

How fast were my rocks? Modeling Seismic Velocities for Exhumed Rocks

Part 1: Seismic velocity basics

Basics of seismic waves

When an earthquake happens, elastic energy stored up during the interseismic period is released in the form of vibration. These vibrations can travel through the Earth (body waves) or along the surface of the Earth (surface waves). For the purposes of these calculations, we're only going to consider body waves. There are two types of body waves:

- Primary (or 'P') waves, which are compressional waves and are the fastest seismic waves. P-waves pass through solids, liquids, and gases.
- Secondary (or 'S') waves, which are shearing waves and travel slower than P-waves but faster than surface waves. S-waves only pass through solids.

What controls seismic velocities and what does it tell us?

If a rock is squeezed or sheared, it will deform (reduction in volume or accumulating shear strain) in response to the stress that is applied to it. If the applied differential stress is small enough, we remain in the elastic regime of deformation and the strain accumulated in response to the applied stress will be recovered when the stress is released. The properties of the rock that define its response to this stress determine how fast a seismic wave can propagate through the rock. To characterize wave speeds, we use three physical properties:

- K (the bulk modulus), which is a measure of incompressibility of the material,
- G (the shear or rigidity modulus), which is a measure of the material's resistance to shearing,
- and ρ (the density), which is a measure of the mass per unit volume.

We can define p- and s-wave velocities using these properties.

$$V_P = \sqrt{\frac{K + \frac{4}{3}G}{\rho}}$$

$$V_S = \sqrt{\frac{G}{\rho}}$$

Depending on what other classes you've had, you might notice that these are not technically **velocities**. Velocity is a vector quantity, meaning that it has magnitude and direction. These values are magnitudes (numbers) only, but we still refer to them as velocities and use V as an abbreviation.

Wave speeds can tell us something about the subsurface

For example, S-waves do not pass through liquids. We can see this from G , which goes to 0 in liquids. This also means that p-waves are slower in liquids, because the numerator is a smaller number.

Different minerals and rocks have different physical properties (e.g., higher or lower G , K , and ρ). Geophysical data like tomography create velocity models for the subsurface. Theoretically, researchers can then fit those velocities to determine the materials in the subsurface. This is, however, difficult to do in practice because of the multiple variables that go into the calculations and the overlap of velocities for different rocks. This is commonly a question with multiple potential solutions.

So what do we do? One option is to use what we know from the rock record to evaluate whether the rock record fits with modern geophysical data. This gives us one of two options:

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- The rock record overlaps with geophysical data, suggesting that the rock record is permissibly representative of the rocks at depth creating the modern geophysical signature.
- The rock record is not similar to the geophysical data, suggesting that a different conceptual model must be used.

Note that overlap between modelled seismic velocities from the rock record overlapping with the modern geophysical signature does not mean that you've found the solution and it is the only possible one. There are typically multiple solutions that satisfy the geophysical data, but evidence from the rock record strengthens that interpretation.

Why might we want to do this?

Some areas have enigmatic seismic velocities that might tell us something about deformation processes that are happening at those depths. A good example of this is anomalous seismic velocities that are observed in the down-dip of the seismogenic zone in most modern subduction zones (e.g., Delph et al., 2018; Park et al., 2010; Peacock et al., 2011). These zones are characterized by anomalously low p-wave and s-wave velocities and anomalously high V_P/V_S ratios. Researchers have concluded that this is indicative of high pore fluid pressures in the subduction interface at these depths.

One comparison that we can make is to calculate the seismic velocities of exhumed subduction complexes to estimate the prograde and/or retrograde velocities, taking into account mineralogical and lithological variations and mineral anisotropy. This allows us to directly compare exhumed subduction complexes to geophysical evidence from modern subduction zones. Depending on how these data sets compare, they can provide insights into how representative exhumed subduction-related rocks are of modern subduction zone processes, which can help us better understand what's potentially happening in modern subduction zones.

References

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