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Geochemistry of Chromitites in Eastern Part of Neyriz Ophiolite Complex (Southern Iran)

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Abstract

The Neyriz ophiolite complex is a part of NW-SE thrust belt (Late Cretaceous) of Iran, which is over the Arabian plate margin. The complex is mainly composed of the upper mantle rocks. Our research was focused on the eastern part of Neyriz ophiolite complex so called as "Dowlat Abad-Tang e Hana". Mantle sequence of this ophiolitic complex is comprising predominantly of harzburgite and minor lherzolite, dunitc sheaths and chromite pods. Harzburgite is the most abundant ultramafic rock and is associated with the less dunite masses. The chromites are known with Cr# 42 to 76 and Mg# 73 to 89. There is a negative correlation between Cr#-Mg# which is one of the features of podiform chromites. The geochemistry of these chromites is consistent with the overall composition of podiform chromites in terms of Cr#, Mg#, the amounts of Cr_2O_3 (13.35% - 54.47%), Al_2O_3 (0.43% - 8%), MgO (13.25% - 38.56%), TiO_2 (0.003% - 0.206%) as well as the correlations between various oxides and all of them are high chromium types.

Keywords

Ophiolite, Podiform Chromite, Neyriz, Iran

1. Introduction

Many researches show that ophiolite complexes are formed in different geotectonic positions [1] [2]. The Tethyan ophiolites in the Alpine-Himalayan orogenic system are exposed along curvilinear suture zones, bounding a series of continental fragments of Gondwana [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

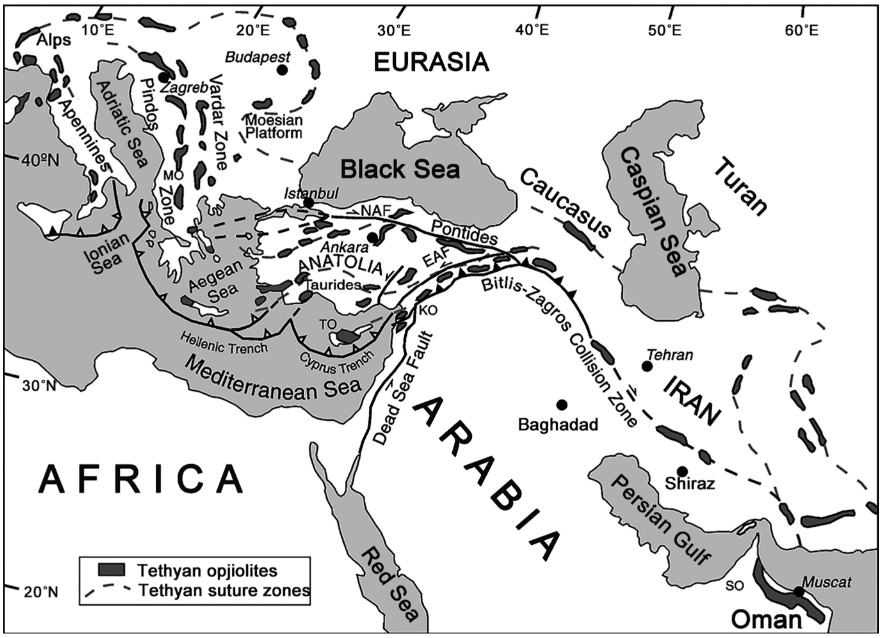

Figure 1. Distribution of Tethyanophiolitic rocks in Alpine-Himalayan orogenic belt [34].

geochemical affinities characteristic of supra subduction zone (SSZ) environments [6]-[15]. The ophiolitic complexes along Bitlis-Zagros Suture Zone include: Baer-Bassit (Syria), Hataya, Kizildag, and Cilo (Turkey); Kermanshah, Neyriz and Esfandagheh (Iran) [16] [17] [18]. Neyriz ophiolite is located in western part of Zagros thrust zone which separates Sanandaj-Sirjan crystalline complexes and Zagros thrust belt [19]. The Zagros fold-and-thrust belt extends in a NW-SE direction from the Iranian-Turkish border to Gulf of Oman (**Figure 1**) [20] [21]. This still-active belt results from the collision of the Arabian and Eurasian plates during Cenozoic and is one of the youngest continental collision belts within the Alpine-Himalayan orogenic system [22] [23]. 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 [24] started in the Late Jurassic [25]. Chromites origin and their formation tectonic environment is a considerable discussion in geology [26]. Chromite, (Mg, Fe^{2+}) (Cr, Al, $Fe^{3+})_2O_4$, is a member of the spinel mineral series and it is usually found in mafic and ultramafic rocks as a rare mineral (approximately one percent) [27]. Chromite accumulates in mafic and ultramafic rocks in two forms: 1) As layers with different thickness and extent in mafic and ultramafic rocks in the continental crust, e.g. Bushveld complex in South Africa [28] and Stillwater complex in America [29]; 2) As podiform chromites in mafic and ultramafic rocks of ophiolite sequences. Chemical composition of chromite shows composition of the primary magma [30] [31]. In terms of chemical properties, chromite minerals existed in ophiolite series are divided into two groups: chromites with high Cr number (Cr# =100* Cr/Cr + Al) (Cr# > 70); and chromite with low Cr number (Cr # < 70). It is believed that the first group of chromites are formed in supra subduction zone as a result of boninite magma ascent and the second group are produced from a tholeiitic magma in an arc tectonic setting of an arc magma [32] [33]. The present paper is aimed to study mineralogy, geochemistry of chromites formed in the Eastern part of Neyriz ophiolite (Dowlat Abad-Tang e Hana).

2. Geological Setting

Iranian ophiolites are part of the eastern Tethys, that are important due to the unique geographic location joining the middle east and other Asia ophiolites (e.g. Pakistan and Tibet) to the Mediterranean and Carpathian ophiolites (e.g. Troodos, Greek and Eastern European) [11] [35]. 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 [36]. Neyriz ophiolite is located in western part of Zagros thrust zone which separates Sanandaj-Sirjan crystalline complexes and Zagros thrust belt. These ophiolites are remnants of the young Tethys oceanic crust and start from Tarus in Turkey and continue to Oman [37] [38]. 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 [39]. However, Neyriz ophiolite massifs were emplaced in Late Cretaceous because these ophiolites are covered by the Late Cretaceous Tarbur formation by discontinuities [40]. The Dowlat Abad-Tang e Hana is mainly formed of tectonized harzburgite, dunite with podiform chromitite, pyroxenite and crustal sequence e.g. basalt, gabbro and pelagic marine sediments with chert and radiolarite [41] [42] [43] [44] [45]. Magnetite veins and veinlets are also found in dunite and harzburgite (**Figure 2**).

3. Materials and Methods

Whole major oxides and elements of host rock and chromite ore were determined by a wavelength dispersive, Philips PW1480 4 PW X-ray fluorescence spectrometer (XRF) at the geochemistry laboratory of Kansaran-E Binalud Company (Tehran) utilizing by a side-window rhodium target X-ray tube. All analyses were made against standard calibration curves which were prepared using a set of USGS reference standards. Analyses of the major elements were conducted on fused glass disks. The disks are prepared using nine parts lithium borate flux and one part rock powder. The melted samples were poured into a preheated platinum mold and then chilled in order to form into a thick glass disk. The results obtained from chemical analysis of the samples are given in **Table 1**.

3.1. Petrography

The most extensive masses of ophiolite rocks in Dowlat Abad-Tang e Hana in-

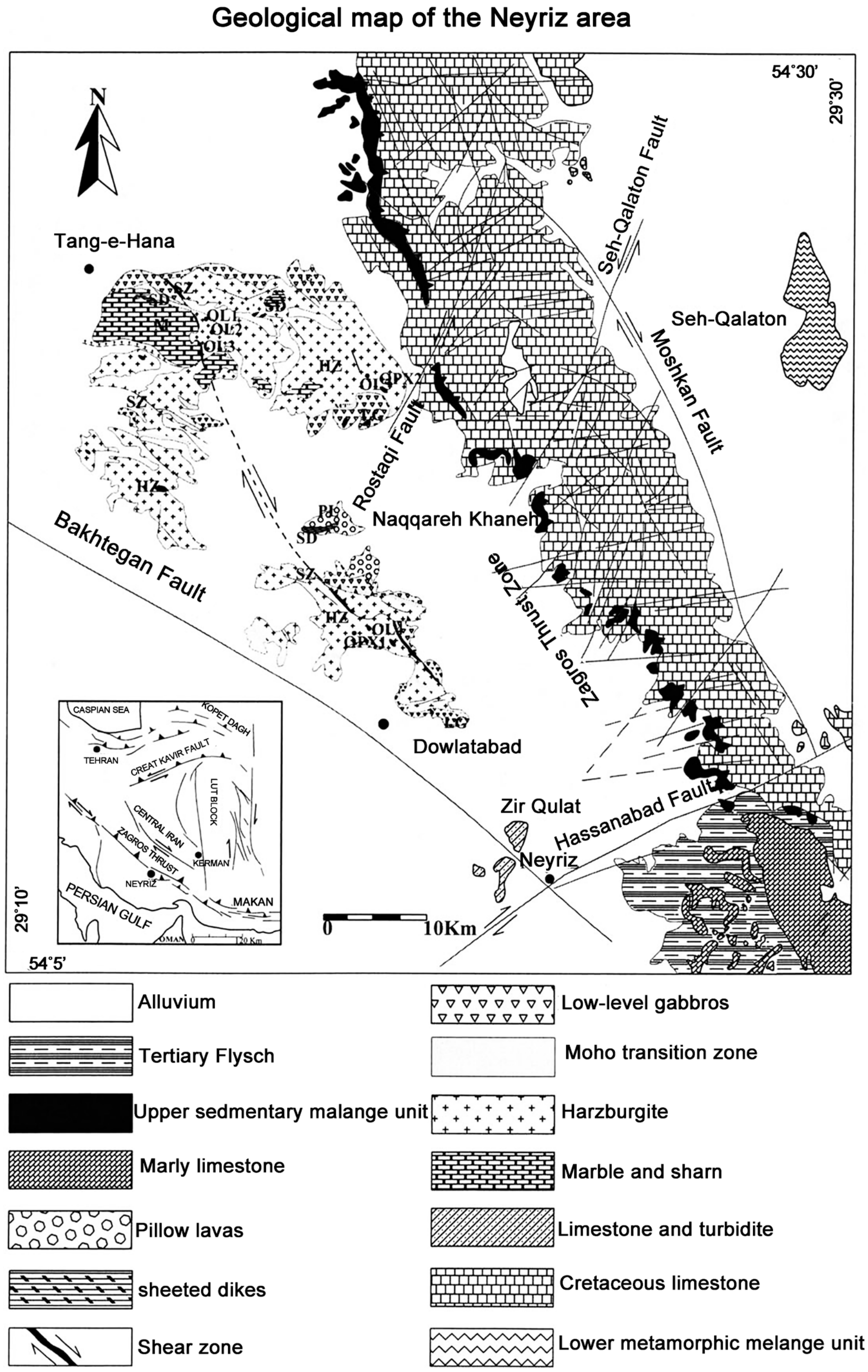

Figure 2. Geological map of Dowlat Abad-Tang e Hana area [36].

clude that mantel sequence containing: harzburgite, dunite, pyroxenite with chromitite, and crustal sequence including basalt, minor gabbro and pelagic sediments [46] [47]. In almost cases serpentinization has been developed along fractures of the rocks. Given that serpentinization is abundant in ultrabasic ophiolite rocks [48] [49], serpentinite alteration of peridotite rocks has occurred in varying degrees (10% - 90% serpentine) in the area [50]. Dunite is the most serpentinized rocks between the mantle peridotites. Harzburgite and serpentini-

Table 1. The results of chemical analysis of chromite ore Dowlat Abad-Tang e Hana area.

Element	SiO_2	Al_2O_3	CaO	Fe_2O_3	FeO	K_2O	MgO	MnO	Na_2O	P_2O_5	TiO_2	Cr_2O_3
Unit	Wt%	Wt%	Wt%	Wt%	Wt%	Wt%	Wt%	Wt%	Wt%	Wt%	Wt%	Wt%
D.T.1	1.5	5.4	0.05	3.48	17.67	0.02	14.56	0.307	0.02	0.02	0.086	54.34
D.T.2	2.87	4.47	0.05	3.3	16.77	0.03	13.82	0.305	0.02	0.02	0.087	54.47
D.T.3	2.94	5.57	0.1	3.74	18.9	0.02	13.25	0.303	0.03	0.02	0.197	51.87
D.T.4	25.07	0.58	0.04	2.01	10.21	0.01	32.11	0.194	0.02	0.02	0.04	16.5
D.T.5	5.8	3.3	0.05	3.33	16.87	0.02	16.53	0.322	0.01	0.001	0.094	46.88
D.T.6	10.11	2.64	0.13	2.95	14.95	0.01	20.44	0.289	0.01	0.02	0.094	41.62
D.T.7	9.55	6.38	0.36	3.27	16.56	0.02	17.18	0.278	0.02	0.02	0.147	41.72
D.T.8	5.86	3.77	0.05	3.71	18.8	0.02	15.16	0.374	0.02	0.001	0.122	47.49
D.T.9	38.53	0.43	0.56	1.41	7.17	0.02	38.56	0.169	0.02	0.02	0.003	41
D.T.10	26.32	0.75	0.16	1.69	8.6	0.01	35.46	0.159	0.03	0.003	0.033	13.35
D.T.11	14.26	5.95	4.71	3.67	18.5	0.01	14.56	0.308	0.01	0.02	0.206	35.07
D.T.12	19.45	1.24	0.18	2.19	11.12	0.02	30.02	0.228	0.03	0.002	0.074	25.98
D.T.13	6.52	3.4	0	3.5	17.75	0.02	17.17	0.333	0.03	0.02	0.094	46.79
D.T.14	6.4	8	0.22	3.69	18.75	0.01	15.22	0.312	0.03	0.02	0.059	42.31
D.T.15	9.5	3.63	0.33	3.34	16.94	0.01	19.14	0.343	0.02	0.01	0.084	41.75
D.T.16	12.16	3.3	0.05	3.51	17.78	0.02	20.22	0.309	0.02	0.02	0.151	37.39
Average	23.15	3.69	0.44	3.049	15.45	0.016	20.83	0.28	0.021	0.014	0.098	39.90

zed harzburgite are the most abundant ultramafic rocks in this area [50] [51]. Harzburgite, including olivine and orthopyroxene (**Figure 3(a)**). Dunites include olivine, pyroxene and chromite spinel (**Figures 3(b)-(d)**) which have been severely broken and crushed as a result of tectonic stress and tensile fractures caused by serpentinization process [46]. Due to alteration, dunites and pyroxenites have been severely serpentinized, called "serpentinit", since their most abundant and detectable mineral is serpentine (**Figure 3(e)**). Lherzolites of the area mainly consist of olivine, clinopyroxene and chrome spinel, which is considered as a minor mineral. Due to the less amount of olivine, these samples often show less serpentinization than harzburgites. Crystals of olivine and clinopyroxene are located within porphyroclasts orthopyroxene in the form of entries (**Figure 3(f)**). Pyroxenite is made up of pyroxene and a little plagioclase (**Figure 3(g)**). Gabbro is also made up of a set of orthopyroxene, clinopyroxene, plagioclase and olivine (**Figure 3(h)**). The main minerals of chromitites are chromite and olivine (serpentine), which generally have leopard skin texture.

3.2. Geochemistry

The weight percent of Cr_2O_3 content in Chromites of east Neyriz area is 13.35 - 54.47. Drastic changes in Cr_2O_3 content in one of the features of podiform chromites [52]. The amount of Al_2O_3 of these chromites varies in weight percent from 0.43 - 8 and these values reflect the depletion Al_2O_3 in the chromitites of

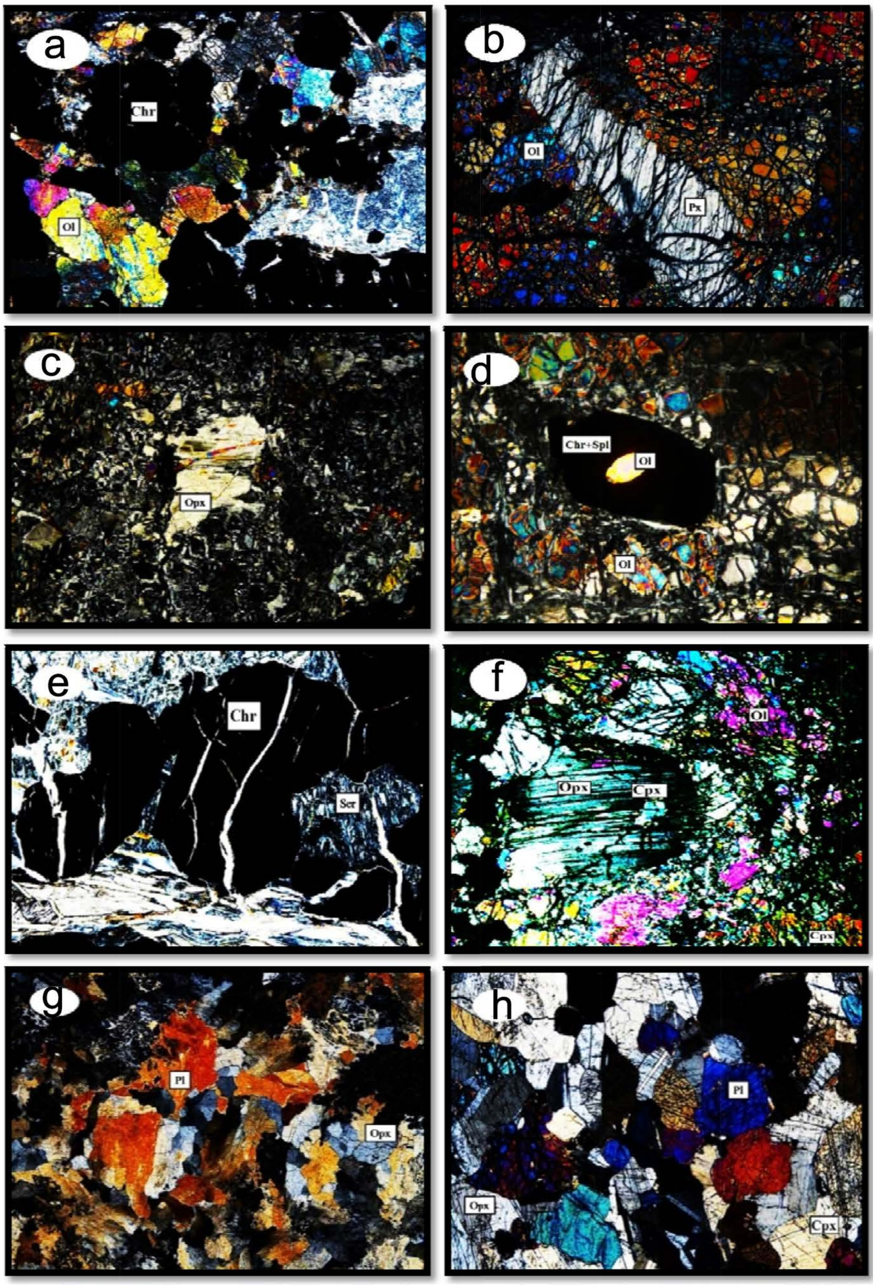

Figure 3. (a) Harzburgite with chromite; (b) Dunite containing olivine and pyroxene; (c) Serpentinizeddunite containing orthopyroxene; (d) Dunite containing olivine and chromite spinel; (e) Chromite with serpentine; (f) Clinopyroxene crystals in lherzolite having king band; (g) Norite with Orthopyroxene and plagioclase minerals; (h) Plagioclase, orthopyroxene and clinopyroxene in gabbro.

this area. The weight percent of MgO in chromites of this area is in the range of 13.25 - 38.56. With regard to the content of Cr_2O_3 and Al_2O_3 in podiform chromitite compounds, they are divided into two types, namely High-Cr (Cr_2O_3 = 45% - 60%) and High-Al (Al_2O_3 > 25%). According to Table 2, chromitites of Dowlat Abad-Tang e Hana area are known with Cr# of 42 to 76 and Mg# of 73 to 89. Considering the Cr_2O_3 content of chromites of Dowlat Abad-Tang e area

Table 2. Cr# and Mg# in the chromite ore of Dowlat Abad-Tang e Hana area.

Element	Al	Cr	Fe	Mg	Cr#	Mg#
D.T.1	0.18	0.313	0.533	1.49	63	74
D.T.2	0.187	0.188	0.841	2.55	50	76
D.T.3	0.271	0.891	1.01	3.07	76	76
D.T.4	0.152	0.180	0.985	6.83	54	88
D.T.5	0.132	0.169	1.21	6.19	56	84
D.T.6	0.116	0.179	0.927	4.44	60	82
D.T.7	0.176	0.169	1.12	7.91	49	88
D.T.8	0.187	0.168	1.04	6.11	47	86
D.T.9	0.0138	0.0106	4.76	30	43	87
D.T.10	0.0668	0.190	1.04	7.72	73	89
D.T.11	0.873	0.815	1.33	5.09	48	80
D.T.12	0.0515	0.111	1.79	13.7	68	89
D.T.13	0.304	0.264	1.22	4.7	46	80
D.T.14	0.490	0.924	1.32	3.48	65	73
D.T.15	0.313	0.231	1.25	5.99	42	83
D.T.16	0.175	0.230	1.25	5.27	56	81
Average	0.230	0.314	1.351	7.28	56	82.25

and their Cr#, these chromites are High-Cr type. As Al_2O_3 content and Cr# of podiform chromitites are main indicators of High-Cr types from High-Al types, the use of Al_2O_3 diagram against Cr# can be useful in distinguishing these two chromitites. The status of chromites is shown in **Figure 4**, this diagram represents a very weak positive correlation (0.041) between these two indices. Chromitites under study are High-Cr types.

High average of MgO (20.83 Wt%) represents the chromitite crystallization of the magmas of the area under study with high degree of partial melting which is related to deep peridotites [53]. This high average of MgO shows the Alpine type of the chromites of Dowlat Abad-Tang e Hana area because in a variety of stratiforms this average is less than 10 Wt% while this average is more in different types of stratiforms [54]. Moreover, the negative correlation of Cr_2O_3-MgO in chromitites of this area confirms that the chromitites are alpine type (**Figure 5**).

A negative correlation exists between Cr# and Mg# in chromitites of Dowlat Abad-Tang e Hana area (**Figure 6**), which reflects the probability of dissimilar associative coefficients for magnesium and iron between chromite and olivine in crystallization process [55]. In other words, along with the crystallization process advancement of chromite from magma, preferably iron enters chromite phase and magnesium tends to enter the composition of olivine. The relationship between Cr# and Mg# is the common feature of ophiolite type chromites [52].

The amount of TiO_2 in chromitites of (Dowlat Abad-Tang e Hana) area is low (average is 0.098 Wt%). The low amount of TiO_2 is one of the distinguishing features of podirom chromitities from stratiforms. In other words, the amount of TiO_2 in podiform chromitites in other parts of the world is less than 0.3% [52] [56]. The samples of area in the segregated diagram of TiO_2 against Cr_2O_3 are in the range of podiform chromitites (**Figure 7**).

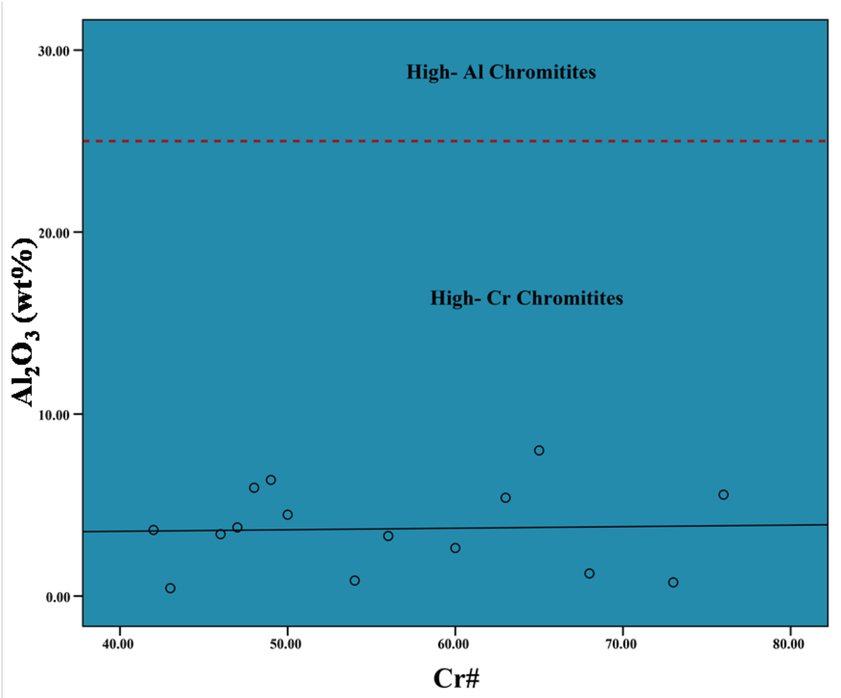

Figure 4. The status of chromitites of Dowlat Abad-Tang e Hana area in Cr#-Al_2O_3 diagram.

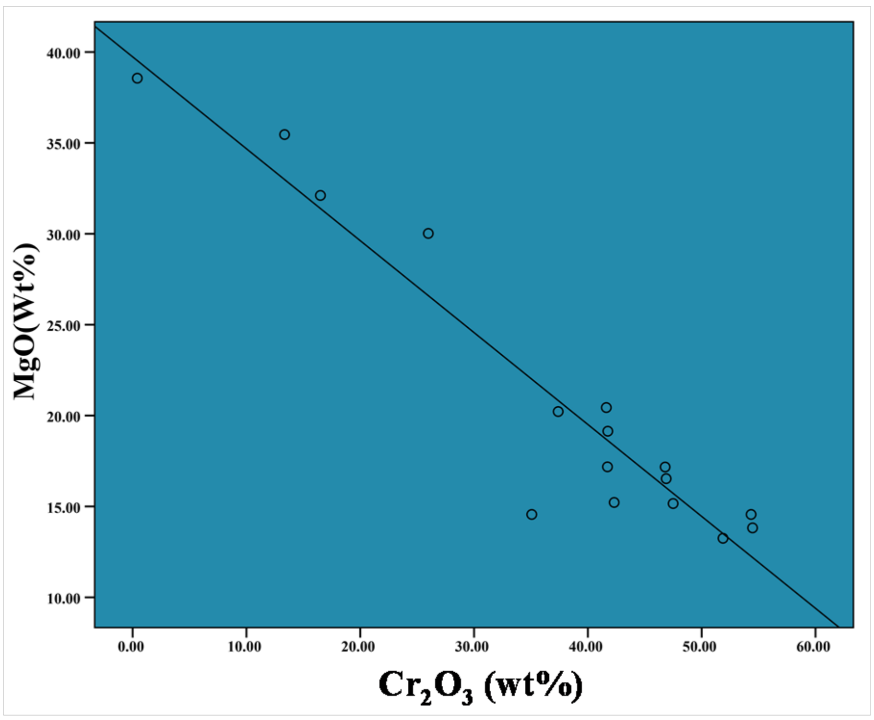

Figure 5. Cr_2O_3-MgO distribution diagram.

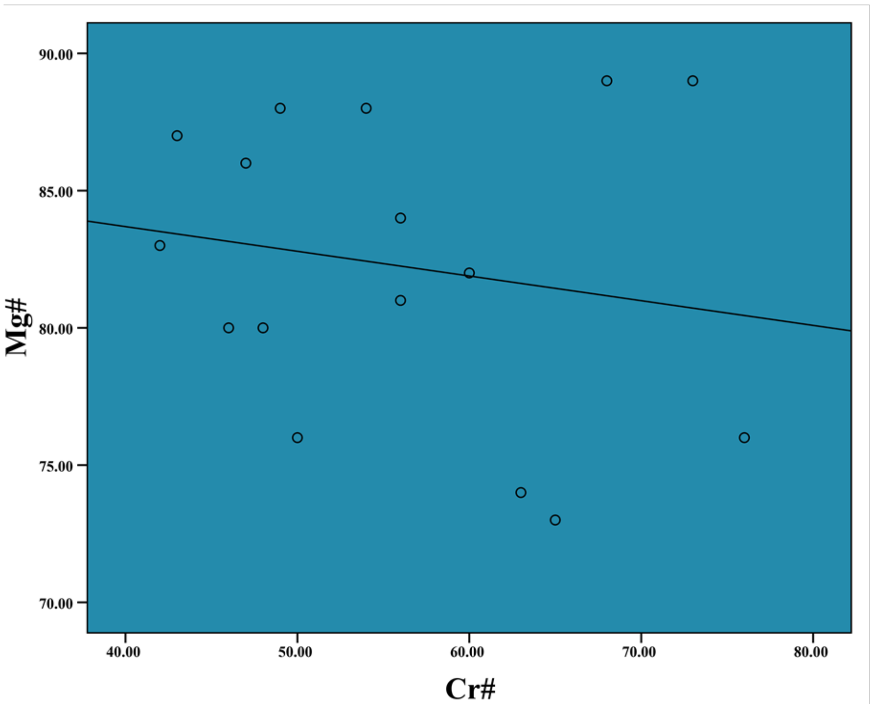

Figure 6. Negative correlation between Cr# and Mg# in chromitites of Dowlat Abad-Tang e Hana.

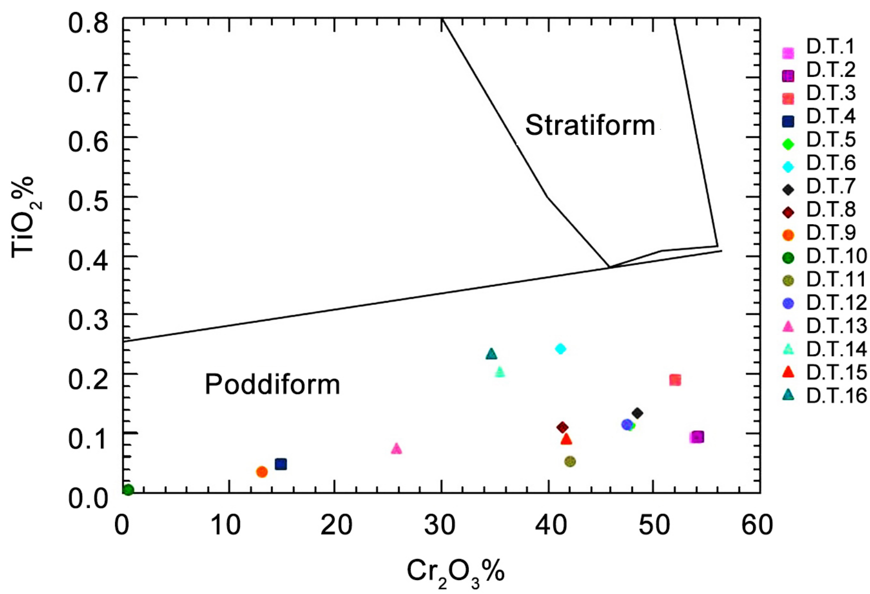

Figure 7. The status of Dowlat Abad-Tang e Hana area chromitites [57].

The low amount of TiO_2 may be related to melting and subtraction processes of parent magma. By increasing the amount of melting in some parts of the primary rock, due to magma dilution, titanium oxide concentration decreases [58] [59]. Compared to High-Al chromites, High-Cr chromites (such as Dowlat Abad-Tang e Hana area chromites), are depleted from titanium more, which is regarded as a sign for more titanium with drawal during melting of upper mantle with higher degree [60] [61]. Taking the depletion of Dowlat Abad-Tang e Hana chromites from TiO_2 into account, it is concluded that after melting the depleted mantle with higher degree above the subduction zone, the rising melt from the primitive mantle causes chromite mineralization. The effective role of Mg-rich boninite magmatism resulted from partial melting with higher degree is another interesting point [55] [62] [63], since one of the features of bonitite magma is high amount of MgO (over 9%) and low amount of TiO_2 (less than 3%) which is usually created at low pressure (less than 50 km) and areas above subduction zone [64].

4. Results and Discussion

Based on previous work [65], the high amount of Cr# and low amount of Al_2O_3 of the chromites of the area under study clarifies the lack of chromite formation of the area in expanding areas behind the arc and rift zone. In the other hand, the study area is situated on the northern margin of 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 [66]-[81] and neotectonic regime in Iran [82]-[87], Zagros is the most active zone [88]-[115]. Then, Alborz [116]-[156] and Central Iran [157]-[174] have been situated in the next orders.

5. Conclusion

Peridotites of Dowlat Abad-Tang e Hana area (East of Ophiolite Complex of Neyriz) often consist of harzburgite. Serpentinization is widely seen in the rocks of the area. Cr_2O_3 content and chrome number in chromitites of Dowlat Abad-Tang e Hana area represent ophiolite chromitites rich in chromium. High amount of MgO, on one hand, represents the chromitite crystallization of the magmas of the area under study with high degree of partial melting, which is related to deep peridotites and represents the alpine type of the chromites of Dowlat Abad-Tang e Hana area, on the other hand. In the chromitites of this area, a negative correlation between Cr# and Mg# was observed. This type of relation is the common feature of ophiolite type chromites. The average of Cr# = 56 in chromites of Dowlat Abad-Tang e Hana area indicates that the parent magma of the chromite may be rooted from an area devoid of Al. The high amount of Cr# and low amount of Al_2O_3 of the chromites of the area under study clarifies the lack of chromite formation of the area in expanding areas behind the arc and rift zone [65]. Depletion of Dowlat Abad-Tang e Hana chromites from TiO_2 and Al_2O_3 shows that after melting the depleted mantle with higher degree above the subduction zone, the rising melt from the primitive mantle causes chromite mineralization. Furthermore, high average of MgO and TiO_2 depletion of the chromites of Dowlat Abad-Tang e Hana area are regarded as the features of bonitite magma.

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