Argillaceous formations as barriers to flow: Knowns and unknowns

Chris Neuzil
Argillaceous formations: Knowns

Low matrix permeability
Apparent pressure anomalies surprisingly common
Appear to be hydrodynamic responses to forcing
Plausible forcing can *usually* be identified
Imply matrix permeability at local formation scale
Clay and Shale Matrix Permeability

Log hydraulic conductivity, m s⁻¹

Percent clay

Not reported

Erosional / terrestrial
Depositional
Accretionary complex

Porosity

Log permeability, m²

Various sources

Neuzil AREPS (2019)
Clay-Rich Media - Onshore Sedimentary Terranes

Neuzil (2015)
Anomalies Defined by Multiple Boreholes

Gonçalves et al. (2004)
NAGRA (2002)
Intera Eng. Ltd. (2011)
Neuzil (1993)
Steady forcing model
Anomaly present when

\[
\frac{|\Gamma|}{K^\ell} \geq 1
\]

where \( K \) is hydraulic conductivity (L/T),
\( \ell \) is formation half-thickness (L),
\( \Gamma \) is forcing rate (1/T)

Neuzil (1995)
Decaying perturbation model
Anomaly persists until

\[ t \approx 0.4 \ell^2 \left( \frac{S_s}{K} \right) \]

where \( K \) is hydraulic conductivity (L / T)
\( \ell \) is formation half-thickness (L)
\( S_s \) is specific storage (1 / L)
Active forcing

Past forcing

Neuzil (2015)
Anomalies Defined by Multiple Boreholes

Meuse / Haute Marne, France

Wellenberg, Switzerland

Ontario, Canada

S. Dakota, USA

Gonçalvès et al. (2004)
NAGRA (2002)
Intera Eng. Ltd. (2011)
Neuzil (1993)

Neuzil (2019)
Bruce Site - Hydraulic Head

DGR 1 & 2
DGR 3
DGR 4

Neuzil and Provost (2014)
Adapted from NWMO (2011)
Bruce Site - Simulated Head

Neuzil and Provost (2014)
Pressure Anomaly Permeability Overlay

Log hydraulic conductivity, m s\(^{-1}\)

Porosity

Log permeability, m\(^2\)

Various sources

Neuzil AREPS (2019)
Argillaceous formations: Unknowns

Constitutive flow law - Darcian?
Reliability of pressure and other data
Role of gas phase methane
Plausible forcing can’t always be identified
Dynamic permeability
Darcy's Law observed

Conditions of interest

Modified from Neuzil (1986)
Pressure (as head) derived from transient behavior.

Bruce site

Pressure (as head) as measured.

Neuzil and Provost (2014)
Neuzil (2015)
Anomalies Defined by Multiple Boreholes

Meuse / Haute Marne, France

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Gonçalvès et al. (2004)
NAGRA (2002)
Intera Eng. Ltd. (2011)
Neuzil (1993)
Overpressure in the Callovo-Oxfordian Bure, France

Robinet (2018)
Shale permeability enhanced by seismic shaking

A. Preseismic

B. Postseismic

"Large-scale" permeability

Clay-rich lithologies
- Yellow: 1 - 10 km$^2$
- Orange: $> 10^3$ km$^2$

Other lithologies
- Blue: Basalt
- Green: Other sedimentary & crystalline
- Ingebritsen & Manning

Neuzil (2019) from Ingebritsen & Manning (1999), Townend & Zoback (2000), Saar & Manga (2004), and numerous other sources
Argillaceous formations: Needs

Data from more formations!
   Fluid pressure
   Lab and borehole permeability
   Mechanical properties (long-term)
   Fluid geochemistry
   Identify forcings

Constitutive flow law
   (Molecular Dynamics simulations?)

Multiphase physics in clays

Dynamic permeability

Local - regional scale permeability


Ingebritsen, S. E., and C. E. Manning (2010), Permeability of the continental crust: dynamic variations inferred from seismicity and metamorphism, *Geofluids* 10, 193-205


Saar, M. O., and M. Manga (2004), Depth dependence of permeability in the Oregon Cascades inferred from hydrogeologic, thermal, seismic, and magmatic modelling constraints, *J. Geophys. Res.* 109 B04204


Townend, J., and M. D. Zoback (2000), How faulting keeps the crust strong, *Geology* 28, 399-402

Wang, C-Y., C-H.Wang, and M. Manga (2004), Coseismic release of water from mountains: Evidence from the 1999 (Mw = 7.5) Chi-Chi, Taiwan. Earthquake, *Geol.* 32, 769-772