High-Resolution Seismic Reflection to Delineate a 400 m Deep Coalbed Methane Layer under Fort Yukon, Alaska

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Energy for Rural Alaska

- **150 roadless rural communities**
- **Diesel**
  - **½ electric power**
    - **4 x $/kWh**
  - **½ heating**
    - **2 to 4 x $/gallon**
  - **pollution**

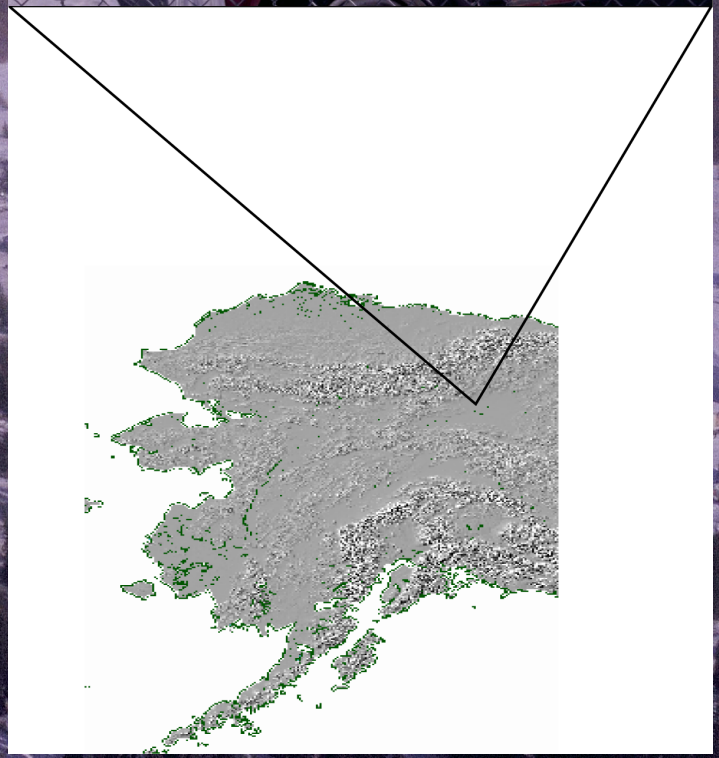
Community with 700 residence use 250,000 of gal/yr of diesel fuel

Barge in the summer (if waterways support barge traffic)

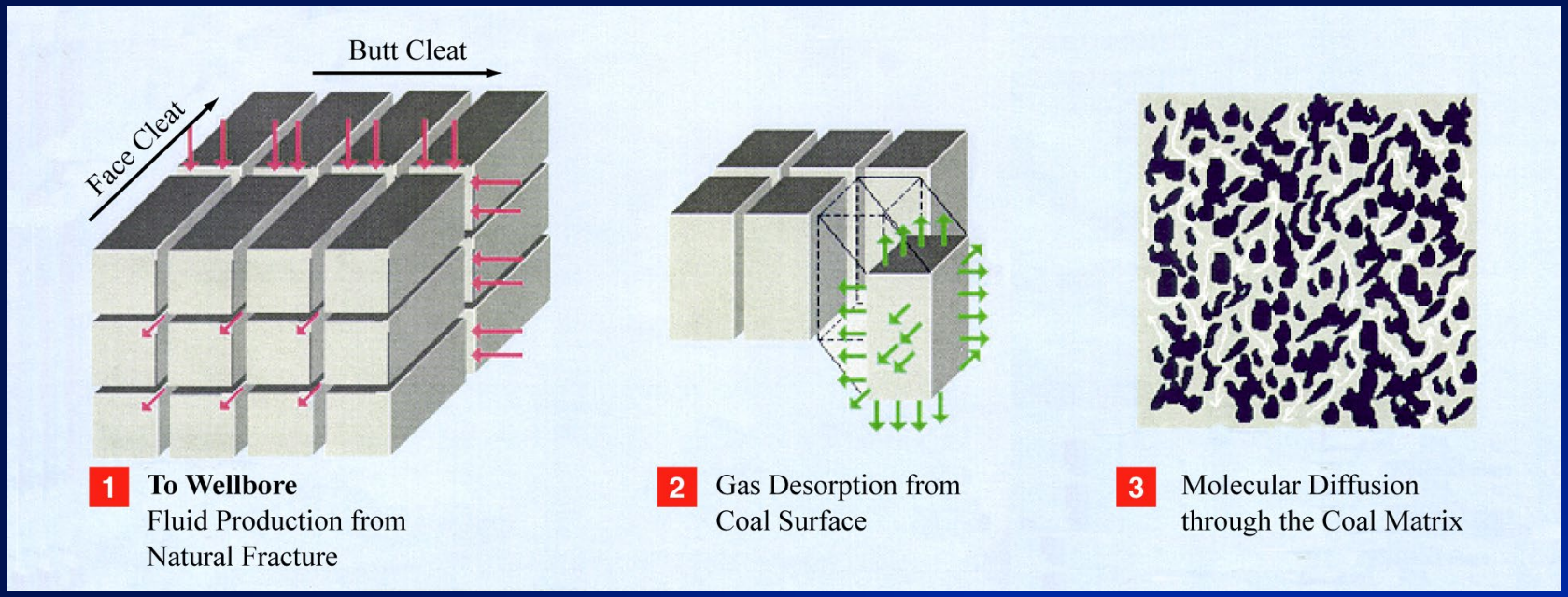
Fly on transport aircraft in winter

Fort Yukon, Alaska

- Few miles inside Arctic Circle
- One of 25 remote communities on or near AK coal fields
- USAF radar station (2 people)
- Local employment-community services (school, city works, social services, etc)
- Hunting and fishing a primary food source
- Unemployment can hit 80% during winter months



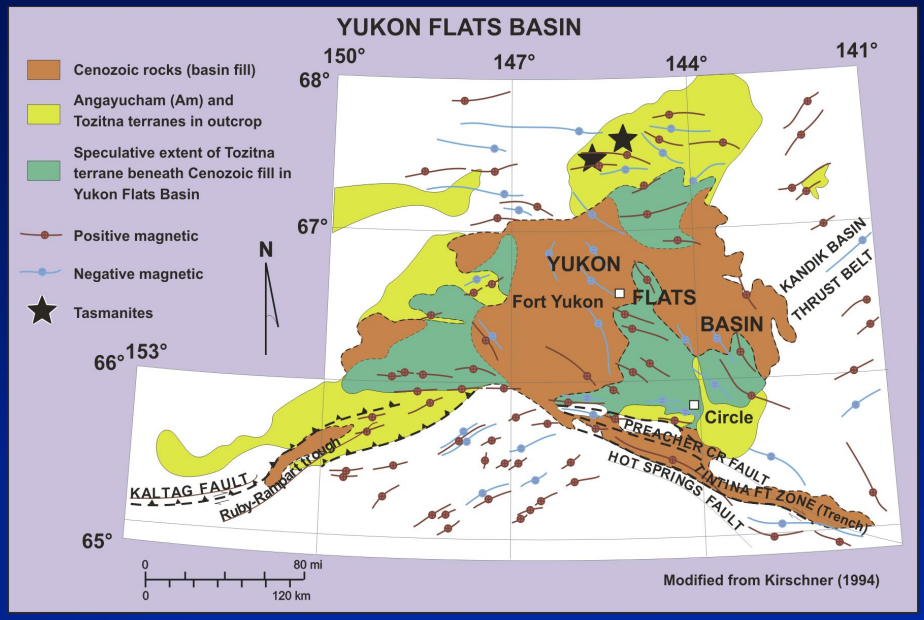
Methane From Coal



- Coal
  - is both the source and reservoir rock
  - is microporous solid w/ an enormous internal surface area
  - permeability comes from fractures (cleats)
  - can sorb > 600 ft^3 of gas/ton

Generalized Geologic Setting

- **Yukon Flats Basin**
  - **South of Brooks Range & north of Yukon-Tanana Uplands**
  - **8,500 sq. miles**
  - **Pull-apart basin or rhombus graben—crustal rotation**
  - **3000 to 4000 m deep Cenozoic fill**
    - **~1000 m @ Fort Yukon**
  - **Upper 100 m Tertiary lacustrine silts & clays**

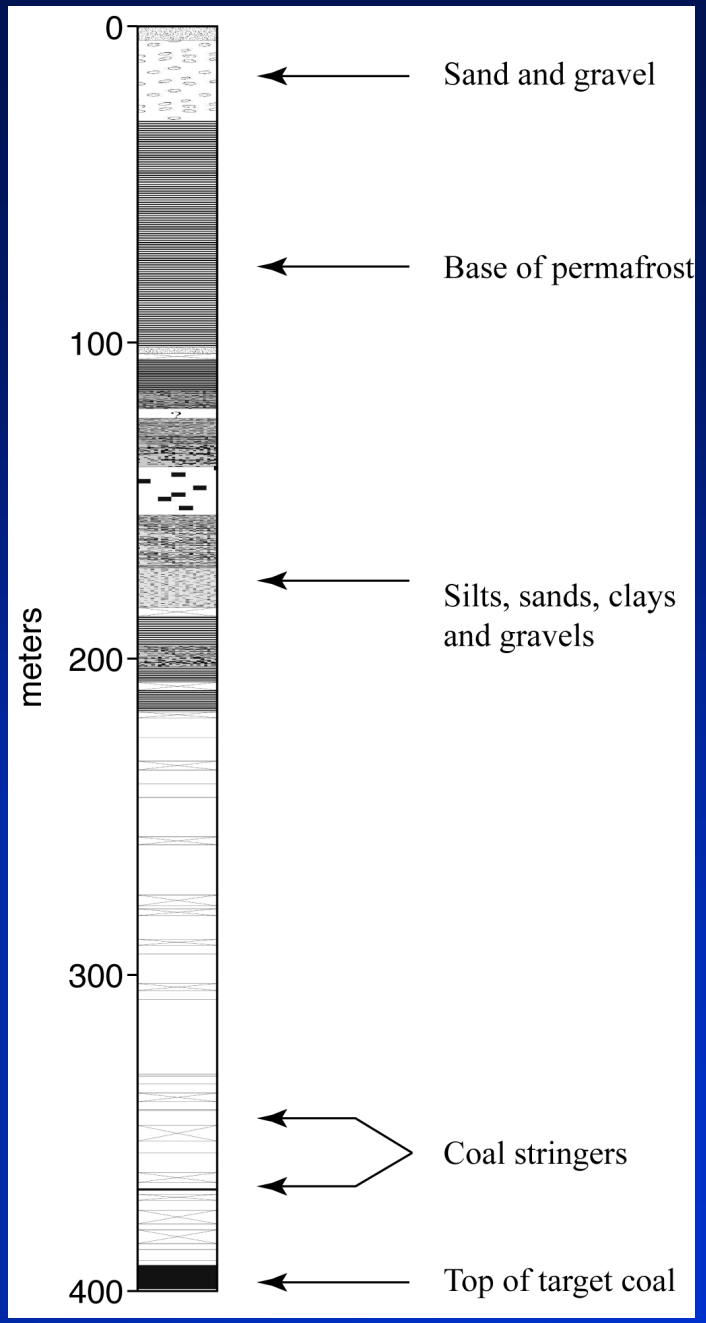


Surface is anomalously flat for Quaternary river deposits resembling a coastal plain environment rather than inland basin

Lithology Log from 1994 USGS Corehole

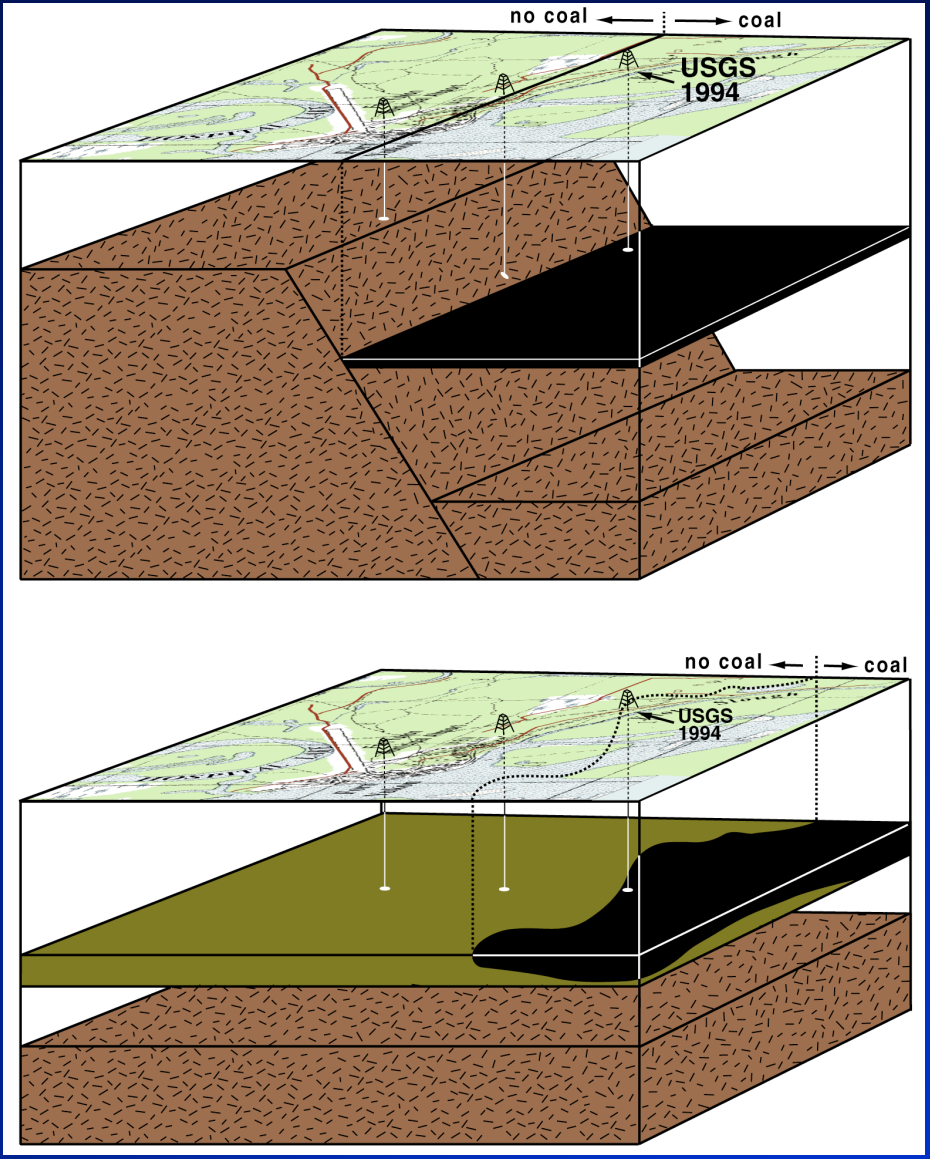
Climate studies hole, USAF prop.

- **Drilling not optimally designed for CBM sampling or evaluations**
- **400 m of lacustrine sands, silts, and gravels**
- **Coal stringers (< 1 m) @ ~350 m & 370 m**
- **> 9 m thick lignite coal at 390 m**
  - **0.3% mean random vitrinite reflectance**
  - **40 scf/ton @ 400 m depth**
  - **lacustrine**



What If ???

- **We know there are 9+ meters of gassy coal**
  - Why not start designing and building a power plant?
  - Why go to the expense of seismic reflection?
- **What if a major basement fault?**
- **What if this lacustrine coal bed was deposited as a narrow stream channel?**
- **We need to know about changes in coal bed geometry & characteristics**

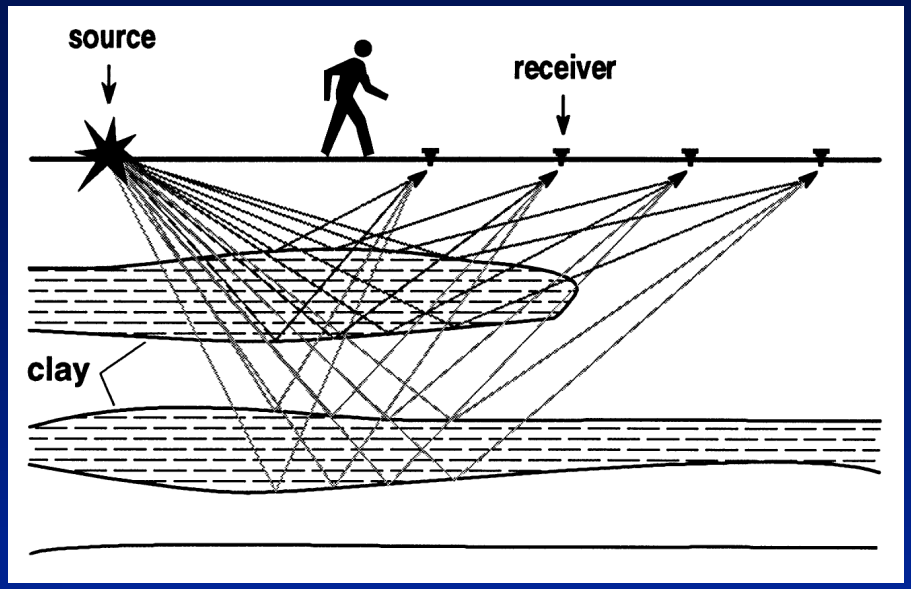


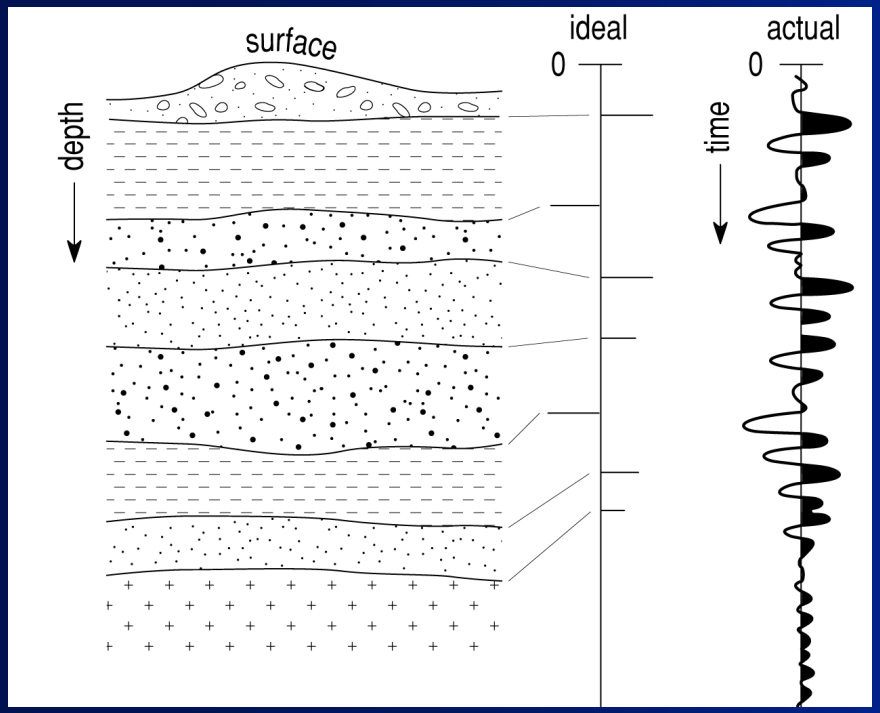
High-Resolution Seismic Reflection

NEED:

dominant frequency > 80 Hz

velocity &/or density contrast

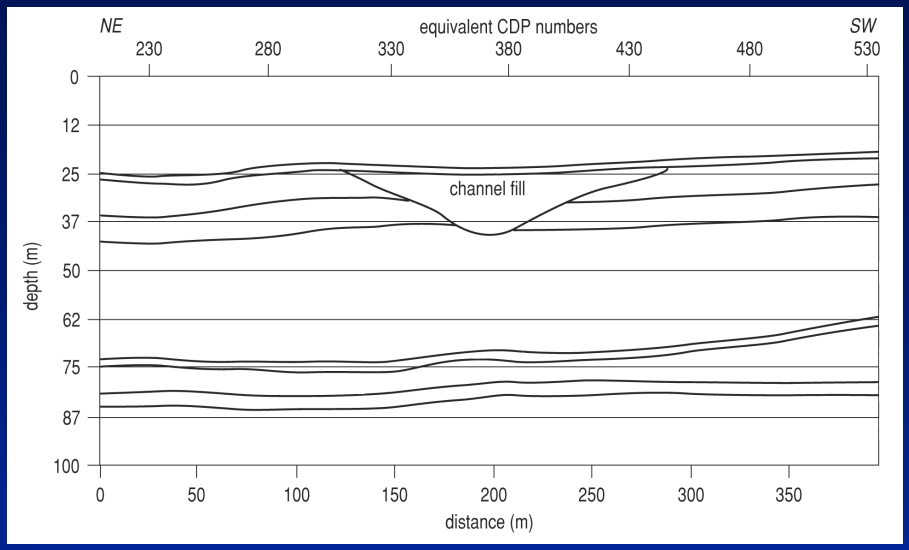


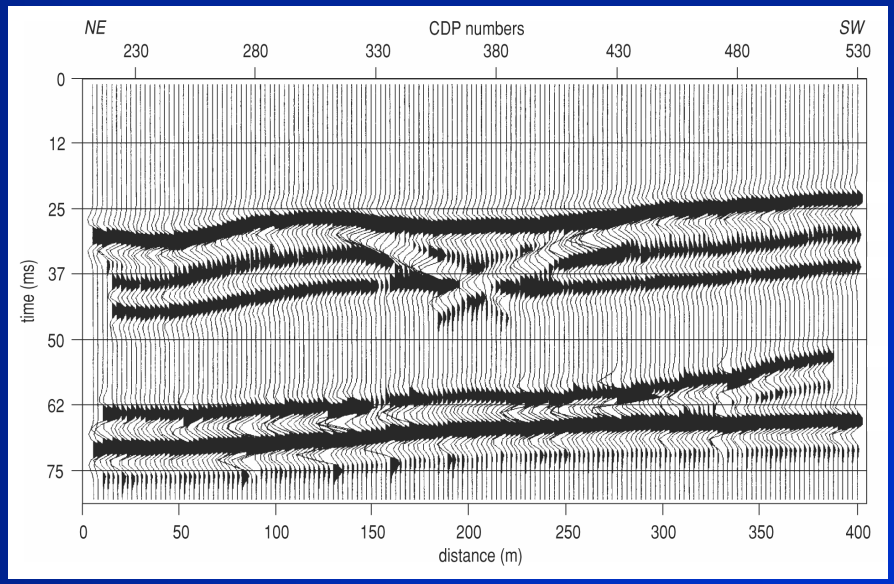


- **Imaging—detect layer**
- **Resolving—map top and bottom of layer**
  - **Separating top & bottom reflections when < λ**
  - **Interference phenomena**

Interpreting Thin Bed Phenomena

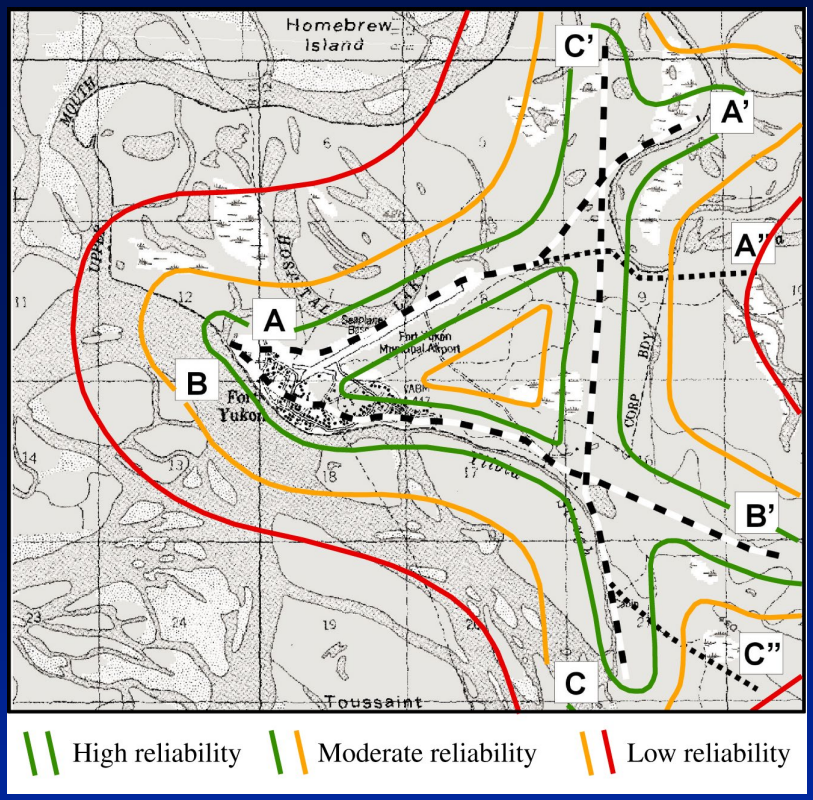
- **Vertical resolution**
  $\cong \frac{1}{2}\lambda$
- **Horizontal resolution**
  $\cong \frac{1}{2}V\sqrt{T_o/f}$
- **For example:**
  - 180 Hz dominant frequency reflection provides a practical potential vertical resolution of 5 m.
  - 180 Hz reflection from the 390 m deep coal allows a channel 20 m wide to be resolved.





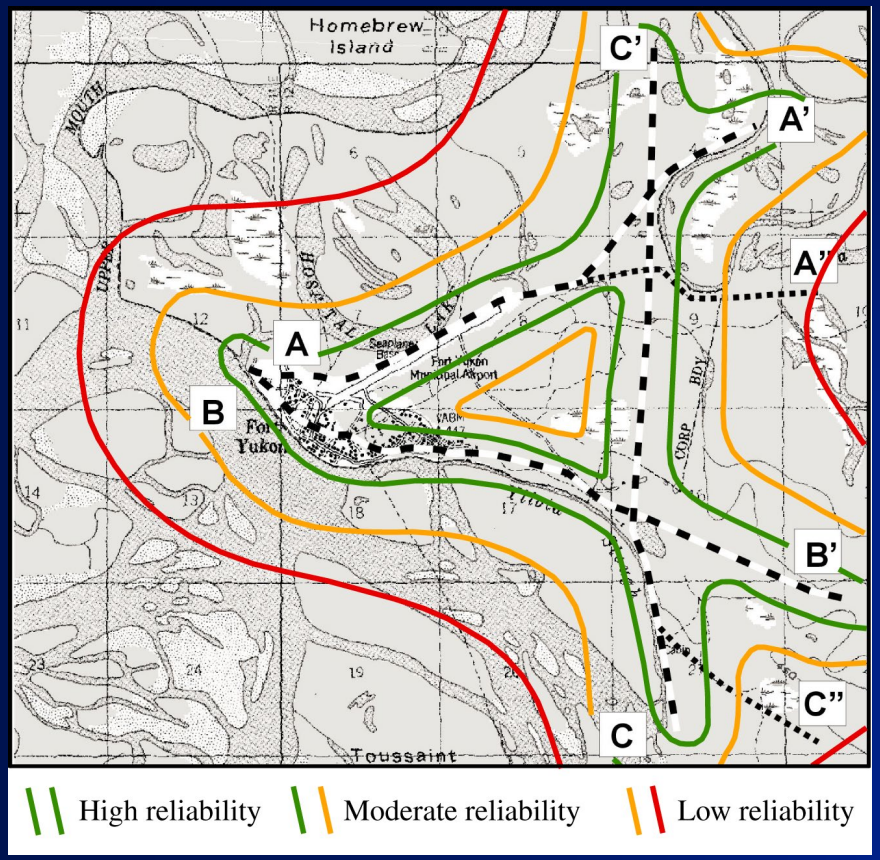
Survey Design

- Geostatistical analysis prior to site visit
  - Minimize interpolation errors by considering:
    - Line spacings
    - Line orientations
    - Resolution requirements
    - Max. rate of change expected

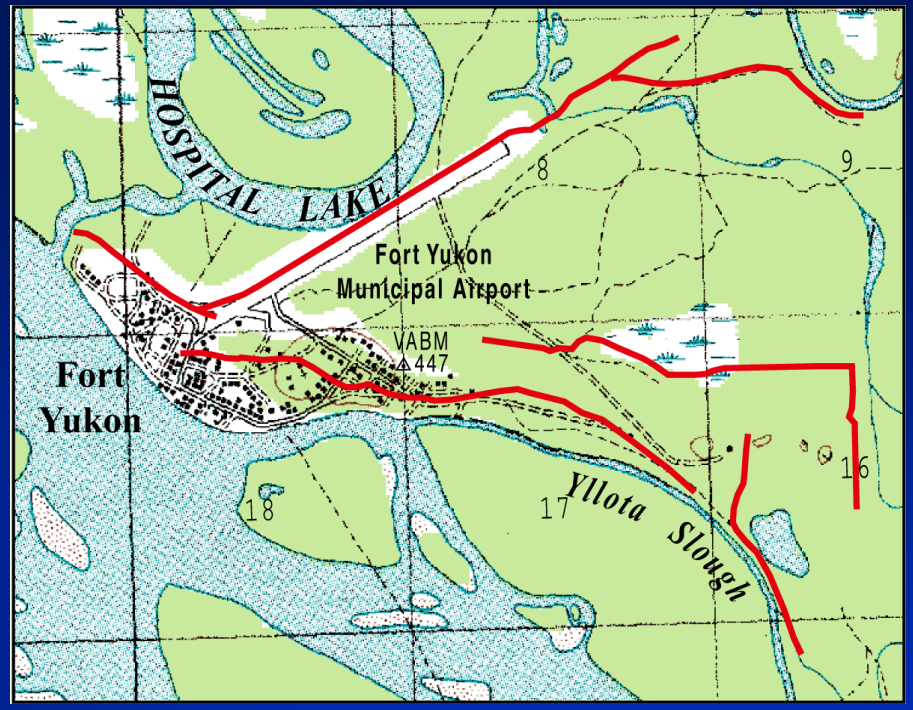


Survey Design

Before site visit



After site visit



- **Site visit dramatically modified idealized survey design.**
  - **Environmental constraints, cultural obstacles, thaw, access, subsurface coverage, and proximity of lines and potential tie points.**

Transporting Equipment

- L-382 Hercules Transport
- 24,000 kg payload
- 16 m x 3 m cargo hold
- 1.5 km ice/snow packed gravel runway
- 6 pallets cables/phones, two 6 x 6 ATVs, one 4 x 6 recording ATV, 1 snowmobile, IVI minivib, 1 pallet computers, and one pallet personal gear.

Seismograph

- 240-channel Geometrics Strataview
- 24 bit A/D
- 12,000 samples/ trace
- 1 ms sampling interval
- Uncorrelated, unstacked
- 10 Mb/ shot gather
- 60 Gigabytes for project

Source

- IVI minivib
- 25-250 Hz, 10 s sweep
- 10 m station spacing
- 3 sweeps/station
- Couple on packed snow, ice, or frozen ground

Proto-type valve 4k ft·lbs @ 150 Hz

Land Surveying

- Trimble 4800 & 4700
- DGPS
- ± 2 cm x, y, z
- Base station tied to AK DoT airport bench locations
- Stations (5 m) were chain located followed by after occupation land surveyed

Receivers

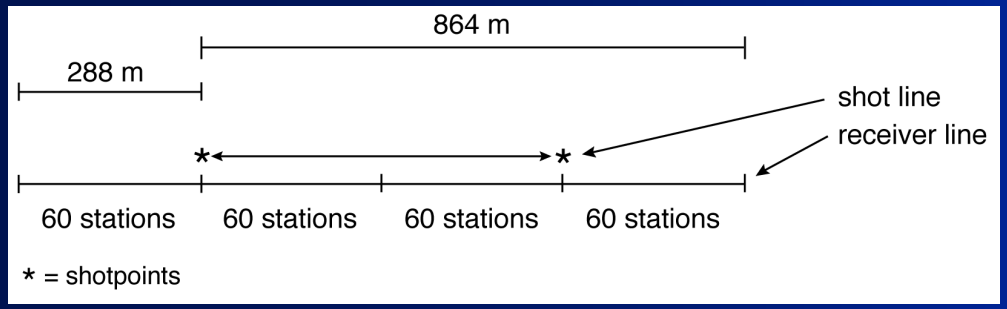
- 3 – 10 Hz Mark Products digital grade Ultra Phone®
- Coupling
  - Ice/rock plates not good enough
  - Dig hole through snow and ice (up to 1 m)
  - Electric drill melt pilot holes
  - Freeze geophones in place
- Lots of effort but > 180 Hz makes it worth it.

Site Limitations

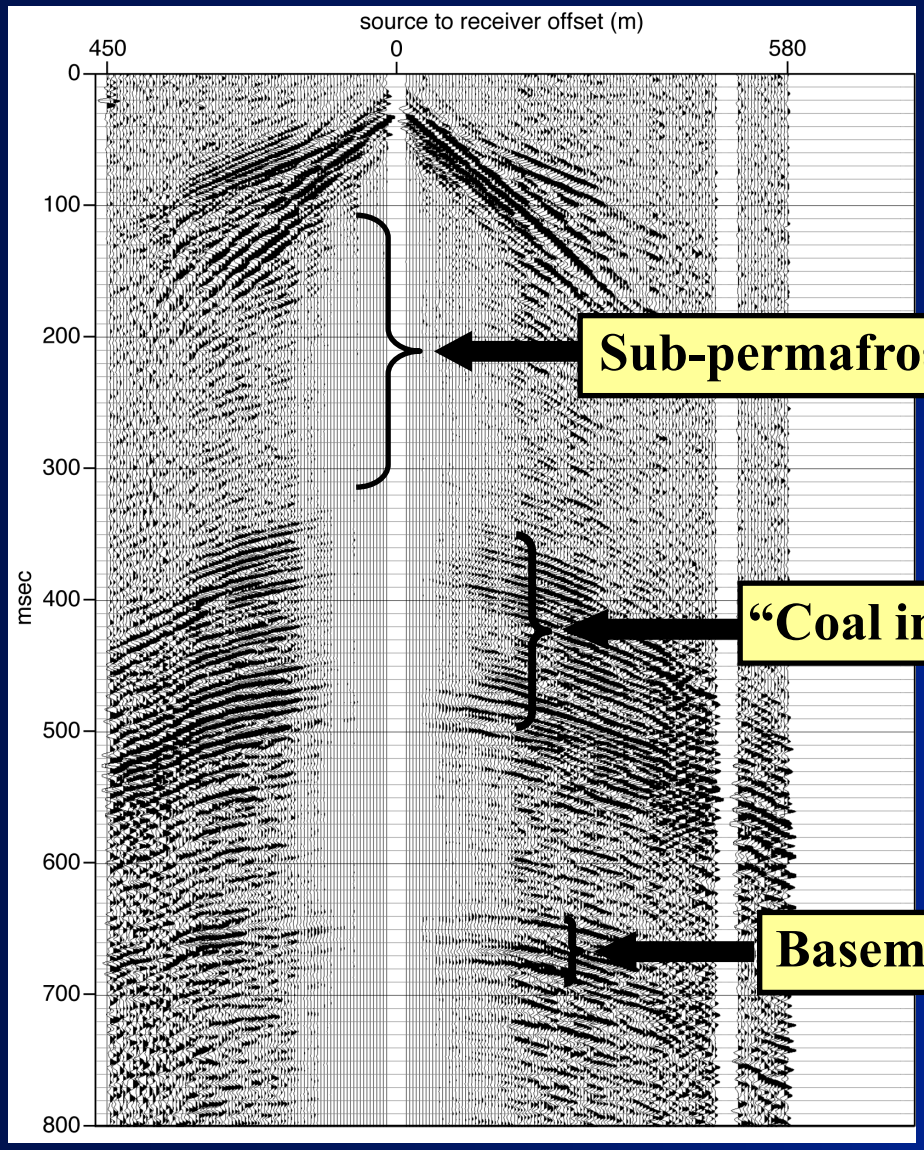
- Snow up to 2 m deep
- Narrow trails
- Temperatures ↓ -25° F
- Spring thaw
- Vegetation
- Access
- Rivers, sloughs, draws

Field Geometry-Source/Receiver

- Station spacing 5 m
- 1.2 km spread
- Optimum source to receivers offset window 50 to 300 m (most of the time)
- Maximum offset ~850 m
- Source, receivers, and support vehicles occupied the same ~4 m wide path



Shot Gather Characteristics



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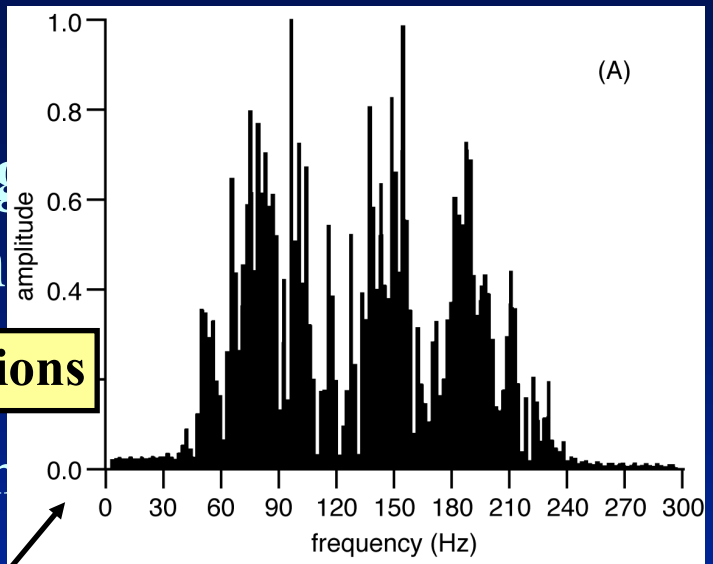
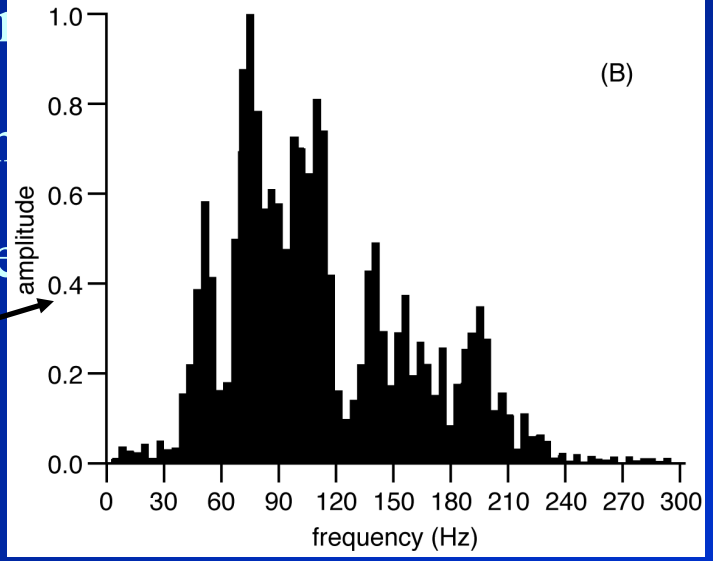
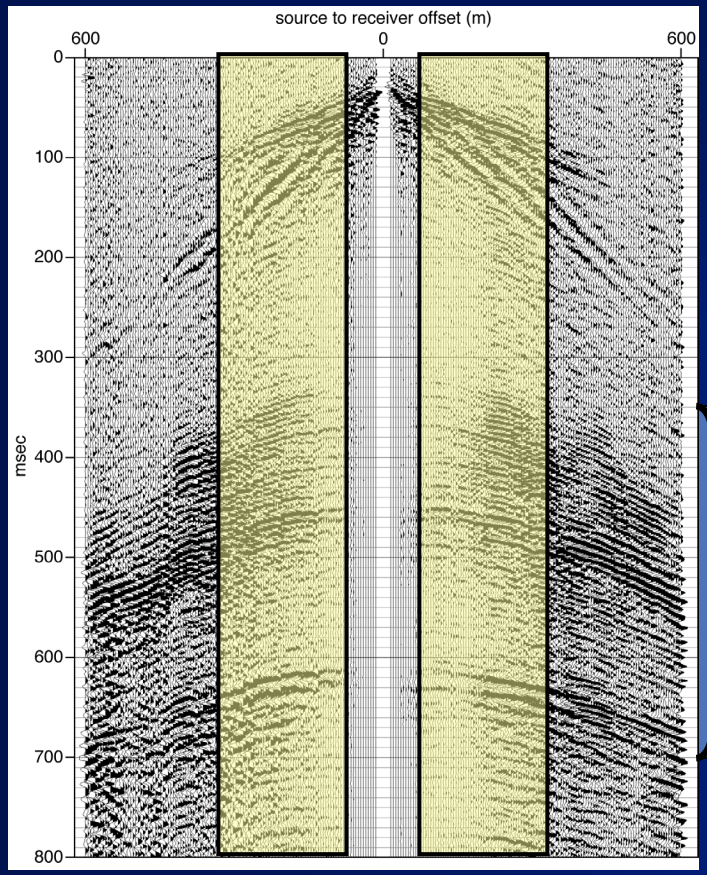


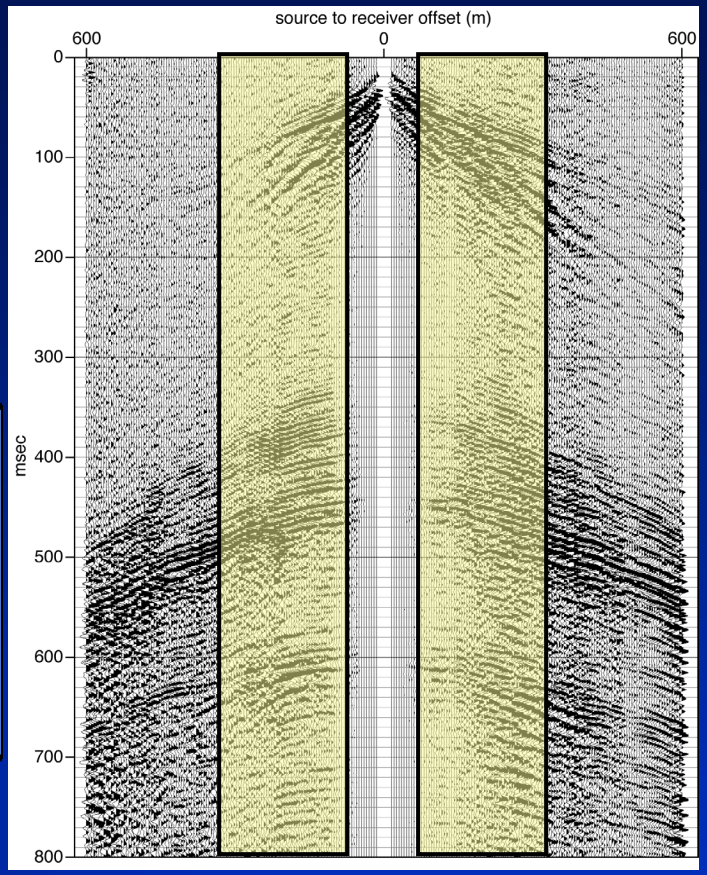


Representative Shot Gathers



NMO velocity from 1750 m/s and 2200 m/s

High amplitude reflections

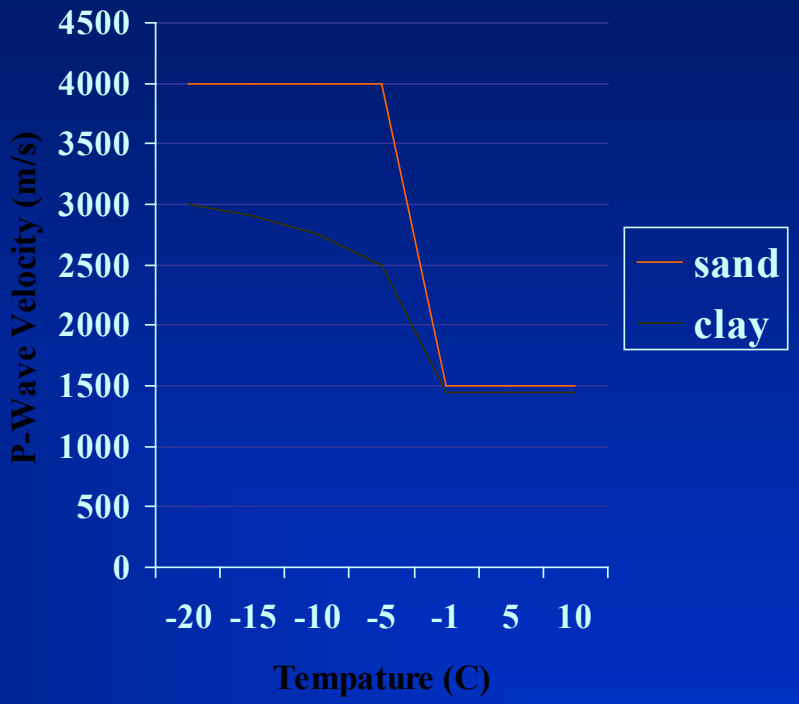


Optimum source to receiver offset window

Dominant frequency 150 Hz to 180 Hz with upper useable corner over 220 Hz on reflections within “coal interval.”

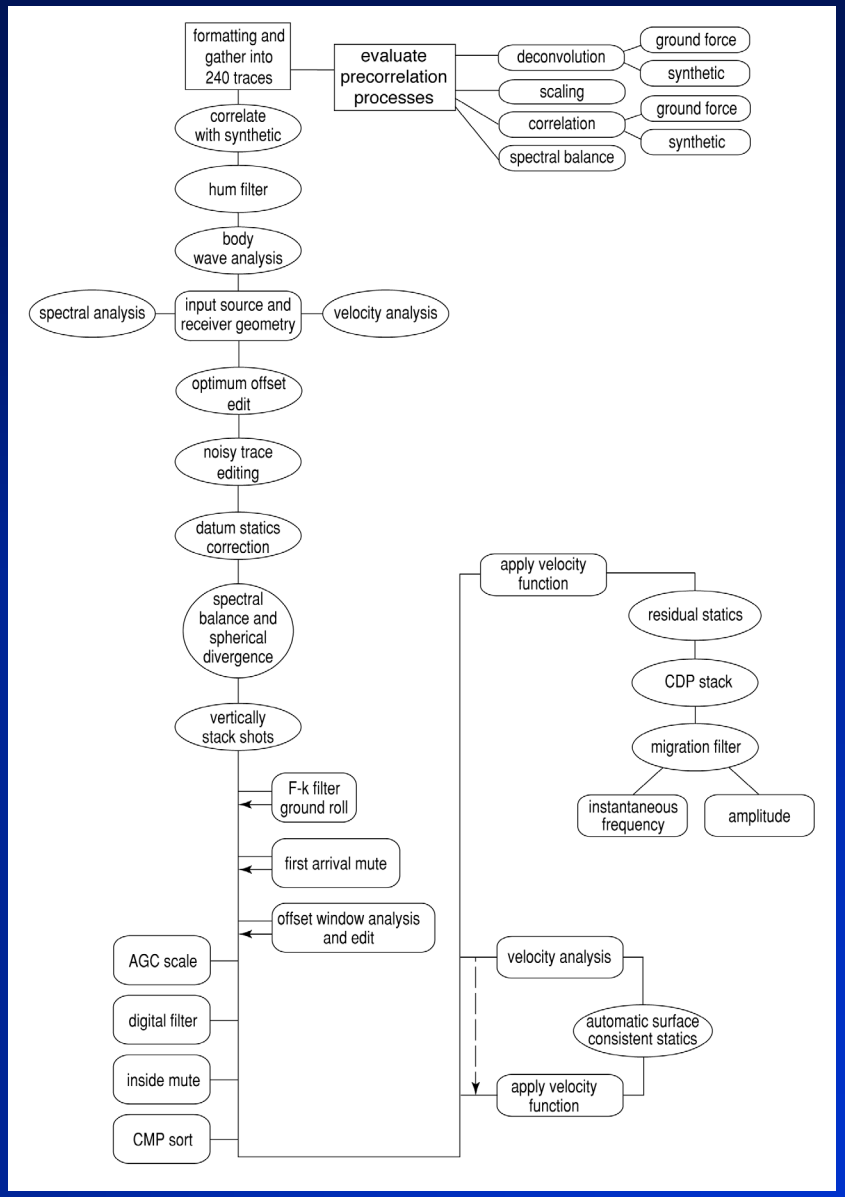
Generalized Velocity Relationship with Temperature in Permafrost

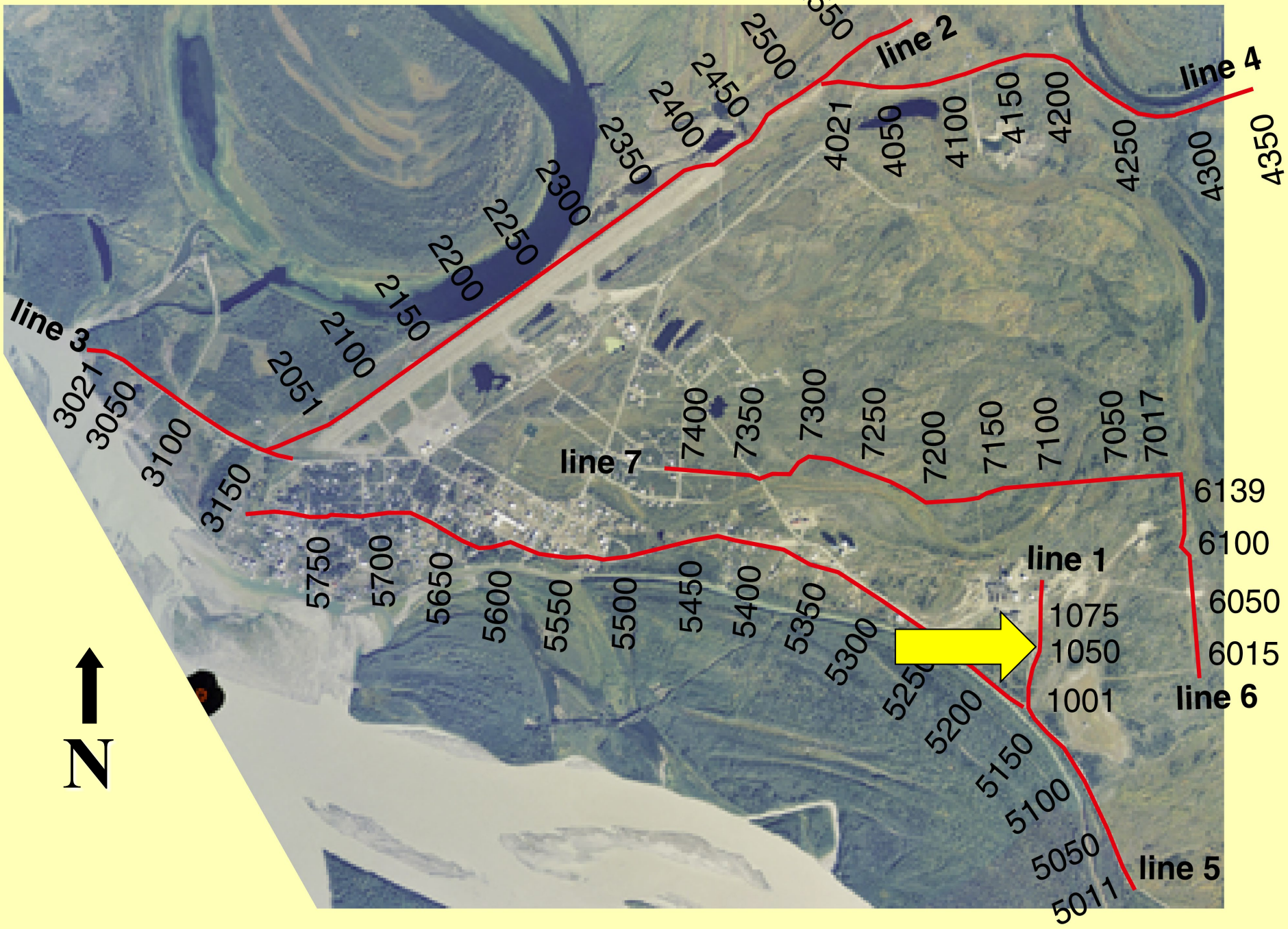
- Velocity decrease prior to melting
- >clay content greater, effects over larger temperature range
- Lateral changes in % clay dramatically effects velocity function in permafrost section



CMP Data Processing

- Precorrelation operations
  - Correlate with synthetic
  - AGC scale
- Noise reduction
  - Hum filter (power line)
  - Severe editing
    - People
    - Vehicles
    - Radar station
- NMO distortion
  - Velocity inversion
- Static & permafrost
  - Changes in thickness
  - Changes in lithology

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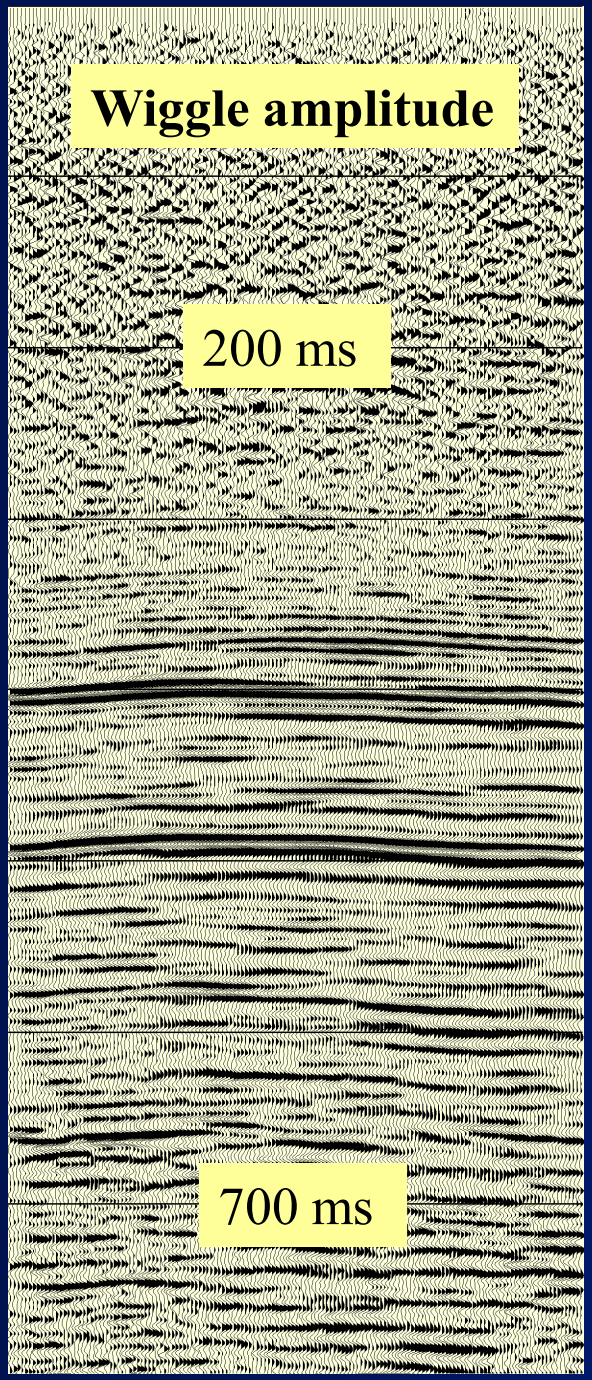
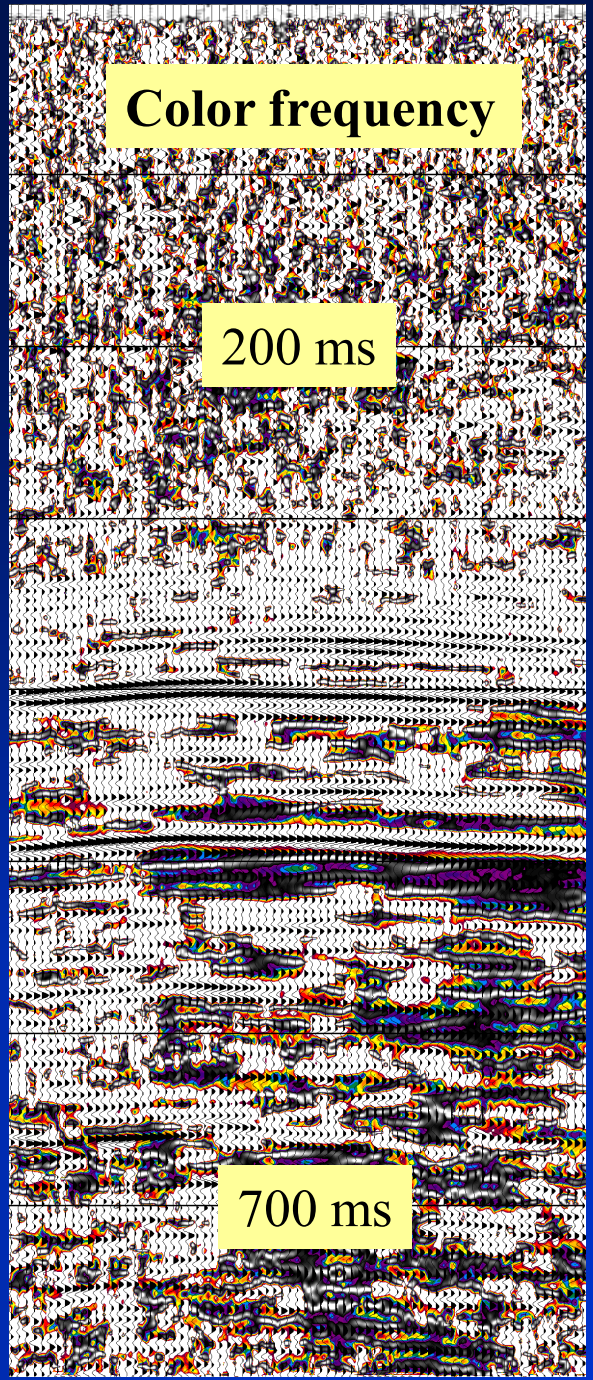
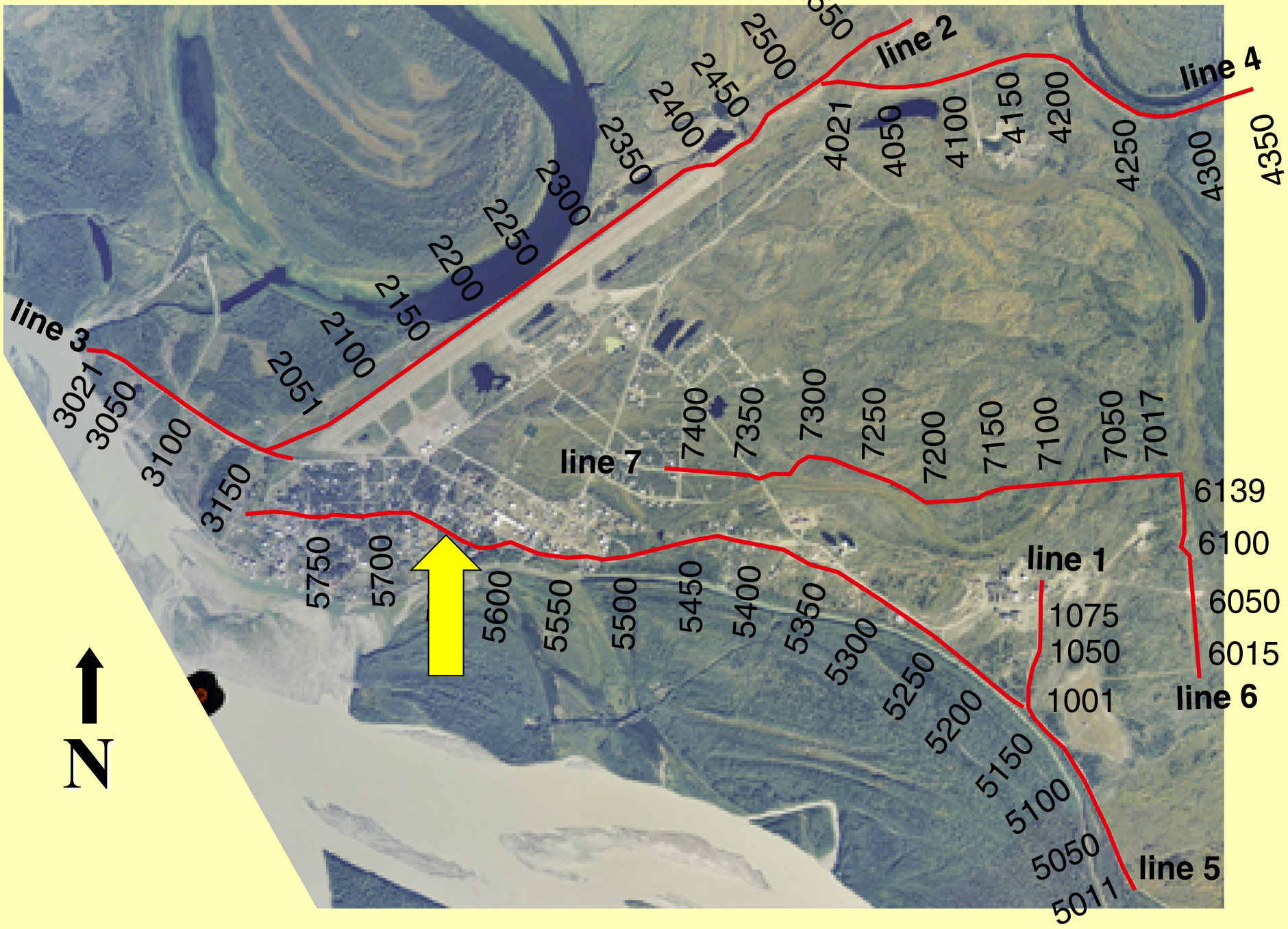
Interpretations



- Site wide
  - Gross structure and lithology consistent
  - Microstructures difficult to track
- Reflection above 300 ms low S/N and not the focus of the data processing
- Coherent events below basement are multiples & out-of-plane
- frequency and amplitude changes relate to physical characteristics

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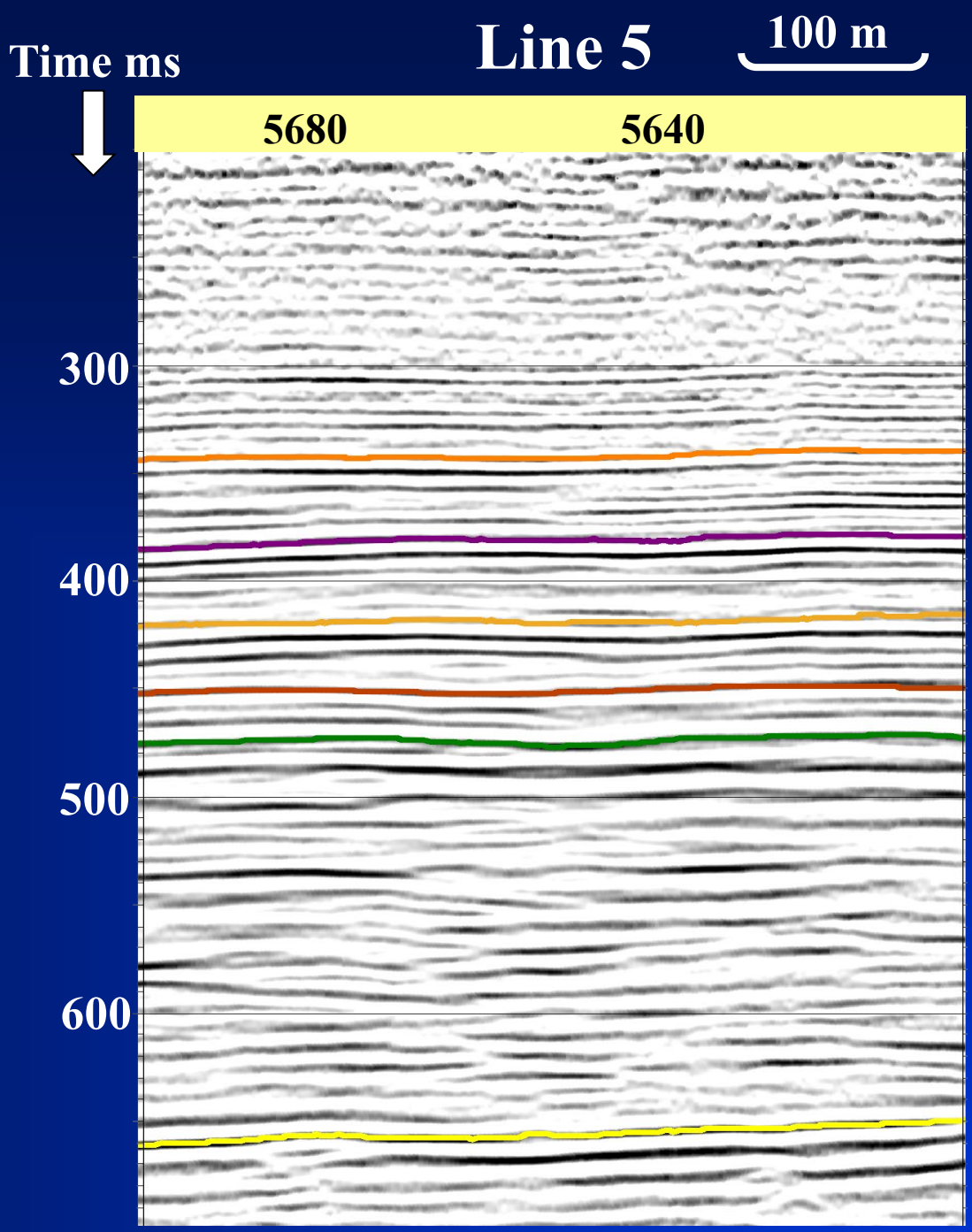
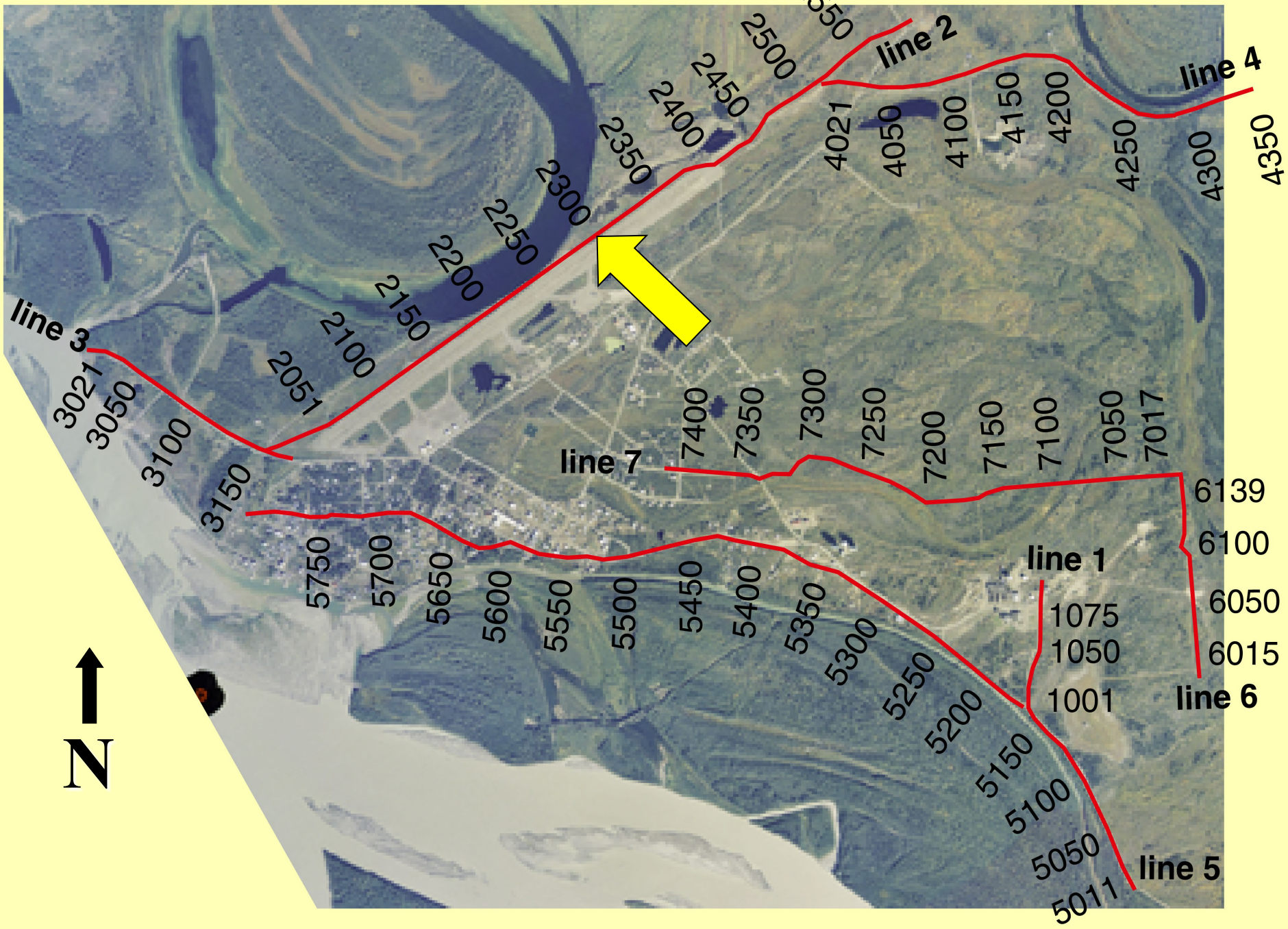
Correlating Reflections

- **Low/no fold ties due to environmental, cultural, or access obstacles**
- **Reflection colors**
  - **Orange**: 370 m coal
  - **Violet**: 391 m coal
  - **Tan** & **Red**: site-wide reflectors in "coal interval"
  - **Green**: base of "coal interval"
  - **Yellow**: basement

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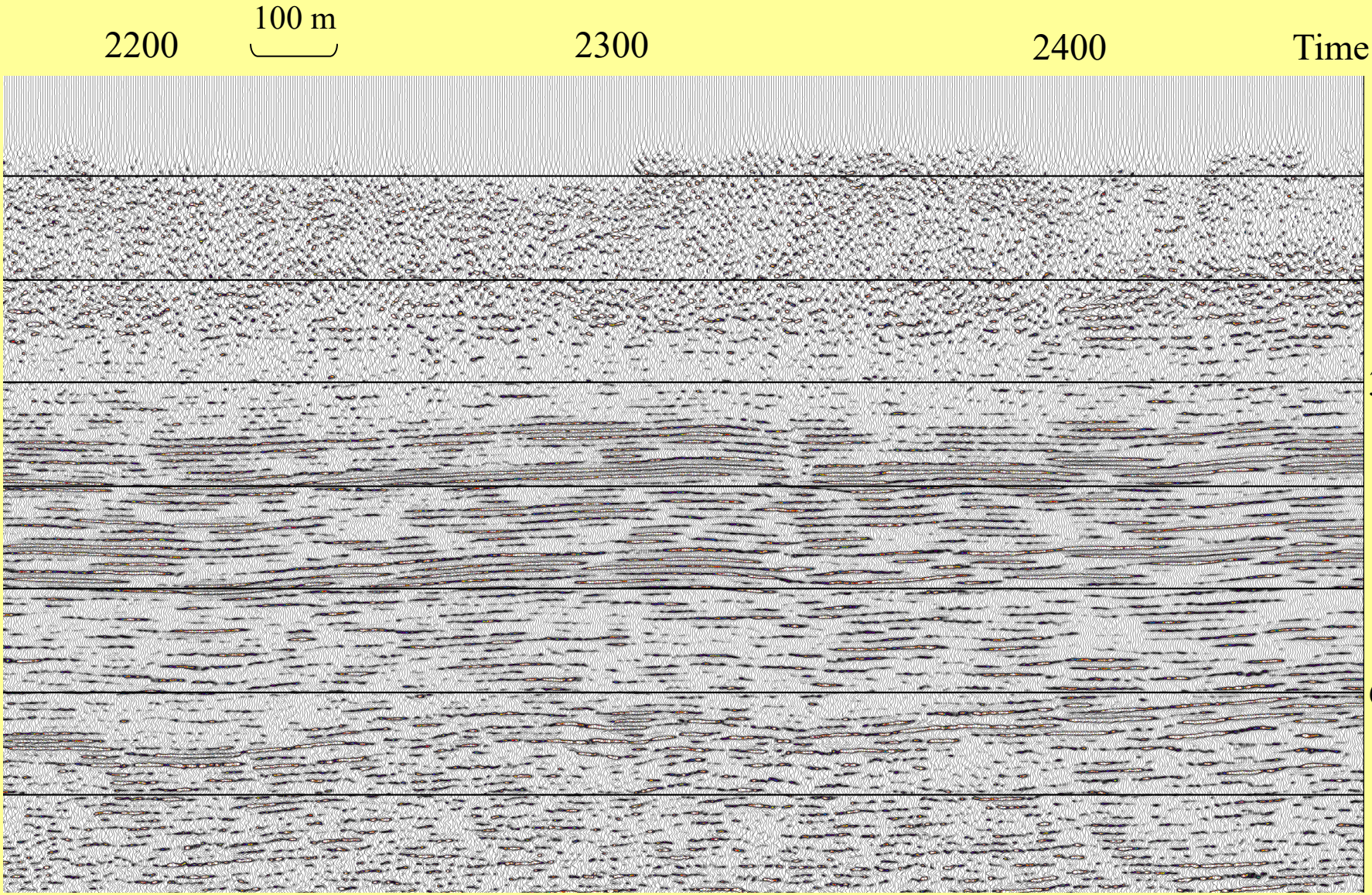
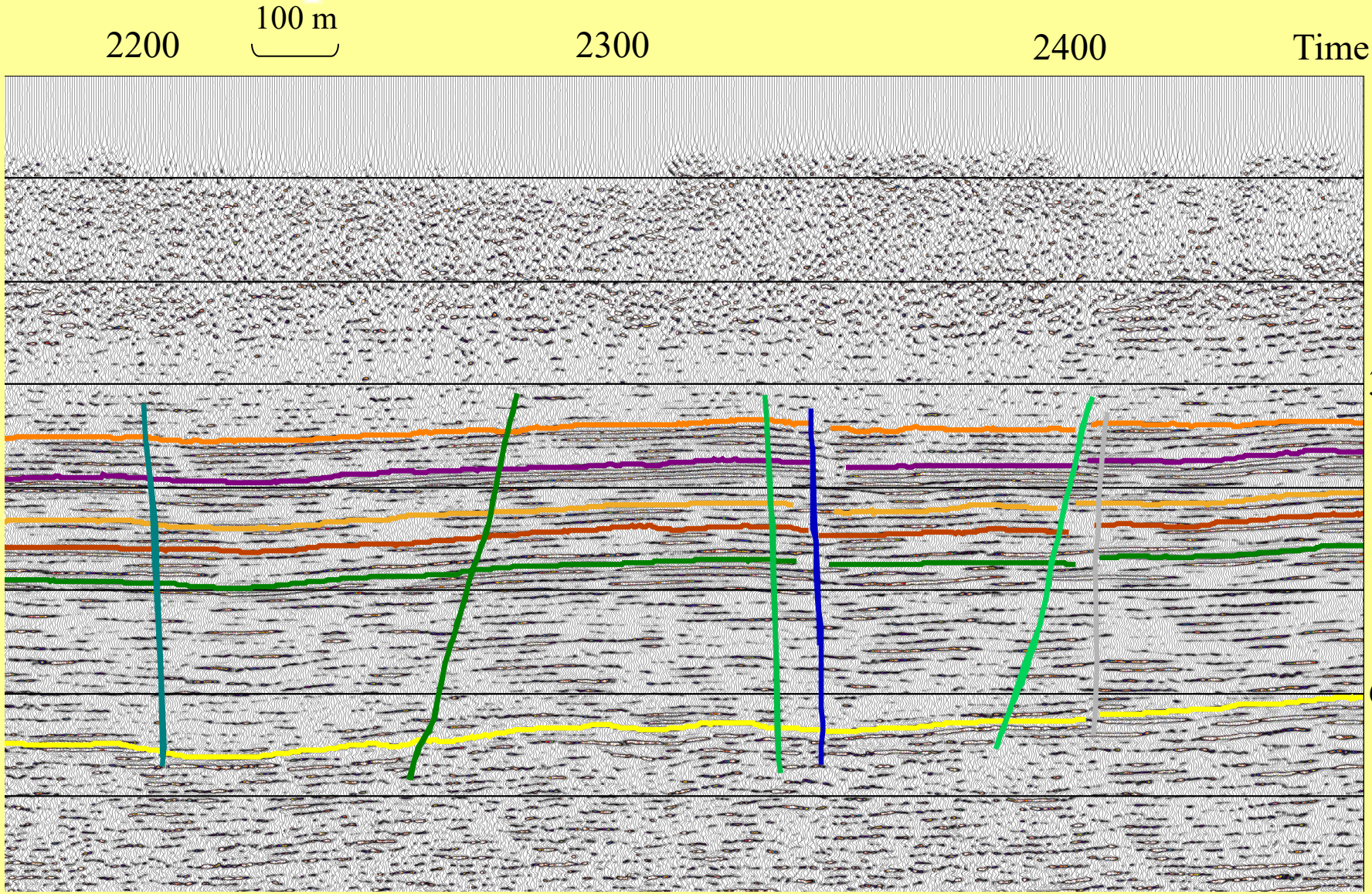
CMP Stacked Section Line 2



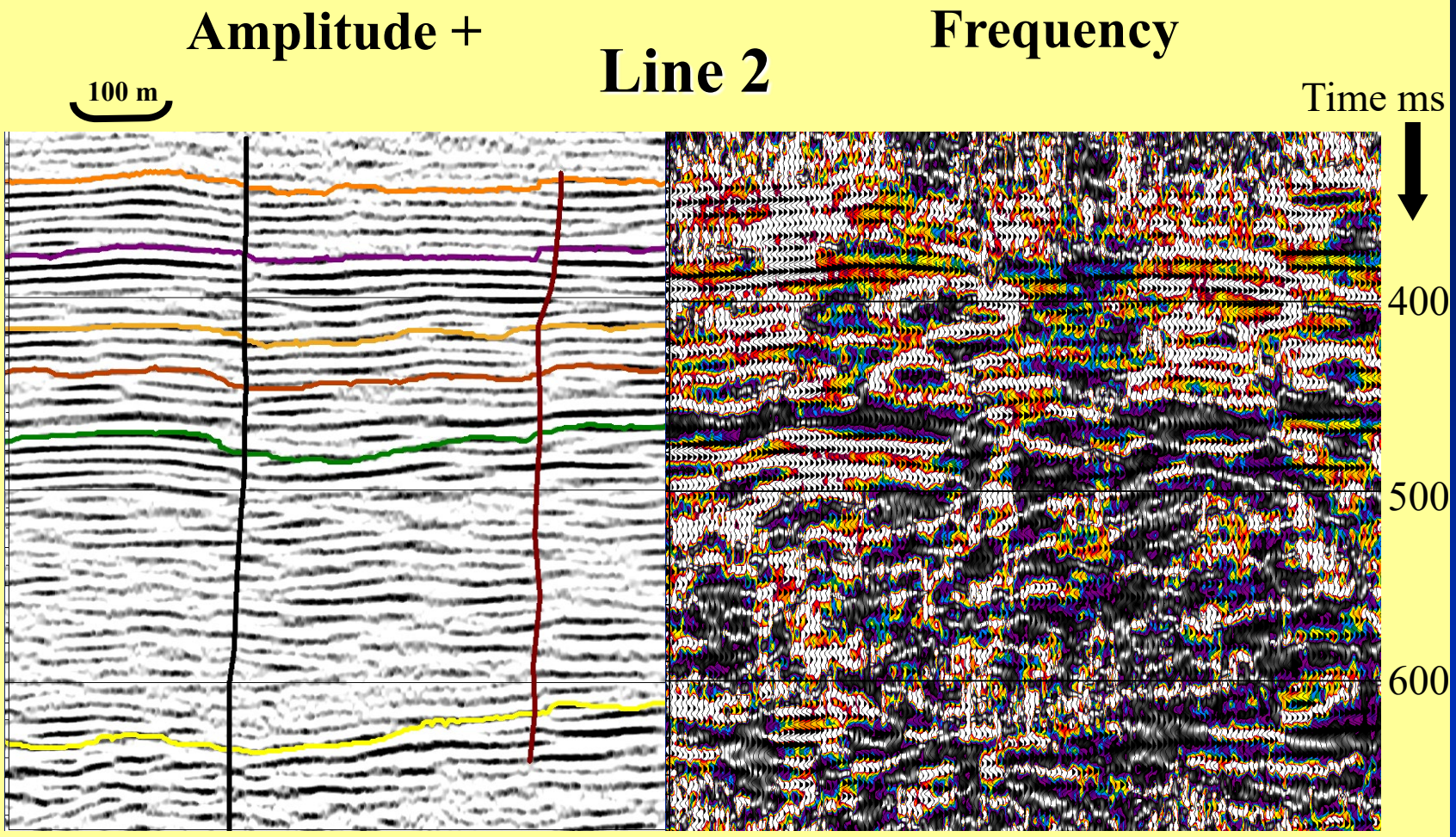
- **After optimization of traces, fold ranges from 12 to 18, down from the 60 fold maximum potential of these data**

Interpreted CMP Section Line 2



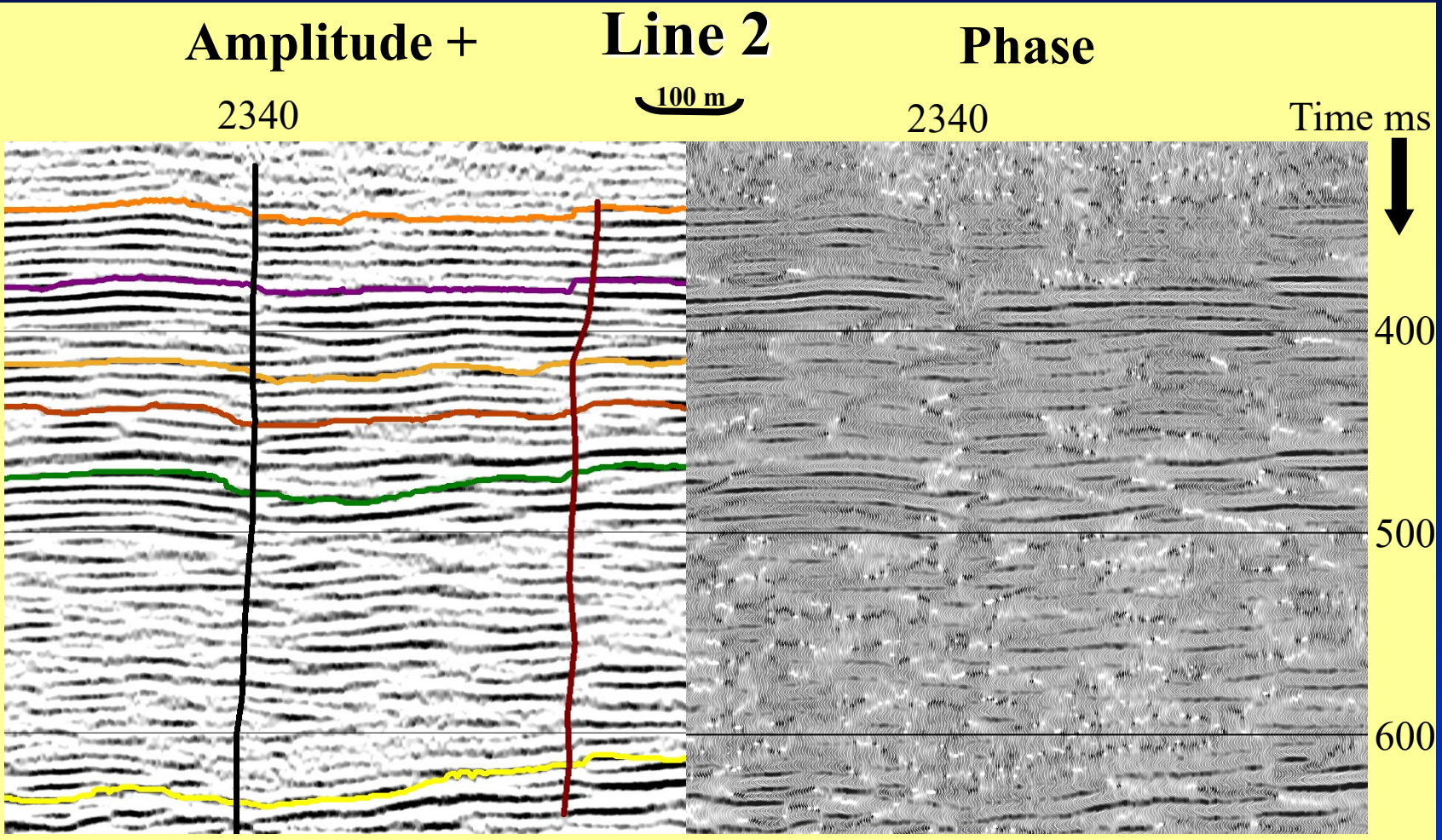
- **Violet layer is the 391 m coal and the orange is the 370 m coal sampled in the 1994 corehole. Green layer is interpreted as the base of the coal interval**

Attribute Analysis

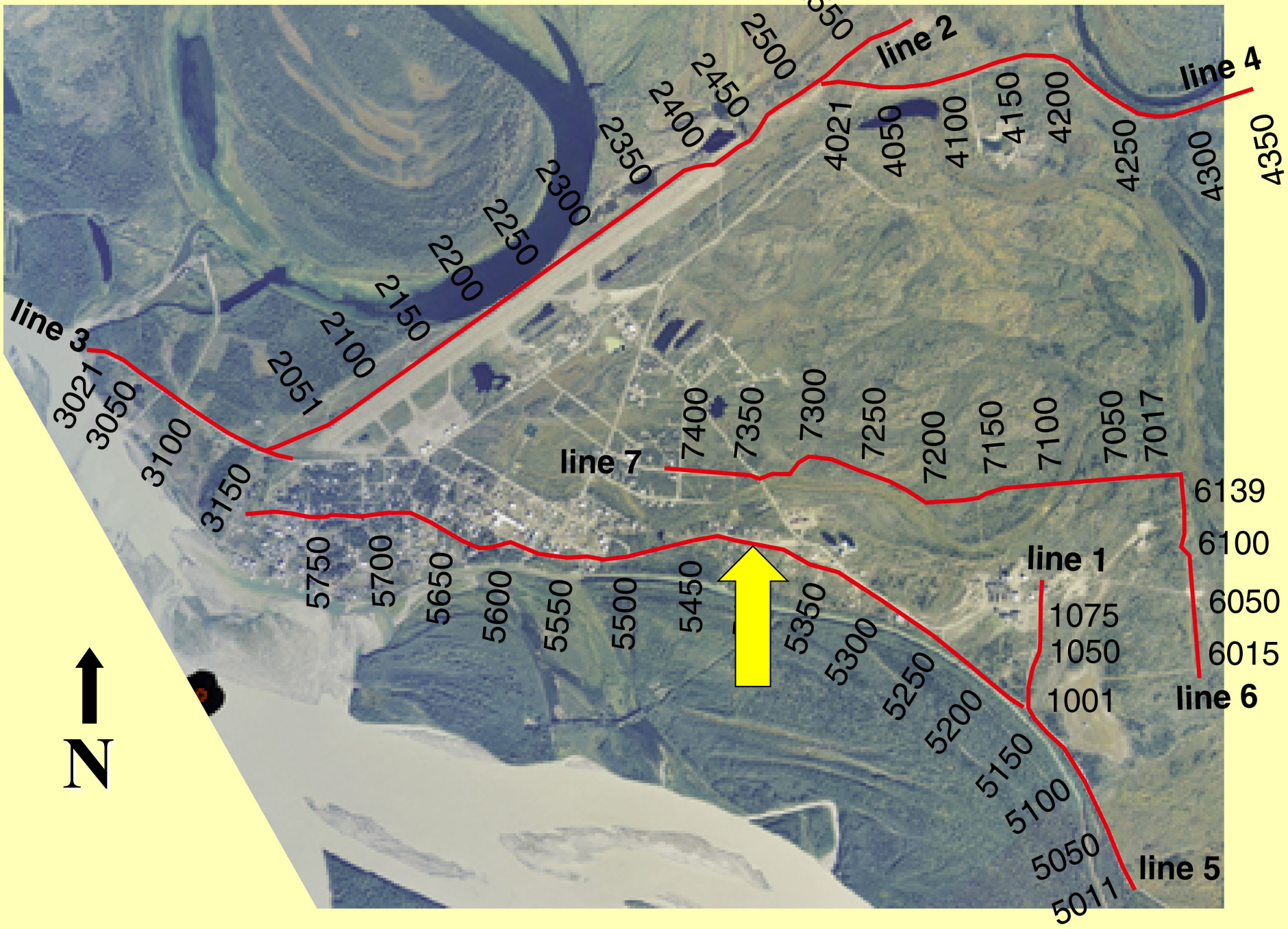


- **Diffractions indicative of faulting (bed terminations) are enhanced with sign frequency analysis.**

Attribute Analysis



- **Contrasting phase variations provided key insights into micro-faulting and fracture systems**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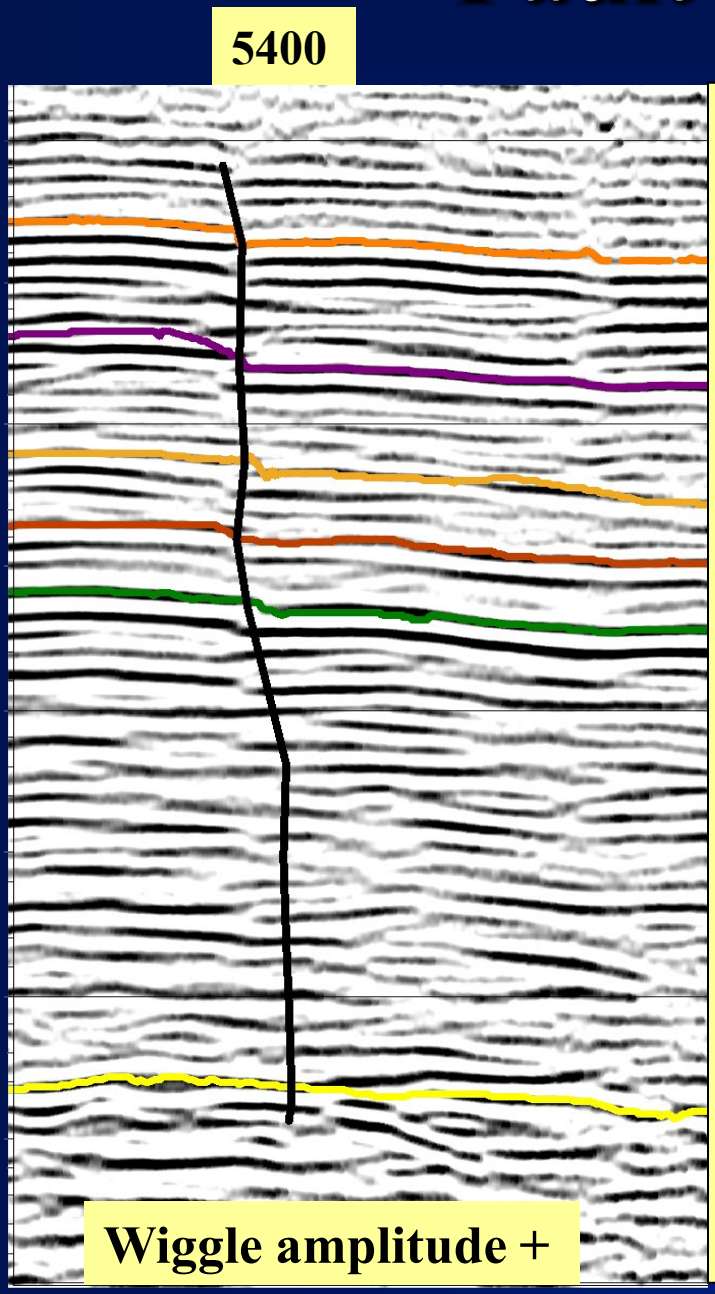
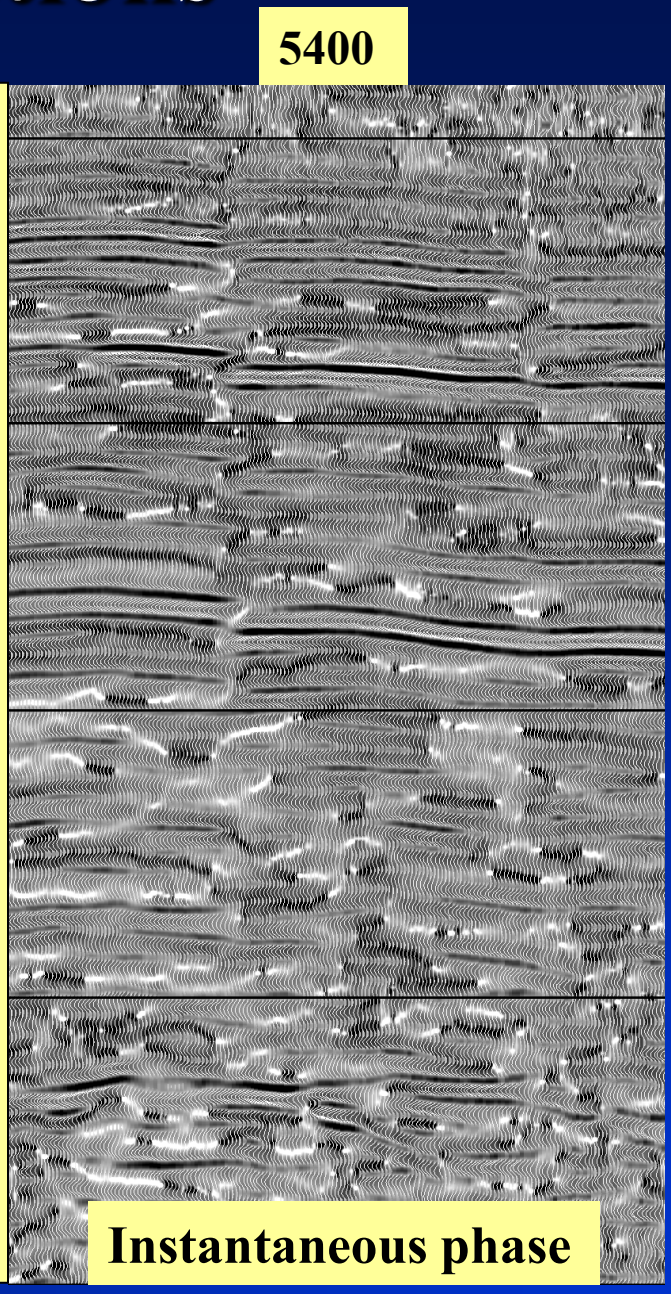
Fault Interpretations

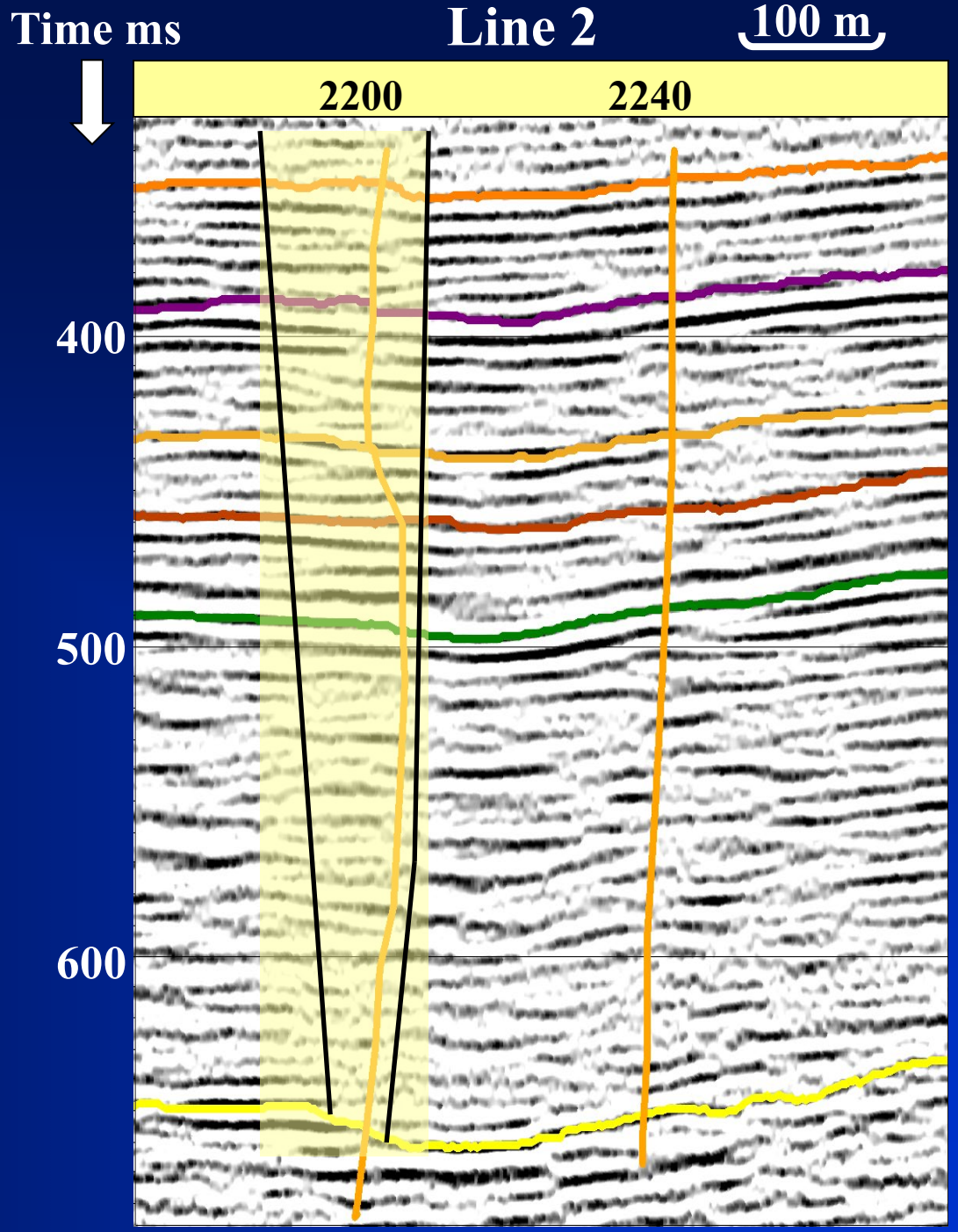


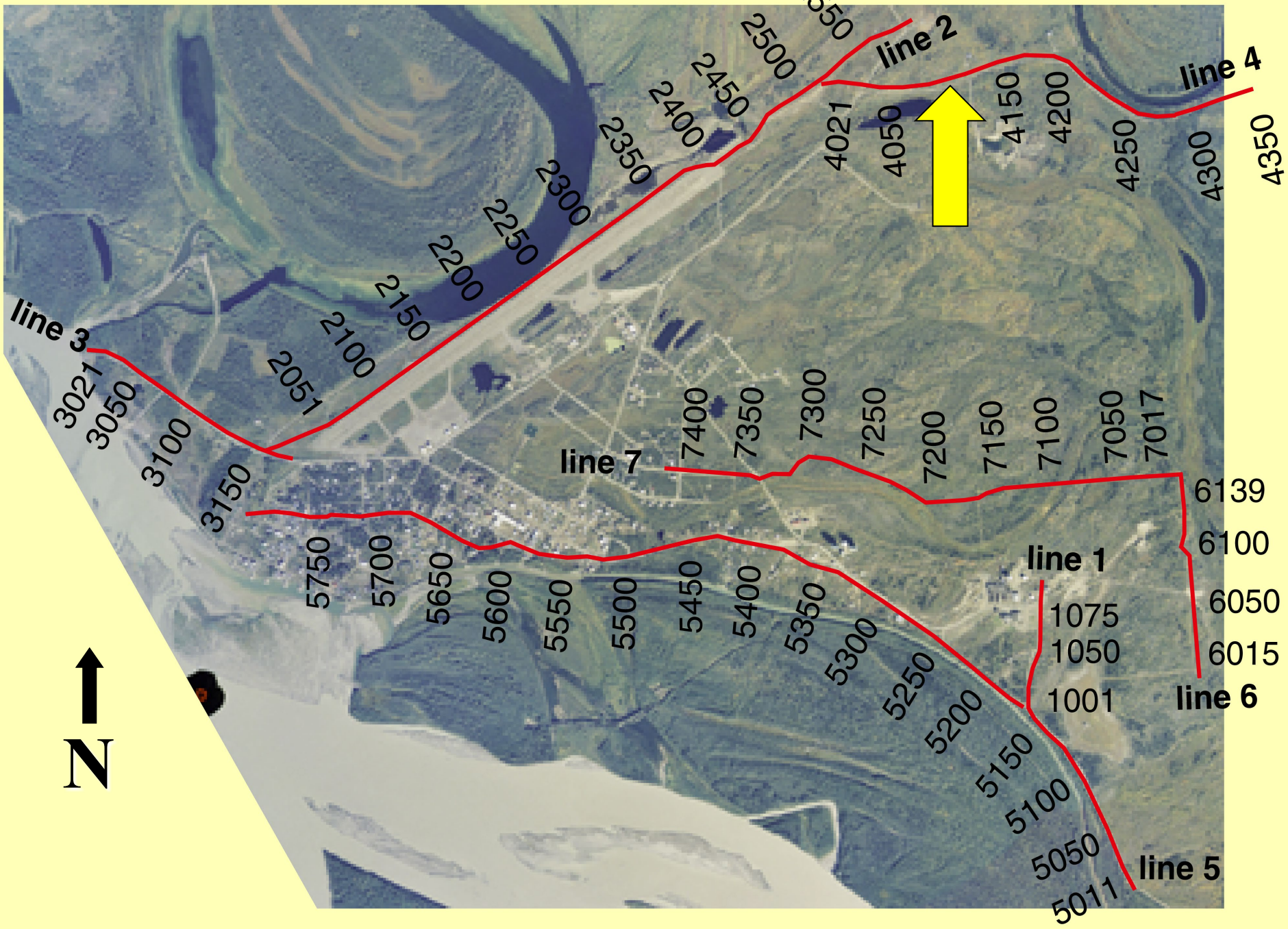
Identify unique fault and fracture signatures based on geometry and attributes allowing correlations in areas without seismic coverage



Basement Structures

- "Non-vertical" synforms
- Fault interpreted based on vertically consistent offset in reflections
- Relative movement used as a key factor in line-to-line correlations
- Most appear very high angle
  - Normal? Or Reverse?
  - Strike-slip?
    - Indications on line 3

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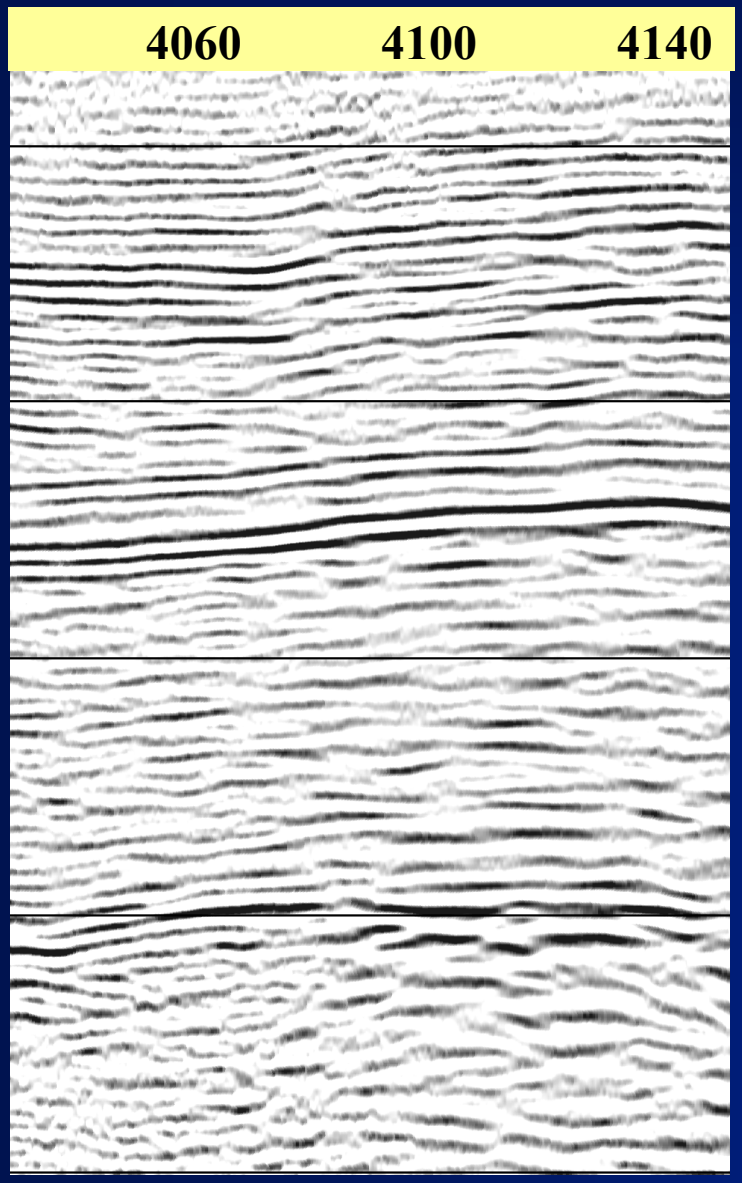
Fault or Monocline?

Line 4

100 m



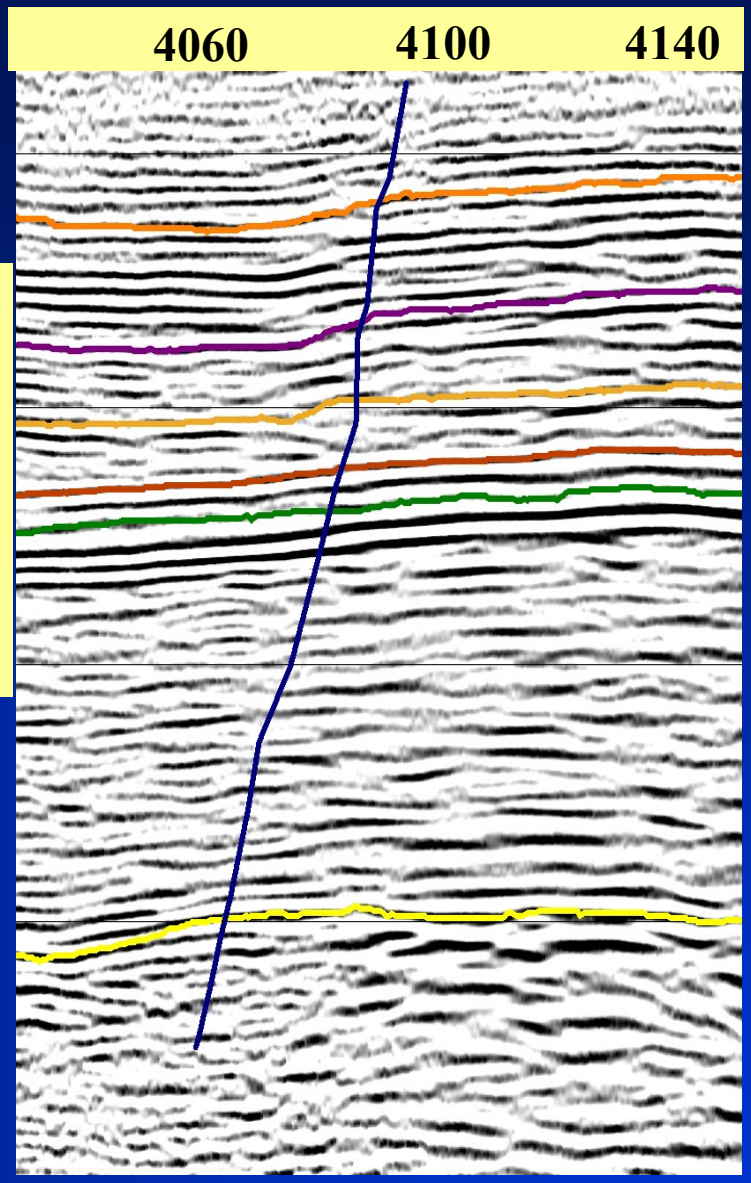
Time ms

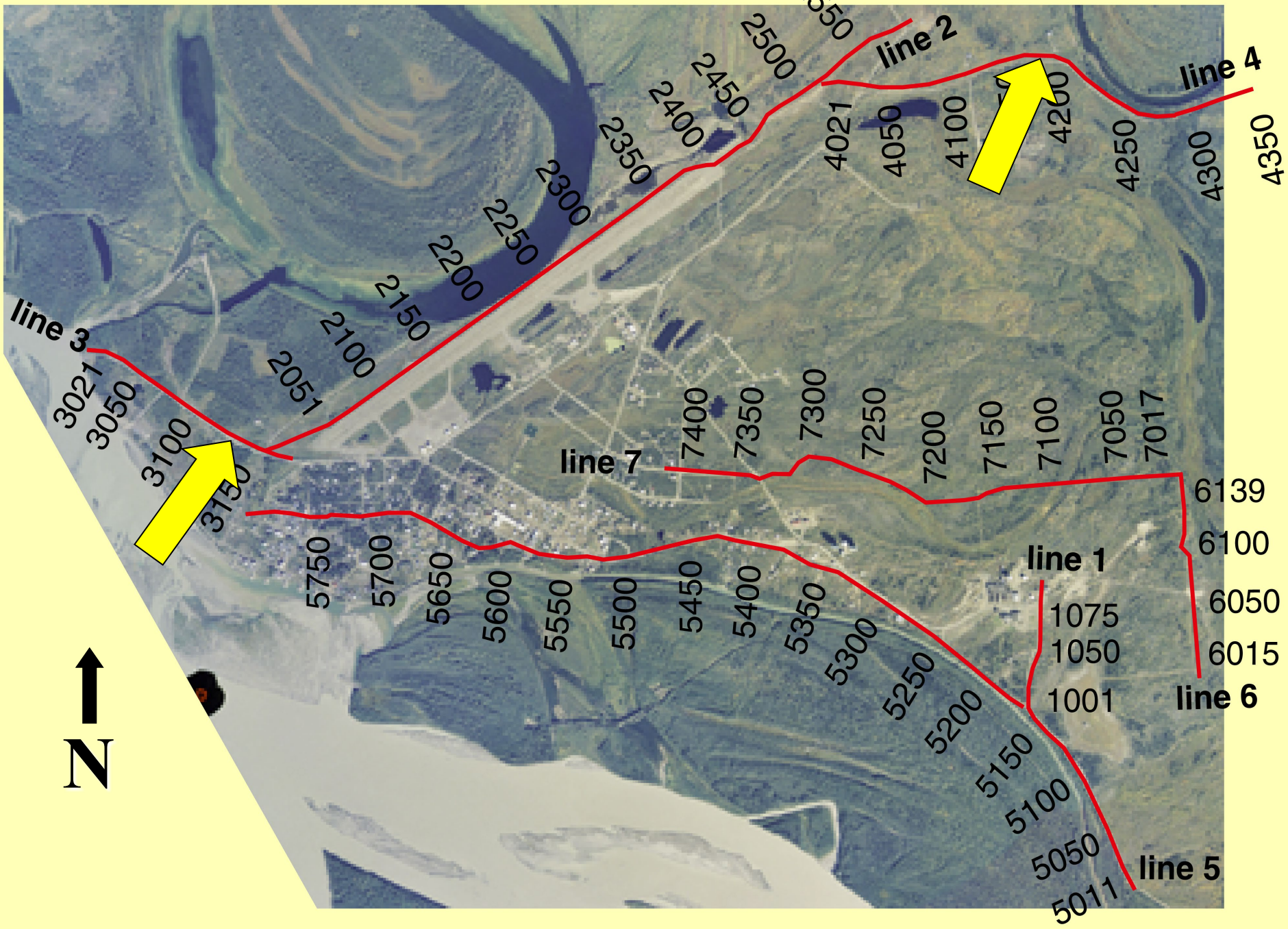
Reflection drape

Diffractions

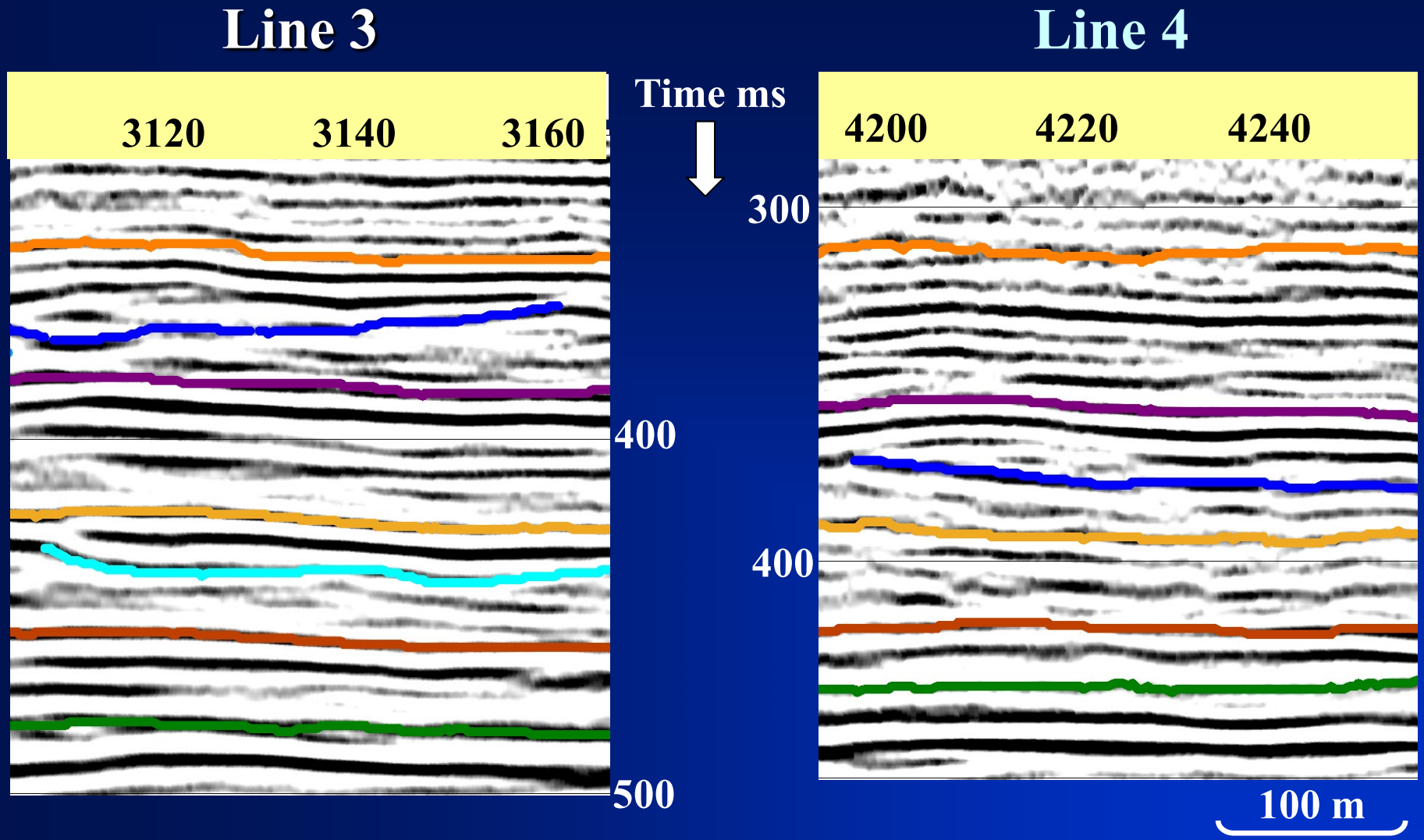
Continuity of beds

600

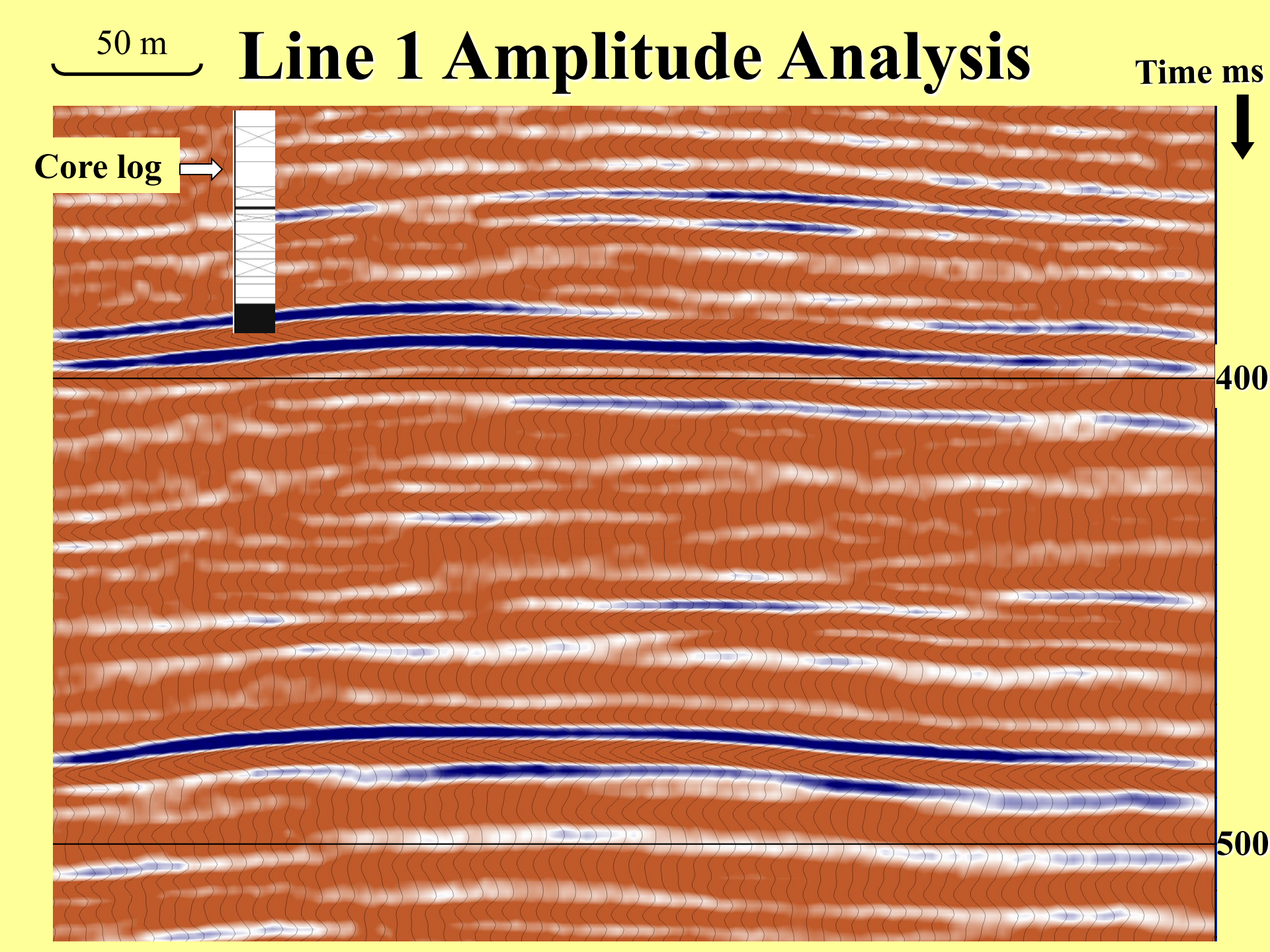



line 1
line 2
line 3
line 4
line 5
line 6
line 7
N
2550
2500
2450
2400
2350
2300
2250
2200
2150
2100
2051
4021
4050
4100
4200
4250
4300
4350
3021
3050
3100
3150
7400
7350
7300
7250
7200
7150
7100
7050
7017
6139
6100
6050
6015
1075
1050
1001
5750
5700
5650
5600
5550
5500
5450
5400
5350
5300
5250
5200
5150
5100
5050
5011

Channel Features



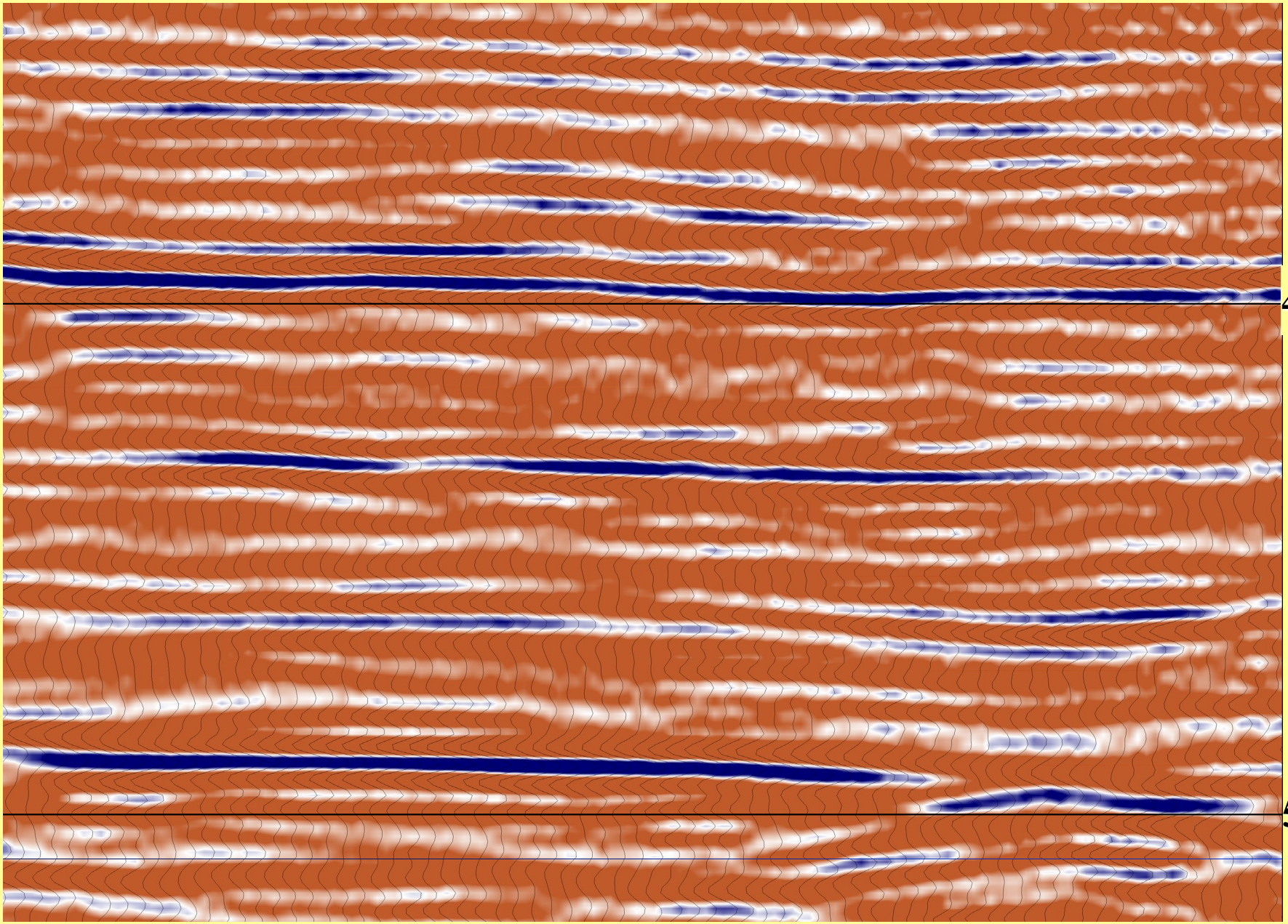
- Geometries suggestive of cut and fill features throughout the part of the section classified as the “coal interval”


50 m
Line 1 Amplitude Analysis
Time ms
Core log
400
500

50 m

Line 2 Amplitude Analysis

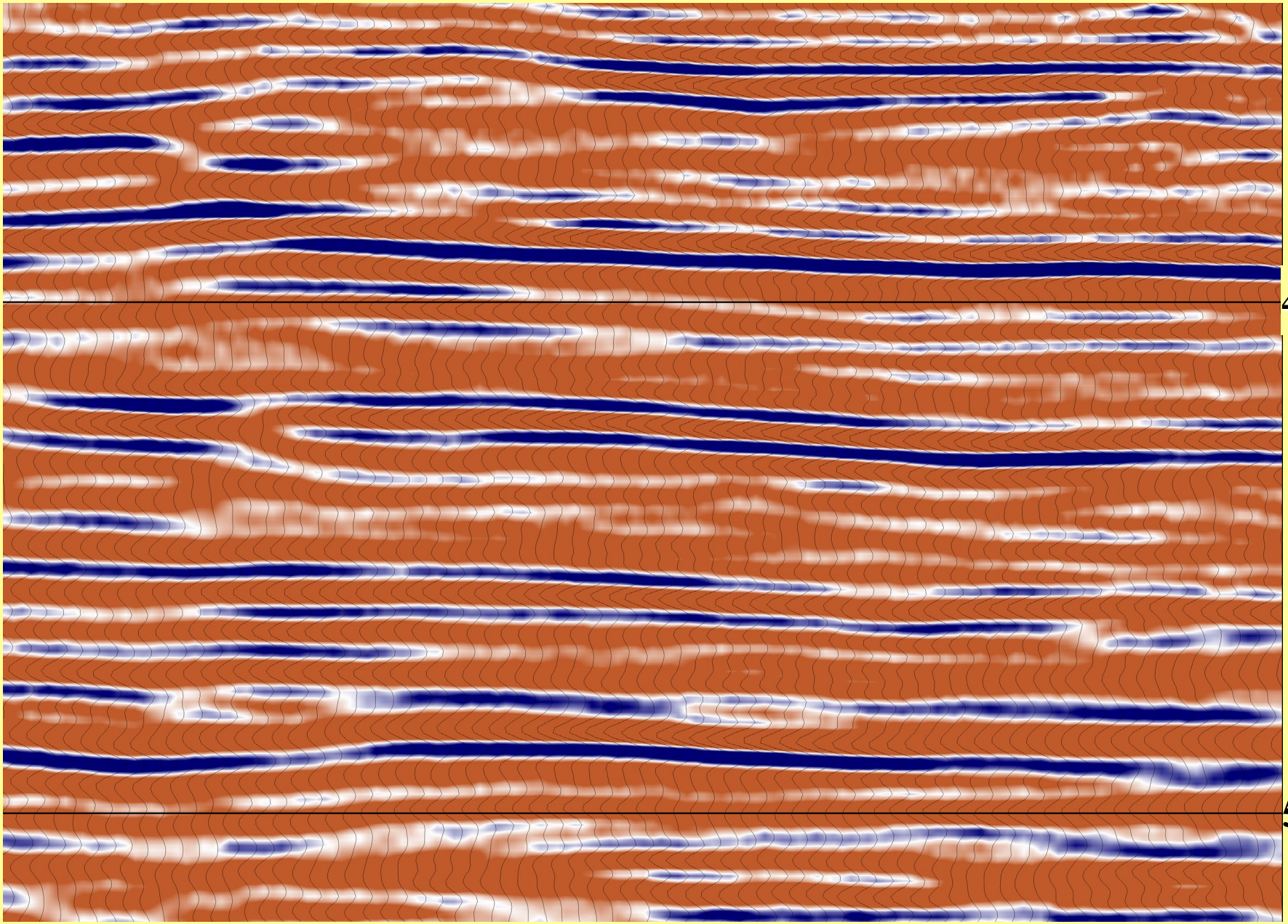
Time ms



50 m

Line 3 Amplitude Analysis

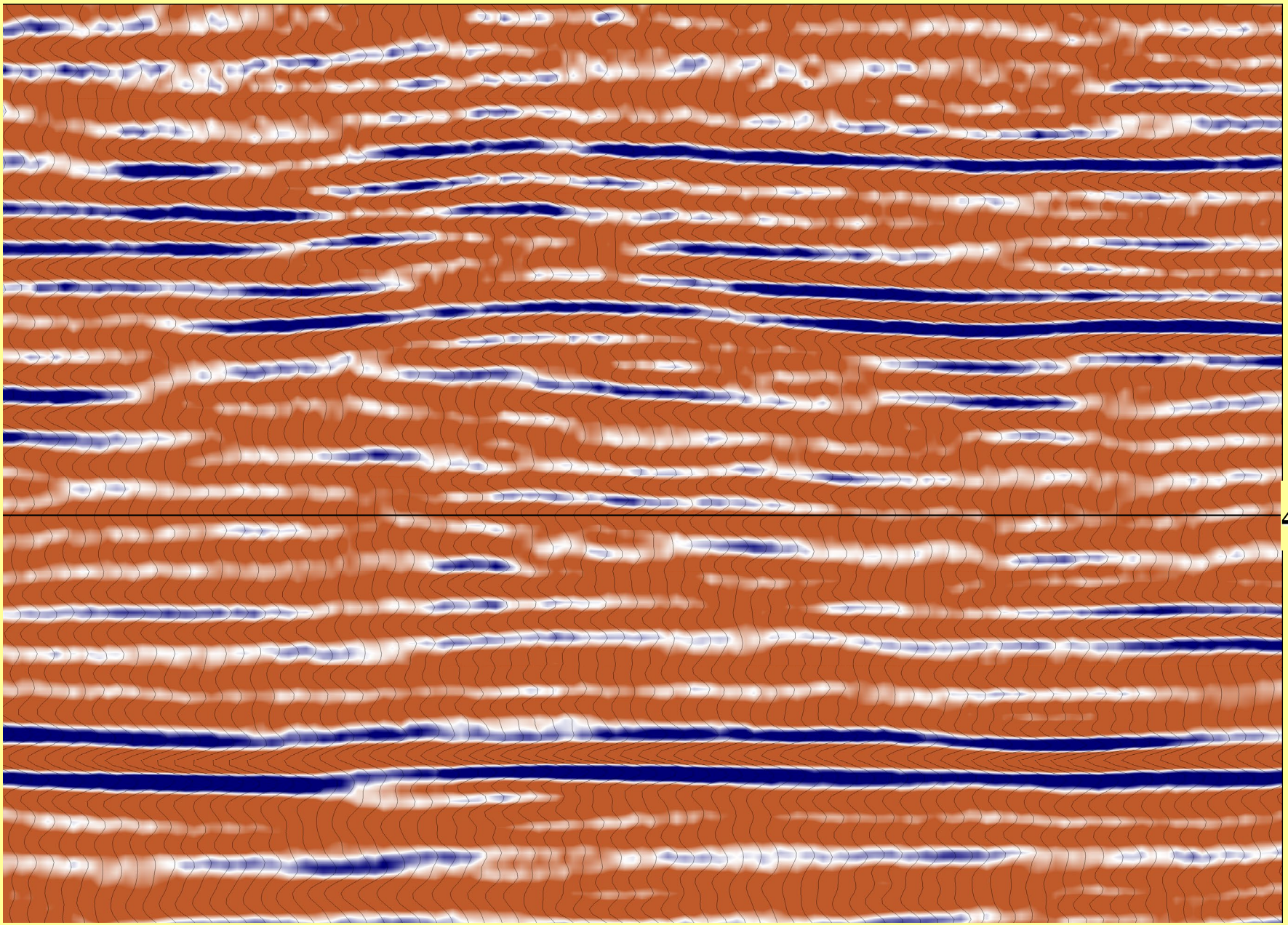
Time ms



50 m

Line 4 Amplitude Analysis

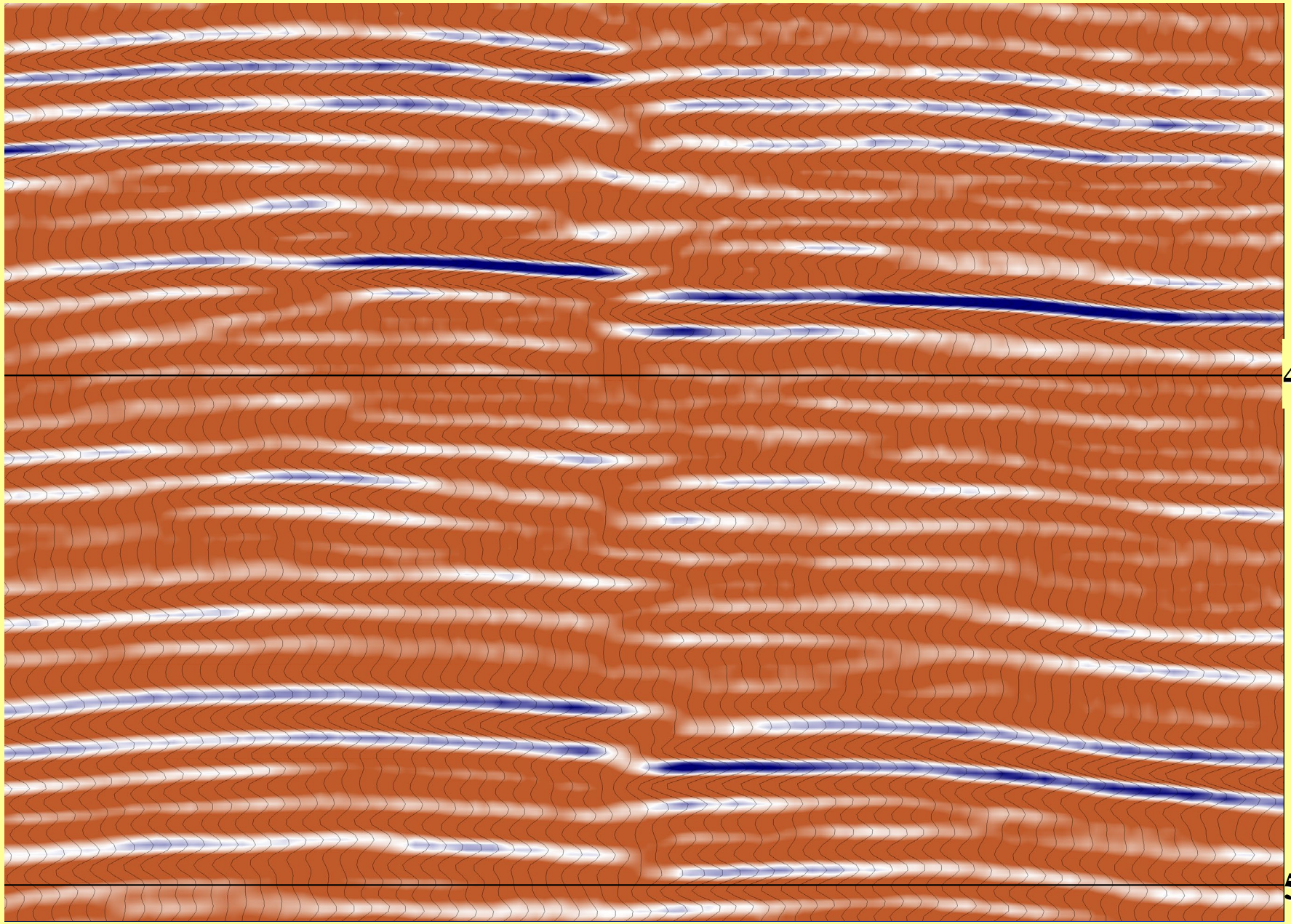
Time ms

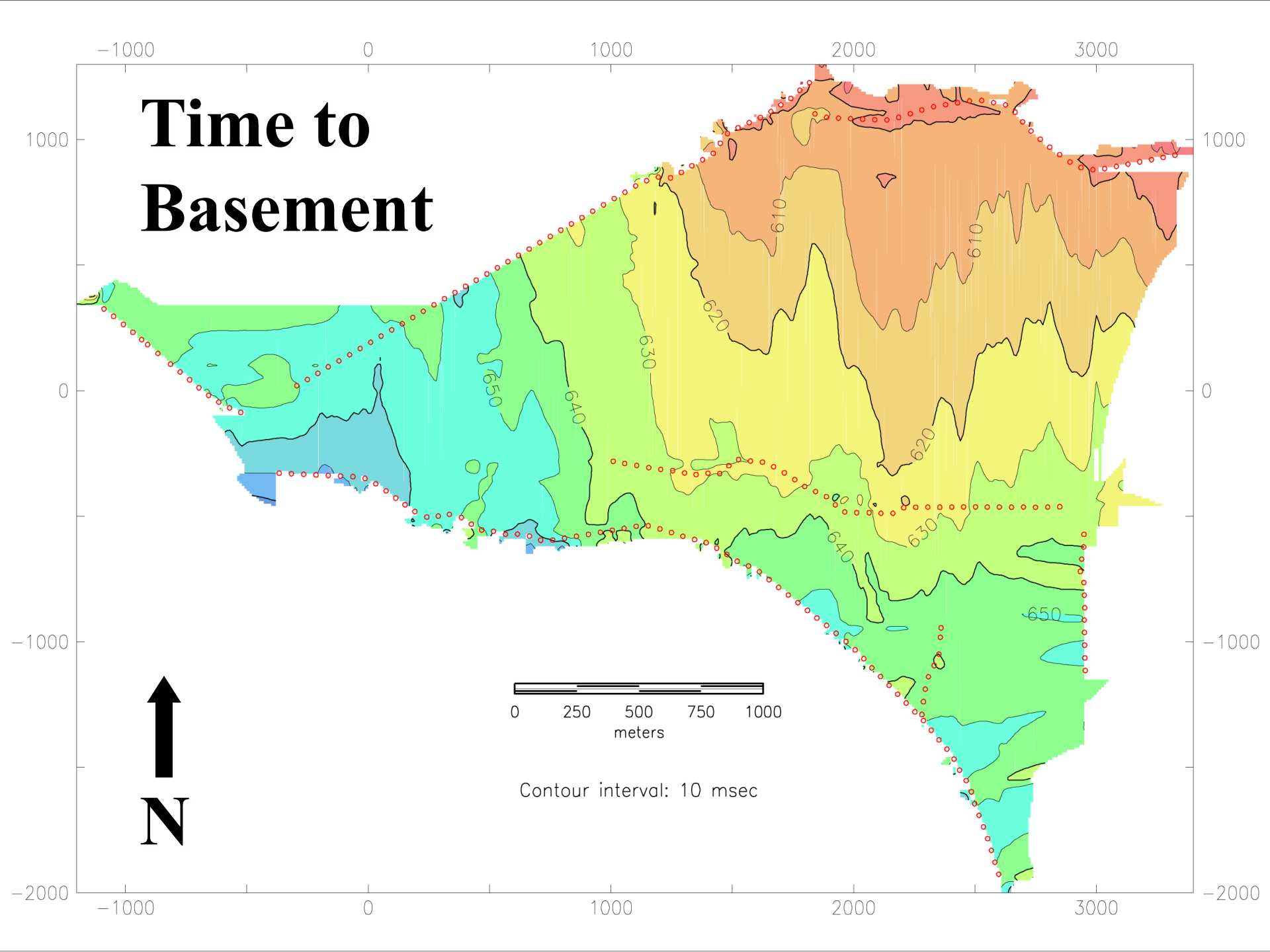


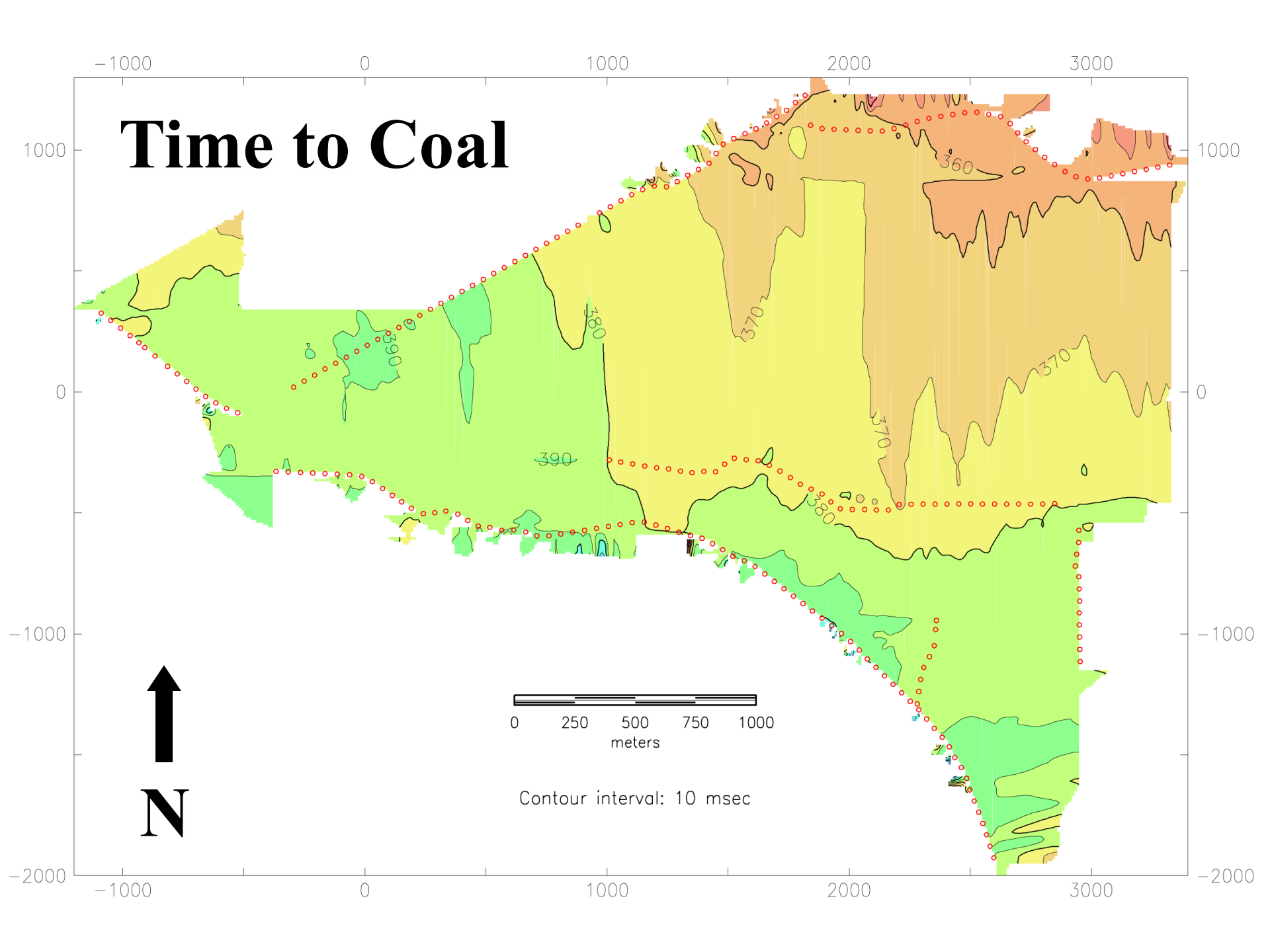
50 m

Line 5 Amplitude Analysis

Time ms

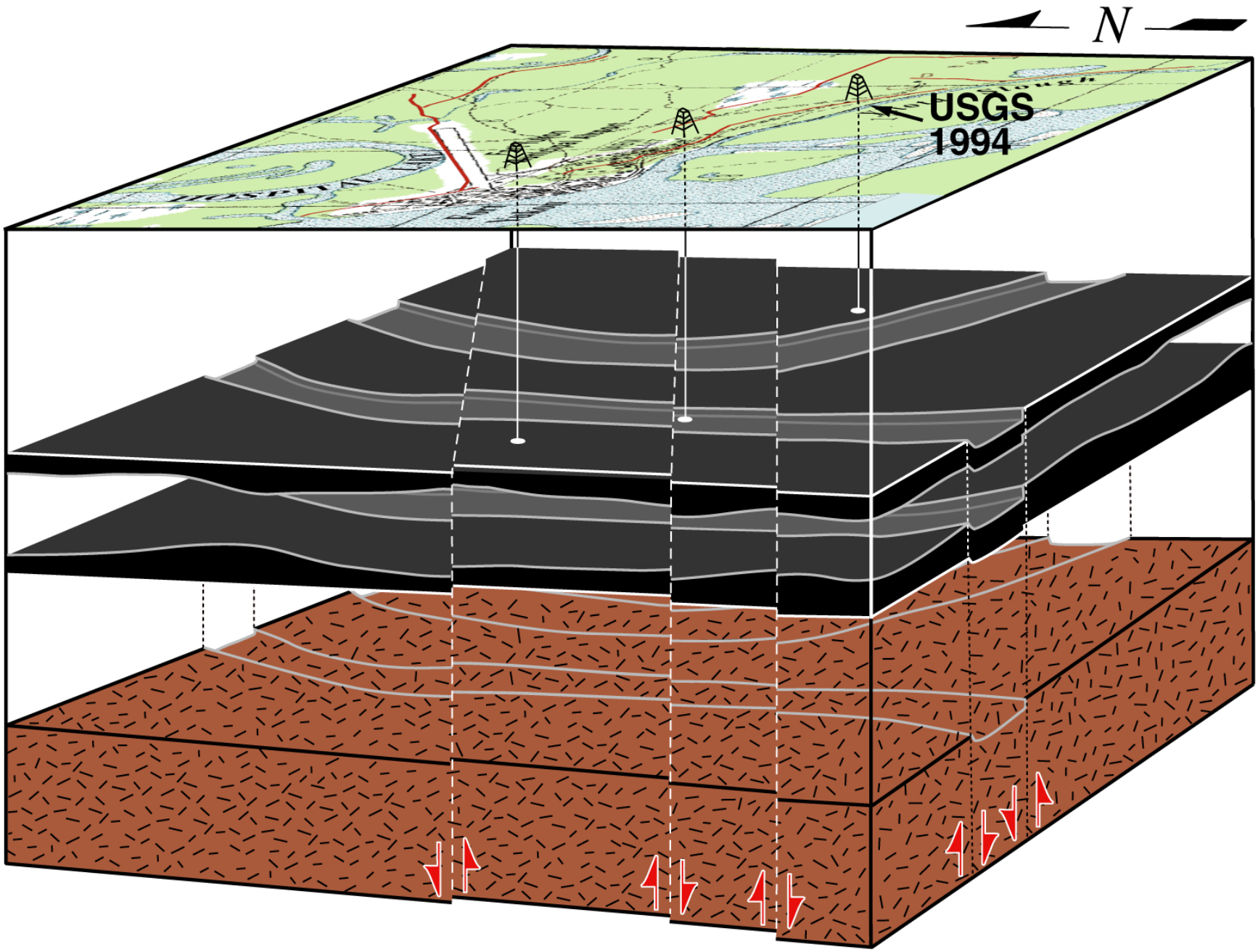



Time to Basement
−1000
0
1000
2000
3000
1000
0
−1000
−2000
610
620
630
640
650
N
0 250 500 750 1000
meters
Contour interval: 10 msec


Time to Coal
−1000
0
1000
2000
3000
1000
0
−1000
−2000
360
370
380
390
370
370
380
390
N
0
250
500
750
1000
meters
Contour interval: 10 msec

Conclusions/Findings

- **391 m coal bed appears continuous in study area**
- **391 m coal bed is between 15 and 20 m thick**
- Small displacement faults (< 5 m) interpreted in several places within the study area
- No major faults (offsets > 10 m)
- Highly reflective interval > 100 m thick, possessing a large # of reflections w/ characteristics consistent w/ the 391 m coal reflection
- Basement generally dips to the southwest at about 2°
- Reflection frequencies over 200 Hz recorded from depths over 400 m. Dominant frequencies average around 150 Hz
- Reflections within the coal interval can be correlated around the 4 km^2 study area


N
USGS
1994

Bonus: High School Science Class

- Fort Yukon High School Science class (Junior & Senior level) invited us to give:
  - an overview of the local geology and CBM
  - a demonstration of the seismic technology and a discussion of the objectives of our study

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- Funding provided: State of Alaska and US Dept. of Energy
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  - Mitch Fiedler, Chad Gratten, David Laflen, and Chris Tapie (KGS)
  - Valerie Webb, Paige Peapples (AGGS)