

# Geochemistry of Detrital Chromite from Gercus Formation (M. Eocene), Northern Iraq: Implications for the Provenance and Paleotectonic

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## Abstract

The current research dealt with the mineralogical and geochemical characteristics of the detrital chromite mineral in the sandstone from the Gercus Formation (Middle Eocene). Three sections of the north of Iraq were selected to identify the nature and type of the source rocks and the tectonic setting. Detrital chromite is found in high concentrations in fine sandstone with glossy black color. Based on the geochemical analysis, it is evident that the mineral contains 33.35% - 6.534% Al<sub>2</sub>O<sub>3</sub>, 65.36% - 33.27% Cr<sub>2</sub>O<sub>3</sub>, 16.44% - 6.49% MgO, 22.37% - 10.806% FeO, 0.0 - 9.012% Fe<sub>2</sub>O<sub>3</sub>, and 0.014% - 0.9% TiO<sub>2</sub>, therefore, it can be classified as Al-chromite. Additionally and according to the ternary plot of Cr<sup>3+</sup>, Al<sup>3+</sup>, and Fe<sup>3+</sup>, it is concluded that the origin of the chromite in question is compatible with Alpine-type peridotites chromite (which contains harzburgitic mantle peridotites) and it was developed primarily in a supra-subduction zone environment.

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**Keywords:** Detrital chromite, the Gercus Formation, Provenance, Tectonic setting.

## 1. Introduction

The use of heavy mineral assemblages to identify and describe sediment source areas has become familiar. In provenance studies, the variation of the chemical composition of a single mineral species is a very important technique (Morton, 1985), because the weathering, diagenesis, and sedimentation do not affect these minerals (Morton and Hallsworth, 1999).

The data of heavy minerals (especially chromite) in sedimentary rocks are commonly used as indicators of the petrological characteristics of the parent rocks. Many petrological studies point out the relations between the chromite spinel group (that includes chromite, chromite-spinel, and spinel) chemistry, rock type, and provenance (Lee, 1999).

Chromite is used as a guide in petrological studies. Some chemical ratios of oxides in chromite are considered important parameters, such as Mg# (Mg/Mg + Fe<sup>2+</sup>), Cr# (Cr/Cr + Al), and TiO<sub>2</sub>.

The chemistry of chromite is important for classifying mantle-derived peridotites in terms of the origin and the tectonic setting. Chromite from stratiform deposits has (Cr#: 0.6 to 0.8), (Mg# 0.2 to 0.8). On the other hand, chromite from podiform deposits may have (Cr#: 0.15-0.85; Mg# (0.4-0.8) (Steele et al., 1977; Al-Juboury et al. 2009).

The present research deals with the geochemistry of chromite from the Gercus Formation (Middle Eocene) in the north of Iraq (Fig. 1) and it discusses the use of chromite

mineral chemistry to make inferences regarding provenance and tectonic setting.

## 2. Material and Methods

Nine samples were collected from Gercus Formation from three sections: three samples from the Dohuk section, four samples from the Badi section, and two samples from the Shaqlawa section. The mineralogy of the samples has been revealed optically and by electron probe microanalysis (EPMA) and back-scattered electron imaging.

The analysis was conducted in the labs of the US Geological Survey. To diagnose and describe the chromite grains, a binocular microscope was used, with a fully automated JEOL JXA-8900 five-spectrometer electron microprobe that uses wavelength-dispersive X-ray spectroscopy and quantitative electron microprobe to determine the main and minor elements. The points of analysis were defined using optical and back-scattered electron imaging. Analyses were performed using a 1 to 20-micrometer diameter probe spot and a 15 keV (silicates and carbonates) or 20 keV (oxides) accelerating voltage, 10, 20, or 30 nA probe current and the counting times were 10 to 120 seconds.

Standard reference materials, both natural and synthetic were used. The analyses were corrected for electron beam/matrix effects, experimental drift, and dead time using the JEOL JXA-8900 electron microprobe's Phi-Rho-Z (CITZAF; (Armstrong, 1995) method. Based on a comparison of measured and published compositions of standard reference materials, the relative accuracy of the analyses was 1-2% for major oxides and 5-10% for minor oxides concentrations.

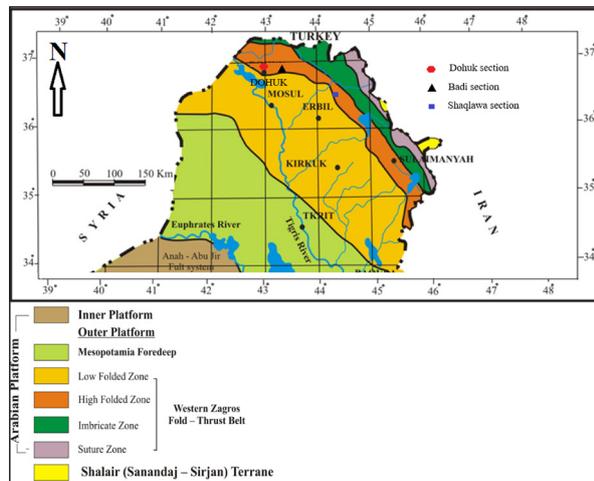
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### 3. Geological Setting

The Gercus Formation is made up of clastic, carbonate, and evaporate sequences. It consists of sandstone, mudstones, conglomerates, siltstone, and marls with a gypsum lens and little thin micritic carbonate beds. These beds were deposited in a range of sedimentary environments, such as arid to semiarid (dry) alluvial fans, ephemeral streams, interdunes, and lakes, aeolian dunes (Hussain and Aghwan, 2015; Awad and Ahmed Alsultan, 2020) Dohuk Dam, Brifca, and Shaqlawa. Moreover, this Formation can be regarded as part of Megasequence AP 10 (Arabian Plate10) (Sharland. et al., 2001) and it is regarded as a Middle-Late Eocene sequence, which is part of the Megasequence Middle Paleocene–Eocene (Jassim and Goff, 2006).

The deposition of the Gercus Formation during the period of renewed uplift of the eastern margin (Zagros margin) of the Arabian Plate at the end of the Early Eocene (Aqrawi et al., 2010). As it was deposited in the period of the final phase of the subduction and the closing of the remains of the New Tethys Ocean, it was deposited in a basin located to the southwest of the Balambo-Tanjero zone (Jassim and Goff, 2006).

The area studied is located in the northern part of Iraq, in high folded zones according to tectonic divisions of Iraq (Fouad, 2015) (Fig.1). Three sections were chosen and these sections are represented by Dohuk (near Dohuk dam), Badi and Shaqlawa.



**Figure 1.** Tectonic map of Iraq (Fouad, 2015) and location of the studied sections.

### 4. Result and Discussions

#### 4.1 Petrography and Field Description

According to previous petrological and chemical research (AL-Rawi, 1982; Dhannoun et al. 1988), dolomite and serpentinite were the primary sources of the Gercus sediments. The chromite grains are glossy black under the reflected light, with sharp edges and conchoidal fracture (plate 1-A). Scanning electron microscope (SEM) and back-scattered electron (BSE) images show the typical millimeter-scale oxide (chromite, magnetite, and ilmenite) detrital layers separated by detrital silicate and carbonate grains (plate 1-B), while the enlargement of a typical oxide layer demonstrates the predominance of angularity in both the

oxide and silicate-carbonate grains in the sample.

Most chromite grains exhibit weak deformations such as polygonal or angular crystal appearances and ductile deformations (such as elongated worm-like shapes) and cluster to form chromite bands or disseminated varieties (plate 1-B and C). In the Dohuk section, sandstone beds (0.2 to 6.0 m thick) are often moderately to well sorted, with sedimentary structures such as wind lamination, massive bedding, and cross-bedded strata with high-angle inclination. Sometimes the sandstones are badly sorted and pebbly. The mineral assemblage mainly comprises dolomite, quartz, serpentine, and altered Fe-oxides. EPMA- revealed amphibole, chlorite, chromite, and feldspar. In the Badi section, reddish brown, red-orange, pale yellow, and dark grey sandstones (0.2-1.0 m thick) with peat were distinguished. Good bedded or lenticular beds can be observed in the sandstones, especially where they are interbedded with conglomerates and can be followed laterally several hundred meters. Some of the sand sheets are made up of fine -to medium-grained, well-sorted sandstones with a parallel lamination and low-angle tabular cross-bedding. Both types of bedded sandstone have local burrows and pebble lineation with ventifacts. The sand sheet consists of medium to coarse-grained sandstones that have been inadequately sorted in other circumstances. These sandstones can be found as thick beds with scattered mud pebbles and wind-worn clast (gravels) or as tabular cross-bedding that is laterally persistent.

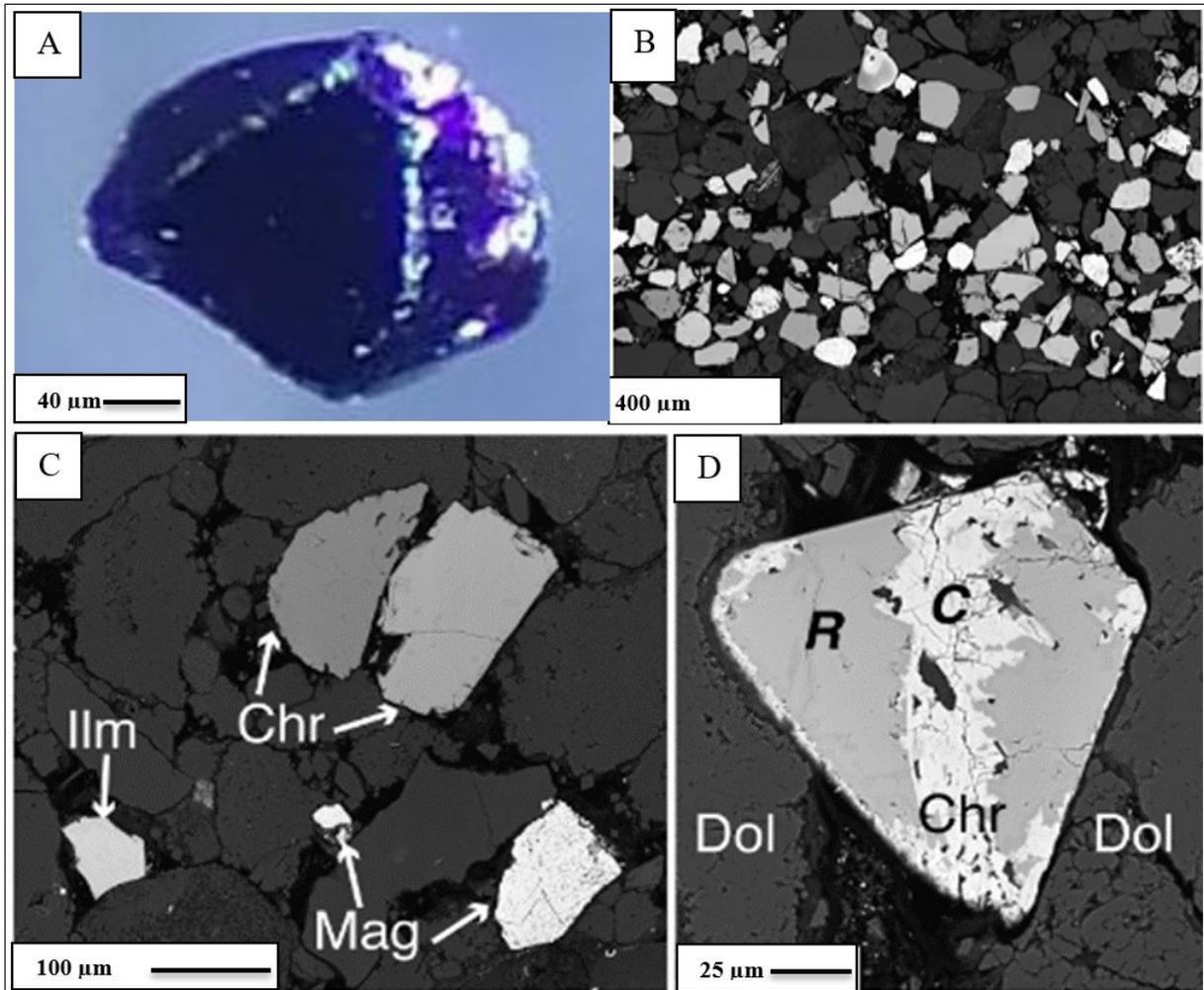
The mineral assemblage of the Badi section consists mainly of dolomite, quartz, serpentine, altered Fe oxides, and rare titanite -EPMA- documented the presence of chlorite, chromite, and feldspar. In the Shaqlawa section, the sandstone thickness ranges from 0.2 to 4.0 m. Moreover, the fresh surfaces are normally pink to light reddish brown, and even dark brown peat. However, weathered surfaces are often pale. These sandstone beds are usually fine- to medium-grained, well-sorted, massive, laminated, and commonly cross-bedded. Some sandstone beds are massive and structureless rock, sheet-like beds with parallel laminations and are typical in laminated sandstone in addition to that low-angle cross-bedding is occasionally observed. The mineral assemblage consists of Calcite, calcite cement, dolomite, quartz, altered serpentine EPMA: amphibole, chlorite, chromite, and feldspar.

#### 4.2 Mineral chemistry of Chromites

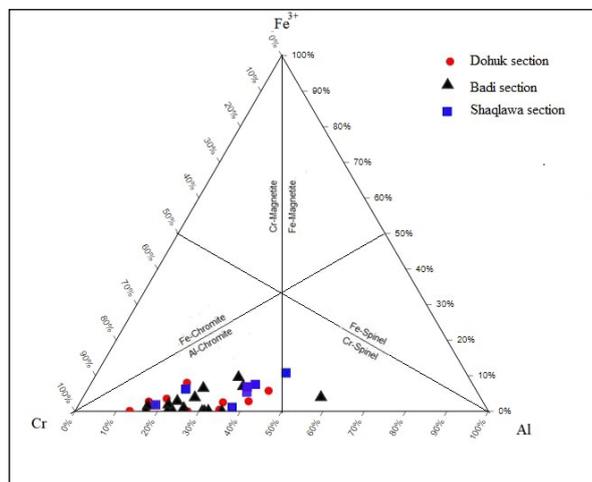
The structural formula for representative analyses was recalculated based on 32 oxygen and determined in atoms per formula unit (a.p.f.u.) as shown in Tables 1, 2, and 3. Excel spreadsheets from GabbroSoft (<http://www.gabbrosoft.org/spreadsheets>) were used to calculate mineral formulas. Fe<sup>+2</sup> and Fe<sup>+3</sup> were determined stoichiometrically. The analysis indicates that the chromite contains 33.35% - 6.534% Al<sub>2</sub>O<sub>3</sub>, 65.36% - 33.27% Cr<sub>2</sub>O<sub>3</sub>, 16.44% - 6.49% MgO, 22.37% - 10.806% FeO, 0.0 - 9.012% Fe<sub>2</sub>O<sub>3</sub> and 0.014% - 0.9% TiO<sub>2</sub>. MnO and ZnO are typically present in only minor abundance, generally < 0.5%. Titanium (Ti<sup>4+</sup>), which occurs in magma, can enter the spinel structure by coupling with Fe<sup>2+</sup> and replacing two Fe<sup>3+</sup> in the octahedral site (Ghosh and Konar, 2011). According to the nomenclature of Stevens (1944), the

studied chromite is classified as Al-chromite (Fig.2). Basaltic melts or metasomatic processes are the primary sources of Al-rich chromite (Franz and Wirth, 2000; Daczko et al., 2012). Zoning has not been observed, except the analysis of one grain of the sample (GD3) that shows compositional zonation were chromite (Chr) illustrating alteration along

a crack and on the edges. EPMA analysis of Rim wt% ( $Al_2O_3 = 16.2$ ,  $Cr_2O_3 = 53.1$ ,  $FeO$  total = 20.5) and Core wt% ( $Al_2O_3 = 0.67$ ,  $Cr_2O_3 = 47.2$ ,  $FeO$  total = 44.5) shows that the alteration fluids were iron-rich and preferentially removed Al, dolomite (Dol) grains surrounding the chromite show evidence of pressure dissolution (plate1-D).



**Plate 1.** A- Magnified photomicrograph of chromite grain with shiny black under reflected light; B- Scanning electron microscope (SEM) of enlargement of a typical oxide layer (sample GD4); C- SEM-BSE images of typical habits of the oxides; chromite (Chr), magnetite (Mag) and ilmenite (Ilm); sample GD3. D- SEM-BSE images for Chromite (Chr) illustrating alteration along a crack and on the edges, dolomite (Dol), rim (R), and core (C).



**Figure 2.** ( $Fe^{3+}$ , Al, Cr) diagram shows a type of detrital chromite from the Gercus Formation, The fields from (Stevens, 1944).

**Table 1.** Chemical composition of detrital chromite from Dohuk section, Gercus Formation.

Section	Dohuk section									
	Sample no	GD1				GD3				GD4
Spots	1	2	3	4	1	2	3	4	1	2
SiO <sub>2</sub> %	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TiO <sub>2</sub> %	0.04	0.31	0.06	0.01	0.05	0.04	0.07	0.04	0.06	0.04
Al <sub>2</sub> O <sub>3</sub> %	24.87	11.87	22.42	8.48	6.53	9.17	18.79	10.50	18.47	14.44
Cr <sub>2</sub> O <sub>3</sub> %	42.39	52.75	46.57	61.79	63.91	65.36	52.33	58.18	50.15	57.45
Fe <sub>2</sub> O <sub>3</sub> %	5.10	6.44	2.43	2.20	0.07	0.00	0.35	2.84	2.11	0.00
%FeO	14.87	18.72	16.80	18.04	15.59	14.09	17.00	18.16	15.77	14.97
%MnO	0.27	0.42	0.32	0.45	5.45	0.72	0.33	0.66	0.37	0.56
%MgO	13.85	9.78	12.12	9.83	7.08	9.66	11.65	9.62	12.06	11.51
%CaO	0.02	0.05	0.06	0.06	0.05	0.07	0.02	0.08	0.01	0.01
%ZnO	0.12	0.14	0.21	0.13	1.29	0.40	0.15	0.20	0.14	0.19
TOTAL	101.54	100.49	100.99	100.98	100.03	99.50	100.70	100.27	99.13	99.22
apfu										
Si	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ti	0.01	0.06	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Al	7.03	3.67	6.49	2.64	2.11	2.89	5.55	3.27	5.52	4.40
Cr	8.03	10.94	9.04	12.92	13.85	13.83	10.36	12.15	10.06	11.75
V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe <sup>+3</sup>	0.92	1.27	0.45	0.44	0.02	0.00	0.07	0.56	0.40	0.00
Fe <sup>+2</sup>	2.98	4.10	3.45	3.99	3.57	3.15	3.56	4.01	3.34	3.24
Mn	0.05	0.09	0.07	0.10	1.27	0.16	0.07	0.15	0.08	0.12
Mg	4.95	3.82	4.44	3.87	2.90	3.85	4.35	3.79	4.56	4.44
Ca	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.02	0.00	0.00
Zn	0.02	0.03	0.04	0.02	0.26	0.08	0.03	0.04	0.03	0.04
TOTAL	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
#Mg	0.62	0.48	0.56	0.49	0.45	0.55	0.55	0.49	0.58	0.58
Fe3+#	0.06	0.08	0.03	0.03	0.00	-	0.00	0.04	0.03	0.00
#Cr	0.53	0.75	0.58	0.83	0.87	0.83	0.65	0.79	0.65	0.73

Table 2. Chemical composition of detrital chromite from Badi section, Gereus Formation.

Section	Badi section															
	GB2				GB3				GB4				GB5			
Sample no.	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Spots	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SiO <sub>2</sub> %	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.04	0.30	0.14	0.05	0.04	0.05	0.08	0.29
TiO <sub>2</sub> %	11.08	14.56	14.28	8.30	18.41	12.00	20.01	33.35	12.68	13.03	11.23	19.18	16.79	8.90	16.96	17.08
Al <sub>2</sub> O <sub>3</sub> %	58.15	51.23	54.28	59.69	43.88	56.51	44.73	33.27	61.00	54.96	57.96	51.82	56.23	64.13	55.41	53.48
Cr <sub>2</sub> O <sub>3</sub> %	1.50	5.33	3.20	1.17	7.92	2.29	5.92	3.58	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.09
FeO%	19.34	17.65	15.78	22.37	17.05	18.08	15.75	11.19	16.91	21.30	22.10	18.54	15.36	17.75	16.67	17.33
MnO%	0.40	0.42	0.38	0.55	0.35	0.53	0.35	0.21	0.39	0.36	0.36	0.32	0.32	0.46	0.39	0.30
MgO%	9.16	10.86	11.77	6.49	11.07	9.74	12.39	16.44	8.85	7.98	7.15	8.66	10.87	7.94	10.20	11.31
CaO%	0.02	0.09	0.05	0.02	0.33	0.10	0.03	0.06	0.00	0.02	0.02	0.04	0.05	0.02	0.01	0.01
ZnO%	0.14	0.13	0.12	0.24	0.17	0.21	0.11	0.18	0.19	0.09	0.10	0.18	0.12	0.26	0.16	0.08
TOTAL	100.03	100.51	100.10	99.07	99.41	99.70	99.53	98.52	100.05	98.71	99.05	98.78	99.78	99.51	99.88	99.95
Apfu																
Si	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ti	0.03	0.08	0.02	0.02	0.05	0.01	0.04	0.01	0.01	0.06	0.03	0.01	0.01	0.01	0.01	0.06
Al	3.46	4.40	4.32	2.70	5.54	3.73	5.92	9.20	3.94	4.11	3.58	5.87	5.07	2.84	5.13	5.12
Cr	12.18	10.40	11.02	13.02	8.85	11.79	8.88	6.15	12.72	11.63	12.40	10.63	11.38	13.75	11.25	10.75
V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe <sup>+3</sup>	0.30	1.03	0.62	0.24	1.52	0.46	1.12	0.63	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.02
Fe <sup>+2</sup>	4.29	3.79	3.39	5.16	3.64	3.99	3.30	2.19	3.73	4.77	5.00	4.02	3.29	4.02	3.58	3.69
Mn	0.09	0.09	0.08	0.13	0.08	0.12	0.07	0.04	0.09	0.08	0.08	0.07	0.07	0.11	0.08	0.06
Mg	3.62	4.16	4.51	2.67	4.21	3.83	4.64	5.73	3.48	3.19	2.88	3.35	4.15	3.21	3.90	4.29
Ca	0.01	0.02	0.01	0.01	0.09	0.03	0.01	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Zn	0.03	0.02	0.02	0.05	0.03	0.04	0.02	0.03	0.04	0.02	0.02	0.03	0.02	0.05	0.03	0.01
TOTAL	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
Mg#	0.46	0.52	0.57	0.34	0.54	0.49	0.58	0.72	0.48	0.40	0.37	0.45	0.56	0.44	0.52	0.54
Fe3+#	0.02	0.07	0.04	0.02	0.10	0.03	0.07	0.04	-	0.01	-	-	-	-	-	0.00
Cr#	0.78	0.70	0.72	0.83	0.62	0.76	0.60	0.40	0.76	0.74	0.78	0.64	0.69	0.83	0.69	0.68

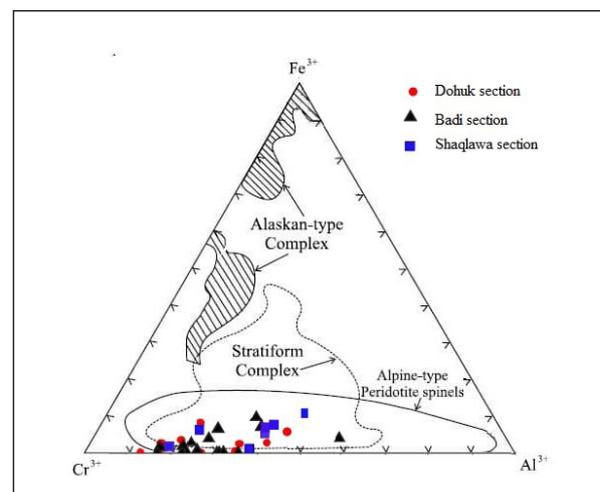
**Table 3.** Chemical composition of detrital chromite from Shaqlawa section, Gercus Formation.

Section.	Shaqlawa section						
	Sample no	GS3				GS4	
Spots	1	2	3	4	1	2	3
SiO <sub>2</sub> %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TiO <sub>2</sub> %	0.15	0.90	0.05	0.15	0.75	0.15	0.10
Al <sub>2</sub> O <sub>3</sub> %	9.56	20.96	20.60	12.38	24.34	21.74	20.96
Cr <sub>2</sub> O <sub>3</sub> %	60.84	44.77	50.36	54.58	34.62	42.76	44.86
Fe <sub>2</sub> O <sub>3</sub> %	1.48	4.56	0.96	5.11	9.01	6.47	5.91
FeO%	15.66	14.94	10.81	15.94	19.23	14.42	14.19
MnO%	0.33	0.31	0.20	0.34	0.33	0.32	0.31
MgO%	11.41	13.58	15.56	11.55	10.68	13.31	13.57
CaO%	0.05	0.03	0.04	0.11	0.15	0.10	0.02
ZnO%	0.04	0.12	0.05	0.08	0.14	0.13	0.10
<b>TOTAL</b>	<b>99.52</b>	<b>100.17</b>	<b>98.63</b>	<b>100.24</b>	<b>99.25</b>	<b>99.40</b>	<b>100.02</b>
<b>apfu</b>							
Si	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ti	0.03	0.17	0.01	0.03	0.14	0.03	0.02
Al	2.97	6.09	5.99	3.78	7.18	6.35	6.10
Cr	12.68	8.73	9.82	11.17	6.85	8.38	8.76
V	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe <sup>+3</sup>	0.29	0.85	0.18	0.99	1.70	1.21	1.10
Fe <sup>+2</sup>	3.45	3.08	2.23	3.45	4.02	2.99	2.93
Mn	0.07	0.06	0.04	0.07	0.07	0.07	0.06
Mg	4.48	4.99	5.72	4.46	3.98	4.92	5.00
Ca	0.01	0.01	0.01	0.03	0.04	0.03	0.01
Zn	0.01	0.02	0.01	0.02	0.03	0.02	0.02
<b>TOTAL</b>	<b>24.00</b>	<b>24.00</b>	<b>24.00</b>	<b>24.00</b>	<b>24.00</b>	<b>24.00</b>	<b>24.00</b>
Mg#	0.57	0.62	0.72	0.56	0.50	0.62	0.63
Fe3+#	0.02	0.05	0.01	0.06	0.11	0.08	0.07
Cr#	0.81	0.59	0.62	0.75	0.49	0.57	0.59

#### 4.3 Chromite provenance and paleotectonic setting

The chemical composition of chromite gives information on the types of source rocks in various tectonic settings (Lee, 1999). Chromite spinels form under a variety of settings, either from partial melting of upper-mantle peridotite or from mafic and ultramafic magmas. As a result, they are significant indicators of the host rock's original composition (Roeder, 1994). The geochemistry of chromite in mantle peridotites provides information about the residual mantle like its melting degree and melting condition, as well as the nature and the extent of melt/rock interaction, thus this information can be used to determine whether the mantle sequence was formed at Mid-Ocean Ridge (MOR) setting, at a Supra-Subduction Zone (SSZ), or those that were formed due to multiple tectonic settings. The important chemical parameters, which are used to determine the provenance of chromite are Cr #, Mg#, Fe<sup>3+</sup>#, and Ti content (Al-Juboury et al., 2009). Cr # [Cr/(Cr + Al)] ranges between 0.4 and 0.87; Mg# [Mg/(Mg + Fe<sup>2+</sup>)] ranges from 0.34 to 0.72; Fe<sup>3+</sup># [Fe<sup>3+</sup>/(Cr + Al + Fe<sup>3+</sup>)] ranging from 0.00 - 0.11 and Ti content ranging from 0.00 - 0.17. The TiO<sub>2</sub> content of chromite is also a very useful tool to elucidate the paleotectonic setting, low Ti, and Fe<sup>3+</sup> of chromite point to peridotites origin. This issue

can be supported by using the ternary plot of Cr<sup>3+</sup>, Al<sup>3+</sup>, and Fe<sup>3+</sup> (Fig. 3), which indicates that all samples are compatible with Alpine-type peridotites chromite.



**Figure 3.** Ternary diagram of Cr<sup>3+</sup>, Al<sup>3+</sup>, and Fe<sup>3+</sup> for detrital chromite of Gercus samples. The fields of Alpine-type peridotite, stratiform and Alaskan-type complexes are from (Cookenboo et al. 1997).

The high refractory nature of chromite ( $Cr\# = 0.4 - 0.87$ ) is more typical of supra-subduction zone chromite than chromite generated during the petrogenesis of mid-ocean ridge basalts (Dick and Bullen, 1984; Batanova and Sobolev, 2000). This conforms with the plotting of  $TiO_2$  vs.  $Al_2O_3$ , which shows that the majority of samples fall in the field of supra-subduction zone peridotite (SSZ peridotite) (Fig. 4). Through using the discrimination plot of (Poher and Faupl, 1988) (Fig. 5), it is evident that the samples fall within the range of harzburgite, which is more common than lherzolite.

The  $Cr\#$  of chromite from on-land Alpine-type peridotites ranges between 0.08 - 0.95. Peridotites that are predominate around the harzburgite-lherzolite boundary have  $Cr\# = 0.5$  (Values greater than 0.5 are harzburgites).

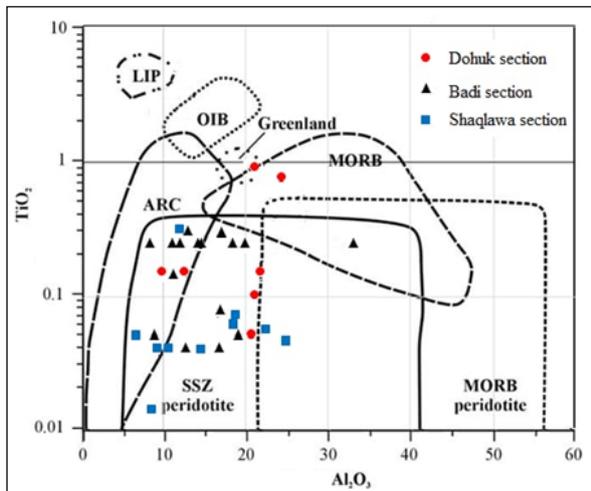


Figure 4.  $TiO_2$  vs.  $Al_2O_3$  relationship showing the tectonic setting for detrital chromite of the Gercus Formation (after Kamenetsky et al., 2001).

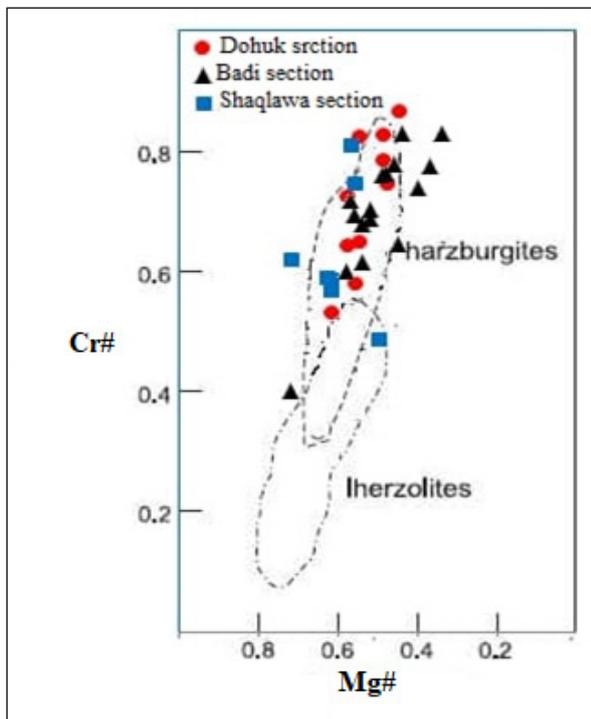


Figure 5.  $Cr\# - Mg\#$  diagram showing the discrimination fields of chromite derived from the two major peridotite subtypes (Poher and Faupl, 1988).

Ophiolitic harzburgites have similar characteristics to fore-arc peridotites, which belong to ocean-floor peridotites (Arai, 1994). When using  $Cr\# - Mg\#$  diagram (Fig. 6), the samples plot within the forearc peridotite field with a minor boninite signature. We primarily describe chromite chemistry to Tethyan ophiolites as chromites are Al-chromite (with intermediate  $Cr\#$  0.4 to 0.9) more related to the podiform Alpine-type and they can be compared to other chromites from Iraqi and Turkish ophiolitic complexes, (chromites from Iraq's Zagros ophiolitic complexes (Buda and Al-Hashimi, 1977), as well as those from Turkey's Ortakale region (Tiysiiz, 1993). The Zagros ophiolite peridotites have high  $Cr\#$  spinel compositions, which mostly plot in the fore-arc field (Moghadam and Stern, 2011). The serpentinized peridotites and related chromites from north of Iraq according to (Al-Jawadi, 1980) are chemically, mineralogically, and texturally closer to Alpine-type peridotites. They are rich with Al in general and more similar to those of podiform alpine-type. This supports the interpretation of the current research findings. The subduction of the Neo-Tethyan oceanic crust beneath the Iranian and Turkish microcontinents is part of the history of the Alpine Orogeny in the north of Iraq. Subduction in this area lasted for most of the Cretaceous and Tertiary periods and the continental plate collision between the Arabian passive margin and the active edges of Turkey and Iran consumed the Neo-Tethyan oceanic crust completely (Buday and Jassim, 1987).

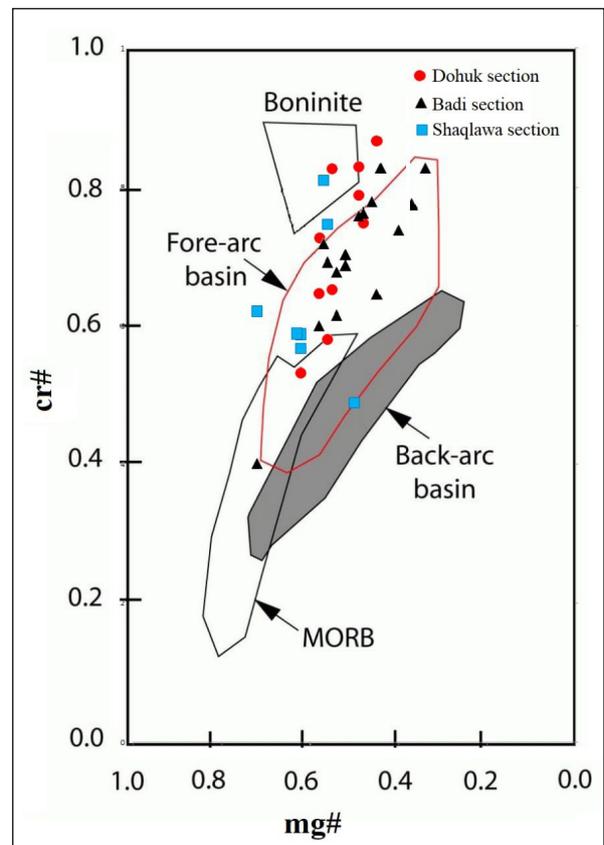


Figure 6. Cr-number vs. Mg-number diagram. Individual data fields are the composition of chromites from back-arc and fore-arc basin peridotites (Dick and Bullen, 1984).

## 5. Conclusion

Chromite is a sensitive mineral that indicates the source and tectonic setting of the rocks, which host the mineral. In the current study, a mineralogical and geochemical study of the detrital chromite mineral was conducted in the sandstone of the Gercus Formation (middle Eocene). Chromite exists in fine sandstone and is characterized as grains with shiny black color. Based on the geochemistry of detrital chromite from the Gercus Formation, it can be concluded that detrital chromite grains are almost classified as Al-chromite. The comparison of the chromite displays relatively high Cr# (0.4 to 0.87) and low TiO<sub>2</sub> content (0.014% - 0.9%) suggesting that clastics of the formation were derived from ophiolite source rocks that contain harzburgitic mantle peridotites and developed primarily in a supra-subduction zone environment. The Al-chromite is more related to the podiform Alpine type and they are equal to other chromite from Iraqi and Turkish ophiolitic complexes (chromites from Iraq's Zagros ophiolitic complexes and Turkey's Ortakale region).

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