40 Years using high power CSEM/EM for hydrocarbon/geothermal exploration

K. Strack, KMS & LEMI

Special Event: Hydrocarbon Exploration,
June 28-29, 2022, Indonesia

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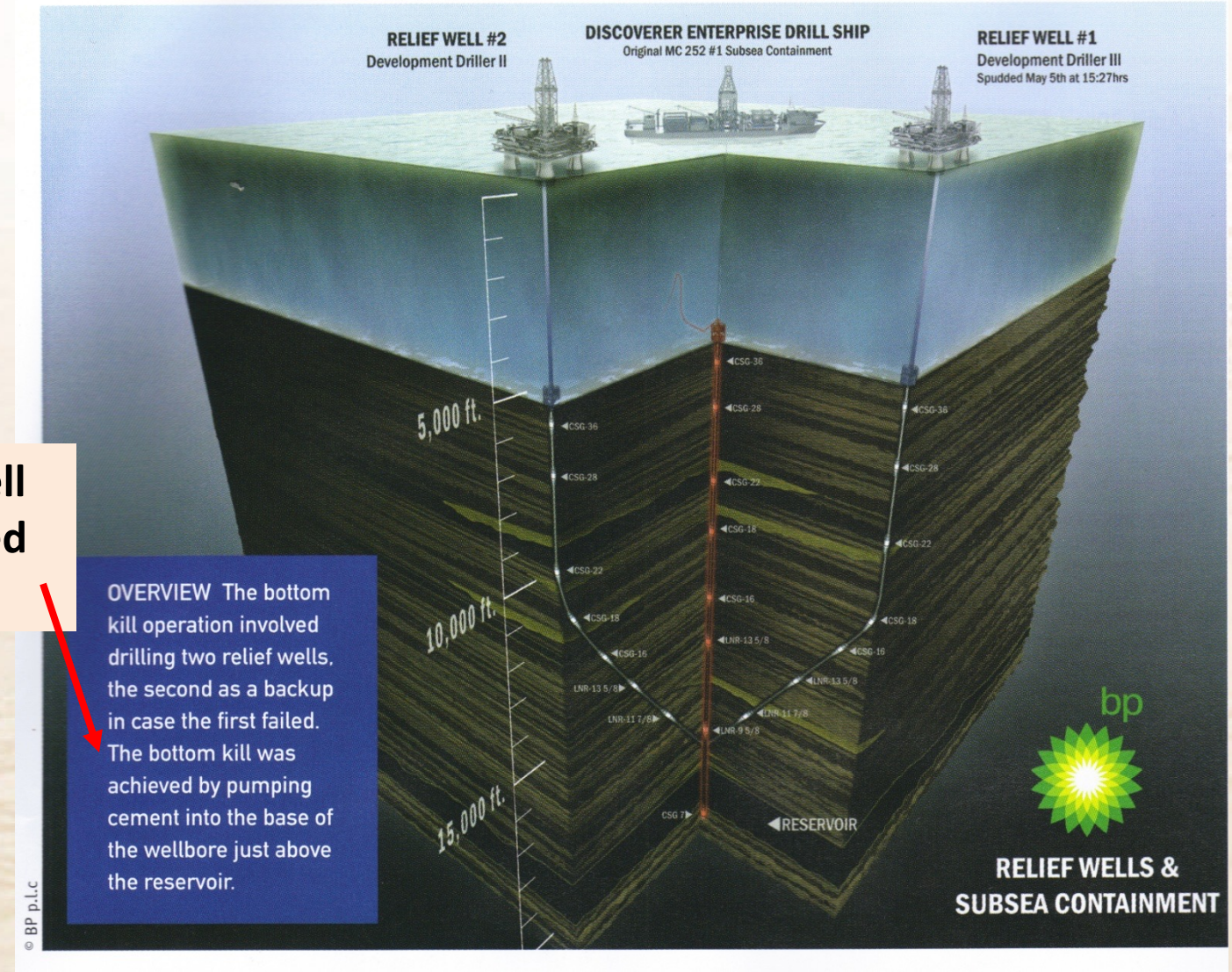
Importance of electromagnetics

Early years >>> Resistors – DHI >>> MORE? >>> Case histories

The relief well was navigated with 3D EM



After Marshall, L., 2011

How I got started – 1980 - Colorado
Early years >>> Resistors – DHI >>> MORE? >>> Case histories

- How did I get started? 1980 Dotzero Volcano, CO survey

- Same problem: truck & generator

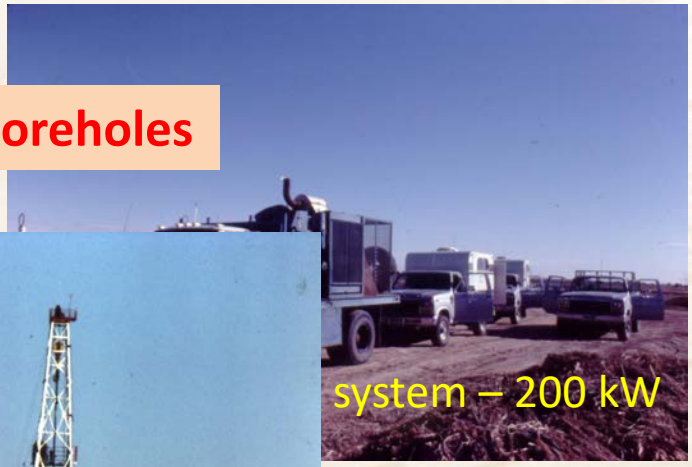
→ 1981 Group 7 Inc.

How I got started – 1981 – AZ- CO - CA
Early years >>> Resistors – DHI >>> MORE? >>> Case histories

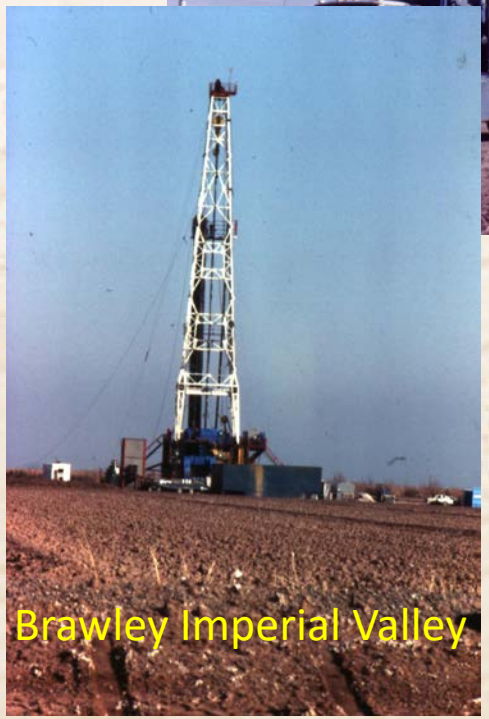
- G7I: Many problems: Software to complicated/slow; Trucks unreliable; sensor (SQUIDs) too complicated/uncalibrated; MT versus Lotem, TX 0.5 to 1 MW BUT. Data looks very strong – not smart

1981: O.5 MW transmitter

ALWAYS challenged by boreholes

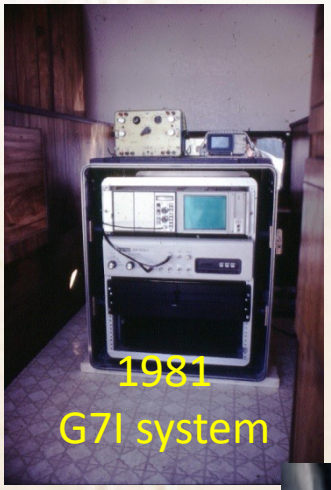

system – 200 kW

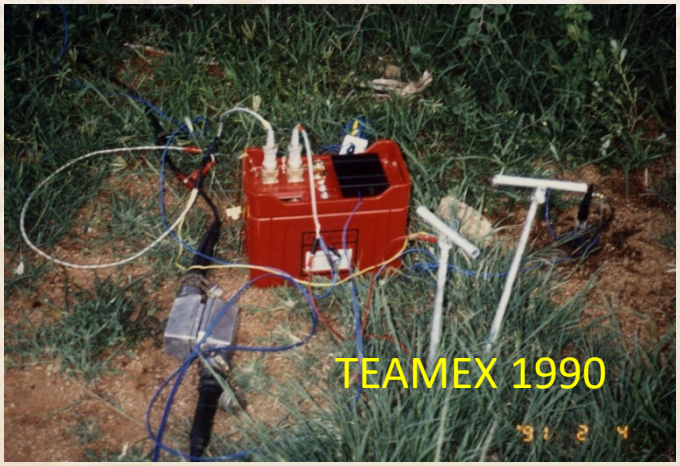
Fort Mogan, CO - calibration


Brawley Imperial Valley

How I got started – 1982 – NEW concepts – hard to tests
Early years >>> Resistors – DHI >>> MORE? >>> Case histories

- NEW ideas: follow seismic experience – dense data – cheaper system 1000 receivers (my boss thought I was NUTS)
  smaller sensors → coils ; new amplifiers; WWVB – GPS; portable computers





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Toward fluid mapping – early 1980s – Australia - Germany

Early years >>> Resistors – DHI >>> MORE? >>> Case histories

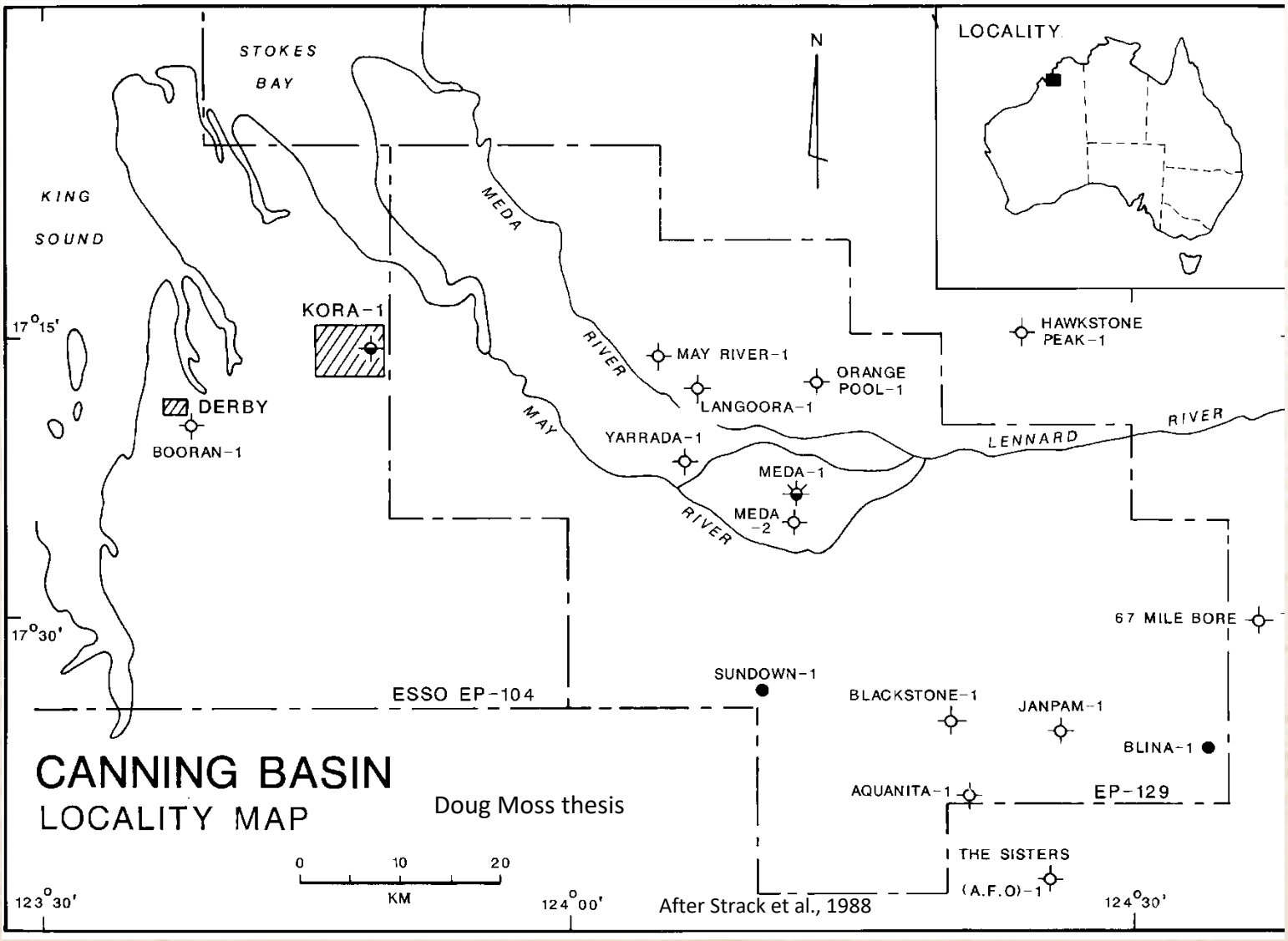
- Key results: Germany - Australia work in 1980s
- Need BETTER data
- Need electric fields
- Hopeless without anisotropy

History:

- Initial work at U of T & CSM (Eadie, 1979 and Passalacqua, 1979). M.Sc & Ph.D. Strack et al. 1989. First land CSEM case histories
- Eidesmo et al. 2002, Ellingsrud et al. 2002. First marine theory and examples.
- NOW standard for offshore & onshore

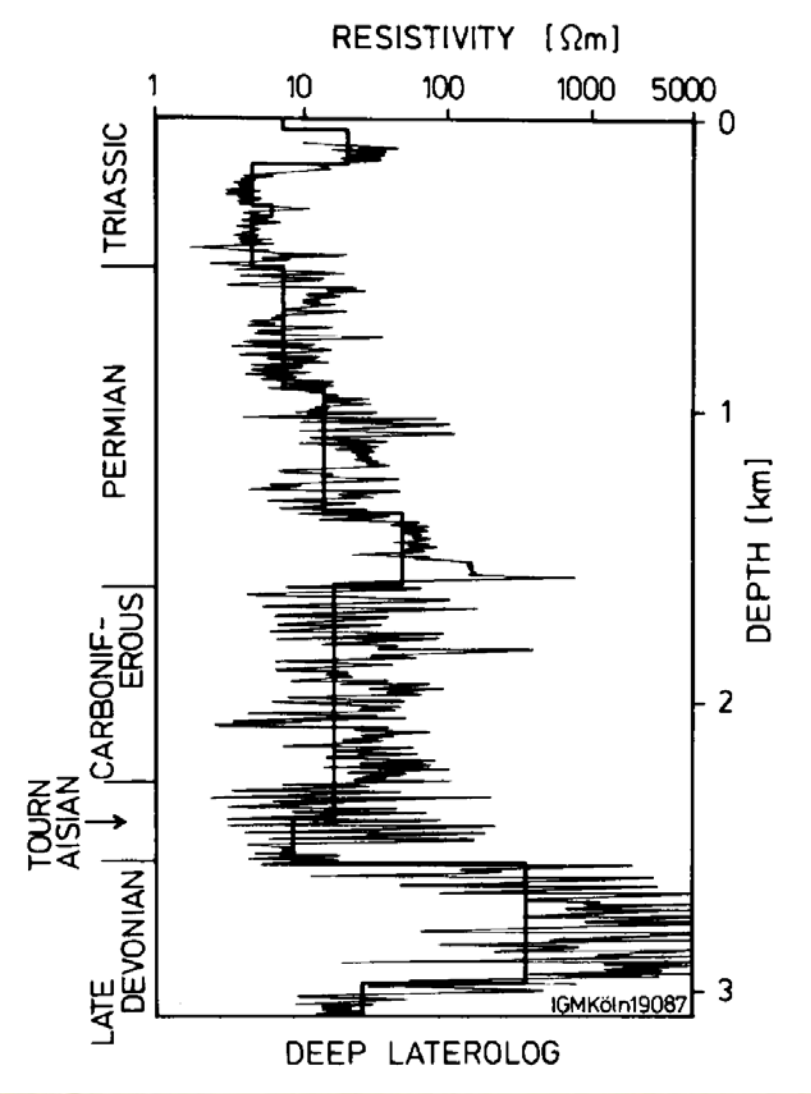
Canning Basin, Australia base map

Early years >>> Resistors – DHI >>> MORE? >>> Case histories



Canning Basin: well 2 log

Early years >>> Resistors – DHI >>> MORE? >>> Case histories



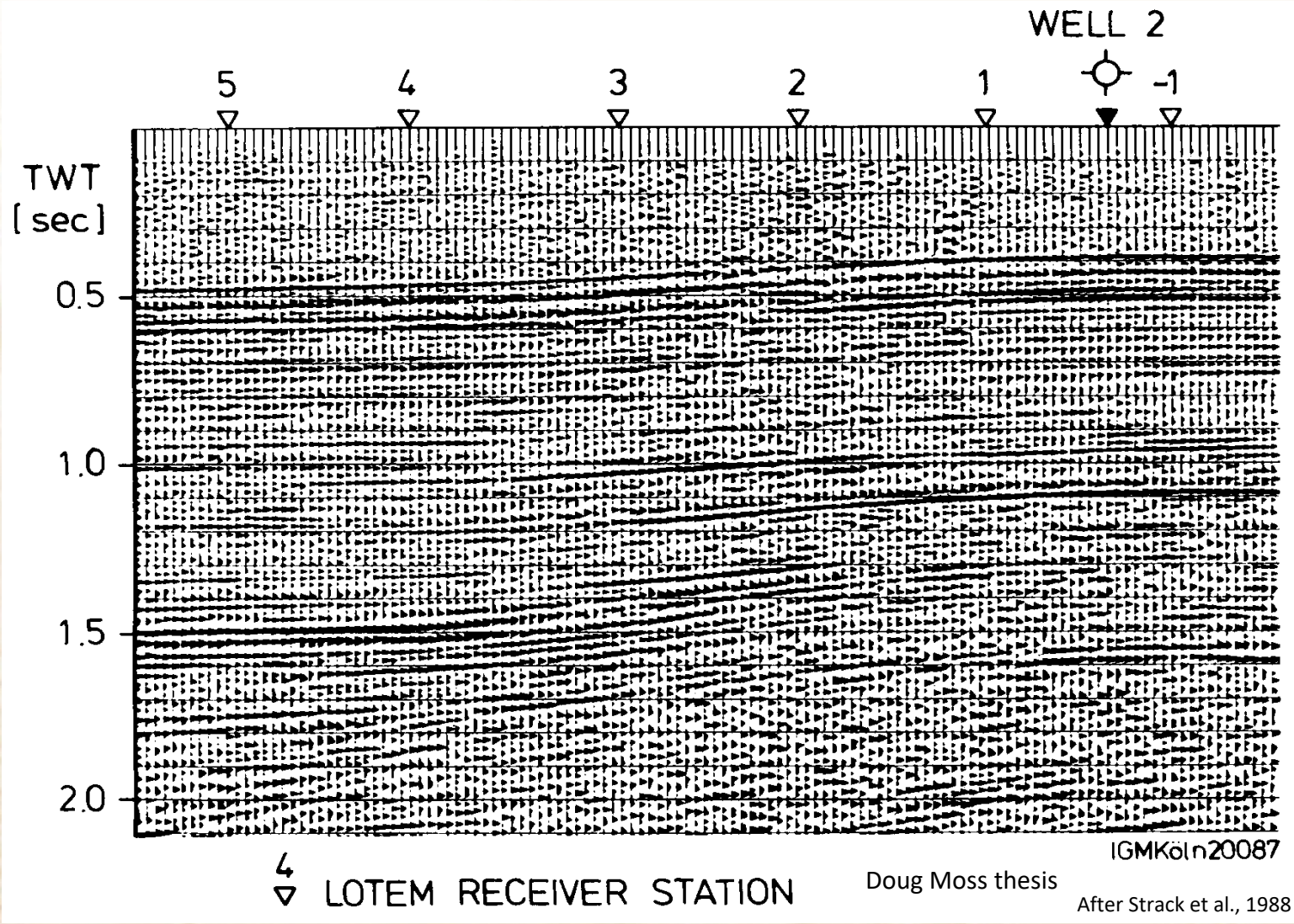
- 22 layers were used
- WE laughed in 1980s
- TODAY we do more & full anisotropy

Doug Moss thesis,

After Strack et al., 1988

Canning Basin: seismic section

Early years >>> Resistors – DHI >>> MORE? >>> Case histories

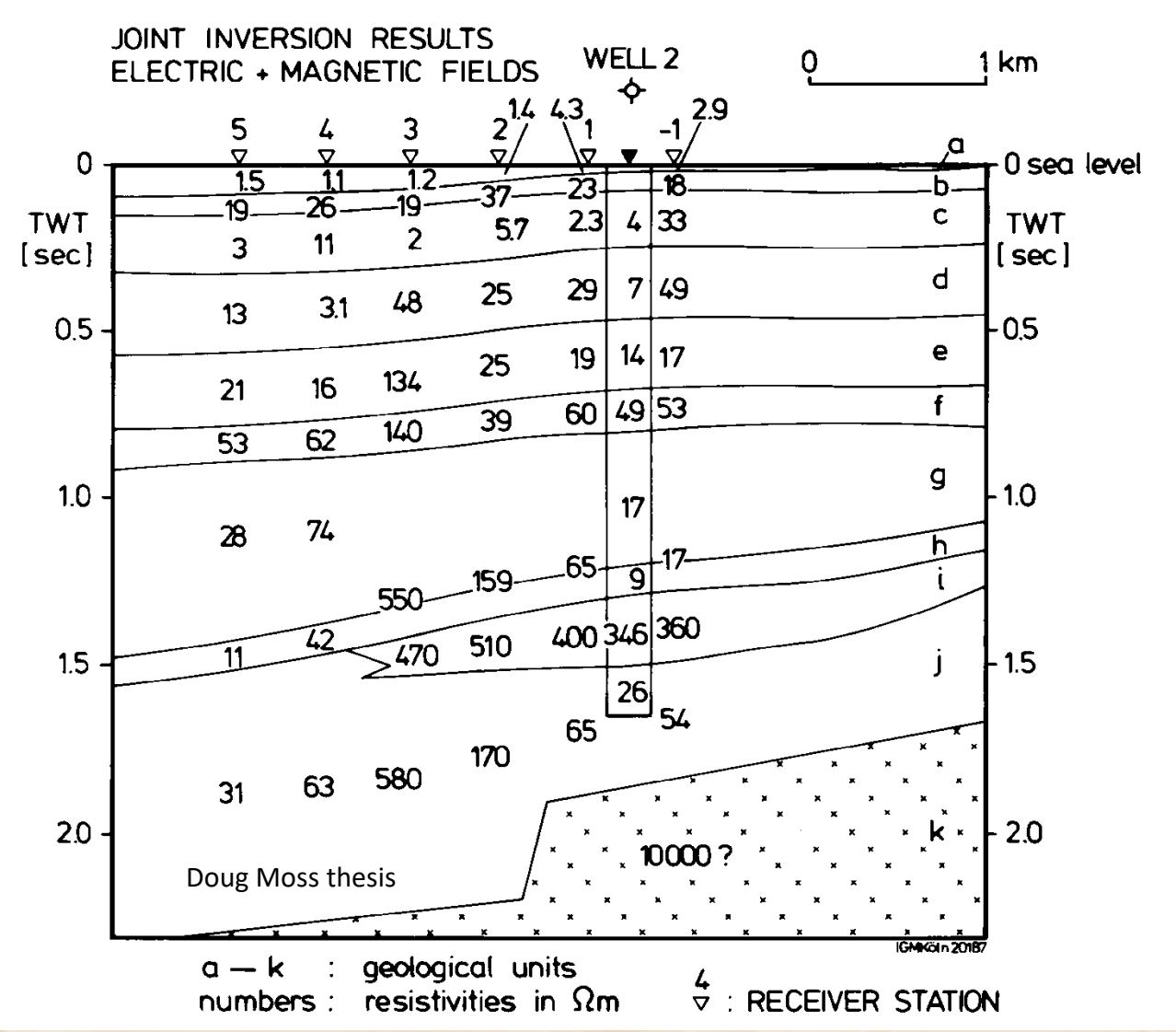


Doug Moss thesis

After Strack et al., 1988

Canning Basing: joint inversion results

Early years >>> Resistors – DHI >>> MORE? >>> Case histories



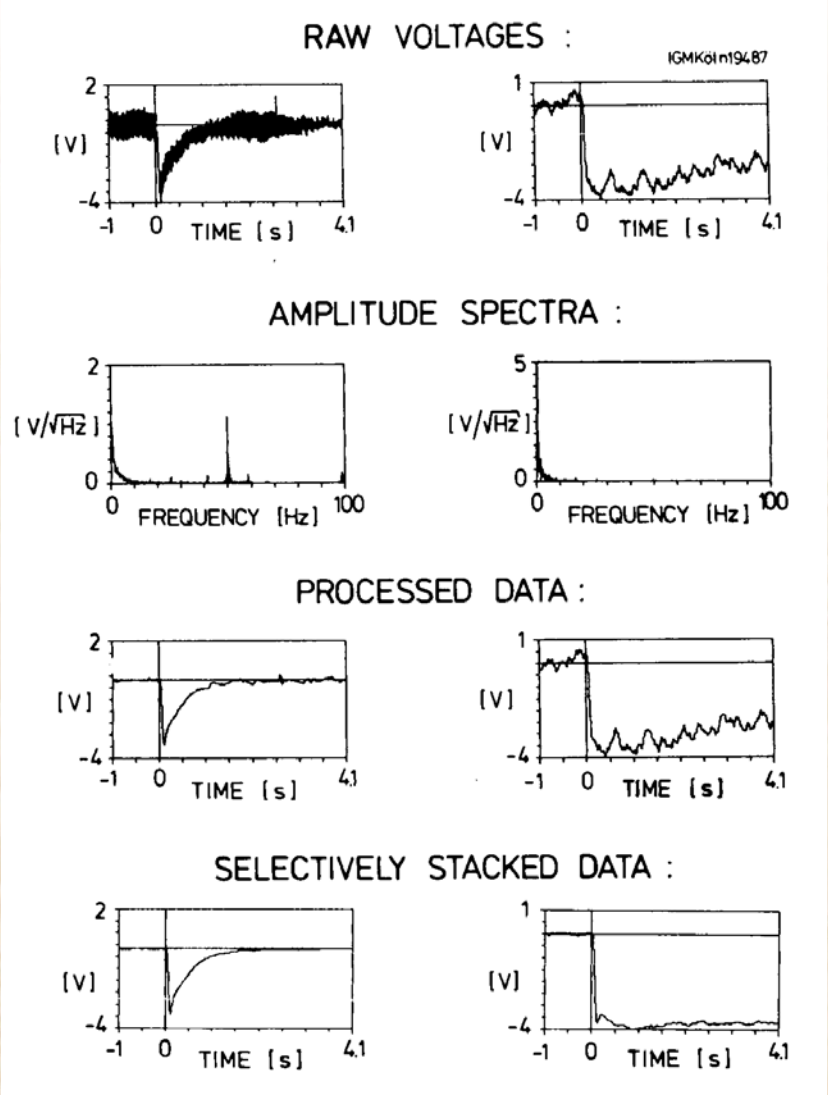
After Strack et al., 1988

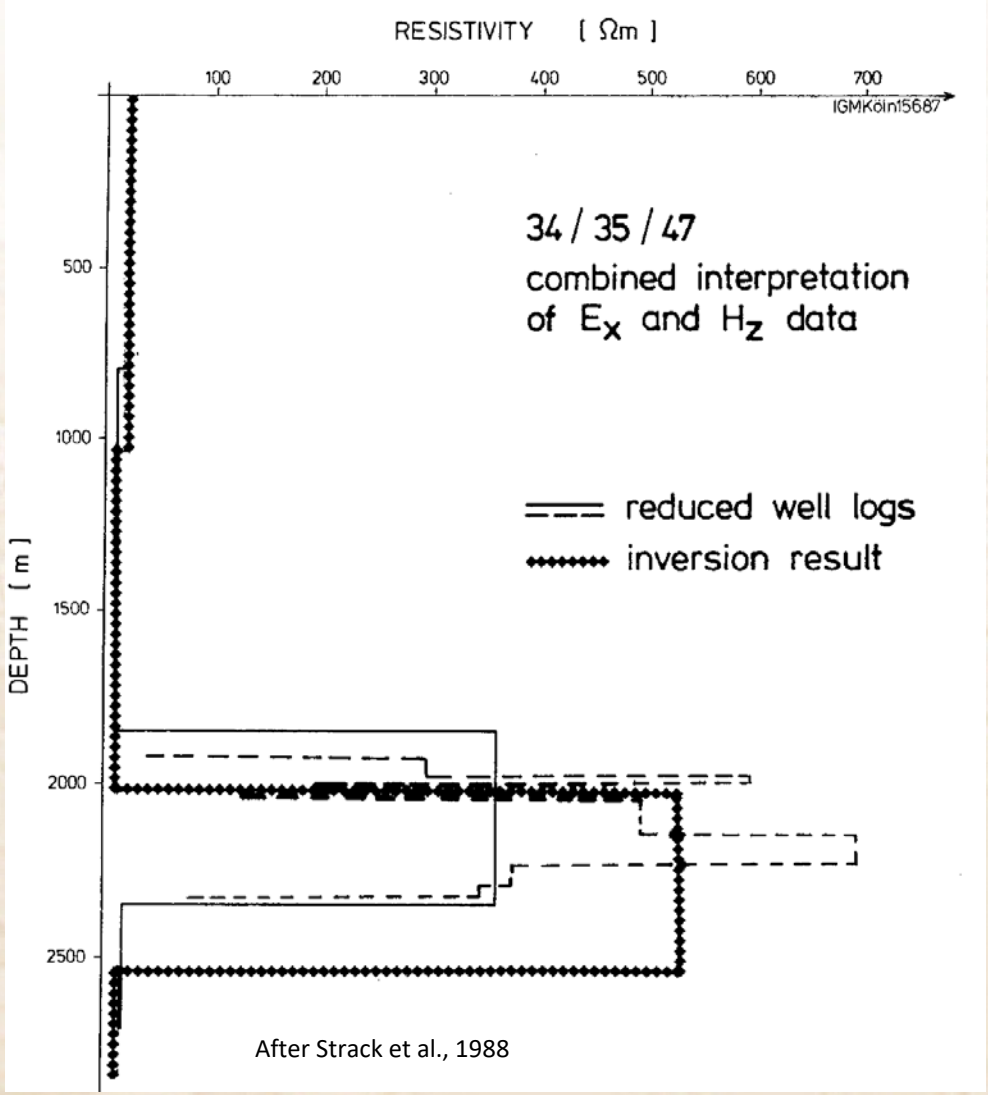
Southern Germany

Early years >>> Resistors – DHI >>> MORE? >>> Case histories

Germany: Data examples H & E

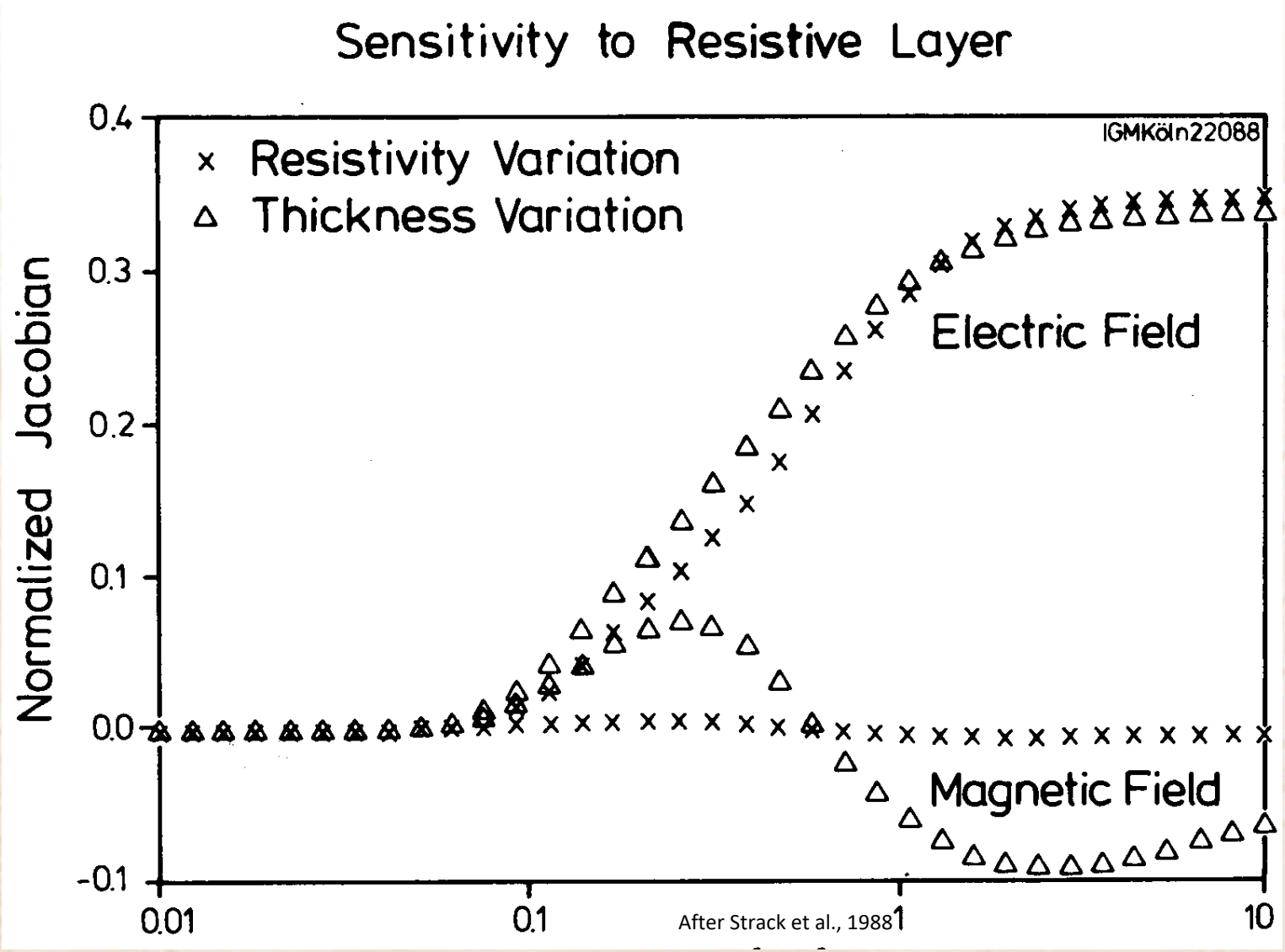
Early years >>> Resistors – DHI >>> MORE? >>> Case histories





Germany: layer sensitivity – E→ resistor

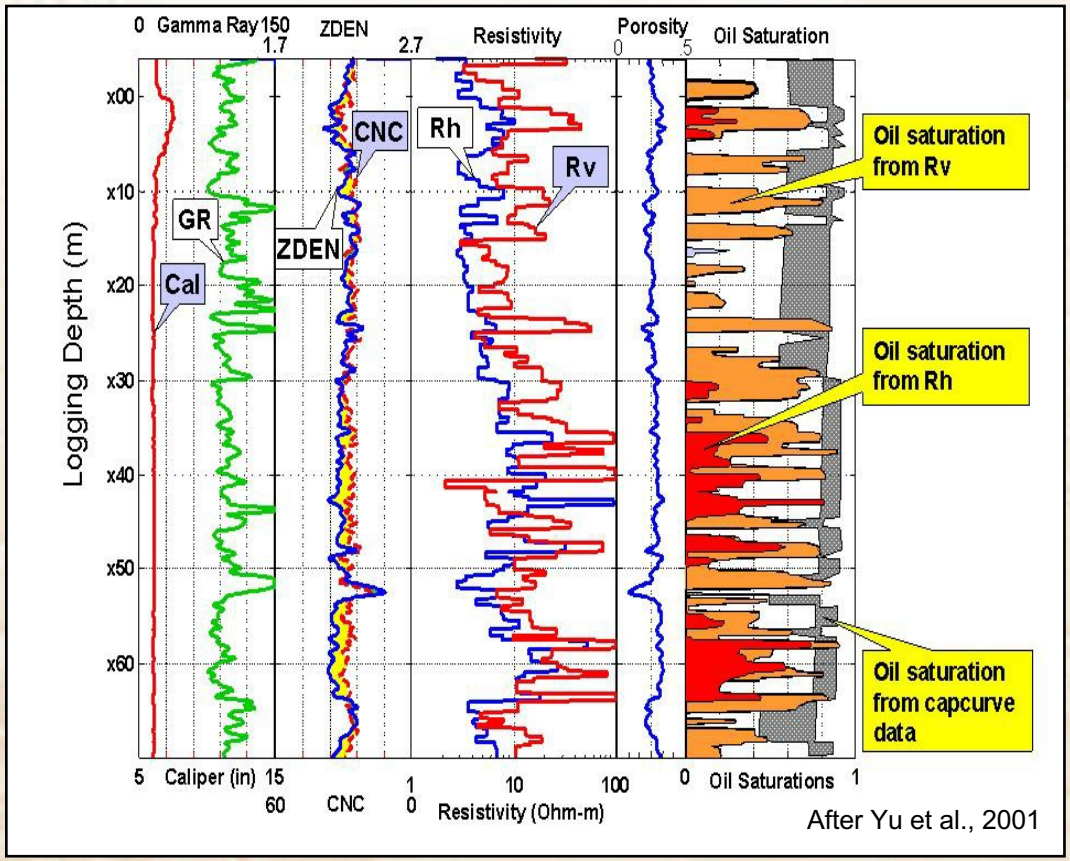
Early years **>>> Resistors – DHI** >>> MORE? >>> Case histories

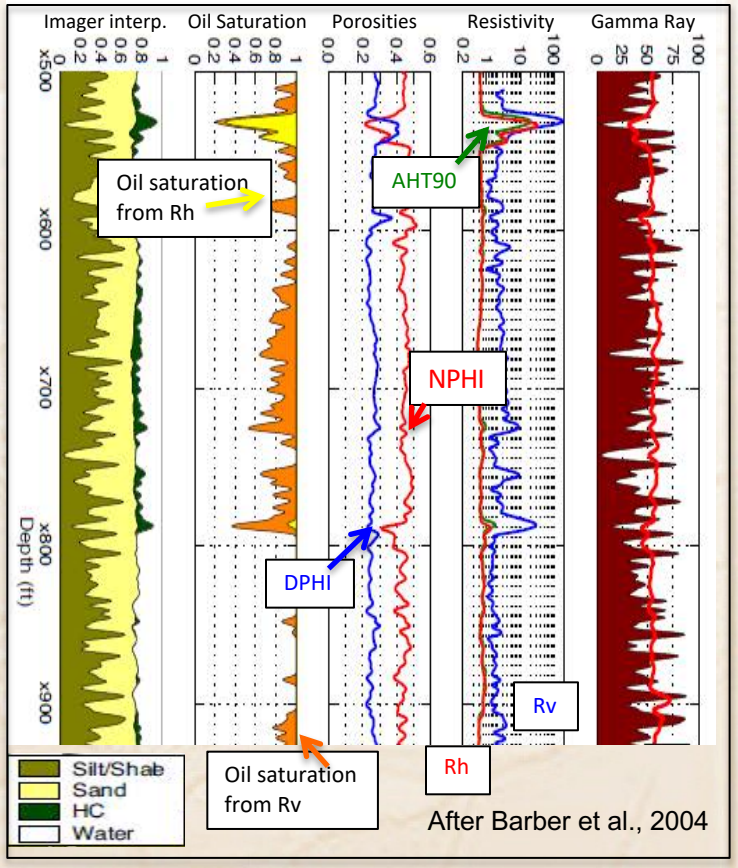


What are we missing: dense data and anisotropy

Early years >>> Resistors – DHI >>> MORE? >>> Case histories

- 1990 s monitoring started – limited success (anisotropy – 40% error)
- Development of 3D induction log KEY – 40 % more oil





Exploration – seismic integration- China - India – Europe - USA
Early years >>> Resistors – DHI >>> MORE? >>> Case histories

- Map subsurface where seismic is bad
  - Here carbonates & poor seismic
- Great difficulty in inversion
- Data quality good → tested imaging

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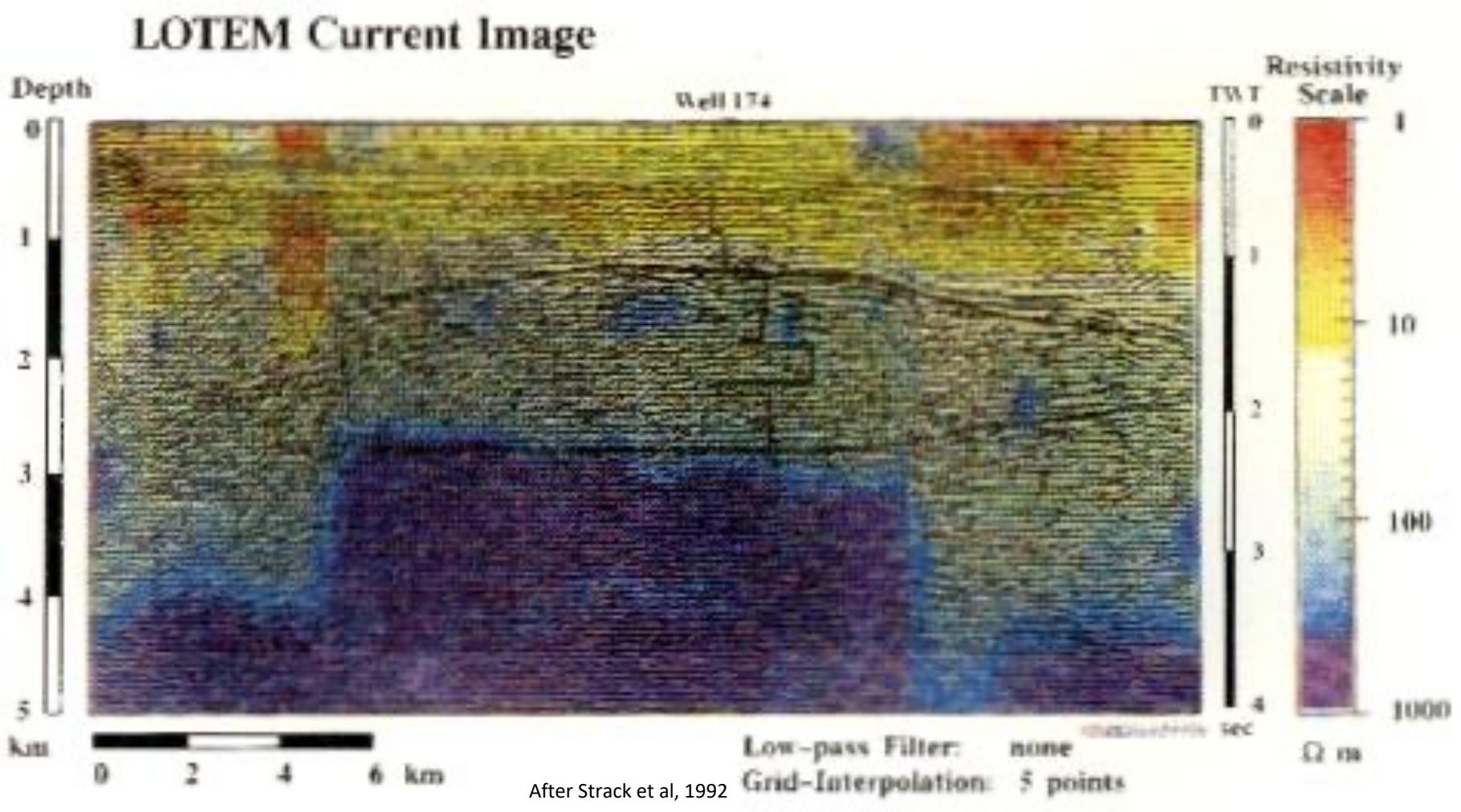
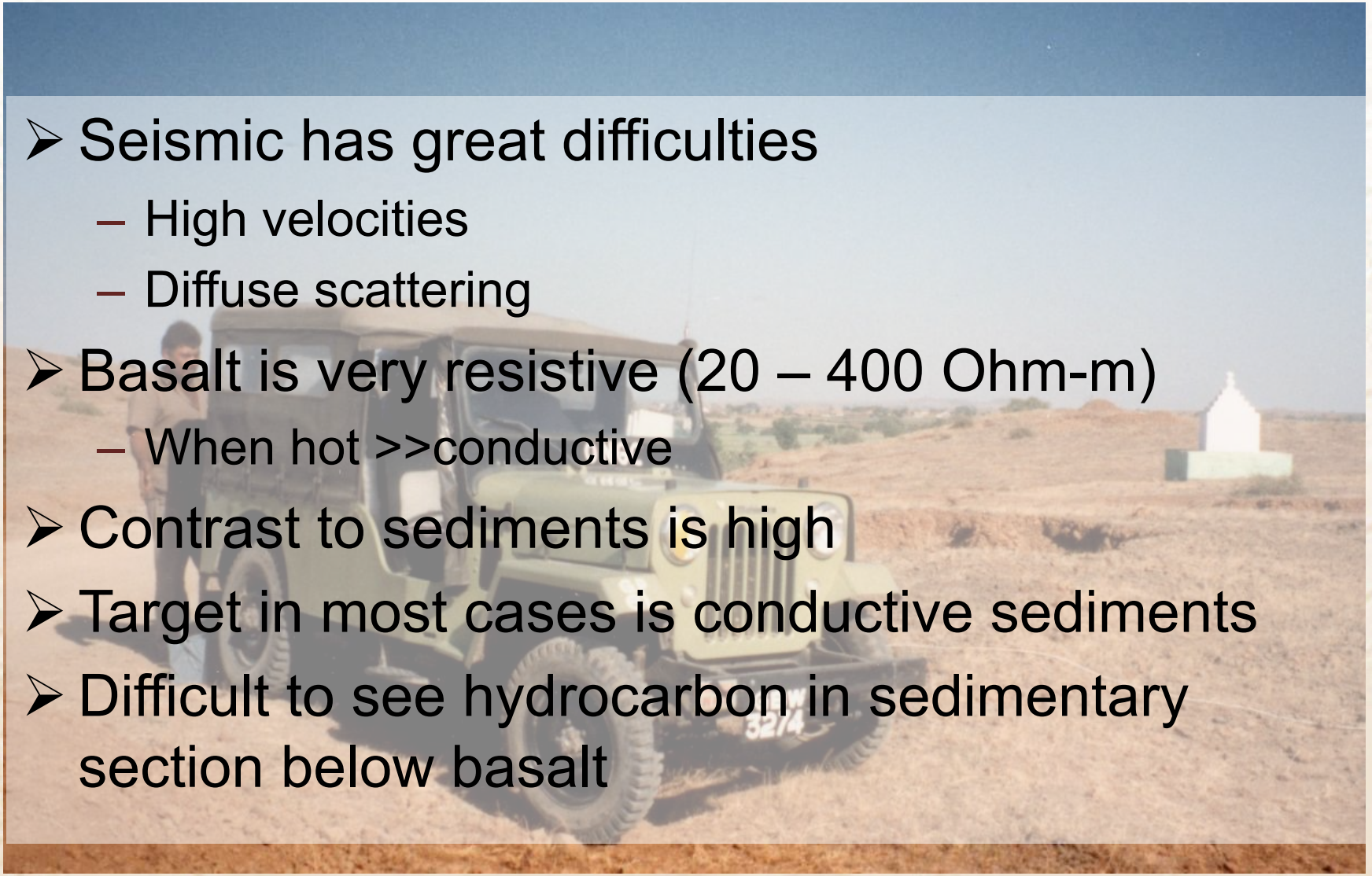
Exploration – seismic integration- China - India – Europe - USA
Early years >>> Resistors – DHI >>> MORE? >>> Case histories



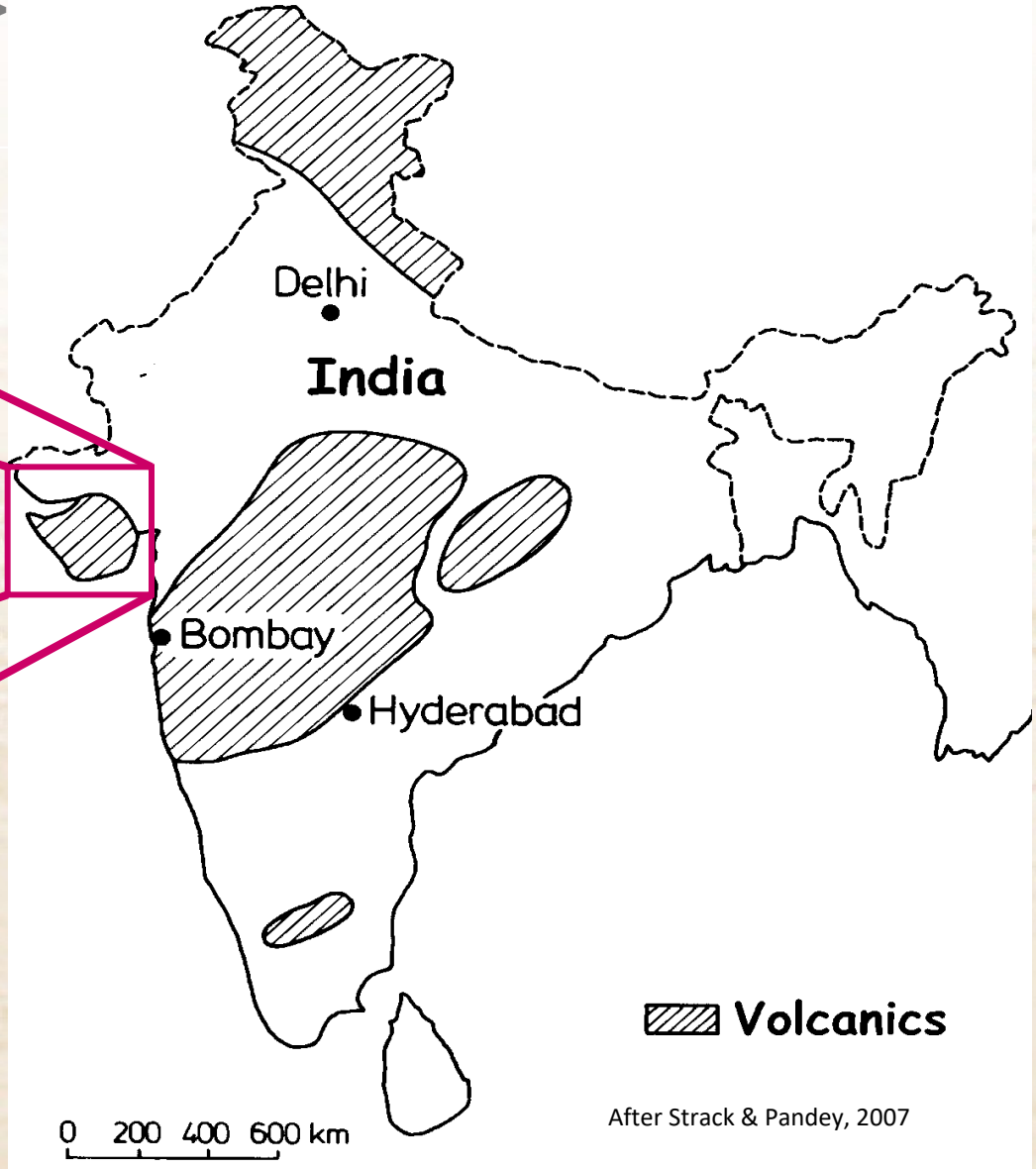
After Strack et al, 1992



- Seismic has great difficulties
  - High velocities
  - Diffuse scattering
- Basalt is very resistive (20 – 400 Ohm-m)
  - When hot >>conductive
- Contrast to sediments is high
- Target in most cases is conductive sediments
- Difficult to see hydrocarbon in sedimentary section below basalt

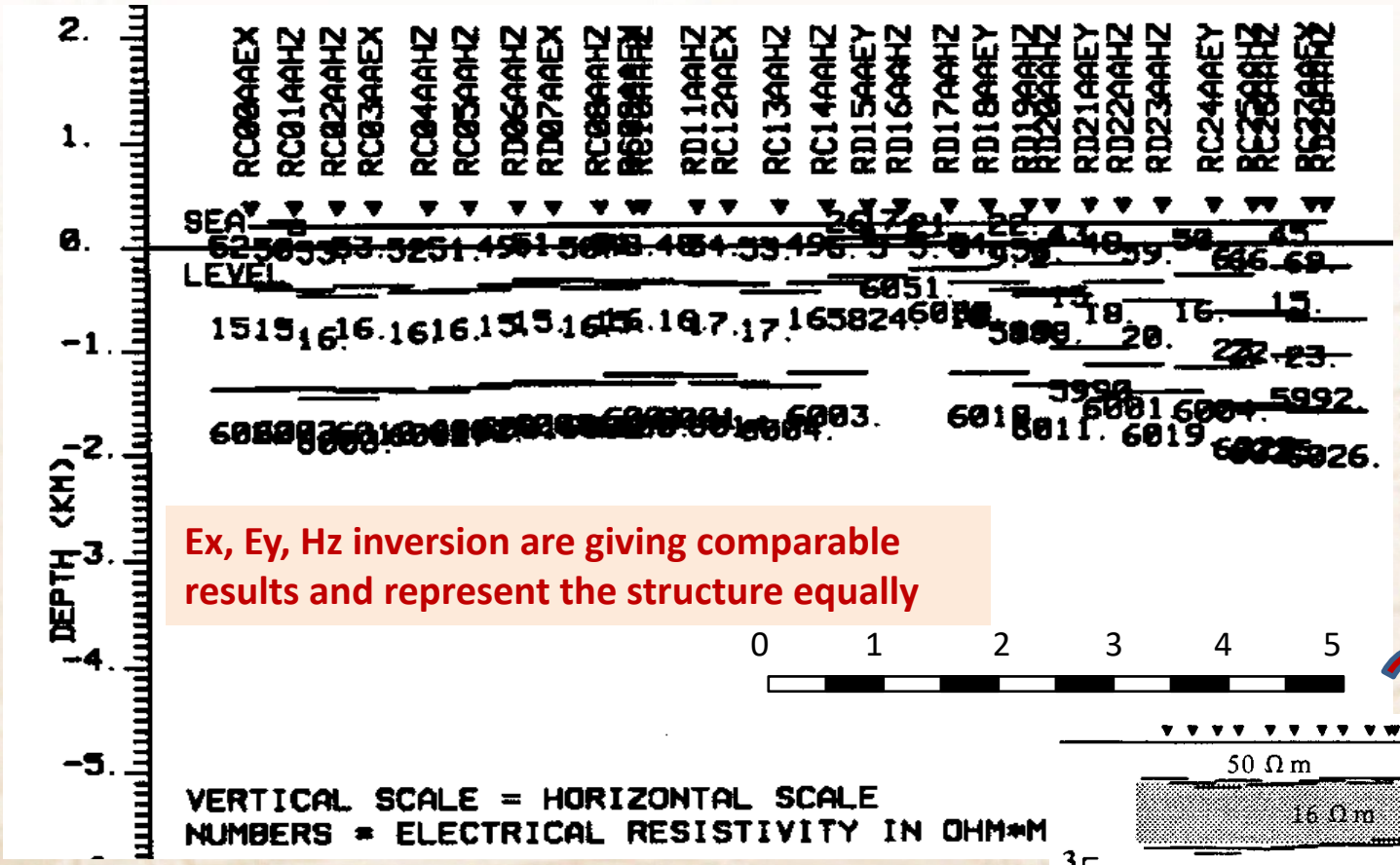
Exploration – seismic integration- China – India/Brazil – Europe - USA

Early years >>> Resistors – DHI >



Exploration – seismic integration- China – India/Brazil – Europe - USA

Early years >>> Resistors – DHI >>> MORE? >>> Case histories



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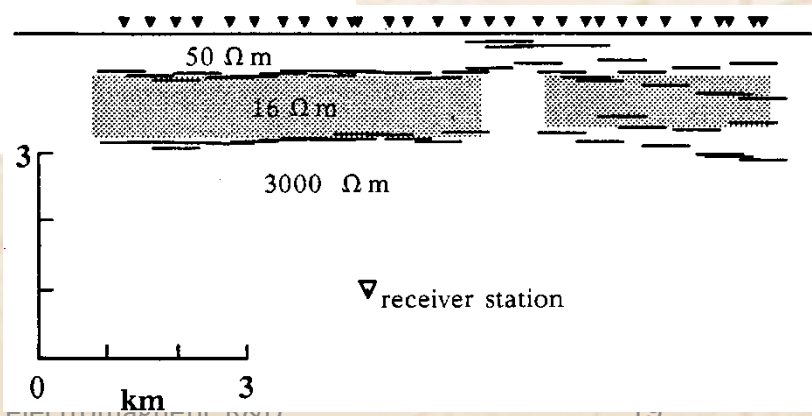
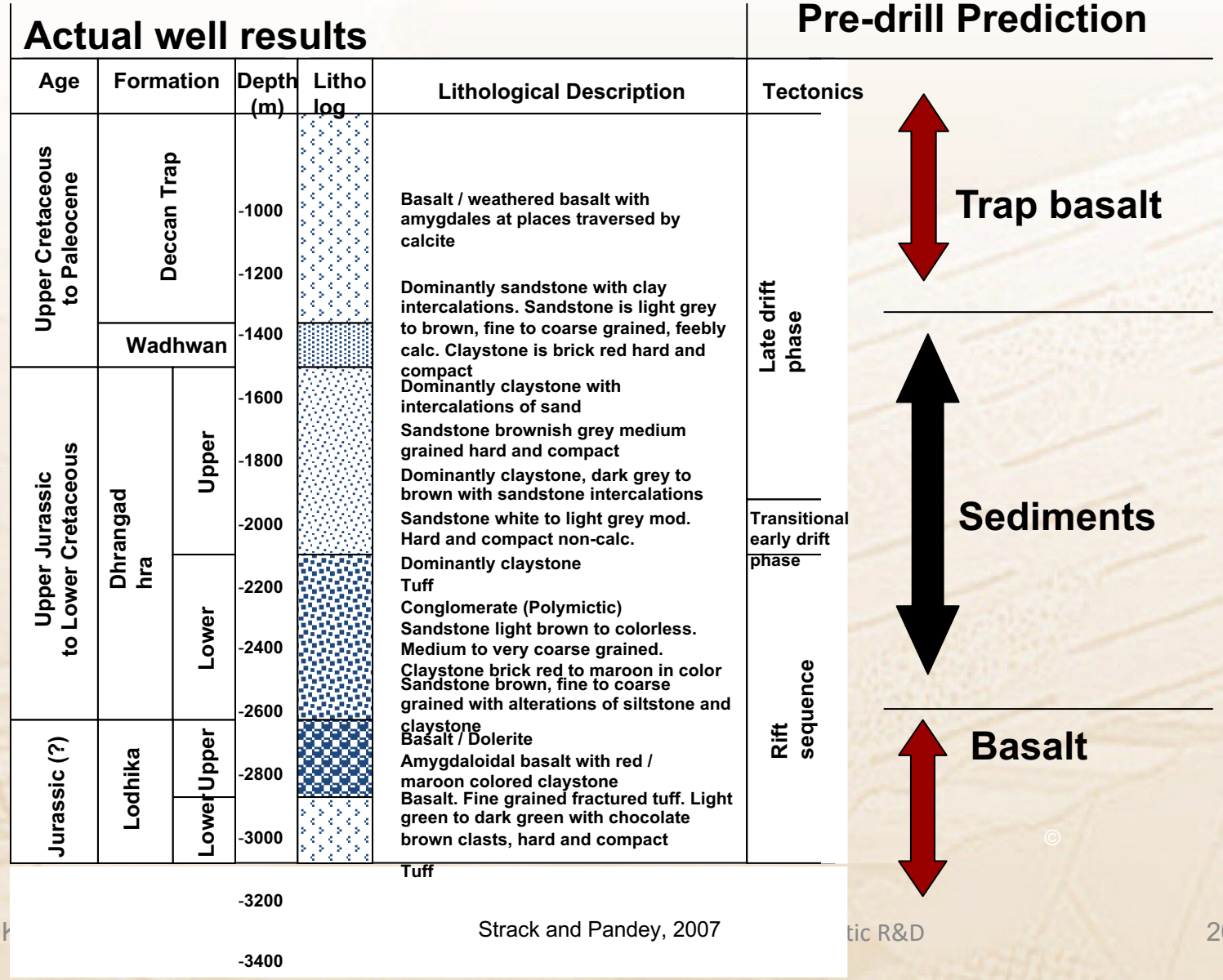


Exploration – seismic integration- China – India/Brazil – Europe - USA

Early years >>> Resistors – DHI >>> MORE? >>> Case histories



Strack and Pandey, 2007

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Actual well results

- Lotem interpretation done w/ ONGC
- Well drilled on results
- ONGC claims Lotem predictions are within 90-95% certainty.

•Survey was designed using Feasibility modeling 3 years BEFORE survey – ALL CORRECT

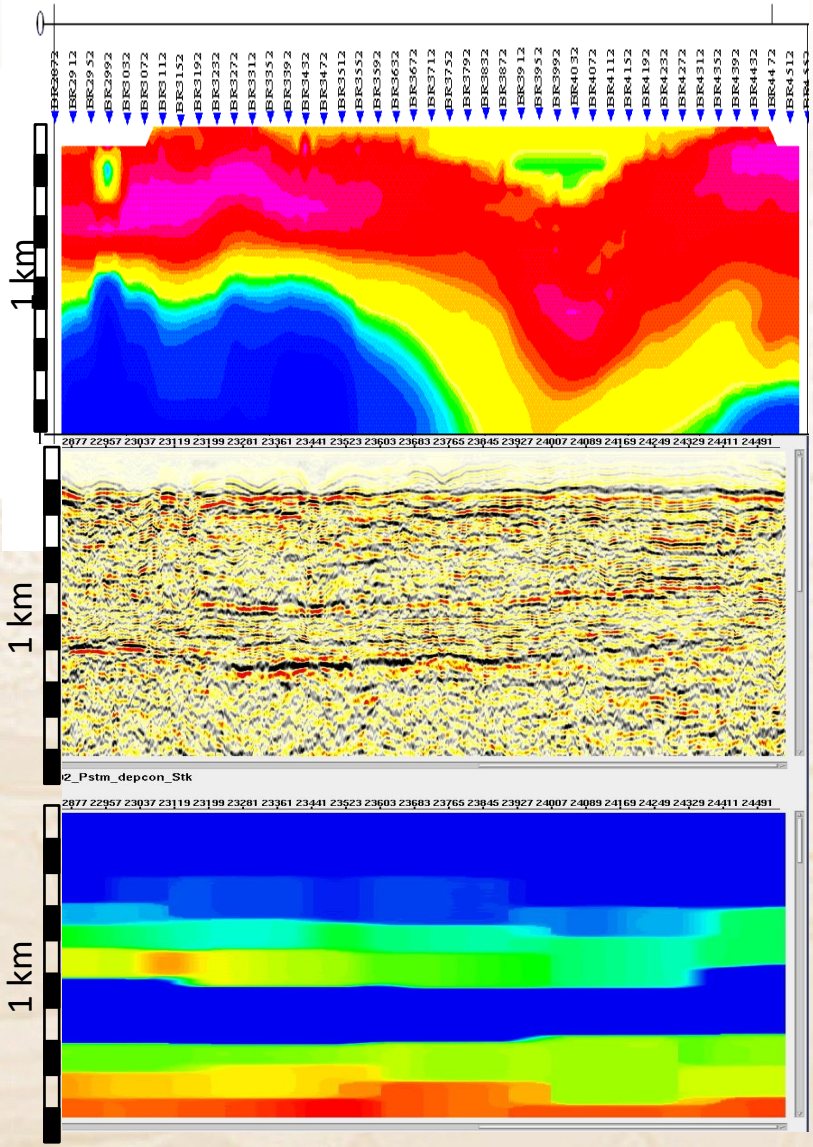
Strack and Pandey, 2007

Exploration – seismic integration- China – India/Brazil – Europe - USA

Early years >>> Resistors – DHI >>> MORE? >>> Case histories

MT section

unpublished



Seismic

Interval velocities

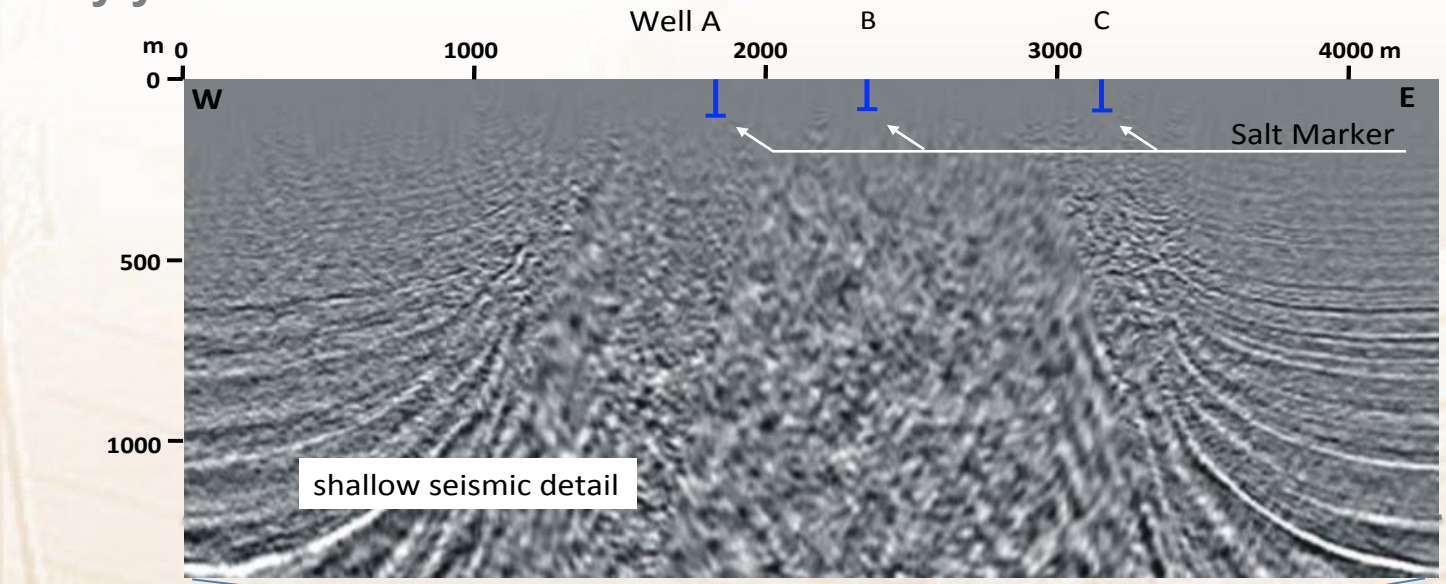
Exploration – seismic integration- China – India/Brazil – Europe - USA

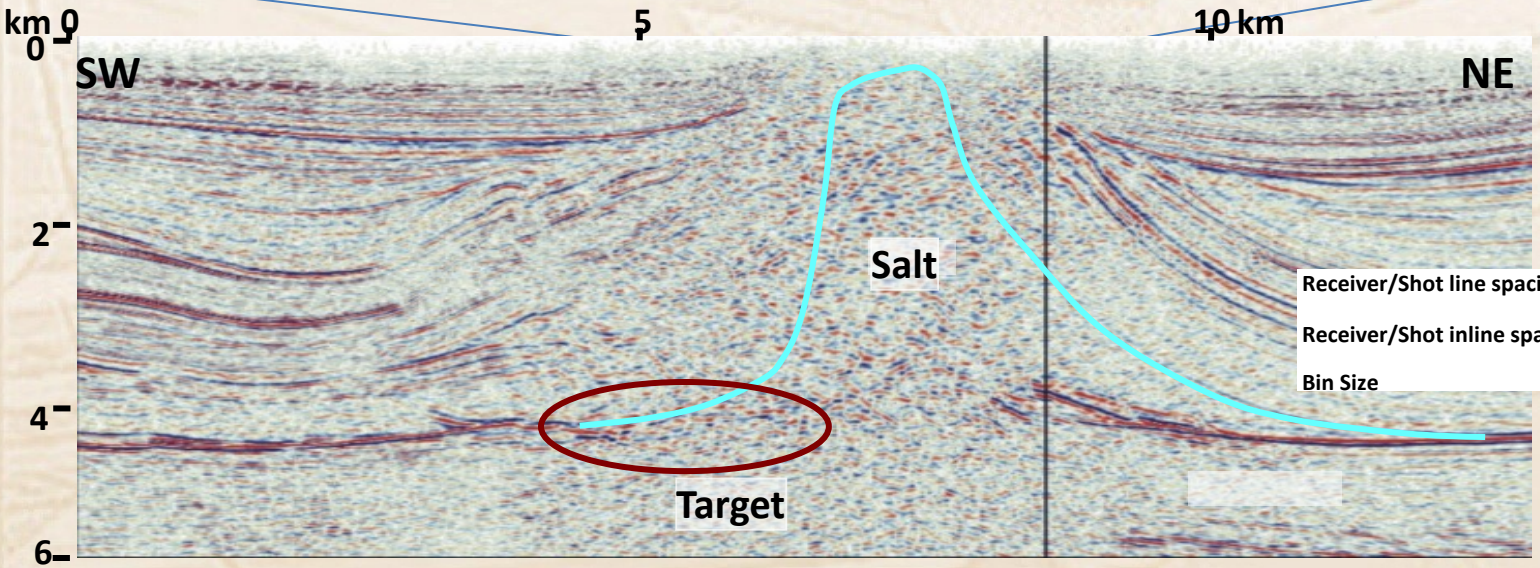
Early years >>> Resistors – DHI >>> MORE? >>> Case histories

After Henke et al., 2020

Exploration – seismic integration- China – India/Brazil – Europe - USA

Early years >>> Resistors – DHI >>> MORE? >>> Case histories

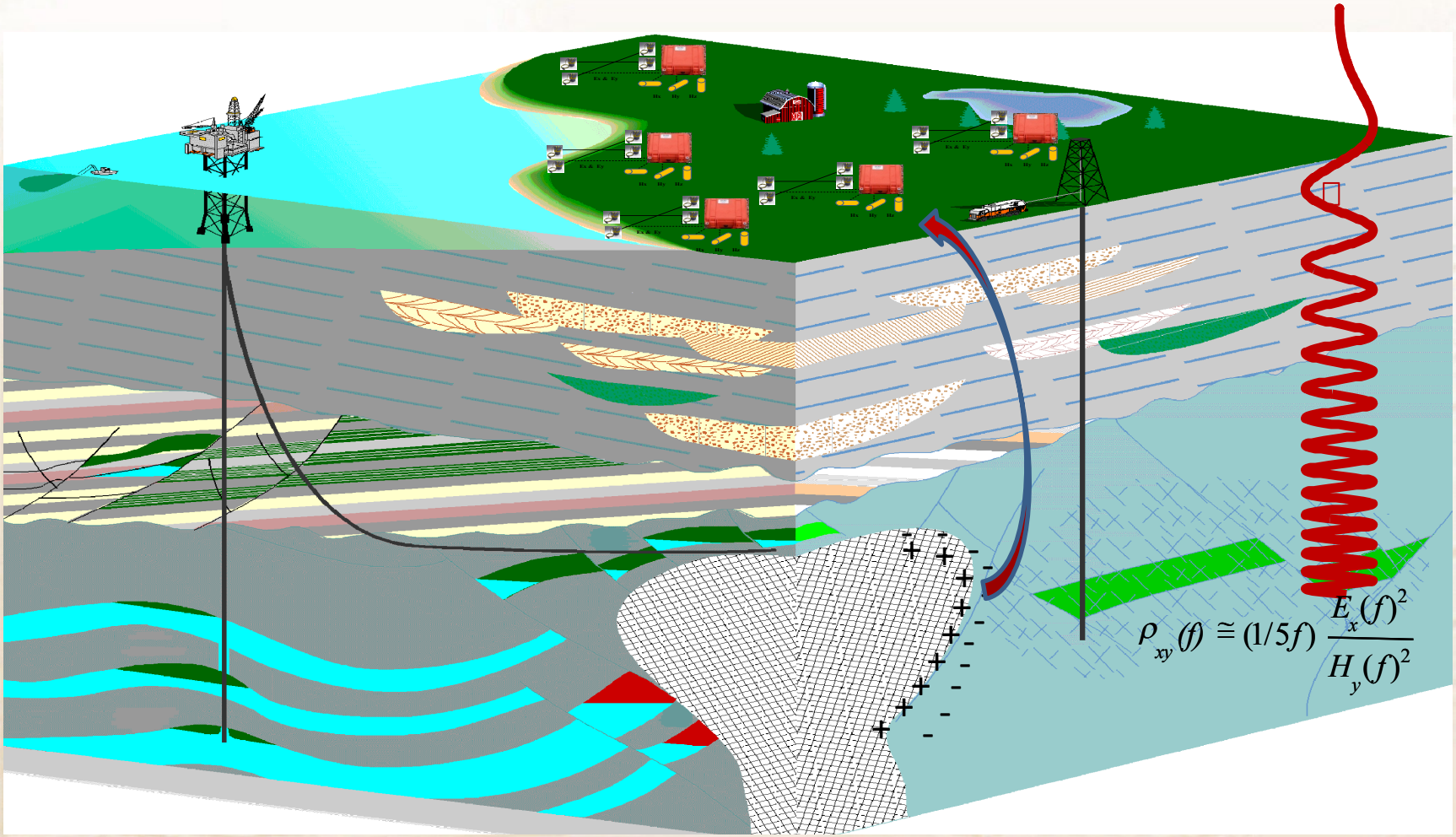




After Henke et al., 2020

Exploration – seismic integration- China – India/Brazil – Europe - USA

Early years >>> Resistors – DHI >>> MORE? >>> Case histories



After Henke et al., 2020

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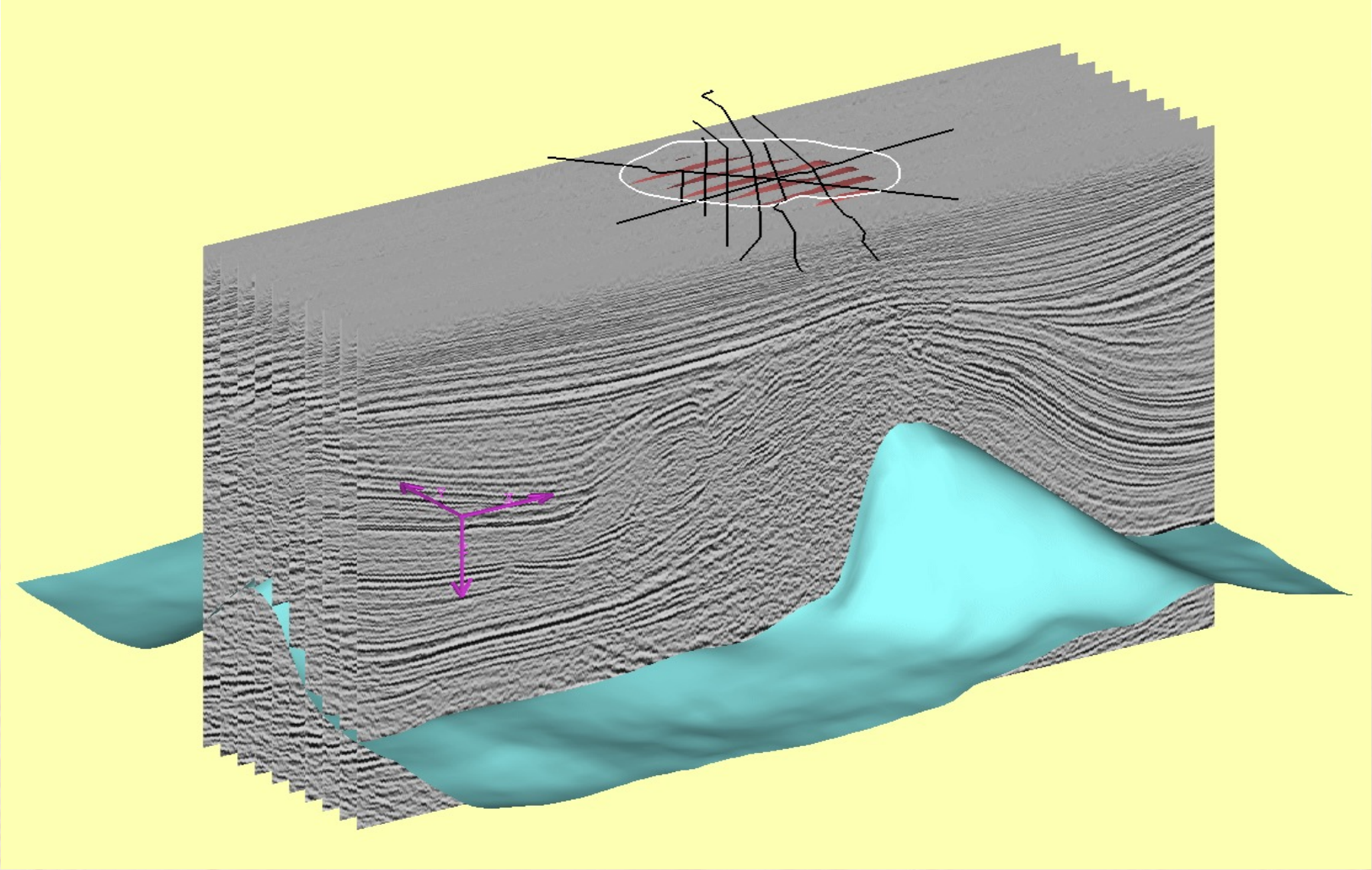
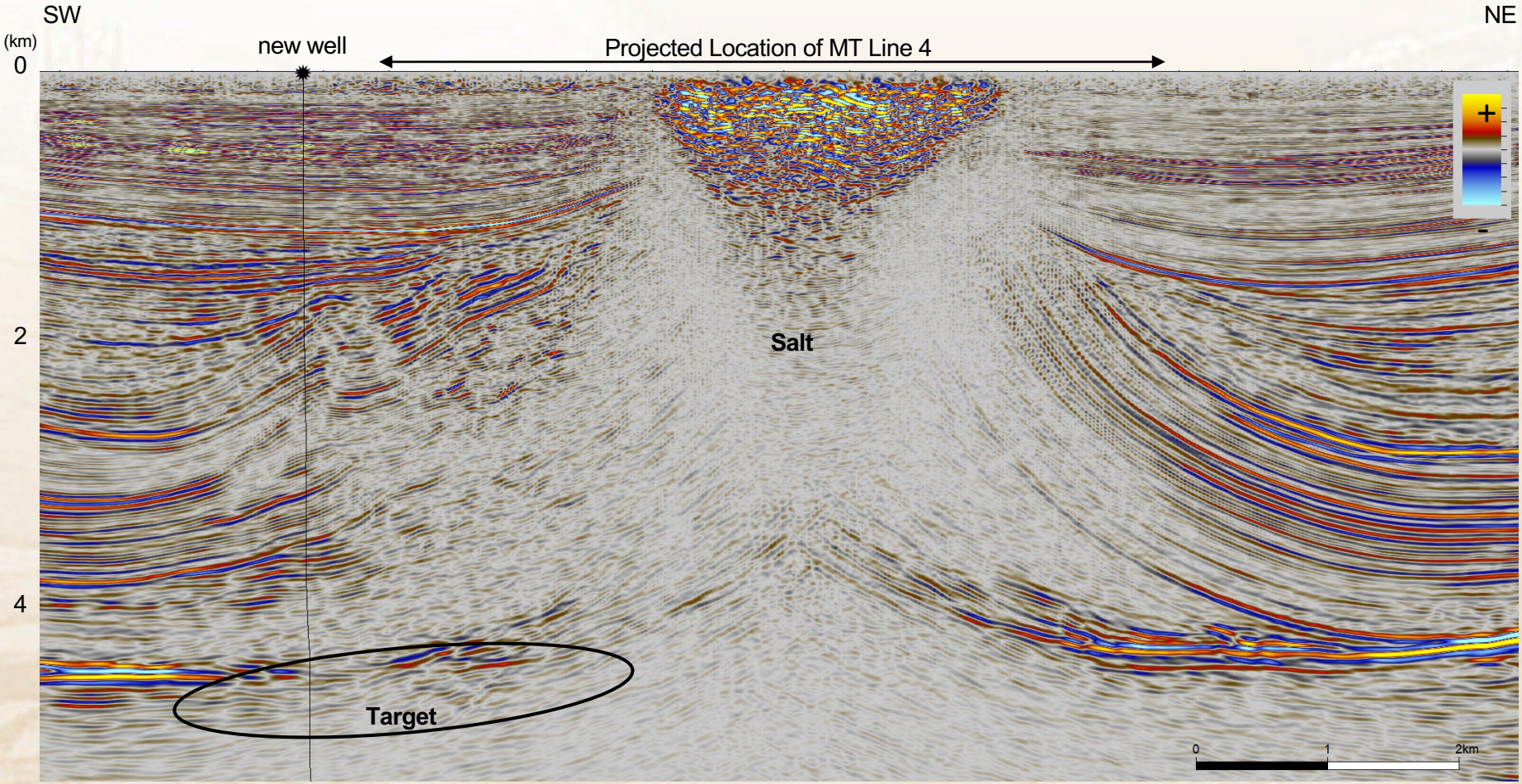
Early years >>> Resistors – DHI >>> MORE? >>> Case histories



Zerilli, et al 2002

Exploration – seismic integration- China – India/Brazil – Europe - USA

Early years >>> Resistors – DHI >>> MORE? >>> Case histories

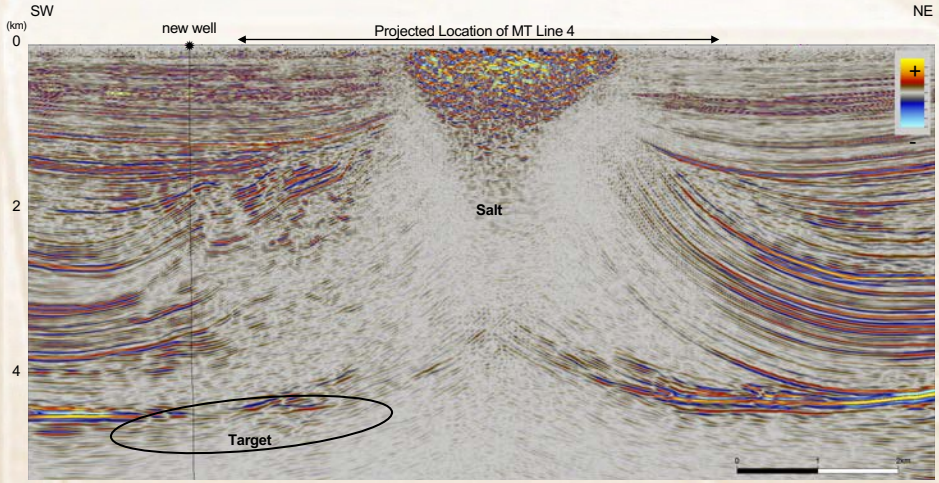


After Henke et al., 2020

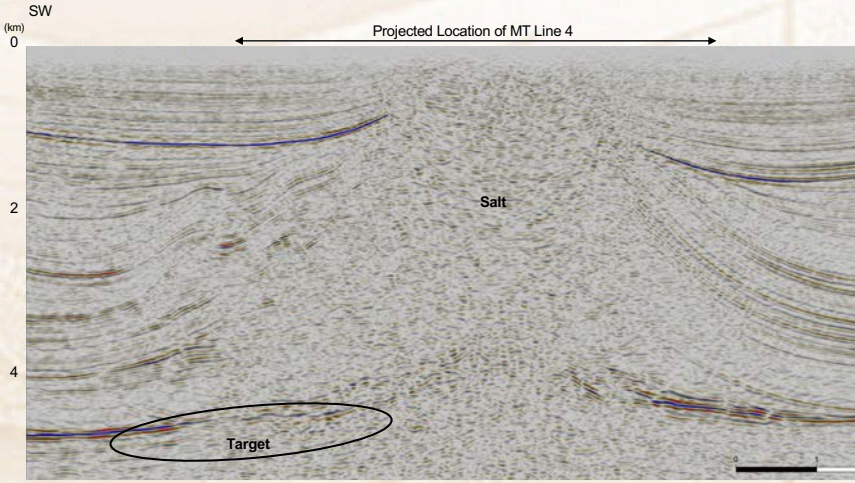
Exploration – seismic integration- China – India/Brazil – Europe - USA

Early years >>> Resistors – DHI >>> MORE? >>> Case histories

New EM integrated seismic



Previous seismic



After Henke et al., 2020

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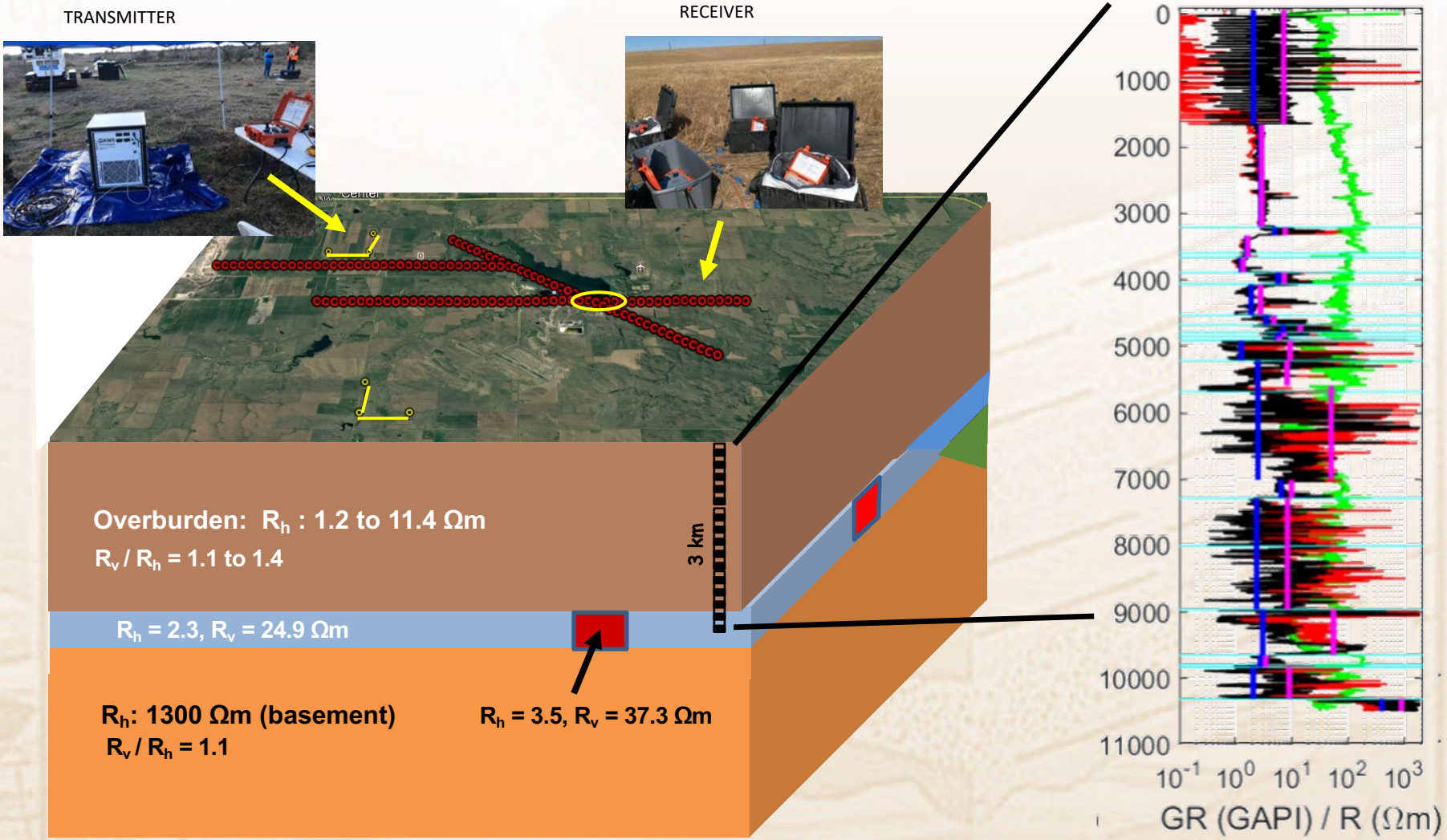
Exploration – seismic integration- China – India/Brazil – Europe - USA

Early years >>> Resistors – DHI >>> MORE? >>> Case histories



After Barajas–Olalade, 2021

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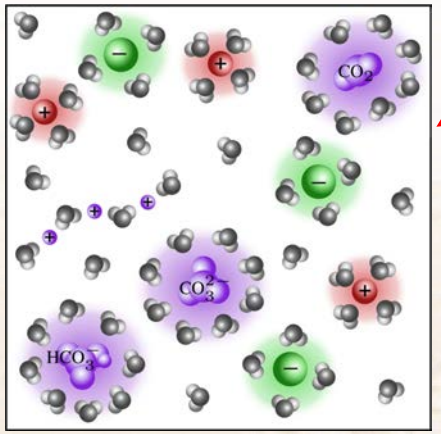
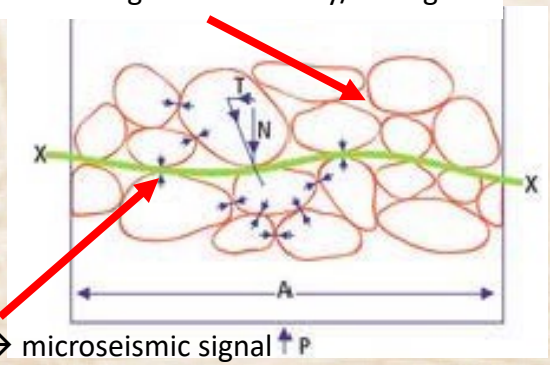
Early years >>> Resistors – DHI >>> MORE? >>> Case histories



CO_2 dissolves → reservoir fluid RESISTIVE

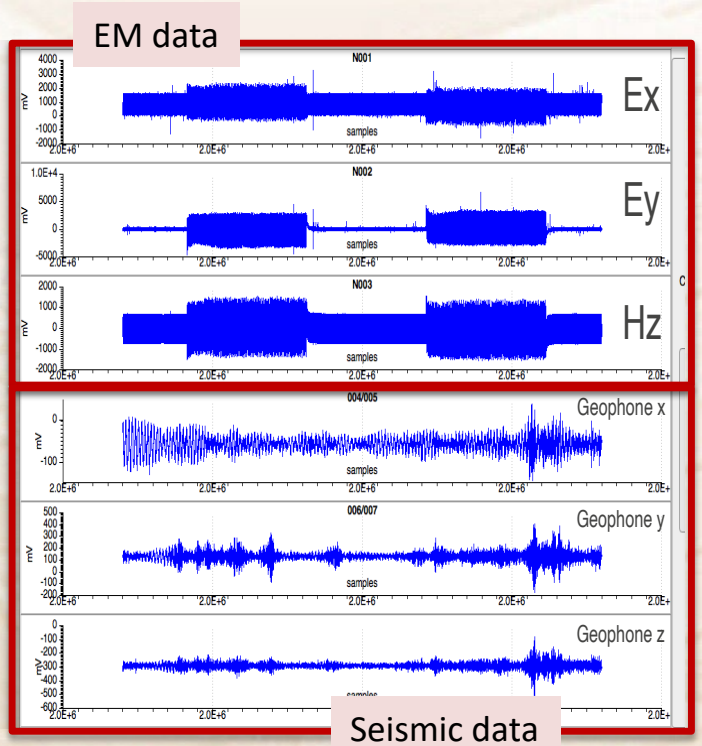
After Boerber eta l., 2015

Pore fluid changes → resistivity/EM signal



'Cracks' → microseismic signal

After Carlson, 2012



Exploration – seismic integration- China – India/Brazil – Europe - USA
Early years >>> Resistors – DHI >>> MORE? >>> Case histories

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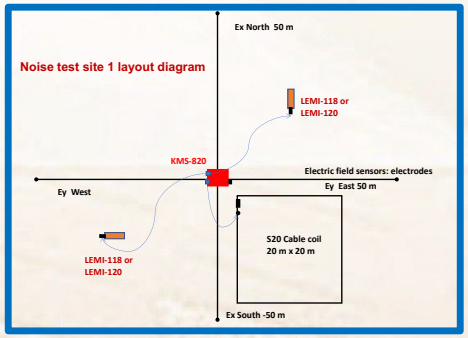
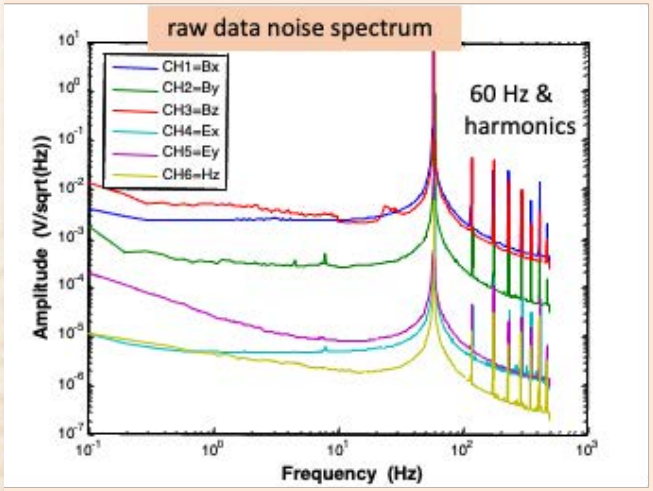
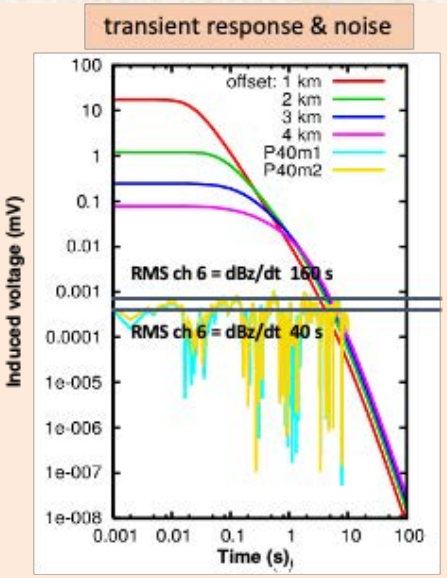
Noise test – multiple sensors, verify noise sources

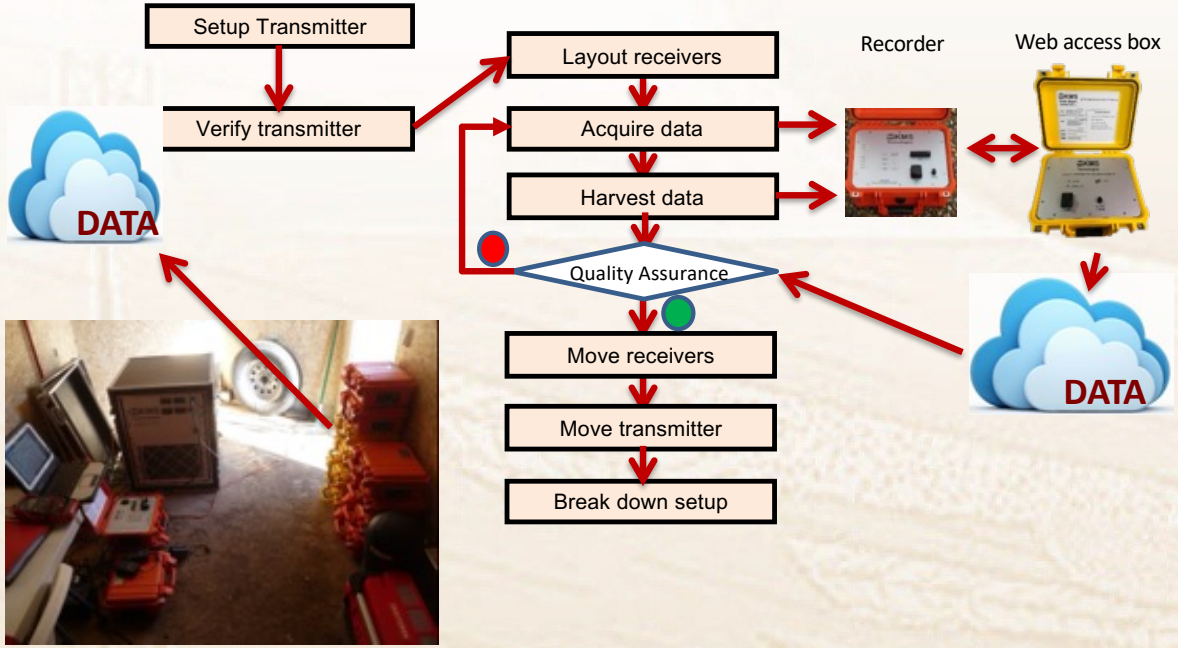






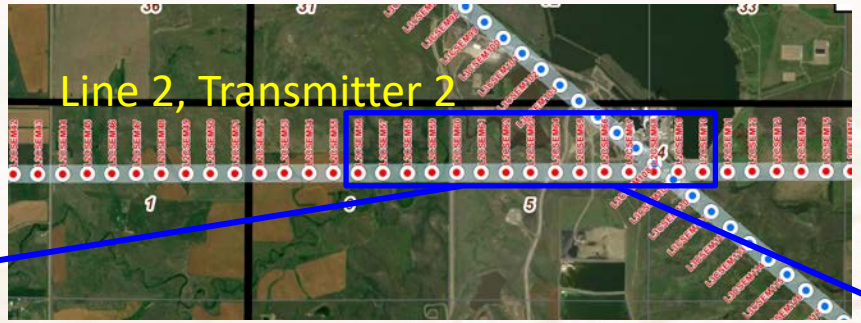
Exploration – seismic integration- China – India/Brazil – Europe - USA

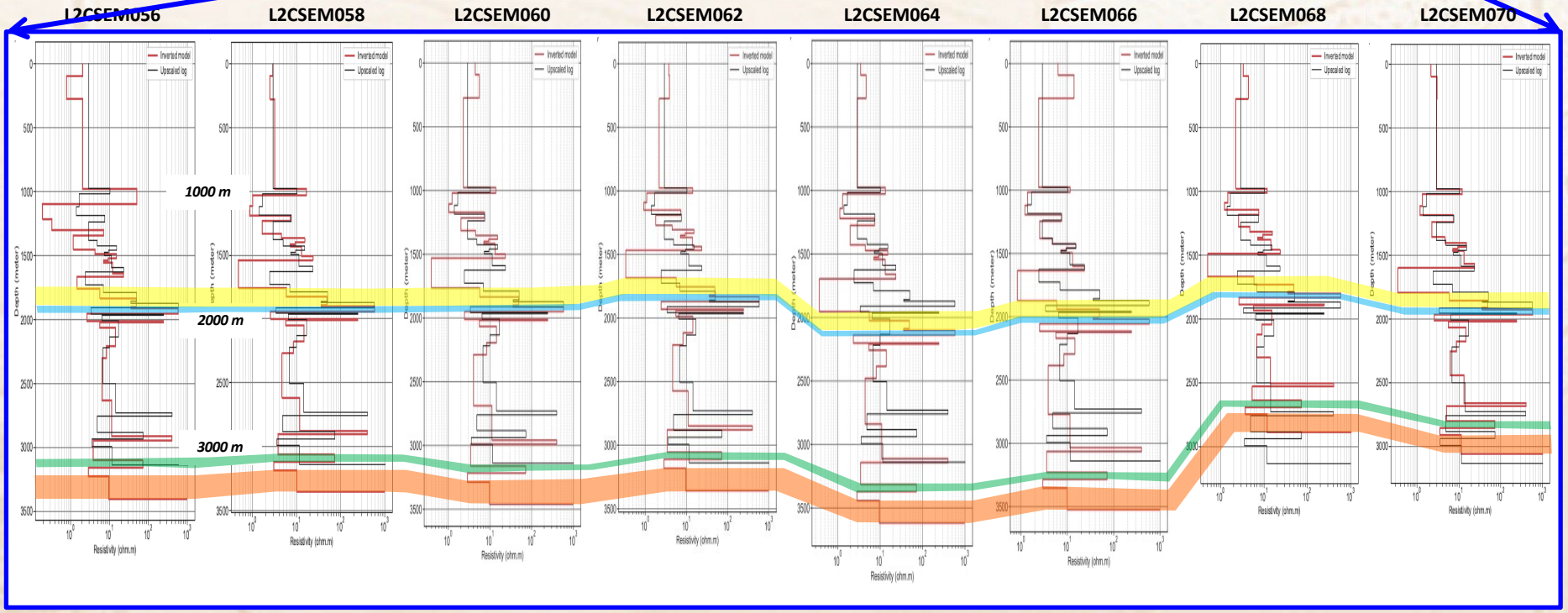
Early years >>> Resistors – DHI >>> MORE? >>> Case histories



Exploration – seismic integration- China – India/Brazil – Europe - USA

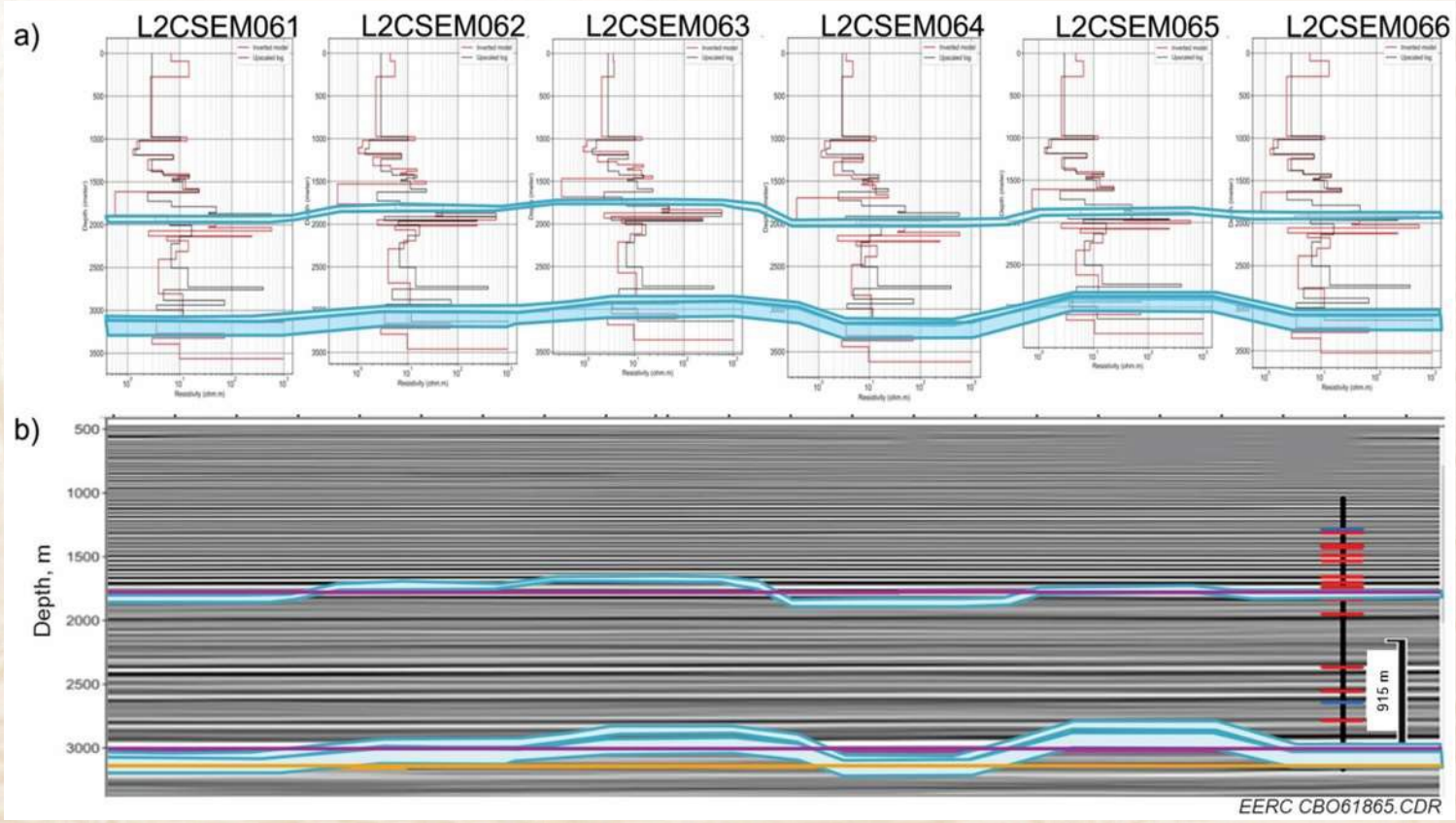
Early years >>> Resistors – DHI >>> MORE? >>> Case histories





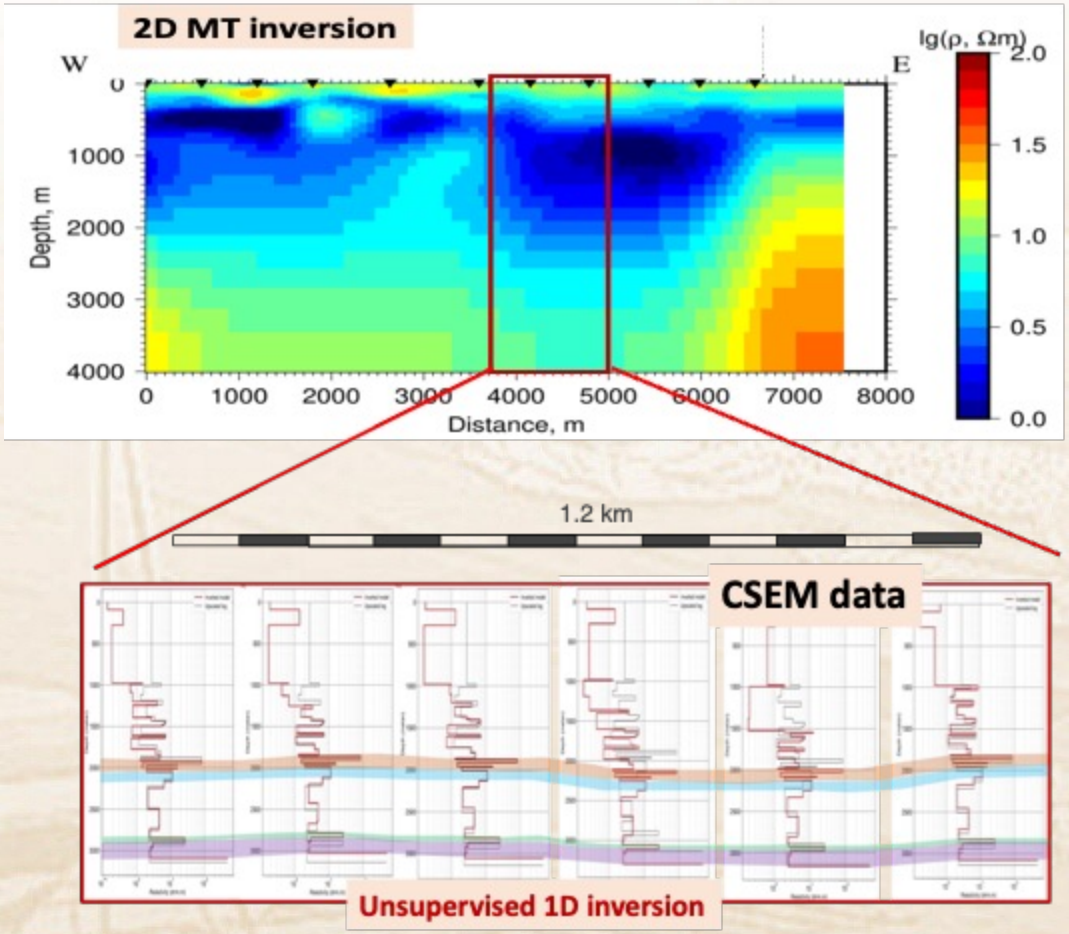
Exploration – seismic integration- China – India/Brazil – Europe - USA

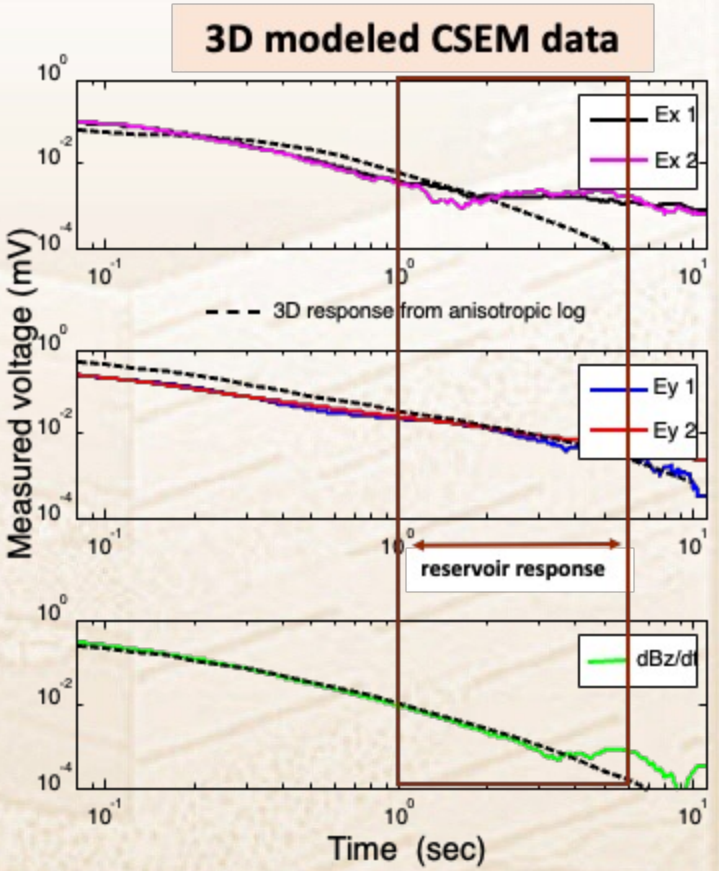
Early years >>> Resistors – DHI >>> MORE? >>> Case histories



Exploration – seismic integration- China – India/Brazil – Europe - USA

Early years >>> Resistors – DHI >>> MORE? >>> Case histories





Conclusion & Future: THE PATH

Early years >>> Resistors – DHI >>> MORE? >>> Case histories

- Technology path over 40 years
  - Sensors: SQUIDS (>100 k$) → FG (5 k$)
  - TX: 0.5-1 MW → 200 kW
  - DAU: custom →27 bit FP → 24 → 32 bit
  - Manual processing 20 Hz 8 sites/crew (30 min)→ continuous time series to Cloud at 1 kHz, unlimited (4-5 hours normal)
  - Slow 1D inversion – unsupervised anisotropic inversion & 3D modeling

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Conclusion & Future: THE PATH

Early years >>> Resistors – DHI >>> MORE? >>> Case histories

- EM works – MT or CSEM; rarely seen bad data
- Dense data allow integration with seismic
- Formal integration still needed
- BOREHOLE → better images
- Anisotropy – otherwise 30-50% error
- CLOUD usage revolutionizes acquisition → processing → 3D modeling

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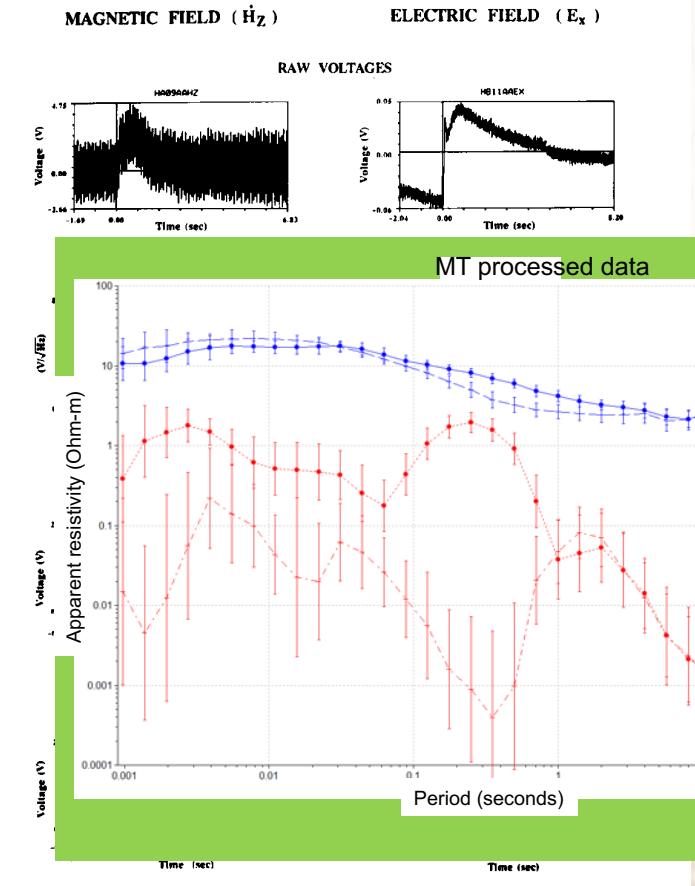
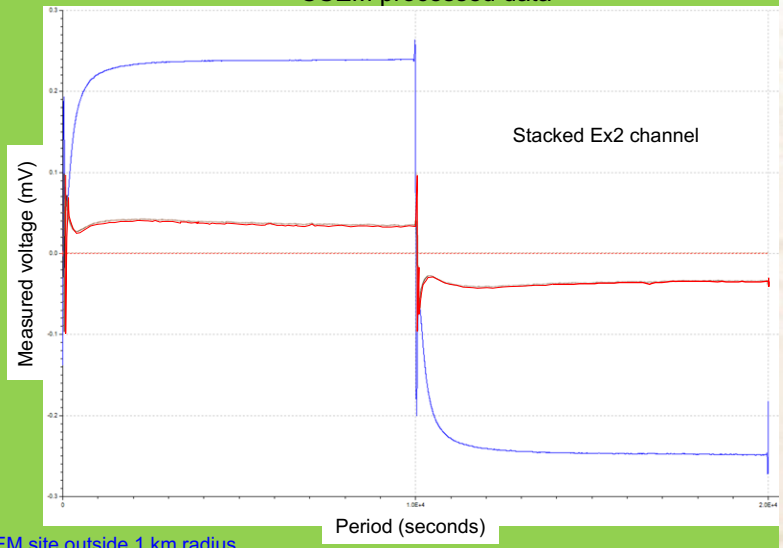
Old (1989) processing versus new (2022)



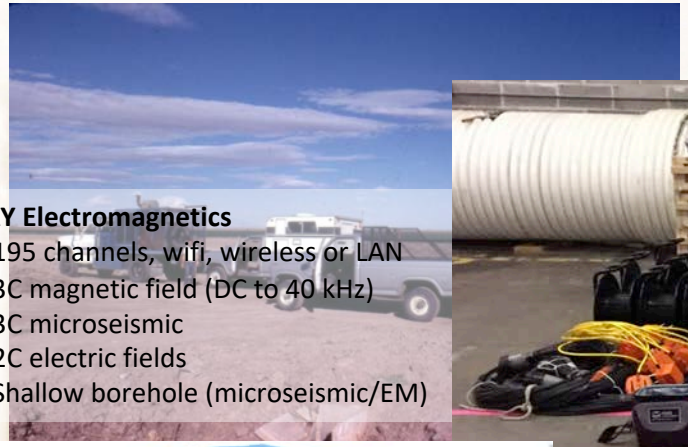
MT processed data

CSEM processed data



Low noise MT/CSEM site outside 1 km radius
High noise MT/CSEM site inside 1 km radius

Old (1981) hardware versus new (2022)



200 kVA

ARRAY Electromagnetics

- 195 channels, wifi, wireless or LAN
- 3C magnetic field (DC to 40 kHz)
- 3C microseismic
- 2C electric fields
- Shallow borehole (microseismic/EM)

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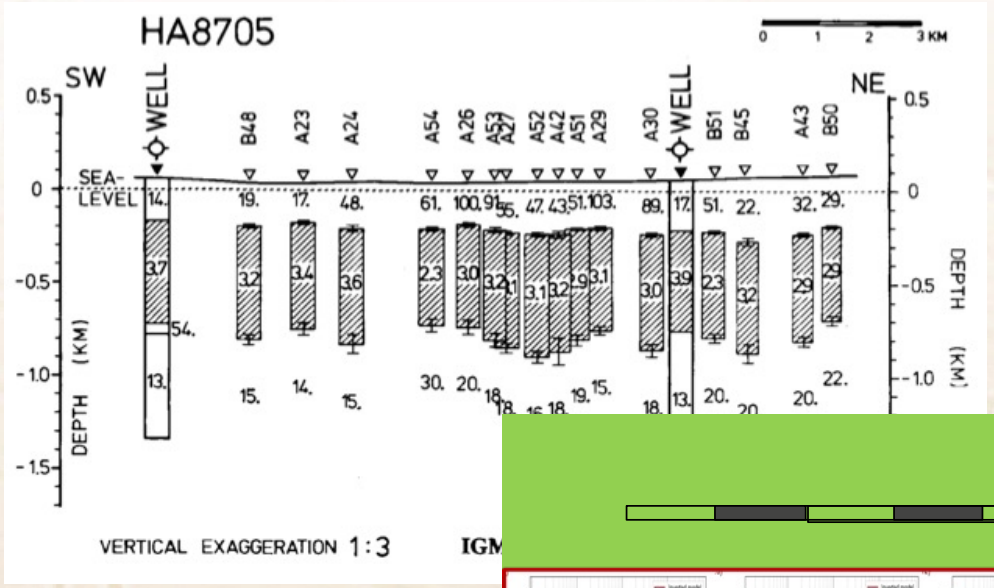
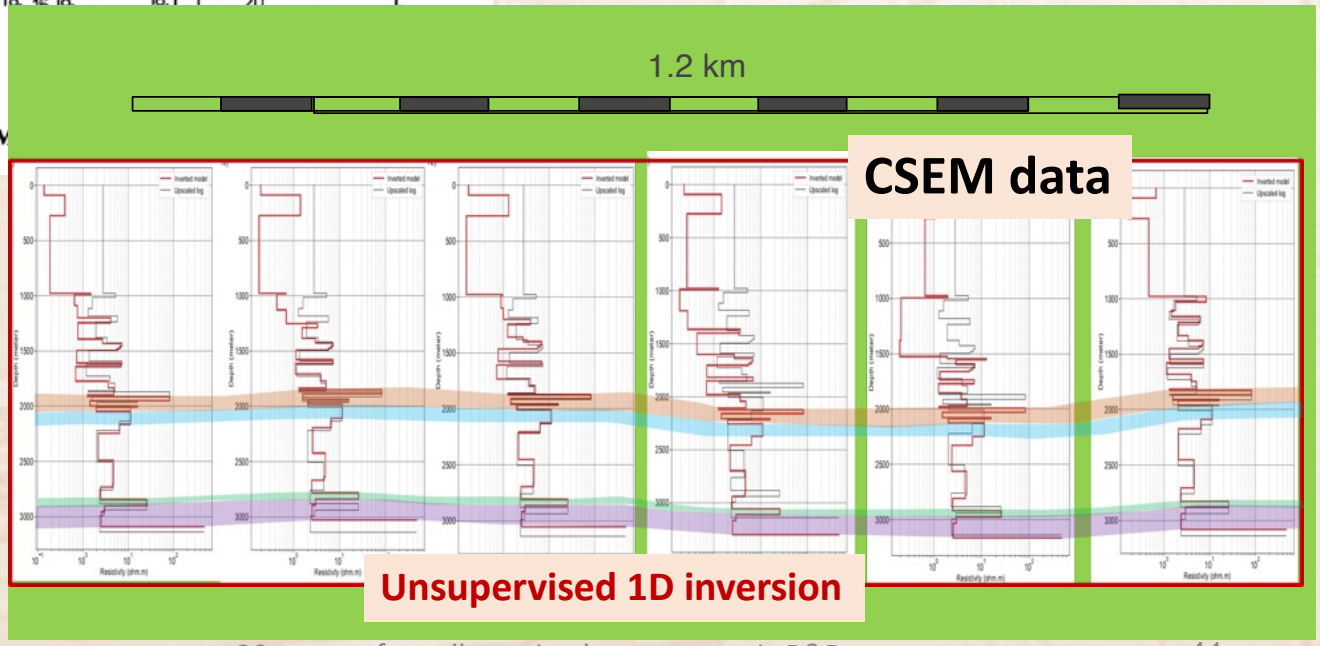
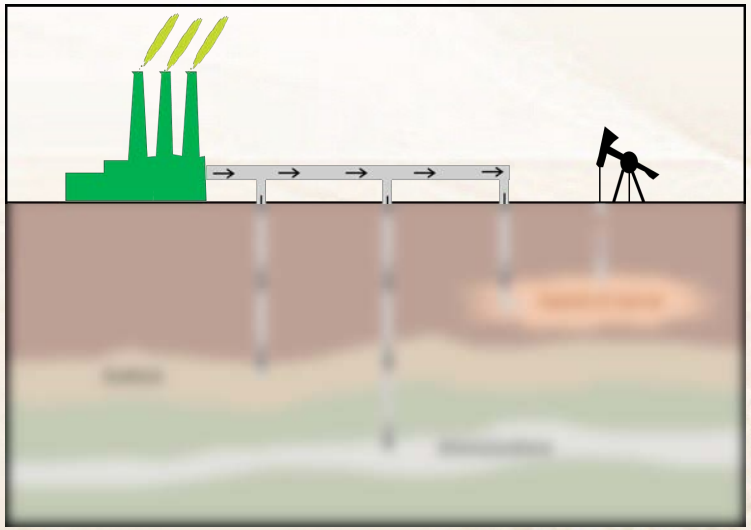
Old (1989) processing versus new (2022)



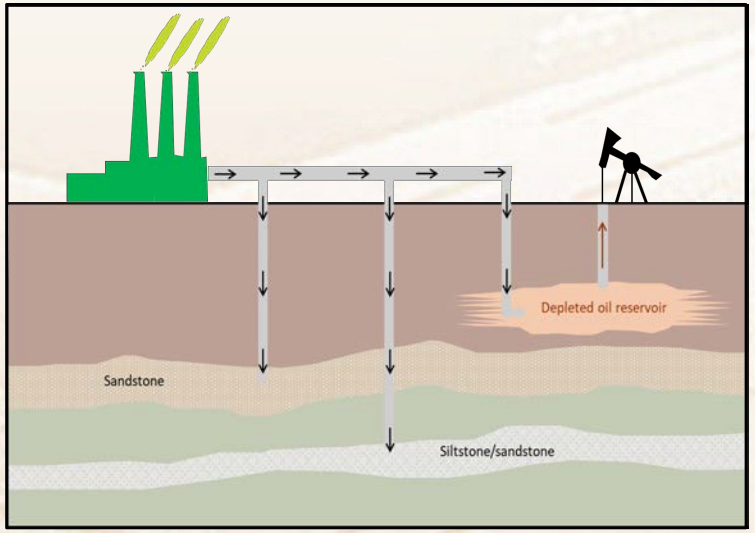


MT & CSEM good and bad data

MT



CSEM



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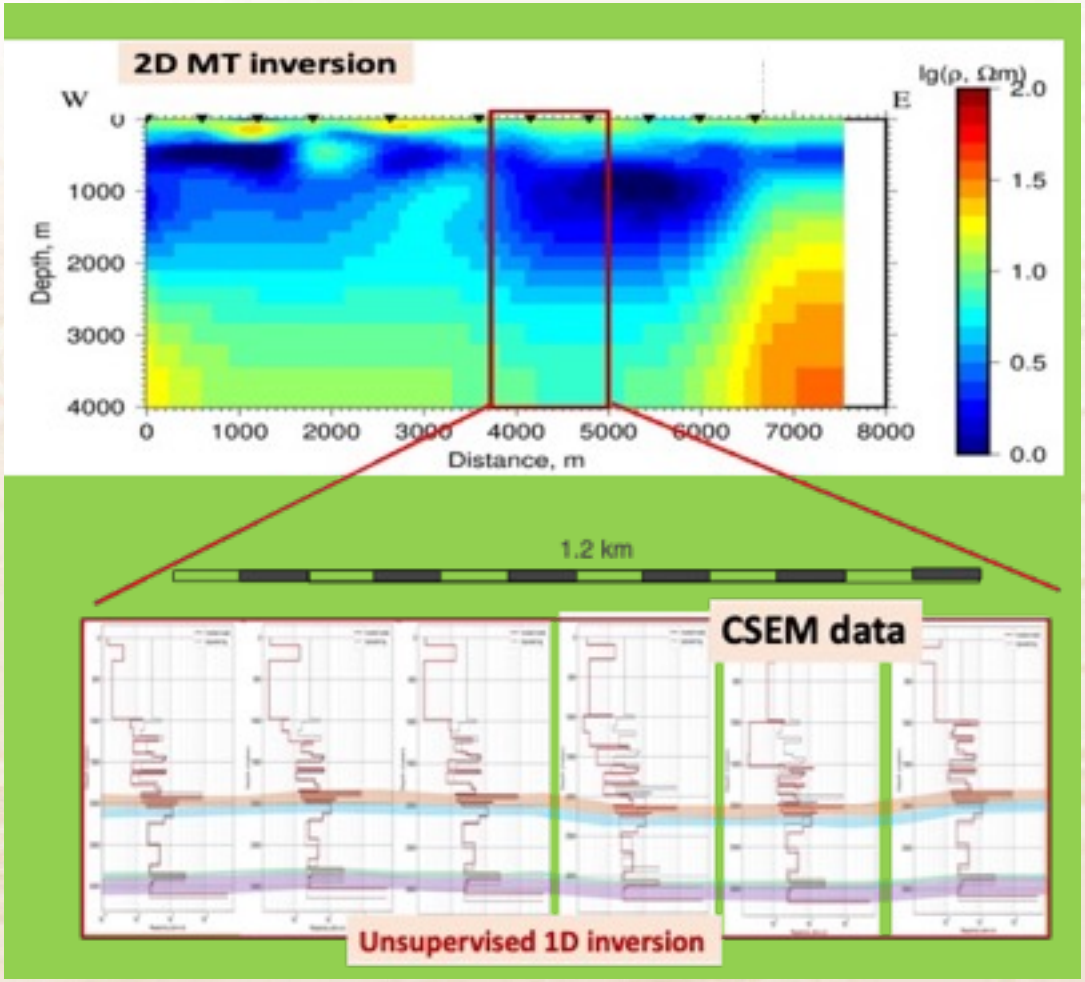
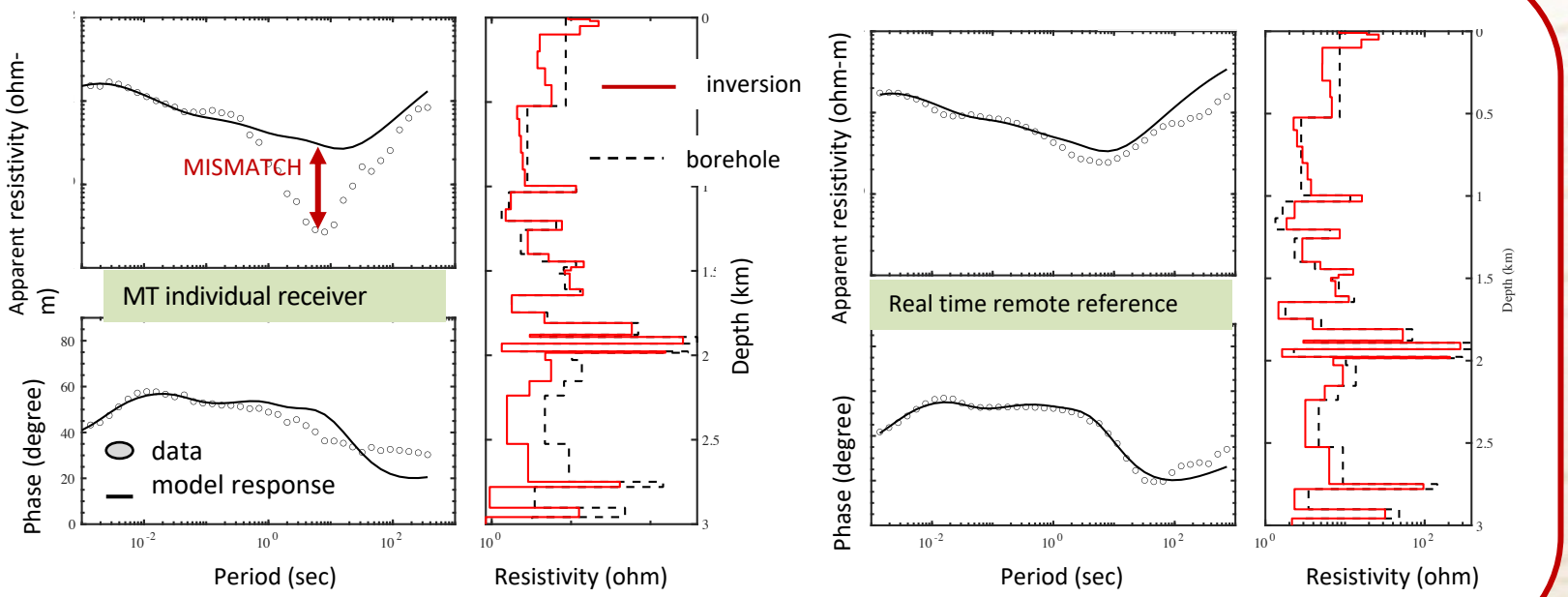
MT & CSEM good and bad data



The CLOUD is revolutionizing the future



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Thank you!.. Question