Can we detect fast fabric changes in glaciers and ice sheets remotely?

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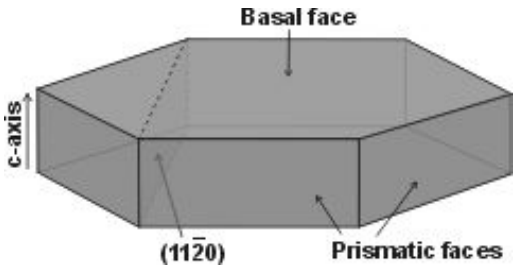
icy anisotropy

- ice 1h: anisotropic crystal, effects on
  - rheology ("softness" of ice)
  - electromagnetic wave speed:



$$c = \frac{c_0}{\sqrt{\varepsilon'}}$$

$$\varepsilon'_{||} - \varepsilon'_{\perp} \approx 1\%\varepsilon', \qquad \varepsilon' \approx 3.1 - 3.2$$

  - seismic (acoustic) wave speed:

$$v^s_{||} - v^s_{\perp} \approx 100\ \mathrm{ms}^{-1} \approx 5\% v^s, \qquad v^s \approx 1900\ \mathrm{ms}^{-1}$$

$$v^p_{||} - v^p_{\perp} \approx 100\ \mathrm{ms}^{-1} \approx 5\% v^p, \qquad v^p \approx 3900\ \mathrm{ms}^{-1}$$

Detection and Relevance

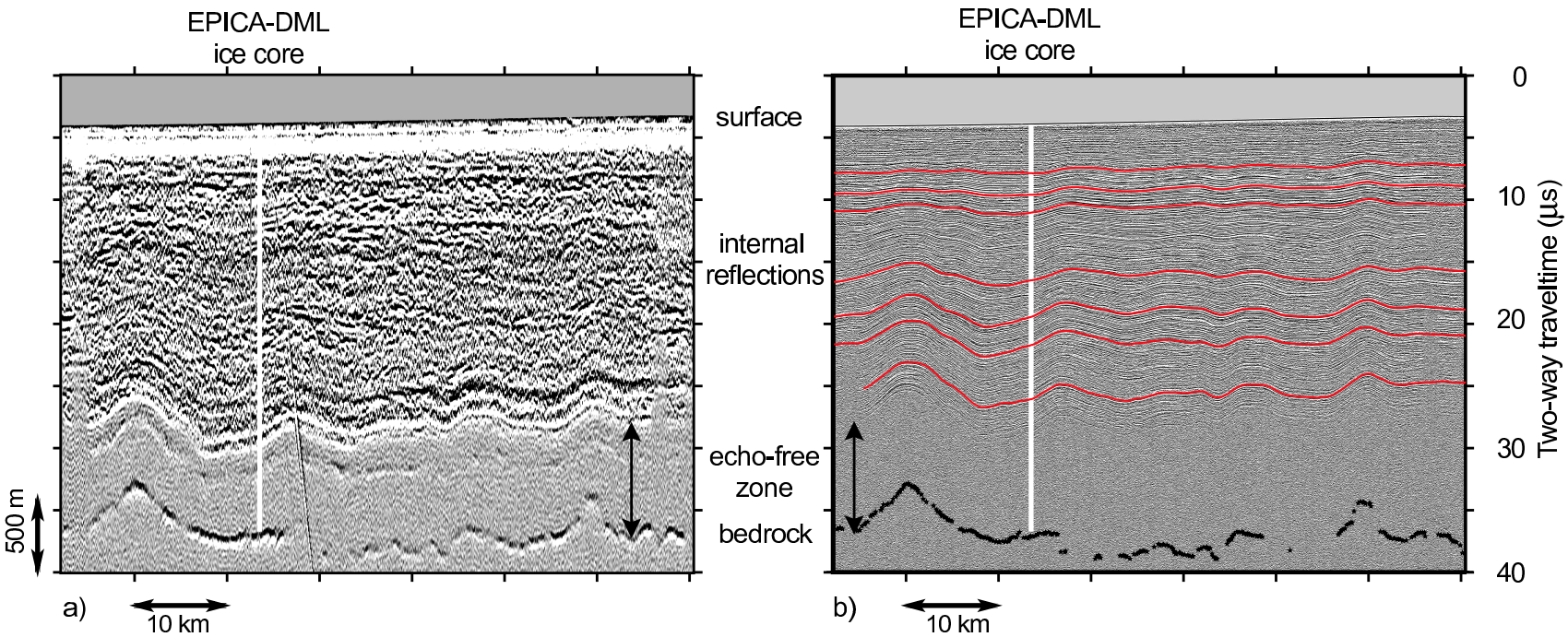
- active geophysical methods (radar & seismics):
  reflections occur where impedance changes
  $\Rightarrow$ "fast" changes in COF = reflections?

- relevance:
  improved ice-dynamical modeling
  distribution of fabric properties in space

- terminology:
  fabric: a lot of crystals
  COF: crystal fabric orientation
  fast changes: vertically over $\sim$wavelength $\approx 10^0 - 10^1$ m

Radio-echo sounding

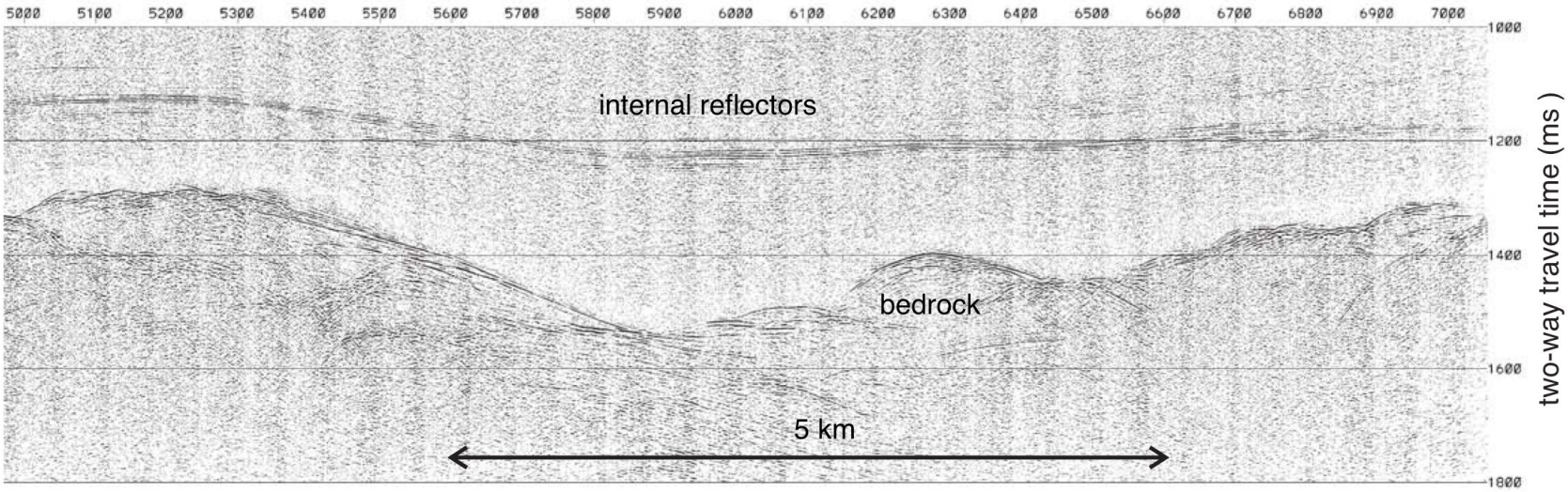
EPICA drill site, Dronning Maud Land



- most internal layers from volcanic acidity = isochrones
- reflectors from COF

Seismics

Rutford ice stream, Antarctica



King et al., WAIS meeting 2003

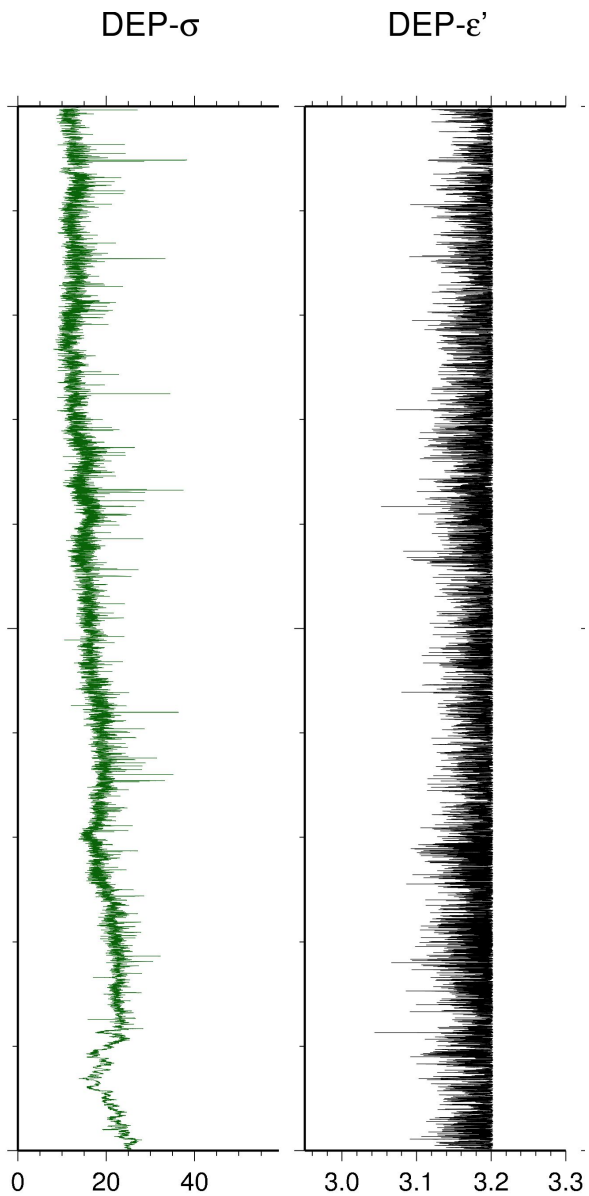
- properties of internal reflectors?

Merging ice-core data and geophysics

- DEP: dielectric profiling of ice core
  $\Rightarrow \sigma, \varepsilon$
- RES: AWI airborne system
  frequency 150 MHz
  pulse width 600 ns / 60 ns
- synthetic RES trace (FD):
  $\sigma, \varepsilon \rightarrow$ 1D nummerical model of Maxwell equations

  $\Rightarrow$ reflectors originating from conductivity
  (isochrones of volcanic origin)
- COF: crystal orientation fabric
  principle components

. . . merging data sets . . .



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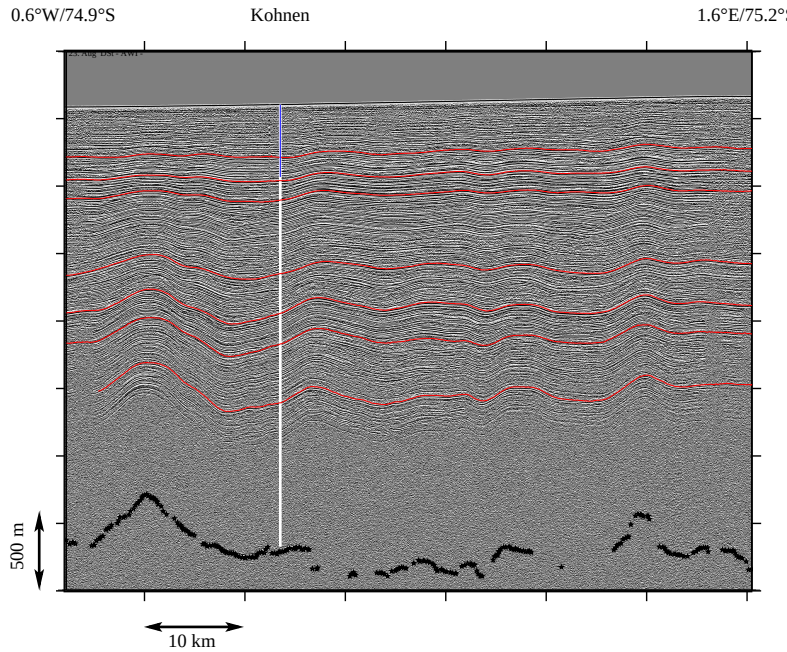

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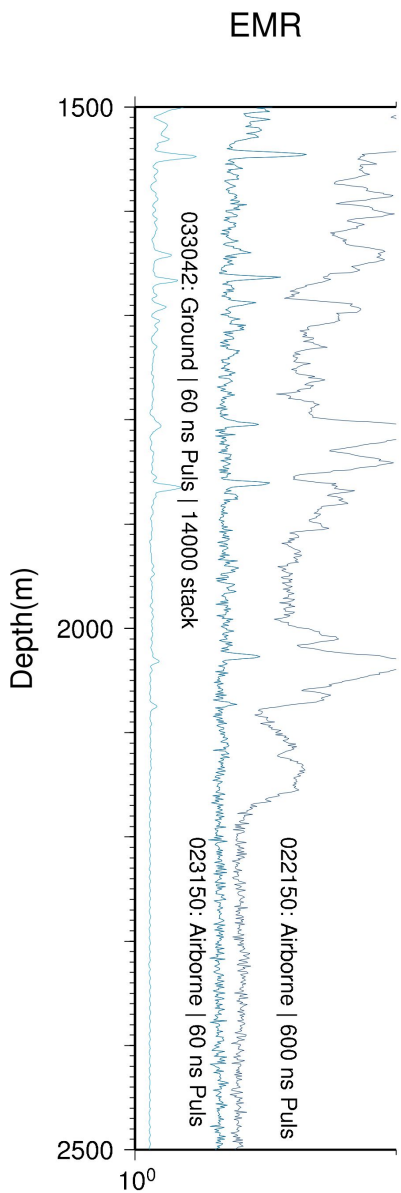

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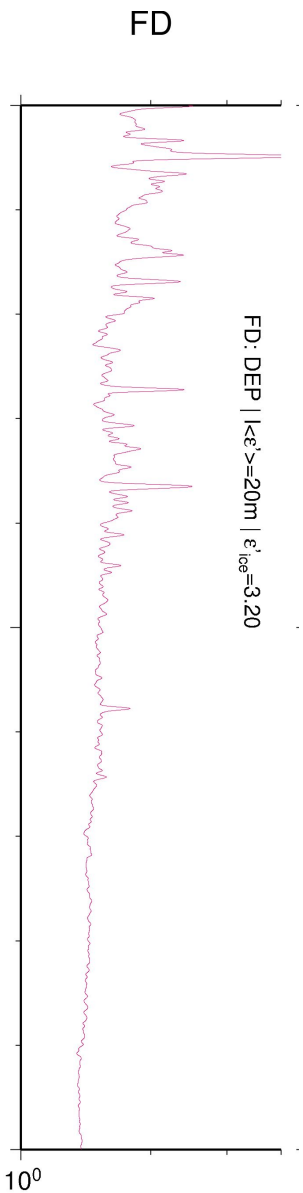

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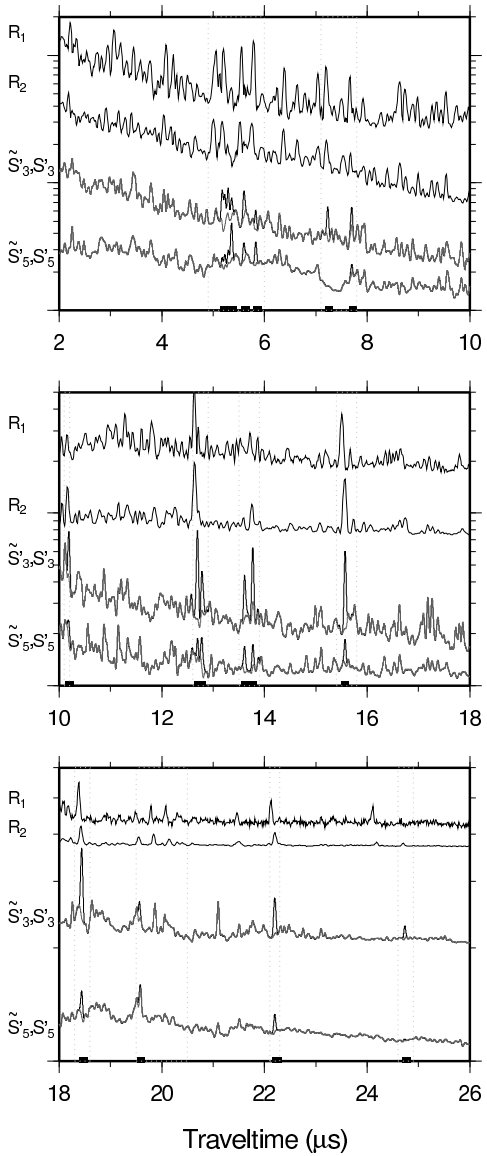

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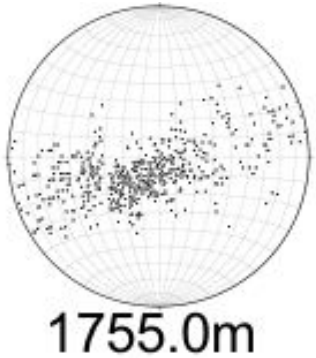

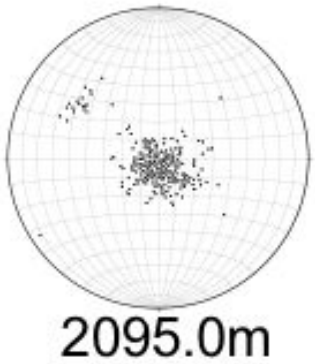

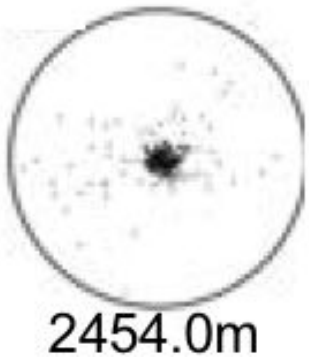

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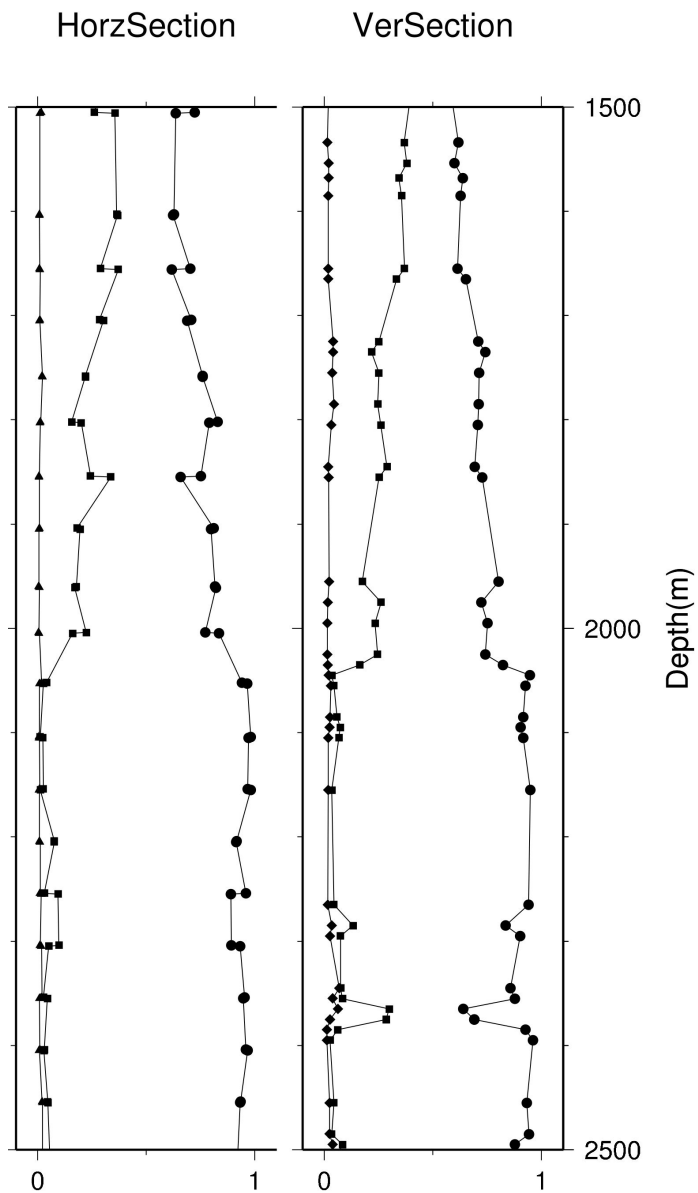

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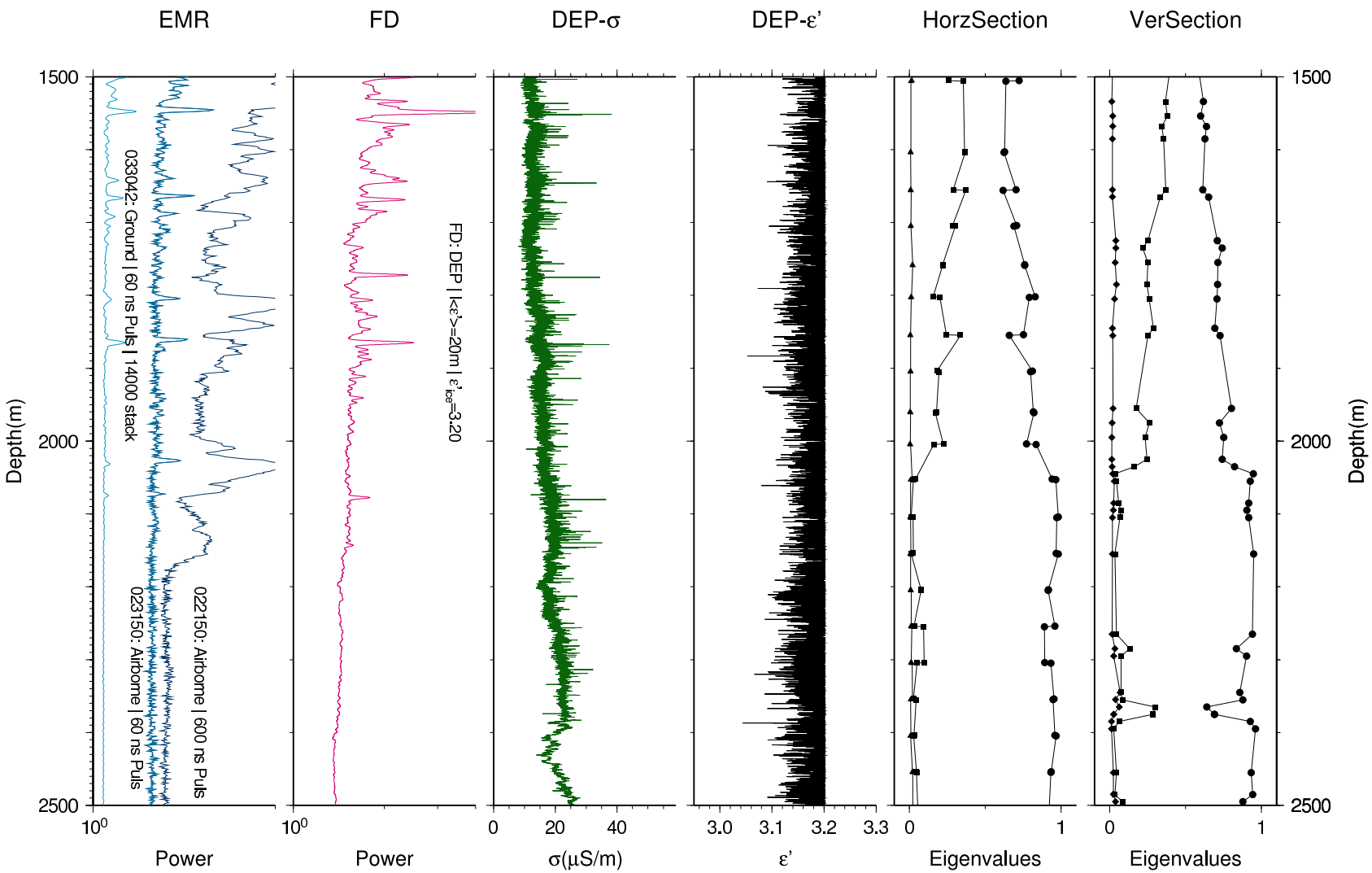

Findings

- conductivity cannot explain radar reflector at 2030 m
- but COF changes:
  from girdle-type to increased single-pole orientation
- other factors:

  bubble orientation
  clathrate transition

  rather "diffuse" processes over depth.

$\Rightarrow$ reflector likely from change in COF

Result

Can we detect fast fabric changes remotely?

Answer

Yes, with radar and seismics

But more important:

Can we exploit geophysical data to determine fabric properties?

Answer

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Outlook

- suggested research project:

  Alpine pilot study at Colle Gnifetti

- comparable to polar environment:
  - low accumulation, frozen to bed
  - $T_{firn} = -15°C$, $T_{bed} = -11°C$
  - slow glacier velocity

    $\Rightarrow$ old ice $\Rightarrow$ oriented fabrics likely
- dedicated data acquisition: seismics in firn
  - cross-borehole seismic and radar tomography
  - vertical seismic and radar profiling
  - AVO analysis
  - ice-core analysis

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determine physical properties remotely

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Alpine test site for polar deployment: Colle Gnifetti