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The USGS National Crustal Model and the San Francisco Bay Region

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U.S. Department of the Interior
U.S. Geological Survey

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Depth to Bedrock and Basement

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Petrologic and Mineral Physics Database

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Model Input

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Advisory committee

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3D Geologic Framework

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Petrology and Mineral Physics Database

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Thermal Model

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- **Yuehua Zeng**—USGS, Geologic Hazards SC

Calibration

- **Bill Stephenson and Morgan Moschetti**—USGS, Geologic Hazards SC
- **Brandon Dugan**—Colorado School of Mines

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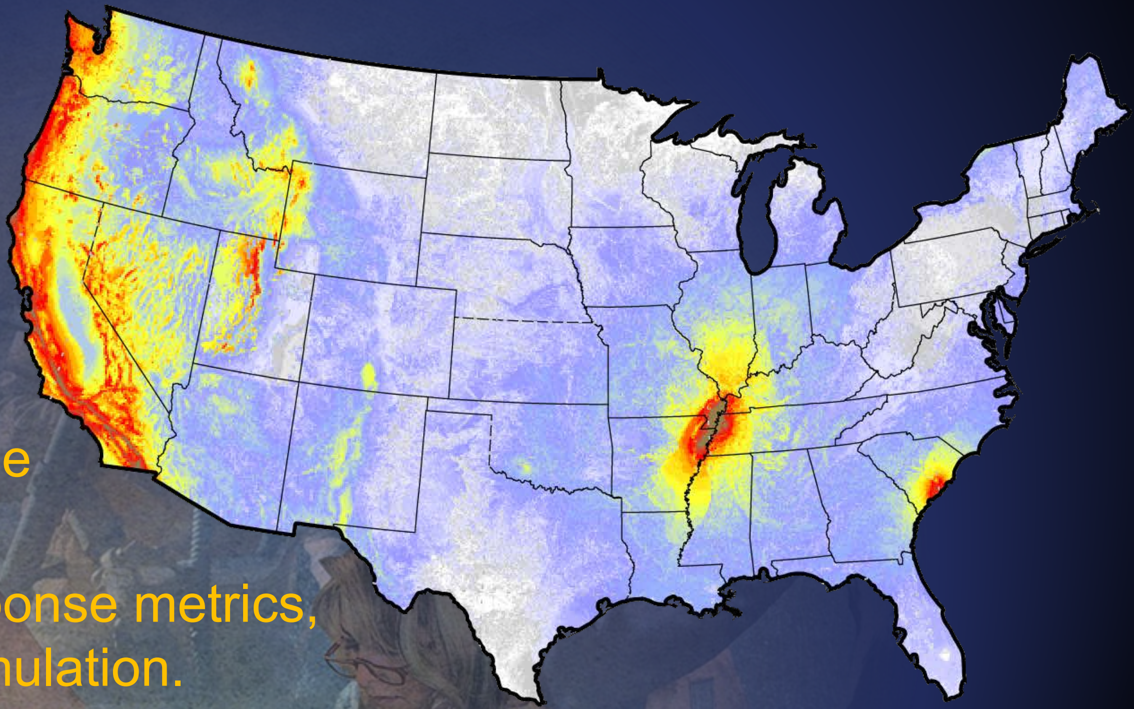
Outline

- National Crustal Model (NCM)
  - What is it? How is it constructed, validated, applied, and accessed?
  - What information is applied in the San Francisco Bay Region
- Next steps

USGS National Seismic Hazard Model: 20??

With a National Crustal Model

- Provide consistently-derived site response metrics to GMMs across the conterminous U.S.
- Prepare for future site response metrics, regionalization, and 3D simulation.



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GMM—Ground Motion Model

What is the NCM?

– Profiles defined on 1-km grid across the conterminous United States from the surface to below the Moho
  - Geology and petrology
  - Geophysics

- *K, Bulk Modulus*
- *G, Shear Modulus*
- ρ*, Density*
- $1/Q_P$*, P-wave attenuation*
- $1/Q_S$*, S-wave attenuation*
- *T, Temperature*
- ϕ*, Porosity*

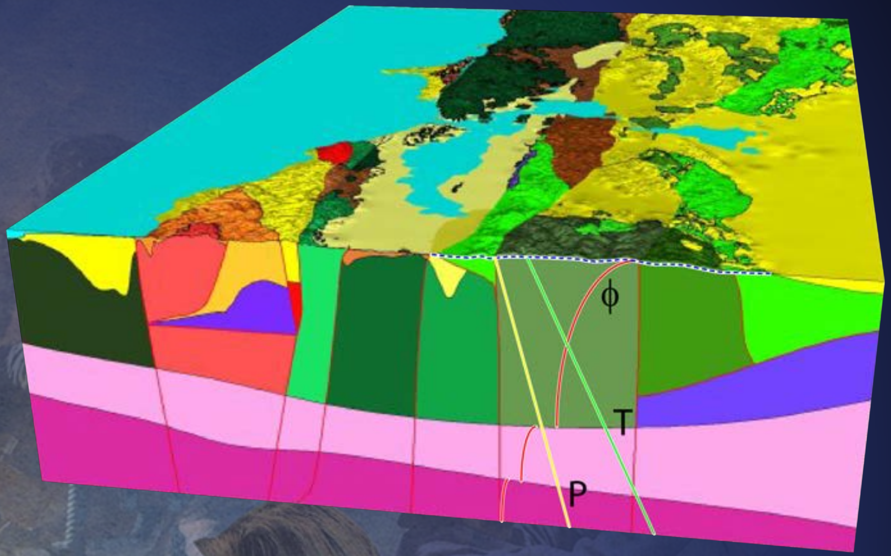
How is it constructed?

Biot-Gassmann and mineral physics theory

➔ K, G, ρ

Requires

- 3D geologic model
- Petrologic and mineral physics database
- Pressure, temperature, and porosity as functions of depth
- Water saturation

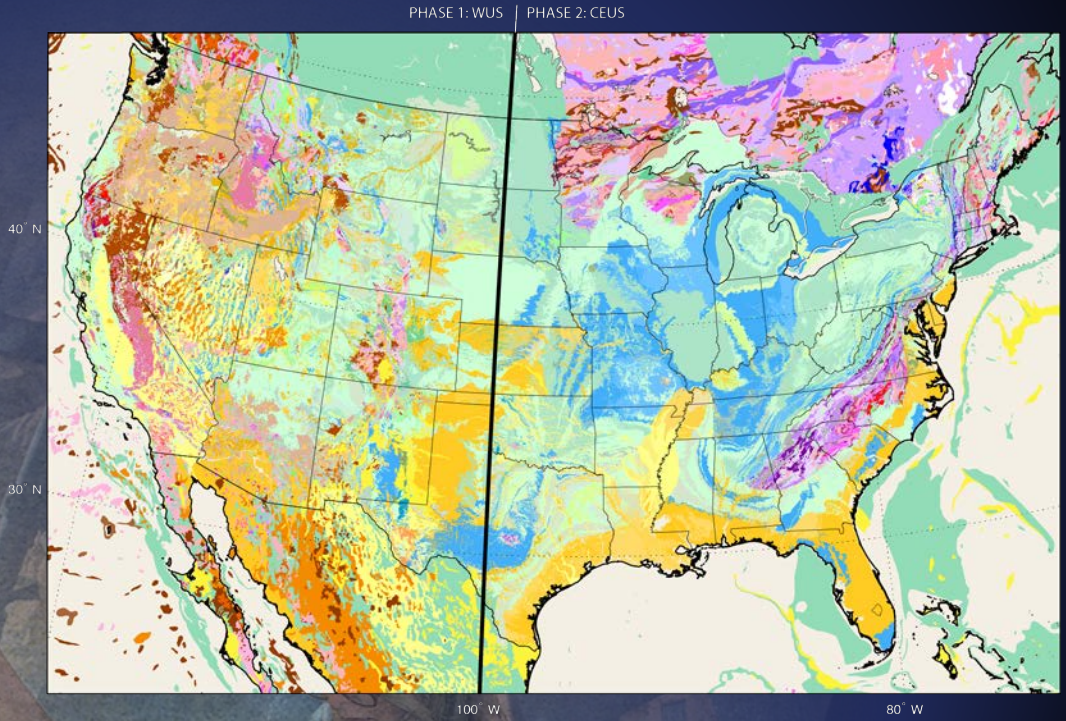


Adapted from Aagaard and others (2010)

3D Geologic Framework

Constructed from:

- Geologic maps
- Depths to significant subsurface contacts
  - Bedrock, basement, mid crust, Moho, top of the oceanic plate



Boyd (2019)

San Francisco Bay Region

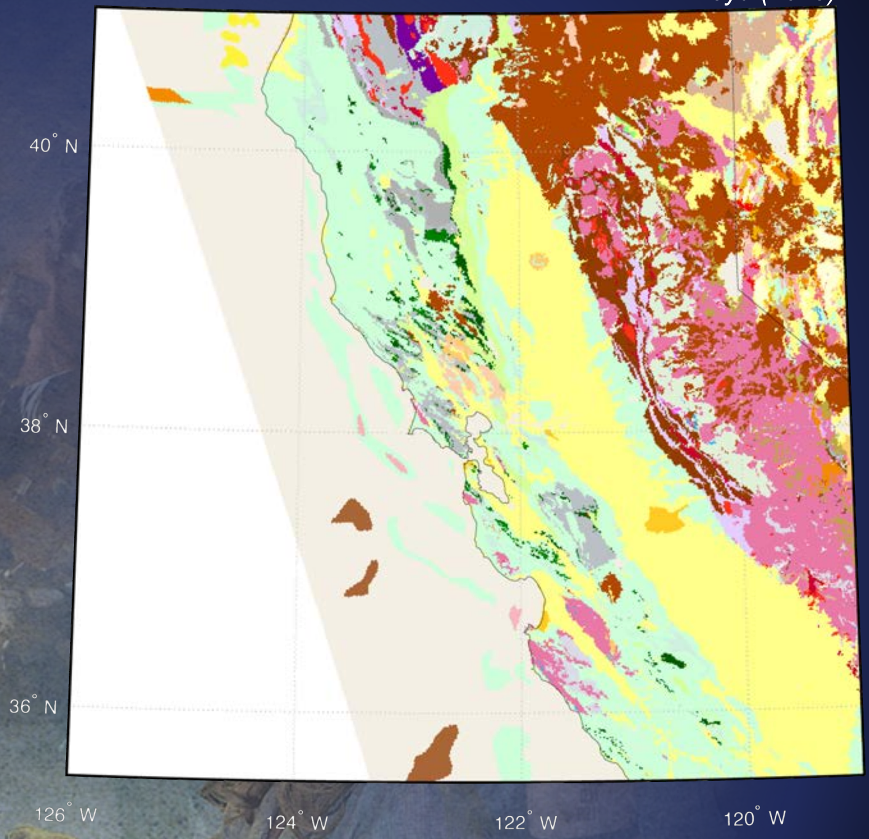
Surface geology defined by:

- Geologic Map of North America
- State Geologic Map Compilation

Basement geology:

- Whitmeyer and Karlstrom (2007)

Boyd (2019)

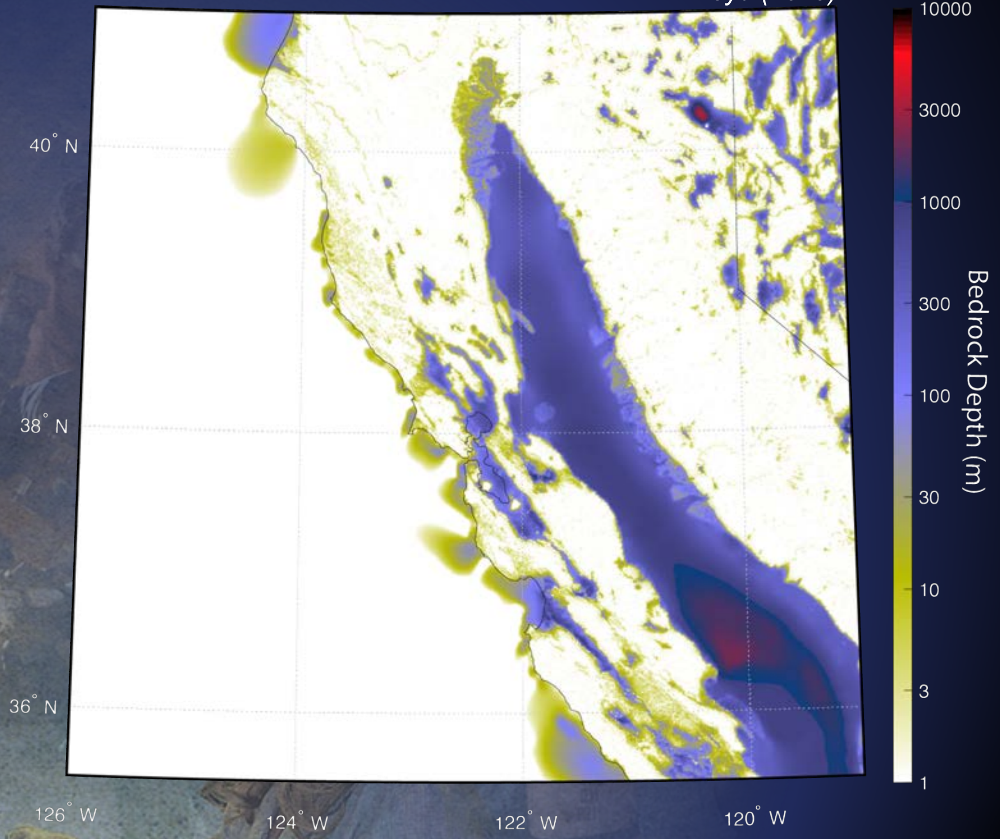


San Francisco Bay Region

Bedrock depth (base of Miocene deposits) defined by:

- Pelletier and others (2016) as a background model
- Langenheim and others (2010), modified for the northern Bay Area
- Williamson and others (1989) in the Central Valley
- Whittaker and others (2013) offshore

Boyd (2019)

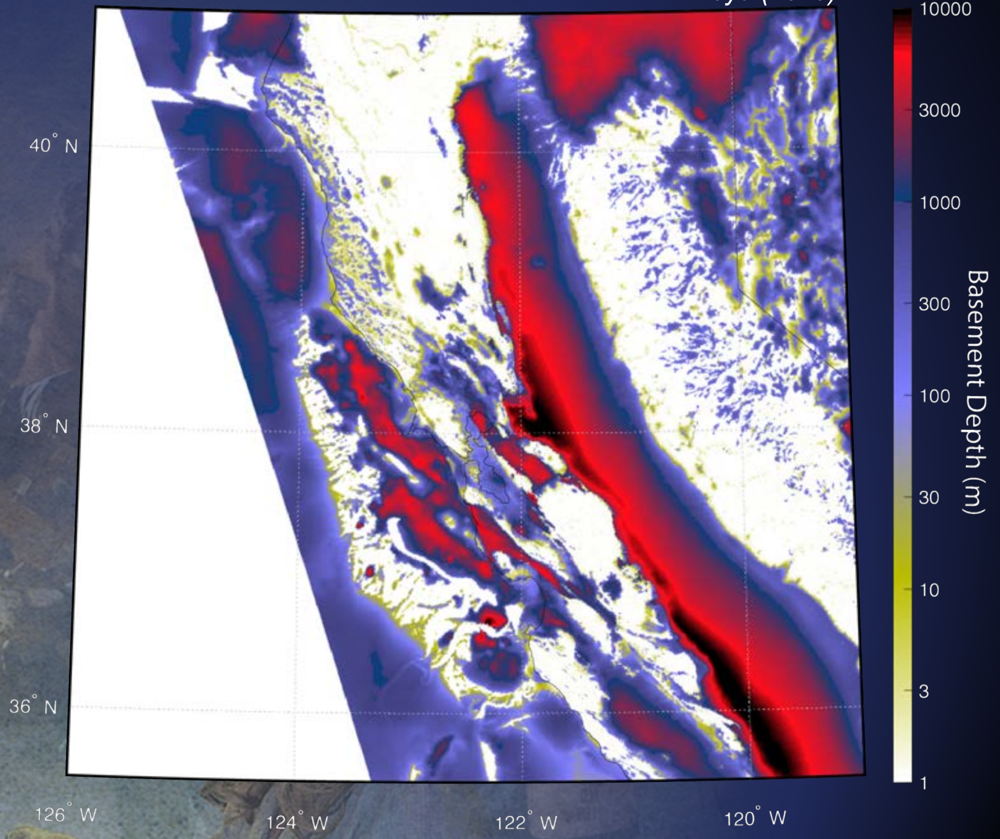


San Francisco Bay Region

Basement depth (base of Cenozoic deposits) defined by:

- Mooney and Kaban (2010) for a regional baseline
- Aagaard and others (2010) in the greater Bay Area
- Langenheim and others (2010) in the northern Bay Area

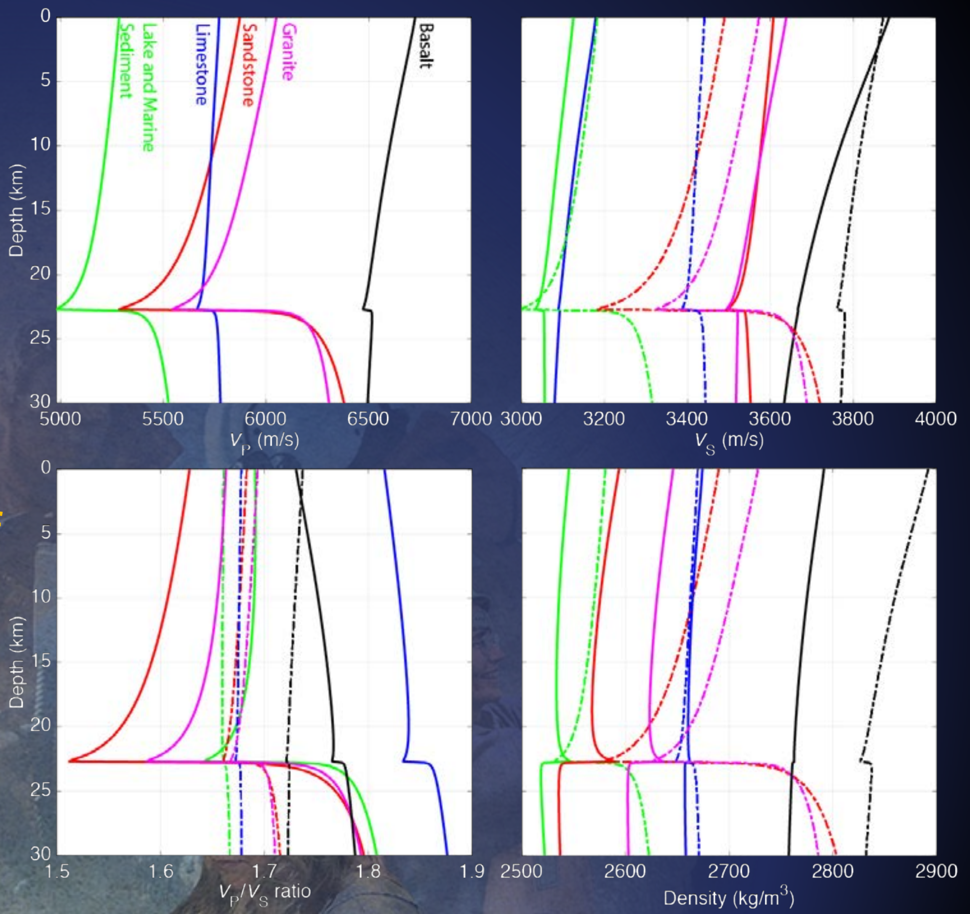
Boyd (2019)



Petrology and Mineral Physics

- Each lithology is assigned a mineral composition
- Equation of State methods are used to calculate V_P, V_S, and ρ of the solid rock matrix as functions of temperature and pressure

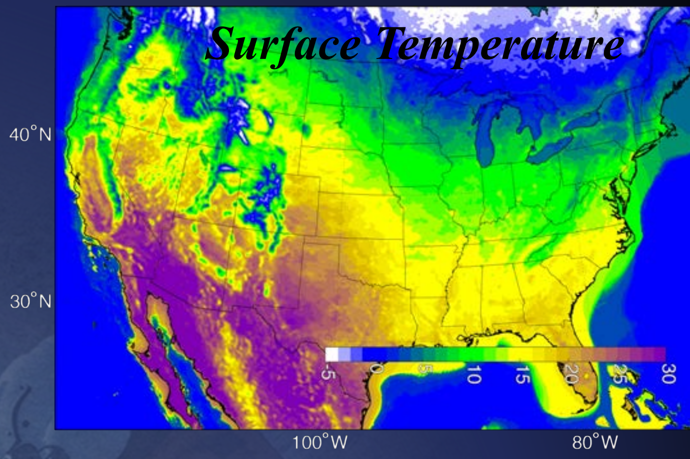
Solid lines are mineral physics calculations. Dashed lines use Vp and the empirical relations of Brocher (2005).

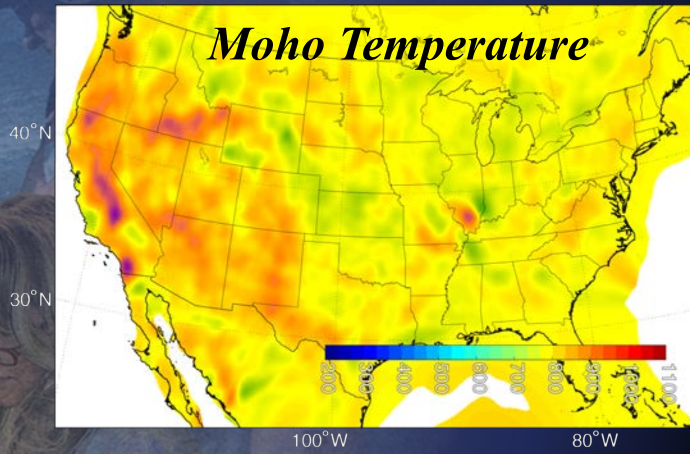


Sowers and Boyd (2019)

Temperature Model

- Continents
  - Heat conduction with heat production
    - » Surface temperature (from MODIS monthly averages)
    - » Moho temperature (from Pn velocity—P-wave velocity at the top of the mantle just below the Moho)
    - » Surface temperature gradient (observed in boreholes)
- Ocean
  - Cooling of a half space
    - » Surface temperature
    - » Age of oceanic crust





Boyd (2020a)

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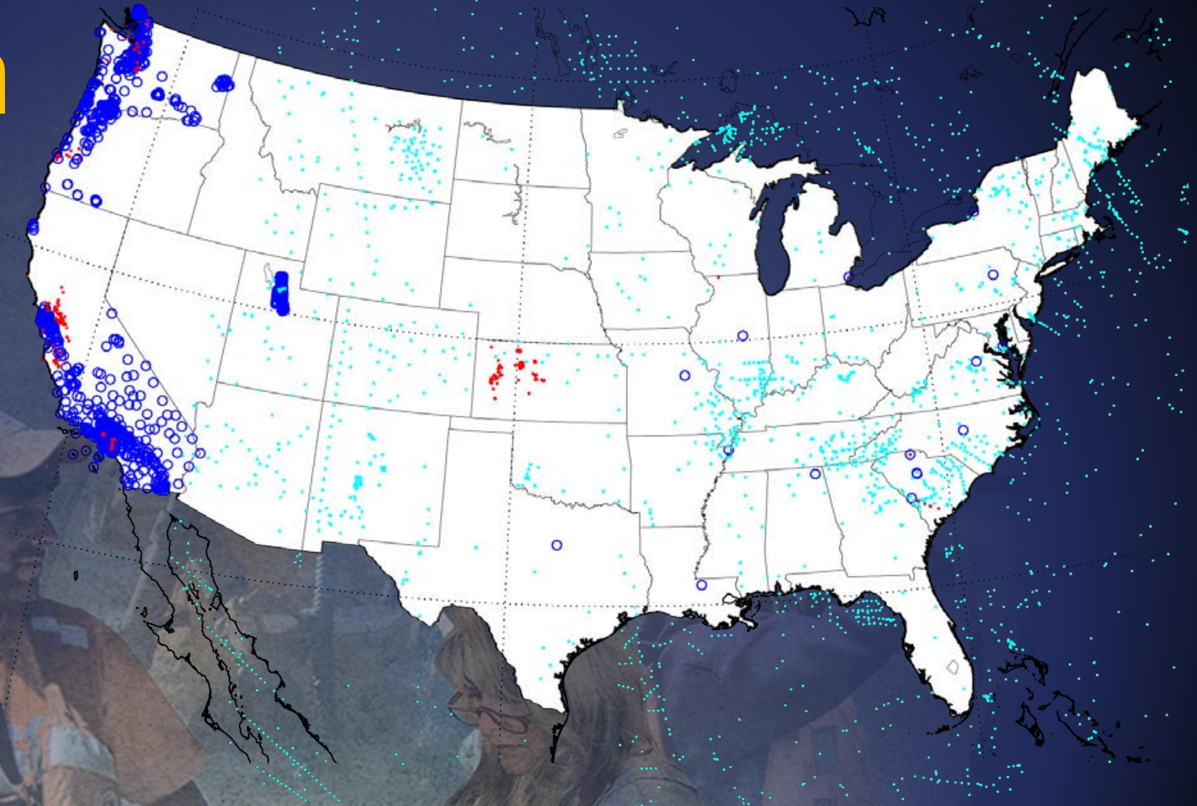
Porosity Calibration

- Using as constraints
  - V_S profiles
  - Sonic and density logs
  - Deep velocity profiles



Boyd (2020b)

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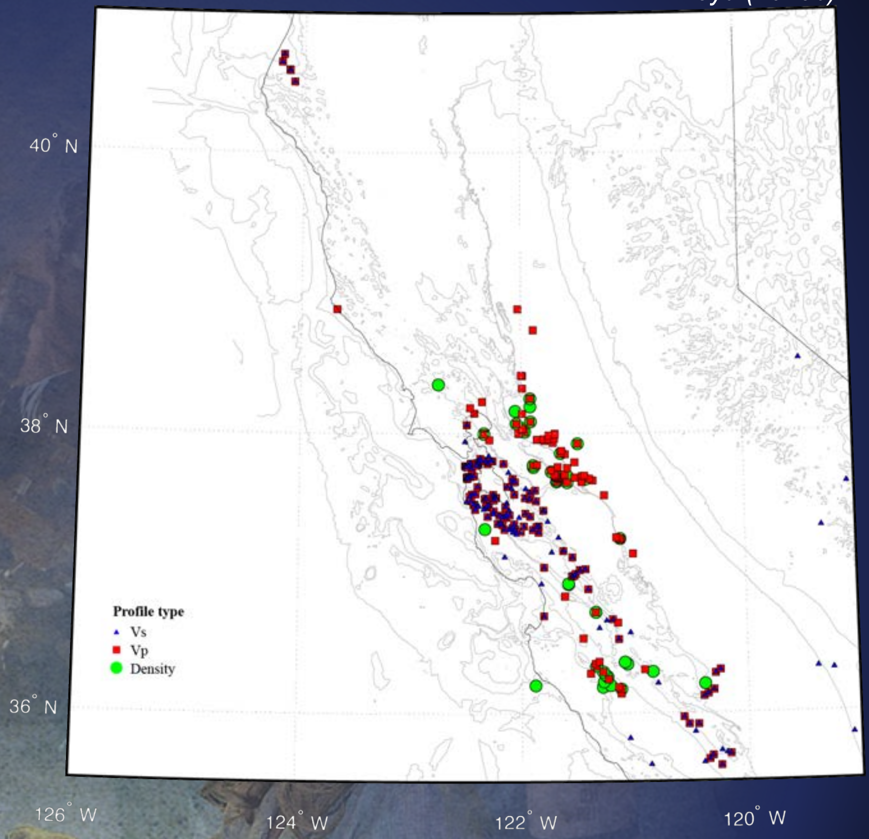
San Francisco Bay Region

Data used to calibrate the porosity model in the Bay Region:

- 150 Vs profiles from a variety of sources (see Boyd, 2020)
  - Up to 1.2 km deep representing sediments and sedimentary, volcanic, igneous and metamorphic rocks
- 103 Sonic and Density logs from Brocher (pers. comm.), up to 5.2 km deep

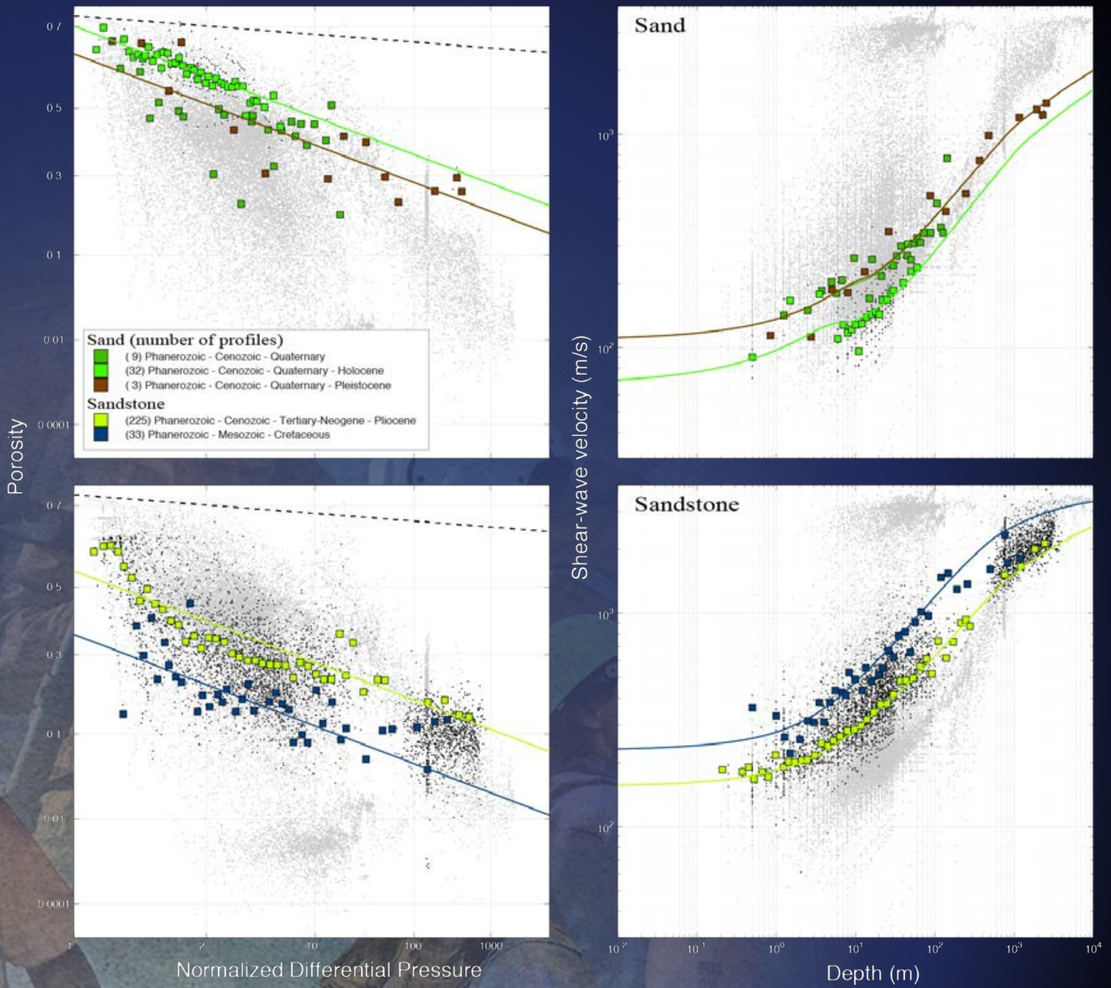
Boyd (2020b)



Porosity Calibration

$$\log(-\log(\phi)) = A\log(\Delta P_N)^{0.5} + B$$

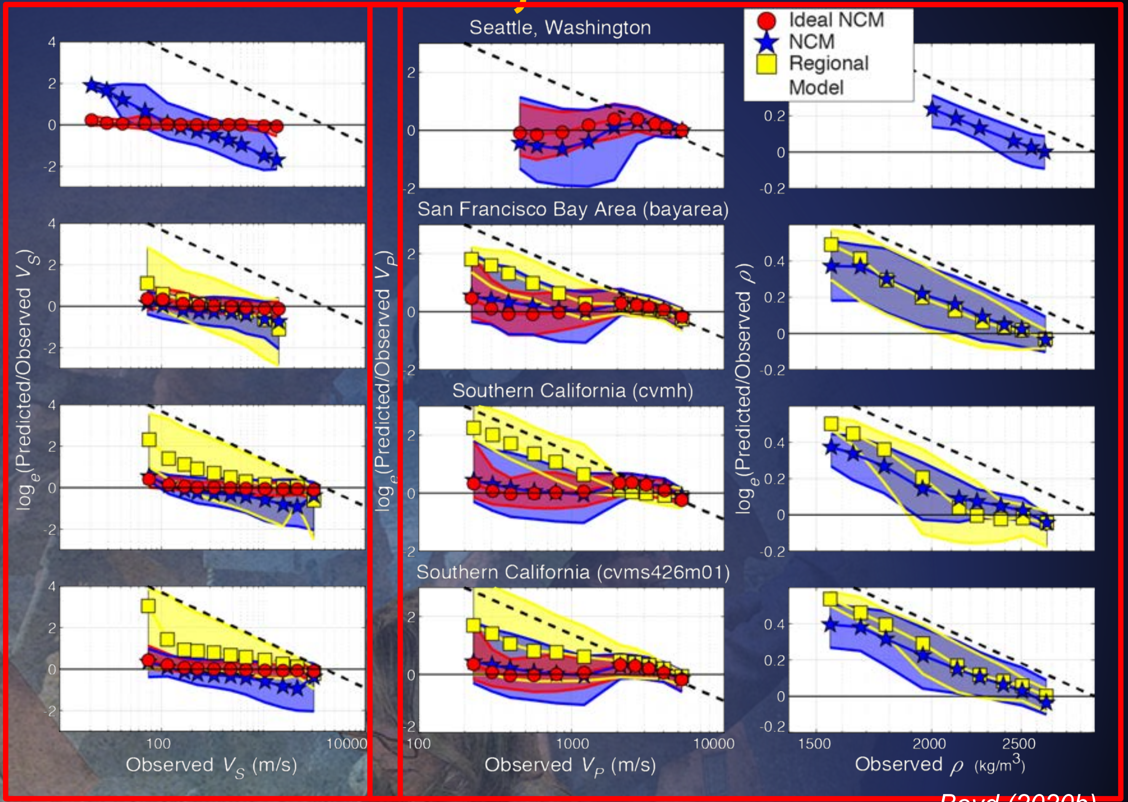
ϕ—porosity
ΔP_N—normalized differential pressure
A,B—constants dependent on lithology



Boyd (2020b)

Verification, Validation, and Comparison

- Red symbols and polygons—Ideal NCM with known geology and spatially varying porosity relationships
- Blue, Published NCM
- Yellow, existing models
- Dashed, constant prediction



Boyd (2020b)

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Model/Data comparison

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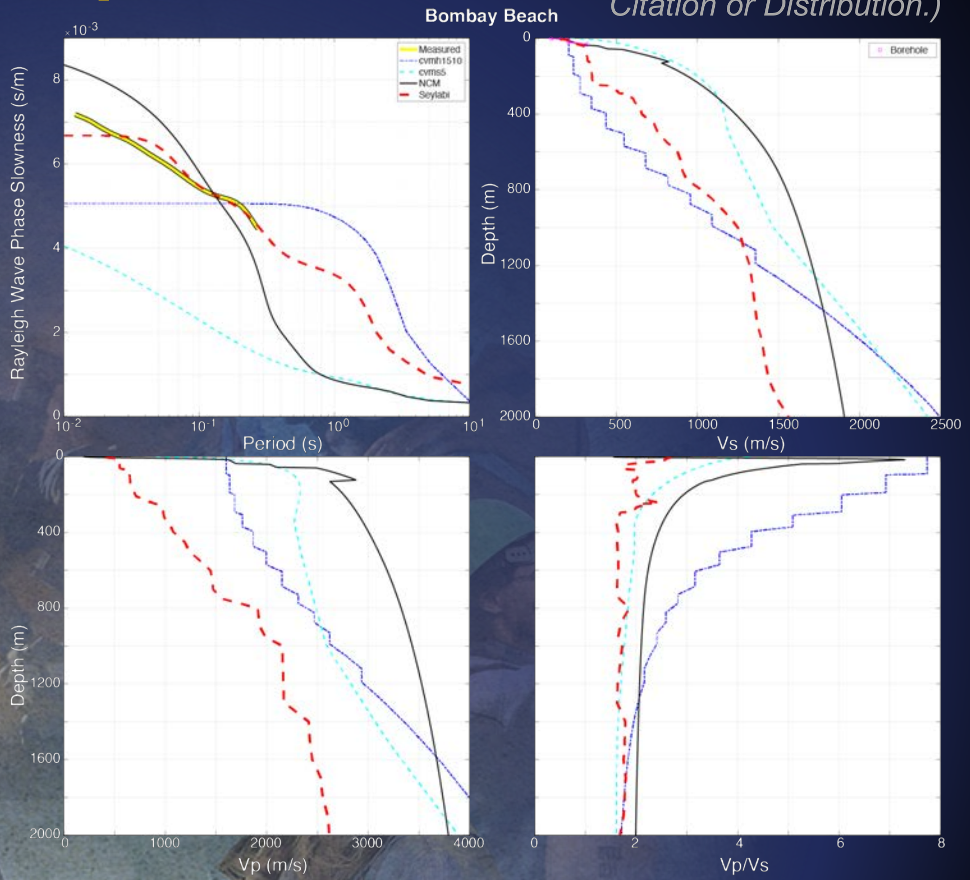
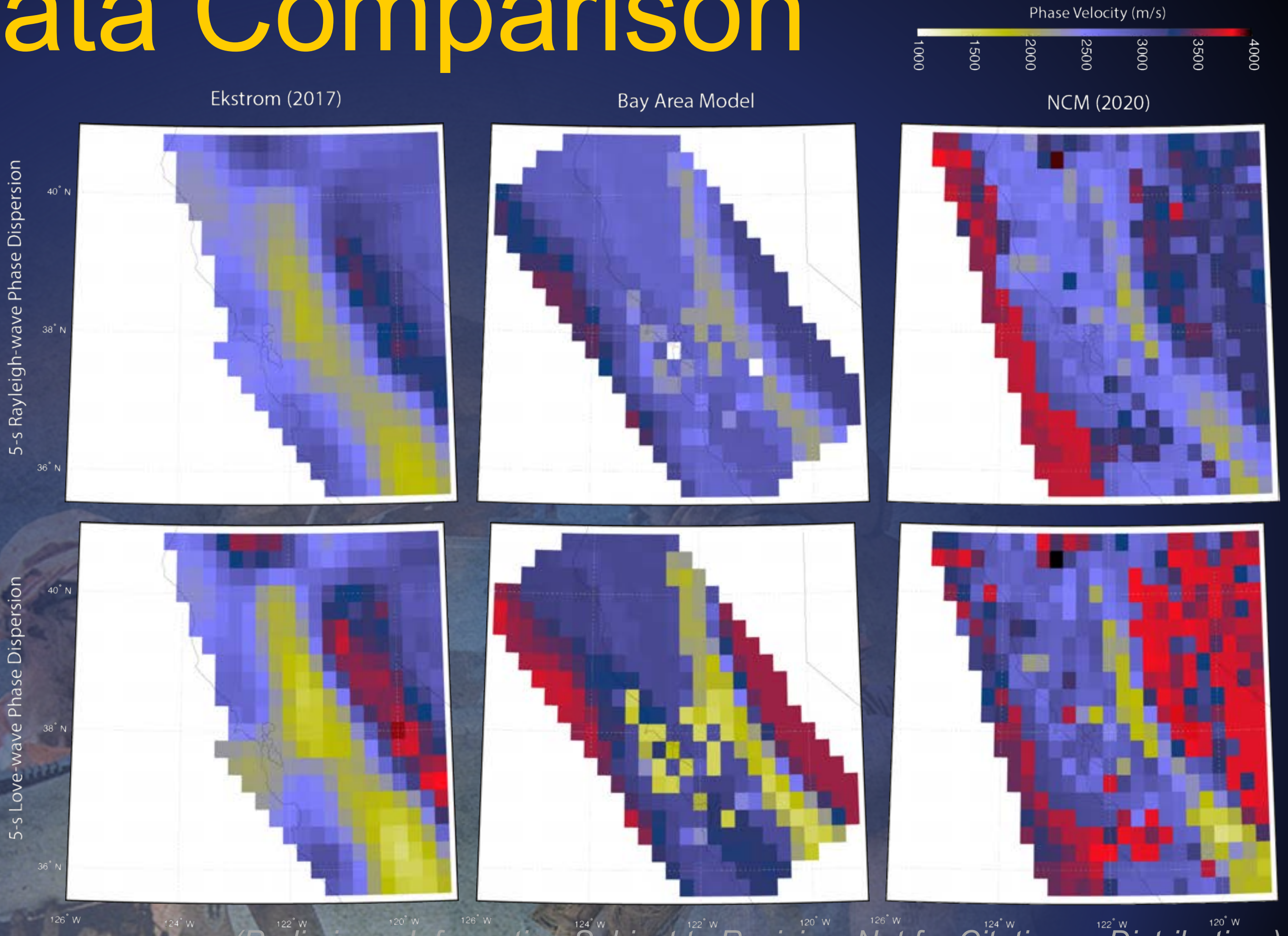
- Bombay Beach
  - Measured (Yong and others, 2013)
  - CVMH (Shaw and others, 2017)
  - CVMS5 (Lee and others, 2014)
  - NCM (2020)
  - Seylabi (pers. comm.)
- Multiple models are useful to capture the epistemic uncertainty



Model/Data Comparison

- 5-s surface-wave dispersion
  - Ekstrom, 2017
  - Bay Area Model (Aagaard and others, 2010)
  - NCM, 2020



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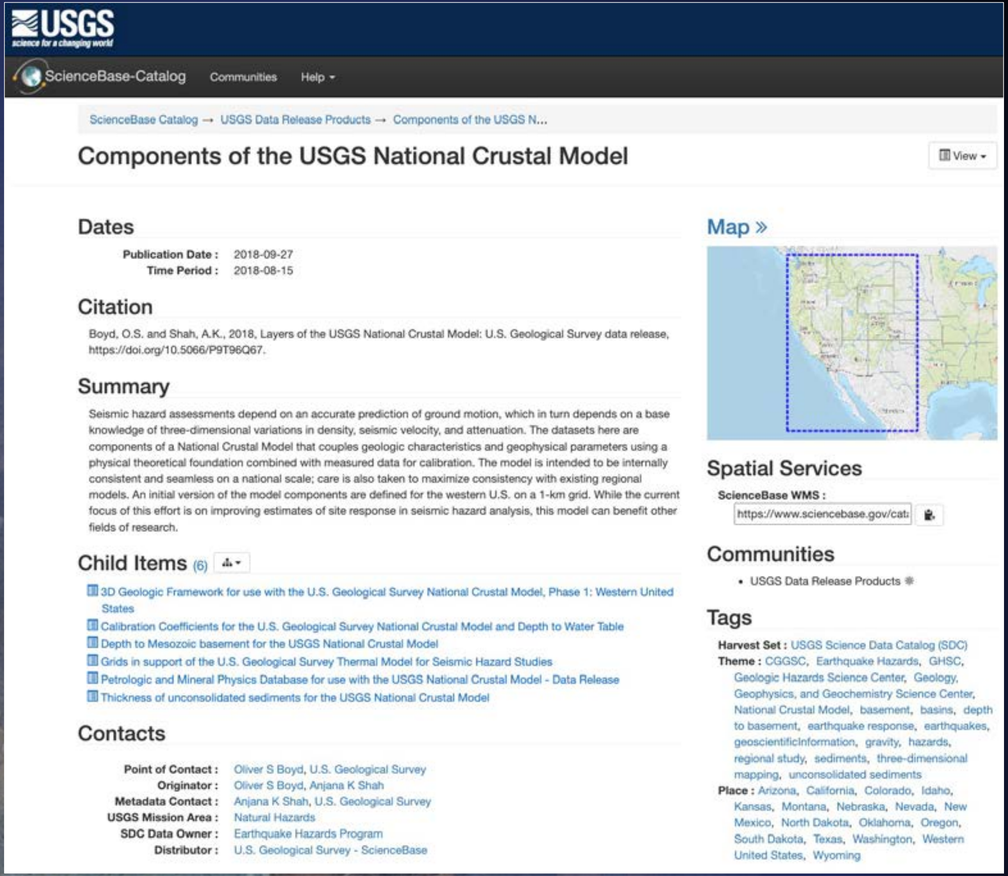
Accessibility

- ScienceBase
- Open File Reports
- Code
  https://code.usgs.gov/ghsc/nshmp/ncm
- Web services
  https://earthquake.usgs.gov/nshmp/ncm/
- Jupyter Notebooks
  Available upon request



Summary

USGS National Crustal Model for Seismic Hazard Studies

- Consists of geologic, petrologic, and geophysical profiles on a 1-km grid across the U.S.

Summary

USGS National Crustal Model for Seismic Hazard Studies

- Constructed from
  - 3D geologic framework based on surface and subsurface geologic mapping, and the depths to bedrock, basement, mid crust, Moho, and the top of the oceanic plate.
  - 3D temperature model
  - Petrologic and mineral physics database
  - Calibrated porosity model

Next Steps

- Completion of CEUS
- Continued validation exercises
- Continued comparison with existing models
- Model improvement
- Application to hazard and risk assessment