OFFICE MEMORANDUM ◇ STAR LABORATORY

February 23, 1995

To: Diane Shankle

From: Tony Fraser-Smith   Electromagnetics

Subject: Ph.D. Quals Question, 1995

Question: Suppose an earthquake occurs in the earth at a depth of d meters (Figure 1). Although we have no idea what kind of electromagnetic signals, if any, are generated in the earth by earthquakes, let us assume that they do produce electromagnetic fields and that these fields have the same amplitude at all frequencies. Given the electrical conductivities (σ) shown in the figure, and given also that the skin depth δ at 1 Hz is 1.6 km for $\sigma = 0.1$ S/m, what frequencies are likely to be observed on the surface for earthquakes in California? Is there any delay? Are there any ways by which the seismic changes in the earth associated with earthquakes might generate electromagnetic signals?

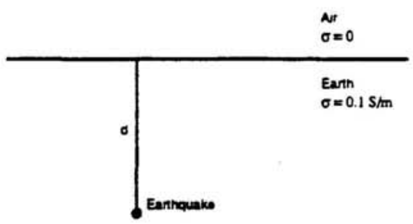

Figure 1. Earthquakes in California typically occur at depths (d, in meters) of around 10 km

Answer: After a brief discussion of good conductors and poor conductors, leading to the conclusion that the above problem must treat the earth as a good conductor ($\sigma/\omega\epsilon \gg 1$, where ω is the angular frequency and ϵ is the permittivity), the student must either remember or derive an expression for the attenuation of electromagnetic fields in a conducting medium in terms of the skin depth, i.e., $\delta = [2/(\omega\mu\sigma)]^{1/2}$, where μ is the permeability. In addition, the student should demonstrate some knowledge of how (1) the wave propagates with phase velocity $v = \omega/\beta = \omega\delta$, (2) it has a wavelength $\lambda = 2\pi\delta$, and (3) it is exponentially attenuated with attenuation constant $\alpha = 1/\delta$. Given the preceding information, it is easy to show that the phase velocity has a $\omega^{1/2}$ frequency dependence (*dispersion*!), meaning that it propagates more slowly as the frequency gets smaller.

With the information given in the problem, em signals with frequencies above 1 Hz will be severely attenuated as they propagate a distance of 10 km to the surface. On the other hand, for $f = 0.01$ Hz, it is easy to derive a skin depth of 16 km from the information given, showing that em signals will not be severely attenuated for frequencies less than about 0.01 Hz. Thus measurements at frequencies less than about 0.1 Hz appear most desirable if em signals from earthquakes are to be detected (more specifically, the frequency for which $\delta = 10$ km is close to 0.3 Hz).

Consideration of the phase (and group) velocity indicate delays of about 1 sec for the signals to reach the surface, which are not likely to be significant. Pressure changes in the earth associated with the earthquake seismic waves might produce electric charges through the piezoelectric effect, and the charge distributions might radiate em waves (very speculative). If the charge is on the surface the em waves will not be heavily attenuated and high frequencies may be observed.

$k \approx \beta + i\alpha$. $\delta = \frac{1}{\alpha}$

$v_{ph} = \omega/\beta = \omega\delta = \sqrt{\frac{2\omega}{\mu\sigma}}$