V_P/V_S ratio and dehydration reactions in subduction zones

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European Geosciences Union Annual Meeting, 06 May 2020

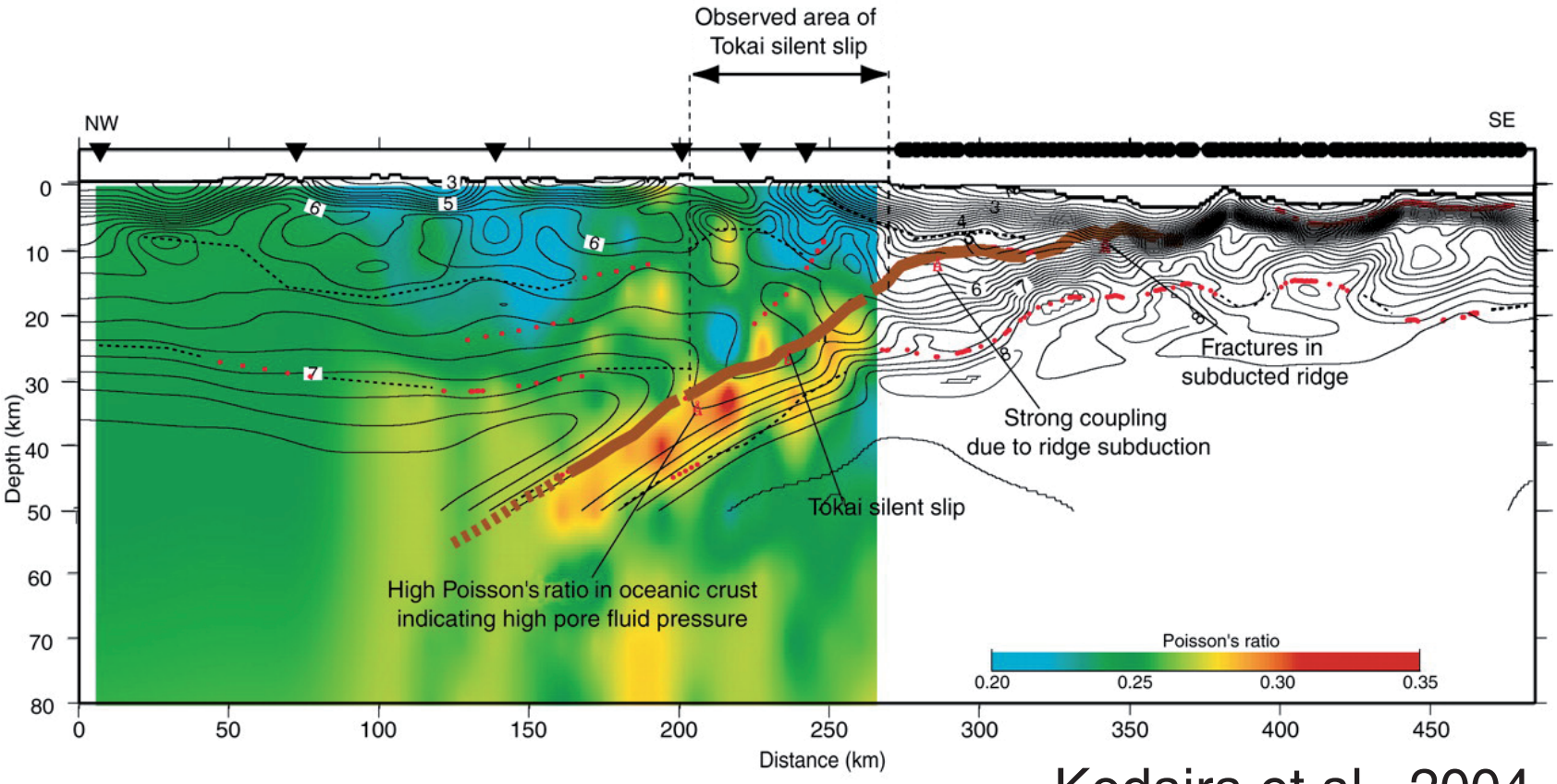
Funding

European Research Council

Established by the European Commission

Natural Environment Research Council

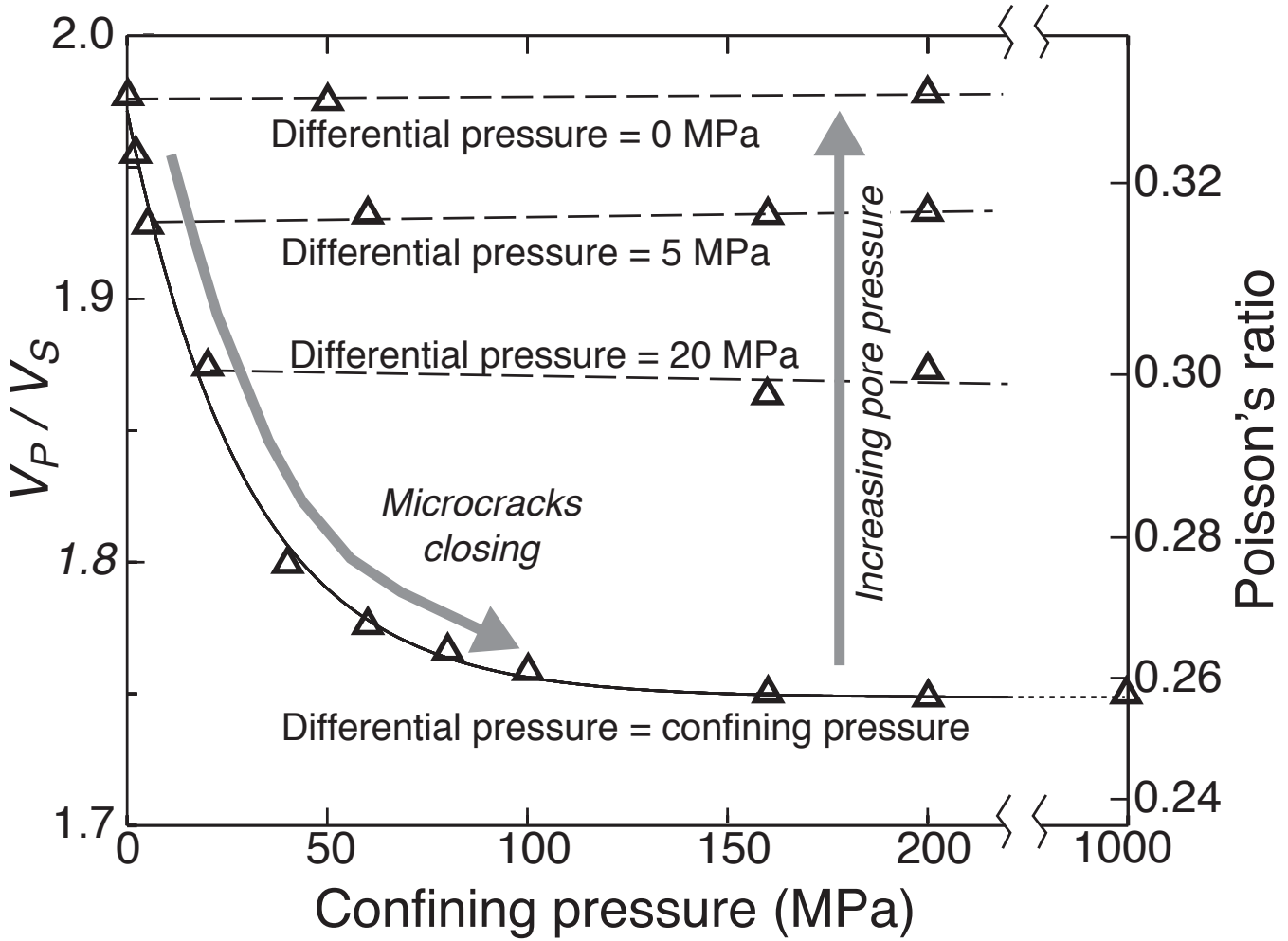
Common interpretation of V_P/V_S: fluids



Kodaira et al., 2004

Where does this interpretation come from?

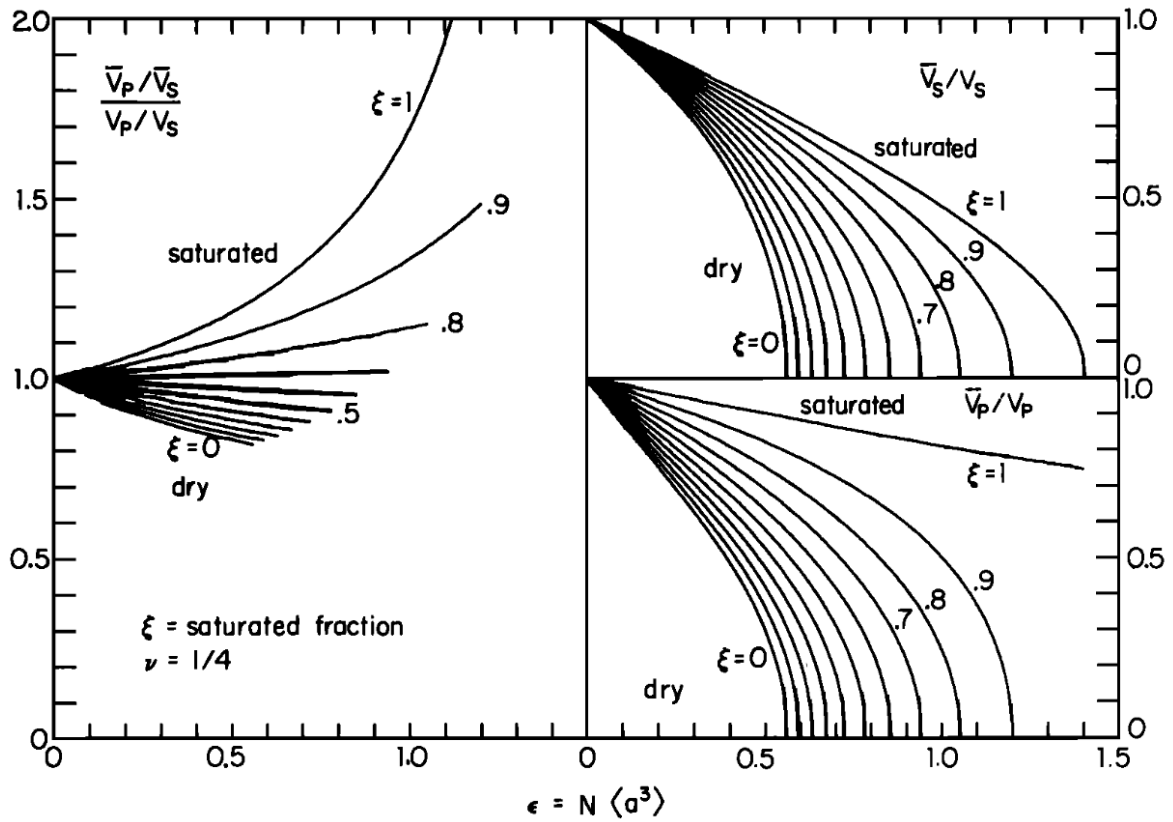
Many rock physics measurements:



Peacock et al., Geology 2011
Christensen, GSA Mem. 1989

Theoretical justification

All models for **cracked** rocks show that V_P/V_S should increase with increasing fluid-saturated crack density, **as long as the compressibility of the fluid is not too small compared to crack aspect ratios.** [O'Connell and Budiansky, 1974, and many many others]



Is V_P/V_S **always** increasing?

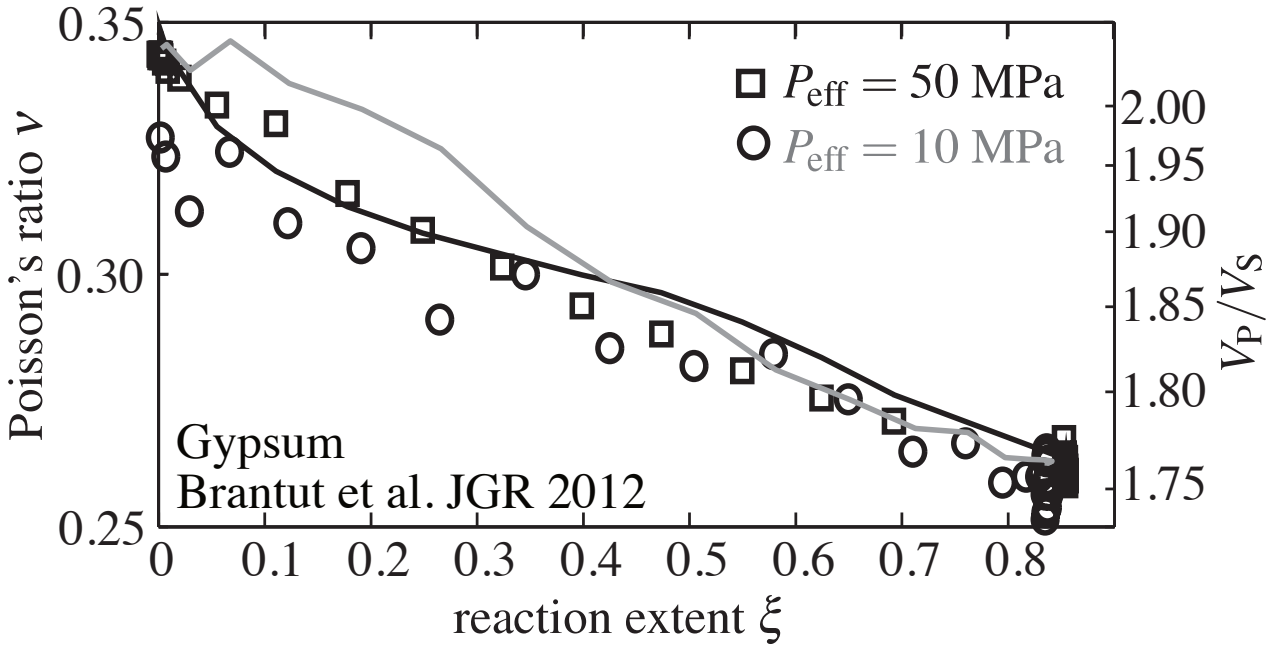
Basic logic

High fluid pressure (relative to confining pressure)
$\rightarrow$ cracks remain open
$\rightarrow$ V_P/V_S increases.

Potential caveats

- dependence on fluid compressibility,
- dependence on crack aspect ratio,
- dependence on initial V_P/V_S of the solid material!
- ... not mentioning anisotropy issues (Wang et al. GRL 2012)

V_P/V_S seesm to decrease during dehydration reactions



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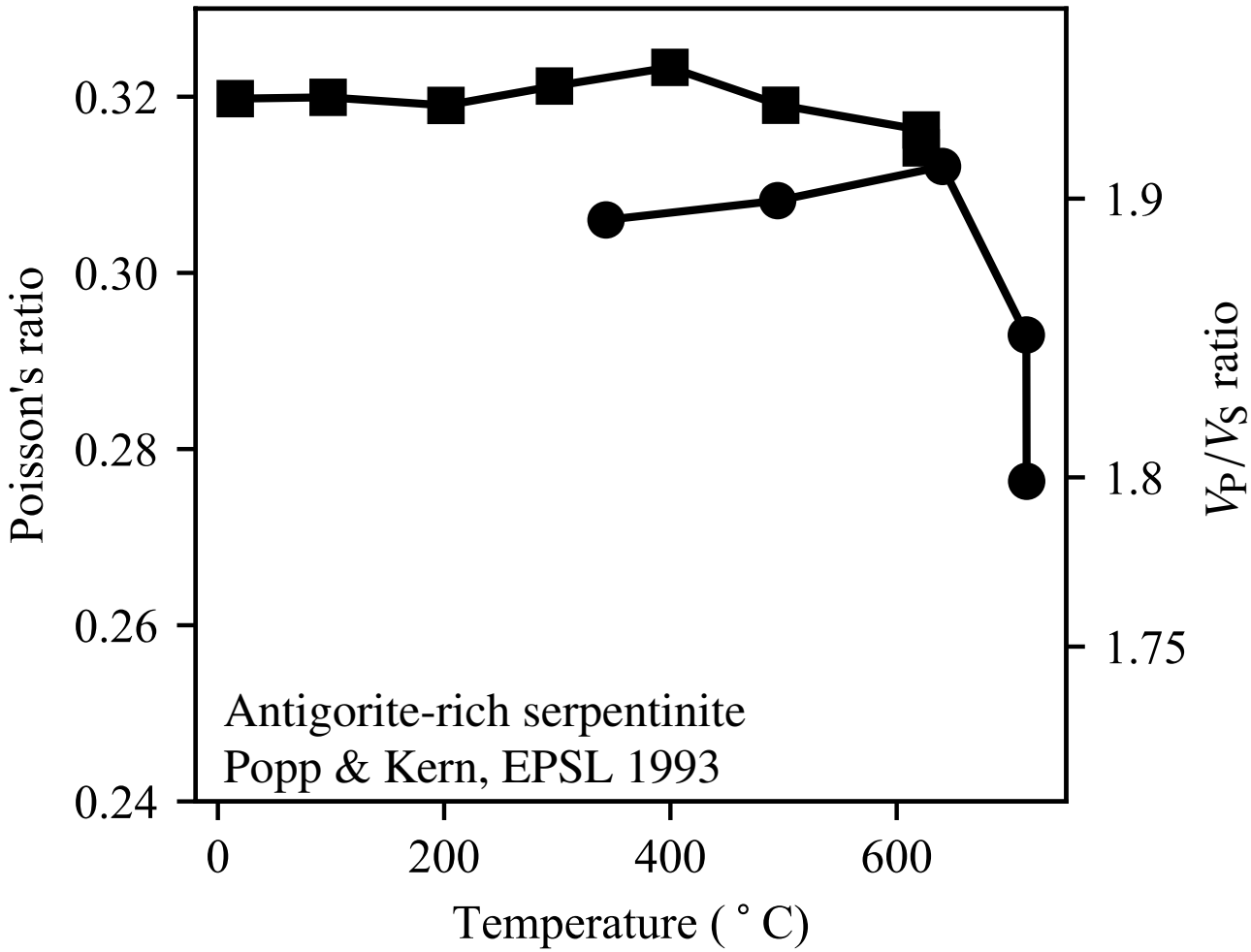


Objectives

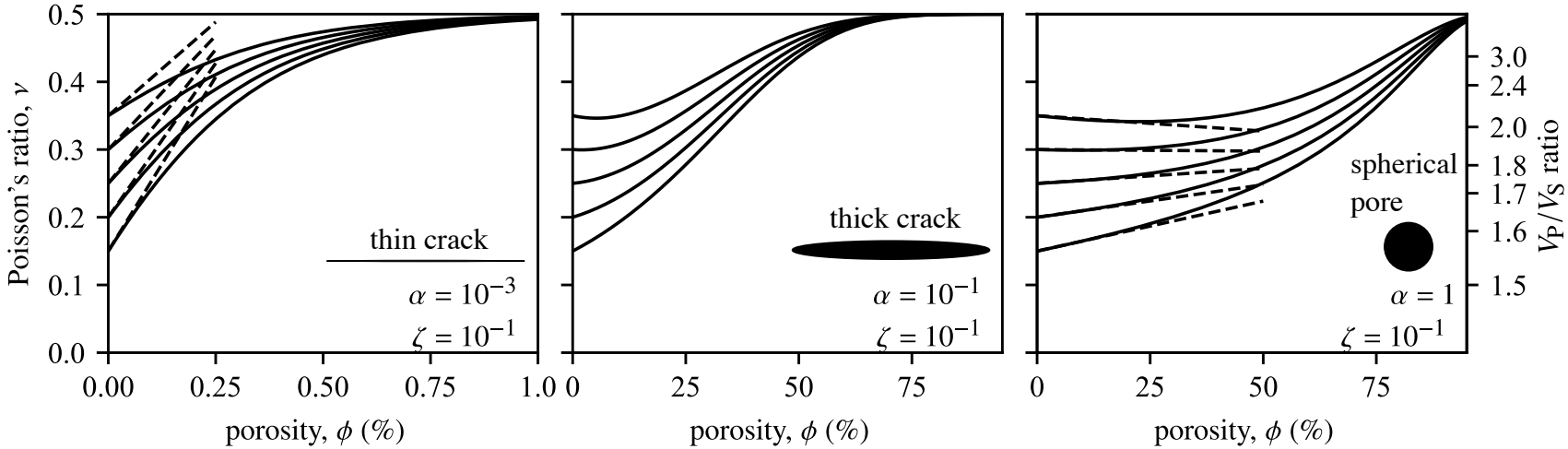
- find simple conditions for increase in $V_{\mathrm{P}}/V_{\mathrm{S}}$ with increasing fluid-saturated porosity,
- study the influence of matrix $V_{\mathrm{P}}/V_{\mathrm{S}}$ (porosity-free rock) on the result.
- Tool: effective medium approach. Isotropic case.

Differential effective medium approach

Compute effective elastic properties of material containing isotropic distribution of spheroidal pores filled with fluid.
Key parameters are:

- ζ = matrix compressibility/fluid compressibility,
- α = pore aspect ratio,
- ν_0 = Poisson's ratio of intact matrix.

Complex behaviour for non-thin cracks



Evolution of V_P/V_S depends on apsect ratio, but also on the initial Poisson's ratio!

Critical Poisson's ratio

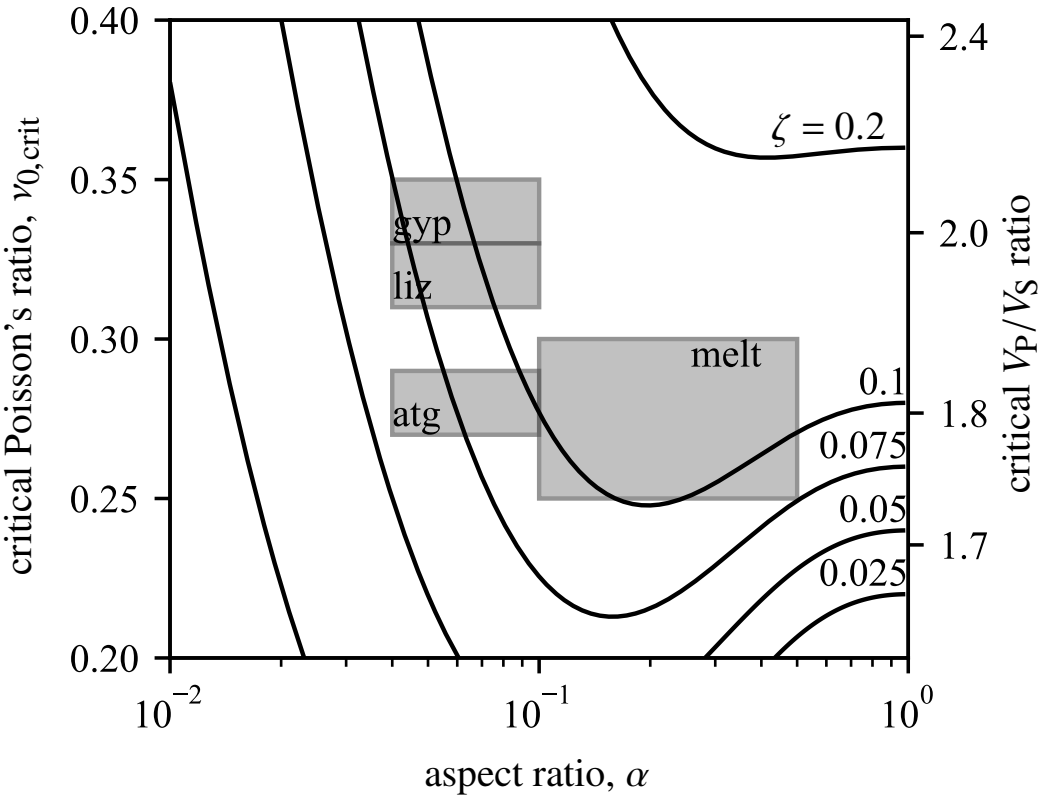
Define $\nu_{0,\mathrm{crit}}$ such that:

- if $\nu_0 > \nu_{0,\mathrm{crit}}$, then $V_\mathrm{P}/V_\mathrm{S}$ *initially decreases* with increasing fluid -saturated porosity,
- else $V_\mathrm{P}/V_\mathrm{S}$ initially increases (this is the conventional interpretation).

Key result for two end-member cases:

- for thin cracks, $\nu_{0,\mathrm{crit}} \approx 0.157\zeta/\alpha$,
- for spherical pores, $\nu_{0,\mathrm{crit}} \approx 0.2 + 0.8\zeta$.

Critical Poisson's ratio



For dehydration reactions, considering $\alpha \sim 10^{-1}$ (not very thin cracks, needed to accomodate large volume changes), $V_\mathrm{P}/V_\mathrm{S}$ might actually slightly decrease or remain stable at the onset of reaction. This is consistent with lab data shown previously.

Conclusions

- $V_\mathrm{P}/V_\mathrm{S}$ increases with fluid-saturated porosity for thin cracks and relatively incompressible fluid (classic result, not new),
- **but** this may not always be the case in nature, if pores have higher aspect ratio (or equivalently, tubular shapes, see Watanabe 1993, Takei 2002).
- at the onsest of dehydration reactions, $V_\mathrm{P}/V_\mathrm{S}$ might not increase dramatically, and might even decrease.
- a condition like $\nu_0 \lesssim 0.157\zeta/\alpha$ should be made clear when interpreting high $V_\mathrm{P}/V_\mathrm{S}$ ratio as "fluid pressure" from seismic imaging.

Reference: Brantut N. and E. C. David (2019), Influence of fluids on V_P/V_S ratio: increase or decrease?, *Geophys. J. Int.* (216), 2037–2043.
Codes: `https://github.com/nbrantut/Poisson.git`