Seismic survey considerations in glaciology.

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Why seismics on ice?

Characterizing subglacial conditions/geology

Landseismics, the job:

- Drilling shots
- Preparing charges
- Staking geophones
- Many hands needed

Problems with landseismics:

- Labour intensive.
- Small coverage.

Can we fix this? We try

Seismic hardware and operational areas

- Large set-up, covers the ice sheet and shelf:
  - Source: Failing Y1100: 120kN p-wave vibrator, 10-110Hz
  - Source: Envirovib: 66kN p-wave vibrator, 5-300Hz
  - Receiver: 1500m, 60ch snow streamer, gimballed 14Hz p-geophone arrays.

- Small set-up (transportable by helicopter), covers ablation zone, ice streams, mountain glaciers:
  - Source: minivib Elvis: 450N p and s-wave vibrator, 5-320Hz
  - Receiver: 300m streamer, 96ch gimballed 30Hz p-geophones

Both set ups can cover the entire ice sheet.

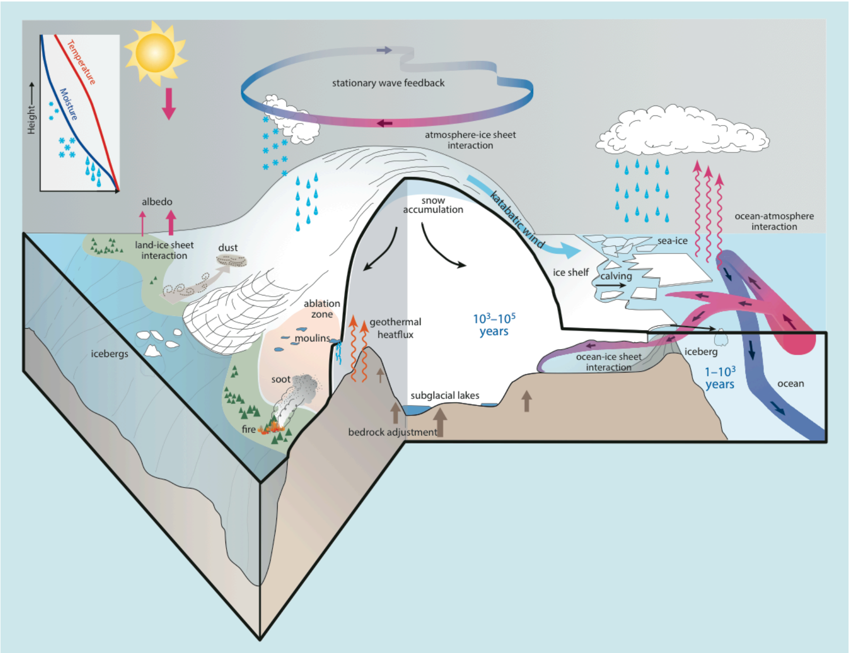


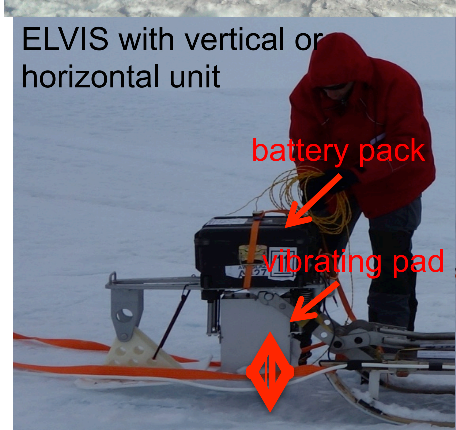
Figure ipcc 5

Seismic equipment

Top: Failing Y1100 vibrator on skis + 1.5km snow streamer.

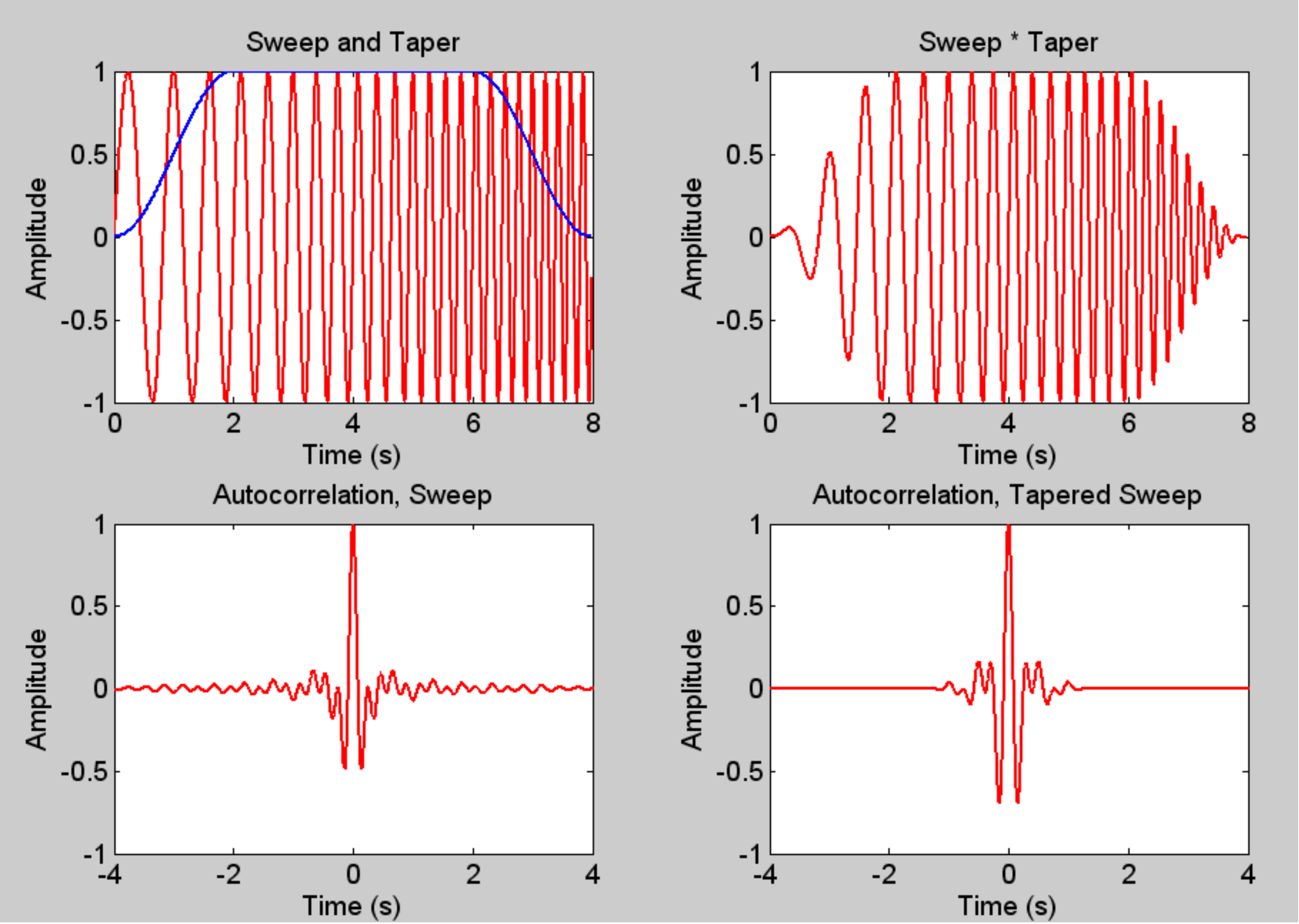
Middle: Tracked vibrator Envirovib on a PE sled.

Bottom: Minivibrator Elvis + 300m snow streamer.

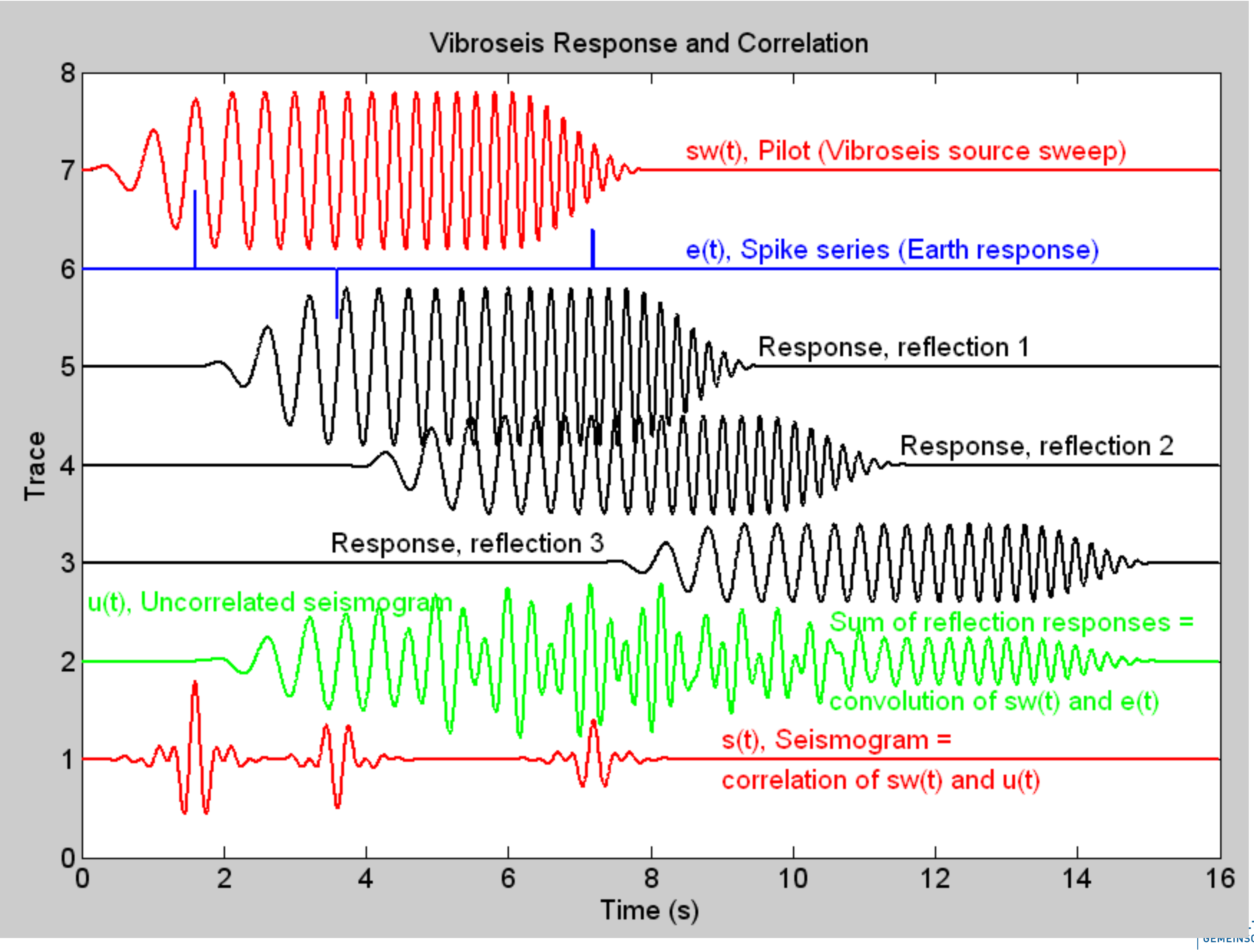


HELMHOLTZ GEMEINSCHAFT

Vibroseis principle 1: the sweep



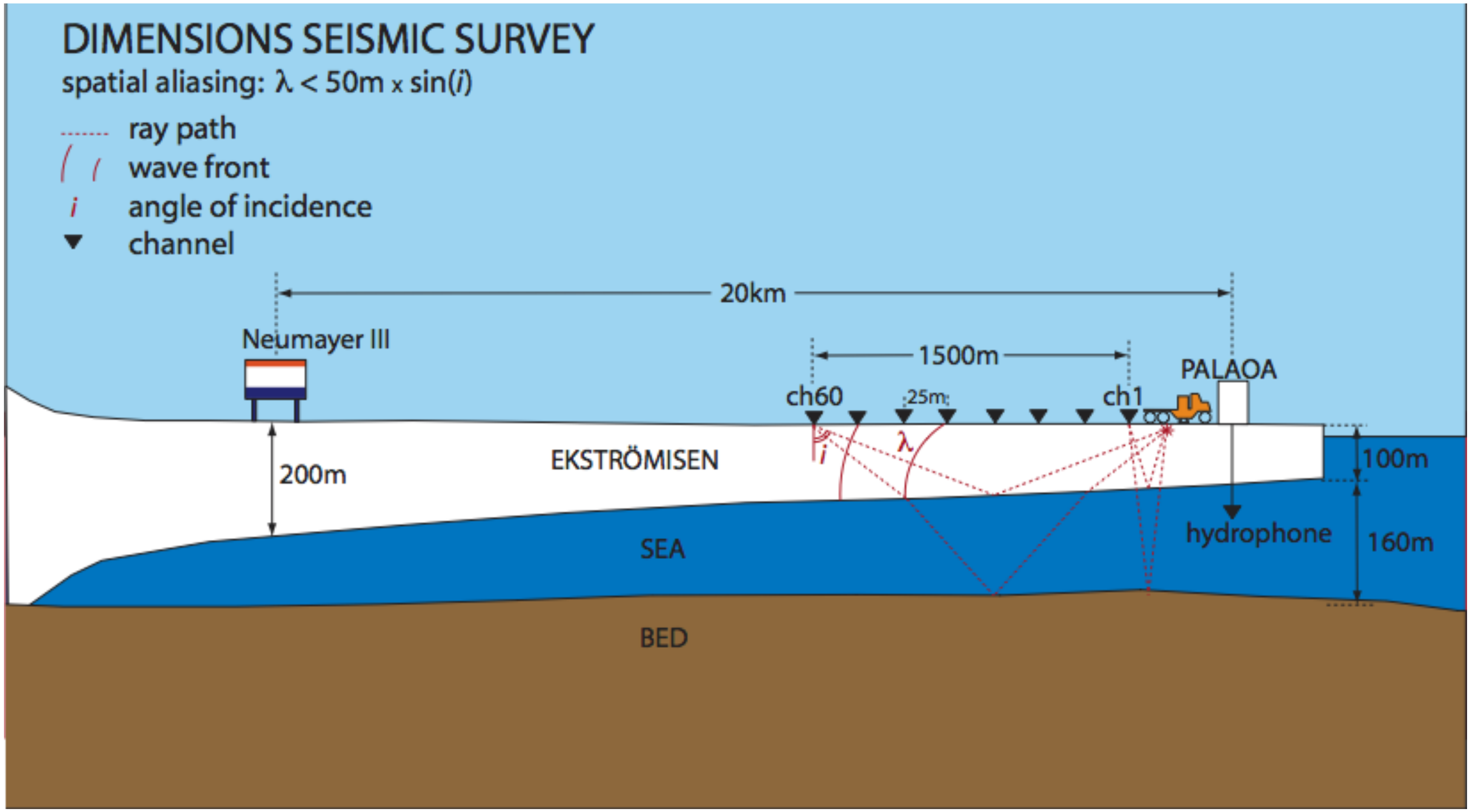
Vibroseis principle 2: a 3 reflector case



Vibrating in practice

- 1st 10 s sweep to compact the firn.
- 2nd sweep first recording.
- 3rd sweep second recording.

2010, vibrator seismics on Ekström Ice Shelf



- Wide angle seismics, shelf is thin, streamer is long.
- Channel distance 25m => spatial aliasing large offsets.

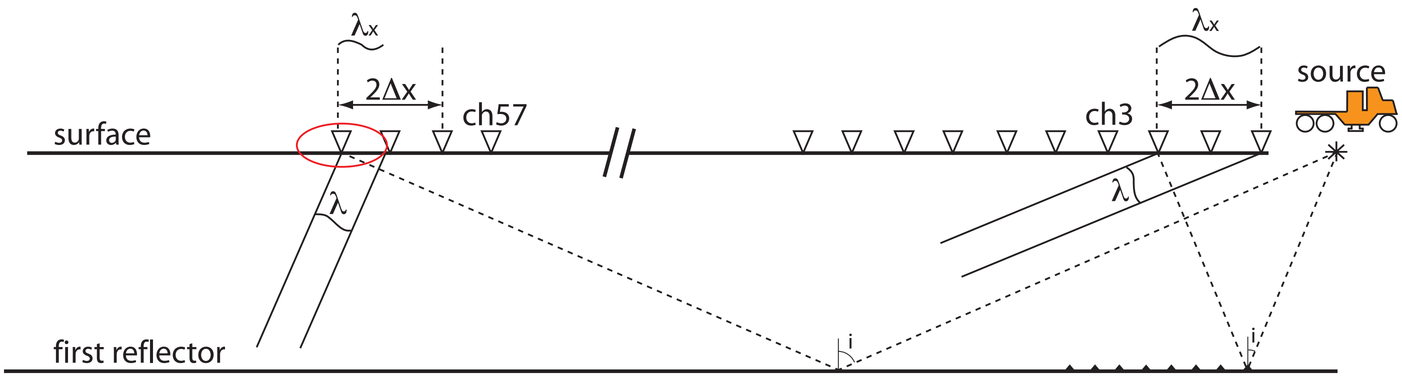
Shortcomings for shallow target depths

- Δt: sample rate
- Δx: channel spacing
- ▽ : channel
- ✳: sweep
- ▲ : CDP

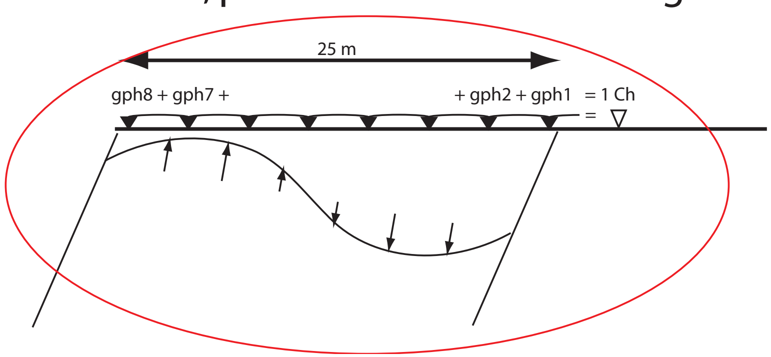
Spacial aliasing and unwanted HF filtering :

Spatial aliasing:
$\lambda_x < 2\Delta x$ or $f > 1/(2\Delta x)$

No spatial aliasing:
$\lambda_x > 2\Delta x$ or $f < 1/(2\Delta t)$

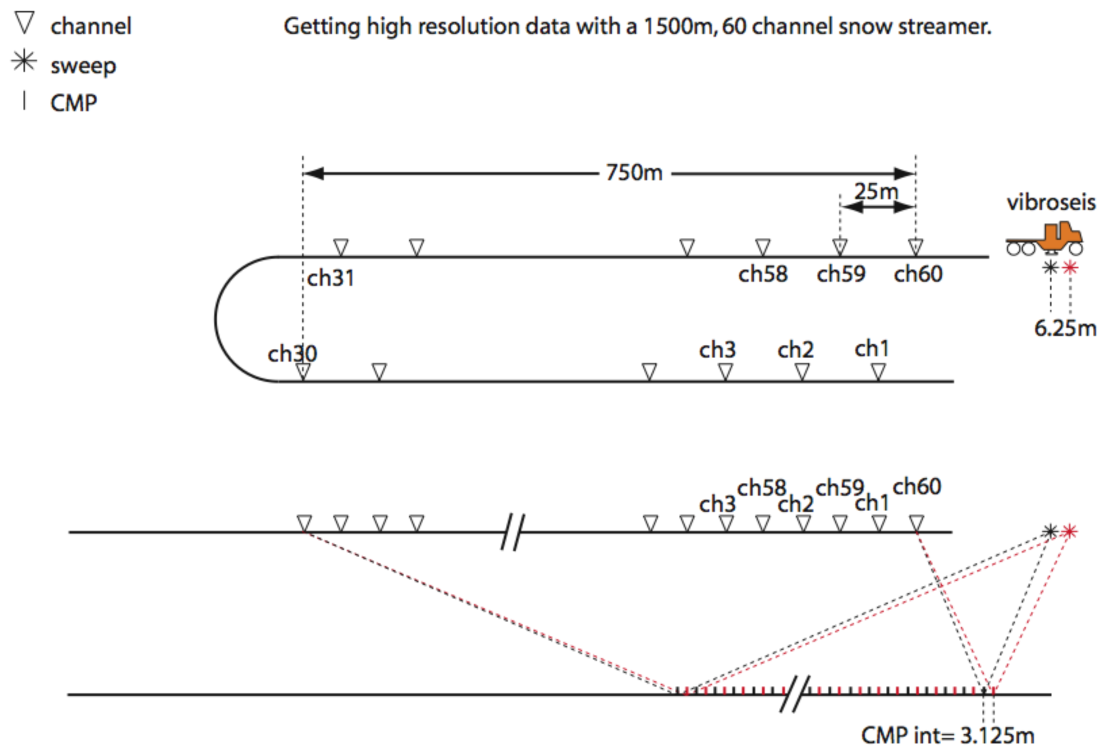


Detail, p-wave cancels out at large incidene :

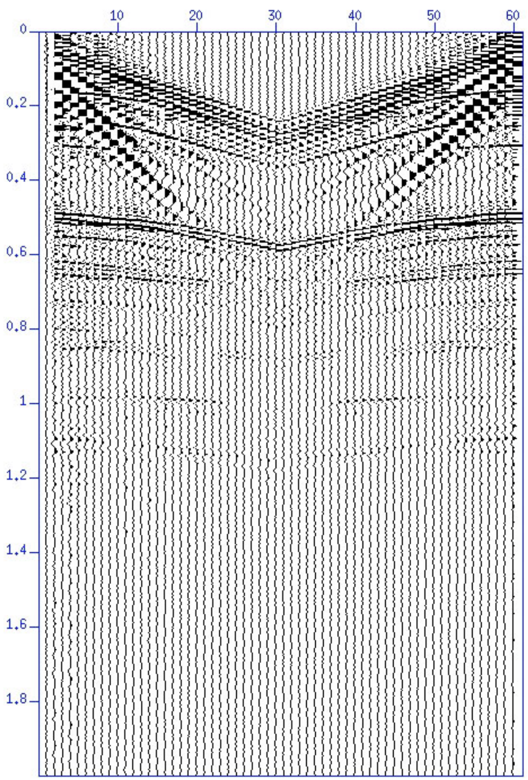


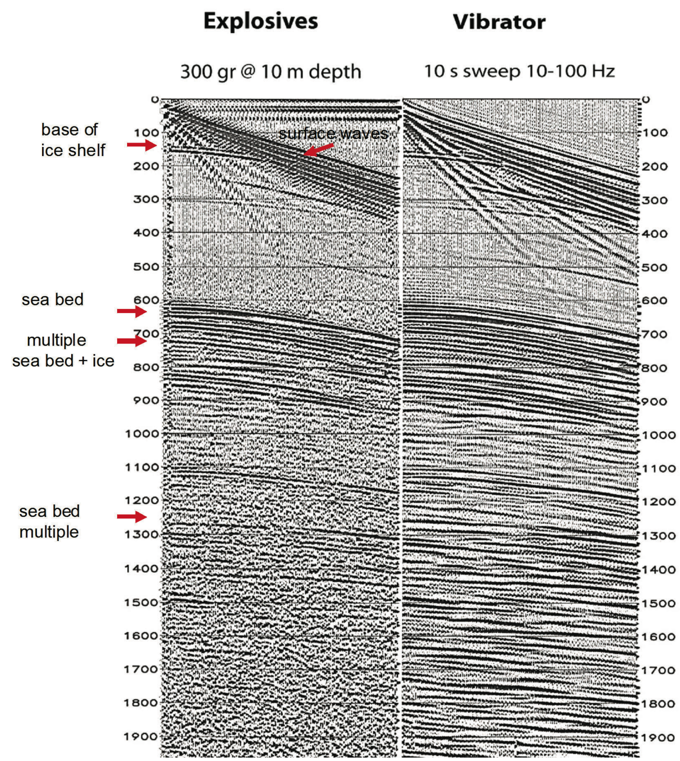
Quick and dirty solution:

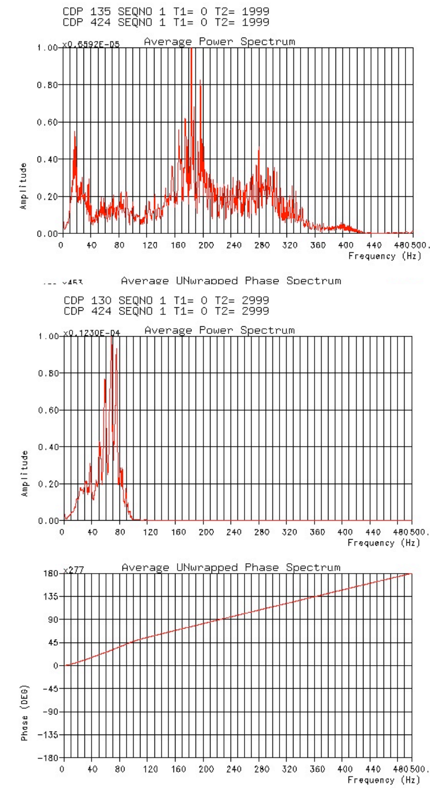
- Streamer in loop, 12.5m channel spacing



Explosive vs Vibrator on the shelf





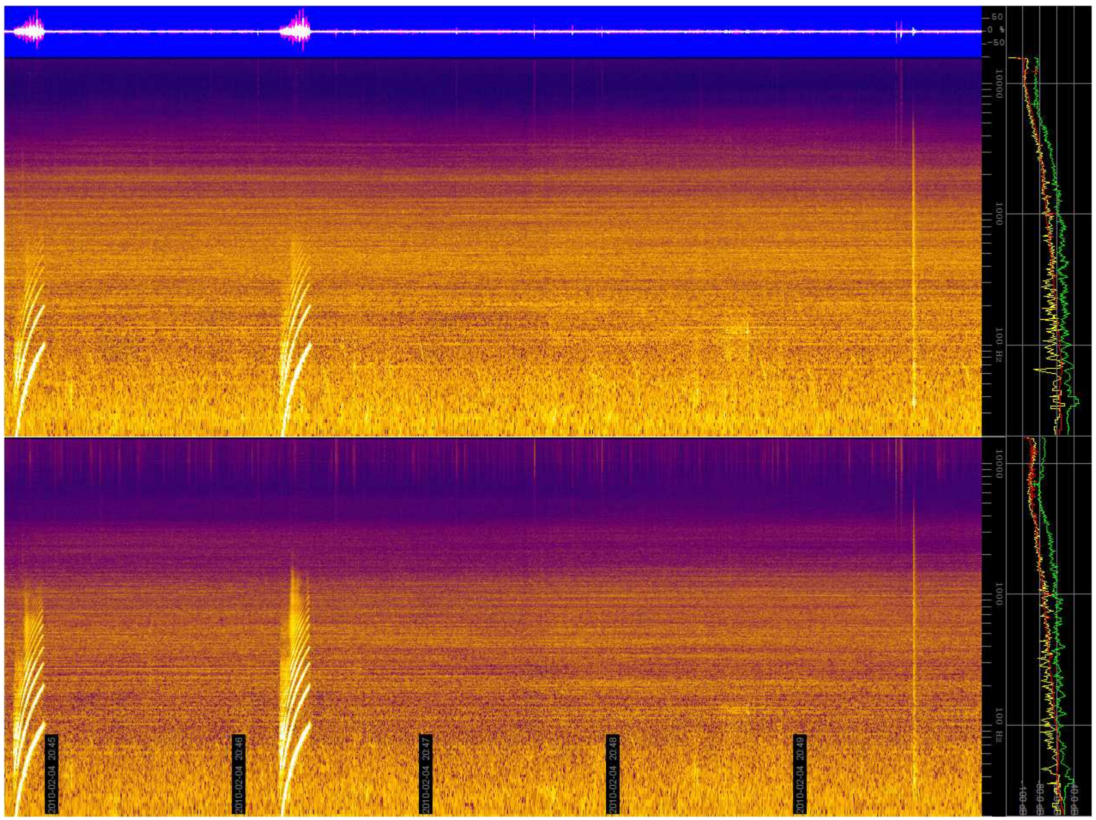


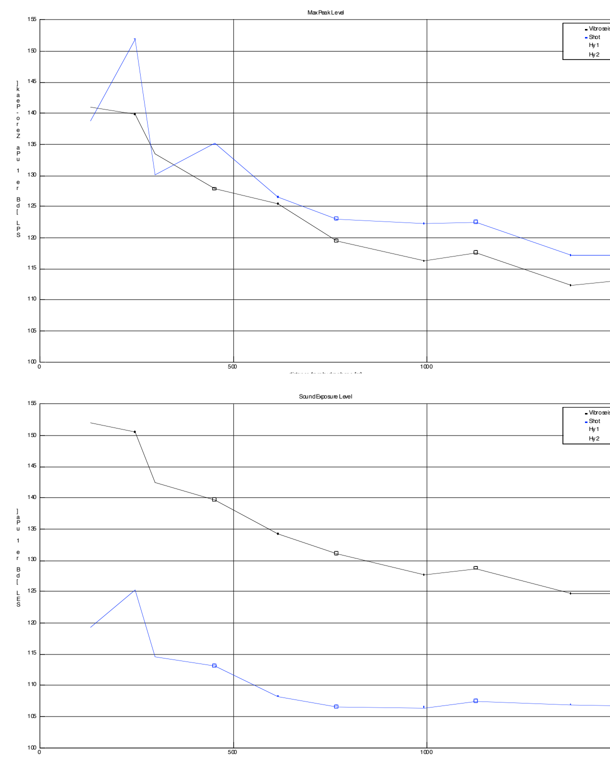
- Left: Field record Vibroseis (streamer in loop).
- Middle: Explosive vs Vibroseis, notice resolution and penetration.
- Right: Amplitude spectra Explosive and Vibrator (10-100Hz).

Eisen et. al EOS 2010

Explosive vs Vibrator under the shelf

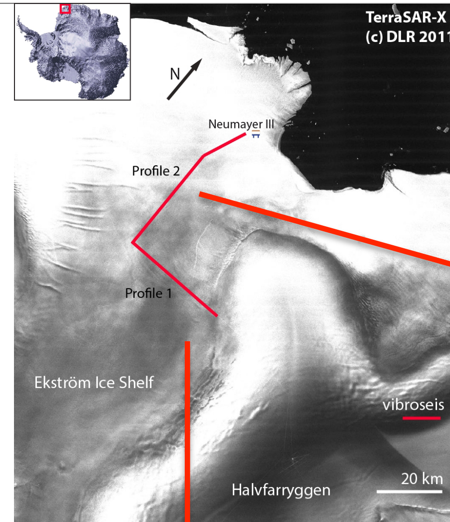
- Left: 2 hydrophones, two sweeps, one shot. Time vs amplitude.
- Right: Amplitude vs distance, maximum peak level almost equal, sound exposure level vibrator stronger.

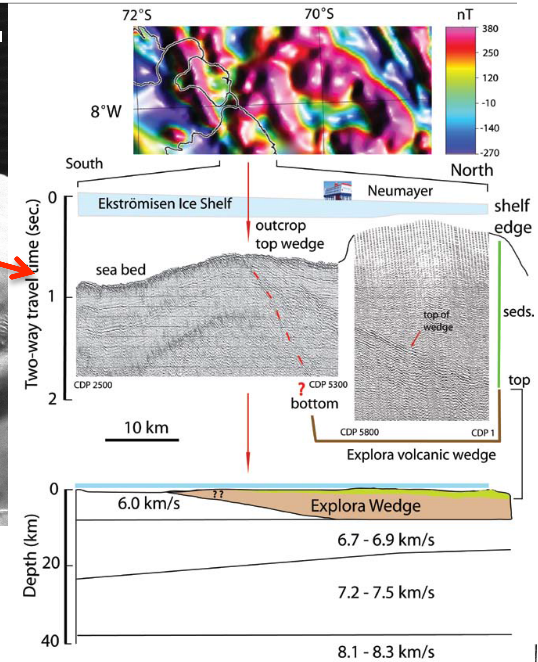


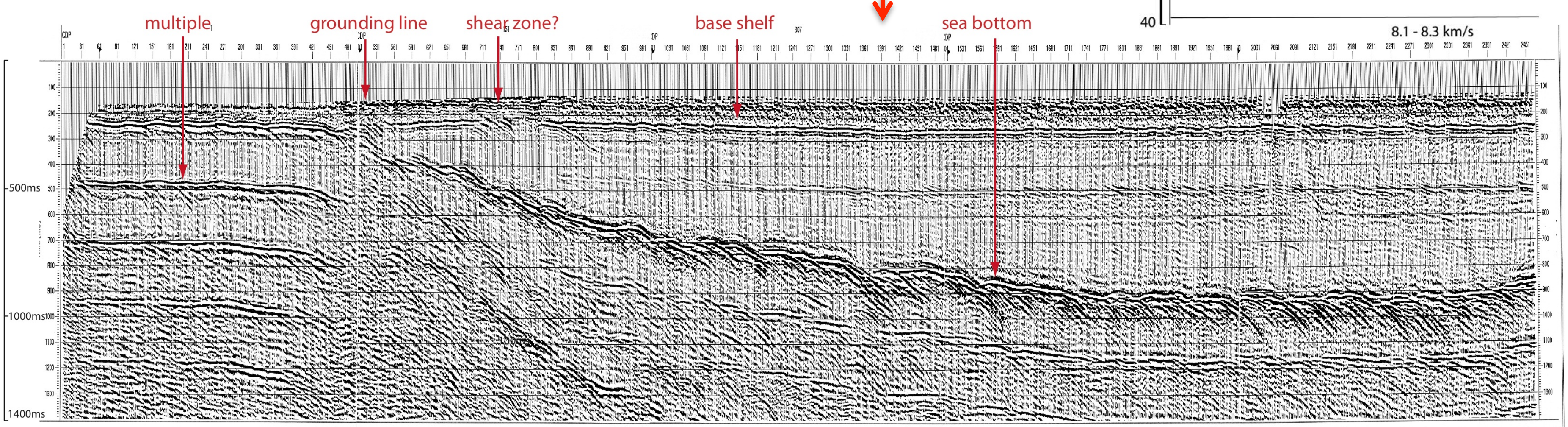


60km shelf survey 2011

- Discovery of Explora Wedge, a volcanic wedge that formed during Gondwana break-up.
- Vibroseis penetrates well in base.
  - 300m thick shelf.
  - 600m of sea water.
  - At least 2km deep data visible.
  - Good source control.
- High production, 20km/day, 8 fold data.
  - Ideal tool for shelf surveys like ANDRILL.



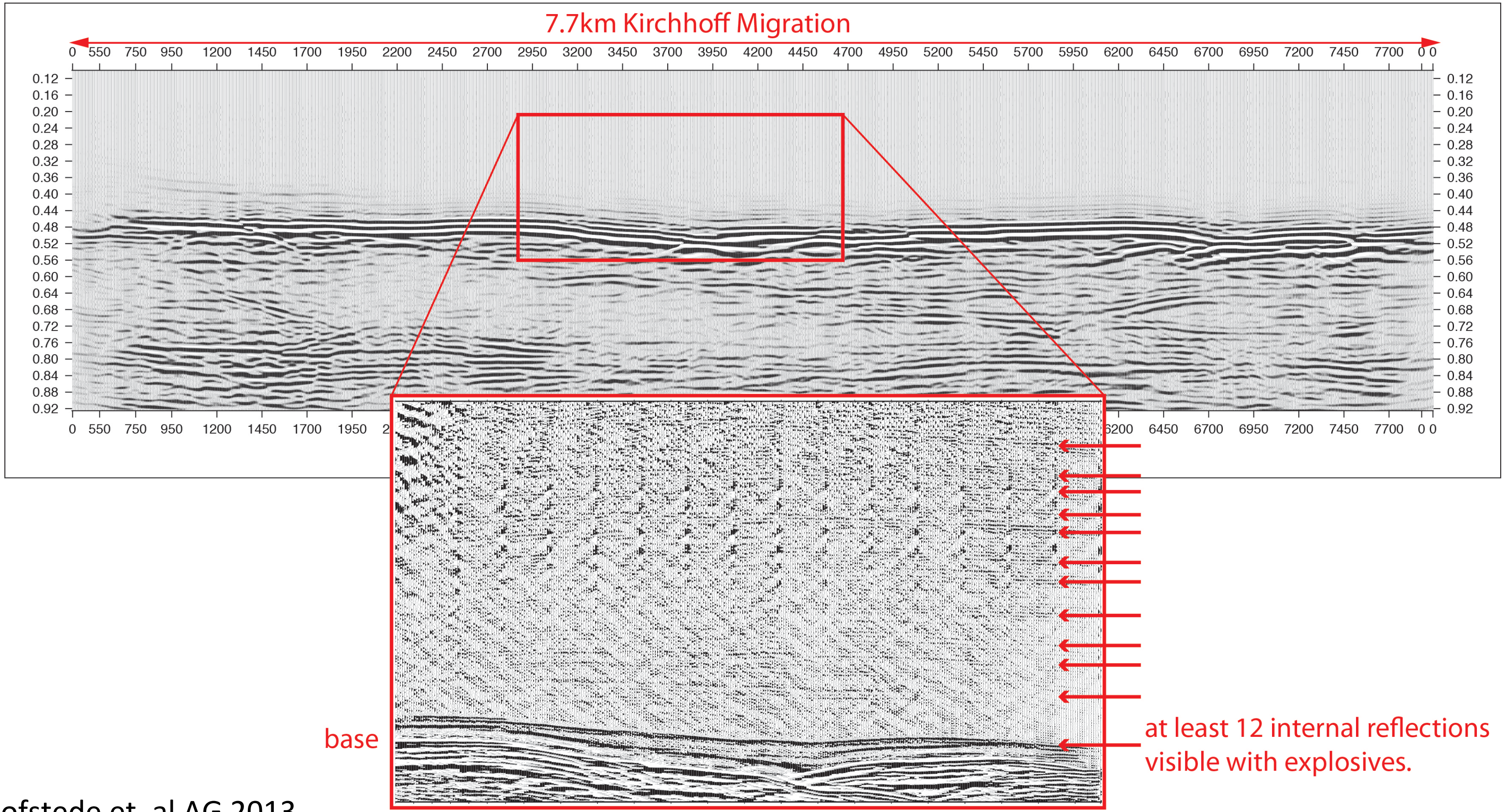




Kristoffersen et. al JGR 2014

Halvfarryggen a coastal dome

- Vibrator 10-100Hz vs explosives (400g)
- Penetration good, resolution less as explosives.

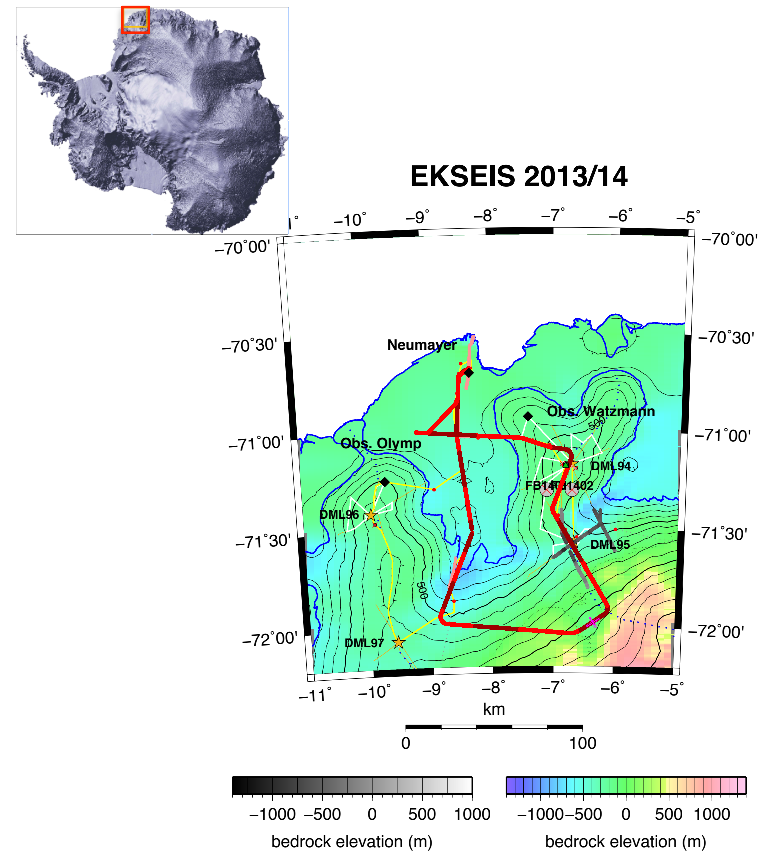


Hofstede et. al AG 2013

Ekströmisen survey 2014

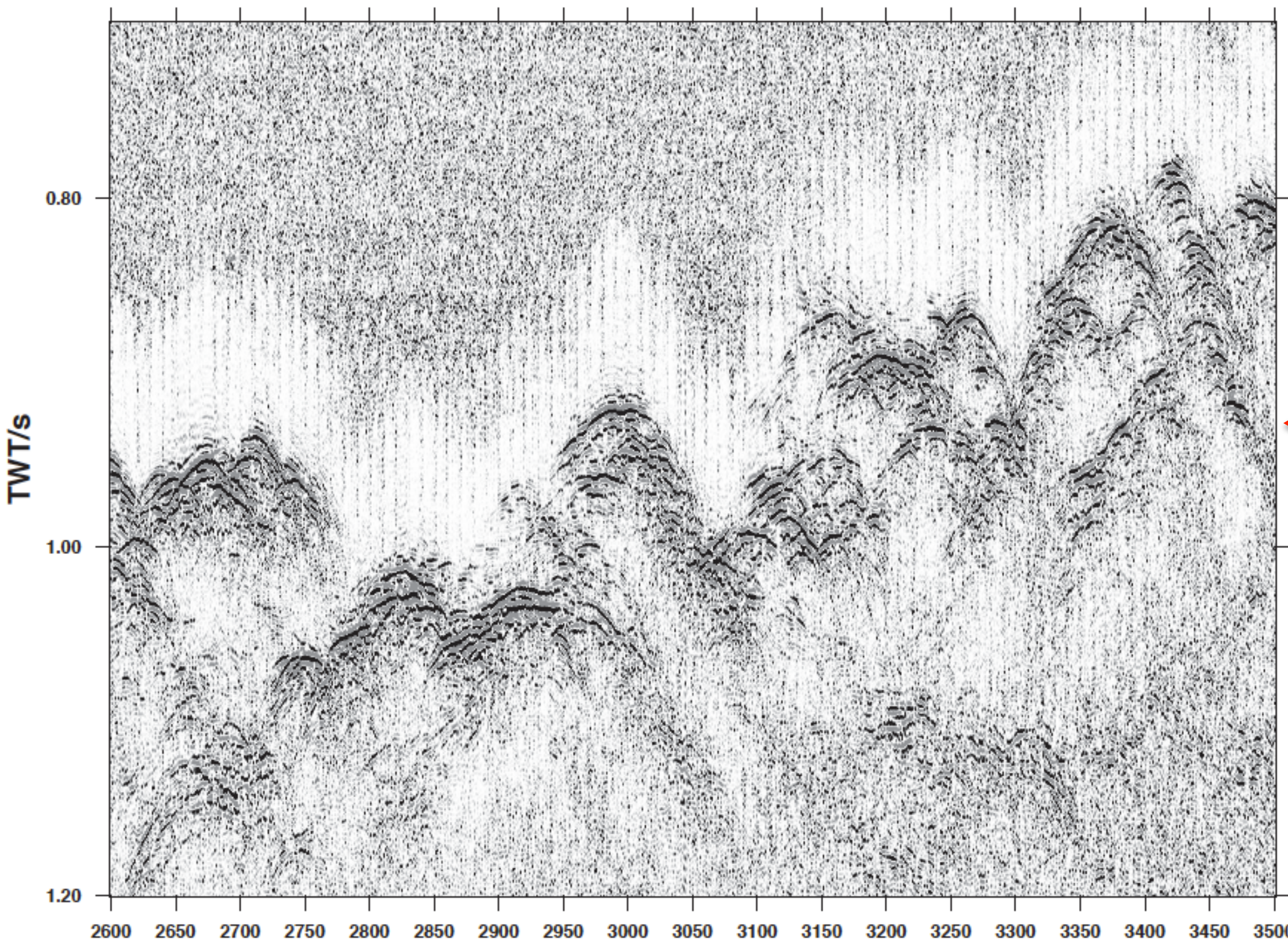
- 420 km seismic survey
- Vibrator + 1.5km snow streamer
- 5 persons
- Four weeks of data collection

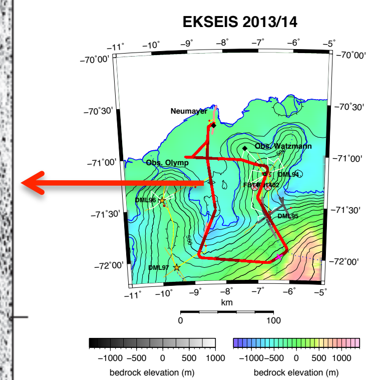
fold	shot interval	time/shotpoint	production rate	
	m	min	km/h	km/d
1	750	10	4.4	40
2	375	6 3.	7	33
3	250	4.5	3.3	30
6	125	3.5	2.2	20



Eisen et. al Polar Science 2014

Sea bottom from the shelf

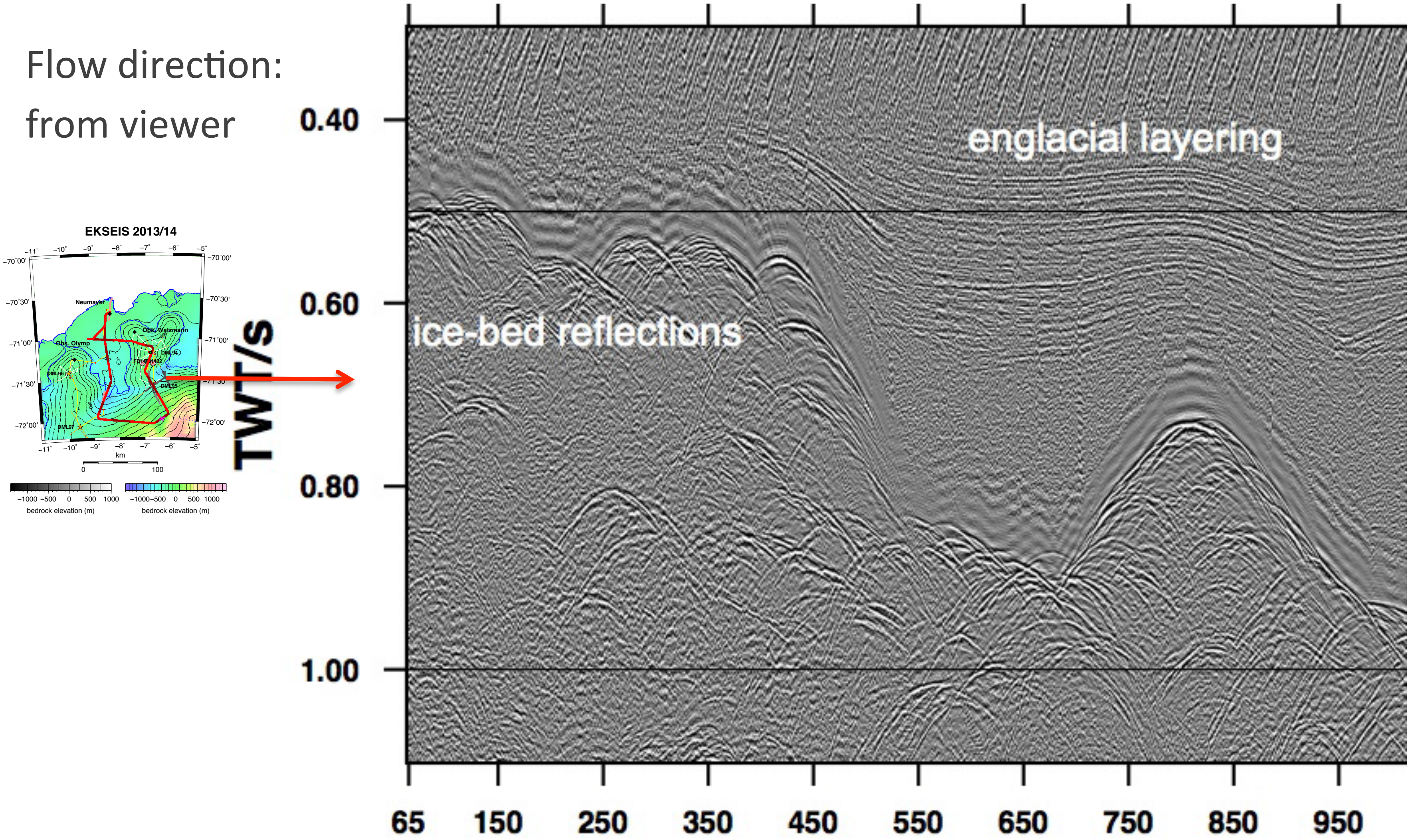




Onset of an ice stream channel

Flow direction:

from viewer



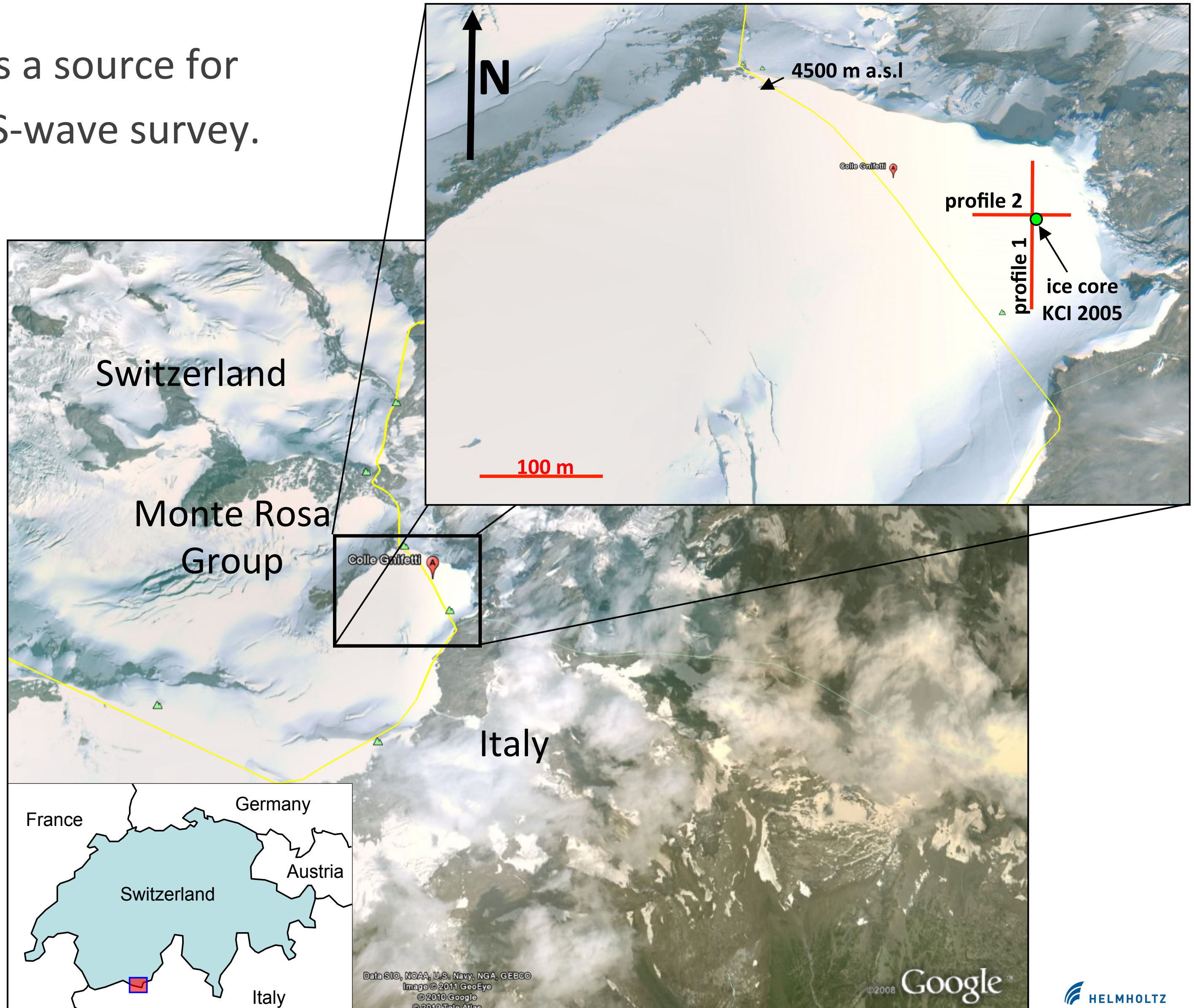
Projects with small seismic set up

- Alpine saddle, Colle Gnifetti
- Two locations on Russell Glacier, a land terminating glacier in West Greenland
- Tide water glacier Store Glacier in Uummannaq Fjord

Work in progress:

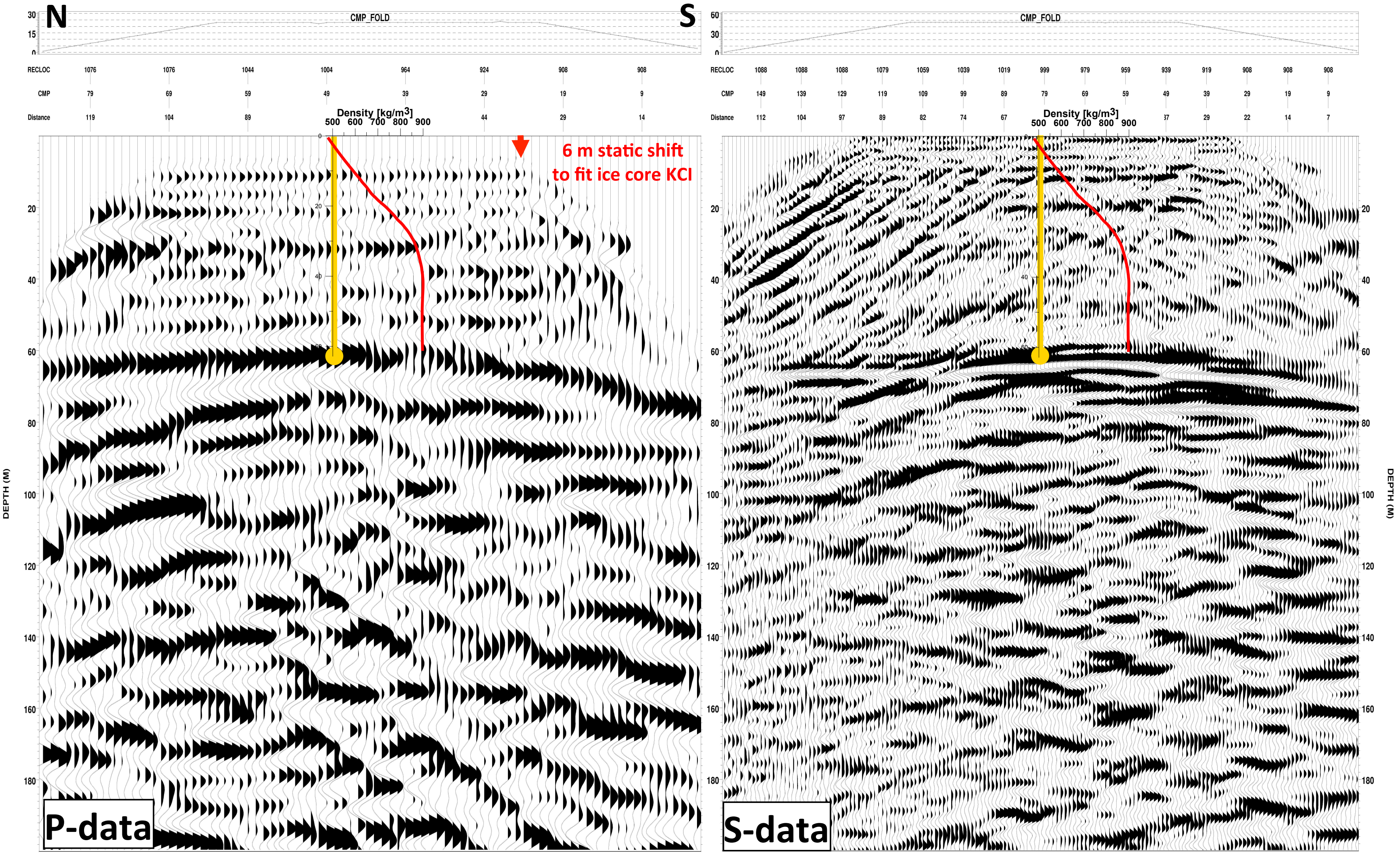
Colle Gnifetti, at 4500m altitude

Used Elvis as a source for
Both P and S-wave survey.



A mini ice-cap, no melt

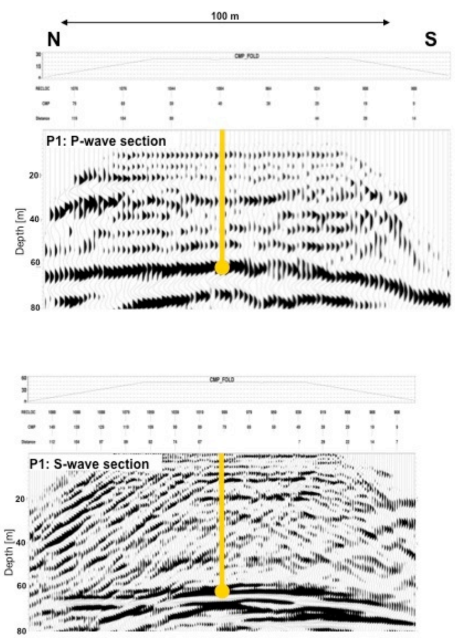
Comparing S and P data:

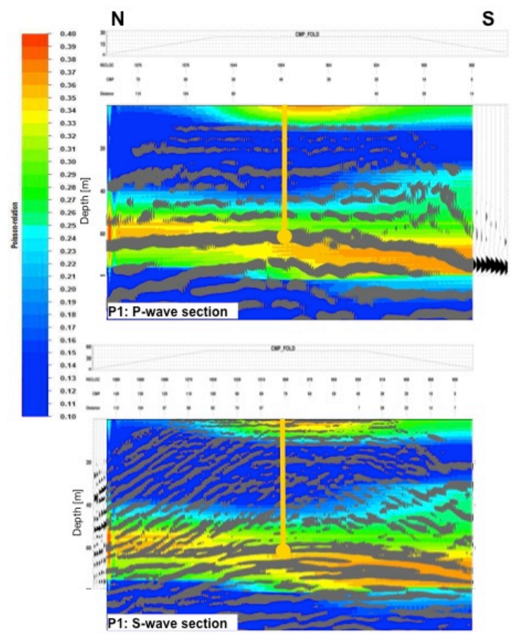


Polom et. al NSG 2014

Poisson ratio (υ) from P and S data

P and S data → Poisson ratio → Fracture mechanics





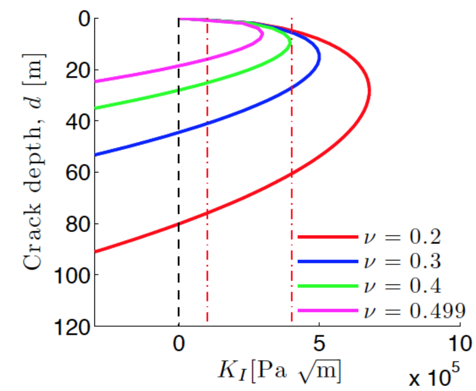


Plate et al. 2012

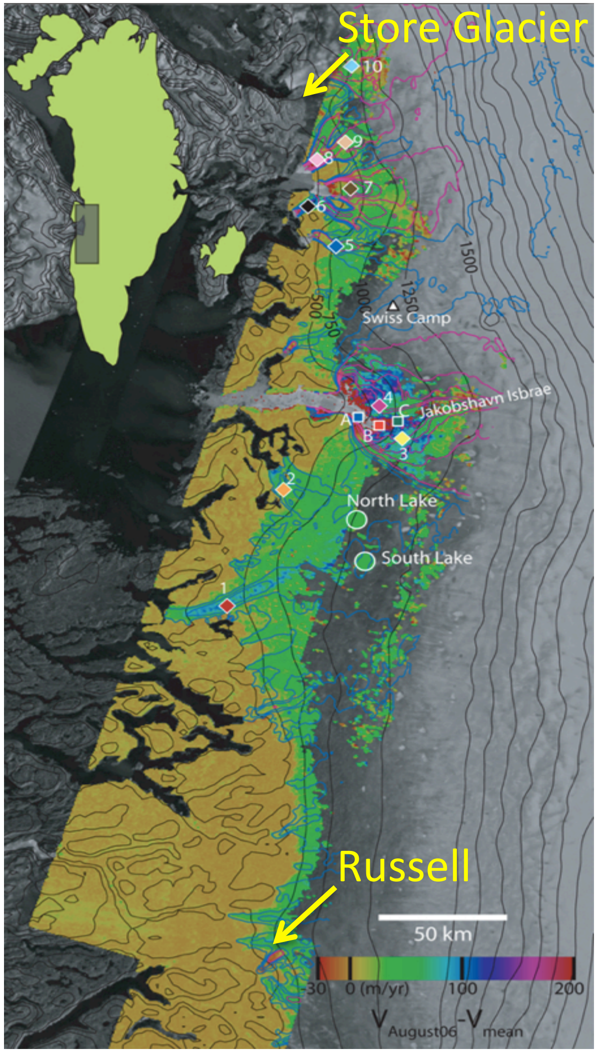
Locations Russell and Store

Summer speed up August 2006-September 2004:

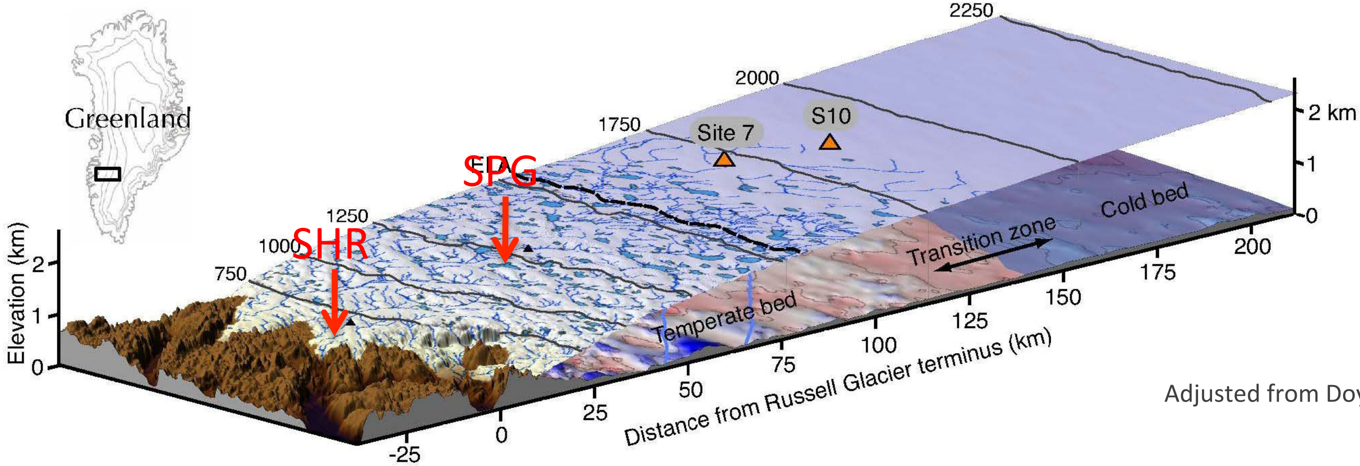
- sheet: 50-100%
- outlet: < 15%

=> Check the basal conditions of the sheet at Russell

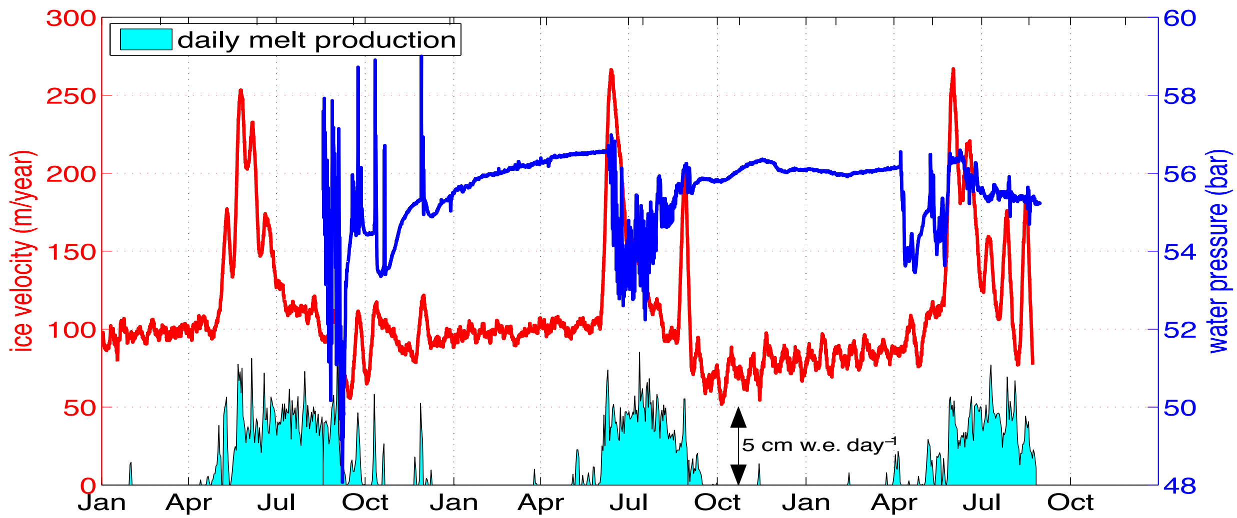
Joughin et al. 2008



Dynamics of SHR Russell Glacier



Adjusted from Doyle et al, GRL 2014



data: courtesy R.S.W. van de Wal

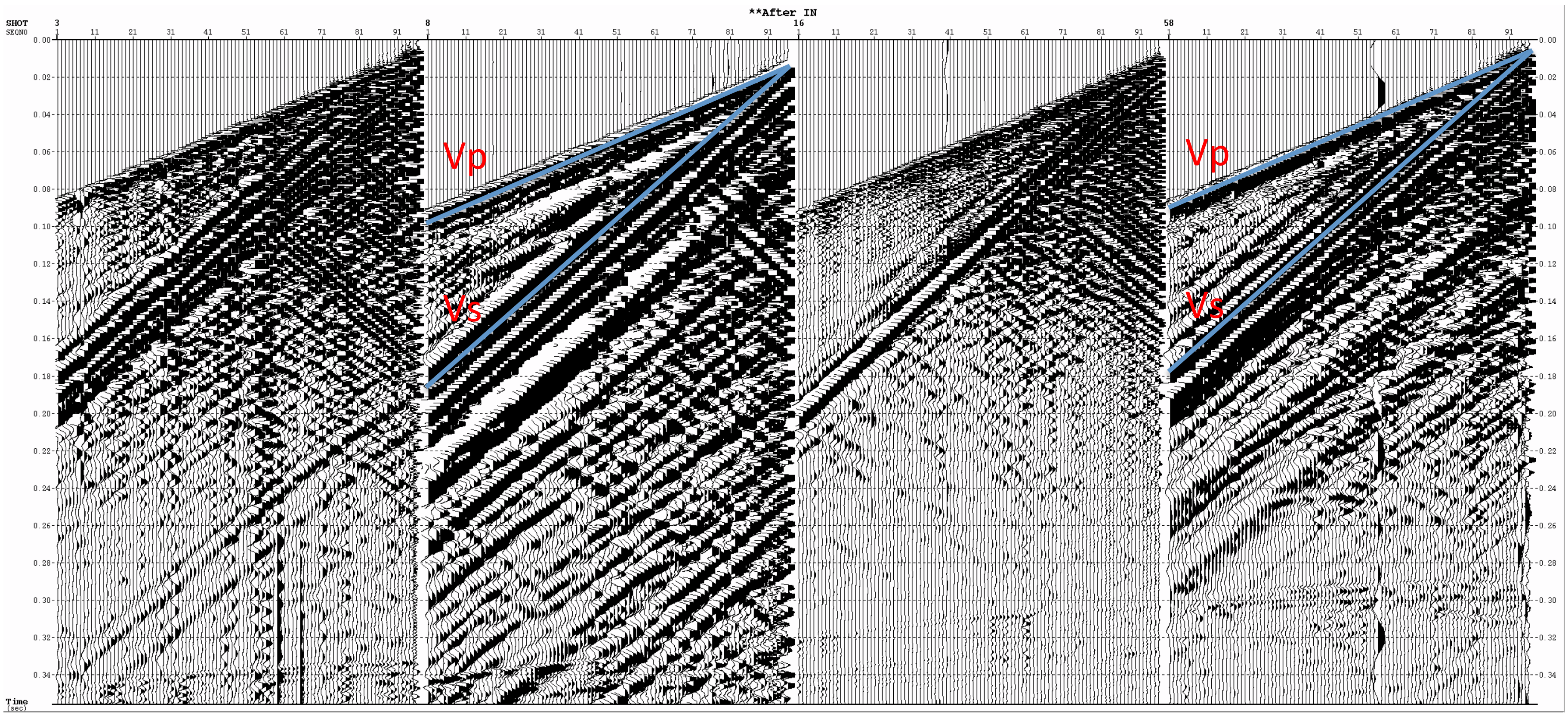
Reintroducing a British approach, May 2014:

Slow but steady

Contact with the ice?

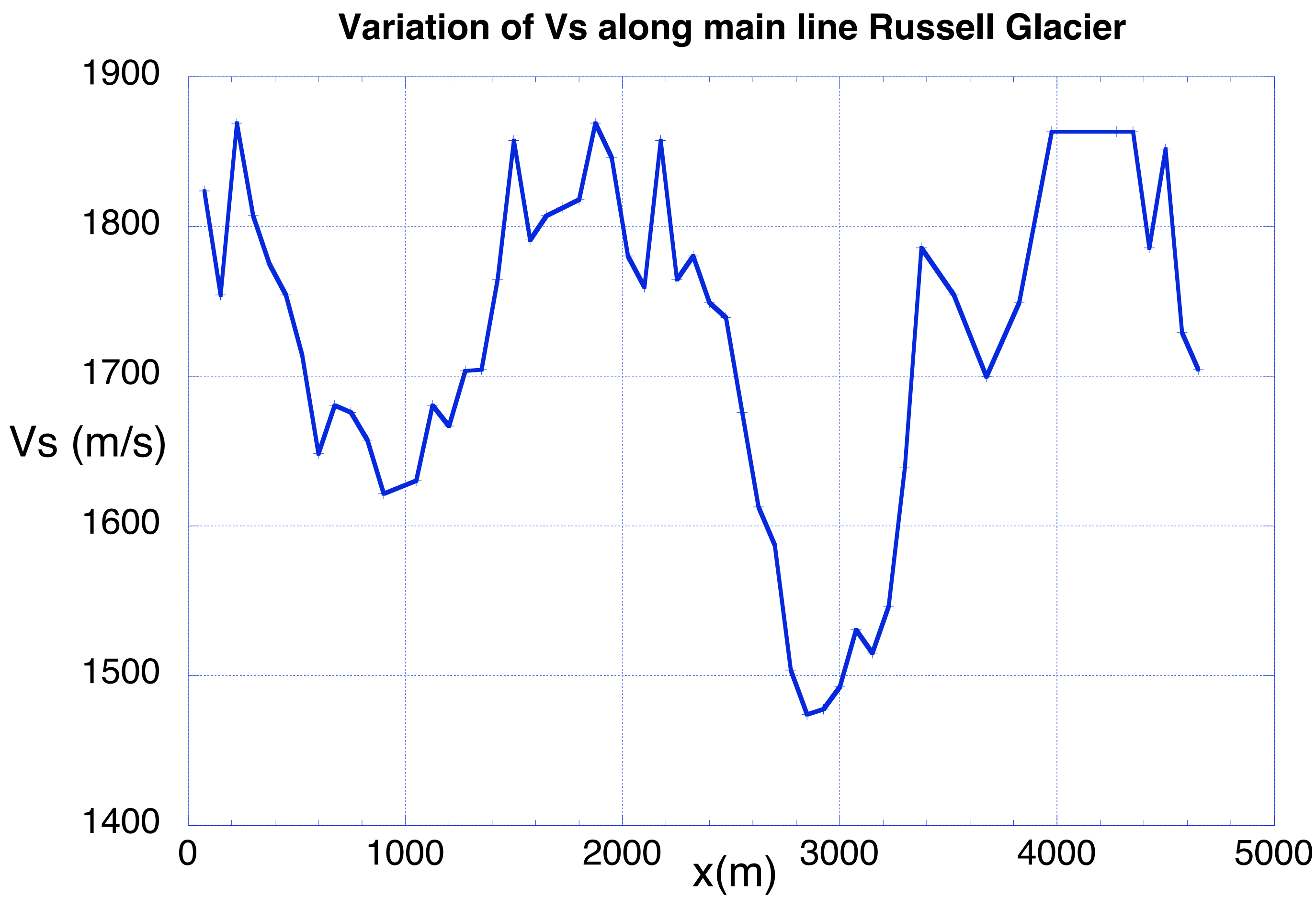
May 2014: variation in Vs and Vp

caused by water content of the ice matrix?

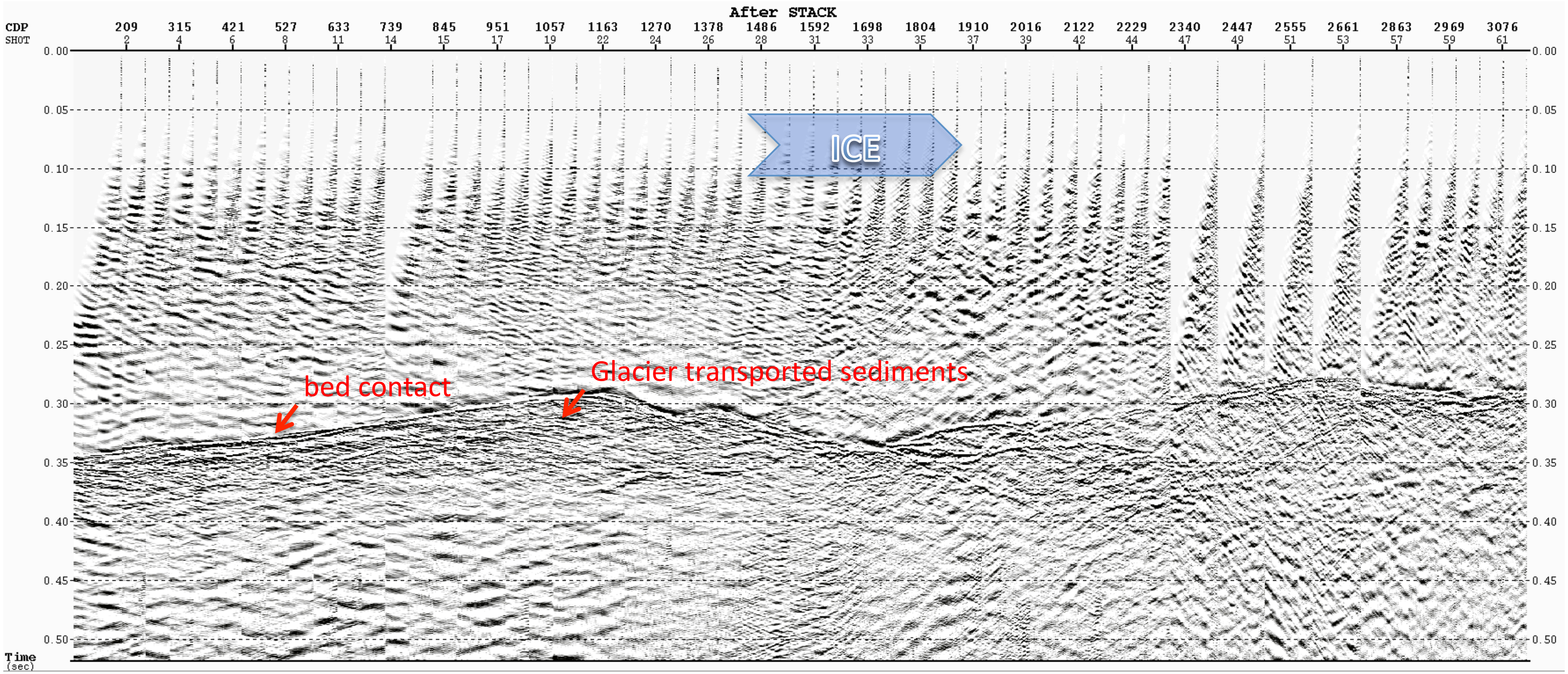


Plot Vs along the main line SHR

For Vp as well, => water content



Bed Russell May 2014:



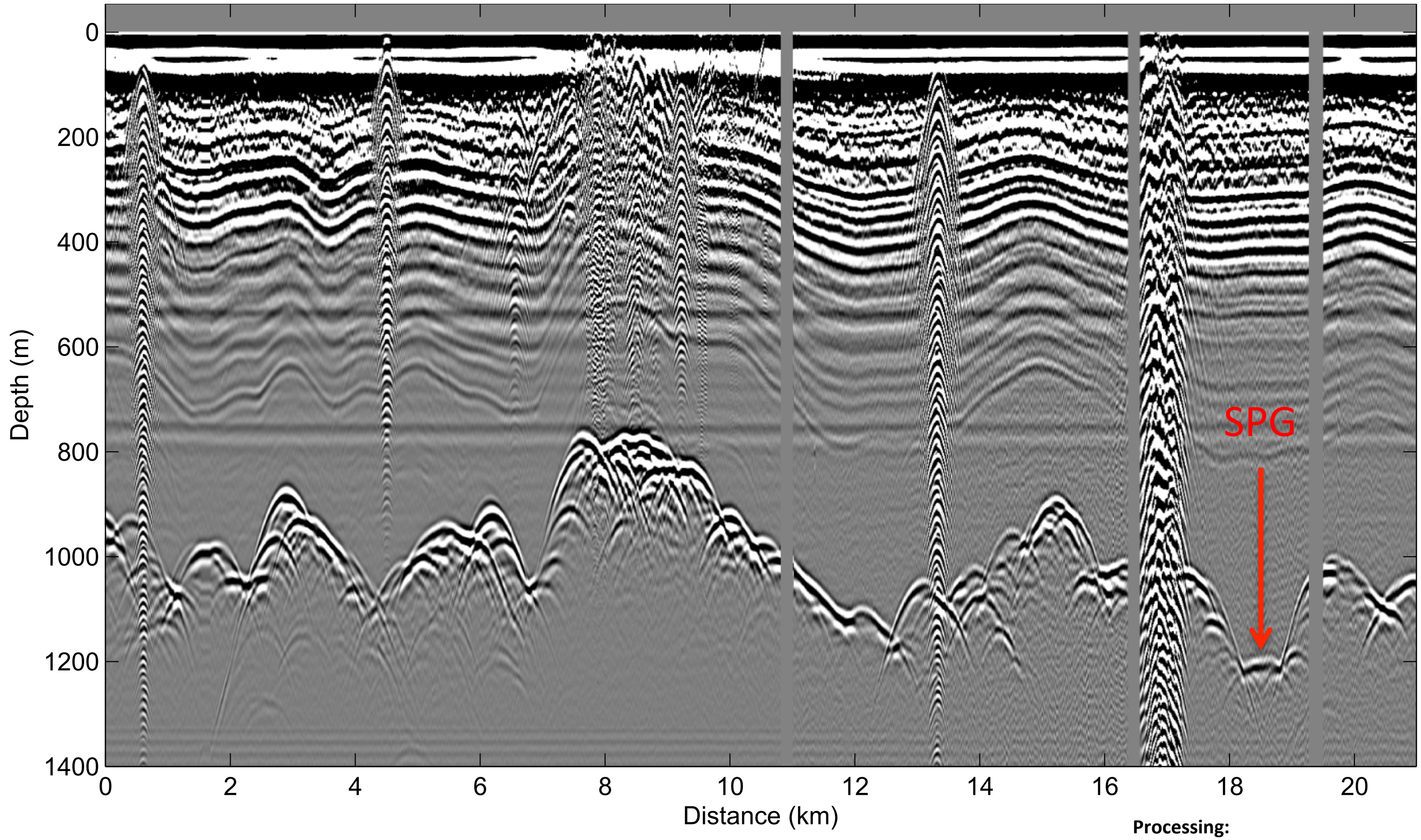
Proceed

- Russell, SHR:
  - Process Amplitude vs Offset (AVO) data to recover the reflection coefficient.
  - Compare seismic data from September 2013 and May 2014.

Site SPG, a drainage lake?

Example of radar profile

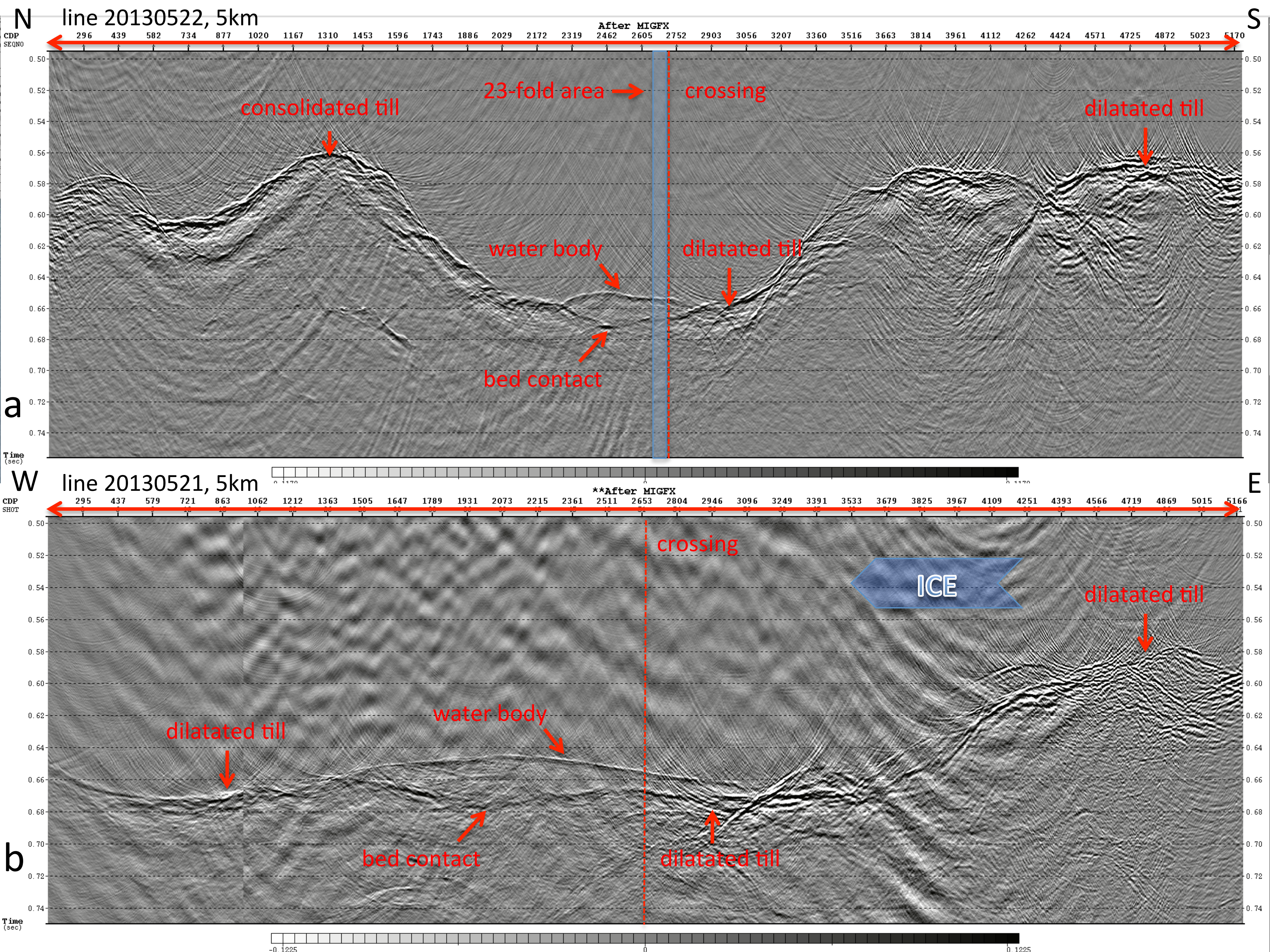
(RS22–RS21)

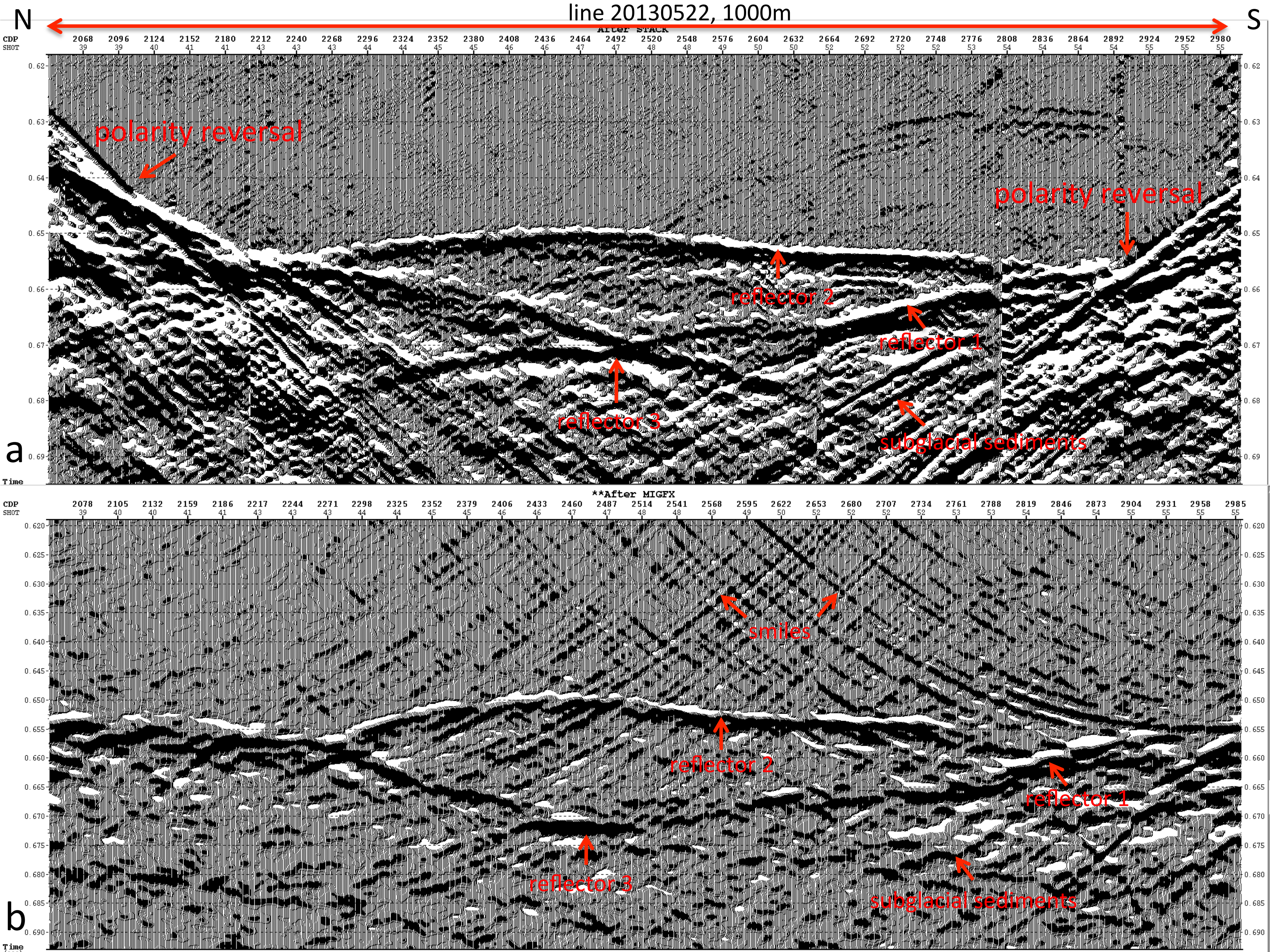


Processing:
Lowpass filtered,
normal move-out corrected.
Using 168 m/µs in depth conversion

data: Rickard Petterson

Russell September 2013, ideal circumstances:


N
line 20130522, 5km
S
After MIGFX
CDP
SEQNO
296 439 582 734 877 1020 1167 1310 1453 1596 1743 1886 2029 2172 2319 2462 2605 2752 2903 3056 3207 3360 3516 3663 3814 3961 4112 4262 4424 4571 4725 4872 5023 5170
0.50 0.52 0.54 0.56 0.58 0.60 0.62 0.64 0.66 0.68 0.70 0.72 0.74
Time (sec)
23-fold area
crossing
consolidated till
dilatated till
water body
dilatated till
bed contact
a
W
line 20130521, 5km
E
**After MIGFX
CDP
SHOT
295 437 579 721 863 1062 1212 1363 1505 1647 1789 1931 2073 2215 2361 2511 2653 2804 2946 3096 3249 3391 3533 3679 3825 3967 4109 4251 4393 4566 4719 4869 5015 5166
0.50 0.52 0.54 0.56 0.58 0.60 0.62 0.64 0.66 0.68 0.70 0.72 0.74
Time (sec)
crossing
ICE
dilatated till
water body
dilatated till
bed contact
dilatated till
b
-0.1225
0
0.1225



N
line 20130522, 1000m
S
After STACK
CDP
SHOT
polarity reversal
polarity reversal
reflector 2
reflector 1
reflector 3
subglacial sediments
a
Time
**After MIGFX
CDP
SHOT
smiles
reflector 2
reflector 1
reflector 3
subglacial sediments
b
Time

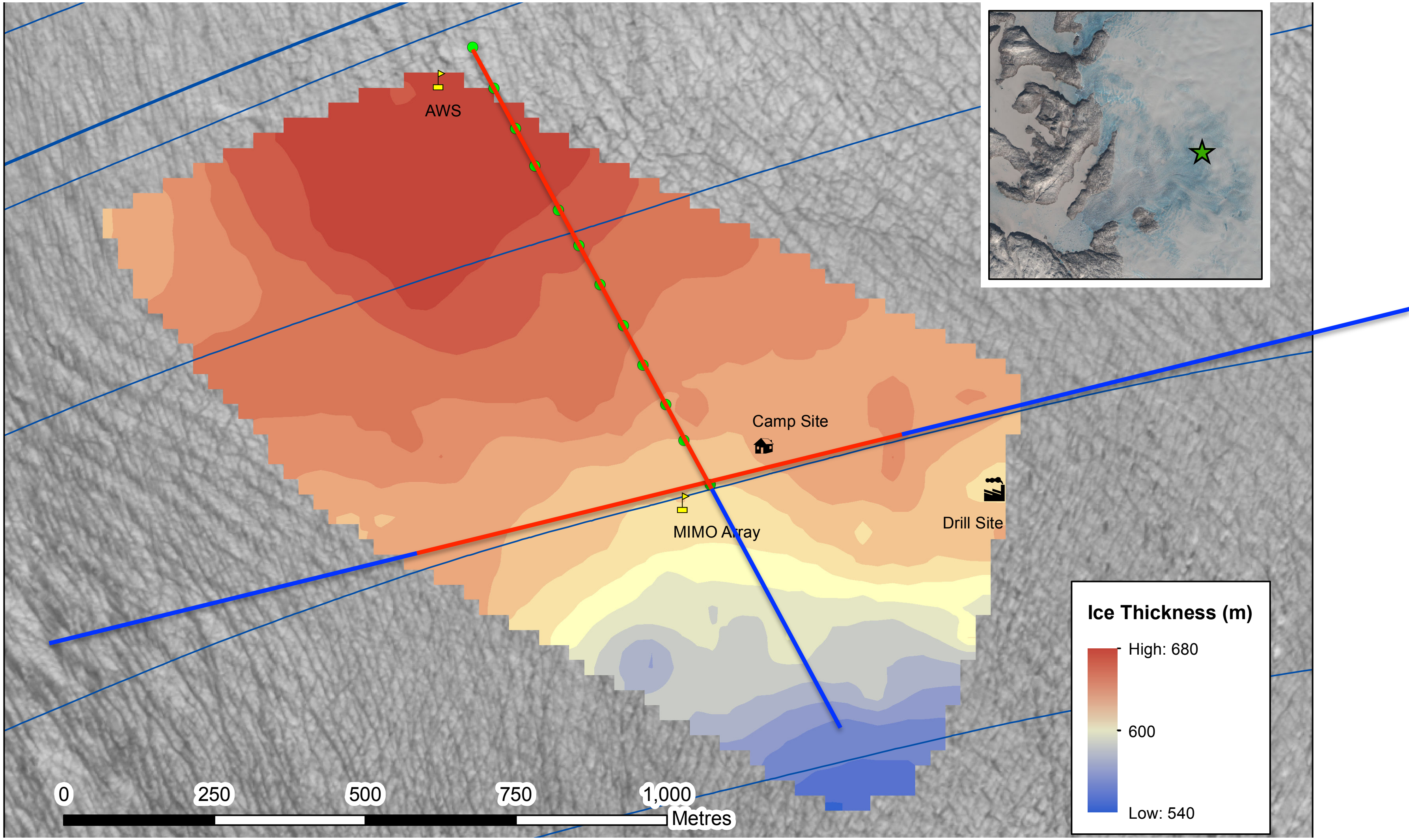
Subglacial Access and Fast Ice Research Experiment (SAFIRE)

Store glacier, 2nd largest glacier (ice flux) in West Greenland

- Identify and characterize the basal mechanical and hydrological conditions
- Determine the role of basal processes in modulating ice flow and calving
- Locate potential drilling location sediment samples

July 2014, survey area Store Glacier

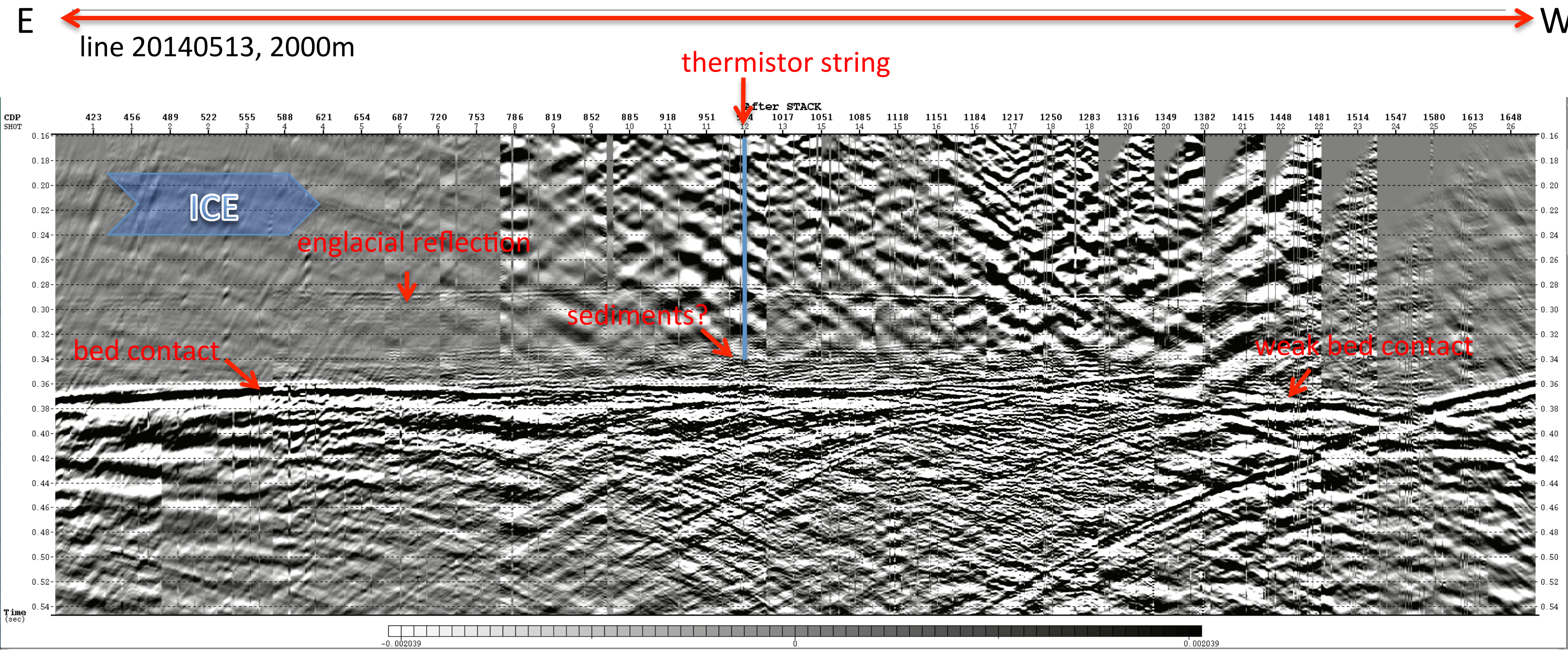
What was recorded



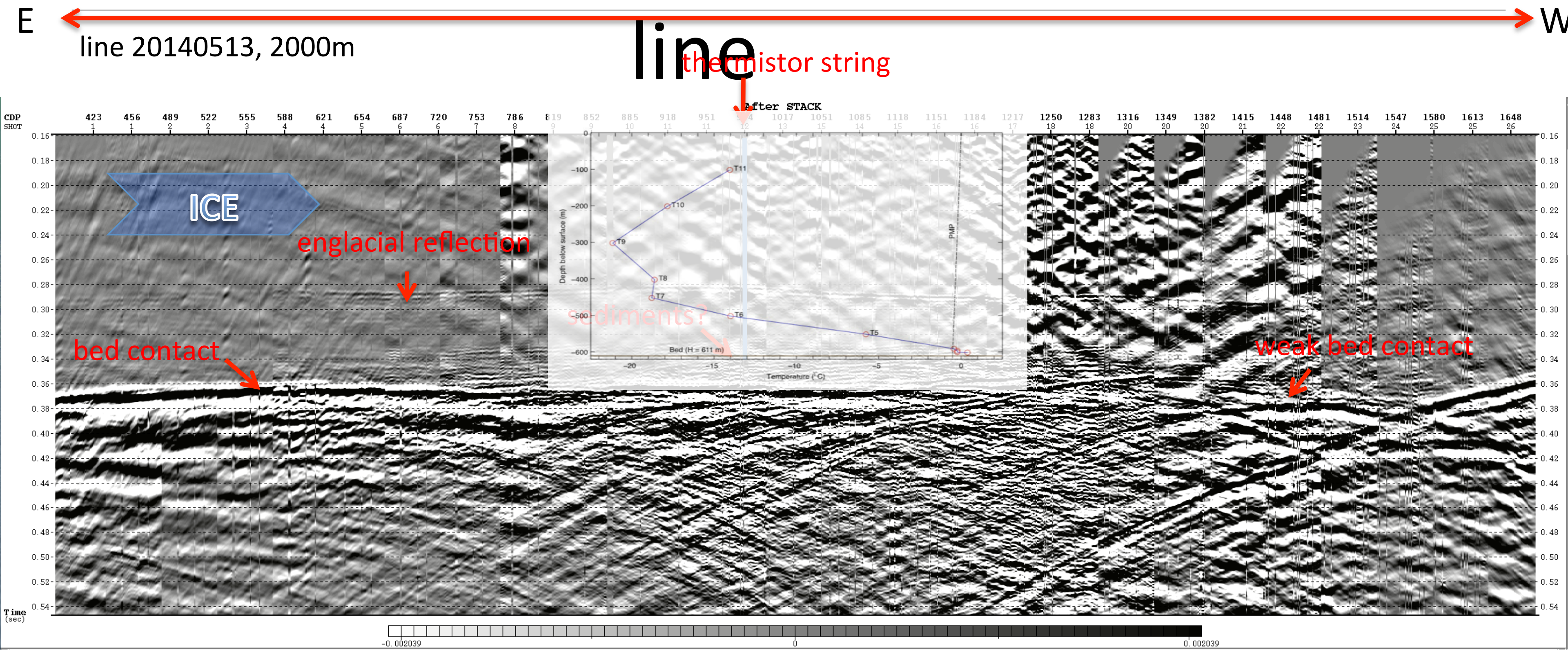
streamer and shot move

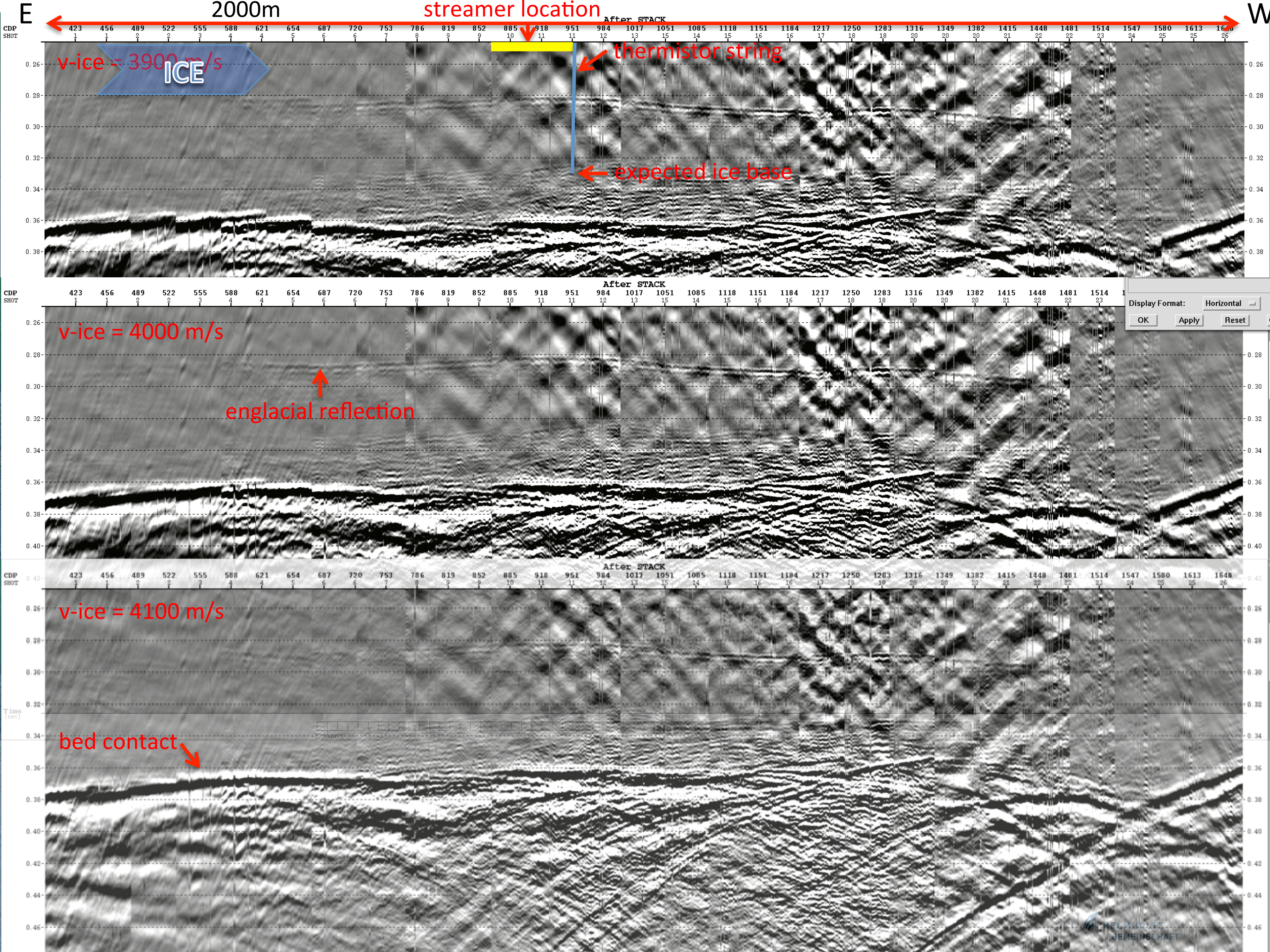
shots, streamer at fixed location

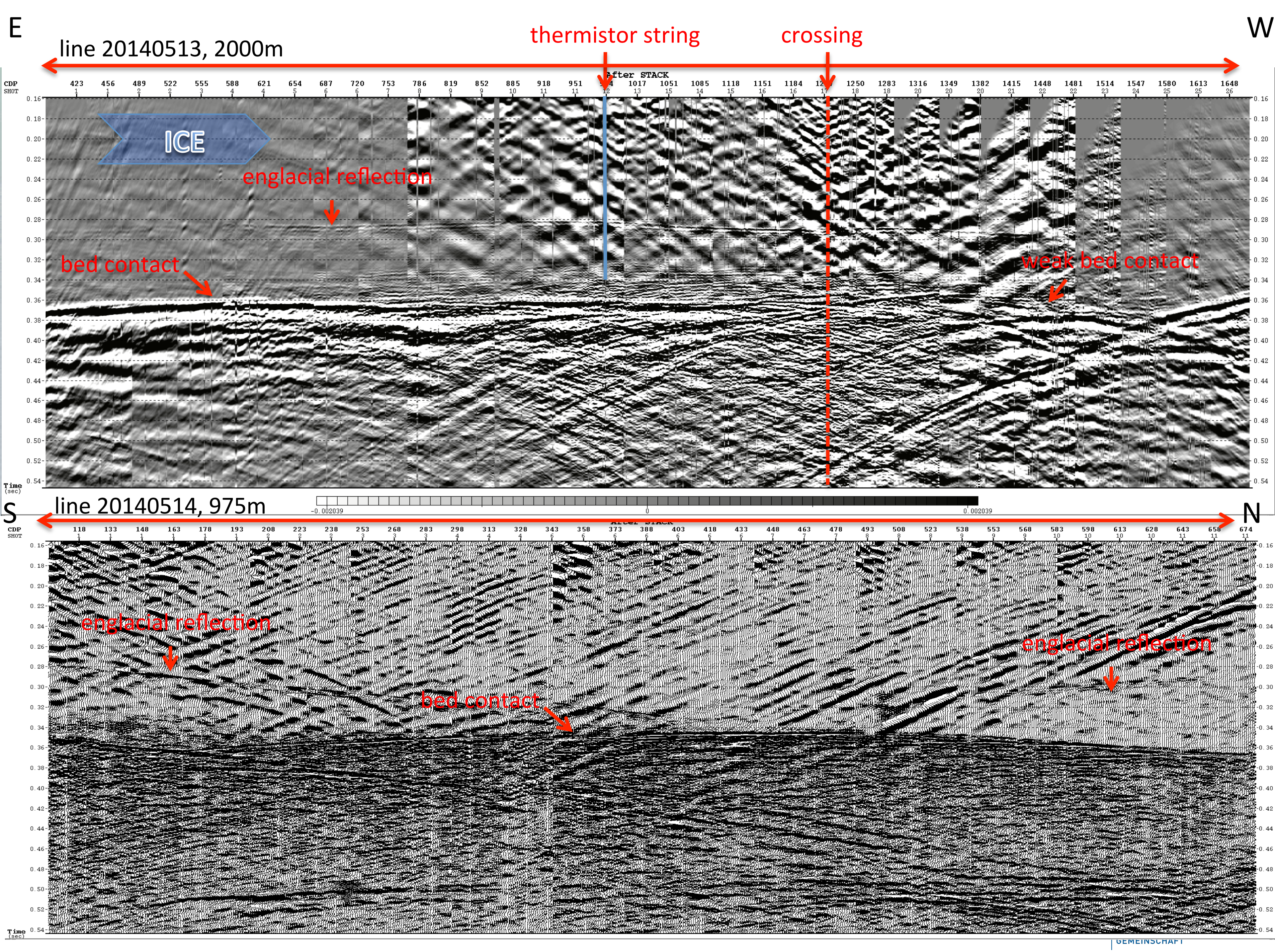
Store Glacier, parallel ice flow line



Store Glacier, parallel ice flow line




E
2000m
streamer location
W
After STACK
CDP
SHOT
v-ice = 3900 m/s
ICE
thermistor string
expected ice base
v-ice = 4000 m/s
englacial reflection
Display Format:
Horizontal
OK
Apply
Reset
v-ice = 4100 m/s
bed contact


E
W
line 20140513, 2000m
thermistor string
crossing
After STACK
CDP
SHOT
ICE
englacial reflection
bed contact
weak bed contact
Time (sec)
S
N
line 20140514, 975m
englacial reflection
bed contact
englacial reflection
Time (sec)

My questions:

- Bed reflector deeper than encountered, why?
  - Timing delay?
  - Low velocity surface layer? I did encounter a slow HF direct wave Vp 2400m/s to 3000m/s. Shallow layer, app 20m.
- Different Vp values, why?
  - Vp stack ≈ 4100m/s (bed, far offset)
  - Vp stack ≈ 4000m/s (englacial, far offset)
  - Vp hor ≈ 3690m/s (diffraction)
- Water content in ice? Unlikely, fast ice = cold ice

Your questions?

Thank you

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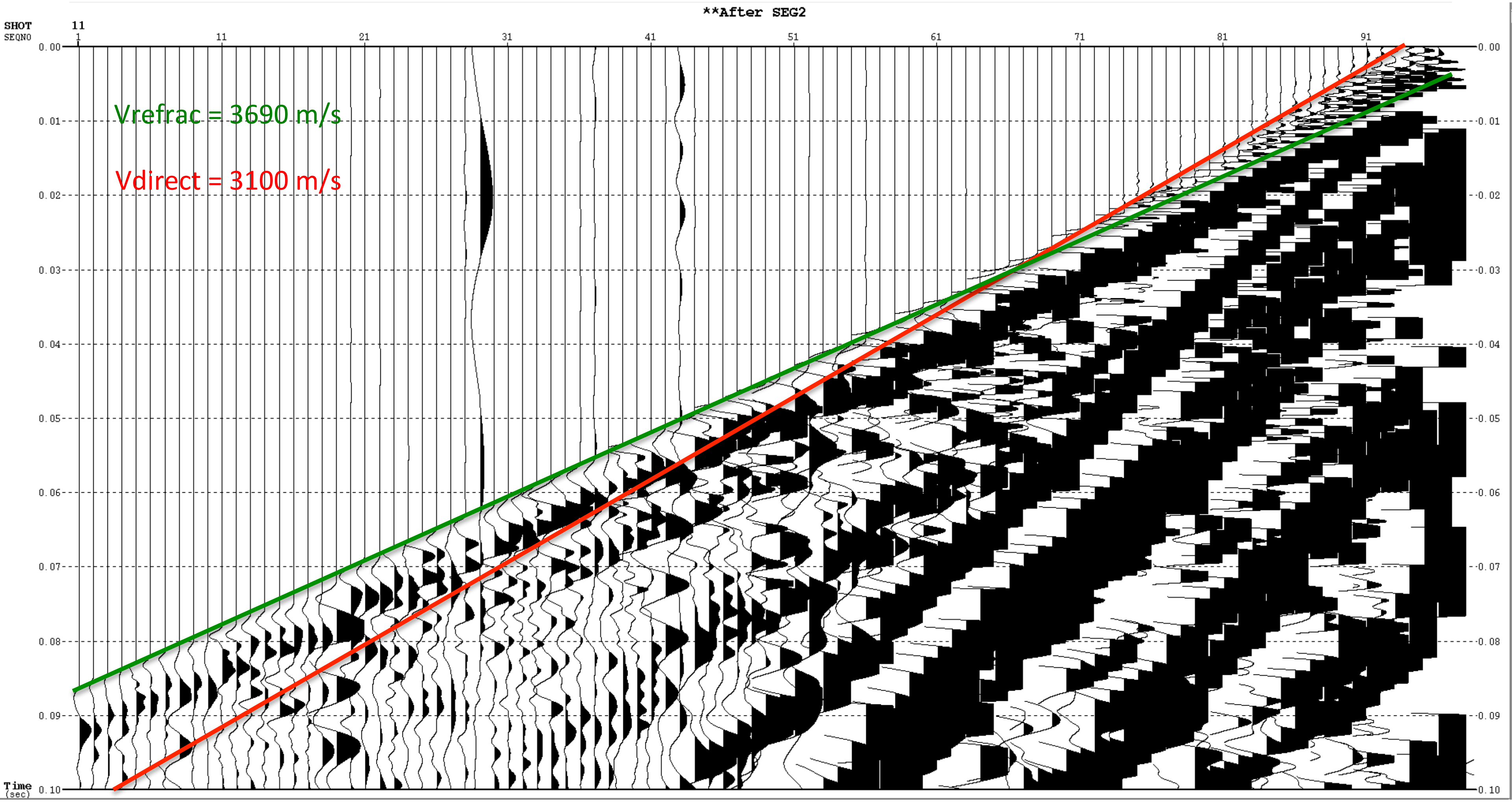
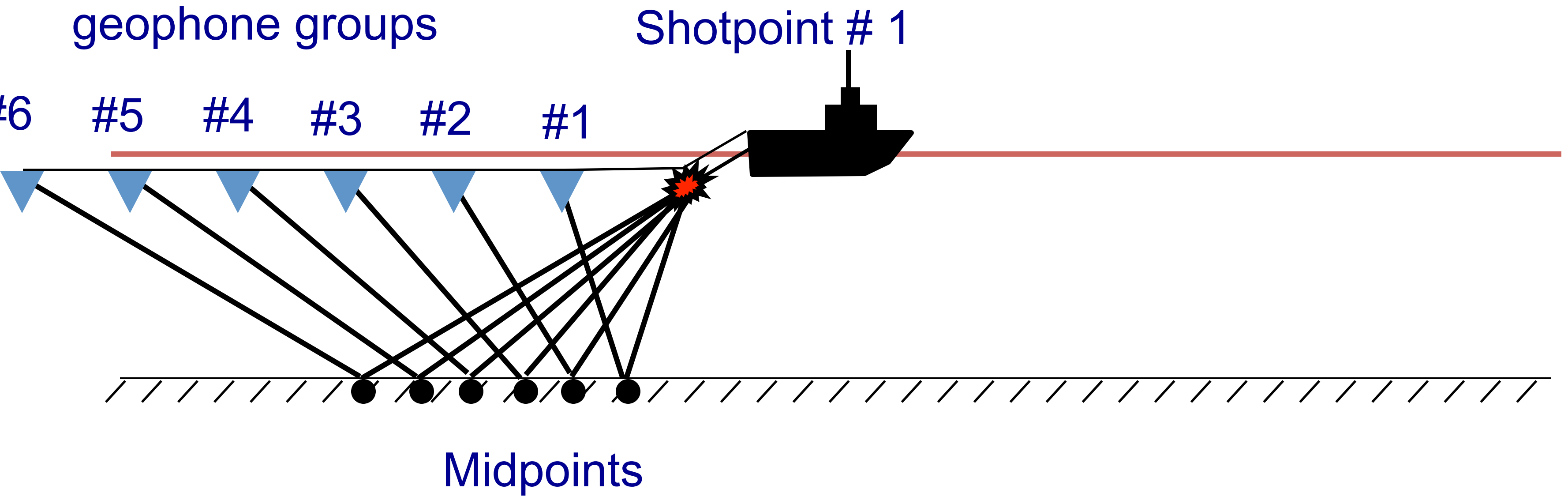
Thanks to Alun Hubbard and the SAFIRE group for giving me this opportunity.


**After SEG2
SHOT 11
SEQNO
Vrefrac = 3690 m/s
Vdirect = 3100 m/s
Time (sec)

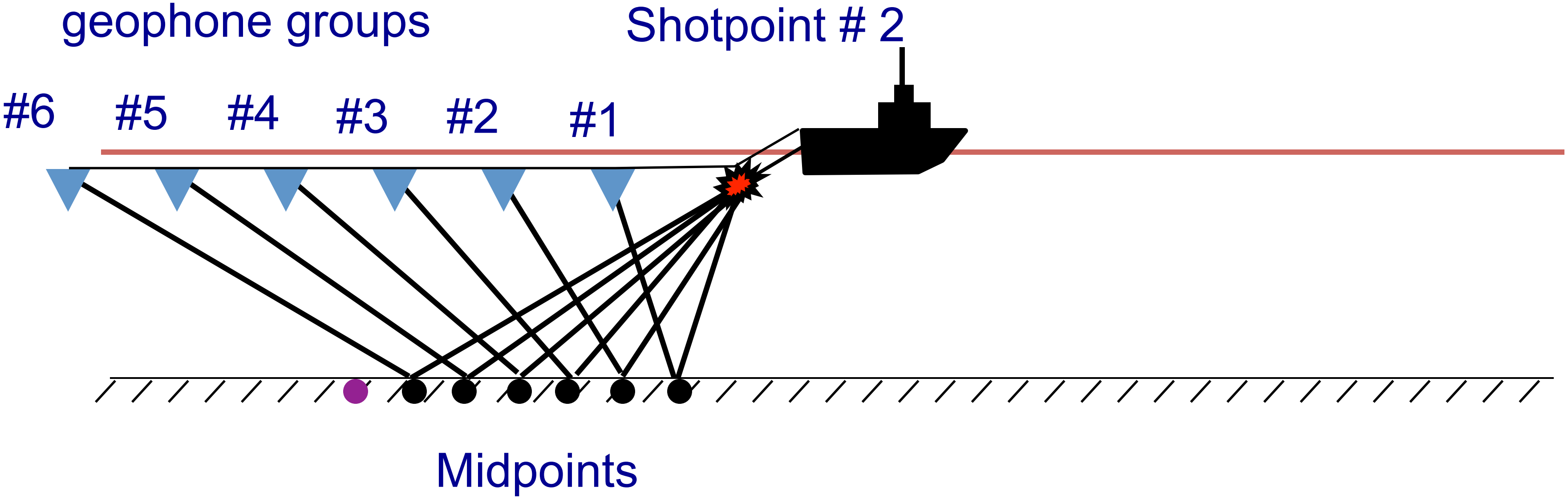
6-fold example of the Common Mid Point (CMP) method.



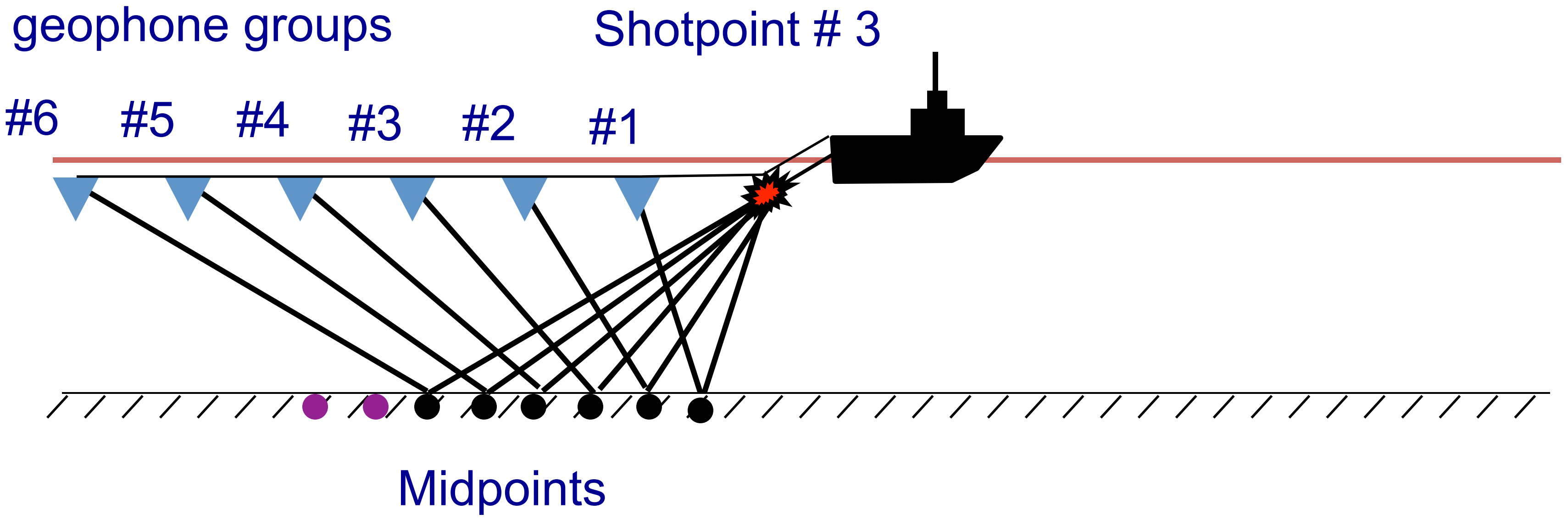
Separation between midpoints is

1/2 separation between geophone groups

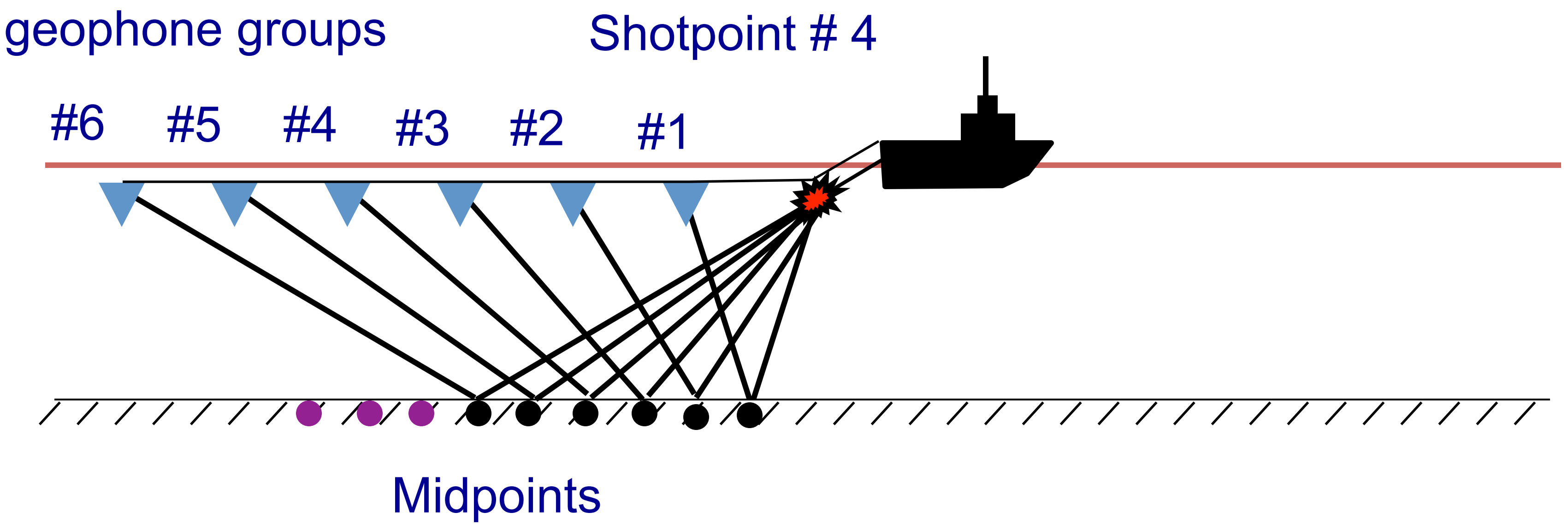
Common Midpoint Method (CMP Method)



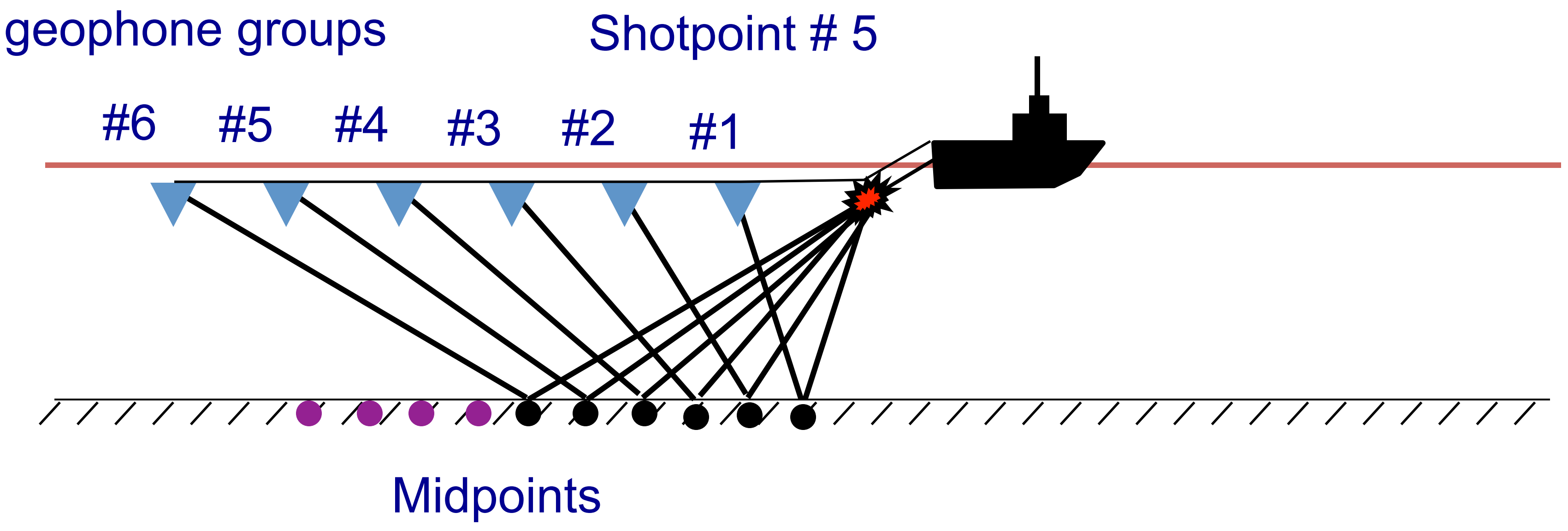
Common Midpoint Method (CMP Method)



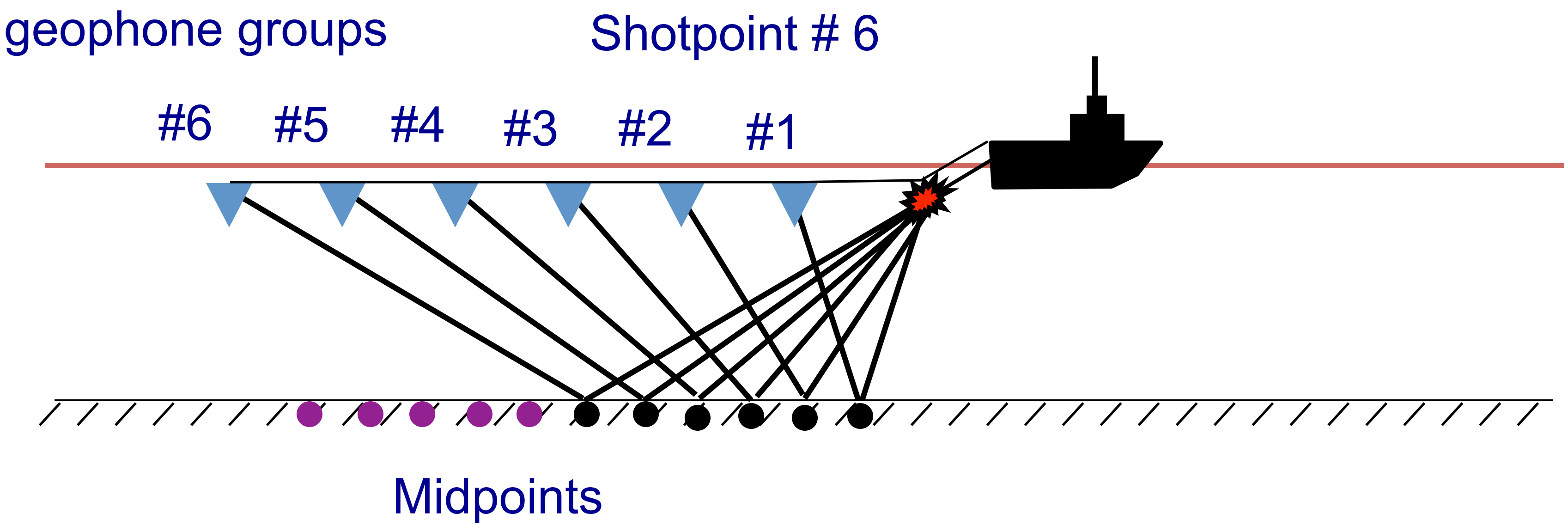
Common Midpoint Method (CMP Method)



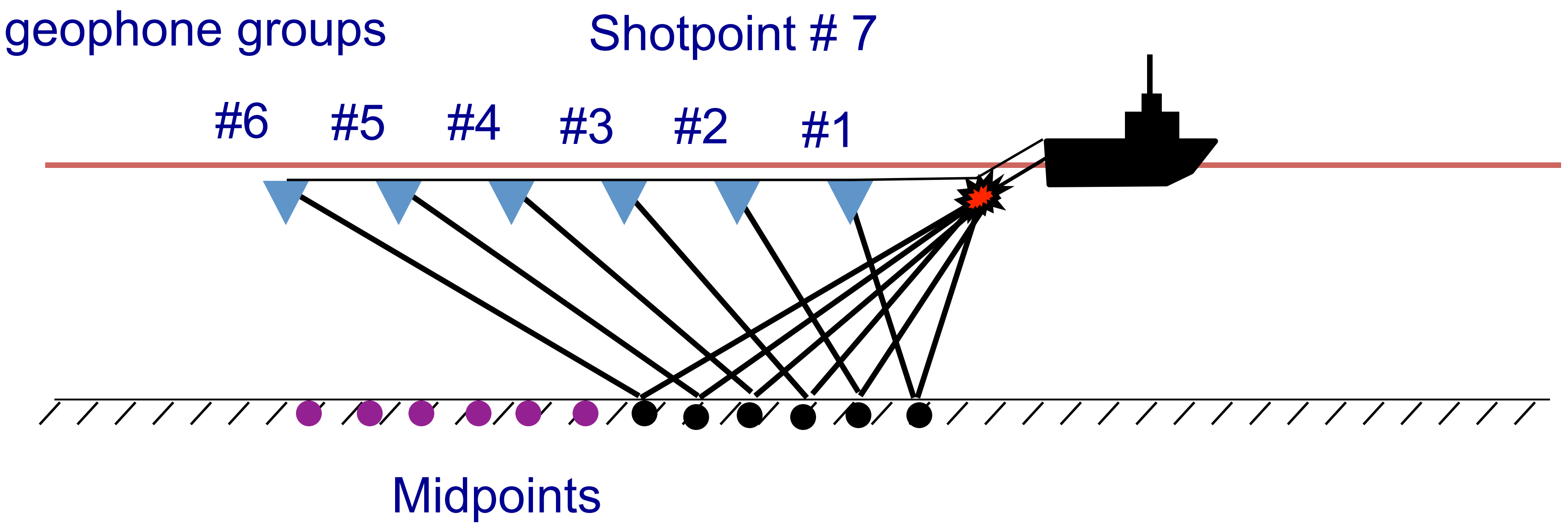
Common Midpoint Method (CMP Method)



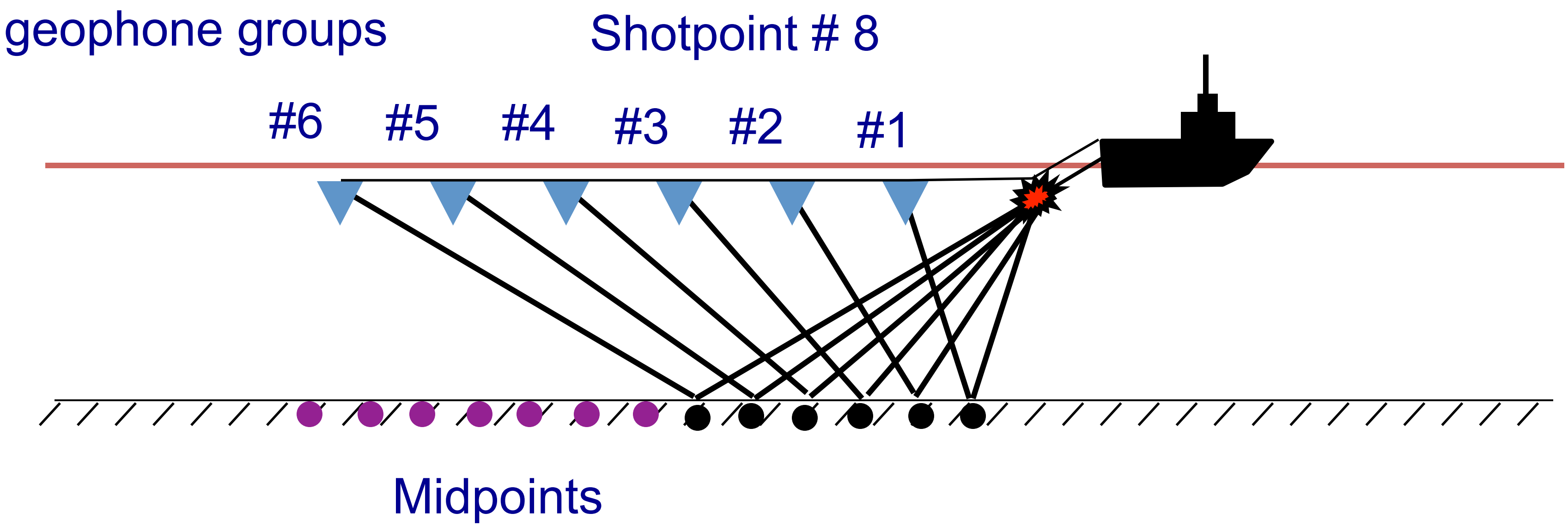
Common Midpoint Method (CMP Method)



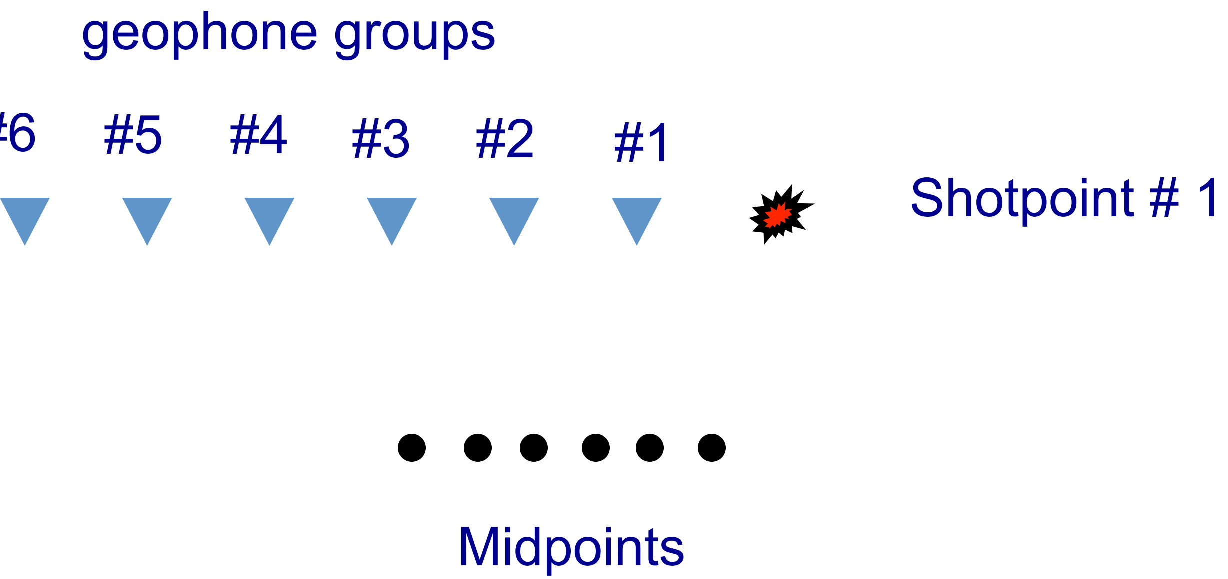
Common Midpoint Method (CMP Method)



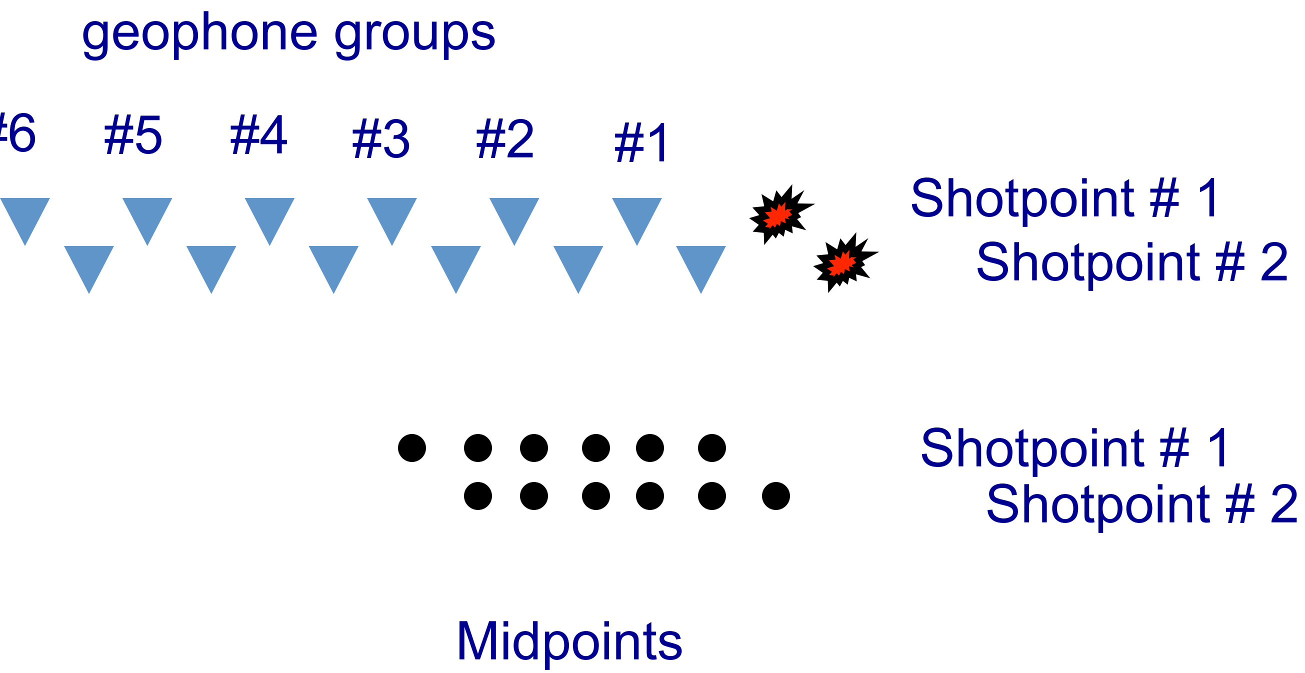
Common Midpoint Method (CMP Method)



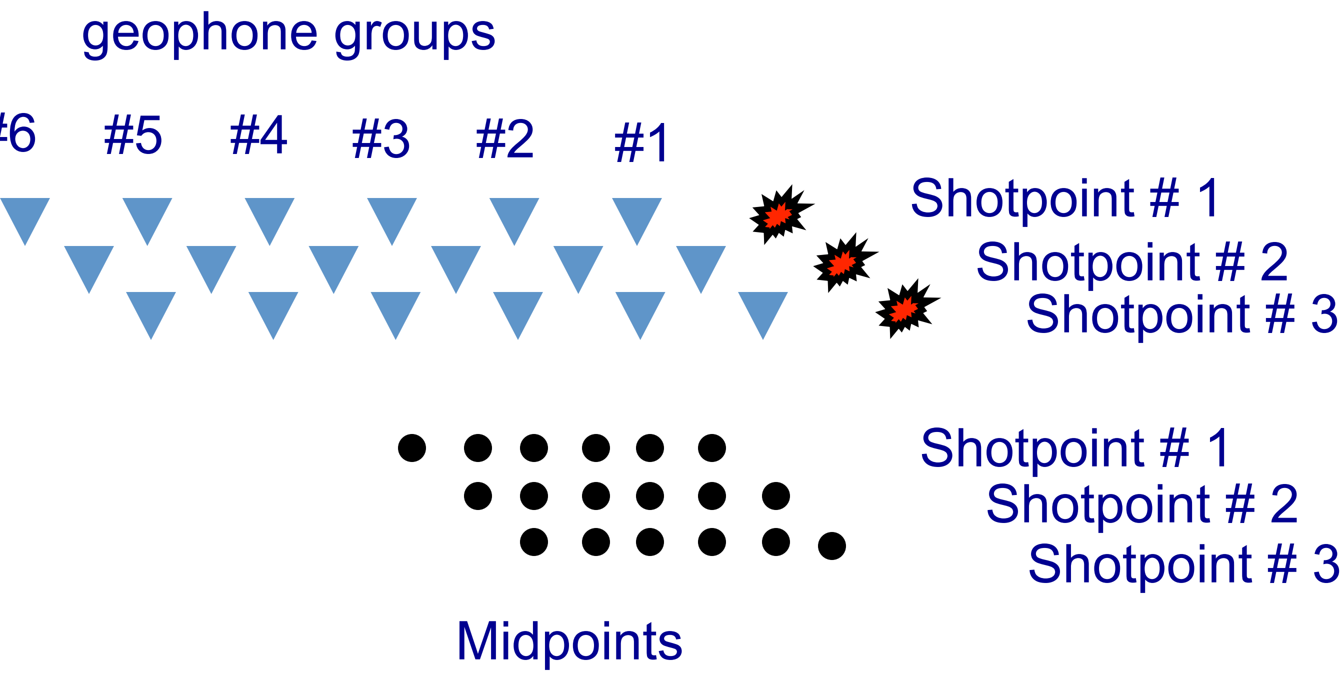
Common Midpoint Method (CMP Method)



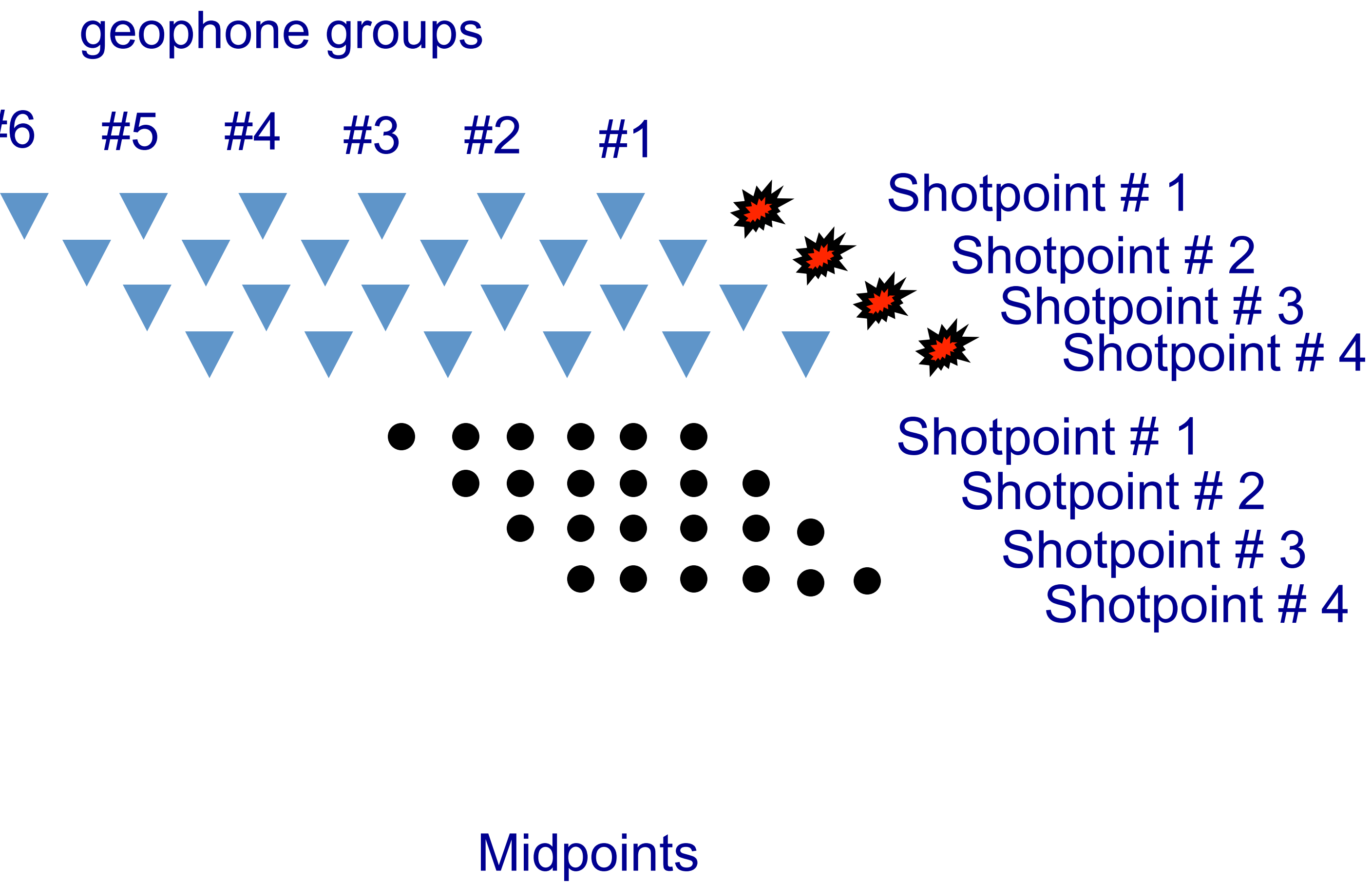
Common Midpoint Method (CMP Method)



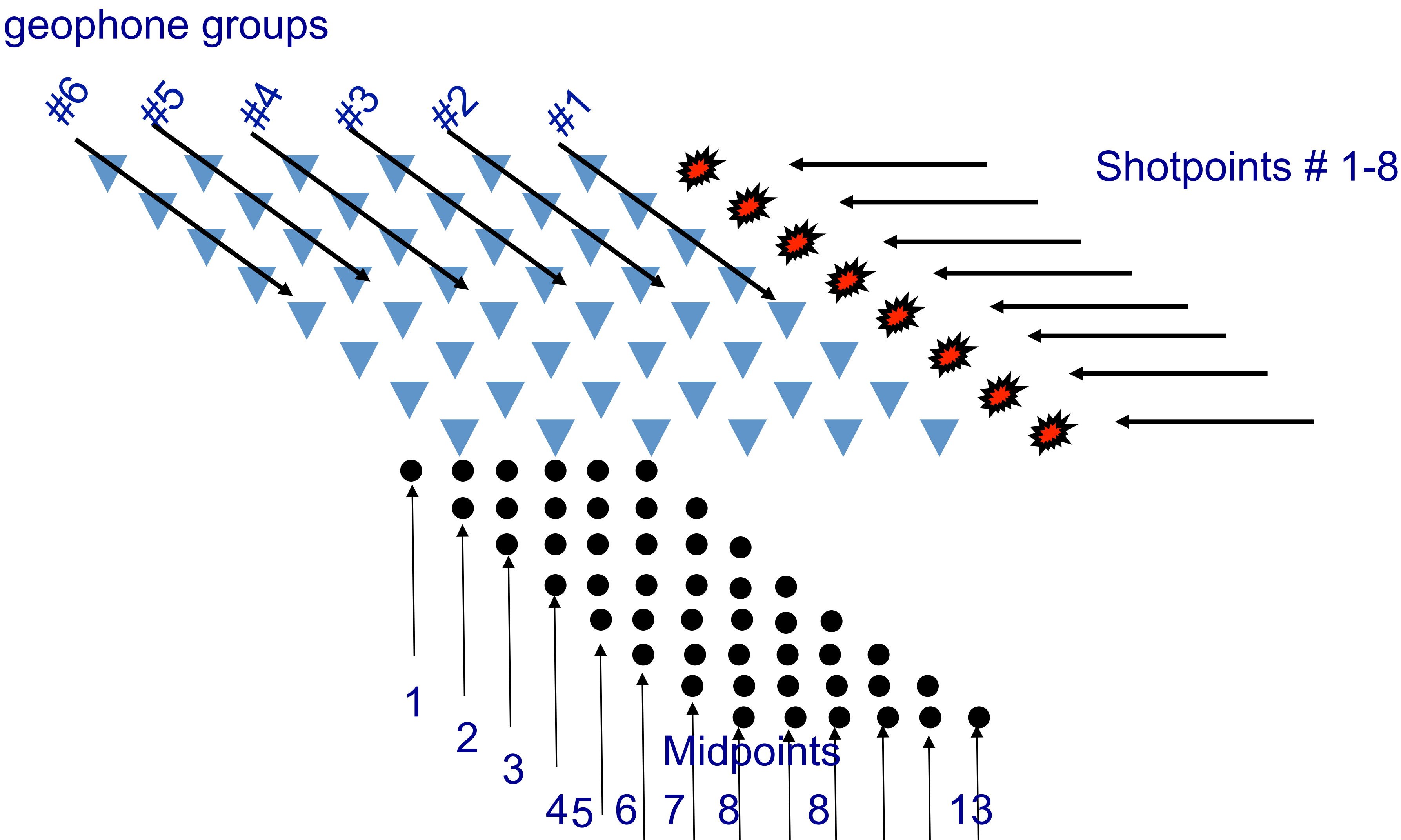
Common Midpoint Method (CMP Method)



Common Midpoint Method (CMP Method)



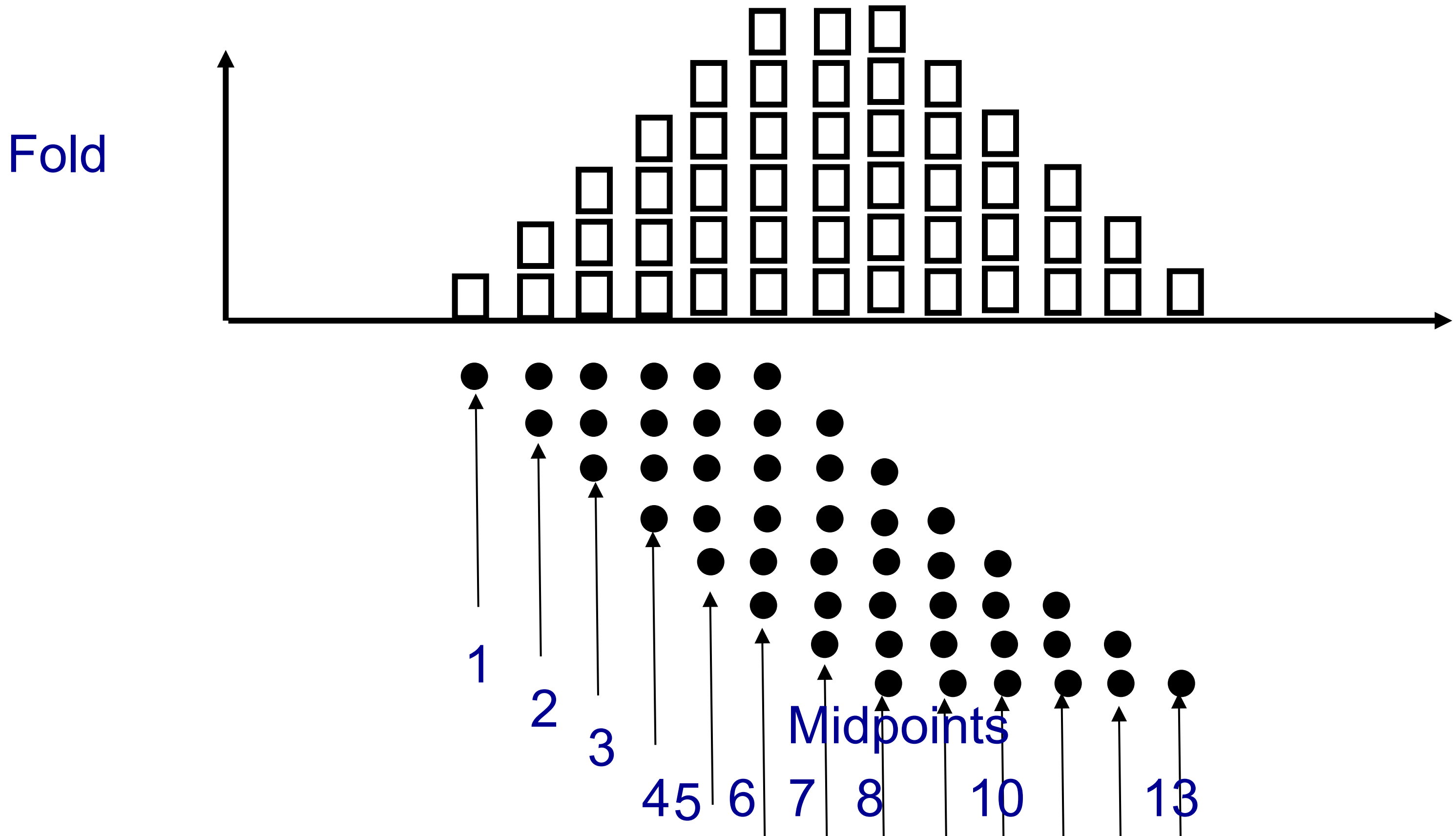
Common Midpoint Method (CMP Method)



Common Midpoint Method (CMP Method)

Fold or Multiplicity is the number of times that the same midpoint is sampled by different shots and different receivers

Signal-to-Noise increases as the square root of the fold



Drill site, why seismics in summer sucks:


OY-HGT


086
15kg
AWI
GLAZ


6086


MOUNTAIN HARD WEAR
adbury
SUKKER
everyday

OY-HCU
air greenland
8231
6022
6010
8082
8082
ZARGES
ZARGES


Rab
HH