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A REVIEW OF TECTONO-MAGMATIC EVOLUTION AND GOLD METALLOGENY IN THE INNER PARTS OF ZAGROS OROGENY: A TECTONIC MODEL FOR THE MAJOR GOLD DEPOSITS, WESTERN IRAN

The metamorphic-magmatic Sanandaj-Sirjan Zone (SSZ) and Urumieh-Dokhtar Magmatic Belt (UDMB) are the most important gold metallogenic provinces of Iran, occurring as two NW-SE parallel tectono-magmatic zones in the inner parts of Zagros orogeny, a part of the Alpine-Himalayan orogenic belt. In an orogenic system such as the one which has occurred in Iran, various gold deposits associated with each stage of the Neo-Tethys evolution are expected. Hence, occurrence of a certain deposit type in each stage indicates dominant conditions for the formation of the deposits at that time and conversely, lack of some deposit types points to the change and removal of those conditions. Therefore, identification of mineralized phases and geological settings of their formation in the development of the orogenesis plays an important role in the delineation of very narrow phases of gold mineralization in these regions.

Based on tectono-magmatic setting, notable gold deposits in the SSZ and the UDMB could be categorized as: 1) Gold-bearing stratabound deposits such as massive sulfide and sedimentary exhalative deposits in the interval of Triassic-Upper Cretaceous, simultaneous with formation and annihilation of Neo-Tethys, 2) Orogenic and intrusion-related gold deposits during Paleocene-Eocene coincided with influx of magmatic activity as continental arc, asthenosphere upwelling, slab roll-back, formation of metamorphic core-complex and shear zones, and 3) Gold deposits related to the Miocene magmatic activity including epithermal deposits (high and low sulfidation), porphyry Cu-Mo (Au), porphyry Cu-Au and skarn in collisional and post-collisional settings.

Meanwhile, in the SSZ and UDMB, main concentrations of gold mineralization occur in tectono-magmatic phases of Paleocene-Eocene and Miocene. The maximum gold mineralization restricted to the SSZ was formed in depths during Paleocene-Eocene. However, major gold mineralization in the UDMB and SSZ occurred in shallow levels in Miocene. Although similar development conditions after Oligocene (particularly Miocene) justify anticipation of similar mineralization types in the SSZ and the UDMB, different settings of these zones in this time interval cause different types of gold mineralization.

Since magmatic arc crust in the UDMB is thicker than the magmatic arc of SSZ, it has more differentiation and contamination resulting in the development of Cu-Mo porphyry and associated epithermal gold deposits. While in the SSZ, extension and shortening are associated with magma emplacement, lack of thick continental crust and presence of metamorphic rocks, resulting in gold mineralization related to sub-deep intrusive (subvolcanic) in the form of sedimentary host and epithermal gold deposit types. In final stages of Neo-Tethys evolution, collision to post-collision regime, identical development of uplifting and erosion didn't occur all over these zones but it is evident that severe erosion coupled with remittent frequent over-thrusting led to thickening of the SSZ crust. Thus, deepening of mineralization in these zones contributed to its intactness and uplifting was the major factor in their outcropping, promising that there are reserves of notable potential in areas with no outcropping.

Key words: *Gold metallogeny, Magmatism, Neo-Tethys evolution, Sanandaj-Sirjan Zone, Urumieh-Dokhtar Magmatic Belt, Iran.*

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Introduction

Mining reserves are non-renewable assets, so it is required to perform their operations, from reconnaissance to production, with maximum care and scientific knowledge. This is possible only through proper recognition and understanding of control and operational mechanism of mineralization and identification of metallogenic provinces of ore deposits (Robb, 2005). To this aim, many authors have presented various classifications according to the importance given to deposit specifications such as mineralography and paragenesis of gold mineralization, genesis, nature of ore-bearing fluid, tectonic setting, relevance or non-relevance to intrusive body, temperature and depth formation, host rock type, alteration type and etc (Kerrich et al., 2000; Leahy et al., 2005; Pirajno, 2009).

Special geologic setting of Iran (active and relatively young) and its correspondence with active continental margins make it as a geodynamic setting appropriate for the formation of various types of deposits particularly gold deposits. Such settings have different magmatism and metallogeny events during their development (rifting, sea floor spreading, subduction, colliding and post-colliding) influenced by different parameters such as velocity and angle of subduction, volume of water and down-going sediments and crustal thickness that manifest themselves as various deposit types (Groves and Bierlein, 2007; Pirajno, 2009).

According to remnants from ancient periods, history of gold mining in Iran dates back to several thousand years ago (Shadadi mining) (Momenzade and Rashidnejad Omran, 1985). This antiquity in some districts is so apparent in such a way that the development of some villages was based on mining activities, so some villages were named based on Persian meaning of gold and gold-washing. For example, Zarshuran means the place where gold-washing is performed and its name points to the placer gold, or Koh-e-Zar that means a mountain of gold. Although these reserves are of high diversity in terms of the age of their host rocks but most of known gold deposits and their metallogeny are related to the Neo-Tethys metal creating belt (Moosavi et al., 2009). This belt continues to neighbor

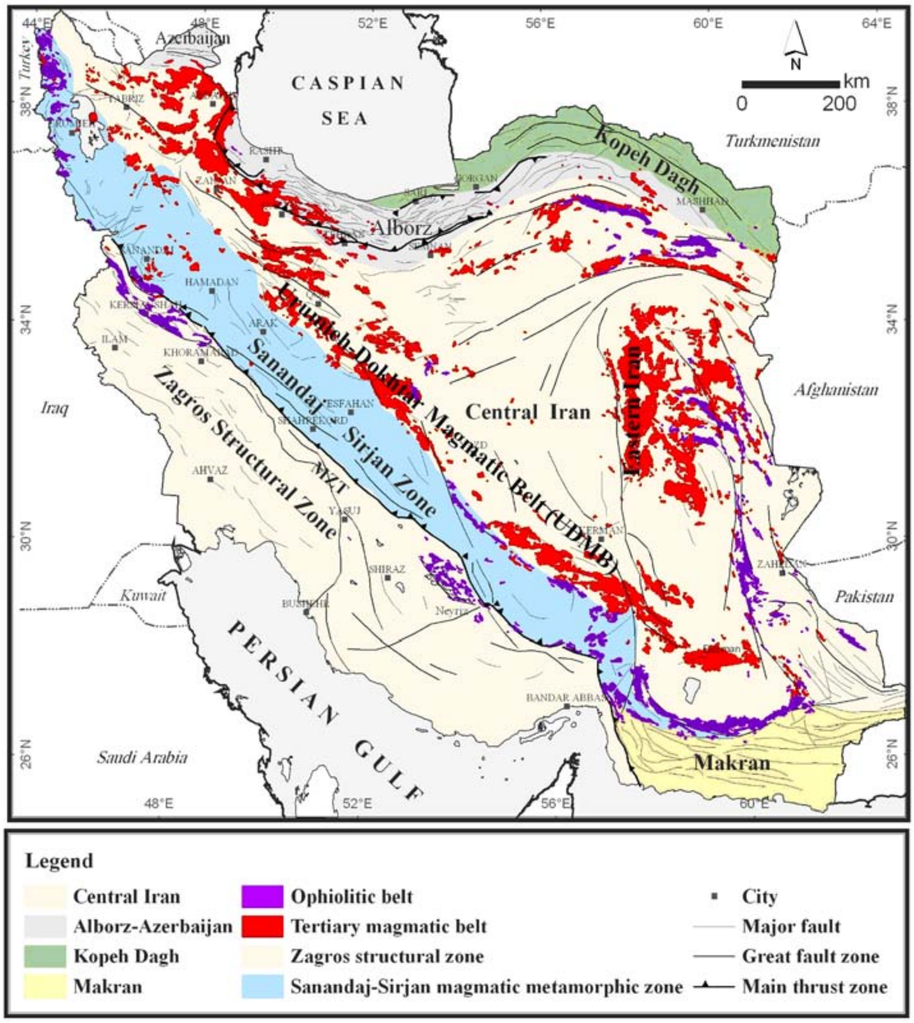


Fig. 1. Geological map of Iran, showing the locaction of Cenozoic magmatic of Urumieh–Dokhtar Magmatic belt, which runs parallel to the main thrust of Zagros with the Sanandaj–Sirjan metamorphic-magmatic zone and ophiolite belt (Compiled based on the 1:2,500,000 digital geologic map of Iran, Geological Survey of Iran, unpububished data, with additional information from Berberian and King 1981, Bonini et al 2003, Mohajjel et al 2003, and Regard et al 2005, Richard et al 2006, Shafiei et al 2009)

countries such as Turkey, Pakistan and Afghanistan and its trend is traceable (Doebrich, et al., 2007; Yilmaz, 2010; Richards et al., 2012).

Such settings have various magmatic phases during their evolution due to various parameters and their ore-forming types manifest themselves as special gold deposit types such as epithermal, porphyry, Carlin and orogenic (Jensen and Barton, 2000; Goldfarb et al., 2007).

Although several studies have been conducted in the field of genesis and dating of some gold mines and deposits in Iran in recent years, this part of the Alpine-Himalayan orogenic belt has been rarely studied for gold metallogeny. For example, studies of Momenzade and Rashidnejad Omran (1988), Aftabi, et al (1991), Mahdavi and Gorabjiripour (2002), Shafiei and Shahabpour (2008) and Richards (2012) are a few studies carried out on gold deposits of Iran. At the present time, the main products of gold in Iran come from few mines such as Zarshuran, Muteh, Kohe-e-Zar and Agh-Darreh and its byproducts from copper porphyry mines such as Sarchesmeh and Meiduk. Therefore, despite the position of Iran in active continental margin, its current gold production rate is much lower than the world market and even neighbor countries with similar geologic settings. Regarding existing potential and presence of vast spectrum of gold deposits such as gold deposits of sedimentary host, epithermal, porphyry, orogenic, gold-bearing skarns, gold-rich massive-sulfides and etc, it isn't unlikely to explore new reserves and gain more production. Since study and classification of certain deposit types regarding their temporal and spatial position yield reciprocal understanding of geodynamical settings and metallogenic processes (Leahy, et al., 2005; Sillitoe, 2008), this article attempts to highlight the Neo-Tethys development and related magmatic activities (tectonomagmatic events) in formation of more than 400 gold deposit, mine and indices base on distribution, type and tectonomagmatic setting of main concentrations of gold mineralization in the Sanandaj-Sirjan zone (SSZ) and the Urumieh-Dokhtar magmatic belt (UDMB). These studies represent new applicable approach in exploration of various deposit types (explored and non-explored) in the studied structural zones regarding their geodynamical history.

Regional geology and geodynamic setting

Formation and evolution of the Neo-Tethys between Gondwana and Eurasia created the Alpine-Himalayan orogenic belt (Sengor, 1984). Iran is located in the middle part of this orogenesis belt (Alpine-Himalayan) and its major mineralization relates to development of Neo-Tethys Ocean, Zagros orogenesis (Alavi, 1994) between the Arabian plate and the micro-continent of Central Iran. This evolution during its development from Permo-Triassic up to Cenozoic era in each step, spreading, subduction, collision and post-collision has changed the dominant regime on the micro-continent of Central Iran and manifested itself as different structural zones such as the Sanandaj-Sirjan zone (SSZ), Tertiary magmatic belt (including magmatic belts of Alborz-Azerbaijan, Urumieh-Dokhtar (UDMB) and Eastern Iran) from west to east (**Fig. 1**). Moreover, northern margin of the Arabian plate where subduction did not occur, forms the structural zone of Zagros as folded and thrusted sedimentary units (**Fig. 1**) which is now located parallel to the SSZ (due to closing Neo-Tethys) and separated from it by the abducted ophiolitic belt (remnants of Neo-Tethys) and the main thrust of Zagros (**Fig. 1**).

Although there is consensus among experts about the Neo-Tethys Ocean crust subduction in the direction of northeast under Central Iran, but available data from subduction time indicates non-simultaneity of the Neo-Tethys subduction in all active continental margins (Central Iran) and oceanic crust (Neo-Tethys) from Jurassic to Cretaceous. The collision time between the Arabian and Iranian plate is another subject of controversy, for instance that this time is considered to be upper Cretaceous (Berberian and King, 1981; Glennie, 2000), Oligo-Miocene (Hooper et al., 1994; Agard et al., 2005; Fakhari et al., 2008), Miocene-Pliocene (Axen et al., 2001; Mc Quarrie et al., 2003; Aftabi et al., 2006; Aghnabati, 2006). According to recent studies, the idea of collision in Miocene gained more support (Richards et al, 2006; 2012; Shafie et al., 2009; Agard et al., 2011; Verdel et al., 2011). Among other new discoveries about Neo-Tethys developments are considerations of slab rollback process, upwelling asthenosphere and slab break off for development of Neo-Tethys in Iran (Agard et al., 2008; Shafie et al., 2009; Verdel et al., 2011) and other parts of the Alpine-Himalayan orogenesis belt (O'Brien, 2001) which are performed base on geochemical and radiometric data.

As the studied area structurally involves the SSZ and the UDMB (inner part of Zagros orogen) and these two zones are the outcomes of the Neo-Tethys development in the western part of Central Iran, investigation and decryption of these two structural zones is essential to gain consistent understanding about formation of various gold deposits in these areas.

The SSZ: this zone stands as magmatic-metamorphic belt and has been stretched in the direction of northwest-southeast with more than 1500 km length and 150 to 200 km wide between folded and faulted zone of Zagros in the southwest and the UDMB in the northeast (**Fig. 1**) and it can be followed in Iraq and Turkey (Khalatbari et al., 2003; McCall, 1997). Many geologists believe that this zone is an inter-continental rift and aulacogen or aulaco-geosynclinal basin (Sabzehei, 1974; Berberian and King, 1981; Sengor, 1984) which their development and evolution led to emersion of the Neo-Tethys Ocean as the primary settings in the formation of the SSZ.

Lithologically, Prior to Permo-Triassic (rifting), the SSZ was similar to Central Iran (Stocklin, 1968) and had most of Gondowanian characteristics (Hassanzadeh et al., 2008). Stratagraphically, this zone consists of sedimentary, volcano-sedimentary, volcanic, intrusive units and ophiolitic sequences as color-m lange, flysch and molasse that have been formed since the initiation of the Neo-Tethys subduction beneath Central Iran with formation of accretionary wedges in compressional setting and has emerged (formed) as a magmatic, metamorphic, deformed, tectonized and exhumed zone. As shown in **Fig. 1**, approximately two parallel ophiolitic belts could be recogniz in this zone: the northern edge ophiolits belong to remnants of Neo-Tethys in the converging part of Central Iran and southern edge ophiolits that form the abducted parts on the non-active margin of Zagros. Effective radius of this zone is delineated according to Jurassic-Upper Cretaceous magmatism outcropped all over this zone (the western margin of Central Iran) and regional metamorphism. Shortening, folding and thrusting in shear zones are the distinct characteristics of this part that caused disarrangement of stratigraphic sequence and crust thickening in this zone.

The UDMB: this belt, indeed, forms the western part of Tertiary magmatism in Iran (**Fig. 1**) which is long and discontinuous belt of various thicknesses, predominately in the direction and parallel with the SSZ (part of it located in the interior of the SSZ) and reaches to Turkey and Caucasia to the north (Moinevaziry, 1998). Most of the constituent units belong to Paleocene-Eocene and Oligo-Miocene ages. This zone with a length of more than 2000 km is stretched from the west of Caspian Sea (part of the magmatic belt referred to Alborz-Azerbaijan) to Bazman in the north of Makran in the northwestern-southeastern direction (**Fig. 1**). This magmatic belt predominantly consists of volcanic-intrusive series. Volcanic-pyroclastic activities of felsic composition have commenced from early Tertiary (Paleocene) and reached to their climax in Eocene and formed vast areas of outcrops of this belt invaded by intrusive bodies of predominately granitoidic composition after Eocene (Oligo-Miocene) (Arvin et al, 2004). Nogol Sadat (1978) believes that geometrical dependency of different structural elements in this belt corresponds with right-lateral shear mechanism of 100 km width and most of faults are Trap-door and curve-shaped and often associated with opening and exiting of magma.

Tectono-magmatic events

In the following, we address magmatic phases based on available data such as geochemical analyses, radiogenic dating and geology in order to gain better understanding of the Neo-Tethys development and more information about dominant condition on the SSZ and the UDMB. In general, magmatic activities in these parts can be classifies into five groups of Permo-Triassic, Triassic-Jurassic to Upper Cretaceous, Paleocene-Eocene, Oligocene-Miocene and Pliocene-Quaternary.

1. Permo-Triassic magmatic activity: this magmatism is predominantly consists of basalt and alkaline diabase associated with rifting and initiation forming of Neo-Tethys Ocean (Dercourt et al., 1986; Stampfli and Borel, 2002; Ricou, 1994; Besse et al., 1998). This phase is associated with epirogenic uplifting and lack of sedimentation (Unconformity) in the SSZ. Distribution and dispersal of outcrop of these rocks is very limited due to performance of many tectonic processes and effect of erosion (**Fig. 2**). Continuation of this opening after this magmatic activity was associated with formation of oceanic crust, the remnants of which are found as dispersed ophiolitic belts and mélanges (**Fig. 2**).

2. Triassic-Jurassic to Upper Cretaceous magmatic activity: This magmatic activity of calc-alkaline nature and related to magmatic arc is predominantly limited to the western margin of the Central Iran micro-continent during its formation (**Fig. 2**). This magmatic phase may be considered as the first magmatic activity resulted from subduction of the Neo-Tethys oceanic crust beneath the Central Iran micro-continent, and its outcrops occur as deep intrusive bodies and volcanic rocks (**Fig. 2**). In the southern parts, this activity is considered Triassic-Jurassic regarding the age of the intrusive bodies (Berberian et al., 1982; Kazmin et al., 1986; Arvin et al., 2007) but they are younger toward northern parts. In addition, magmatic arc has formed as andesitic lavas simultaneous with sedimentation of sedimentary units (carbonates, shales and sandstones) in Upper Cretaceous, which is one of characteristics of this magmatic activity. Major volcanic units of this zone are andesite and andesite-basalts and rarely rhyolites to rhyo-dacits. Magmatic activities as intrusive bodies are other outcropped igneous units in this time interval that outcrop due to exhumation in some parts of the SSZ. Among these bodies are intrusive rocks of Ju-

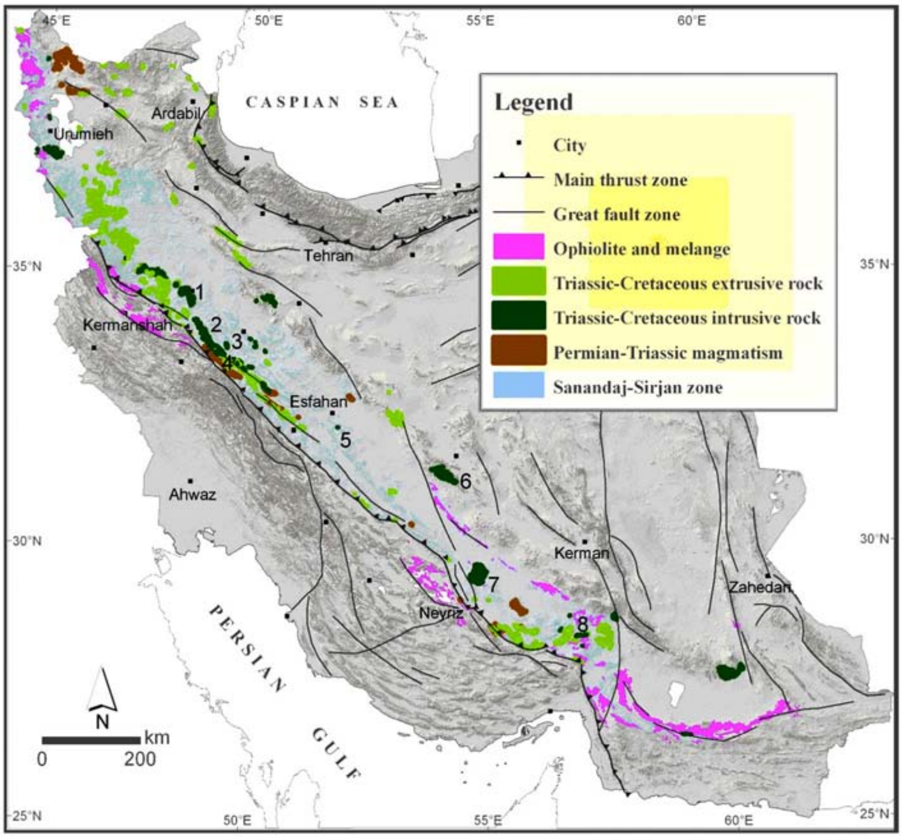


Fig. 2. Distrubution map of permo-Triass to Createaceous magmatic rocks in western Iran (SSZ and Central Iran):

1 — Hamadan batolite, *2* — Borojerd granitoid, *3* — Astaneh granodiorite, *4* — Nezam-Abad granitoid, *5* — Kolah-Ghazi granite, *6* — Shir-Kuh granite, *7* — Chahe-Dozdan granitoid; *8* — Siah-Kuh granitoid

rassic such as the Borojerd granitoids (172–169 Ma, according to dating by U-Pb Ahmadi khalaji et al., 2007), the Chahe-Dozdan granitoid (170.5±1.9 and 173±1.6 Ma according to dating by U-Th and U-Th-Pb; Fazlnia et al., 2007), the Siah-Kuh granitoid (199±30 Ma, according to dating by Sm-Nd; Arvin et al., 2007) and intrusive rocks of Cretaceous such as the Astaneh granodiorite (98.9±0.1 Ma according to dating by Rb-Sr; Masoudi, 1997 and 99 Ma according to dating by Rb-Sr, Nekouvaght Tak, 2008), the Nezam-Abad granodiorite (98.9±0.1 Ma according to dating by Rb–Sr; Masoudi, 1997) and the Hamadan batolith (70–91 Ma according to dating by K–Ar ; Baharifar et al., 2004) (**Fig. 2**).

Some characteristics of intrusive bodies of this zones that occur extensively from middle Jurassic (Borojerd and Siah-Kuh granodiorite) to Upper Cretaceous (Astaneh, Nezam-Abad granodiorites, Hamadan, Shir-Kuh and Kolah-Ghazi granites) to be mentioned are their immense volume as batolite, felsic composition, affinity to calc-alkaline series and I types (Baharifar et al., 2004; Sepahi and Athari, 2006 Arvin et al., 2007; Ahmadi Khalaji et al., 2007; Nekouvaght Tak, 2008), and their low alumina to a little rich- alumina composition (Arvin et al., 2007; Fazlnia et al., 2007; Ahmadi Khalaji et al., 2007). As well as specification of magmatic-arc, somewhere they show crustal characteristics, according to Nd-Sr data (e.g. Astaneh, Nezam-Abad and Chahe-Dozdan granitoides) (Fazlnia et al., 2007; Nekouvaght Tak, 2008).

In addition to assuming of continental arc for the SSZ, some authors believe that the subduction of the Neo-Tethys crust with formation of islands arc initiated before formation of continental arc and in fact, initiation of the Neo-Tethys oceanic crust subduction beneath oceanic crust has occurred before formation of continental crust in the Neyriz ophiolits (Shahabpour, 2005) and the Kermanshah ophiolits (Agard et al., 2008) (**Fig. 2**).

3. Paleocene-Eocene magmatic phases: In continuance of magmatic activities of Neo-Tethys subduction beneath Central Iran, the Paleocene-Eocene magmatic phases with NW-SE and N_S direction have initiated their activities predominately at the back of SSZ Mesozoic continental arc and rarely in the interior of the SSZ (**Fig. 3**). This magmatic phase forms the bulk of Tertiary volcanic rocks that outcrop all over Iran (**Fig. 1**). One characteristic of this phase is concordance of its linear distribution with other structural zones. Outcrops of this magmatism aren't alike in all part of this zone (**Fig. 3**) due to intensity of non- monotonous activity that exists all over this zone.

This step of magmatism in the UDMB include volcanic and volcano-sedimentary rocks such as andesite, basalt, dacite, rhyo-dacite, rhyolites and pyroclastic rocks of calc-alkaline nature occurred in the active continental margins from melting oceanic crust (Forster et al., 1972; Hassanzadeh, 1993; Aftabi and Atapour, 2000; Shafiei et al., 2009). Geochemical pattern of arc magmatism (rich in large ion lithophile elements (LILE) and depletion in high field strength elements (HFSE)) and exit of igneous materials especially during Eocene (climax of volcanic activity) are other characteristics of this magmatic activities (Shafiei et al., 2009; Atapour et al., 2010; Verdel et al., 2011; Richards et al., 2012). Initiation of this magmatic activity in northern area has been delayed (about 5–10 Ma) in comparison with other areas (central-southern areas). This implies non-uniformity of the magmatism development all over the western edges of Iran (the Cenozoic magmatic activity). According to available dating data from the oldest and the youngest rocks of this duration of volcanic activity done during These 15–20 years (Verdel et al., 2011), initiation of this activity has been from Late Paleocene-Early Eocene (54.7 ± 3.1 Ma) to upper Eocene (37.3 ± 1.2 Ma).

The outcrops of this activity occur sporadically and rarely in SSZ, most of the outcropped units of this part are intrusive bodies (**Fig. 3**). These intrusive bodies commonly intruded in the Jurassic-Cretaceous batholiths and metamorphosed rocks. This indicates higher uplifting and more erosion of western part (SSZ) than eastern part (UDMB). Reducing nature and affinity to illeminite series (Nekouvaghte Tak, 2008) in comparison with volcanic units of this age in the UDMB are very important characteristics of these intrusive bodies in the SSZ, while all of them have been formed in the margin of the continental arc (**Fig. 3**). Extension of this magmatism can also be traced from the SSZ to the inner part of the northern-edge ophiolitic belt (the Khoy ophiolits) (**Fig. 3**). Predominate volcanic rocks of this zone are andesite, andesites-basalts, rhyolites, rhyo-dacites and dacits. Intrusive bodies of this part are of various compositions involving gabbros, diorites and granites. According to the available dating data, rocks of this volcanic duration predominately belong to Paleocene and Lower Eocene (Farhadian, 1991; Nezafati et al., 2005; Verdel et al., 2011).

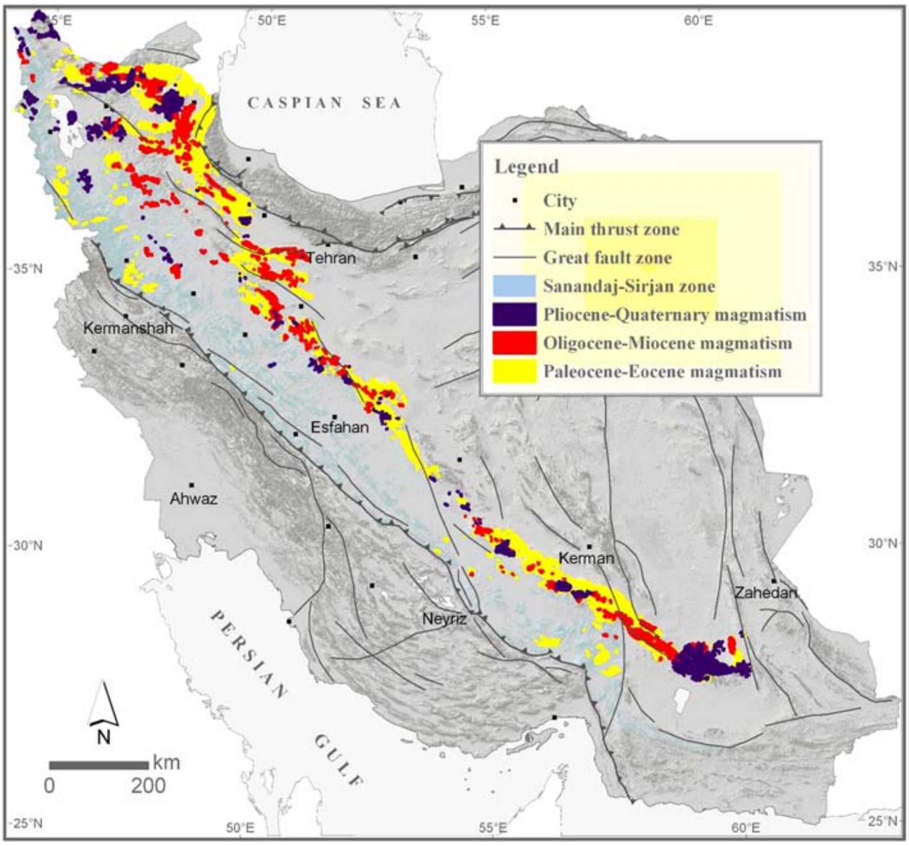


Fig. 3. Distrubution map of UDMB with Paleocene to Miocene ages in SSZ and west of Central Iran

4. Oligo-Miocene magmatic activity: this magmatic phase has occurred in the late stages of the Neo-Tethys evolution during Paleogene and continental collision between the Arabian plate and the Central Iran micro-continent. The Oligo-Miocene magmatic activity in the UDMB has initiated with basaltic lavas of Late Oligocene and continued with volcanic-intrusive activities of Miocene (Verdel, 2009). As shown in **Fig. 3**, outcrops of this magmatic activity occur in interior of the UDMB and independently in metamorphosed and uplifted basement of the SSZ. Localization in fractures, predominately in general direction of NW-SE is one of the characteristics of this magmatic activity, the directions of which has locally changed due to subsequent activities (**Fig. 3**). This phase commonly replaced in extensional fractures. Formation setting of this magmatic phase is coupled with sedimentation of terrigenous and chemical units in intracontinnetal shallow basins during uplifting. One of the characteristics of this magmatic activity is its more alkalinity than Paleocene-Eocene magmatic arc (Amidi et al., 1984; Kazmin et al., 1986; Emami, 2000; Richards et al., 2006) that is validated by presence of sub-alkaline and sub-abyssal volcanic rocks including trachyte, trachy-andesite (latite), rhyolites, lamprophyric dykes and alkali and potassic andesites and basalts in the active continental margins of the SSZ and the UDMB. Composition of this phase of magmatic is different in various parts and shows different outcrops depending on the intensity of magmatism and setting location. Its intrusive usually has porphyric textures with various compositions, which involve a range from diorite to quartz-diorite, granodiorite and locally quartz-monzonite. These rocks are alumina- rich and belong to magnetite granitoid series. Based on isotopic data (Nd-Sr-Pb), Shafieie et al (2009) origin of this magmatic phase in southwestern part of UDMB is semi-adakitic intrusives derived from partial melting of lower crust in the thickened continental arc that has been formed in Syn to post-collisional setting. Also, Richards et al. (2006) attributed the Miocene Qorve-Takab magmatic belt in northern part of the SSZ to collision and post-collision activity.

5. Pliocene-Quaternary magmatic phases: This magmatic activity constitutes the last magmatic activity in these two zones that involves basaltic, andesitic and alkali-trachytic lavas, located on sedimentary deposits (Allen et al., 2004). This magmatic activity shows more extension in UDMB than SSZ (**Fig. 3**). These activities often relate to deep fractures (especially strike-slip faults) and their alkalinity increase toward west. Isotopic studies (Nd-Sr) of these rocks indicate their derivation from rather depleted mantle and melting continental lithosphere (spinel lerzolite) (Kheirkhah and Emami, 2010). This magmatic activity is ascribed to post-collision (Allen et al., 2004) then it is related to orogenesis deformation and uplift and probably is the main cause for frequent occurrence of quaternary alluvium in these areas.

Metamorphism

Existing metamorphism phases in the Alpine-Himalayan orogenic belt, especially in relation to evolution of Neo-Tethys, during the time interval of Mesozoic-Tertiary, show high similarity in formation conditions. Dominant metamorphic units, attributes of the Tethys belt in Iran, belong to SSZ as it relates to active continental margin (**Fig. 4**). Despite occurrence of metamorphic rocks all over of this zone, previous studies indicated different metamorphic phases overlaid on each other (Aghanabati, 2006). Of the most distinct metamorphisms of this zone, we can refer to regional, contact metamorphisms and core complex (**Fig. 4**). The former belong to Mesozoic (predominantly Triassic-Cretaceous) formed in the green schist-amphibolite facies (Pamic et al., 1979; Rashidnejad-Omran et al., 2002; Aftabi et al., 2006; Azizi et al., 2006; Fazlnia et al, 2007; Sheikholeslami et al., 2008) and outcrops of its rocks occur as transported thrusted slices (Alavi,1994, 2004). Moreover, evidence of

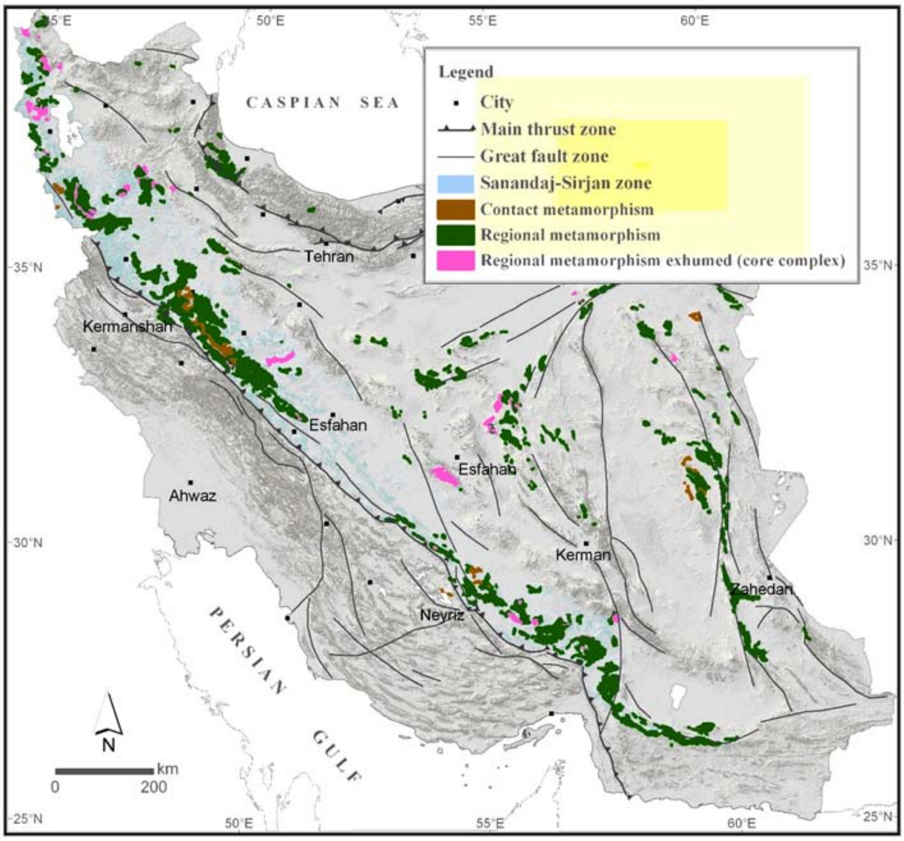


Fig. 4. Distribustio map of metamorphic rocks in Iran, showing the locaction of regional, contact and core complex metamorphic rocks in the SSZ and Central Iran (Compiled based on the 1:2,500,000 digital geologic map of Iran, Geological Survey of Iran, unpublished data, with additional information from Verdel, 2009, Heidari et al 2013, and Hassanzadeh et al 2008)

glaucophane schist has been reported in relation with this type of metamorphism especially in abducted ophiolits (Pamic et al., 1979; Agared et al., 2011). In some areas, this regional metamorphism is disrupted by intrusive bodies of Jurassic-Upper Cretaceous (**Fig. 4**), and contact metamorphism has been formed in their margins (Sepahi et al., 2004; Fazlnia et al., 2007; Ahmadi Khalaji et al., 2007; Nekouvaght Tak, 2008). An extraordinary characteristic of these metamorphism phases is their conformation with NW-SE trend and their concordance with the main Zagros thrust (**Fig. 4**).

Core complex metamorphism is another type of regional metamorphism (**Fig. 4**) that is attributing of uplifting and extension in Eocene (Moritz et al., 2006; Verdel et al., 2011). In this type of metamorphism, rock deformation mechanisms and metamorphic reactions have close correlations with each other (Stel, 1986), identified by high-grade metamorphism cores and presence of mylonitic fabrics and reported in the Mute, Takab and khoy regions (Thiele et al., 1967; Stockli et al., 2004; Moritz et al., 2006; Mazhari et al., 2010; **Fig. 4**). This metamorphism has been reported in other structural zones such as Central Iran (Hassanzadeh et al., 2005; Verdel et al., 2011; **Fig. 4**) and other parts of the Alpine-Himalayan belt (Searle et al., 2003). Occurrence of this type of metamorphism does not show uniform extension in all part of this zone.

What is important about core complex units is their uplifting to surface after formation and erosion of their surface parts during the development and closure of Neo-Tethys. Regarding structural fabrics in different scales, this uplifting indicates the effects of regional shear zones and toleration of deformation in various phases as elastic and brittle fabrics that are typical characteristics of orogenesis settings.

Structures

Structural investigations carried out based on geologic maps, remote sensing and geophysical studies in the SSZ and the UDMB revealed two dominant trends (**Fig. 1**). The NW-SE trend is concordant to Zagros main thrust and the axis of spreading and subduction. This trend has dominantly faults of vertical displacement components that show various senses from normal to thrusted and vies-a-versa appropriated with the change of tectonic regime. These displacements are uniform all over the zone (**Fig. 1**). Another trend encompasses vast spectrum of trends including N-S, NE-SW and NW-SE that disrupted former trend and does not have uniformity all over this zone (**Fig. 1**). Directions and mechanisms of this trend are different and manifest themselves with strike-slip components under transpiration and transtensional regimes.

Gold reserves and resources

Classification of gold deposits provides a convenient framework for assessment of explored deposits, development of prospecting strategies and exploration of unexplored deposits. The Iranian gold deposits distribute in the form of various deposit types in different structural zones. Although presence of various types of gold mineralization in a structural or metallogenic zone makes some complexities, it is an evidence of tectonic conditions and setting of mineralization in various times and metallogenic development of the structural zones. In the following, various types of available gold deposits in the SSZ and the UDMB will be describe and their topic examples will be presented separately (**Fig. 5**). The information used in this paper are from available data about indices, deposits and mines, compiled from available papers, theses and reports in Geological Survey of Iran (GSI) and related sites (WWW.NGDIR.COM). Considering the fact that more than 400 deposit, district and mining indices exist in this study area, more scientific works and researches are need to gain more integrated understanding of metallogenic phases and tectonic setting of the gold deposits in these regions.

Types and distribution of gold mineralization in the SSZ

In despite of structural complexity of the Sanandaj-Sirjan tectonomagmatic for its position, geodynamical setting and understanding of the Neo-Tethys development up to present, it is very important because of its high potentiality for gold (more than 40 percent of total gold of the country) and existence of the biggest gold reserves of the country in this zone (**Fig. 5**). Generally, major gold deposits in this zone could be classify into four classes including stratabound gold deposits, orogenic gold deposits and gold deposits related to intrusive and sub-volcanic bodies.

Stratabound gold deposits

The stratabound gold deposits of the SSZ involve reserves formed by exhalative process during submarine volcanism and generally relate to volcanic-sedimentary sequences. Distribution of this type of mineralization in this zone relates to the time of Neo-Tethys ocean floor spreading and formation of continental arc in Triassic-Jurassic to Paleocene. Volcanic rocks of these reserves predominantly include basalt, basalt-andesite and dacite that often undergone metamorphic phases in green-schist to amphibolite facies. In these deposits, gold usually is a byproduct. Botros (2004) has divided these deposits into three types including 1) gold-rich volcanogenic massive sulfides, 2) gold rich tuffic sediments (Sedex) and 3) gold-rich banded iron formations (the Algoma type). Among them, only the gold-rich massive-sulfide type has been declared as economic deposit in the SSZ. However, about two other types namely sedimentary exhalative and gold-rich banded sedimentary iron, there is no report about economic potential of gold, and previous studies imply their weak gold-bearing potential that will be discussed in the following part. Various stratabound mineralizations in the SSZ can be categorized in the following groups (**Fig. 5**).

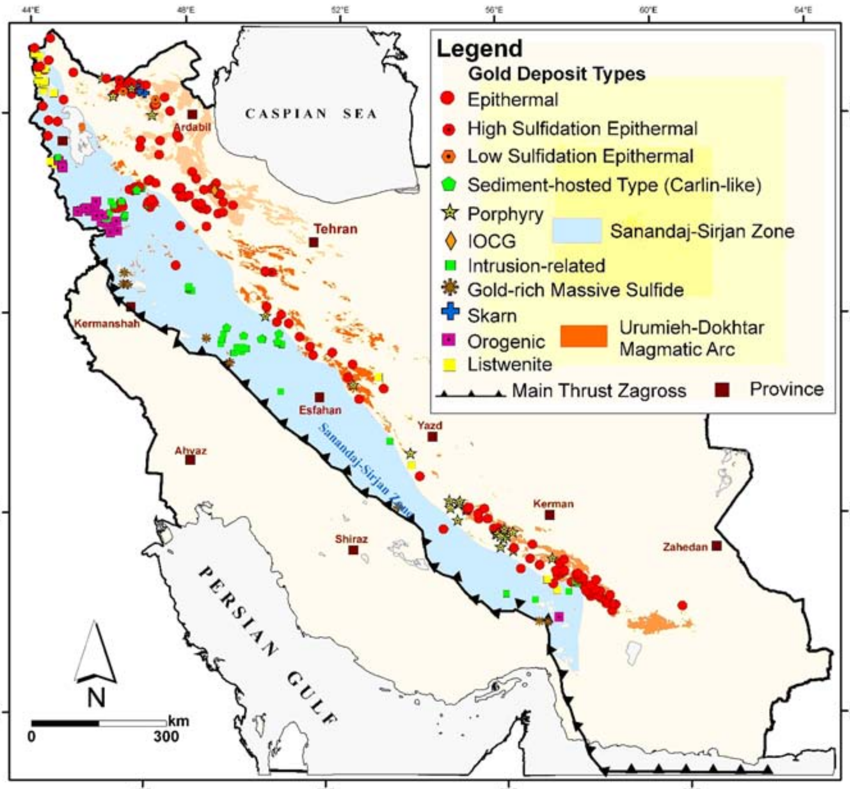


Fig. 5. Distribution map of gold metallogeny in the SSZ and UDMB, west of Iran

Gold rich massive sulfide

These deposits occur in volcanic-sedimentary and volcanic units of Triassic-Jurassic and Late Cretaceous in the SSZ and involve various massive sulfide deposits types such as Besshi, Bathurst, Cyprus and Kuroko (Mousivand, 2003; Mousivand et al., 2011; Tajedin, 2012). Researches on sediments that are forming at present on the sea floor provide better understanding of formation process and suitable tectonic setting for gold-rich massive sulfides (Robert et al., 2007). This type of mineralization occurs typically in extensional basins related to back-arc, island and continental arcs (Gemmel et al., 1998; Haninngtone et al., 1999; Larg et al., 2001).

Among this type of reserves in the SSZ, only the Kuroko-type massive sulfide type of Barika in the northern part and the Cyprus-type massive sulfide deposit of Sheikh Ali in the southern part of this zone have gold and can be categorized in gold-rich massive sulfides. Atapour (2007) evaluated the existence of this type of mineralization as an important factor in development of Tertiary metallogensis especially in the UDMB and Cu-porphyry deposits.

Kuroko-type massive sulfides

Gold-rich massive sulfides deposit of Barika is an important deposit of this type in Iran that its specifications are presented in **Table 1** and **Fig. 5**. This deposit in northwestern part of the country consists of two parts, involving stratabound ore and stringer zone that are located wholly in the andesite metavolcanic unit. The stratabound part consists of sulfide and barite ores that overlie massively over siliceous veins of stringer zone that form footwall of the stratabound zone. Stratabound part of deposit is of high mineralogical diversity and consists of pyrite, sphalerite, galena, stibnite and a series of sulfosalts and gold (electrum). Mineralogy of siliceous veins of stringer zone is simple and consists of pyrite, sphalerite, galena, tetrahedrite and rare amounts of chalcopyrite. Researches about the mineralization of this deposit indicate occurrence of gold mineralization prior to regional metamorphism in green-schist facies and deformation related to shear zones. Gold mineralization occurrences are non-visible and situated in the interior of framboidal pyrites and in close association with sulfosalts and other sulfide minerals. Thus, this deposit is an imperfect and undeveloped form of Kuroko-type massive sulfides with total grade of base metals of lower than one percent that is categorized as pertaining to gold-rich polymetalic reserves according to Poulson and Haninngton classification (1995) (Yarmohammadi et al., 2007; Tajedin, 2012).

Table 1. Some of the most important gold deposit types in the SSZ and UDMB (Note: Small=<1tone, 1<Medium=<10 tone, 10<Large<100 tone).

Deposit/prospect name	Zone	Au reserve/status	Host rock	Age of host rocks	Age of mineralization	Gold deposit type	References
Au Astaneh	SSZ	Large/Ancient mine	Microgranite	Eocene	Eocene	Intrusion-related	Nezafati, 2006; Nekovaght, 2008
Sn, Au, Cu Deh Hossein	SSZ	Small/Prospect	Granite	Jurassic	Eocene	Intrusion-related	Nezafati 2006, Nekovaght, 2008
Au, Zn, Pb, Ag Barika	SSZ	Medium/Mine	Meta-andesite, tuff, phylite	Cretaceous	Cretaceous	Kuroko VMS	Yarmohammadi et al, 2011, Tajeddin, 2012
Au Kharapeh	SSZ	Small/Deposit	Schist, marble	Cretaceous	Cretaceous-Tertiary	Orogenic	Niroomand et al., 2011
Au Zartorosht	SSZ	Small/Deposit	Green schist	Paleozoic-Mezozoic	Eocene	Orogenic	Aliari, 2011
Au Kervian	SSZ	Medium/Mine	Green schist	Neoproterozoic to Cretaceous	Eocene	Orogenic	Aliari, 2011, Heidari, 2006
Au Muteh	SSZ	Large/Mine	Schist and gneiss	Neoproterozoic to Cretaceous	Eocene	Intrusion-related	Moritz et al, 2006
W, Sn, Au Nezam Abad	SSZ	Small/Prospect	Quartzdiorite and granite	Eocene	Eocene	Intrusion-related	Farhadian,1991; Nezafati 2006
Au, As, Sb, Hg Aghdareh	SSZ	Large/Mine	Reefal limestone	Miocene	Miocene	Carlin like	Daliran, 2008; Daliran et al., 2002
Au, Cu Touzlar	SSZ	Medium/Prospect	andesitic lava	Miocene	Miocene	Epithermal	Heidari et al., 2013
Au, As, Sb, Hg Zarshuran	SSZ	Large/Deposit	Shale and carbonate rocks	Neoproterozoic	Miocene	Carlin like	Mehrabi et al., 1999; Asadi Harooni et al., 2000
Au, As, Sb, Hg Sary Gunay	SSZ	Large/Ancient mine	Latite, trachyt, dacite	Miocene	Miocene	Epithermal	Richards et al., 2006
Cu, (Au, Ag, Mn) Sheikh Ali	SSZ	Small/Ancient mine	Basalt lavas	Upper Cretaceous	Upper Cretaceous	Cyprus-type VMS	Rastad et al., 2002
Au Akhtarchi	SSZ	Medium/Mine	Crystaline limestone	Permian	Cenozoic	Carlin like	Moosavi, 2011
Au, Cu Nabi Jan	UDMB	Small/deposit	Volcano-sedimentary rocks	Upper Cretaceous	Oligocene	Skarn-porphyry	Shokohi, 2007; Vaziri-Heshi et al, 2010
Cu, Fe, Au Mazraeh, Anjerd	UDMB	Small/ mine	Limestone and granodiorite	Upper Cretaceous	Oligocene	Skarn	Mollaee,1993; Atalu, 2006
Cu, Au Kharvana	UDMB	Medium/Prospect	Sedimentary rocks with granodiorite	Paleocene	Miocene	Skarn and epithermal	Alirezaei et al., 2005; Jamali et al., 2009
Au, Cu, Au (Sb) Miveh rood	UDMB	Small/deposit	Sedimentary rocks with granodiorite	Cretaceous- Palaeocene	Oligo-Miocene	Porphyry, skarn, epitherma	Alirezaei et al., 2005, Jamali et al., 2009
Cu,Mo,Au,Ag Dareh Zereshk	UDMB	Small/deposit	Quartzdiorite, tonalite and limestone	Cretaceous-Eocene	Miocene	Porphyry	Zarasvandi et al., 2005, 2007
Cu, Au Masjed Daghi	UDMB	Medium/deposit	Andesite and felsic rocks	Eocene	Oligo-Miocene	Porphyry, HS epithermal	Fard et al., 2005; Akbarpur, 2007
Au, Ag Chah Zard	UDMB	Medium/deposit	andesite–dacite–rhyolite porphyry	Late-Miocene	Miocene	Medium, LS epithermal	Kouhestani et al., 2011
Au Zaglik	UDMB	Small/deposit	Andesitic tuff to andesitc lava	Eocene	Oligocene	LS epithermal	Ebrahimi et al., 2009; 2011
Au Sharaf Abad-Hyzehjan	UDMB	Small/deposit	Andesitic to pyroclastic rocks	Upper Eocene	Oligocene-Miocene	LS epithermal	Nakhjevani, 2005; Purnik, 2006; Ebrahimi et al., 2009
Au Bazman	UDMB	Small/deposit	Andesite to dacite and pyroclast	Neogene	Pliosen-Quaternary	LS epithermal	Daliran et al., 2005
Au (Cu) Safikhanlu, Sarilar	UDMB	Small/deposit	Dacitic to andesitic and granite	Eocene	Oligocene	LS epithermal	Ghadimzadeh, 2002; Heidarzadeh, 2006; Ebrahimi et al., 2009
Au Noghdooz	UDMB	Small/deposit	Alkaline granite to monzogranite	Eocene	Oligo-Miocene	HS epithermal	Ghadimzadeh et al., 2002
Cu, Mo, Au Agharak & Annigh	UDMB	Small/Mine	Granodiorite, monzonite and diorite	Eocene	Oligocene	HS epithermal	Ghadimzadeh, 2002; Sohrabi, 2006; Mokhtari, 2009
Au Mianeh	UDMB	Small/depositt	Basalt to rhyolit and granodiorite	Oligo-Miocene	Oligo-Miocene	Epithermal-Porphyry	Karimzadeh Somarin, 2006
Au,Cu,Ag Glojeh	UDMB	Small/depositt	Ryodacite, trachandesite and dacite	Eocene - Oligocene	Oligocene	Epithermal, mesotermal	Mehrabi et al., 2014
Cu, Au Ghezalja	UDMB	Small/depositt	Dacitic to andesitic volcanic rocks	Eocene-Oligocene	Oligocene	Epithermal, mesothermal	Ghadirzadeh., 2002; Ebrahimi et al., 2009
Au Latala	UDMB	Small/depositt	Pyroclastic and detrital rocks	Eocene-Oligocene	Miocene	Epithermal	Azimie Shahla, 2007
Cu, Mo Sungun	UDMB	Large/Mine	Granodiorite, monzodiorite & Limestone	Miocene	Miocene	Porphyry	Mehrpartov and Tarkian, 1993; Calagari, 1997; Hezarkhani, 1998, 2006
Cu, Mo, (Au) Iju	UDMB	Small/deposit	Pyroclastic to diorite, quartzdiorite	Eocene	Miocene	Porphyry	Nedimovic,1973; McInnes et al., 2005; Ghaderi et al, 2007
Cu, Au Dalli	UDMB	Medium/deposit	Andesitic to dacitic and granodiorite	Miocene-pliocene	Miocene	Porphyry	Ayati et al., 2008
Cu,Mo, (Au) Dareh Zar	UDMB	Medium/deposit	Andesite & pyroclastic with diorite	Eocene	Miocene-pliocene	Porphyry	Shafiei and Shahabpour, 2008; Ravankhah et al., 2010
Cu,Mo, (Au) Sarcheshmeh	UDMB	Large/Mine	Granodiorite to quartz-monzonite	Eocene-Miocene	Miocene	Porphyry	McInnes et al., 2005; Hezarkhani 2006; Shafiei et al., 2009
Cu,Mo,Ag,(Au) Ali Abad	UDMB	Small/deposit	Dacite, rhyodacitic tuff to granodiorite	Eocene	Miocene	Porphyry	Zarasvandi et al., 2005, 2007
Cu-Mo, (Au) Meiduk	UDMB	Medium/Mine	Diorite porphyry and pyroclastic rocks	Eocene-Miocene	Miocene	Porphyry	Boomeri et al., 2009; McInnes et al, 2005
Cu, Mo, (Au) Seridune	UDMB	Small/deposit	Andesitic volcanic to granodiorite	Eocene-Miocene	Miocene	Porphyry	Barzegar, 2007
Cu, Mo, Au Sar Kuh	UDMB	Small/deposit	Volcanic to porphyritic granodiorite	Eocene-Oligocene	Miocene	Porphyry	Shafiei and Shahabpour, 2008; Nedimovic, 1973; Barzegar, 2007
Mo, Cu, (Au) Now Chun	UDMB	Medium/deposit	Rhyodacitic volcanic to diorite	Eocene-Oligocene	Oligo-Miocene	Porphyry	Honarmand et al., 2011; Soltaninajad and Shafie, 2014
Cu, Mo, (Au) Bagh Khoshk	UDMB	Small/deposit	Tuff, andesite to rhyolitic and diorite	Eocene-Miocene	Oligo-Miocene	Porphyry	Khakzad and Shaban, 2007
Cu, Mo Kuh Panj	UDMB	Small/deposit	Volcano-sedimentary and quartzdiorite	Eocene-Miocene	Oligo-Miocene	Porphyry	Shafiei and Shahabpour, 2008; Honarmand et al., 2011
Cu, Mo, (Au) Dar Alu	UDMB	Small/deposit	Porphyritic granodiorite	Eocene-Miocene	Oligo-Miocene	Porphyry	Shafiei and Shahabpour, 2008; Nedimovic, 1973
Cu,(Mo) Serenu	UDMB	Small/deposit	Andesite to pyroclastic and diorite	Eocene-Miocene	Oligo-Miocene	Porphyry	Zeinodin et al., 2005
Cu,Mo, Au Abdar	UDMB	Medium/deposit	Andesite to pyroclastic and diorite	Eocene-Miocene	Miocene-Pliocene	Porphyry	McInnes et al., 2003; Shafiei and Shahabpour, 2008
Cu, Mo, Au Kahang	UDMB	Large/deposit	Tuff, dacite to andesit and monzodiorite	Eocene to Miocene	Oligo-Miocene	Porphyry	Afzal et al., 2010, 2011

Cyprus-type massive sulfides

Cyprus-type massive sulfides are other types of gold mineralizations in the SSZ that occur typically as geochemical indices and anomalies and are limited to abducted and uplifted ophiolits. The Sheikh-Ali massive sulfide deposit in southern part of the SSZ of Upper Cretaceous age is only occurrence of this type of gold-rich massive sulfide. This is a Cu-Pb–Zn Cyprus-type massive sulfide, which its Mn–Fe cherts are rich in Au, Fe, Mn and Mo (**Table 1**). The ore is situated as lens and stratiform in pelagic limestones and basaltic lavas. Its major alterations are chloritization and propylitization. Ore mineral paragenesis consists of pyrite, chalcopyrite, sphalerite, quartz, chalcedony, and calcite. Ore textures are massive, laminated, colloform, disseminated and rarely stockwork (**Table 1**).

Sedimentary exhalative deposits

These deposits are located in sedimentary-volcanic of Triassic-Cretaceous age in the SSZ. One of the very important characteristics of this type of mineralization is its role as mineralization origin in subsequent phases and events that led to enrichment and concentration of gold and other elements as economic deposits. These potentials and deposits in the gold deposits of Muteh (Rashidnejad-Omran, 2002), Kervian (Heidari et al., 2006), Gholgoleh (Aliyari et al., 2009), Zartorosht (Rastgooye Moghaddam, 2006) as primary Au-bearing phase (prior to metamorphism and deformation phase) have been reported as sedimentary exhalative deposits. However, their contents have not been evaluated reach enough at economic level. Regarding the higher average of grade in surveyed geochemical sheets of regional scales by GSI in the SSZ than other structural zones, these anomalies are justifiable in regional scales. Under regional metamorphism, these volcanic-sedimentary sequences have converted to green-schist in subsequent phases.

Orogenic Gold Deposits

Orogenic gold deposits and occurrences in the SSZ involve deposits formed simultaneous with metamorphic, deformation and granitoid magmatism processes in the intermediated levels of the crust and compressional- transpressional regimes. This step of orogenic phase led to formation of various deformation fabrics and subsequently, formation of quartz-carbonate veins with different direction in the Sanandaj-Sirjan magmatic-metamorphic zone (predominantly green schist and slate). Strong structural controller such as faults, shear zones, often controls these deposits; folds and/or boundary regions meddled between two strata of different rheology.

Therefore, this definition has caused fundamental doubts among orogenic gold model and other models such as intrusive-related gold model (Robert et al., 2007). So, this type of deposits and mining occurrences have formed during main phase of crustal shortening, uplifting of metamorphosed basement unit (core complex) in compressional- transpressional regimes and all have metamorphism and deformation fabrics.

Most of the orogenic deposits and occurrences in the SSZ include mineralizations formed in different and metamorphosed host rocks such as metagranitiods, green schists, and turbidites (phylitie) and in relation with shear zones in deep depth (**Table 1**).

Considering age, this mineralization-host, deformed and metamorphosed sequence, involve vast spectrum of Neoprotrozoic to Upper Cretaceous-Paleocene according to dating surveys (Hassanzadeh et al., 2008; Aliyari et al., 2009) of outcrops due to uplifting. In these deposits, mineralizations occur predominantly in siliceous-sulfide veins in direction of plastic to brittle shear zones and interior of metamorphosed land, often metamorphosed in green schist facies. In addition to Au–Ag, these veins are rich in As and somewhat W, Te, Bi and Mo and their contents of Au and Ag increase 4 to 10 times (**Table 1**). Their hydrothermal alterations often include sericitization, carbonatization, kaolinitization and rarely turmalinization that form around Au bearing sulfide siliceous ore, considering type and composition of host rock (**Table 1**).

Researches on these deposits and reserves, present deformation mechanisms and structural component changes of shear zones as main forming, controlling and concentrating processes of mineralization in these deposits (Heidari et al., 2004; Rastgooye Moghaddam, 2006; Aliyari et al., 2009; Niroomand et al., 2011). There are incremental changes in deformation degree and intensity in shear zones related to mineralizations in these zones by going from margin to center and previous surveys point to mineralization concentration in intensely deformed to fractured (ultramilonitic) parts. Therefore, as other hydrothermal deposits related to shear zones in other parts of the world, deformation is the main controller of migration and geometry, concentrator of economic values of gold and associated elements, regulator of alteration and rock-fluid reactions in these deposits (Groves et al., 1998; Goldfarb et al., 2010).

As listed in **Table 1**, the main gold deposits of this type are gold-bearing quartz veins of Gholgholeh, Ghabaglojeh, Kervian, Hamzeh-Gharanein, Mirgeh Nagshineh, and Kharapeh in northern part of the SSZ and Zartorosht in southern part of this zone (**Fig. 5**). According to type of metamorphosed host rock and formation depth, these deposits are divided into three groups including turbiditic and epizonal host gold deposits (Kharapeh), green stone and mesozonal (Gholgholeh, Kervian and Zartorosht) and granitoidic and hypozonal host (Ghabaglojeh) (**Table 1**). Mineralization time is an important factor in these deposits (**Table 1**). Due to cutting metamorphosed units by siliceous mineralized veins, age of the deposits of Kharapeh, Kervian and Ghabalojeh belongs to after regional metamorphism in Cretaceous. However, dating results obtained from deformed intrusive bodies of milonitic fabric and host rock the Gholgholeh, show the Paleocene age of this deposit that conform with mineralization age (Tajedin, 2012). Nevertheless, Eocene age has been proposed for this deposit using dating results obtained from siliceous mineralized veins in the Zartorosht deposit in southern part (**Table 1**). Moreover, in other parts of the SSZ, Eocene age reports gold mineralizations of metamorphosed hosts (**Table 1**).

Gold deposits related to listwanites are other types of orogenic gold mineralization in SSZ. This type of gold mineralizations occurs as geochemical anomalies and indices limited to ophiolitic serpantites of intense alteration that thrusted in the Zagros suture such as Sahneh, Khoy and Baft within lineaments in the direction of shear and thrusting zones (**Fig. 5**). Gold-bearing ophiolite rocks, predominantly involve altered serpantinized and listwanited harzborgites that undergone tectonic process such as faulting and shearing. The mineralizing fluids are visible through local structural conduits as carbonate-siliceous stockworks. Calcite, dolomite, ankerite and magnetite occur as paragenesis of carbonate minerals.

Gold deposits related to intrusive bodies

Thompson and Newberry (2000) for the first time, presented characteristic specifications for better understanding of gold deposits and used the term of "gold related to reductive intrusive bodies". According to dating data from the deposits related to reductive intrusive bodies in this zone, they predominantly belong to Eocene (**Table 1**) and their distribution is concordant temporally with magmatic activities in the UDMB. The Gold occurrences of Astaneh, Nezam-Abad, Gozalbolagh and Muteh are known deposits of this type in this zone located in the central to northern part (**Fig. 6**). However, granitoidic bodies associated with these deposits have weak oxidizing specifications. Lack of metamorphism and deformation in the deposits related to reductive intrusive bodies (in the deposits that this relation has been recognized for example the Astaneh, Nezam Abad deposits) is one of the characteristics of this type of deposits that points to occurrence of mineralization prior to metamorphism and deformation.

Geometrically these deposits occur as siliceous-sulfide veins (pyrite, chalcopyrite and arsenopyrite) having tourmaline and tungsten located in the NW-SE aligned intrusive bodies or at a distance, in the metamorphic rock. Gold occurrences are invisible in the sulfide phase and free in silica. There is no hydrothermal alteration in these veins and alteration is limited to narrow halo in surrounding of sulfide-bearing quartz veinlets of sericite-carbonate-feldspar. Type of host rock, especially metamorphic host rock play decisive role in changing original fluid composition and even changing in elements associated with mineralization. The mineral deposits have a geochemical Te-Au-Bi-As-Sb-Ag signature in common, are relatively low in base metals, low in oxidation state and are associated with granitic intrusions of relatively reduced nature (illeminite series) (Nekouvaght Tak, 2008; **Table 1**). The values of stable isotopes confirm the magmatic or magmatic-metamorphic origin of the hydrothermal fluids (Nekouvaght Tak, 2008; Heidari, 2013). Existence of aplitic-pegmatite dykes and quartz-tourmaline veins and lack of their extrusive equivalents are geological evidence of this mineralization, but high-temperature mineralization, indicates deep emplacement depth (**Table 1**). Moritz, et al (2006) considered that this type of mineralization relates to extensional phase associated with late Eocene core complex and its related magmatic phase that emplaces in older metamorphic units during exhumation of the metamorphic complex.

Gold deposits related to oxidized sub-volcanic bodies

These deposits are important gold deposits of Iran and consist more than 30 percent of proved reserves of the country (**Table 1**). These types of mineralizations have been divided based on host rocks and their situation considering formation depth into two subgroups namely deposits related to sub-volcanic bodies of sedimentary-hosted epithermal gold deposits (Carlin like) and volcanic hosted epithermal gold deposits related to sub-volcanic bodies.

Sediment hosted gold deposits (Carlin like)

These deposits or Carlin Like deposits in the SSZ are related to sub-volcanic intrusive bodies that intruded into Proterozoic to Paleogene sedimentary rocks (**Table 1**). Intrusion of subvolcanic related to mineralization in basement rocks (Neo-Protrozoic) implies uplifting and extension together with magma emplacement. Somewhere, these types of deposits constitute distal parts of an oxidizing intrusive system (such as Aghdarreh), but are mainly are arranged in clusters and in direction of narrow zones with large fractures.

These deposits have been formed in Miocene (Mehrabi, 1999; Daliran, 2008; Heidari, 2015) and show similarity in their temporal distribution with large porphyry systems in the UDMB such as Sarchesmeh, Meiduk and Sungun (**Table 1**). According to recent studies about tectonic setting formation of this type of mineralization, regarding their related magmatism specifications, suggest syncollisional to postcollisional extensional processes for them (Richards et al., 2006; 2012). Of recognized deposits of this type in the SSZ, Zarshuran and Agh-Darreh deposits can be referred to Mehrabi, et al, 1999; Asadi Harooni et al., 1999; 2000; Daliran and Valter, 2002; Daliran et al., 2002; Daliran, 2008 (**Table 1**).

These deposits often occur as disseminated, replacement, vein and veinlet, sheared and stratabound ores in carbonate and stratabound horizons and are controlled by a fault zone (**Table 1**). Major alterations associated with mineralization are decalcification, silicification, dolomitization and rarely potassic-argillic. Invisible gold occurs predominantly in jasperoids and shows strong correlation with Sb, Hg, As, Te, Se, Tl, Ag, Cd and Bi and medium correlation with base metals (**Table 1**). According to Daliran (2008), arsenopyrite may be carrier mineral of primary gold (invisible). Ratio of Au/Ag in the Zarshuran deposits is about 1:1 (Karimi, 1993).

Volcanic hosted epithermal gold deposits

Studies about Volcanic hosted epithermal deposits in the SSZ refer to their formation in Miocene (**Table 1**). These mineralizations generally relate to subvolcanic felsic or volcanic rocks which are located in the volcanic centers and imply the longevity of magmatic activities. Known deposits of this type include the Sari Gunay, Baychebagh and Touzlar deposits (**Table 1**) that show their maximum occurrences in northern part the SSZ (**Fig. 6**). Ores occur as banded, shear veins, filling empty spaces, and fractures, and as stockwork, disseminated in fractures and their altered margins (**Table 1**). Their mineralogy is diverse and includes gold, pyrite, realgar, orpiment, pyrrhotite, bornite, galena, sphalerite, blangreite, stibiconite and kramzite (**Table 1**).

Alterations associated with these deposits predominantly include chloritization, sericitization, turminalization and silicification. Surrounding rocks predominantly include andesites, trachyts, dacits, and latites, and rhyolites, pyroclastic and stocks of sub-alkaline with high potassium to alkali composition (Richards et al., 2006; Heidari et al., 2015). Gold shows maxim geochemical correlation with Te, Au, Bi, As, Sb, Ag and to a lesser degree with base metals. According to petrogenesis studies, the formation setting of these magmatic phases relate to Precollisional to syncollisional processes (Richards et al., 2006; Heidari et al., 2015).

Type and distribution of gold mineralization in the UDMB

It is a long time, the Tertiary magmatic belt of western Iran, better known as UDMB, gained attention of experts due to possession of large deposits of porphyry Cu-Mo of the world. A vast spectrum of magmatic process from Paleocene to present era, adds to its importance in terms of gold mining potentials. In order to gain a better understanding of gold mineralization phases of this belt, we examine the existing gold deposits in this magmatic belt.

Gold related to porphyry deposits

Cu porphyry deposits of the UDMB constitute main Cu-Mo mineralization phase of Iran (**Fig. 1**) which main concentration exists in southeastern part of this belt (**Fig.** and **Table 1**). Although the gold grade of this mineralization is low and classified as gold-poor porphyry copper deposits, (Shafiei and Shahabpour, 2008), huge tonnages of porphyry deposits provide a sizeable resource of gold and they are important due to their major role in the gold production of the country as their by-product. However, from all of the Cu-Mo porphyry deposit of Iran gold does not extract.

Intrusives of this type have porphyric texture and cover a range from diorite to quartz-diorite, granodiorite and quartz monzonite. Although these rocks have high-alumina composition and belong to magnetite granitoid (calc-alkaline) (Aftabi and Atapour, 2000) from geochemical aspect, reveal characteristics of adakitic-like intrusions (Shafiei et al., 2009). According to age dating, these porphyry copper deposits have formed in Miocene, especially Middle-Upper Miocene (**Table 1**). The deposits of Sarchesmeh, Sungun, Meiduk, Aliabad, Darre Zereshk and Sarkoh are some of the known deposits of this type in this belt (**Table 1**). shallow emplacement of the Abdar and Meiduk deposits with higher gold contents than Sarchesmeh that is characterized by lower Au content and deeper emplacement, indicates a negative correlation between emplacement depth and the amount of gold in these deposits that may have been caused via higher level emplacement and high oxidation conditions of ore-forming magmas (Shafiei and Shahabpour, 2008). Recent studies about formation settings of these deposits indicate that these magmatic phases relate to collision to post-collisional extensional settings formed in the UDMB (Shafiei et al, 2009; Atapour et al, 2010; Richards et al., 2012).

The Cu-Au porphyry deposits are another type of porphyry deposits in this magmatic belt, which were explored since 10 years ago and contain high portion of gold reserves. Deposits of Dali, Mivehrod, Masjeddaghi and Mianeh are some of the known deposits of this type in UDMB (**Table 1**). Among these, the Cu-Au porphyry deposit of Dali in the central part of the UDMB is a typical instance of this type of mineralization (**Table 1** and **Fig. 6**). This type of mineralization of Lower Miocene age (about 21 Ma) is associated with calc-alkaline (diorite, granodiorite and quartz monzonite) and alkaline (monzonite, quartz syenite) magmas and locally with contemporary volcanic rocks (Ayati et al., 2013). Serisitic and propylitic alterations are the major alterations in this type associated with potassic alteration and concentration of mineralization in center. Mineralized and silicified veins and veinlets occur as stockwork and disseminated in the intrusive body and host rock (**Table 1**).

Gold skarn deposits are another type of deposits related to intrusives in this belt that limestones as well as volcanic rocks constituted their host rocks. The deposits of Nabijan, Mazraeh, Anjerd, Gavdel, Kharvana and parts of the Mivehrod and Sungun deposits in northwestern part are some known deposits of this type in this magmatic belt (**Table 1**). These mineralization types are in close association with magnetite bearing granitoids substituted in deep levels. These deposits occur predominately as veins with disseminated to massive texture. Gold often occurs as accessory mineral associated with sulfide phase that relate to

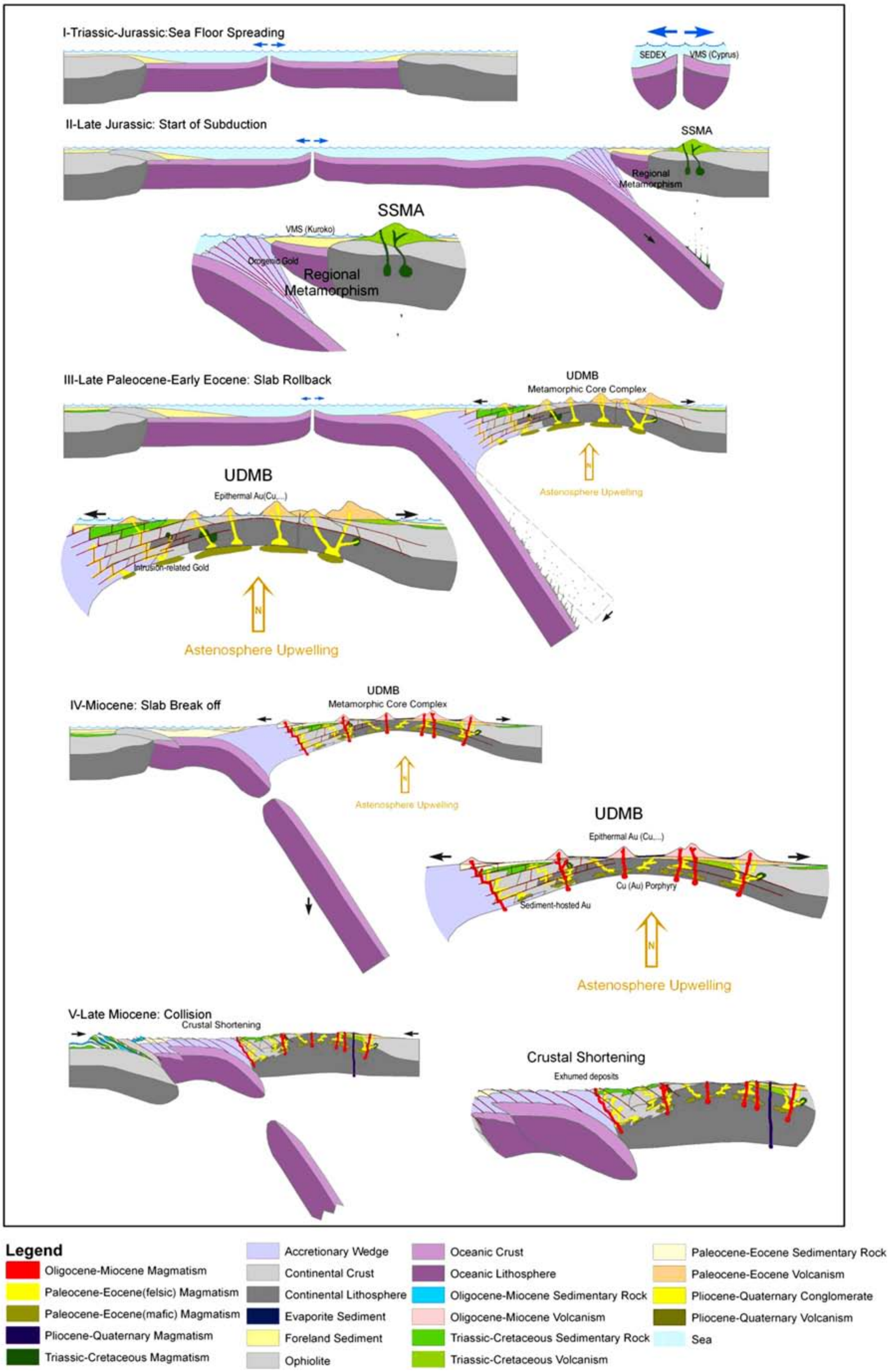


Fig. 6. Simplified tectono-magmatic model for the inner parts of Zagros orogeny, western Iran

retrogressive stages of alteration (**Table 1**). The major mineralization pragensises are pyrite, pyrrhotite, arsenopyrite and chalcopyrite with high concentration of As, Bi, Mo, Cu, Ag with various ratios of Au/Ag (**Table 1**). In addition to gold skarns, some of Cu porphyry deposits of this belt have skarn sections, such as porphyric skarns of Mivehrod and Sungun. However, all of them do not have gold or have very little gold contents (**Table 1**).

Epithermal gold deposits

Due to low age and low formation depth and various climatic, tectonic and topographic conditions, epithermal gold deposits of UDMB have not eroded uniformly, so these systems outcrop in various levels in their vertical zoning, in a manner that some of them relate to deeper sections of higher grade and others are in higher levels of lower grade. More than 80% of existing epithermal gold deposits of this belt have reserves of lower than one tone, more than 15% have reserves between one to 1.5 tone and about 5% of them have reserves of over than 1.5 tone (**Fig. 5** and **Table 1**). These deposits in clustered form show their maximum extension in three southern, middle and northern regions of the UDMB (**Fig. 6**).

According to mineralization age, all of the epithermal deposits of this belt have formed in the time of Oligo-Miocene. Host rocks of these deposits are often calk-alkaline intrusive-volcanic arc including andesite basalts to andesite, dacits and rhyolites in the upper parts of subduction zone, which formed during the main phase of upper crustal shortening coupled with compression strike-slip tectonic regime. However, major mineralizations of this type have correlation with subsequent phase of magmatism, known as Miocene in terms of age. Due to the lack of sufficient radiometric data of existing mineralization of this part and actions of younger magmatic phases (after Miocene), it is very hard to differentiate Oligocene epithermal mineralization systems from gold systems related to Miocene phase. However, according to available data (**Table 1**), mineralization and alteration paragenesis series and classification of Sillitoe and Hedenquist (2003), Oligocene epithermal mineralization of this part are classified as gold deposits related to oxidizing subvolcanic intrusives of low sulfidiation (**Table 1**). The Zeglick, Shrafabad-Hizejan and Gebjagh are some of the known deposits of this type (**Table 1**). Although epithermal gold deposits related to the Miocene phase are associated temporally and spatially with some of porphyric systems, they have formed in lower crustal levels. These deposits mainly occur in margin of outcropped sections of porphyric systems (**Fig. 6**). Since these magmatic phases have more alkalinity affinity than Eocene arc phase and have formed in extensional tectonic regime and syn-postcollisional setting, this type of mineralization is considered predominantly as epithermal deposits of intermediate sulfidiation associated with subvolcanic intrusives as high-sulfidiation type. The deposits of Chah Zard, Glojeh, Masjeddaghi, Mivehrod, Latala and Mianeh are some instances of this type in this magmatic belt (**Table 1**).

In addition to Oligo-Miocene epithermal gold deposits, there are occurrences of Pliocene-Quaternary epithermal deposits in southern part of this belt, related to subduction of the Oman oceanic crust beneath Makran (**Table 1**).

Discussion

In an orogenic system such as what has occurred in Iran plateau, various gold deposit types related to processes of rifting, subduction, collision and post-collision can be formed (**Table 2**). In fact, gold deposits of these tectonomagmatic belts are outcomes of Neo-Tethys development process from Permo-Triassic to present era (**Fig. 6**). Nevertheless, diverse processes during development as metamorphism, erosion and uplifting lead to vast non-presence of various types. In addition to the known gold deposits and existing important gold deposit types of Iran, there may be other probable deposits and potentials formed in various geodynamic setting during development and may be important as exploratory potentials (**Table 2**). According to the previous studies and gold metallogenic phases, important geodynamic setting in the inner part of the Zagros orogeny can be divide into five following stages:

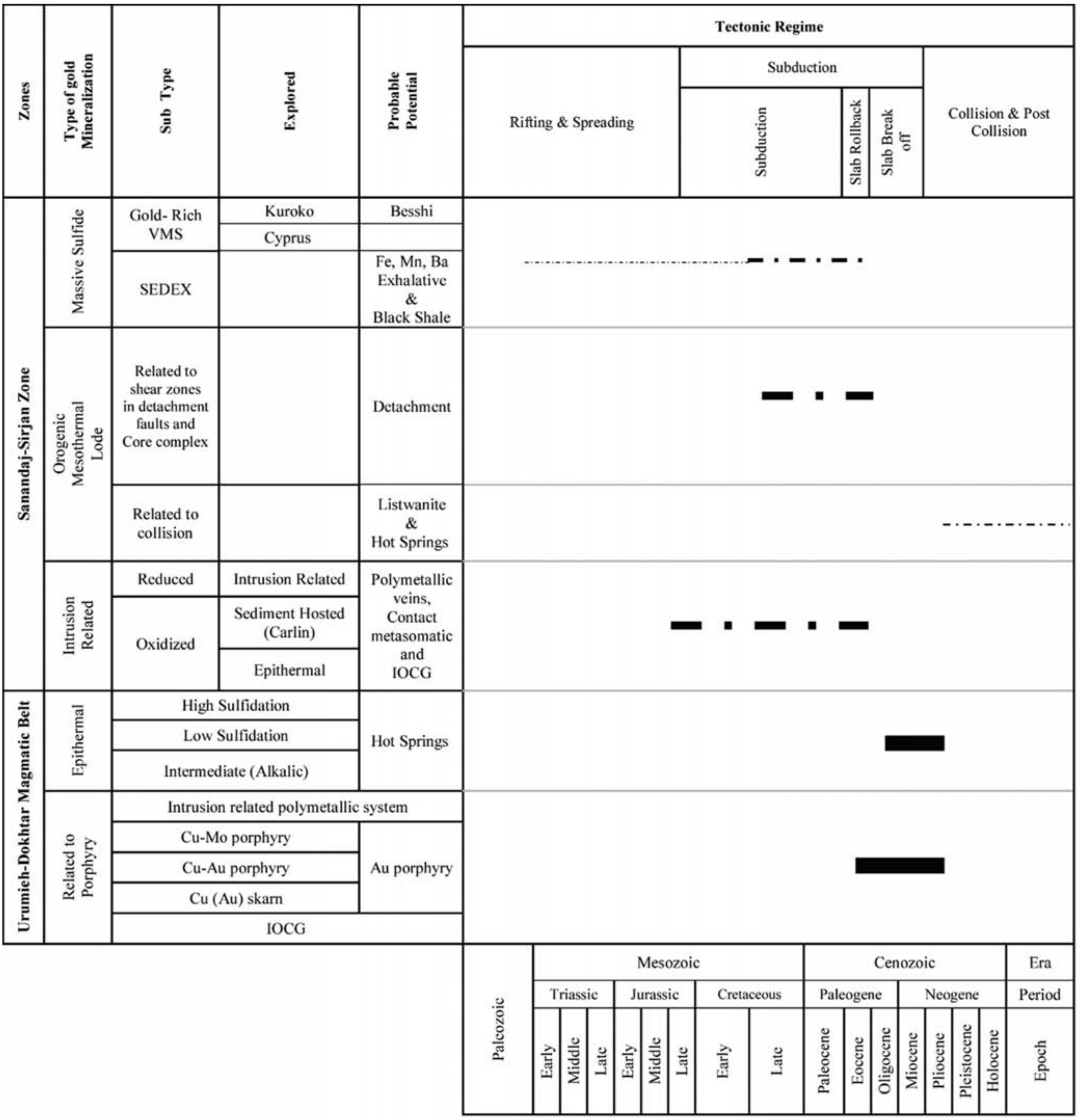
Riftting and spreading from Permo-Triassic to Cretaceous

This class indeed contains deposits formed as sedimentary exhalative and massive sulfide (Cyprus-type) in upper section of ophiolitic sequence known as basaltic lavas and sediments that overlaid them (**Fig. 6**, **Table 2**). According to ages of ophiolits, time interval of this mineralization is from Triassic to Cretaceous. Mineralization has occurred due to subduction of the major part of oceanic crust beneath Central Iran and collision which is limited and related to abducted ophiolitic parts (Sahneh, Neyriz and Hajiabad) and uplifted mélanges (Khoy, Naeen and Shahr Babak). These deposits occur as Cyprus-type massive sulfide such as Sheykh Aali and Zoorabad Khoy and as sedimentary exhalative deposits. However, uplifted and m lange parts have epithermal and listwanite potentials as well as sedimentary exhalative and massive sulfide types formed due to activity and action of subsequent tectonomagmatic phases (**Fig. 6**, **Table 2**). Existing gold potential in sedimentary sections of this ophiolitic sequence is hardly recognizable due to emplacement in accretionary wedges. However, available data of this type of deposits indicates gold association predominately with Fe and Mn nodules. Although the surveys indicated that these deposits do not constitute large economical potentials of gold, but they imply anomalousness of the Neo-Tethys oceanic crust regarding gold distribution (**Table 2**).

Subduction from Triassic to Upper Cretaceous

In this stage, subduction of oceanic crust with high slope beneath oceanic crust and continental margin of Central Iran lead to formation of accumulative sediments as accretionary wedges, regional metamorphism, and SSZ in the edge of Central Iran (**Fig. 6**). This magmatic arc shows its maximum activity in this zone as batholitic intrusive bodies of predominantly Jurassic age emplaced in deep parts of continental crust. The compositions of these intrusive bodies cover a range from magnetite to illeminite granitoid bodies and type I to S granites together regional metamorphism of subduction zones. Although the importance of this phase is widely known as host rock of mineralization in the gold deposits such as… up to now, there is no report about gold mineralization potential of these bodies (**Table 2**). Major volcanic activities ascribed to this magmatic arc of this zone belong to Upper Cretaceous that show their maximum extension all over of this zone as the last magmatic phase related to this stage. Despite the vast presence of magmatic activities in Mesozoic, gold mineralization of this part is merely constrained to last phases of magmatism in SSZ and its western margin in this interval that occurs with Kuroko massive sulfide deposits. Low crustal thickness and magmatic

Table 2. Correlation between tectono-magmatic events and gold metallogeny in UDMB and SSZ.



Zones	Type of gold Mineralization	Sub Type	Explored	Probable Potential
Sanandaj-Sirjan Zone	Massive Sulfide	Gold- Rich VMS	Kuroko	Besshi
			Cyprus	
		SEDEX		Fe, Mn, Ba Exhalative & Black Shale
	Orogenic Mesothermal Lode	Related to shear zones in detachment faults and Core complex		Detachment
		Related to collision		Listwanite & Hot Springs
	Intrusion Related	Reduced	Intrusion Related	Polymetallic veins, Contact metasomatic and IOCG
		Oxidized	Sediment Hosted (Carlin)	
			Epithermal	
Urumieh-Dokhtar Magmatic Belt	Epithermal	High Sulfidation		Hot Springs
		Low Sulfidation		
		Intermediate (Alkalic)		
	Related to Porphyry	Intrusion related polymetallic system		
		Cu-Mo porphyry		Au porphyry
		Cu-Au porphyry		
		Cu (Au) skarn		
		IOCG		

specifications such as low differentiation and lack of formation of sub-deep intrusives in this stage and high slope of subduction are not the suitable condition for formation of porphyry deposits (**Fig. 6**, **Table 2**). However, some geologists believe that these deposits have formed and were completely destroyed due to erosion. Although rate of produced magma in this time interval indicates non-uniform development of Neo-Tethys in this zone, shows similar formation process. This non-uniformity occurs due to effect of transform faults, and rate of various opening and displacements. It is evident that in this interval, the SSZ consists subducted sedimentary units, magmatism related to continental arc on subducted slab, regional metamorphic rocks, and sedimentary and volcanic rocks accumulated in forearc position. It is required to note the immaturity of Iranian continental crust during accretionary tectonic and formation of magma that is different from usual continental arc.

Uplifting asthenosphere during Paleocene-Eocene

Under effect of rollback process, this stage of subduction beneath Central Iran has been associated with asthenosphere uplifting, metamorphism, deformation, and magmatic process (**Fig. 6**). Invasion of magmatic arc in the back of Sanandaj-Sirjan magmatic arc and SSZ leads to formation of UDMB in this interval. Though this magmatic phase as volcanic-intrusive bodies occur linearly with direction of NW-SE in the UDMB, but intrusive bodies related to this phase occur sporadically in SSZ. This uplifting and metamorphism are associated with formation of shear zones in western margins (forearc) and normal faults (detachment). Mineralization of this stage encompasses vast spectrum of deposits related to shear zones in metamorphosed host rock (orogenesis) and predominately reductive deep intrusive bodies. Major gold mineralization related to shear zones of metamorphosed host rock in this zone and gold deposits related to reductive magmatic bodies have formed during this time interval (**Fig. 6**, **Table 2**). Two contrary movements, closing of the Arabian plate to Iran and asthenosphere uplifting in opposite direction are the main factors in formation of shear zones in large scale. It is worthwhile to note that various factors such as bedrock faults and transform have caused many regional distortions and changed the general trend of NW-SE in the development of structural zones.

Oligo-Miocene

This stage is coincided with last phases of the Neo-Tethys development in the Zagros Orogeny that is associated with shortening, more uplifting, collision, break-off, and creation of vast spectrum of post-collisional magmatic activities from Miocene to present era in this part (**Fig. 6**). In the SSZ and the UDMB, magmatic activities have extended in syncollisional and postcollisional extensional settings as sub-deep and intrusive bodies that lead to formation of various gold deposits as porphyry deposits, epithermal deposits related to oxidizing sub-deep body and carbonate-hosted deposits related to sub-deep bodies, etc (**Table 2**). This phase does not have the same performance in all of the inner part of the Zagros orogeny. This phase has continued by shortening and thickening in compression regime especially in the SSZ and finally by thrusting under effect of shear zones and was turned to present form due to uplifting, outcropping of lower units and stripping. Quick uplifting and stripping are major factors of outcropping deep mineralization such as deposits related to orogenesis and reductive bodies in the SSZ (**Table 2**). This phase applies maximum influence in distortion of former sequences and outcropping of bedrock units and mélanges.

Crustal thickening and uplifting are other consequences of this phase. The boundary of this uplifting is located in SSZ between two thrusting fault of Zagros.

Pliocene-Quaternary

Postcollisional uplifting and seismicity indicate, continuance of Neo-Tethys development indicated by hot springs, intense rising and erosion. There is no report about occurrence of any deposit regarding these systems.

Conclusion

This review demonstrates that major gold deposits in inner part of the Zagros orogeny show maximum temporal and spatial similarity with tectonomagmatic phases of the Neo-Tethys development. These tectonomagmatic phases show continuous spectrum of magmatic activities from subduction to post-collision, in which major gold mineralization has occurred in relation with the Paleocene-Eocene and Oligocene-Miocene phases. The Paleocene-Eocene show reductive specifications but the Miocene phases show alkaline to shoshonitic affinity of adakitic composition. Situation of formation, formation depth of extensional regimes and crustal thickness are the essential controllers in the formation of these deposit types. As a result, the gold deposits of the extensional phases of the SSZ of Miocene age and the gold deposits of the UDMB constitute two distinct deposit types compositionally due to oxidation of different magmas (Magnetite series), higher contamination (Molybdenum) and different water content. Major magmatic rocks related to gold mineralization phases have oxidation specifications and intermediate to high potassium calc-alkaline nature and belong to magnetite series. Sedimentary-hosted epithermal gold deposits related to oxidation sub-deep intrusives and gold porphyries belong to this group. Among described deposits, orogenesis gold deposits have the least relation with magma, however regarding temporal relation with core complex magmatic phase and their shear zones and emplacement with this magmatic phase, it seems that this mineralization type was located distally from deep reductive magmas and their mixture with metamorphic fluids caused some ambiguities. Thus, this magmatic activity caused suitable origin for gold.

Collision to post-collision (Miocene, 10–20 Ma) and uplifting are the main elements in outcropping gold mineralization related to reductive bodies and orogenesis in the SSZ.

Therefore, investigations of sequences before Upper Eocene in SSZ indicate occurrence of gold deposits of deep depths and orogenic gold deposits that are not associated with regional metamorphism but have formed with core complex metamorphic phase coupled with large scale deformation zones in shear zones. Although surrounding rocks are metamorphic, fluid transmission conduits are shear zones coupled with exhumation.

Deformation

Generally, orogenic gold deposits and occurrences in SSZ have formed via metamorphism, deformation, and magmatism process in all over of convergent forearc of this zone. So, this type of mineral deposits and occurrences have formed during main phase of crustal shortening and uplifting of metamorphosed units from deep depths in compressional-transpressional regimes and all of them have metamorphic and deformation fabrics. These deposits are often controlled by strong structural controller such as faults (trusting and normal), shear zones, folds, and/or boundary regions between two strata of different reology. This stage of orogenic phase causes formation of different deformation fabrics and consequently leads to formation of orogenic deposits as quartz veins of various trends in Sanandaj-Sirjan metamorphic belts. Thus, in parts of this zone where uplifting could not cause outcropping of granitoid rocks, it is futile to carry out exploration surveys. It is worthwhile to note that, deposits in shear zones in Paleocene rocks, merely show deformation is visible due to lack of metamorphism.

Various studies indicate that some parameters such as tectonic setting, emplacement depth and specification of mineralizing fluid, control gold content in these deposits.

Investigation of the gold deposits in SSZ and the UDMB has revealed presence of two intervals: one is formation and development of the SSZ until Paleocene and the next relates to the formation of UDMB and application of various processes in SSZ.

Suggestions for exploration

Understanding and recognition of suitable geologic settings and recognition of their favorite controllers in regional scale are key elements for exploration of non-explored deposits. Better understanding of erosion surfaces in relation with formation depth of an explored system, reveals rather preserved environments (Robert et al. 2007).

Paleocene-Eocene: Major orogenic mineralization of this stage relates to uplifted parts in the surface.

Investigations of tectonomagmatic settings of the gold deposit demonstrate these deposits imply a continuous spectrum of Neo-Tethys development deposits, predominantly related to two phase of Eocene and Miocene. The outcroppings of Eocene phase of this zone requires stripping due to the formation in deeper depth, so recognition of shear zones and milonitic granites of orogenic gold deposits are the best approaches for their recognition. This uplifting is not uniform in all part of this zone.

Miocene phase was associated with collision, many of its deposits occur as anomalies and indices, and it is required to perform detailed exploration to reach larger deposits in depth covered by alluvium. These deposits have various directions due to effect of local processes. Many gold deposits reported in these two zones, have special importance in the world, but do not constitute a large gold reserve. This is while, they are still worthy due to their geodynamic position and tectonic situation in the country. In the following, some probable potential of these zones will be mentioned.

Probable mineral potentials in the SSZ and the UDMB

Hydrothermal iron oxide Cu-Au deposits (IOCG) are more diverse than other hydrothermal deposits and their metosomatic and altered minerals are skapolite, diopside, termolite, aktinolith and andradite (Gumus, 1998). These deposits often have obvious temporal-spatial dependence with batholitic granitoids that occurs in crustal settings and associate with intense alkali metasomatism together enrichment of distinctive composition of F, U, P, Co, Ni, As, Mo, Ag, Ba, and LREE (Williams et al., 2005).

Major source rocks of this type are diorites, gabbros and oxidizing calc-alkaline to alkaline granodiorites formed in back arc extensional setting, intracontinnetal rifts, intracontinnetal hot spots and continental post-collisional extensional basins (Karimpour, 2005). Mineralogical suites of most of the IOCG deposits indicate saline, oxidized and sulfide-poor mineralizing fluid that have high ratios of Cl/S (Barton and Johnson, 1996).

So far, there is no report of occurrence of this type of deposits in the SSZ. However, these types of deposits are reported as Fe skarn deposits, deposits related to intrusive bodies, Cu-indices, etc due to lack of accurate scientific investigation. According to frequent presence of Fe deposits, intrusive bodies and suitable geodynamic setting of this zone, occurrence of this type of deposit is probable that is important for exploration of gold potentials.

Ophiolite-related gold mineralizations or massive sulfides and listwanites are other types of gold mineralization in SSZ that occur mainly as geochemical indices and anomalies limited to abducted ophiolitic sequences in the Zagros suture such as Sahneh, Khoy and Baft. As mentioned before, this mineralizations have formed during ocean floor spreading and sedimentary exhalative conditions, but subsequent events especially metamorphism and deformation (orogenesis) have caused concentration and formation of suitable potentials.

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