Handout from "Exploration Geophysics of the Shallow Subsurface",
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THE EARTH'S MAGNETIC FIELD

The earth's magnetic field at any point on the earth's surface is a vector quantity that is defined by measuring its total intensity and direction. Intensity can be measured by any number of instruments, some of which are described in a following section. Orientation is readily determined by allowing a compass needle to rotate freely in all directions. Just as in the case of a bar magnet, the needle will rotate into parallelism with the earth's field.

Field Elements

The total-field vector is defined by its intensity B_E; its *inclination* i, which is the angle the vector makes with a horizontal plane; and its *declination* d, which is the angle the vertical plane containing the total-field vector makes with geographic north. These relationships are illustrated in Figure 7-7. F_E can be resolved into a vertical component Z_E and a horizontal component H_E. The vertical plane containing B_E, Z_E, and H_E is a magnetic meridian. H_E can also be resolved into horizontal components directed toward geographic north (X_E) and geographic east (Y_E). These seven geomagnetic elements are interrelated in several ways that are readily apparent from Figure 7-7. Any three elements are sufficient to determine the

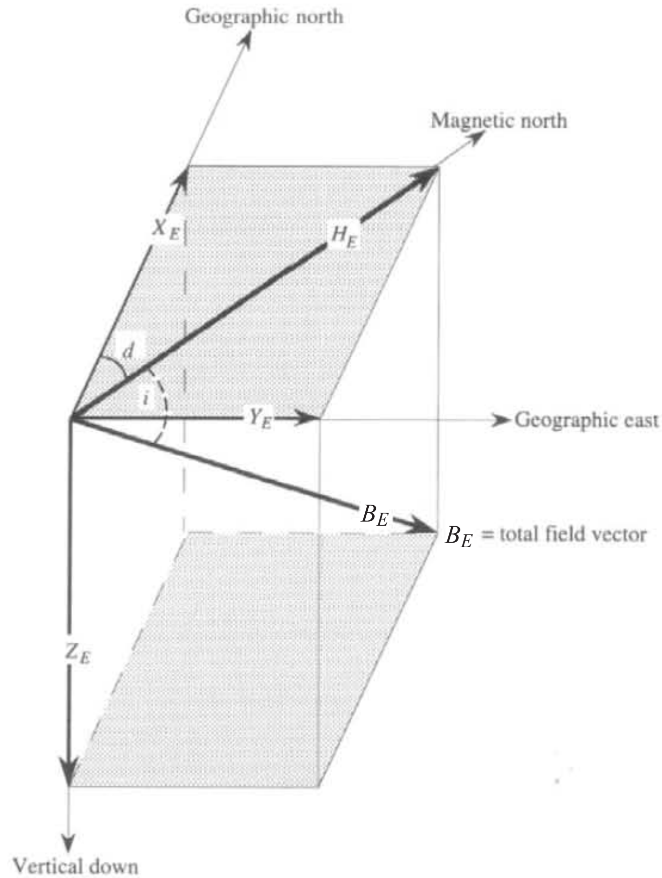

Figure 7-7 The elements of the earth's magnetic field: B_E = total-field vector, H_E = horizontal component, Z_E = vertical component, d = declination, and i = inclination.

remaining four. A thorough grasp of these relationships is essential for later derivations, so be sure you can reproduce each of the following:

$$B_E = \sqrt{H_E^2 + Z_E^2} = \sqrt{X_E^2 + Y_E^2 + Z_E^2}$$

$$Z_E = B_E \sin i, \quad H_E = B_E \cos i, \quad \text{and} \quad \tan i = \frac{B_E}{H_E} \tag{7-9}$$

$$X_E = H_E \cos d \quad \text{and} \quad Y_E = \sin d$$

The positions on the earth's surface where $i = 90°$ are known as the *magnetic dip poles* (see Fig. 7-11), and the *magnetic equator* is defined by positions of $i = 0°$. At the dip poles $Z_E = B_E$, and the intensity is approximately 70,000 nT (nanotesla). At the magnetic equator, $H_E = B_E$, and the intensity is approximately 30,000 nT. Note that the earth's magnetic field varies in intensity by more than 200 percent, whereas the gravity field varies only by approximately 0.5 percent.

Total-Field Anomalies

As a first step in this process, let's decide on our terminology. We have already chosen H_E, Z_E, and B_E as references to the earth's main field. We use H_A, Z_A and B_A in a similar sense for a magnetic field induced in a geologic body by the earth's field. We normally derive the vertical and horizontal anomalous-field components (H_A and Z_A) in an attempt to compute the induced field due to various subsurface geometries. B_A is the resultant of these components and is computed from them just as B_E is determined from H_E and Z_E (Eq. 7-9).

At any point on the surface at which a total-field measurement is taken, the measurement includes the main field plus the anomalous field (plus the very small contribution from the external field, which is discussed in the following section). For instance, in the situation illustrated in Figure 7-13(a) the total-field reading from a magnetometer would equal 55,005 nT, which includes the undisturbed main-field reading B_{EU}, which is 55,000 nT, plus the contribution of the anomalous field, which is 5 nT. We refer to this total as B_{ET}. However, since we do not know the orientation of B_{ET}, how do we proceed with interpretations? First, we assume that $B_{EU} >>> B_A$, which is almost always the case, especially in most shallow subsurface surveys, unless the survey is close to large steel objects or encounters rocks with very high susceptibilities. If this assumption holds, then the total-field vector B_{ET} that includes the contribution from the anomalous field is for all practical purposes parallel

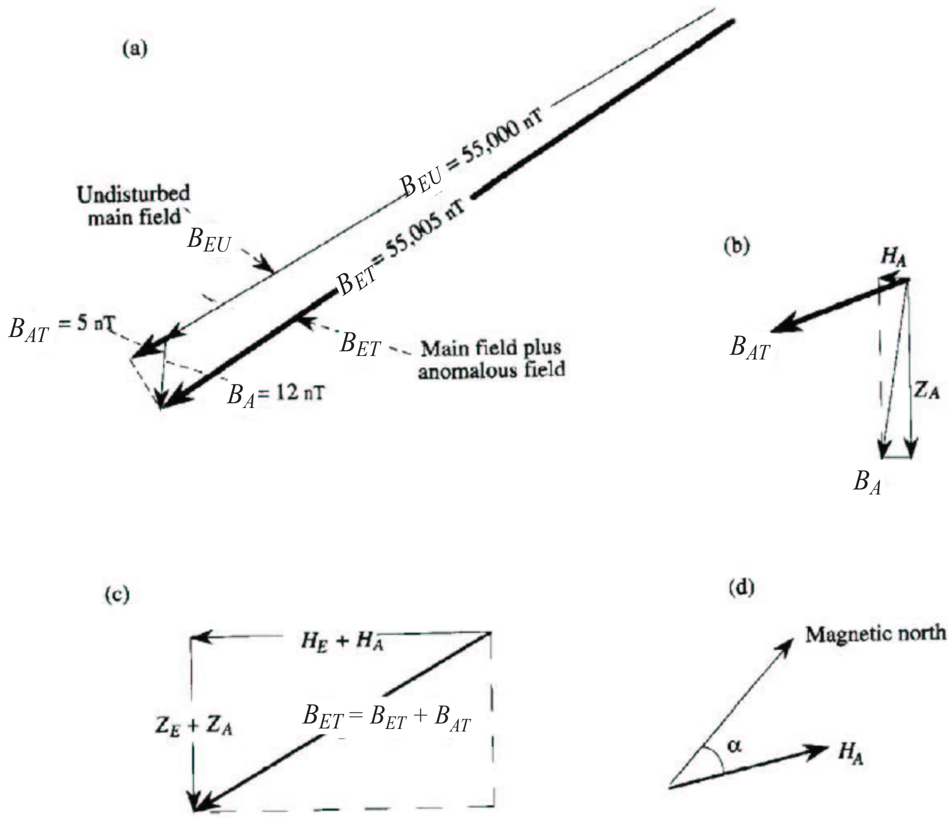

Figure 7-13 Relationships surrounding the meaning of the total-field anomaly. (a) Vectors of the main field and anomalous field. (b) Components of the anomalous field. (c) Components of the undisturbed main field and the anomalous field. (d) Correction for horizontal component of the anomalous field when it does not lie along a magnetic meridian.

to the direction of the main field in the absence of the anomaly (the undisturbed main field B_{EU}). Thus, the effect of the anomaly on the magnetometer reading essentially is the component of the anomaly B_A in the *direction of the undisturbed main field.* We refer to this anomaly component as B_{AT} (see Fig. 7-13(b)). This relationship allows us to develop equations to determine total-field anomalies B_{AT} from H_A and Z_A and to reduce total-field magnetometer readings for interpretation.