Int. J. Econ. Environ. Geol. Vol. 12 (1) 01-08, 2021

Journal home page: www.econ-environ-geol.org

Open Access

ISSN: 2223-957X

The Alteration and Mineralization Characteristics of Miocene Porphyry Cu-Au Deposits of Chagai Magmatic Belt, District Chagai, Balochistan, Pakistan

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Received: *20 January, 2021* ***Accepted:*** *13 February, 2021*

Abstract: Subduction related Miocene porphyry type deposits are found in the east-west trending Chagai magmatic belt (CMB) in Pakistan's western margin, Balochistan. This arc exists on the west segment of the Tethyan metallogenic belt in the south-west of Pakistan. Tethyan metallogenic belt is widely spread over 12,000 km from east to west direction from Indochina, Tibet, Pakistan, Iran, Turkey and Alpine mountain range in Europe. During the last thirty to forty years several porphyry deposits have been reported in the Chagai magmatic arc, including the very large Reko Diq H14-H15, large Saindak, Tanjeel, H35, H8 and medium Dasht-e-Kain porphyry deposits and many small porphyry copper deposits. These porphyry deposits were developed within the phase of calc-alkaline type magmatism in the Chagai arc. Tonalite, quartz diorite, and monzonite host the porphyry deposits within the adjacent sedimentary wall rock units of Sinjrani Volcanic Group, Juzzak, Saindak, and Amalaf Formations. The concentric zonal pattern of hydrothermal alteration in these porphyry deposits of the Chagai magmatic arc follows the world's major porphyry deposits' alteration pattern. Zones of hydrothermal alteration from distal to proximal part includes a potassic alteration, sericitic-clay-chlorite alteration, sericitic alteration, argillic alteration and propylitic alteration. Major ore mineralization in these deposits is of copper, gold, silver, molybdenum, and minor constituents of other base metals that have been reported to occur within hydrothermal alteration zones in the Miocene porphyry Chagai magmatic arc.

Keywords: Chagai magmatic belt, porphyry, hydrothermal alteration, mineralization.

Introduction

The porphyry type of hydrothermal deposits mainly consist of copper, gold and molybdenum which form along the active subduction zone (Sillitoe, 1972; Sillitoe and Hedenquist, 2003; Richards, 2003; John et al., 2010). Porphyry deposits mainly occur in the calc-alkaline batholiths and volcanic chains associated with Andean-type arc-system, numerous porphyry deposits originated from the late Paleozoic to Pliocene time in the continental margin type magmatic arc due to subduction of Nazca and Farallon oceanic plate beneath the South America continental plate (Sillitoe, 1972; Richards, 2003; Sillitoe and Perelló, 2005). In western Pacific and south-east Asia, multiple porphyry deposits belong to the Cenozoic magmatic arc formed due to the subduction of oceanic plates beneath the continental crust (Garwin and Others 2005). The Oligocene to Miocene Reko Diq and Saindak porphyry deposits occur in the Chagai magmatic arc in western part of Pakistan, formed due to northward subduction of the Arabian plate under the Afghan micro-continental plate (Siddiqui and Jan 2007; Perelló et al., 2008; Richards et al., 2012; Razique et al., 2014; Siddiqui et al., 2015). Late Triassic Zhongdian porphyry deposit located in the Zhongdian region in the northwest of Yunnan province in China forms the southern part of late Triassic Yidun arc, formed due to the westward subduction of Ganzi-Litang division of Paleo-Tethys ocean (Hou, 1993; Mo et al., 1994). The intra-arc is created by the subduction of the Ganzi-Litang oceanic plate, while the subduction of oceanic plate develops the latter underneath the Zhongza micro-block (Li et al., 2011 b) and late Cretaceous Pontide porphyry deposit occurs in the northern part of Turkey Pontide volcanic arc, which had developed due to the northward subduction of Izmir-Ankara-Erzincan oceanic plate (Yavuz at al., 1999; Nakov et al., 2002; Kekelia et al., 2004).

Numerous authors have discussed the tectonics, geochemistry, geochronology, mineralogy, and petrology during the last thirty to forty years. (Hunting Survey Corp, 1960; Ahmed et al., 1972, 1984, 1992; Dykstra, 1978; Arthurton, 1979; Britzman, 1979; Schmidt, 1980; Khan, 1986; Siddiqui, 1996, 2004, 2005, 2007, 2009, 2010, 2012, 2015). Furthermore, published work on the porphyry deposits in the Chagai magmatic arc is very limited (Sillitoe and Khan, 1977; Rowen et al., 2006; Perelló et al., 2008; Razique et al., 2014; Mastoi et al., 2019). This paper discusses the alteration and mineralization characteristics of Miocene porphyry deposits of Chagai magmatic arc which is mainly based on recent geological studies and available literature on alteration and mineralization pattern of porphyry deposits in the region. This study helps in understanding the hydrothermal alteration and mineralization model of porphyry deposits in the Chagai magmatic arc.

Geology of the Study Area

Chagai magmatic arc extends from the east to west direction and has a width of 150 km and length of about 400 km trending toward Iran (Spector and Associates Ltd., 1981, Farah et al., 1984, Siddiqui, 2005). This arc formed the western part of the Tethyan metallogenic belt in the south-west of Pakistan (Berberian et al., 1982; Jankovic and Petraschek, 1987). Tethyan metallogenic belt extend about 12,000 km long from east to west direction that begins from Indochina - south-east Tabit, southern Tabit, south-west Pakistan, south-east Iran, northwest Iran, lesser Caucasus north-east Turkey and Carpathians-Balkans-Rhodopes-Alpine mountain range in Europe. This metallogenic belt is formed due to the closed of Paleo-Tethys ocean in the southern part of Laurasia during late Triassic to early Jurassic (Richards, 2015). The eastern part of the Chagai magmatic arc is terminated by the Chaman transform fault system and the western part of the arc is terminated by the Harirud transform zone (Hunting Survey Corp., 1960; Arthurton et al., 1979, 1982; Farah et al., 1984; Siddiqui, 1996, 2004, 2007; Perelló et al., 2008). Chagai magmatic arc formed as a result of the Arabian oceanic plate northward subduction under the Afghan continental block's southern part. Towards the south, the Chagai magmatic arc is bounded by four major structural units, these units include; Hamun-i-Mashkil trough, Dalbandin basin, Mirjawa and Ras Koh ranges and on the northern margin, surrounded by the Helmand basin (Perelló et al., 2008) (Fig.1 A and B).

Chagai magmatic arc occurs about 350-400 km north of Makran trench and is associated with Kharan forearc basin, Mashkel depression, and Makran accretionary belt. The Makran accretionary belt extends from east to west direction about 1000 km (Fig. 2) (Farhoudi and Karig, 1977; Dykstra and Birnie, 1979; Jacob and Quittmeyer, 1979). The east to north-east trending Balochistan volcanic arc consists of three major calc-alkaline volcanic constituents i.e., Koh-i-Bazman and Koh-i-Taftan south-east to the east of Iran and Koh-i-Sultan volcanic in the south-west of Pakistan, these volcanic arcs have wide space from each other (Dykstra and Birnie, 1979; Jacob and Quittmeyer, 1979). The oldest rock unit in the Chagai magmatic arc is the Sinjrani volcanic group of Late Cretaceous age (Hunting Survey Corp, 1960; Ahmed et al., 1972; Sillitoe and Khan, 1977; Arthurton et al., 1979, 1982; Siddiqui, 1996, 2004; Perelló, 2008). It consists of submarine volcanic rocks of basaltic to andesitic flow and pyroclastic materials, including volcanic agglomerate, breccia, volcanic conglomerate, and tuff. (Hunting Survey Corp, 1960, Ahmed et al., 1972; Sillitoe and Khan, 1977; Siddiqui, 1996, 2004). Basal part of Sinjrani volcanic group is not exposed in the Chagai magmatic arc and the upper part of this group is overlain with Humai Formation (Arthurton et al., 1979). Late Cretaceous Humai Formation predominantly consists of a massive thick bed of limestone interbedded with the conglomerate, volcanic, and plutonic debris (Arthurton et al., 1979, 1982). Late Cretaceous Humai Formation conformably overlies the Paleocene Juzzak Formation in the Chagai hills region (Hunting Survey Crop., 1960; Ahmed et al., 1972; Arthurton et al., 1979, 1982; Siddiqui, 1996, 2004).

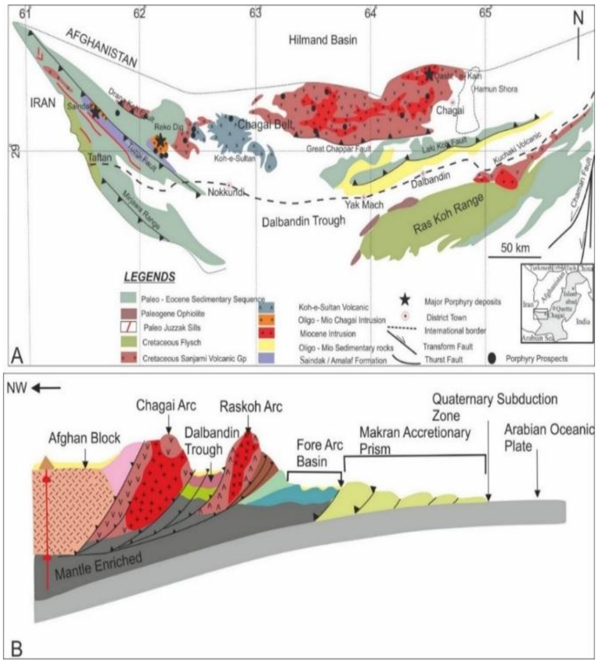

Fig. 1. Regional map and Tectonic model of Chagai magmatic belt (A and B) (after Siddiqui, 2004; Perelló, et al., 2008).

Amalaf Formation predominantly consists of siltstone, shale, mudstone, and a thin bed of limestone with intercalation of tuff, agglomerate with andesitic lava flow (Sillitoe, 1978). It has a disconformable contact with Miocene Dalbandin Formation and sub Recent to Recent deposits (Fig. 3) (Siddiqui, 2004). Late Oligocene to Miocene Reko Diq Formation is mainly exposed in the north of Yak Mach in the western margin of Chagai magmatic arc (Perelló et al., 2008). It consists of the andesitic lava flow, volcanic breccia, and pyroclastic debris of lapilli intercalated with siltstone, sandstone, and conglomerate (Khan and Ahmed, 1981; Perelló et al., 2008). Plio-Pleistocene Koh-e-Sultan volcanic group is the youngest volcano in Chagai magmatic belt and is comprised of andesitic and dacitic volcanic and volcanic-clastic agglomerate, volcanic tuff, lapilli tuff, volcanic breccia, and volcanic conglomerate (Fig.3) (Hunting Survey Corp, 1960; Siddiqui, 2004). Paleo-Eocene Juzzak and Saindak Formations volcanic-sedimentary sequence in this magmatic belt are composed of shale, sandstone, conglomerate and shelly limestone interbedded with lava flow, porphyritic andesite, and massive amygdaloidal basalt (Hunting Survey Crop, 1960; Ahmed et al., 1972; Arthurton et al., 1979, 1982; Siddiqui, 1996, 2004). Juzzak Formation has at transitional contact with Saindak Formation which has a conformable contact with Oligocene Amalaf Formation (Siddiqui, 1996, 2004).

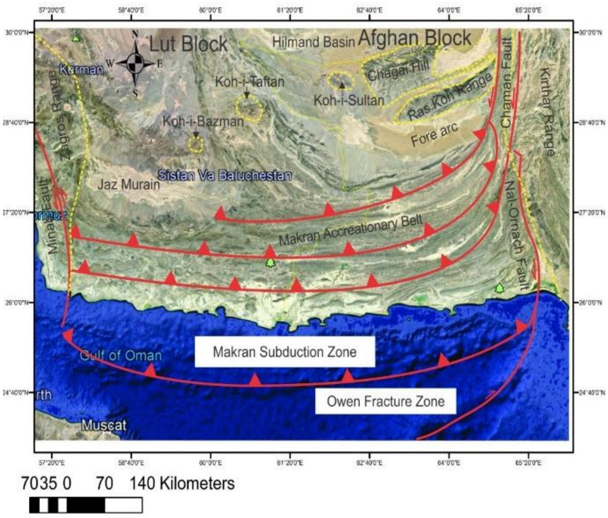

Fig. 2. Google map illustrates a regional tectonic of Chagai magmatic arc with the context of Makran trench-arc gap.

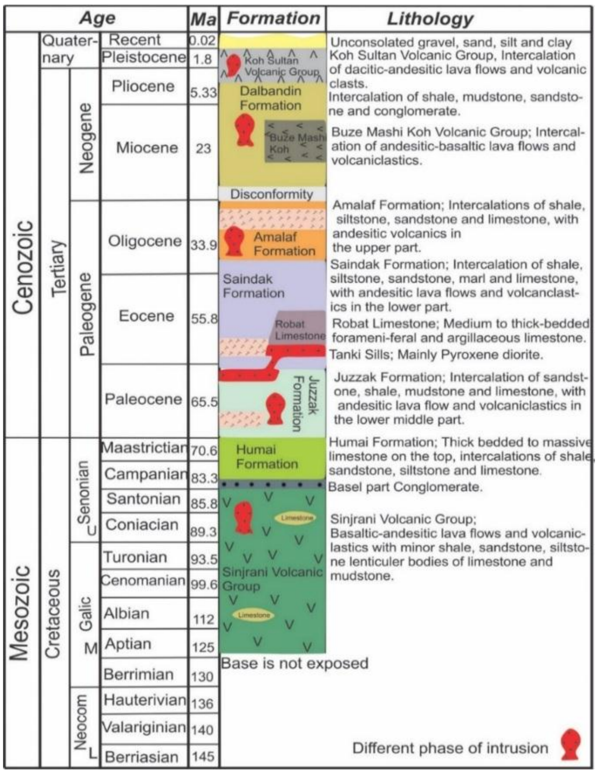

Fig. 3 Specified the Stratigraphic sequence in the Chagai magmatic arc (After, HSC, 1960; Siddique, 2010).

Materials and Methods

This manuscript discusses the secondary data of porphyry intrusion and hydrothermal alteration as well as mineralization of Miocene porphyry deposits at Reko Diq, Saindak and other prospects including Dasht-e-Kain. Previous studies were carried out by different analytical methods to determine the composition, genesis, trend of mineralization, pattern of hydrothermal alteration and petrogenesis of Chagai magmatic arc. Further, Thirty least altered grab samples were taken from all the Miocene porphyry deposits for petrographic and hydrothermal alteration study. These studies were accomplished by Leica DM 500 binocular microscope connected with digital camera.

Results and Discussion

Intrusions/Intrusive Rocks in CMB

The Chagai magmatic belt's intrusions are collectively called the Chagai and Sor Koh intrusions (Hunting Survey Corp, 1960; Negell, 1975; Britzman, 1979; Britzman et al., 1983). Predominant intrusions comprised of the large masses of composite batholith are widely exposed and cover an area of ~150 km along the bottom of Chagai hills frequently intruded within the Sinjrani volcanic group (Siddique, 2004; Perelló et al., 2008). Chagai and Sor Koh intrusions are predominantly composed of diorite and granodiorite intrusions associated with minor constituents of quartz monzodiorite, granite, and gabbro (Hunting Survey Corp, 1960; Arthurton, 1979, 1982). The western part of confined intrusions in the Chagai magmatic belt, composed of stocks, sill, dike, and dome shaped lopoliths of various sizes ~ 100 m exposed at the surface are called Sor Koh intrusion (Hunting Survey Crop, 1960; Arthurton et al., 1982; Perelló et al., 2008). Sor Koh intrusions are mainly composed of basaltic andesite, dacitic to rhyo-dacitic composition where porphyry phase in quartz diorite, granodiorite and monzodiorite are predominant. Mineralization of porphyry deposits in the Chagai magmatic belt is geographically and genetically linked within the porphyry stocks at Reko Diq, Saindak, and all other prospects (Ahmed et al., 1972; Sillitoe and Khan, 1977; Schloderer and McInnes, 2006; Razique et al., 2007; Perelló et al., 2008). The porphyry intrusions are hosted within the late Cretaceous Sinjarni volcanic group, Paleocene Juzzak, Eocene Saindak, Oligocene Amalaf, and late Oligocene to Miocene Reko Diq Formations. Eocene to Miocene volcanism is intensely altered regionally by hydrothermal fluids (Siddiqui, 2004; Perelló et al., 2008).

Tonalite Porphyry

Tonalite porphyry is light to medium brown, fine to medium grain, holocrystalline, porphyritic texture with hypidiomorphic to allotriomorphic granular groundmass and panidiomorphic to hypidiomorphic granular phenocrysts. Tonalite porphyry is mainly composed of quartz, plagioclase, biotite, and K-feldspar (Fig.4). Tonalite porphyry is highly subjected to hydrothermal alteration and pyritization. This is overprinted with a hydrothermal alteration zone that has been recognized as a potassic alteration.

Quartz Diorite Porphyry

Quartz diorite porphyry has a dark grey color with fine to coarse grain texture, holocrystalline, euhedral to subhedral shapes. Quartz diorite porphyry mainly consists of quartz, plagioclase, K-feldspar, Fe-rich biotite with hornblende. Plagioclase has subhedral crystal laths shaped with albite twining and Fe-rich biotite and hornblende are subhedral to euhedral tubular in shape (Fig. 4).

Monzonite Porphyry

Monzodiorite porphyry has micro-granular to porphyritic texture with subhedral to euhedral shapes. It is mainly composed of quartz, plagioclase, K-feldspar, amphibole with minor biotite. Plagioclase grains have well-developed crystal shapes with multiple albites and Carlsbad twining. The amphibole has well-developed two set of cleavages (Fig. 4) (Mastoi et al., 2019).

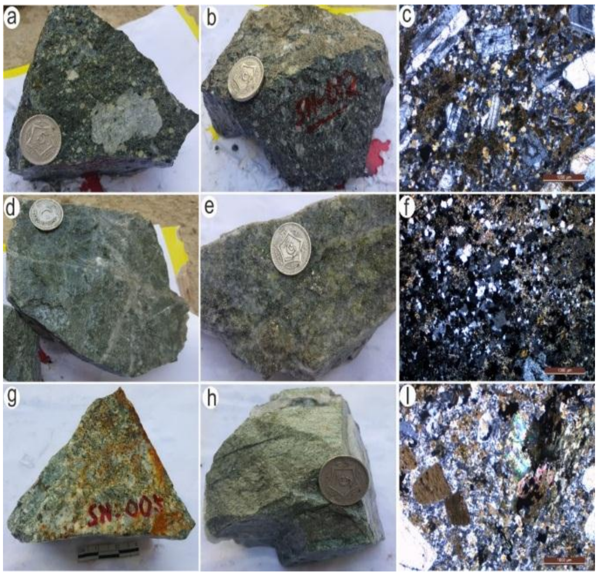

Fig. 4. Photograph of hand specimen and photomicrograph showing a different type of rocks in porphyry deposits at Chagai magmatic belt. Granodiorite, tonalite and quartz diorite porphyry at Saindak porphyry deposits (a, b, and c). Quartz diorite porphyry at Reko Diq porphyry deposits (d, e, and f) and monzonite porphyry at Saindak porphyry deposits (g, h, and i).

Hydrothermal Alteration in CMB

Miocene porphyry deposits have been recognized in the Chagai magmatic arc which are commonly hosted within the Oligocene to Miocene episode of calc-alkaline types of magmatism in the diorite to granodiorite stocks (Sillitoe, 1978; Siddiqui and Khan, 1986; Siddiqui, 1996, Perelló et al., 2008; Razique et al., 2014). Major prospects of porphyry deposits in Chagai magmatic arc include the Reko Diq and Saindak deposits and other small prospects of Dasht-e-Kain, Zairat Pir Sultan, and Missi (Siddiqui et al., 2015). Hydrothermal alteration is mainly associated within the porphyry deposits throughout the world and represents the significant mechanism for identifying mineralization of porphyry copper deposits (Lowell and Guilbert, 1970). Three major types of hydrothermal alteration zones have been recognized in the Chagai magmatic arc i.e. potassic alteration, sericitic-clay-chlorite alteration, and propylitic alteration. At some places argillic alteration have also been identified, this concentric pattern follows the model of hydrothermal alteration described by Lowell and Guilbert (1970) (Fig.5).

Potassic Alteration

Mineral assemblages of potassic alteration zone are mainly predominant K-feldspar, biotite, anhydrite, and quartz with minor albite and apatite constituents are present in the potassic alteration zone. Hydrothermal biotite forms by the replacements of ferromagnesian constituents mainly by magmatic hornblende and biotite and occurs in the parts to complete replacements of volcanic rocks and major constituents of sedimentary rocks (Perelló et al., 2008). K-feldspar is a significant constituent of potassic alteration in the porphyry stocks, while it appears in the aggregates of microgranular, anhedral grains and is associated with quartz grains (Sillitoe and Khan, 1977; Perelló et al., 2008).

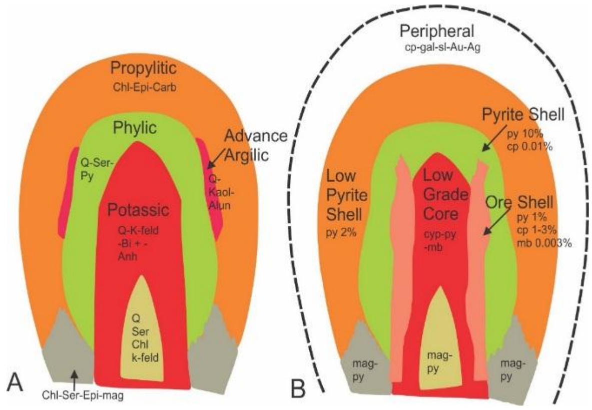

Fig. 5. The model illustrates a Porphyry copper deposit (Lowell and Gilbert, 1970). The representative model indicates the hydrothermal alteration minerals and their types (A). The model represents the ore mineralization associated with each type of alteration (B).

Sericite-Clay-Chlorite Alteration

Sericite-Clay-Chlorite alteration overprints the potassic alteration zone in Reko Diq area, (H14, H15, H13, and H79). Minerals assemblage of sericite-clay-chlorite alteration is mainly composed of pale-green to olive soapy sericite, fine-grain clay minerals, smectite, and chlorite minor amounts of calcite, albite, hematite, and rutile (Sillitoe and Gappe, 1984). Sericite is widely distributed throughout the host rock and is randomly oriented in flakes and also occurs in disseminated to well-developed selvages in millimeter to a centimeter of veinlets. Chlorite is an alteration product of ferromagnesian minerals of biotite, secondary biotite or magmatic hornblende albite forms by the replacement of plagioclase with minor constituents of fine-grain micro granular mosaic texture. The presence of soapy aggregates in huge quantities reflects that the veins comprise a mixture of fine grain chlorite and flaky clay minerals like smectite mainly developed in the high mineralized zone at H8 in the Reko Diq (Perelló et al., 2008).

Propylitic Alteration

Propylitic alteration is the proximal part of the alteration zone in porphyry deposits at the Chagai metallogenic belt and is hosted with diorite to andesitic rocks. Mineral assemblages in this alteration zone mainly includes chlorite, epidote, and calcite. Epidote is an alteration product of plagioclase and other ferromagnesian minerals while chlorite results due to biotite and hornblende's alteration product. Propylitic alteration zone extensively extends from the surface of porphyry deposits surrounding the phyllic alteration zone in the western porphyry belt in the Chagai magmatic arc (Perelló et al., 2008; and Razique et al., 2014).

Mineralization

Hydrothermal fluids play a vital role in ore mineralization in the porphyry belt at Chagai magmatic arc. In western porphyry complex Reko Diq (H15 and H14) and Saindak, the ore mineralization is typically associated with an intense potassic alteration zone comprised of quartz, quartz-magnetite known as A-type vein. Similar types of other veins have also been recognized in other porphyry deposits (Gustafson and Hunt, 1975; Dilles and Einaudi, 1992; Proffett, 2003; Padilla et al., 2004; Perelló et., 2008; Vry et al., 2010; Redmond and Einaudi, 2010). Ore mineralization of Cu-Fe-sulfides in fine-grained, disseminated to micro-veinlet is associated with chalcopyrite, bornite, pyrite, and molybdenite potassic alteration and A-type quartz veins and chalcopyrite and pyrite in sericite-clay-chlorite and sericite alteration with D-types veins. A and B type veins cut across to 1-20 mm thick zone in the main stage of ore mineralization in the potassic alteration zone. Pyrite-chalcopyrite D-type quartz veins make up to 5 cm thick wide zone of sericite-clay-chlorite alteration overprinted with potassic alteration. Ore mineralization of Cu-Fe-sulfides enriched in the A-types quartz veins are within the potassic alteration zone in the porphyry intrusions and average grade of Cu 2.0% and Au 0.29 g/t in the Reko Diq prospects (H15 and H14) (Perelló et al., 2008) and an average grade of Cu 0.5% and Au 0.25 g/t in the Saindak prospects (Sillitoe, 1979).

Conclusion

Porphyry deposits at Chagai magmatic belt is hosted with tonalite porphyry, quartz diorite porphyry, and monzonite porphyry within the Paleocene to Miocene volcano-sedimentary rock units. Porphyry deposits are the hydrothermal alteration product in Chagai magmatic belt prevalent hydrothermal alteration identified is potassic-silicates sericite-clay-chlorite alteration, argillic alteration, and propylitic alteration. Ore mineralization is typically confined to the potassic and sericite-clay-chlorite alteration.

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