Seismic activity, crustal high conductivity and the role of carbon during shear deformation

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Plan

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- Introduction
- Transdanubian conductivity anomaly
- Field correlation of electrical conductivity and seismicity
- Field sesimic attenuation measurements
- Laboratory triaxial shearing experiments
- Interpretation
- Conclusions

Introduction

Plan

Introduction

Transdanubian anomaly

Conductivity & seismicity

Seismic attenuation

Triaxial shearing measurements

Interpretation

Conclusions

- Crustal conductivity anomalies widespread
- Grain boundary carbon is one mechanism
- Carbon increases conductivity and reduces shear strength
- Are there correlations between crustal high conductivities and seismicity?
- Is there a further correlation with seismic attenuation?
- Can triaxial deformation experiments provide evidence for weak electrically conductive fractures containing carbon?

Transdanubian conductivity anomaly

- Large, highly conducting, in NW Hungary.
- Between Periadriatic-Balaton and Insubric-Raba lines
- Material expelled eastwards from alpine orogeny
- Correlated with graphitic schists and black shales cropping out in the Gail Valley Alps
- Several wide conducting stripes (3-12 km depth)
- Consistent with sub-vertical fractures striking 60 ± 8^{o}
- Conductance up to 2×10^{4} S
- Lateral electrical anisotropy 1:1000 in direction of fracture zones

Transdanubian conductivity anomaly

Plan

Introduction

Transdanubian anomaly

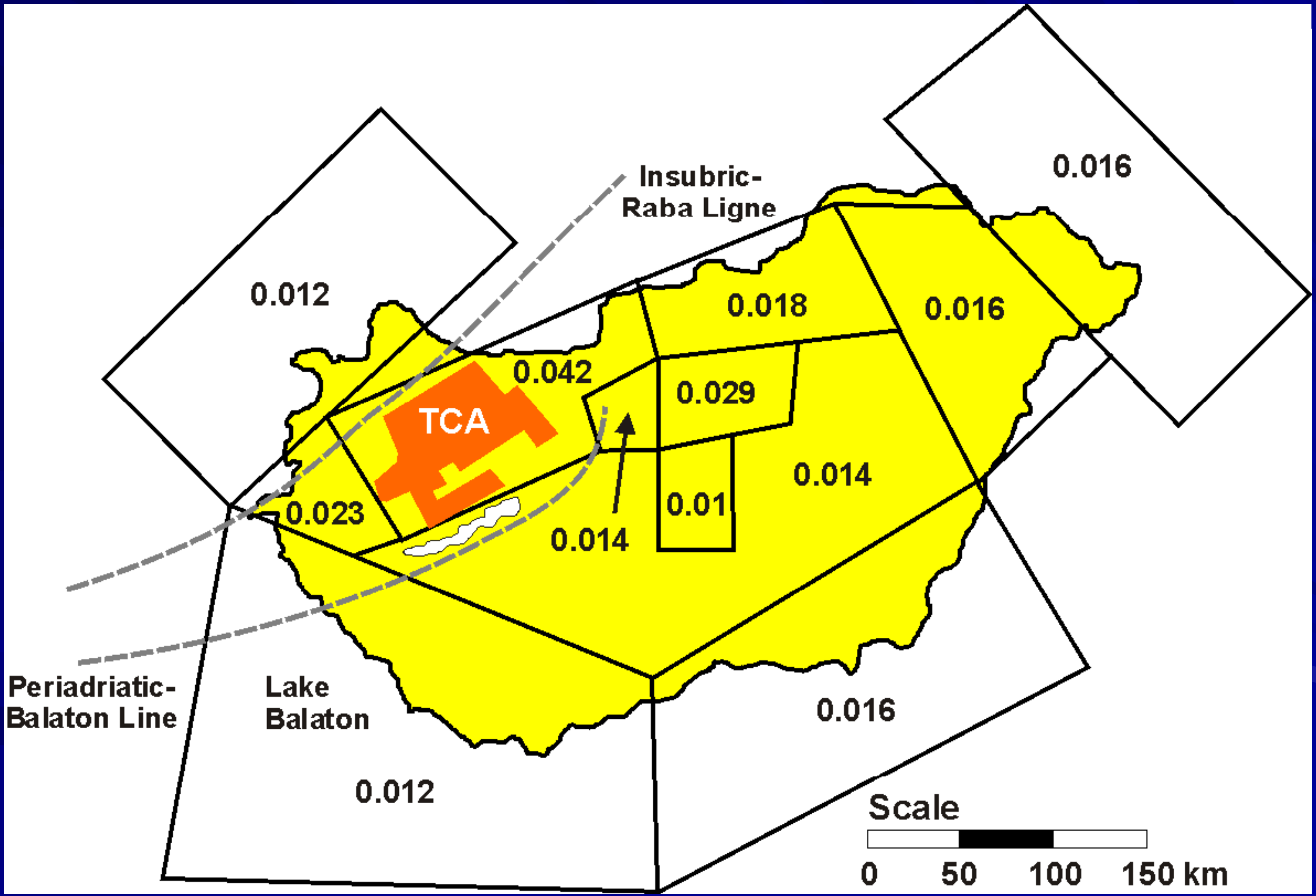
Conductivity & seismicity

Seismic attenuation

Triaxial shearing measurements

Interpretation

Conclusions



Transdanubian conductivity anomaly

UNIVERSITÉ LAVAL

Plan

Introduction

Transdanubian anomaly

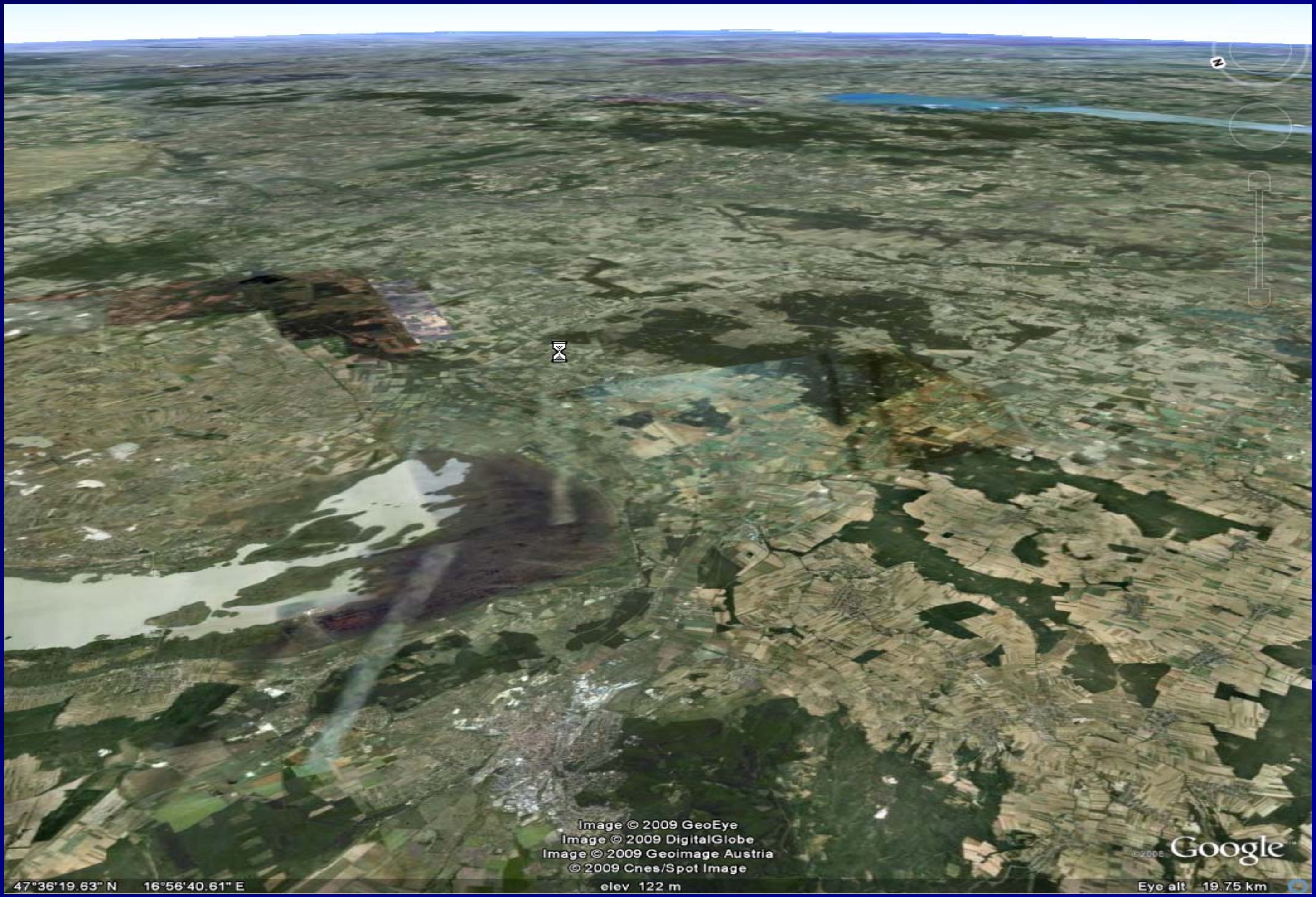
Conductivity & seismicity

Seismic attenuation

Triaxial shearing measurements

Interpretation

Conclusions



Field correlation of electrical conductivity and seismicity 1

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Plan

Introduction

Transdanubian anomaly

Conductivity & seismicity

Seismic attenuation

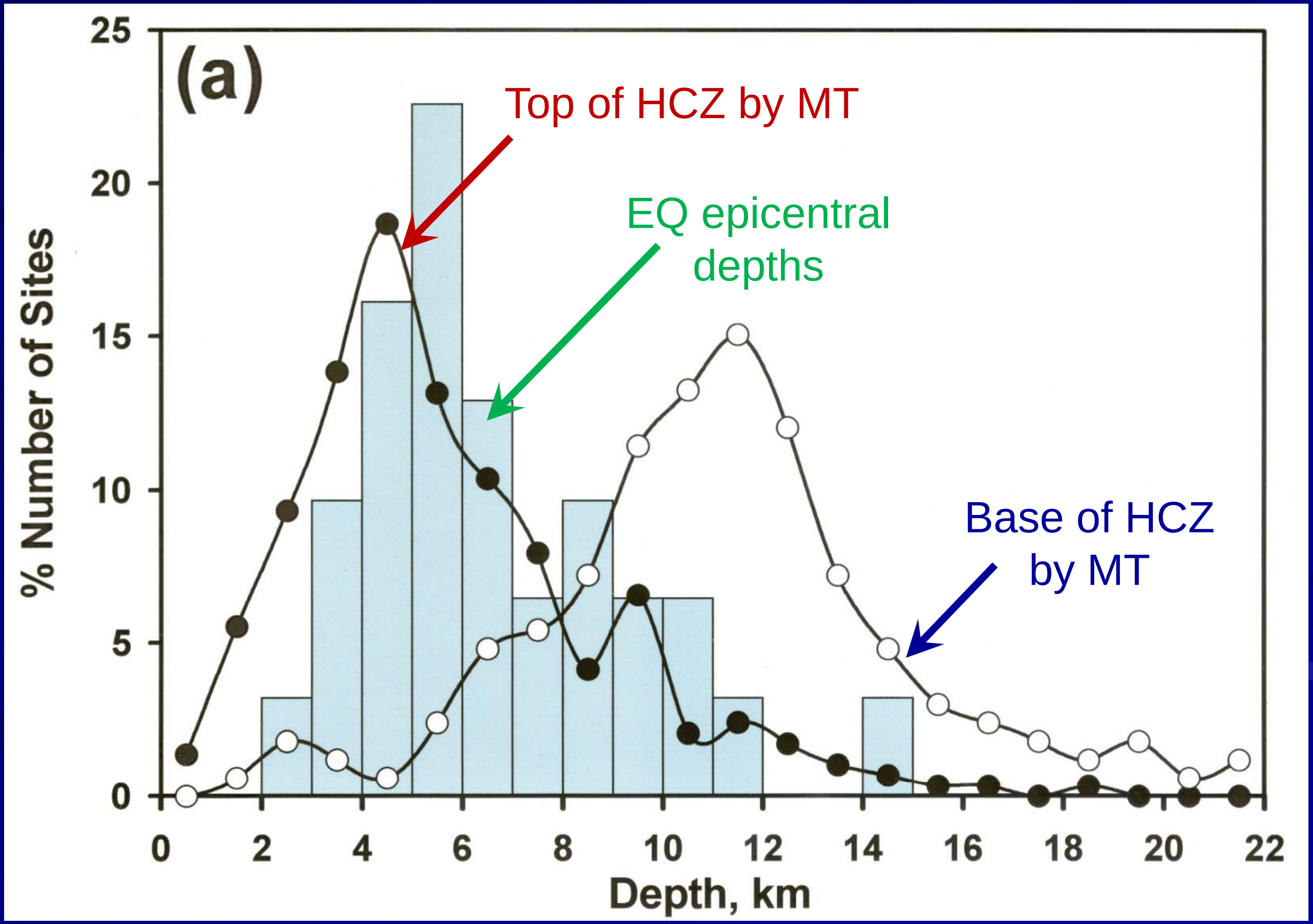
Triaxial shearing measurements

Interpretation

Conclusions

- Local earthquake catalogue
- Results of 284 MT sites in Transdanubia
- High density ⇒ MT site within 5 km of each epicentre
- 94% of seismic events within the HCZ
- Most earthquakes occur a few km deeper than top of the HCZ
- Location by location analysis confirms it

Field correlation of electrical conductivity and seismicity 2



Field correlation of electrical conductivity and seismicity 3

Plan

Introduction

Transdanubian anomaly

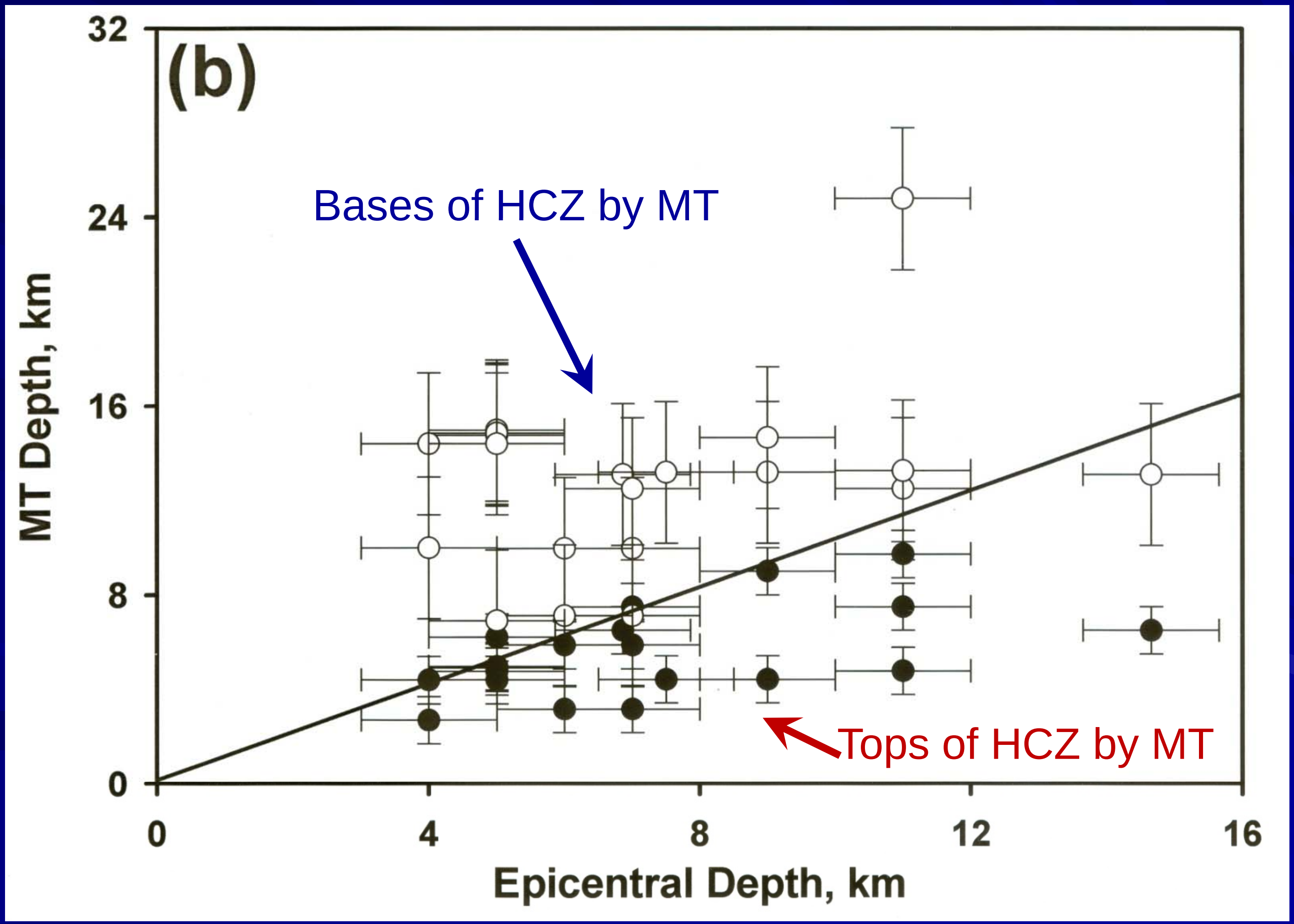
Conductivity & seismicity

Seismic attenuation

Triaxial shearing measurements

Interpretation

Conclusions



Seismic attenuation

Plan

Introduction

Transdanubian anomaly

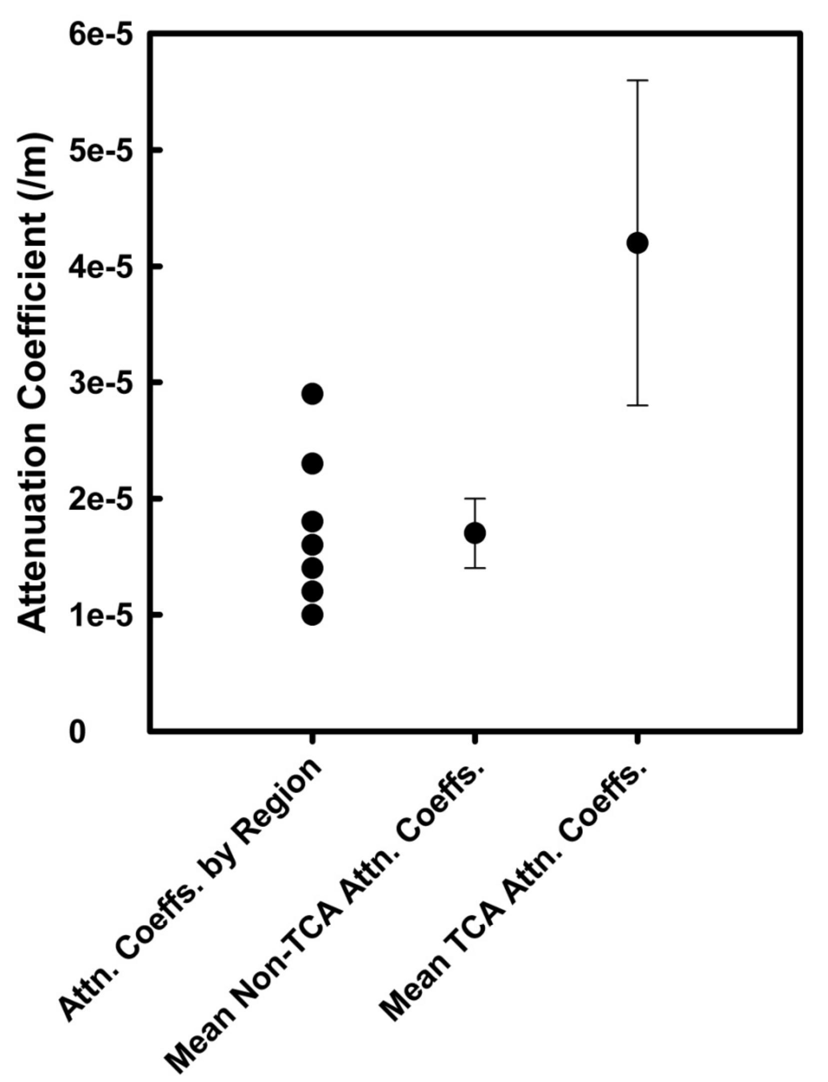
Conductivity & seismicity

Seismic attenuation

Triaxial shearing measurements

Interpretation

Conclusions



TCA:
$(4.2 \pm 1.4) \times 10^{-5}$ m^{-1}

Other 11 areas:
$(1.7 \pm 0.3) \times 10^{-5}$ m^{-1}

The TCA is highly attenuating compared with all other Hungarian regions

Triaxial shearing experiments 1

Plan

Introduction

Transdanubian anomaly

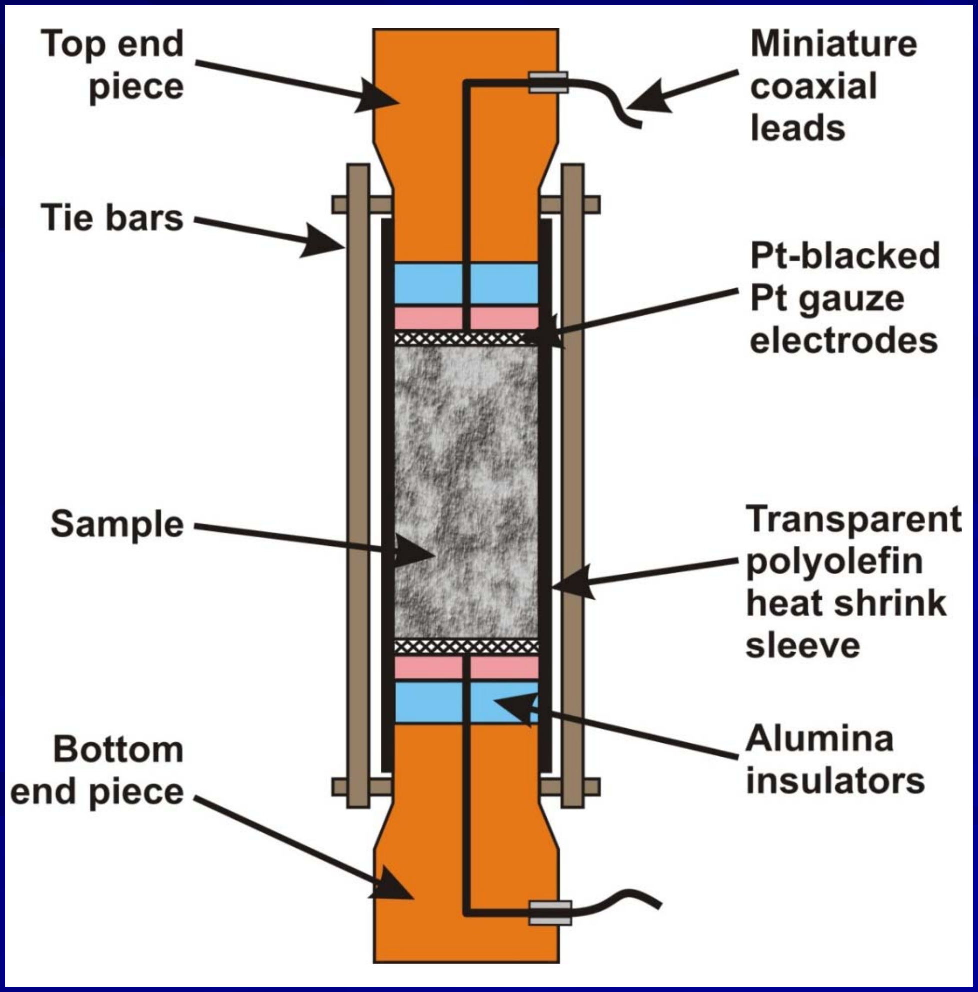
Conductivity & seismicity

Seismic attenuation

Triaxial shearing measurements

Interpretation

Conclusions



Complex resistance measurements at 1 kHz

Solartron 1260

Temperature 22ºC

Triaxial shearing Experiments 2

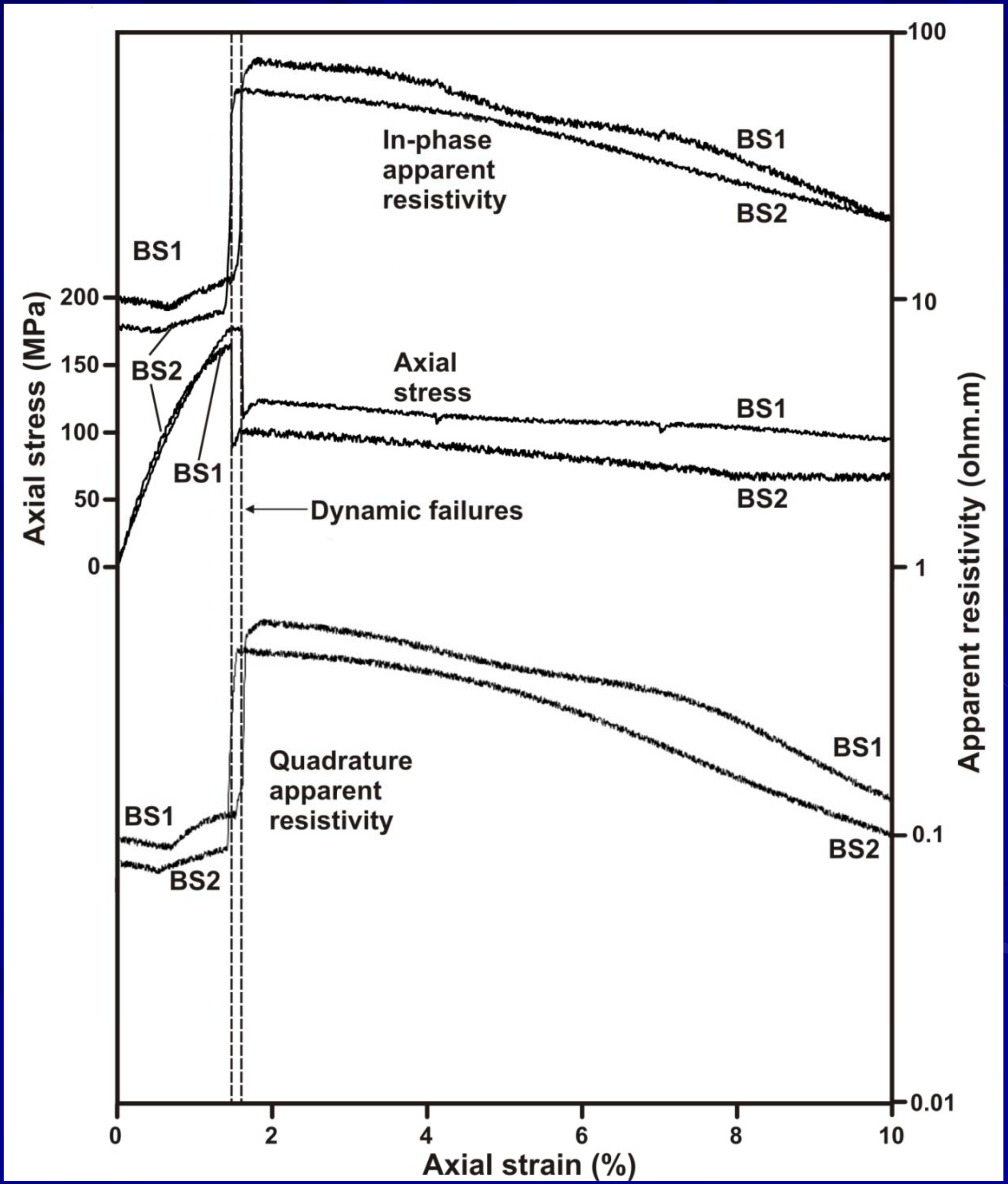
Black shales (Gail Valley Alps)

No significant change in C content

He porosity BS1 3.24% BS2 2.67%

Strain rate 2×10^{-6} s^{-1}

Confining pressure 55 MPa



Triaxial shearing Experiments 3

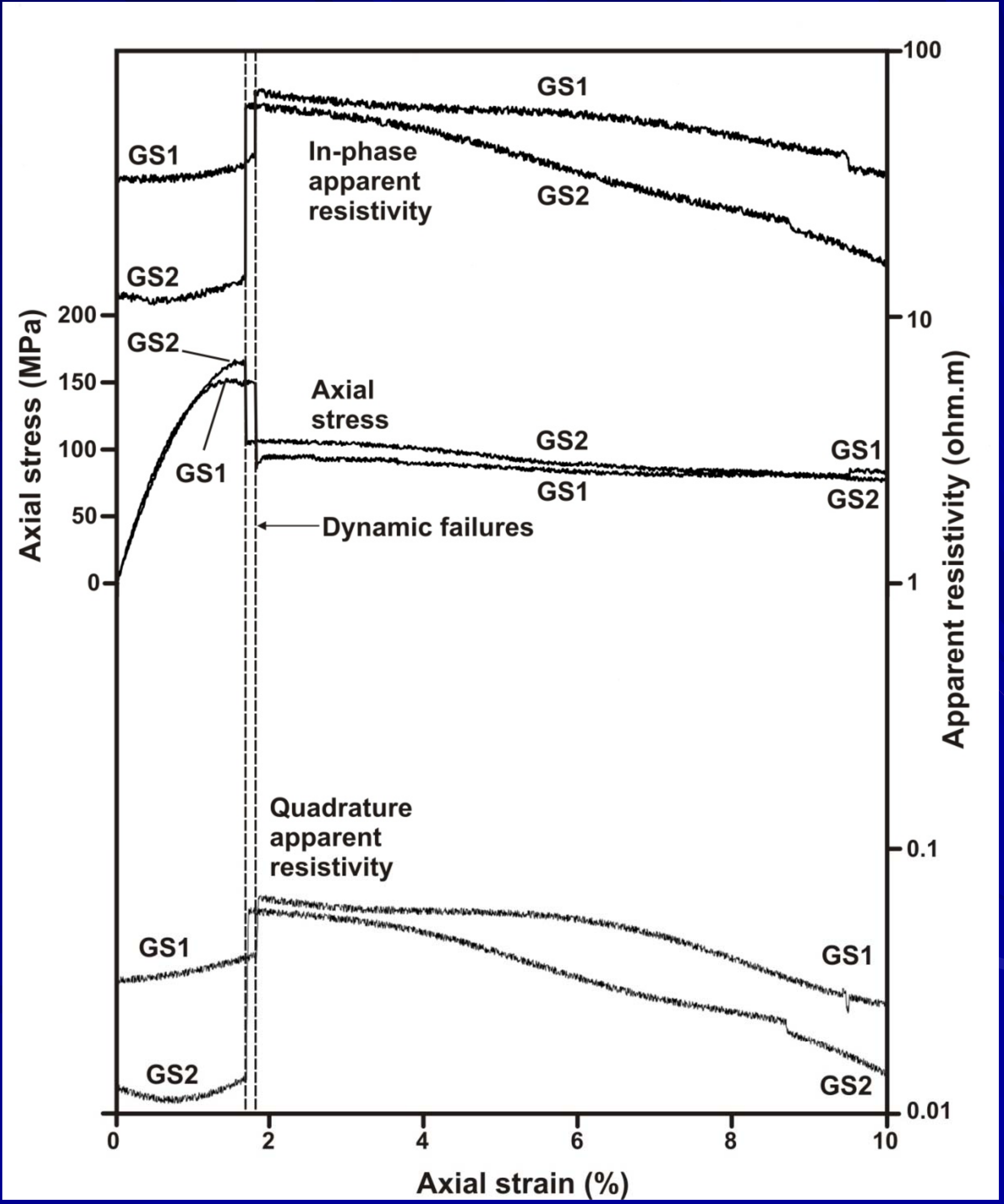
Graphitic schists (Gail Valley Alps)

No significant change in C content

He porosity GS1 1.52% GS2 1.03%

Strain rate $1\times10^{-6}\ s^{-1}$

Confining pressure 50 MPa



Triaxial shearing Experiments 4

Plan

Introduction

Transdanubian anomaly

Conductivity & seismicity

Seismic attenuation

Triaxial shearing measurements

Interpretation

Conclusions

Post-deformation analyses

Before and after analysis

Leco CS225 Carbon and sulphur analyzer

Sample	Prerun Carbon (% wt)	Postrun Carbon (% wt)
BS1	8.12±0.05	7.95±0.05
BS2	10.06±0.05	10.86±0.05
GS1	3.10±0.05	3.02±0.05
GS2	7.37±0.05	7.80±0.05

Hypothesis 1

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- **If a fracture that contains carbon fails**
  carbon smears,
  becomes better connected,
  the conductivity increases
  and the fault becomes weaker making it more likely to fail again (positive feedback).
  Development of slickensides.
  Consequently, conductivity anisotropy develops in the direction of failure.

Hypothesis 2

- **If a fracture that contains water fails**
  - **Progressive shearing leads to gouge formation, grain comunition and permeability reduction up to 5 magnitudes.**
  - **There is loss of fluid connectivity and consequently a reduction of conductivity.**
  - **Over-pressurisation can promote further shearing (positive feedback).**
  - **Consequently, no conductivity anisotropy develops in the direction of failure.**

Conclusions 1

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- There is a clear correlation between epicentral depths and the extent of the crustal high conductivity zone.
- Seismic attenuation values provide further evidence for deep fracturing consistent with the presence of graphite.
- Experiments show that the stress supported by the fracture decreases after failure as the conductivity increases.
- Both effects can be caused by the smearing of graphite.

Conclusions 2

- The graphite acts as a lubricant. Further deformation results in more shearing, more smearing and a weaker fracture.
- The conductive graphite, when smeared, becomes more connected. The rock then becomes more conductive.

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