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Petrology and Geochemistry of Ophiolitic Host Rocks of Copper Mineralization in Dowlat Abad-Tang e Hana Area (Neyriz-Iran)

Pedram Attarzadeh[1*], Mohammad Yazdi[2], Mehrdad Karimi[3], Kamal Noori Khankahdani[3]

[1]Department of Geology, North Tehran Branch, Islamic Azad University, Tehran, Iran
[2]Department of Geology, Faculty of Earth Sciences, Shahid Beheshti University, Tehran, Iran
[3]Department of Geology, Shiraz Branch, Islamic Azad University, Shiraz, Iran
Email: *attarzadeh.pedram@yahoo.com

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Abstract

Dowlat Abad-Tang e Hana area is a part of Neyriz ophiolite zone, parallel to the Zagros thrust, SW of Iran. It is also a part of obduction thrusting belt over the edge of the Arabian continent during the late Cretaceous. Petrographic investigation indicates the main host rocks are harzburgite, dunite, pyroxenite, basalt, gabbro and pelagic marine sediments. The main magma type of this ophiolite complex is sub-alkaline. The geochemical data of analysed samples show depletion of Na and K, and enrichment in Ca. Copper mineralization in Dowlat Abad-Tang e Hana is hosted mainly in peridotite rocks. The mineralizations are vein type and are associated as copper carbonate (malachite and less azurite). The average of Cu grade is 2.3 wt%. The geochemical and mineralogical data show that the primary source of copper is ortho-magmatic (from ultra-basic rocks and ferro magnesium minerals), which later influenced by hydrothermal processes.

Keywords

Ophiolite, Copper Mineralization, Tang-e-Hana, Neyriz, SW of Iran

1. Introduction

Many researches show that ophiolite complexes are formed in different geotectonic positions [1] [2]. The Te-

*Corresponding author.

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thyan ophiolites in the Alpine-Himalayan orogenic system are exposed along curvilinear suture zones, bounding a series of continental fragments of Gondowana [3]. The Jurassic ophiolites in the Alpine-Apennine mountain belt in the west (**Figure 1**) commonly display MORB geochemistry [4] [5], while that Late Jurassic-Cretaceous ophiolites in the Taurid-Pontide (Turkey), Zagros (Iran), and the Himalayan mountain belts to the east show geochemical affinities characteristic of suprasubduction zone (SSZ) environments [3] [6]-[16]. The ophiolitic complexes along Bitlis-Zagros Suture Zone include: Baer-Bassit (Syria), Hataya, Kizildag, and Cilo (Turkey); Kermanshah, Neyriz and Esphandagheh (Iran) [17]-[19]. The ophiolites from Iran may be classified into two groups, the less abundant Paleozoic and the more abundant Mesozoic ophiolites [20]. Stöcklin (1974) [21] divided Iranian ophiolites into four groups: i) ophiolites of the Zagros; ii) ophiolites (coloured melanges) of north-west Iran; iii) ophiolites and coloured mélanges that mark the boundaries of the Central and Eastern Iranian microcontinent [23]; and iv) ophiolites at the northern foot of the Alborz range [22] [23]. Alavi(1991) used information from field relations to classify the Iranian ophiolites into three groups: i) the Proterozoic, which are present as isolated outcrops on the western edge of the central Iranian microcontinent (CIM), ii) the pre Jurassic, which are located within the Alborz Range to the north, and iii) the post-Jurassic, which are the most abundant. Neyriz ophiolite is located in western part of Zagros thrust zone which separates Sanandaj-Sirjan crystalline complexes and Zagros thrust belt [24]. The Zagros fold-and-thrust belt extends in a NW-SE direction from the Iranian-Turkish border to Gulf of Oman (**Figure 1**) [25] [26]. This still-active belt results from the collision of the Arabian and Eurasian plates during Cenozoic times and is one of the youngest continental collision belts within the Alpine-Himalayan orogenic system [27] [28]. The geodynamic evolution of the Zagros Belt is mainly related to the opening and closure of the Neo-Tethys Oceanic basin. A Late Permian rift episode led to the opening of the Neo-Tethyan Ocean between the Arabian and Iranian plates. The NE-dipping subduction of this oceanic branch beneath the Iranian continental margin [29], started in the Late Jurassic [30]. The obduction of the oceanic crust began in the Late Cretaceous and was accompanied by a diachronous emplacement of ophiolites on to the southern. Tethyan passive margin, which occurred during Santonian in Oman and Maastrichtian in NW Zagros [31].

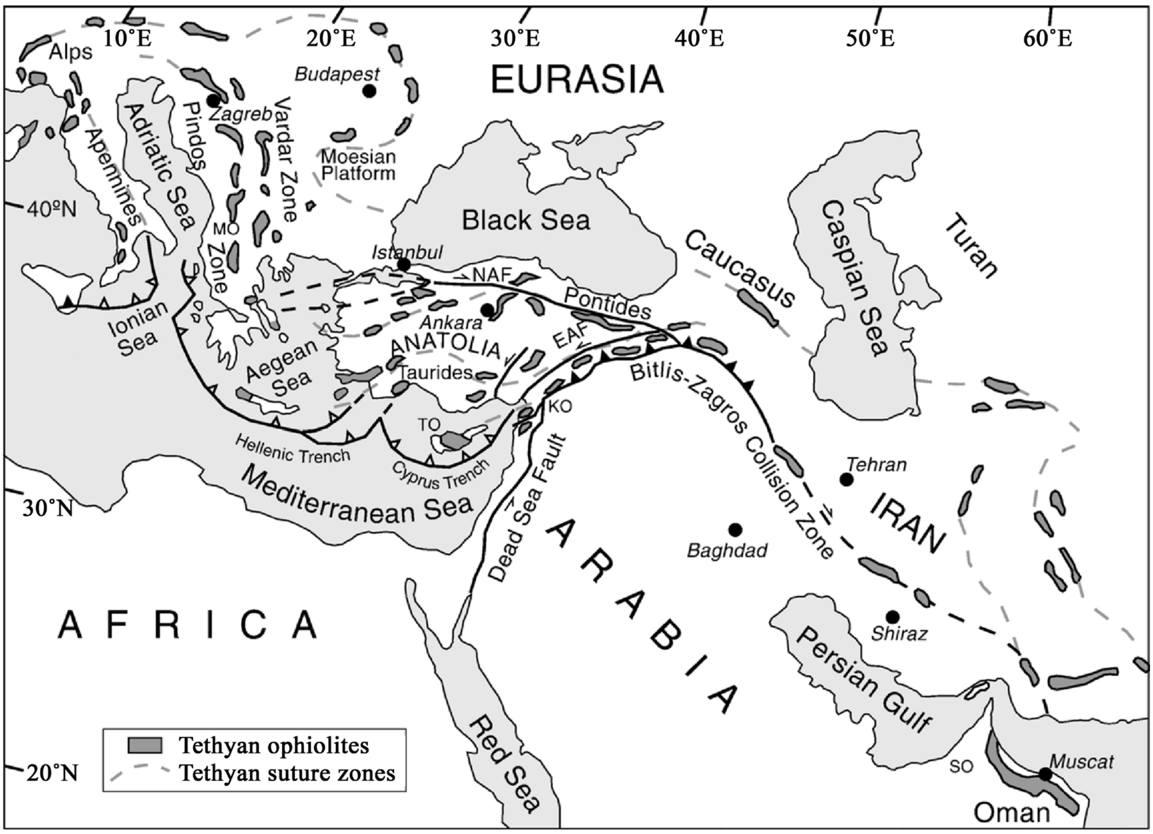

Figure 1. Simplified tectonic map of the eastern Mediterranean region showing the distribution of the Neotethyan ophiolites and suture zones [38].

The consumption of the Neo-Tethys and the associated continental collision are recorded by the southern Iranian ophiolites (Kermanshah, Neyriz) (**Figure 1**), which surface along the Main Zagros Thrust Zone [29] [32] [33]. In general ophiolite belt along the south-western Zagros main Zagros thrust divided into two parts as ophiolite-radiolarites of Kermanshah [34] and Neyriz [35] in the Fars [36]. According to spectrometry from biotite-bearing layers in garnet of amphibolite, related to mafic and ultramafic rocks of Neyriz ophiolite, primitive age of ophiolite replacement is middle Jurassic (170 Ma) and metamorphic stage was in last Cretaceous [37]. In this paper, we present results on petrology and geochemistry of the Neyriz ophiolite(Dowlat Abad-Tang e Hana). The goal of this paper is to use field data, petrographic analyses and geochemical data, to i) identify different lithologic units of this complex, ii) shed light on the geochemistry and petrogenetic processes of formation, and iii) suggest a possible tectonic environment of formation for this ophiolite.

2. Materials and Methods

2.1. Geological Setting

Iranian ophiolites are part of the Tethyan ophiolite belt of the Middle East. They join the Middle Eastern and Mediterranean Hellenides-Dinarides ophiolites (such as Turkish, Troodos, Greek and East European) to more easterly Asian ophiolites (such as Pakistani and Tibetan) [33]. The Neyriz ophiolite, found in a semi-arid environment along the Zargos thrust Zone, SW Iran, is a well-preserved part of the Tethyan oceanic lithosphere [39]. Neyriz ophiolite complex; is located in the north of the Neyriz city; it limits to the eastern Sanandaj-Sirjan zone, and the Bakhtegan Lake to west and the Zagros thrust to south. As structural division, studied area is a part of the high Zagros or crushed zone. An important feature of Zagros crushed zone is severity of deformation and also exposed ophiolite sequence. In the scope of the subject of this study (Dowlat Abad-Tang e Hana) (**Figure 2**), a series of Neyriz ophiolites observed; Three main ophiolite sections can be seen in this row: frequency of dunite and harzburgite and little chromite which forms the base of this Periodicity. Periodicity of webstrite, lherzolite, clinopyroxenite, olivine-webstrite and a little bit chromite in the middle part of the sequence, and in some articles referred to as the transition region. Section of gabbro is composed of and feldspar-bearing peridotites, from melagabro and norite gabbro, troctolite and anorthosite, respectively in the bottom part and in the middle section ferrogabbros, locogabros and finally in the end is composed of quartz and quartzdiorite and ferodiorite [40]-[43].

2.2. Analytical Methods

To evaluate the Eastern range part of Neyriz ophiolite complex (Dowlat Abad-Tang e Hana), after field surveying, the 84 samples selected from host rocks, trenches and wells logs. Thin sections of different rock-types were studied, achieving more information about the petrographic characteristics of the Dowlat Abad-Tang e Hana area. The sections gathered from harzburgite, dunite, chromitite, pyroxenite rock-types. Whole rock major elements of ultramafics and trace elements were determined by X-ray fluorescence (XRF) spectrometer. Also, these samples were analyzed by ICP-OES for REE and minor elements. The measurement results are presented in **Table 1** and **Table 2**.

3. Results and Discussion

3.1. Petrography

The main host rocks, according to their composition divided into several groups: peridotite, pyroxenite, gabbro, diabase dikes, basaltic rocks, radiolarites, serpentinite [44], small masses of metamorphic rocks, lumps of chromite and magnetite veinlets. The most extensive rocks in Neyriz ophiolite are dunite, harzburgite, pyroxenite, little lherzolite and with norite, gabbro, serpentinite and chromitites often with dunite host rocks and some harzburgite host rocks [45]. Serpentinite alteration of peridotite rocks with varying degrees (10% to 90% serpentine) has been made. The most abundant rock in the ophiolite complex of Dowlat Abad-Tang e Hana region is harzburgite [46]. Based on abundance of pyroxene, rocks can be divided into two main groups wich are harzburgite (homogeneous) and depleted harzburgite. Harzburgites composed of olivine (55% - 75%), orthopyroxene (30% - 35%), clinopyroxene (3% - 5%) and chrome-bearing spinel (3% - 5%). Depleted harzburgite also contain olivine (60% - 80%), orthopyroxene (15% - 20%), clinopyroxene (1% - 3%) and chrome-bearing spinel (less than 2%). It is believed that harzburgite is the result of increasing in degrees of partial melting in the upper mantle and by evolution of rock lherzolite is formed [47]. In the course of the deep zones to the upper part of ophiolite column, depleted harzburgite the rocks and metamorphic foliation intensity increased and the mineral alteration in the rocks decreases (**Figure 3**). In this rocks, spinel often forms amorphous to hypidiomorphic and can be seen both the crystalline and the inclusion in olivine crystals (**Figure 4** and **Figure 5**).

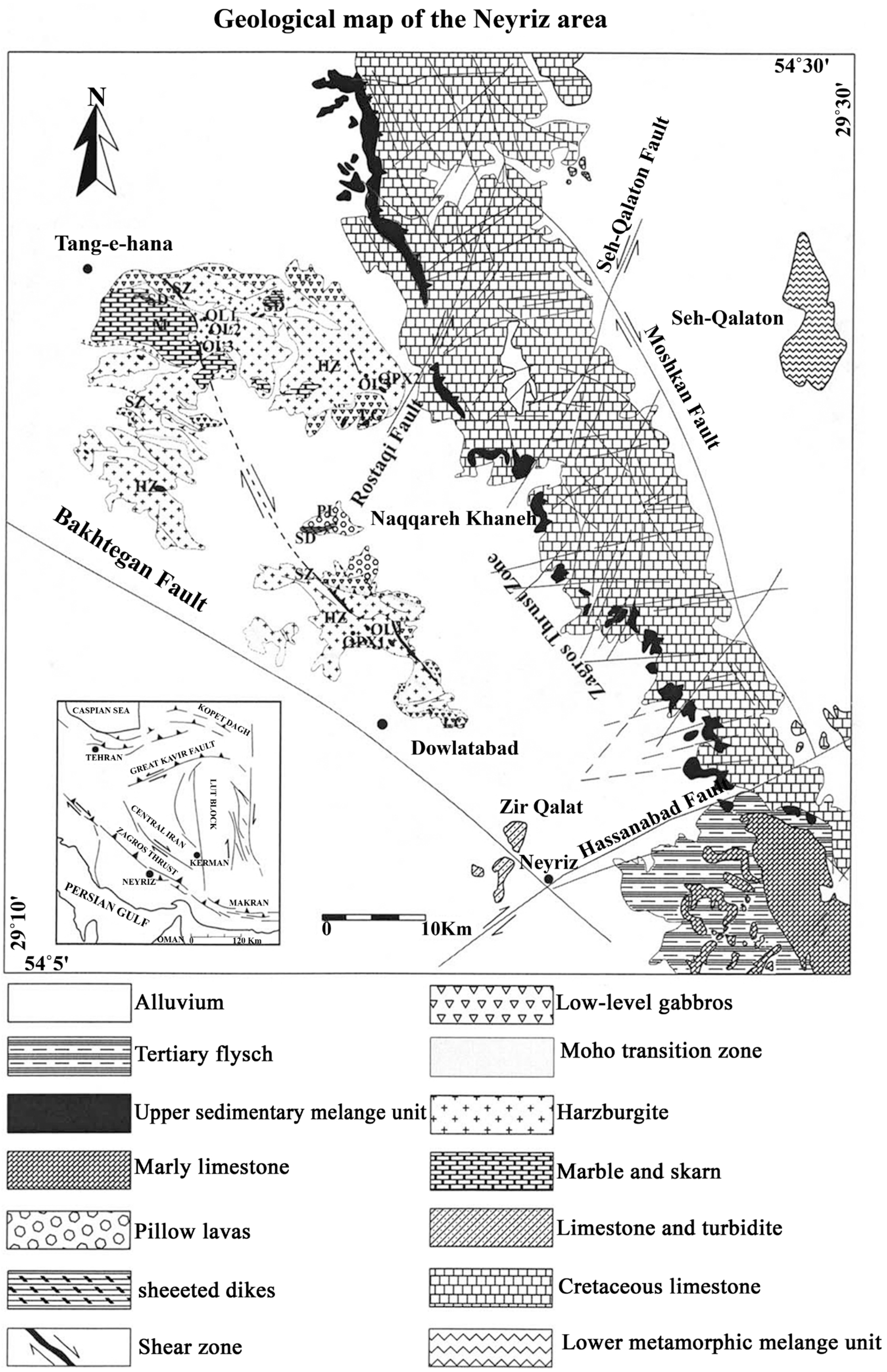

Figure 2. Geological map of Dowlat Abad-Tang e Hana area [39].

Table 1. ICP-OES analysis results of Dowlat Abad-Tang e Hana samples.

Element	Al	Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	Pb	S	Ti	Zn
Sample	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
D.T.1	4366	21,036	270	1891	24,251	98,575	327	28,483	5608	0.98	324	3409	28	447	53	742
D.T.2	9672	2144	19	64	4911	27,811	100	7946	163	0.99	153	38	6	1492	141	37
D.T.3	90,865	75,423	66	175	30,509	91,223	100	21,295	743	0.86	243	108	25	271	617	117
D.T.5	107,291	135,133	10	82	19,795	76,621	100	3104	814	0.93	195	15	16	566	298	72
D.T.7	14,493	1408	24	51	10,637	36,950	100	10,119	195	0.95	125	24	6	52	181	54
D.T.12	3505	43,526	112	1627	21,763	167,274	100	24,188	7536	0.87	251	1846	57	1200	45	491
D.T.16	35,554	5093	30	48	12,922	30,767	204	11,881	341	0.98	16,922	35	6	437	1417	72
D.T.28	9104	28,614	10	39	14,459	22,322	197	6841	302	1.06	291	43	5	187	74	411
D.T.40	9432	10,931	230	1908	37,142	49,581	100	30,719	549	0.78	181	2218	9	299	167	243
D.T.46	60,404	219,261	16	20	931	53,968	100	9310	1298	0.8	387	57	13	110	8133	26
D.T.71	1967	4019	26	43	26,258	48,476	100	285	41	7.2	211	8	7	318	95	106
D.T.73	15,127	2158	103	474	14,229	66,275	135	3440	376	12.8	252	83	11	322	1752	89
D.T.75	4553	1910	31	65	11,513	40,618	100	2314	182	7.9	195	29	6	235	294	50
D.T.115	5073	1515	927	1875	21,468	70,070	119	50,313	1069	0.86	211	1427	9	500	83	151
D.T.116	50,393	11,705	291	2606	94,376	116,640	-	28,758	233	6.11	-	369	40	5896	-	1216
D.T.118	13,001	157,444	172	2285	622	117,094	-	33,455	6615	1.19	-	1303	46	1544	-	106
D.T.119	8396	1302	125	3619	150,000	203,041	100	14,611	2196	1.2	228	2427	54	401	102	1448
D.T.121	14,055	53,528	151	2903	39,918	172,943	-	8890	764	1.43	-	1629	84	792	-	1527
D.T.122	67,635	1302	41	21	4720	203,041	33	19,534	1079	0.92	17,657	22	18	136	3834	81
D.T.124	-	19,143	101	311	10,537	84,923	-	12,536	417	0.8	-	109	25	173	-	119
D.T.126	70,987	54,979	21	59	119	64,956	5357	19,254	1126	0.9	18,522	26	6	81	7940	79
D.T.128	64,950	40,588	22	7	51	73,512	10,082	16,994	1137	0.85	22,048	10	6	115	10,091	76
D.T.129	87,994	36,241	22	11	66	61,858	-	12,538	762	0.95	-	10	10	74	-	92
D.T.130	71,614	60,120	22	22	46	69,690	5663	17,010	1390	0.84	20,021	15	7	109	9718	77
D.T.131	-	45,470	27	9	184	54,989	-	17,125	690	0.95	-	23	10	76	-	92
D.T.132	48,077	13,333	24	80	31,119	45,544	319	19,884	555	1	12,270	42	16	532	1804	146
D.T.133	48,122	4952	37	787	2081	31,072	-	18,856	262	1.1	-	189	6	195	-	100
D.T.134	11,378	3797	200	1324	51,226	65,641	-	41,043	520	1.1	-	1207	18	613	-	479
D.T.138	3860	7741	138	499	49,336	60,374	-	46,818	689	0.92	-	2186	17	245	-	354
Average	34,513.63	36,683.31	112.68	789.82	23,627.21	79,512.03	1171.8	18,536	1298.34	2.007	5808.57	651.96	19.55	600.62	2341.95	298.37
Sum	931,868	1,063,816	3268	22,905	685,189	2,305,849	23,436	537,544	37,652	58.22	110,687	18,907	567	17,418	46,839	8653
Max	107,291	219,261	927	3619	150,000	203,041	10,082	50,313	7536	12.8	22,048	3409	84	5896	10,091	1527
Min	1967	1302	10	7	46	22,322	33	285	41	0.78	125	8	5	52	45	26

Table 2. XRF analysis results of Dowlat Abad-Tang e Hana samples.

Element	SiO_2	Al_2O_3	FeO	Fe_2O_3	CaO	Na_2O	K_2O	MgO	TiO_2	MnO	P_2O_5	SO_3	LOI
Sample	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
1	39.73	0.35	8.38	1.5	0.77	0.02	0.01	37.97	0.003	0.166	0.001	0.001	10.38
2	40.22	0.42	8.36	1.5	0.97	0.01	0.02	36.86	0.003	0.162	0.002	0.002	10.54
3	38.25	0.27	7.34	1.5	0.53	0.01	0.01	39.15	0	0.164	0.002	0.001	10.94
4	40.21	0.48	6.34	1.5	0.8	0.01	0.02	38.23	0.001	0.154	0.002	0.002	11.58
5	40.11	0.26	7.81	1.5	0.65	-	0.03	39.2	0.003	0.156	0.001	0.002	9.43
6	40.11	0.51	7.01	1.51	0.75	0.01	0.01	38.45	0.005	0.166	0.002	0.001	10.63
7	37.85	0.58	9.55	1.5	0.96	-	0.01	38.85	0.002	0.169	0.002	0.002	9.82
8	39.52	0.34	6.3	1.5	0.73	0.02	0.01	32.55	0.003	0.151	0.001	0.002	10.74
9	37.71	0.45	8.33	1.5	0.87	0.01	0.02	38.66	0.001	0.163	0.002	0.001	11.23
10	40.67	0.38	7.28	1.51	0.91	0.01	0.01	36.75	0.004	0.149	0.001	0.001	9.91
11	27.3	0.82	11.51	2.8	0.29	0.01	0.01	17.48	0.009	0.211	0.001	0.003	2.14
12	10.64	0.34	9.89	1.1	0.99	0.001	0.01	17.58	0.004	0.171	0.001	0.003	1.86
13	15.15	0.36	5.43	1.04	0.33	0.02	0.01	24.82	0.007	0.133	0.001	0.001	5.33
Average	34.42	0.42	7.96	1.53	0.73	0.01	0.01	33.58	0.003	0.16	0.001	0.001	8.81
Sum	447.47	5.56	103.53	19.96	9.55	0.131	0.18	436.55	0.045	2.115	0.019	0.022	114.53
Max	40.67	0.82	11.51	2.8	0.99	0.02	0.03	39.2	0.009	0.211	0.002	0.003	11.58
Min	10.64	0.26	5.43	1.04	0.29	0	0.01	17.48	0	0.133	0.001	0.001	1.86

Figure 3. Out cropped harzburgites in Dawlat Abad area.

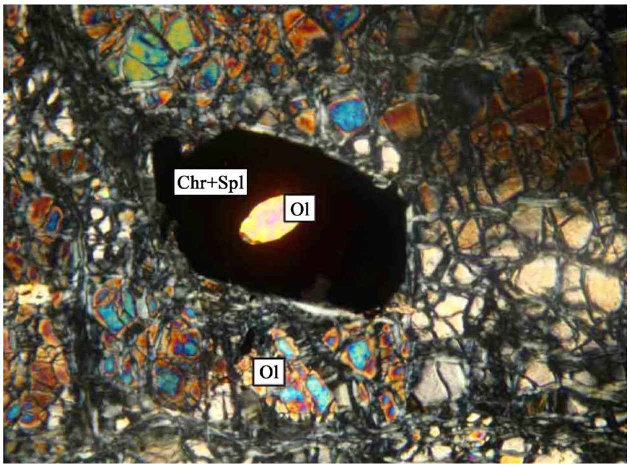

Figure 4. Olivine crystal in a Chromite Spinel (PPL × 200).

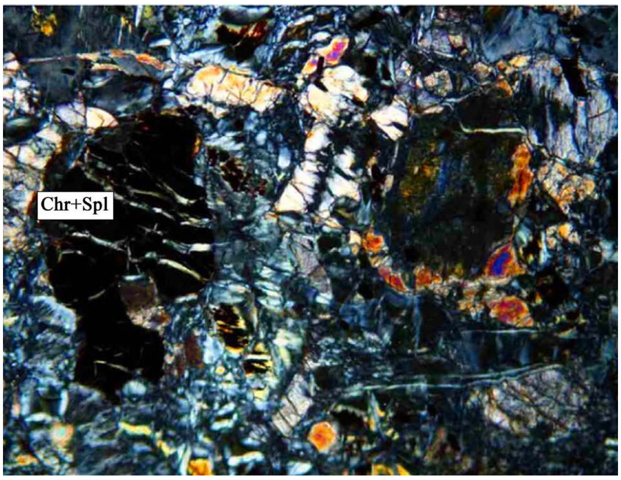

Figure 5. Chromite spinel thin sections (PPL × 200).

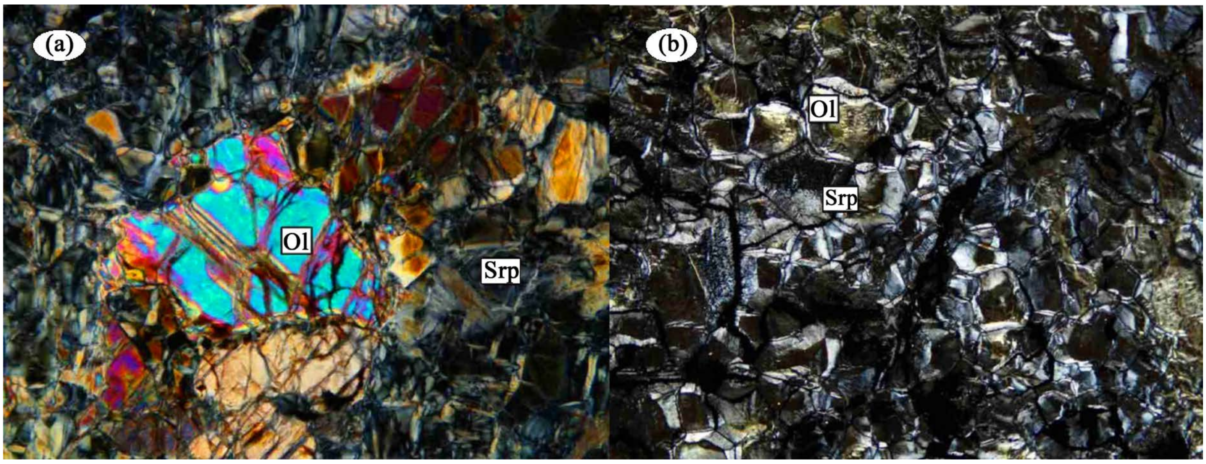

Figure 6. Photomicrographs of thin sections (a) Orthopyroxene thin section bearing dunite (PPL × 100); (b) Completely serpentinized (PPL × 40).

Amount of olivine in dunites increases to more than 90%. Orthopyroxene changes between 1-8% and chrome spinel between 1% - 2%. Clinopyroxene has been completely removed from this rock. Amorphous olivine crystals, sometimes they are hypidiomorphic and crystallized as aggregation and accumulation (**Figure 6(a)**). Intensity of serpentinized rocks are often very high and usually less altered olivine crystals settled in the field of lizardite (**Figure 6(b)**).

Orthopyroxenite rock composed of from 0% - 3% olivine, more than 95% orthopyroxene, 0% - 2% clinopyroxene and 1% - 2% chrome bearing spinel. Orthopyroxene crystal size in orthopyroxenites is much larger than lherzolite and harzburgite and some of them also extend to 3 mm (**Figure 7(a)**). However, such as the covering rocks, severe deformation can be seen in this rock as perceived texture in orthopyroxene crystal bar orthopyroxene, yet the minerals are in the same shape and size and the boundaries between crystals, have contact with three 120-degree angle which is an indication that orthopyroxenite units have produced from magma [48]. Orthopyroxenite is almost weathered and contain serpentine group minerals (not sepentinized). Gabbro is Mainly formed of calcium-rich plagioclase feldspar and augite clinopyroxene. Small amounts of olivine and orthopyroxene may also exist in these rocks. Plagioclase in a gabbro has poly synthetic. Plagioclase crystals can be seen as amorphous to hypidiomorphic, also clinopyroxene can be seen as large and semicrystalline crystals in large scale (**Figure 7(b)**).

3.2. Geochemistry

According to **Table 1**, MgO content is variable between 17.48 wt% to 39.2 wt%. Al_2O_3 content changes from

0.26 wt% to 0.58 wt% and CaO changes from 0.29 wt% to 0.99 wt% also CaO content decreases with the rise of serpentinization [49]. P_2O_5 content is subjected to CaO changes, because phosphorus in magma has a close relation to calcium. Fe_2O_3, MnO and TiO_2 content decreases in result of increasing the amount of SiO_2; this represents pyroxene and olivine crystallization from magma. Since the amount of mantle peridotites, Mg# is considered as an indicator to determine degree of partial melting or mantle depletion [50]; a high proportion of peridotites, Mg# in the region are expressing a high degree of partial melting [51] [52]. Given that serpentinization cause MgO values increase and CaO decreases, it is concluded that Neyriz peridotites are similar to magnesium serpentinized peridotites in the Alpine type ophiolites. In the case of partial melting of incompatible elements such as Al, Na and Ti are depleted, while compliant elements such as Cr and Ni do not change to the source. Ti depletion in rocks of the area is environmental characteristics of subduction and boninite ophiolite [53] [54]. Neyriz peridotites have lower Al_2O_3 content than adjacent ophiolite in Turkey and Iraq [55]. In addition to the low amount content of Al_2O_3, Neyriz ophiolites are also very poor in TiO_2. One of the resource depleted reasons is forming magma in subduction zones [56]. Looking at the chart Cr-Ni (**Figure 8**) can be concluded that the rocks chemical compositions of the area are within the tholeiitic and komatiietic basalts (rich in Mg).

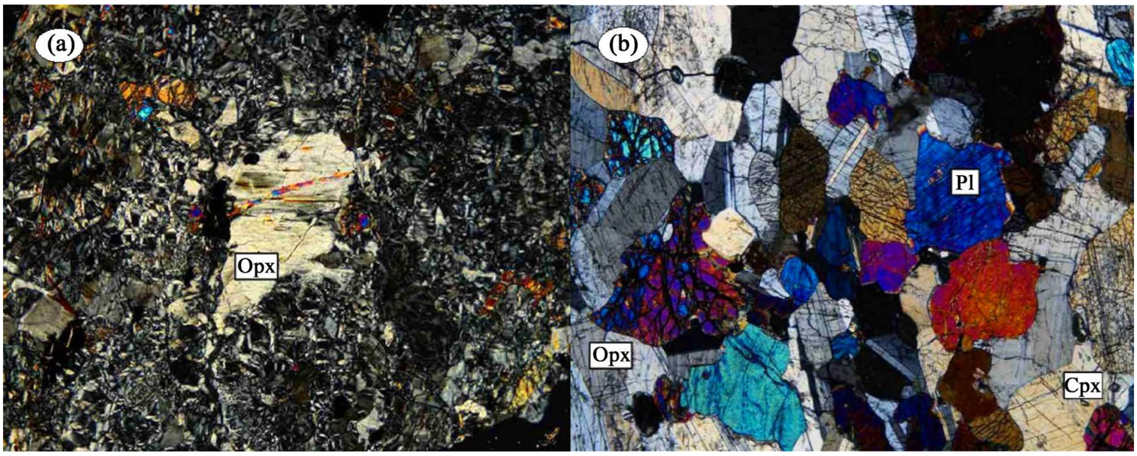

Figure 7. Photomicrographs of thin sections: (a) Orthopyroxene minerals; (b) Plagioclase, orthopyroxene linopyroxene in norite (PPL × 40).

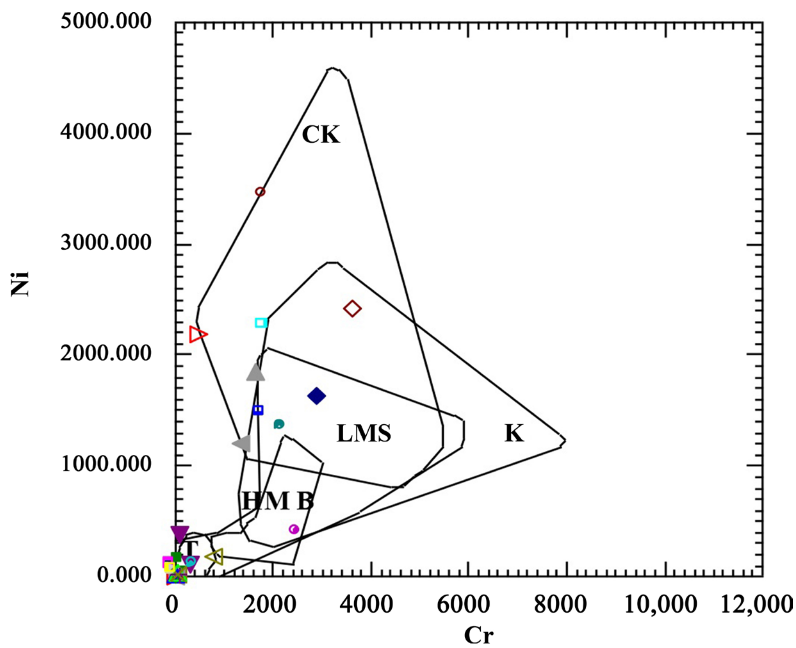

Figure 8. The composition of the rocks of the studied area in the diagram Ni/Cr [Rock *et al*. 1990].

K_2O, Na_2O and SiO_2 chart (**Figure 9**) presented the type of magmatic zone as sub-alkaline. Also, the Ti-Cr graph (**Figure 10**) indicates low-K tholeiite of this kind of magma in the region. Ca-K-Na graph (**Figure 11**) showing Na and K depletion in rocks and enrichment in Ca.

In this (**Figure 11**), basaltic rocks that contain calcium and sodium minerals are located in Ca-Na pole. This subject indicates that ophiolite complex is formed in a pre-arc subduction zone [59]. In such an environment in the presence of volatile substances by high-grade partial melting, boninitic magnesium-rich magma has formed. The elements such as Mg, Ni and Cr are abundant in the rocks which have produced from this magma. In addition, they are saturated or supersaturated of silica. Being rich in magnesium, abundance of volatiles and satura-

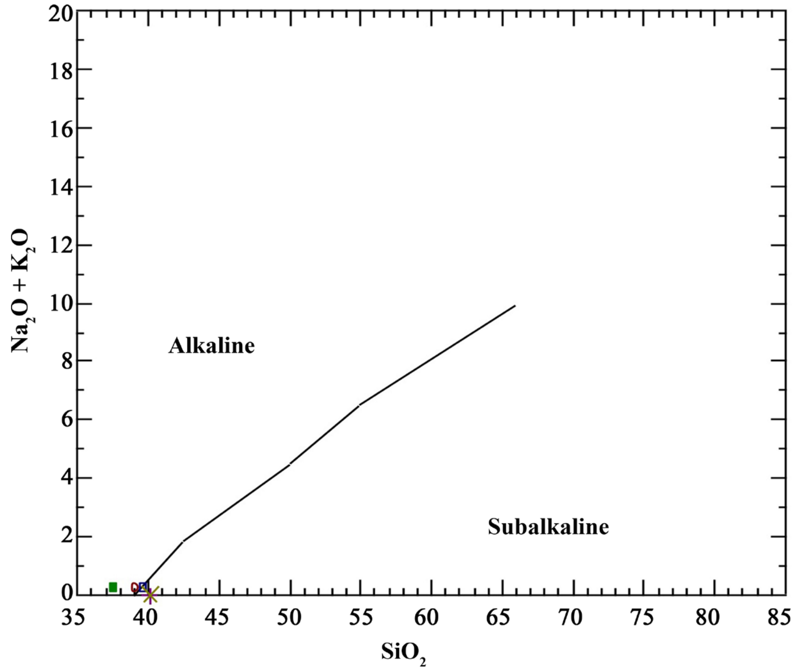

Figure 9. The distinction Naming diagram of basalt [57].

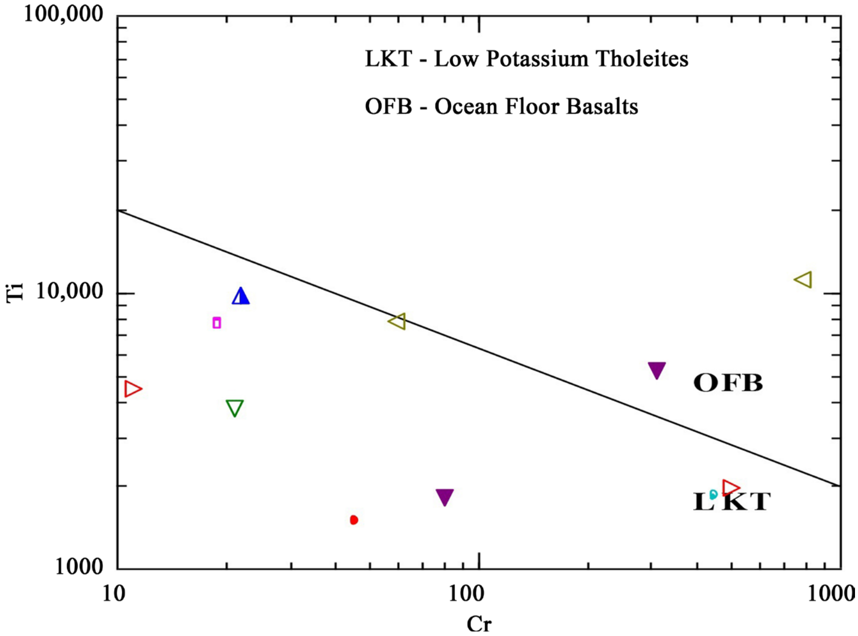

Figure 10. Log Cr-Log Ti [58].

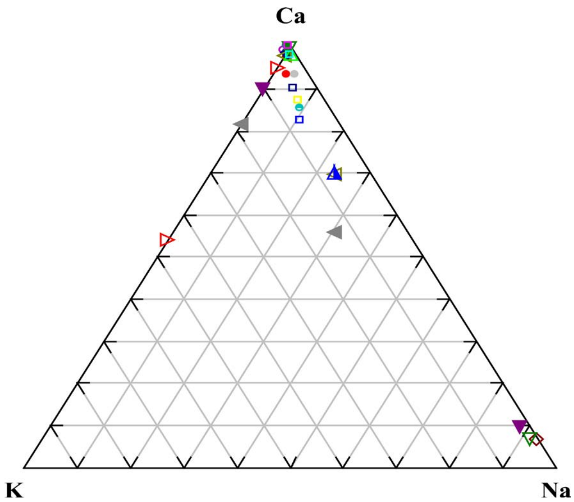

Figure 11. The ophiolite rocks in the study area in diagram of Na-K-Ca.

Figure 12. Silicification in Dawlat Abad area.

tion of silica may be contributing factors in the spread of silica and chlorite alteration and the presence of abundant silica and quartz masses in the study area. Along with copper mineralization within Dowlat Abad-Tang e Hana, there are high dispersion masses of silica and silicification alteration (**Figure 12**).

Extention of silica masses of the area cause acidic nature of altered fluid and as a result of destruction condition of silicate and ferromagnesian minerals, listonits are formed. Also these solutions cause copper washed out of primary copper minerals such as chalcopyrite and pyrite or supergene minerals, soluble copper in oxidation zone in presence of carbonate minerals cause to form malachite and azurite, which has spread throughout the region; among metals, copper shows supergene enrichment more significant than the other metals. Based on the ICP-OES analysis (**Table 1**), average copper cutie in the Dowlat Abad-Tang e Hana range reaches up to 2.3 by weight percentage.

In the other hand, the study area is situated in Zagros fold and thrust belt. From tectonics point of view, it contains orogenic belt of Arabian plate. Based on previous work on the salt and mud diapirism [60]-[74] and neotectonic regime in Iran [75]-[80], Zagros is the most active zone [81]-[101]. Then, Alborz [102]-[150] and Central Iran [151]-[168] have been situated in the next orders.

4. Conclusion

The rocks of the Neyriz ophiolite include both rocks of the mantle and of the crustal suite. The mantle rocks are peridotites (dunite and harzburgite) and serpentinite with minor chromitites. The crustal rocks are cumulate gabbros, diorites, pillow and massive basalts as well as asequence of fossiliferous pelagic sedimentary rocks including umber and radiolarian chert. Harzburgite is observed in the most part of the area (Dowlat Abad-Tang e

Hana) and occasionally accompanied with small dunite lenses. The major and trace-element geochemical results indicate that Neyriz ophiolite formed from sub-alkaline magma, tholeiitic-komatiietic type and low in K, Na and Ca-Mg-rich. This type of magmas is typical for subduction zone. Ti depletion in rocks of the area is environmental characteristics of subduction and boninite ophiolite. These characteristics are similar to other Tethyan ophiolites along the seam suture zone-Zagros (Bitlis-Zagros suture zone) are exposed. Mg-rich magma and the abundance of volatiles and saturation of silica made pervasive serpentinization, silica and chlorite alteration in the region. The hydrothermal processes were destructed ferromagnesian minerals of ultramafic host rocks and make fair conditions for Cu-mineralization. Although the Cu-mineralization average is high but it does not seem economic deposit.

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