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# Introduction to Potential Fields: Gravity

## Introduction

Gravity and magnetic exploration, also referred to as "potential fields" exploration, is used to give geoscientists an indirect way to "see" beneath the Earth's surface by sensing different physical properties of rocks (density and magnetization, respectively). Gravity and magnetic exploration can help locate faults, mineral or petroleum resources, and ground-water reservoirs. Potential-field surveys are relatively inexpensive and can quickly cover large areas of ground.

## What is gravity?

Gravitation is the force of attraction between two bodies, such as the Earth and our body. The strength of this attraction depends on the mass of the two bodies and the distance between them.

A mass falls to the ground with increasing velocity, and the rate of increase is called gravitational acceleration, *g*, or gravity. The unit of gravity is the Gal (in honor of Galileo). One Gal equals 1 cm/sec$^2$.

Gravity is not the same everywhere on Earth, but changes with many known and measurable factors, such as tidal forces. Gravity surveys exploit the very small changes in gravity from place to place that are caused by changes in subsurface rock density. Higher gravity values are found over rocks that are more dense, and lower gravity values are found over rocks that are less dense.

***A modern pioneer—U.S. Geological Survey geophysicist takes a gravity reading on the Oregon Trail.***

## How do scientists measure gravity?

Scientists measure the gravitational acceleration, *g*, using one of two kinds of gravity meters. An absolute gravimeter measures the actual value of *g* by measuring the speed of a falling mass using a laser beam. Although this meter achieves precisions of 0.01 to 0.001 mGal (milliGals, or 1/1000 Gal), they are expensive, heavy, and bulky.

A second type of gravity meter measures relative changes in *g* between two locations. This instrument uses a mass on the end of a spring that stretches where *g* is stronger. This kind of meter can measure *g* with a precision of 0.01 mGal in about 5 minutes. A relative gravity measurement is also made at the nearest absolute gravity station, one of a network of worldwide gravity base stations. The relative gravity measurements are thereby tied to the absolute gravity network.

## What is a gravity anomaly?

Gravity meters measure all effects that make up the Earth's gravity field. Many of these effects are caused by known sources, such as the Earth's rotation, distance from the Earth's center, topographic relief, and tidal variation. Gravity caused by these sources can be calculated using realistic Earth models and removed from the measured data, leaving gravity anomalies caused by unknown sources. To the geologist, the most important unknown source is the effect of the irregular underground distribution of rocks having different densities.

A sequence of gravity corrections are applied to the original gravity reading and result in various named gravity anomalies. The **observed gravity** anomaly has been corrected for Earth rotation, latitude, tidal effects, and gravity meter fluctuations.

The **free air** gravity anomaly has been corrected for the gravity effect caused by the elevation difference between the station and sea level (a correction for distance) and is a standard for oceanic gravity interpretation. The **Bouguer** (pronounced Boo-**gay**´) gravity anomaly has been further corrected for the mass that may exist between sea level and the observer (a correction for mass) and is a standard used in geologic interpretation on land. A **simple-Bouguer** anomaly has undergone a simplified removal of topographic effects, which suffices in relatively flat areas. A **complete-Bouguer** anomaly contains a terrain correction that uses a more complete representation of the local topography, which is necessary for accurate gravity values in mountainous areas. The **isostatic** (pronounced iso-**stăt**´-ic) gravity anomaly is calculated by subtracting the gravitational effect of low-density mountain roots below areas of high topography. Although these roots have never been seen, their isostatic effect has been measured and models calculated using topography. Isostasy is typified by floating icebergs that have 90% of their mass of ice below water that supports a smaller mass of ice projecting above water.

## What is a gravity map?

A gravity map is made using numerous gravity measurements across the area of interest. Gravity surveying by aircraft is still a new science, so most gravity measurements are made on the ground at discrete stations. Because access is often a problem, gravity stations may be randomly spaced, although detailed surveys are usually made at regular intervals.

Gravity measurements are often processed to a complete-Bouguer or isostatic gravity anomaly. These data are then gridded, so that the randomly spaced data are converted to a representation of the gravity field at equally spaced locations. The distance chosen between grid points depends on the average distance between gravity stations. Too large a grid interval would not use all the information from the original data set, whereas too small a grid interval fragments the continuity of anomalies across a region—either result is a poor representation of the true gravity field.

Gravity anomaly maps can be shown as color figures—with warm colors (reds and oranges) showing areas of higher gravity values and cool colors (blues and greens) showing lower values—or as contour line maps, where each contour line follows a constant gravity value.

## What is rock density?

Density is a rock property described by the ratio of mass to volume. Rock densities commonly range between 2.0 and 4.0 grams per cubic centimeter ($g/cm^3$). Pure water, by comparison, has a density of 1 $g/cm^3$. Each rock type can have a range of density values, and tables in the scientific literature show the general range of densities for various rock types. Often, the geoscientist will collect samples of exposed rocks in the study area and measure their densities to estimate the actual density of the rock unit where it is buried.

Various rock types within a study area often contrast enough in density to cause gravity anomalies. For example, sedimentary rocks that fill basins almost always have low densities and are characterized by gravity lows on anomaly maps. Mafic rocks, which contain high-density minerals, often are associated with gravity highs. The scientist can use these differences to map large regions where rocks are inaccessible or concealed, to look for faults that juxtapose rocks of different densities, or to infer structures such as basins, arches, and buried intrusions.

## What is a derivative gravity map?

A gravity anomaly map contains information about rock density, and depth and distribution of anomaly source rocks. Maps can be derived from the original gravity anomaly grid by using mathematical tools to enhance parts of the gravity field. Derivative maps can show, for example, anomalies that have been mathematically filtered for size and that show deeper or shallower sources. Other derivative techniques can magnify gravity gradients, places where the gravity field changes from high to low—these places often mark edges of rock units or faults, or they can mimic a geologic map by converting (or "terracing") the gravity anomalies into discrete, bounded units representing rock units. All of these maps can be used together to make a geologic interpretation.

## Additional information

U.S. Geological Survey Open-File Report 95–77 lists many USGS computer programs and databases used to create gravity maps, and it is available on the web site listed below.

Information on gravity base stations and availability of gravity maps and data in specific areas can be obtained from:


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