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Aeromagnetic survey

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Definition

An **aeromagnetic survey** (AMS) is an air-borne geophysical survey performed using a magnetometer aboard or towed behind an aircraft. A magnetometer is an instrument used to measure the magnetic field. Aeromagnetic surveys are probably one of the most common types of air-borne geophysical surveys. The applications of AMS in engineering geology include but are not limited to near-surface geological mapping, structural geology mapping, aiding three-dimension (3D) geological subsurface model construction, groundwater study, environmental study, and geologic hazards assessment.

In an aeromagnetic survey, an airplane flying at a low-altitude, carrying a magnetic sensor flies back and forth in a grid-like pattern over an area, recording disturbances in the magnetic field (Fig. 1). Height and gridline spacing determine the resolution of the data. Geologic processes often bring together rocks with slightly different magnetic properties, and these variations cause very small magnetic fields above the Earth's surface. The differences in the magnetic field are called "anomalies." (Blakely et al. 1999).

Introduction

Rocks or soils containing iron and nickel can have strong magnetization and, as a result, can produce significant local magnetic fields. The magnetic minerals contain various combinations of induced and remanent magnetization. At exploration depths, the Earth's primary magnetic field is perturbed by the presence of magnetic iron oxide (magnetite, the most strongly magnetic and the most common magnetic mineral), iron-titanium oxides (titanomagnetite, titanomaghemite, and titanohematite), and iron sulfides (pyrrhotite and greigite) (Reynolds et al. 1990). The remnant magnetization in the earth's magnetic field occurred during the mineral formation process, while the induced magnetization was created by the presence of the earth's magnetic field. The magnitudes of both induced and remnant magnetizations depend on the quantity, composition, and size of the magnetic-mineral grains. The goal of the magnetic method is to map changes in the magnetization that are, in turn, related to the distribution of magnetic minerals (Hoover et al. 1992).

The magnetometer was invented in 1832 and was designed and constructed to measure the intensity of the Earth's magnetic force (Gauss 1832). However, development of magnetometers used in exploration, i.e. usable for taking a large number of readings over a given area of interest in a reasonably short period of time, dates only from the invention of the electronic magnetometer during the Second World War (Reeves 2005). Aeromagnetic surveys were performed, using a Magnetic Anomaly Detector attached to an aircraft, in World War II to detect submarines.

The aeromagnetic survey technology was progressively refined with time. In the late 1950s the proton precession magnetometer was invented but, despite on-going refinement of the flux-gate instrument, eventually was replaced in routine survey operations (Reeves 2005). The U.S. Geological Survey (USGS) pioneered the first airborne magnetic survey in 1944, during which10,000 line miles of magnetic data were collected over Naval Petroleum Reserve 4 in the northernmost part of Alaska (Hildenbrand and Raines 1987). In the following years, airborne geophysics evolved into a major component of earth science. Today aircraft are capable of acquiring a wide variety of geophysical data (for example, gravity, magnetic, electromagnetic, radiometric, spectral, and thermal), which are critical to solving national resource, environmental, and geologic hazards problems.

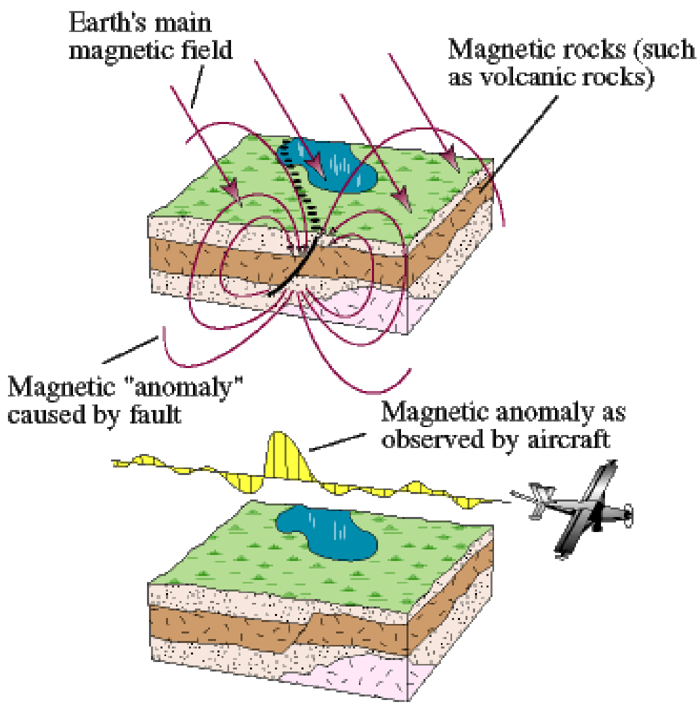

Fig. 1. Schematic illustration of an aeromagnetic survey. The low-altitude flying airplane flies back and forth in a grid-like pattern to measure the magnetic anomalies caused by changes in the magnetic field by different rocks and geologic structures (Blakely et al., 1999).

After pioneering the first airborne magnetic survey in 1944, the USGS collected piecemeal aeromagnetic data for most of the U.S., including offshore areas on both coasts. The USGS's digital and analog archives comprise more than 1,000 surveys, covering approximately 8,000,000 line-km of data, flown at various flight heights and line spacings (Hanna 1987).

Aeromagnetic Survey Method

Magnetic measurements are usually made from low-flying airplanes flying along closely spaced, parallel flight lines. Additional flight lines are flown in the perpendicular direction to assist in data processing. These huge volumes of measurements are processed into a digital aeromagnetic map. Assisted by computer programs, the geophysicist builds a geologic interpretation from the digital aeromagnetic data, incorporating geologic mapping and other geophysical information (gravity, seismic-reflection) where available (Fig. 2). Interpretations often involve both map-based information (e.g., a fault map) and three-dimensional information (e.g., a geologic cross section, and 3D geological model) (Blakely et al. 1999).

The workflow of the aeromagnetic survey method includes the aeromagnetic survey design, data acquisition, data processing, and interpretation. There are many parameters to be considered in a typical aeromagnetic survey design. These parameters include the line spacing of flying, flying heights, the flight line direction with the intention of maximizing the magnetic signature, and features of the survey aircraft. Flight-line spacing is determined by the degree of detail required in the final mapping or the size of exploration target, the funding available for the survey. The strength of a magnetic field decreases approximately as the inverse of the square of the distance from the magnetic source. Therefore, to record small variations in the fields, aircraft must fly close to the ground (Horsfall 1997).

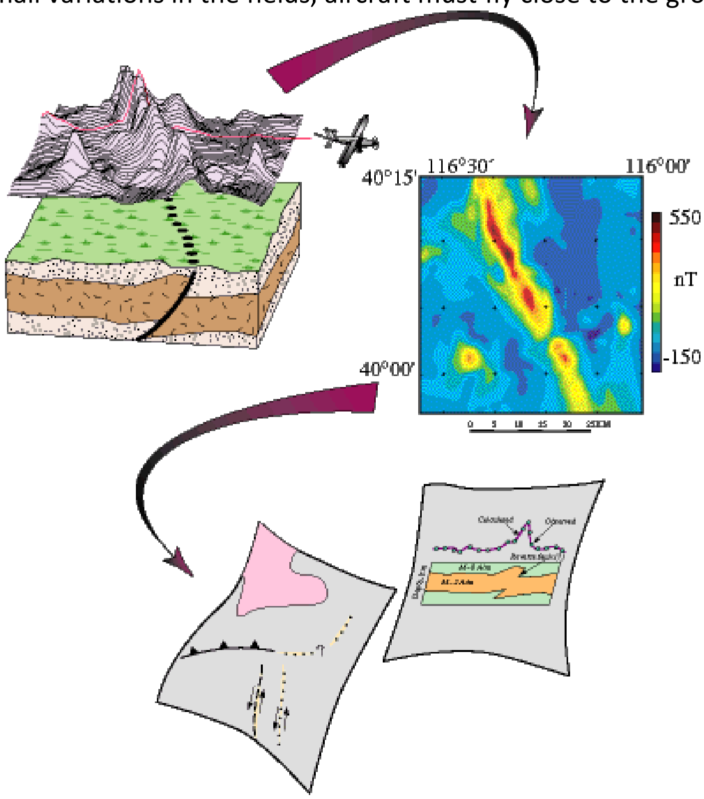

Fig 2. Schematic illustration of steps of an aeromagnetic survey, and products (Blakely et al., 1999).

As the aircraft flies, the magnetometer measures and records the total intensity of the magnetic field at the sensor. Aeromagnetic data can be presented as contour plots, and thematic maps (e.g., Fig. 3). Intensity of the aeromagnetic anomalies are expressed in these plots, or maps, as contour lines or different colors. The shape, depth and properties of the rock bodies causing the aeromagnetic anomalies can be interpreted by a trained geophysicist. The magnetic anomaly map also allows a visualization of the geological structure of the upper crust in the subsurface, particularly the spatial geometry of bodies of rock and the presence of faults and folds because different rock types differ in their content of magnetic minerals even if the bedrock is obscured by surficial materials, such as sand, soil, or water.

Selected Case Studies

Aeromagnetic surveys, in conjunction with other geophysical methods, are used to help in geological mapping, structural geology mapping, environmental and groundwater studies, 3D geological modeling, mineral exploration, and petroleum exploration. This section focuses on case studies of the aeromagnetic applications in engineering geology and its closely related fields.

Hood (1965) presented the measurement of the first vertical derivative of the total field in aeromagnetic surveys by using two sensitive magnetometer heads, separated by a constant vertical distance.The difference in outputsrevealed that steeply dipping geological contacts in high-magnetic latitudes are outlined by the resultant zero-gradient contour. It also demonstrated that it is possible to obtain the depth of a subsurface contact from an aeromagnetic survey. Measurements of the vertical gradient during aeromagnetic surveys would, therefore, be of great value in subsequent geological mapping of the areas surveyed (Hood 1965).

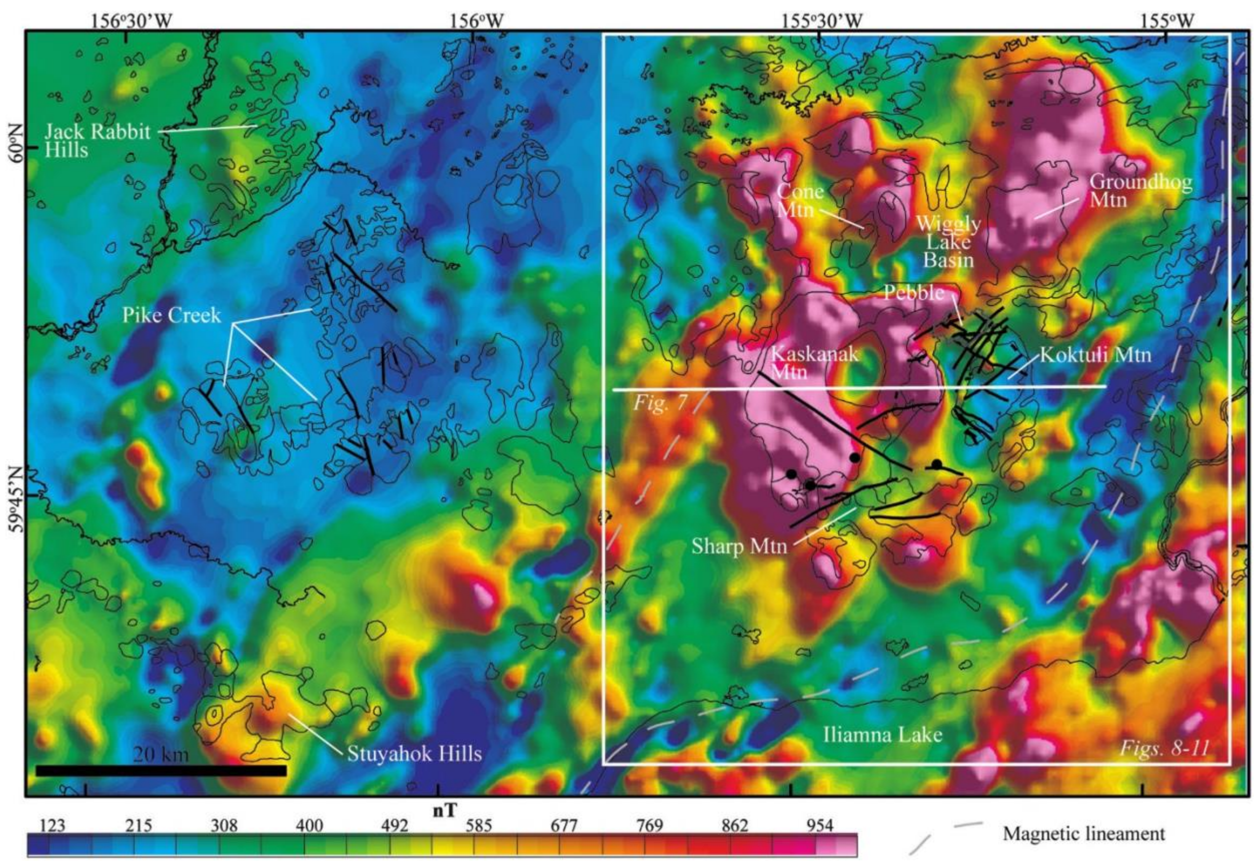

Fig. 3. The magnetic anomaly map of the Pebble district and Pike Creek–Stuyahok Hills area, in southwest Alaska. Both areas show contrasting magnetic signatures. Dashed lines represent major magnetic lineaments discussed in the text. Black dots show the location of middle Cretaceous porphyry-style ores (Anderson, 2014).

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Blakely et al. (2000) presented the results of a high-resolution aeromagnetic survey of the Amargosa Desert, and surrounding areas, an area of approximately 7,700 km^2, extending from Beatty, Nevada, to south of Shoshone, California, that includes parts of Nevada Test Site and Death Valley National Park. Aeromagnetic flight lines were oriented east-west, spaced 400 m apart, and flown at an altitude of 150 m above the terrain, or as low as permitted by safety considerations. This survey provided insights into the buried geology of this structurally complex region.

Ranganai and Ebinger (2008) integrated aeromagnetic (AM) and Landsat Thematic Mapper (TM) data from the south-central Zimbabwe Craton to map the regional structural geology and to develop strategic models for groundwater exploration in hard-rock areas. The derived maps reveal several previously undetected lineaments corresponding to dykes, faults, shear zones, and/or tectonically-related joints, striking predominantly NNE, NNW, and WNW. The open groundwater conduits and recharge area were inferred from the AM and TM, which are of hydrological significance (Ranganai and Ebinger 2008).

Anderson et al. (2014) demonstrated that aeromagnetic data could be used to understand the 3D distribution of plutonic rocks near the Pebble porphyry copper deposit in southwestern Alaska, USA (Fig. 4). In this study, magnetic inversion was constrained by a near-surface 3D geologic model that is attributed with measured magnetic susceptibilities from various rock types in the region. It was concluded that Aeromagnetic data were an effective tool for mapping middle Cretaceous igneous rocks in southwest Alaska and should provide valuable insights during exploration for similar-age porphyry copper deposits in the region.

Summary and Conclusions

An aeromagnetic survey is one of the most common airborne geophysical survey methods. AMS infers the underlain geology by measuring and interpreting magnetic anomalies caused by magnetic minerals. There are many applications of AMS in the areas of petroleum and mineral exploration. The applications of AMS in engineering geology include but are not limited to, near-surface geological mapping, structural geology mapping, aiding 3D geological modeling, groundwater study, environmental study, and geologic hazards assessment.

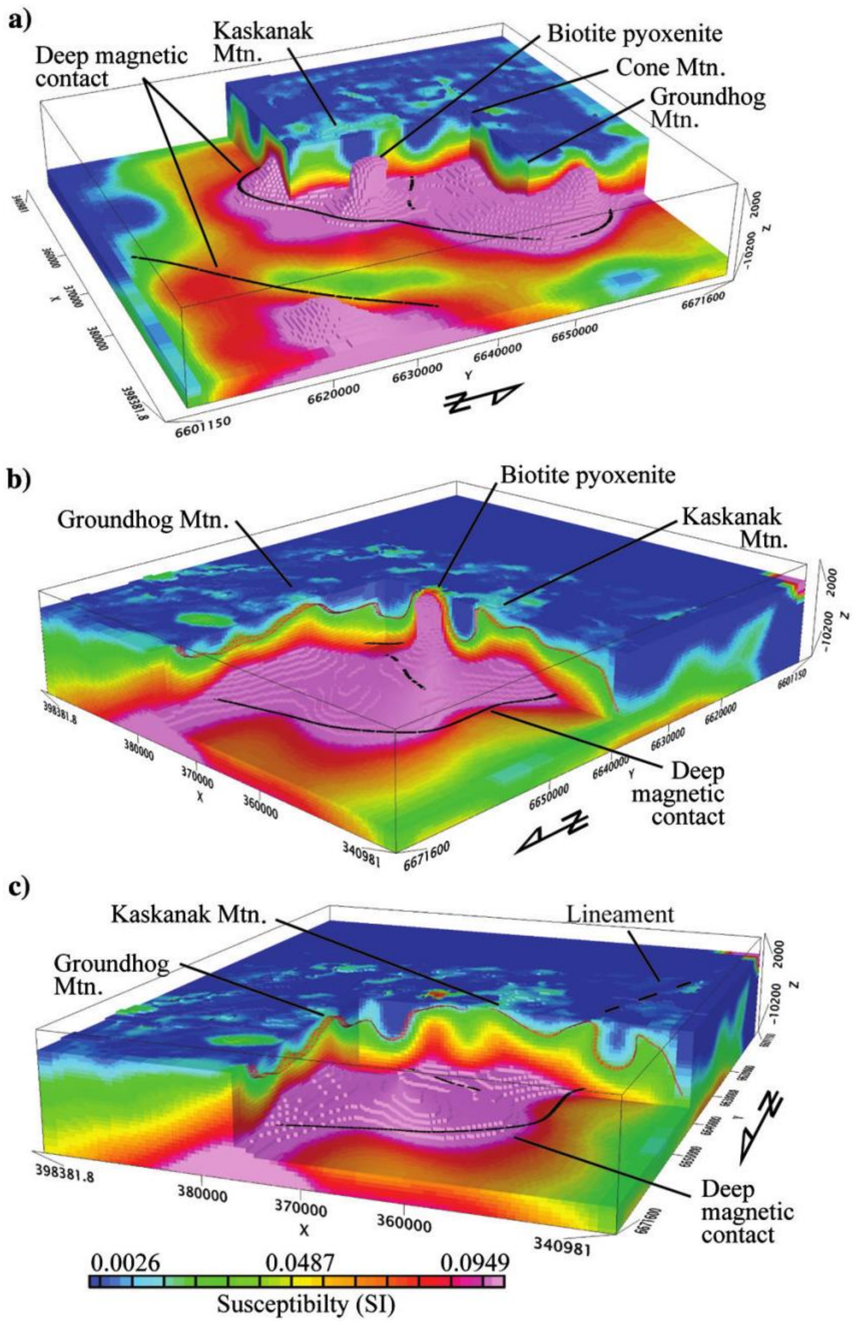

Fig. 4. The result of 3D magnetic inversions. The model shows that relatively highly magnetic material occurs below Kaskanak Mountain, Alaska, and extends continuously to the north of Groundhog Mountain (Anderson 2014).

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Cross-References

Magnetic anomalies, Magnetometer, Magnetic minerals

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