Symbiosis Between Geophysics and Medicine

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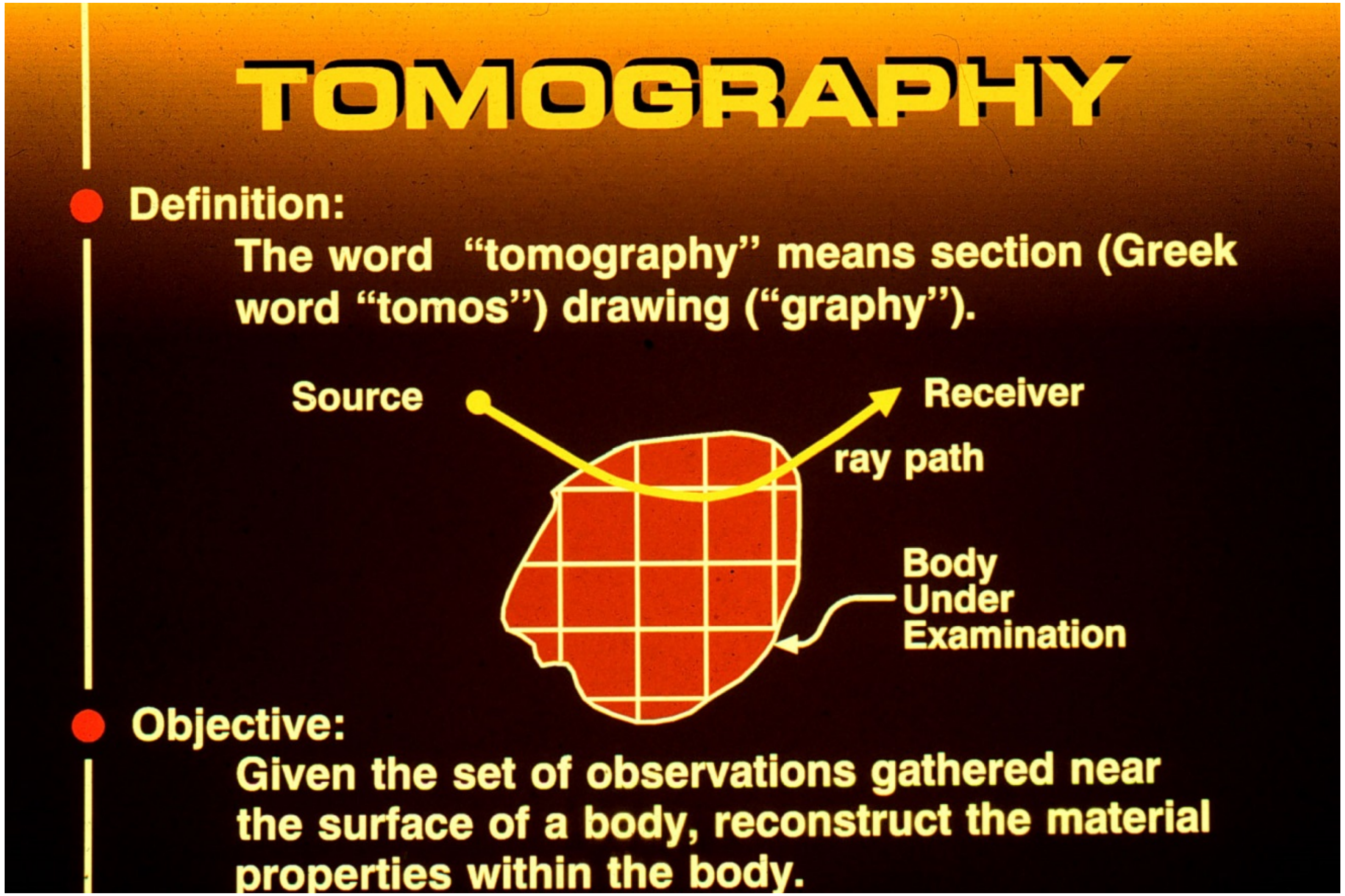
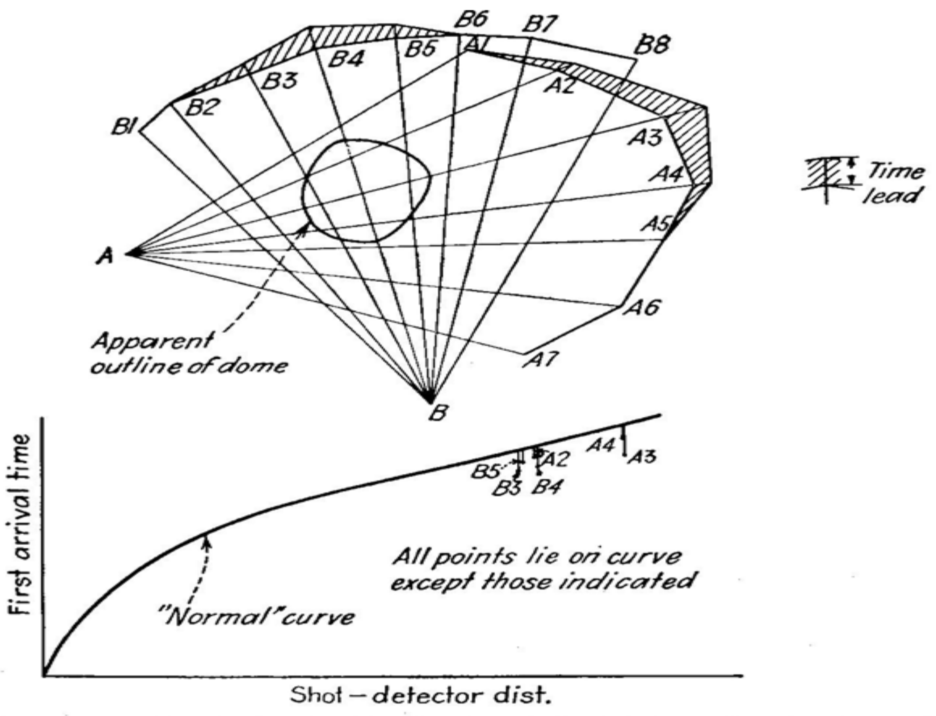


Note rays bending according to Snell's Law and the medium's wave velocity contrasts. Generally, there are greater velocity contrasts in rocks than in the human body, hence more ray bending in seismic tomography.

The Earliest (?) Tomography
Seismic Refraction Fan Shooting in 1920’s

This figure from Dobrin (1960) describes the geometry of seismic refraction fan shooting for salt dome location – used in the Gulf of Mexico in the 1920’s..

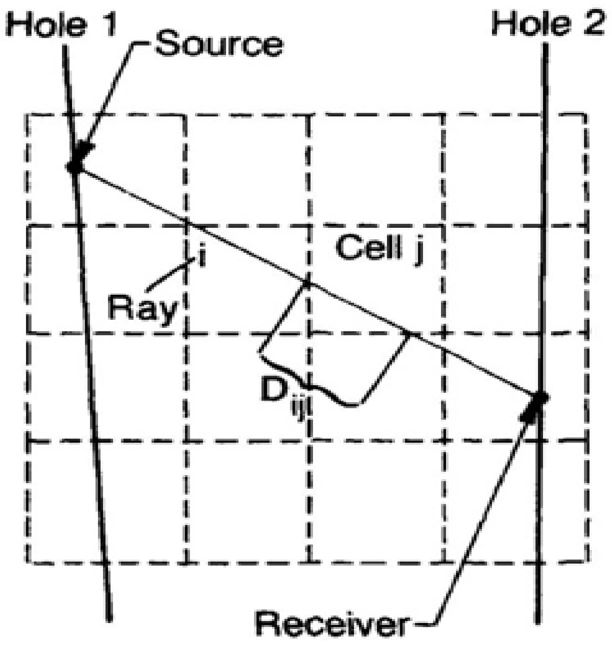


Traveltime tomography

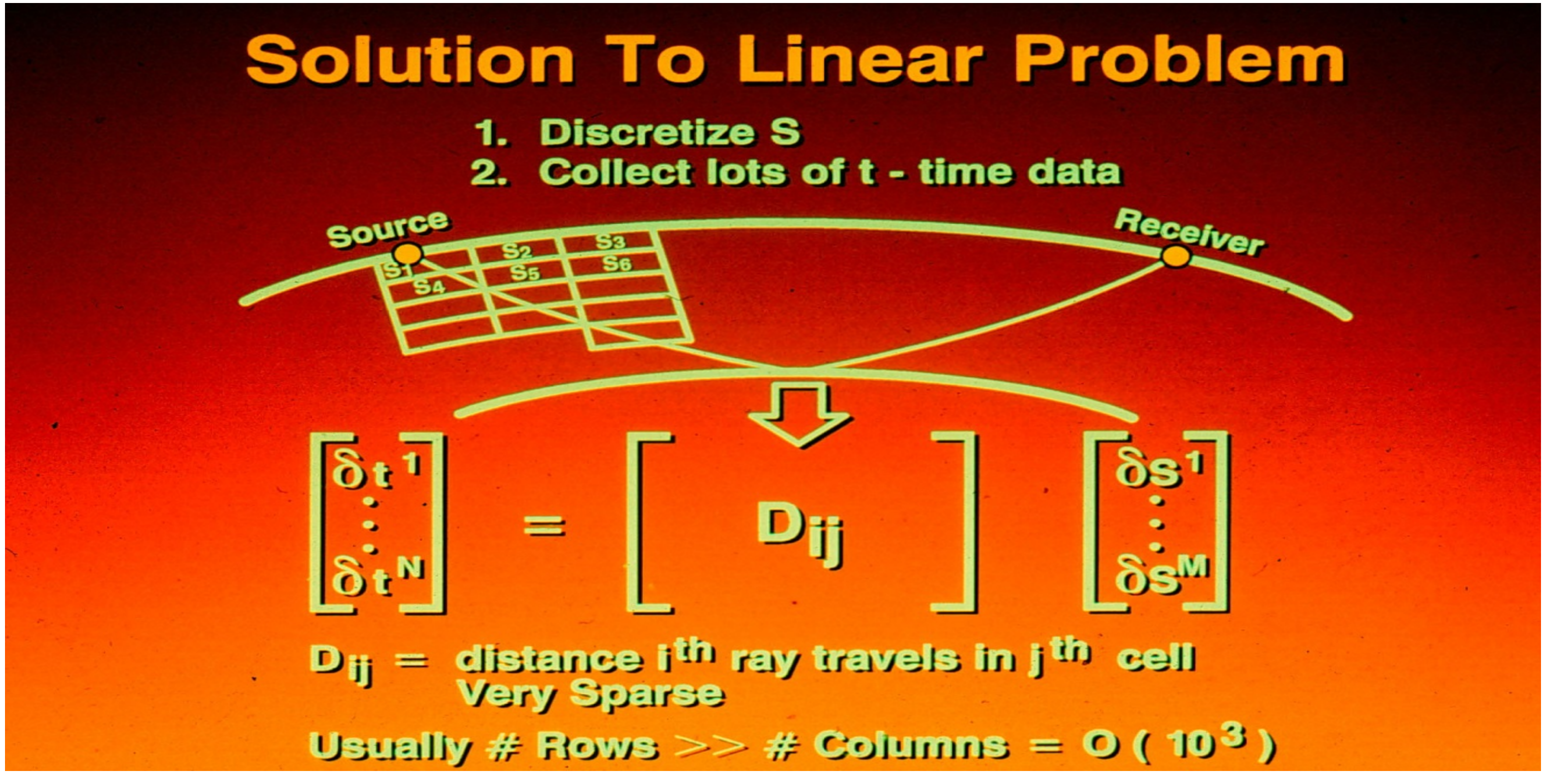
. If v(x,z) is the 2-D velocity field, s(x,z)=1/v(x,z) is the slowness or reciprocal velocity, and dl is the differential distance along the ray, the modeled traveltime associated with a given ray in a two-dimensional case is given by:

$$t(ray) = \int_{ray} s(x, y)\,dl$$

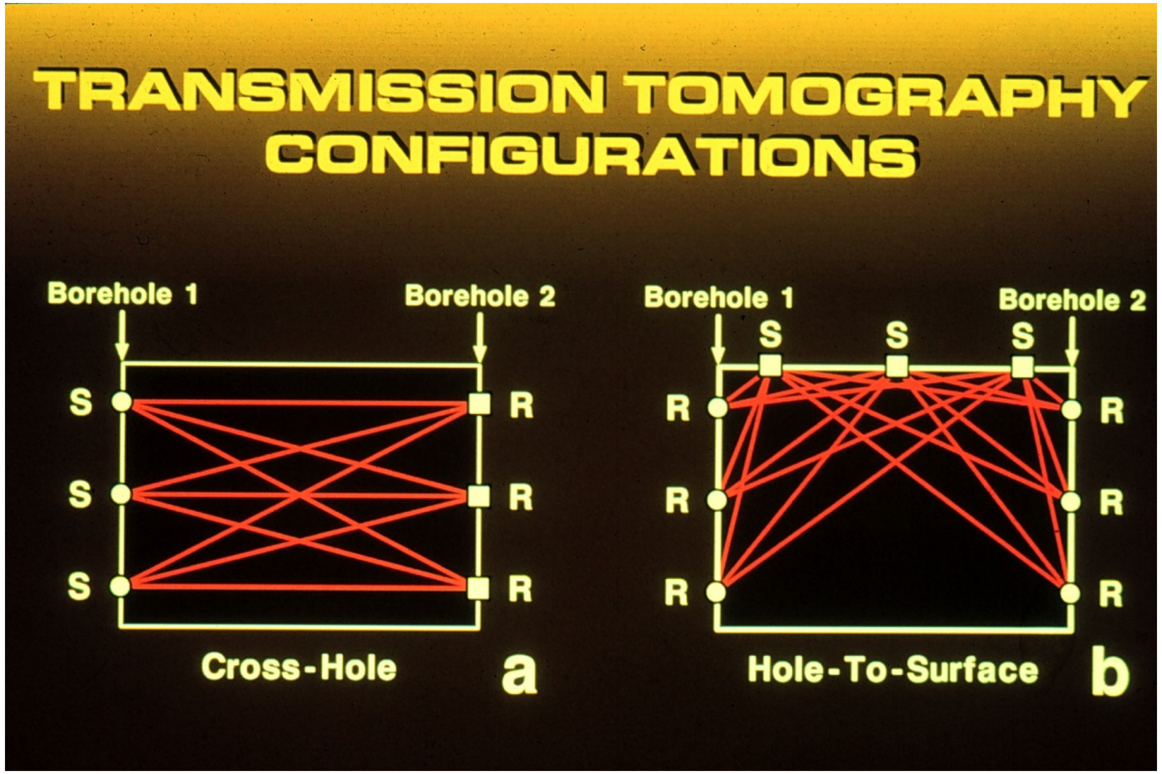
Tomography Velocity Cell Discretization



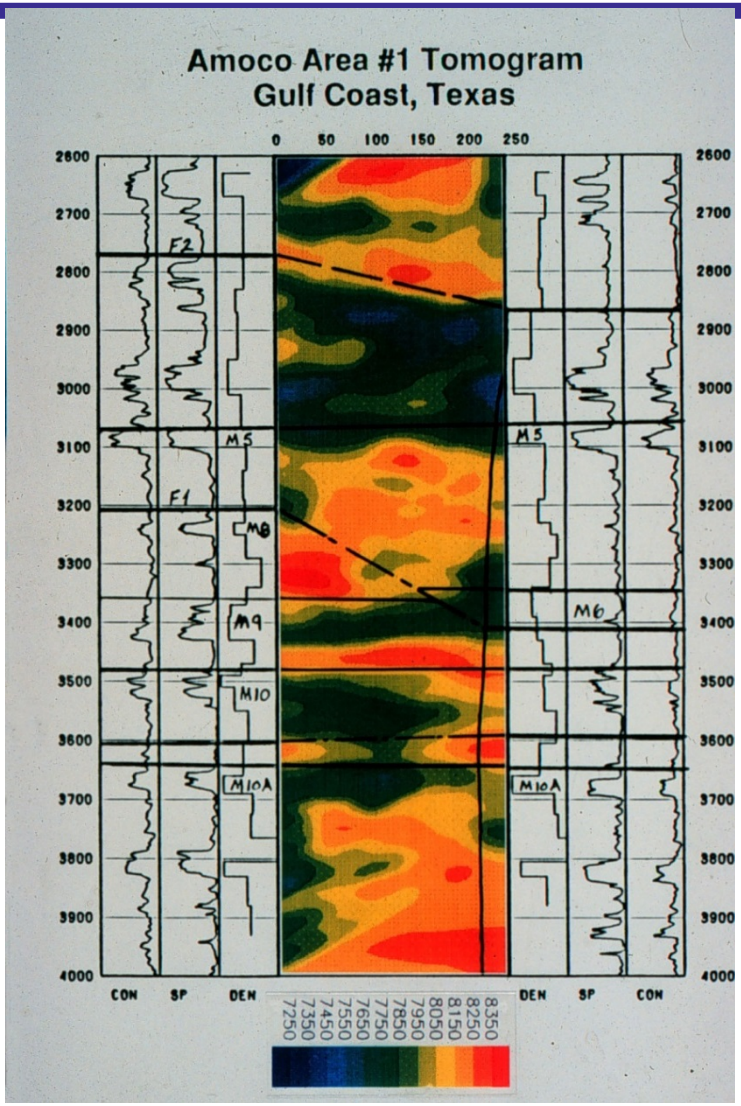
The ith ray travels a distance D_{ij} *in the jth cell (after Bording et al., 1987).*



These sets of equations are iteratively solved and **D** is updated at each iteration after ray tracing with the updated slowness model. Convergence is said to occur when the differences between data and modeled traveltimes are small enough.



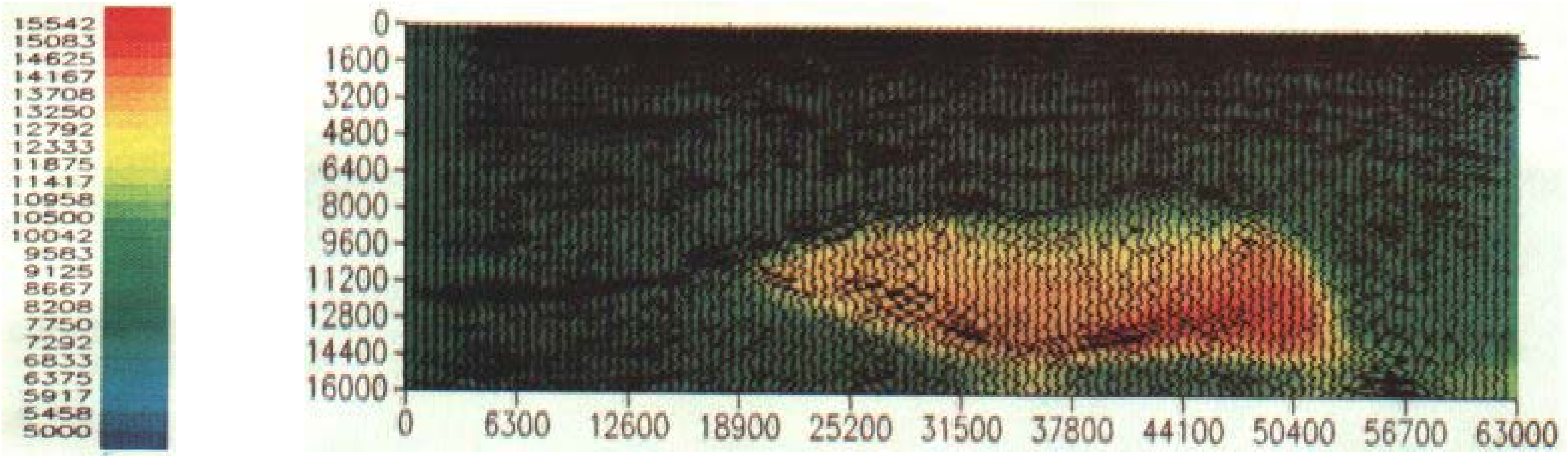
Combining these borehole configurations will allow us to do CT scans of the Earth – albeit with incomplete apertures.



This cross-borehole tomogram, from Harris et al. (1990 SEG annual meeting) and later shown in Lines (1991), indicates the location of two faults between boreholes in East Hastings field, Texas.

Reflection Tomography Complements Depth Imaging

This figure from Lines (1991) shows the overlay of a velocity tomogram on a depth migration for a Gulf of Mexico salt dome. Tomography provides velocities for the depth migration.



Comparison of Traveltime and Attenuation Tomography

- Traveltime equations

$$\mathbf{Ds} = \mathbf{t}$$

- Attenuation (Centroid Method
  (Quan and Harris, 1997)

$$\mathbf{D}\alpha_0 = \mathbf{f}_s - \mathbf{f}_r$$

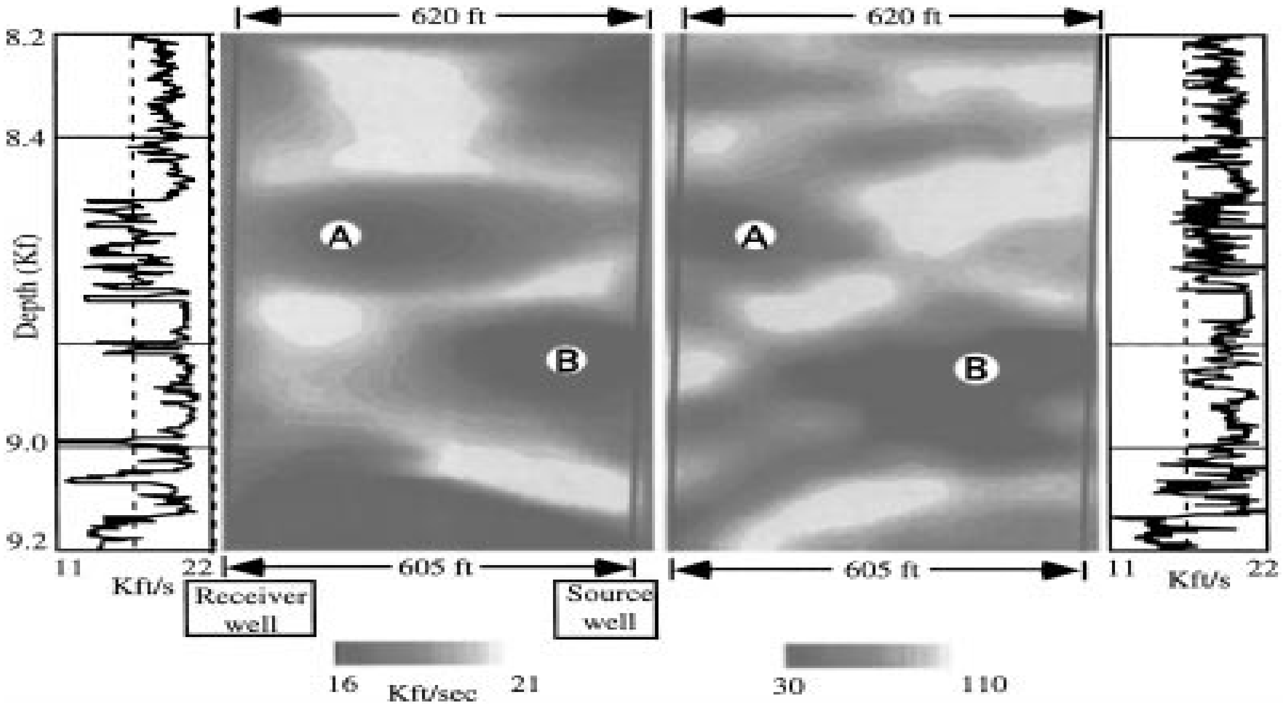
α_0 = attenuation coefficient/frequency

f_s = centroid frequency at source normalized by variance

f_r = centroid frequency at receiver normalized by variance

Q Tomograms and Velocity Tomograms

Results from Quan and Harris (1997) show that high Q and high velocity rocks tend to correlate on crosswell surveys from west Texas. High velocity areas generally correlate with high Q areas.



CT medical scans and the projection slice theorem

CT scanning equipment as shown in a figure from Wikipedia. The patient inside the donut shaped apparatus is completely surrounded by sources and receivers.

CT medical scans and the projection slice theorem

The line integral in this situation is similar to the traveltime equations but involves the attenuation coefficient, $\alpha(x,z)$ rather than slowness s(x,z). This can be viewed as a linear system since the rays are straight:

$$\gamma_k = \int_{ray} \alpha(x,y)\,dl \qquad ,$$

where $\gamma_k = -\ln \frac{A_k}{A_0}$ is the integrated attenuation, where A_k is the amplitude at the end of the ray and A_0 is the initial amplitude at zero distance (reference: Dines and Lytle, 1979).

CT medical scans and the projection slice theorem

This will result in a set of linear equations:

$$\mathbf{D}\alpha = \gamma$$

These equations for attenuation of CT scans generally have a complete 360 degree aperture, and different solution methods can be used – including those that use the projection slice theorem.

CT scans and the projection slice theorem

The line integrals represent the projection of 2-D functions. The projection slice theorem states that 2-D Fourier transforms of an image can be constructed by taking 1-D Fourier transforms of the line integral for integrated attenuation.
An inverse 2-D Fourier transform can then be applied to produce an image.

Since the projection slice theorem uses data recorded with a 360 degree aperture, application of the projection slice theorem **will generally not work in seismic tomography.**

Ultrasound imaging – the reflection seismology of the body

The closest similarity to reflection seismology in medical imaging is ultrasound medical imaging. Reflections of high frequency sound waves or ultrasound waves (frequencies greater than 20,000 Hz) are used to creat images. An ultrasound image of a human fetus 2 months prior to birth is shown (courtesy of Dr. Wendy Benoit).

Electromagnetic Methods in Geophysical and Medical Imaging

If ρ is density and v is P-wave velocity, the reflection coefficient for normal incidence P-waves waves is given by the ratio of reflected amplitude to incident amplitude by:

$$R_{12} = \frac{\rho_2 v_2 - \rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1}\,.$$

If velocity variation is much greater than density variation, as is often the case for sedimentary rocks, the reflection coefficient is given by:

$$R_{12} = \frac{v_2 - v_1}{v_2 + v_1}$$

Electromagnetic Methods in Geophysical and Medical Imaging

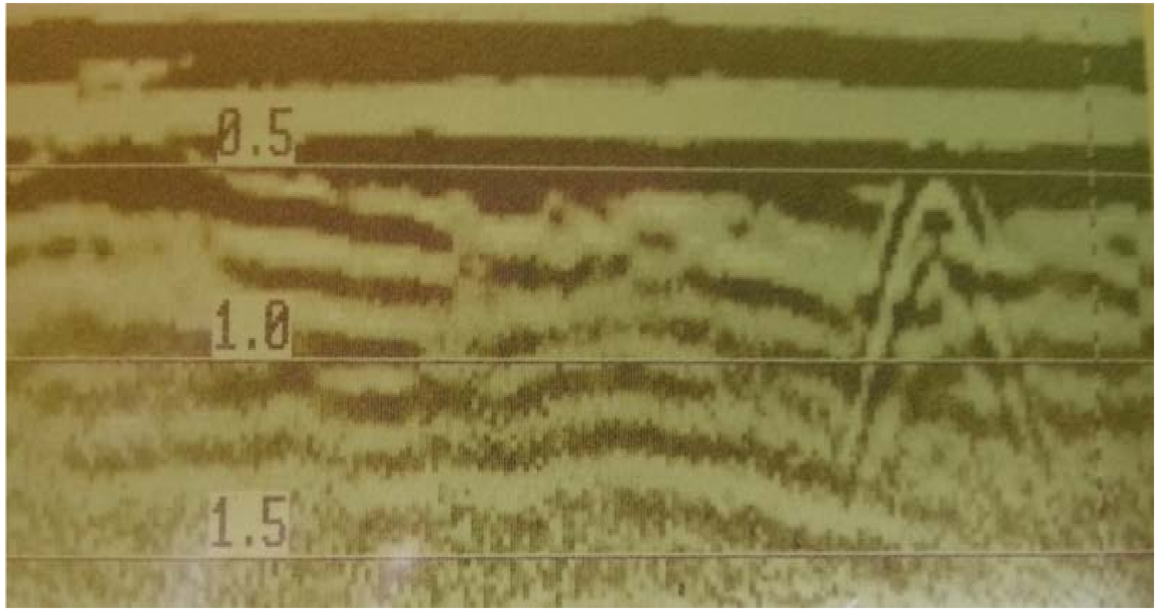
The previous equation is essentially the same as in ground-penetrating reflection (GPR) surveys.

The EM velocities are given by $v = \frac{1}{\sqrt{\mu\varepsilon}}$ where μ is magnetic permeability and ε is electric permittivity. Therefore for EM waves, the reflection coefficient for non-magnetic materials (where μ does not vary) is given by:

$$R_{12} = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}}.$$

Electromagnetic Methods in Geophysical and Medical Imaging

GPR in geophysics is useful for geophysical imaging of the near surface down to depths of a few meters.



Electromagnetic Methods in Geophysical and Medical Imaging

For medical EM imaging of the human body, wavelengths must be smaller and are typically on the order of a few centimeters. For these purposes, high frequency EM waves, known as microwaves are used with frequencies on the order of 1 to 10 GHz.

Bourqui and Fear's 2016 IEEE paper entitled "System for Bulk Dielectric Permittivity Estimation of Breast Tissues at Microwave Frequencies"describes an apparatus for measuring microwave transmission responses to estimate dielectric properties of the human breast in order to detect possible tumours.

Conclusions and Possible Future Research Directions

Similaries exist between geophysical and medical imaging methods – especially in areas of tomography (acoustical and EM), acoustical reflection imaging and EM reflection imaging

Due to restricted aperture and ray bending due to large velocity variations, geophysical imaging cannot always use the same algorithms as those used in medical imaging.

Key question: Are there geophysical algorithms such as deconvolution and migration that will enhance medical images?

Recommendation: More communication between geophysical and medical imaging scientists could bring synergistic improvement in both fields.

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