Saqez–Sardasht Goldfield, North Sanandaj-Sirjan Zone, Iran: A Tectono-Metallogenic Synthesis

Erfan HAJI[1,*], Hojjatollah SAFARI[2], Behnam SHAFIEI BAFTI[2] and Mehdi MOJALLAL[2]

[1] *Department of Geology, Faculty of Sciences, University of Kurdistan, Sanandaj, Iran*
[2] *Department of Geology, Faculty of Sciences, Golestan University, Gorgan, Iran*

Abstract: The Sanandaj–Sirjan Zone (SSZ), as the metamorphic-magmatic core of the Zagros Orogen in southwestern Iran, contains several styles of gold deposit of Phanerozoic age. The northern SSZ includes an ENE-trending goldfield belt. This area that encompasses the main orogenic gold deposits, e.g., Qolqoleh, Kervian, Qabaqhlujeh, and the Barika VMS goldfield, was chosen for this research to study the spatial and temporal relationships between gold mineralization and orogenic phases. Regarding the rock unit variations, metamorphism, magmatism and the settings of the structures, the study area is divided into four distinct tectonic blocks, separated by three main NW-trending thrust faults (suture lines) including, from NE to SW, the Tamugheh, the Ebrahim Hesar and the Zagros main thrust (ZMT) faults. The area between the Tamugheh and Ebrahim Hesar faults is a tectonized/uplifted basement of accretionary wedge-originated thrust slivers, hosting the above orogenic gold mineralizations. The other area between the here termed Ebrahim Hesar fault and the ZMT is an island-arc basin, proposed here as the Sardasht–Barika zone, including the only recognized massive sulfide gold district all over the SSZ, named Barika. The Barika goldfield was metamorphosed, deformed and enriched due to the island-arc collision to the Arabian continent, before the closure of Neotethys on the eastern flank.

Key words: tectonic evolution, massive sulfide gold, orogenic gold, Sanandaj–Sirjan Zone, Saqez–Sardasht Zone, Sardasht–Barika Island Arc

Citation: Haji et al., 2020. Saqez–Sardasht Goldfield, North Sanandaj-Sirjan Zone, Iran: A Tectono-Metallogenic Synthesis. Acta Geologica Sinica (English Edition), 94(5): 1693–1710. DOI: 10.1111/1755-6724.14586

1 Introduction

The Sanandaj–Sirjan Zone (SSZ) is a metamorphosed-magmatic belt, associated with the Zagros Orogen and part of the Alpine-Himalayan orogenic system in Iran (Takin, 1972; Ricou et al., 1977; Alavi, 1980; Berberian and Berberian, 1981; Dercourt et al., 1986; Sengor et al., 1988; Mohajjel and Fergusson, 2000; Stampfli and Borel, 2002; Golonka, 2004; Agard et al., 2005; Mehdipour Ghazi and Moazzen, 2015). The rocks of the SSZ, now comprising a 1500-km long, 150 to 200-km wide outcrop, were separated from central Iran during much of the Mesozoic (Sengor, 1990; Mohajjel et al., 2003). The SSZ rocks are the most highly deformed in the Zagros orogen, sharing the NW–SE trend of the surrounding structures (Berberian, 1995; Ghasemi and Talbot, 2006; Azizi and Jahangiri, 2008; Agard et al., 2011). The geodynamic evolution of the SSZ was controlled by the opening and subsequent closure of the Neotethys Ocean at the northeastern margin of Gondwanaland (Berberian and King, 1981; Alavi, 1994; Sengor and Natal'in, 1996; Hassanzadeh et al., 2008; Fig. 1).

The SSZ is subdivided into two parts (Eftekhar-Nejad, 1981): southern and northern. The southern SSZ consists of rocks deformed and metamorphosed in the Middle to Late Triassic (Berberian, 1995). The northern SSZ, termed as the Sanandaj–Mahabad zone, was deformed in the Late Cretaceous and contains many intrusive felsic rocks. Both metamorphic events and young (Upper Cretaceous–Paleogene) batholiths are accumulated mostly in the northern SSZ (Mehdipour Ghazi and Moazzen, 2015). Based on close observations of the Late Mesozoic continental margin/arc, which formed during the northwestward subduction of Neotethys under the Iranian Continent (Eurasian plate), the SSZ was subdivided by Mohajjel and Sahandi (1999) into five subzones from southwest to northeast: 1) the radiolarite sub-zone; 2) the Bisoton sub-zone; 3) the ophiolite sub-zone; 4) the marginal sub-zone; and 5) the complexly deformed subzone. In the northern SSZ, there are three parallel NW–SE trending magmatic belts, situated between two major faults (Azizi and Moinevaziri, 2009), the Tabriz fault in the northwest and the Zagros fault (ZMT) in the southwest. Along these two major faults, some dismembered ophiolitic complexes were exposed, including the Khoy ophiolite to the east and the Kermanshah ophiolite to the west (Ghazi and Hassanipak, 1999; Azizi et al., 2006). From NE to SW, the mentioned volcanic belts are termed by Azizi and Moinevaziri (2009) as: 1) the Hamedan-Tabriz (HTV) zone (northern part of UDMA volcanic arc); 2) the Sanandaj volcanic belt (SCV); and 3) the Sonqor-Baneh volcanic belt (SBV).

In Iran, there are various gold occurrences specific to Paleozoic thru to Eocene times, spread over the so-called

* Corresponding author. E-mail: erfan.haji@gmail.com

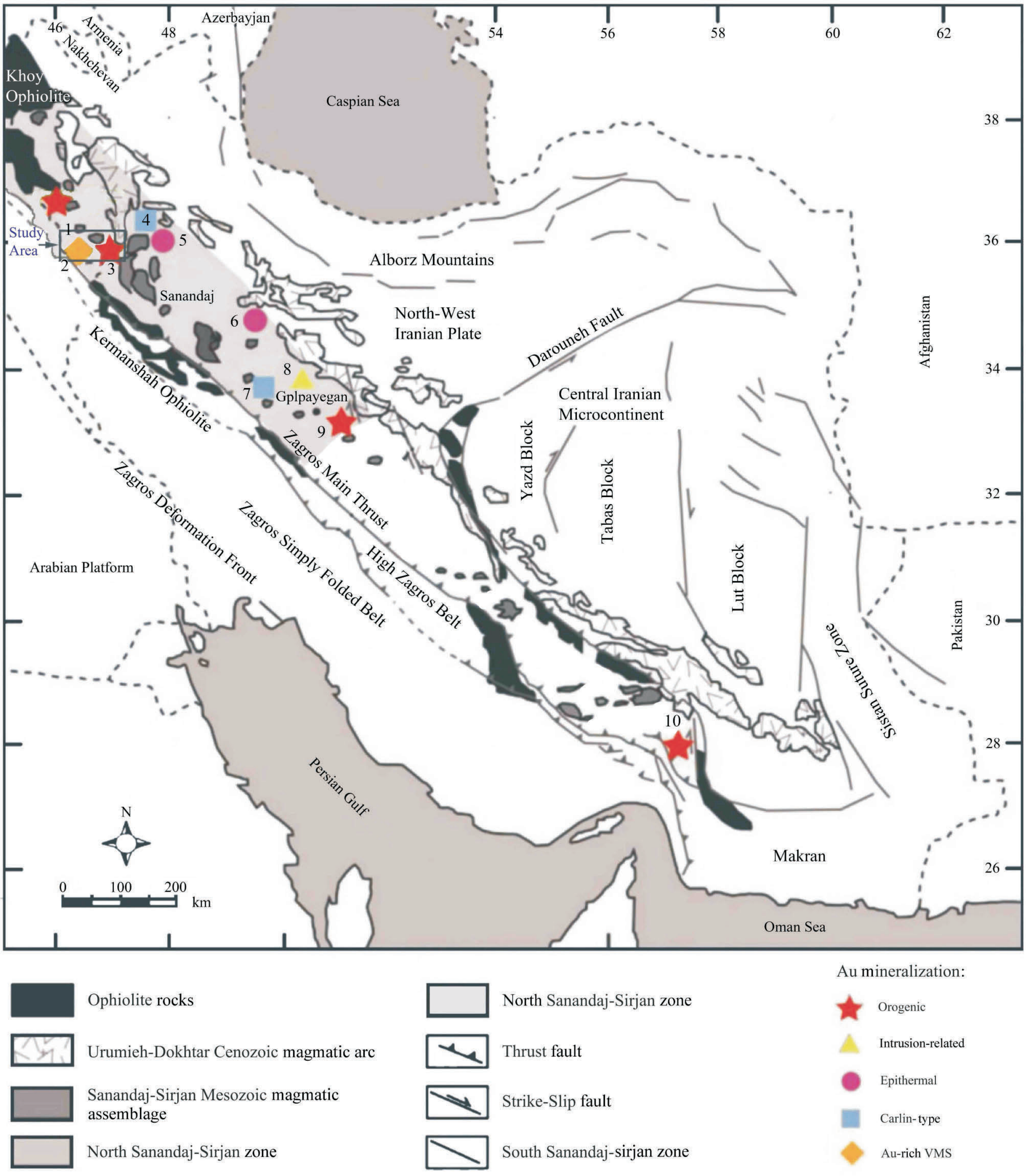


Fig. 1. Structural division of Iran and locality of the main gold prospects in the SSZ (from Alavi, 1994; Ghasemi and Talbot, 2006; Almasi et al., 2014).

1- Kharapeh, 2- Barika, 3- Saqez–Sardasht greenstone-hosted orogenic gold zone (Qolqoleh, Kervian, Qabaqhlujeh and Mirgeh Naghshineh), 4- Aghdarreh–Zarshuran, 5- Tuzlar, 6- Sari Gunay, 7- Akhtarchi, 8- Astaneh–Sarband, 9- Muteh, 10- Zartorosht. The study area is shown by a rectangle.

northern, central and southern metallogenic provinces of the SSZ. These deposits/prospects have been classified as orogenic-type (e.g., Qolqoleh, Kervian, Qabaqhlujeh, Pir Omaran, Kharapeh, Mirgeh Naghshineh, Hamzeh Gharanain, Sheikh Chupan, Zaveh Kouh, Sardeh Kouhestan, Shoy, Chah Bagh), epithermal-type (e.g., Aghdarreh, Sari Gunay, Guzal Bolaqh), Carlin-type (e.g., Zarshuran, Akhtarchi), intrusion-related type (e.g., Muteh, Astaneh, Zartorosht) and gold-rich VMS (massive sulfide) type (e. g. Barika) goldfields (Tajeddin et al., 2006;

Aliyari et al., 2012; Kouhestani et al., 2014; Fig. 2).

The first recorded gold occurrences within the SSZ metallogenic belt contained the Muteh and Zartorosht goldfields at the central and southern provinces, respectively (Aliyari et al., 2012); nonetheless, the Northern SSZ has been potentially considered as a gold-bearing zone only during the recent two decades, especially with regard to orogenic gold deposits. Zagros orogenic gold typology is rather comparable to some other Gondwanan Phanerozoic subduction systems, e.g., New Zealand, South American (Bierlein et al., 2001; Goldfarb et al., 2001) and Lachlan orogenies (Hough et al., 2007). Orogenic/metamorphic golds have been generally associated with 'ophiolitic and greenschist basement of Late Proterozoic–Early Cambrian' age by Ghorbani (2013) as well as being ascribed to the 'greenstone-hosted

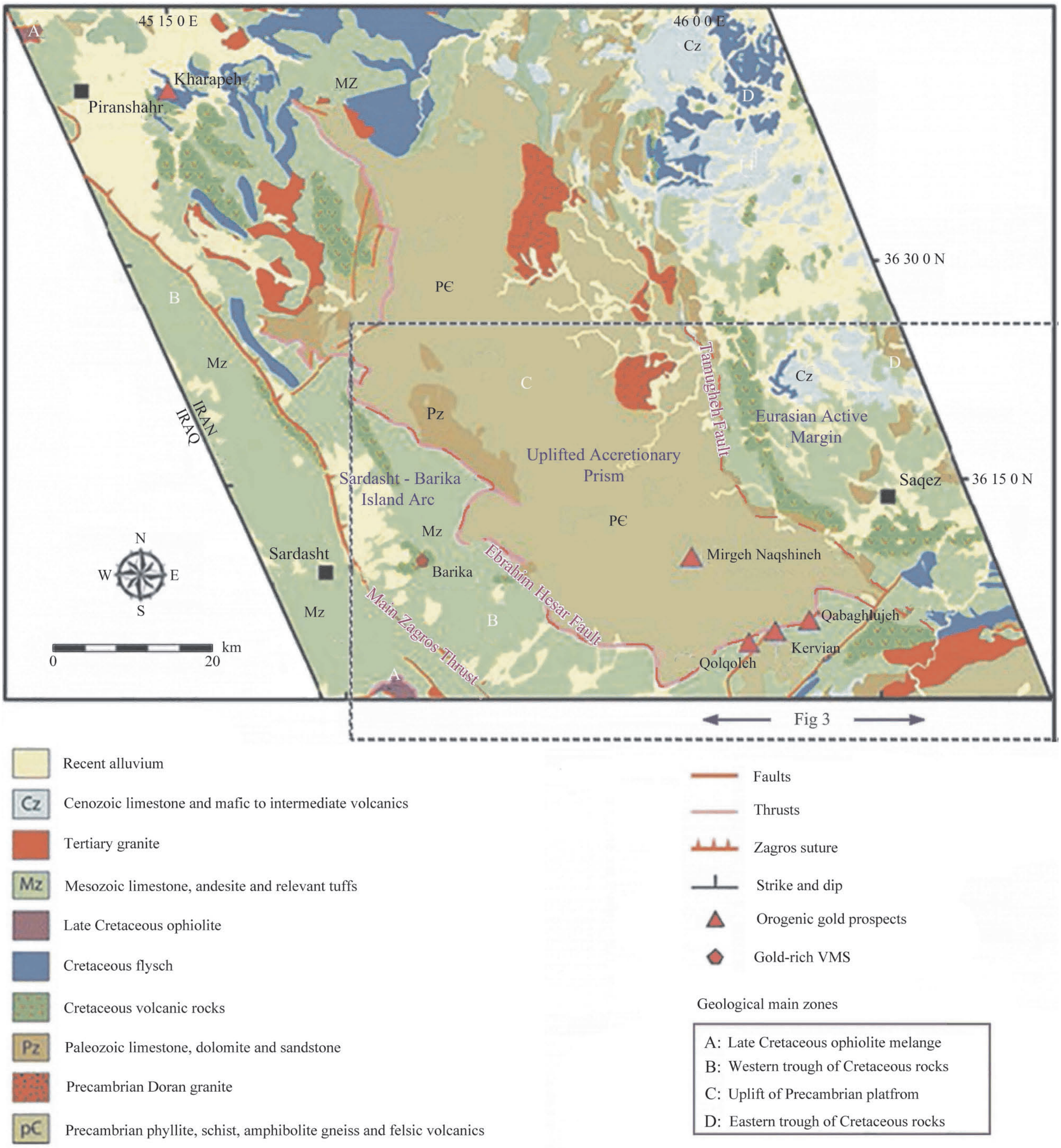


Fig. 2. Simplified geologic map of the Saqez–Sardasht–Piranshahr area (Eftekhar-Nejad, 1973, 2004) showing the distribution of various types of gold deposits and prospects in the northern SSZ. Gold occurrences are shown related to metamorphic and plutonic rocks and various structural settings (after Aliyari et al., 2012). The map is adopted by adjusting to the proposed tectonic division in this work. The study area in the rectangle is restricted by a dashed boundary.

quartz-carbonate vein' mineralization model among a total of 16 proposed global gold types by Robert et al. (2007). Again, orogenic gold deposits of Iran have been affiliated to 'mesothermal vein deposits' among five proposed models classified by Lescuyer et al. (2003).

Being considered as an exceedingly important area of the Northern SSZ goldfields, the Saqez–Sardasht zone is an ENE-trending gold-bearing belt, hosted by mafic to intermediate metavolcanic and metasedimentary rocks (Aliyari et al., 2012). This ample elongated zone, which embodies the main orogenic gold deposits (Qolqoleh, Kervian, Qabaqhlujeh, Hamzeh Gharanain and Mirgeh Naghshine) and the only VMS goldfield (Barika), is located to the west of the North SSZ (predominantly covering Kurdistan Province; Fig. 3). The Saqez–Sardasht zone was chosen for this research to study the chronological links between gold metallogeny and tectonic events. All the above deposits are of ductile to brittle shear styles, located within or adjacent to the major deep Saqez–Sardasht thrust fault and/or other confining normal faults across the shear zone-affiliated metamorphic rock units. In the Qolqoleh, Kervian, Qabaghloujeh, Alut and Hamzeh Gharanein deposits, disseminated quartz-sulfide veins and veinlets are primarily foliation-parallel but the next veins/veinlets have occasionally cross-cut the foliation planes across the mineralization zone. Taken together, they are developed predominantly inside the highly altered and deformed Upper Cretaceous mafic to intermediate metavolcanic and metasedimentary rocks. Individual auriferous veinlets, typically 10 millimeters to 2–3 centimeters wide, have been extensively silicified. These silicic veinlet systems, containing high gold contents, tend to overprint earlier disseminated gold deposits, especially in the Qolqoleh district (Aliyari et al., 2007, 2009, 2012; Fig. 4). The above veinlets represent spatial associations with highly pyritized,

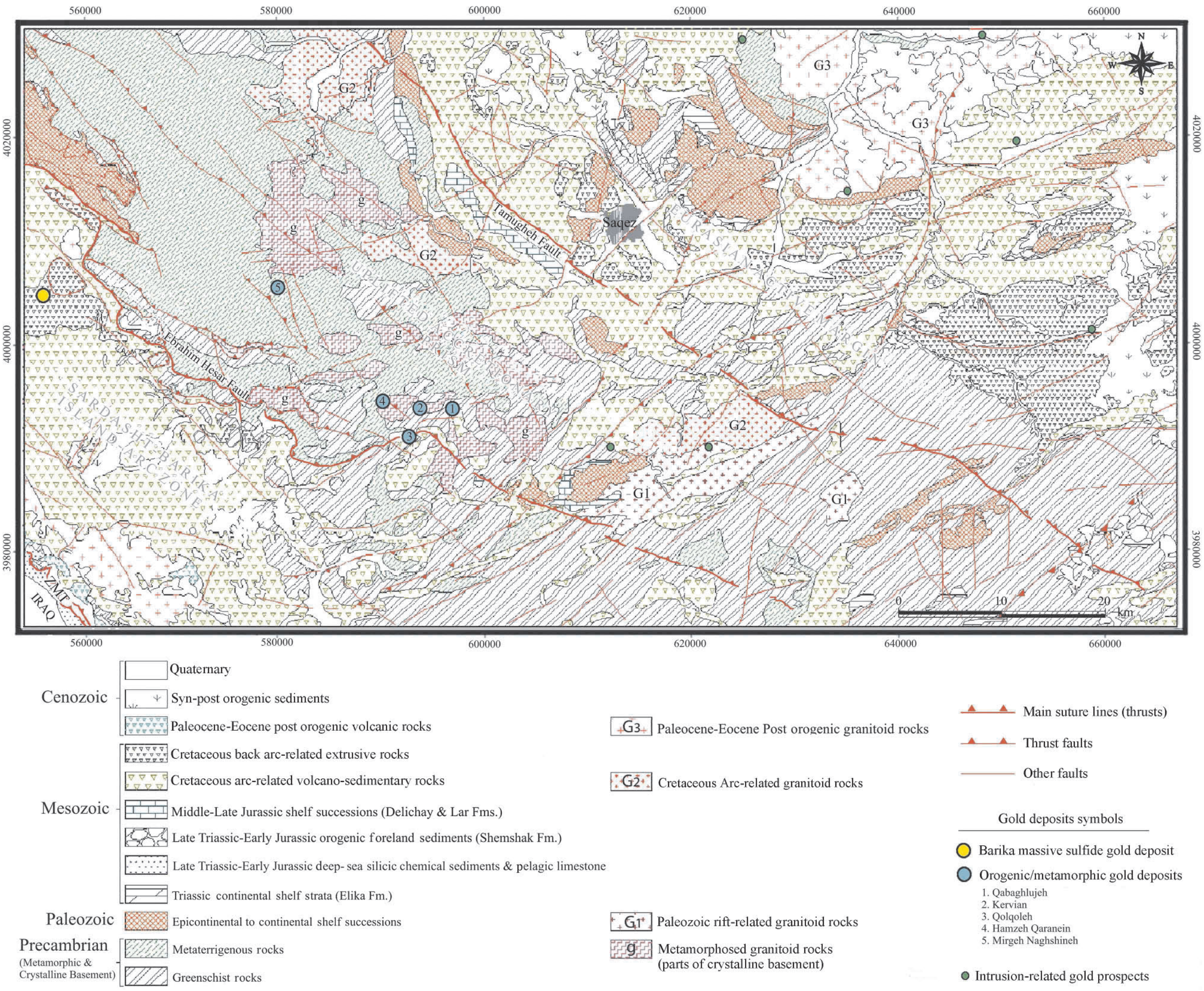


Fig. 3. Structural division of the study area, the Saqez–Sardasht region in association with geological features (adopted from Kholghi Khasraghi, 1999; Fonoudi and Sadeghi, 2000; Omrani and Khabbaznia, 2003; Hariri and Farjandi, 2003; Shah Pasandzadeh and Goorabjiri, 2006; Sabzehi et al., 2009), embodying orogenic and massive sulfide gold deposits and intrusion-related gold indexes. Granitoid bodies are revised according to Sepahi and Athari (2006b), Athari et al. (2006b), Hassanzadeh et al. (2008), Mahmoudi et al. (2011), Aryan et al. (2011), Rashidnejad Omran et al. (2013), Abdullah et al. (2013) and Azizi et al. (2017); faults are extensively revised based on Haji et al. (2016).

Fig. 4. Drilling and other exploratory operations at the Qolqoleh gold deposition; view to NW. Qolqoleh village is located some hundreds of meters to the south (to the right of the picture).

silicified and sericitized alterations. The orebody has occurred mainly in the form of veins and/or irregular to lenticular bodies inside the altered rocks (Heydari, 2004; Aliyari et al., 2007), controlled generally by the newer brittle structures within the ductile shear zones (Aliyari et al., 2009).

Although petrology, geochemistry, typology, structure and the dating of ore deposition of the above goldfields are well discussed by previous workers, there remain some important questions about the regional tectonic conditions of some gold occurrences, exclusively the Barika deposit. The Barika Massive Sulfide gold is different from orogenic (and intrusion-related) orebodies with regard to its typology as well as to mineralization onset.

Gold deposits/prospects of the Saqez–Sardasht zone are distributed in a well-nigh ENE–WSW trend, crosscutting at least three significant deep-seated lineaments (suture zones) and consequently encompass four distinct structural blocks (Fig. 2). Reviewing/synthesizing all the patchworks and published data/analyses in addition to conducting a host of field observations, here we try to give an authentic description and illustrate the Saqez–Sardasht zone in a comprehensive model. To find out the spatial and temporal relationships between the major structural units and gold concentration events, inevitably we also consider stratigraphic successions, metamorphic phases and geochemical typology of the intruded bodies.

2 Geological Settings

The oldest rocks of the Saqez–Sardasht area are phyllite, schist, amphibolite and gneiss of Precambrian age (Zahedi et al., 1992; Aghanabati, 2006; Horton et al., 2008; Nutman et al., 2014), which have been overlain by the Upper Paleozoic (Sabzehi, 1996) metamorphosed detrital and chemical sediments consisting of phyllite, crystalline limestone, dolomite, quartzite and mafic to felsic volcanic rocks, and eventually Upper Mesozoic (Mohajjel and Fergusson, 2000) to Tertiary deposits accompanied by a series of intrusive bodies (Kholghi Khasraghi, 1999; Fonoudi and Sadeghi, 2000; Mohajjel, 2002; Omrani and Khabbaznia, 2003; Babakhani et al., 2003; Hariri and Farjandi, 2003; Shah Pasandzadeh and Goorabjiri, 2006; Sabzehi et al., 2009; Fig. 3). Most parts of the Saqez–Sardasht area, which hosts the orogenic/metamorphic gold deposits, are situated in the complexly deformed subzone at the northeastern side of Neotethys, through which the Late Paleozoic–Mesozoic passive margin succession formed and then was overlaid by a Late Mesozoic convergent (active) margin assemblage (Mohajjel and Sahandi, 1999).

In another sense, this region has predominantly spanned the SCV magmatic zone. The central complexly deformed subzone (equivalent to SCV volcanic belt) is separated from the eastern back-arc basin with the Tamugheh fault zone (Haji et al., 2016). Similarly, there is another important boundary (fault) between the central block and the westernmost part of the study area (extending from NE Baneh to the ZMT), introduced here as the Ebrahim Hesar fault zone. The cited western block hosts the Barika VMS goldfield and is attributed to the marginal to ophiolitic-radiolarite subzones, namely the Late Jurassic–Early Cretaceous volcanic arc succession deposited in shallow-marine environments (Mohajjel and Sahandi, 1999). This block is regarded, on the other hand, by Azizi and Moinevaziri (2009) as the SBV zone. According to previous works as well as a panoply of observations and successive analyses given here, it will be argued that the referred western active margin-originated block encompasses an island arc system in which the only VMS goldfield has been developed.

2.1 Metamorphism

The complexly deformed subzone is recognizable from the other subzones by an abundance of metamorphic rocks. Earlier reports of Hercynian or older orogenies in the Paleozoic rocks of the southeastern part of the subzone were disputed by Alavi (1994), and much of the orogenic activity in the SSZ is now ascribed to the closing of Tethys (Mohajjel et al., 2003).

The oldest metamorphic rock units are Precambrian–Cambrian in age (equivalent to Kahar to Mila formations), spreading over the northwest to southeast, and embodying the large meta-granites of Alut (Omrani and Khabbaznia, 2003). Besides, a variety of Lower–Mid Paleozoic metamorphic rocks has been reported from the north of Saqez to the north of Takab (Hariri and Farjandi, 2003).

As the next phase, some low-grade metamorphism deformed the pre-Upper Jurassic metamorphic rocks with the same trend ascribed to the first regional metamorphic event (Baharifar et al., 2004). The Jurassic–Early Cretaceous Iranian–Arabian convergence and its subsequent metamorphism can be deduced from the unconformities inward of the marginal and complexly deformed sub-zones as well as the marginal subzone conglomerates, containing metamorphic clasts (Mohajjel et al., 2003). This phase happened as progressive regional metamorphism, leading thermodynamically to various degrees of greenschist facies, as well as developing S1 mylonitic foliations (Aliyari et al., 2005; Heydari et al., 2005; Nosratpour and Hassanzadeh, 2007; Shahrokhi et al., 2009; Tajeddin et al., 2012). Most researchers have managed to propose a valid ascription to rocks between this later metamorphic phase and the first orogenic golds at Saqez–Sardasht (e.g., Shamsa, 1998; Nosratpour and Hassanzadeh, 2007; Heydari et al., 2005).

The resultant strained features from the foregoing uplift within the complexly deformed sub-zone are poorly documented since the next ductile deformation has rigorously overprinted them in the Late Cretaceous (Mohajjel et al., 2003); this is regarded by many of the authors as the most dominant metamorphism/deformation phase over the shear zone. This phase developed the general S2 foliation-bearing mylonites/ultramylonites as well as the widespread commonplace folds (Aliyari et al., 2005; Heydari et al., 2005; Nosratpour and Hassanzadeh, 2008). Compared to all other phases, the gold deposits attributed to this metamorphic event, regarded as the peak of the regional metamorphism over the SSZ, are much more prolific (Shahrokhi et al., 2009; Nosratpour and Hassanzadeh, 2008; Heydari et al., 2005; Mohammadpour et al., 2012).

The abovementioned strain event was later followed by retrograde metamorphism via a newer transitional ductile-brittle phase of deformation, waning the latter metamorphic features to lower greenschist facies in the Early–Mid Paleocene (Nosratpour and Hassanzadeh, 2008). Finally, a vast array of hornfels aureoles, indicating extensive contact metamorphism due to the intrusion of the Ghalegah granitic batholith in the Paleocene (located northeast of Saqez), within Cretaceous-dominated detrital to volcano-sedimentary rocks, are considered as the last metamorphic features all over the Saqez–Sardasht zone (Aryan et al., 2011).

2.2 Deformation

Aside from the very old orogenic phases (mainly postulated as Neoproterozoic Katangan), the Sanandaj–Sirjan principal deformations are attributed to successive opening/closure events of the Neotethian Ocean. At first, deformation, as a phase of rifting, commenced in the Zagros Basin to the south of the SSZ during Permian time and continued to the north, flanking the SSZ in the Upper Permian (Koop and Stoneley, 1982; Sengor, 1990; Kazmin, 1991; Grabowski and Norton, 1994; Stampfli et al., 1991, 2001; Ghasemi and Talbot, 2006). The foregoing process is regarded as the establishment of an active arm of the Tethys continental rift in the Permian. The extensional strain regime kept on widening the juvenile rift and the passive margins moved away from each other during the Late Triassic; then followed Jurassic subduction, the beginning of the compressional regime, along the northeastern margin. Afterward, the Tethys closed in Late Cretaceous, followed by ophiolite obduction along the southwestern margin, namely the northeastern margin of the Arabian platform. Eventually, the Arabian component collided with Central Iran in the Miocene (Mohajjel et al., 2003).

The next phase of deformation termed the D1 compressional strain by many authors, is compatible with the S1 metamorphic phase in the Jurassic–Early Cretaceous (Heydari et al., 2005; Aliyari et al., 2005; Nosratpour and Hassanzadeh, 2007; Shahrokhi et al., 2009). This event accounts for the first orogenic gold in the study area (Aliyari et al., 2005; Mir et al., 2014; Heydari et al., 2005; Mohammadpour et al, 2012; Asghari et al., 2018).

The most intense and pervasive deformation phase, entitled as D2, occurred in the Late Cretaceous, associated with the peak of the convergence event (Mohajjel et al., 2003) and ascribed to contemporaneous S2 regional metamorphism. Yet this phase was ductile (shear zone-bounded) in type (Heydari et al., 2005; Aliyari et al., 2005; Nosratpour and Hassanzadeh, 2007; Shahrokhi et al., 2009).

The present-day morphology of the study area preponderantly resulted from the D3 brittle deformation phase in the Paleocene; hence the most dominant D3 structures are fractures/faults. This deformation phase was coincident with Paleocene retrograde metamorphism throughout the region (Heydari et al., 2005; Aliyari et al., 2005; Nosratpour and Hassanzadeh, 2007; Shahrokhi et al., 2009). Fully similar history of deformation is reported by Kouhestani et al. (2014) for the Chah Bagh gold district in the Muteh goldfield.

The major fault sets of the final deformation phase are classified by Haji et al. (2016) into three sets: 1) the oldest (Precambrian–Cambrian) N135 dextral fault set; 2) the younger (Jurassic) N70 sinistral/reversed fault set; and 3) the youngest (Paleocene) N15 sinistral fault set. The first two older fault groups were reactivated accompanying the birth of the third set in the Paleocene (Haji et al., 2016;

Haji and Safari, 2017).

2.3 Magmatism

The SSZ is characterized by the emplacement of subduction-related, mainly Mesozoic calc-alkaline plutons and lavas (Agard et al., 2011). The SSZ felsic bodies form as much as 30% of the surface outcrops and are an essential component of the continental crust (Ahadnejad, 2013). In the northern SSZ, numerous granitoids are exposed within extensive realms of lower greenschist-facies sheared rocks of Precambrian protolith ages, most of which have been assigned to the so-called Doran-type granite by Eftekhat-Nejad (1973); yet their intrusion time has been revised by later authors (e.g., Omrani and Khabbaznia, 2003; Rashidnejad Omran et al., 2013).

The oldest Sheikh Chupan and Bubaktan granitoid bodies, marked as ‘g’ in the regional geology map (Omrani and Khabbaznia, 2003) are situated west of Saqez. These batholiths were dated using the U-PB zircon geochronology method by Hassanzadeh et al. (2008) as 551 and 544 Ma (Late Precambrian–Early Cambrian), respectively. Thus, these bodies did not intrude into the basement metamorphic rocks and are interpreted to be part of the protoliths, demonstrating the Gondwanan affinity of the Iranian plate (Hassanzadeh et al., 2008).

The preceding bodies are, in fact, the two largest outcrops of a series entitled the Alut granites, which are spread over a vast terrain of the study area, exclusively the central–west parts (within the block between Tamugheh and Ebrahim Hesar suture lines). Geochemical and petrographic traits of the Alut group has been studied by Rashidnejad Omran et al. (2013). Unlike the previous study, some members of the Alut granitoids, called Qazanta-Hamzeh Abad, Chahardivar, Eski Baghdad, Sheikh Chupan, Bubaktan, Darvishan and West Inkaj are assigned to the Late Jurassic for two reasons: 1) detection of contact metamorphism in some granite–host rock boundaries; and 2) shear zone-related folding and abundant juvenile intrusions indicating a Mesozoic age for the metamorphic host rock. Accordingly, the Alut series are considered as I-type granitoids of a magmatic arc/ active margin system, related to the Late Cimmerian tectonic event. The Late Jurassic I-type magmatism of the Northeastern SSZ was previously studied by Berberian and Berberian (1981).

Later Mesozoic intrusions observed by Rashidnejad Omran et al. (2013) have overprinted the older intruded masses. It should be particularly noted that the relevant structural and magmatic events to this intrusion (e.g., shear zone-related orientations or enclave embodiments) are prevailingly specific to small stocks or large pluton margins (Rashidnejad Omran et al., 2013). Therefore, the Alut granites are of two different geneses: firstly, the old Precambrian–Cambrian metagranites–gneisses as protoliths of metamorphic country rock and, secondly, the newer intruded granites of Upper Mesozoic time.

Other main intrusive bodies, located southwest of Saqez city (central–south of the study area) are known as the Hasan Salaran granitoid complex. These plutonic units were generated in an arc setting followed by collisional and post-collisional magmatism, and are composed of two distinct granitic rock suites with different petrogenesis, petrography and geochemistry. The southern smaller body (Talijar Granite), known as ‘G1’ is an A-type granite and the northern one called ‘G2’ is of I-type origin (Sepahi and Athari, 2006b; Athari et al, 2006a, b; Abdullah et al., 2013).

There are two far different dating reports for the G1 granite: Mahmoudi et al. (2011) suggested Early Paleocene (60 Ma), whereas Azizi et al. (2017) ascribed it to Late Carboniferous (360 Ma). The Late Carboniferous age seems much more acceptable regarding the geological relationships between this body and the adjacent rock units. For example, there is no contact metamorphism in the surrounding Permian to Cretaceous country rocks. Indeed, the G1 granite has cut the Late Paleozoic–Early Mesozoic metasedimentary rock units (Athari et al., 2006b). Moreover, the G1 granite has been sheared in company with Cretaceous limestone as well as being cut by the Mid-Cretaceous aged G2 granite dykes (Azizi et al., 2017).

A-type granites of the northern SSZ are less abundant than the I-type series, but they have been reported from some regions including Saqez, Almogholagh (Sepahi and Athari, 2006a; Athari et al, 2006b) and Hasanrobat (Golpayegan area; Alirezaei and Hassanzadeh, 2012). The Talijar G1 granite is associated with intra-plate magmatic activities, termed idiomatically as A2-type or post-collisional granites by some researchers (e. g. Sepahi and Athari, 2006b; Athari et al, 2006a, b; Abdullah et al., 2013). Conversely, Azizi et al. (2017) ascribed it strictly to a within-plate tectonic regime, namely to the A1-type (rift-related) granitoids; thus, the southern member can be attributed to the initiation of the opening of Neotethys in the Late Paleozoic. Widely distributed A-type granites in Turkey and northwestern Iran have been similarly dated to Carboniferous–Permian by Saccani et al. (2013), Ahankoub et al. (2013) and Moghaddam et al. (2015).

The northern G2 Hasan Salaran granite body is assigned in date to 109 to 110 Ma (Mid Cretaceous; Mahmoudi et al., 2011). This batholith has been introduced as an I-type granite (Sepahi and Athari, 2006a, b; Athari et al, 2006a, b; Abdullah et al., 2013). The I-type-natured plutons of the SSZ are related to the Mid–Upper Mesozoic northeastward subduction of the southern Neotethyan sea-floor beneath the continental blocks (Mohajjel, 1997; Arvin et al., 2007).

The outcrop accommodations of G2 granites in the study area are rather controlled by the major fault trends/ intersections (Fig. 3). Moreover, these intrusions have provided the adjacent orogenic goldfields (Qolqoleh, Qabaghloujeh and Kervian) with a considerable temperature source/magmatic-associated fluid circulation during the Mid-Upper Mesozoic, bringing the ore deposits about to experience some extra enrichment processes. This way, the three cited districts were segregated by Tajeddin (2013) from the background orogenic golds (i.e., epizonal) as mesozonal deposits.

The Saqez–Sardasht I-type intrusions are not restricted to the Alut/Hasan Salaran areas, but they go almost suddenly younger to the East–Northeast of Saqez (NE of the study area). These series, reported formerly by

Mohajjel et al. (2003) as Paleocene gabbroic to granodioritic intrusions of the complexly deformed subzone, are called the Ghalegah granites and are currently attributed to the Upper Cretaceous–Paleogene. The Ghalegah batholith has penetrated mostly Cretaceous country rocks, imposing on them some degrees of weak–medium contact metamorphism (Aryan et al., 2011). Analyses of the geochemical samples were accomplished by Abolmaali et al. (1999) and Hassanipak (2000) indicated an intrusion-related affinity for the gold prospects through the intruded area.

Finally, there are some intrusive to extrusive units at the west of the Saqez–Sardasht region that have formed the magmatic belt of the SBV zone, aged from Mid Cretaceous (Omrani and Khabbaznia, 2003) to Late Eocene–Miocene (Leterrier, 1985; Izadi, 2006; Moinevaziri et al., 2008). The Upper Cretaceous granitoids of Baneh and Naghadeh (Ghalamghash et al., 2009; Mazhari et al., 2011) and Kanimiran, located Northwest of Marivan (located adjacent to ZMT; Sabzehi et al., 2009) are the felsic members within the abovementioned magmatic belt. Geochemical studies demonstrated two distinct basalt types among them: the first is a kind of sub-alkaline basalt with an island arc affinity, and the second is a kind of alkaline basalt illustrating a typical oceanic island signature (Ghazi and Hassanipak, 1999; Ghasemi and Talbot, 2006; Azizi and Jahangiri, 2008). These results are of great importance when used along with the other conclusions to make a new approach to the Barika gold tectonic evolution.

3 Gold Mineralization

The best field clue for fluid circulation during progressive metamorphism is the general existence of quartz and carbonate in the host rock of the metamorphic terrains in orogenic gold deposits (Pirajno, 2009). Many of the Iranian orogenic golds hosted in the Carboniferous to Cretaceous metamorphic rocks have occurred along ductile to brittle-ductile shear zones. In general, the mineralization-bearing structures exhibit a ductile deformation phase/phases that is/are overprinted by later brittle structures (fracturing), both of them appear to be gold related (Aliyari et al., 2012; Kouhestani et al., 2014). Gold mineralization events in the Saqez–Sardast zone are addressed in more detail in Table 1

Table 1 Gold deposits/prospects of the Saqez–Sardasht zone (modified from Aliyari et al., 2012).

Deposit/ prospect	Geographic coordination	Host rocks	Style of mineralization	Genetic type	Age of mineralization	Gold related to ore minerals	Alteration minerals	Resource (mt) grade	Data source
Barika	E 36°11′16″ N 45°39′03″	Cretaceous metaandesite and tuff (marine volcano-sedimentary deposits)	- Quartz-sulfide bearing zone; 50 m wide, 100 m long - Massive sulfide and sulfosalt zone; 3–4 m wide, 100 m long - Barite ore zone; 10 m Wide, 60 m Long	Au-rich massive sulfide	Lower Cretaceous to Tertiary	Electrum, chalcopyrite, galena, tennantite, chalcopyrite	Quartz, sericite, pyrite, calcite and albite	Average 0.5 to 5 g/t	1, 2, 3, 4, 5, 6, 7, 8, 9 & 10
Qolqoleh	E 36°08′08″ N 46°06′08″	Upper Cretaceous mafic to intermediate (andesite to andesitic basalt), marble, metavolcanic rocks, sericite schist and gneiss	Metamorphic/magmatic fluids; narrow quartz-gold-sulfide zones; 250 m wide, 2500 m long, 280 m down-dip	Orogenic (ductile to brittle shear zone)	Mid-Upper Cretaceous to Tertiary	Pyrite, chalcopyrite, pyrrhotite, sphalerite	Quartz, carbonate, sericite, chlorite, epidote and tourmaline	Up to 3 mt 3.5 g/t	10, 11, 12, 13, 14, & 15
Qabaqlouje h	E 36°05′35″ N 46°06′59″	Upper Cretaceous metavolcanic phyllite, schist, mylonite and marble	Metamorphic/magmatic fluids; aarrow quartz veins and veinlets, 20–40 m wide, 800 m long	Orogenic (ductile to brittle shear zone)	Mid-Upper Cretaceous to Tertiary	Pyrite, chalcopyrite, arsenian pyrite	Quartz, carbonate, sericite and biotite	1 mt 1 g/t	16, 17, 18 & 19
Kervian	E 36°08′00″ N 46°06′00″	Upper Cretaceous felsic to mafic metavolcanic and metasedimentary rocks, marble and dolomite	Metamorphic/magmaticgluids; narrow quartz veins and veinlets with gold mineralization; 60 m wide, 2500 m long	Orogenic (ductile shear zone)	Mid-Upper Cretaceous to Tertiary	Pyrite, chalcopyrite, arsenian pyrite, realgar	Quartz, carbonate, sericite and chlorite	Average 1–3 to 7 g/t	20, 21, 22 & 23
Mirgeh Naghshineh	E 36°17′00″ N 46°55′00″	Precambrian-Cretaceous metasedimentary to metavolcanic rocks	Metamorphic/meteoric fluids; quartz-gold-sulfide zones	Orogenic (ductile to brittle shear zone)	Mid-Upper Cretaceous to Tertiary	Electrum, pyrite, arsenopyrite, chalcopyrite, sphalerite, monazite, galena	Quartz, sericite, carbonate and chlorite	Average 0.1–1 to 7 g/t	24 & 25
Ghalegah	E 36°15′00″ N 46°26′00″	Upper Cretaceous to Paleocene metavolcanic units, marble, hornfels and granitoid bodies	Unknown	Intrusion-related	Tertiary (Paleocene to Oligo-Miocene)	Unknown	Quartz, sericite, chlorite, epidote, biotite and kaolinite	Unknown	26 & 27

Data References Numbers: 1) Tajeddin et al. (2006); 2) Tajeddin et al. (2010); 3) Tajeddin et al. (2013); 4) Tajeddin (2013); 5) Yarmohammadi et al. (2005); 6) Yarmohammadi (2006); 7) Yarmohammadi and Rastad (2006); 8) Shahrokhi et al. (2009); 9) Aliyari et al. (2005); 10) Aliyari et al. (2007); 11) Aliyari et al. (2008); 12) Aliyari et al. (2009); 13) Taghipour and Ahmadnejad (2012); 14) Nosratpour (2008); 15) Nosratpour and Hassanzadeh (2007); 16) Nosratpour and Hassanzadeh (2008); 17) Mir et al. (2014); 18) Shamsa (1998); 19) Heidari (2004); 20) Heidari et al. (2006); 21) Mohammadpour et al (2012); 22) Asghari et al. (2018); 23) Abolmaali et al. (1999); 24) Hassanipak (2000).

(adopted and modified from Aliyari et al., 2012).

The oldest gold mineralization event in the study area is the Barika VMS goldfield (18 km E of Sardasht; Fig. 2), which is related to the Early Cretaceous (Tajeddin et al., 2013; Yarmohammadi and Rastad, 2006). The Barika rocks are a complex of volcano-sedimentary units (metamorphosed in the Cretaceous; Omrani and Khabbaznia, 2003), which originated from an enriched mantle-related to a continental-arc system (Tajeddin et al., 2010). Other occurrences, i.e., the orogenic goldfields of Qolqoleh, Qabaghlujeh, Kervian, Hamzeh Gharanein and Mirgeh Naghshineh (situated 25 to 30 km SW of Saqez; Fig. 2), are considered to be formed in the Late Jurassic when their mineralization commenced with precipitation/ enrichment keeping up to the Late Cretaceous/Early Paleocene time. The younger gold deposition phases are assigned to the Tertiary (Shamsa, 1998; Aliyari et al., 2007; Nosratpour and Hassanzadeh, 2007; Heydari et al., 2005), and particularly from the Paleocene (Aliyari et al., 2007; Nosratpour and Hassanzadeh, 2007; Heydari et al., 2005) to Oligo-Miocene times (Abolmaali et al., 1999; Hassanipak, 2000). The ore-forming fluids of the Saqez–Sardasht orogenic golds are mainly derived from metamorphic and some contributions of magmatic fluids in mesozonal goldfields (e.g., Qolqoleh, Qabaghlujeh and Kervian) or meteoric water in the relatively shallow epizonal gold districts (e.g., Mirgeh Naghshineh, Sheikh Chupan, Ebrahim Hesar, Sardeh Kuhestan and Zaveh Kouh), being localized along with convenient structural traps, namely shear zones and faults. The mesozonal gold deposits are larger and economically more significant than epizonal ones (Tajeddin, 2013).

The Qolqoleh goldmine is composed of phyllite (with intercalations of marble), schist and gneiss, which have been penetrated by the later granitic bodies (Hariri and Farjandi, 2003). These intrusive bodies (to the age of Late Cretaceous; Aliyari et al., 2005) have been displaced reversely several times; exacerbating the structural complexity of the area (Moinevaziri et al., 2017). The Qabaghlujeh gold district is located within Precambrian gneiss and granite-gneiss and Cretaceous metasedimentary rocks, containing schist, phyllite and marble (Hariri and Farjandi, 2003). The lithological units of the Kervian gold district are composed of metavolcano-sedimentary rocks, being affected by the NE–SW trending, NW-dipping shear zone containing phyllite, crystallized limestone, dolomite, quartzite and metamorphosed felsic-mafic volcanic rocks of Late Mesozoic age (Mohajjel, 2002; Hariri and Farjandi, 2003). Granitic bodies of this area are noteworthy. In the Mirgeh Naghshineh goldfield, the Precambrian schist, phyllite, slate and gneiss form the most dominant lithologies (Hariri and Farjandi, 2003). The rocks of the Hamzeh Gharanein district are metavolcano-sedimentary units of Cretaceous age (Hariri and Farjandi, 2003). Gold occurrences of the Saqez–Sardasht zone are described by their attributed time order below.

3.1 Massive sulfide gold mineralization (Early Cretaceous)

The first phase of gold mineralization in the study area is observed in Barika as a gold-rich VMS occurrence. The Barika deposit was formed in an allochthonous terrane with a back-arc tectonic setting (Aliyari et al., 2012).

Gold mineralization in Barika is formed both as stratiform and stringer (stockwork) ore morphology. The stratiform ores are composed of sulfide and barite ore bodies accompanied by minor silicic bands. The stringer ores contain silicic bands or masses embedded with some simple groups of sulfide minerals (Tajeddin, 2013). Vicinity to the sea-floor and elevation of the silicic veins control the concentration of gold and other associated metals. Gold mineralization in Barika has been compared to some gold-bearing massive sulfide deposits such as Tasmania and Kuroko (Yarmohammadi et al., 2005).

3.2 Orogenic gold mineralization (Late Cretaceous to Early Paleocene)

(a) Ductile condition:

The second and more important gold mineralization event of Barika was contemporaneous to the first orogenic gold occurrences of the Saqez–Sardasht area in the Late Cretaceous. Throughout this phase, regional metamorphism and deformation have modified the deposit geometry and mineralogy by locally redistributing some of the constituents into structurally controlled sites (Yarmohammadi, 2006; Shahrokhi et al., 2009). This shear zone-related mineralization has been localized within Phanerozoic metamorphic rocks (Yarmohammadi, 2006). The host rock of the Barika goldfield was only metamorphosed to lower greenschist facies; but deformed rigorously according to the shear zone activity (Yarmohammadi and Rastad, 2006; Tajeddin et al., 2013). The former massive sulfide-type mineralization was deformed to a mylonitic complex via the ductile phase. The orebodies are commonly tabular and discordant. They have been often deformed and tilted, representing a foliation-parallel pipe-like geometry due to their strong transposition along the main foliation and stretching lineation (Aliyari et al., 2012).

Being exposed both to continuous preponderant directional stress phases and increasing temperature through the ductile phase, the rocks of Qolqoleh, Qabaghlujeh, Kervian and Mirgeh Naghshineh deposits have been extensively transformed to mylonites/ ultramylonites (Aliyari et al., 2005; Heydari et al., 2005; Shahrokhi et al., 2009; Nosratpour and Hassanzadeh, 2008; Mohammadpour et al., 2012). The first generation of sulfide minerals in the mentioned areas are the automorphic and coarse-grained pyrites formed individually or along the quartz vein boundaries. Gold mineralization has occurred among the silicic zones in the form of bedding-parallel quartz-rich veins (Aliyari et al., 2005; Heydari et al., 2005; Shahrokhi et al., 2009; Mohammadpour et al., 2012; Mir et al., 2014; Asghari et al., 2018).

(b) Ductile-Brittle condition:

The ore-hosting alteration zones in Barika have controlled the shearing intensity as well as the geometrical/structural characteristics of the shear zone. Sericite, silicic, sulfide and chlorite alterations have obliterated most of the porphyritic features of the source/ host rock. Gold has been concentrated in company with the foliation-parallel sulfide minerals across the stratiform member of the Barika deposit, whilst the primary silicic veins of the stringer member are fractured and then filled with new gold-bearing silica. Almost all the newly-formed veins and veinlets were enriched with gold and accompanying sulfosalt minerals (Tajeddin et al., 2010).

Native gold can occasionally be observed among the silicic gangues and/or the sulfidic (pyritized) mineralization networks; therein pyrite and silica are the cornerstone ore-hosting minerals in Qolqoleh, Qabaghlujeh, Kervian and Mirgeh Naghshineh deposits. Gold-bearing minerals are associated with sulfidic (pyritized), silicic and carbonate alterations (Aliyari et al., 2005; Shahrokhi et al., 2009; Taghipour and Ahmadnejad, 2012; Nosratpour and Hassanzadeh, 2007; Heydari et al., 2005; Asghari et al., 2018). The most abundant gold is concentrated within the highly deformed parts in which the maximum level of silicic-sulfide alteration is being observed; this concentration is ascribed to the final stage of ductile/first stage of brittle deformation (Aliyari et al., 2005; Nosratpour and Hassanzadeh, 2008; Heydari et al., 2005; Asghari et al., 2018).

(c) Brittle condition:

Being concurrent with the retrograde metamorphism, the brittle deformation phase in Barika developed the last series of silicic veins in which no signs of ore-formation occurrences have been recorded. These barren tensional fractures have cut all the former structural features of the study area (Tajeddin et al., 2010).

Again, the brittle deformation phase has influenced the interior parts of the mylonitic zones in Qolqoleh, Qabaghlujeh, Kervian and Mirgeh Naghshineh gold districts, developing concordant and/or discordant microfractures and brecciated silicic-sulfide veins and veinlets that have crosscut the previous hydrothermally altered areas (Shahrokhi et al., 2009; Mir et al., 2014; Asghari et al., 2018). Normal faults have had a prominent effect on the mobilization, migration and concentration of gold and the accompanying minerals (Aliyari et al., 2005; Olyaee, 2008). These structures have had a considerable influence on the activation of the hydrothermal leaching. Spatial correlation between dissipated sulfides, mylonitic textures and sulfidic veinlets is considered as a key factor in gold concentration during this deformation event in Qolqoleh (Aliyari et al., 2005; Shahrokhi et al., 2009; Taghipour and Ahmadnejad, 2012).

Gold deposits of SSZ are spatially associated with the first and second ordered major deep-seated fault systems (Mohajjel et al., 2003; Aliyari et al., 2009). Gold deposits in the northern SSZ have been linked to deep fault structures that can penetrate to a greater depth and, therefore, be the source of hydrothermal fluids (Aliyari et al., 2012). These faults, not have only acted as regional focusing structures for crustal fluids, but have also controlled the emplacement of intruded bodies from the Piranshahr to Saqez gold districts (Mohajjel et al., 2003; Almasi et al., 2014).

The Hasan Salaran–Boeen fault zone, previously nominated as the Saqez–Sardasht fault zone by Mohajjel et al., 2003 and Almasi et al., 2014, is a steeply dipping major reversed fault of Late Cretaceous to Early Tertiary timespan. This sinistral-reversed fault is oriented approximately perpendicular to the ZMT with the mean strike of N70º and is regarded as the most important structure, which has controlled both the emplacement of G2 felsic bodies, as the probable temperature sources for gold deposition, and the mineralization spatial trend in mesozonal gold districts (Haji et al., 2016).

3.3 Intrusion-related gold mineralization (Late Paleocene)

Most of the intrusion-related gold mineralization events in the SSZ are genetically related to Eocene to Pliocene calc-alkaline to alkaline collisional/post-collisional intrusions in the UDMA (Aliyari et al., 2012). Moritz et al. (2006) related the Late Eocene gold mineralization in the Muteh deposit to the brittle extension during magmatic activity. Geochemical exploration programs of the Saqez–Sardasht zone have operated during the last 20 years (Abolmaali et al., 1999; Hassanipak, 2000), detecting prodigious amounts of non-metamorphogenic gold prospects in the central east of the study area (toward Takab), related to intrusive activities during the Paleocene near the Ghalegah granite (G3) to the northeast of Saqez.

4 Discussion

As mentioned above, the Saqez–Sardasht zone is composed of four significant tectonic basins, bounded together by three important NW–SE trending, NE-dipping structural lineaments (Fig. 3). We should reiterate that the general characteristics of most of the structures (trends, strikes and dip senses) are the same as the referring boundaries. The three mentioned boundaries are as follows:

(1) The ZMT to the southwest of the study area (adjacent to Iraqi political boundary), dividing the Triassic –Jurassic deep-sea pelagic sediments (Fonoudi and Sadeghi, 2000; Sabzehi et al., 2009) covered with flysch/ red beds equivalent to the Amiran formation, as well as some radiolarite outcrops (Sadeghian and Delavar, 2006) in the SW from the Lower Cretaceous volcano-sedimentary dominated rocks (Omrani and Khabbaznia, 2003) in the NE. The ancient bedrock of the SW block is the passive margin of Neotethys; i.e., the NE margin of the Arabian continent (Fonoudi and Sadeghi, 2000). The NE-side block, being thrust by numerous NW–SE trending, NE-dipping faults, predominantly originated from an oceanic arc system, occasionally encompassing a series of ophiolitic slivers (over Bisoton Limestone/radiolarites) near the ZMT (Mohajjel and Sahandi, 1999) equivalent to the Kermanshah ophiolites. This structural basin, between the ZMT and the Ebrahim Hesar fault, is to be called the 'Sardasht–Barika Zone' from now on. Due to its distinct geological and tectonic settings, this area was classified as the Cretaceous Sardasht–Piranshahr zone by Eftekhar-Nejad (2004). Moreover, the Sardasht–Barika zone is coincident to the SBV zone (Sonqor-Baneh Volcanic belt) proposed by Azizi and Moinevaziri (2009), based on gabbroic to dioritic bodies accompanied by a huge mass of dismembered basaltic to diabasic rocks.

(2) A deep-seated NE-dipping thrust fault to the

northeast of Barika village, termed here the Ebrahim Hesar Fault, separates the Upper Mesozoic semi-imbricated volcano-sedimentary rocks in the southwest from the uplifted/tectonized Alut Precambrian metamorphic basement as well as the Early Cretaceous thrust volcano-sedimentary rock lenses (Hariri and Farjandi, 2003) in the northeast. The later Cretaceous units are less abundant and restricted to the northeastern margin of the block, near to the Tamugheh suture zone. The whole block is tectonically equivalent to the accretionary prism located at the Iranian active margin (Tajeddin et al., 2006).

(3) A significant contact southwest of Saqez city between the tectonized Precambrian/Cretaceous rocks in the southwest and the Cretaceous-Tertiary rock units (overlying the Iranian Precambrian-Cambrian basement; Kholghi Khasraghi, 1999) in the northeast. This considerable boundary was introduced by Haji et al. (2016) as the Tamugheh Fault, cutting through both the Cretaceous volcanic rocks and the ancient bedrock. From the Tamugheh fault line position to central Iran in the northeast, the rock units become gradually younger as well as less deformed. The oldest and most southwesterly rocks through this block are of Early Cretaceous age; toward the northeast, the overlying less deformed Upper Cretaceous volcanoclastic sediment outcrops appear. Eventually, the Cenozoic successions, chiefly semi-horizontal Oligo-Miocene limestones of the Qom formation, are the most northeasterly rocks within the whole block (Kholghi Khasraghi, 1999). This way, the aforesaid NE-side tectonic block is assigned as the back-arc basin of the Zagros collisional system.

As mentioned above, we consider that the Sardasht–Barika zone originated from an oceanic island-arc system. During an ocean–ocean subduction near to the Arabian passive margin, an immature island arc developed before ocean closure. According to Ghasemi and Talbot (2006), Late Cretaceous greenschist metamorphism and the intrusion of felsic granitoids along the SSZ mark the continuation of the subduction of Neotethys along the western margin of the SSZ after the suturing of the intra-Neotethys oceanic island arc to Arabia.

Leterrier (1985) proposed that magmatic rock units of the SBV (located within the Sardasht–Barika zone) are the same as the transitional basalts that are attributed to spreading zones with low opening rates. Aryan (2001) and Izadi (2006) argued that they were generated through oceanic crust melting under the ophiolite nappes. Agard et al. (2005) proposed an active continental margin source for these rocks. Referring to Azizi and Moinevaziri (2009), the MORB and calc-alkaline basalts of the SBV zone indicate an island-arc affinity. The SBV subzone that formed between the ophiolite-bearing suture zone and the SSZ belongs to an oceanic arc, resulting from the subduction of part of the Neo-Tethys oceanic crust under another oceanic crust fragment (Azizi and Moinevaziri, 2009; Jamali et al., 2012).

Many geologists have considered the collision of the Zagros island arcs to date from Mid–Late Cretaceous with the Zagros final continental collision as Miocene (e. g., Mohajjel et al., 2003; Agard et al., 2005; Ghasemi and Talbot, 2006). Intra-oceanic island arcs in Neotethys were obducted as ophiolites onto the northern margin of Arabia and South SSZ in the Late Cretaceous (Dercourt et al., 1986; Knipper et al., 1986; Hacker et al., 1996; Mohajjel et al., 2003; Ahmadi Khalaji et al., 2007). The Neyriz–Kermanshah ophiolites are highly dismembered rock complexes formed in both the intra-plate oceanic islands (supra-subduction ophiolites) and the island-arc systems before being thrust over the Triassic–Cretaceous Bisoton seamount-type limestone (Pearce et al., 1984; Lippard et al., 1986; Berberian, 1995; Ghazi and Hassanipak, 1999). Ao et al. (2016) dated different parts of the Kermanshah ophiolites using the U-Pb zircon method; according to their results, the southwestern Harsin member is 79.3 Ma and the northeastern the Sahneh–Kamyaran member is 35.7 Ma in age. They argued that the younger Sahneh–Kamyaran part is probably a fossil oceanic core complex and the older Harsin part is probably a continental-oceanic transition complex. Simply put, the Kermanshah ophiolites consist of two distinct members with two different ages. The above results are of fundamental value in shedding light on the island-arc model. On the one hand, the Middle Cretaceous SW-side Harsin ophiolite member was imbricated toward the ZMT (western SBV subzone) contemporaneously with the continent–island-arc collision. On the other hand, the emplacement of the NE-side Eocene Sahneh–Kamyaran ophiolite member is equivalent to the final phases of the Zagros collision. This member is probably situated along the Ebrahim Hesar fault zone (imbricated toward the southwestern margin of the accretionary wedge).

The Sardasht–Barika zone (equivalent to the so-called Sardasht–Piranshahr zone of Niroomand et al., 2011) conjoins the Saqez–Sardasht gold deposit to the Kharapeh goldfield east of Piranshahr (SE of Khoy ophiolite; Fig. 2). Kharapeh is an orogenic deposit (Niroomand et al., 2011) and, together with the other orogenic-type goldfields in the study area, is located on the NE-side of the Ebrahim Hesar fault line; whereas Barika, as the only VMS deposit, is situated to the southwest of it. In general, the Kharapeh district, is located within the marginal subzone (Niroomand et al., 2011) and the Saqez–Sardasht orogenic gold districts are situated at the beginning of the complexly deformed subzone. Orogenic goldfields are tectonically associated to an accretionary prism (Groves et al., 1998). Similarly, the Saqez–Sardasht gold deposits are controlled by a ductile-brittle shear zone with affinity to the accretionary wedge of the Neotethys subduction system (Tajeddin et al., 2006).

The rock units of Barika are deep-sea metavolcano-sedimentary complexes, with a preponderance of metavolcanites and tufites. The primary hydrothermal fluids precipitated the stratiform ore-body over the ocean floor. The later mineralization event occurred because of the next progressive metamorphism (Tajeddin et al., 2013). In other words, the first mineralization stage in Barika is postulated here as the formation of an island arc in the Early Cretaceous between two oceanic lithospheres. The second phase of gold mineralization/enrichment is correlated to the increasing compressional strain that resulted from the Arabia–Sardasht–Barika collision, during the Late Mesozoic.

5 Results

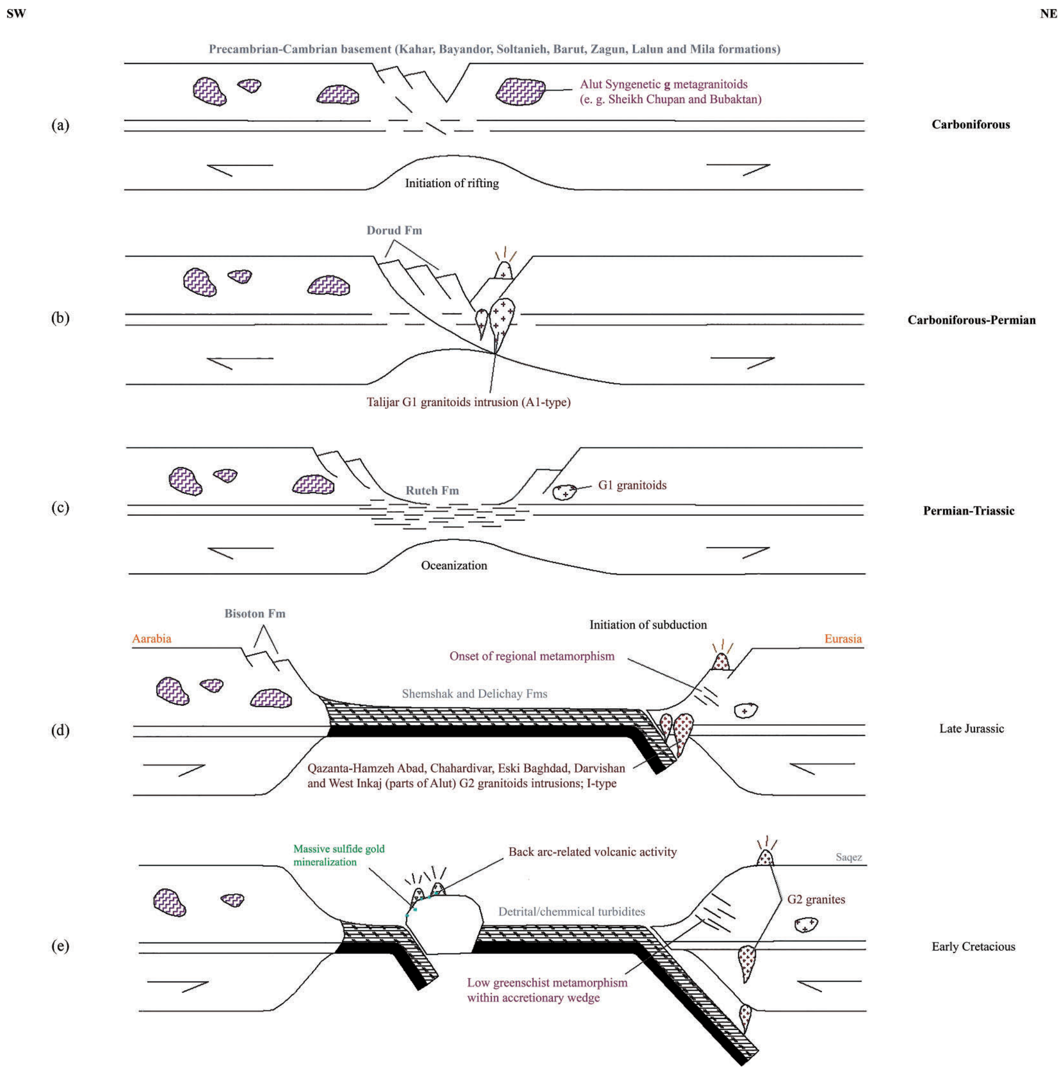
Significant tectonic, structural, metamorphic and intrusive events in chronological order as well as the synchronous gold mineralization phases are shown in Table 2. The table contents are also projected as episodic graphical sections in Fig. 5.

As mentioned above, some significant outcrops of Alut metagranitic batholiths are considered to be part of the primary Gondwanan basement. This old bedrock has experienced a complete Wilson cycle succession in the Phanerozoic with rifting initiation in the Carboniferous due to the Hercynian orogenic phase (Fig. 5a). Along with the rifting process, the Talijar G1 within-plate (rift-related A1-type) granitoids (the southern sector of Hasan Salaran body) intruded the basin in the Carboniferous–Permian (Figs. 5–b). Divergence of the two, separated, juvenile Arabian–Lurasian continents continued in Permo-Triassic time (Early Cimmerian), indicating the embryonic stage of Neotethys (Fig. 5c).

The Late Cimmerian orogenic phase, related to Late Jurassic, is equivalent to the ending of the ocean-floor spreading and the onset of the convergence process via the subduction of Neotethys beneath the Eurasian (Iranian) active margin. The subducting lithosphere stimulated the first stage of intrusion of magmatic arc-related (I-type) G2 granites in Qazanta-Hamzeh Abad, Chahardivar, Eski Baghdad, West Inkaj and other parts of the Alut region. Also, the first ductile phase of regional metamorphism (between the recent geographical positions of Saqez and Baneh), generally termed S1 (equivalent to D1 ductile deformation phase), developed during this time (Fig. 5d).

The next important event was the birth of an island-arc system due to an ocean–ocean subduction event in the Early Cretaceous, regarded here as the Sardasht–Barika zone. This tectonic province is exclusive for hosting the only massive-sulfide gold deposition. Volcanic eruptions have occurred both in sea-water and shallow-water back-arc basins, precipitating the primary stratiform and afterward the stringer gold deposits via the circulation of hydrothermal fluids, cooling gradually due to entering of sea-water (Fig. 5e).

The Arabian continent collided with the Sardasht–Barika island arc in the Middle Cretaceous. This compression phase metamorphosed the Barika volcanic rocks toward the Arabian passive margin into lower greenschist facies, enhancing the primary VMS-type golds via an orogenic ductile condition. Hereon, gold-bearing pyrites were recrystallized and concentrated among the mylonitic structures. Simultaneously, development/



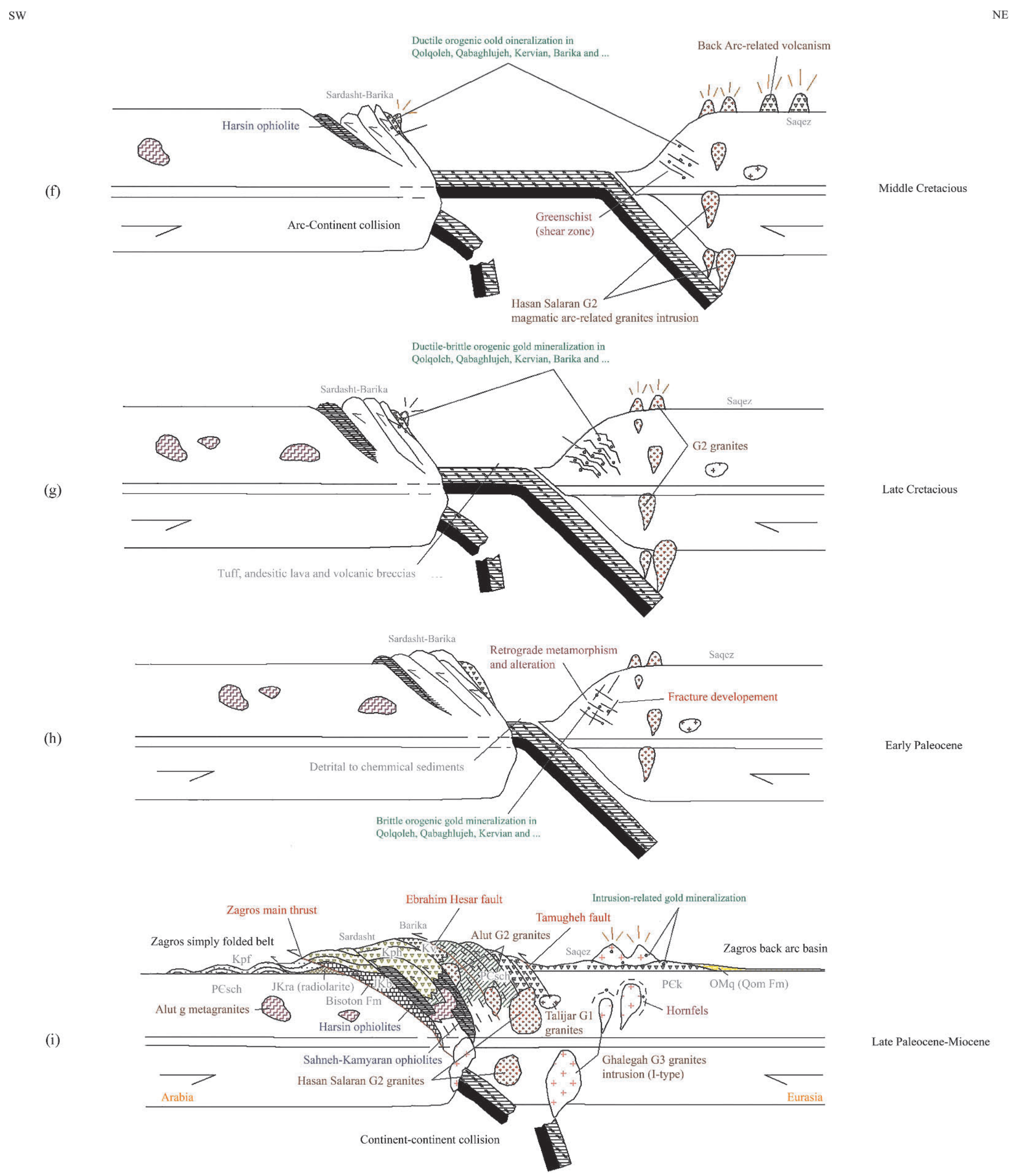


Fig. 5. Tectonic events of the study area regarding gold mineralization phases.

uplifting of an accretionary prism occasioned the rocks of the Iranian active margin to undertake some higher greenschist-facies metamorphism as well as hosting the primary orogenic golds. By this time the second G2 I-Type granites began to intrude some parts of the wedge. Moreover, the Harsin ophiolite was obducted over the Bisoton Limestone, adjacent to the ZMT (Fig. 5f). The climax of regional metamorphism, regarded as the S2 thermodynamic phase throughout the accretionary wedge, led to shearing and refolding of the primary foliated structures by the Late Cretaceous (relevant to Laramian orogenic phase). This high greenschist-facies metamorphism, in addition to silicic and sulfide alterations, hosted the most significant orogenic gold deposits of Qolqoleh, Qabaghlujeh, Kervian, Hamzeh Gharanein, Mirgeh Naghshineh and the other gold reservoirs of the study area. Furthermore, some of the orogenic golds (Qolqoleh, Qabaghlujeh and Kervian) underwent an extra phase of ore proliferation, being in contact/adjacent to the outcrops of ongoing I-type granite intrusions (G2 granites equivalent to northern Hasan Salaran body); subsequently, these were classified as mesozonal orogenic golds. In concomitance with the above events, some brittle structures developed over the active margin's forehead, regarded as the D2 semi-ductile deformation phase. In comparison, both the alteration zones and the fractures developed more rigorously than before at Barika, being postulated as the final gold mineralization controllers (Fig. 5g).

Following on, the closure of Neotethys in terms of a steady compressional tectonic regime was initiated contemporaneously with the Laramide orogenic phase,

Table 2 Temporal association between the Saqez–Sardasht gold mineralization and important tectonic, structural, metamorphic and intrusion events (vertical chronological units not to scale)

Geochronology				Orogenic phases	Tectonic events	Deformation phases	Metamorphic phases	Intrusive bodies	Gold mineralization
Cenozoic	Quaternary		Holocene						
			Pleistocene						
	Tertiary	Neogene	Pliocene	Pasadenan	Finalizing the collision event				
			Miocene	Savian					
			Oligocene						
		Paleogene	Eocene	Pyrenean	Kamyaran-Sahneh ophiolite obduction				
			Paleocene		Completion of Zagros collision	D_3 brittle deformation phase; developing the main fractures	Hornfels halos due to contact metamorphism of Ghalegah granite Retrograde metamorphism accompanying with alteration phases	Ghalegah granite; I-type, termed as G_3	Intrusion-related gold mineralization Orogenic brittle gold mineralization in Qolqoleh, Qabaghlujeh, Kervian & …
Mesozoic	Cretaceous			Laramide	Closure of Neo-Tethys Harsin ophiolite obduction	Intense shear zone-related compressional D_2 deformation phase	Thermodynamic progressive metamorphism to upper greenschist grade; developing S_2 schistosity	Northern Hasan Salaran granitoid; 109-110 Ma; I-type, attributed as G_2	Orogenic ductile-brittle gold mineralization in Qolqoleh, Qabaghlujeh, Kervian & … Orogenic ductile gold mineralization in Qolqoleh, Qabaghlujeh, Kervian, Hamzeh Gharanein, Mirgeh Naghshineh & … Barika massive sulfide gold mineralization
	Jurassic			Late Cimmerian	Subduction initiation	Compressional D_1 deformation phase assigned to subduction	Regional metamorphism at greenschist grade in ductile condition; causing S_1 mylonitic structures	Alut G_2 bodies of Qazanta-Hamzeh Abad, Chahardivar, Eski Baghdad, Darvishan & West Inkaj; I-type	
	Triassic			Early Cimmerian					
Paleozoic	Permian				Oceanization of Neo-Tethys	Tensional deformation associated to sea-floor spreading			
	Carboniferous			Hercynian	Rifting initiation			Talijar granitoid (Southern Hasan Salaran) remarked as G_1; 360 Ma, A_2-type	
	Devonian						Lower greenschist rocks at North of Saqez		
	Silurian								
	Ordovician			Caledonian					
	Cambrian								
Precambrian				Katangan Carolian		Ductile deformation zones attributed to Alut metamorphism	Alut metamorphic rocks in greenschist grade equivalent to Kahar & Soltanieh Fms.	Sheikh Chupan & Bubaktan (parts of Alut "g" granitoids) regarded as the protolith of metamorphic rocks; 551-544 Ma	

and afterward triggered the development of D3 brittle deformation, retrograde metamorphism and some pervasive phases of alteration in the Early Paleocene. This brittle deformation, overprinting the older structures, is regarded as the last structural controller of the orogenic gold mineralizations, specifically through the mesozonal goldfields (Fig. 5h).

The Arabian–Eurasian plates rejoined each other and were uplifted progressively via the final steps of collision during the Late Paleocene to Miocene. The accretionary prism, the deformed island-arc system, the newer syn-tectonic Cretaceous volcano-sedimentary rocks and the Sahneh–Kamyaran ophiolite member were thrust/obducted successively over the foreland basin in the southwest. In the Late Paleocene, the Iranian plate was intruded by some other I-Type granite series (G3), called Ghalegah. This batholith spread toward the inner parts of the hinterland (NE of Saqez) causing widespread contact metamorphism among the country rocks. Some other similar plutons (both in petrography and time of intrusion) are also situated alongside the ZMT suture zone, west of Baneh. The Ghalegah granite is characterized by hosting some intrusion-related gold prospects between Saqez and Takab cities (Fig. 5i).

6 Conclusions

(1) The Barika massive sulfide gold district is localized at an island arc basin, proposed here as the *Sardasht–Barika zone*. This goldfield hosted VMS gold mineralization in the Early Cretaceous both in the sea-water and the shallow-water back-arc basin via island-arc activity. This primary gold reservoir was enriched during the later compressional orogenic phases, which took place due to the closure of the island-arc basin in the Middle to Late Cretaceous.

(2) The Saqez–Sardasht zone is composed of four tectonic blocks, bonded together by three main suture lines/zones. From east to west these blocks are: A. the Eurasian back-arc basin, covered with Late Cretaceous-Tertiary volcano-sedimentary to chemical rocks (to the eastern side of the Tamugheh fault zone); B. the uplifted and highly tectonized Precambrian basement, amalgamated with intensely metamorphosed oceanic volcano-sedimentary sediments of Cretaceous age, regarded as an active margin/accretionary wedge (restricted NW–SE-trending block between Tamugheh and Ebrahim Hesar faults); C. the Lower Cretaceous tectonized volcano-sedimentary rocks of the Sardasht–Barika island arc imbricated with Kermanshah ophiolite lenses (restricted between Ebrahim Hesar fault and ZMT); and D. the Arabian platform passive margin, covered by flysch and/or radiolarite sediments, equivalent to the Zagros simply folded belt towards Iraq (from ZMT to the west).

Acknowledgments

This research is a revision of the first author's [EH] Ph.D. thesis dissertation at Golestan University. The authors give special thanks to Dr. Maryam Agh Atabay for her useful advice on microscopic studies and Foad Meysami for helping us to study the core samples. We sincerely thank the editors of *Acta Geologica Sinica* (English Edition) for improving our work with their thorough reviews and comments. Susan Turner (Brisbane) is also greatly thanked for her excellent assistance with the manuscript.

Manuscript received Nov. 30, 2019
accepted Apr. 21, 2020
associate EIC: FEI Hongcai
edited by Susan TURNER

References

Abdullah, F.M., Sepahi, A.A., and Ahmad, S.S., 2013. Geochemistry and petrogenesis of Hassan Salaran granitoid complex in SE Saqez, Western Iran., Florence, Italy: 23rd Goldschmidt Conference, 25-30 Aug. 2013, https://www.minersoc.org/#/ms-5/3, DOI:10.1180/minmag.2013.077.5.13 Abstract: 1776.

Abolmaali, S., Shamsa, M.J., Alavi, M., and Zaeem Farrokhzadi, N., 1999. Systematic Geochemical Explorations of Saqez Quadrangle, Scale 1:100000. Tehran: Geological Survey of Iran (in Farsi).

Agard, P., Omrani, J., Jolivet, L., and Mouthereau, F., 2005. Convergence history across Zagros (Iran): Constraints from collisional and earlier deformation. International Journal of Earth Sciences, 94(3): 401–419.

Agard, P., Omrani, J., Jolivet, L., Whitechurch, H., Vrielynck, B., Spakman, W., Monie, P., Meyer, B., and Wortel, R., 2011. Zagros orogeny: A subduction-dominated process. Geological Magazine, 148(5–6): 692–725.

Aghanabati, A., 2006. Geology of Iran. 1st ed., Tehran, Iran: Geological Survey of Iran (in Farsi).

Ahadnejad, V., 2013. Comparative review of the Northern Sanandaj-Sirjan Zone granitoids. Journal of Tethys, 1(2): 128–137.

Ahankoub, M., Jahangiri, A., Asahara, Y., and Moayyed, M., 2013. Petrochemical and Sr-Nd isotope investigations of A-type granites in the east of Misho, NW Iran. Arabian Journal of Geosciences, 6: 4833–4849.

Ahmadi Khalaji A., Esmaeily D., Valizadeh M. V., and Rahimpour Bonab H., 2007. Petrology and geochemistry of the granitoid complex of Boroujerd, Sanandaj-Sirjan Zone, Western Iran. Journal of the Asian Earth Sciences, 29: 859–877.

Alavi, M., 1980. Tectonostratigraphic evolution of the Zagrosides of Iran. Journal of Geology, 8(3): 144–149.

Alavi, M., 1994. Tectonics of the Zagros orogenic belt of Iran: New data and interpretations. Journal of Tectonophysics, 229: 211–238.

Alirezaei, S., and Hassanzadeh, J., 2012. Geochemistry and zircon geochronology of the Permian A-type Hasanrobat granite, Sanandaj-Sirjan belt: a new record of the Gondwana break-up in Iran. Lithos, 151: 122–134.

Aliyari, F., Rastad, E., Mohajjel, M., and Shamsa, M.J., 2005. Deformation and alteration role in gold mineralization via a ductile and brittle shear zone of Qolqoleh, SW of Saqez. Tehran: 24th Geoscience Symposium, Geological Survey of Iran https://civilica.com/doc/210226 (in Farsi).

Aliyari, F., Rastad, E., and Zengqian, H., 2007. Orogenic gold mineralization in the Qolqoleh deposit, Northwestern Iran. Journal of Resource Geology, 57: 269–282.

Aliyari, F., Rastad, E., and Chen, Y., 2008. Fluid inclusion characteristics of the Qolqoleh gold deposit, Northwestern Iran. Oslo, Norway: 33rd International Geological Conference, http://www.33igc.org/ 112.

Aliyari, F., Rastad, E., Mohajjel, M., and Arehart, G.B., 2009. Geology and geochemistry of D-O-C isotope systematics of the Qolqoleh gold deposit, Northwestern Iran: Implications for ore genesis. Ore Geology Reviews, 36(4): 306–314.

Aliyari, F., Rastad, E., and Mohajjel, M., 2012. Gold deposits in the Sanandaj–Sirjan Zone: Orogenic gold deposits or intrusion -related gold systems? Resource Geology, 62(3): 296–315.

Almasi, A., Jafarirad, A., Kheyrollahi, H., Rahimi, M., and Afzal, P., 2014. Evaluation of structural and geological factors in orogenic gold type mineralization in the Kervian area, North-West Iran, using airborne geophysical data. Journal of Exploration Geophysics, 45(4): 261–270.

Ao, S., Xiao, W., Khalatbari, J.M., Talebian, M., Chen, L., Wan, B., Ji, W., and Zhang, Z., 2016. U-Pb zircon ages, field geology and geochemistry of the Kermanshah ophiolite (Iran): from continental rifting at 79 Ma to oceanic core complex at ca. 36 Ma in the Southern Neotethys. Gondwana Research, 31: 305–318.

Aryan, M.A., 2001. Petrography and petrology of intrusion bodies in the Sonqor-Marivan belt. Ph.D. Dissertation, Tehran, Iran: Azad University, (in Farsi).

Aryan, M.A., Emamali Pur, A., and Mohammad, A.A., 2011. Petrology and geochemistry of granite bodies of NE Saqez and the attributed metamorphic aureole. The Earth, 19: 65–80 (in Farsi).

Arvin, M., Pan, Y., Dargahi, S., Malekizadeh, A., and Babaei, A., 2007. Petrochemistry of the Siah-Kuh granitoid stock southwest of Kerman, Iran: implications for initiation of Neo-Tethys subduction. Journal of Asian Earth Sciences, 30: 474–489.

Asghari, G., Alipour, S., Azizi, H., and Mirnejad, H., 2018. Geology and mineral chemistry of gold mineralization in Mirge-Naqshineh occurrence (Saqez, NW Iran): Implications for transportation and precipitation of gold. Acta Geologica Sinica (English Edition), 92(1): 210–224.

Athari, S.F., Sepahi, A.A., Aliani, F., Moazzen, M., and Sheikhian, S., 2006a. Investigation of tectonic environment and genesis of Hasan Salaran granitoid complex, NW Saqez. Tehran, Iran: 10th Iran Geological Association Symposium, Tarbiat Modarres University, https://civilica.com, 728–735 (in Farsi).

Athari, S.F., Sepahi, A.A., and Moazzen, M., 2006b. Hasan Salaran granitoids: A complex of 2 granitoid types in the metamorphic belt of Sanandaj–Sirjan Zone. Research Journal of Isfahan University, 1385: 77–99 (in Farsi).

Azizi, H., and Jahangiri, A., 2008. Cretaceous subduction-related volcanism in the Northern Sanandaj-Sirjan Zone, Iran. Geodynamics, 45: 178–190.

Azizi, H., Moinevaziri, H., Mohajjel, M., and Yaghoubpour, A., 2006. PTt path in metamorphic rocks of the Khoy region (Northwest Iran) and their tectonic significance for Cretaceous -Tertiary continental collision. Journal of Asian Earth Sciences, 27: 1–9.

Azizi, H., and Moinevaziri, H., 2009. Review of the tectonic setting of Cretaceous to Quaternary volcanism in Northwestern Iran. Geodynamics, 47: 167–179.

Azizi, H., Kazemi, T., and Asahara, Y., 2017. A-type granitoid in Hasansalaran complex, Northwestern Iran: Evidence for extensional regime in Northern Gondwana in the Late Paleozoic. Geodynamics, 108: 56–72.

Baharifar, A., Moinevaziri, H., Bellon, H., and Pique, A., 2004. The crystalline complexes of Hamadan (Sanandaj-Sirjan zone, western Iran): metasedimentary Mesozoic sequences affected by Late Cretaceous tectono-metamorphic and plutonic events. C. R. Geosciences, 336: 1443–1452.

Berberian, M., 1995. Master “blind” thrust faults hidden under the Zagros folds: active basement tectonics and surface morphotectonics. Tectonophysics, 241(3–4): 193–224.

Berberian, F., and Berberian, M., 1981. Tectono-Plutonic Episodes in Iran. Zagros Hindu-Kush-Himalaya Geodynamic Evolution, Vol. 3., https://doi.org/10.1029/GD003p0005, Book Series: Geodynamics Series.

Berberian, M., and King, G.C.P., 1981. Towards a paleogeography and tectonic evolution of Iran. Canadian Journal of Earth Sciences, 18: 210–265.

Bierlein, F.P., Arne, D.C., Key, S.M., and McNaughton, N.J., 2001. Timing relationships between felsic magmatism and mineralization in the central Victorian gold province, SE Australia. Australian Journal of Earth Sciences, 48: 883–899.

Dercourt, J., Zonenshian, L.P., Ricou, L.E., Kazmin, V.G., Le Pichon, X., Knipper, A.L., Grandjacquet, C., Sbortshikov, I.M., Geyssant, J., Lepvrier, C., Pechersky, D.H., Boulin, J., Sibuet, J.C., Savostin, L.A., Sorokhtin, O., Westphal, M., Bazhenov, M. L., Lauer, J.P., and Biju Duval, B., 1986. Geological evolution of the Tethys belt from the Atlantic to the Pamirs since the LIAS. Tectonophysics, 123(1–4): 241–315.

Eftekhar-Nejad J., 1973. Mahabad Quadrangle Geologic Map, Scale 1:250000. Tehran: Geological Survey of Iran (in Farsi).

Eftekhar-Nejad, J., 1981. Tectonic division of Iran concerning sedimentary basins. Journal of Iranian Petroleum, 82: 19–28 (in Farsi).

Eftekhar-Nejad, J., 2004. Text Report of Mahabad Quadrangle Geological Map B-4, Scale 1:250000. Tehran: Geological Survey of Iran (in Farsi).

Fonoudi, M., and Sadeghi, A., 2000. Baneh Quadrangle Geological Map, Scale 1:100000. Tehran: Geological Survey of Iran (in Farsi).

Ghalamghash, J., Nedelec, A., Bellon, H., Vosoughi Abedini, M., and Bouchez, J.L., 2009. The Urumieh plutonic complex (NW Iran): A record of the geodynamic evolution of the Sanandaj-Sirjan Zone during Cretaceous times – Part I: Petrogenesis and K/Ar dating. Journal of Asian Earth Sciences, 35(5): 401–415.

Ghasemi, A., and Talbot, C.J., 2006. A new tectonic scenario for the Sanandaj–Sirjan Zone (Iran). Journal of Asian Earth Sciences, 26: 683–693.

Ghazi, A.M., and Hassanipak, A.A., 1999. Geochemistry of subalkaline and alkaline extrusives from the Kermanshah ophiolite, Zagros suture zone, Western Iran: implications for Tethyan plate tectonics. Journal of Asian Earth Sciences, 17 (3): 319–332.

Ghorbani, M., 2013. The Economic Geology of Iran. London: Springer Geology Publication, 569.

Goldfarb, R.J., Groves, D.L., and Gardoll, S., 2001. Orogenic gold and geologic time: A global synthesis. Ore Geology Reviews, 18(1–2): 1–75.

Golonka, J., 2004. Plate tectonic evolution of the southern margin of Eurasia in the Mesozoic and Cenozoic. Tectonophysics, 381: 235–273.

Grabowski, J., and Norton, J.O., 1994. Tectonic controls on the stratigraphic architecture and hydrocarbon systems of the Arabia Plate. The Middle East Petroleum Geosciences (GEO), 1: 413-430.

Groves, D.I., Goldfarb, R.J., Gebre Mariam, M., Hagemann, S.G., and Robert, F., 1998. Orogenic gold deposits: A proposed classification in the context of their crustal distribution and relationship to other gold deposit types. Ore Geology Reviews, 13: 7–27.

Hacker, B.R., Mosenfelder, J.L., and Gnos, E., 1996. Rapid emplacement of the Oman ophiolite: thermal and geochronologic constraints. Tectonics, 15(6): 1230–1247.

Haji, E., Safari, H., Shafiei Bafti, B., and Agh Atabay, M., 2016. Studying structural characteristics of Saqez–Takab Region (NW of Sanandaj–Sirjan Zone) using GiT (geoinformation techniques). Zankoi Sulaimani (JZS), 201-I, Part A.

Haji, E., and Safari, H., 2017. Investigation on deformation stages in the NW part of the Sanandaj-Sirjan structural zone. Geosciences (Geological Survey of Iran), 103: 183–200 (in Farsi).

Hariri, A., and Farjandi, F., 2003. Saqez Quadrangle Geological Map, Scale 1:100000. Tehran: Geological Survey of Iran (in Farsi).

Hassanipak, A.A., 2000. Systematic Geochemical Explorations of Alut Quadrangle, Scale 1:100000. Tehran: Toseae Oloume Zamin Co. (in Farsi).

Hassanzadeh, J., Stocki, D., Horton, B.K., Axen, G.J., Stocki, L.D., Grove, M., Schmitt, A.K., and Walker, J.D., 2008. U-Pb zircon geochronology of Late Neoproterozoic–Early Cambrian granitoids in Iran: implications for paleogeography, magmatism, and exhumation history of Iranian basement. Tectonophysics, 451: 71–96.

Heydari, S.M., 2004. Mineralography, geochemistry and fabric of gold mineralization in Kervian ductile shear zone, SW Saqez, Kurdistan Province. M.Sc. Thesis, Tehran: Tarbiat

Modarres University, Faculty of Sciences (in Farsi).
Heydari, S.M., Rastad, E., Mohajjel, M., and Shamsa, M.J., 2005. Gold mineralization in the ductile shear zone of Kervian (SW Saqez). Geosciences (Geological Survey of Iran), 58: 18–37 (in Farsi).
Horton, B.K., Hassanzadeh, J., Stockli, D.F., Axen, G.J., Gillis, R.J., Guest, B., Amini, A., Fakhari, M.D., Zamanzadeh, S.M., and Grove, M., 2008. Detrital zircon provenance of Neoproterozoic to Cenozoic deposits in Iran: implications for chronostratigraphy and collisional tectonics. Tectonophysics, 451: 97–122.
Hough, M.A., Bierlein, F.P., and Wilde, A.R., 2007. A review of the metallogeny and tectonics of the Lachlan Orogen. Mineralium Deposita, 42(5): 435–448.
Izadi, F., 2006. Petrology and geochemistry of Tah-Baysaran intrusive bodies. M.Sc. Thesis, Tehran: Kharazmi University (in Farsi).
Jamali, H., Yaghubpur, A., Mehrabi, B., Dilek, Y., Daliran, F., and Meshkani, A., 2012. Petrogenesis and tectono-magmatic setting of Meso-Cenozoic magmatism in Azerbayjan Province, Northwestern Iran. In: Al-Juboury, A. (ed.), Petrology: New Perspectives and Applications. DOI: 10.5772/24782, ISBN: 978-953-307-800-7, (InTech).
Kazmin, V.G., 1991. Collision and rifting in the Tethys Ocean: Geodynamic implication. Journal of Tectonophysics, 196 (3-4), 371–384.
Kholghi Khasraghi, M.H., 1999. Chapan Quadrangle Geological Map, Scale 1:100000. Tehran: Geological Survey of Iran (in Farsi).
Knipper, A., Ricou, L.E., and Dercourt, J., 1986. Ophiolites as indications of the geodynamic evolution of the Tethyan Ocean. Tectonophysics, 123(1–4): 213–240.
Koop, W.J., and Stoneley, R., 1982. Subsidence history of the Middle East Zagros basin, Permian to Recent. Philosophic Transactions of the Royal Society of London, Mathematics and Physics Sciences, 305(1489): 149–167.
Kouhestani, H., Rashidnejad, Omran, N., Rastad, E., Mohajjel, M., Goldfarb, R.J., and Ghaderi, M., 2014. Orogenic gold mineralization at the Chah Bagh deposit, Muteh gold district, Iran. Journal of Asian Earth Sciences, 91: 89–106.
Lescuyer, J.L., Hushmand Zadeh, A., and Daliran, F., 2003. Gold metallogeny in Iran: A preliminary review. Mineral Exploration and Sustainable Development, 2: 1185–1188.
Leterrier, J., 1985. Mineralogical, geochemical and isotopic evolution of two Miocene mafic intrusions from the Zagros (Iran). Lithos, 18: 311–329.
Lippard, H., Shelton, A.W., and Gass, I.G., 1986. The Ophiolites of Northern Oman. Geological Society, London, Memoir 11.
Mahmoudi, S., Corfu, F., Masoudi, F., Mehrabi, B., and Mohajjel, M., 2011. U-Pb dating and emplacement history of granitoid plutons in the Northern Sanandaj-Sirjan Zone, Iran. Journal of Asian Earth Sciences, 41: 238–249.
Mazhari, S.A., Amini, S., Ghalamghash, J., and Bea, F., 2011. Petrogenesis of the granitic unit of Naghadeh complex, Sanandaj-Sirjan Zone, NW Iran. Arabian Journal of Geosciences, 4(1–2): 59–67.
Mehdipour Ghazi, J., and Moazzen, M., 2015. Geodynamic evolution of the Sanandaj-Sirjan Zone, Zagros Orogen, Iran. Turkish Journal of Earth Sciences, 24: 513–528.
Mir, A., Zarei, R., Shahrokhi, S.V., and Hezareh, M.R., 2014. The study of mineralogy and petrography of Qabaghlujeh gold deposit, SW Saqez (Kurdistan). Orumieh, Iran: 32nd Geoscience Symposium, Geological Survey of Iran https://civilica.com/doc/267764: 6 pp (in Farsi).
Moghadam, H.S., Khademi, M., Hu, Z.C., Stern, R.J., Santos, J.F., and Wu, Y.B., 2015. Cadomian (Ediacaran–Cambrian) arc magmatism in the Chah Jam–Biarjmand metamorphic complex (Iran): magmatism along the northern active margin of Gondwana. Gondwana Research, 27: 439–452.
Mohajjel, M., 1997. Structure and tectonic evolution of Paleozoic-Mesozoic rocks, Sanandaj-Sirjan zone, western Iran. Ph.D. Dissertation, University of Wollongong, New South Wales, Australia.
Mohajjel, M., 2002. Text Report of Kervian District Geological, Structural and Alteration Map, Scale 1:5000. Gold Exploration Program. Tehran: Geological Survey of Iran (in Farsi).
Mohajjel, M., and Fergusson C. L., 2000. Dextral transpression in Late Cretaceous continental collision, Sanandaj-Sirjan Zone, Western Iran. Structural Geology, 235: 1125–1139.
Mohajjel, M., and Sahandi R., 1999. Tectonic evolution of NW Sanandaj-Sirjan Zone: Introducing new subzones. Geosciences (Geological Survey of Iran), 31–32: 28–46 (in Farsi).
Mohajjel, M., Fergusson, C.L., and Sahandi, M. R., 2003. Cretaceous-Tertiary convergence and continental collision, Sanandaj–Sirjan Zone, Western Iran. Journal of Asian Earth Sciences, 21: 397–412.
Mohammadpour, M., Rahimipour, G., and Ghazanfari, M., 2012. The separation of geochemical anomalies from the background by classical statistics and fractal methods; case study: Mirgeh Naghshineh, Saqez area. In: eds? 4th Symposium of Economical Geology Association of Iran, Birjand Azad University, https://civilica.com/papers/l-4556, 7 pp (in Farsi).
Moinevaziri, H., Azizi, H., Mehrabi, B., and Izadi, F., 2008. Oligocene magmatism in the Zagros thrust zone (Sahneh-Marivan axis): the second period of the Neotethyan subduction in the Paleogene. Science (Tehran University), 34 (1): 113–122 (in Farsi).
Moinevaziri, H., Haji, E., Nouri, N., and Meysami, F., 2017. Geological Map of Qolqoleh Gold District, Scale 1:1000. Internal Report. Sanandaj, Iran: Toseae Talaye Kurdistan Co. (in Farsi).
Moritz, R., Ghazban, F., and Singer, B.S., 2006. Eocene gold ore formation at Muteh, Sanandaj-Sirjan zone, western Iran: A result of late-stage extension and exhumation of metamorphic basement rocks within the Zagros orogeny. Economic Geology, 101: 1497–1524.
Niroomand, Sh., Goldfarb, R.J., Moore, F., Mohajjel, M., and Marsh E.E., 2011. The Kharapeh orogenic gold deposit: Geological, structural, and geochemical controls on epizonal ore formation in West Azerbaijan Province, Northwestern Iran. Mineralium Deposita, 46: 409–428.
Nosratpour, H., 2008. A study of gold mineralization in Qabaghlujeh shear zone (Southwest Saqez, Kurdistan Province). M.Sc. Thesis, Tehran: Tehran University, Iran (in Farsi).
Nosratpour, H., and Hassanzadeh, J., 2007. Studying gold mineralization in the Qabaghlujeh shear zone (SW Saqez, Kurdistan). Tehran: 26th Geoscience Symposium, Geological Survey of Iran, https://civilica.com/papers/l-7207, 8 pp. (in Farsi).
Nosratpour, H., and Hassanzadeh, J., 2008. A study of mineral deformation and alteration and its role in Au mineralization in the ductile-brittle shear zone at Ghabaghlujeh (SW Saqez, Kurdistan Province). 15th Conference of Crystallography and Mineralogy, Ferdowsi Univ. of Mashhad (in Farsi).
Nutman, A.P., Mohajjel, M., Bennet, V.C., and Fergusson, C.L., 2014. Gondwanan Eoarchean-Neoproterozoic ancient crustal material in Iran and Turkey: zircon U-Pb-Hf isotopic evidence. Canadian Journal of Earth Sciences, 51: 272–285.
Olyaee, Y., 2008. Gold extraction from Hamzeh Gharanein orebodies. Website: http://drillig.gsi.ir/fa/ReportsData/MoreInfo/All/640/1715, Internal Report, Zarnab Ekteshaf Co. Accessed: 2015 (in Farsi).
Omrani, J., and Khabbaznia, A.R., 2003. Alut Quadrangle Geological Map, Scale 1:100000. Geological Survey of Iran (in Farsi).
Pearce, J.A., Lippard, S.J., and Roberts, S., 1984. Characteristics and tectonic significance of supra-subduction zone ophiolites. Geological Society, London, Special Publication, (16): 77–94.
Pirajno, F., 2009. Hydrothermal Processes and Mineral Systems. Perth, Australia: Springer Publication, 1250 pp.
Rashidnejad Omran, N., Honarmand, M., and Mohajjel, M., 2013. Petrography, geochemistry and genesis of Alut intrusion complex, NW Saqez. Science (Kharazmi University), 12(2): 435–460 (in Farsi).
Ricou, L.E., Braud, J., and Brunn, J.H., 1977. Le Zagros. Memoire h. Ser., Société Géologique de France, 8: 33–52.

Robert, F., Brommecker, R., Bourne, B.T., Dobak, P.J., McEwan, C.J., Rowe, R.R., and Zhou, X., 2007. Models and exploration methods for major gold deposit types. "Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration" edited by B. Milkereit, 2007: 691-711.

Sabzehi, M., 1996. An introduction to general geological features of metamorphic complexes in Southern Sanandaj-Sirjan Zone. Internal Report. Tehran: Geological Survey of Iran (in Farsi).

Sabzehi, M., Goorabjiri, A., and Eslamdoust, F., 2009. Marivan Quadrangle Geological Map, Scale 1:100000. Tehran: Geological Survey of Iran (in Farsi).

Saccani, E., Allahyari, K., Beccaluva, L., and Bianchini, G., 2013. Geochemistry and petrology of the Kermanshah ophiolites (Iran): Implication for the interaction between passive rifting, oceanic accretion and OIB-type components in the Southern Neo-Tethys Ocean. Gondwana Research, 24(1): 392–411.

Sadeghian, M., and Delavar, S.T., 2006. Kamyaran Quadrangle Geological Map, Scale 1:100000. Tehran: Geological Survey of Iran (in Accompany with Tozco Company; in Farsi).

Sengor, A.M.C., 1990. A New Model for the Late Paleozoic–Mesozoic Tectonic Evolution of Iran and Implications for Oman. Geological Society, London, Special Publication, 49: 797–831.

Sengor, A.M.C., Altiner, D., Cin, A., Ustaomer, T., and Hsu, K.J., 1988. Origin and Assembly of the Tethyside Orogenic Collage at the Expense of Gondwana Land. Geological Society, London, Special Publication, 37: 119–181.

Sengor, A.M.C., and Natal'in, B.A., 1996. Paleotectonics of Asia: Fragments of a synthesis. In: Yin, A., and Harrison, T.M. (eds.), The Tectonic Evolution of Asia. Cambridge University Press, 486–640.

Sepahi, A.A., and Athari, S.F., 2006a. A study of granite typology in Sanandaj-Sirjan Zone, Zagros Orogen, Iran. Florence, Italy: 23rd Goldschmidt Conference, 25-30 Aug. 2013, https://www.minersoc.org/#/ms-5/3, DOI:10.1016/j.gca.2006.06.1055, Abstract: A570.

Sepahi, A.A., and Athari, S.F., 2006b. Petrology of major granitic plutons of the northwestern part of the Sanandaj-Sirjan metamorphic belt, Zagros Orogen, Iran: with emphasis on A-type granitoids from the SE Saqez area. Neues Jahrbuch fuer Mineralogie, Abhandlungen 183/1: 93–106.

Shah Pasandzadeh, M., and Goorabjiri A., 2006. Bayenjub Quadrangle Geological Map, Scale 1:100000. Tehran: Geological Survey of Iran (in Farsi).

Shahrokhi, S.V., Khakzad, A., and Rasa, E., 2009. Investigation of gold mineralization in Qolqoleh district, SW Saqez. J. Pure Sciences (Islamic Azad Univ.), 73: 45–62 (in Farsi).

Shamsa, M.J., 1998. The regional geochemical exploration for gold in the Saqez area. Internal Report. Tehran: Geological Survey of Iran (in Farsi).

Stampfli, G.M., and Borel, G.D., 2002. A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrones. Earth and Planetary Science Letters, 196(1–2): 17–33.

Stampfli, G.M., Marcoux, J., and Baud, A., 1991. Tethyan margins in space and time. Paleogeography, Palaeoclimatology, Palaeoecology, 87(1–4): 373–409.

Stampfli, G.M., Mosar, J., Faver, P., Pillevuit, A., and Vannay, C.J., 2001. Permo-Mesozoic evolution of the western Tethyan realm: The Neotethys/East Mediterranean connection. Mémoires du Muséum national d'histoire naturelle (1993)., Vol 186, pp 51-108; Illustration ; ref : 12 p.1/4

Taghipour, B., and Ahmadnejad, F., 2012. Geochemistry of altered areas and shear zone in Qolqoleh gold deposit (Kurdistan): Emphasizing on REE elements behavior. Petrology, 10: 45–64 (in Farsi).

Tajeddin, H., 2013. Controller factors of gold mineralization in metamorphic rocks of Saqez–Sardasht region, NW Sanandaj-Sirjan metamorphic zone. Ph.D. Dissertation, Tehran: Tarbiat Modarres University, Faculty of Pure Sciences (in Farsi).

Tajeddin, H., Shamsa M. J., Abedian N., and Ghazanfari M., 2006. Orogenic gold in Saqez-Sardasht Zone: A criterion for gold exploration in NW Sanandaj-Sirjan Zone metamorphic rocks. Tehran: Geological Survey of Iran, 25th Geoscience Symposium, https://civilica.com/doc/93850, 9 pp. (in Farsi).

Tajeddin, H., Rastad E., Yaghoubpour A., and Mohajjel M., 2010. Formation and evolution process of Barika gold-rich massive sulfide reservoir, East Sardasht, NW Sanandaj-Sirjan Zone: Implication of studying structure, texture and micrometry of fluid inclusions. Journal of Economic Geology (Mashhad Ferdowsi Univ.) 2(1): 97–121 (in Farsi).

Tajeddin, H., Rastad, E., Yaghoubpour, A., and Mohajjel, M., 2012. Lithification, geochemistry and role of alteration in the dissemination of mineralogenic elements at Barika gold-enriched massive sulfide deposit, east of Sardasht, North Sanandaj-Sirjan Zone. Geosciences (Geological Survey of Iran), 83: 141–156 (in Farsi).

Tajeddin, H., Rastad, E., Yaghoubpour, A., and Mohajjel, M., 2013. Metamorphism and deformation effects on Barika gold-reach volcanogenic massive sulfide deposit, Northern Sanandaj-Sirjan Zone. Geosciences (Geological Survey of Iran), 87: 23–40 (in Farsi).

Takin, M., 1972. Iranian geology and continental drift in the Middle East. Nature, 235: 147–150.

Yarmohammadi, A., 2006. Mineralization, geochemistry, structure, texture and genesis of gold in the east of Barika gold (accompanying silver, primary metals and barite) district, East of Sardasht. M.Sc. Thesis), Tehran: Tarbiat Modarres University, Faculty of Pure Sciences (in Farsi).

Yarmohammadi, A., Rastad E., Mohajjel M., and Shamsa M. J., 2005. Barika gold occurrence: volcanogenic massive sulfide gold-rich mineralization type in Iran. 24th Geoscience Symposium, Tehran: Geological Survey of Iran (in Farsi), civilica.com/doc/210229, 11 pp.

Yarmohammadi, A., and Rastad E., 2006. Role of deformation in increasing gold extraction at Barika massive sulfide gold-rich reservoir, East Sardasht. 25th Geoscience Symposium, Tehran: Geological Survey of Iran (in Farsi), https://civilica.com/doc/93821, 8 pp.

Zahedi, M., Hajian, J., and Bolurchi H., 1992. Sanandaj Quadrangle Geological Map, Scale 1:100000. Tehran: Geological Survey of Iran (in Farsi).

About the first and corresponding author

Erfan HAJI, male, born Apr. 17, 1978 Sanandaj, Iran, Ph.D., graduated from Golestan University, and is a Professor at the University of Kurdistan, Sanandaj. He is an expert in structural geology and tectonics, remote sensing and GIS, being interested in tectonic-metallogeny studies as his essential career.