Target Detectability
in a
Marine Controlled-Source EM Survey

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SIO Marine EM Lab
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www.marineemlab.ucsd.edu
Seismic method shortfalls

Creating a conductivity model

Testing common scenarios in 1-D

Target thickness
Target resistivity
Target depth
Effect of shallow resistors
  hydrate
  evaporite
  salt
Effect of shallow water

Discussion / Conclusions
Seismic Direct Hydrocarbon Indicator analysis is not foolproof:

- Rugose seafloor
- Large acoustic impedance contrast at seafloor
Seismic Direct Hydrocarbon Indicator analysis is not foolproof:

- Rugose seafloor
- Large acoustic impedance contrast at seafloor
- “Fizz gas”
- Oil-Water contact
Seismic Direct Hydrocarbon Indicator analysis is not foolproof:

- Rugose seafloor
- Large acoustic impedance contrast at seafloor
- "Fizz gas"
- Oil-Water contact
- mud volcanoes, gas clouds
- subsalt imaging
- complex structure
seismic method shortfalls

Will a Marine CSEM survey be sensitive to the resistivity of your target stratum?

“Do the modeling.”
outline

Seismic method shortfalls

Creating a resistivity model

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Discussion / Conclusions
creating a resistivity model

seismic section

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resistivity log

depth, m

resistivity, $\Omega$m

=)

Seawater
$0.3 \ \Omega$m

Hydrate
$3 \ \Omega$m

Sediment
$1 \ \Omega$m

Target
$50 \ \Omega$m, 100 m
using resistivity logs

Hz - kHz range: low frequency approximation, same as CSEM

MHz range: dielectric effects, unlike CSEM

Logs can be decimated.

If directional logs are available, use vertical (or dip-normal) resistivities.

Laterolog vs. Induction tool
outline

Seismic method shortfalls

Creating a resistivity model

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Discussion / Conclusions
quick modeling studies

1 - D forward models using Flosadottir and Constable code

Available as WHAM

Instantaneous

Rapid assessment of many targets / fields
quick modeling studies

1 - D forward models using Flosadottir and Constable code

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Rapid assessment of many targets / fields

Radial mode sensitivity to target resistivity

Transmitter height 50 m
quick modeling studies

1 - D forward models using Flosadottir and Constable code

Available as WHAM

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Rapid assessment of many targets / fields

Radial mode sensitivity to target resistivity

Transmitter height 50 m

Caution: burial depth vs. lateral extent
generic survey layout

plan view

suspected target
multiple frequencies available

Transmitter Waveform: Square Wave

- **Amplitude spectrum, non-normalized**
  - Frequency range: 0 to 10 Hz
  - Amplitude range: 0 to 1.5

- **Transmitter waveform**
  - Time range: 0 to 4 seconds
  - Amplitude range: -1 to 1
Seismic method shortfalls

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Discussion / Conclusions
reference model

<table>
<thead>
<tr>
<th>Layer</th>
<th>Conductivity (Ω m)</th>
<th>Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>(\infty)</td>
<td></td>
</tr>
<tr>
<td>Seawater</td>
<td>0.3</td>
<td>1000</td>
</tr>
<tr>
<td>Sediment</td>
<td>1</td>
<td>1000</td>
</tr>
<tr>
<td>Target</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
reference model
reference model

**Top Diagram**
- **colors**: \(\Delta \log_{10}|E|\)
- **contours**: \(\log_{10}|E|\)
- **Legend**: solid = sediments, dashed = w/ target

**Bottom Diagram**
- **colors**: \(\Delta \text{phase}\)
- **contours**: phase
- **Legend**: solid = sediments, dashed = w/ target

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**Layers**
- **Atmosphere**: \(\infty \Omega_m\)
- **Seawater**: \(0.3 \Omega_m, 1000 \text{ m}\)
- **Sediment**: \(1 \Omega_m, 1000 \text{ m}\)
- **Target**: \(100 \Omega_m, 100 \text{ m}\)
reference model: 100 m
thinner target: 50 m
thinner target: 10 m
thinner target: 1 m

Atmosphere $\infty \ \Omega$ m

Seawater 0.3 $\Omega$ m, 1000 m

Sediment 1 $\Omega$ m, 1000 m

Target 100 $\Omega$ m, 1 m

1 m thick
Seismic method shortfalls

Creating a resistivity model

**Testing common scenarios in 1-D**

- Target thickness
- **Target resistivity**
  - Target depth
  - Effect of shallow resistors
    - hydrate
    - evaporite
    - salt
  - Effect of shallow water

Discussion / Conclusions
reference model: 100 Ωm

Atmosphere $\infty$ Ωm

Seawater 0.3 Ωm, 1000 m

Sediment 1 Ωm, 1000 m

Target 100 Ωm, 100 m

canonical model: target resistivity 100 Ωm
less resistive target: 50 Ωm
less resistive target: 10 Ωm
less resistive target: 5 \( \Omega \)m

### Atmosphere

- \( \infty \) \( \Omega \)m

### Sediment

- 1 \( \Omega \)m, 1000 m

### Target

- 5 \( \Omega \)m, 100 m

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**SEDIMENT RESPONSE**

**Boundary Conditions**

- Atmosphere: \( \infty \) \( \Omega \)m
- Seawater: 0.3 \( \Omega \)m, 1000 m
- Sediment: 1 \( \Omega \)m, 1000 m
- Target: 5 \( \Omega \)m, 100 m

**Instrument Noise**

- \( 5 \Omega \)m target

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**Figure:**

- **Left Panel:**
  - Sediment and cm6a responses
  - Color scale: \( \Delta \log_{10} |E| \)
  - Contours: \( \log_{10} |E| \)
  - Solid = sediments
  - Dashed = w/ target

- **Right Panel:**
  - cm6a 0.31623 Hz, Radial mode
  - |E| w/o target
  - |E| w/ target
  - "Air wave"
  - Instrument noise level
  - Phase

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**Legend:**

- Instrument noise level
- Detection window?
Seismic method shortfalls

Creating a resistivity model

**Testing common scenarios in 1-D**

- Target thickness
- Target resistivity
  - **Target depth**
    - Effect of shallow resistors
      - hydrate
      - evaporite
      - salt
    - Effect of shallow water

Discussion / Conclusions
reference model: 1 km
deeper target: 1.5 km
deeper target: 2 km
deeper target: 2.5 km
deeper target: 3 km
Seismic method shortfalls

Creating a resistivity model

**Testing common scenarios in 1-D**

- Target thickness
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  - hydrate
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Discussion / Conclusions
reference model: no hydrate
gas hydrate layer at 100 - 150 m
outline

Seismic method shortfalls

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  - hydrate
  - **evaporite**
  - salt
- Effect of shallow water

Discussion / Conclusions
reference model: no evaporite or salt

- **Atmosphere**: $\infty \, \Omega_m$
- **Seawater**: $0.3 \, \Omega_m, 1000 \, m$
- **Sediment**: $1 \, \Omega_m, 1500 \, m$
- **Target**: $50 \, \Omega_m, 50 \, m$
evaporite at 1 km

Atmosphere $\infty \Omega m$

Seawater $0.3 \Omega m$, 1000 m

Sediment, 1000 m

Evaporite $100 \Omega m$, 15 m

Target $50 \Omega m$, 50 m

Instrument noise level

"air wave"

difference between models

data uncertainty

overlying evaporite does not obscure target

☑
salt centered at 1km

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colormap: $\Delta \log_{10} |E|$ contours: $\log_{10} |E|$ solid = sediments dashed = w/ target

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colormap: $\Delta \text{phase}$ contours: phase solid = sediments dashed = w/ target

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colormap: $|E|$ w/o target $|E|$ w/ target

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colormap: $\Delta \log_{10} |E|$, $\Delta \text{phase}$

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Atmosphere $\infty \Omega_m$
- Seawater $0.3 \, \Omega_m$, 1000 m
- Sediment, 900 m
- Salt $100 \, \Omega_m$, 200 m
- Target $50 \, \Omega_m$, 50 m

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overlying salt obscures target

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Source-receiver offset (km)
- Frequency (Hz)
- $|E|$ (V/Am$^2$)
- Phase (deg)
- $\Delta \log_{10} |E|$
- $\Delta \text{phase}$

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$\Delta |E|$ $\Delta \text{phase}$

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Instrument noise level
Seismic method shortfalls

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Effect of shallow water

Discussion / Conclusions
reference model: 1 km water depth
shallow water: 750 m water depth

colorscale: $\Delta \log_{10}|E|$  
contours: $\log_{10}|E|$  
solid = sediments  
dashed = w/ target

colorscale: $\Delta \text{phase}$  
contours: phase  
solid = sediments  
dashed = w/ target

Atmosphere $\infty \Omega$ m

Seawater 0.3 $\Omega$ m, 750 m

Sediment 1 $\Omega$ m, 1000 m

Target 50 $\Omega$ m, 50 m

water depth 750 m

Atmosphere $\infty \Omega$ m

Seawater 0.3 $\Omega$ m, 750 m

Sediment 1 $\Omega$ m, 1000 m

Target 50 $\Omega$ m, 50 m

water depth 750 m

Atmosphere $\infty \Omega$ m

Seawater 0.3 $\Omega$ m, 750 m

Sediment 1 $\Omega$ m, 1000 m

Target 50 $\Omega$ m, 50 m

water depth 750 m

Atmosphere $\infty \Omega$ m

Seawater 0.3 $\Omega$ m, 750 m

Sediment 1 $\Omega$ m, 1000 m

Target 50 $\Omega$ m, 50 m

water depth 750 m

Atmosphere $\infty \Omega$ m

Seawater 0.3 $\Omega$ m, 750 m

Sediment 1 $\Omega$ m, 1000 m

Target 50 $\Omega$ m, 50 m

water depth 750 m

Atmosphere $\infty \Omega$ m

Seawater 0.3 $\Omega$ m, 750 m

Sediment 1 $\Omega$ m, 1000 m

Target 50 $\Omega$ m, 50 m

water depth 750 m

Atmosphere $\infty \Omega$ m

Seawater 0.3 $\Omega$ m, 750 m

Sediment 1 $\Omega$ m, 1000 m

Target 50 $\Omega$ m, 50 m

water depth 750 m
shallow water: 500 m water depth

Atmosphere \( \sim \) \( \infty \) Ohm
Seawater 0.3 Ohm, 500 m
Sediment 1 Ohm, 1000 m
Target 50 Ohm, 50 m

water depth
500 m

|E| w/o target
|E| w/ target

"air wave"

instrument noise level

Sediments
"solid = sediments"
dashed = w/ target

colorscales:
- \( \Delta \log_{10} \|E\| \)
- \( \Delta \text{phase} \)

Contours:
- \( \log_{10} \|E\| \)
- \( \text{phase} \)

Instrument noise level

Detection window

|E| w/ target

|E| w/o target
shallow water: 250 m water depth

colorscale: $\Delta \log_{10} |E|$
contours: $\log_{10} |E|$
solid = sediments
dashed = w/ target

colorscale: $\Delta \text{phase}$
contours: phase
solid = sediments
dashed = w/ target

source-receiver offset (km)

frequency (Hz)

$|E|$ w/o target
$|E|$ w/ target

Atmosphere $\propto \Omega_m$

Atmosphere
$\infty$

Seawater 250 m

Seawater 250 m, 250 m

Target
50 $\Omega_m$, 50 m

Instrument noise level

$|E|$ w/o target

$|E|$ w/ target

Water depth
250 m
shallow water: 55 m water depth

- **colors**
  - sed55 : (-) & cm2a55 (-) : $|E|$ (V/Am$^2$)
  - cm2a55 0.31623 Hz, Radial mode
  - Phase: solid = sediments, dashed = w/ target
  - Instrument noise level
  - "air wave"

- **axes**
  - frequency (Hz)
  - source-receiver offset (km)
  - phase (deg)

- **models**
  - Atmosphere $\propto \Omega m$
  - Sediment $1 \Omega m, 1000 m$
  - Target $50 \Omega m, 50 m$

- **water depth**
  - 55 m

- **legend**
  - Atomsphere
  - Sediment
  - Target
  - Water depth
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Discussion / Conclusions
What to do next?
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Ask contractors to model your best target(s) in 3-D.
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If it still looks good: get on the boat.
What to do next?

Ask contractors to model your best target(s) in 3-D.

If it still looks good: get on the boat.

Drill (or don’t).
What to do next?

Ask contractors to model your best target(s) in 3-D.

If it still looks good: get on the boat.

Drill (or don’t).

* technology and data interpretation advancing rapidly
conclusions

Seismic DHI methods aren’t foolproof
conclusions

Seismic DHI methods aren’t foolproof

Seismic sections + resistivity log = model
conclusions

Seismic DHI methods aren’t foolproof

Seismic sections + resistivity log = model

1-D modeling for rapid assessment of targets
conclusions

Seismic DHI methods aren’t foolproof

Seismic sections + resistivity log = model

1-D modeling for rapid assessment of targets

Target detectability depends on many factors
conclusions

Seismic DHI methods aren’t foolproof

Seismic sections + resistivity log = model

1-D modeling for rapid assessment of targets

Target detectability depends on many factors

Contractor capabilities differ