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كلية العلوم -قسم الجيولوجيا التطبيقية

اسم المادة بالعربي: الجيوفيزياء الجهدية - الطريقة الجذبية

اسم المادة بالإنكليزي: Potential Geophysics- Gravity Method

عنوان المحاضرة بالإنكليزي:Introduction

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Introduction

The principles and limitations of geophysical exploration methods

The science of geophysics applies the principles of physics to the study of the Earth. Geophysical investigations of the interior of the Earth involve taking measurements at or near the Earth's surface that are influenced by the internal distribution of physical properties. Analysis of these measurements can reveal how the physical properties of the Earth's interior vary vertically and laterally. By working at different scales, geophysical methods may be applied to a wide range of investigations from studies of the entire Earth (global geophysics; e.g. Kearey & Vine 1996) to exploration of a localized region of the upper crust for engineering or other purposes (e.g. Vogelsang 1995, McCann et al. 1997). In the geophysical exploration methods (also referred to as geophysical surveying) discussed in this book, measurements within geographically restricted areas are used to determine the distributions of physical properties at depths that reflect the local subsurface geology. An alternative method of investigating subsurface geology is, of course, by drilling boreholes, but these are expensive and provide information only at discrete locations. Geophysical surveying, although sometimes prone to major ambiguities or uncertainties of interpretation, provides a relatively rapid and cost-effective means of deriving areally distributed information on subsurface geology. In the exploration for subsurface resources the methods are capable of detecting and delineating local features of potential interest that could not be discovered by any realistic drilling programme. Geophysical surveying does not dispense with the need for drilling but, properly applied, it can optimize exploration programmes by maximizing the rate of ground coverage and minimizing the drilling requirement.The importance of geophysical exploration as a means of deriving subsurface geological information is so great that the basic principles and scope of the methods and their main fields of application should be appreciated by any practising Earth scientist.This book provides a general introduction to the main geophysical methods in widespread use.

The survey methods

There is a broad division of geophysical surveying methods into those that make use of natural fields of the Earth and those that require the input into the ground of artificially generated energy.The natural field methods utilize the gravitational, magnetic, electrical and electromagnetic fields of the Earth, searching for local perturbations in these naturally occurring fields that may be caused by concealed geological features of economic or other interest. Artificial source methods involve the generation of local electrical or electromagnetic fields that may be used analogously to natural fields, or, in the most important single group of geophysical surveying methods, the generation of seismic waves whose propagation velocities and transmission paths through the subsurface are mapped to provide information on the distribution of geologicalboundaries at depth. Generally, natural field methods can provide information on Earth properties to significantly greater depths and are logistically more simple to carry out than artificial source methods. The latter, however, are capable of producing a more detailed and better resolved picture of the subsurface geology. Several geophysical surveying methods can be used at sea or in the air. The higher capital and operating costs associated with marine or airborne work are offset by the increased speed of operation and the benefit of being able to survey areas where ground access is difficult or impossible.

Table 1.1 Geophysical methods.

Method	Measured parameter	Operative physical property
Seismic	Travel times of reflected/refracted seismic waves	Density and elastic moduli, which determine the propagation velocity of seismic waves
Gravity	Spatial variations in the strength of the gravitational field of the Earth	Density
Magnetic	Spatial variations in the strength of the geomagnetic field	Magnetic susceptibility and remanence
Electrical		
Resistivity	Earth resistance	Electrical conductivity
Induced polarization	Polarization voltages or frequency-dependent ground resistance	Electrical capacitance
Self-potential	Electrical potentials	Electrical conductivity
Electromagnetic	Response to electromagnetic radiation	Electrical conductivity and inductance
Radar	Travel times of reflected radar pulses	Dielectric constant

Geophysical methods are often used in combination. Thus, the initial search for metalliferous mineral deposits often utilizes airborne magnetic and electromagnetic surveying. Similarly, routine reconnaissance of continental shelf areas often includes simultaneous gravity, magnetic and seismic surveying. At the interpretation stage, ambiguity arising from the results of one survey method may often be removed by consideration of results from a second survey method.

Geophysical exploration commonly takes place in a number of stages. For example, in the offshore search for oil and gas, an initial gravity reconnaissance survey may reveal the presence of a large sedimentary basin that is subsequently explored using seismic methods. A first round of seismic exploration may highlight areas of particular interest where further detailed seismic work needs to be carried out. The main fields of application of geophysical surveying, together with an indication of the most appropriate surveying methods for each application, are listed in Table 1.2.

Table 1.2 Geophysical surveying applications.

Application	Appropriate survey methods*
Exploration for fossil fuels (oil, gas, coal)	S, G, M, (EM)
Exploration for metalliferous mineral deposits	M, EM, E, SP, IP, R
Exploration for bulk mineral deposits (sand and gravel)	S, (E), (G)
Exploration for underground water supplies	E, S, (G), (Rd)
Engineering/construction site investigation	E, S, Rd. (G), (M)
Archaeological investigations	Rd, E, EM, M, (S)

* G, gravity; M, magnetic; S, seismic; E, electrical resistivity; SP, self-potential; IP, induced polarization; EM, electromagnetic; R, radiometric; Rd, ground-penetrating radar. Subsidiary methods in brackets.

Gravity surveying

In gravity surveying, subsurface geology is investigated on the basis of variations in the Earth's gravitational field arising from differences of density between subsurface rocks. An underlying concept is the idea of a causative body, which is a rock unit of different density from its surroundings.A causative body represents a subsurface zone of anomalous mass and causes a localized perturbation in the gravitational field known as a gravity anomaly.A very wide range of geological situations give rise to zones of anomalous mass that produce significant gravity anomalies. On a small scale, buried relief on a bedrock surface, such as a buried valley, can give rise to measurable anomalies. On a larger scale, small negative anomalies are associated with salt domes, as discussed in Chapter 1. On a larger scale still, major gravity anomalies are generated by granite plutons or sedimentary basins. Interpretation of gravity anomalies allows an assessment to be made of the probable depth and shape of the causative body. The ability to carry out gravity surveys in marine areas or, to a lesser extent, from the air extends the scope of the method so that the technique may be employed in most areas of the world.

Basic theory

The basis of the gravity survey method is Newton's Law of Gravitation, which states that the force of attraction F between two masses m1 and m2, whose dimensions are small with respect to the distance r between them, is given by

$$F = \frac{Gm_1m_2}{r^2}$$

Where G is the Gravitational Constant (6.67 ¥ 10-11 m3 kg-1 s -2).

Units of gravity

The mean value of gravity at the Earth’s surface is about 9.8ms-2 .Variations in gravity caused by density variations in the subsurface are of the order of 100 mms-2 .This unit of the micrometer per second per second is referred to as the gravity unit (gu). In gravity surveys on land an accuracy of ±0.1gu is readily attainable, corresponding to about one hundred millionth of the normal gravitational field.At sea the accuracy obtainable is considerably less, about ±10gu.The c.g.s. unit of gravity is the milligal (1mgal = 10-3 gal = 10-3 cms-2), equivalent to 10gu.

Measurement of gravity

Since gravity is acceleration, its measurement should simply involve determinations of length and time. However, such apparently simple measurements are not easily achievable at the precision and accuracy required in gravity surveying. The measurement of an absolute value of gravity is difficult and requires complex apparatus and a lengthy period of observation. Such measurement is classically made using large pendulums or falling body techniques (see e.g. Nettleton 1976, Whitcomb 1987), which can be made with a precision of 0.01gu. Instruments for measuring absolute gravity in the field were originally bulky, expensive and slow to read (see e.g. Sakuma 1986).A new generation of absolute reading instruments (Brown et al. 1999) is now under development which does not suffer from these drawbacks and may well be in more general use in years to come. The measurement of relative values of gravity, that is, the differences of gravity between locations, is simpler and is the standard procedure in gravity surveying. Absolute gravity values at survey stations may be obtained by reference to the International Gravity Standardization Network (IGSN) of 1971 (Morelli et al. 1971), a network of stations at which the absolute values of gravity have been determined by reference to sites of absolute gravity measurements (see Section 6.7). By using a relative reading instrument to determine the difference in gravity between an IGSN station and a field location the absolute value of gravity at that location can be determined.

Previous generations of relative reading instruments were based on small pendulums or the oscillation of torsion fibers and, although portable, took considerable time to read. Modern instruments capable of rapid gravity measurements are known as gravity meters or gravimeters. The necessity for the spring to serve a dual function, namely to support the mass and to act as the measuring device, severely restricted the sensitivity of early gravimeters, known as stable or static gravimeters.

An example of an unstable instrument is the LaCoste and Romberg gravimeter.The meter consists of a hinged beam, carrying a mass, supported by a spring attached immediately above the hinge (Fig. 6.2).The magnitude of the moment exerted by the spring on the beam is dependent upon the extension of the spring and the sine of the angle ϴ. If gravity increases, the beam is depressed and the spring further extended. Although the restoring force of the spring is increased, the angle q is decreased to ϴ. By suitable design of the spring and beam geometry the magnitude of the increase of restoring moment with increasing gravity can be made as small as desired. With ordinary springs the working range of such an instrument would be very small. However, by making use of a ‘zero-length’ spring which is pretensioned during manufacture so that the restoring force is proportional to the physical length of the spring rather than its extension, instruments can be fashioned with a very sensitive response over a wide range. The instrument is read by restoring the beam to the horizontal by altering the vertical location of the spring attachment with a micrometer screw. Thermal effects are removed by a battery-powered thermostatting system. The range of the instrument is 50000gu.

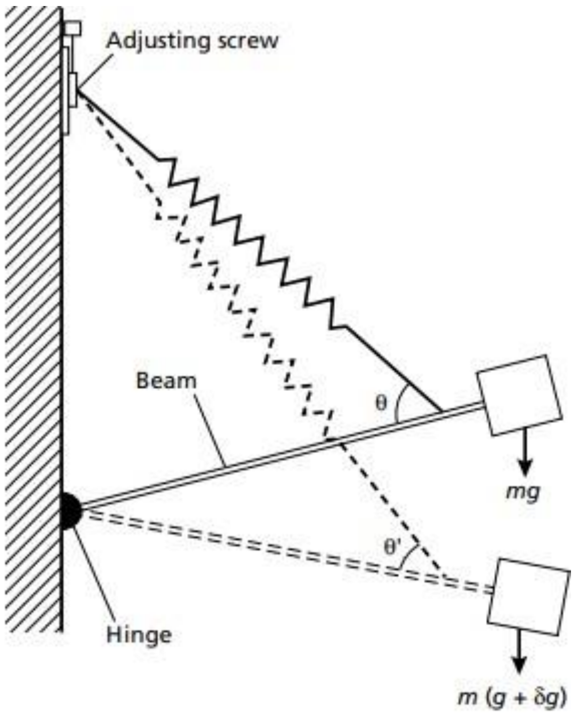

Fig. 6.2 Principle of the LaCoste and Romberg gravimeter.

Gravity can be measured at discrete locations at sea using a remote-controlled land gravimeter, housed in a waterproof container, which is lowered over the side of the ship and, by remote operation, levelled and read on the sea bed. Measurements of comparable quality to readings on land can be obtained in this way, and the method has been used with success in relatively shallow waters.The disadvantage of the method is that the meter has to be lowered to the sea bed for each reading so that the rate of surveying is very slow. Moreover, in strong Gravity Surveying 127 Adjusting screw Beam Hinge θ θ' mg m (g + δg) Fig. 6.2 Principle of the LaCoste and Romberg gravimeter. tidal currents, the survey ship needs to be anchored to keep it on station while the gravimeter is on the sea bed.

Gravity measurements can be made continuously at sea using a gravimeter modified for use on ships. Such instruments are known as ship borne, or shipboard, meters. The accuracy of measurements with a ship borne meter is considerably reduced compared to measurements on land because of the severe vertical and horizontal accelerations imposed on the ship borne meter by sea waves and the ship's motion

Gravity surveying

The station spacing used in a gravity survey may vary from a few metres in the case of detailed mineral or geotechnical surveys to several kilometers in regional reconnaissance surveys. The station density should be greatest where the gravity field is changing most rapidly, as accurate measurement of gravity gradients is critical to subsequent interpretation. If absolute gravity values are required in order to interface the results with other gravity surveys, at least one easily accessible base station must be available where the absolute value of gravity is known. If the location of the nearest IGSN station is inconvenient, a gravimeter can be used to establish a local base by measuring the difference in gravity between the IGSN station and the local base. Because of instrumental drift this cannot be accomplished directly and a procedure known as looping is adopted. A series of alternate readings at recorded times is made at the two stations and drift curves constructed for each (Fig. 6.9). The differences in ordinate measurements (Dg1–4) for the two stations then may be averaged to give a measure of the drift-corrected gravity difference. During a gravity survey the gravimeter is read at a base station at a frequency dependent on the drift characteristics of the instrument. At each survey station, location, time, elevation/water depth and gravimeter reading are recorded.

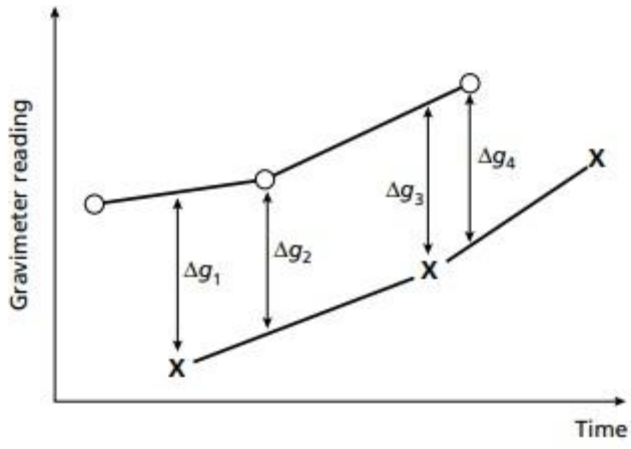

Fig. 6.9 The principle of looping. Crosses and circles represent alternate gravimeter readings taken at two base stations. The vertical separations between the drift curves for the two stations (Δg_{1-4}) provide an estimate of the gravity difference between them.

In order to obtain a reduced gravity value accurate to ±1gu, the reduction procedure described in the following section indicates that the gravimeter must be read to a precision of ±0.1gu, the latitude of the station must be known to ±10m and the elevation of the station must be known to ±10mm.The latitude of the station must consequently be determined from maps at a scale of 1:10000 or smaller, or by the use of electronic positionfixing systems. Uncertainties in the elevations of gravity stations probably account for the greatest errors in reduced gravity values on land; at sea, water depths are easily determined with a precision depth recorder to an accuracy consistent with the gravity measurements. In well-surveyed land areas, the density of accurately determined elevations at bench marks is normally sufficiently high that gravity stations can be sited at bench marks or connected to them by leveling surveys. Reconnaissance gravity surveys of less well-mapped areas require some form of independent elevation determination. Many such areas have been surveyed using aneroid altimeters.The accuracy of heights determined by such instruments is dependent upon the prevailing climatic conditions and is of the order of 1–5m, leading to a relatively large uncertainty in the elevation corrections applied to the measured gravity values. The optimal equipment at present is the global positioning system (GPS) (Davis et al.

1989), whose constellation of 24 satellites is now complete and an unadulterated signal is broadcast. Signals from these can be monitored by a small, inexpensive receiver. Use of differential GPS, that is, the comparison between GPS signals between a base 132 Chapter 6 X X X Gravimeter reading Time Δg1 Δg2 Δg3 Δg4 Fig. 6.9 The principle of looping. Crosses and circles represent alternate gravimeter readings taken at two base stations.The vertical separations between the drift curves for the two stations (Dg1–4) provide an estimate of the gravity difference between them. set at a known elevation and a mobile field set, can provide elevations to an accuracy of some 25mm.

References

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