Recent seismic results from the Blake Ridge Hydrate Province: Implications for direct detection, gas injection, and methane escape

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A deeper understanding of marine methane hydrate systems requires progress on several key issues, including: (1) the global and local distribution and concentrations of hydrate and associated free gas, (2) the sites, rates, and mechanisms of interaction between the Earth's hydrate reservoir and the global carbon cycle, and (3) the dynamics of hydrate systems. Addressing these issues requires improved methods of remotely detecting and quantifying methane hydrate and gas using seismic reflection data. We present new seismic reflection data from the Blake Ridge hydrate province, offshore South Carolina, that yield new insights on both hydrate processes and seismic detection of hydrate.

The Blake Ridge is an excellent field laboratory to study hydrate processes, largely because the relatively simple tectonic setting and uniform lithologies provide a virtual *tabula rasa* against which seismic anomalies can be confidently interpreted in terms of gas and hydrate. A large array of background knowledge exists on the Blake Ridge, from numerous seismic, drilling, coring, and submersible studies. Sedimentary biological, and physical processes produce a wide array of methane flux environments within a relatively well-understood

We acquired long-offset (6000 m), high-resolution (6.25 m CMP spacing) seismic reflection data in Fall 2000 on the Blake Ridge in a project jointly sponsored by NSF and DOE. These data provide remarkably clear images of the entire hydrate and free gas zone, up to depths of 1000 mbsl. Examples of direct seismic detection of hydrate within the hydrate stability zone include (1) "bright spots" from layers of concentrated hydrate (up to 70% of porosity), (2) cross-cutting paleo-BSR reflections formed after erosional events, and (3) a lens of amplitude "blanking" that has been confirmed as a high-velocity layer that likely contains elevated concentrations of hydrate (~30% of porosity). The free gas zone on the Blake Ridge is surprisingly dynamic, with numerous chimneys through which gas can migrate hundreds of meters into the hydrate stability zone. Large quantities (0.6 Gt) of methane gas have apparently escaped through a large depression on the ridge crest that represents a large sediment wave field.

Recent Seismic Results from the Blake Ridge Hydrate Province:

Implications for direct detection, gas injection, and methane escape

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Seismic Studies of the Blake Ridge:

Implications for Gas Dynamics, Hydrate Distribution, and Methane Expulsion

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Seismic Studies of the Blake Ridge:

Implications for Gas Dynamics, Hydrate Distribution, and Methane Expulsion

Acknowledgments:

Andrew Gorman
Matt Hornbach
Jeff Nealon
Demian Saffer
Kara Hackwith

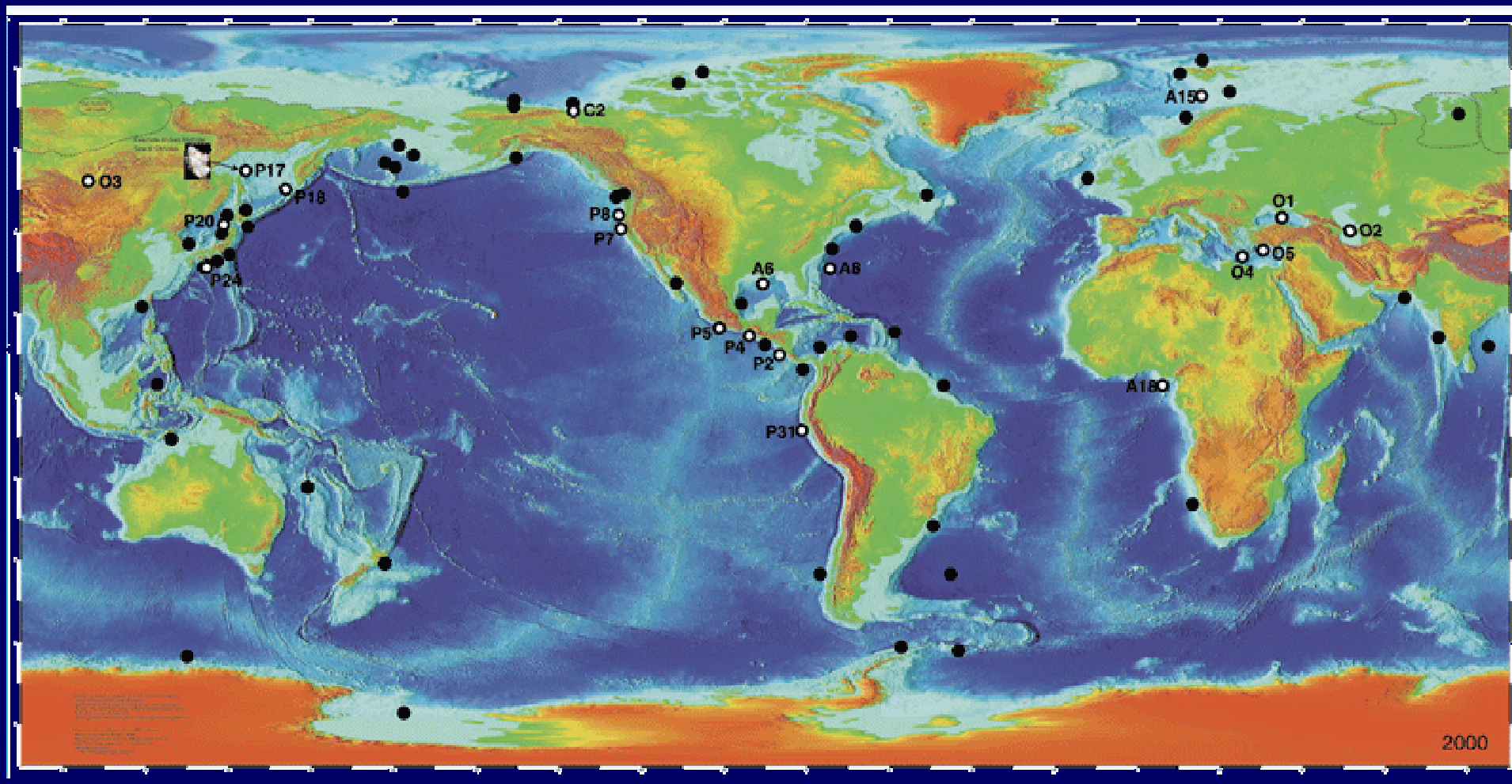
Outline

- Hydrates: Some Big Questions
- Why Study the Blake Ridge?
- Blake 2000: Gas injection, direct detection
- The "Collapse:" A Blast of Gas in the Past?

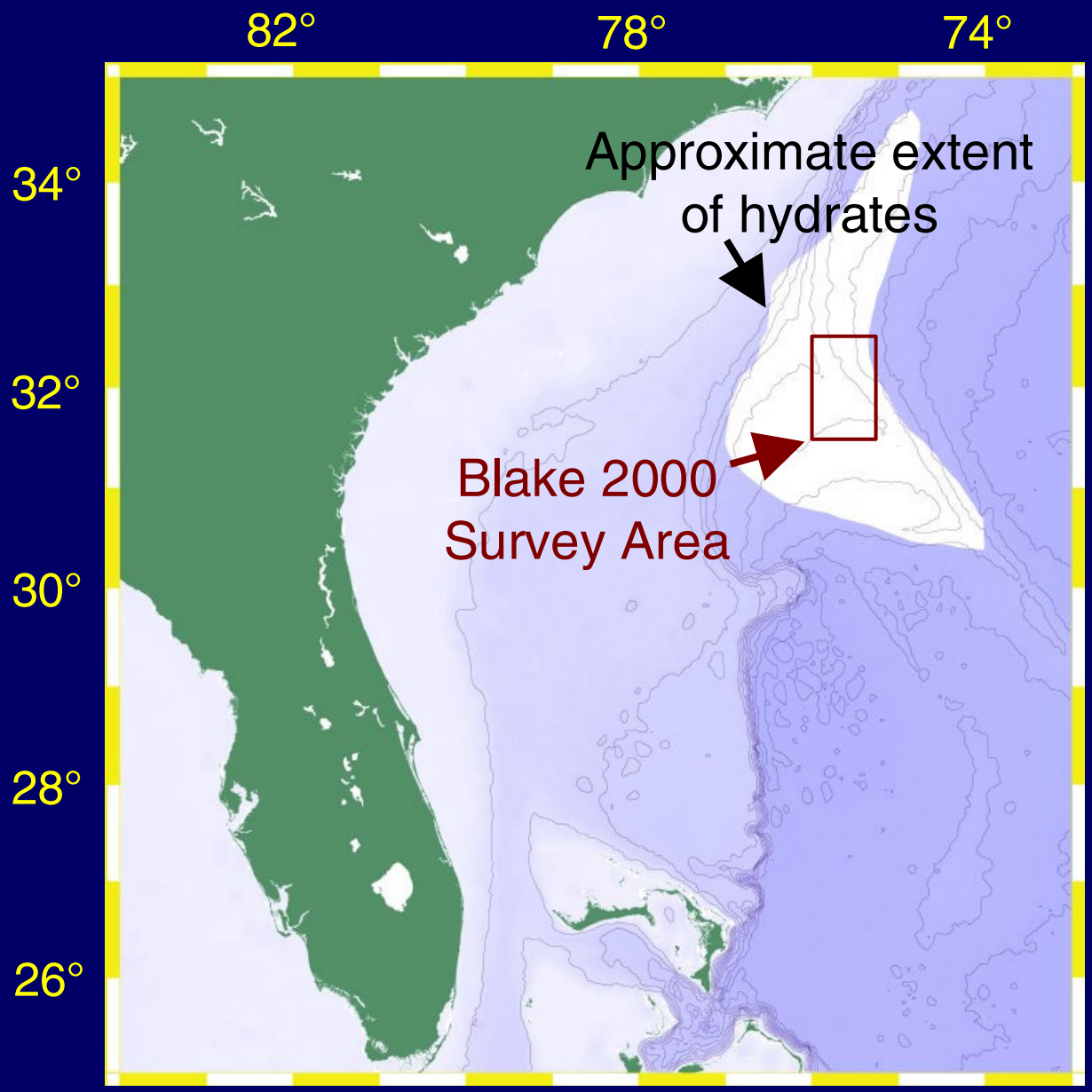
Hydrates: Some Big Questions

- Global/Local Distribution of Hydrate/Gas
- Seismic Detection/Quantification of Hydrate
- Interactions with Climate/Carbon Cycle
- Dynamics of Hydrate Systems

Global Distribution of Hydrate

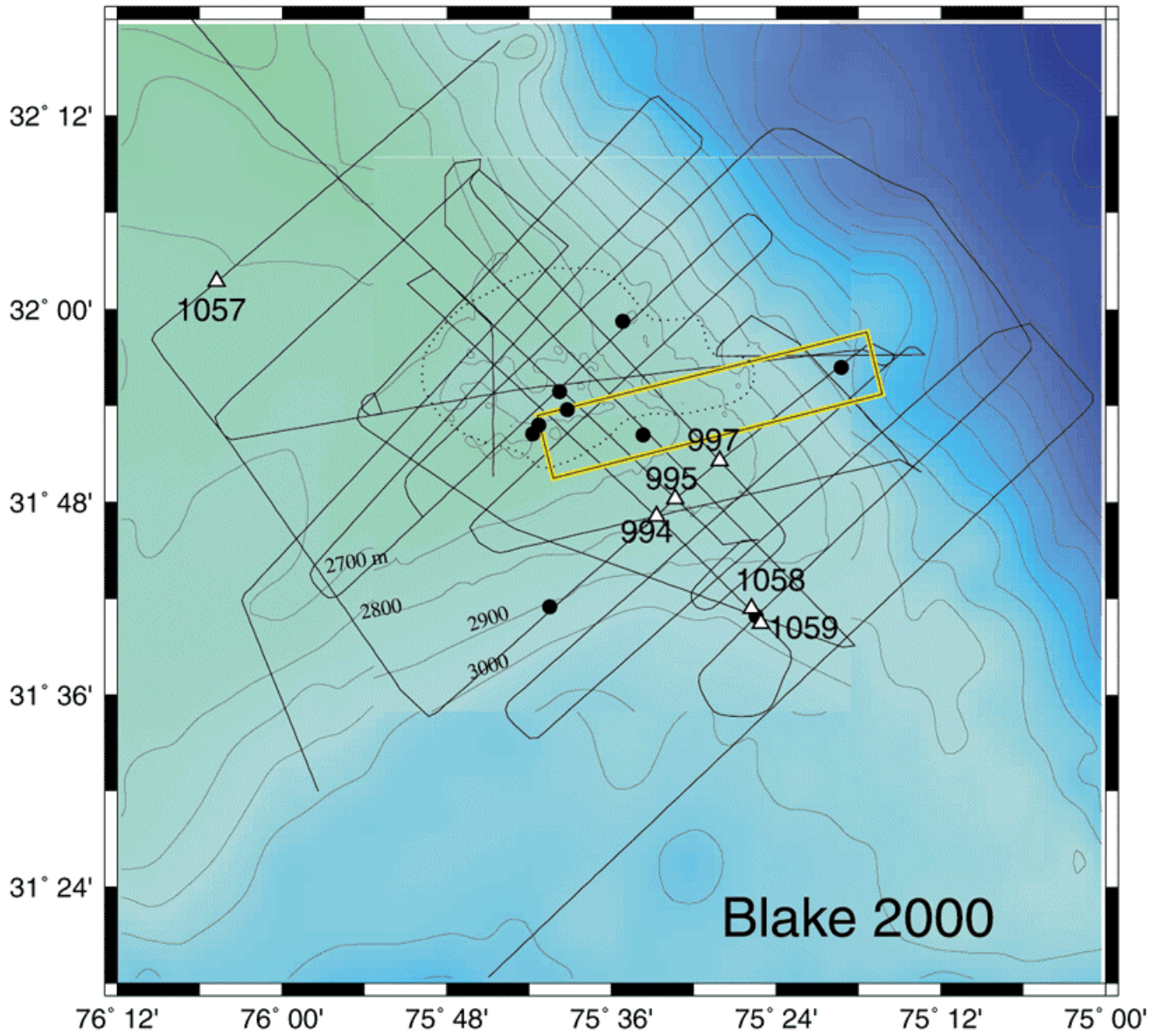


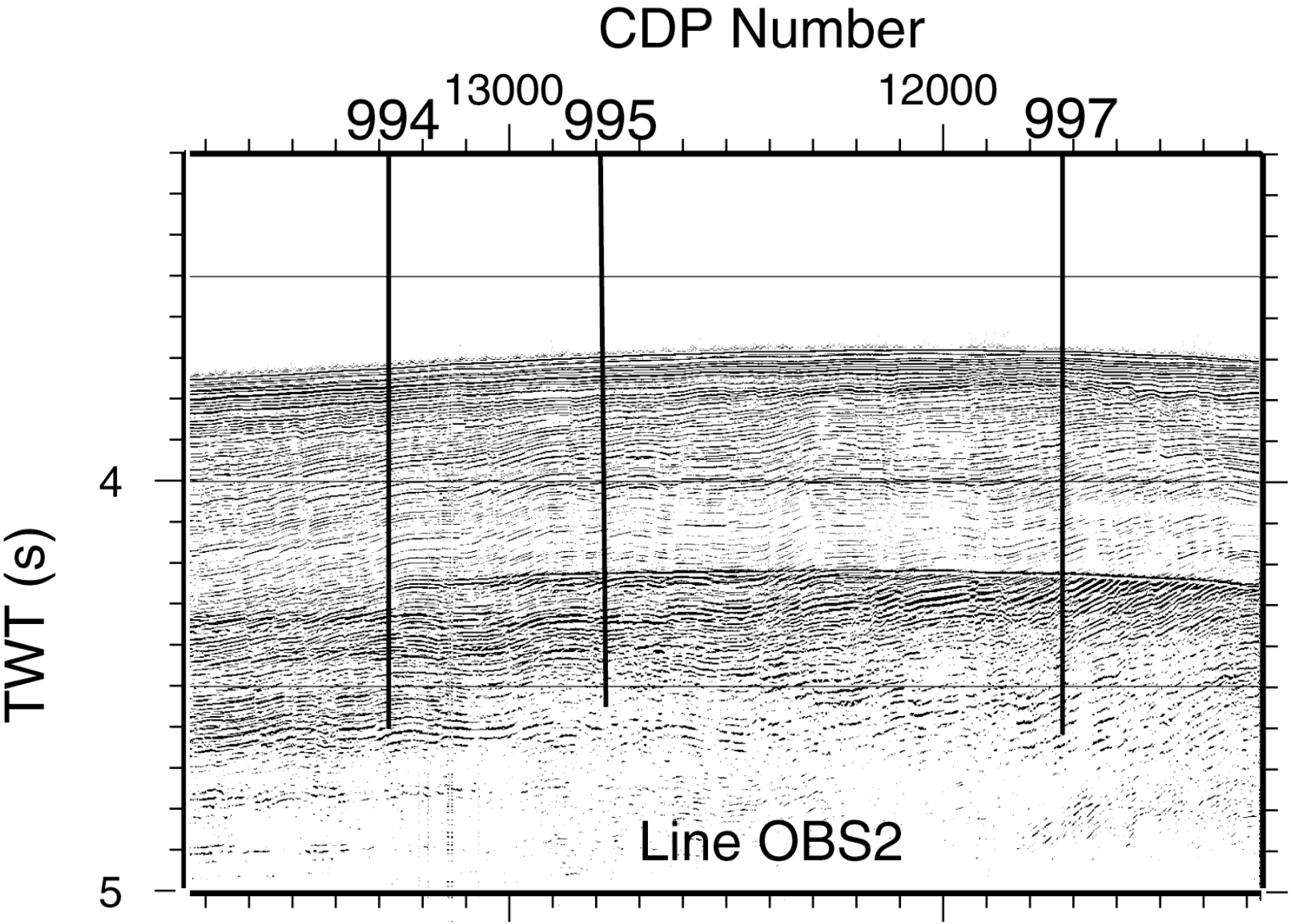
Kvenvolden and Lorenson, 2001


82°
78°
74°
34°
32°
30°
28°
26°
Approximate extent of hydrates
Blake 2000 Survey Area

Why Study the Blake Ridge?

- **Because it's simple!**
  - **virtually homogeneous lithology (mud/silt)**
  - ***tabula rasa* for interpreting hydrate/gas**
- **Range of quantifiable fluxes**
- **Background knowledge**
  - **drilling, seismic, geochemistry, coring**
- **Evidence for large-scale gas escape**


32° 12'
32° 00'
31° 48'
31° 36'
31° 24'
76° 12'
76° 00'
75° 48'
75° 36'
75° 24'
75° 12'
75° 00'
1057
997
995
994
1058
1059
2700 m
2800
2900
3000
Blake 2000


CDP Number
994
13000
995
12000
997
TWT (s)
4
5
Line OBS2

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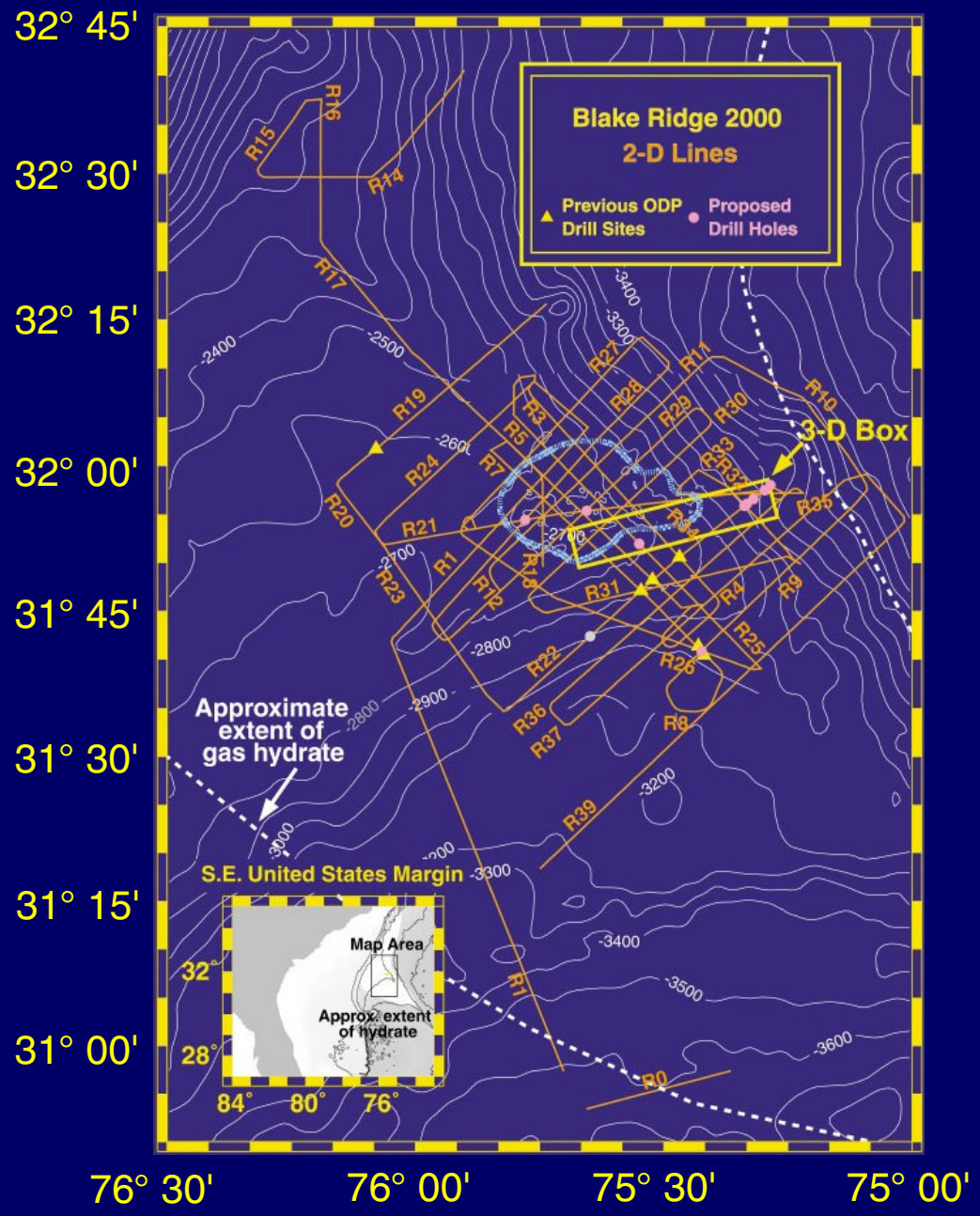
- The Blake Ridge
- Blake 2000: Gas injection, direct detection
- The "Collapse:" A Blast of Gas in the Past?

R/V *Maurice Ewing*



Blake Ridge 2000

- ~2500 km MCS data
- 2 G.I. airgun source
- 40 - 200 Hz
- 6.25 m CMP spacing

- 2-D data
  - 480 channels
  - 6 km streamer
  - 80 fold

- 3-D data
  - 324 channels
  - 4 km streamer
  - 75 m line spacing

Direct Seismic Detection of Hydrate

1. Bright Spots

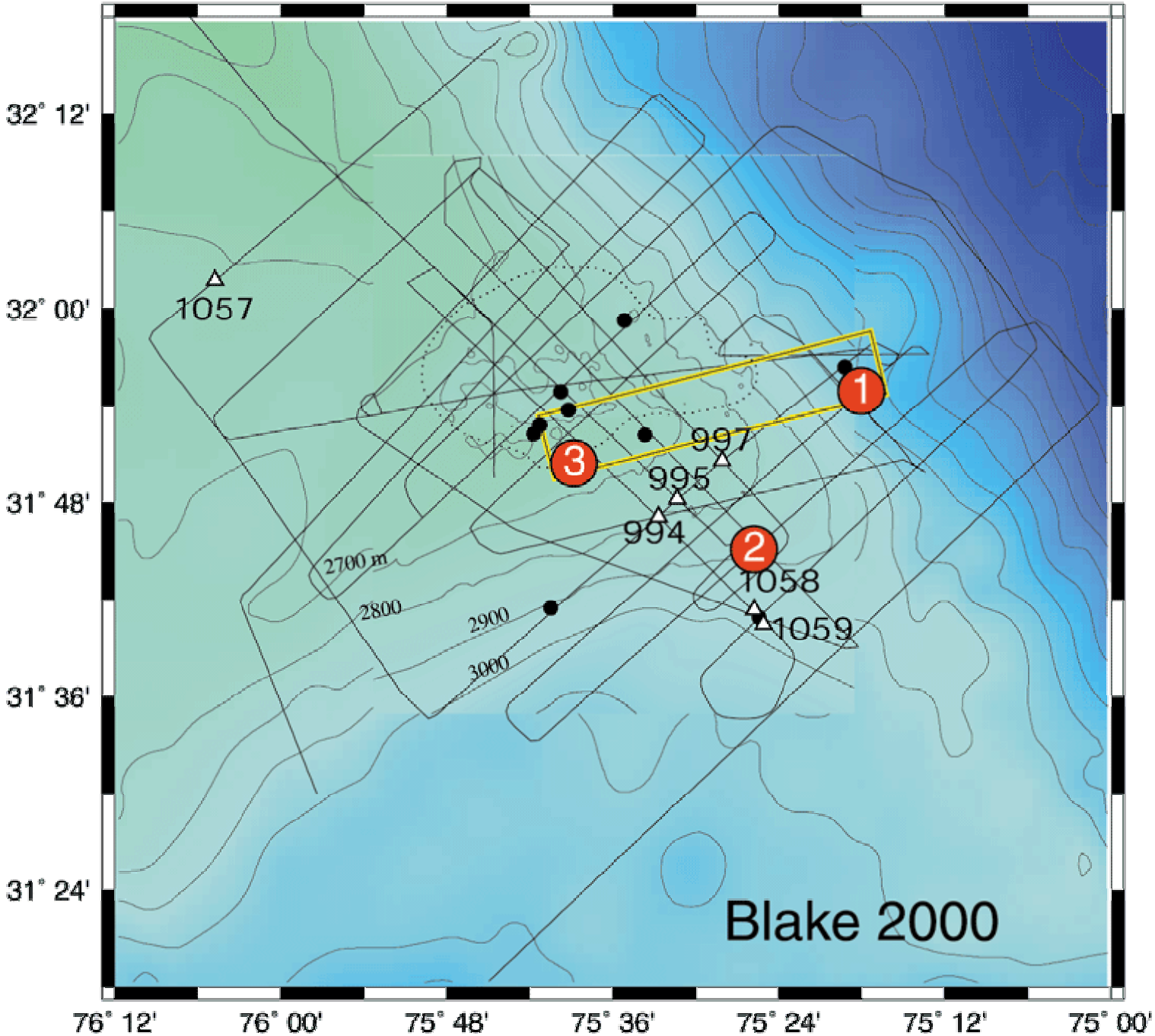
   => esp. when assoc. w/ fluid flow features

2. Paleo-BSR reflections in HSZ

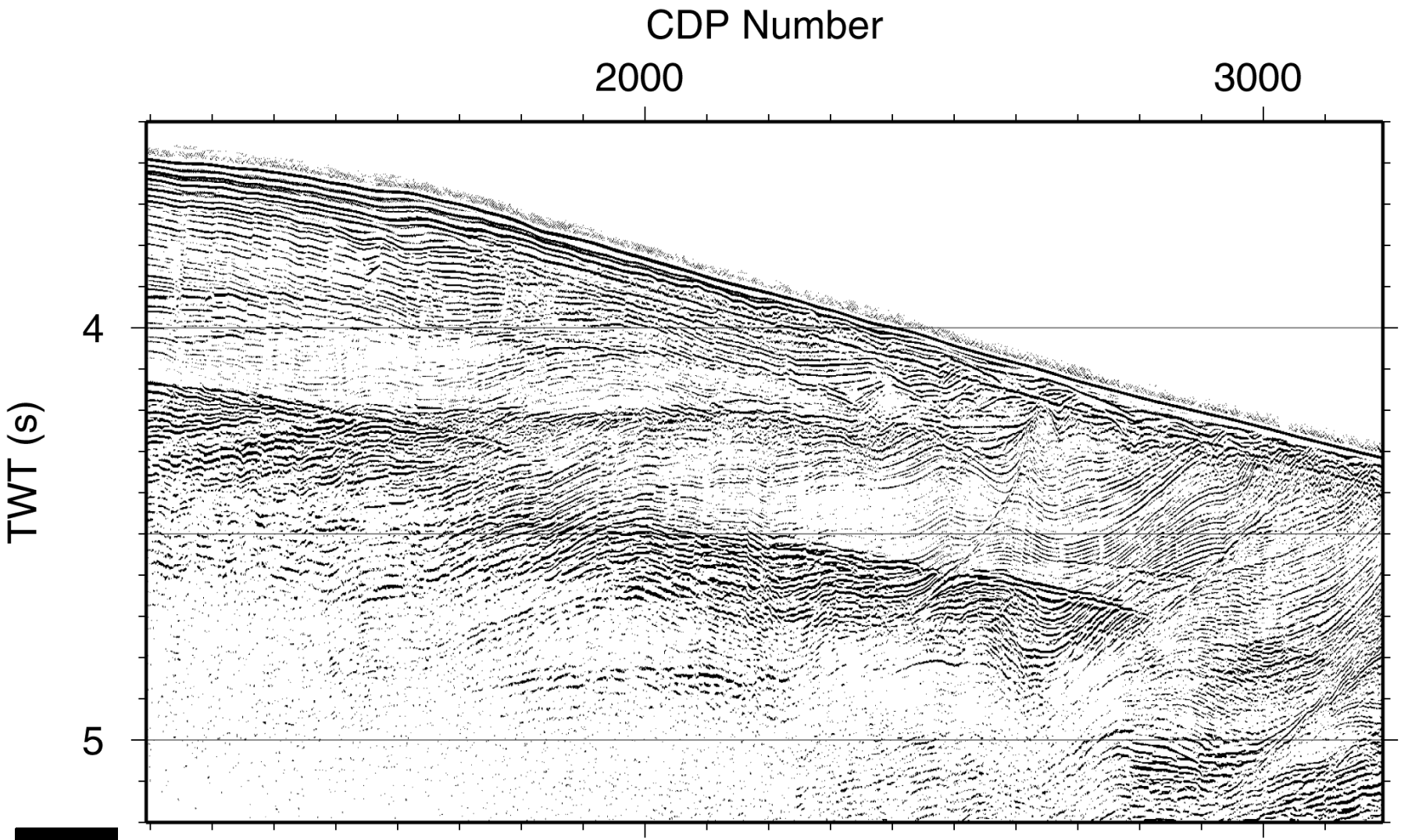
   => consequence of erosion

3. Amplitude Blanking

   => only when verified by Vp analysis


32° 12'
32° 00'
31° 48'
31° 36'
31° 24'
76° 12'
76° 00'
75° 48'
75° 36'
75° 24'
75° 12'
75° 00'
1057
997
995
994
1058
1059
1
2
3
2700 m
2800
2900
3000
Blake 2000

Line 3D-13



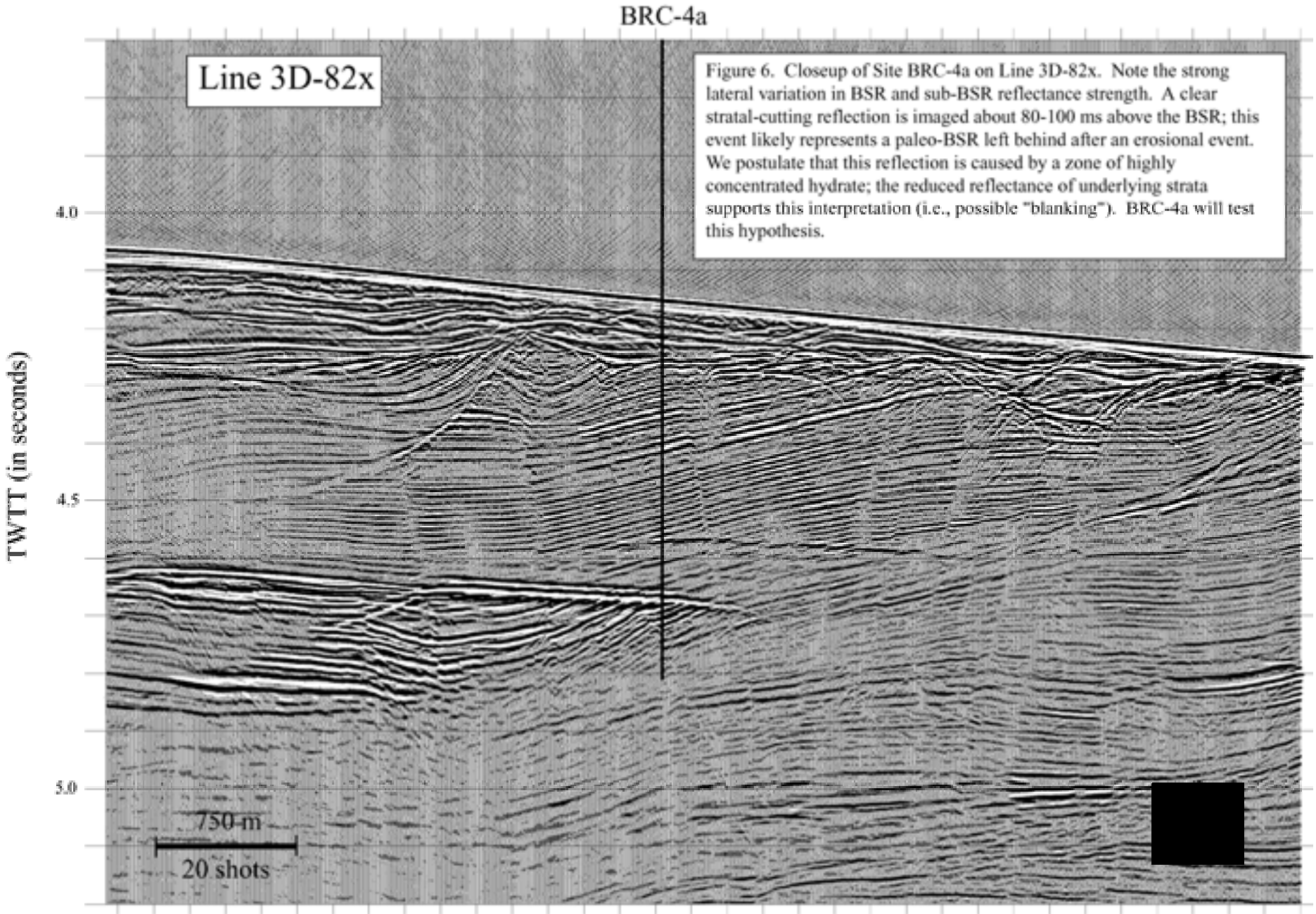
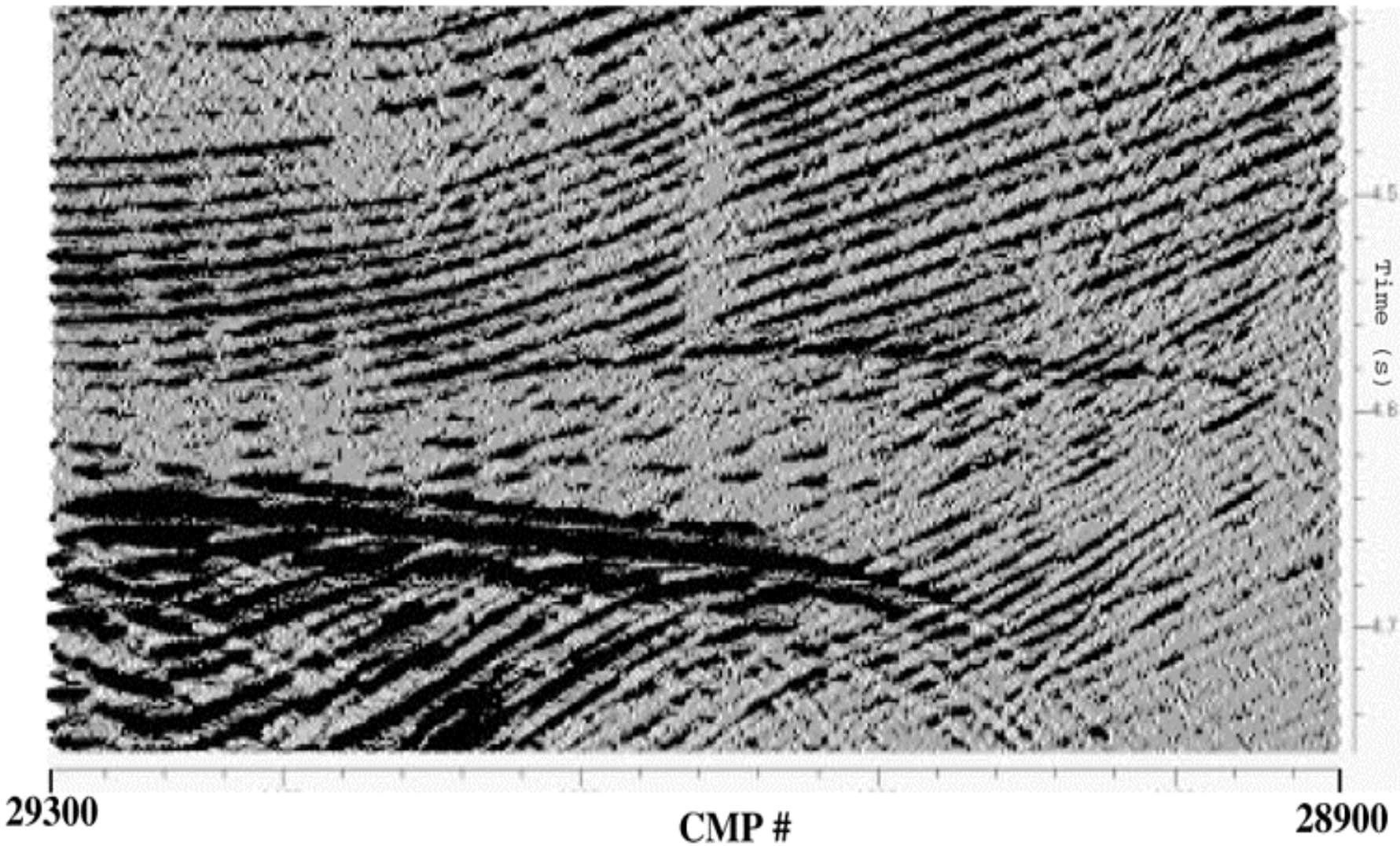
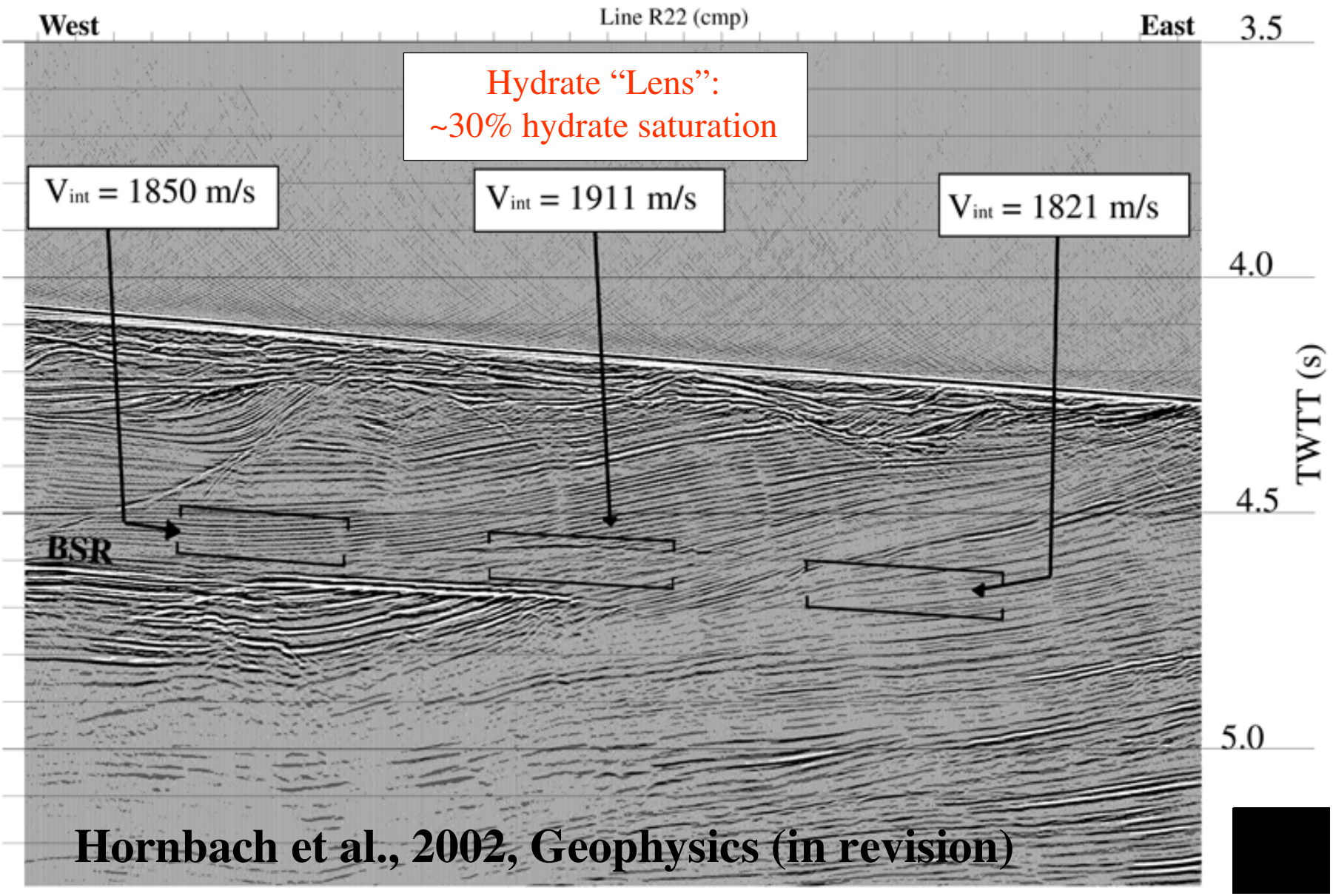


Figure 6. Closeup of Site BRC-4a on Line 3D-82x. Note the strong lateral variation in BSR and sub-BSR reflectance strength. A clear stratal-cutting reflection is imaged about 80-100 ms above the BSR; this event likely represents a paleo-BSR left behind after an erosional event. We postulate that this reflection is caused by a zone of highly concentrated hydrate; the reduced reflectance of underlying strata supports this interpretation (i.e., possible "blanking"). BRC-4a will test this hypothesis.

Wiggle Trace True Amplitude Display of the Lens



Hornbach et al., 2002, Geophysics (in revision)



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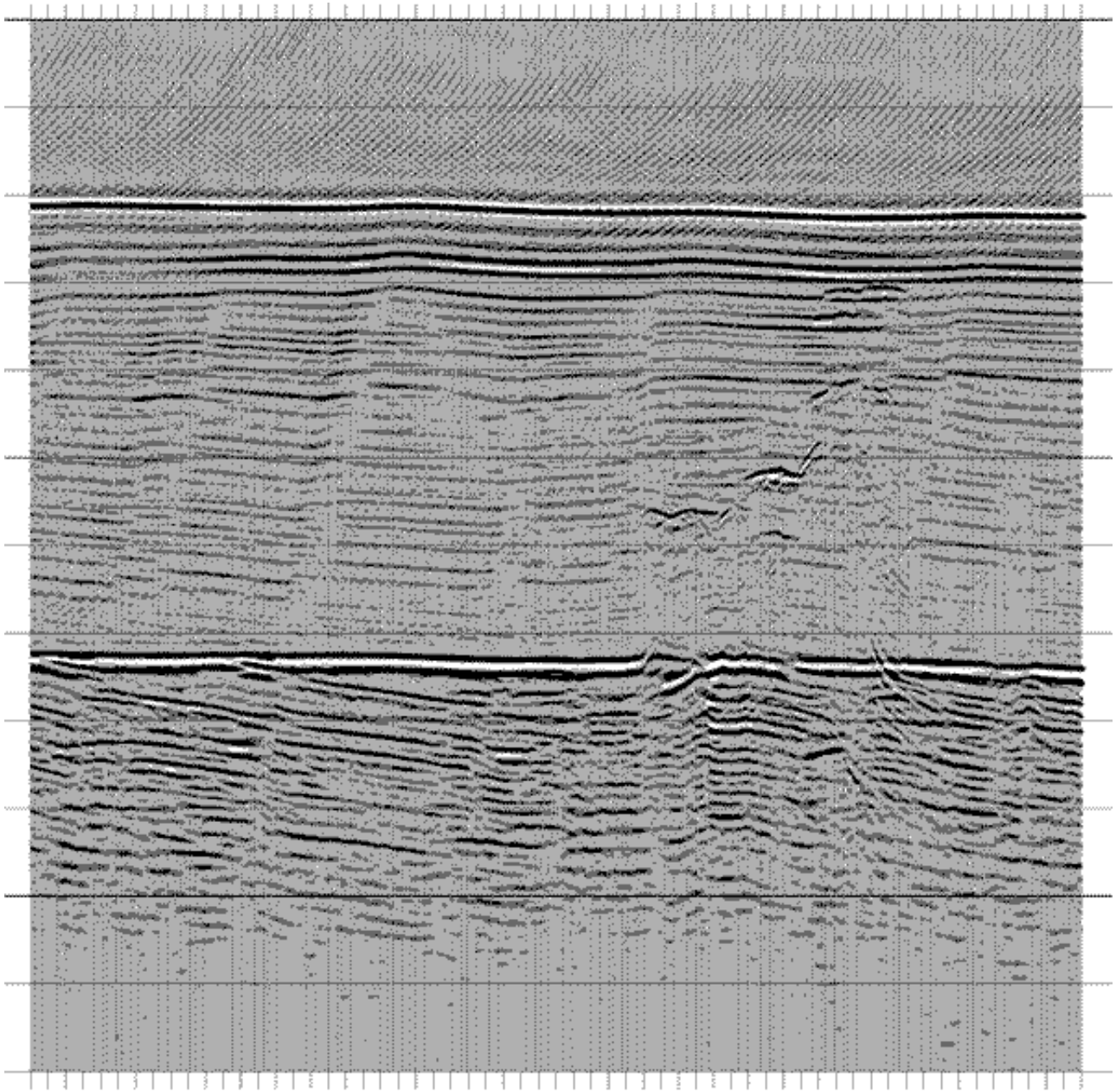
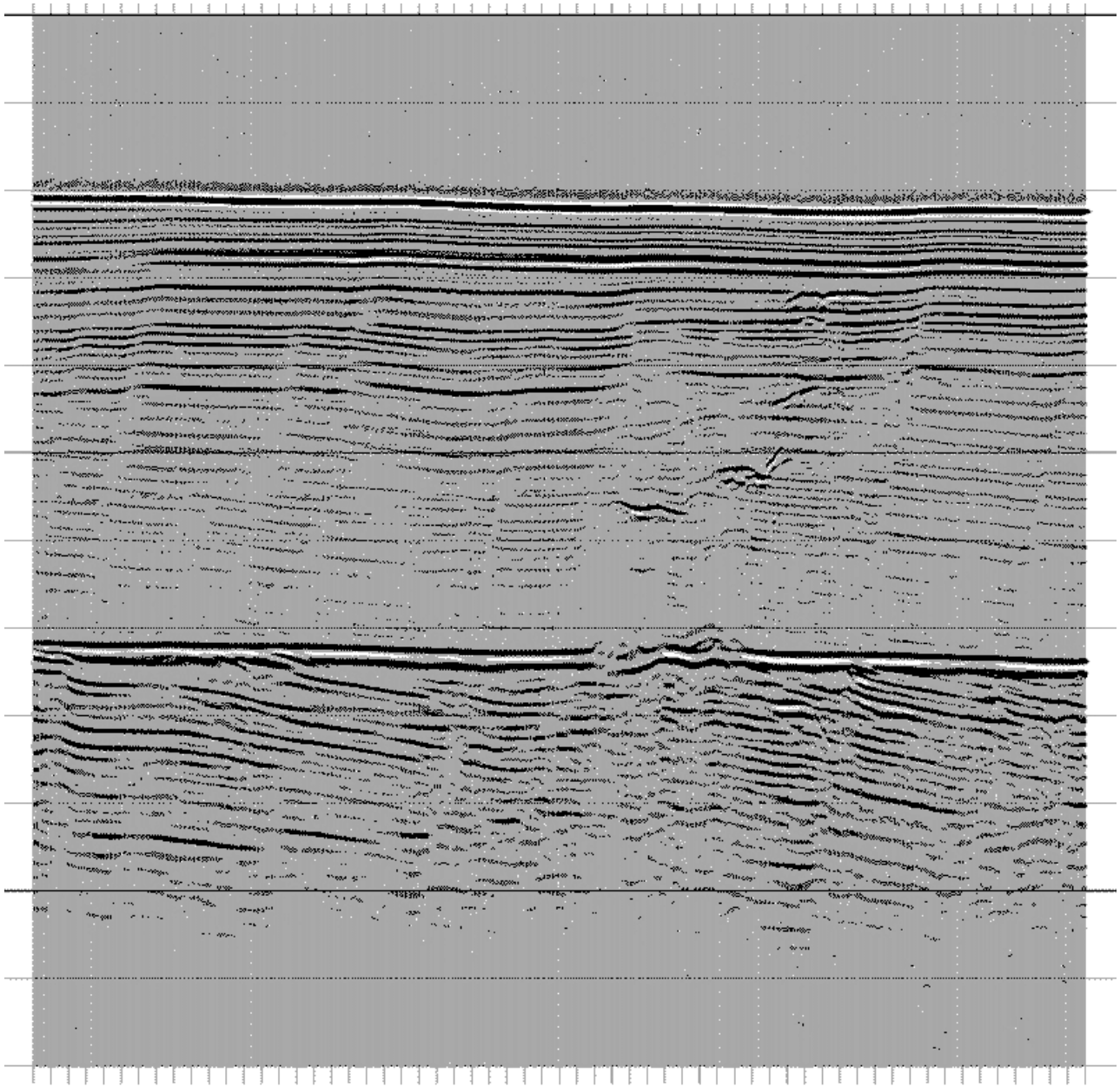
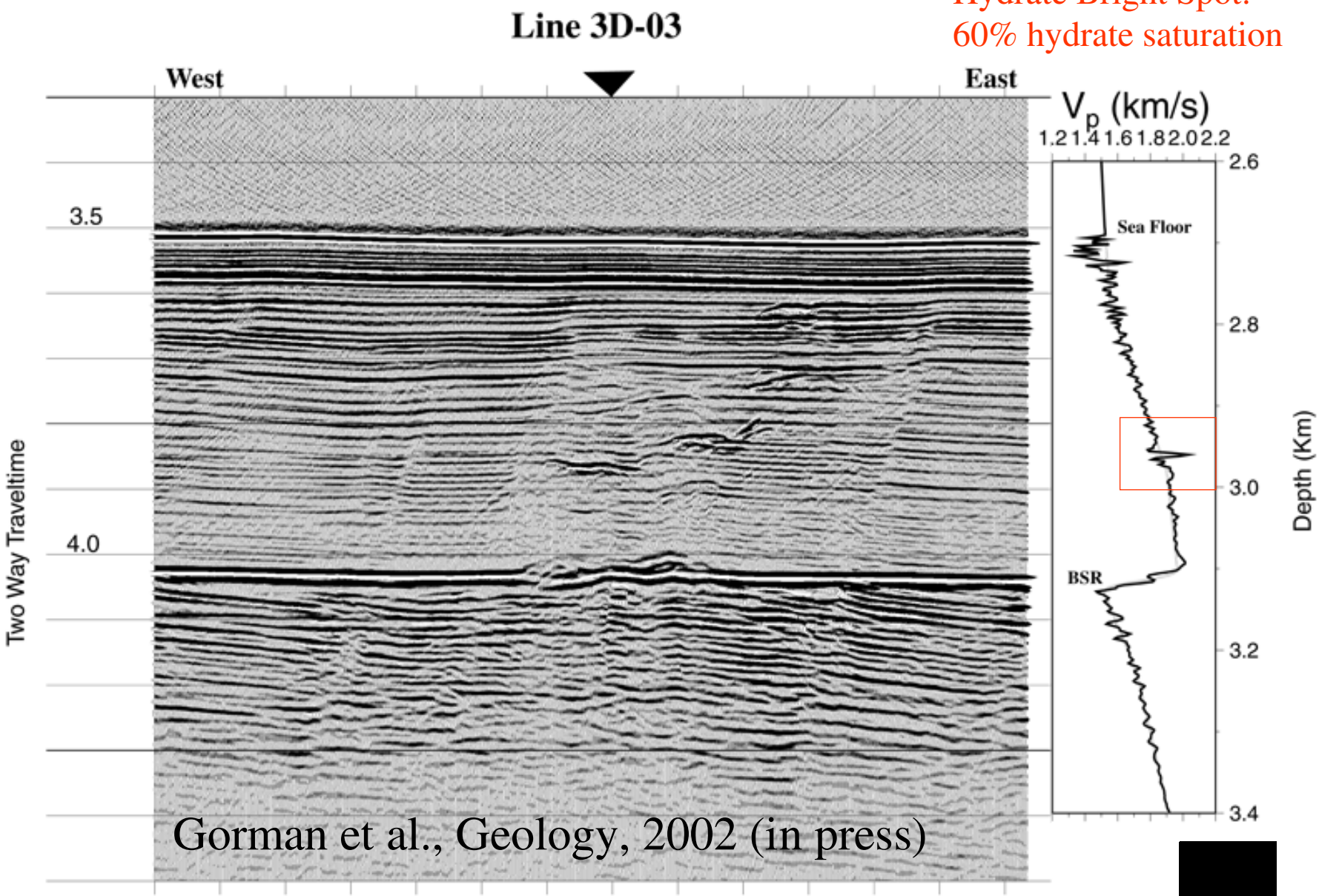


Line 3D-01



Line 3D-03

Hydrate Bright Spot:
60% hydrate saturation



Gorman et al., Geology, 2002 (in press)

The Dynamic Free Gas System

- Gas can migrate through the HSZ

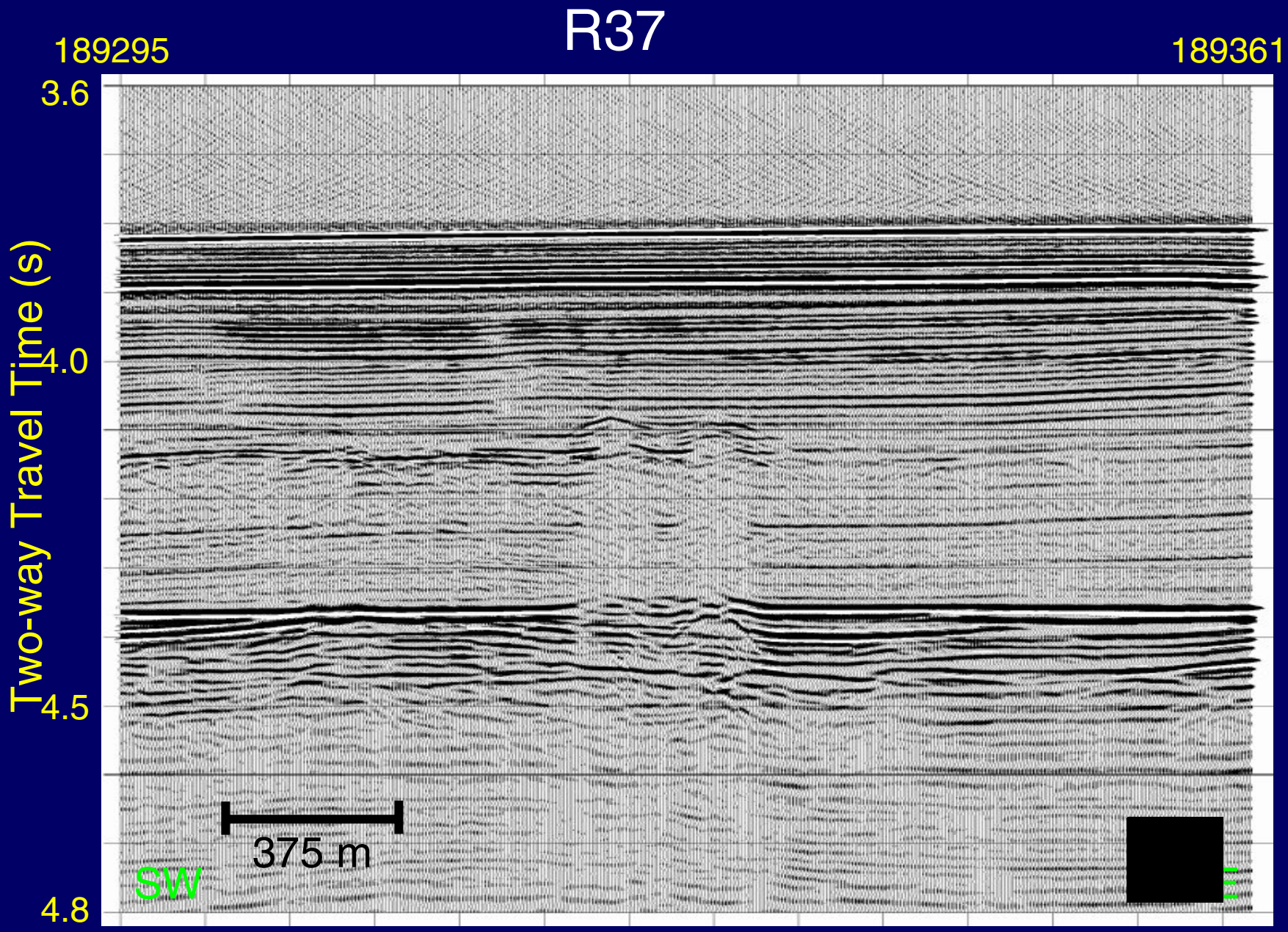
  => doesn't freeze immediately into hydrate

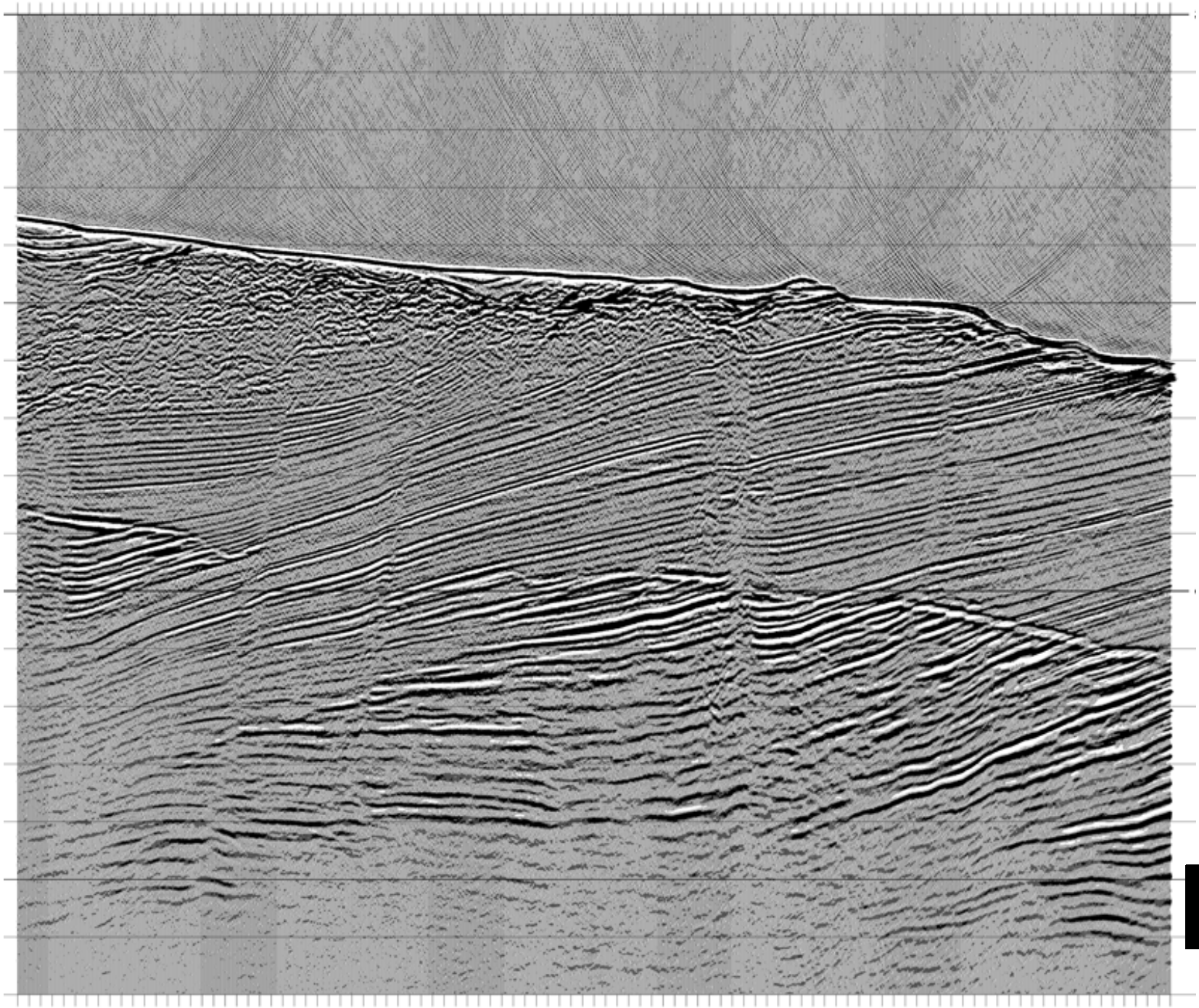
- Pathways: Faults ± Hydrofractures

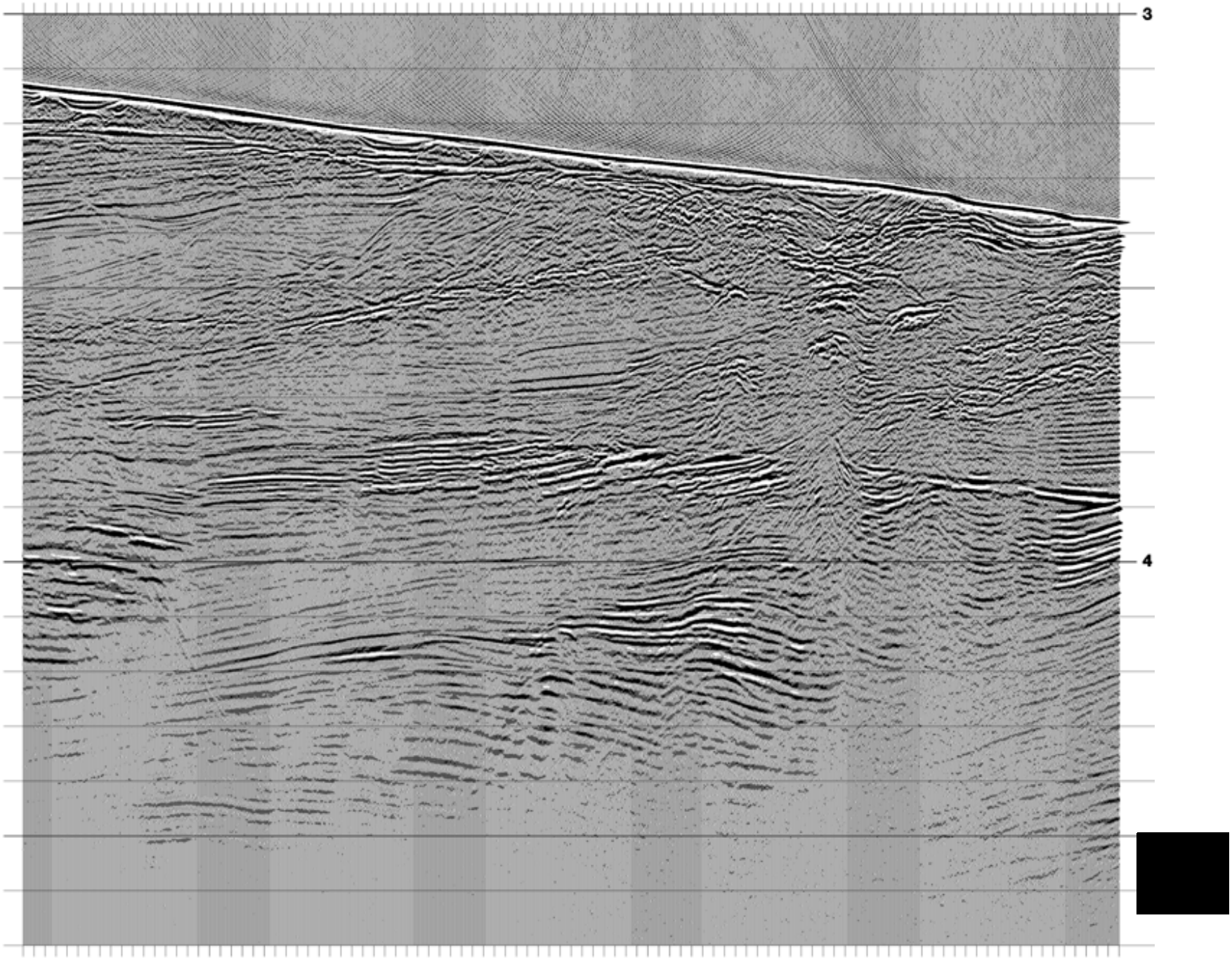
  => young impermeable cap can block migration

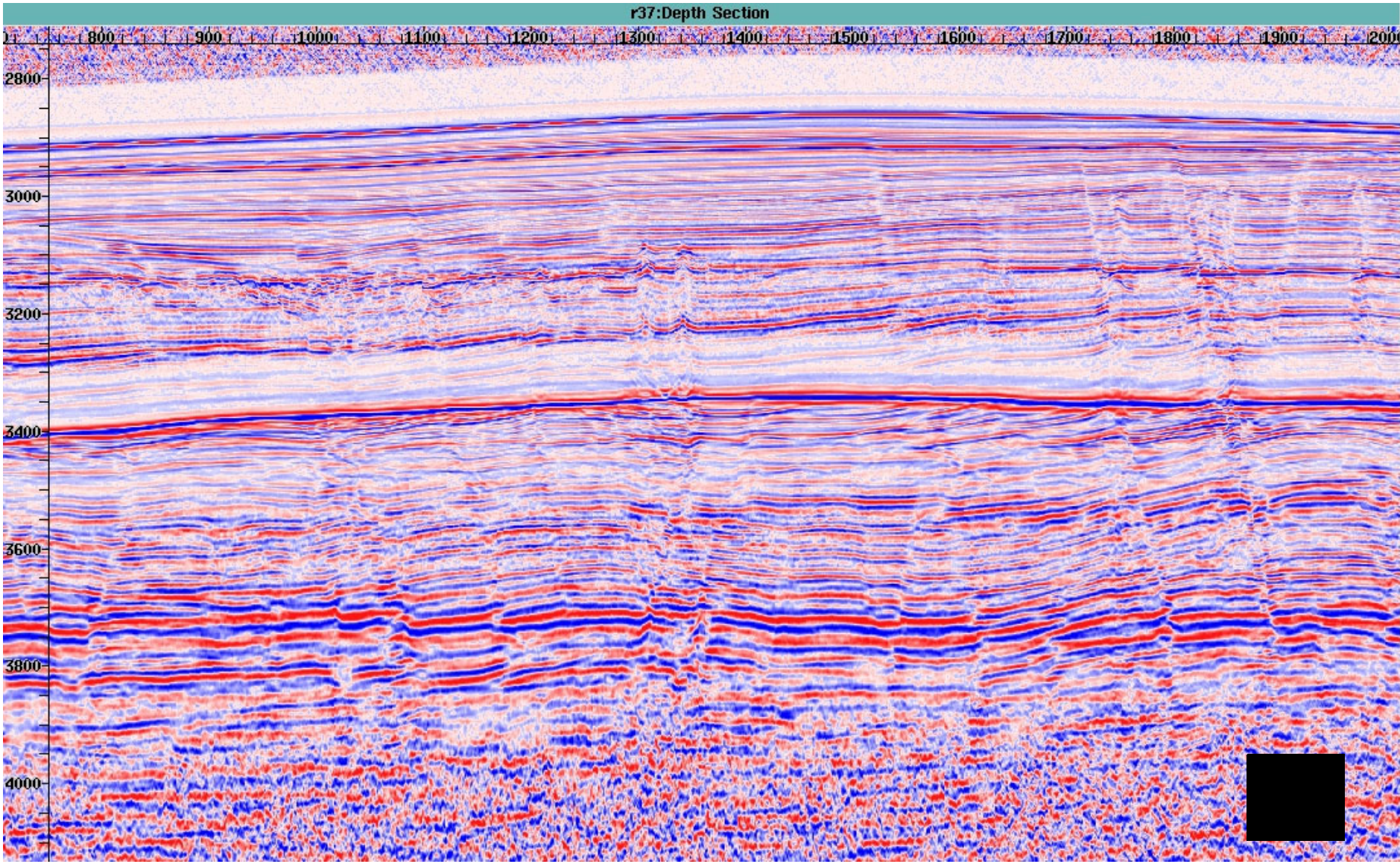
- Threshold System?

  => ~300 m gas column overcomes overburden pressure

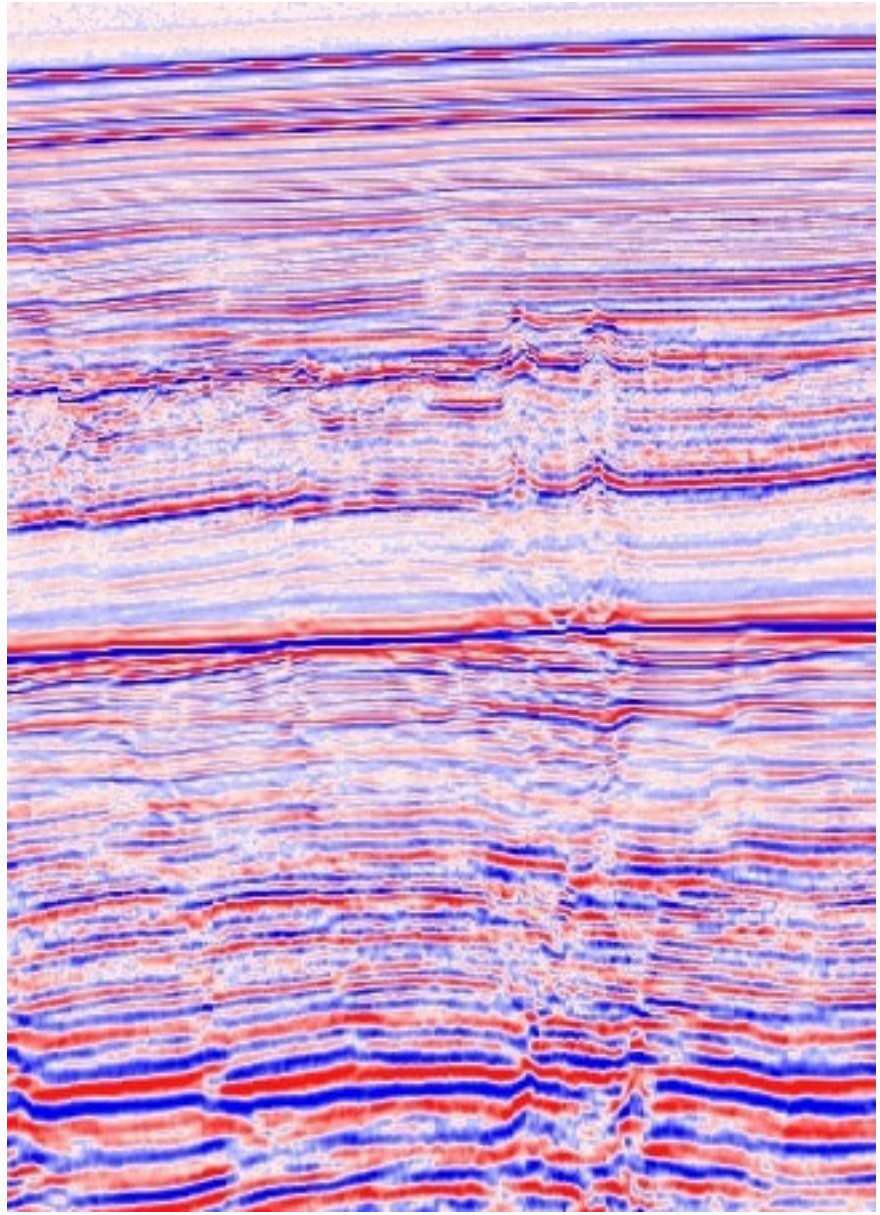

R37
189295
189361
3.6
4.0
4.5
4.8
Two-way Travel Time (s)
375 m
SW
E



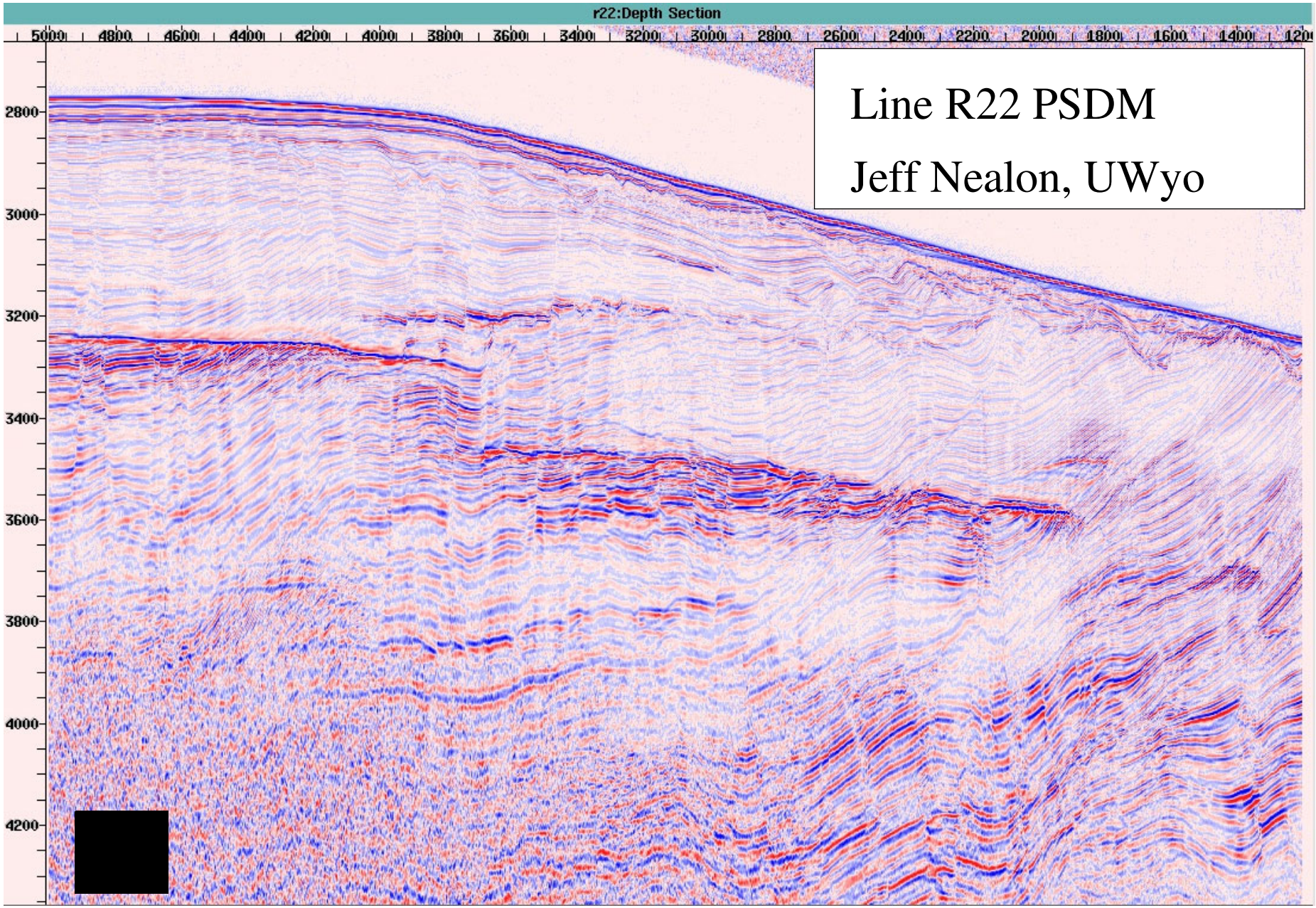

3
4


r37:Depth Section
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2800
3000
3200
3400
3600
3800
4000

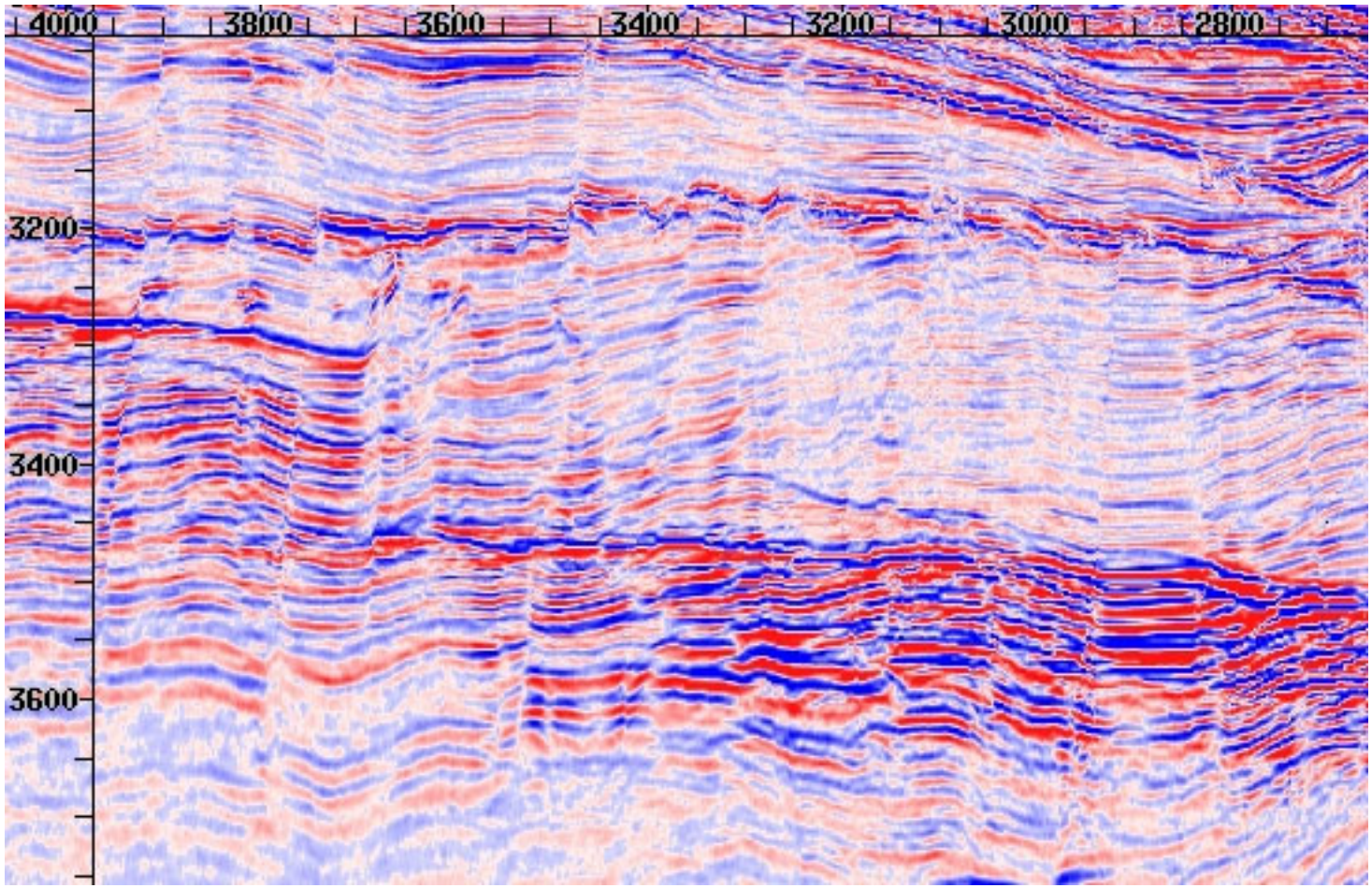
Gas “Chimneys” and deep-seated flow paths



Jeff Nealon, UWyo


r22:Depth Section
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
2800
3000
3200
3400
3600
3800
4000
4200
Line R22 PSDM
Jeff Nealon, UWyo

BSR "Corner:" A Gas Escape Feature?



Jeff Nealon, UWyo

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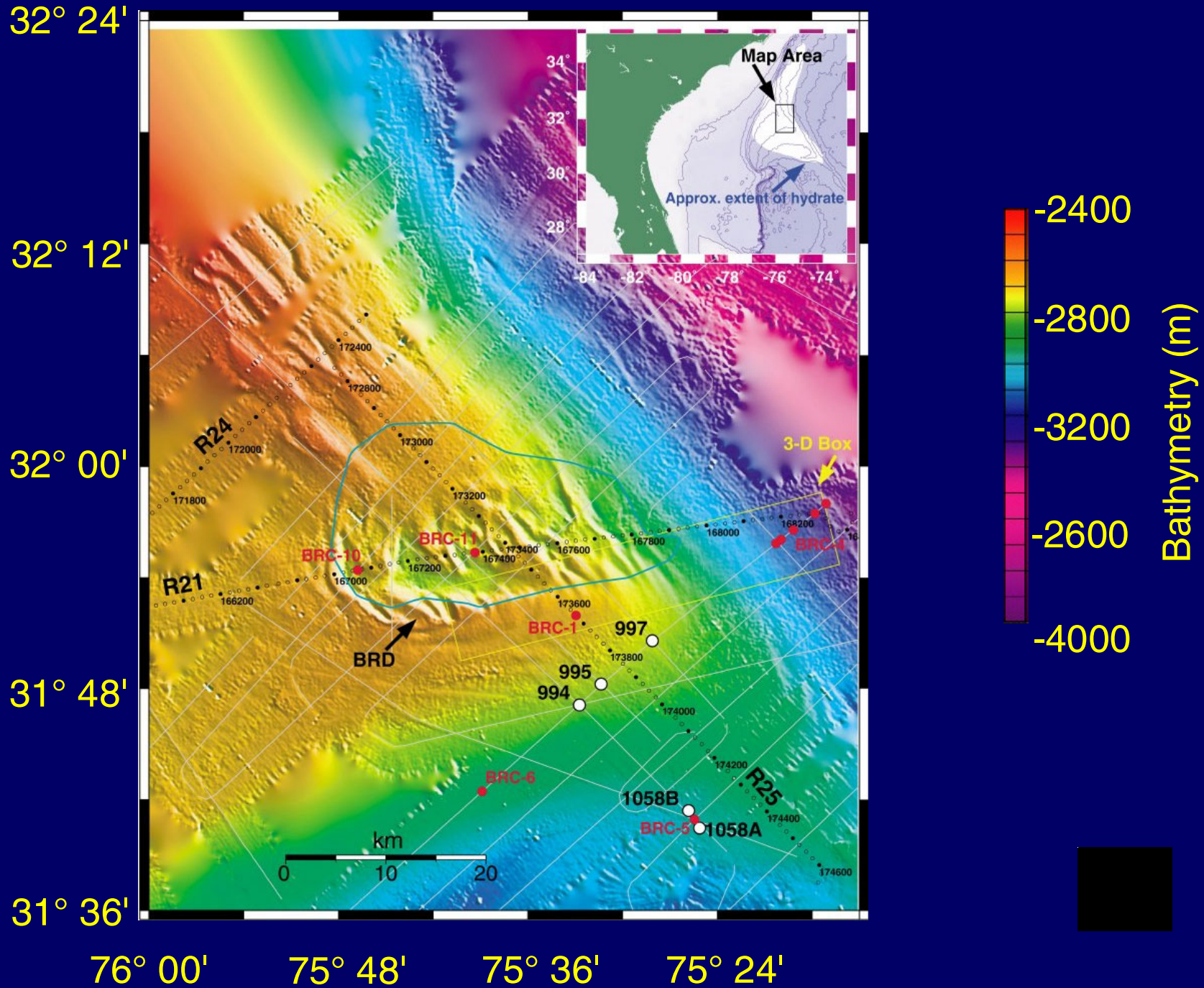
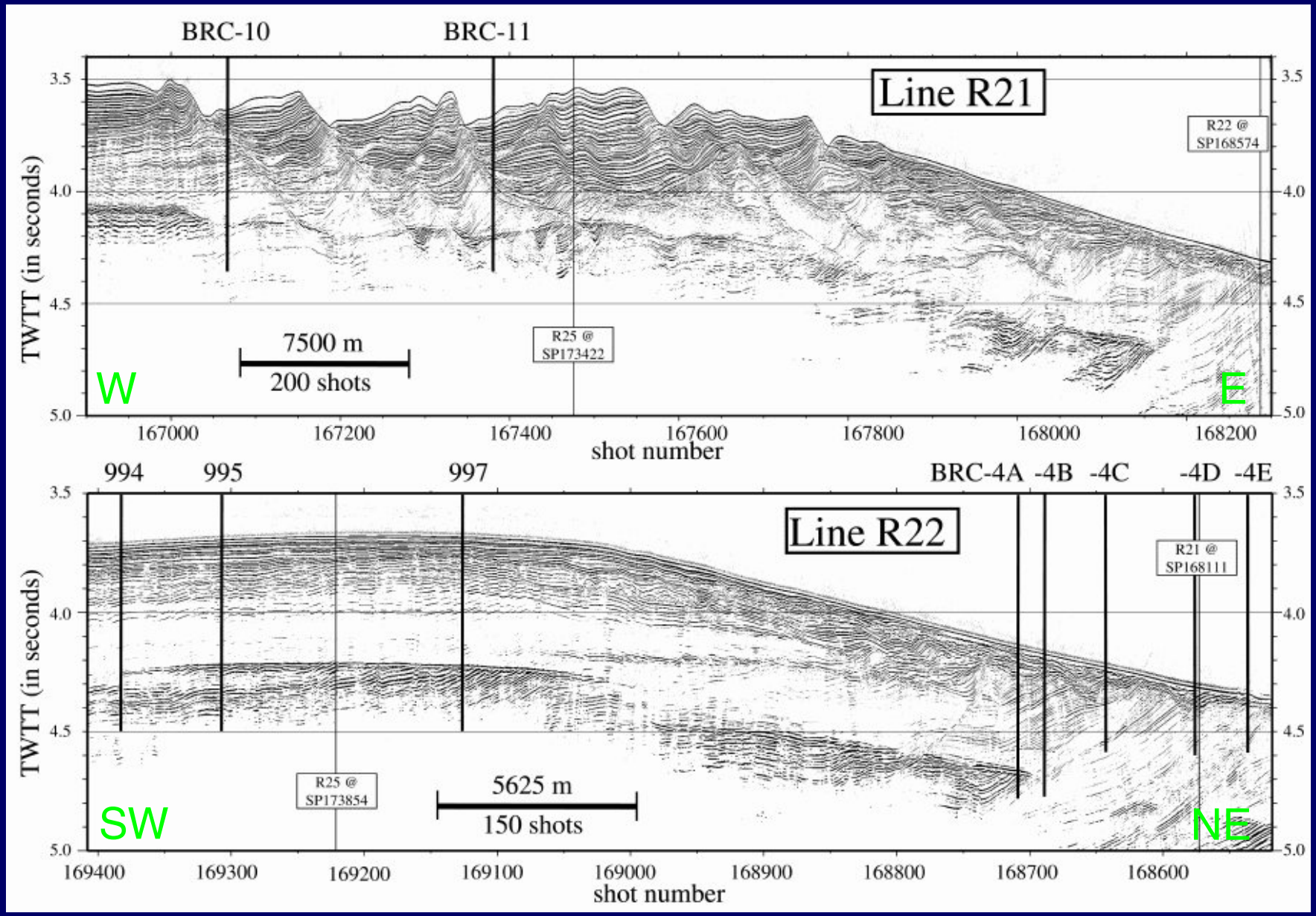

32° 24'
32° 12'
32° 00'
31° 48'
31° 36'
76° 00'
75° 48'
75° 36'
75° 24'
Map Area
Approx. extent of hydrate
34°
32°
30°
28°
-84
-82
-80
-78
-76
-74
R24
R21
R25
3-D Box
BRC-10
BRC-11
BRC-1
BRC-4
BRC-5
BRC-6
BRD
997
995
994
1058B
1058A
172400
172800
172000
171800
173000
173200
173400
167400
167600
167800
168000
168200
167200
167000
166200
173600
173800
174000
174200
174400
174600
km
0
10
20
-2400
-2800
-3200
-2600
-4000
Bathymetry (m)


BRC-10
BRC-11
Line R21
R22 @ SP168574
R25 @ SP173422
7500 m
200 shots
W
E
TWTT (in seconds)
3.5
4.0
4.5
5.0
167000
167200
167400
167600
167800
168000
168200
shot number
994
995
997
BRC-4A
-4B
-4C
-4D
-4E
Line R22
R21 @ SP168111
R25 @ SP173854
5625 m
150 shots
SW
NE
169400
169300
169200
169100
169000
168900
168800
168700
168600
shot number

The BRD is a sediment wave field

Evidence:

- Stratal geometries characteristic of sediment waves

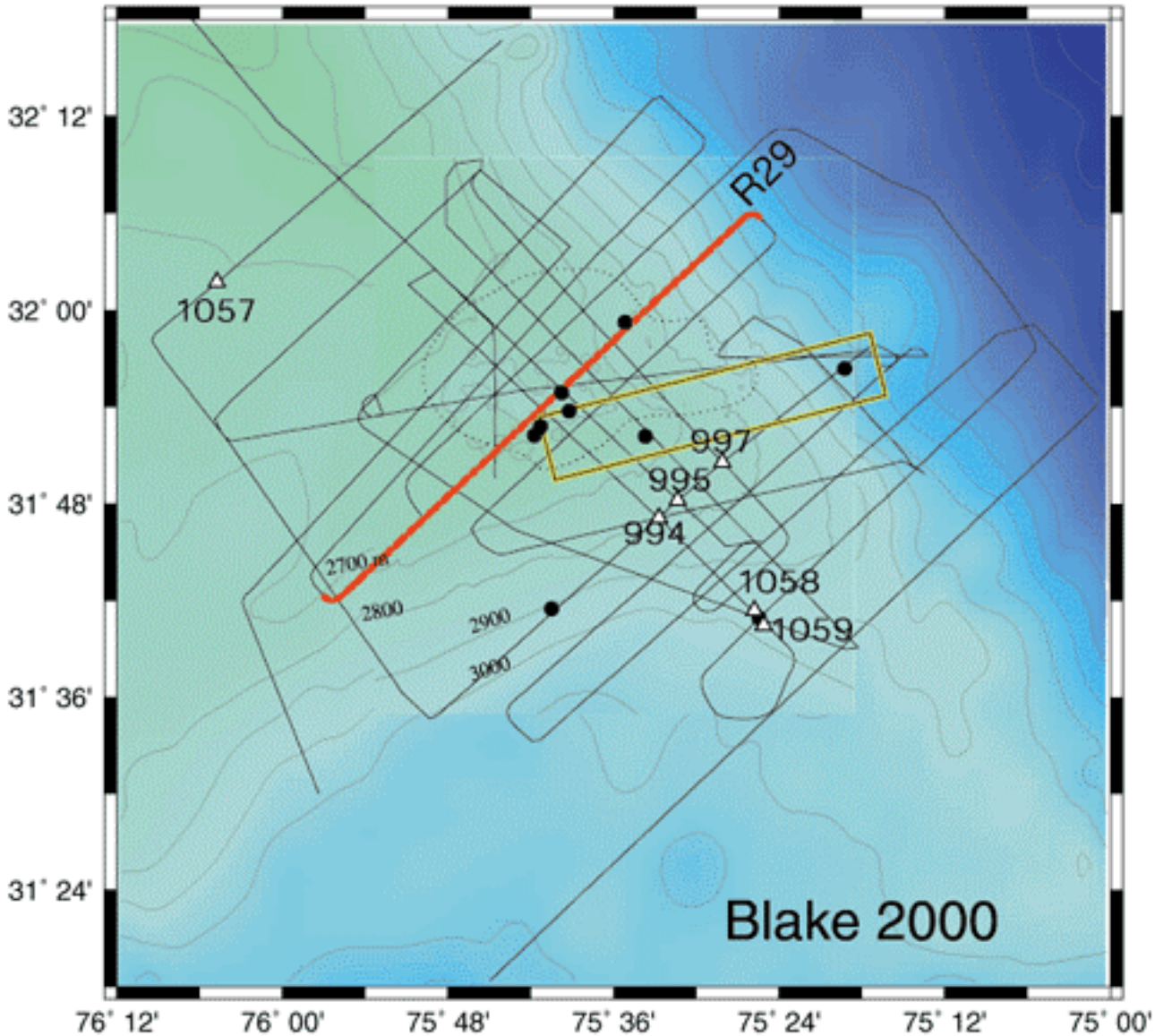
  => sigmoidal shapes, climbing crests
- “Faults” are sedimentary in origin (bounding surfaces)

  => strata thin toward bounding surfaces

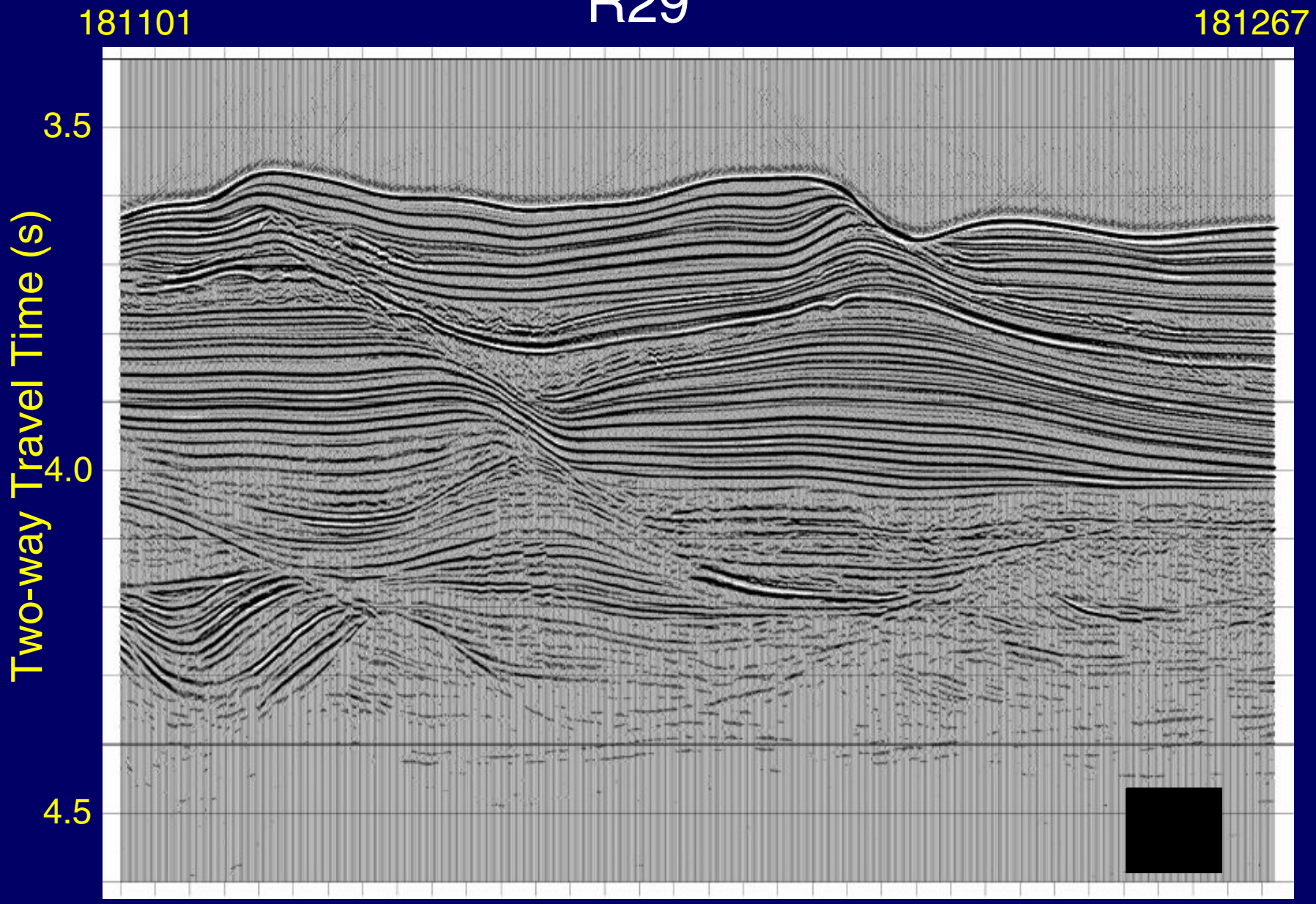
  => strata lap onto bounding surfaces

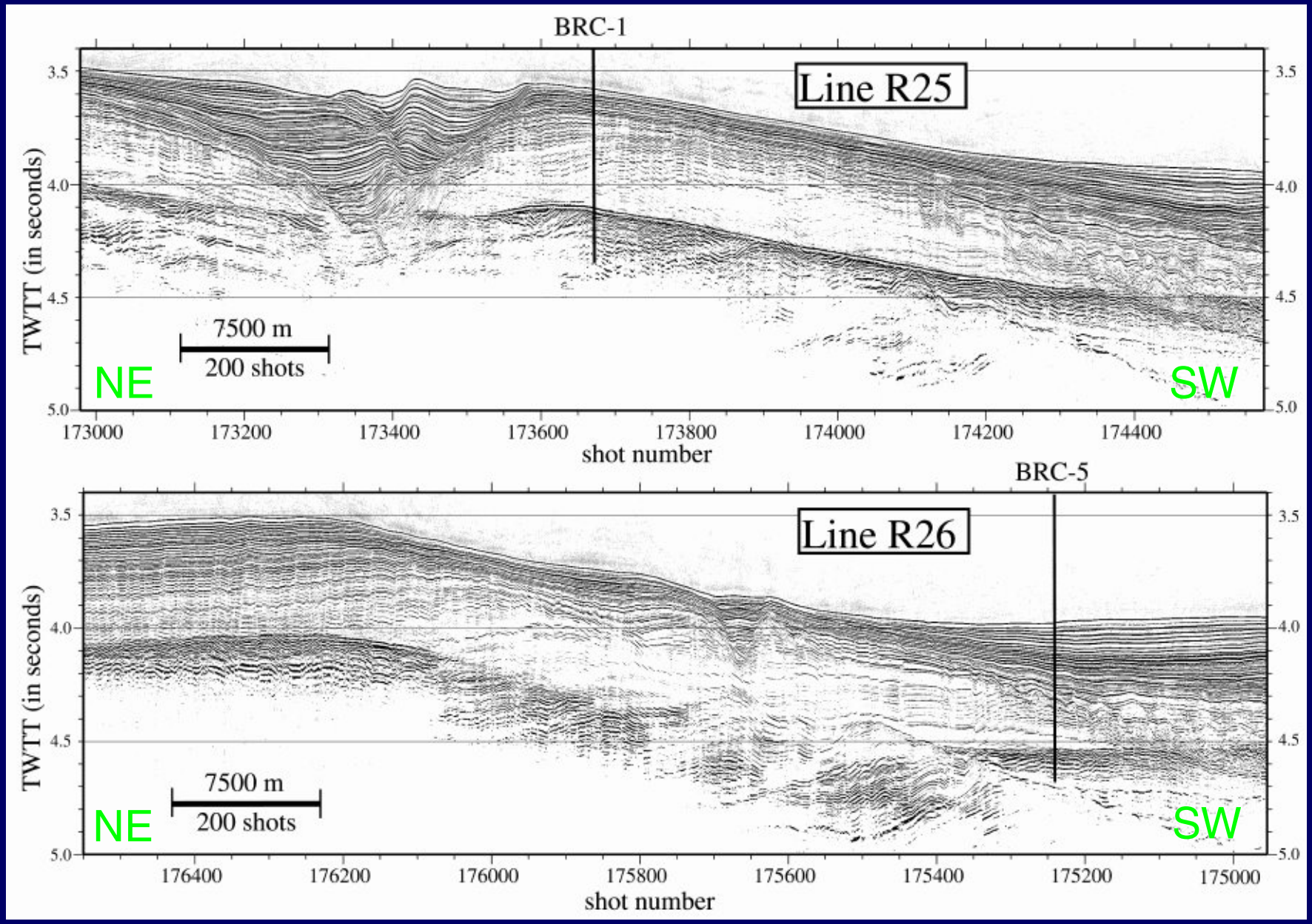
  => strata cannot be palinspastically restored

  => dips only 2-7ˆ
- Seafloor scarps are erosional scours
- No evidence for disrupted or ejected sediments

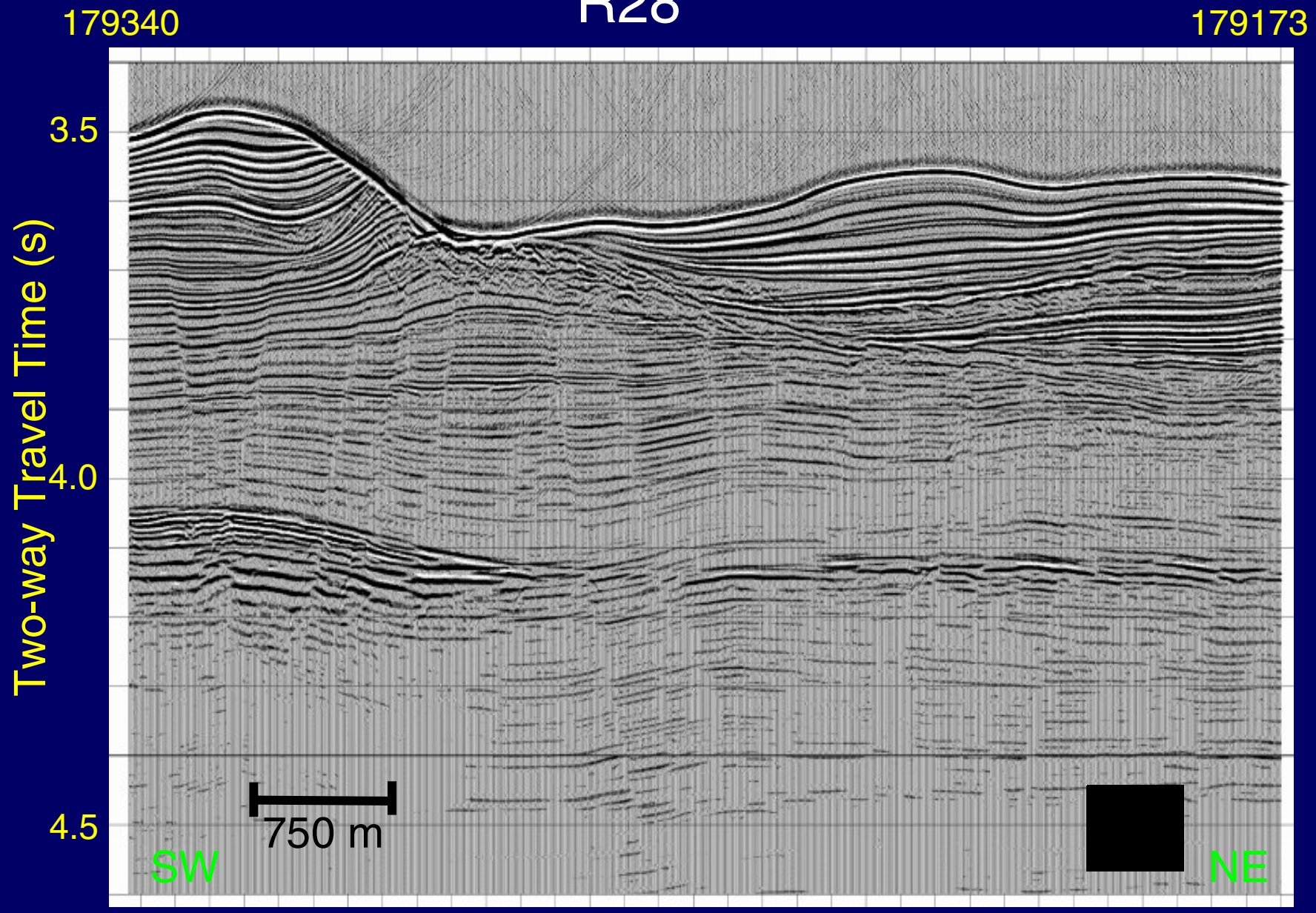

32° 12'
32° 00'
31° 48'
31° 36'
31° 24'
76° 12'
76° 00'
75° 48'
75° 36'
75° 24'
75° 12'
75° 00'
R29
1057
997
995
994
1058
1059
2700 m
2800
2900
3000
Blake 2000

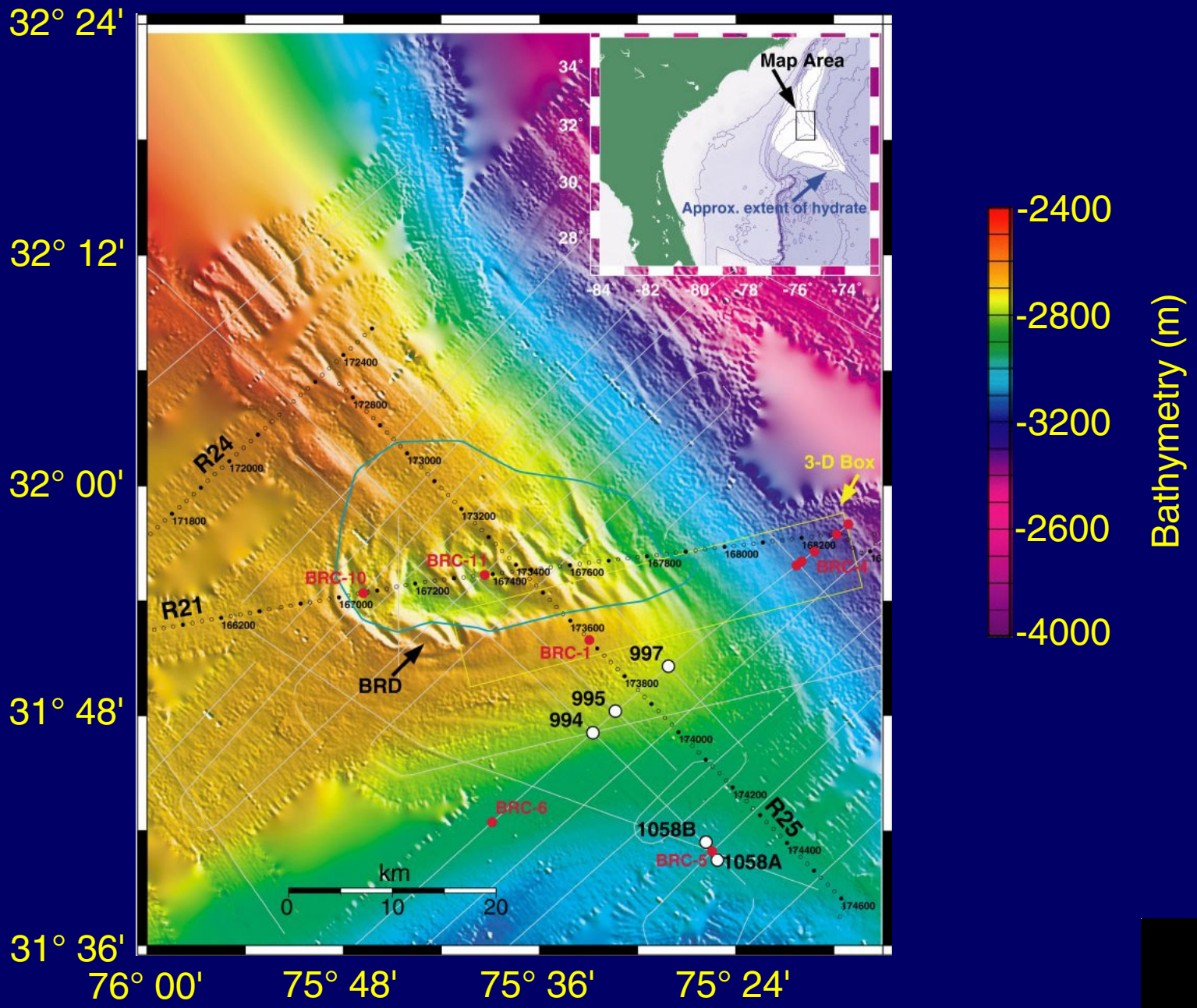
R29




BRC-1
Line R25
TWTT (in seconds)
3.5
4.0
4.5
5.0
7500 m
200 shots
NE
SW
173000
173200
173400
173600
173800
174000
174200
174400
shot number
BRC-5
Line R26
TWTT (in seconds)
3.5
4.0
4.5
5.0
7500 m
200 shots
NE
SW
176400
176200
176000
175800
175600
175400
175200
175000
shot number

R28




32° 24'
32° 12'
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75° 48'
75° 36'
75° 24'
Map Area
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R25
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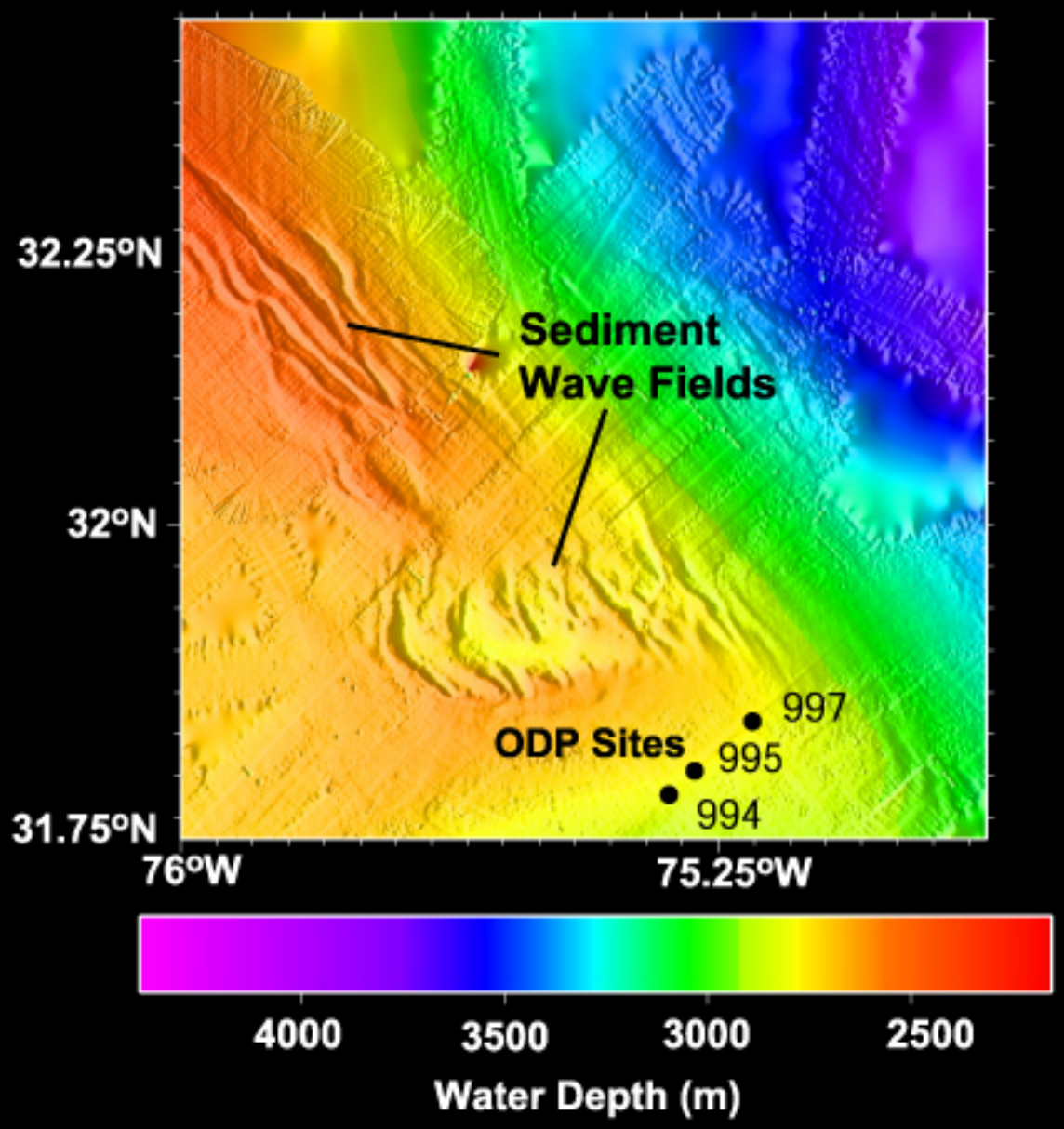
BRC-10
BRC-11
BRC-1
BRC-4
BRC-6
BRC-5
BRD
997
995
994
1058B
1058A
km
0
10
20
-2400
-2800
-3200
-2600
-4000
Bathymetry (m)



Data from Holbrook (NSF/DOE) and Ruppel (NOAA)

Conclusions

- *The Blake Ridge is a highly dynamic system*
  - *Gas injection into hydrate zone*
- *Direct seismic detection of concentrated hydrate*
  - *bright spots, blank zones, hydrate paleo-BSR*
- *The Blake Ridge Depression: a sediment wave field*
  - *0.6 Gt (30 TCF) of missing methane*

=> Long-offset, high-resolution MCS profiling is a critical tool in studies of the marine hydrate system