A LOOK AT A PURELY MINERALOGICAL DEPENDENCE ON WAVE SPEEDS IN HOMESTAKE MINE

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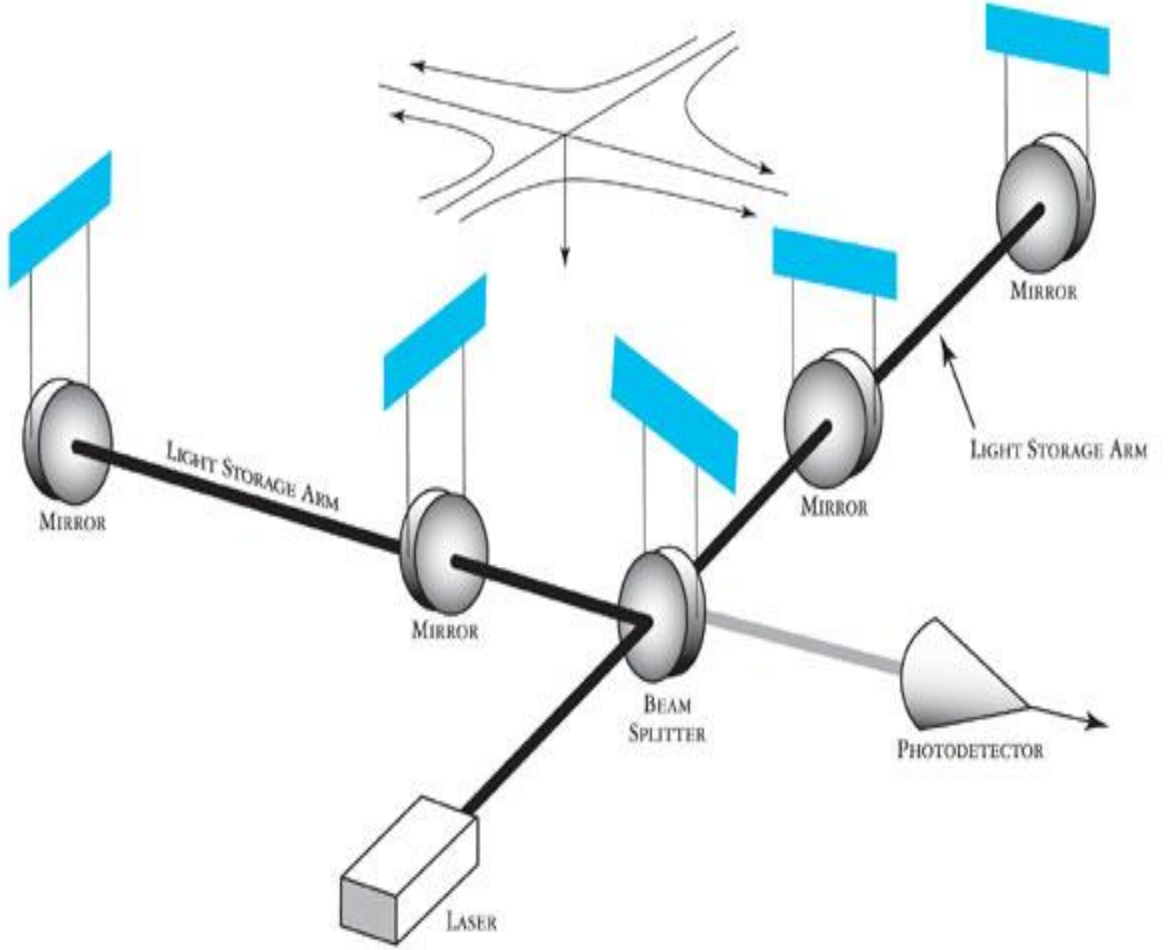
A bit about LIGO

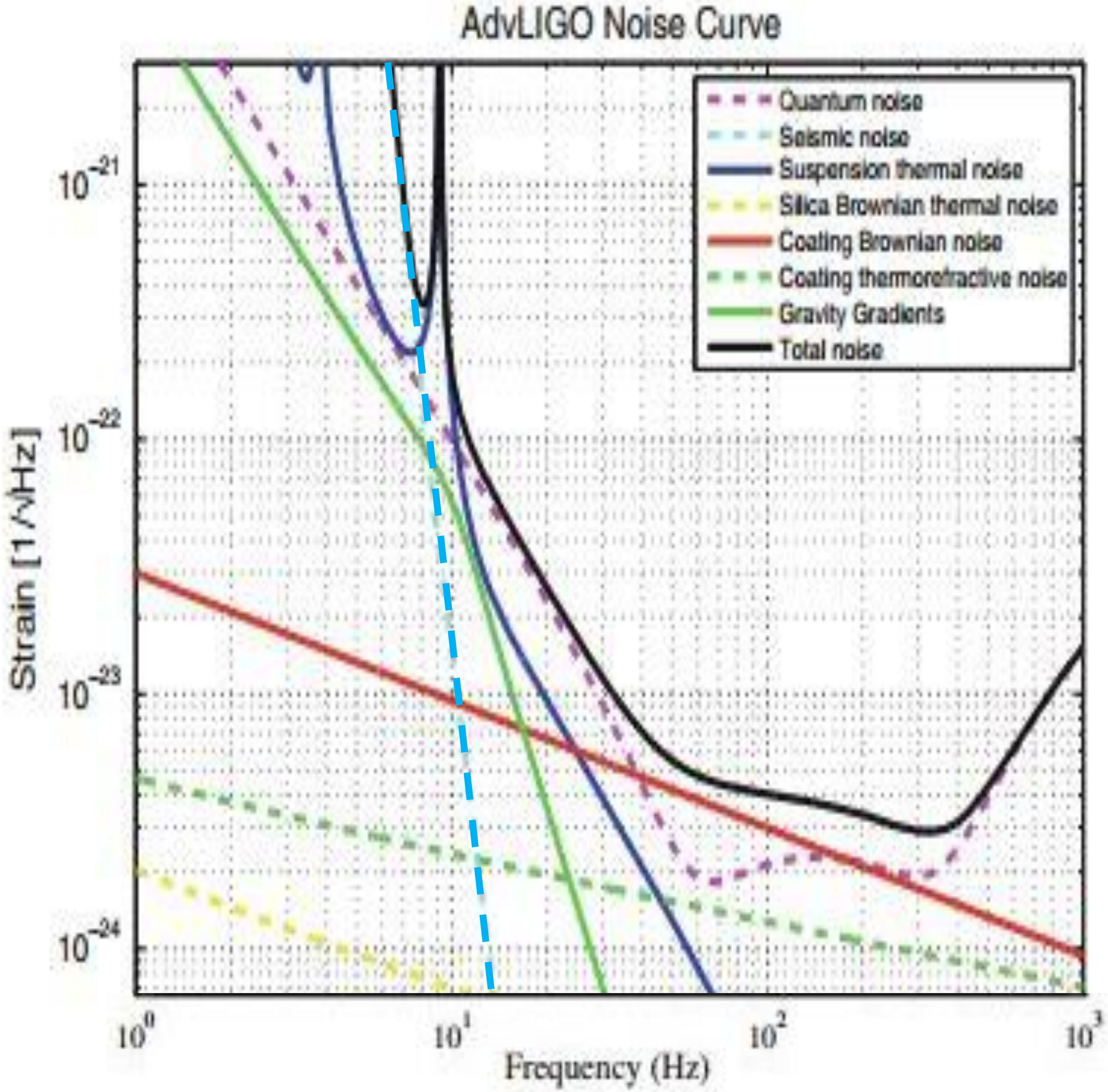
- Laser Interferometer Gravitational Wave Observatory (LIGO) works as follows:
- Laser → Beams split → Beams travel down arms of identical length → Reflected by mirrors → Beams coincide at beam splitter → Photodetector
- If no light output is measured: No signal
- If you do measure some light: Possible GW signal



(Image courtesy of California Institute of Technology)

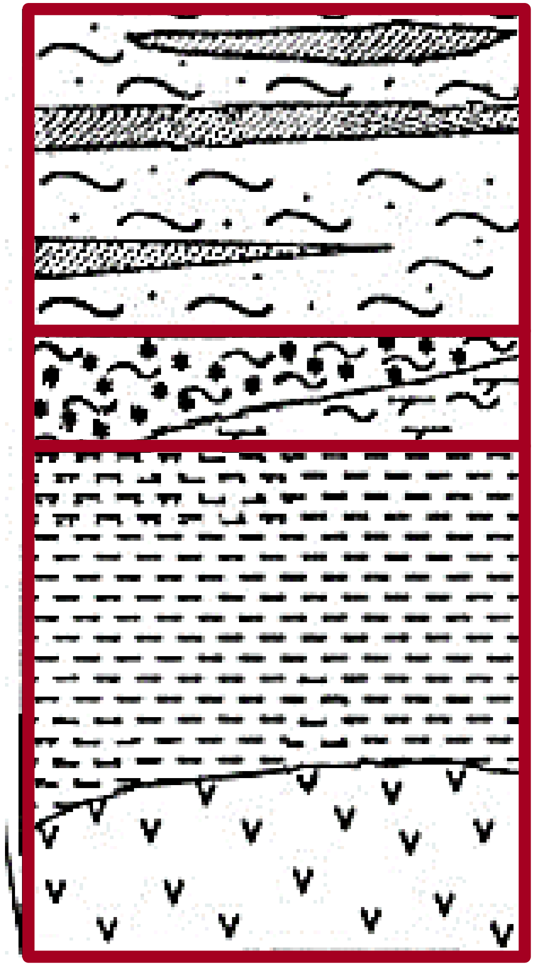
Motivation

- The next generation of LIGO-like GW detectors will likely be built underground (Beker et. al, 2011, *General Relativity and Gravitation*)
  - At very low frequency, seismic noise (SN) dominates.
  - Seismic waves cause vibrations of test masses and mirrors which could muddle any potential signal.
  - They can induce other types of noise as well e.g. Newtonian Noise
- We will use a 3D array of seismometers to characterize the seismic environment



(Beker et. al, 2011, *General Relativity and Gravitation*)

Homestake Mine, Lead, SD



LEFT: We see the seemingly simple structure of three main formations within the Homestake Mine.

RIGHT: A generalized cross-section through a particular ledge within the mine; we see that the (overly) simple stratification is not realized.

This greatly complicates attempts at determining how seismic waves propagate throughout the mine.

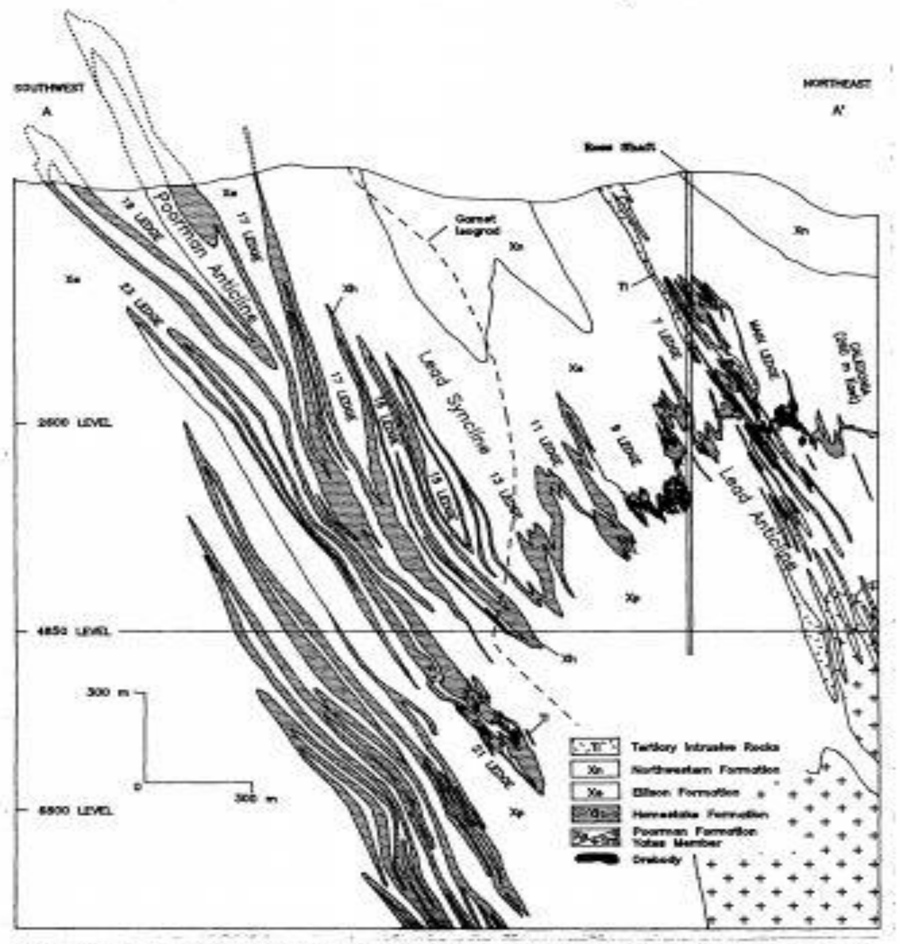


Fig. 3. Generalized geologic cross-section through 33 Stope - Main Ledge Reference Line, Homestake mine, Lead, SD. See fig. 2 for location. Modified from Caddey et al. (1990).

(Adapted from Caddey & Geological Survey, 1992)

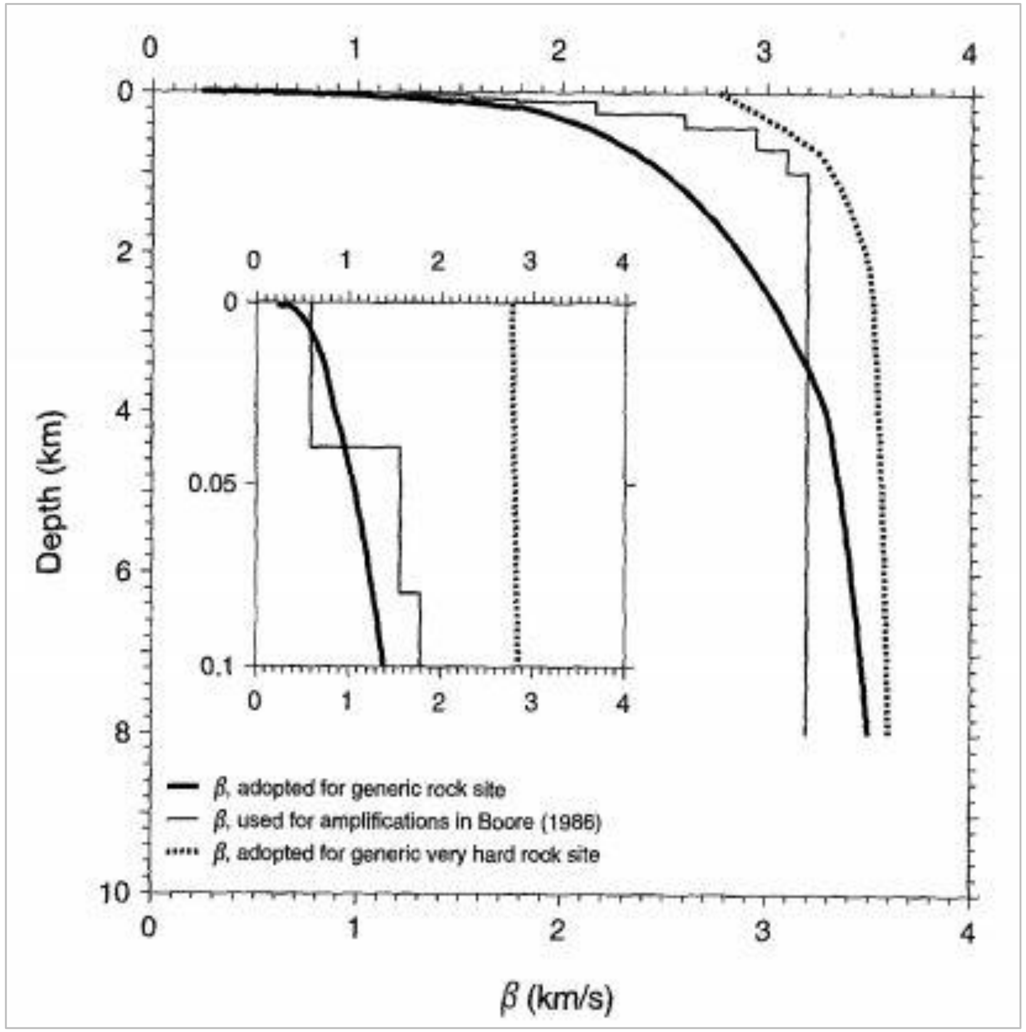
Calculating Elastic Wave Speeds

- Main assumption: wave speed through materials is an additive quantity
- Using Tables J1, J3, and J5 (Caddey & Geological Survey, 1992):
  - Estimate elastic wave speed ($\bar{V}_M$) of each site using a normalized weighted average; i.e.

$$\bar{V}_M = \sum_{i \in S} w_i (V_M)_i \tag{1}$$

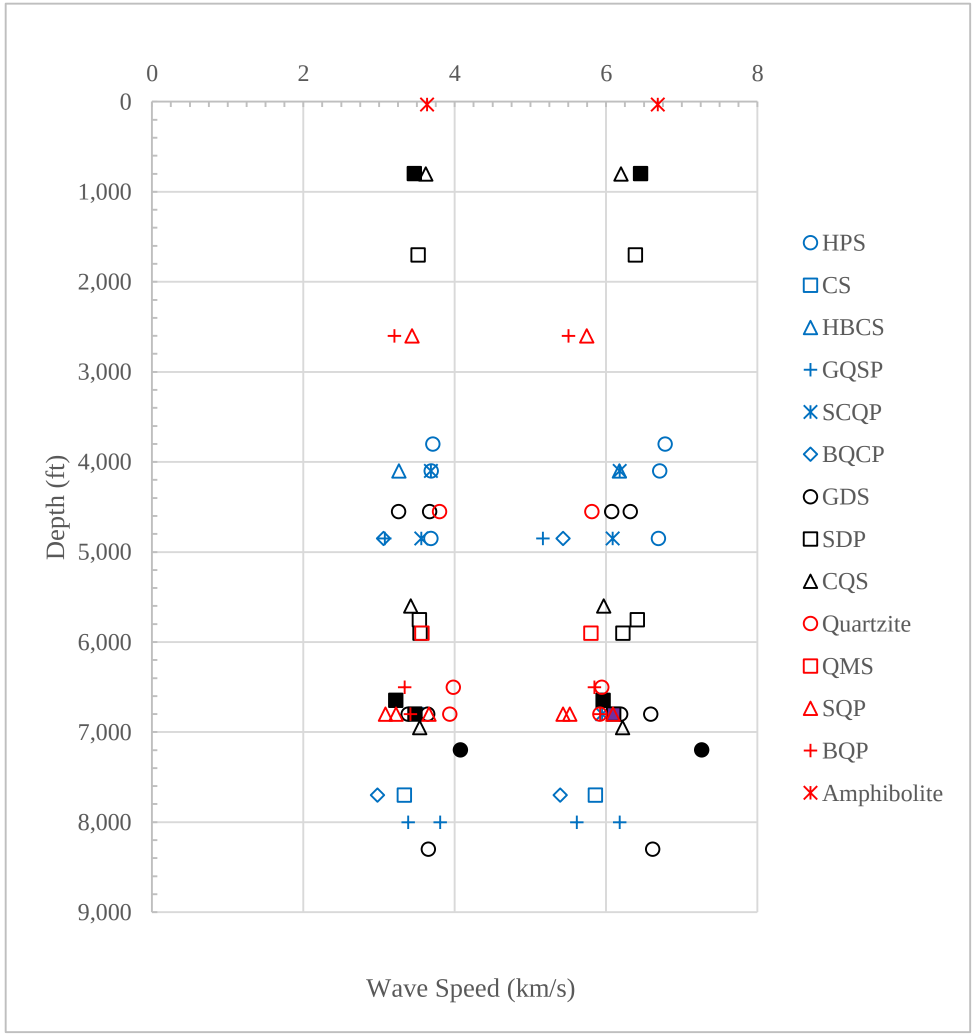
where S spans the sample space consisting of the pertinent minerals in each table, w_i is the percent mineral composition, and $(V_M)_i$ is the wave speed of each constituent mineral

Results



(Boore and Joyner, 1997)

S-wave P-wave



A Look at Porosity

A look at the porosity of Homestake rocks could give an idea of how the mining and geological history has affected seismic wave propagation.

Definition:

$$\Delta t = \frac{\phi}{V_f} + \frac{1-\phi}{V_m} \quad \text{or} \quad \phi = \frac{\Delta t - \Delta t_m}{\Delta t_f - \Delta t_m} \qquad (2)$$

Where:

$\Delta t = \frac{1}{V_p}$: is the formation transit time (or *slowness*) and V_p is the formation (P-wave) velocity

$\Delta t_m = \frac{1}{V_m}$: is transit time through the rock matrix

$\Delta t_f = \frac{1}{V_f}$: is the transit time through pore-filling substance

(Telford, Geldart, and Sheriff, 1990)

Parameters

- Recommended: assume water and air as the pore filling substance.
  - In essence: At these depths, most porosity is water-filled. The exception would be places near where the mine is pumping, but those are only close to drifts. It would be worth doing both.

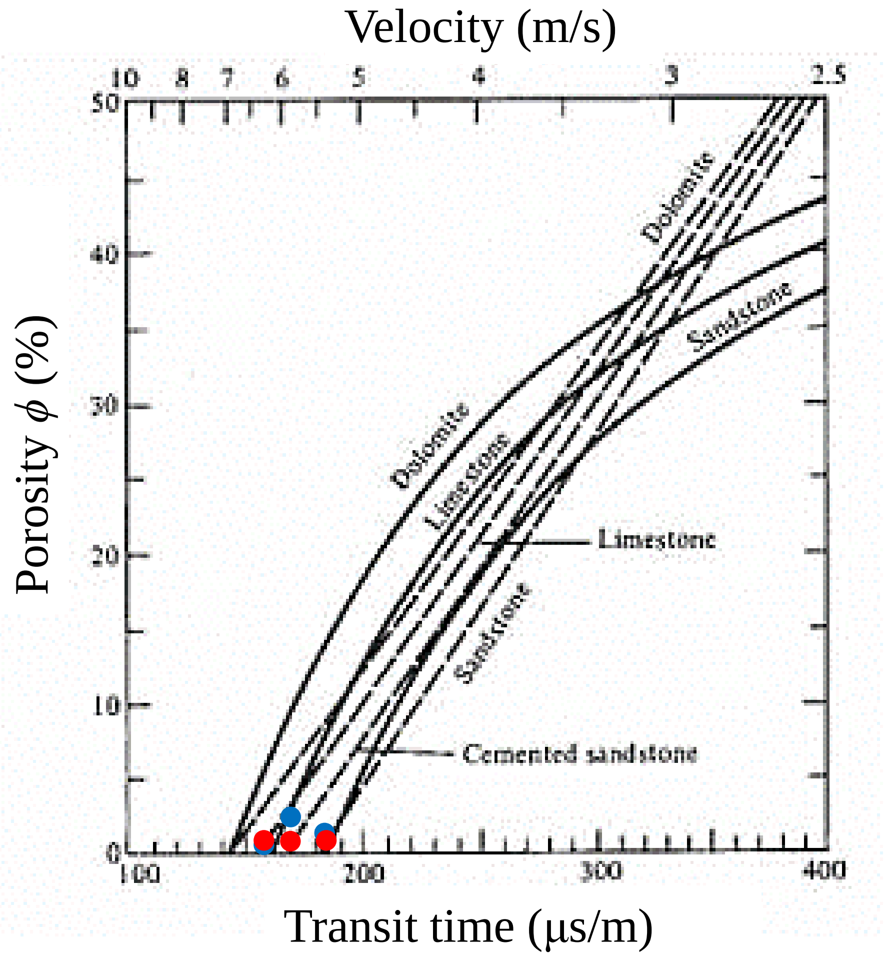
- For water:

$$V_{f,water} \cong 1{,}500\,\frac{m}{s} \Rightarrow \Delta t_{f,water} \cong 667\,\frac{\mu s}{m}$$

- For air:

$$V_{f,air} \cong 340\,\frac{m}{s} \Rightarrow \Delta t_{f,air} \cong 2.94 * 10^3\,\frac{\mu s}{m}$$

Results: Porosity at the 2000-level



LEFT: In calculating the porosity for the 2000-level in the Homestake mine, we see that the porosity for both water- filled (blue points) and air-filled (red points) pores is consistent with the literature. In essence: At the 2000-level, the rocks are not very porous.

(Adapted from Telford, Geldart, and Sheriff, 1990)

Conclusion

- Ground-based GW detectors are limited by seismic noise at frequencies below 10 Hz
- Moving them underground could limit many noise sources, but a characterization of seismic environment is needed
- Calculated seismic wave speeds through Homestake rocks based solely on mineral composition
- Model yields wave speeds independent from depth, indicating that any depth-dependence would have to come from porosity and other imperfections in the rock
- Porosity calculations were made; we can compare mineral composition model with measurements made at 2000-level

Acknowledgements

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- I would also like to thank Gary Pavlis and James Atterholt at Indiana University—Bloomington for providing data at 2000-level in Homestake.

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