GEOPHYSICS, VOL. 67, NO. 2 (MARCH-APRIL 2002); P. 448–458, 9 FIGS.
10.1190/1.1468604

Atmospheric sources for audio-magnetotelluric (AMT) sounding

Xavier Garcia* and Alan G. Jones‡

ABSTRACT

The energy sources for natural-source magnetotelluric (MT) frequencies >1 Hz are electromagnetic (EM) waves caused by distant lightning storms and which propagate within the Earth–ionosphere waveguide. The properties of this waveguide display diurnal, seasonal, and 11-year solar-cycle fluctuations, and these temporal fluctuations cause significant signal amplitude attenuation variations—especially at frequencies in the 1- to 5-kHz so-called audiomagnetotelluric (AMT) dead band. In the northern hemisphere these variations increase in amplitude during the nighttime and the summer months, and they correspondingly decrease during the daytime and the winter months. Thus, one problem associated with applying the AMT method for shallow (<3 km) exploration can be the lack of signal in certain frequency bands during the desired acquisition interval. In this paper we analyze the time variations of high-frequency EM fields to assess the limitations of the efficient applicability of the AMT method. We demonstrate that magnetic field sensors need to become two orders of magnitude more sensitive than they are currently to acquire an adequate signal at all times. We present a proposal for improving AMT acquisition involving continuous profiling of the telluric field only during the daytime and AMT acquisition at a few base stations through the night.

INTRODUCTION

Natural-source time-varying electromagnetic (EM) waves observable on the surface of the Earth are generated by distant lightning activity at high frequencies (above about 1 Hz) and generally by the interaction of the Earth's magnetosphere with particles ejected by the Sun (solar plasma) at low frequencies (<1 Hz). These waves propagate around the globe in the electrically charged Earth–ionosphere waveguide, and they penetrate the Earth and respond, in both amplitude and phase, to the subsurface electrical conductivity structure. The frequency-domain transfer function relationship between the horizontal electric and magnetic field components measured on the surface of the Earth forms a 2×2 complex tensor, $\mathbf{Z}(\omega)$, which can be interpreted in terms of ground structure to depths given by the inductive scale length at the frequencies of interest. This geophysical technique, proposed independently yet simultaneously in the early 1950s in Russia (Tikhonov, 1950) and France (Cagniard, 1953) and now developed to be a highly advanced geological mapping tool, is called the magnetotelluric (MT) method (e.g., Vozoff, 1986, and references therein).

The high-frequency MT method, called audiomagnetotellurics (AMT), has recently seen widespread application for problems related to imaging the conductivity structure within the accessible part of the crust, i.e., the top 3 km. In Canada over the last few years, there have been more than 12 000 AMT soundings made for mineral exploration purposes, mostly around Voisey's Bay (Labrador), Sudbury (Ontario), and the Thompson nickel belt (Manitoba), particularly for regional mapping and for imaging structures at depths deeper than traditionally mined (>500 m) (e.g., Balch et al., 1998; Stevens and McNeice, 1998; Zhang et al., 1998). Controlled-source EM methods, used effectively in the past (Boldy, 1981), have their limitations for probing depths > ∼500 m, and the AMT method offers greater depth penetration as well as a number of other attractive features: easier logistics, more tractable mathematical solutions for multidimensional targets, and the availability of 2-D and 3-D modeling and inversion codes.

However, critical to the successful application of AMT is the acquisition of high-quality time series data, which require sufficient natural signals during acquisition; the prior difficulties of the AMT method for shallow exploration were documented by Strangway et al. (1973). As a response, the controlled-source AMT method (CSAMT) was developed in the early 1970s (Goldstein and Strangway, 1975) because the sensors and instrumentation of the day could not detect the weak natural signals. Since that time there have been advances in sensors, instrumentation, and time-series processing schemes, such that

Manuscript received by the Editor February 23, 2000; revised manuscript received August 10, 2001.

*Formerly Geological Survey of Canada, 615 Booth Street, Ottawa, Ontario K1A 0E9, Canada; presently Woods Hole Oceanographic Institution, Deep Submergence Laboratory, Department of Applied Ocean Physics and Engineering, MS 9, Woods Hole, Massachusetts 02543. E-mail: xgarcia@whoi.edu.
‡Geological Survey of Canada, 615 Booth St., Ottawa, Ontario K1A 0E9, Canada. E-mail: ajones@nrcan.gc.ca.