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Novel Marine Electromagnetics: from Deep into Shallow Water

Thomsen, L., Meaux, D., Li, S., Weiss, C., Sharma, A., Allegar, N., and Strack, K.-M.

Recent Advances and the Road Ahead
SEG, San Antonio
2007

Novel Marine Electromagnetics: from Deep into Shallow Water

DRAFT 5, 9/19/07

Leon Thomsen[1], David Meaux[1], Shenghui Li[1], Chet Weiss[1,2], Arvind Sharma[1], Norm Allegar[1,3], Kurt Strack[3]

Recent Advances and the Road Ahead

Society of Exploration Geophysicists, San Antonio, Sept. 24, 2007

[1] BP
[2] Virginia Tech
[3] KMS

Outline

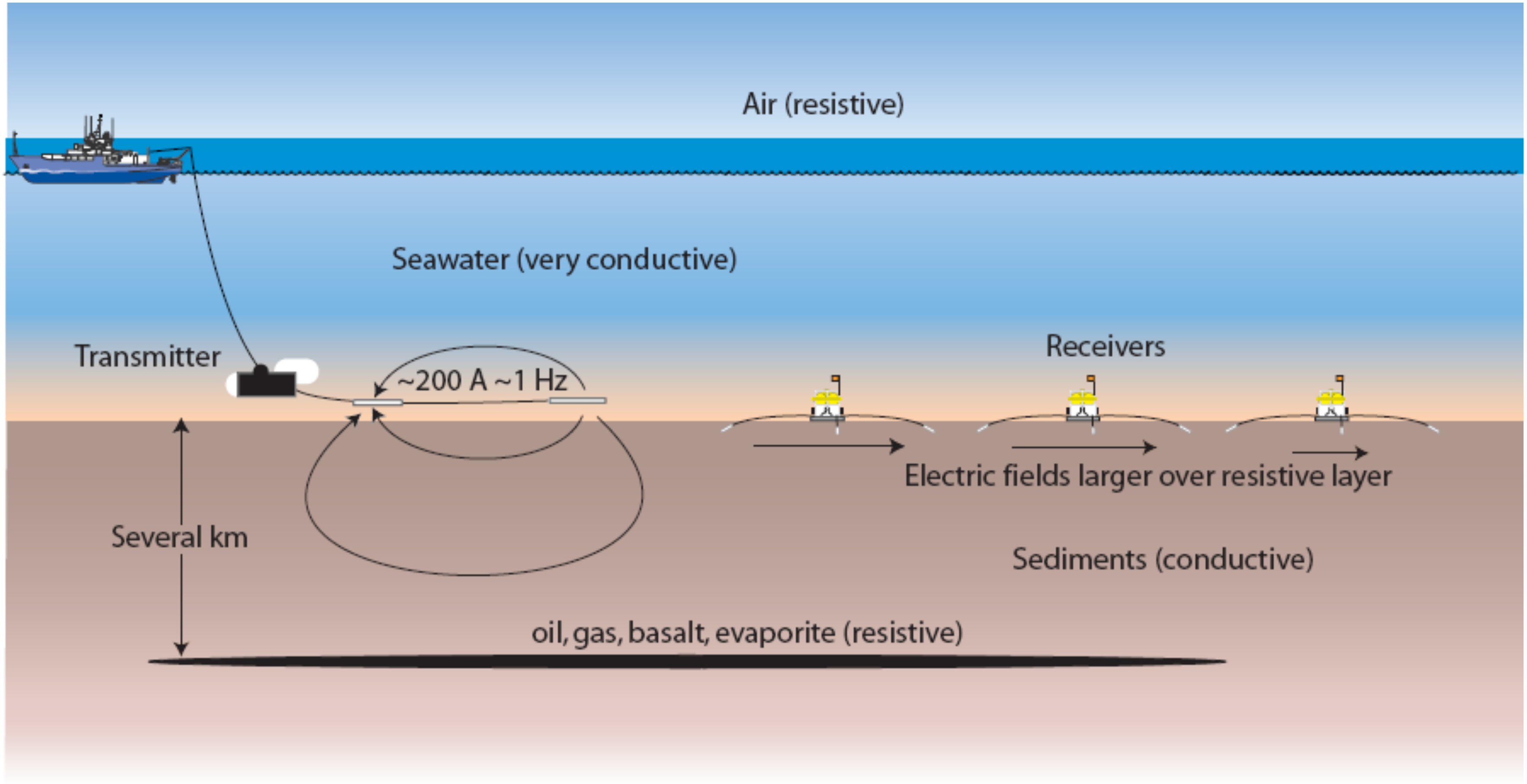
- Context
- Seismics and EM: the deep connection
- CSEM, seismic-style
- The Egyptian Field Trial
- Conclusions

A Brief History of CSEM

- **Deep roots in whole-earth, academic geophysics:**
  - ***e.g.* Parker,1977…**
  - ***e.g.* Constable et al, 1987…**
- **Grew out of <u>natural</u>-source EM ("magnetotellurics"), *inherently* a continuous source ("always on"); moved to <u>controlled</u>-source, as technology developed.**

- **Note analogies with seismics:**
  - **Seismic refraction, using techniques adapted from whole-earth, academic seismologists (with natural (earthquake) sources).**
  - **Ocean Bottom Seismics evolved late.**

CSEM Acquisition



Base figure courtesy of:

SCRIPPS INSTITUTION OF OCEANOGRAPHY Marine EM Laboratory

CSEM in practice

- **Marine CSEM practice evolved with a set of expectations:**
  - **Source same as natural source = “<u>always on</u>”.**
    - (Uses variations on a square wave,   with frequency < 1 Hz.)
  - **Data averaged over many cycles.**
    - Expressed as <u>amplitude (MVO) and phase (PVO)</u> as functions of source/receiver positions.
  - **Data formally <u>inverted</u> for resistivity distribution in subsurface.**
    - (Requires accurate knowledge of source & orientation; *navigation uncertainty* is currently accuracy limitation .)
  - **Offset larger than depth of investigation**

As a consequence?

- The technique ;imited to deep water (> ~2x target depth)
  - Water shields from interference by the “air wave”
  - Many proprietary solutions to the “deep-water limitation” exist; none satisfactory.

- Could there be a fundamentally different solution?

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There is a deep similarity, between seismic and EM data, <u>despite</u> the difference in the fundamental equations

- **Previous work highlights similarity between seismic and EM, by *e.g.***
  - **Jackson (1962), Feynman *et al* (1964)**
  - **Ursin (1983), Lee *et al* (1987)**
  - **Land CSEM: Rueter & Strack, 1991**
  - **Marine CSEM: Amundsen, Hokstad, Rosten; Ellingsrud; Carcione, (2004-07)**
- **Further, EM energy propagates at speeds similar to seismic velocities!**
  - ***e.g.* at ω=.25 Hz, ρ=1 Ω-m: V_{phs} = 1.6 km/sec; V_{grp} = 3.2 km/sec**
- **As for land CSEM, seismic-style acquisition may be used for marine EM acquisition.**

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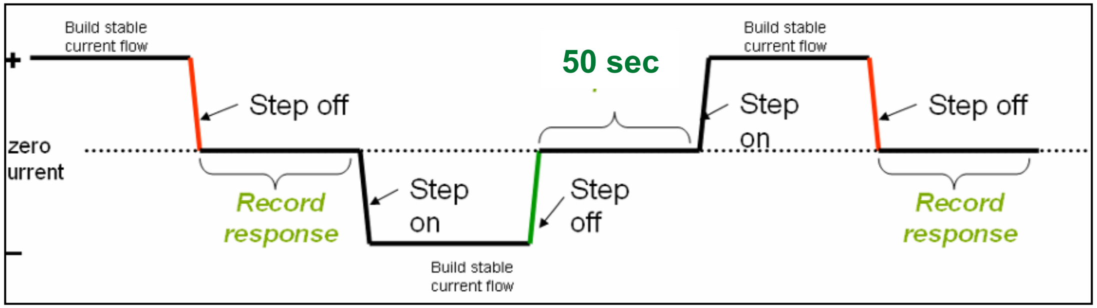
Acquisition considerations

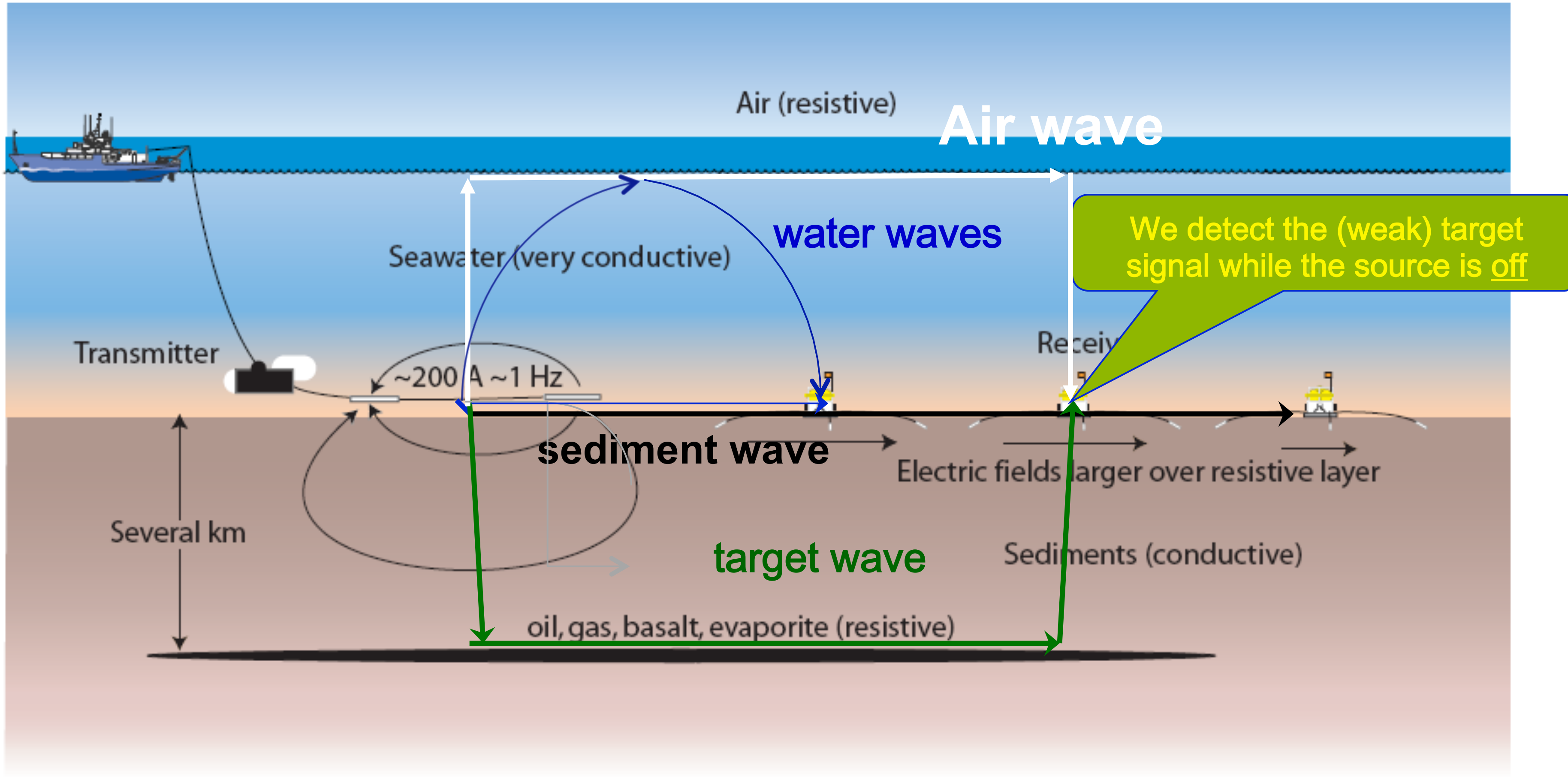
- **In EM, as in seismics, the subsurface signal is very weak;**
  - **best to detect it in the absence of source-generated noise.**



- **Data should be acquired *unaliased*.**
  (We had sources @ 50 m; receivers @ 400 m)

- **Modeling is important, prior to acquisition.**

Transient-source CSEM acquisition



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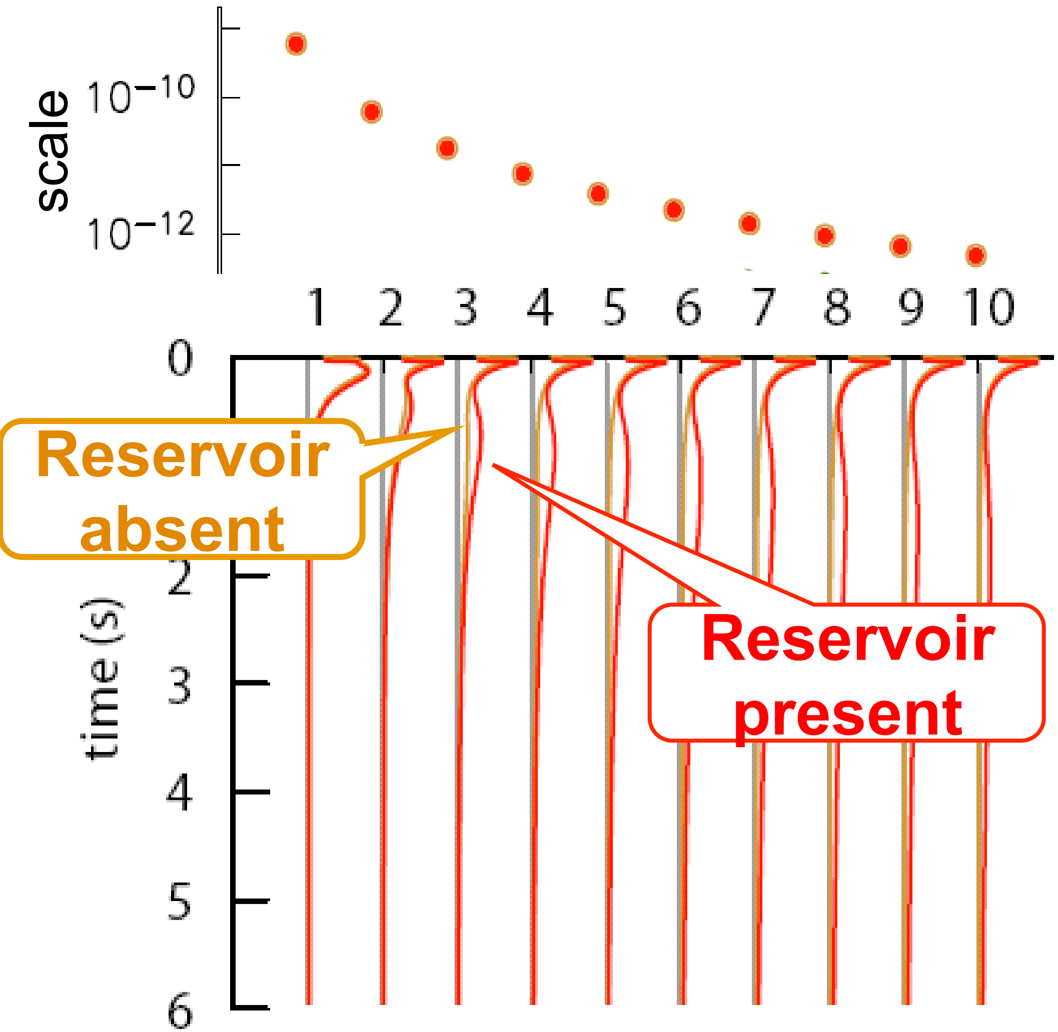
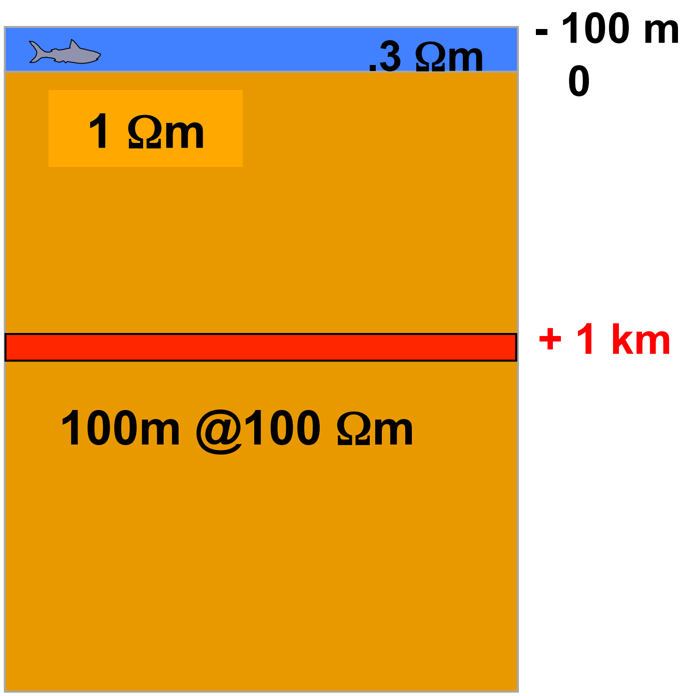
Marine EM Short Course, copyright Steven Constable, version May 25, 2004 23

1-D transient-source modeling





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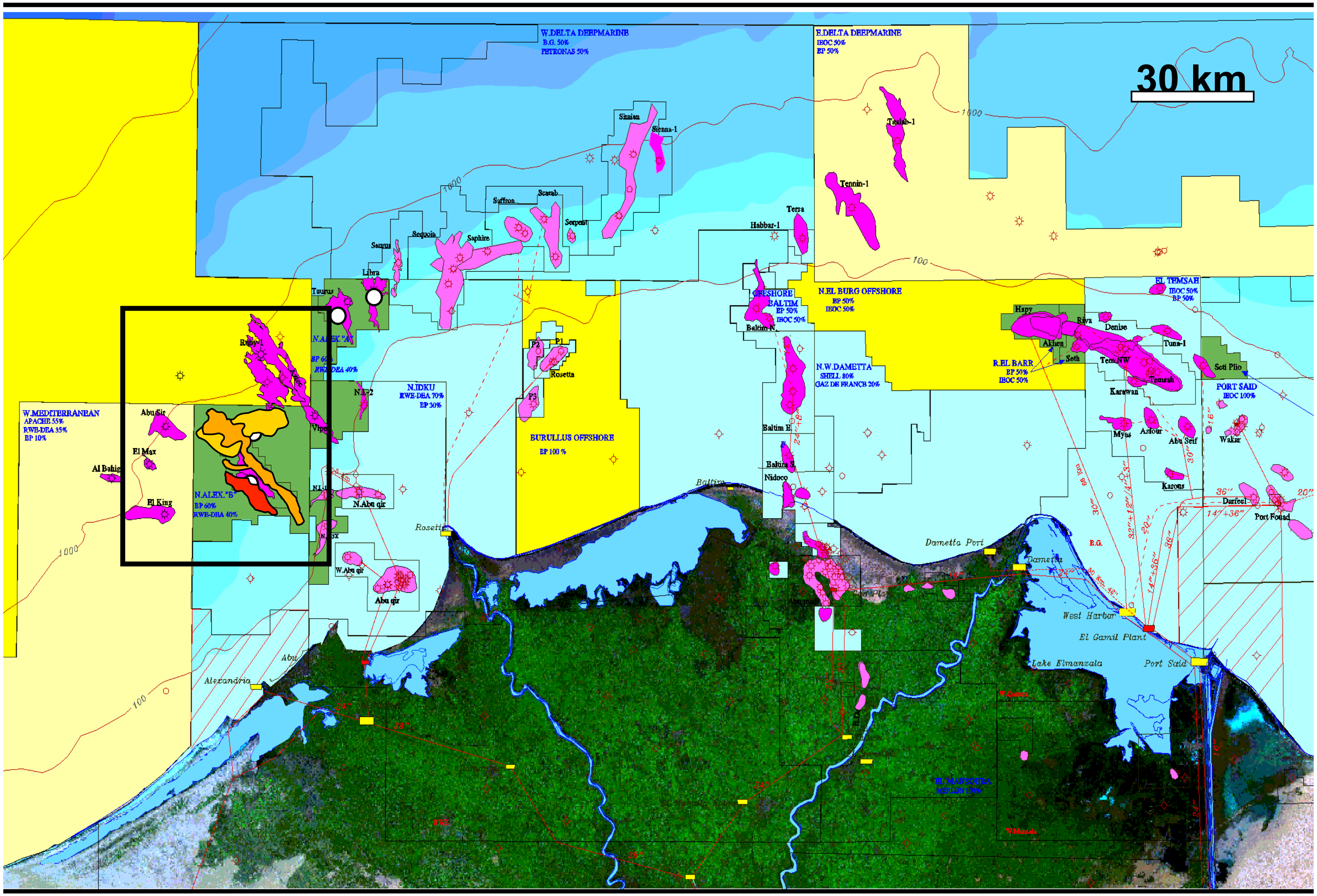
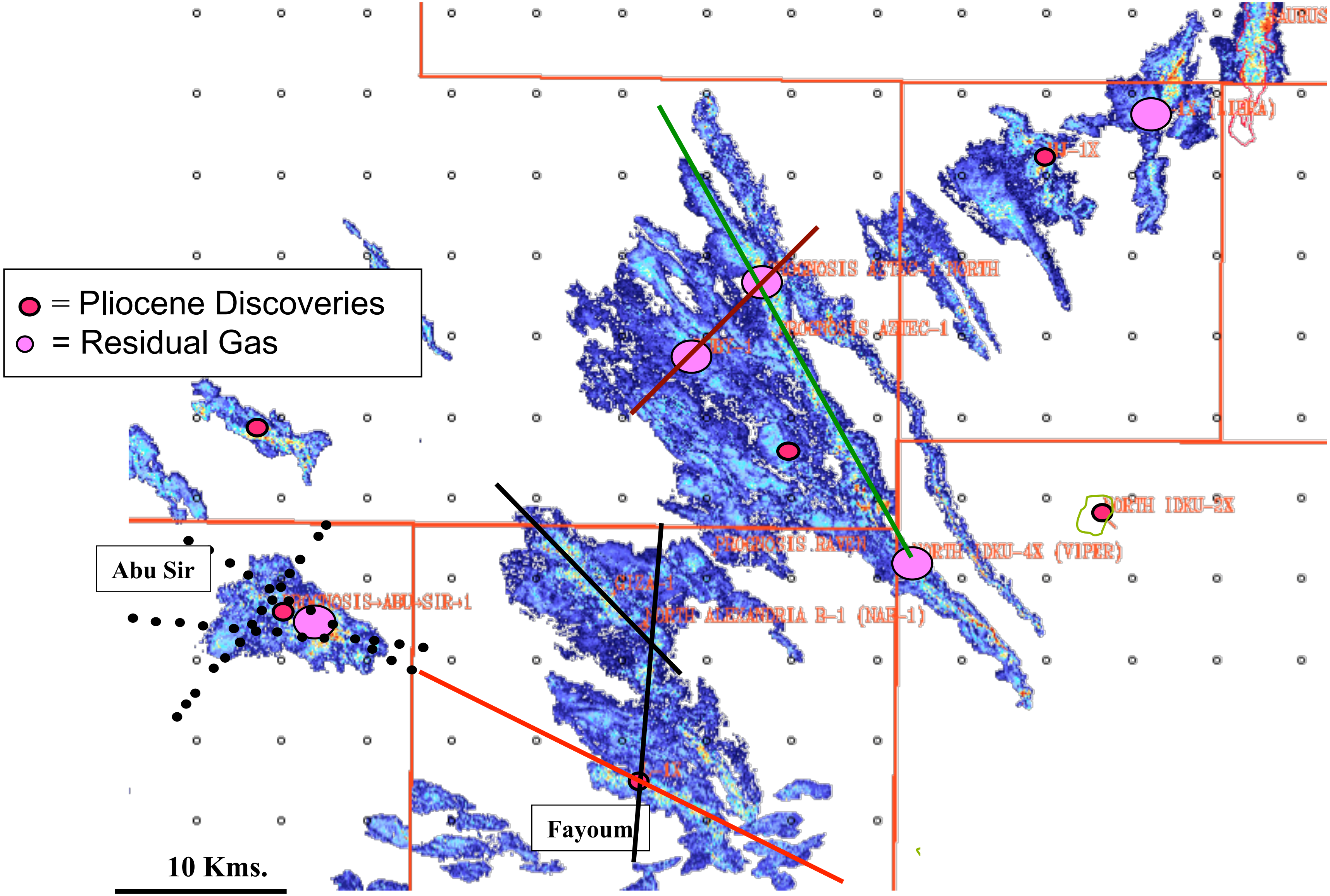
  - Field context
  - Acquisition
  - Results
- Conclusions

Exploration Context



Several 2-D lines were acquired, with both continuous and transient sources



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The BP Acquisition Team

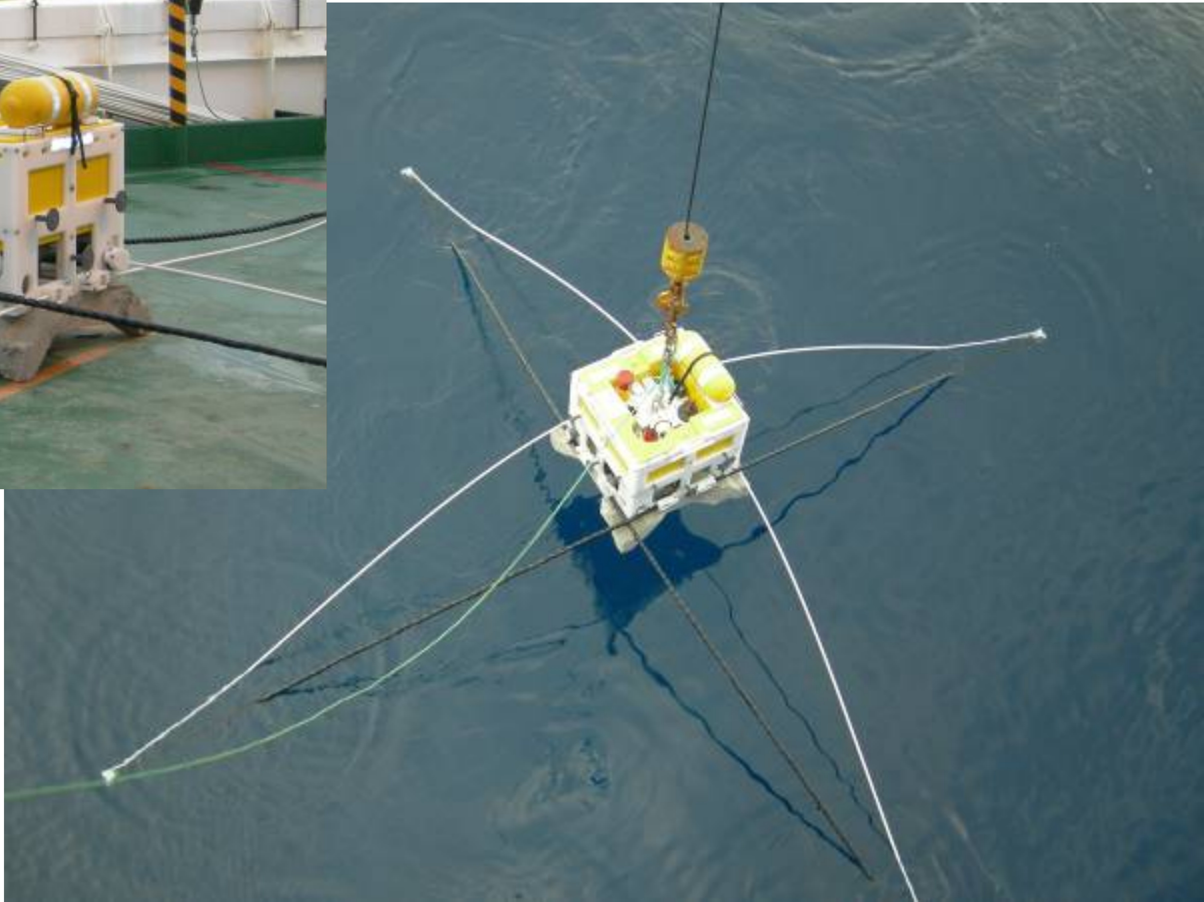
BP records world's first successful at-scale marine transient CSEM data: December 5th, 2006

Survey Operations: 11/29/06 – 1/2/07

>> 200 5C receiver deployments

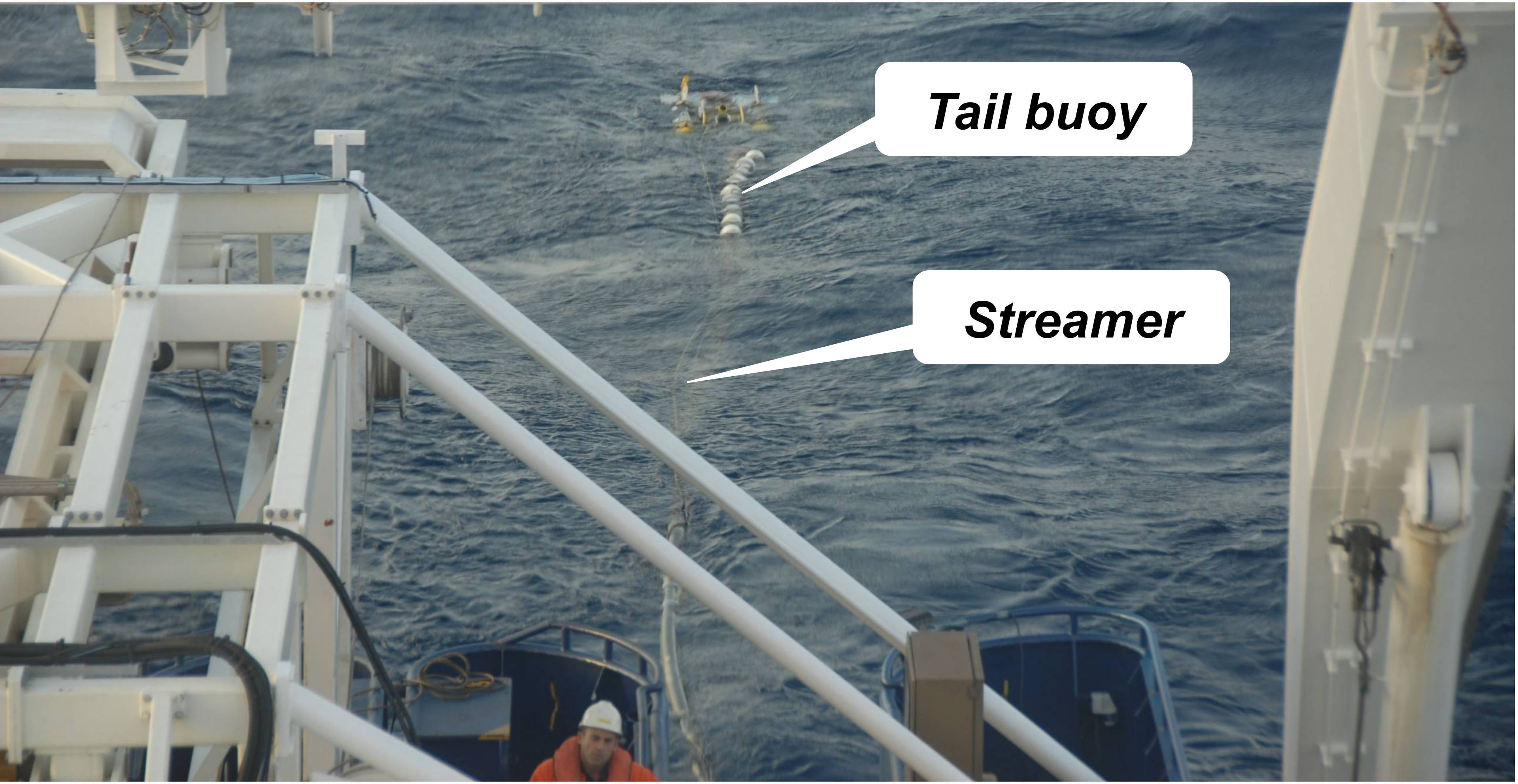
Duration: 33 days

Conventional receiver deployment



Photos courtesy of emgs

Conventional antenna deployment



Photos courtesy of emgs

Deploying modified source transform

Photos courtesy of emgs

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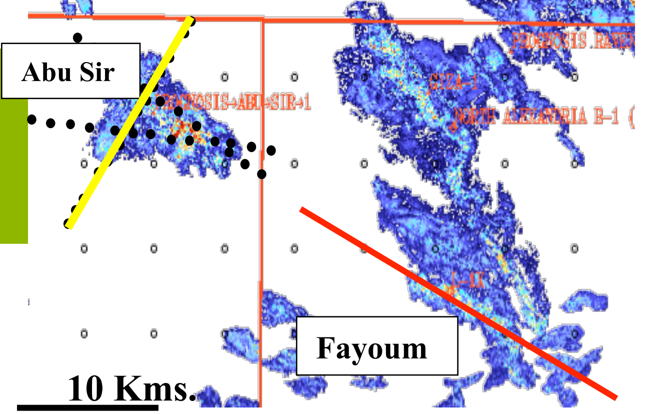
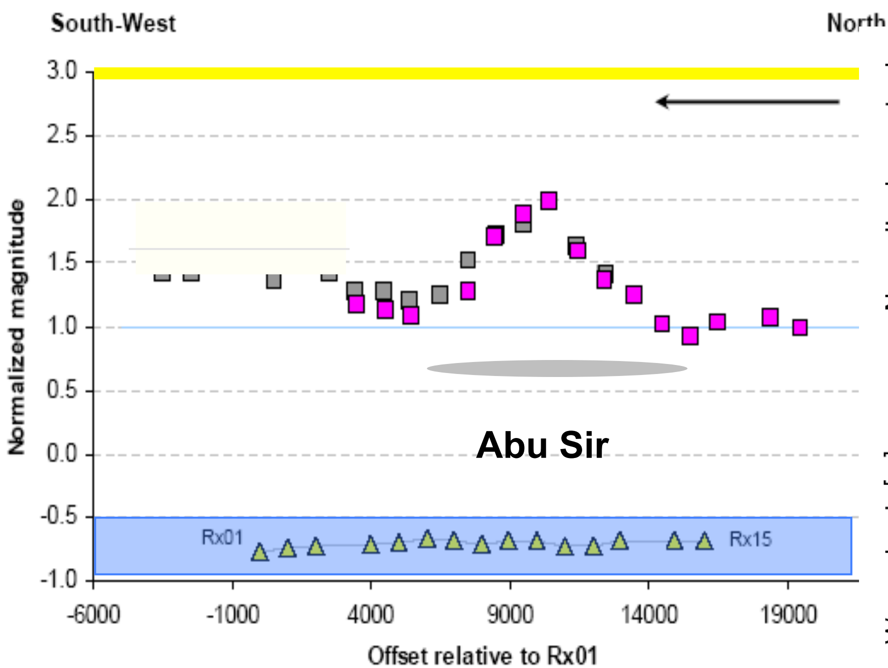
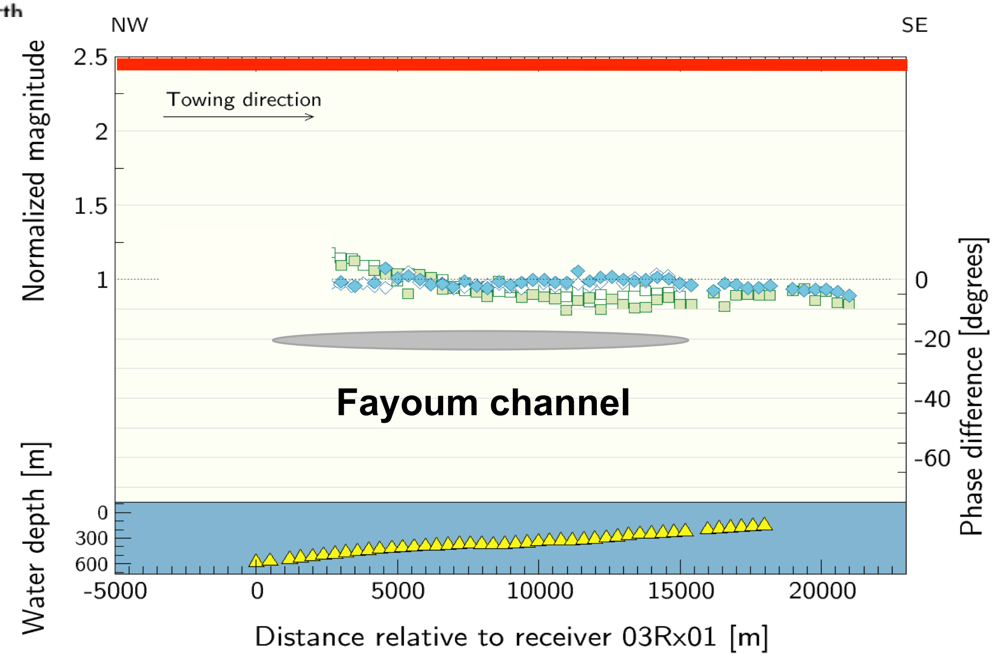
Continuous-source results



Abu Sir is clearly detected by such analysis



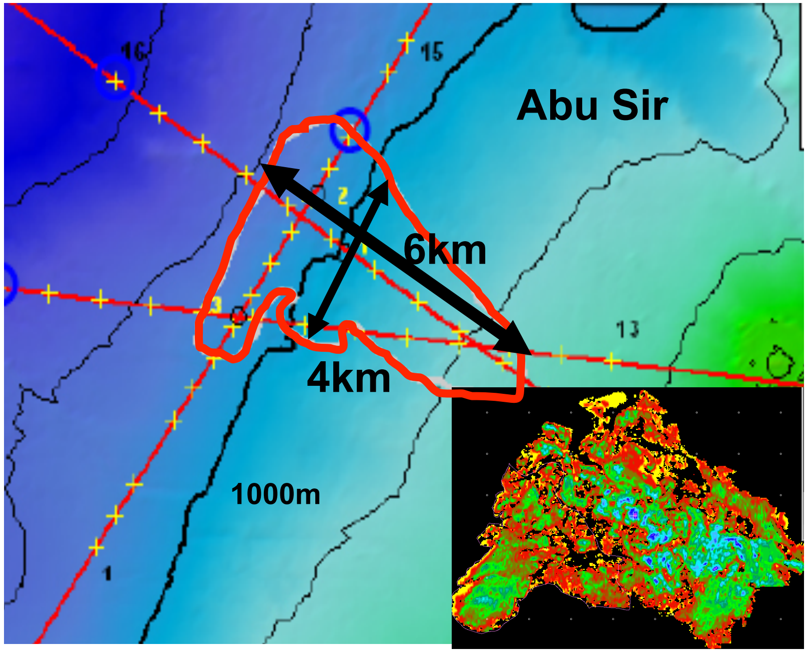
But conventional techniques fail to detect Fayoum



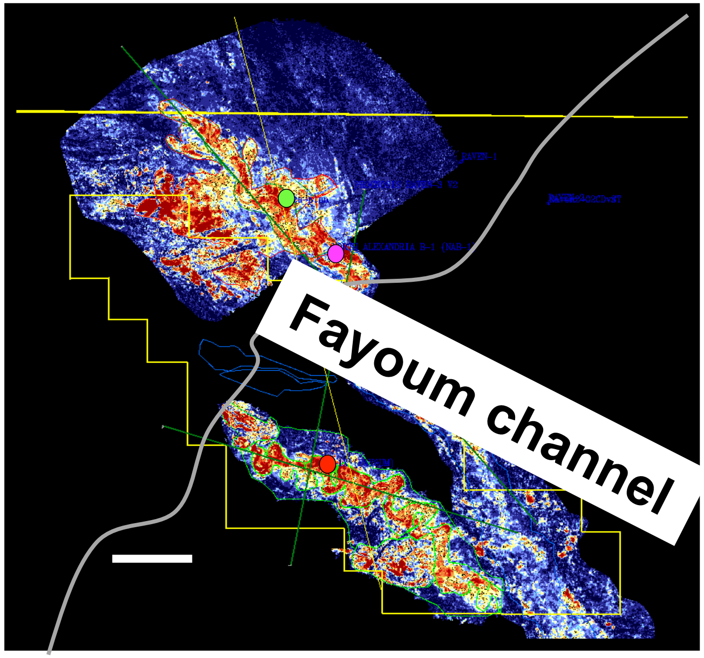
Analysis by emgs

These differences are probably due to differing subsurface geology

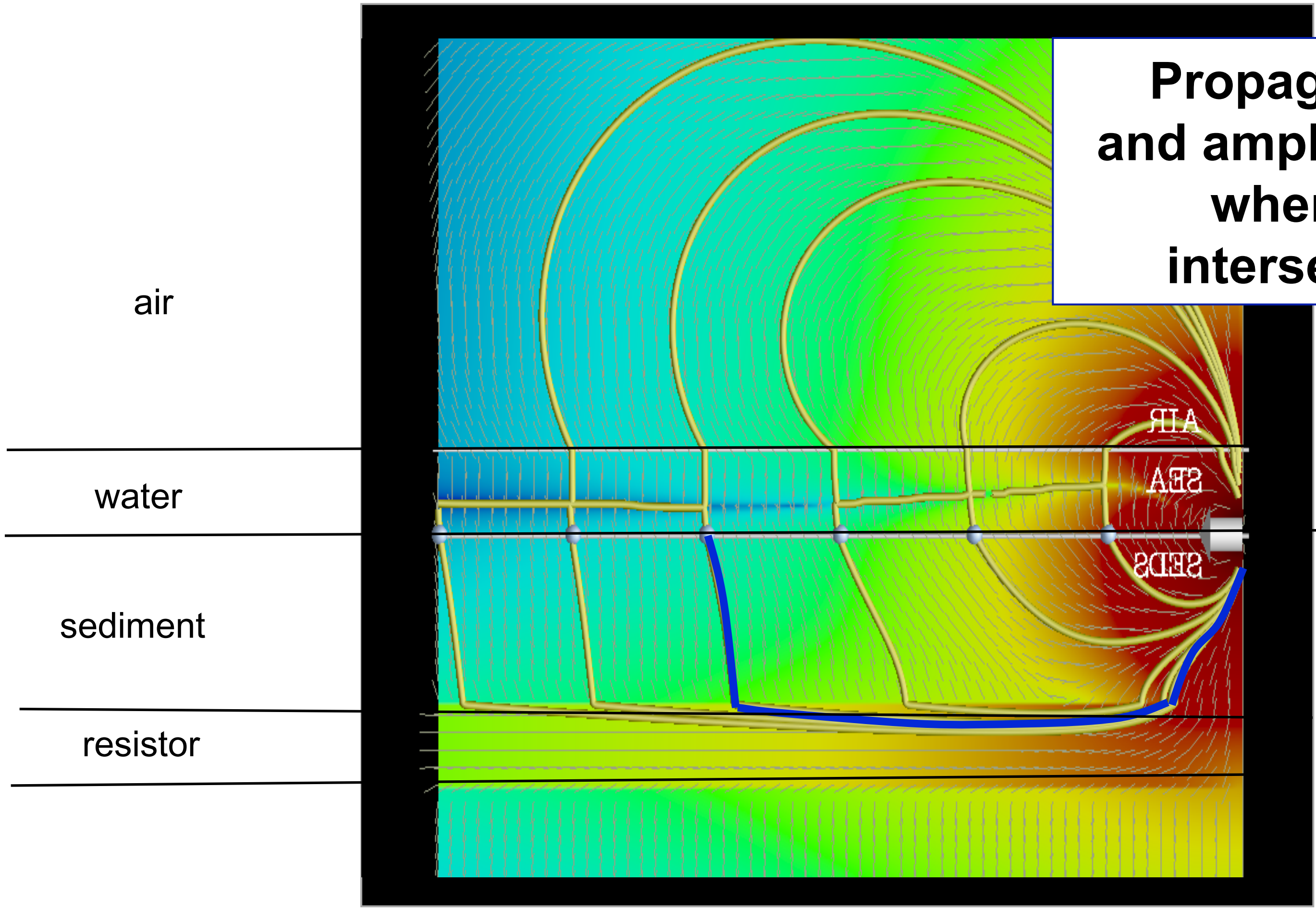
Abu Sir reservoir more oblate



Narrow channels at Fayoum



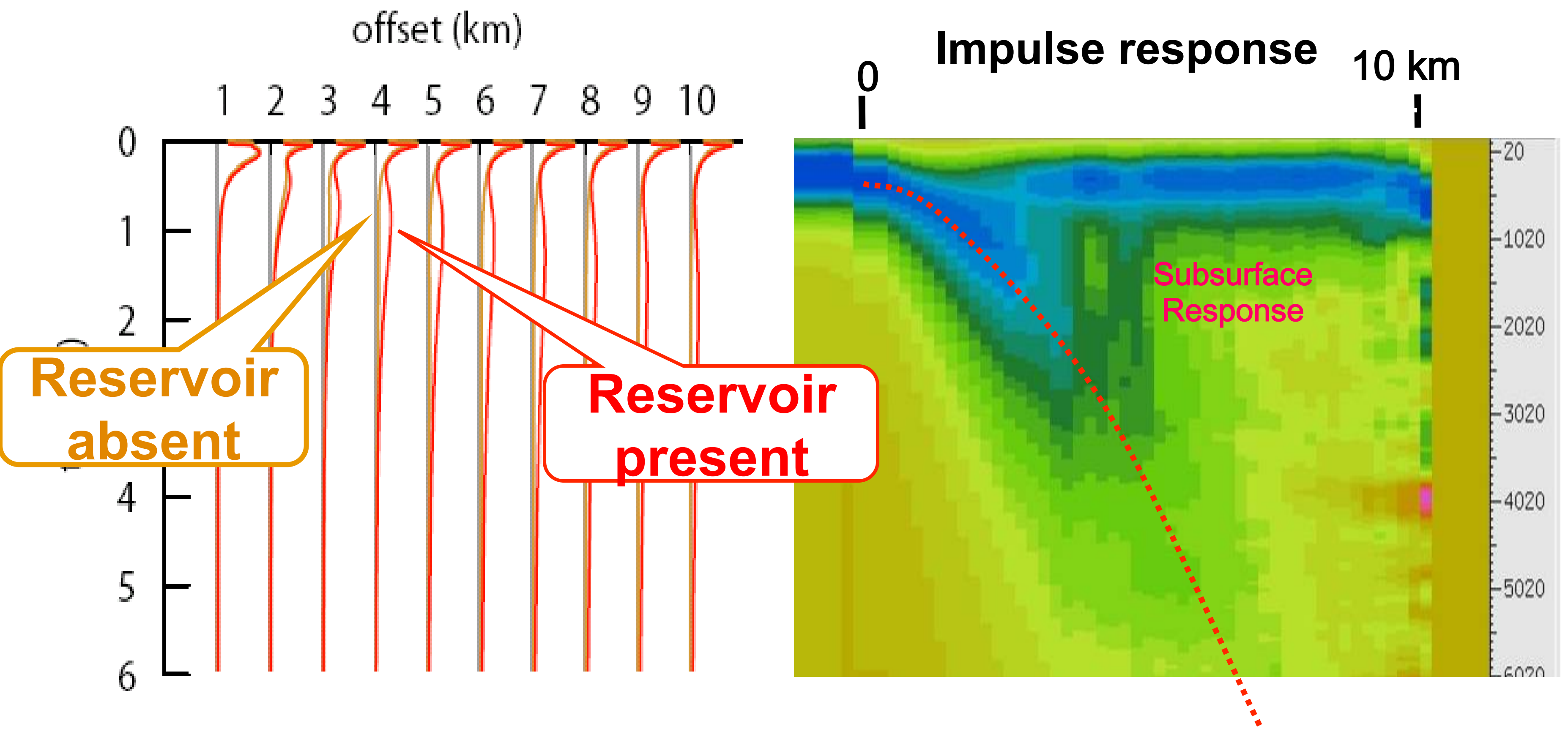
1-D modeling of EM energy transport



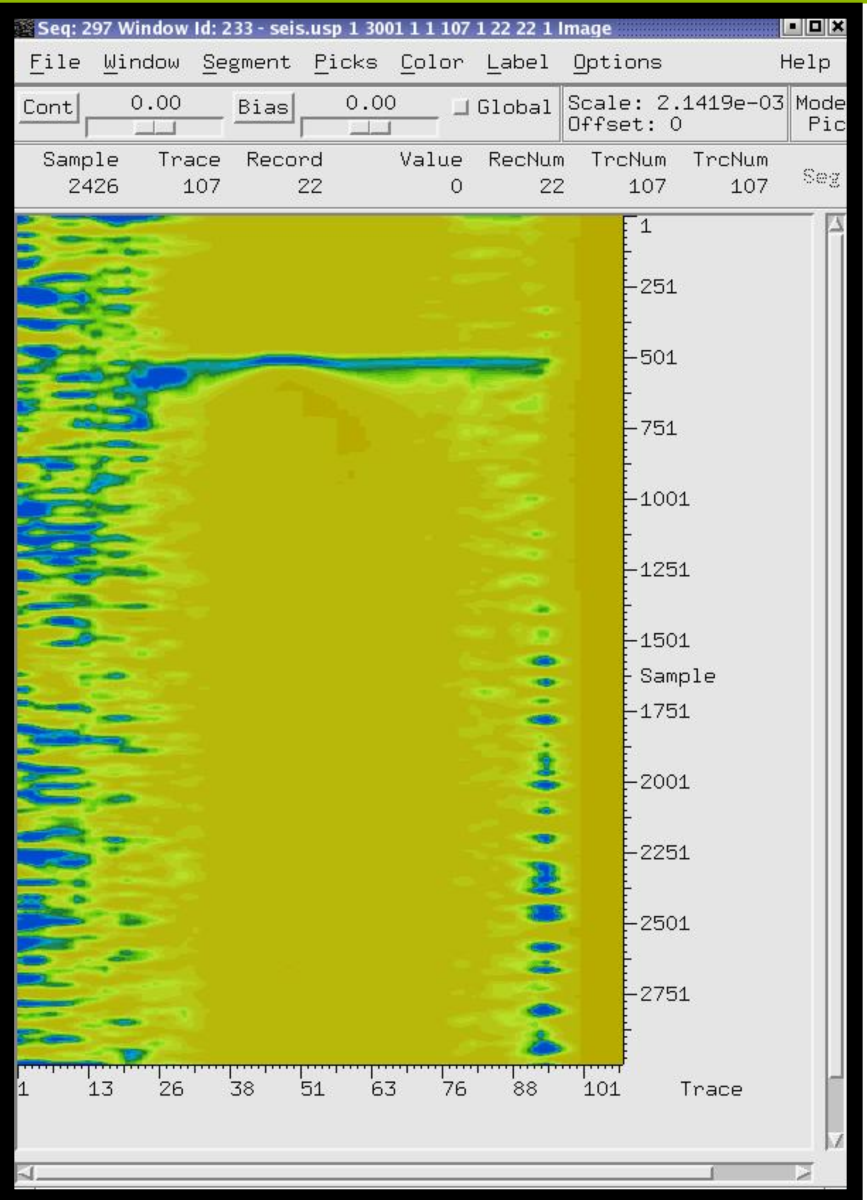
Propagation is faster, and amplitude is stronger when the current intersects a resistor

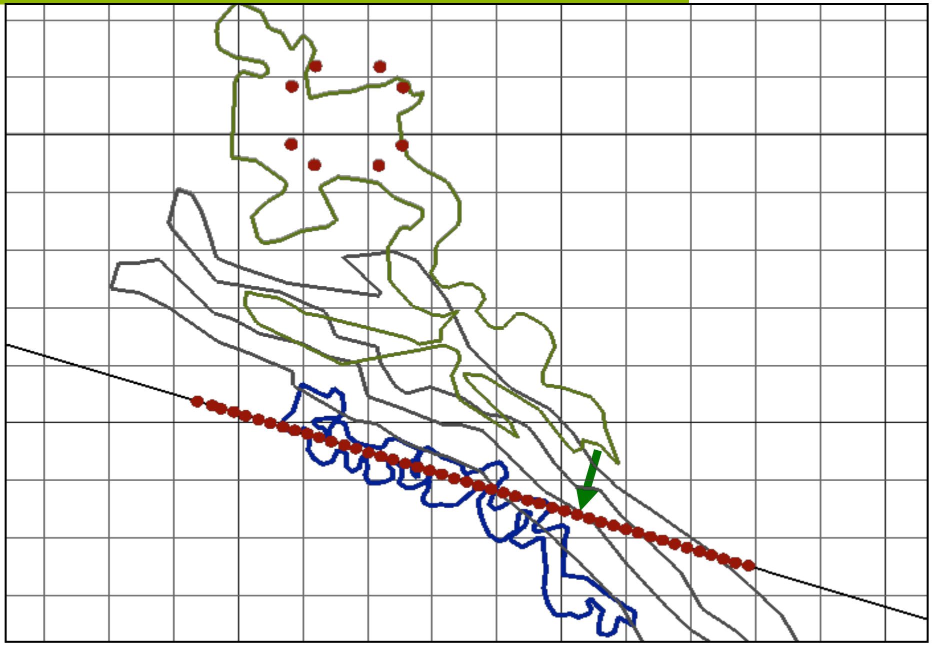
Computed pathways of EM energy transport

1-D transient-source modeling compared to real data



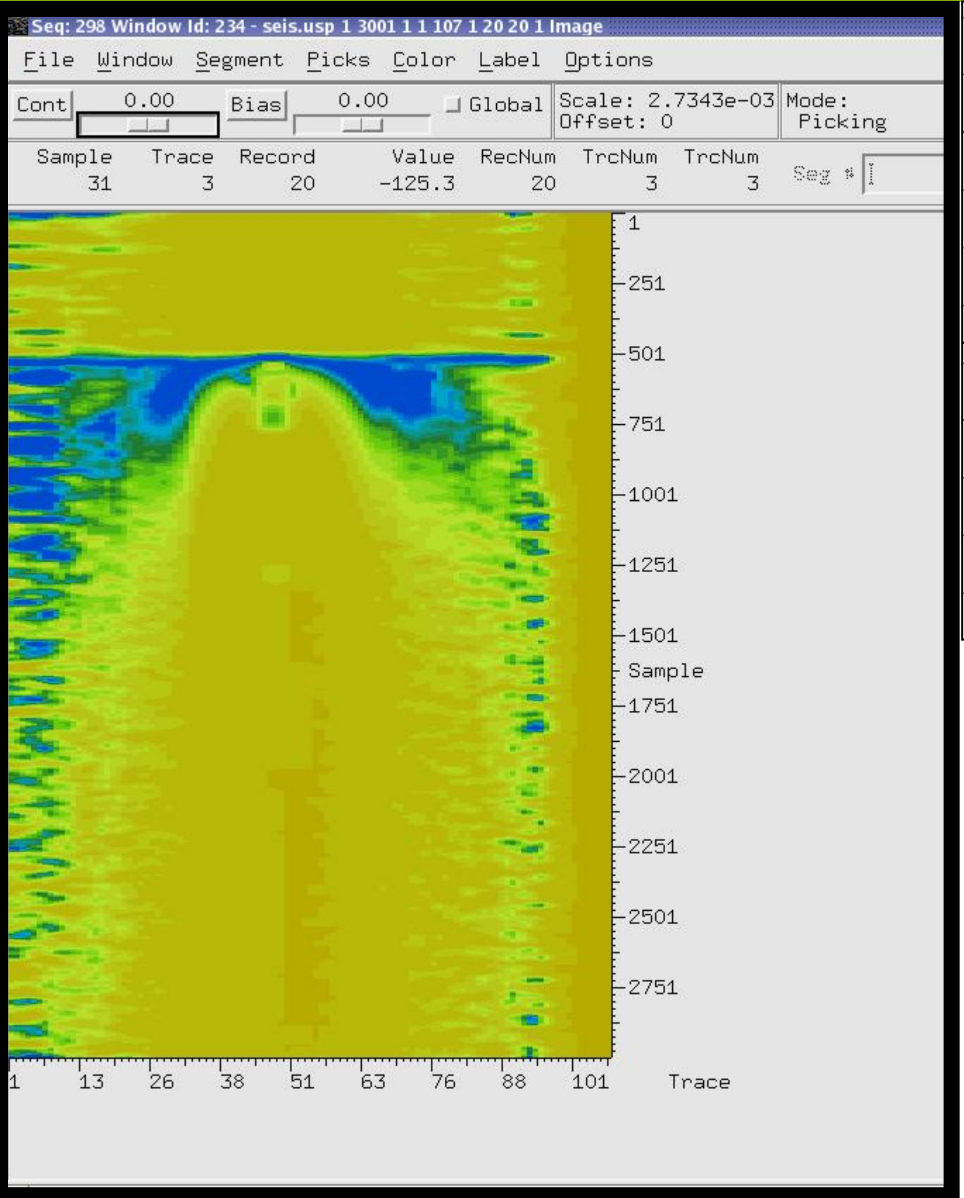
Common receiver gather, off the reservoir

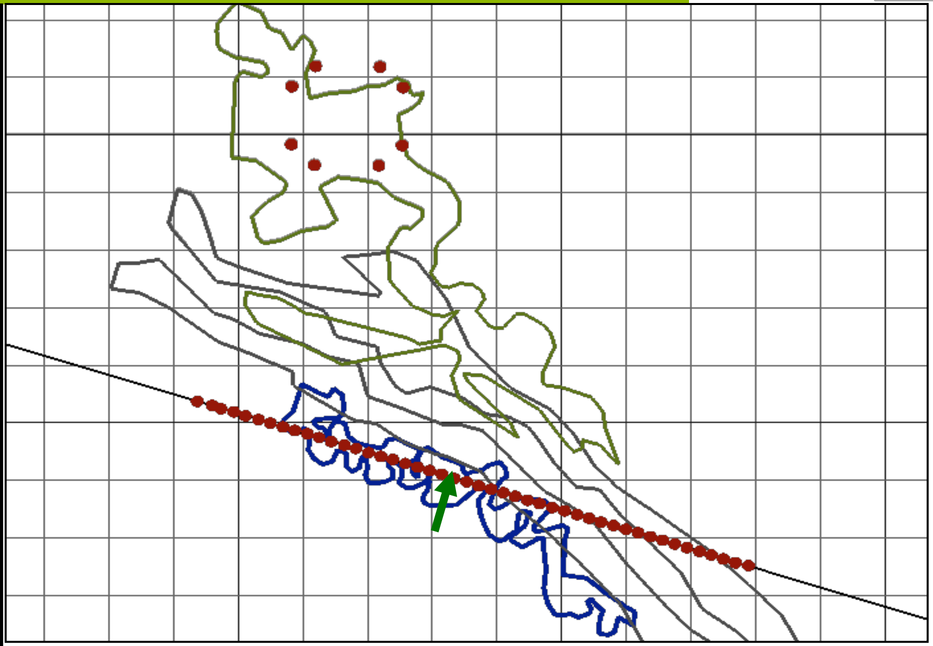




- **trace-normalization**
- **Only**
  - **air-wave,**
  - **water-wave**
  - **sediment-wave visible**

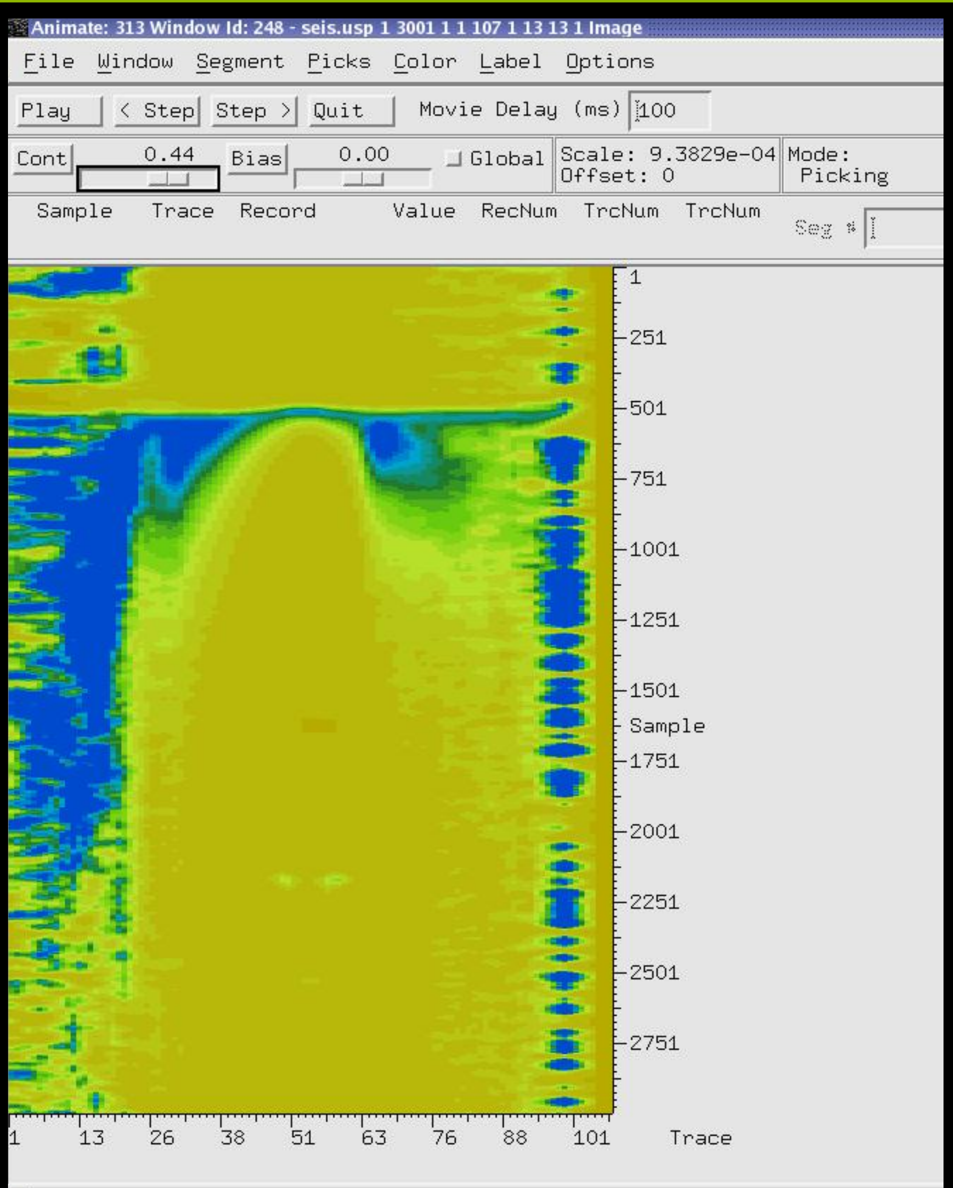
Common receiver gather, on the reservoir

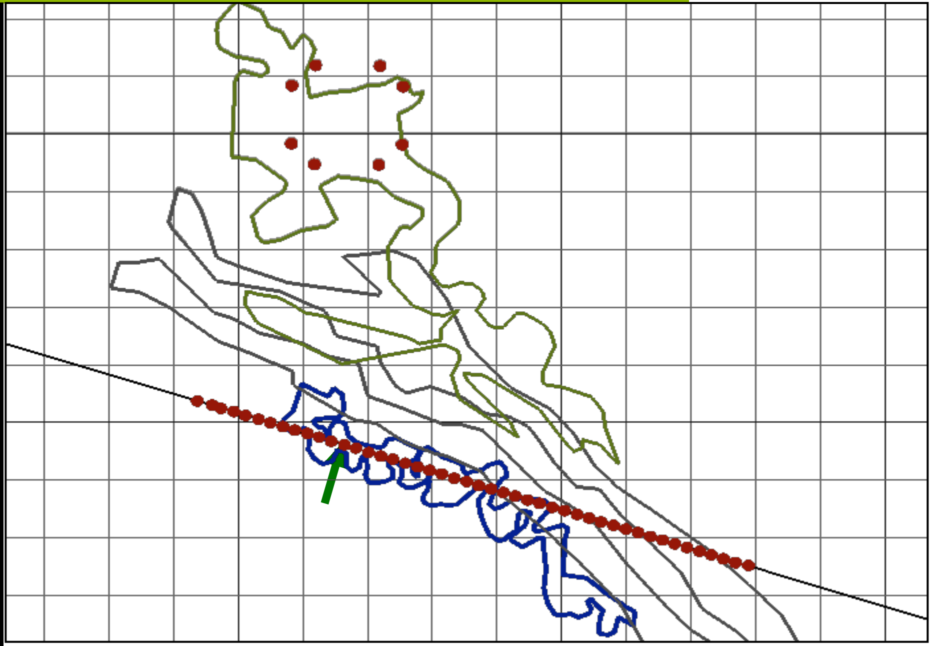




- Additional energy visible
- Arriving late
- Moving out at seismic-style velocities

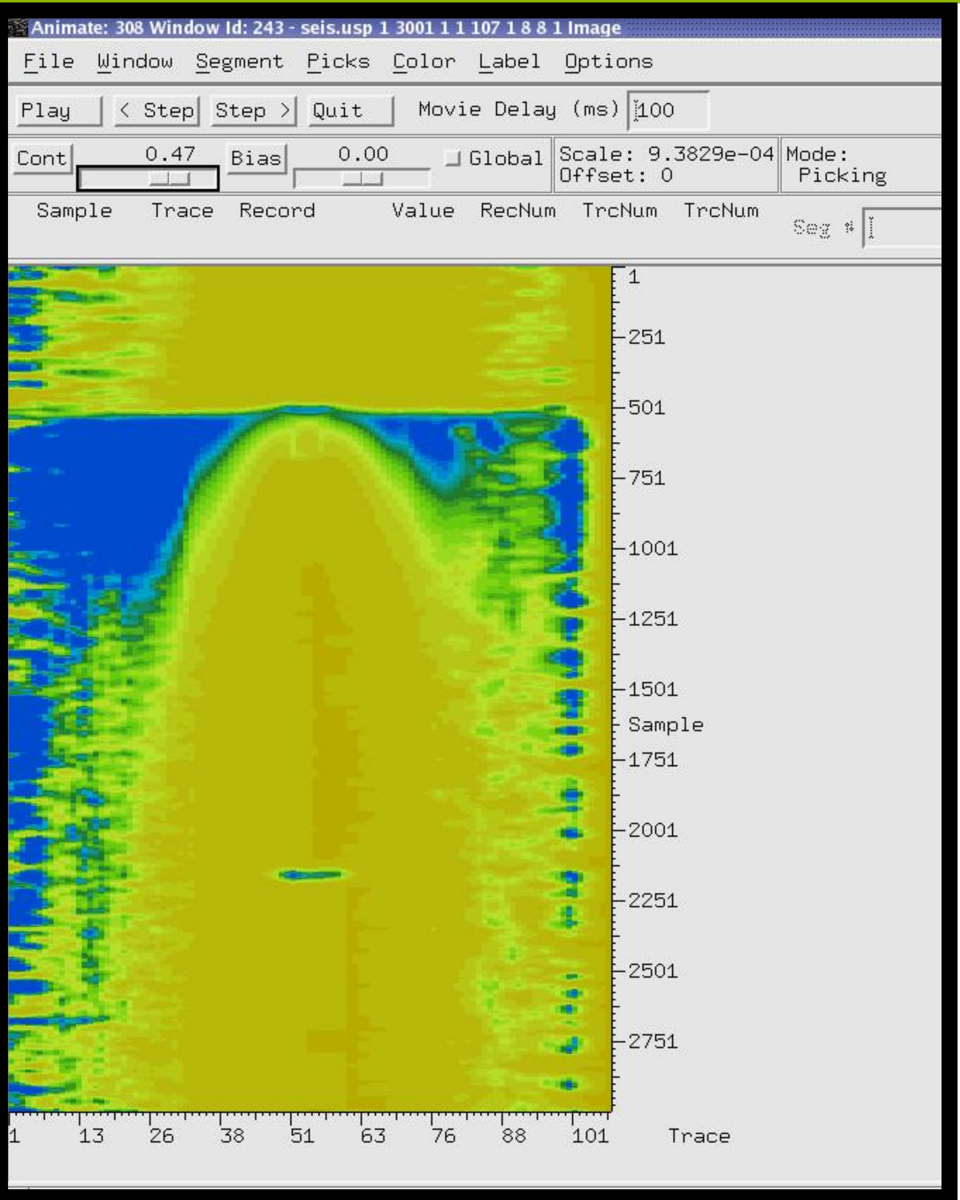
Common receiver gather, <u>on</u> the reservoir

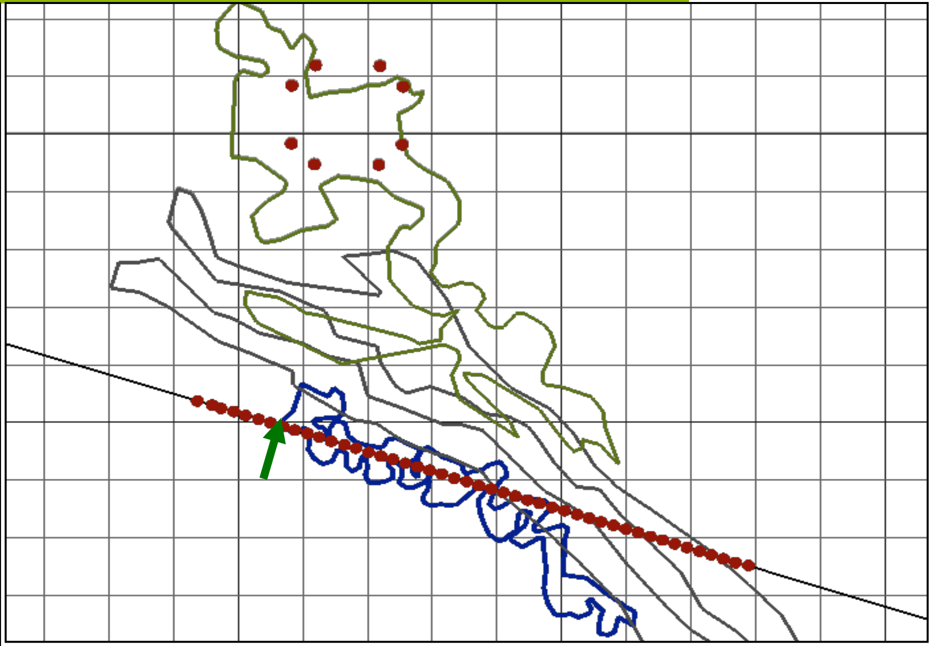




- Additional energy visible
- Arriving late
- Moving out at seismic-style velocities

Common receiver gather, at edge of reservoir





- Additional energy visible
- Arriving late
- Moving out at seismic-style velocities

West end deep water only

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Conclusions

- **Similarities between EM & seismic allows seismic style acquisition and processing for EM**
- **It is viable for marine EM data:**
  - **acquisition with a transient source**
  - **seismic-style acquisition design**
  - **moveout – based noise removal**

Conclusions

- **Results:**
  - **Pilot demonstration of marine deep transient measurements**
  - **Case history linked known gas reservoir**
  - **Acquisition completed with industrial CSEM system (with special modifications)**
  - **Frequency & time domain CSEM acquired with one receiver deployment**
  - **Data proves the “seismic-style” understanding**
  - **Time domain CSEM reveals known reservoir where conventional CSEM is not successful.**

Acknowledgements

We thank:

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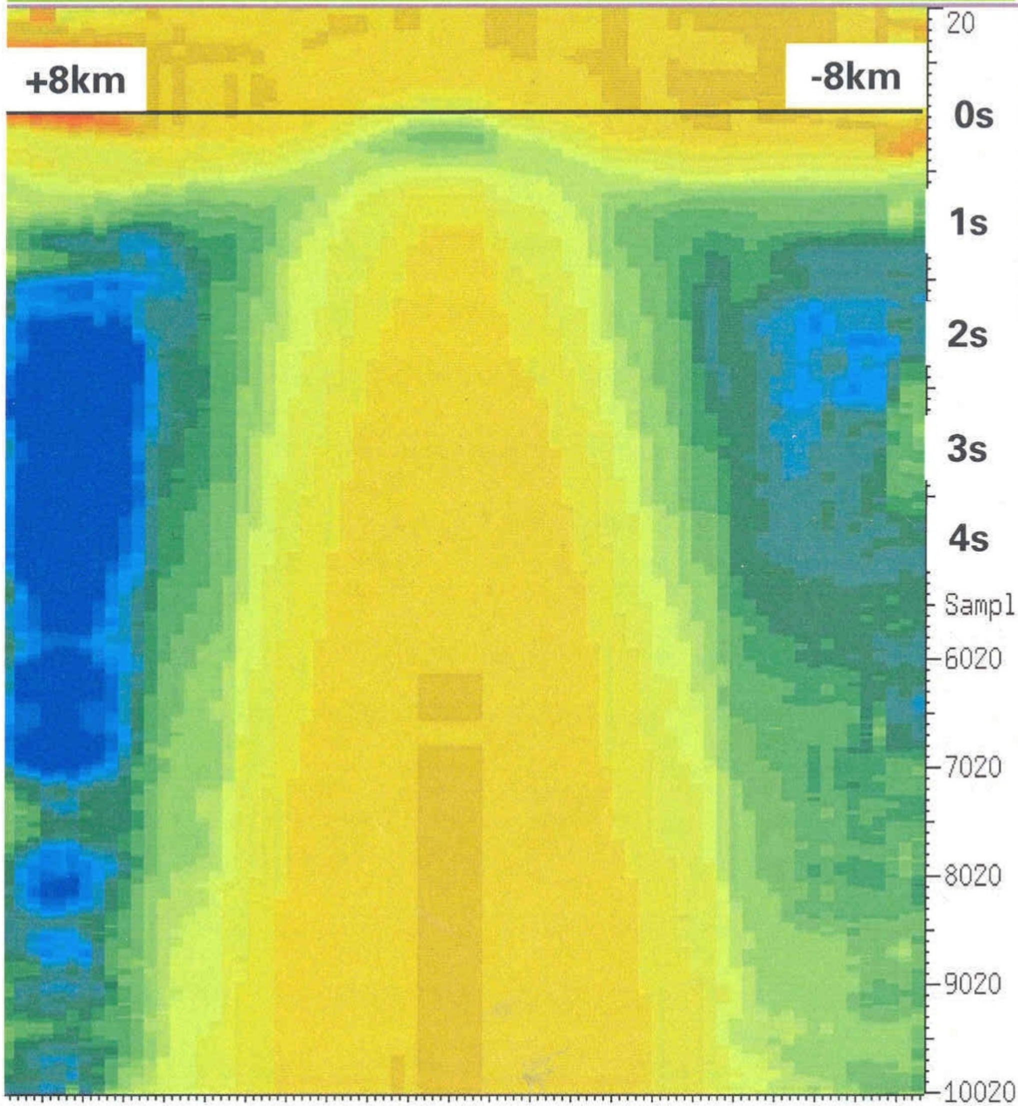
  - **Duncan Attoe, Gary Nicol, Brian Barley, Lisa Rebora and Dave Cowper (BP Egypt) for material assistance**
  - **Eric Green, Michelle Judson, Tim Lane, Mark Truxillo, and Tim Summers for organizational support**
- **Charles Stoyer (KMS) for custom programming**
- **Tilman Hanstein (KMS) for field operations & processing and Yardenia Martinez (KMS) for processing assistance**
- **emgs, inc. for field operations**

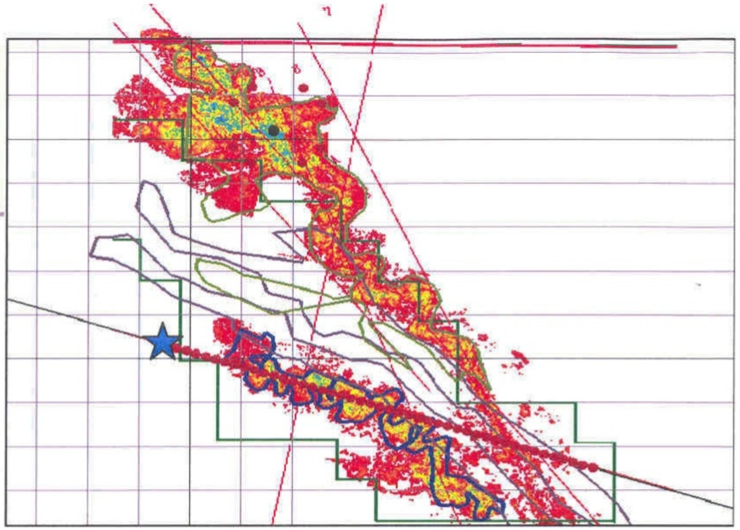
Comments

- After BP agreed before the presentation, we contributed for free, and after, they finally gave us a paper copy version of the following slides.

- Please do NOT publish or handout or publically present this material. It should be only used for KMS internal use.

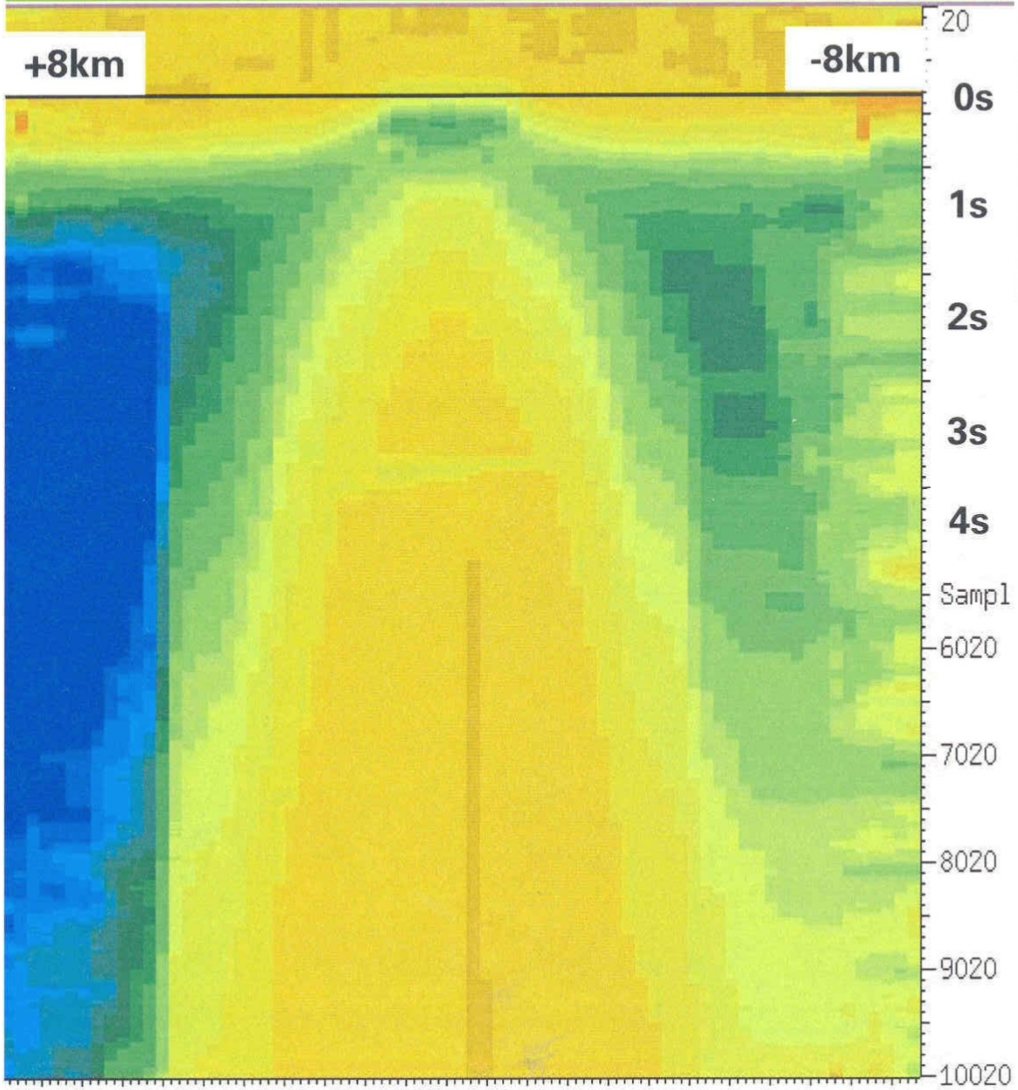
Common Receiver Gather
Off reservoir: deep water

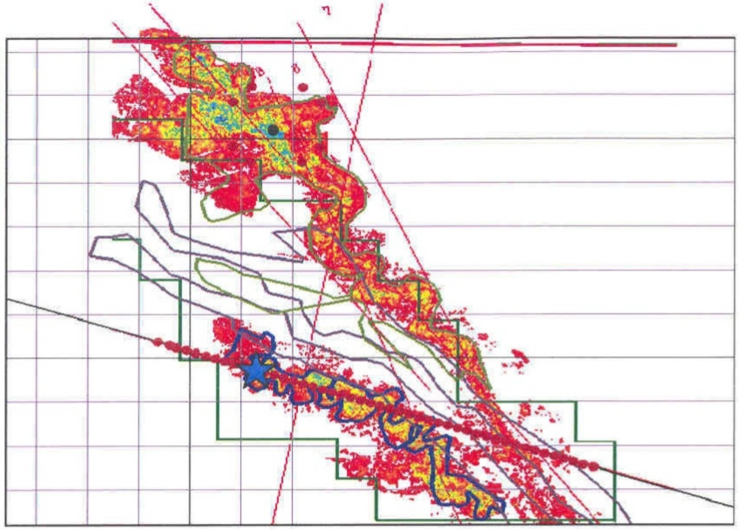




- **data clean-up, rotation, time-differentiation, trace-normalization**
- **Only visible:**
  - **air-wave,**
  - **water-waves**
  - **sediment-wave**

Common Receiver Gather
Edge of reservoir

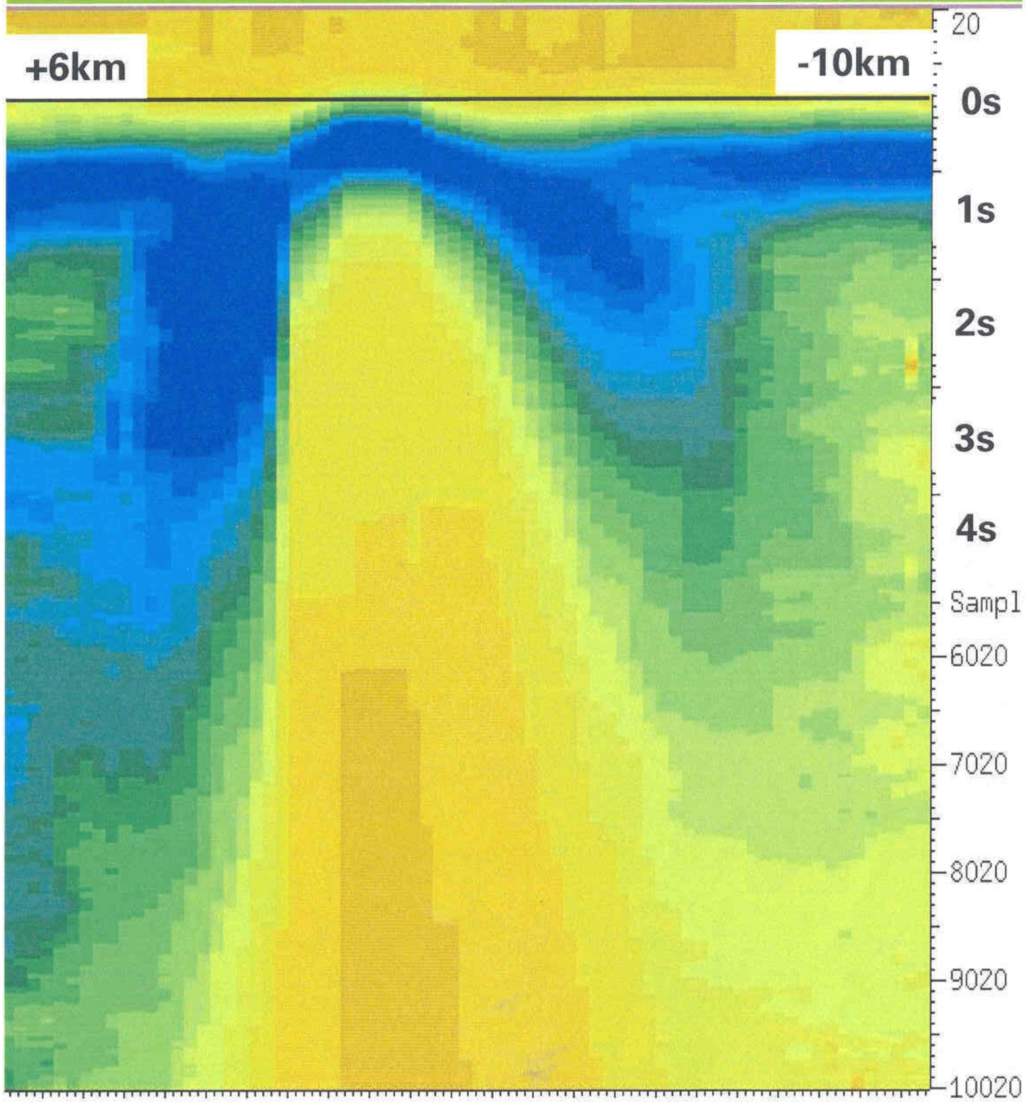


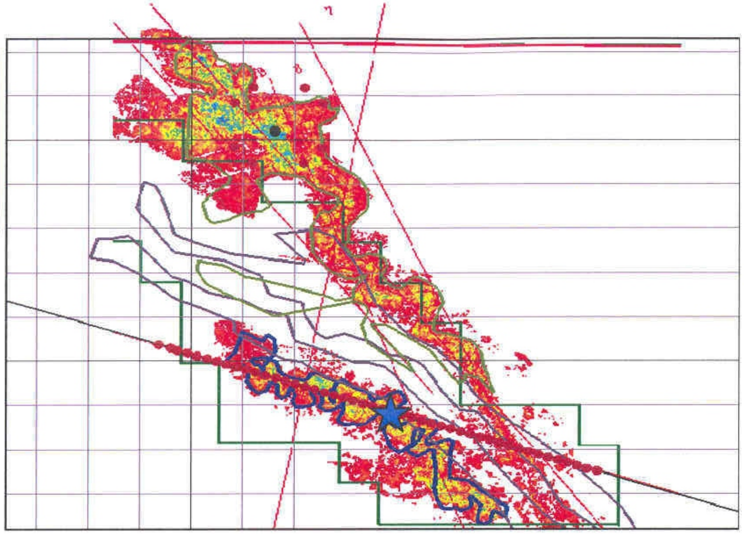


- data clean-up, rotation, time-differentiation, trace-normalization

- **Additional energy visible: reservoir-side only; arriving late, moving out at seismic-style velocities**

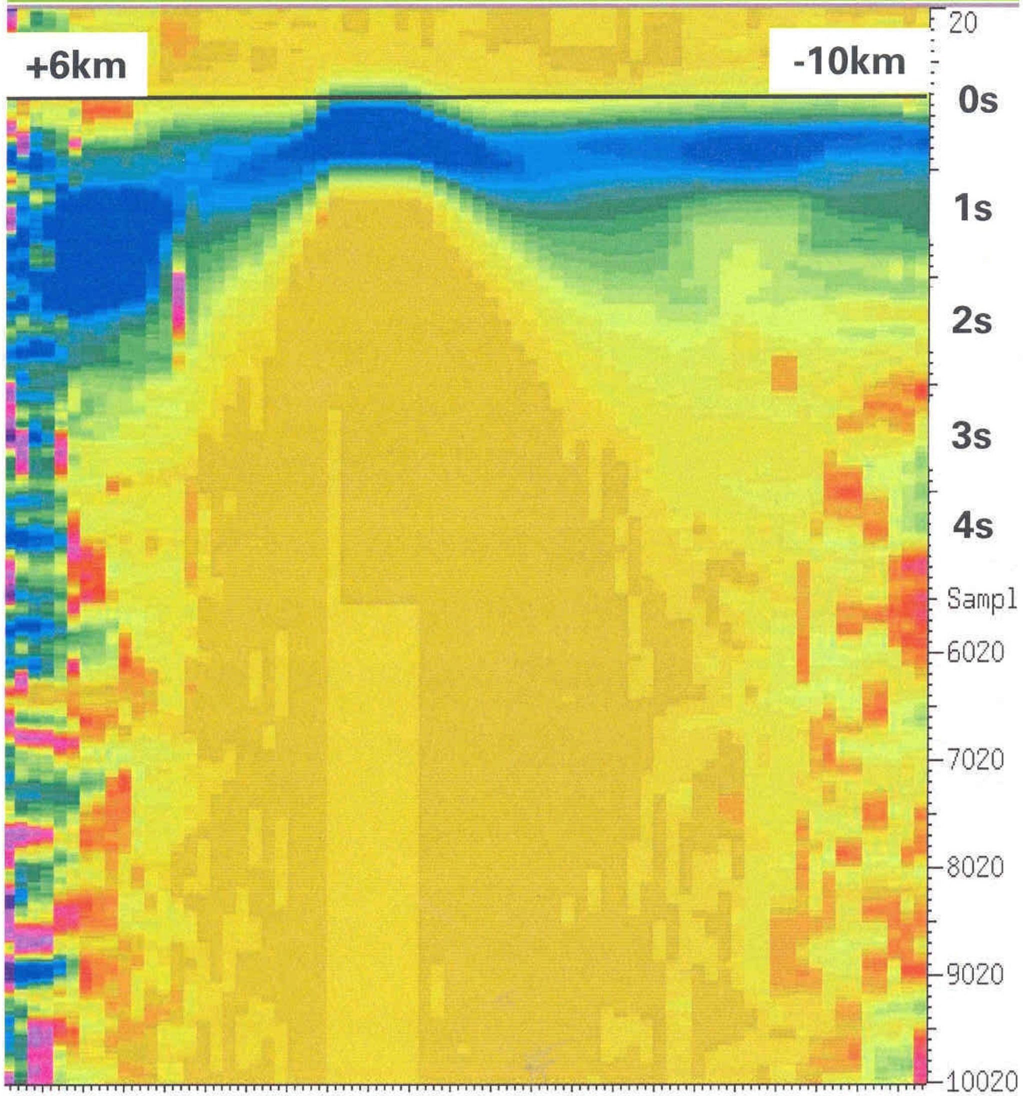
Common Receiver Gather Within reservoir complex

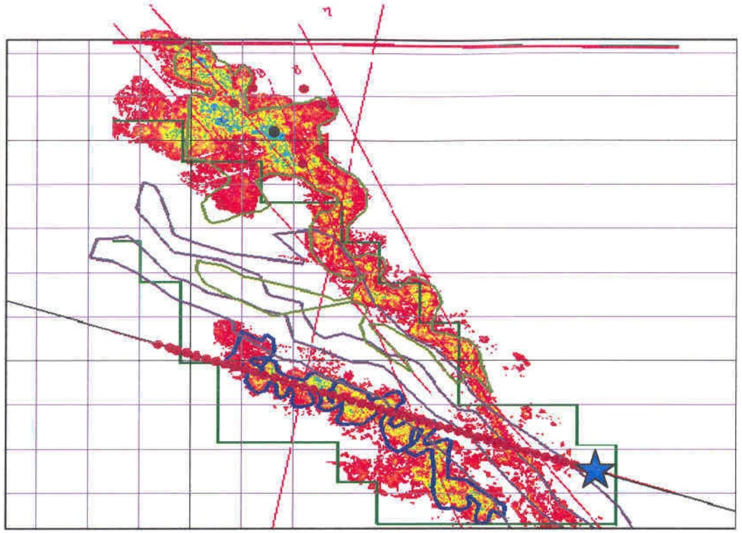




- data clean-up, rotation, time-differentiation, trace-normalization
- **Additional energy visible: complex reservoir geometry**

Common Receiver Gather
Off reservoir:shallow water





- **data clean-up, rotation, time-differentiation, trace-normalization**
- **Only visible:**
  - **air-wave (arriving sooner)**
  - **water-waves**
  - **sediment-wave**

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