Future applications for CSEM: shales and monitoring

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Objective

To show how NEW array electromagnetics can address some issues for shale resources & reservoir monitoring

Issues

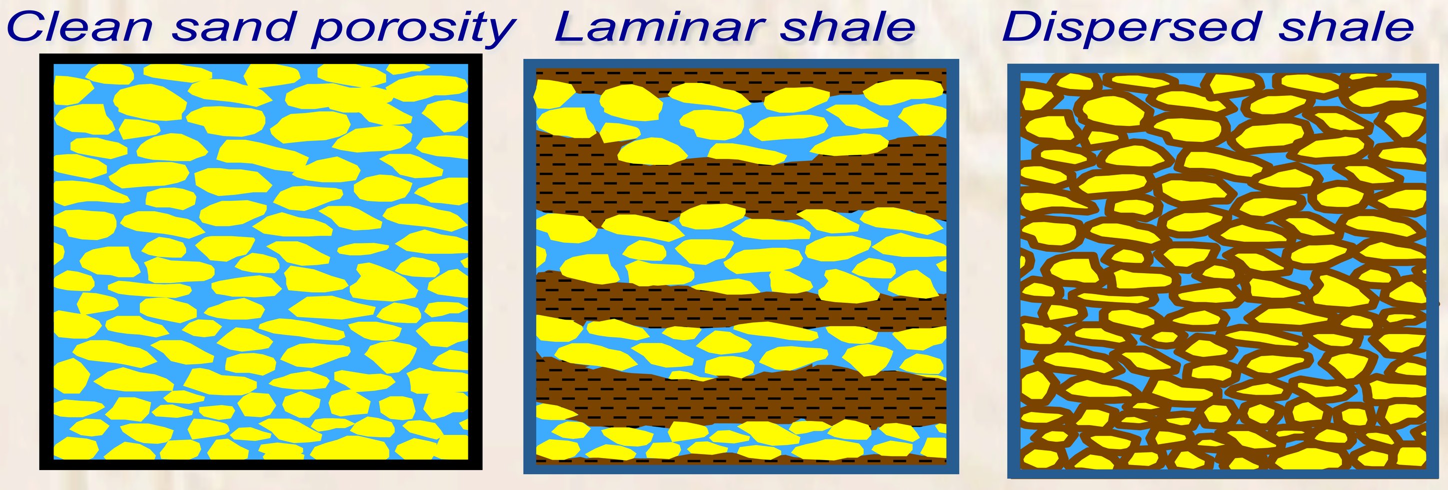
1. Anisotropy
2. Borehole-to-surface calibration/integration
3. Surface measurements:
   - noise & resolution
   - 3D subsurface focus of information
4. Borehole measurements: upscaling

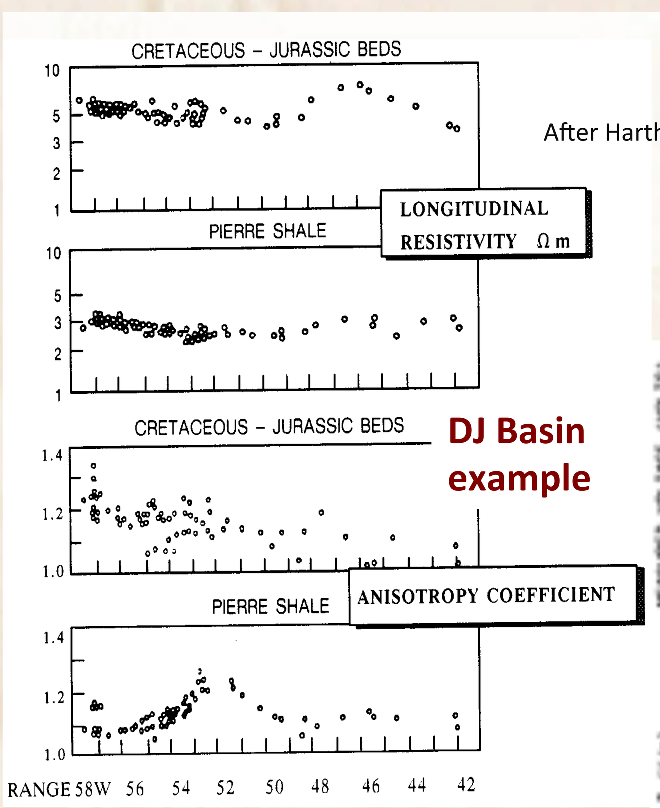
→NEED: - Tensor measurements;
- Full 3D integration

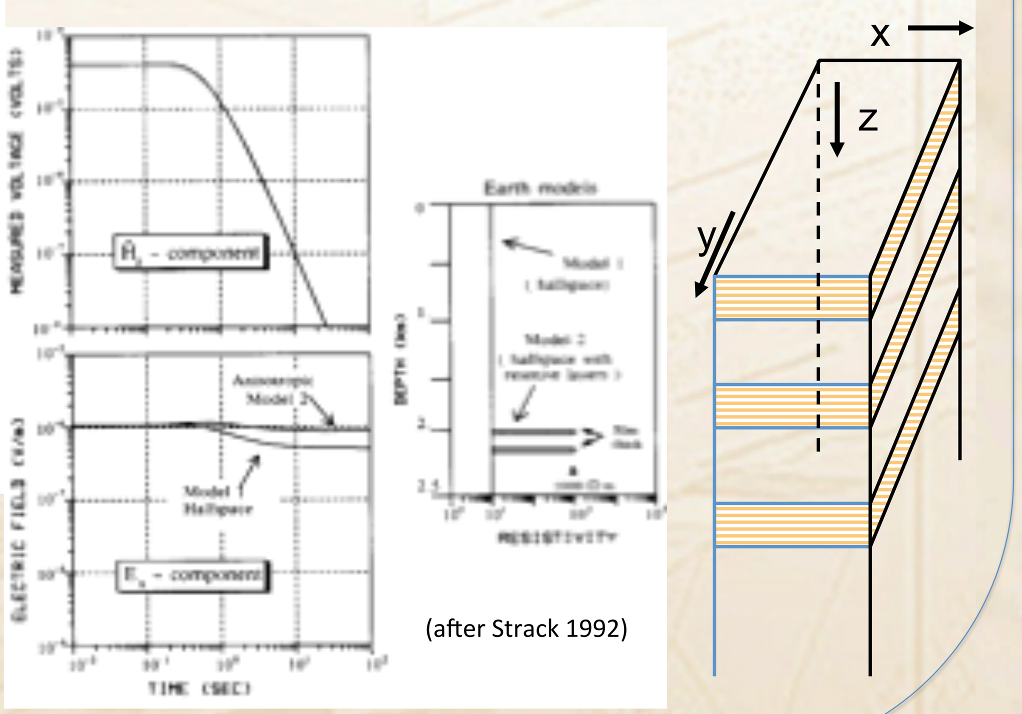
Shale gas/oil issues – **EM answers**

- Oil/gas is inside shales – **Resistor in a conductor**
- Reservoirs are thin – **Thin resistive layer effect**
  DHI for surface, 3D induction log for borehole
- Low porosity/perm. → fracturing
  Larger volume → conductance/resistance changes
- Drilling → horizontal / highly devi. wells - **geosteering**
- Fractures → anisotropy – **3D EM anisotropy**

Clean sand porosity *Laminar shale* *Dispersed shale*

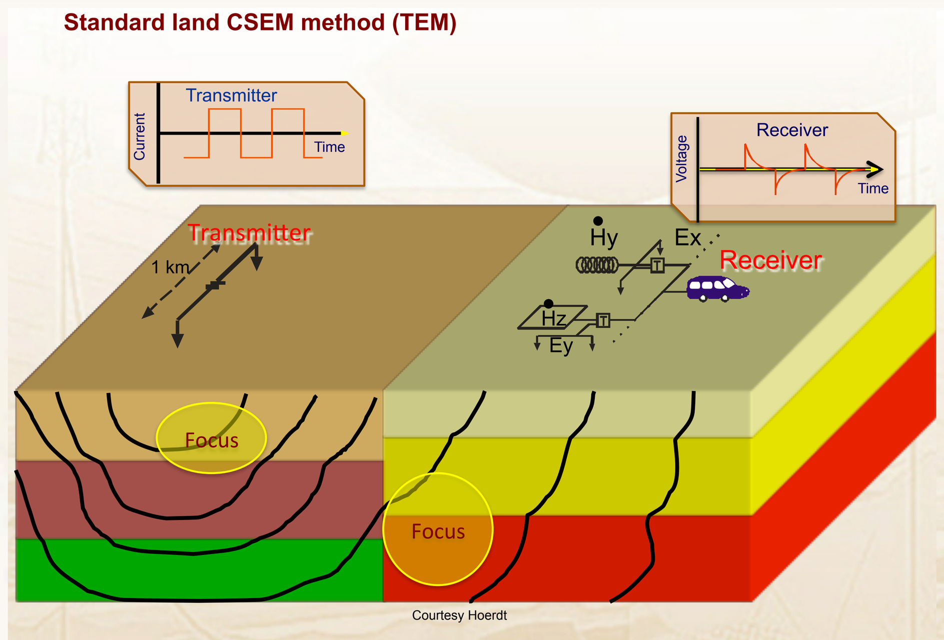


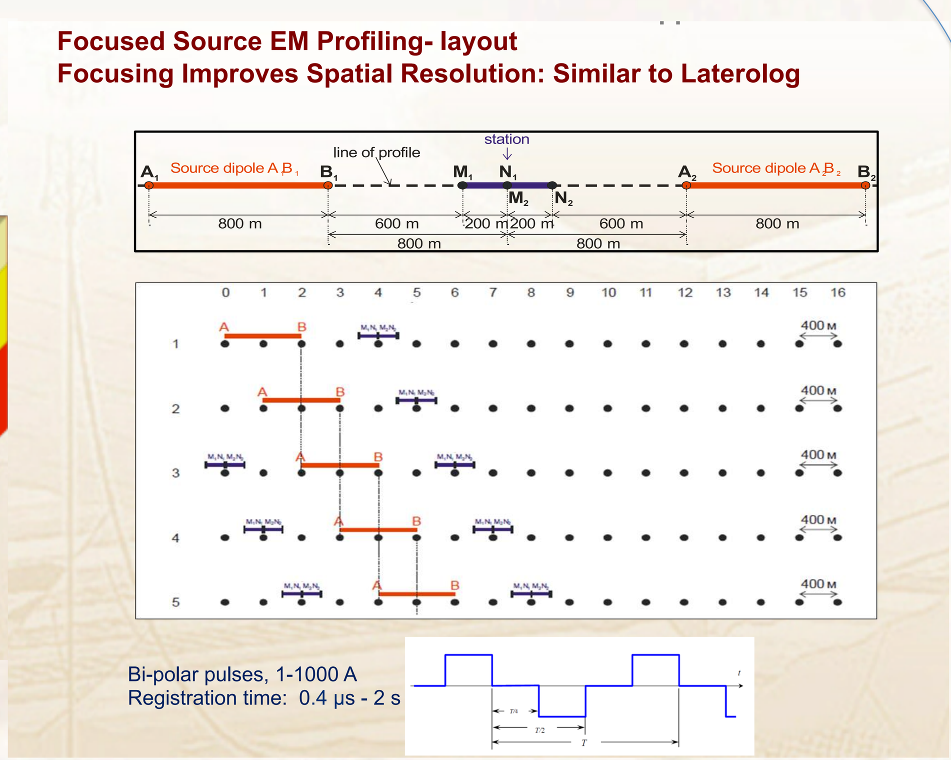


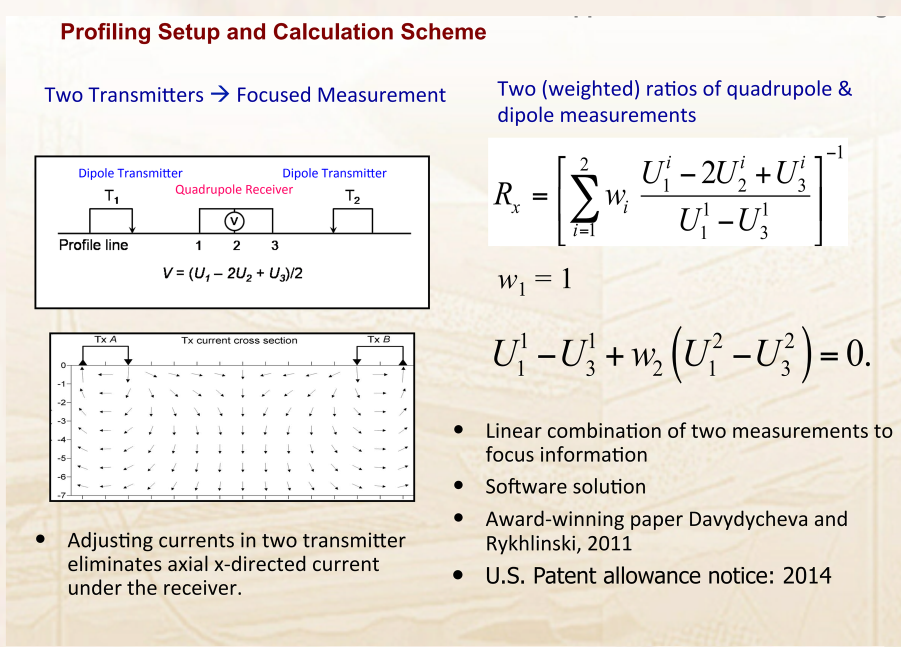


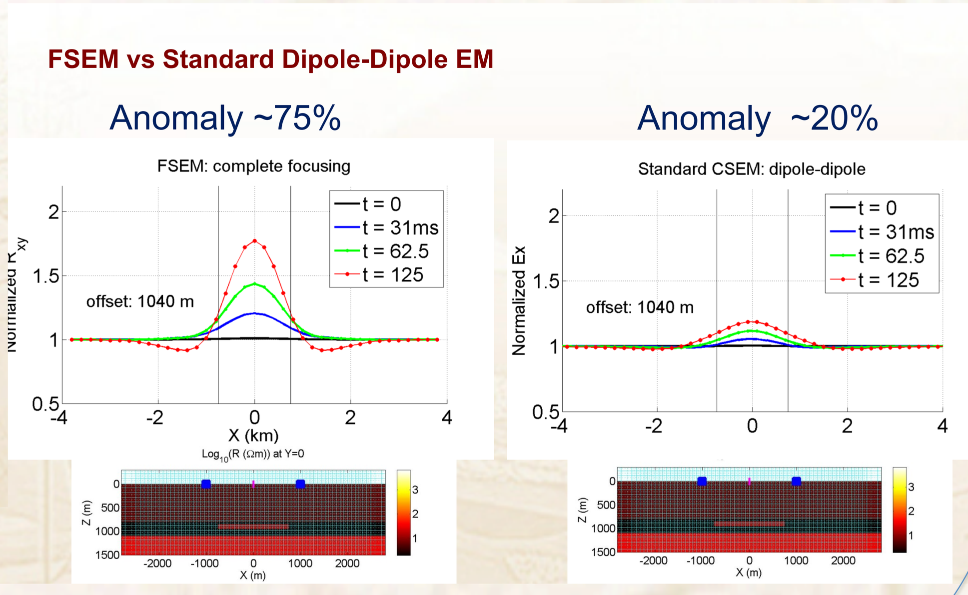
EM Methods

- Magnetotellurics – **passive not detailed enough**
- Controlled Source Electromagnetics (CSEM)
  (the ONLY way to get vertical current flow)
  - Time domain EM – a single signal generating event, volume focused
  - Frequency domain EM – a fixed frequency continuous event, information spread between Tx & RX





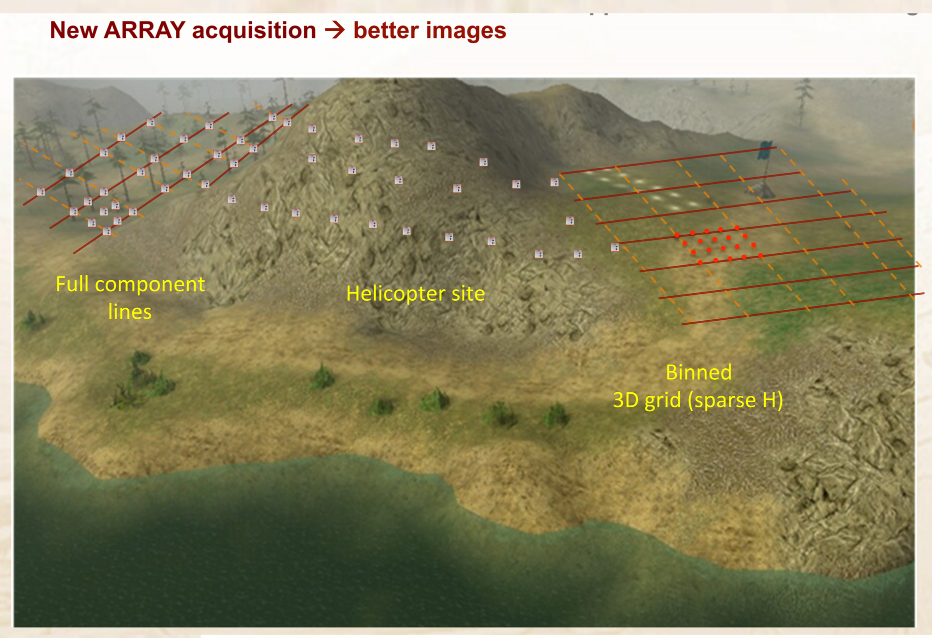


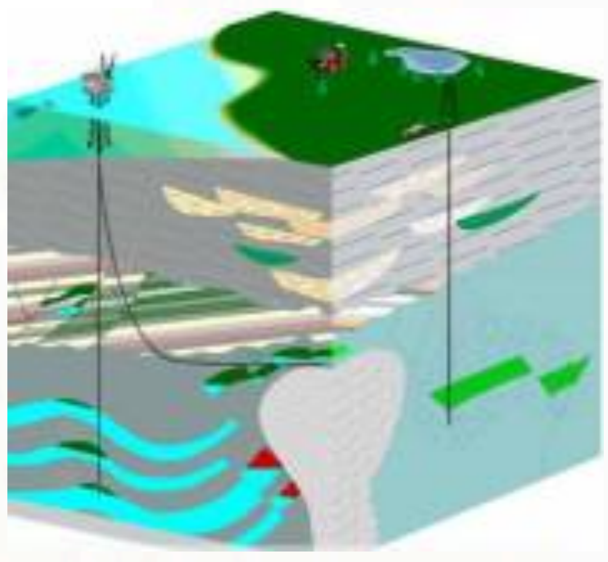


Methods

- **EM array for land & marine, borehole.**
  - **Land Magnetotelluric (MT) system**
  - **Marine seismic/EM broadband station**
  - **Sensors: coils, fluxgate mags, electrodes**
- **Wireless, array, 24 or 32 bits**
- **Unlimited components per site (fully synchronized)**
- **High channel CSEM system**
- **Land MT/CSEM seismic-style EM acquisition**
  - **Nodal tCSEM™ (fully commercial)**
  - **Sources: schedule controllable = multi source operation**

Hardware





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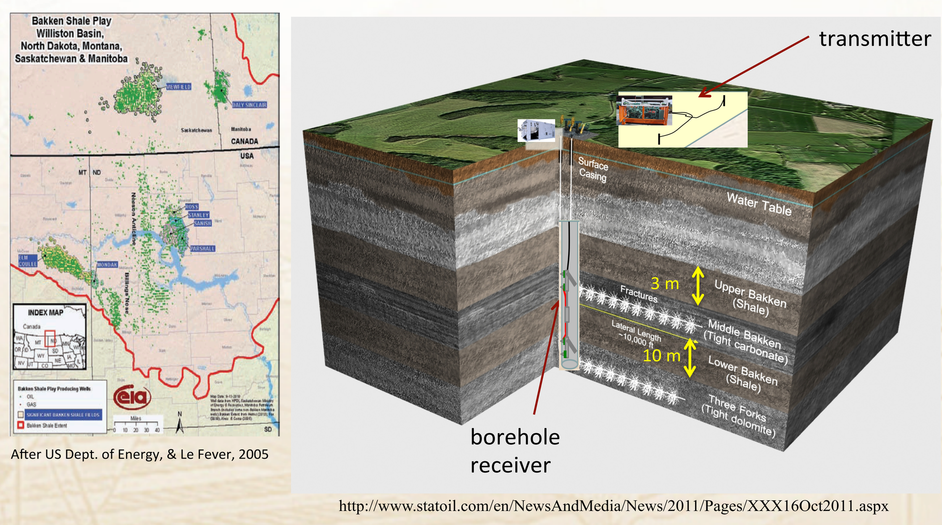
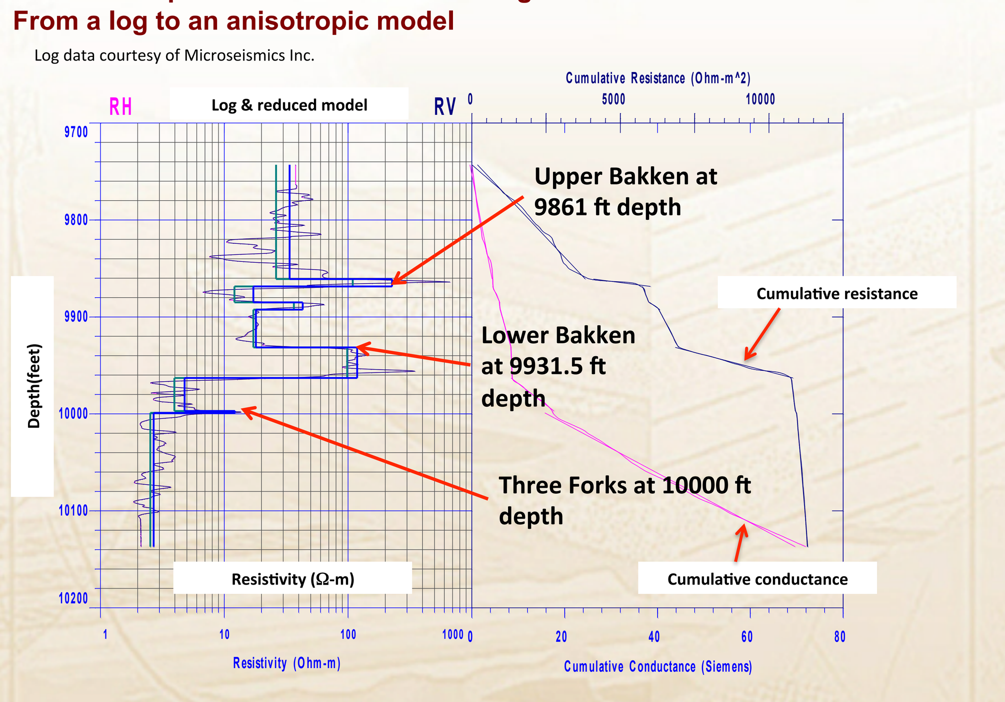
Shale applications: Bakken

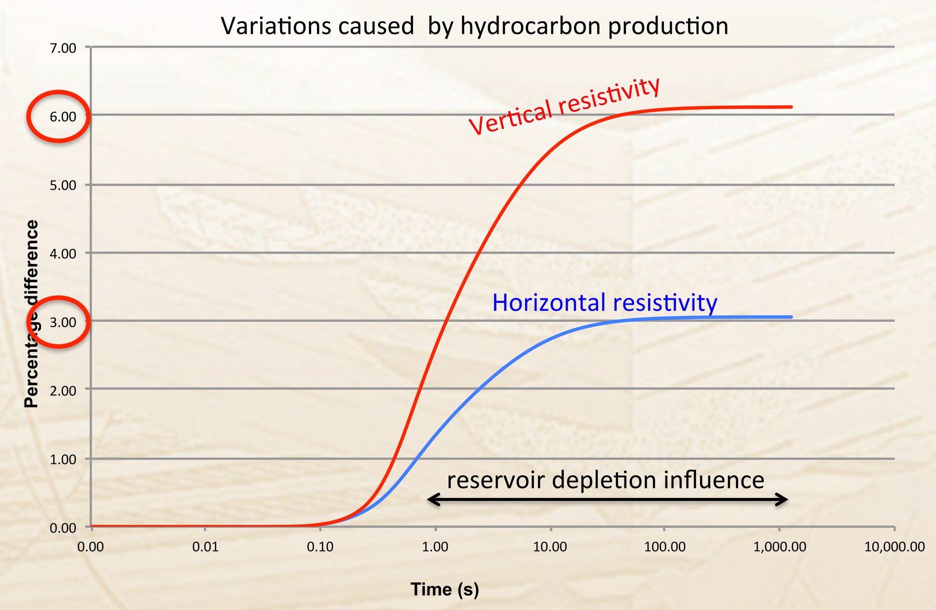
How did we get started? Bakken – depletion & fracture monitoring



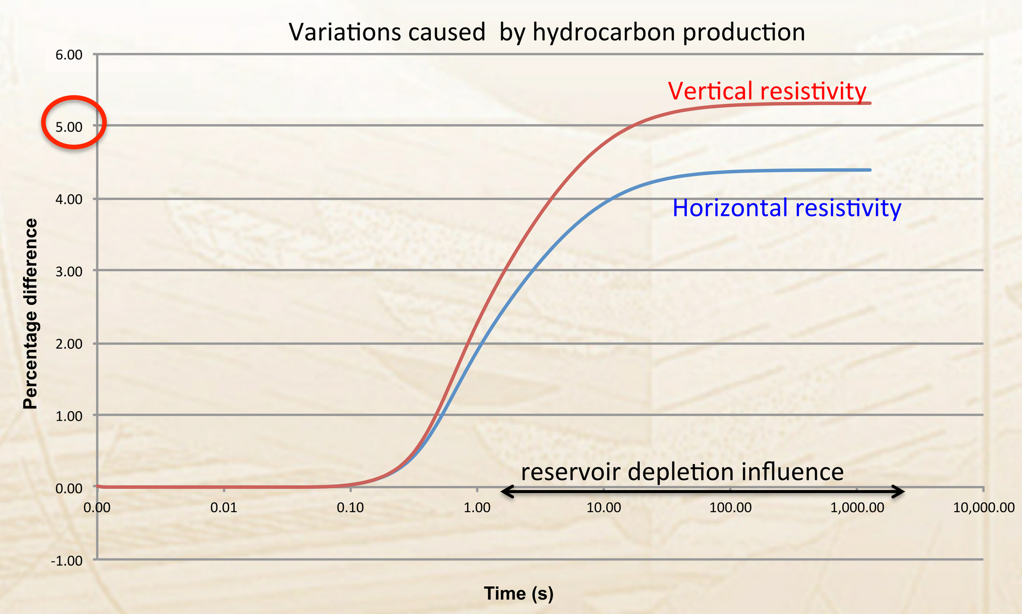
Bakken – depletion & fracture monitoring
From a log to an anisotropic model



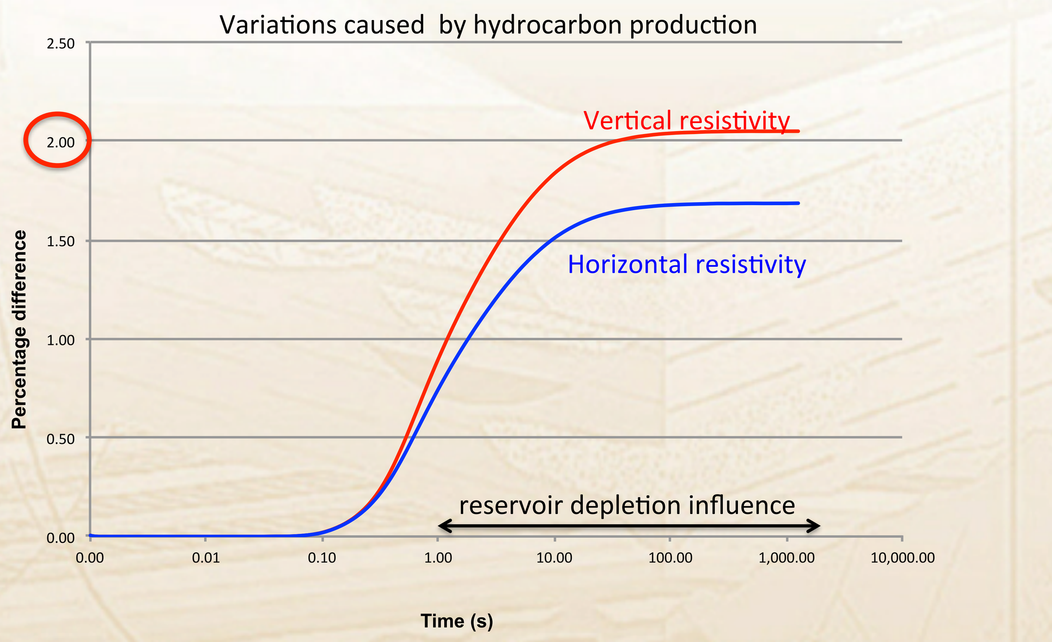
CSEM time lapse: before & after production (full fluid substitution)



Shale plays: CSEM time lapse: ALL 3 reservoirs, 10% depleted, horiz. well



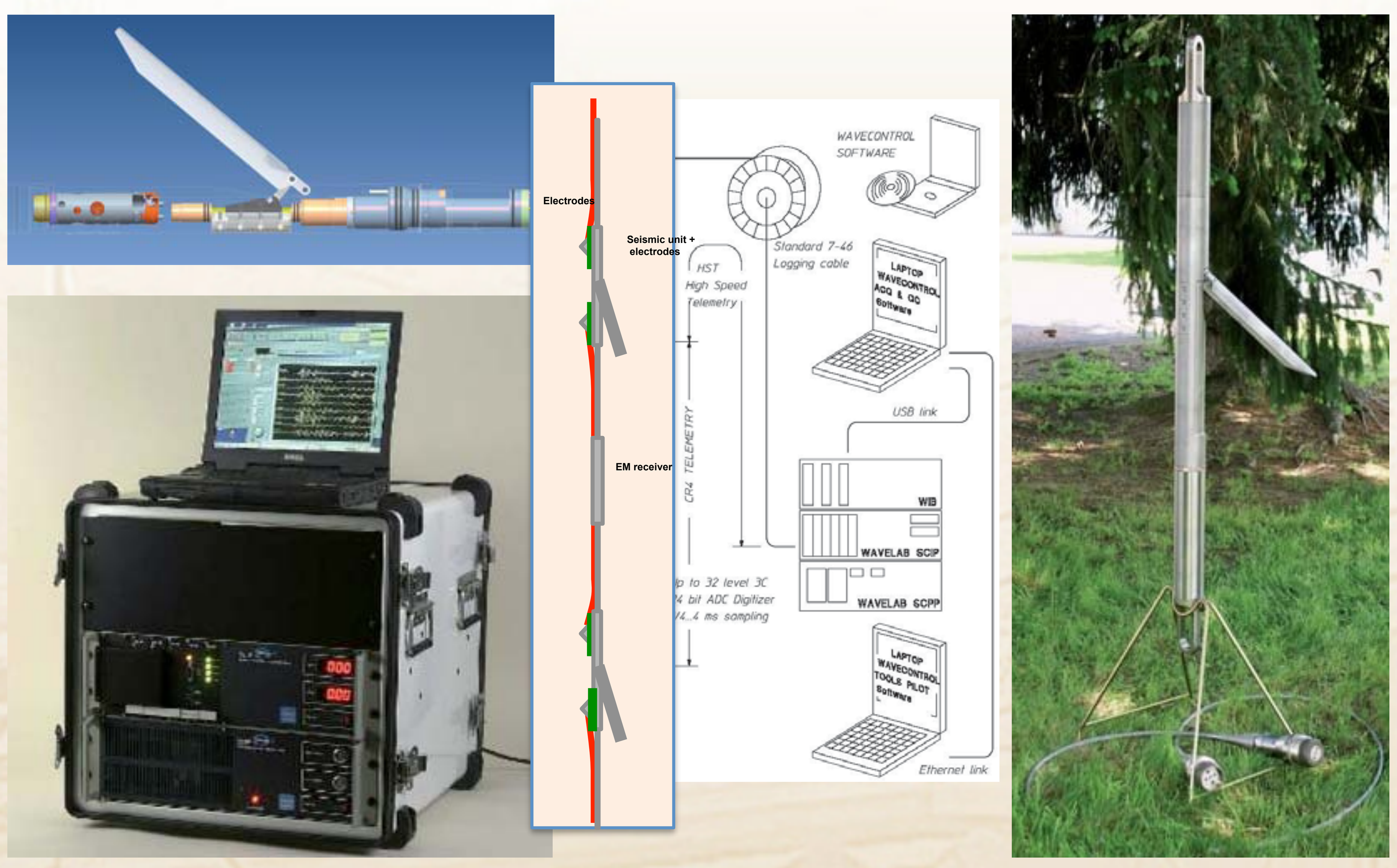
CSEM time lapse: before & after… LOWER BAKKEN



Time-lapse scenarios

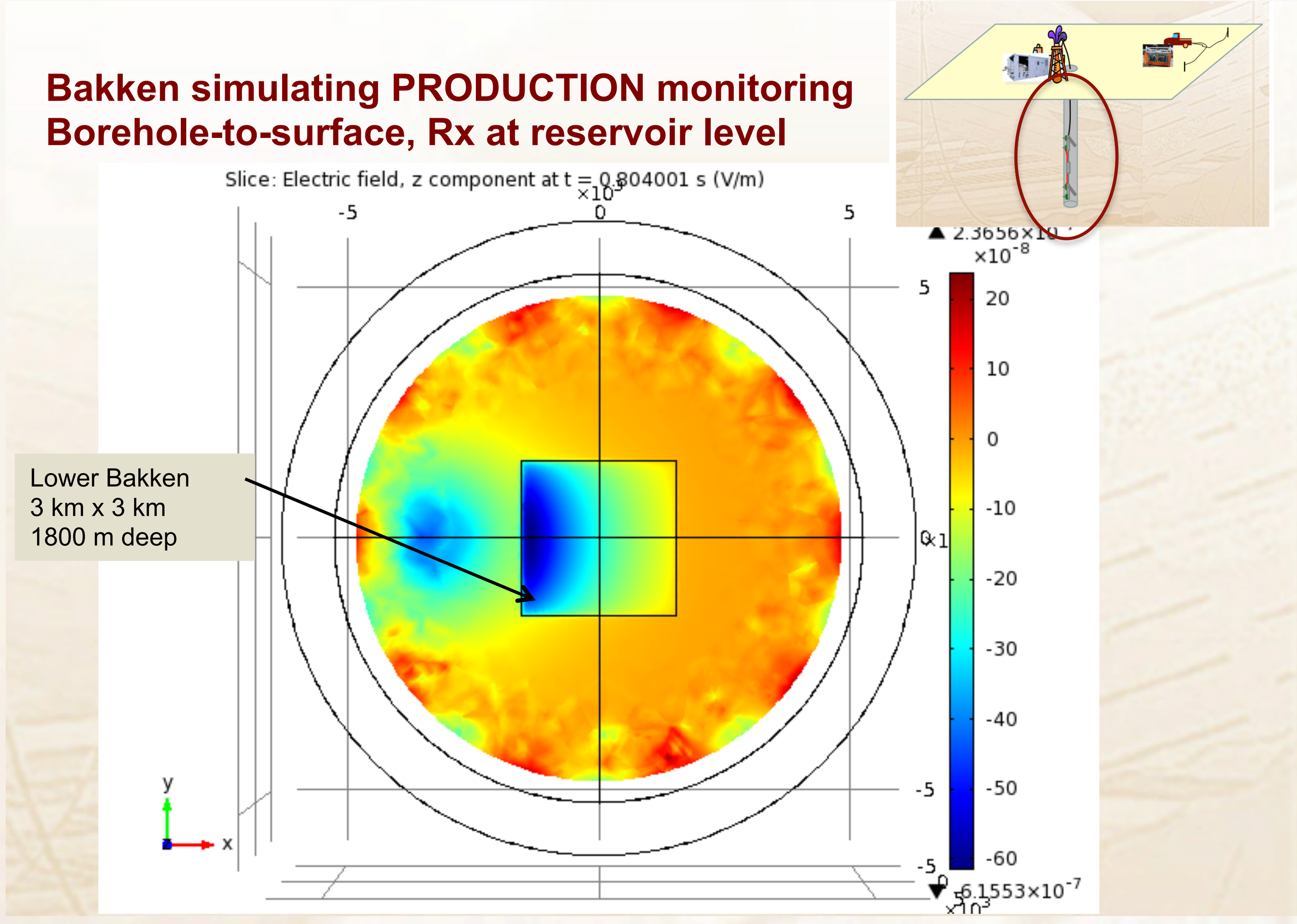
Borehole prototype

GeoWaves™ downhole seismic acquisition system

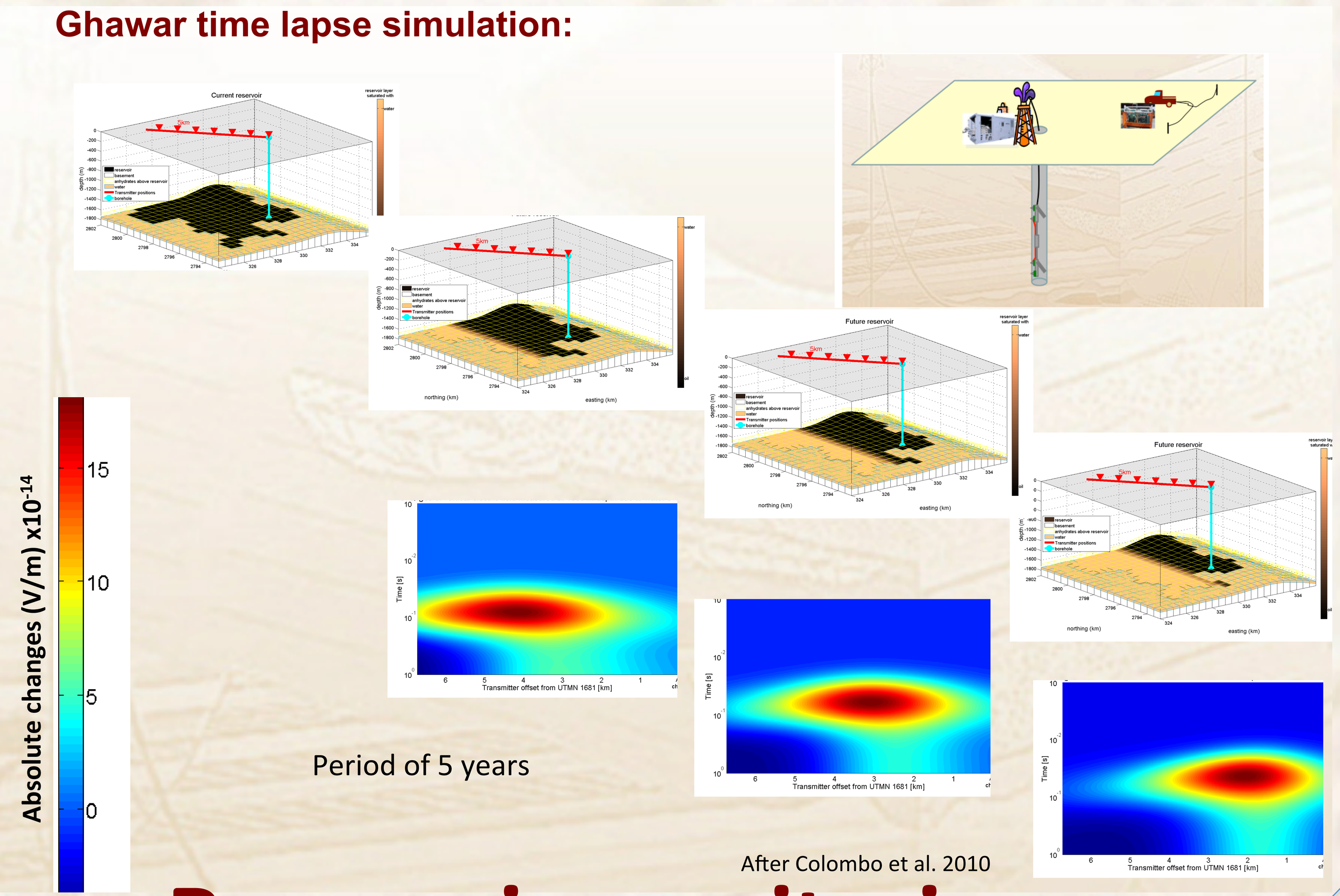


3D CSEM at reservoir with borehole

Bakken simulating PRODUCTION monitoring
Borehole-to-surface, Rx at reservoir level



Ghawar time lapse simulation:



Reservoir monitoring

Summary

- EM is prime candidate for shale and monitoring applications
- We need NEWEST methodology
  - Methods: focused to control 3D
  - 3D induction logs calibration
  - Surface-to-borehole integration
- Todays acquisition technology is well suited for this
- Integration with seismic mandatory
- → PILOT study is needed! (in progress!)

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