Geomagnetic deep sounding (GDS) is a unique geophysical experiment that can provide information on the Earth's electrical conductivity down to depths of the order of 1200–1800 km. It seems therefore appropriate to discuss in detail the data of GDS, their processing and interpretation.

Global GDS is the oldest of the methods dealt with in this book. As long ago as 1883, Lamb proposed the theory of electromagnetic induction in a conducting sphere. In 1889, Schuster made an analysis of daily variations of the geomagnetic field, having presented the latter as the sum of external and internal parts. Proceeding from Lamb's theory, Schuster demonstrated that the internal part can be attributed to electric currents induced in the Earth by the external part, and was thus the first to show that the Earth behaves as a conducting body. Further progress in global GDS has been associated in the first place with the names of Chapman (since 1919), Price (since 1930), and Benkova (since 1941). Since the 1960's, many new investigators have entered this field. Beginning with this period, the level of investigations has been greatly enhanced, mainly due to the following three reasons. First, a more extensive body of experimental evidence has become available after the IGY 1957–1958, and the accuracy of the data has significantly improved (the experimental evidence used in GDS is discussed in Sects. 4.2 and 4.3); second, a presentation of the experimental data of GDS in terms of the impedance, apparent resistance, and apparent depth, which has allowed the interpretation by the well-developed frequency sounding methods; this important advance resulted from the works by Eckhardt (1963, 1968), Srivastava (1965, 1966), Berdichevsky et al. (1969b) Banks (1969), and Schmucker (1970); and third, there has been general progress in the theory [the theorem of uniqueness has been proved (Tikhonov 1965)] and in the technique of solving the inverse problem. Global GDS is, however, facing some significant problems that restrict the accuracy and reliability of the information about the electrical conductivity distribution (see Sect. 4.4); but the data resulting from GDS are nevertheless much more reliable and accurate than the geothermic data on the temperature and state of the matter at depths of hundreds of kilometers. Using the hypothetical relation between the electrical conductivity and the temperature of the Earth's interior, based on laboratory investigations of rocks, a geothermic interpretation of global GDS can be presented (see Sect. 4.6).

Regional and local GDS (see Sect. 4.7) rests on a firm theoretical foundation only when local sources are used, of which two—the auroral and the equatorial
electrojets—are known. However, a local nature of the electrojet field causes its rapid geometric attenuation and thus restricts the investigation depth of the method to only the first hundreds of kilometers.

The use in GDS of fields of nonlocal sources in local regions is an improperly posed problem. Local GDS can reveal an anomaly, but interpreting it by the GDS methods will result in a considerable ambiguity, in incredible models of electrical conductivity distribution in the Earth. Anomalies detected in observing the geomagnetic variations should be studied and interpreted by magnetovariational profiling (MVP) and magnetotelluric sounding (MTS) techniques specially intended for this purpose.

4.1 General

The physical principle of GDS rests on the fact that the relation between the variation of the vertical component $Z$ and that of the horizontal components $H$ and $D$ (or $X$ and $Y$), induced by external (ionospheric and magnetospheric) currents, of the geomagnetic field $B$ at the Earth's surface is dependent on the conductivity of the Earth. If the conductivity is low and the secondary field of currents induced in the Earth at its surface is much weaker than the primary one, the observed amplitudes of spatial harmonics of $Z$ and $H$ are the same. If the Earth were an ideal conductor, then currents shielding the Earth's interior from penetration of a variable electromagnetic field would be induced on its surface and, because of continuity of the normal component of the magnetic field [Eq. (2.11)], at the Earth's surface the vertical component would be zero, while the horizontal one would be enhanced by $n/(n + 1)$ of the primary field ($n$ is the order of the spherical harmonic) or, in a flat case, doubled. If at some depth there is an ideal conductor overlain by a substantially nonconducting layer, then, on account of the geometric attenuation, the secondary field on the Earth's surface will be weaker than the primary one, and the vertical component will be the greater, the deeper the conductor. No phase shift between the secondary and the primary field exists over an ideal conductor. If the Earth's conductivity is not very high or rises progressively with the depth, the secondary field is phase-shifted with respect to the primary one, and their ratio and other response functions (see Sect. 2.3) are dependent on the period of variations. Observing the variations over as wide a range of periods as possible we can use the skin-effect and investigate the electrical conductivity distribution with depth.

The theoretical fundamentals of the GDS have been presented in Sections 2.2 and 2.3, where all the equations were given for some spatial harmonic of order $n$. We will now write some expressions, taking into account that geomagnetic variations are described by the sum of several magnetic-mode spatial harmonics. Proceeding from Eqs. (2.69) and (2.39), we write equations for the magnetic field at the Earth's surface (at the right, as before, are the corresponding equations for the Cartesian coordinate system; $v_n^2 = v_x^2 + v_y^2$)