PETROGRAPHICAL AND GEOCHEMICAL CHARACTERISTICS OF THE ULTRAMAFIC ROCKS OF JABAL ZALM, CENTRAL ARABIAN SHIELD, SAUDI ARABIA

Mustafa M. Hariri *

Department of Earth Sciences

King Fahd University of Petroleum & Minerals,

Dhahran, Saudi Arabia

الخلاصة:

تعتبر تراكيب جبل ظلم فوق الغامق (من العصر الكمبري) جزءاً من نطاق ملتحم نبيطة ويشكل هذا التكوين حزاماً يمتد في اتجاه الشمال الغربي. تتكون منطقة الدراسة من وحدة الصخور فوق الغامقة الشديدة التشوه التي تحوّلت بالكامل إلى سربنتينيت، إلا أن الدراسة الميكروسكوبية التي تمت على نسيج معادن السربنتنيت والشكل البلوري دلّت على أن المعادن الأصلية ربما كانت أولوفين، اورثوبيروكسين، كلاينوبيروكسين أو هورنبليند على التوالي ويتواجد الكروميت مع السربنتينيت على هيئة منتثرات، عدسات صغيرة وجسيمات. وقد أظهرت التحليلات الكيميائية لصخور السربنتينيت ارتفاعاً في تركيزات عناصر الكروم، والنيكل والمنجنيز، حيث كانت أكبر القيم لعناصر الكروم، والنيكل، والمنجنيز، هي 5000، 3000 و 3000 جزء في المليون على التوالي وقد دلّت الدراسات الحقلية والمعملية على أن في المنطقة إمكانية جيدة لتواجد خام الكروميت والنيكل.

* Address for correspondence:

Dr. Mustafa M. Hariri

P O Box 5070

King Fahd University of Petroleum & Minerals, 31261,

Dhahran, Saudi Arabia

e-mail: mmhariri@kfupm.edu.sa

Keyword: Geology, Economic Geology, Ore Deposits, Chromium and Nickel Mineralization, Ultramafic Rocks

ABSTRACT:

The Jabal Zalm ultramafic complex (Precambrian) is part of the Nabitah suture zone and forms a belt striking northwest. The ultramafic rocks within the complex are highly deformed and have been completely altered to serpentinite. Petrographic study conducted on the serpentinite mineral textures and crystal shapes indicates that they may have been derived from olivine, orthopyroxene, clinopyroxene, and/or hornblende, respectively. Chromite is present within the serpentinite in the form of disseminations, small lenses, and pods.

Chemical analysis of serpentinite rock samples showed elevated concentrations of Cr, Ni, and Mn. The maximum values for Cr, Ni, and Mn are 5000 ppm, 3000 ppm, and 3000 ppm, respectively. Field and laboratory studies indicate that the area may have a good potential for chromium and nickel mineralization.

PETROGRAPHICAL AND GEOCHEMICAL CHARACTERISTICS OF THE ULTRAMAFIC ROCKS OF JABAL ZALM, CENTRAL ARABIAN SHIELD, SAUDI ARABIA

INTRODUCTION:

The Jabal Zalm ultramafic complex is located within the Zalm quadrangle (22/42A) (Figure 1). It is situated at latitude 22º 50′ N and longitude 42º 12′ E, about 10 km north–northwest of Zalm in the central Arabian Shield.

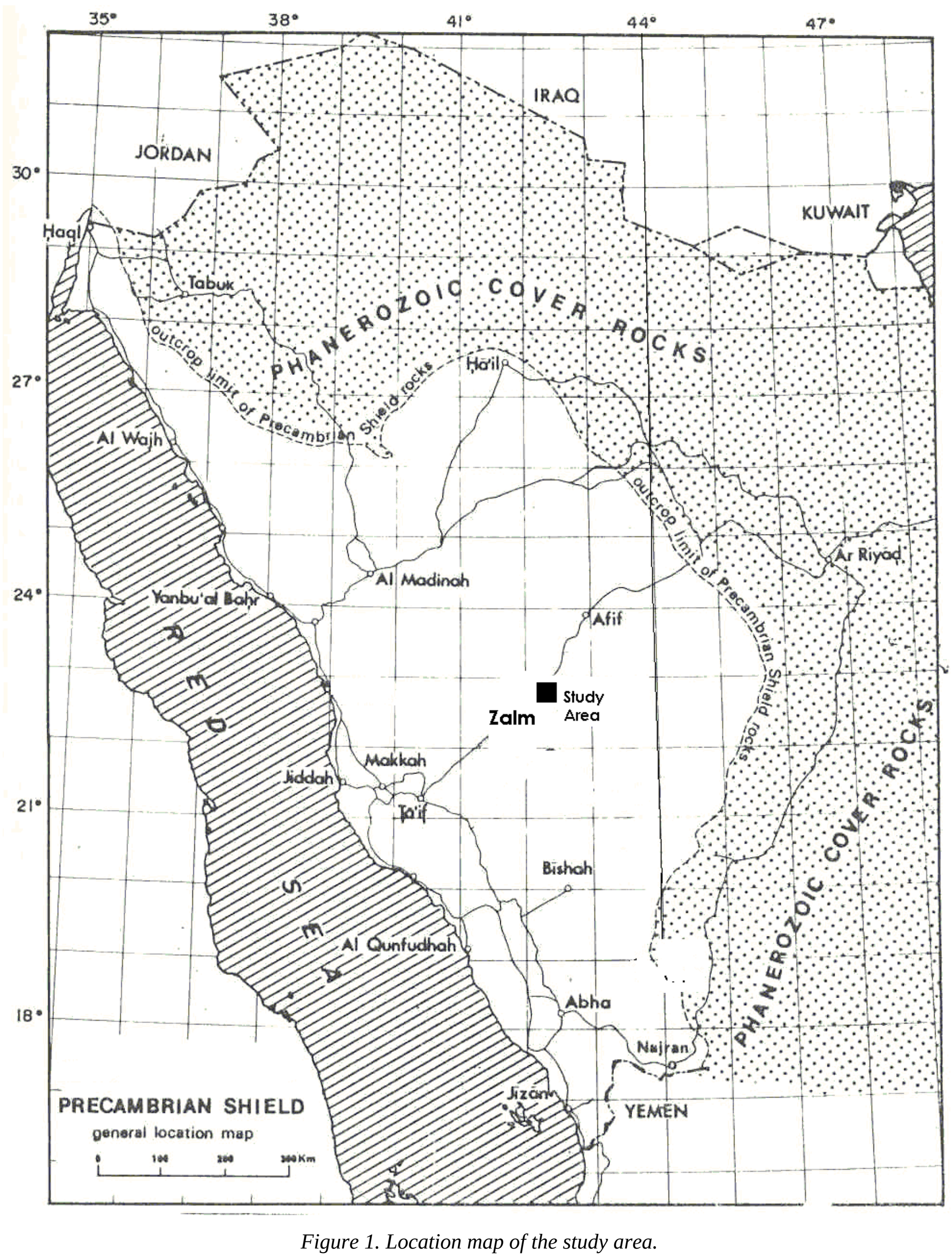

Figure 1. Location map of the study area.

The earliest work on the Zalm quadrangle was conducted in 1953 and included mainly a study of gold mineralization [1]. The quadrangle was also mapped at a scale of 1:500 000 during the geological mapping of the southern Najd quadrangle [2]. Dehalavi [3], Laurant [4], and Bounny [5] investigated the marble and other mineral occurrences in Zalm area. Sahl [6] mapped the area at a scale of 1:100 000 and later his work was incorporated into the 1:250 000 compilation for the Zalm quadrangle [7].

The current study is based on the ultramafic rock units in Zalm quadrangle. The aim of the study is to evaluate the chromium and nickel potential of Jabal Zalm, using petrographical, geochemical, and field studies. Pods, lenses, and disseminates of chromium mineralization are present within the ultramafic rocks of the Zalm quadrangle. No previous study has been conducted on the ultramafic rocks and chromium mineralization in the area.

METHODS OF INVESTIGATION:

During this study the Jabal Zalm area was mapped at a scale 1:15,000 using aerial photographs as basis. 150 rock samples were collected from the area representing all rock units. However, thin sections were prepared and semi-quantitative spectrographic analysis for Cr, Ni, Mn, and Fe conducted for 77 ultramafic rock samples only. The samples were also analyzed for major oxides using atomic absorption and X-ray-fluorescence methods. All analyses were performed in the DGMR/USGS Laboratory, Jeddah.

GEOLOGICAL SETTING OF THE ZALM QUADRANGLE

The Precambrian rocks in the Zalm quadrangle are part of the Siham and Bani Ghayy groups as illustrated in Figure 2. The Siham group in the Zalm quadrangle is composed entirely of Bahjah formation. This formation is exposed in the east and around Zalm village and mainly consists of mafic to intermediate flows, subordinate silicic pyroclastic rocks, and marble [6].

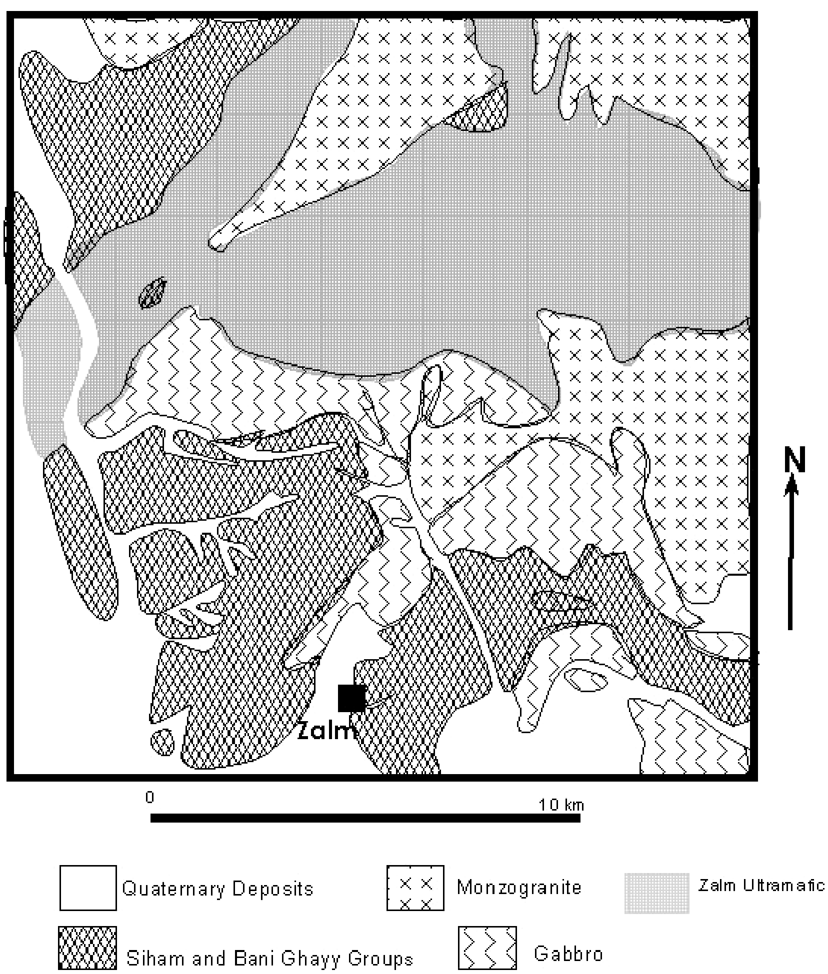

Figure 2. Simplified geologic map of the Jabal Zalm area (modified after Sahl, [6])

The Bani Ghayy group is represented by Tamaran and Mahall formations. Tamaran formation crops out in the northwestern part of the quadrangle, and consists of metamorphosed pyroclastic, volcanoclastic, and epiclastic rocks. It is intruded by monzogranite and bounded to the east by ultramafic rocks. The Mahall formation crops out in the south and center of the quadrangle. It consists of purple and flaggy sandstone and siltstone, with pyritic arkose, pebble conglomerate, and thin beds of limestone breccia [6].

Precambrian intrusive rocks include ultramafic varieties (discussed in the following section), gabbro, diorite, and granite. Felsic to mafic dikes are present, and quartz veins are also common. The Precambrian rocks are overlain by Tertiary alkali olivine basalt and local sediments of quaternary alluvium (Figure 2).

GEOLOGY OF THE ULTRAMAFIC ROCKS:

The ultramafic rock units in the Zalm Quadrangle form a segment of the larger Ad-Dafinah belt which has been interpreted by Stoeser and Camp [8] as part of the Nabitah suture zone. These rocks form both Jabal Zalm and Zuraybat al Mahall. They also occur as scattered bodies near the eastern boundary of the quadrangle.

The Zalm ultramafic complex forms a 20 km long and 5 to 10 km wide belt striking northeast (Figure 2). It is emplaced within the Bahjah formation and is bounded to the south by layered gabbro and to the southeast, east, and northeast by post-orogenic monzogranite intrusions. Small batches of volcanic and metavolcanic rock units crop out along the northern side of the complex.

The ultramafic rocks are almost completely altered to serpentinite. Their color varies from light green to purple and light pink. The pink color is due to iron oxides.

Hills in the eastern and central parts of the complex are capped by gossan-like beds, the largest having a thickness of about 20m. This gossan is thought to have formed by concentration of iron and silica, and leaching of magnesium and calcium. Magnesium and calcium have been redeposited in the form of carbonates along fractures and minor faults.

The ultramafic rocks of the Zalm complex form a structural unit, with folds, refolded folds, and faults recognized in several parts. The axial traces of the folds trend northeast parallel to the strike of the ultramafic exposures. The folds are predominantly asymmetric antiforms and synforms. Faults with both small (10 cm) and large (>100m) scale displacements have been observed. The small-scale faults are both of normal and reverse types and vary in orientation, but are mostly parallel to the general trend of the ultramafic belt. Several large-scale faults trend northwest and north–northwest parallel the Najd fault system.

PETROGRAPHY STUDY OF THE ULTRAMAFIC ROCKS:

Although most of the ultramafic rocks are completely serpentinized, primary crystal shapes, and texture are commonly preserved and allow recognition of the original minerals. Mesh, bastite, and lattice structures of serpentine minerals indicate derivation from olivine, orthopyroxene, clinopyroxene, and/or hornblende respectively (Figures 3 and 4) and [9].

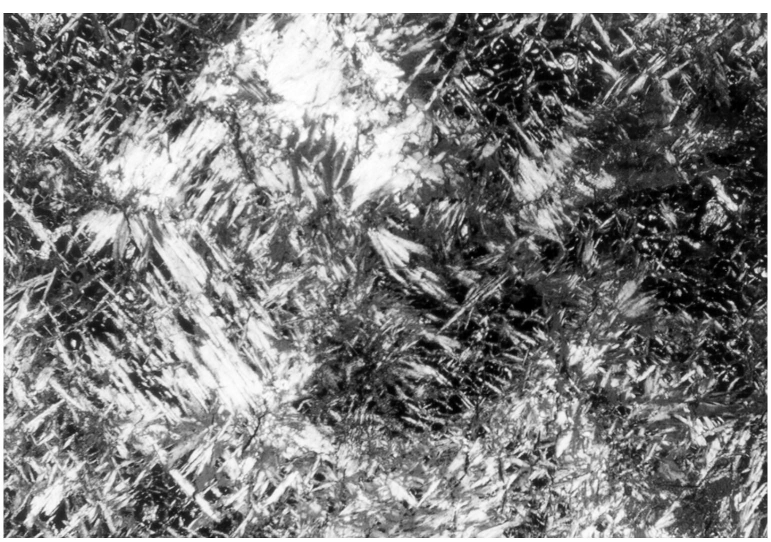

Figure 3. Thin section photograph showing the relict textures of the altered pyroxene within the serpentinite (X10)

Figure 4. Thin section photograph for the serpentinite showing the mesh textures (X10).

Table 1. Original Modal Composition (volume %) of Representative samples of Jabal Zalm Ultramafic (Determined from Relict Shapes).

Sample Number	Orthopyroxene	Clinopyroxene	Olivine	Chromium	Calcite
110	39	11	17	8	25
118	60	9	9	17	5
147	35	4	13	34	14
167	29	32	30	8	1
168	11	33	54	3	0
140	66	19	2	11	2.4
126	71	4	2	4	20
149	54	10	4	1	31
179	45	10	15	3	27
142	45	36	5	5	8
150	19	40	33	4	5
178	43	23	0.2	3	30
181	63	17	11	0	9
160	24	37	28	4	7

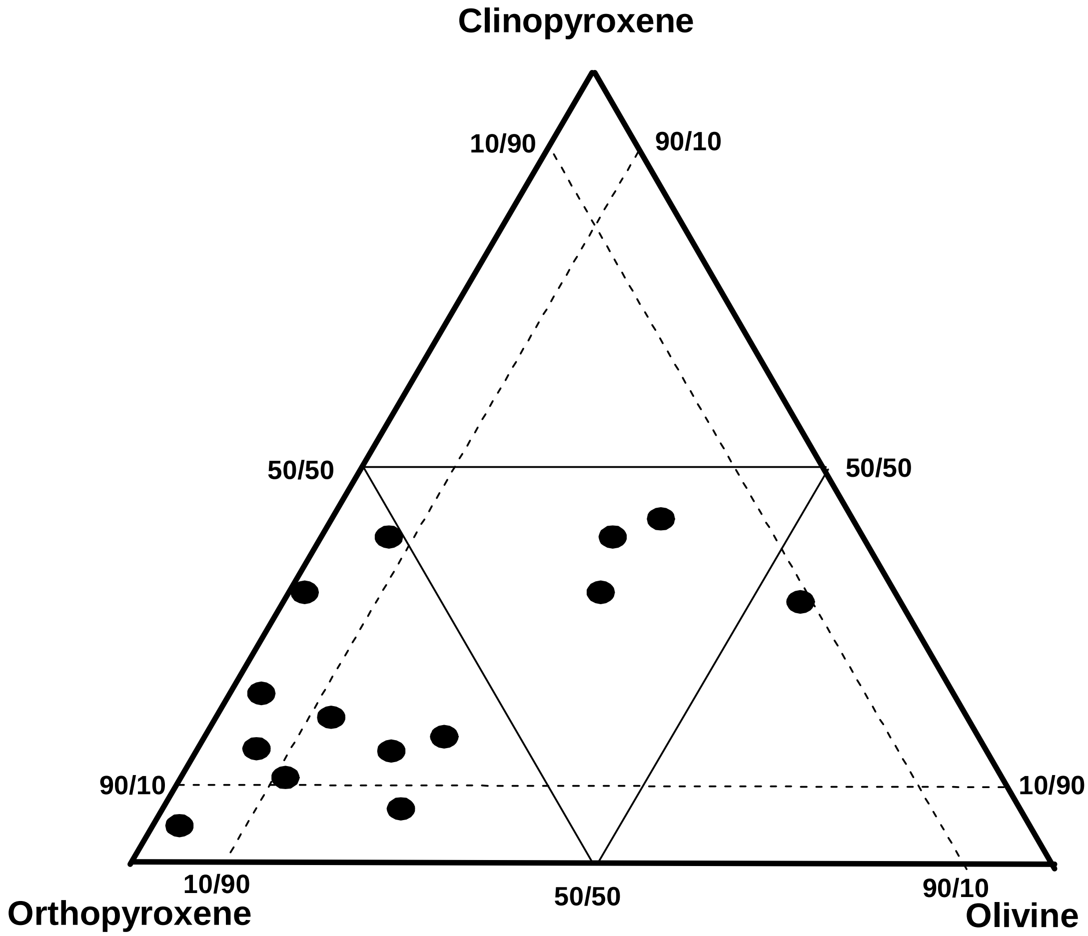

Figure 5. Model composition (orthopyroxene–olivine–clinopyroxene) of Jabal Zalm ultramafic rocks

Petrographically, the ultramafic rocks consist mainly of serpentinite minerals antigorite and chrysotile. Chromite and calcite are present as accessory minerals. Relicts of the original minerals indicate that they were coarse to medium–grained and anhedral to subhedral. Chromite occurs as fine- to coarse-grained disseminations in various proportions. Calcite is mainly found as minor veinlets. Table 1 shows the possible original main mineral components determined from the relict shapes in representative samples. The possible rock types based on the minerals content are Websterite, and Olivine Websterite (Figure 5).

Thin section studies for the gossan indicate a composition of medium-grained to fine-grained, anhedral secondary quartz (50-60 %) and hematite (30%). Chromite and calcite occur as accessory minerals.

GEOCHEMISTRY OF THE ULTRAMAFIC ROCKS:

In the course of geochemical studies on the ultramafic rocks of Jabal Zalm, twenty samples were analyzed for major oxides. Table 2 lists the results of these samples that are analyzed for major oxides. Trace element concentrations were determined for 77 samples collected from different parts of the Jabal Zalm area. The samples were analyzed for Mn, Mg, Co, Cr, and Ni by emission spectroscopy. Maximum, minimum and average values for these elements are listed in Table 3.

As shown in Table 2, SiO_2 values range from 32% to 78.2%. The highest silica and iron oxide values are observed in samples collected from or near the leached gossan bed. Probably due to the alteration, MgO and CaO, in some samples, are higher than the averages for the ultramafic rocks, (Table 2). Na_2O and K_2O values are generally lower compared to ultramafic rocks due to alteration or metasomatic processes (Table 2).

In the SiO_2 versus FeOt/ FeOt+MgO variation diagram, most of the Jabal Zalm samples plot within or near to the cumulate of Colmen [10] as illustrated in Figure 6. Samples with more than 45% SiO_2 are ignored in this diagram, as they are collected from locations near to the gossan bed.

Table 2. Major Oxides Composition (wt%) of Twenty Samples Selected from Jabal Zalm Area. Pyroxinite Average Oxide Values are Taken from Nockolds and others [11].

No	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	TiO_2	P_2O_5	MnO	CO_2
1	33.9	1.4	3.08	3.2	29.8	10.04	0.01	0.07	10.16	6.02	6.03	0.09	7.9
2	78.2	1.4	8.9	0.4	6.7	0.6	0.01	0.03	2.9	0.04	0.07	0.17	-
3	76.2	1	6.4	0.2	11.4	0.25	0.01	0.02	3.8	0.01	0.03	0.13	-
4	32.4	1	5.7	0.6	25.3	13.07	0.01	0.01	2.7	0.03	0.03	0.17	19.1
5	59.8	1.1	4.8	1.1	28.6	0.38	0.01	0.02	3.7	0.07	0.02	0.04	-
6	39.8	15.5	5.1	12.3	6.3	13.9	1.48	0.38	1.8	2.56	0.25	0.36	-
7	73.8	0.9	6.4	0.5	12.6	0.52	0.01	0.02	4.6	0.01	0.05	0.1	0.16
8	39.3	1.8	6.3	0.09	37.4	1.21	0.03	0.01	11.6	0.05	0.02	0.07	1.5
9	38	1.3	7.6	0.5	36.6	1.64	0.01	0.01	17.1	0.04	0.03	0.12	1.64
10	41.1	1.5	6	1.5	37.5	0.23	0.01	0.07	11.2	0.02	0.02	0.11	0.34
11	32	1	6.3	0.5	30.8	10.83	0.01	0.04	10.9	0.01	0.04	0.1	7.96
12	38.9	1.4	8	0.4	36.7	0.52	0.02	0.27	13.2	0.01	0.03	0.07	-
13	51.8	19.8	2.1	5	4.6	6.3	4.96	1.78	2.5	0.93	0.2	0.11	-
14	36.5	1.5	4.2	2.3	34.3	4.4	0.06	0.01	10.5	0.01	0.03	0.13	6.38
15	36.5	1.4	4.1	1.3	33.6	5.58	0.17	0.07	9.25	0.01	0.05	0.11	7.79
16	74.4	13.9	0.6	0.4	0.8	0.52	5.14	2.81	1.05	0.01	0.11	0.04	-
17	36.9	1.3	4.9	1.9	34.2	4.4	0.11	0.09	9.84	0.08	0.04	0.11	6.15
18	59.7	1.2	7.1	0.5	20.6	1.58	0.01	0.02	6.62	0.04	0.06	0.13	2.3
19	68.3	0.8	7.4	0.3	11.4	3.2	0.09	0.04	7.06	0.02	0.09	0.11	1.84
20	40.1	1.3	7	1.1	25.7	9	0.01	0.01	3.33	0.01	0.07	0.11	11.8
Average Pyroxinite rock	50.50	4.1	2.4	7.37	21.17	12.00	0.45	0.21	0.47	0.53	0.09	0.13	-
Average Alkali Pyroxinite	41.55	7.25	6.8	7.77	13.02	16.93	1.38	0.70	0.50	3.31	0.50	0.20	-

Table 3. Maximum, Minimum, and Average Values for Fe, Mg, Mn, Co, Cr, and Ni for 77 Selected Samples from Jabal Zalm Ultramafic Rocks (all Elements Values are in ppm), Compared to the Average Values for Fe, Mn, Cr, and Ni in Ultramafic Rocks (After Turekian and Wedepohl [12])

	Fe	**Mg**	**Mn**	**Co**	**Cr**	**Ni**
Maximum	**22 0000**	**120 000**	**3000**	**1500**	**6000**	**3000**
Minimum	**15 000**	**30 000**	**300**	**7**	**150**	**15**
Average	**63 680**	**99 861**	**1126.39**	**112.04**	**2243.06**	**1528.57**
Average [12]	**94 300**	**-**	**1620**	**-**	**1600**	**2000**

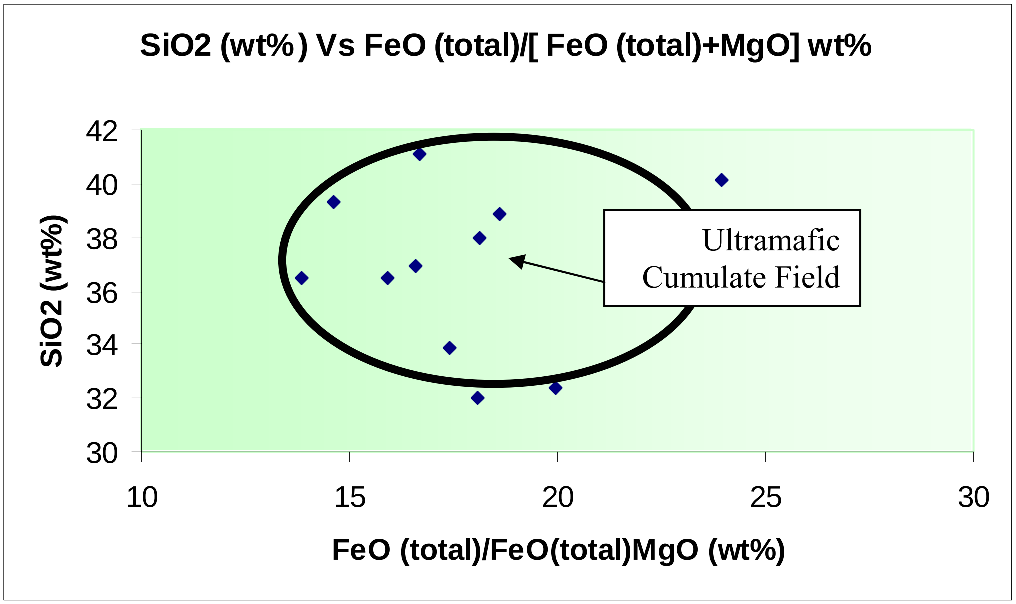

Figure 6. SiO_2 Versus FeOt/(FeOt+MgO) diagram for Jabal Zalm ultramafic rocks (boundary after Colmen [10]).

The average value of Cr in the Jabal Zalm area is higher than the average value for ultramafic rocks of Tuerkian and Wedpohl, as shown in Table 3 [12]. Maximum Cr values exceed 6000 ppm, the upper detection limit of the spectrograph. The enrichment of Cr is also well observed within both the rock units in the field and thin sections. Ni, Mn, and Fe averages are lower than the corresponding average values for the ultramafic rocks (Table 3) and the maximum Fe values (about 20%) obtained from samples collected near or from the gossan cap.

The ternary diagram of Cr, Ni, and Mn indicates that the concentrations of these three elements within the ultramafic rocks of Jabal Zalm are about the same, except for some samples that are enriched in Cr and Mn compared to Ni (Figure 7).

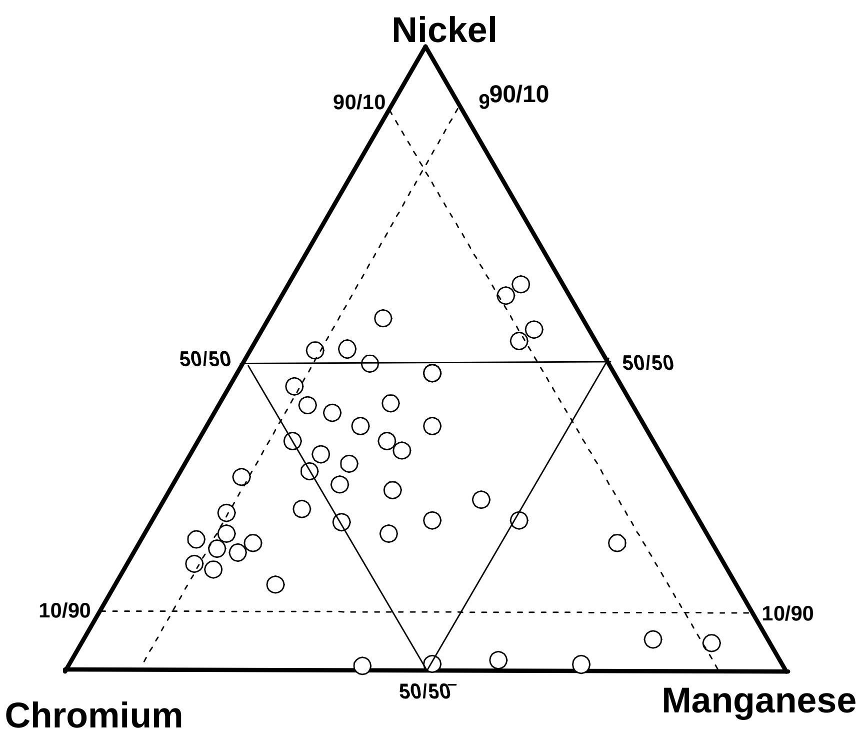

Figure 7. Ternary diagram for Mn, Cr, and Ni concentrations within the ultramafic rocks of Jabal Zalm area

DISCUSSION AND CONCLUSIONS

The Jabal Zalm ultramafic complex is an elongated body which has been folded and faulted. The complex is part of the Nabitah suture zone and forms as a belt striking northwest. Ultramafic rock units within the complex are almost completely altered to serpentinite. Petrographic studies show that the original rocks were probably websterite and olivine websterite.

The field relationship and the geological characteristics of the Zalm ultramafic complex indicate similarity to Alpine-type bodies according to Naldrett and Cabri [13] classification. Moreover, it may represent a segment of the large obducted sheet that is represented by Nabitah suture zone. The absence of the complete sequence of ophiolite in the area and within Nabitah suture may be attributed to erosion.

Chemical data indicates that these ultramafic rocks were probably cumulates (Figure 6). Anomalous concentrations of Cr, Ni, and Mn were observed in samples collected from the area. High anomalies of Cr content can also be recognized in the field through the presence of chromite disseminations, small lenses, and pods in all rock units. The pods and lenses reach a maximum length of 100 to 150 m and vary in thickness between 50 cm to about 1.5 m. The ultramafic rock units in high elevations are capped with gossan like beds, characterized by an enrichment of iron and silica.

The presence of podiform chromites may indicate that the conditions necessary for massive chromites formation only locally prevailed [14]. These deposits are also concordant with the foliations and lineations that are present within the ultramafic rocks. Lago and others [15] stated that the concordant nature of the podiform chromite may indicate high plastic strain. Size and dimension of the pods and lenses within the ultramafic rocks may also indicate a formation scenario similar to that proposed by Lago and others [15]. According to this scenario the ore may have been formed in a large cavity 100–200 m high and 2 to 5 m thick, inside the ultramafic rock diaper, and fed by a narrow dike (5–50 cm thick).

Relatively high Cr and Ni values coupled with the presence of lenses and pods of chromites suggest the possibility of larger lenticular bodies of chromites within the ultramafic complex. Therefore, ground geophysical survey should be carried out to test the presence of such bodies and identify drilling targets.

ACKNOWLEDGMENTS

Major part of this work was conducted in the DMMR (Deputy Ministry for Mineral Resources). The author would like to express his thanks and gratitude to the DMMR for permitting the publication of the data. Thanks and appreciation are to the KFUPM for providing facilities and support to continue this work.

REFERENCES

[1] D. F. Schaffner "Zelm (22/42A)", *Open File Report DGMR-431*, Saudi Arabian Directorate General of Mineral Resources,1953, 30p.

[2] R. O. Jackson, R. G. Bogue, G. F. Brown, and R. D. Giehat, "Geologic Map of Southern Najd Quadrangle, (20-23/42-44)", *U. S. Geological Survey Miscellaneous Investigations Map I-211A, Scale 1:500,000*, 1963.

[3] M. R. Dehalavi, "Prospecting for Marble Around Zalim", *Open File Report, 71-JED-10*. French Bureau de Recherches Geologiques et Minières, 1971, 18p., 8 ill.

[4] D. Laurent, "Prospecting for Marble in Saudi Arabia", *Open File Report, 72-JED-19.* French Bureau de Recherches Geologiques et Minières, 1972, 58p., 1 ill.

[5] I. Bounny, "Mineral Exploration in the Halaban Formation, Al Muwayh (22/41 B, D) and Zalim (22/42 A) Area, (Completion Report), *Open File Report, 77-JED-21*. French Bureau de Recherches Geologiques et Minières, 1977, 20p., 23 ill.

[6] M. Sahl, "Reconnaissance Geology of Zalm Quadrangle, Sheet 22/42A", *Open File Report, DGMR-OF-04-17*, Kingdom of Saudi Arabia, Saudi Arabian Deputy Ministry for Mineral Resources, 1985, 40p.

[7] R. A. Agar, "Geology of Zalm Quadrangle, Sheet 22F" *Open File Report, DGMR-OF-04-1*, Kingdom of Saudi Arabia, Saudi Arabia Deputy Ministry for Mineral Resources,1985, 30p.

[8] D. Stoeser and V. Camp, "Pan-African Microplate Accretion of the Arabian Shield", *Technical Record, USGS-TR-04-17*, Saudi Arabian Deputy Ministry for Mineral Resources, 1984, 26p.

[9] H. Williams, F. Turner, and C. Gilbert, *Petrography*. San Francisco: W. H. Freeman 1954, 406p.

[10] R. G. Colmen, *Ophiolites*. Berlin: Springer-Verlag, 1977, 229p.

[11] S. R. Nockolds, R. W. O'B. Knox, and G. A. Chinner, *Petrology for Students*. Cambridge: Cambridge University Press, 1978, 435p.

[12] K. K. Turekian and K. H. Wedepohl, "Distribution of the Elements in Some Major Units of Earth's Crust", *Geological Society of America Bulletin*, **72** (1961), pp. 175–192.

[13] A. J. Naldrett and L. J. Cabri, "Ultramafic and Related Mafic Rocks: Their Classification and Genesis with Special Reference to the Concentration of Nickel Sulfide and Platinum-Group Elements", *Econ Geol*, **71** (1976), pp.1131–1158.

[14] M. Duke, "Magmatic Segregation Deposits of Chromite". in: *Ore Deposits Models*, ed. R.G. Roberts and P.A. Sheanan. *Geosciences Canada Reprint Series* 3, 1990, pp. 133–143

[15] N. L. Lago, M. Rabinowicz, and A. Nicolas, "Podiform Chromite Ore Bodies: a Genetic Model", *Journal of Petrology*, **23** (1982), pp.103–125

Paper Received 28 August 2002; Revised 21 April 2003; Accepted 11 June 2003