

مقایسه کانسار Cu-Ag-Au قلعه زری با دیگر کانسارهای نوع Iron Oxides Cu-Au (IOCG) و ارائه رده‌بندی جدید

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چکیده: کانسار Cu-Au-Ag غنی از اسپیکولاریت قلعه زری در ۱۸۰ کیلومتری جنوب بیرجند واقع شده است. سنگ میزبان عمدتاً اندزیت و اندزیت بازالت‌های ترشیری و تا حدی شیل - ماسه سنگ ژوراسیک است. اندزیت‌های بخش غربی قلعه زری دارای سن 40.5 ± 2 میلیون سال می‌باشند. چهار سری گسل و درزه در منطقه شناسایی شده‌اند. کانی‌سازی در قدیمترین سری تشکیل شده است. سه رگه نسبتاً موازی در منطقه شناسایی شده است. رگه شماره ۲ (رگه اصلی) دارای گسترش طولی حدود ۳/۵ کیلومتر و عمق ۳۵۰ متر و دارای امتداد $N40^{\circ}W$ است. پاراژنز مرحله ۱: اسپیکولاریت، کوارتز، کلریت غنی از آهن، کالکوپریت و کانی‌های سولفوسالت. اسپیکولاریت ابتدا تشکیل شده و ۱۰ تا ۲۵ درصد رگه را شامل می‌شود. عیار مس ۲ تا ۹٪، نقره ۱۰۰ تا ۶۵۰ و طلا ۰/۵ تا ۳۵ گرم در تن است. آلتراسیون پروپیلیتیک بیشترین گسترش را دارد و کلریت و اپیدوت نسبتاً فراوان هستند. آلتراسیون آرژیلیک بسیار محدود و در نقاط خاصی مشاهده شد. آلتراسیون سیلیسی فقط در محدوده رگه مشاهده می‌شود. دمای همگنی سیالات اولیه در کوارتز همراه با کانی‌سازی اسپیکولاریت Cu، Ag و Au در حدود ۲۴۰ تا ۳۶۰°C، میزان شوری معادل ۱ تا ۶ درصد NaCl و میزان CO_2 کمتر از ۰/۱ مول است. بر اساس حضور هماتیت، اسپیکولاریت و کلریت غنی از آهن، و نبود مگنتیت و پیروتیت، محلول کانه‌ساز شرایط فوق اکسیدان داشته است. تفاوت‌های اساسی بین کانسار قلعه زری و دیگر کانسارهای Iron-Oxides Cu-Au عبارتند از: (۱) شوری بسیار کم (کمتر از معادل ۶٪ NaCl)، (۲) نبود مگنتیت و اپاتیت، (۳) پایین بودن میزان عناصر کمیاب و فسفر، و (۴) بالابودن عیار Cu، Ag، Au. تفاوت میزان فراوانی عناصر Cu، Ag، Au، REE، P، U، F در کانسارهای IOCG به عواملی مختلفی مرتبط است که مهمترین آنها عبارتند از: موقعیت تکتونیکی، عمق تشکیل ماگما، منشأ ماگما، میزان ذوب جزئی، شرایط فیزیکوشیمیایی ذوب، آهنگ بالابودن، میزان آمیختگی با پوسته قاره‌ای، میزان تفریق ماگما و عمق جایگزینی.

واژه‌های کلیدی: قلعه زری، Iron oxides، IOCG، ایران، Cu-Ag-Au.

Comparison of Qaleh Zari Cu-Au-Ag deposit with other Iron Oxides Cu-Au (IOGC-type) deposits, a new classification

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Abstract: The Qaleh-Zari specularite- rich Cu-Au-Ag deposit is located 180 Km south of Birjand. Host rocks are mainly Tertiary andesites and andesitic basalts and some Jurassic shales and sandstones. Andesitic rocks from the western region of Qaleh-Zari were dated to 40.5 ± 2 Ma. Four trends of faults and joints are identified in the mine area. The oldest is mineralized. Three major sub-parallel quartz veins are present. No. 2 vein is the main vein and can be traced for more than 3.5 km along strike ($N40^\circ W$) and more than 350 m down dip. Paragenesis: Stage I: specularite, quartz, Fe-chlorite, chalcopryite and sulfosalts. Specularite deposited first and forms 10 to 25 percent of the vein. Ore grade is 2 to 9% Cu, Ag 100 to 650 ppm, and Au 0.5 to 35 ppm. Propylitic alteration is dominant and epidote is very abundant. Argillic alteration is locally present. Silicification is mainly found within the vein zone. Temperature of homogenization of primary fluid inclusions in quartz associated with specularite and Cu, Ag, and Au mineralization was between $240^\circ C$ and $360^\circ C$. The salinity of ore fluid was between 1.0 and 6.0 wt% equiv. NaCl and the CO_2 was < 0.1 mole%. Based on the presence of hematite, chalcopryite, Fe-rich chlorite, and, locally pyrite, and on the absence of magnetite and pyrrhotite, the ore fluid was very oxidizing. Some important differences between Qaleh-Zari and other iron-Oxides Cu-Au deposits are: (1) The salinity is very low (< 6 wt% NaCl equiv.), (2) absence of magnetite and apatite, (3) low REE and P., and 4) high grade Cu, Ag, and Au. Differences in the amount of Cu, Au, REE, P, U, F and some other elementals in iron-oxides Cu-Au deposits are related to: Tectonic setting, depth of magmatism, source of magma, degree of partial melting, physicochemical condition of melting, rate of ascending, crystal assimilation, degree of fractionation, and depth of emplacement.

Keywords: *Qaleh Zari, Iron oxides, IOCG, Iran, Cu-Ag-Au.*

1. Introduction

The iron oxides deposits are divided into two groups: the iron oxide copper-gold (IOCG) deposits and the magnetite-apatite type [1, 2 & 3]. The author classifies the iron oxides deposits in two major groups (Fig. 1). The magnetite group is divided into three types: (1) magnetite-apatite type such as Choughart deposit, (2) magnetite-REE type such as Esphourdi deposit, and (3) magnetite type such as Sangan deposit (Fig. 1). The iron-oxide Cu-Au (IOCG) group is divided to: (1) IOCG magnetite Cu, Au, REE, Au type such as Olympic Dam deposit, (2) IOCG magnetite Cu, Au type such as Candelaria Chile, and (3) IOCG Specularite Cu-Au type such as Qaleh Zari deposit, and (4) IOCG specularite Au-Cu type such as Kuh-Zar deposit (Fig. 1).

The youngest and, therefore, most readily understandable IOCG belt is located in the Coastal Cordillera of northern Chile and southern Peru, where it is part of a volcano-plutonic arc of Jurassic through Early Cretaceous age [4]. The IOCG deposits display close relations to the plutonic complexes and broadly coeval fault systems [4]. They can be separated into several styles: veins, hydrothermal breccias, replacement mantos, calcic skarns and composite deposits that combine all or many of the preceding types. The vein deposits tend to be hosted by intrusive rocks, especially equigranular gabbrodiorite and diorite, whereas the larger, composite deposits (e.g. Candelaria-Punta del Cobre) occur within volcano-sedimentary sequences up to 2 km from pluton contacts and in intimate association with major orogen-parallel fault systems [4]. The deposits formed in association with sodic, calcic and potassic alteration, either alone or in some combination, reveals evidence of an upward and outward zonation from magnetite-actinolite-apatite to specular hematitechlorite-sericite [4].

2. Regional Geology

Qaleh-Zari is situated within the Central Lut Block at 31° 50' N, 59° 00' E about 180 Km south of Birjand (Province of Southern Khorasan) in the eastern part of Iran (Fig. 2). Lut Block is bounded by Nayband fault and Shotori Range in the west and the Eastern Iranian Ranges in the east (Fig. 2). The oldest rocks exposed in Qaleh Zari area are Jurassic sandstones and shales (Fig. 3) which form the core of an anticline in the central part of the study area (Fig. 3). These are unconformably overlain by Upper Cretaceous conglomerates and sandy limestones (200 m). This sequence is followed by massive pale cream limestone (130 m) of Paleocene age. The Jurassic shales and sandstones in the Dom-e-Robah mountain area are overlapped with angular unconformably (with an angular relationship of 40°) by the reddish Upper Cretaceous conglomerates.

| | |
|--|--|
| I- Magnetite Type | 1- Magnetite-apatite Chughart Deposit |
| | 2- Magnetite- REE Sphourdi Deposit |
| | 3- Magnetite Sangan Deposit |
| II- Iron oxides copper gold (IOCG) <i>Karimpour 2005</i> | 1- IOCG Magnetite (Cu- Au- U- REE) Olympic Dam Deposit |
| | 2- IOCG Magnetite (Cu- Au) Candelaria Deposit |
| | 3- IOCG Specularite (Cu-Au) Qaleh Zari Deposit |
| | 4- IOCG Specularite (Au-Cu) Kuh-Zar Deposit |

Figure 1 Classification of iron oxide deposits.

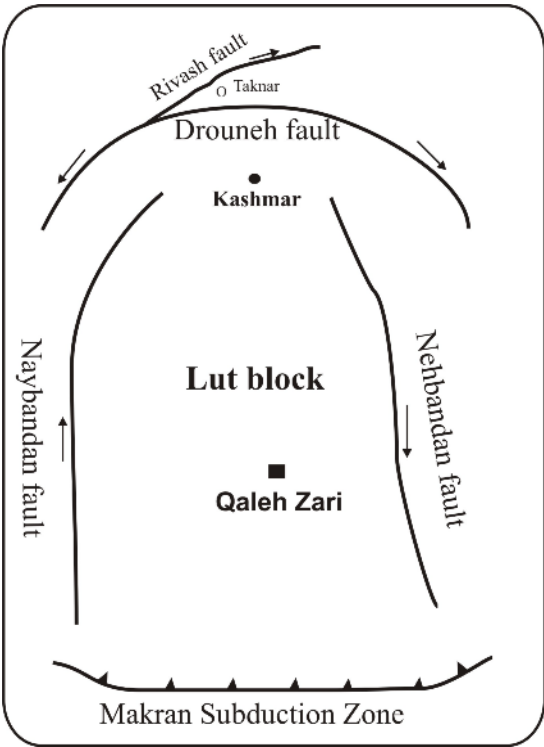


Figure 2 Map showing the location of Qaleh Zari mine in central Lut region.

Volcanic and some plutonic rocks of the Lut Block are the result of west dipping subduction. Maximum volcanic activity took place at the end of Eocene. The Middle Eocene (47 m.a) is distinguished by alkaline and shoshonitic volcanism [5]. Andesites from the western region of Qaleh-Zari were dated at 40.5 ± 2 ma [6]. These rocks are calc-alkaline to K-rich calc-alkaline and have a geochemical signature typical of subduction-related magmatism [7, 8]. A highly altered intermediate intrusive rock (as a small exposure) is also reported from the area. In addition to calc-alkaline series, basalts and basaltic-andesite were formed in Eocene-Oligocene (40 to 31 m.a) and in Quaternary.

3. Method of Study

Samples were collected from No. 1 deposit (vein I, II, and III) for petrography, fluid inclusion, electron microprobe, and isotopic analyses.

A Fluid Inc. modified USGS heating/freezing stage was used for fluid inclusion studies. The general method and procedure for heating/freezing experiments are reported elsewhere [10]. The precision of the temperature measurements is better than ± 1 °C for heating and ± 0.3 °C for freezing. Accuracy of the measurements was insured by calibration against the triple point of CO₂ (-56.6 °C), the freezing point of water (0.0 °C), the critical point of water (374.6 °C) and synthetic fluid inclusions.

Laser Raman spectroscopy (LRS) method is an important development in the field of non-destructive fluid inclusion technique for *in situ* pin-point analysis of individual, unopened fluid inclusions [9]. Laser Raman spectroscopy can be used to quantitatively determine the gaseous components (e.g. H₂S, CO, CO₂, CH₄, SO₂, H₂, NH₃, N₂) with a detection limit of 0.1 mole % for some species and for identifying daughter minerals. In this study, a DILOR MICRODIL-28[®] Raman microprobe at the Australian Geological Survey Organisation (AGSO), Canberra was used to quantitatively determine the composition of gaseous components and to identify the daughter minerals in fluid inclusions from the deposit.

4. Mineralization

The history of mining at Qaleh Zari dates back more than 2000 years. At that time, mining reached only a shallow depth of 90 meters. Based on the observed old workings, the total ore mined in ancient times has been estimated to be about 900 000 tons.

Three main mineralized zones were identified in the area (Fig. 3). The NW part of the deposit (No. 1), which is associated with three major sub-parallel quartz veins, the SE portion (No. 3) and the central part (the main vein set - No. 2) (Fig. 3). Volcanic rocks are host to the veins in No. 1 and No. 3 zones, whereas Jurassic shales and sandstones are the host rocks to the No. 2 zone. Four main trends of faults and joints (NW-SE, NE-SW and N-S sets) are identified in the area. The NW-SE set is the oldest one and the main mineralization in the area is structurally confined to this set.

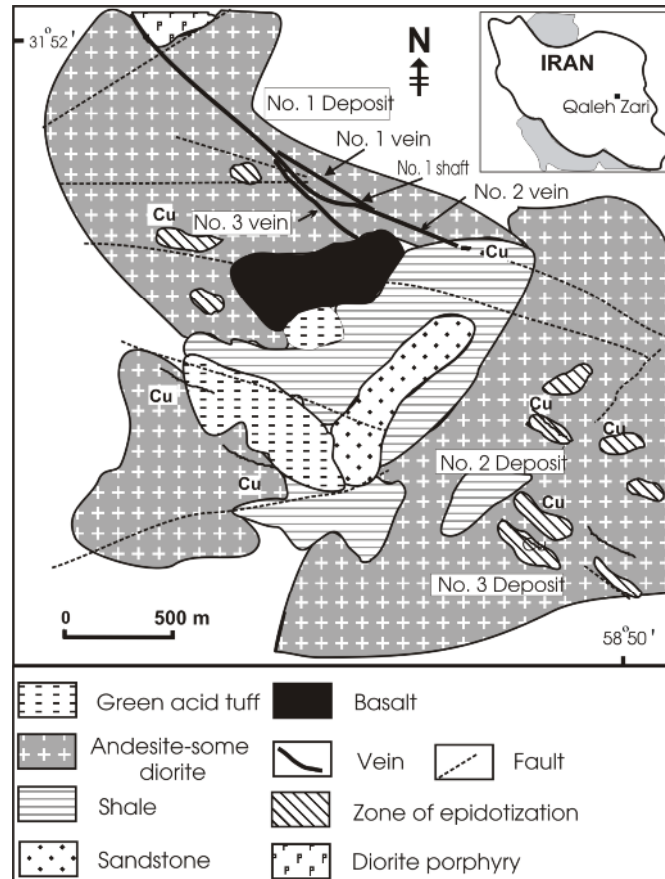


Figure 3 Geological map of Qaleh-Zari area, revised [11].

Mineralized Veins strike N 20° W to N 50° W and dip 70° to 90° NE (Fig. 3). Three major sub-parallel quartz veins are present. No. 2 vein is the main vein and can be traced for more than 3.5 km along strike (N40°W) and more than 350 m down dip (75° to 90° NE) (Fig.1). No. 1 vein is about 650 m long and No. 3 is less than 500 m long. Veins are in general very steep and dipping 70° to 90° NE. Textures, such as crustification, comb structures, symmetrical banding, cockade structure and cavities, which are indicative of open space filling, are present.

Quartz is the most common constituent in all of the veins, forming euhedral crystals, 1 to 10 cm long. The quartz veins and veinlets typically have hematite bands at the margins (Fig. 4). Hematite (specularite) makes up 10 to 25% of the veins and is the most abundant oxide after quartz. In all veins and veinlets, the general paragenetic sequence is: hematite followed by quartz–chlorite associations and finally chalcopyrite (Fig. 4).

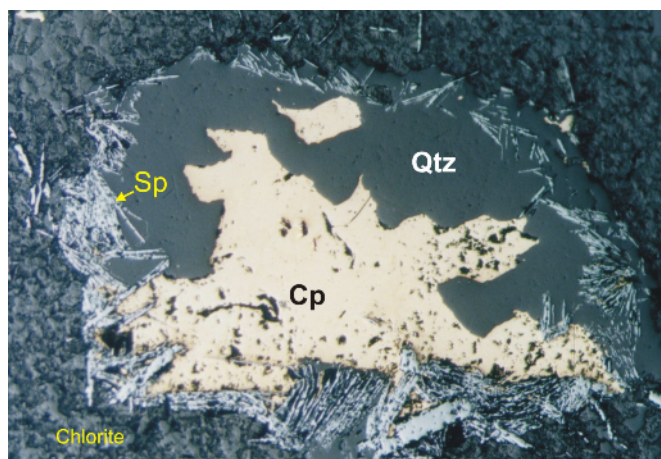


Figure 4 Paragenesis peculiarity (Sp), chlorite, quartz (Qtz) and chalcopyrite (Cp) in veins.

Propylitic alteration assemblages are very widespread in the Qaleh-Zari area. Epidote and chlorite are the two characteristic minerals of this assemblage. Epidote is very abundant and formed by alteration of plagioclase, pyroxene, and hornblende. Epidote is also abundant as veinlets filling the joints. Chlorite formed by alteration of mafic minerals or directly from the ore fluid within the vein (Fig. 4). Chlorites are generally Fe-rich types such as ripidolite with minor bronsvigite-pycnochlorite [10]. Argillic alteration is locally present. Silicification is mainly found within a zone adjacent to the veins.

The ore grade ranges between 2 to 9 wt% Cu, 100 to 650 ppm Ag and 0.5 to 35 ppm Au (Table 1).

Table 1 The average ore grade and width of veins [11].

| Vein | Depth (m) | Width (m) | Cu % | Au (ppm) | Ag (ppm) | Bi (%) | Pb (%) | Zn (%) | As (%) |
|------|-----------|-----------|------|----------|----------|--------|--------|--------|--------|
| 1 | 100-135 | 2.7 | 7 | 4.5 | 180 | N.A | N.A | N.A | N.A |
| 2 | 70 | 3 | 8.7 | 0.3 | 264 | N.A | N.A | N.A | N.A |
| 2 | 100 | 0.3 | 8.9 | 8.7 | 620 | 0.28 | 0.33 | 0.1 | 0.007 |
| 3 | 100 | 0.8 | 7.3 | 40 | 255 | 0.24 | 0.13 | 0.03 | 0.005 |

N.A= not available

On the basis of paragenesis and the temperatures of homogenization of fluid inclusions, the mineralization in the area can be divided into 4 stages as follows.

Stage I. comprises hematite (specularite), quartz, chlorite, and chalcopyrite, sulfosalt minerals, ± pyrite, and ± trace of galena (Fig. 5). Based on the fluid inclusion analysis, the temperature of the homogenization was determined as 380 to 290°C and the salinity was measured as between 5.0 and 3.0 wt % NaCl equivalent (Appendix 1).

Stage II. Comprises quartz, chalcopyrite, pyrite, chlorite, hematite, aikinite (with inclusions of Ag-rich sulfosalts, and intergrowths with galena), and some other types of sulfosalt minerals (Fig. 5). The temperature of the homogenization was determined as between 290°C and 230°C and the salinity between 4.0 and 2.5 wt% NaCl equivalent (Appendix 2).

Stage III. Comprises quartz ± pyrite ± chalcopyrite ± Ag-rich sulfosalts ± arcubisite ± galena (Fig. 5).

Stage IV. Comprises hematite, quartz, and ± calcite. Calcite is very abundant in the deposit No 3 (Fig. 5).

The temperature of homogenization of fluid inclusions for the third and fourth stages of the mineralization was determined as between 250°C and 180°C (Appendix 3). The salinity of fluid for this stage was between 2.3 to 1.3wt % NaCl equivalent (Appendix 3). The CO₂ content was measured by Laser Raman spectroscopy and it is less than 0.1 mole %.

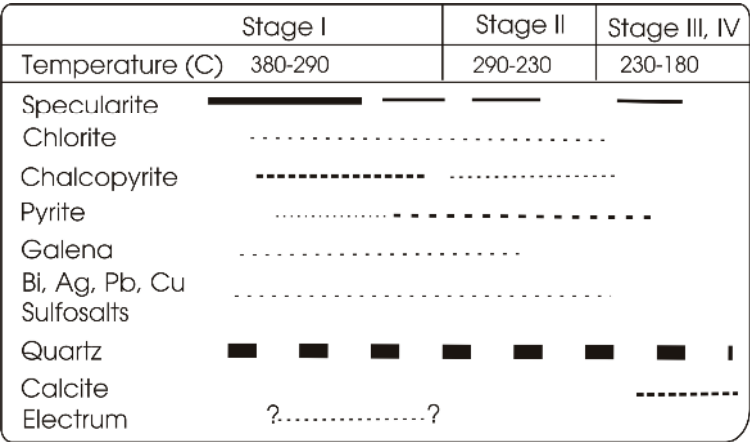


Figure 5 Mineral paragenese (hypogene) of the Qaleh-Zari Cu-Au-Ag deposit.

5. Comparison with iron oxides Cu-Au deposits

The apparent oxidized character and the Cu-Au metal assemblage of the Qaleh-Zari deposit has many similarities with other Cu-Au deposits commonly classified as part of iron oxide-hosted Cu-Au deposits [2, 3]. These deposits were classified into three groups [2]: (1) magmatic type (e.g. Palabora, Grasberg, and Bayanobo), (2) non-magmatic type which has two subtypes: and (3) hybrid or superimposed type (e.g. Yerrington, Candelaria).

Group two further is classified into two subtypes: (2a) coeval brines (e.g. Kiruna, Olympic Dam, Humboldt, Cortez), (2b) older brines (e.g. Salto, Korshunovsk). All of these deposits have moderate to high salinity. Fluid with high Cl and low S contents will develop iron-oxides Cu-Au deposit [2].

Qaleh-Zari is compared with other iron-oxides Cu-Au deposits (Table 2). Iron-oxide Cu-Au deposits are common in the coastal range of northern Chile [4, 12]. They are ranging from Early Cretaceous to Plio-Pleistocene. The largest deposits are formed in Cretaceous [13]. Candelaria and Punta del-Cobre are the best examples of iron-oxides Cu-Au deposits in South America. Candelaria is associated with Cretaceous diorite. Reserve plus production is 400 Mt of 1% Cu, with 0.2 g/t Au, 4.5 g/t Ag [13]. Locally they show signs of LREE, Zn and Mo concentrations. F and U are low [13] (Table 2). The hypogene minerals are magnetite, hematite (specularite), chalcopyrite, pyrite, and locally pyrrhotite-rich zones. Iron oxides are formed first and sulfide mineralization is later. Alteration assemblages from the central zone to outside are biotite + quartz, biotite + quartz + K-feldspar + chlorite, chlorite + albite + calcite + hematite.

Deposit with the most similarities to Qaleh-Zari is the Manto Verda deposit in Northern Chile (Table. 2). The Manto Verda copper deposit is a specularite-rich deposit [14]. This deposit is very similar to the Qaleh-Zari deposit. The only differences are: 1) the salinity of Manto Verda is between 32 to 56 wt % NaCl equiv., while Qaleh-Zari salinity has between 5.5 to 1 wt % NaCl equivalents (Fig. 6). Temperature of homogenization at Manto Verda reaches up to 450°C, whereas in Qaleh-Zari it is less than 370 °C (Fig. 6). The Manto Verda ore grade are, Cu less than 4 %, Ag 0.2 to 0.7 ppm, Au = 0.25 ppm, and very low Bi. Qaleh-Zari ore grades are Cu 4 to 8 %, Ag up to 620 ppm, Au 0.3 to 40 ppm, and Bi 2000 ppm (Figs. 7, 8).

The Qaleh-Zari deposit is similar to the detachment Au-Cu deposits of California (Picacho mine) and Arizona (Table 2). Qaleh-Zari has higher Cu content in comparison with Picacho mine (Figs. 7, 8). These deposits, which are associated with detachment faults (e.g. Picacho mine) [15], are veins characterized by quartz-hematite-chalcopyrite-pyrite mineral assemblages that commonly contain barite, fluorite and carbonate, and by textures indicative of open space filling. The ore fluids have had maximum temperatures between 200°C and 230°C (Table 2). The alteration mineralogy is characterized by chlorite with some epidote [15]. All of these characteristics are similar to Qaleh-Zari. Like the Manto Verda deposit, the most striking difference is the relatively low salinity of the Qaleh-Zari deposits (Fig. 6). Like Qaleh-Zari, the depositional mechanism for detachment Cu-Au deposits is interpreted to be fluid mixing along a detachment.

Table 2 Concentration of some minor and trace elements in Qaleh Zari compared with other IOCG deposits.

| Name of deposit | Hypogen Mineral Paragenesis | Th °(C) Salinity wt % NaCl eqv. | Cu% | Au (ppm) | Ag (ppm) | REE, P, U |
|---|--|--|---------|-------------|-------------|--------------------------------------|
| Qaleh-Zari Cu-Au-Ag Mine (Iran) | Specularite (10- 25%), chalcopyrite, quartz, sulfosalts, minor pyrite, gold, chlorite, calcite, epidote | 385-235 Salinity 1-5.8 | 2-9 | 0.5-35 | 40-650 | REE, P, U = low |
| Picacho Gold mine (California) [15] | Pyrite, gold, specularite, quartz, carbonate, chlorite | 201-226 Salinity 0.-0.7 | low | - 2 | low | REE, P, U = low |
| Candelaria Chile [13 & 16] | Specularite, Magnetite, chalcopyrite, pyrite, gold biotite, K-feldspar, quartz, calcite, anhydrite, albite | 195-340 Salinity 2.5-21 | 1-1.5 | 0.2-0.6 | 2-8 | LREE, U =locally high |
| Tennant Creek District (Australia) [17, 18, & 19] | Magnetite, hematite, chalcopyrite, pyrite, gold, sulfosalts, chlorite, calcite | 200- 550°C Salinity 10-50 | 0.3-4.5 | 0.8-50 | n.a | REE, P = n.a U locally high |
| Dongping Gold (China)[20] | pyrite, gold, sphalerite, calcite, Magnetite, specularite, galena, K-feldspar, chlorite, sericite, epidote | 195-340 Salinity 2.5-21 | n.a | 4-23 | low | n.a |
| Monto Verde (Chile) [14] | Specularite, chalcopyrite, pyrite, quartz, chlorite, magnetite, calcite | 180-320 Salinity 30-47 | 0.8 | 0.11 | 0.3 | REE local P= n.a U = low |
| Montecristo type (Chile) [12] | Specularite, chalcopyrite, minor bornite, magnetite, apatite, quartz, calcite, minor, molybdenite, uraninite, sphalerite, chlorite, albite | 300-400 Salinity n.a | 3-5 | Up to 50 | low | REE = n.a P = high U high |
| Olympic Dam [21, 22 & 23] | Magnetite, specularite, chalcocite, bornite, chalcopyrite, pyrite, chlorite | 130-280 Salinity 7-23 | 1.6 | 0.6 | 3.5 | REE = high P= low U = high |

n.a = not available

Productura Prospect is a good example, indicating that the petrochemistry of the magma is controls different types of iron-oxides Cu-Au deposits. Three episodes of alteration and mineralization are identified at the Productura Prospect which lies within the Chilean Iron Belt 15 km south-southwest of Vallenar [24]. The first episode of mineralization is a magnetite-apatite system, and is associated with dioritic rocks (130 Ma). The

second episode of mineralization is iron-oxide Cu-Au system. The third episode is hematite-gold system and is associated with granodiorite (96 Ma) [24]. Cu, Au, Fe, P, and other metals are originated from the magmas which occurred at about 130 and 96 Ma. Cu and Au did not leach from the country rocks, because if it was the case these elements could have leached at the time of diorite intrusion at 130 Ma.

According to Sillitoe [4], IOCG vein in the Coastal Cordillera showing upward zonation from magnetite to hematite domination, and the possibility of coarse calcite (\pm silver mineralisation) in its top parts and copper-poor massive magnetite at depth (Fig. 9). In this case Qaleh Zari is the middle part of an IOCG deposit.

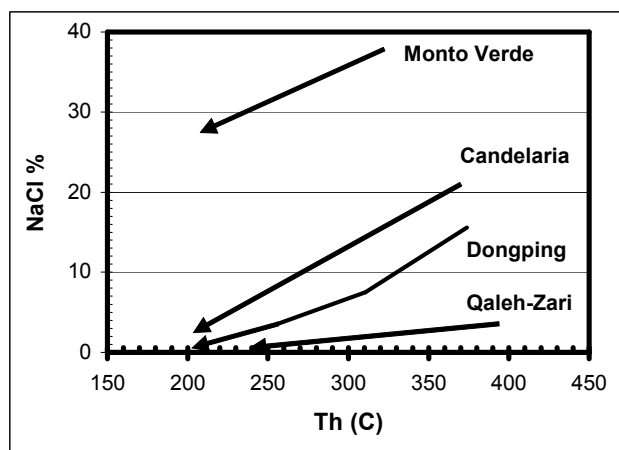


Figure 6. Plot of NaCl% versus Th (C) shows that Qaleh-Zari has the lowest NaCl% content in comparison with Monto Verde, Dongping and Candelaria [13, 14, 16, 20].

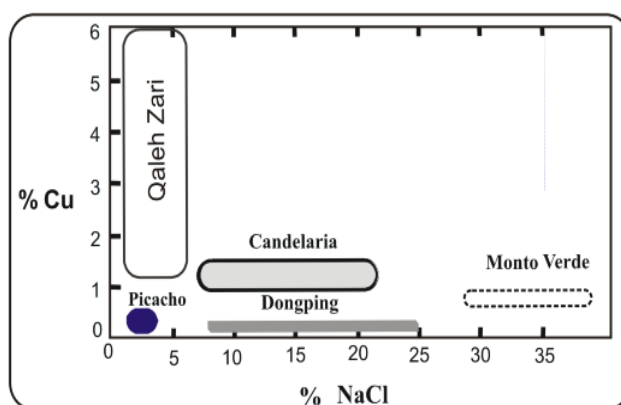


Figure 7 Plot of NaCl% versus Cu% for different types iron oxides Cu-Au deposits [13- 15, 17, 20].

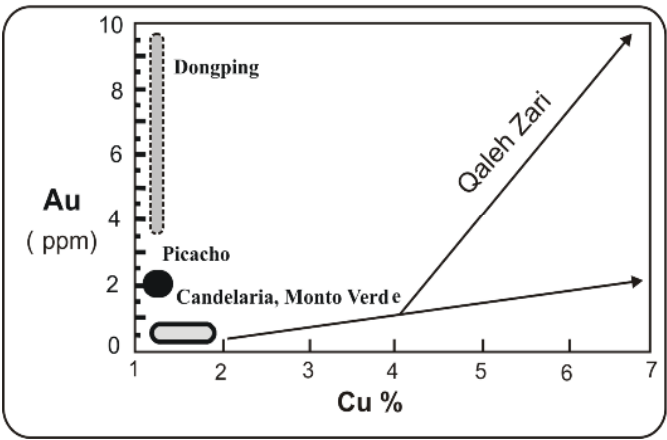


Figure 8 Plot of Au (ppm) versus Cu% for different types of iron oxides Cu-Au deposits [13-16, 20].

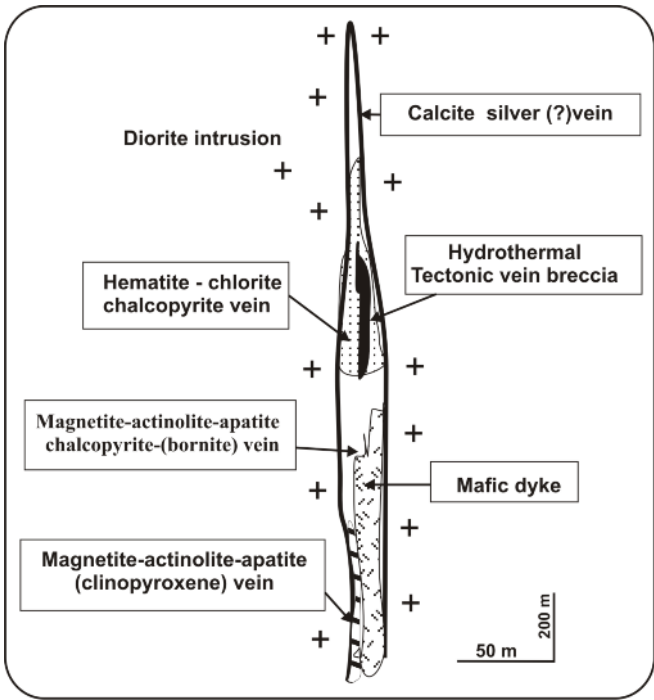


Figure 9 Idealised section of an IOCG vein in the Coastal Cordillera showing upward zonation from magnetite to hematite domination, and the possibility of coarse calcite (\pm silver mineralisation) in its top parts and copper-poor massive magnetite at depth [4].

The nature of magmatism and tectonic settings control different types of iron-oxides Cu-Au deposits (which are formed from a hydrothermal solution). Iron-oxides deposits typically are formed in continental arc and intra-cratonic tectonic settings [25]. The magmatic gold deposits were classified into five groups (Table 3) [26]. Qaleh-Zari deposit is similar to iron-oxides group. Each type of magmatic gold deposit has some kind of metal association. The differences in metal association are mainly controlled by the source of magma and amount of crustal contamination. For instance, both iron-oxides Cu-Au and the Au-Te-Pb-Zn-Cu types are highly oxidized. Both of them have iron-oxides minerals, but their metal association is different. The iron-oxides Au-Cu type is associated with highly oxidized calc-alkaline intrusive and the ore fluid have low in CO_2 and CH_4 . The Au-Te-Pb-Zn-Cu types are associated with alkaline intrusive rocks and the ore bearing fluid is rich in CO_2 and low in CH_4 . The highly oxidizing calc-alkaline magma (iron-oxides Au-Cu type) originates from partial melting of subducted oceanic crust at certain depth and conditions whereas the alkaline type magma (Te-rich Au-type) originates from a deeper source in the mantle. The Ryan Lode (Canada) Au deposit is a reducing type and the CH_4 content of fluid inclusion is 3-10 percent (Table 3).

Table 3 Comparison of Qaleh-Zari with other iron-oxides Cu-Au deposits.

| Deposits (Country) | Metal association & Type | Th $^{\circ}\text{C}$, % NaCl equi, CO_2 , CH_4 | Intrusive rocks | Hypogen Minerals |
|---|--|--|-------------------------------|--|
| Qaleh-Zari (Iran) | Fe-Cu-Au-Ag-Bi (Highly oxidized) (IOCG-Type) | Th = 250-375 Salinity = 1-5.5 Low CO_2 and NH_4 | Intermediate in the region | Hematite (specularite), chalcopryrite, gold, sulfosalts, pyrite, calcite |
| Montos de Punitaqui (Chile) Candelaria (Chile) | Fe-Cu-Au-(Hg) (Highly oxidized) (IOCG-Type) | Th = 123-375 Salinity = 0-4% Low CO_2 and NH_4 | Diorite | Hematite (specularite), chalcopryrite, gold, pyrite, magnetite, calcite, quartz |
| Dongping (China) | Au-Te-Pb-Zn-Cu (Highly oxidized) | Th = 240-350 & Salinity = 5-16% Th = 120-185 Salinity = 1-7% High CO_2 minor NH_4 | Alkali Syenite- Monzonite | Pyrite, specularite, calaverite (tellurium minerals), galena, sphalerite, chalcopryrite, magnetite, and quartz. |
| Snip (British Columbia, Canada) | Au-Cu-Mo-Zn (Oxidizing) | n.a | Quartz monzodiorite | n.a. |
| Paracop-Pataz District (Peru) | Au-As-Pb-Zn-Cu (Less oxidized) | Th = 130-320 Salinity = 4-25 Low CO_2 | Granodiorite- Monzogranite | Pyrite, arsenopyrite, sphalerite, chalcopryrite, quartz, and galena |
| Ryan Lode (Canada) | Au-As-Bi-Sb (Reducing type) | Th = 280- 350 Salinity = 0-8 % | Granite - granodiorite | Arsenopyrite, stibnite, sphalerite, scheelite, |

| | | | | |
|--|--|---|--|---|
| | | CO ₂ 12 % and NH ₄ 3- 10 % | | chalcopyrite, molybdenit, boulangerite, Pb-Bi sulfosalts, and quartz. |
|--|--|---|--|---|

n.a = not available, Th = temperature of homogenization

7. Conclusions

According to Barton and Johnson [2, 31], Haynes [33] and others, the ore bearing fluid in the system of iron oxides Cu-Au are saline- rich type (NaCl of ore bearing > %25) and halite is being leached from the sedimentary rocks. Fluid inclusion studies from Qaleh Zari Cu –Au deposit indicate that the NaCl of the ore fluid was < % 6. O and C isotopic data from calcite and quartz [27, 28] indicate that the ore bearing fluid at Qaleh Zari was originated from magma. The NaCl content of the magmatic fluid was low and did not originated from the sedimentary rocks.

The Qaleh-Zari Cu-Ag-Au deposit has several unique and important features such as: (1) high grade Cu-Ag-Au deposit (Fig. 8), (2) the ore fluid was very oxidizing as evidenced by the presence of abundant specularite, (3) so far no magnetite is being found in the area, (4) low pyrite content, and (5) moderate to high temperature with moderate to low salinities (Fig. 6).

When comparing Qaleh-Zari with other iron-oxide Cu-Au systems [1-3, 29-31], important differences are noticed: (1) the salinity of Qaleh-Zari fluid was much less than that of typical deposits of this type (Fig. 6), (2) the Qaleh-Zari deposit lacks magnetite and apatite, and (3) it contains low REE and P. Despite these differences, it is likely that the Qaleh-Zari deposit is a part of this clan of iron-oxide Cu-Au deposits.

Differences in the amount of Cu, Au, REE, P, U, F and some other elements in iron-oxides Cu-Au deposits are related to tectonic setting, depth of magmatism, source of magma, degree of partial melting, physio-chemical condition of melting, rate of ascending, crustal assimilation, degree of fractionation, and depth of emplacement. The iron-oxides Cu-Au deposits which are formed in the area of continental rifting usually contain La, U, Ce, P and REE.

It is very important to apply the IOCG model to locate the belt which Qaleh Zari is situated in. Along this belt other major IOCG deposits may be found.

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References

- [1] Jensen E. P., Barton M. D., *"Gold deposits related to alkaline magmatism"*, Reviews in Econ. Geol. 13 (2000) 279-314.
- [2] Barton M. D., Johnson D. A., Zurcher L., *"Phanerozoic iron-Oxide (-REE-Cu-Au-U) systems in Southwestern North America and their origins"*, Geological Society of Nevada Symposium (2000).
- [3] Hitzman M. W., Oreskes N., Einaudi M. T., *"Geological characteristics and tectonic setting of Proterozoic iron oxides (Cu-U-Au-REE) deposits"*, Precambrian Research 58 (1992) 241-287.
- [4] Sillitoe R. C., *"Iron oxide-copper-gold deposits: an Andean view"*, Mineralium Deposita 38 (2003) 787-812.
- [5] Lensch G., Schmidt K., *"Plate tectonic, orogeny, and mineralization in the Iranian fold belts results and conclusions"*, N. Jb. Geol. Palaont. Abh. 168, 2/3 (1984) 558-568.
- [6] Kluyver H. M., Griffiths R. J., Tirrul R., Chance P. N., Meixner H. M., *"Explanatory Text of the Lakar Kuh Quadrangle 1:250,000"*, Published by Geol. Surv. Iran (1978).
- [7] Sadaghyani-Avval F., *"Etude geologique de la region de la mine de Khali-Eh-Zari (Iran) mineralization et inclusions fluids"*, Ph.D theses, unpublished equipe de recherche aur les equilibrites entre fluides et mineraux, Universite de Nancy I. (1976) 165p.
- [8] Tarkian M., Lotfi M., Bauman A., *"Tectonic, magmatism and the formation of mineral deposits in central Lut, East of Iran"*, Geol. Survey of Iran, Rep. No. 57 (1983) p. 357-383.
- [9] Roedder E., *"Fluid Inclusions in Ribbe"*, P. Reviews in Mineralogy, MSA. V 12 (1984).
- [10] Karimpour M. H., Khin Z., *"Geochemistry and physicochemical condition of Qaleh-Zari Cu-Ag-Au ore bearing solution based on chlorite composition"*, Iranian Journal of Crystallography and Mineralogy 8 (2000) 3-22.
- [11] Suzuki Yuichi, Katsumi Ogawa, Niihito Akiyama, *"Copper ores from Qaleh Zari mine"*, Iran. Mining Geology 26 (1976) 385-391.
- [12] Espinoza S., Veliz H., Esquivel S., Arias J., Moraga A., *"The cupriferous province of the Costal Range, Northern Chile: Andean copper deposits"*, Society of Economic Geology Spec Publ. 5 (1966) 18-32.
- [13] Leveille R., Marschik R., *"Iron oxides copper-gold deposits in south America"*, International Geological Congress, Rio de Janeiro, Brazil, August 6-17 (2000).
- [14] Vila T., Lindsa, N., Zamora R., *"Geology of the Manto Verde copper deposit, Northern Chile. A specularite-rich, hydrothermal-tectonic breccia*

- related to the Atacama fault zone*", Soc. Econ. Geologist Special Publication No. 5, ed. by: Camus F., Sillitoe R.H., Peterson R., (1996) p.157-170.
- [15] Drobeck P, Hillemeyer F. L., Frost E. G., Liebler G. S., *"The Picacho mine: A gold mineralized detachment in Southeastern California"*, Arizona Geological Society Digest V. XVI (1986) pp. 187-221.
- [16] Marschik R., Leveille R. A., *"The Candelaria-Punta del Cobre iron oxide copper-gold deposits, Chile"*, Geological Society of America, Abstracts with Programs (1998) A-371.
- [17] Skirrow R. G., *"Gold-Copper-Bismuth Deposits of the Tennant Creek District, Australia: A Reappraisal of Diverse High-Grade Systems"*, ed. by: Porter T.M., *"Hydrothermal iron Oxide Copper-Gold & Related Deposits. A Global Perspective"*, Australian Mineral Foundation, Adelaide 1 (2000) 350.
- [18] Large R. R., *"Zonation of hydrothermal minerals at the Juno Mine, Tennant Creek Goldfield"*, Central Australia. Econ. Geol. 70 (1975) pp. 1347-1413.
- [19] Khin Z., Huston D. L., Large R. R., Mernagh T., Hoffmann C. F. *"Microthermometry and geochemistry of fluid inclusions from the Tennant Creek gold-copper deposits: implications for ore deposition and exploration"*, Mineralium Deposita 29 (1994) pp. 288-300.
- [20] Nie-Fengjun., *"Geology and origin of the Dongping alkaline-type gold deposit, northern Hebei Province, People's Republic of China"*, Resource Geology 48 (1998) 139-158.
- [21] Hodgkinson J., *"Olympic Dam-Expanding and Changing the Geological Interpretations of a Major Deposit and Its Implications"*, Technology-Australia's Future: New Technology for Traditional Industries, Academy Symposium, November (1998).
- [22] Haynes D., Cross K., Bills R., Reed M., *"Olympic Dam Ore Genesis. A Fluid-Mixing Model"*, in Econ. Geol. 90 (1995) pp. 281-307.
- [23] Oreskes N., Hitzman M.W., *"A model for the origin of Olympic Dam-type deposits. Mineral deposit modeling"*, Geological Association of Canada, Special paper 40 (1993).
- [24] Fox Kari A., Hitzman M. W., *"Superimposed magnetite and iron oxide-Cu-Au mineralization at Productora, Chilean iron"*, Geol. Soc. Am. Abstr. Programs 33: No. 6 (2001).
- [25] Pollard P. J., *"Evidence of a Magmatic Fluid Source for iron Oxide-Cu-Au Mineralisation"*, ed. By: Porter T.M., *"Hydrothermal iron Oxide Copper-Gold & Related Deposits: A Global Perspective"*, Australian Mineral Foundation, Adelaide, volume 1 (2000) 350.
- [26] Sillitoe R. H., Thompson J. F. H., *"Intrusion-related vein gold deposits: Types, tectono-Magmatic settings and difficulties of distinction from orogenic gold deposits"*, Resources Geology 48, 4 (1998) pp. 237-250.

- [27] Karimpour M. H., Khin Zaw, Huston D. L., *"S-C-O isotopes, fluid inclusion microthermometry, and the genesis of ore bearing fluids at Qaleh-Zari Fe-oxide Cu-Au-Ag mine, Iran"*, (2005) In press.
- [28] Hassan Nejad A. A., *"Geology and Geochemistry of Qaleh-Zari Cu Au-Ag deposit"*, Unpublished MSc thesis, University of Shiraz, Iran (1993).
- [29] Barton M. D., Johnson D. A., *"Evaporitic-source model for igneous-related Fe oxide-(REE-Cu-Au-U) mineralization"*, *Geology* 24(3) (1996) pp. 259-262.
- [30] Barton M. D., Johnson D. A., *"A comparison of Fe-oxide (Cu-Au-REE-U-Co-Ag) mineralization"*, Annual meeting abstracts with programs. Geological Society of America 29; 6 (1997) 51.
- [31] Barton M. D., Johnson D. A., Hanson R. B., *"Evaluation of possible roles of non-magmatic brines in igneous-related hydrothermal systems, especially Fe (-Cu-Au-REE) deposits"*, Annual meeting abstracts with programs, Geological Society of America 30; 7 (1998) 127.
- [32] Barton M. D., Johnson D. A., *"Evaporitic source model for igneous-related Fe oxide-(REE-Cu-Au-U) mineralization"*, *Geology* 24 (1996) pp. 259-262.
- [33] Haynes D. W., *"Iron oxide copper (-gold) deposits: their position in the ore deposit spectrum and modes of origin"*, ed. by: Porter T.M., *"Hydrothermal iron oxide copper-gold and related deposits, A global perspective"*, Australian Mineral Foundation, Adelaide (2000) pp 71–90.

Appendix 1 Temperatures of homogenization and salinities of primary fluid inclusions from stage I of mineralization (fluid inclusions in quartz are studied).

| Vein | Depth | Sample No. | Th°C* Range | Th°C Mean | T ice melting | Salinities** Range | Salinities Mean |
|------|-------|------------|-------------|-----------|---------------|--------------------|-----------------|
| 1 | 70 | R-30 | 310-376 | 343 | - | n.m | - |
| 1 | 100 | R-30 | 296-380 | 355 | -1.45 to -2.1 | 2.5-3.4 | 3 |
| 1 | 135 | R-100 | 300-335 | 315 | -2.4 to -3.3 | 3.9-5.5 | 4.2 |
| 1 | 170 | R-30 | 312-343 | 318 | -1.1 to -1.3 | 1.8-2.2 | 2 |
| 2 | 70 | R-30 | 280-357 | 350 | - | n.m | - |
| 2 | 100 | L-100 | 314-338 | 322 | -2.3 to -3.4 | 3.8-5.5 | 4.6 |
| 2 | 170 | L-50 | 301-347 | 310 | - | n.m | - |
| 3 | 70 | L-50 | 270-287 | 284 | - | n.m | - |
| 3 | 100 | L-50 | 298-324 | 309 | - | n.m | - |
| 3 | 135 | L-50 | 302-325 | 307 | - | n.m | - |

*Th=temperature of homogenization, **Salinities in wt % NaCl equiv, n.m.= not measured. . Sample location (meter) from shaft No.1 (R) to the right and (L) to the left.

Appendix 2 Temperatures of homogenization and salinities of primary fluid inclusions from Stage II of mineralization (fluid inclusions in quartz are studied).

| Vein | Depth | Sample No. | Th°C* Range | Th°C Mean | T ice melting | Salinities** Range | Salinities Mean |
|------|-------|--------------------------|----------------|--------------|---------------|-----------------------|--------------------|
| 1 | 170 | R-100 (qtz-py-het) | 200-270 | 245 | -2.8 to -3.2 | 4.5-5.2 | 4.9 |
| 1 | 170 | R-100 (qtz-py) | 287-298 | 295 | - | n.m | - |
| 1 | 170 | R-30 (qtz-py-ccp-het) | 282-304 | 303 | -1.2 to -1.5 | 2.2-2.5 | 2.3 |
| 2 | 170 | R-250 (qtz-py-ccp) | 177-235 | 230 | -1.2 to -2.1 | 2.3-3.4 | 2.9 |

*Th=temperature of homogenization, **Salinities in wt % NaCl equiv, n.m.= not measured. .
Sample location (meter) from shaft No.1 (R) to the right and (L) to the left.

Appendix 3 Temperatures of homogenization and salinities of primary fluid inclusions from stage III and IV of mineralization (fluid inclusions in quartz are studied).

| Vein | Depth | Sample No. | Mineral | Th°C* Range | Th°C Mean | T ice melting | Salinities** Range | Salinities Mean |
|------|-------|--------------------|---------|----------------|--------------|-------------------|-----------------------|--------------------|
| 2 | 100 | L-100 stage III | Quartz | 246- 256 | 254 | -1.1 to - 1.3 | 1.8-2.3 | 2.1 |
| 2 | 100 | L-50 Stage IV | Quartz | 188- 210 | 200 | - 0.9 to - 1.1 | 1.3-1.8 | 1.5 |

*Th=temperature of homogenization, **Salinities in wt % NaCl equiv. Sample location
(meter) from shaft No.1 (R) to the right and (L) to the left.