

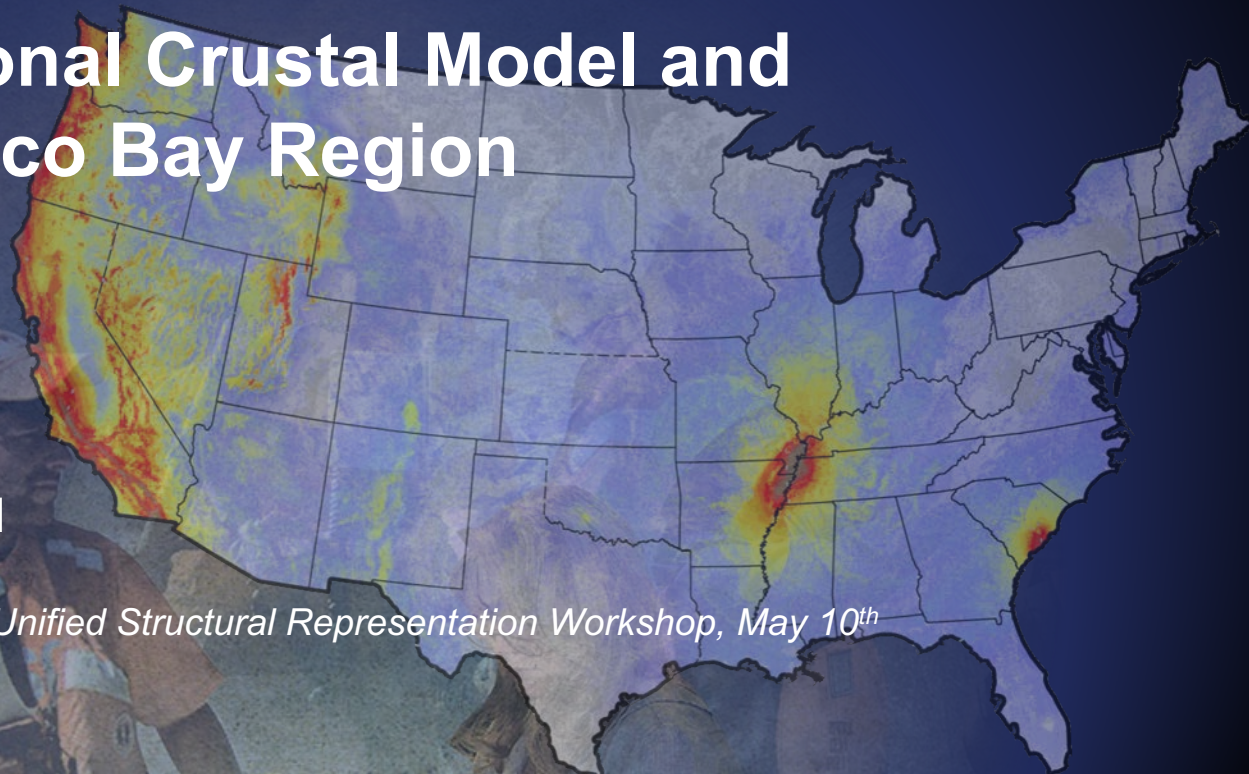
The USGS National Crustal Model and the San Francisco Bay Region

Prepared by Oliver Boyd

U.S. Geological Survey

2021 San Francisco Bay Region Unified Structural Representation Workshop, May 10th

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



Acknowledgements

Depth to Bedrock and Basement

- **Anji Shah**—USGS, Geology, Geophysics, and Geochemistry Science Center (SC)

Petrologic and Mineral Physics Database

- **Theron Sowers**—California State University-Sacramento, UNAVCO RESESS Intern

Model Input

- **Carma San Juan (USGS)**—*Geology at the Earth's surface*
- **Alan Yong (USGS)**—*USGS V_{S30} database*
- **Domniki Asimaki (Caltech), Sean Ahdi (USGS/UCLA), Walter Mooney (USGS)**—*Velocity profiles*
- **Tom Brocher and Dave Boore (USGS), Albert Kottke (PG&E)**—*Well logs*
- **Brad Aagaard (USGS), Scott Callaghan and Phil Maechling (SCEC), Bill Stephenson (USGS), Morgan Moschetti (USGS)**—*3D crustal models in California, Seattle, and the Wasatch Front*

Advisory committee

- **Mike Blanpied, Sue Hoover, Will Levandowski, David Lidke, Nico Luco, Chuck Mueller, Mark Petersen, Sanaz Rezaeian, Eric Thompson, and Rob Williams** (all formerly or presently at the USGS)

Acknowledgements

Document review

Depth to Bedrock and Basement

- **Dave Soller**—USGS, Core Science Systems Mission Area
- **Jeff Phillips**—USGS, Geology, Geophysics, and Geochemistry SC

3D Geologic Framework

- **Don Sweetkind**—USGS, Geosciences and Environmental Change SC
- **Steve Angster**—USGS, Earthquake SC

Petrology and Mineral Physics Database

- **Bradley Hacker**—University of California at Santa Barbara
- **Charles Stern**—University of Colorado at Boulder

Thermal Model

- **Wayne Thatcher**—USGS, Earthquake SC
- **Yuehua Zeng**—USGS, Geologic Hazards SC

Calibration

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

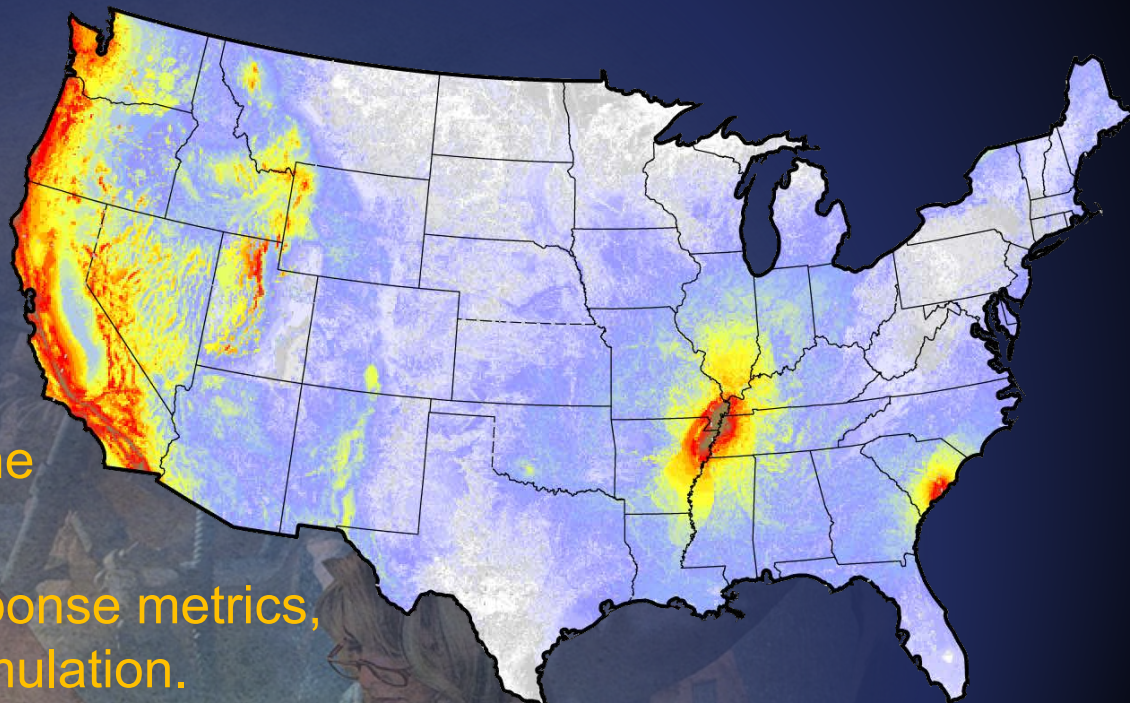
Outline

- 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.



(Preliminary Information-Subject to Revision. Not for Citation or Distribution.)

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

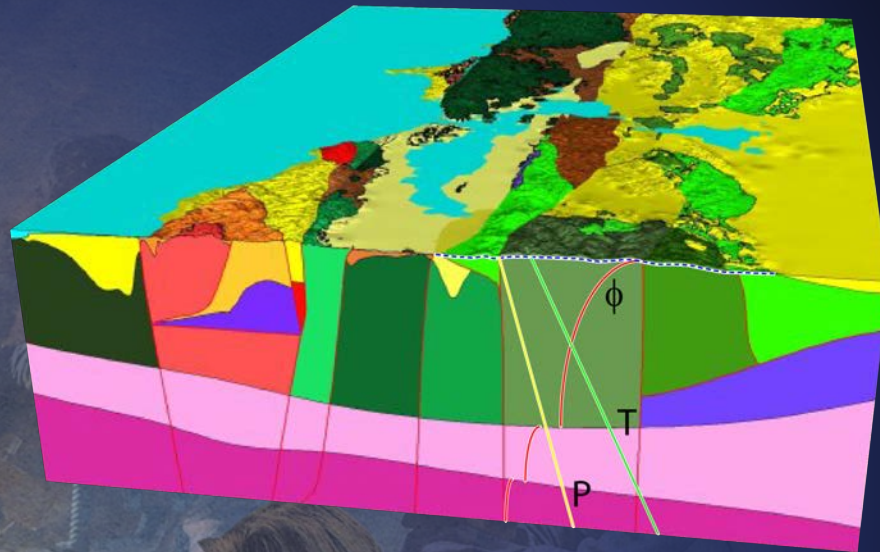
How is it constructed?

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

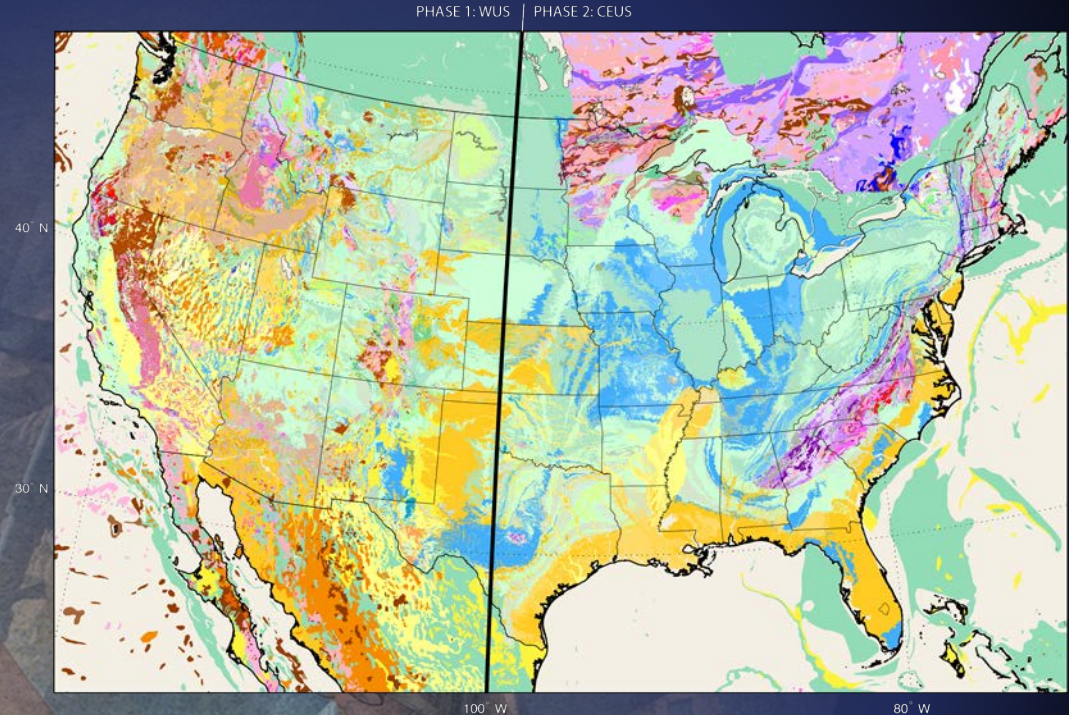


Adapted from Aagaard and others (2010)

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

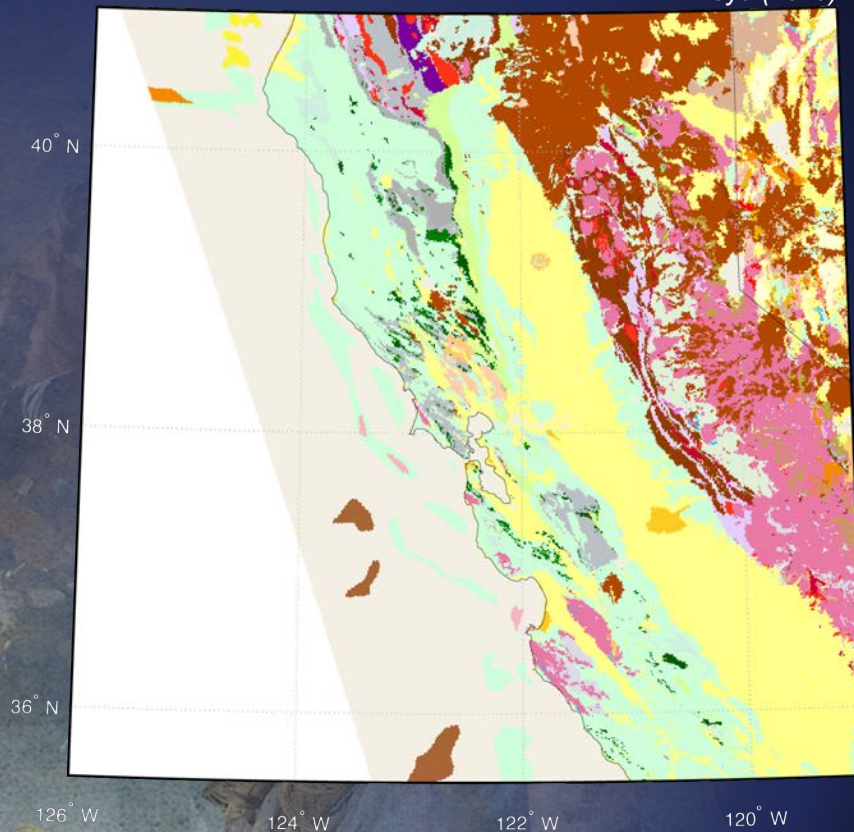
Boyd (2019)

Surface geology defined by:

- Geologic Map of North America
- State Geologic Map Compilation

Basement geology:

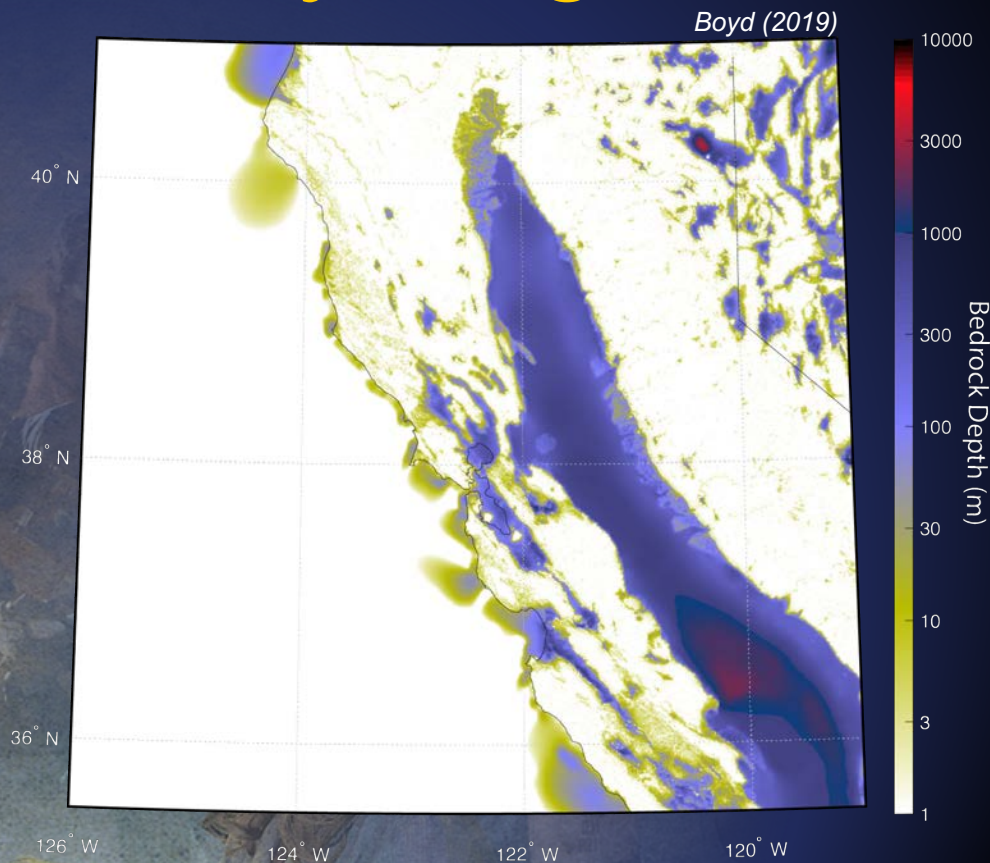
- Whitmeyer and Karlstrom (2007)



San Francisco Bay Region

Bedrock depth (base of Miocene deposits) defined by:

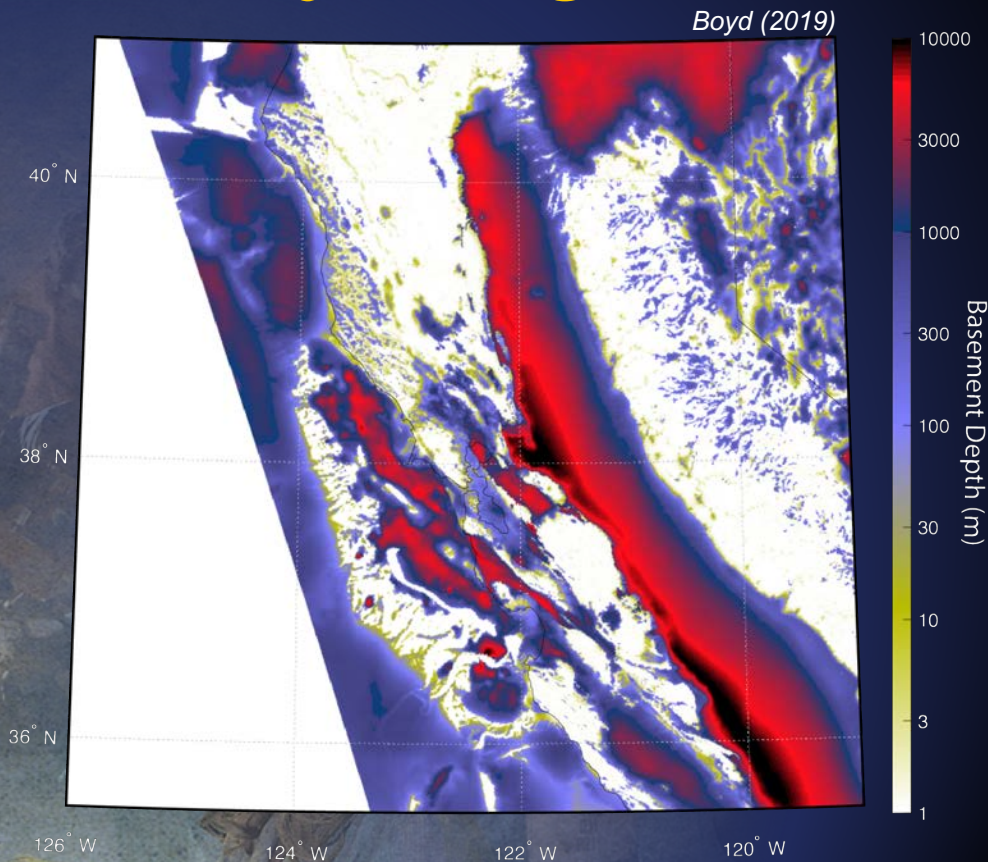
- Pelletier and others (2016) as a background model
- Langenheim and others (2010), modified for the northern Bay Area
- Williamson and others (1989) in the Central Valley
- Whittaker and others (2013) offshore



San Francisco Bay Region

Basement depth (base of Cenozoic deposits) defined by:

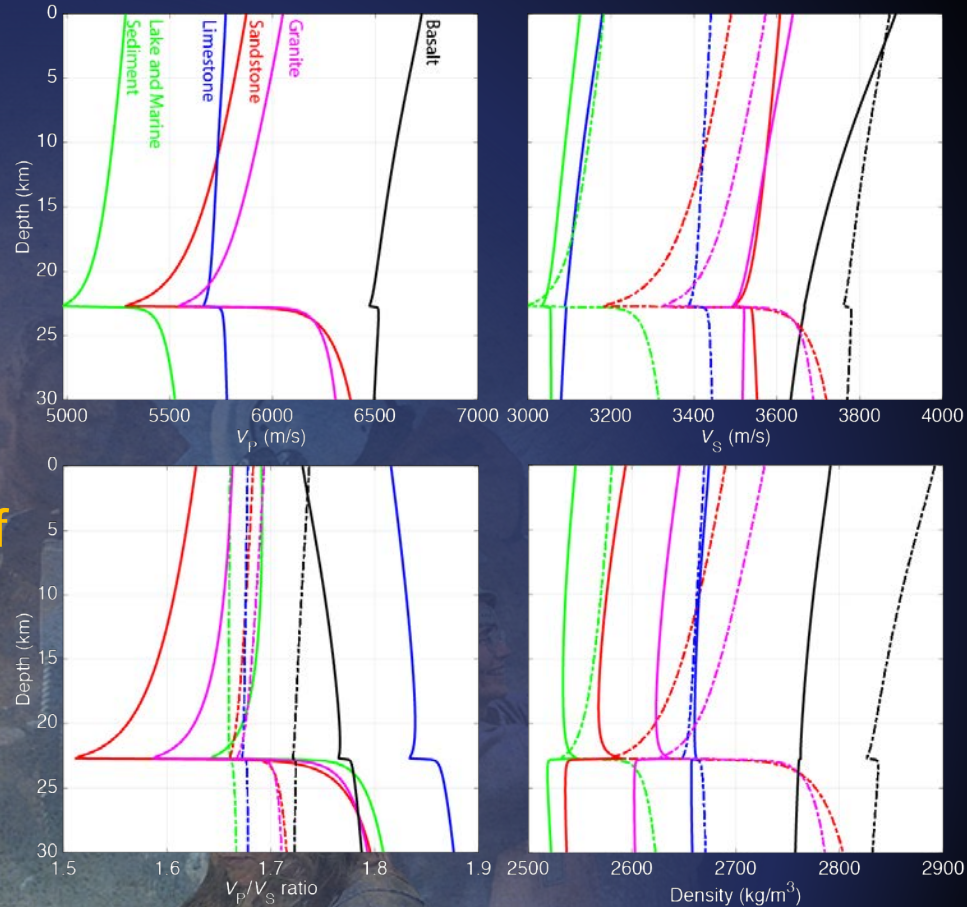
- Mooney and Kaban (2010) for a regional baseline
- Aagaard and others (2010) in the greater Bay Area
- Langenheim and others (2010) in the northern Bay Area



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

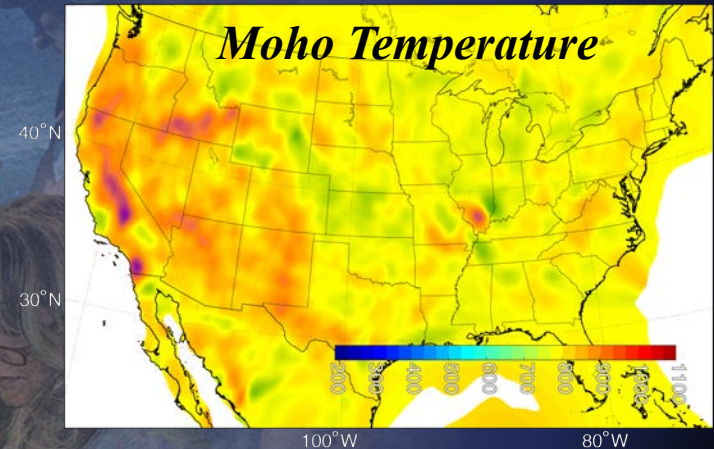
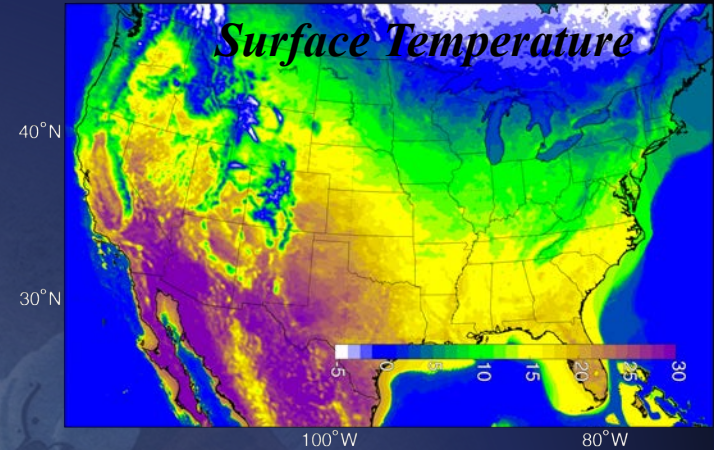
Solid lines are mineral physics calculations. Dashed lines use V_P and the empirical relations of Brocher (2005).



Sowers and Boyd (2019)

Temperature Model

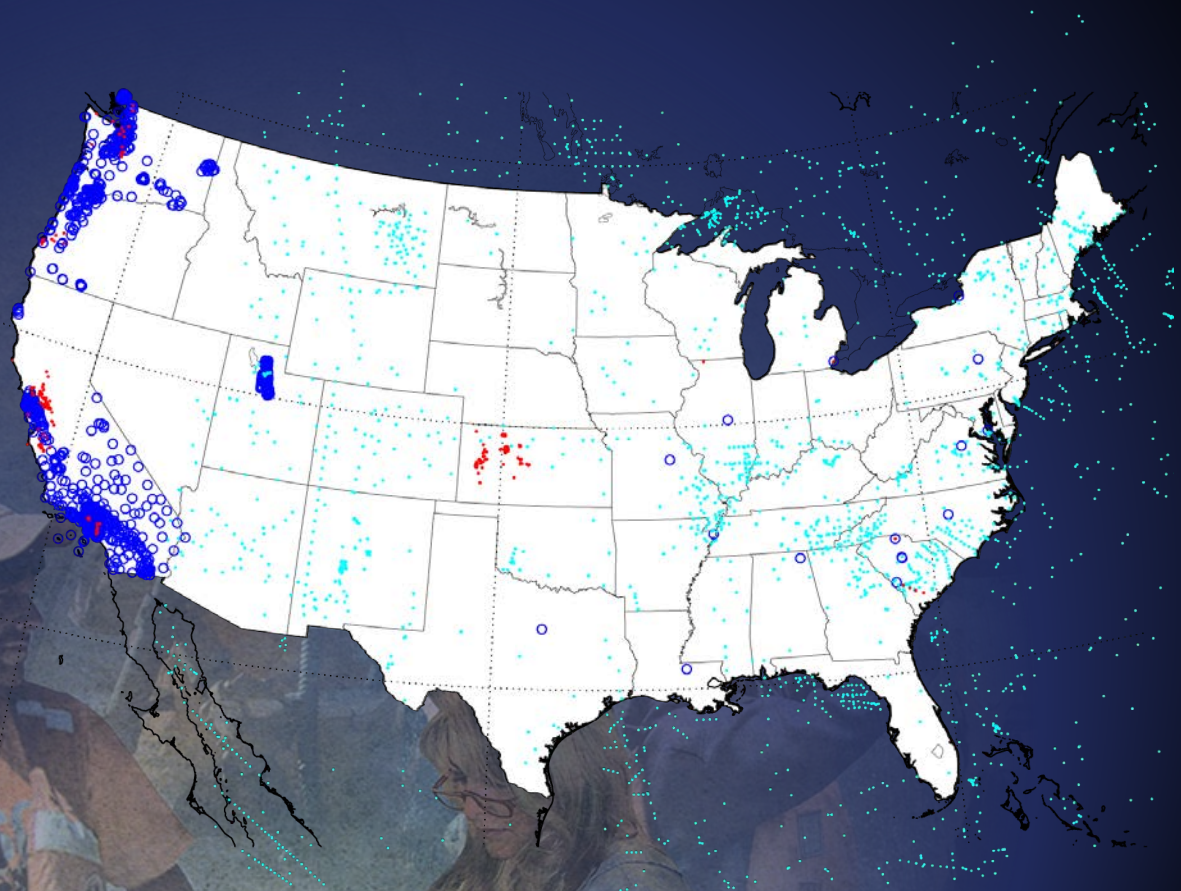
- Continents
 - Heat conduction with heat production
 - » Surface temperature (from MODIS monthly averages)
 - » Moho temperature (from Pn velocity—P-wave velocity at the top of the mantle just below the Moho)
 - » Surface temperature gradient (observed in boreholes)
- Ocean
 - Cooling of a half space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



Boyd (2020a)

Porosity Calibration

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



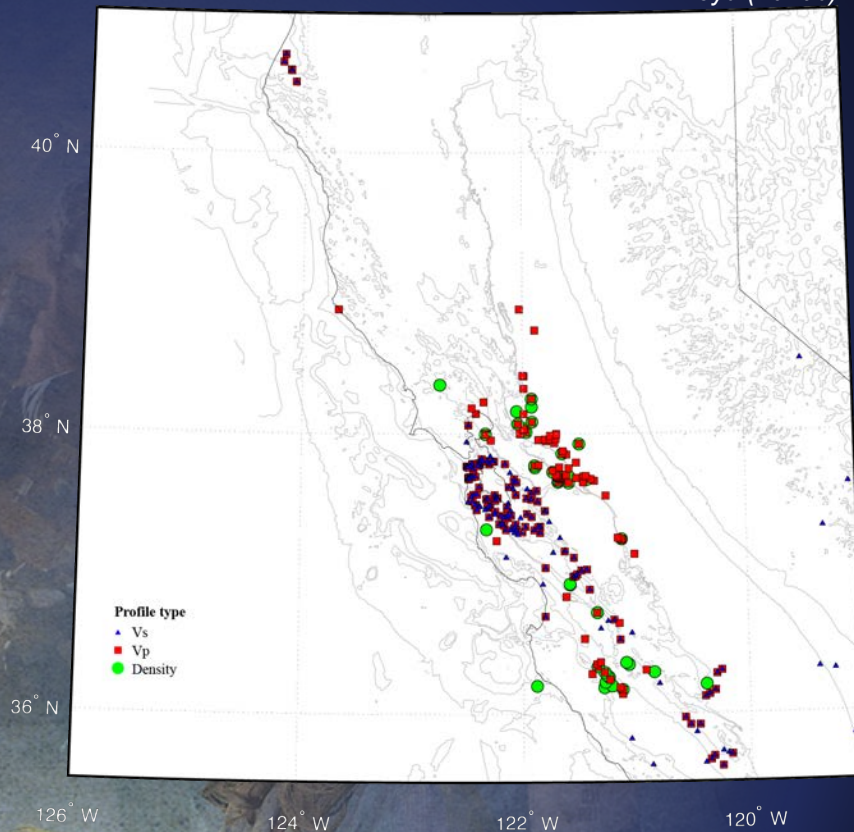
Boyd (2020b)

San Francisco Bay Region

Boyd (2020b)

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



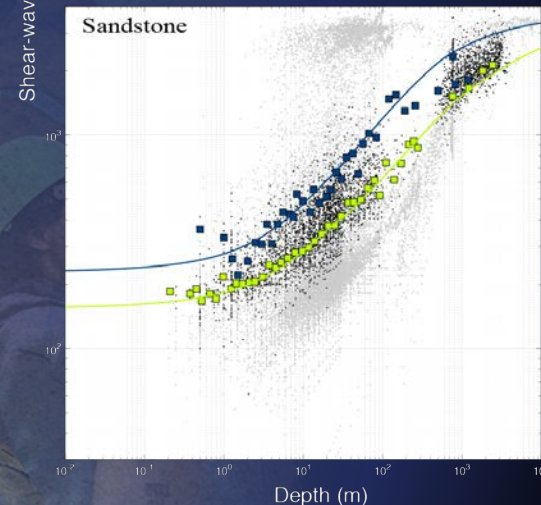
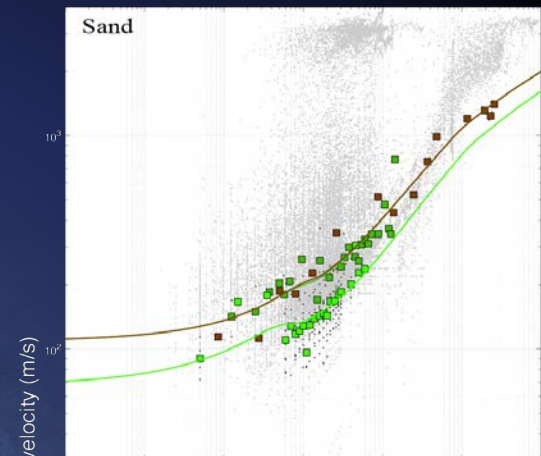
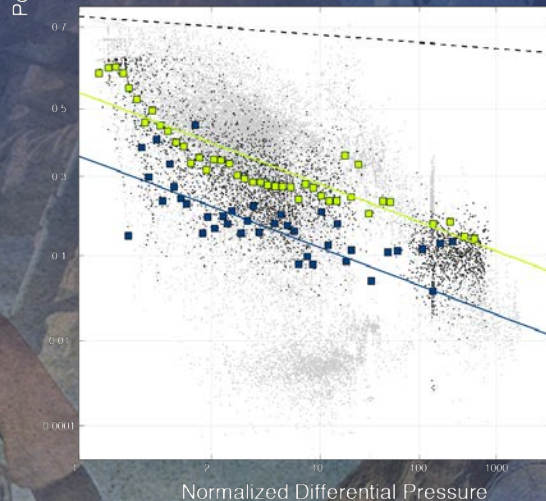
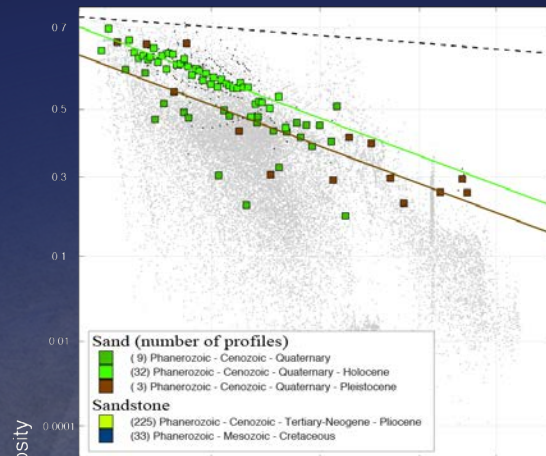
Porosity Calibration

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

ϕ —porosity

ΔP_N —normalized
differential pressure

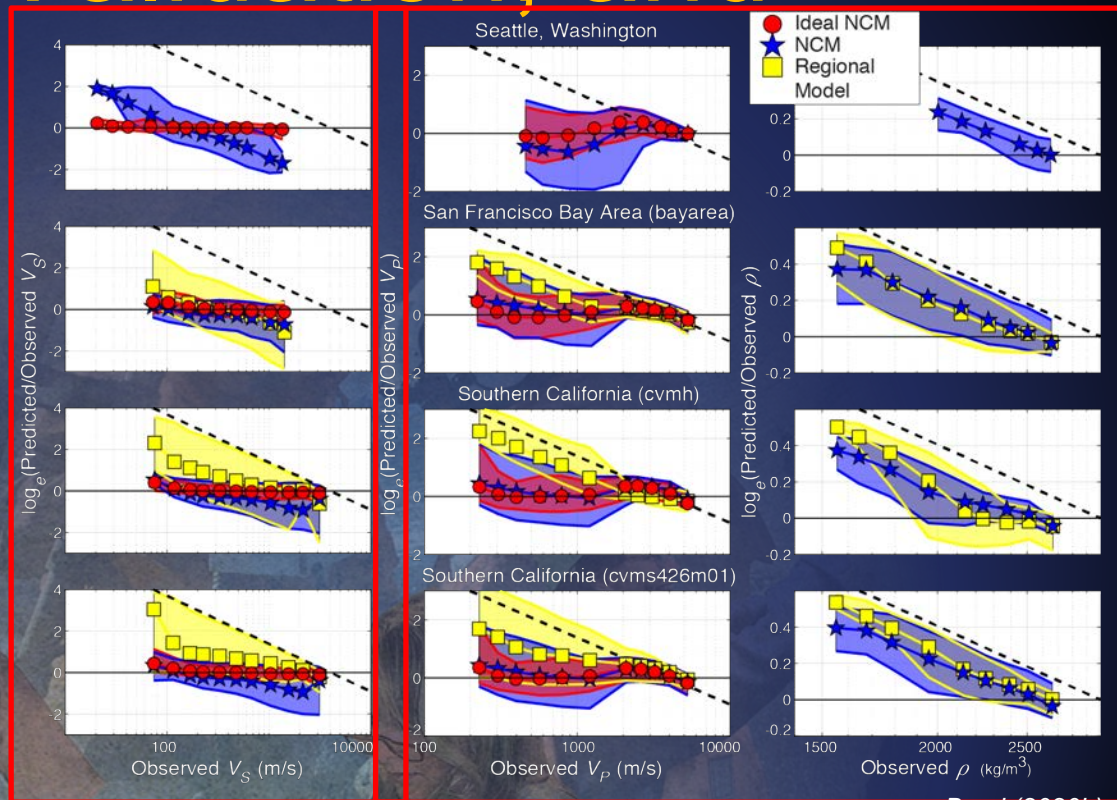
A, B —constants dependent
on lithology



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

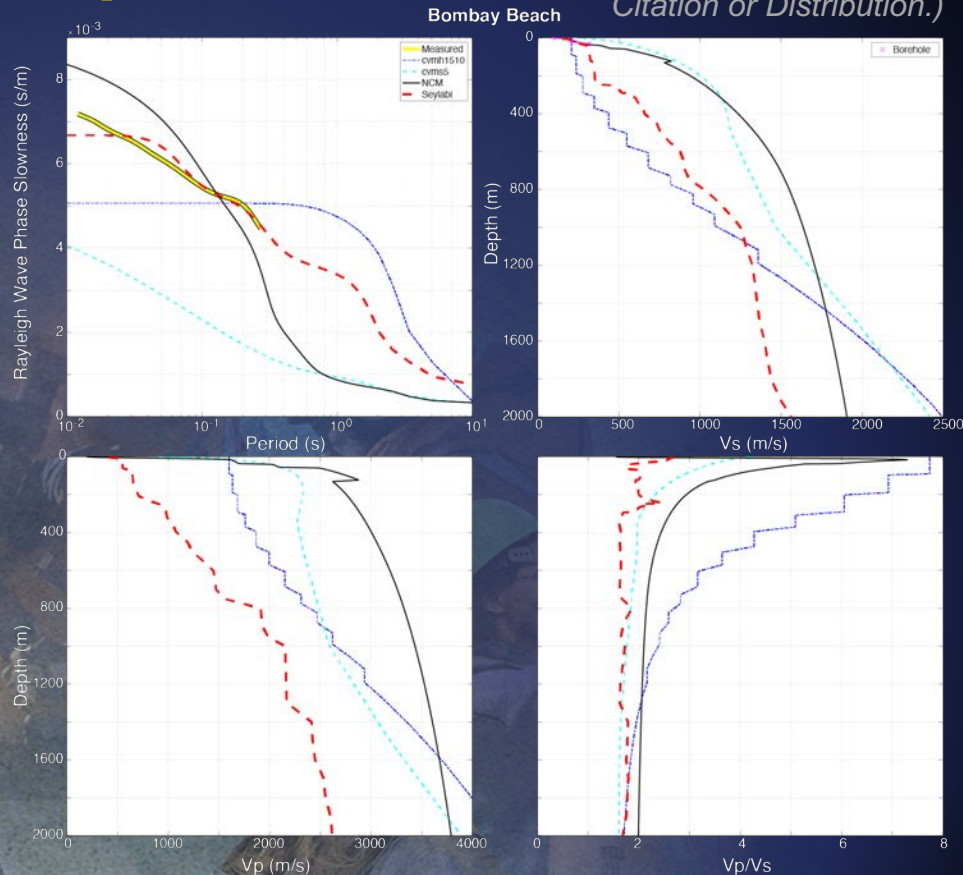


Boyd (2020b)

Model/Data comparison

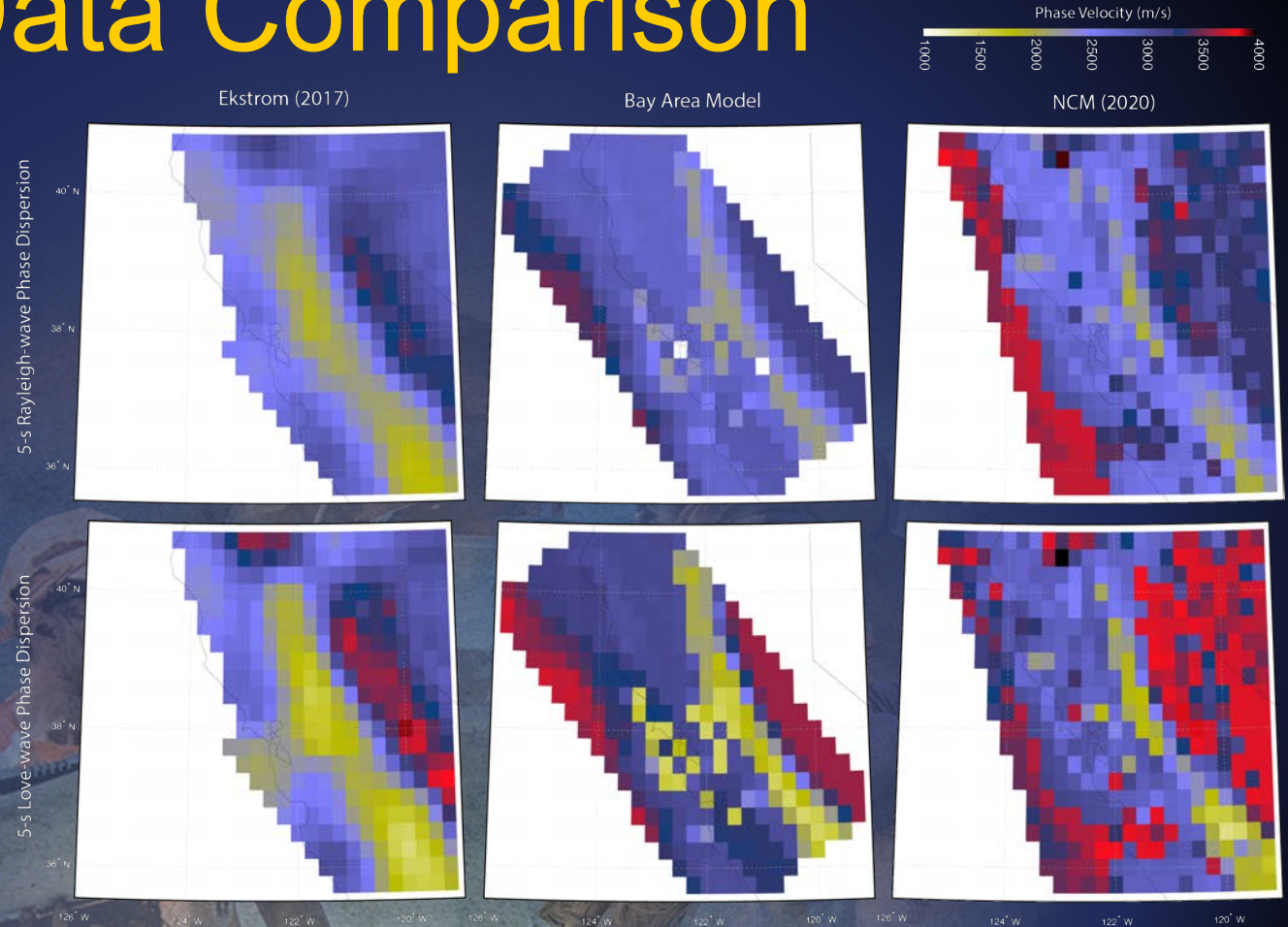
*(Preliminary Information-
Subject to Revision. Not for
Citation or Distribution.)*

- 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

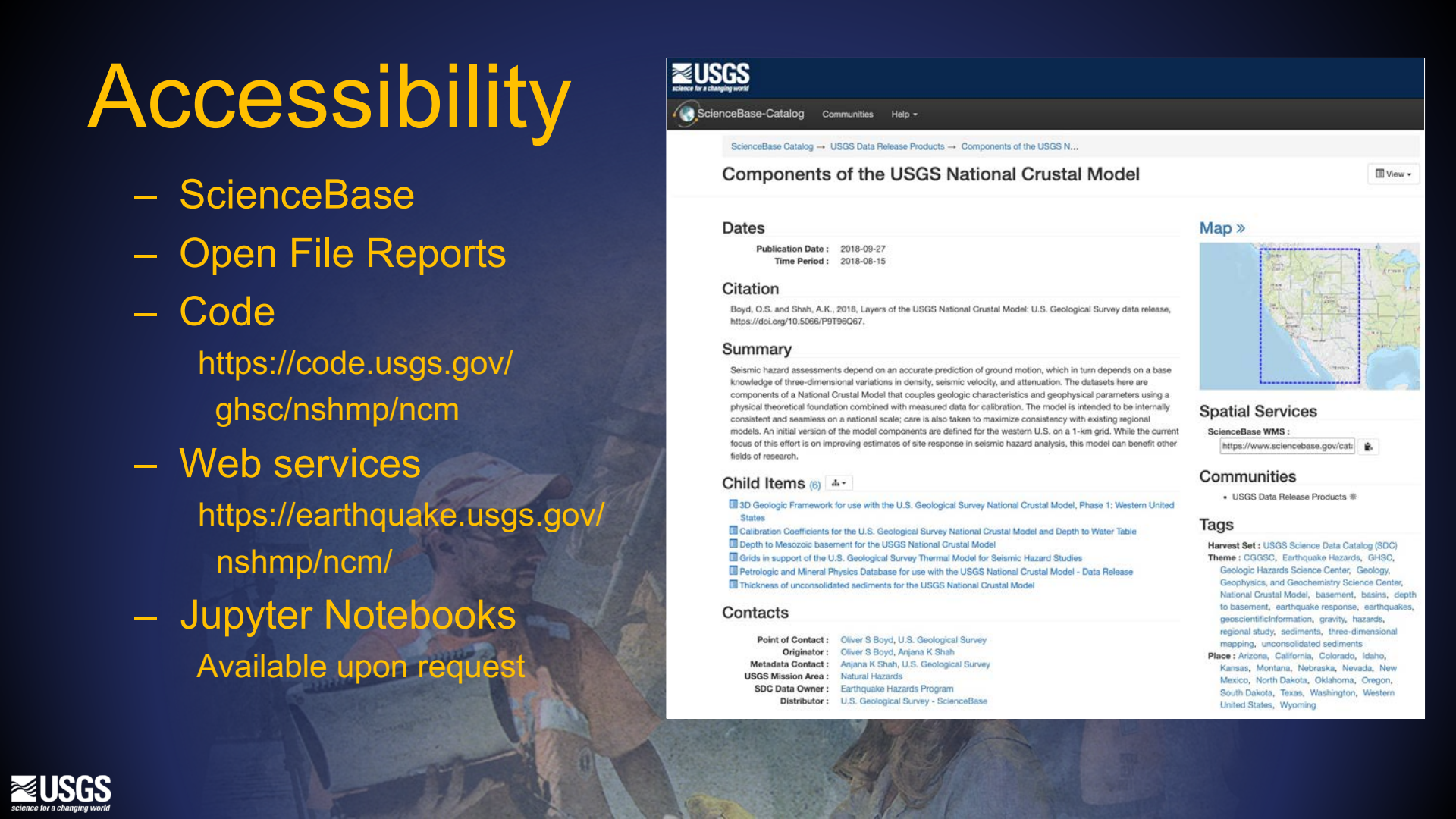
- 5-s surface-wave dispersion
 - Ekstrom, 2017
 - Bay Area Model (Aagaard and others, 2010)
 - NCM, 2020



(Preliminary Information-Subject to Revision. Not for Citation or Distribution.)

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



USGS
science for a changing world

ScienceBase-Catalog Communities Help

ScienceBase Catalog → USGS Data Release Products → Components of the USGS N...

Components of the USGS National Crustal Model

View

Dates

Publication Date : 2018-09-27
Time Period : 2018-08-15

Citation

Boyd, O.S. and Shah, A.K., 2018, Layers of the USGS National Crustal Model: U.S. Geological Survey data release, <https://doi.org/10.5066/P9T96Q67>.

Summary

Seismic hazard assessments depend on an accurate prediction of ground motion, which in turn depends on a base knowledge of three-dimensional variations in density, seismic velocity, and attenuation. The datasets here are components of a National Crustal Model that couples geologic characteristics and geophysical parameters using a physical theoretical foundation combined with measured data for calibration. The model is intended to be internally consistent and seamless on a national scale; care is also taken to maximize consistency with existing regional models. An initial version of the model components are defined for the western U.S. on a 1-km grid. While the current focus of this effort is on improving estimates of site response in seismic hazard analysis, this model can benefit other fields of research.


Child Items (6)

- 3D Geologic Framework for use with the U.S. Geological Survey National Crustal Model, Phase 1: Western United States
- Calibration Coefficients for the U.S. Geological Survey National Crustal Model and Depth to Water Table
- Depth to Mesozoic basement for the USGS National Crustal Model
- Grids in support of the U.S. Geological Survey Thermal Model for Seismic Hazard Studies
- Petrologic and Mineral Physics Database for use with the USGS National Crustal Model - Data Release
- Thickness of unconsolidated sediments for the USGS National Crustal Model

Contacts

Point of Contact : Oliver S Boyd, U.S. Geological Survey
Originator : Oliver S Boyd, Anjana K Shah
Metadata Contact : Anjana K Shah, U.S. Geological Survey
USGS Mission Area : Natural Hazards
SDC Data Owner : Earthquake Hazards Program
Distributor : U.S. Geological Survey - ScienceBase

Map »



Spatial Services

ScienceBase WMS :
<https://www.sciencebase.gov/catalog>

Communities

- USGS Data Release Products

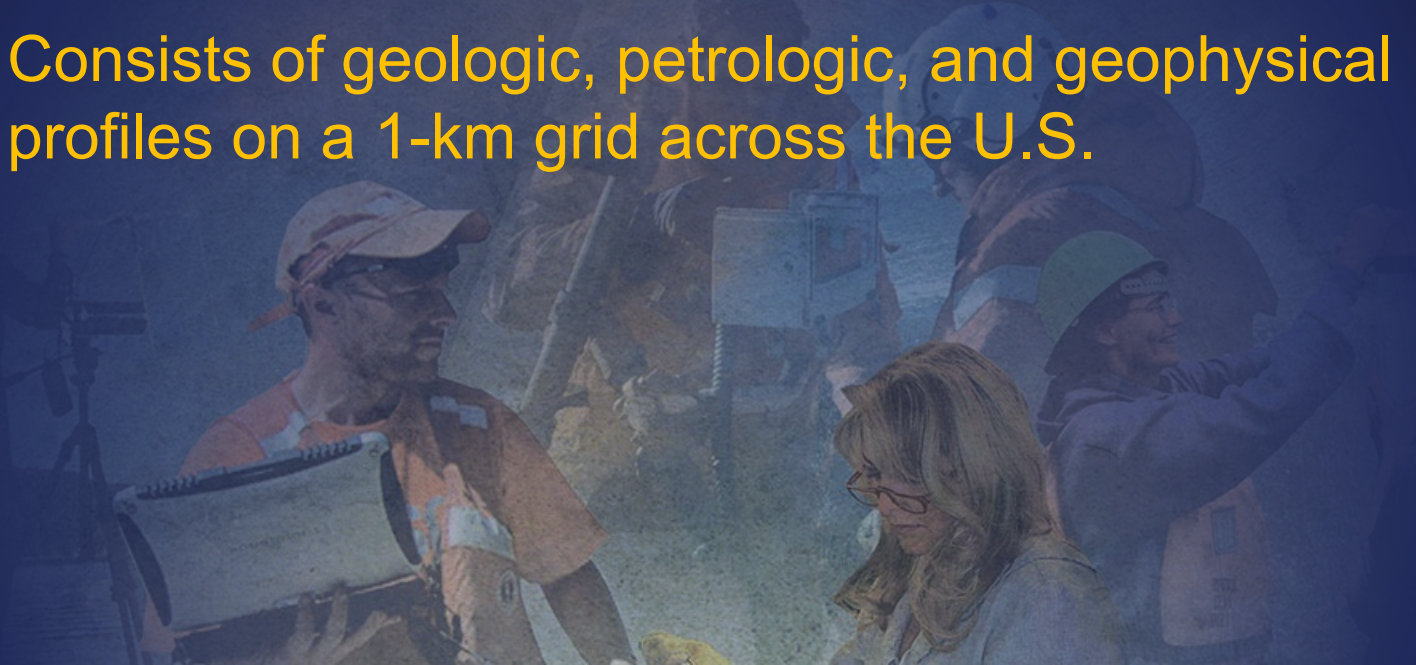
Tags

Harvest Set : USGS Science Data Catalog (SDC)
Theme : CCGSC, Earthquake Hazards, GHSC, Geologic Hazards Science Center, Geology, Geophysics, and Geochemistry Science Center, National Crustal Model, basement, basins, depth to basement, earthquake response, earthquakes, geoscientific information, gravity, hazards, regional study, sediments, three-dimensional mapping, unconsolidated sediments
Place : Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Washington, Western United States, Wyoming

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

