1

Introduction

Geophysics is the study of the earth, based on the principles and laws of physics. The study of the earth, based on the laws of the gravity and the magnetic fields, is known as the gravity and the magnetic methods of geophysical exploration. They are known as the natural methods as they employ the natural fields, namely, the gravity and the magnetic fields of the earth. Contrary to them, there are methods which employ artificial fields created specially for those surveys in an area such as electrical and seismic methods. As the gravity and the magnetic methods employ natural fields of the earth, they are the oldest geophysical methods used for the study of the earth and are easy to operate and cost effective compared to the other geophysical methods. Therefore, they are ideally suited for reconnaissance survey of large areas to limit the areas for detailed investigations. The gravity and the magnetic methods being directly related to the physical properties of the rocks, namely, the density and the susceptibility, respectively they are found to be very useful by field geologists and geophysicists in mapping and identification of various rock types. They are also used for direct detection of minerals with large contrast in density and susceptibility compared to country rock.

The earth has its own gravity and the magnetic fields, which gets modified in the presence of rocks of different properties. The earth's natural field F1 gets modified to F2 near a structure (Fig. 1.1) or anomalous body depending on its shape, size, depth and the physical properties like density or susceptibility in case of gravity and magnetic methods, respectively. The differences between the two fields (F2 - F1) is known as geophysical anomaly, namely, the gravity anomaly or the magnetic anomaly in the two cases. It depends on the configuration of the body, depth and physical properties of the causative sources. These fields are measured with the help of sensitive instruments at the surface of the earth or using different platforms, for example ship, helicopter, aeroplane and satellite depending on the target, their size, desired accuracy of the survey and accessibility to the survey area. The data is processed to obtain the gravity and the magnetic anomalies with respect to the ground position, which, in turn, are related to the surface or subsurface rocks, structures and their physical properties. The two most important characteristics of the anomalies are their spatial size and magnitude, which are popularly referred to as wavelength and amplitude, respectively. Broadly, the geological studies for which the gravity and magnetic methods have shown promise, are as follows:

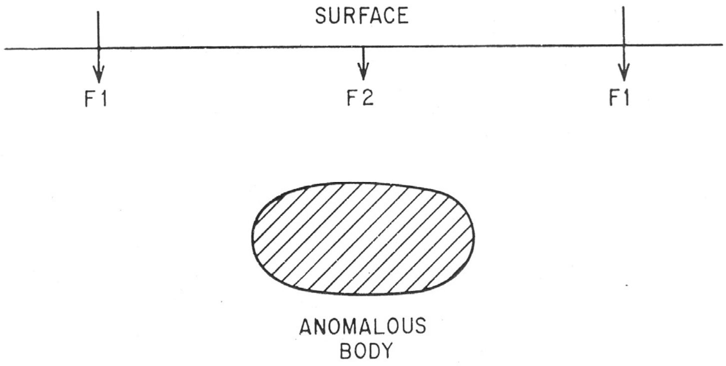

Fig. 1.1 F1 is the normal earth's gravity/magnetic fields which get modified to F2 in the vicinity of sub-surface anomalous bodies or heterogeneity. (F2-F1) is known as gravity/magnetic anomaly which depend on shape, size, depth and physical parameters, namely, density/ susceptibility of the anomalous body which can be derived from the observed/ measured anomaly.

1.1 Geological Studies and Gravity and Magnetic Methods

Gravity and magnetic methods are related to variations in density and susceptibility of rocks, respectively and produces complimentary images of structures which are integrated to provide their details. In fact, they are also integrated with all other available data sets to map subsurface structures. Their applications to various geoscientific studies are briefly described below while their detailed applications integrated with other geophysical - geological data sets are discussed and demonstrated in the forthcoming chapters.

1.1.1 Geodynamics and Plate Tectonics

Since 1912, when Alfred Wegener proposed the theory of continental drift that has explained several geological observations in a unified manner, it therefore, formed one of the most important aspects of geodynamics. However, it did not account for the forces responsible for drifting of the continents and was therefore, replaced by plate tectonics during 1960s, which accounted for these forces due to mantle convection (Uyeda, 1978).

Plate tectonics is presently one of the most important aspects of global geodynamics. Gravity and magnetic methods are used to study the different aspects of geodynamics and plate tectonics of a region. Some of their applications in this regard can be briefly described as follows. However, there are several other applications of geophysical methods in general and gravity and magnetic methods, in particular, that are outlined in the forthcoming chapters.

(i) Plate Tectonics

Plate tectonic theory provides a unified model to explain most of the tectonic processes observed on the surface of the earth and subsurface. It is briefly outlined here to introduce this topic that is essential to discuss gravity and magnetic anomalies due to its certain aspects in Chapters 2 and 3, respectively. Plates may consist of both continental and oceanic parts representing both continental and oceanic lithospheres. It shows some major and some minor plates which are separated by ridges and subduction zones referred to as divergent and convergent plate boundaries where different plates diverge and converge, respectively. Some important mid-oceanic ridge systems are Mid-Atlantic Ridge, Indian Ocean Ridge system, East Pacific Rise etc., named after the oceans they occupy. Collision and subduction zones are found on other side of the plate accompanied by fold belts on continents and trenches in oceans, respectively. Such as besides these two features, the third important element is known as Transform faults, which are similar to strike slip faults along which the two plates slip past each other. San Andreas Transform fault system along west coast of USA. Chamman fault in Pakistan (CH; Fig. 5.13) related to Pakistan Fold Belt between the Indian and the Eurasian plates is an example of transform fault related to the Indian plate.

Mid oceanic ridges are linear features where volcanic rocks wells up from inside the earth and spreads over the ocean bottom forming the ridges, which diverge the plates on either sides and are therefore known as divergent margins (Fig. 1.2). Mid oceanic ridges are, therefore characterized by mafic volcanic rocks and magnetic profiles across them show normal and reverse polarity of rocks located almost symmetric with respect to the ridge. These are known as sea floor spreading magnetic anomalies and their polarity indicate the polarity of earth's magnetic field at the time of their formation. On the other hand, along convergent margins plates on the surface of the earth converge and collide and in the process, one subducts under the other and is therefore known as subduction zones (Fig. 1.2). As shown in this figure, magma erupts and spreads at Mid Oceanic Ridges and pushes the oceanic lithosphere on either side as indicated by arrows. Once the oceanic lithosphere encounters a continental shelf as shown on either margins of this figure, it subducts below the continental crust as it is comparatively heavier (higher density) than the latter. The contact of the two is characterized by deepest parts of the ocean known as trenches where deep basins are formed. During its movement, it may encounter some localized sources of magma such as plume which may give raise to chains of volcanoes that are known as sea mounts in case of oceans. Once the zig saw puzzle of sea floor spreading magnetic anomalies were sorted out and continents were brought back in time, they appeared to join together. This gave rise to plate tectonic theory, which in most simple form suggests that the earth is made up of several plates, which move and collide with each other and on collision, form the mountain chains and depending on the density of rock types subduct one under the other. They are chanacterized by seismic actiurty due to intense tectonic activities at plate boundaries.

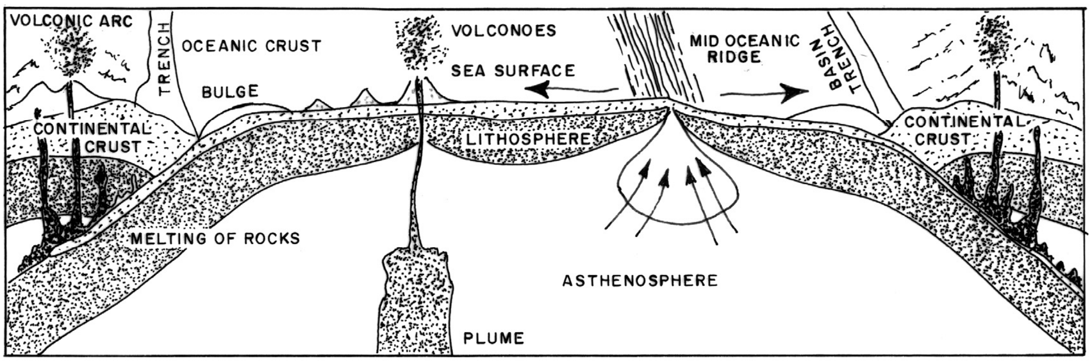

Fig. 1.2 A schematic section of Mid Oceanic Ridge where two plates diverge due to intrusion of magmatic material from asthenosphere forming oceanic crust. During plate motion, they encounter continental shelf where they would subside due to their higher density compared to continental crust. The subducted material melts at the depth giving rise to volcanic arcs. During plate motion, it may encounter plumes giving rise to volcanic chains.

Based on direction of forces in two cases, viz. mid oceanic ridges and subduction zones (Fig. 1.2), the tectonics related to them are termed as extensional and convergence tectonics. The subducted material at certain depth, melts due to frictional heat and high temperature to give rise to magma, which rises through fractures and faults giving rise to volcanic chains known as island arcs or magmatic arcs. However, in case of collision between two continental plates, such as Indian - Eurasian plates, the rocks are deformed as both are of almost same density. In such cases, the upper part of the crust forms the mountain chain through thrusting and folding, while its lower part slips one under the other causing thick crust and several related tectonic activities like earthquakes, volcanoes etc., Due to weight of the overriding plate, the subducting plate flexes and causes bulging of the subducting plate as it happens in case of cantilever beams in civil engineering (Fig. 1.2). This implies that while material is generated at mid oceanic ridges from within the earth, it is consumed at plate boundaries during subduction providing a mass balance in earth's system. Plate tectonics is important not only for tectonics and geodynamics but is also important for resource exploration. Most of the mineralized sections of base metals, precious metals (gold), chromites etc., occur along fold belts (mountains) that are formed due to collision of two plates as shown in Fig 1.2. In this regard, ancient fold belts of Archean- Proterozoic period (Appendix I) assume special significance. It is also important for hydrocarbon exploration as most of the sedimentary basins are formed along fold belts (Fig 1.2) or along rifted margins that are essential elements of plate tectonics.

They are characterized by specific features which produce typical gravity and magnetic anomalies as discussed in sections 2.9 and 3.8 respectively. Gravity and magnetic methods used for various applications in plate tectonics are briefly as follows:

(a) Reconstruction of continents and their movement during different geological periods based on direction of magnetization and seafloor spreading magnetic anomalies.

(b) Crustal structures and physical properties of rocks (density and susceptibility) with depth.

(c) Continuation of large-scale structures from one continent to the other before their breakup based on their gravity and magnetic signatures.

(d) Mantle dynamics related to plate tectonics based on satellite gravity anomalies.

(ii) Crustal Structures

The top most layer of the earth is known as crust. Its structure and composition plays a vital role in geodynamics of a region. Gravity and magnetic methods are extremely useful for crustal studies, which can be summarized as follows:

(a) Delineation of deep seated structures in the upper mantle and the crust and their physical properties, viz density and susceptibility.

(b) Variation in the crustal thickness (depth to Moho) based on gravity anomalies.

(c) Curie point geotherm based on magnetic data, which is defined as the temperature beyond which magnetization in rocks cannot exist. It is equivalent to the Curie point of magnetite equal to 570^{o} C. In some sections, it may coincide with Moho or may be deeper or shallower depending on heat flow in the region.

(d) Compensation of surface load and rheological properties of the crust and the lithosphere based on isostasy such as elastic thickness, flexural rigidity etc., based on gravity anomalies and topography which is described in Chapter 4.

(iii) Plume Tectonics

Plumes are large bodies of gaseous and fluids, which rise from inside the earth (Fig. 1.2) and give rise to large scale volcanic provinces in different parts of the world such as Deccan trap and Rajmahal trap in India, Karoo volcanics in Africa, Columbia flood basalt in USA and islands of Reunion, Kerguelen etc. Due to their high density and high susceptibility, gravity and magnetic methods are widely used for their studies, which are as follows:

(a) Delineation and demarcation of plume affected surface/subsurface regions

(b) Assessment of their physical properties like bulk density and bulk susceptibility and based on them identification of rock types.