UNIVERSITY OF CALGARY

CREWES

Borehole geophone repeatability experiment

Peter Gagliardi

Don C. Lawton

Outline

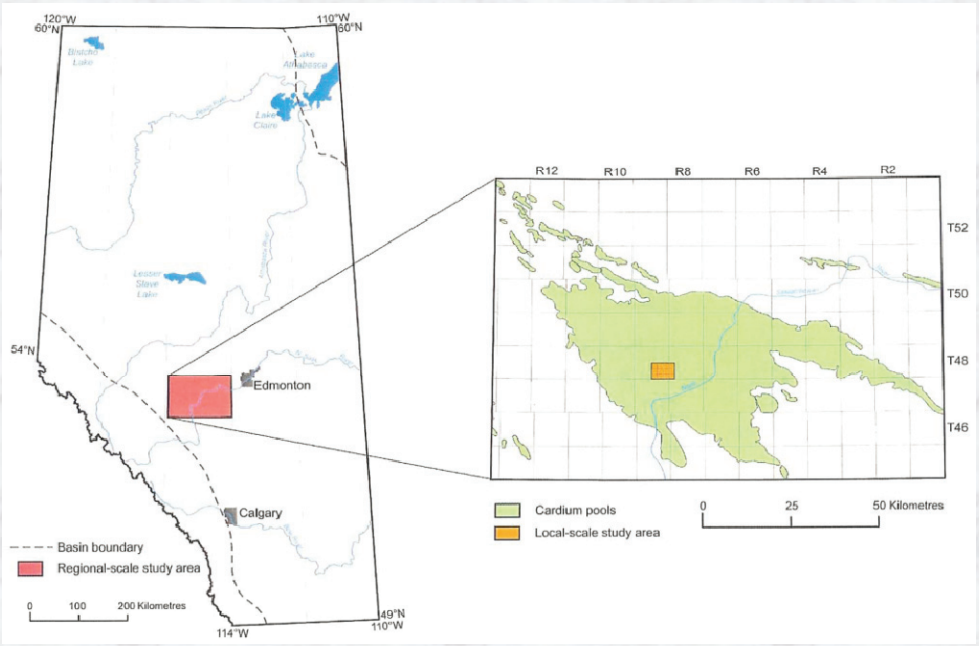
- Background and Study Area
- Orientation Azimuths
  - Survey consistency
  - Time-lapse differencing
- Repeatability
- Conclusions
- Acknowledgements

Objectives of Study

- Determine consistency of geophone orientation azimuths
- Determine repeatability of raw data
- Relate parameters to visual consistency of the raw data

Pembina CO_2-EOR – VSP

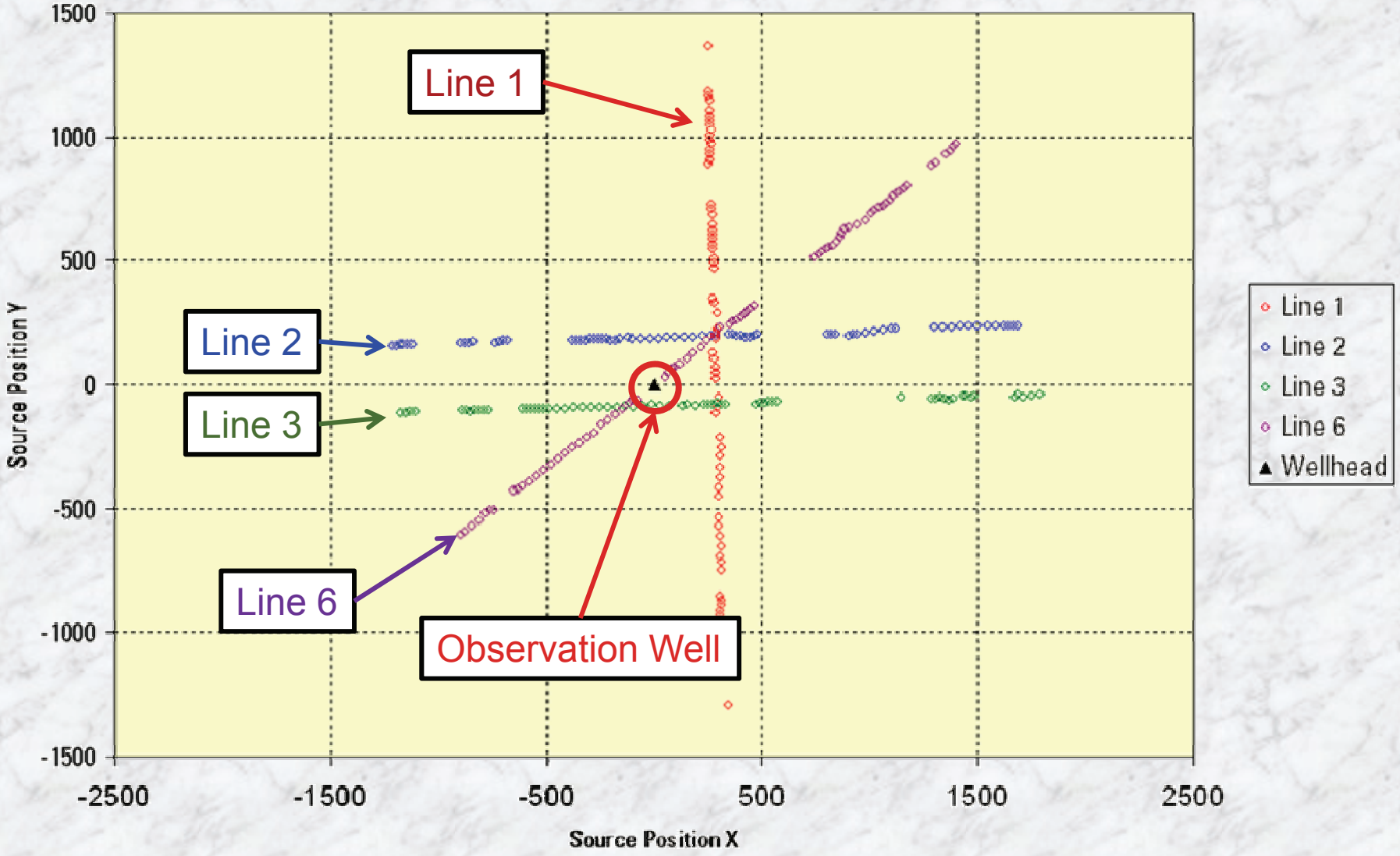
- 8 3-C receivers, cemented into place
- Placed every 20 m from 1500 – 1640 m
- Phase I in 2005, Phase III in 2007
- > 40,000 tons CO_2 injected by Phase III



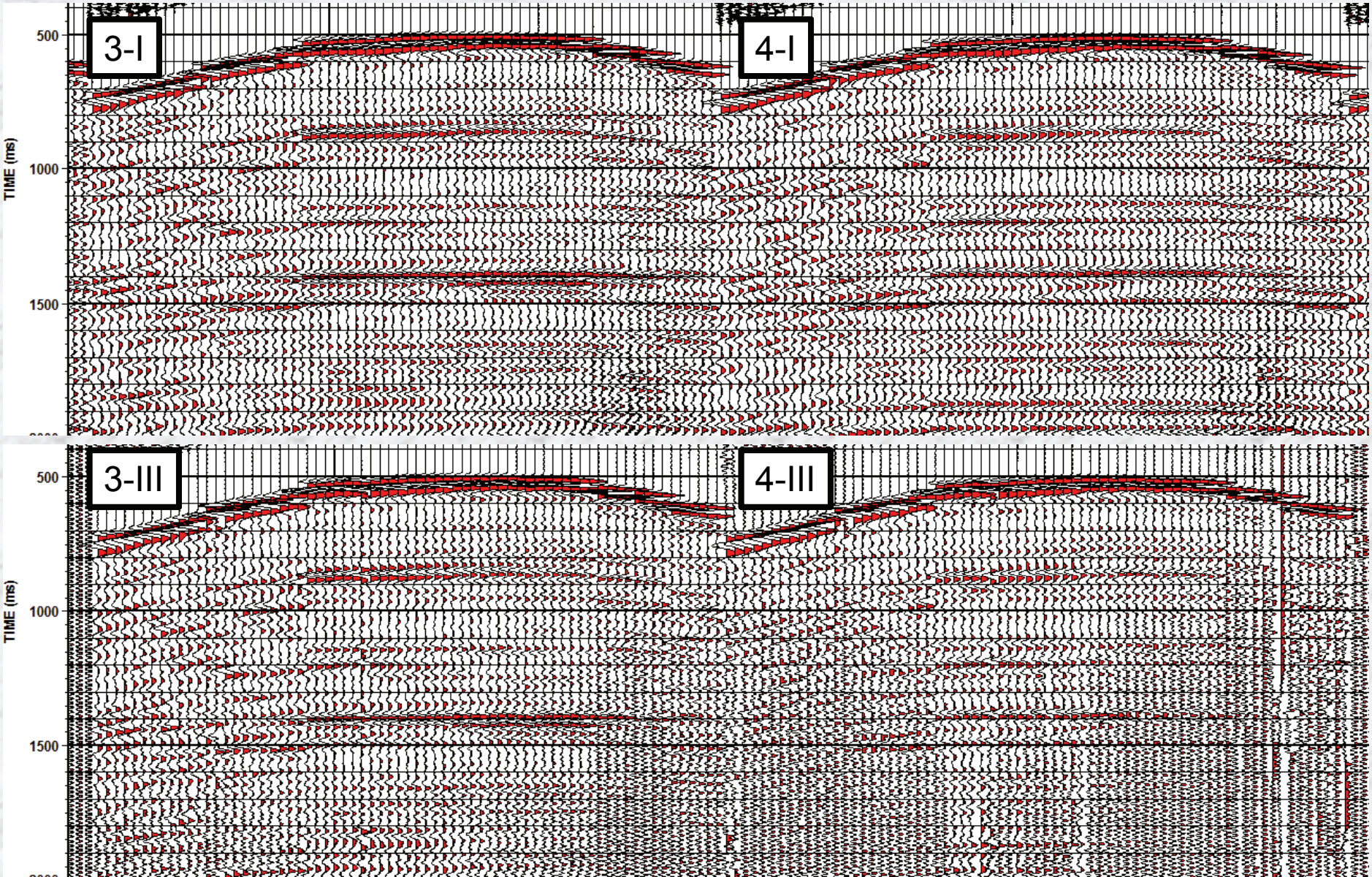
From Dashtgard et al. (2006)

Suggested reading: Hitchon (2009)

Survey Geometry



Common Receiver Gathers (Line 2, Z)



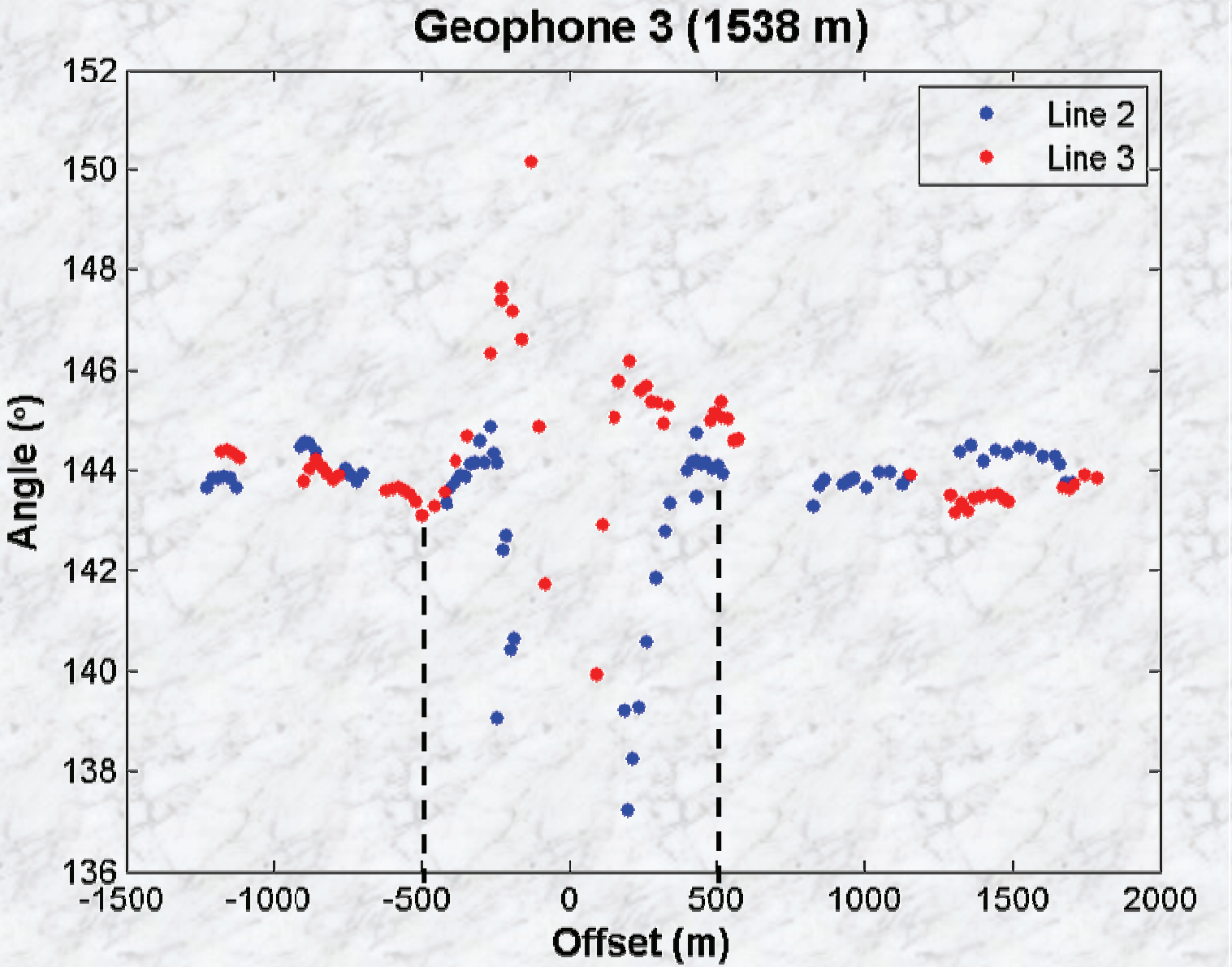
Azimuth Calculations - Method

- The equation used to calculate rotation azimuths (DiSiena et al., 1984) was

$$\tan 2\theta = \frac{2X \otimes Y}{X \otimes X - Y \otimes Y}.$$

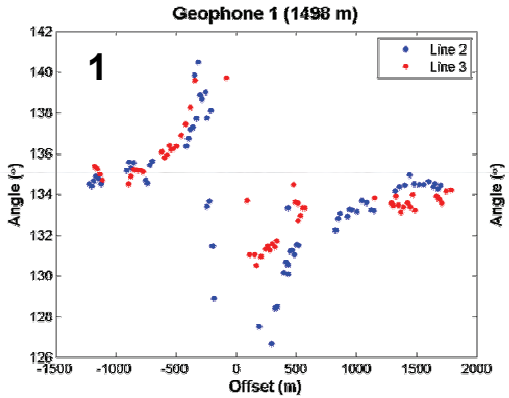
- $\otimes$ is a zero lag cross-correlation
- *X* and *Y* are the windowed data (100 ms)
- θ is the calculated azimuth

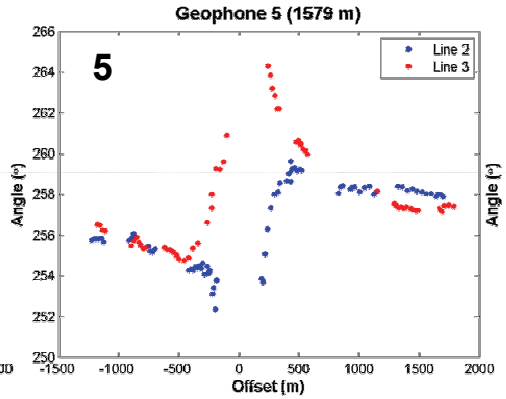
Orientation Azimuths vs. Source Offset

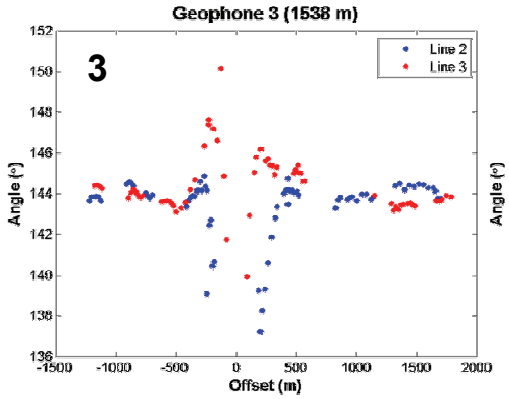


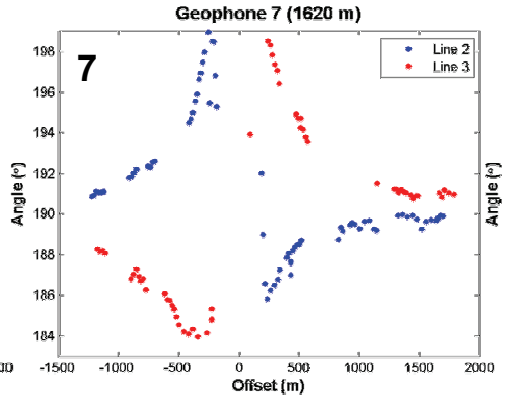
Orientation Azimuths vs. Source Offset

Phase I

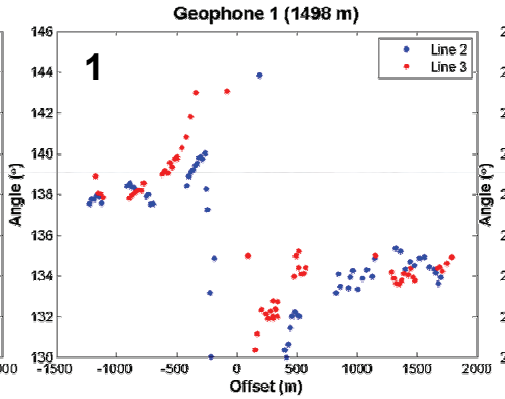


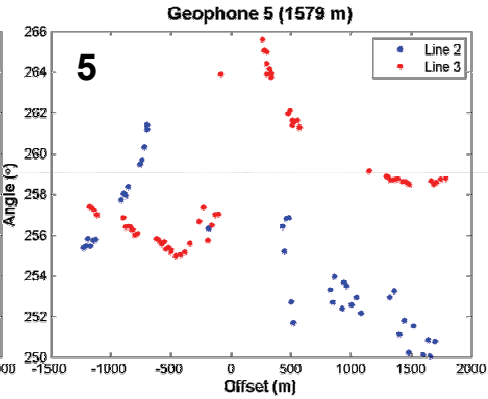


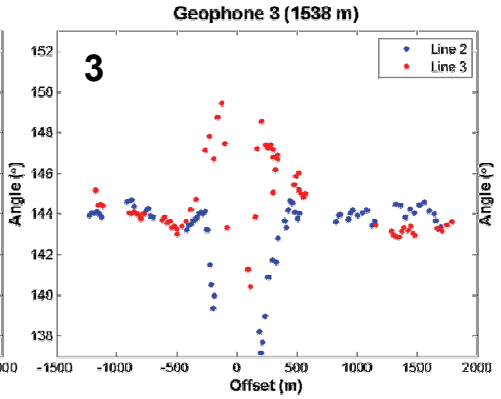


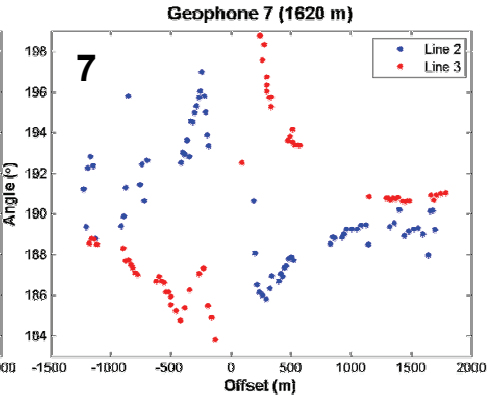


Phase III

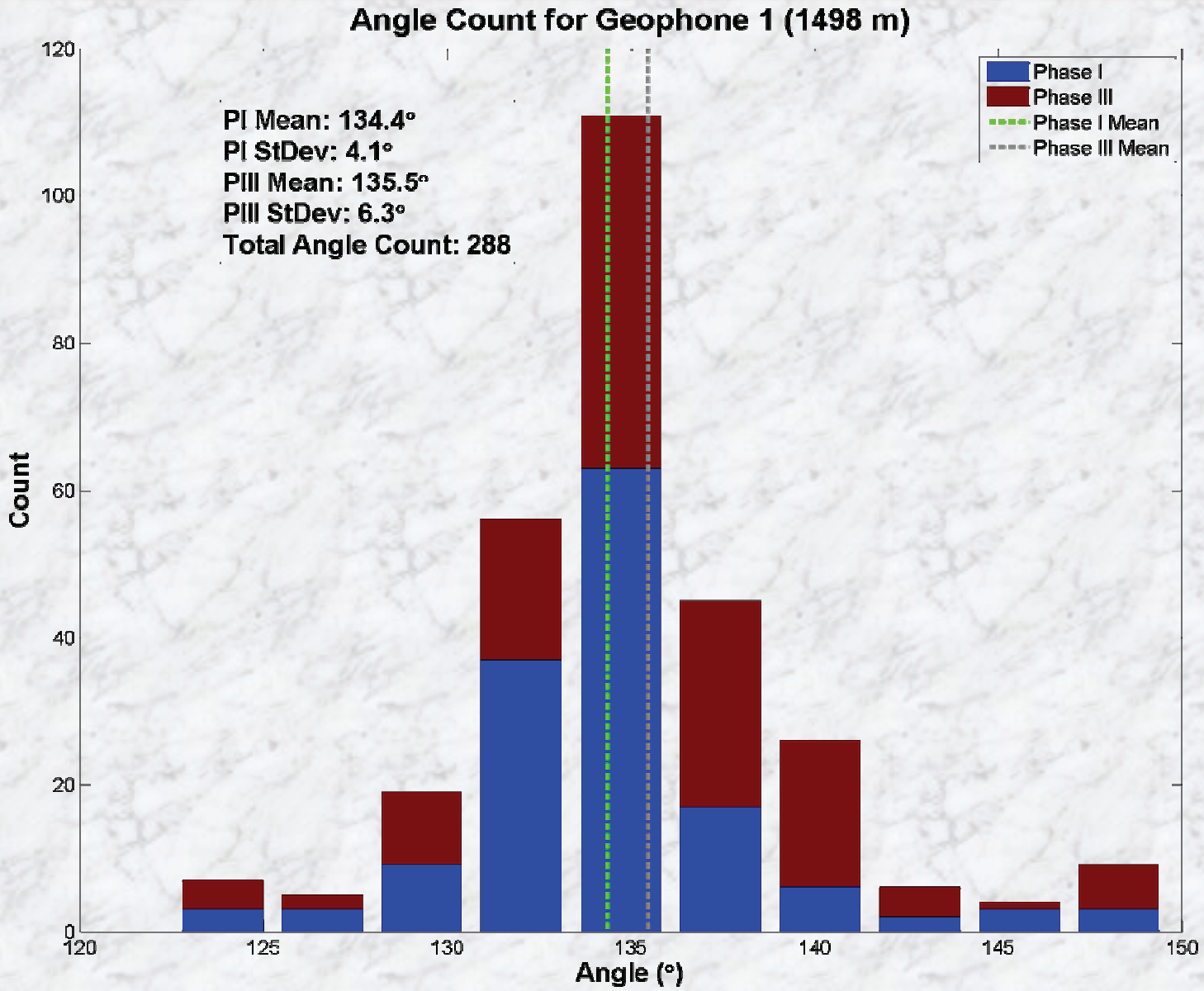




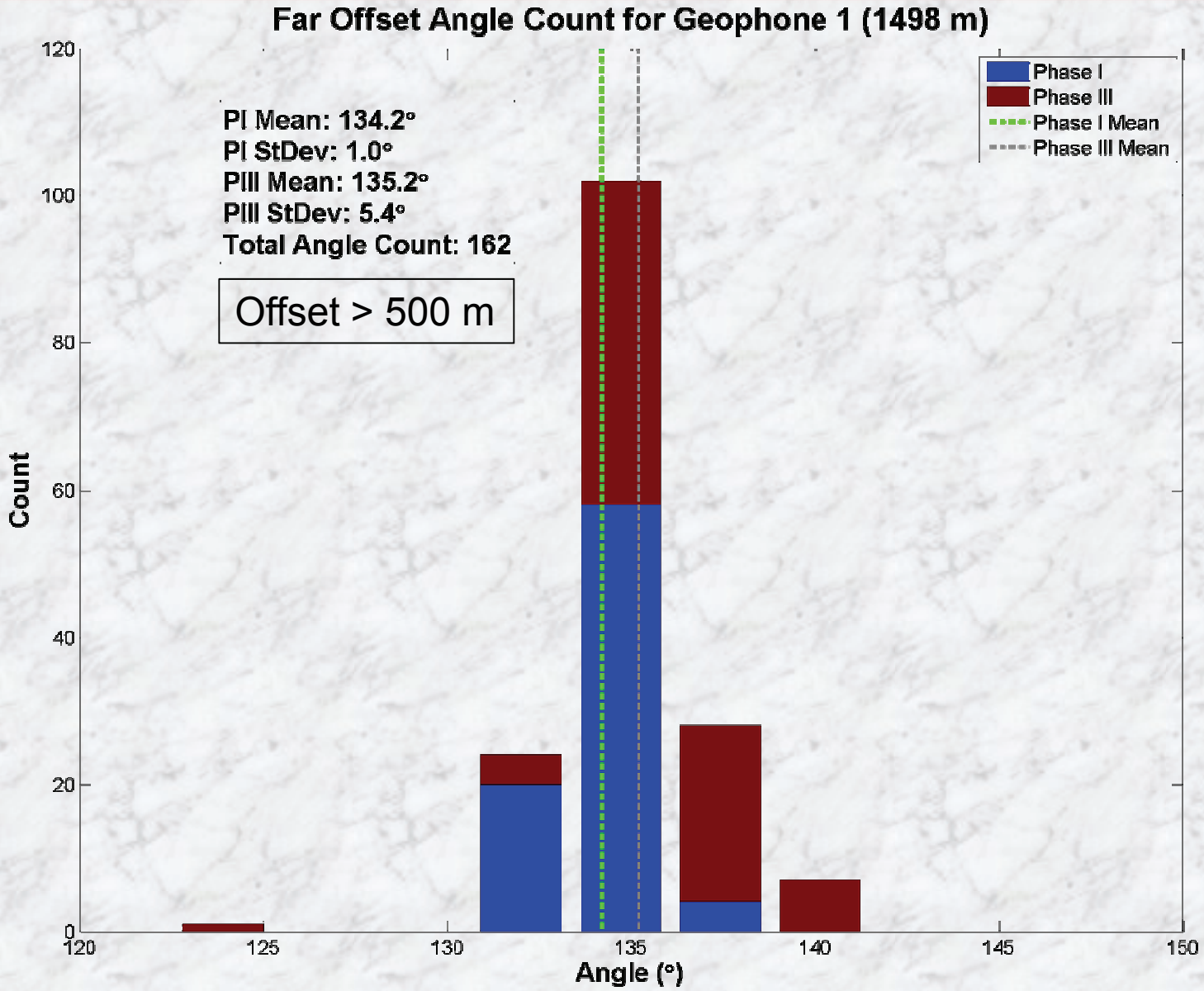




Geophone Azimuth Histograms



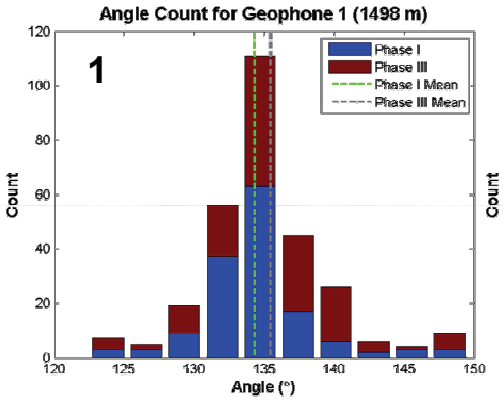
Geophone Azimuth Histograms

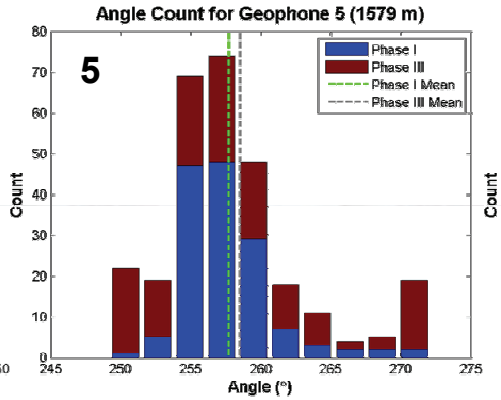


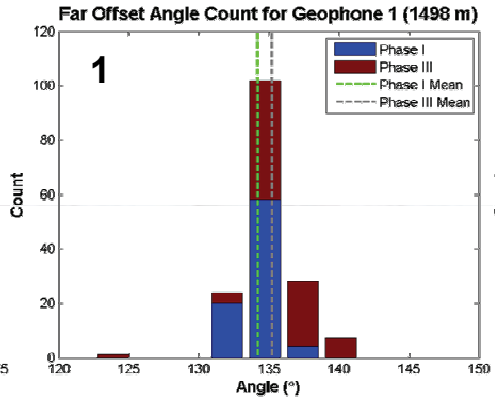
Geophone Azimuth Histograms

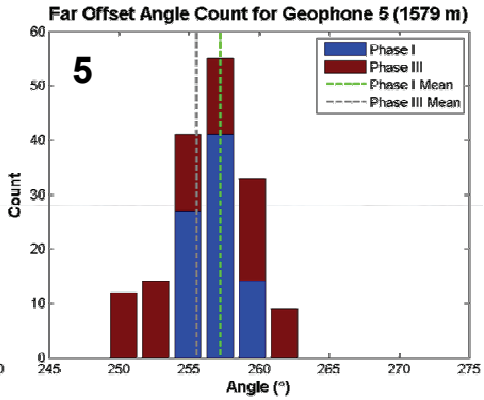
All Offsets

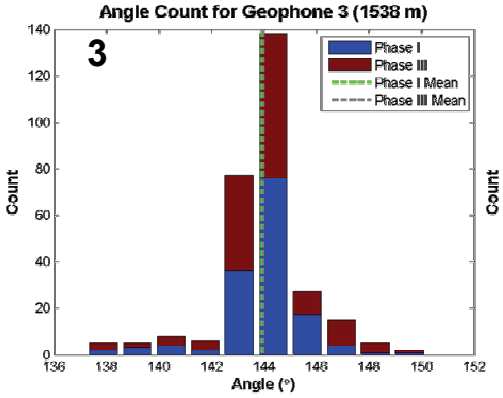
Far Offsets

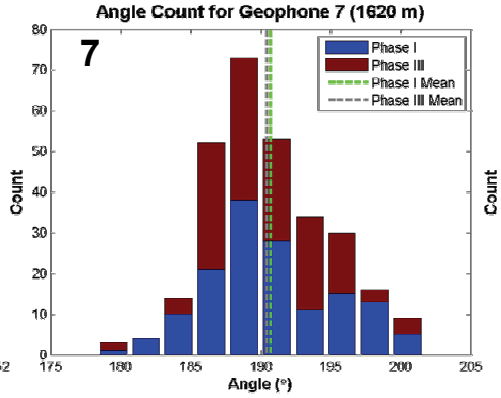


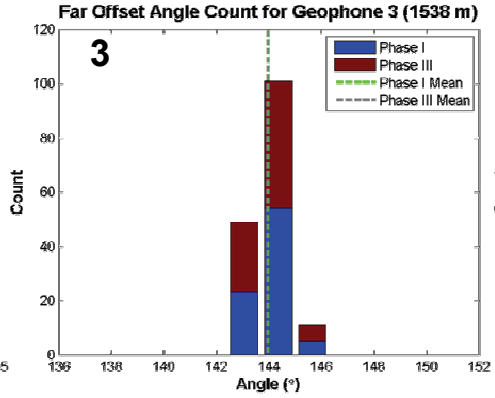


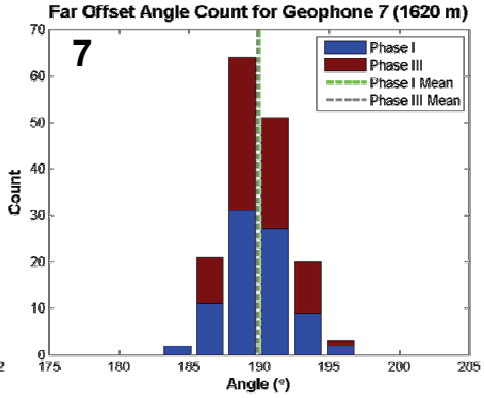












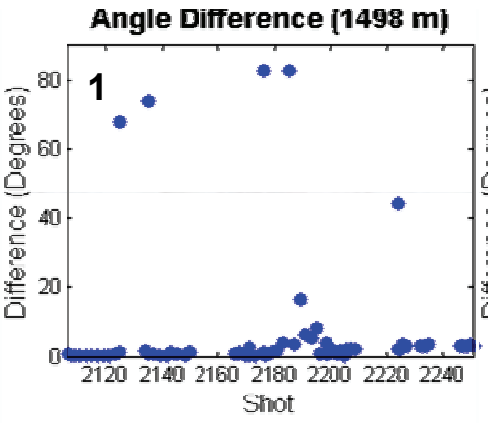
Offset > ~1/3 Receiver Depth

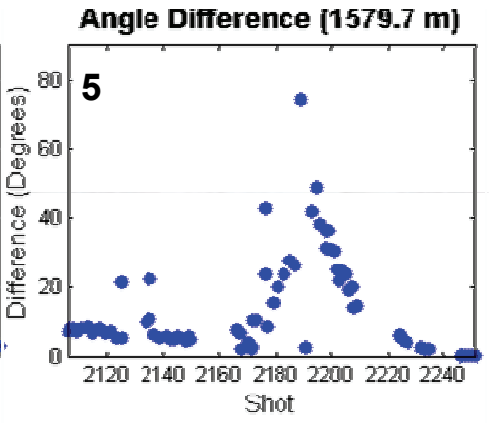
Offset > 500 m

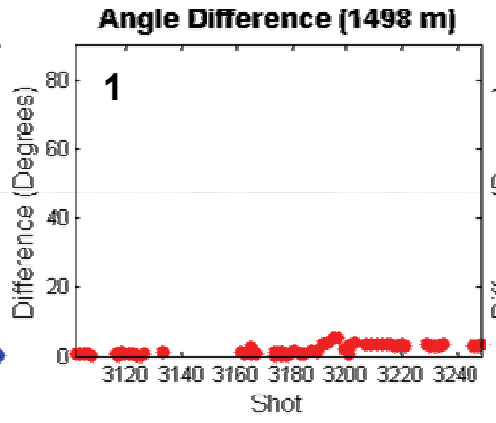
Orientation Azimuth Differences

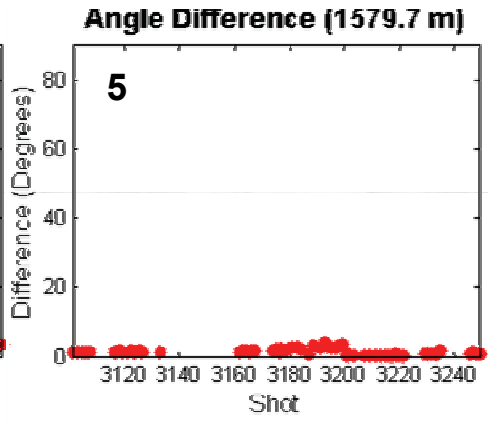
Line 2

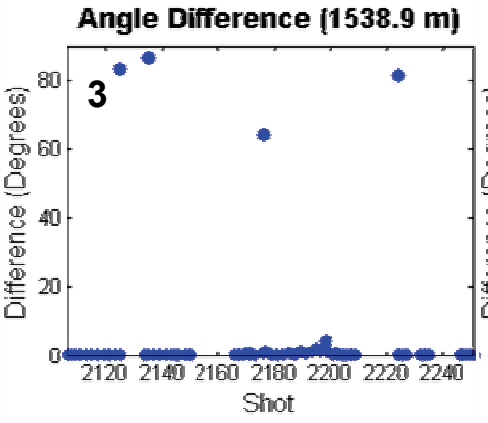
Line 3

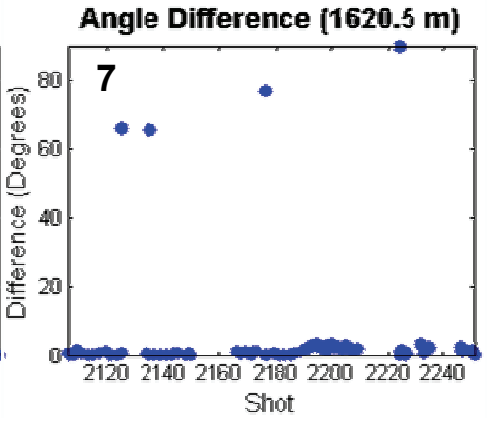


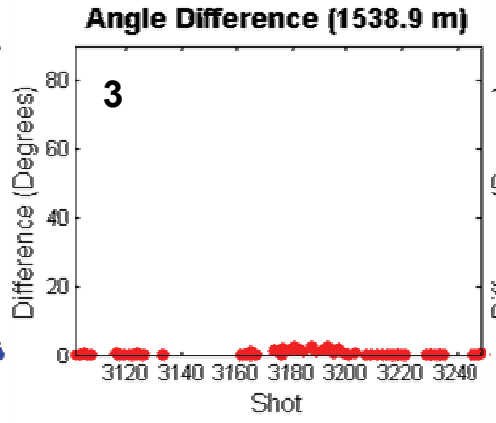


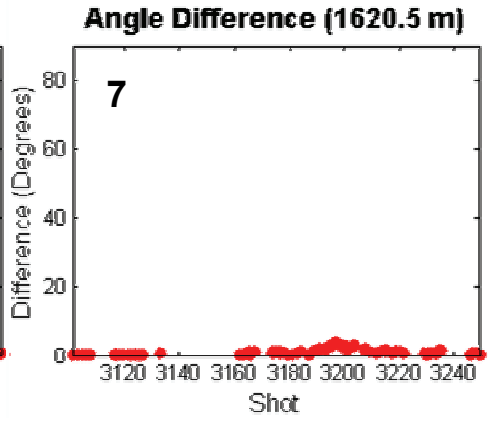












Repeatability – Methods

- Nrms is given as (Kragh and Christie, 2002)

$$NRMS = \frac{200 \times RMS(a_t - b_t)}{RMS(a_t) + RMS(b_t)}.$$

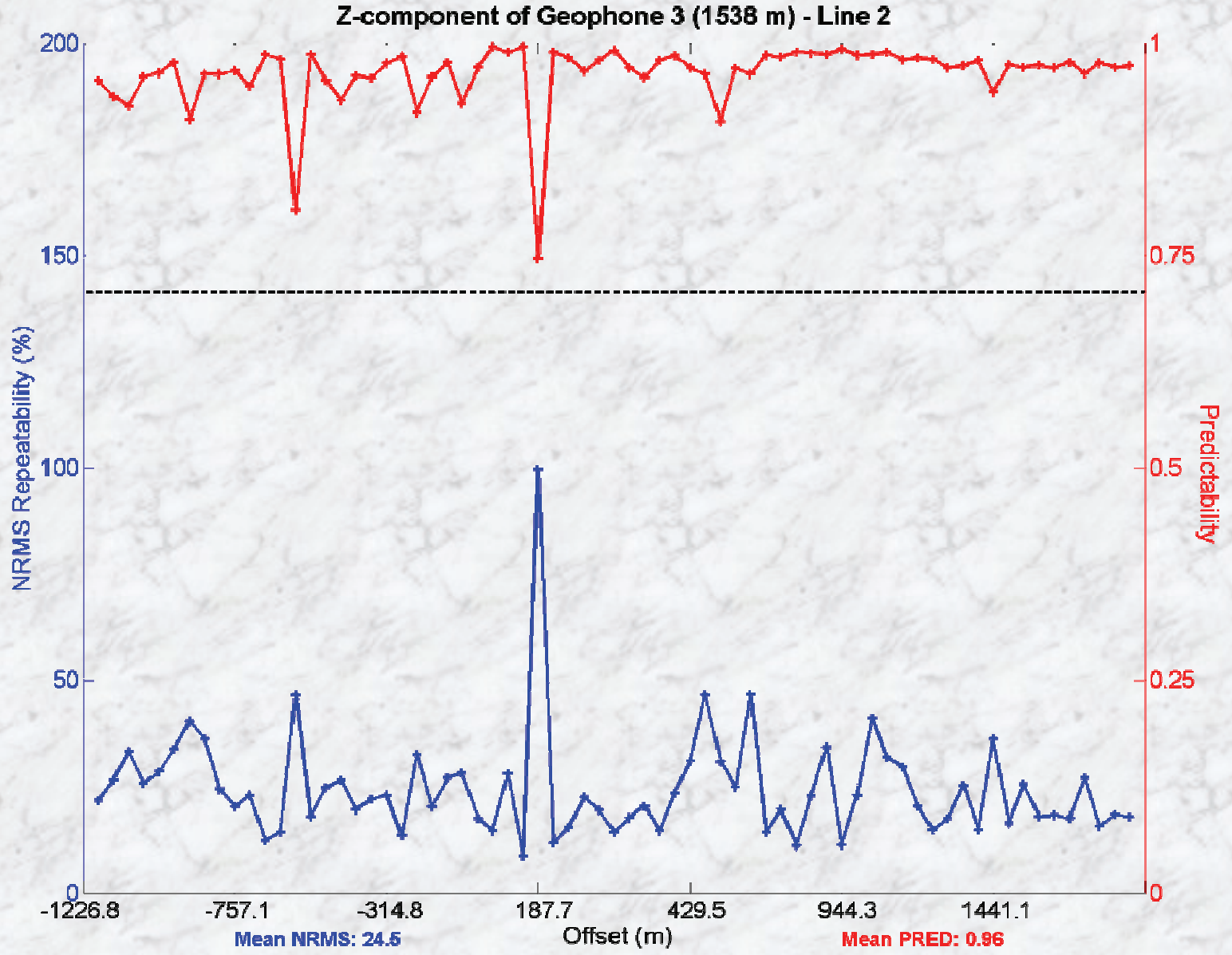
$$RMS(x_t) = \sqrt{\frac{\sum_{t_1}^{t_2} x_t^2}{N}}$$

- Predictability is given as (Kragh and Christie, 2002)

$$PRED = \frac{\sum_{t_1}^{t_2} \Phi_{ab}(\tau) \times \Phi_{ab}(\tau)}{\sum_{t_1}^{t_2} \Phi_{aa}(\tau) \times \Phi_{bb}(\tau)}.$$

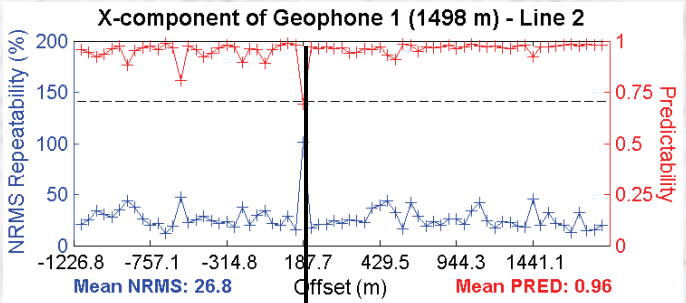
- Φ represents a cross-correlation (zero-lag)
- *a* and *b* are the two traces being compared
- t_1 and t_2 represent time window (whole trace)

NRMS and PRED: Line 2



NRMS and PRED: Line 2

1



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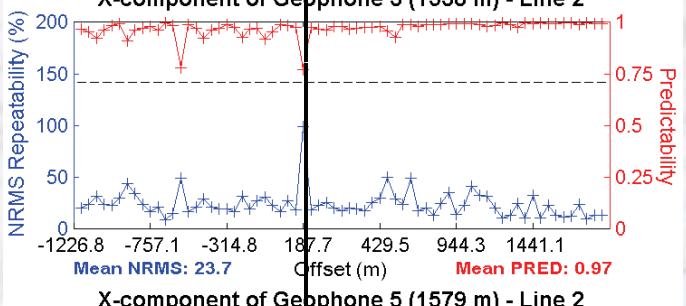

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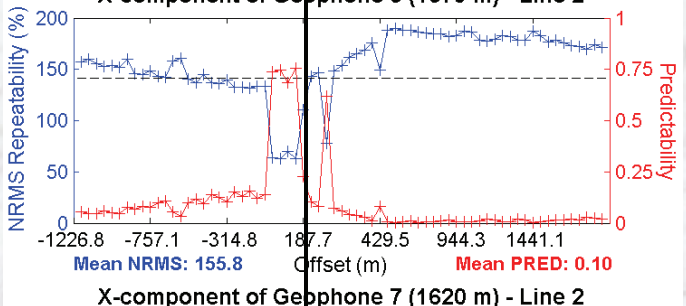

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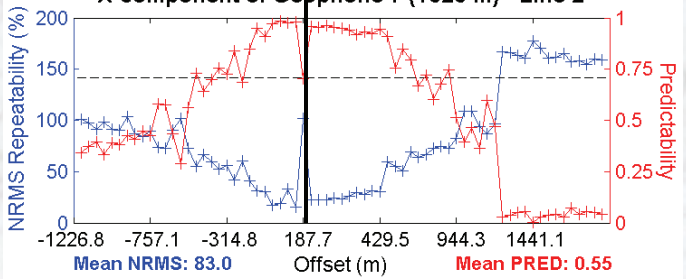
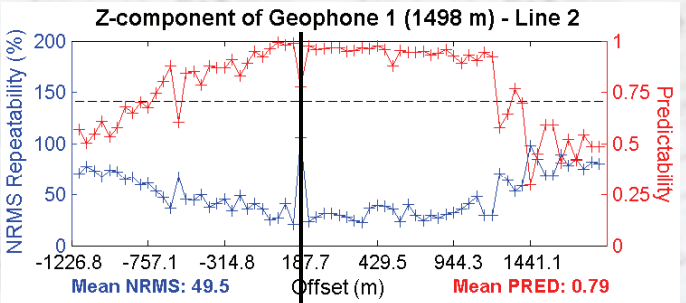


1



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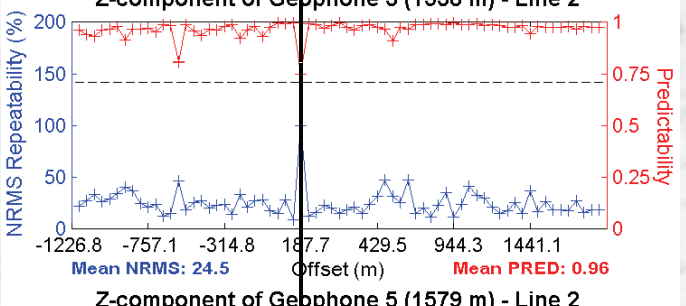

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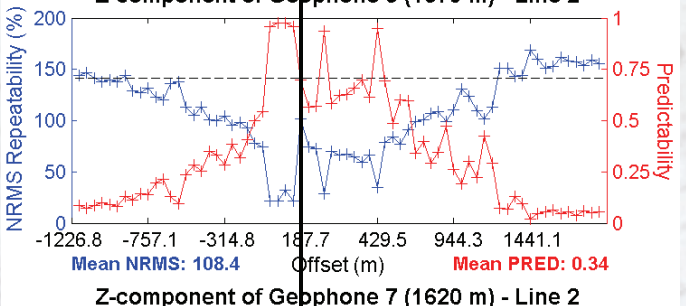

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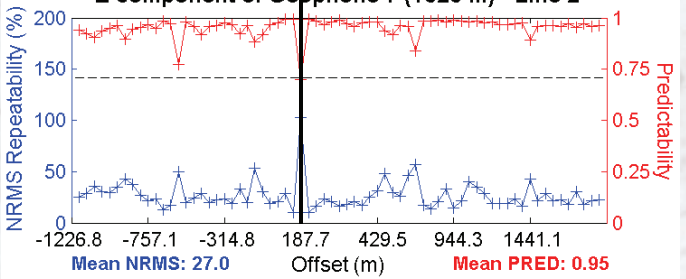
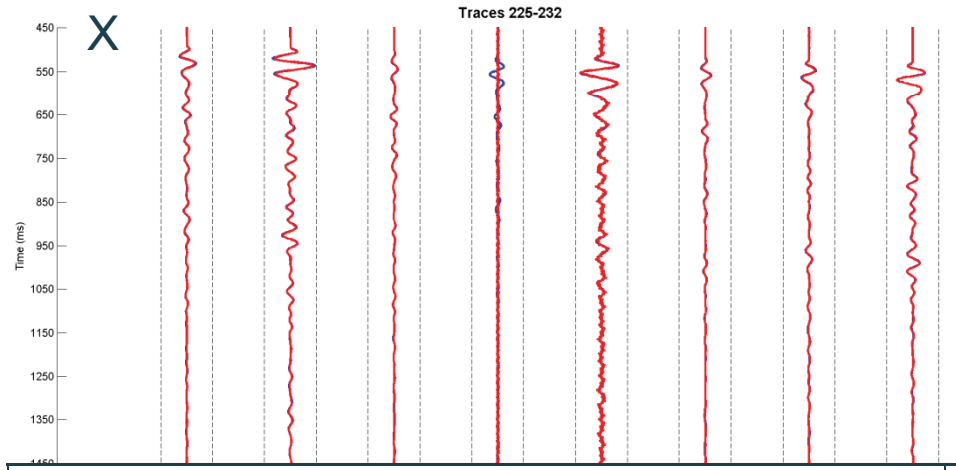


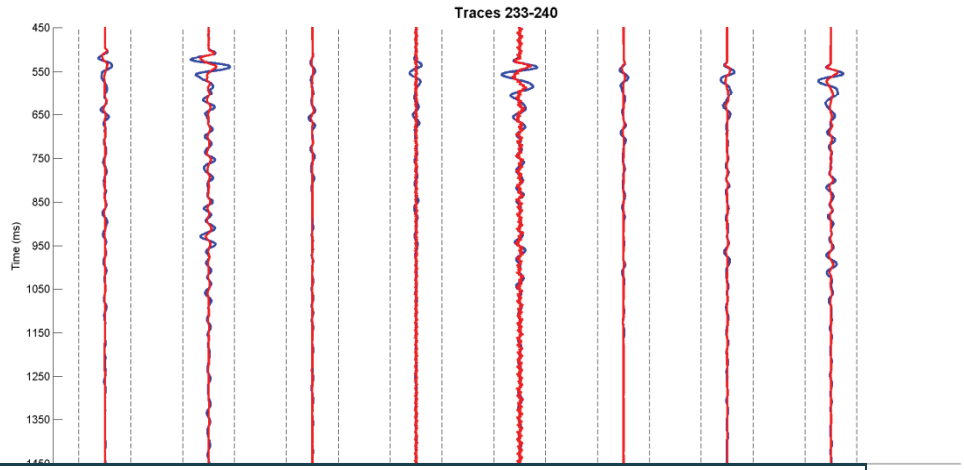
Shot 2171 and 2172

Phase I
Phase III

X

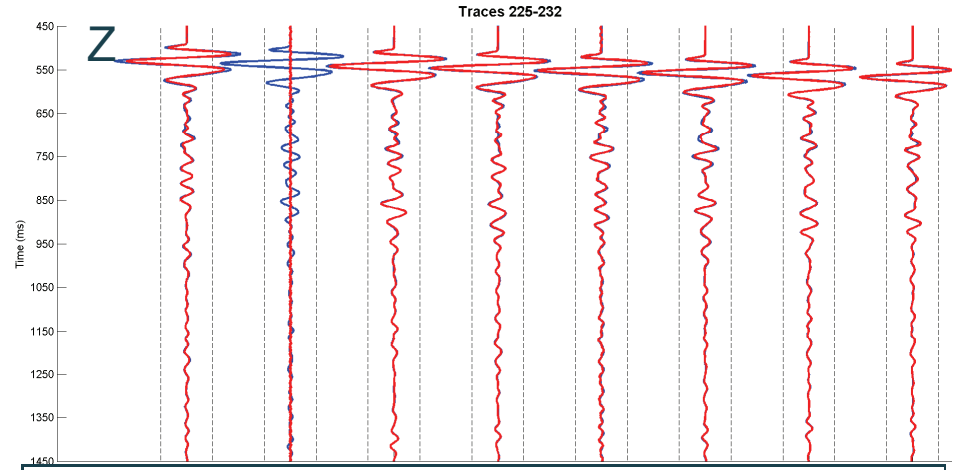


NRMS	15.4	10.5	17.6	141.4	63.0	18.3	15.6	10.7
PRED	0.98	0.99	0.97	0.00	0.76	0.98	0.98	0.99

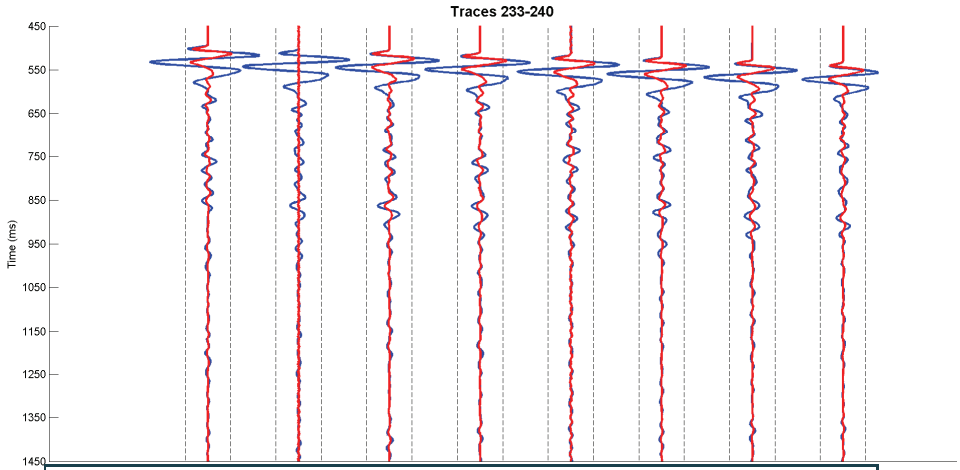


NRMS	101.7	99.3	98.8	141.9	110.9	102.6	101.5	96.1
PRED	0.69	0.80	0.77	0.00	0.23	0.76	0.70	0.74

Z



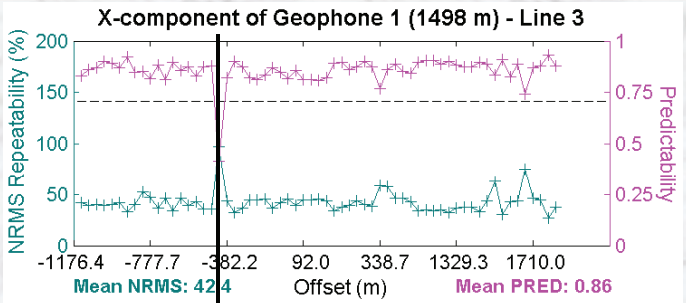
NRMS	20.3	180.5	8.7	11.7	21.7	19.4	9.7	14.2
PRED	0.99	0.00	1.00	0.99	0.96	0.97	0.99	0.98



NRMS	106.0	179.6	99.6	99.9	101.7	101.0	102.6	95.2
PRED	0.78	0.00	0.75	0.72	0.70	0.75	0.70	0.69

NRMS and PRED: Line 3

1



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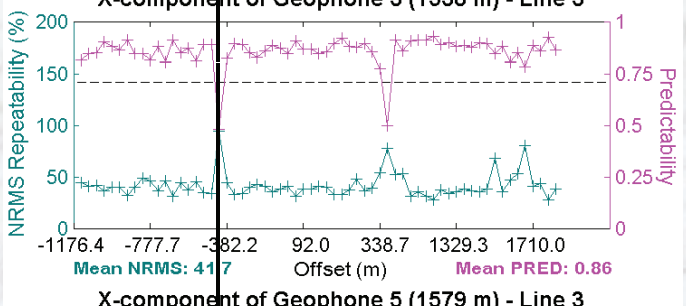

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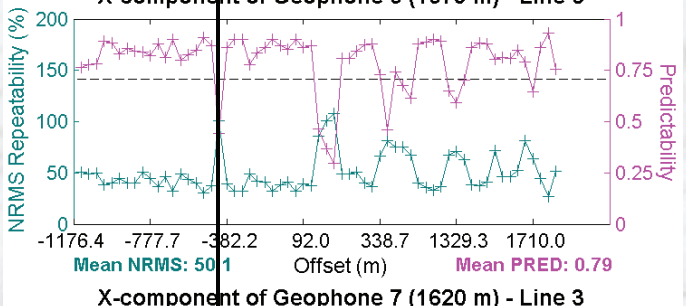

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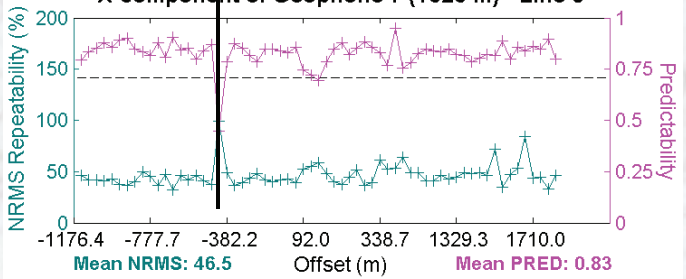
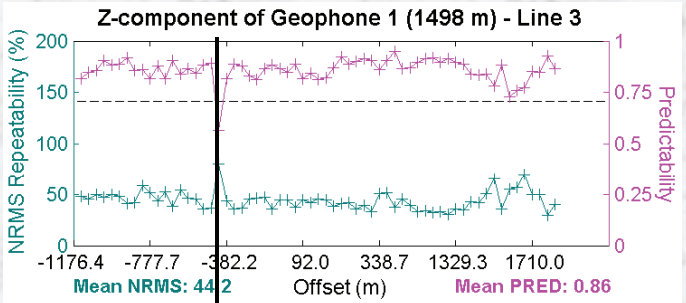


1



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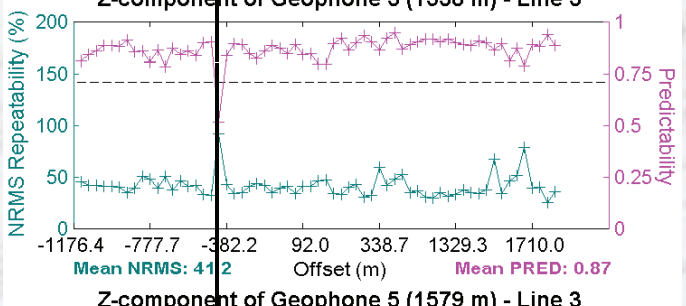

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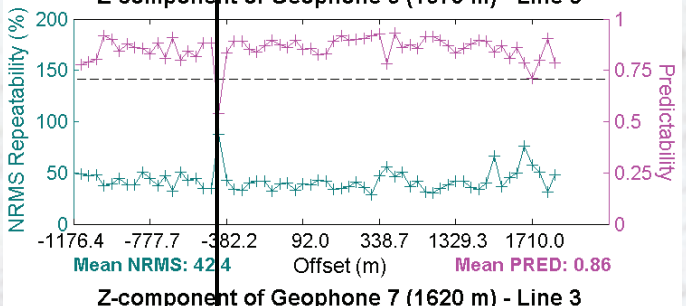

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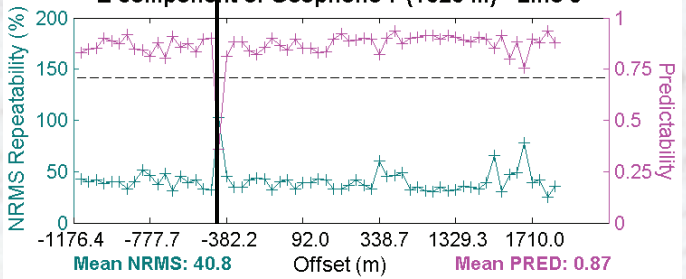
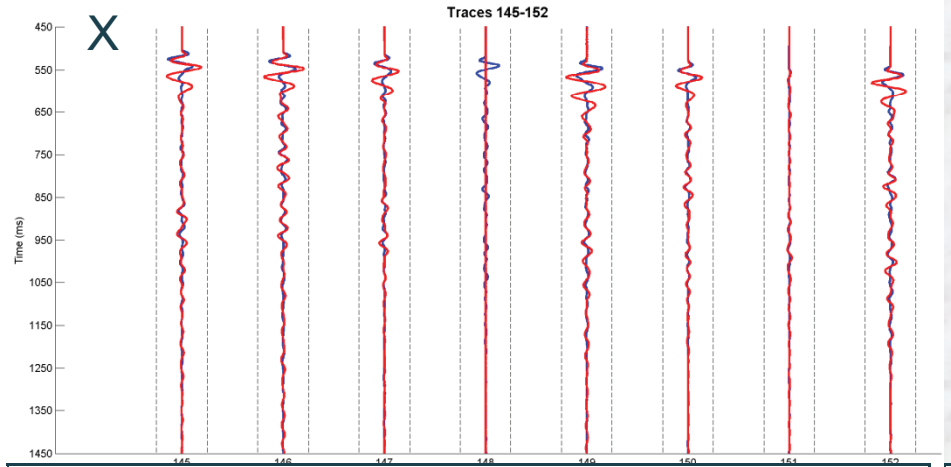


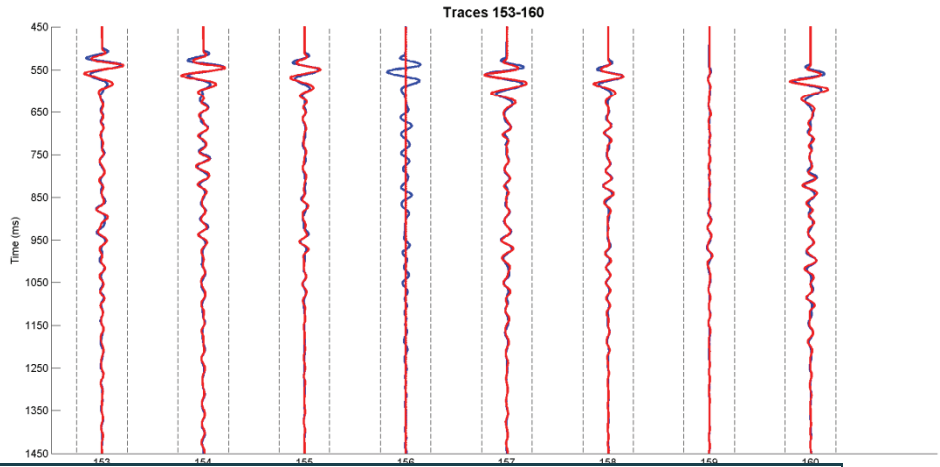
Shot 3164 and 3165

Phase I
Phase III

X

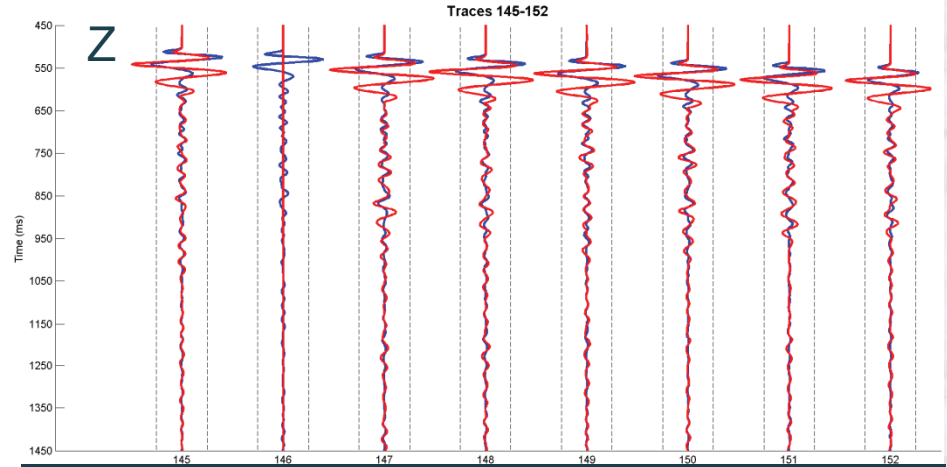


NRMS	97.0	84.2	94.1	174.2	100.9	86.0	98.8	100.3
PRED	0.42	0.60	0.48	0.00	0.44	0.56	0.45	0.43

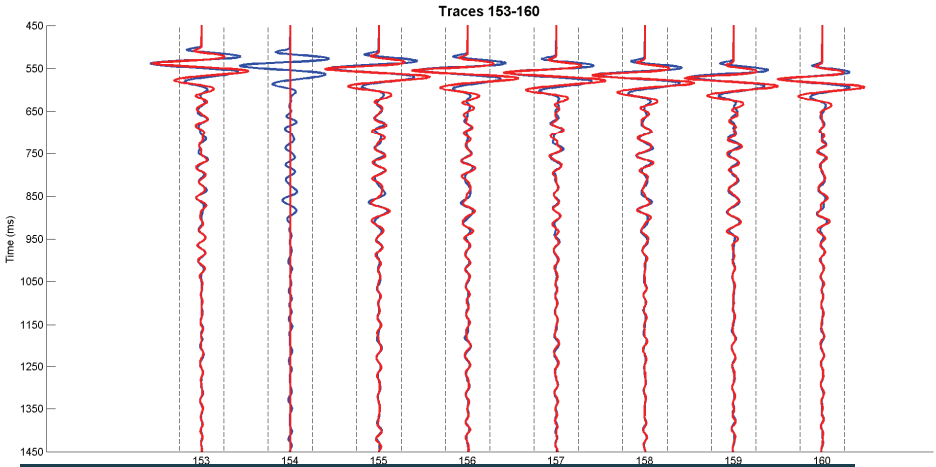


NRMS	43.9	39.3	44.6	193.2	39.0	41.8	48.5	49.2
PRED	0.82	0.86	0.82	0.00	0.86	0.84	0.79	0.79

Z

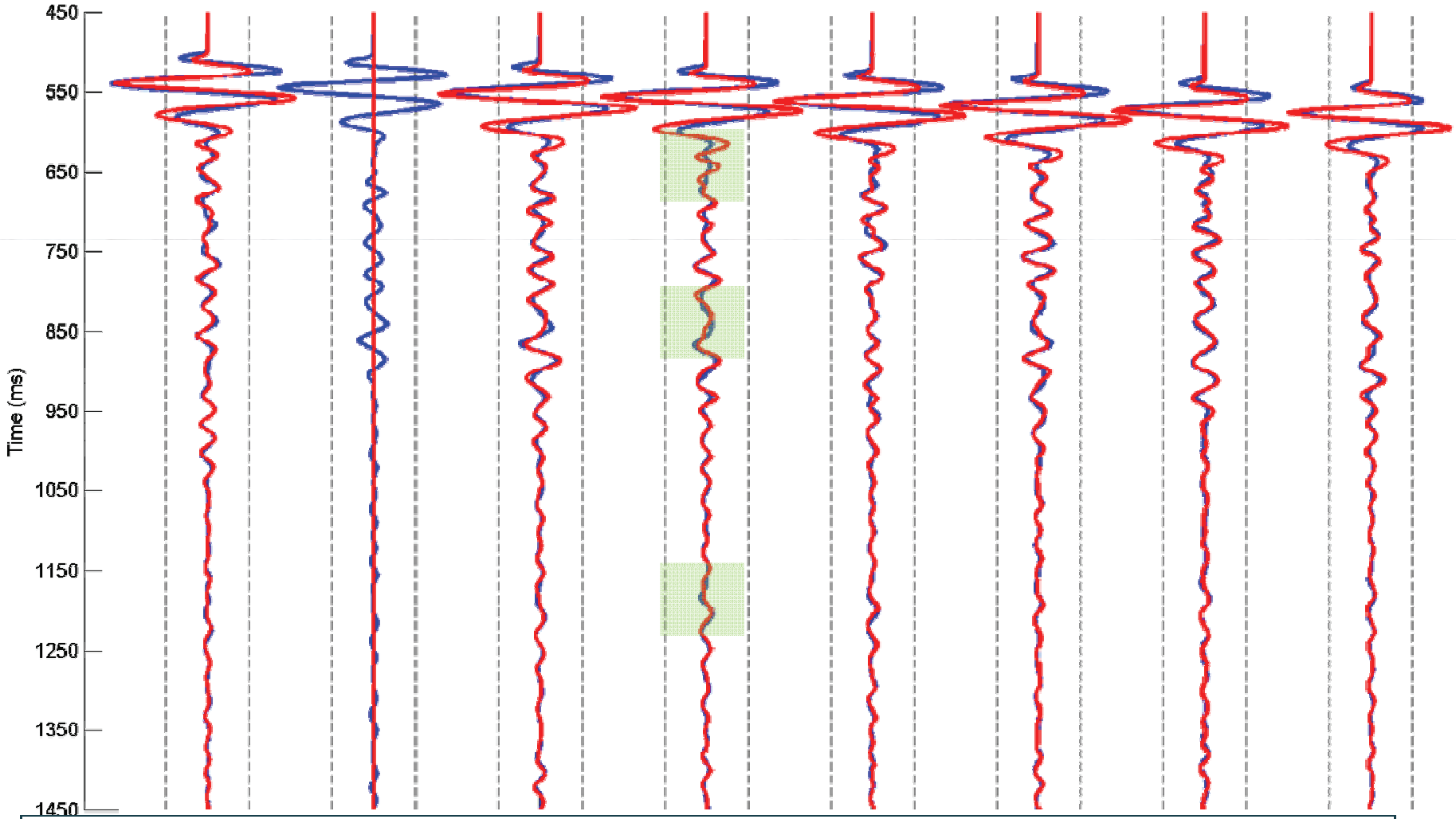


NRMS	80.5	190.7	91.8	92.2	87.9	85.2	102.2	91.6
PRED	0.56	0.00	0.52	0.49	0.54	0.57	0.36	0.59



NRMS	43.7	197.7	42.9	44.7	42.3	38.6	45.2	40.0
PRED	0.82	0.00	0.83	0.82	0.83	0.86	0.81	0.89

Shot 3164 and 3165



NRMS	43.7	197.7	42.9	44.7	42.3	38.6	45.2	40.0
PRED	0.82	0.00	0.83	0.82	0.83	0.86	0.81	0.89

Conclusions (1/2)

- NRMS values (working data):
  - 61.4% and 45.3% (horizontal)
  - 42.8% and 41.4% (vertical)
- Predictability values (working data):
  - 0.72 and 0.83 (horizontal)
  - 0.83 and 0.86 (vertical)
- Visual correlation was good between Phase I and III, but different for Line 2 and Line 3

Conclusions – (2/2)

- Strongest negative effect on repeatability due to small differences in source location and differences in noise
- Geophone orientation analysis:
  - Offsets greater than ~1/3 of receiver depth showed better consistency
  - Calculated angles very consistent between Phase I and III (54.2% and 85.9% within 2°)
- Repeatability of the raw data was found to be of medium quality

Future Work

- Recovery and analysis of Line 1 data
- Relationship between receiver depth and orientation azimuth consistency
- Re-calculating repeatability and orientation azimuth after processing
- Effect of CO_2 on repeatability
- Imaging of CO_2 using all 3 components

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