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Correlation of core and downhole seismic velocities in high-pressure metamorphic rocks: A case study for the COSC-1 borehole, Sweden

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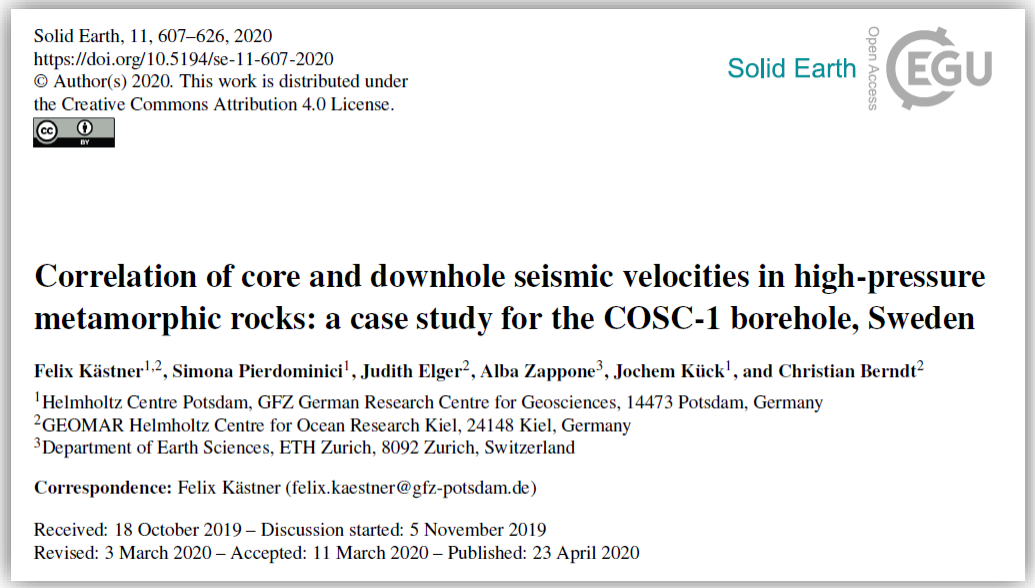

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Correlation of core and downhole seismic velocities in high-pressure metamorphic rocks: a case study for the COSC-1 borehole, Sweden

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Project outline: Core-**L**og-**S**eismic **I**ntegration in a hard rock environments using the ICDP drilling project COSC-1, Sweden

DFG-funded research project (2017-20)
Prof. Dr. Christian Berndt (GEOMAR)
Dr. Simona Pierdominici (GFZ)

- ❑ 1-year post-doc (Judith Elger)
- ❑ 3-year PhD (Felix Kästner)

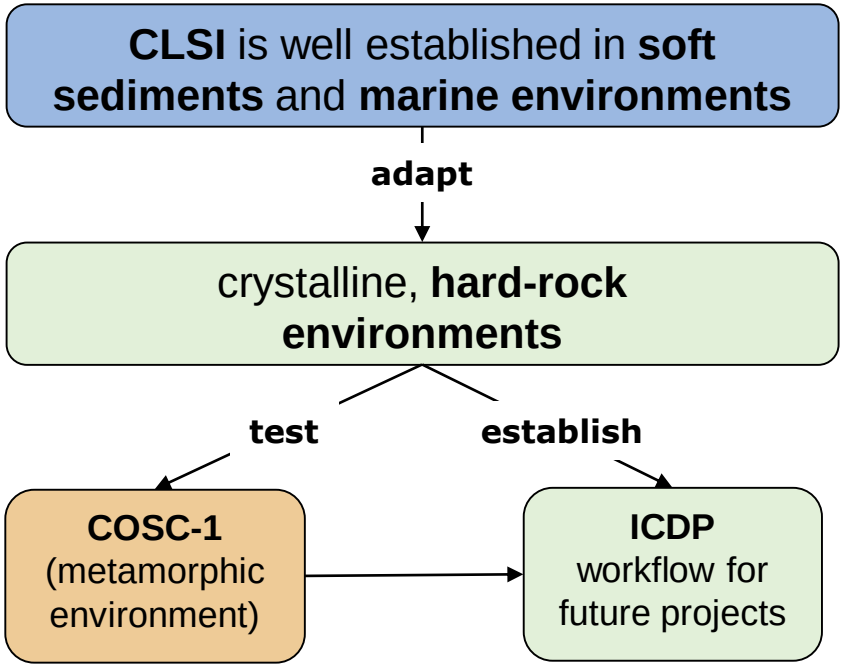
DFG Deutsche Forschungsgemeinschaft

GFZ Helmholtz-Zentrum Potsdam

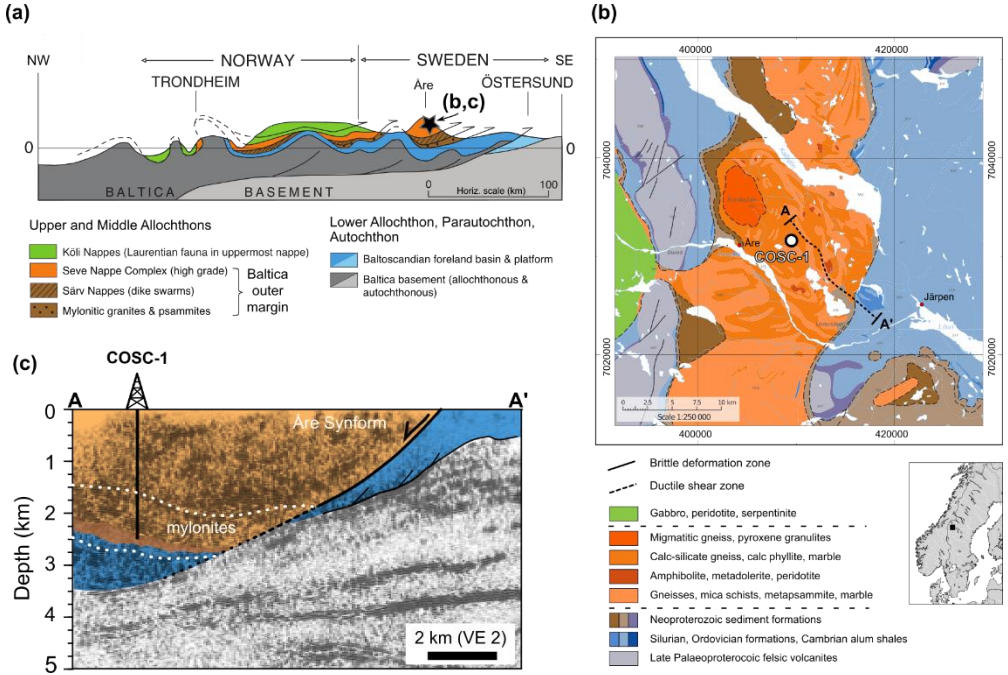
GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel

CAU Christian-Albrechts-Universität zu Kiel

icdp



Study area and motivation



Regional setting and study area

(a) Tectonostratigraphic division of the central Scandinavian Caledonides [1,2]
(b) Bedrock map with location of the COSC-1 borehole (colors modified; SGU Map Service) [3]
(c) Seismic cross section indicated in (b) showing a highly reflective part of the COSC seismic profile [4,5]

Motivation

Use seismic properties from core and downhole data to better characterize and eventually enhance the seismic stratigraphy of the Lower Seve Nappe Complex along the COSC-1 borehole

This study

Investigation of core seismic velocities and comparison with in situ velocities through calibration using laboratory measurements on core samples

[1] Gee et al. (2010)
[2] Lorenz et al. (2015a)
[3] Strömberg et al. (1994)
[4] Hedin et al. (2012)
[5] Juhlin et al. (2016)

Core-log analyses of seismic properties at COSC-1 borehole, Sweden

Why seismic properties?

- ✓ Seismic velocities (v_P) continuously available throughout COSC-1 data sets
- ✓ Controlling parameter in reflection seismic

Determine and characterize seismic properties at core scale

Relate to "in situ" velocities using pressurized core samples

Compare with downhole sonic and borehole seismic (VSP*) velocities

* Vertical seismic profile

Background: COSC drilling project

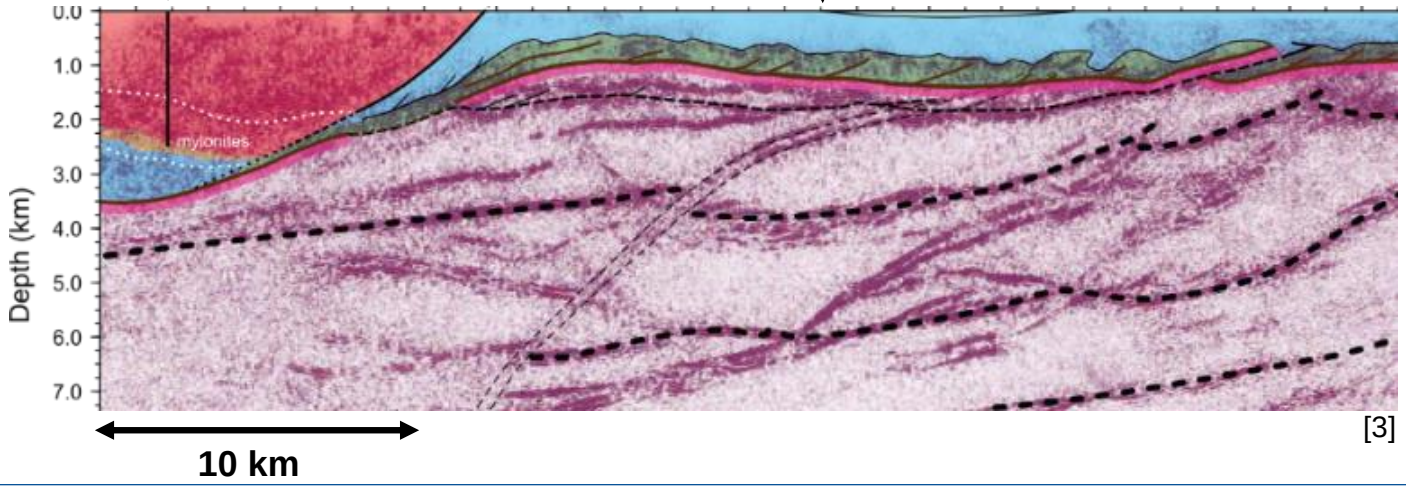
Scientific objectives [1,2]

COSC-1
2014

Nappe emplacement & inner structure of upper, high-grade metamorphic allochthons

COSC-2
2020

Character & age of deformation of underlying thrust sheets, main Caledonian décollement & Precambrian basement



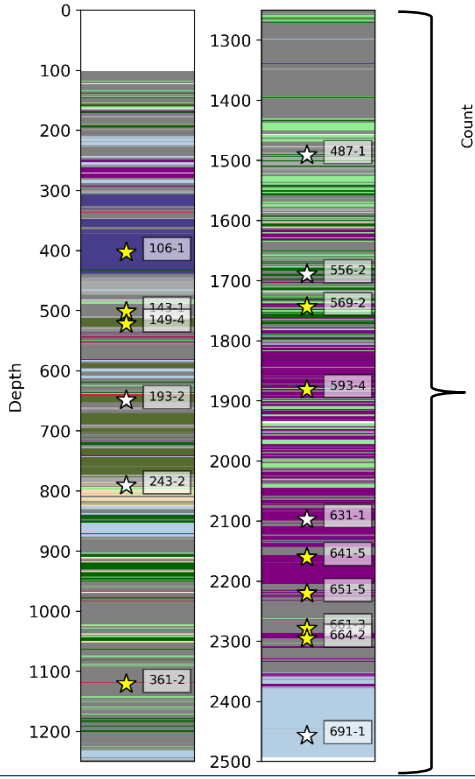
[3]

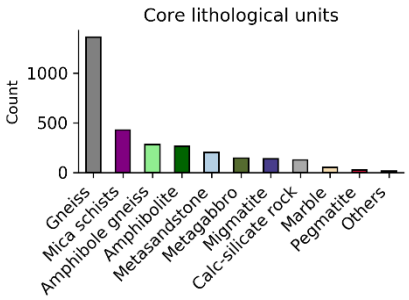
Drill rig *Riksriggen*
Photo © H. Lorenz (2014)

[1] Gee et al. (2010)
[2] Lorenz et al. (2015a)
[3] Juhlin et al. (2016)

Background: COSC-1 drill core

Cores stored at BGR Core Repository Berlin-Spandau (Germany)
Core recovery ~100%





Samples used in this study

- ☆ Wenning et al. (2016)
- ★ Kästner et al. (2020)

Lithology [1] from on-site core description mainly composed of:

- Para/Orthogneiss
- Mica schists
- Amphibolite / Am-rich rocks

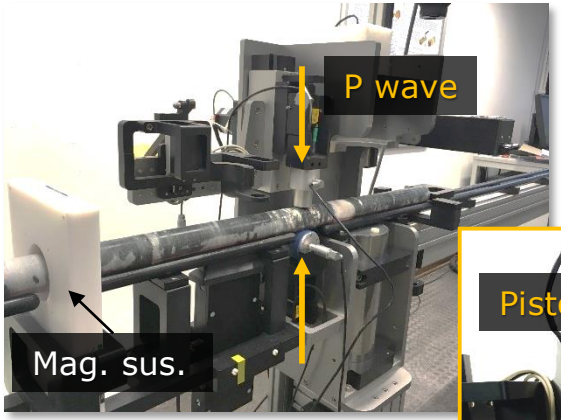
- Different structure/texture
- Metamorphic overprint
- Mylonitic deformation

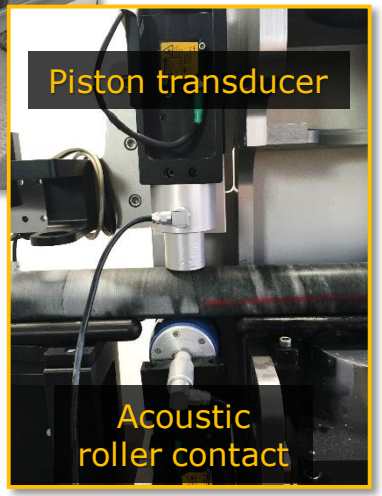
[1] Modified after Lorenz et al. (2015b)

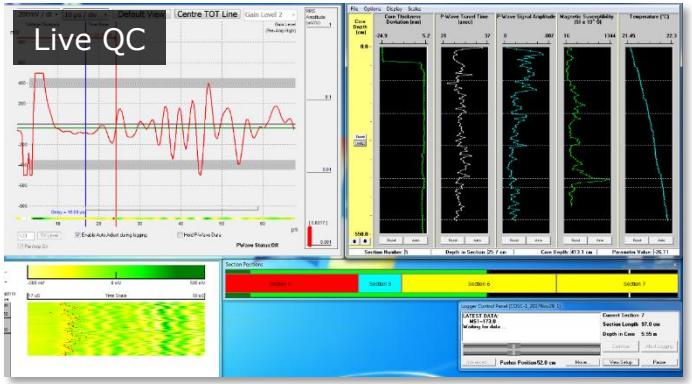
Multi-**S**ensor **C**ore **L**og P-wave velocities

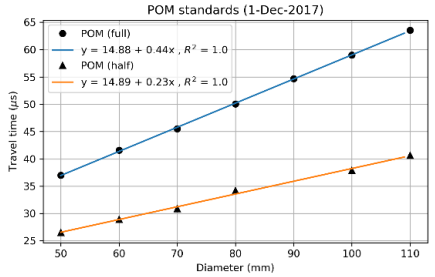
Logging of the acoustic velocities using:

- Piston transducers + acoustic roller contact setup (250 kHz)
- Real-time QC and automatic P-wave first-arrival picking based on first zero-crossing and threshold detection
- Wetting of the core for proper coupling
- Calibration using POM round cores



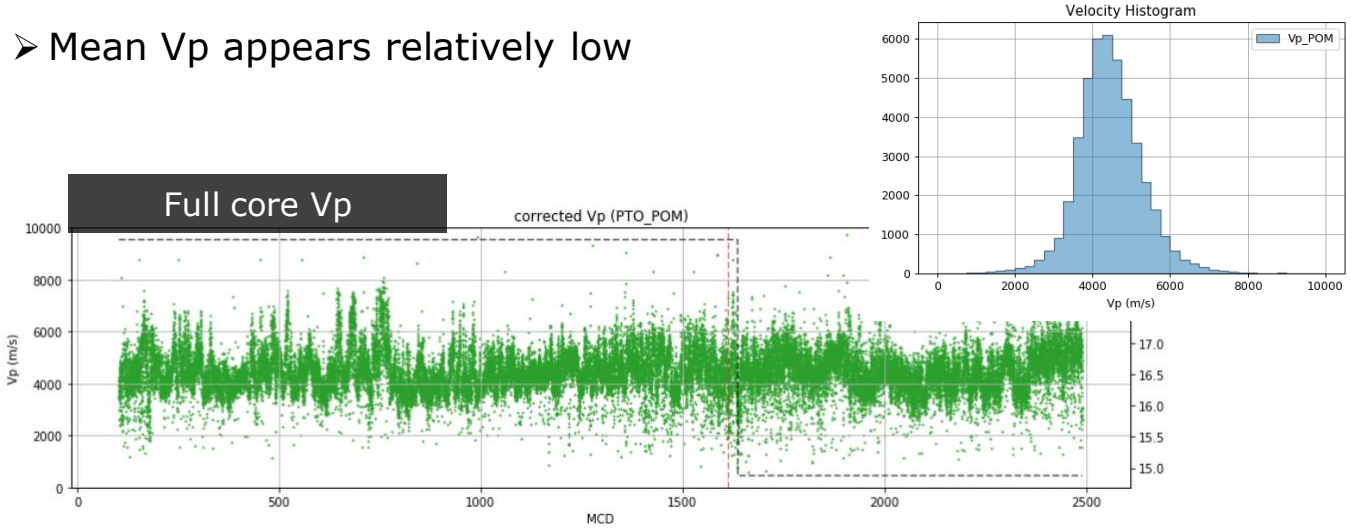


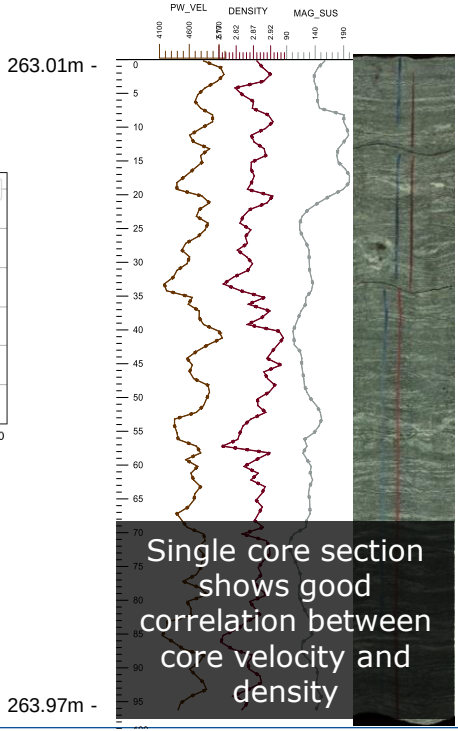


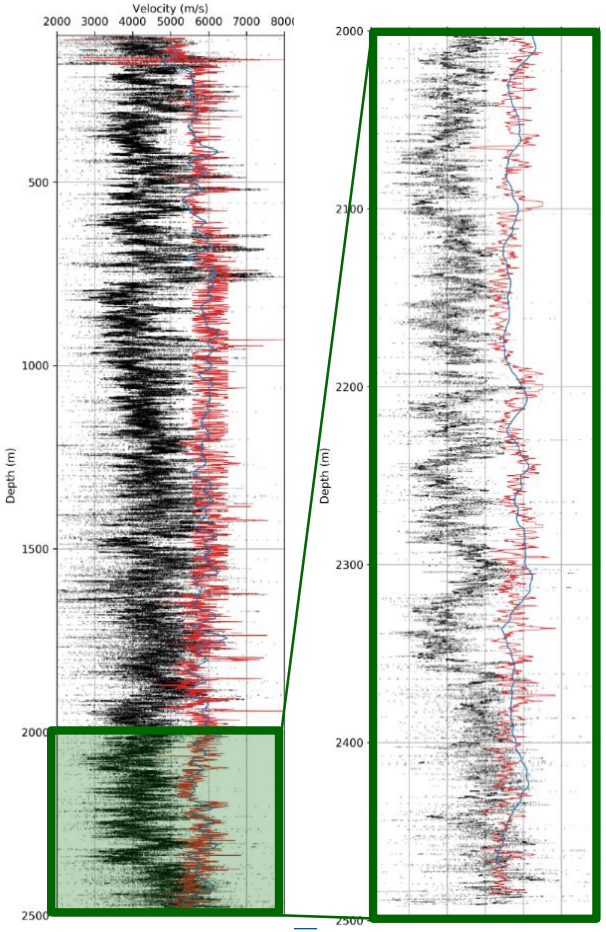


Results: Seismic velocities at core scale

- Core Vp logged under laboratory conditions at atmospheric pressure and room temperature (21° C)
- Mean Vp appears relatively low







Core-Log Vp comparison shows:

- High core Vp variability
- Low visual correlation
- Core Vp considerably lower than downhole sonic and VSP (on avg.)
- Certain intervals (e.g., 400-800 m, >2350 m) show good agreement

MSCL core log

Downhole sonic [1]

Vertical seismic profile [2]

[1] Lorenz et al. (2015b)
[2] Krauß et al. (2015)

Seismic properties at core scale and under in situ conditions

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

RPMLab

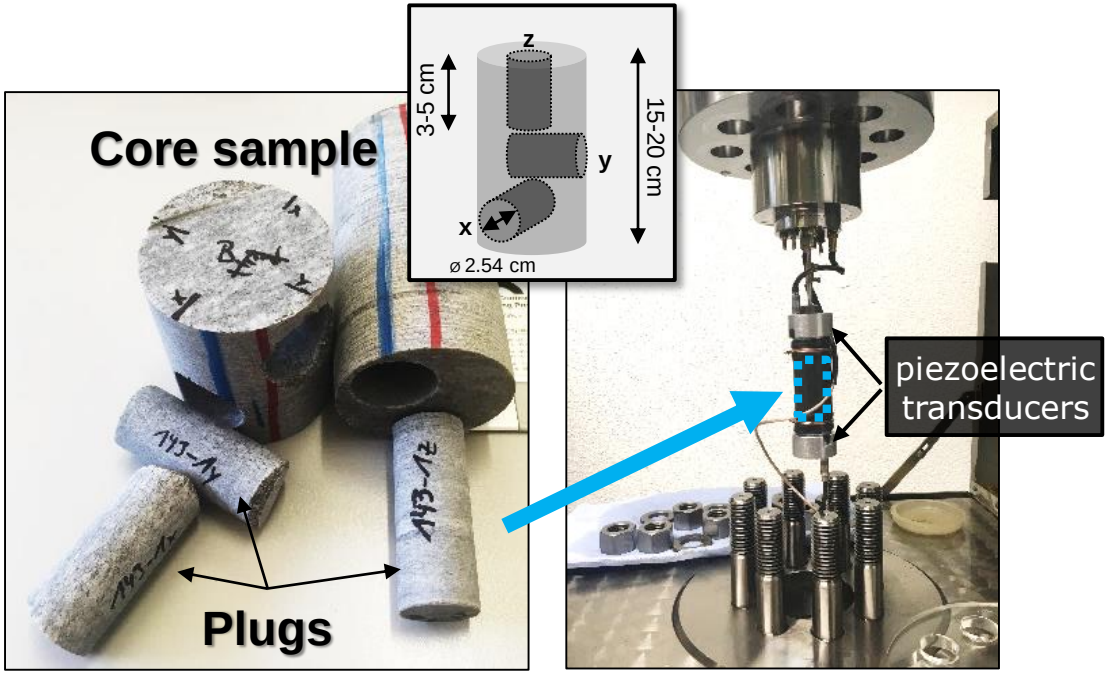
Laboratory measurements:

→ Ultrasonic Vp and Vs at pressure up to 250 MPa (at room temp.)

→ 3 mutually perpendicular plugs drilled along major structural axes (foliation and lineation)*

→ In total 16 samples measured

- 10 samples: Kästner et al. (2020)
- 6 samples: Wenning et al. (2016)



Measured at the Rock Physics and Mechanics Laboratory, ETH Zurich

* not necessarily coaxial with core axis

GFZ Helmholtz Centre Potsdam

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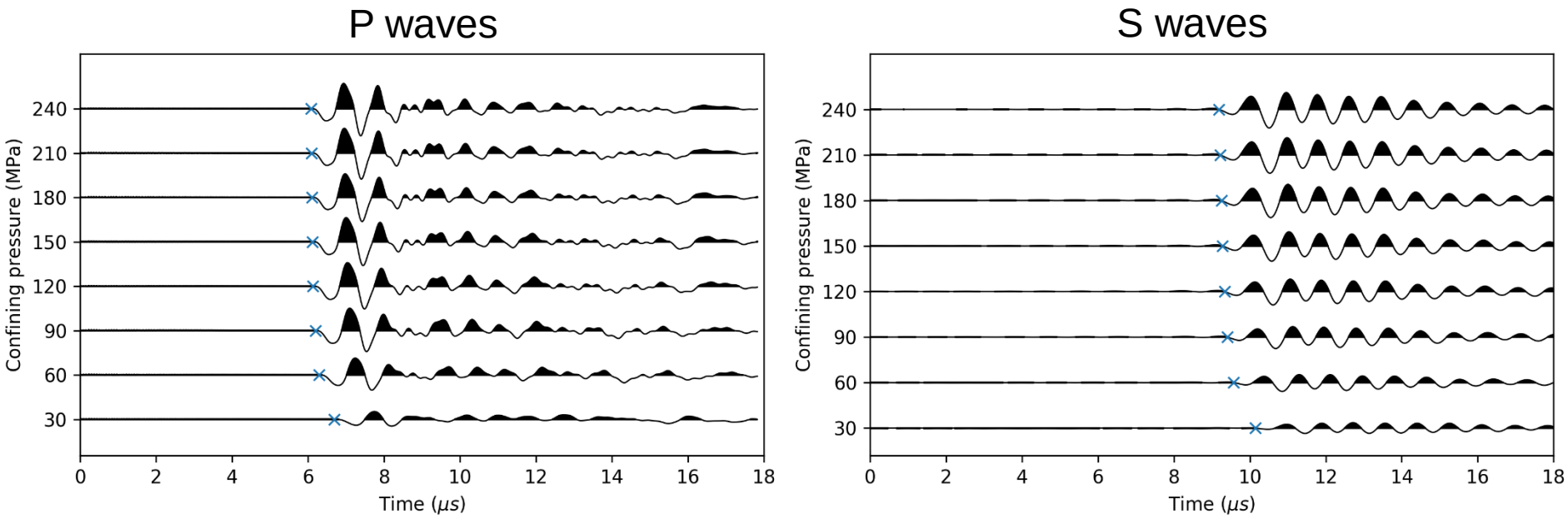
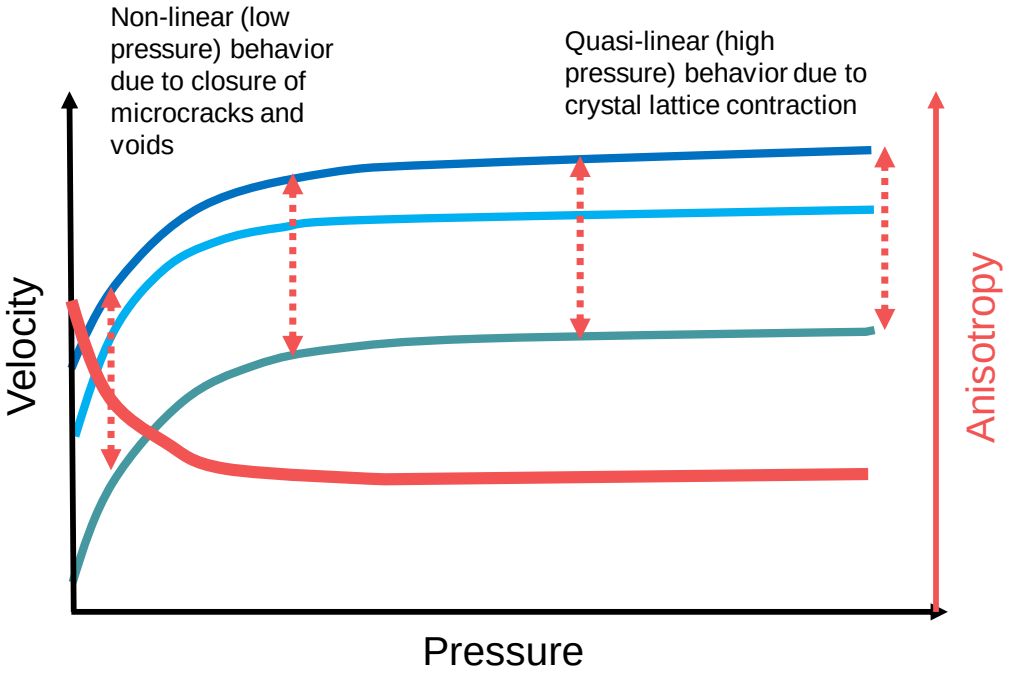
High-quality P-wave (and S-wave) laboratory seismic data

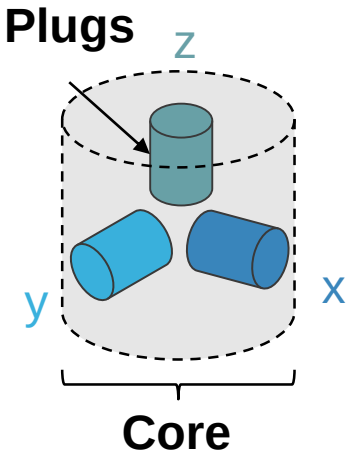


In this study we only considered P-wave data.

x - P- and S-wave first arrivals

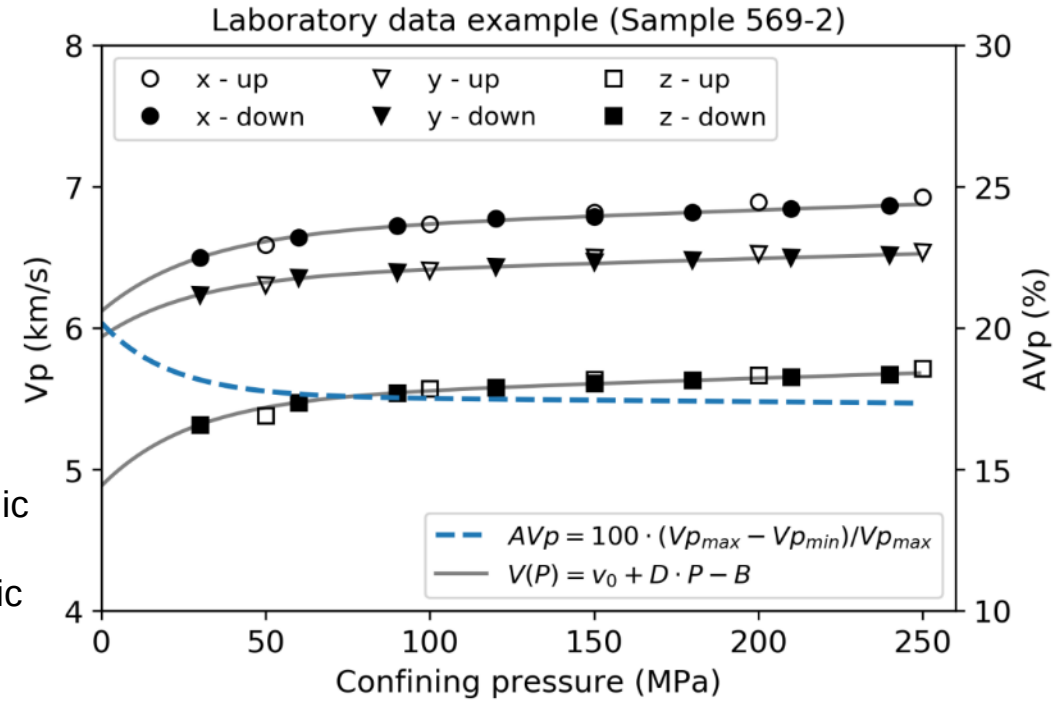
Background: Velocity-pressure relation

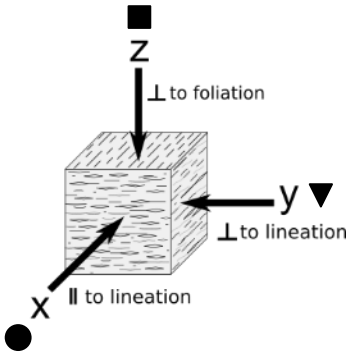




See, e.g., Birch (1960); Wepfer & Christensen (1991); Ji et al. (2007)

Laboratory seismic properties: data example*





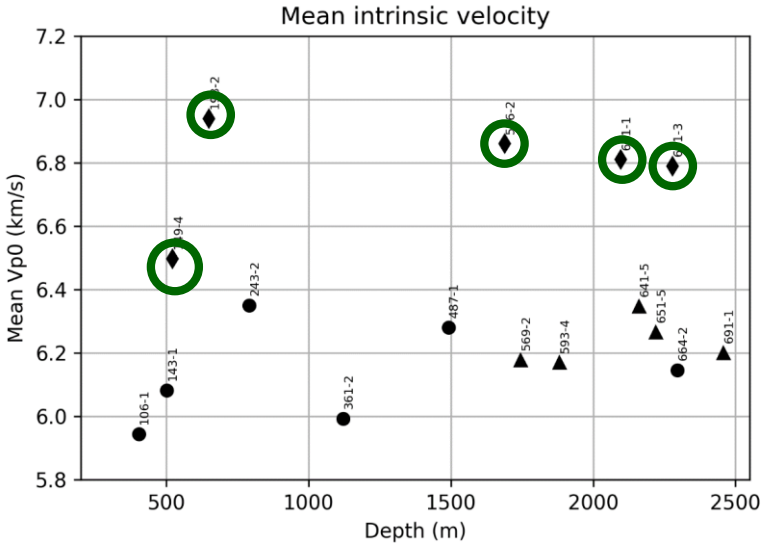
Observations:

- ❑ Overall strong seismic anisotropy (AVp)
- ❑ Transversely isotropic
- ❑ Low crack-related anisotropy

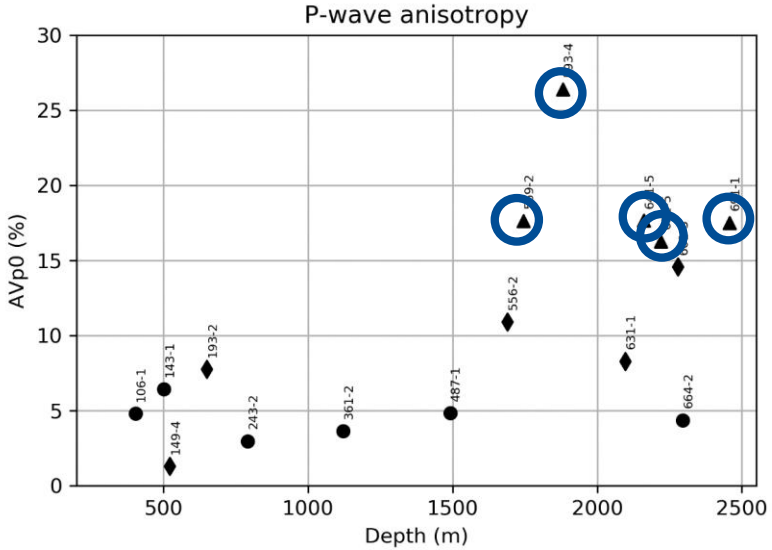
* Mica schist, 1744 m

Results: Mean intrinsic P-wave velocity and anisotropy

Mean intrinsic P-wave velocity and anisotropy show characteristic behavior at depth and can be related to different lithologies.

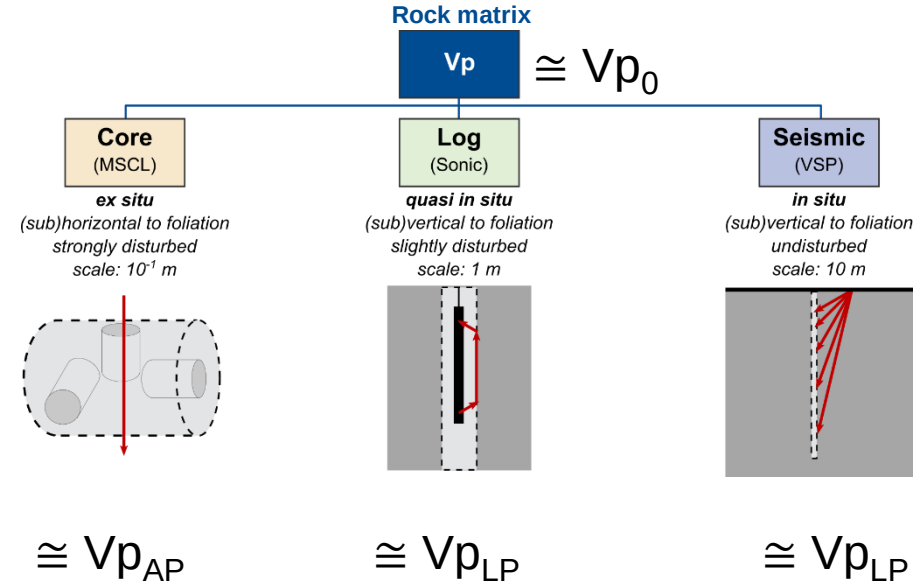


Mafic samples



Mica-rich samples

“Simulation” of seismic velocities at different ambient pressure conditions



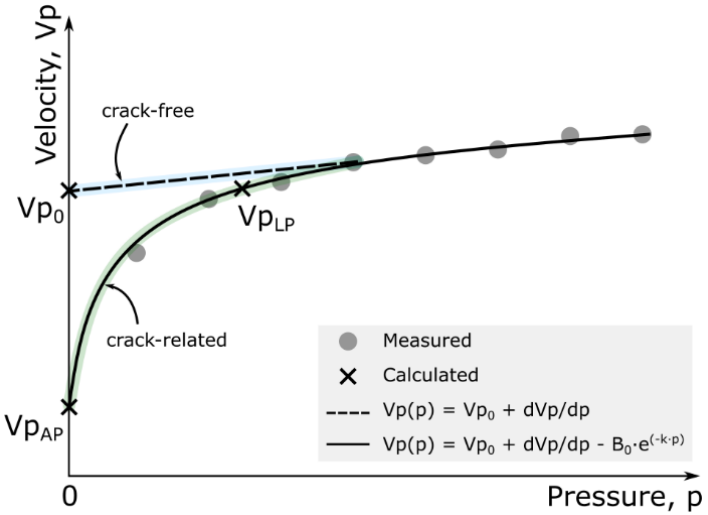
≅ Vp_{AP}

at atmospheric pressure

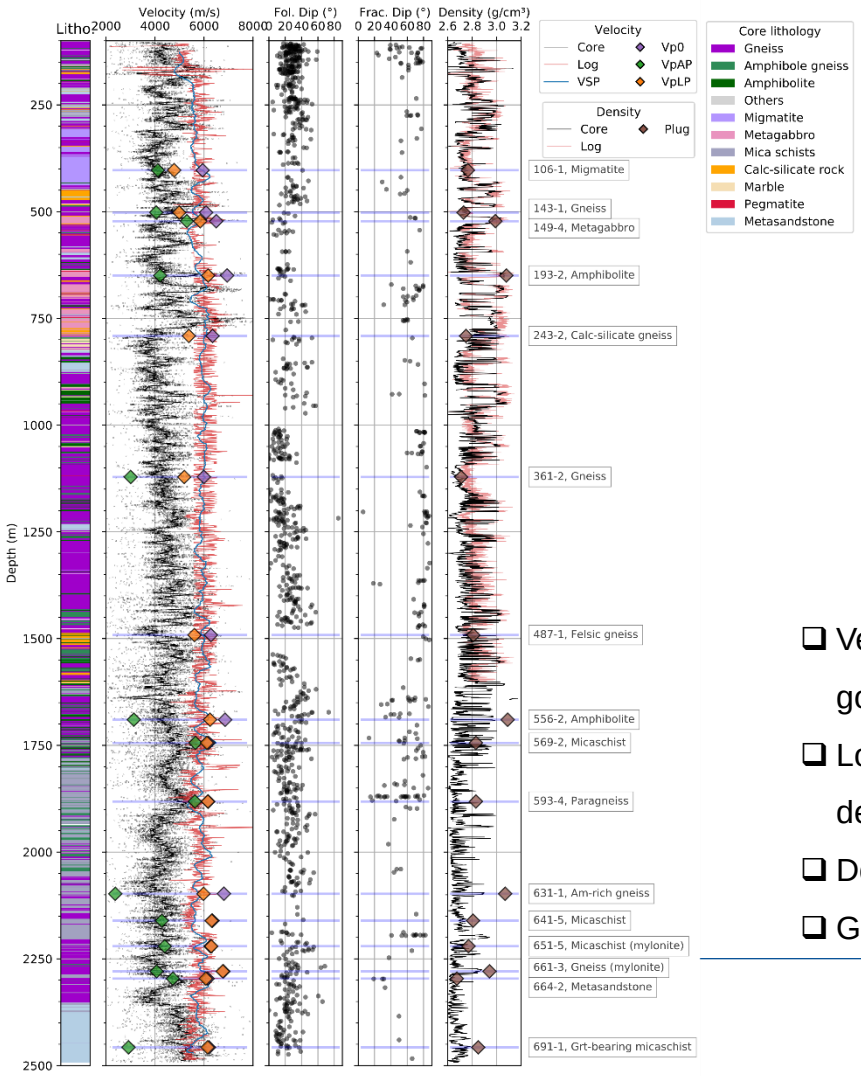
≅ Vp_{LP}

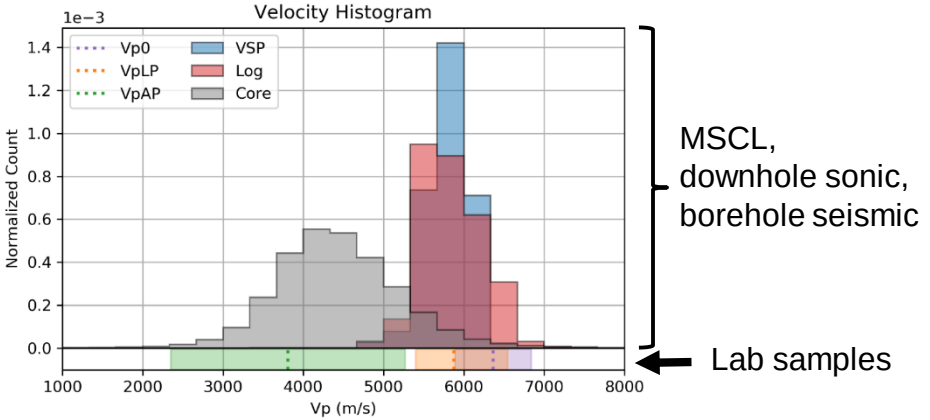
≅ Vp_{LP}

at lithostatic pressure



Correlation of core and downhole logs using sample velocities





- Velocities measured under different environmental conditions show good correlation with laboratory measurements on core plugs
- Low MSCL core velocities most likely caused by microcracks due to depressurization of the cores
- Downhole velocities not significantly affected by microcracks
- Good correlation of core and downhole velocities for mafic units

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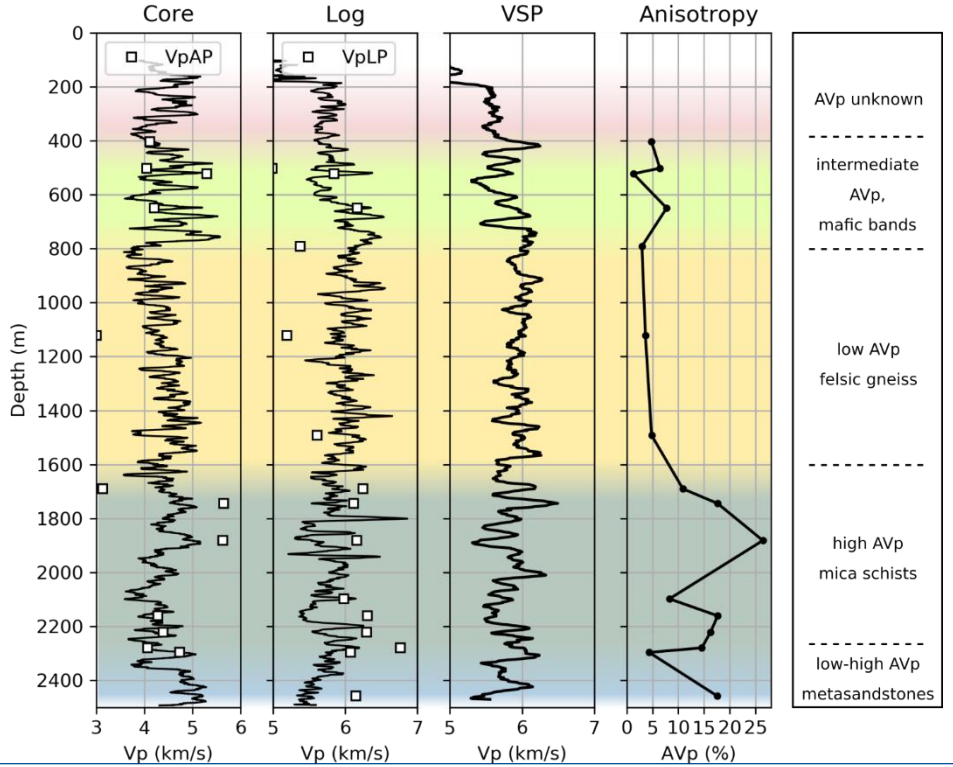
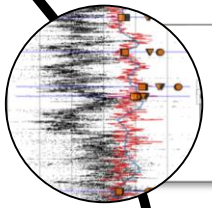
Smoothed core and log seismic properties along the COSC-1 borehole

- Core, downhole sonic (Log), and borehole seismic (VSP) velocities show strong variations among each data set and at depths.
- Good correlation was found for mafic (amphibolite/metagabbro) units throughout all data sets.
- An increase in seismic anisotropy (up to 26 %) can be attributed to mica schists dominated below about 1.6 km.
- Characteristic seismic zones are indicated by the shaded areas.

* The plotted velocity data were smoothed with a 30 m depth average.

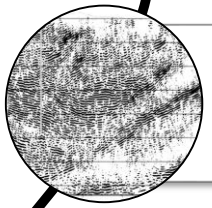


Challenges



Core velocities alone may not be representative for in situ seismic properties as influenced by metamorphic foliation and microcracks

Very complex geology and core lithology are hardly displayed in core and downhole trends except for mafic lithologies



Seismic profiles are likely affected by relatively high seismic anisotropy

Outlook

Ongoing and future investigations:

- Effects of composition and structure on the measured seismic anisotropy with focus on sample mineralogy and petrography and use of complementary structural analysis using EBSD (Kästner et al., in preparation)

- Core-log-seismic integration in metamorphic rocks and its implications for the regional geology (Elger et al., in preparation)

- Seismic stratigraphy and re-interpretation (+sensitivity analysis) of the highly reflective Lower Seve Nappe based on core, log, and laboratory investigations and limited 3D seismic data

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