



Geophysical, Geochemical and Structural Features of Chromite Ore in Kuradawe Village/ Mawat Ophiolite Complex, Kurdistan Region, NE Iraq

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Abstract

Small lensoidal bodies of massive and disseminated chromitites have been examined in association with ultramafic rocks of the Mawat Ophiolite Complex (MOC), Iraqi Zagros Thrust Zone, Northeastern Iraq. The Chromites ore have variable thickness enveloped by dunite and of, exhibiting transitional boundaries to harzburgitic host rocks.

The primary Chromite composition exhibits high Cr varieties; the average Cr# of Chromite is 0.714, with < 0.3 % TiO₂ content, which may reflect the crystallization of Chromite from boninitic magma. The result of the gravity survey leads to lateral delineation of the ore body and estimates an area of about 2800 m². The thicknesses of different Chromite pods were estimated to be in the range of 10 – 35 m. Structural feature show that such ore bodies have internal structure making angle of 10–12 degrees with dunite wall and surrounding peridotite which indicates that Chromite ore subconcordant type.

Introduction

Chromite ((Mg, Fe⁺⁺)(Cr, Al, Fe⁺⁺⁺)₂O₄) is the only source for the metallic element chromium, which is used in the metallurgical, chemical, and refractory industries. Chromite is a source of chromium. It is widely demanded in the steel industry (to induce hardness, toughness and chemical resistance in steel), in making Ni chrome (an alloy with iron and nickel, that is used to form high temperature, abrasion, corrosion and oxidation resistant heating units), and in plating and painting industry [1]

Podiform Chromite deposits are small magmatic Chromite bodies formed in the ultramafic section of an ophiolite complex in the oceanic crust. These deposits have been found in Mid Oceanic Ridge (MOR), off-ridge, and suprasubduction tectonic settings [2]. Most podiform Chromite deposits are found in dunite or peridotite near the contact of the cumulate and tectonite zones in ophiolites. In this study seven individual podiform Chromite deposits in Kuradawe village within MOC have been identified.

The studied area is located in Iraqi Kurdistan Region, about 30km NE of Sulaimani city within the MOC (Figures: 1A and 1B). MOC represents a part of the Iraqi Zagros thrust zone which trends NW-SE. The intrusion massif, extend for 25 km, with a width of 7-12 km, making a total area over 200 square kilometers [3]. The area was visited and there was the decision to use gravity geophysical survey over there to look down in shallow depths for the possibility of tracing the dimension of ore.

Geological Setting

Fragmented ophiolite complexes are abundant in the Iraqi Zagros Suture Zone (IZSZ), as a part of the Mesozoic Tethyan ophiolitic belt that marks the boundary between Arabian and Eurasian plates in northeastern

Iraq. These ophiolites give geological continuity between the Turkish Taurus and the Iranian Zagros ophiolites with other complementary parts extending to Balkans in Europe and to Pakistan and Tibet in Asia. The ophiolites in the IZSZ were emplaced in two major episodes in the Upper Cretaceous and Paleogene [4] and [5].

The Mawat ophiolite complex represented as Mesozoic ophiolites [6] (Figures: 1A, 1B and 1C) which comprise relatively coherent blocks striking NW-SE and displaying nearly complete lithostratigraphic sequence.

The Mawat ophiolite complex extends and covers an area of about 200 square km and crops out in the northeastern part of Iraq (Figures: 1A and 1 B). It is considered as a remnant of oceanic lithosphere formed in the Upper Cretaceous. Together with the Gimo sequence, of marble and calc-schist, the Mawat ophiolite is part of the so called Mawat Nappe. Although tectonically dismembered and affected by oceanic and regional metamorphism, the following stratigraphic and tectonic units have been recognized in the Mawat ophiolite: ultramafic rocks, gabbros, diabases and a volcano-sedimentary cover [4] (Figure: 1C).

The ultramafic, are partially to totally serpentinized, forming a thick sequence (up to 2000 m) and possibly they represent the mantle sequence. They are in tectonic contact with the Walash –Naopurdan nappe which consists of a volcano-flysch sequence of Paleocene to Oligocene age [7]. This nappe is overlain by the autochthonous Red Beds formed in shallow marine to continental environment during Miocene.

The ultramafic bodies varying in size from 1 up to 10 square km and are exposed mostly in the central part of the Mawat nappe. The most abundant ultramafic rocks in the Mawat area consist of harzburgite, cut by pyroxenite dykes, accompanied by minor dunite and lherzolite. The harzburgites host chromitite bodies that occur associated with pod of dunite [8]and [4]

Gabbros are more abundant than the ultramafic rocks in the Mawat ophiolite. They occupy the central part of the ophiolite and cover an area of about 170 square km. According to [8], two main types of gabbro have been recognized: banded and coarse. They are depositional or tectonically overlain by about 400 m thick metavolcanites [3]. These metavolcanites consist of spilitic basalt, metabasalt, metadiabase, green schist and amphibolite and some metapyroclastics [6] and [9].

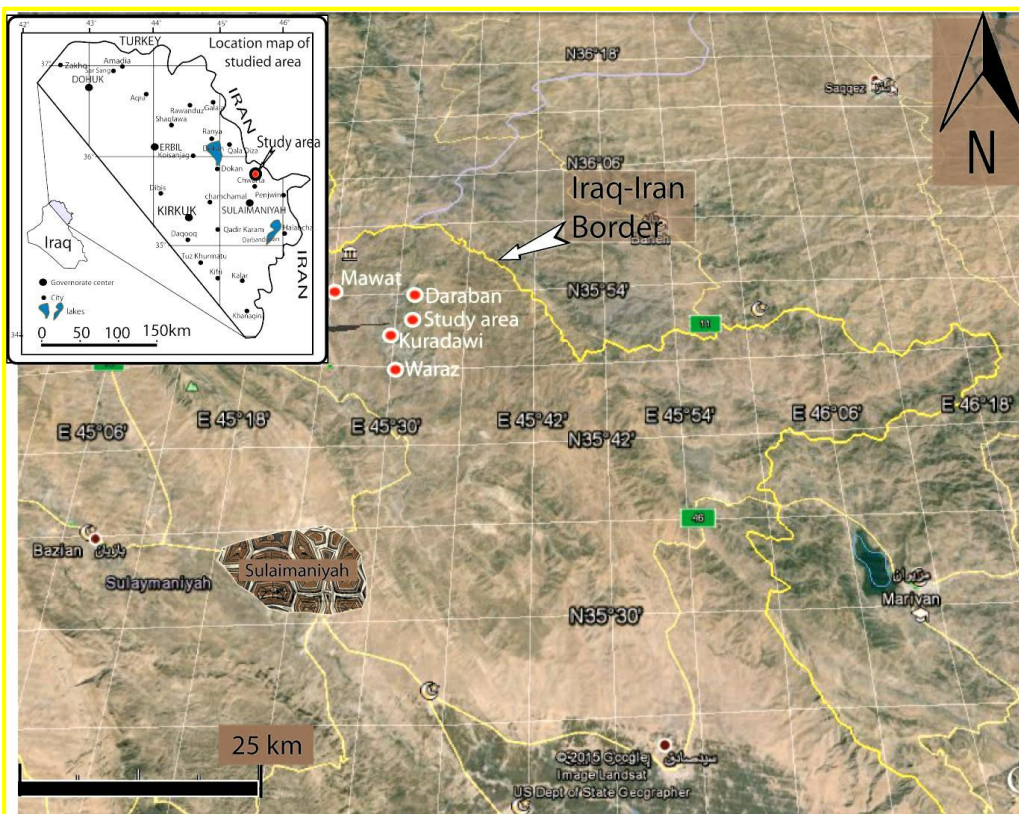


Figure - 1 A: Location map of the studied area on the satellite image from Google Earth.

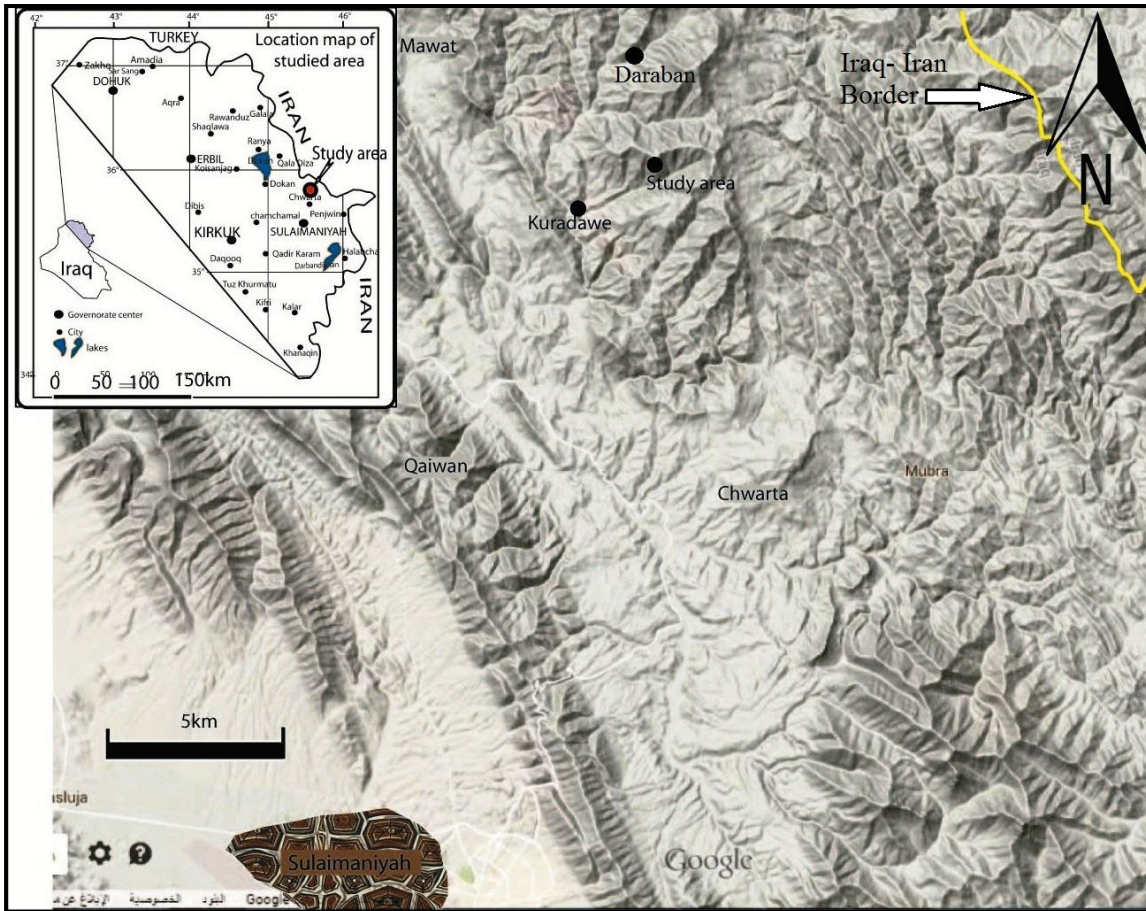


Figure - 1 B: Google map shows the location of the studied area.

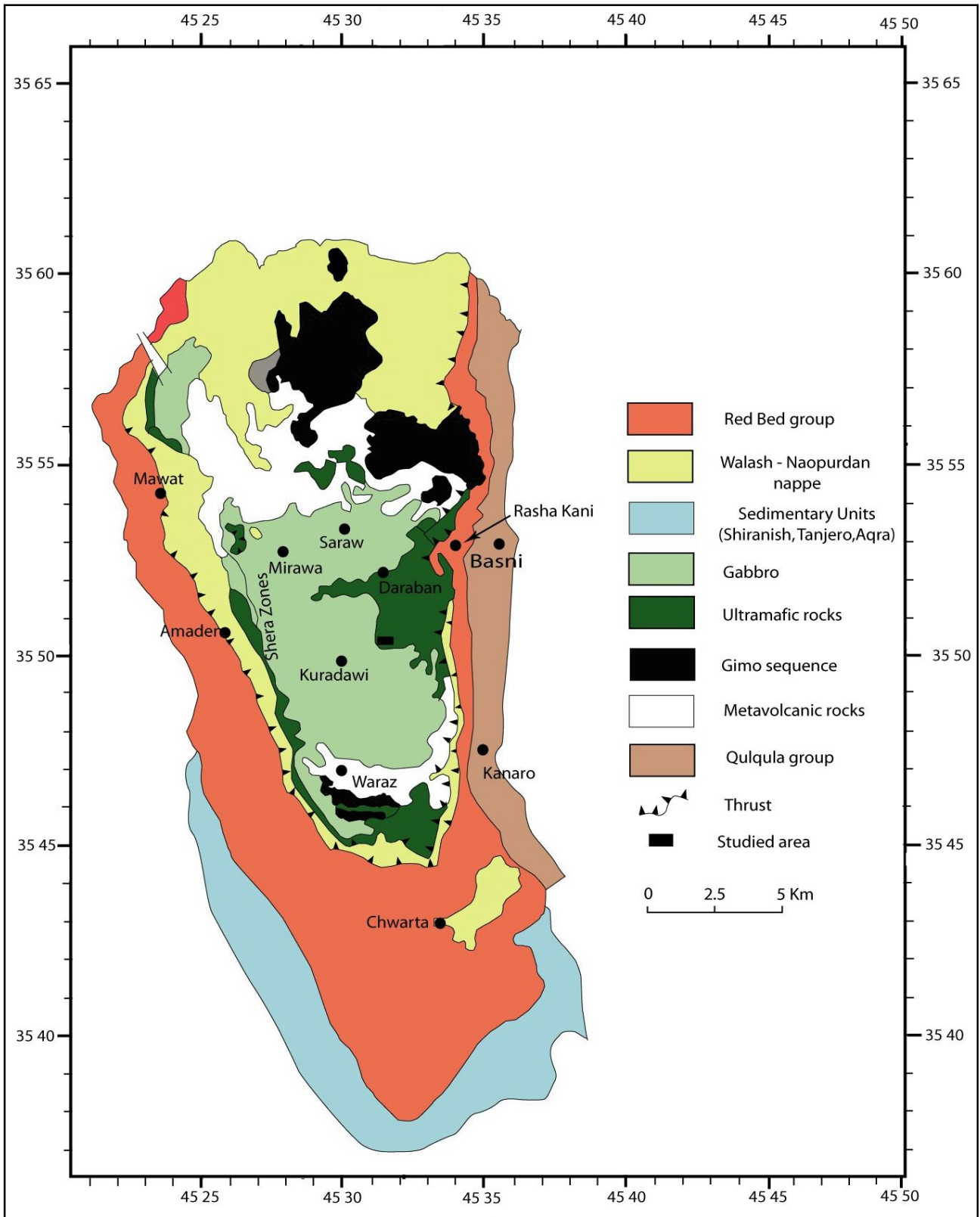


Figure -1C: Geological map of Mawat - Chwarta area, Kurdistan Region, NE Iraq modified after [3]

Chromitite:

The chromitite samples were collected in area located about 5 km south of the Daraban and 3 km north east of the Kuradawe village (*Figure: 1B*). The GPS coordination's of the collected samples are 35° 50.889' N and 45° 31.931'E.

According to their morphology, the Mawat chromitites can be classified as podiform (*Figure: 2*). They are always rimmed by a dunite envelope and occur associated with harzburgite, very close to the contact with gabbro (*Figure: 1C*). Their size varies from 0.3 to 2 m width and from 0.5-12 m length. Chromitite texture is predominantly massive (*Figure: 2A*), however small disseminated and banded chromitites have been also recognized. Late shearing and faulting obliterate these primary textures forming also cataclastic, pull-apart, and brecciated textures.



Figure - 2: Chromitite pod exposed in the studied area.

Previous Studies

Previously the geochemistry of chromitites rocks in Kuradawe area was studied by [10],[11], [8] and [12]

Aim of the Study:

The preliminary geochemical studies of the chromitites rocks indicate a high grade of chromium content. Determination reserves and economic important of the chromitites needs detailed geochemical, geophysical and structural studies. The geophysical study is proposed for determining the dimension and extends of chromitites bodies.

Petrography of Chromitite Rocks

The mode of occurrence of almost all Chromite deposits in Kuradawe area is podiform or a rod and they are highly discontinuous in structure. All the studied samples were collected within a radius of a few meters. Each was taken from different but neighboring chromitite pods. One polished section was prepared for each sample

and ten polished and thin sections were cut from five samples of massive and brecciated chromitite for investigation by reflected light optical microscopy and transmitted light microscopy.

Chromitite texture is predominantly massive, however small disseminated and banded chromitites have been also recognized. Late shearing and faulting obliterate these primary textures forming also cataclastic, pull-apart, and brecciated textures (*Figure: 3A*). The chromium ore of the deposits in Kuradawe vary from anhedral to euhedral, but most are anhedral, and they range in size from less than 1mm to more than 2mm in diameter. The massive chromitite consists of more than 75 volume % of Chromian spinel. Chromian spinel is brecciated and in the matrix is rich in chlorite and amphibole, serpentine, and olivine (*Figures:3 A & B*). Chromian spinel is dark reddish brown in thin section, indicating high-Cr character and exhibited pull - a part texture (*Figure: 3A*). It contains rounded inclusions to primary anhydrous silicates (olivine and clinopyroxene) as well as platinum group mineral (PGM) all PGM are (sulfide mineral Laurit). Chromian spinel has rims, veins and patches of alteration products of ferrite Chromite that have higher reflectivity appearance by reflected light (*Figure: 3C*).

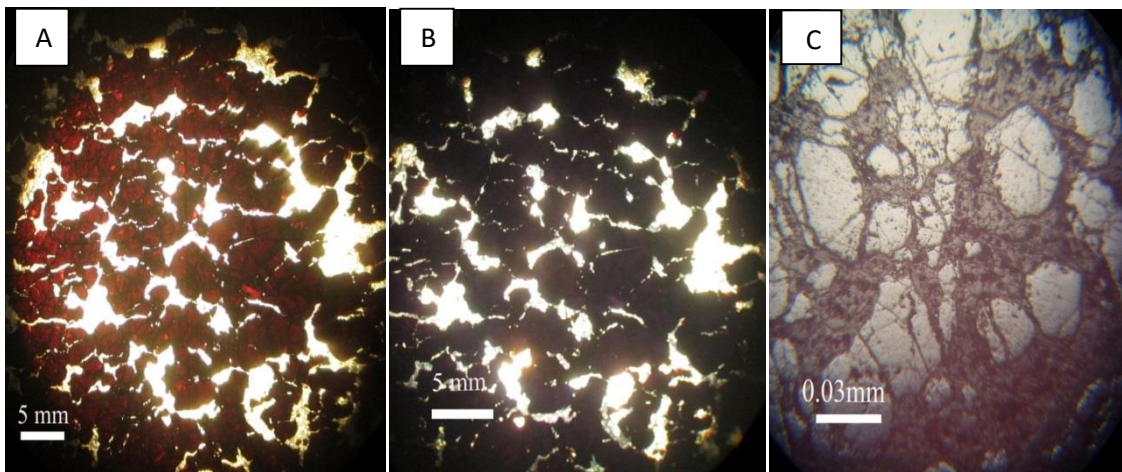


Figure- 3: Chromian Spinel in thin section (A & B) and under reflected light (C).

Geochemistry of Chromitite Rocks

Despite the metamorphic overprint that has affected the Mawat ophiolite, Chromite is generally unaltered, alteration being limited to development of ferrian Chromite along cracks and at the contact among different crystals. As a result, the magmatic composition of Chromite has been obtained in the preserved core of spinel grains. The geochemical analyses are taken from [8] and listed in (*Table 1*). The content of the major oxides is in the following ranges: Cr_2O_3 (49.5 to 52.61wt %), Al_2O_3 (9.79 to 15.96 wt%), MgO (7.19 to 11.49wt%), FeO (13.76 to 20.51wt%) and Fe_2O_3 (5.1 to 7.6 wt %). The TiO_2 content is very low, being in most cases less than 0.3 wt% which is typical of ophiolitic chromitites and classified as Cr-rich.

The chromian spinel is described in this article is relatively high in Cr_2O_3 content varies between 49.26 to 52.61 Wt % and the Cr#, ranges between 0.68 to 0.78, (average Cr# =0.714) and belongs to podiform chromitite of alpine type peridotite. The Mg# ranges between 0.38 and 0.6 (*Table 1*) and average is 0.51 and this is indicative of their unaltered nature [13] and [14].

Table- 1 Mineral Chemistry of Chromium Spinel.

<i>Types</i>	<i>Massive Chromite</i>						<i>Brecciated</i>					
	<i>W19</i>	<i>W19</i>	<i>W19</i>	<i>W25</i>	<i>W25</i>	<i>W28</i>	<i>W28</i>	<i>W30</i>	<i>W30</i>	<i>W33</i>	<i>W33</i>	
<i>Samples</i>	<i>W19</i>	<i>W19</i>	<i>W19</i>	<i>W25</i>	<i>W25</i>	<i>W28</i>	<i>W28</i>	<i>W30</i>	<i>W30</i>	<i>W33</i>	<i>W33</i>	
<i>SiO₂</i>	0.03	0.06	0.04	0.04	0.02	0.05	0.04	0.04	0.03	0.00	0.03	
<i>Al₂O₃</i>	9.79	13.58	13.63	14.24	14.25	14.25	14.15	15.96	14.95	13.70	13.66	
<i>TiO₂</i>	0.21	0.15	0.16	0.16	0.16	0.21	0.21	0.23	0.20	0.16	0.14	
<i>FeO</i>	27.34	24.62	25.64	18.66	18.35	22.07	21.90	19.69	20.53	24.41	23.92	
<i>MnO</i>	0.53	0.48	0.51	0.40	0.40	0.41	0.38	0.34	0.37	0.39	0.44	
<i>MgO</i>	7.19	7.93	8.04	11.49	11.70	10.30	10.45	11.28	10.93	7.99	7.93	
<i>CaO</i>	0.01	0.01	0.00	0.00	0.01	0.03	0.00	0.04	0.02	0.02	0.00	
<i>Na₂O</i>	0.03	0.03	0.03	0.03	0.07	0.03	0.05	0.00	0.01	0.08	0.01	
<i>K₂O</i>	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.03	0.00	0.00	0.01	
<i>NiO</i>	0.03	0.03	0.04	0.07	0.07	0.08	0.09	0.06	0.03	0.06	0.01	
<i>Cr₂O₃</i>	52.61	50.92	50.17	52.60	52.64	50.42	51.03	49.57	51.33	50.68	51.37	
<i>Sum</i>	97.77	97.82	98.20	97.65	97.67	97.74	98.31	97.22	98.38	97.47	97.53	
<i>Fe³⁺</i>	7.60	6.84	7.13	5.19	5.10	6.13	6.09	5.47	5.71	6.79	6.65	
<i>Fe²⁺</i>	20.51	18.47	19.23	14.00	13.76	16.55	16.43	14.76	15.40	18.31	17.94	
<i>Total</i>	98.54	98.51	98.92	98.18	98.18	98.36	98.92	97.77	98.96	98.15	98.20	
<i>Si</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
<i>Al</i>	0.39	0.53	0.53	0.55	0.55	0.55	0.54	0.61	0.57	0.54	0.54	
<i>Ti</i>	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	
<i>Cr</i>	1.42	1.34	1.32	1.35	1.35	1.31	1.32	1.27	1.31	1.34	1.35	
<i>Fe³⁺</i>	0.20	0.17	0.18	0.13	0.12	0.15	0.15	0.13	0.14	0.17	0.17	
<i>Fe²⁺</i>	0.59	0.51	0.53	0.38	0.37	0.45	0.45	0.40	0.42	0.51	0.50	
<i>Mn</i>	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
<i>Mg</i>	0.37	0.39	0.40	0.56	0.57	0.50	0.51	0.55	0.53	0.40	0.39	
<i>Ca</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
<i>Na</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	
<i>K</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
<i>Ni</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
<i>Sum</i>												
<i>cation</i>	2.99	2.97	2.98	2.98	2.99	2.99	2.99	2.98	2.98	2.98	2.97	
<i>Mg#</i>	0.38	0.43	0.43	0.59	0.60	0.53	0.53	0.58	0.56	0.44	0.44	
<i>Cr#</i>	0.78	0.72	0.71	0.71	0.71	0.70	0.71	0.68	0.70	0.71	0.72	
<i>Fe³⁺ #</i>	0.10	0.08	0.09	0.06	0.06	0.08	0.07	0.07	0.07	0.08	0.08	
<i>Fe²⁺ #</i>	0.62	0.57	0.57	0.41	0.40	0.47	0.47	0.42	0.44	0.56	0.56	

Structural Study

The measurements of the thrust attitude of the country rocks and podiform chromitites show that their strikes follow regional strike of the NW segment of the Zagros Fold Thrust Belt (N28°W- N32°W) and the dip is to the NE (*Figure: 4*). The average dip of the bedding planes of the country rocks is 38°while of the chromitites podiforms is (25°) (*Table: 2*). Structurally the podiform chromite ore bodies are classified by [*15*] into three major types: discordant, subconcordant and concordant with (foliation and lineation or bedding planes of hosted rocks). Discordant deposits are very irregular in shape and crosscut banding and foliation in enclosing peridotite. Subconcordant deposits are generally tabular in shape and lie within 10° to 25° in strike and/ or dip to the foliation. Concordant deposits are also tabular in shape and lie parallel to foliation in peridotite. Following this classification the podiform chromite ore bodies in study area are of sub-concordant and lie

within (10-12 degrees) different in dip with dunite wall and surrounding peridotite. StereoWinFull120, 2002, Software by Richard W. Allmendinger were used for construction the attitude bedding planes.

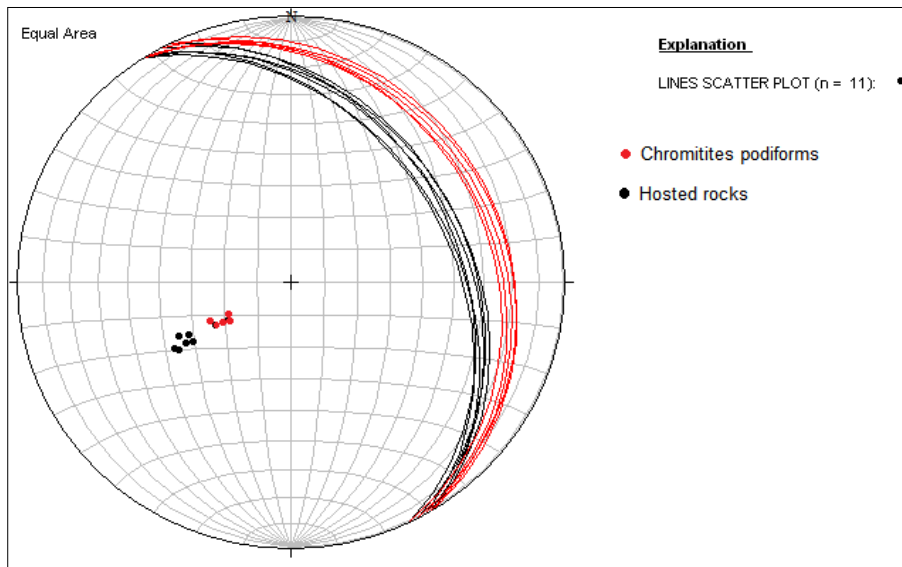


Figure-4: Stereographic projection of the field data.

Table - 2: Measurements of the attitude of the country rocks and podiform chromitites

	<i>Strike</i>	<i>Dip</i>	<i>Dip direction</i>
<i>Hosted</i>	328°	40°	NE
<i>Rocks</i>	328°	35°	NE
	329°	37°	NE
	330°	41°	NE
	332°	35°	NE
	334°	38°	NE
<i>Chromite</i>	334°	27°	NE
<i>Ore</i>	332°	21°	NE
	330°	26°	NE
	329°	24°	NE
	328°	22°	NE

Gravity Geophysical survey

Field work and Data Acquisition

The instrument which was used is Scintrex CG-5 Autograv gravimeter with an accuracy 0.001 mgal (Figure: 5). Also a hand held GPS (Garmin GPSMAP type with ±1m accuracy) was used for location determination and elevation of gravity stations. The survey was done within two days of field work, a sum of 53 gravity points were measured along four profiles in a rectangular area of about 150m x 200m (Figure: 6). Due to the rough terrain of the area (rocky and cliffs); the station spacing could not be kept equal.



Figure -5: Data acquisition using Scintrex CG-5 gravimeter in the field

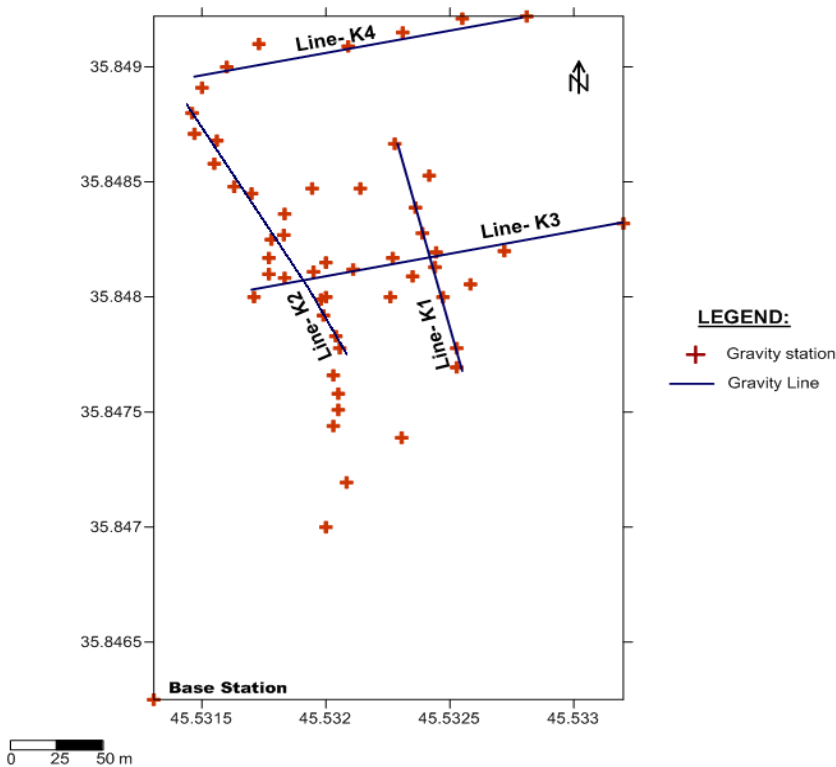


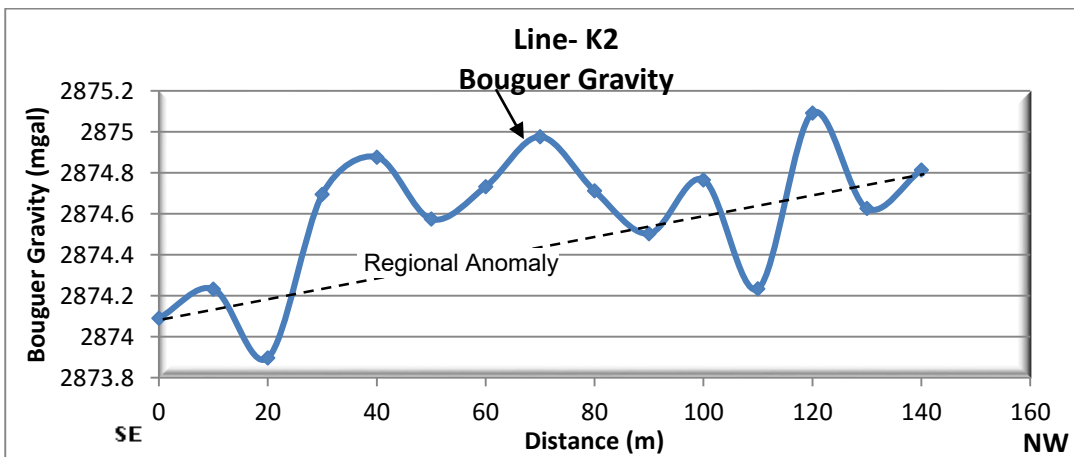
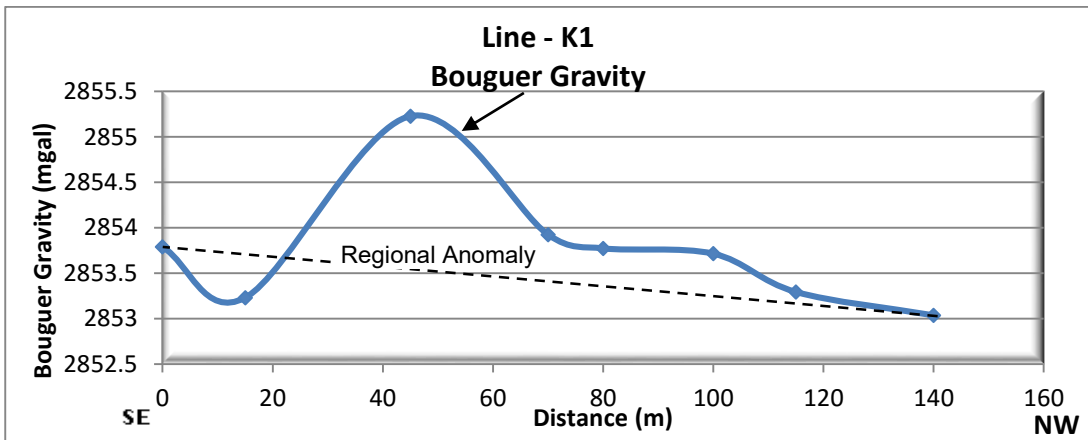
Figure -6: Survey layout indicating the measured gravity points.

Data Correction:

The observed gravity data was corrected for; Drift Correction which was applied by reoccupying a base station. Latitude Correction; was applied using International Gravity Formula (IGF) 1967. In 1980, the normal ellipsoid was subjected to further refinements. The produced changes were too small to be of practical significance. Thus the GRS67 formula stayed adequate for work in gravity exploration [16]

Elevation Correction: was applied using a datum plane of 1500m a.s.l., and a mean density of 3.38 g/cm³. Terrain Correction: was applied using Hammar Chart (circles A-G), and Topographic maps with 1:20000 scale.

Bouguer gravity profiles were obtained (Figure: 7) they could be interpreted after the regional and residual anomaly were separated. All residual gravity profiles contain positive anomalies except the line K4 with is a negative anomaly due to its far distance from other profiles; it may be located out of the outline area of the ore.



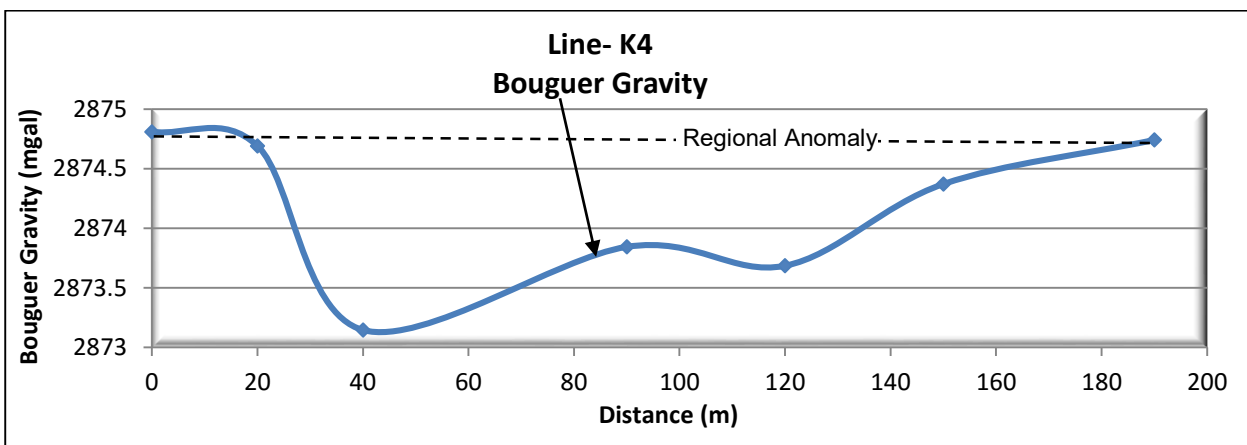
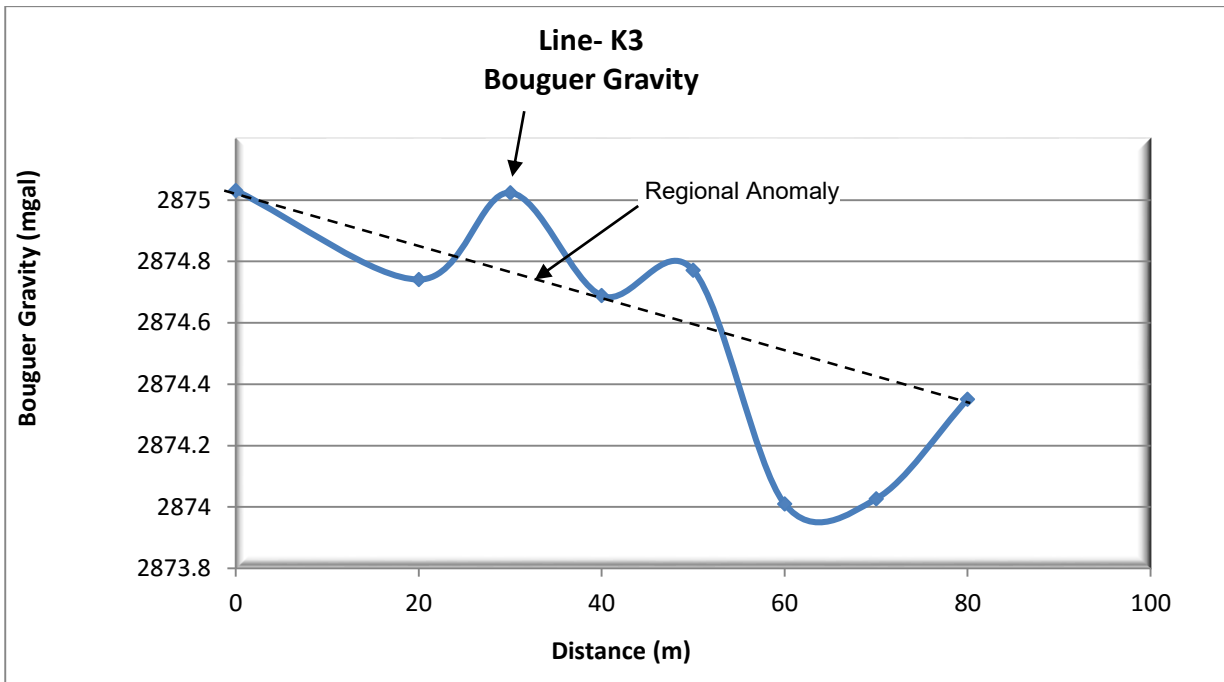


Figure-7: Bouguer gravity profiles along the lines K1, K2, K3 and K4.

Interpretation

The mean density was calculated from densities of different rock samples acquired from rock outcrops in the area which are; (Chromite and Dunite) in the studied area the chromitite are enveloped by dunite. Accordingly, the density contrast between Chromite and the country rocks was found to be 1.10 g/cm^3 .

Direct gravity interpretations using the methods described by [17], [18] and [19] was applied prior to modeling, to obtain initial depth limit of the anomalous bodies. These results were adopted in the modeling procedure along the gravity profiles (Figure: 8).

Table - 3: Densities of different rock types in the area

#	Rock name	Mass (g)	Volume (cm ³)	Density (g/cm ³)
1	Dunite	141.47	50	2.83
2	Chromite	215.94	55	3.93
	Total			6.76
	Mean Density			3.38

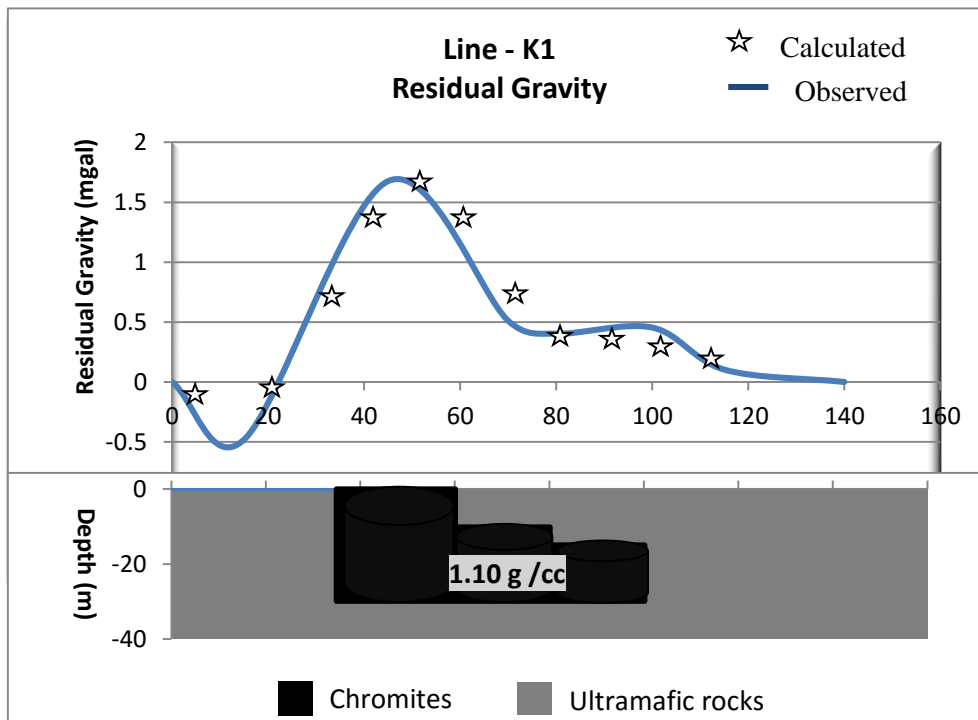


Figure- 8: Simple gravity modeling along Line K1.

Results:

The amplitudes of the positive residual anomalies range from 0.38 mgal to 1.68 mgal, while their width outcrops from 12 m to 70m. They are probably the effect of Chromite pods which are seen on the surface.

From the modeling of the gravity profiles the depth to top of the Chromite pods were calculated and found to be ranging from exposed on the earth’s surface to 15 m below surface. While the thickness of the Chromite pods is ranging from 12 m to 35 m. These results are in *Table: 4*

Table - 4: The summary of obtained results

	Line K1	Line K2	Line K3
Lateral Extension (m)	70	60	40
Thickness (m)	35	20	12

The tonnage of the ore could not be determined without a detailed grid system data collection, as described in [20] using Gauss Theorem;

$$M_E = 23.9 \sum (\Delta g \delta A) \text{ Tonnes} \quad M_E: \text{Total Mass, } \Delta g: \text{Gravity anomaly, } \delta A: \text{Area (m}^2\text{)}.$$

The Outline of Kuradawe Chromite Ore was drawn from the results of the gravity data interpretation and assumed to have dimensions of about 70m x 40m (Figur.:9).

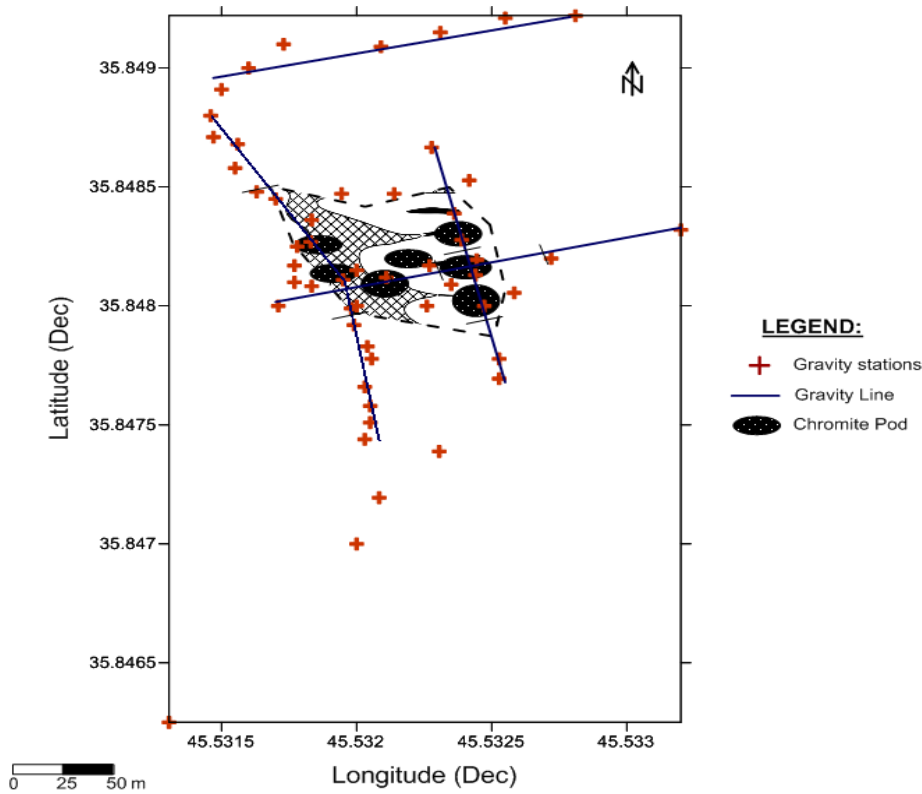


Figure -9: Map of the outline of the Chromite ore.

Discussion:

Since the results of the geochemistry study for Chromitite rocks in Kurradawe area on several samples was very promising, and containing high quantities of Chromium almost 50% and more; therefore a geophysical study was found to be a necessary choice to figure out the dimensions of the ore body regarding its area and thickness over the area under consideration. To have a clear image of the subsurface structural situations of the podiform Chromites, beside the geophysical study, a structural investigation was suggested and found to have contributions in the gravity modeling procedure of the anomalous bodies that suggested a vertical cylinder case to be close to the Chromite pods.

The studied area was mountainous, has rocky surface and cliffs; that restricted the gravity data collection in a grid manner. As a result the tonnage of the ore could not be determined.

Conclusions:

- 1- The geochemical study of chromitites rocks indicates a typical of ophiolitic chromitites and classified as Cr-rich
- 2- Structurally the podiform chromite is of type sub-concordant and lie within (10-12 degrees) different in dip with dunite wall and surrounding peridotite.
- 3- The Chromitite ore area was outlined using the extension of the ore along the gravity profiles, and found to have dimensions of 70 m by 40 m covering an average area of about 2800 m².
- 4- The depth to top of the Chromite pods was found to be ranging from exposed on the earth's surface to about 15 m below surface.
- 5- The thickness of the Chromite pods was found to be ranging from 12 m to about 35 m.

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