Hosseinzadeh et al., 2010).

Intrusion of granitic-granodioritic bodies of Oligocene age produced hydrothermal alteration halos and Cu and Au mineralization in the area (e.g., Sonajil porphyry-type Cu mineralization; Hosseinzadeh et al., 2010). By taking into account the potential of base metal mineralization across the region and the fact that subsequent weathering can release these metals from altered and mineralized rocks into the stream sediments, this study aims to determine the statistical relationships and geochemical characteristics of base metals and associated elements in stream sediments and to help identifying the likely sources of mineralization in the region.

2. Regional geology

Based on the 1:100000 geologic map of Ahar (Mahdavi and Amini Fazl, 1988), the oldest rock units in the area are volcanic and sedimentary rocks of upper Cretaceous. Volcanic units of this age are mainly comprised of porphyritic andesite, andesi-basalt and olivine basalt (K^v), accompanied and overlain by acidic pyroclastics (submarine volcanic breccia and tuffite) and sedimentary rocks, including basal conglomerate (unconformably overlying the volcanic rocks), sandstone, shale, marl (K^s) and micritic fossiliferous limestone (K^l), which have limited outcrops at west and northwest of the region.

About half of the region is covered by volcanic, intrusive and sedimentary rocks of Tertiary age (Fig. 2). Lithologic units of Paleocene-Eocene mainly include volcanic rocks formed in subaerial and subaqueous (shallow marine) conditions. Paleocene volcanic units include porphyritic andesite to trachy-andesite, tuff and agglomerate (P^v). Some sub-volcanic microdioritic and diabasic rocks also accompany this unit. Sedimentary rocks of Paleocene age (P^s) are comprised of alternations of gypsiferous marl, calcareous sandstone and thin-bedded light gray limestone, as well as a purple conglomerate containing volcanic pebbles, 2–15 cm diameter across, set in a completely consolidated matrix, which occupy small areas in the north and south of the Heris town (Fig. 2). Fossil species of *Radiolaria*, *Globigerinids* and *Globorotalids* indicate Paleocene to Lower Eocene ages.

Volcanic rocks of Eocene age cover most parts of the Ahar area, especially at its eastern section and include lava flows of porphyritic to mega-porphyritic andesite to trachy-andesite, pyroxene andesite and andesi-basalt compositions, which have experienced kaolinization and alunitization, trachy-andesitic to trachytic lavas with coarse crystals of secondary analsim, basic lavas of olivine basalt, andesi-basalt and pyroxene andesite compositions, along with pyroclastic rocks of intensely silicified and sericitized acidic tuff, welded and brecciated crystal and lithic tuffs and ignimbrites of dacitic to rhyodacitic composition, and tuffite (E^v). Some thin-bedded nummulite-bearing limestone lenses are also found confined within these volcanics, which indicate early to middle Eocene age (E^l).

Rock units of Oligocene age include scarce occurrences of rhyolitic domes (O^r), dacitic breccias and ignimbrite, and several large intrusive bodies, including Khankandi, Yuseflu, Sonajil and Razgah. The Khankandi pluton is comprised of granodiorite-quartz monzonite and monzonite-gabbro phases and lamprophyric and dacitic dikes, in order of emplacement (Jamali et al., 2012). Monzonites and gabbros form the main part of this pluton (Aghazadeh et al., 2010). Yuseflu pluton is composed of quartz monzonite, granodiorite and granite phases, later intruded by a non-altered and non-mineralized monzonitic stock (Jamali et al., 2012). Both these plutons are tectonically post-collisional (Jamali et al., 2012). The Sonajil intrusive complex includes a porphyritic microdioritic stock (the host of porphyry-type Cu mineralization) and a dioritic to quartz-dioritic body (known as Incheh granitoid), in order of emplacement, which are emplaced within the pyroxene andesites, brecciated tuffs and ignimbrites of Eocene age during the post-collisional stage of the Neo-Tethys ocean closure (Hosseinzadeh et al., 2010).

Another body of monzosyenite to pseudoleucite-bearing monzosyenite (ms) is located at the southeast of Ahar quadrangle (Razgah area) with 15–20 km^2 surface area (Mahdavi and Amini Fazl, 1988), having indistinct contact with parts of Miocene units. Several other intrusive bodies of granitic to granodioritic composition have also outcropped in the area (Mahdavi and Amini Fazl, 1988). It must be noted that hydrothermal alterations in the study area are mainly related to Oligocene intrusive magmatism, which have mostly affected Eocene volcanic host rocks.

Miocene units are sedimentary, comprised of marliferous limestone, gypsiferous marl and gypsum with no fossil traces, as well as alternations of sandstone, siltstone and marl intercalated with thin-bedded fossiliferous (*gastropoda*) limestone (maximum thickness of 10 m) (M^s), which have mainly outcropped at the southern and southwestern parts of the Ahar quadrangle.

Pliocene is characterized by a red-colored basal conglomerate and sandy conglomerate (Pl^s), unconformably overlying sedimentary and submarine volcanic rocks of upper-Cretaceous and Eocene, as well as Miocene marls. Conglomerate is locally accompanied by thin red-colored gypsiferous marl layers. Additionally, outcrops of volcanic rocks, including rhyolitic to dacitic ignimbrite and andesitic to trachy-andesitic lavas are found at the southwest of the study area (Pl^v). In the SE part of the study area, Pliocene-Quaternary volcanic fumaroles have produced alterations within the surrounding rocks, particularly andesitic to trachy-andesitic lavas of Pliocene.

Plio-Pleistocene units are mainly found at the western part of the Ahar area, especially covering Ahar plain, and include weakly-sorted and rounded conglomerate, along with siltstone and layers of gypsum and purple-colored tuff. Additionally, lacustrine deposits comprised of gray bedded clay, marl, siltstone and fine-grained sandstone, accompanied by thin beds of microconglomerate to conglomerate are observed in the Heris plain (QPl^s).

Quaternary units include unconsolidated pebble-bearing alluvial fans with variable thicknesses reaching up to several meters and unconformably overlying Plio-Pleistocene sediments in some