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Controlled-Source Audio-frequency MagnetoTelluric methods from the near- to the far-field: theory and applications

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Controlled-Source Audio-frequency MagnetoTelluric (CS-AMT) is an active electromagnetic (CSEM) sounding technique, sensitive to the resistivity variations of the subsoil from a few meters to a few kilometers depth. It derives from the magnetotelluric (MT) method, which is based on measurements of natural electrical and magnetic fields related by induction; the interaction between natural EM signals at the Earth surface is controlled by the underground resistivity. With MT methods, the sources of these signals are distant enough from the measurement station, so that the EM waves are considered to behave as “far-field” waves. In this configuration, the Cagniard formula expresses the apparent electrical resistivity of the sensitive area as a function of the squared ratio of the electrical field amplitude to the magnetic induction amplitude.

Because natural sources are irregular, AMT data acquisition and processing can be improved by the use of controlled source (CSEM). In most of the active geophysical techniques, and amongst others for CSEM, the input signal is voluntarily transmitted close to the measurement location, in order to maximize the signal to noise ratio. This implies that the measurements are sensitive not only to the area underneath the measurement location, but also to the area in between the transmitter and the receiver. This area needs therefore to be modelled. In the special case of CS-AMT, the source (transmitter that is either a horizontal electric dipole or a vertical magnetic dipole) is located as far as possible from the measurement location, so that the measured signals comply to the requirement of far-field waves. This assumption allows using the standard processing used for the MT methods, ignoring the effect of diffusion pattern and change of direction and intensity of the EM waves from the transmitter to the receiver.

In practice, the distance between the transmitter and the receiver is often limited by the decrease in signal strength when moving away from the transmitter, and because the choice of the source location is also affected by accessibility or environmental constraints. For these reasons, the measured signals are more often in a “transitional domain” where the behavior of the signal corresponds either to the far-field or to the near-field, depending on its frequency.

We propose a reformulation of the Cagniard formula to the interpretation of the ratio of the electrical to magnetic fields in the case of near-field magnetotelluric signals. We illustrate the use of these atypical formulations with applications to the granitic catchment of the Strengbach (Vosges mountains, North-East of France), and to the Séchilienne landslide, a micaschist instability in the Alps (South-East of France), where CSAMT data have been acquired in the near field, the transitional-field and the far-field.