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Chapter 1

Introductory Chapter: Mineral Exploration from the Point of View of Geophysicists

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1. Introduction

Mineral exploration is vital in many countries to increase the income of their people, and their economy relies upon discovering minerals. The minerals excavated are iron, copper, gold, silver, molybdenum, zinc, coal, uranium, sulfide, tin, chromite, potash, etc. From the point of view of geophysicists, geophysical methods are playing an important role in mineral investigation, groundwater investigation and hydrocarbon exploration [1–3]. Geophysical methods are grouped into two different kinds which are passive and active methods. Passive techniques measured the Earth's natural fields as gravity, magnetic and self-potential (SP), while active methods distinguish variabilities of physical parameters in the Earth's layers produced by non-natural sources like seismic, electrical resistivity, induced polarization methods, etc. Various geophysical techniques rely upon different physical properties in the subsurface or deeper. The selection of a particular method relies on various parameters including cost, efficiency, accessibility, and type of application. In addition, a single choice of a geophysical method in any application occasionally provides poorly constrained results. So, a combination of two or more approaches certifies much more consistent results. This methodology is called integrated geophysical approach that ensures more prominent precision and higher consistency of results. It has to be emphasized that geophysical models are generally not unique regarding geometry (shape, size, and depth) of the buried structures. The spatial location of the buried sources and their depth can also be precisely assessed by some mathematical ways [4].

2. Geophysical methods: selection and objectives

The worth of geophysical techniques in mineral investigation relies on the variability of physical properties as well as on local geological environment, topography, etc. Each region

Geophysical methods	Measured field	Physical properties	Units	Typical minerals and applications	Exploration depth
Gravity	Natural gravity field of the Earth	Density	mGal	Sulfides including sphalerite, barite, mining, hydrology, plate tectonics	All
Magnetic	Natural magnetic field of the Earth	Magnetic susceptibility Remanent magnetization	nT	Magnetite, ultramafics, iron-rich rocks, basin analysis, plate tectonics	Until curie isotherm
Self-potential	Natural telluric current	Electrical conductivity	mV	Metallic sulfides, serpentinite, graphite, water-filled shears, salt water	A few hundred meters

Table 1. Main natural geophysical methods and their essentials in mineral exploration.

tends to have its own distinct geophysical identity requiring the adoption of appropriate geophysical methods. Typically, more than one method is used in one survey, to decrease the ambiguity in deciphering the nature of unknown resources below the surface. Some important geophysical methods (**Table 1**) have been chosen in this chapter to demonstrate how we use these methods in mineral exploration.

3. Gravity method

The gravity method studies anomalies of the Earth's gravitational field due to changes in densities below the surface. Density changes (density contrast) are induced by an occurrence of

Mineral/rock	Density (g cm^{-3})	Magnetic susceptibility (10^{-6} SI)
Gold	19.28	−0.14
Chromite	4.80	3000–120,000
Iron	7.87	3,900,000
Copper	8.90	−9.63
Graphite	2.16	−80 to 200
Hematite	5.26	500–40,000
Magnetite	5.20	1,000,000–5,700,000
Pyrite	5.01	35–5000
Sphalerite	4.08	−31 to 750
Rock salt	2.5–2.6	-0.01×10^{-3}
Dolomite	2.87	−10 to 940
Granite	2.64	0–50,000

Table 2. Density and magnetic susceptibility of some minerals and rocks.

a causative body (target source) within the surrounding rocks. Rock densities are considered as one of the variables of all geophysical parameters. The density of rocks is dependent on both mineral composition and porosity. **Table 2** shows examples of some mineral and rock density values. Gravity method can be used from the land to the air and in marine environment. Gravity anomalies are due to anomalous density within the Earth. Gravity method has wide-ranging uses in mineral, hydrocarbon, cave, geothermal, and archeological investigations [5–7]. The target of gravity interpretation is to locate and characterize the buried mineral source parameters, in particular, the density contrast, depth, and shape [8–10]. Several methodologies are used to interpret gravity data [11–14]. More recently, three-dimensional modeling and inversion of gravity data provide more accurate results. In these days, new nonconventional methods are used such as particle swarm optimization, very fast simulated annealing, genetic algorithm, forced neural network, and differential evolution algorithm. **Table 2** demonstrates value of the density of rock and mineral examples.

4. Magnetic method

Magnetic method is one of the oldest branches of geophysics and used in many exploration issues such as mineral and ores as massive sulfide, iron, gold, and porphyry copper deposits. Magnetic data interpretation has shown its efficiency in the identification of deep and shallow structures known to employ a structural control on mineralization occurrences [15, 16]. Uniform geological models (geologic contacts, thin sheets, cylinders, and spheres) are frequently employed in magnetic inversion to estimate the body factors (the amplitude factor, the depth, the index angle, the location of the origin, and the shape) and have a vital role in many exploration issues. These models cannot be an exact geologically representation, but are generally a good tool in magnetic interpretation to calculate, in particular, the body parameters. Several elucidation approaches of the magnetic data above inhomogeneous geological structures have been recognized. These approaches can be characterized into four categories as follows: Category I is the well-known two- and three-dimensional magnetic modeling and inversion for irregular structures. Category II is recognized by using residual magnetic anomalies only. Category III is relied upon using not only the residual but also the measured magnetic data. Category IV is dependent on utilizing the metaheuristic algorithms like the particle swarm optimization (PSO) method, the genetic algorithm (GA) method, the differential evolution algorithm (DEA) method, the simulated annealing algorithm (SAA) method, the ant colony optimization (ACO) method, and the neural network (NN) method. Magnetization directionally consists of adding induced and remanent components. Induced magnetization depends on the magnetic susceptibility of the material (**Table 2**) and the magnitude and direction of the Earth's magnetic field, whereas remanent magnetization reflects the past magnetic history of the material.

5. Self-potential method

Self-potential (SP) is one of the passive geophysical techniques that measure the natural Earth's surface electric potential happening by many reasons like the difference between minerals

and their hosting, bioelectric generation from plants, and electrochemical and electrokinetic. Sato and Mooney [17] demonstrated that this potential has different types as electrokinetic potential produced from the stream of a fluid with certain electrical properties going through a pipe or permeable medium with various electrical properties. In addition, several another mechanisms (diffusion, mineralization, etc.) produced this SP. The self-potential method has a wide range in different applications in exploration of geophysics, hydrogeophysics, and environmental problems and mineral exploration such as metallic sulfides, magnetite, graphite, and uranium. Several assessable elucidation approaches of the SP data over the buried geologic structures have been established. These approaches can be classified into two categories. The first category is usually dependent on using simple geological models (spheres and cylinders) to appraise the parameters for buried structures and has a vigorous role in many investigation problems as linear and nonlinear least squares methods, moving average and gradient methods, depth-horizontal curve method. These models are not wholly geologically perfect, but they are often useful in SP interpretation to calculate the body parameters. The second category is dependent on two- and three-dimensional modeling and inversion methods. However, a portion of these methods requires good initial parameters, using a few data point and distances, and requires more time.

Finally, the three potential methods (gravity, magnetic, and self-potential) mentioned above have been used to evaluate the source parameters but are suffering of ill-posedness and nonuniqueness in finding a global solution [18]. The usage of simple geometrical structures in gravity, magnetic, and self-potential inversion helps in overcoming some of these limitations, gives an optimal fit for the buried structures, and plays a vigorous role in solving many investigation problems.

6. Case studies

6.1. Gravity anomaly of chromite deposit body

Figure 1 shows the gravity anomaly of length 180 m over a chromite deposit body in the chromite region of the Camaguey Area, Cuba [19]. This chromite deposits are found in a complex geological environment involving serpentinized peridotite and dunite with slight quantities of gabbro, troctolite, and anorthosite. This complex environment affected by metamorphic rocks and superimposed by upper Cretaceous volcanic rocks with limestone and radiolarian cherts. Severe compressive stresses, started in late Cretaceous or early Eocene time, deformed both the sedimentary rocks and the underlying ultramafic complex and culminated in extensive thrust faulting, probably in the late middle Eocene. Uplift and erosion have detached the overlying rocks from the serpentine except in synclinal areas, the largest of which extends from Central Lugareño to Loma Yucatan. This gravity anomaly has been interpreted by utilizing different inversion methods as demonstrated in **Table 3**. **Table 3** demonstrated that the estimated chromite deposit body parameters, amplitude factor (A), depth (z), location of the body (d), and the shape (q) by utilizing these approaches, have a reasonable agreement especially the depth with that obtained from drilling.

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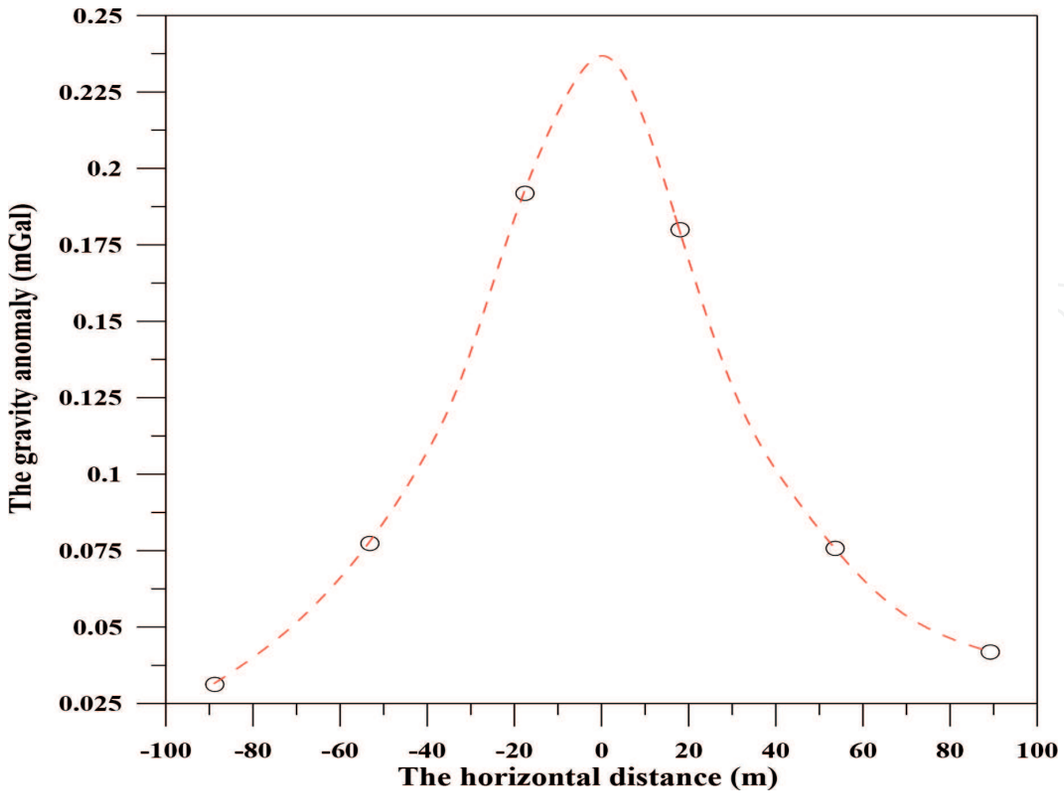

Figure 1. The gravity anomaly of chromite deposit body (Cuba).

6.2. Magnetic anomaly over an olivine diabase dike

Figure 2 demonstrates the magnetic anomaly profile of length 2200 m above an olivine diabase dike from the Pishabo Lake, Canada, and this site is made out of plagioclase, purplish-brown augite, pale green olivine, apatite, some biotite, and large patches of magnetite [20]. This magnetic anomaly has been interpreted by using various inversion algorithms such as moving average method, parametric inversion method, and the PSO method. The elucidation procedure and their produced results are mentioned in **Table 4**. The predicted parameters (M which represents the amplitude factor, z is the depth, θ is the magnetization angle, d is the origin location, and q is the shape) of the body by using these inversion methods have a good agreement together.

Parameters	Drilling information	Essa method [21]	Biswas method [9]	Ekinci et al. method [22]	Essa and Munschy method [23]
A (mGal m^2)	—	412.33	16.80	288.25	408.25
z (m)	21.00	21.02	42.30	23.23	21.15
d (m)	—	—	−2.40	58.73	0.63
q (dimensionless)	—	1.5	1.0	1.5	1.47

Table 3. The results obtained for interpreting gravity anomaly of chromite deposit body (Cuba) using different inversion methods.

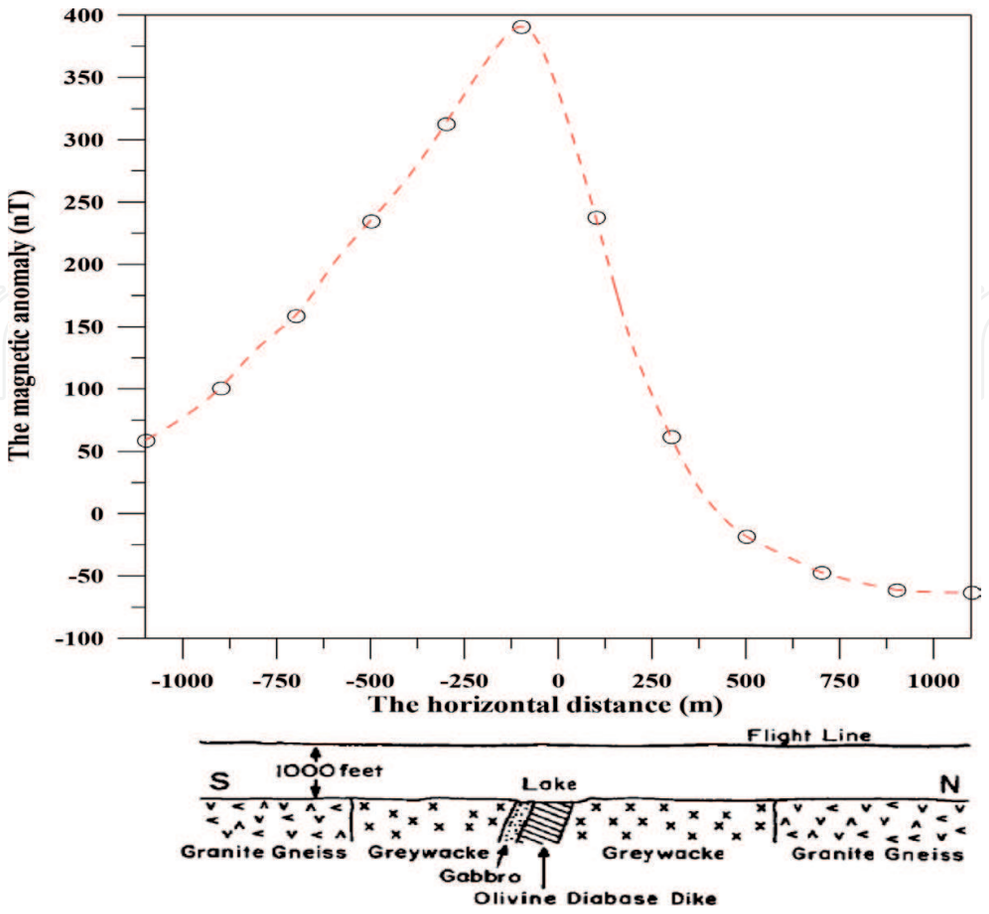

Figure 2. The magnetic anomaly over an olivine diabase dike from the Pishabo Lake, Canada.

6.3. Self-potential anomaly of sulfide orebody

Figure 3 displays the self-potential anomaly of a sulfide orebody in the Sariyer area which is located about 18 km north to Istanbul, Turkey, and characterized by an outcropping of andesite, pyrite veins, and cupriferous waters. The area of this investigation is characterized by a steep surface gradient. In 1951, the sulfide orebodies had been explored by utilizing

Parameters	McGrath and Hood method [20]	Abdelrahman et al. method [24]	Abdelrahman et al. method [25]	Biswas method [26]	Essa method
M (nT)	—	—	1429.0	1411.8	1380.8
z (m)	304	318.9	320	324	305.9
θ (°)	—	—	37.5	−37.9	38.5
d (m)	—	2.86	—	1.7	2.22
q (dimensionless)	—	1.0	1.0	1.0	0.98

Table 4. The results obtained for interpreting magnetic anomaly over an olivine diabase dike from the Pishabo Lake, Canada.

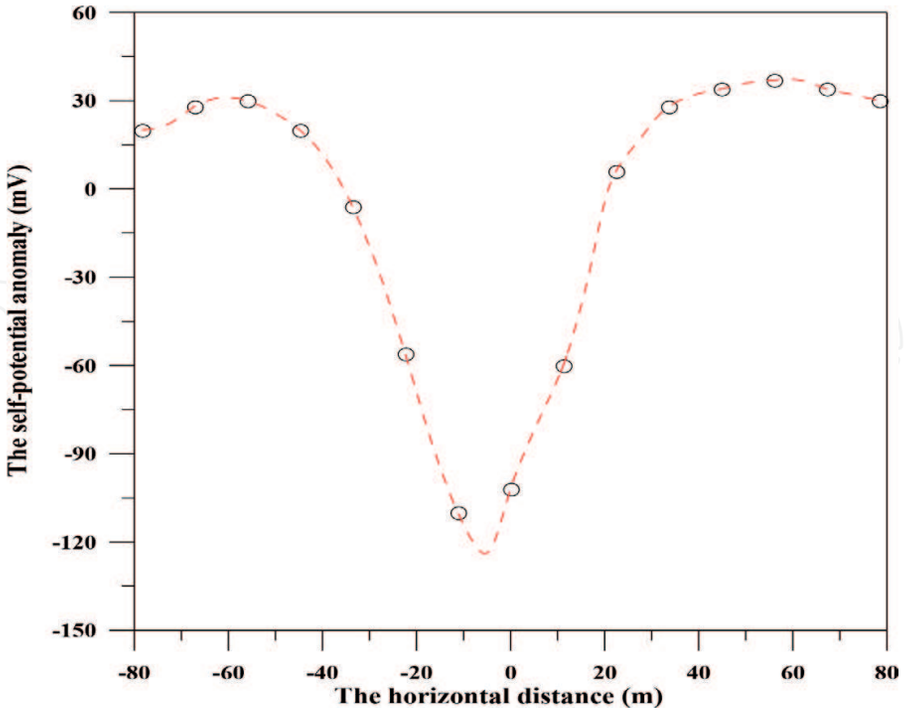

Figure 3. The self-potential anomaly of a sulfide orebody in the Sariyer Area, Turkey.

Parameters	Abdelrahman et al. method [27]	Asfahani and Tlas method [28]	Biswas and Sharma method [29]	Essa method
K (mV × m²)	3245.0	4695.6	2855.4	3447.1
z (m)	24.5	22.6	28.0	25.4
θ (°)	−51.2	−82.9	−70.3	−58.9
d (m)	—	—	−2.5	−0.5
q (dimensionless)	1.5	1.0	1.5	1.5

Table 5. The results obtained for interpreting self-potential anomaly of a sulfide orebody in the Sariyer Area, Turkey.

geophysical techniques where it found to lie under unmineralized schist or alluvium with a depth of 23 m and elongated as a spheroid dimension [21]. This profile has a length of 160 m and has been subjected to many interpretation methods to estimate the sulfide orebody parameters (K is the amplitude factor, z is the depth, θ is the polarization angle, d is the origin location, and q is the shape). The estimated results are displayed in **Table 5**. The estimated parameters of this source by exploiting these methods have a good covenant together.

7. Conclusions

The chapter discussed the importance of the geophysical methods, especially gravity, magnetic, and self-potential methods, in mineral and ore exploration which are considered as an

important issue for many countries to increase their incomes. The results of the published information described in the state of arts mentioned above by the three case studies revealed the pervasiveness of these methods and its capability of elucidating gravity, magnetic, and self-potential data associated with shallow and deep mineralized bodies.

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Conflict of interest

There is no conflict of interest.

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