Analysis of Depth-dependent Behavior of Shear Waves

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Overview

- Overview of Experiment:
  - "Seismic shear-wave velocity as a function of depth for generic rock sites has been estimated from borehole data and studies of crustal velocities, and these velocities have been used to compute frequency-dependent amplifications for zero attenuation for use in simulations of strong ground motion." [1]
- Claim: We can use (nearly) the same power-law representation as originally posited in Boore and Joyner (1997)
  - May need some slight modifications to account for real Homestake data

Note on Amplification

From Boore and Joyner (1997):

[T]he S travel time S_{tt}(z) from the surface to depth z either is taken from downhole surveys or is computed using shear velocity as a function of depth; the average velocity to depth z, $\overline{\beta(z)}$, is z/S_{tt}(z) and the frequency corresponding to the depth, $f(z)$, is 1/[4 × S_{tt}(z)]; a travel-time-weighted average is taken of the density, $\overline{\rho(z)}$; and the amplification is given by:

$$A[f(z)] = \sqrt{\frac{\rho_s \beta_s}{\overline{\rho(z)}\;\overline{\beta(z)}}} \qquad (1)$$

Power Law Representation of Depth-dependent Shear Waves

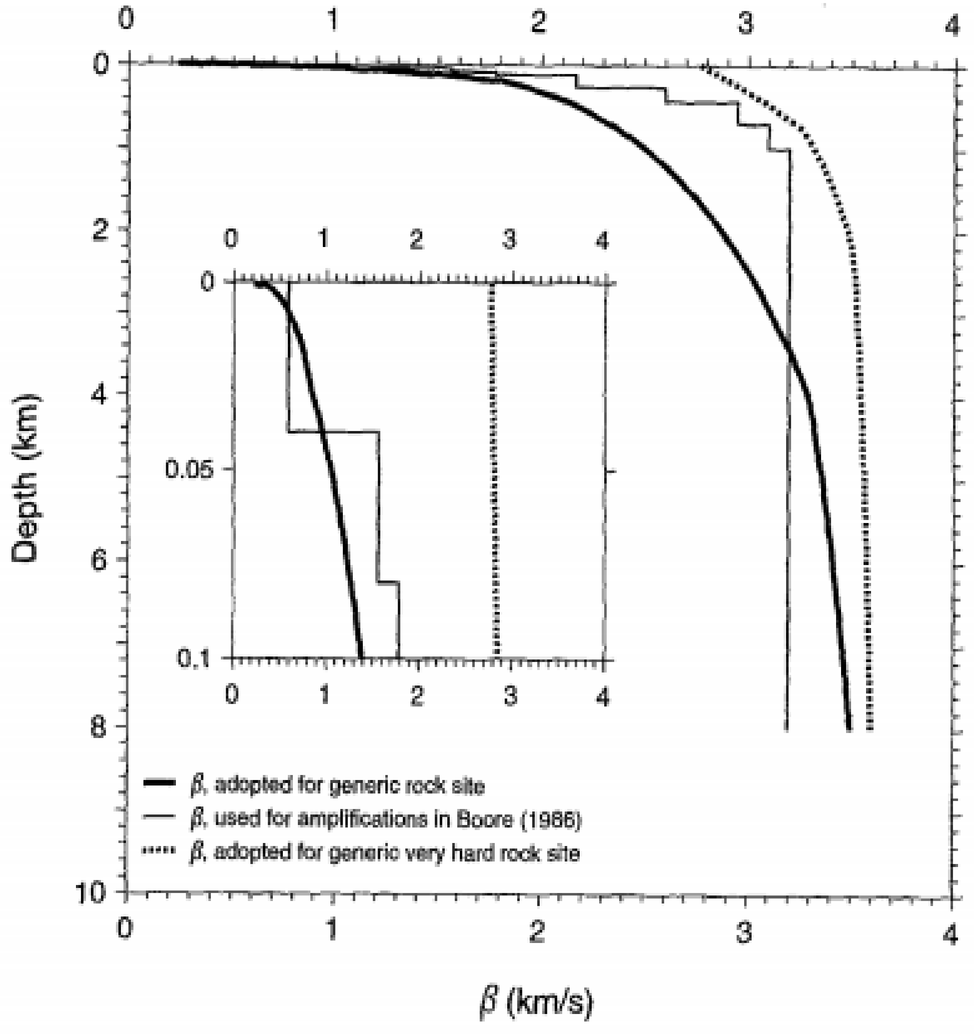


Figure 5. *S* velocity versus depth adopted in this article for generic rock sites (heavy solid line) and generic very hard rock sites (heavy broken line). For comparison, the light line is the velocity model used to obtain the amplifications published in Boore (1986).

Note: Compare this with Victor's slide from the October conference

[1] Boore and Joyner (1997)

Functional Values for Power Law Representation

Velocity for Generic Rock Site

Depth (km)	Shear Velocity (km/sec)*
$z \leqq 0.001$	0.245
$0.001 < z \leqq 0.03$	$2.206z^{0.272}$
$0.03 < z \leqq 0.19$	$3.542z^{0.407}$
$0.19 < z \leqq 4.00$	$2.505z^{0.199}$
$4.00 < z \leqq 8.00$	$2.927z^{0.086}$

*$\bar{V}_{30}$ = 0.618 km/sec.

Velocity for Generic Very Hard Rock Site

Depth (km)	Shear Velocity (km/sec)*
0.00	2.768
0.05	2.808
0.10	2.847
0.15	2.885
0.20	2.922
0.25	2.958
0.30	2.993
0.35	3.026
0.40	3.059
0.45	3.091
0.50	3.122
0.55	3.151
0.60	3.180
0.65	3.208
0.70	3.234
0.75	3.260
$0.75 < z \leqq 2.20$	$3.324z^{0.067}$
$2.20 < z \leqq 8.00$	$3.447z^{0.0209}$

*$\bar{V}_{30}$ = 2.88 km/sec.

[1] Boore and Joyner (1997)

Comparison of Rock and Very Hard Rock

Rock

- “[Rock] sites described by terms such as ‘granite,’ ‘diorite,’ ‘gneiss,’ ‘chert,’ ‘graywacke,’ ‘limestone,’ ‘sandstone,’ or ‘siltstone,’ …” [2]

Very Hard Rock

- “Such as is found in glaciated regions in large areas of eastern North America or in portions of western North America.” [1]

So What is Homestake?

<u>Poorman Formation:</u>

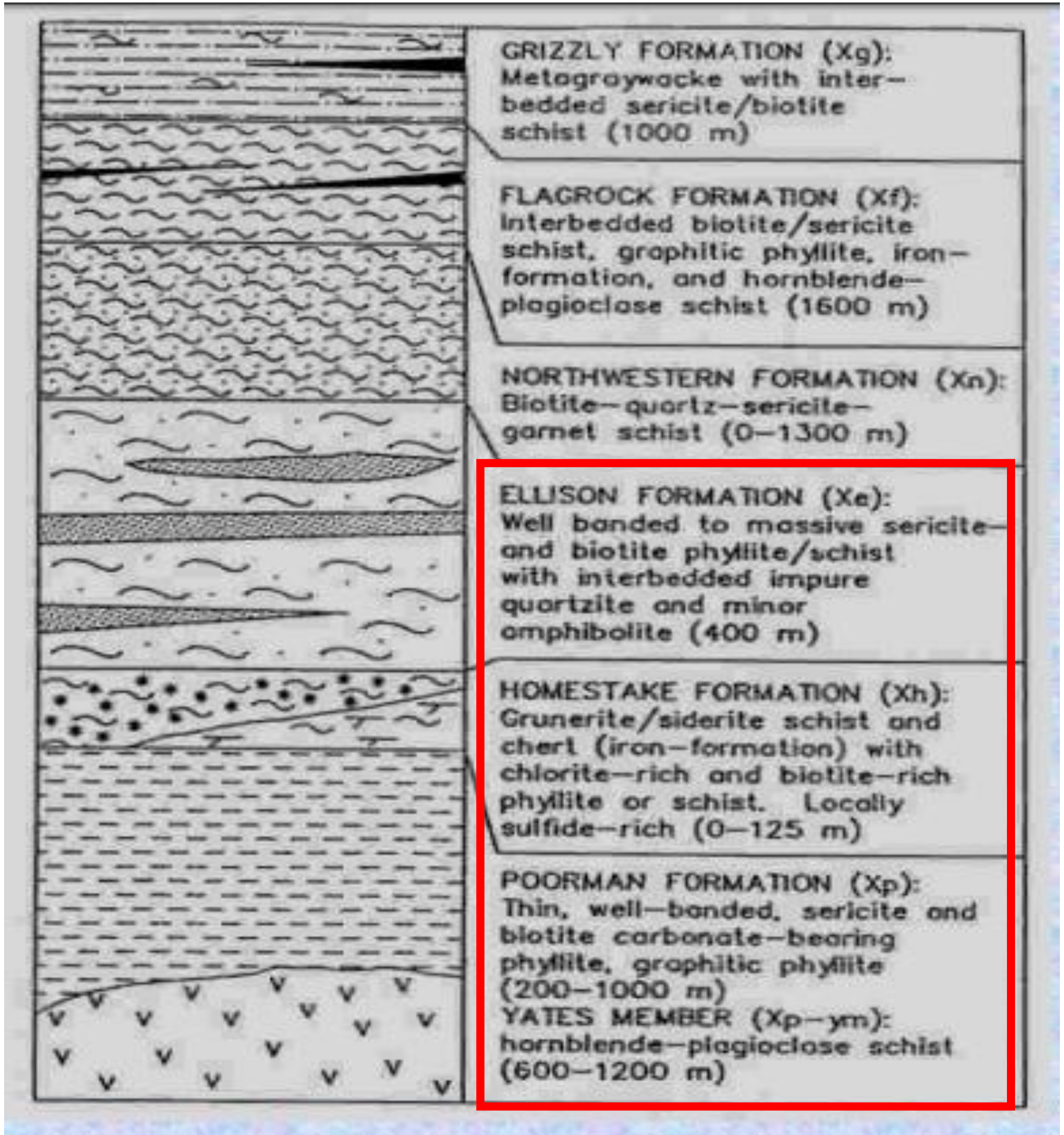
- Horneblende-plagioclase schist
- Thin-bedded, well-layered … sericite and biotite, carbonate–bearing phyllite and graphitic phyllite

<u>Homestake Formation:</u>

- Grunerite-garnet schist in eastern mine, mixed with siderite/grunerite in central mine, and thin-bedded siderite phyllite in western mine ….
- Iron formation with local thin chert interbeds

<u>Ellison Formation:</u>

- Well-banded to massive sericite and biotite phyllite or schist, with interbedded impure quartzite



[3] Caddey, Bachman, and Otto (1990)

[4] Roggenthen

So What is Homestake?

- Comparing geology of Homestake [3] [4] and sites proposed by Boore and Joyner (1997) [1] [2]:

  Homestake can probably be represented by *rock sites*

- Implication:

  We could use the representation (or a slight modification) given in Boore and Joyner (1997)

Potential Issues

- "Directionality of incident seismic wave"
  - "…incidence angles of 30 ° and 45 ° were used to approximate the range of angles that would exist for events not directly under the site (the incidence angles would be smaller for input at shallower depths because of refraction)." [1]

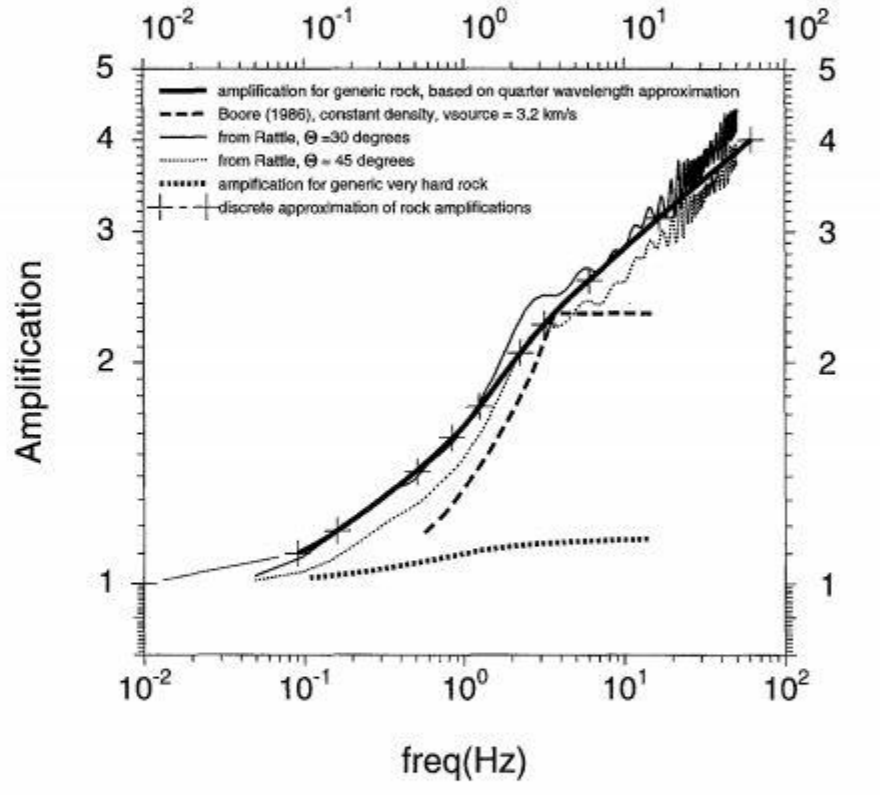


Figure 7. Amplification versus frequency. The heavy solid line is computed using the quarter-wavelength approximation and the velocity profile shown by the heavy solid line in Figure 5. The long-dashed line is from Boore (1986), also based on the quarter-wavelength approximation but using the "Boore (1986)" velocities shown in Figure 5. The results from plane *SH* waves incident at the base of a 8-km-thick stack of constant-velocity layers (with Q = 10,000) closely approximating the adopted continuous shear-wave velocity are shown by the light lines for angles of incidence of 30° and 45°; the results were computed from the Haskell matrix method, as implemented by program *Rattle* by C. Mueller. The quarter-wavelength amplification for generic very hard rock is given by the heavy short-dashed line.

It may be difficult to see in the figure on the left [1], but despite using a range of incident angles for an event, the amplification for generic rock sites are remarkably similar—especially at lower frequencies.

This hints that we may be able to conclude the shear waves are very similar in this range, but we may have to make more assumptions based on Equation 1.

Conclusion

- Using Boore and Joyner’s 1997 paper [1] as a basis, and studying the geology local to Homestake:
  - We could use of their power law representation (possibly with slight modification) for the depth-dependent behavior of shear waves.

References

- [1] Boore and Joyner, *Site Amplifications for Generic Rock Sites,* BSSA, Vol. 87, No.2, pp. 327 – 341, April 1997.
- [2] Joyner and Boore, *Peak Horizontal Acceleration and Velocity From Strong-Motion Records Including Records From the 1979 Imperial Valley, California, Earthquake,* Vol. 71, No. 6, pp. 2011-2038, December 1981
- [3] Caddey, Bachman, and Otto, *15 Ledge Ore Discovery, Homestake Mine, Lead, South Dakota*, Retrieved from: http://homestake.sdsmt.edu/Protected/Lead1990meeting/15%20Ledge%20discovery.pdf, 1990
- [4] Roggenthen, W. *Homestake DUSEL: Contributions to the S-1 Approach,* [PowerPoint slides] . Retrieved from: http://www.phys.vt.edu/~kimballton/dusel/workshop/DUSEL/Homestake%20DUSEL.pdf