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Variations in the magnetic field arising from the motional induction that accompanies seismic waves in far-field regions

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Variations in the electromagnetic field that accompany earthquakes are generated by various mechanisms, of which the present study focuses on variations in the magnetic field arising from motionally induced electric currents that accompany seismic waves at a large distance (several hundred kilometres) from the epicentre. As a simple but informative case, a situation is considered in which seismic waves are approximated by plane waves and the conductivity of the Earth's crust has a stratified structure. Solutions of Maxwell's equations corresponding to this situation have analytical expressions. Analysis of the solutions verifies that SH waves do not generate variations in the magnetic field, thereby implying that Rayleigh waves are dominant in generating variations in the magnetic field at a significant distance from earthquake epicentres.

Using the obtained solutions, variations in the magnetic field due to Rayleigh waves are quantitatively discussed in terms of a crust with a simple structure. Numerical examples demonstrate that the amplitudes of the generated variations in the magnetic field show a monotonic increase with increasing conductivity, although depression of the amplitudes due to the skin effect of electromagnetic waves cannot be ignored. In addition, the amplitudes of the generated magnetic field are sometimes sensitive to the conductivity of both the shallow and deep crust. Given the difficulty of precisely determining the conductivity of the deep crust, it is generally problematic to obtain precise estimates corresponding to the actual Earth. Nevertheless, calculations assuming a simplified conductivity structure provide an upper limit to the possible amplitudes of variations in the magnetic field due to seismic waves. For example, the amplitudes of variations in the magnetic field arising from a Rayleigh wave with a displacement amplitude of 10 cm and a period of 30 sec are as large as 0.1 nT, which is close to the limit of detection by fluxgate magnetometers under typical observation conditions. It is also suggested that phase differences between seismic ground motions and EM variations are not influenced by detailed conductivity structures, and they occur within a rather narrow range of values determined by the direction orientation of the ambient geomagnetic field. In the future, when data with an accuracy of 0.01 nT are available, this property may be used to distinguish variations arising from motional induction, from variations arising from other origins.

Keywords: motional induction, seismic wave, magnetic field