Passive icemology: Fracture and model characterization using microseismicity

Dylan Mikesell, Kasper van Wijk, Matt M. Haney and John H. Bradford

Center for Geophysical Investigation of the Shallow Subsurface
Department of Geosciences
Boise State University, Boise, Idaho

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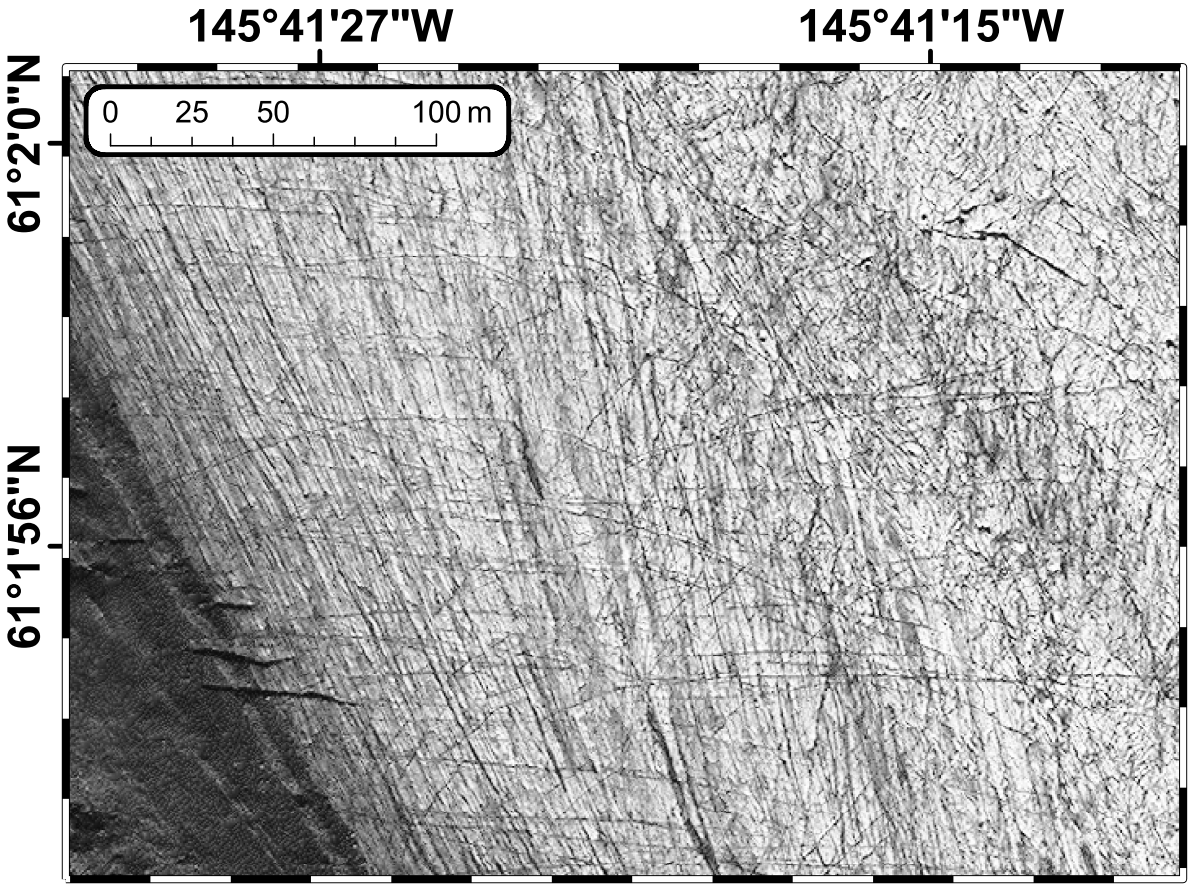
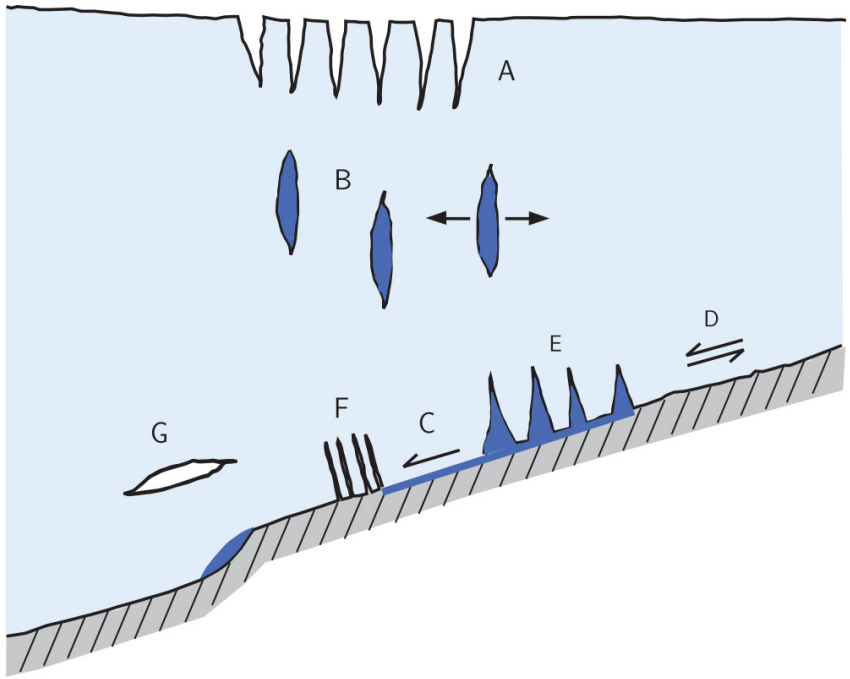
Why use glaciers for passive seismic studies?



- relatively homogeneous model
- rapid changes in stress field
- analog for hydrofracturing

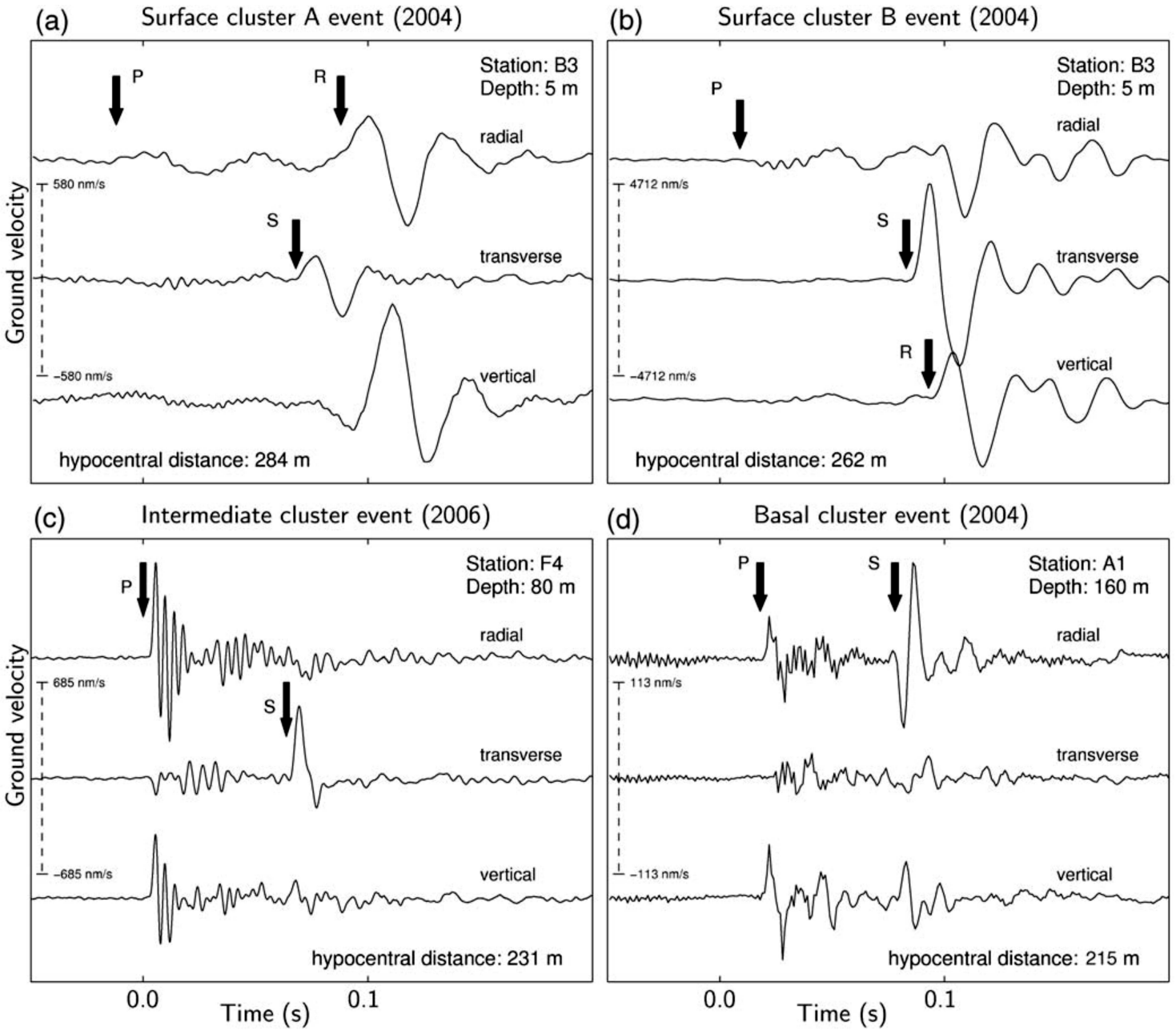
Glacier processes have unique se*ice*mic signatures

- Crevassing (A)
- Fluid driven fracture (B,E)
- Basal sliding (D)
- Calving

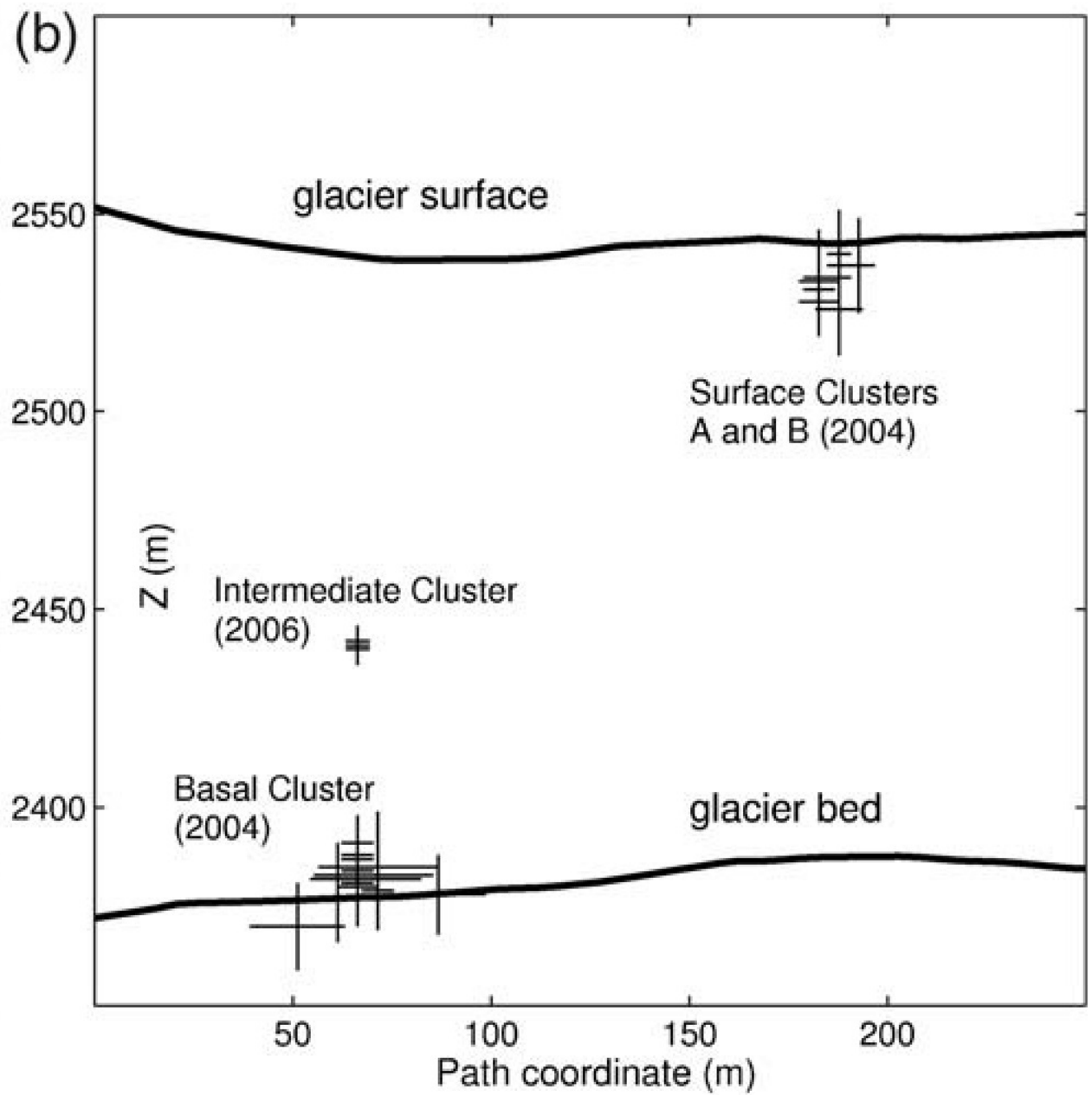


(Walter et al., 2010)

Icequake waveforms *(Walter et. al, 2009)*



Icequake locations *(Walter et al., 2009)*

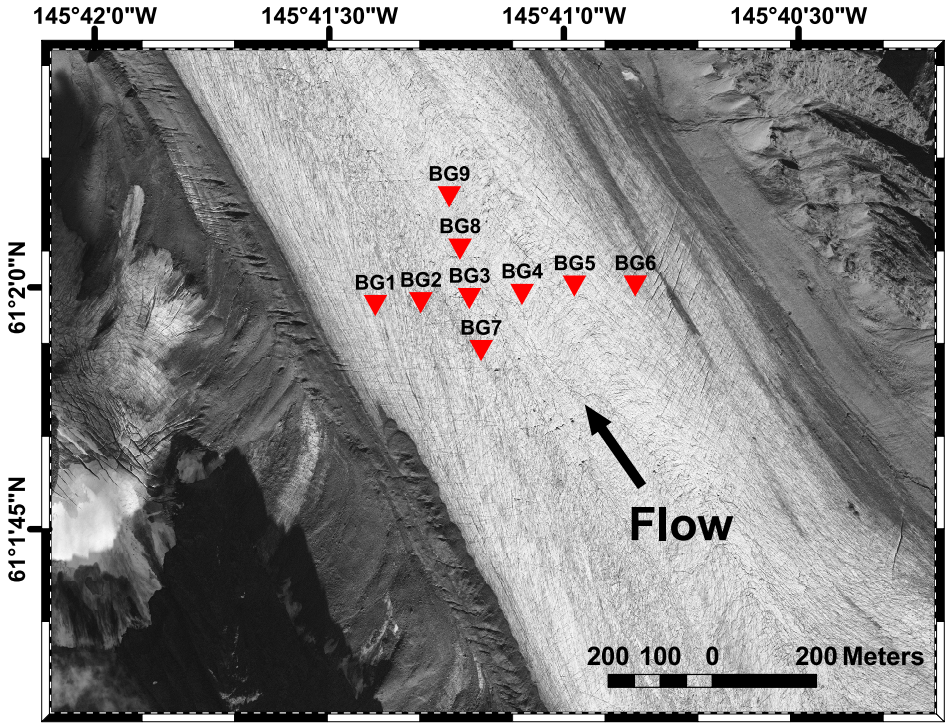


The steps forward

We want to quantify glacier **processes** and **properties**.

- Develop a local magnitude scale
- Estimate source mechanisms
- Characterize fracture distribution

2007 passive seismic network



- 9 stations
- 100 m spacing
- 250 Hz recording (5 days)

- L-28 3C sensors (4.5 Hz)
- REFTEK-130 data loggers
- GPS clocks

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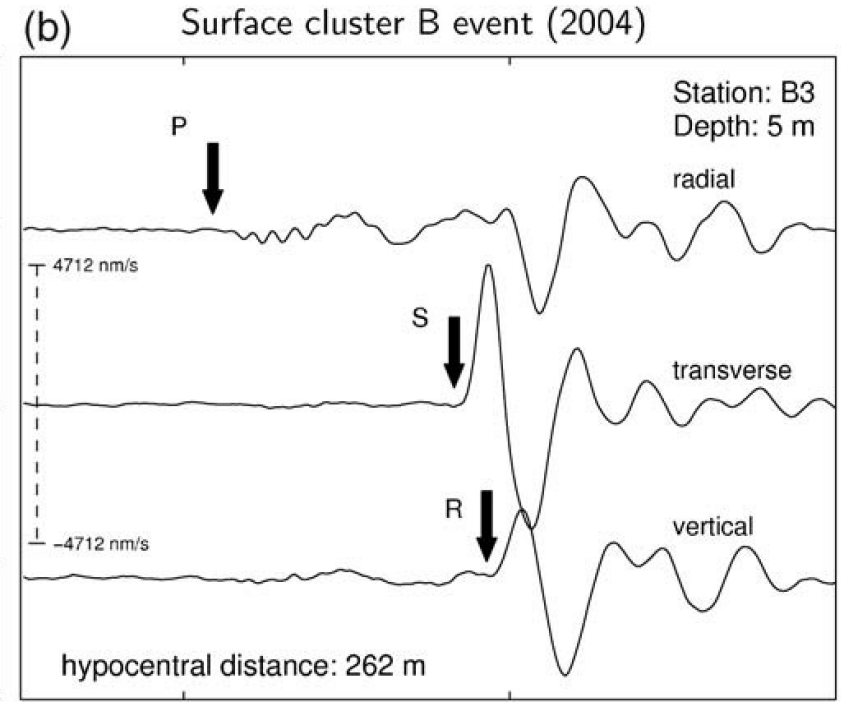
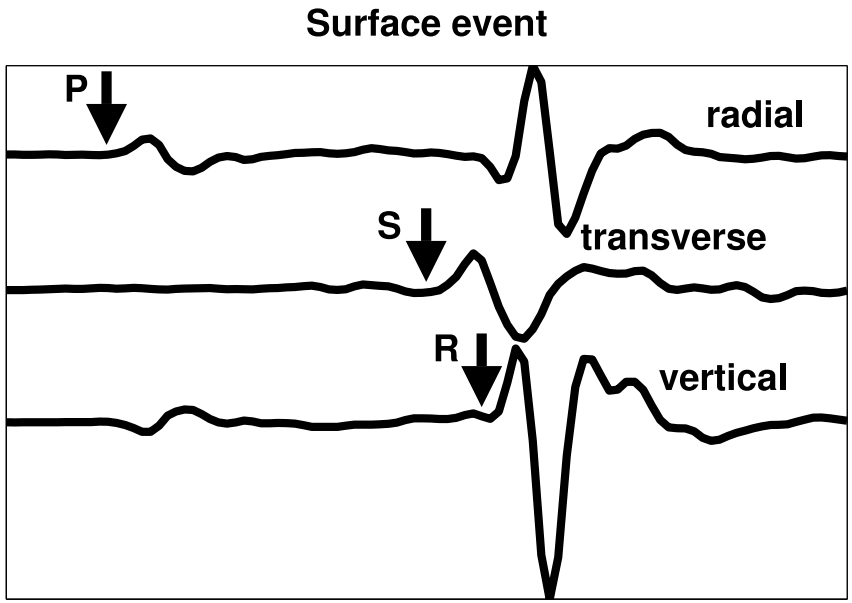
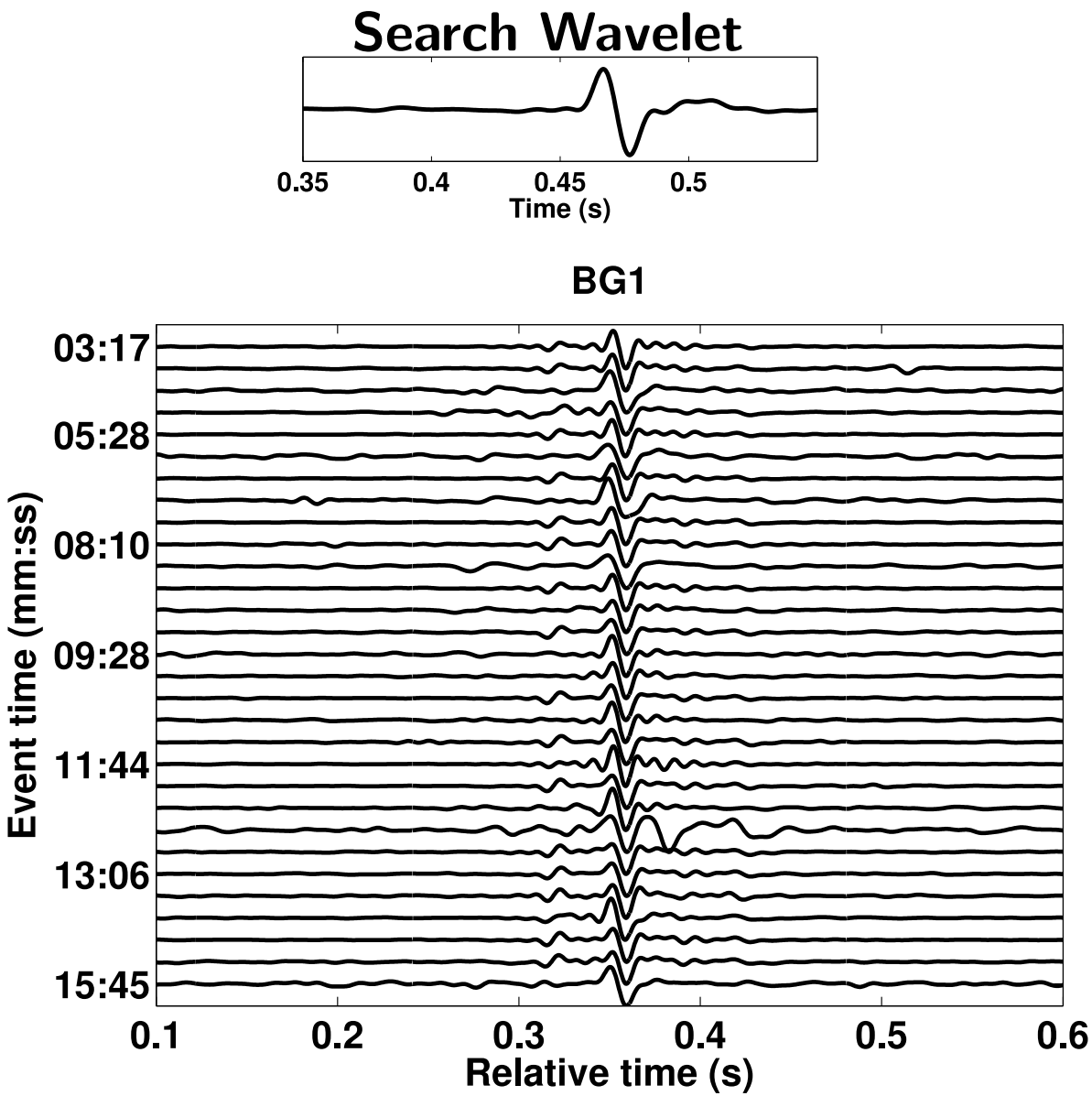
Bench surface waveforms



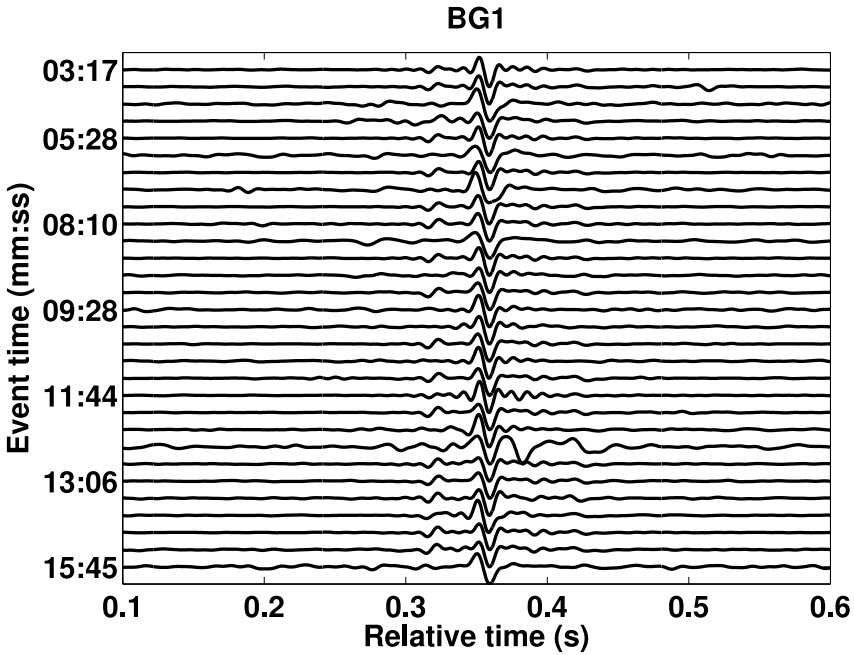
(Walter et. al, 2009)

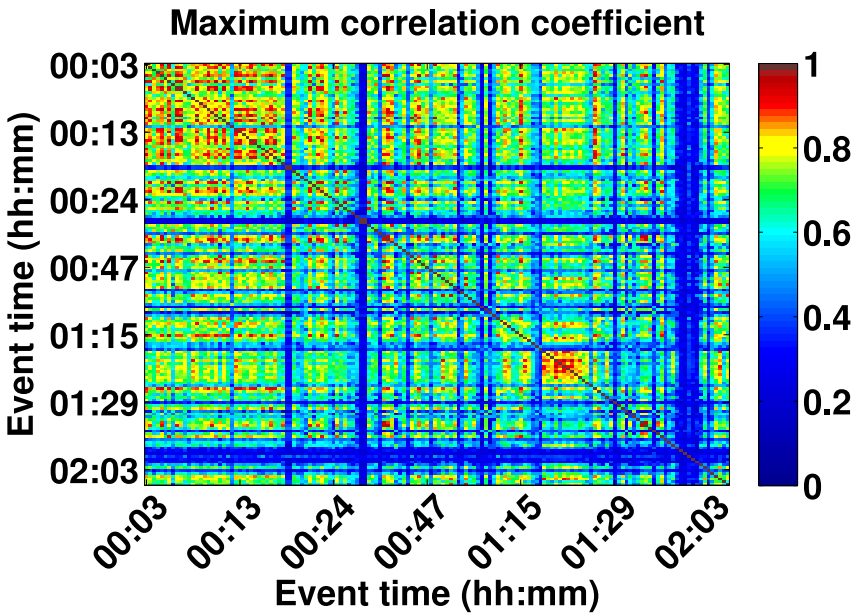


Step 1: event identification

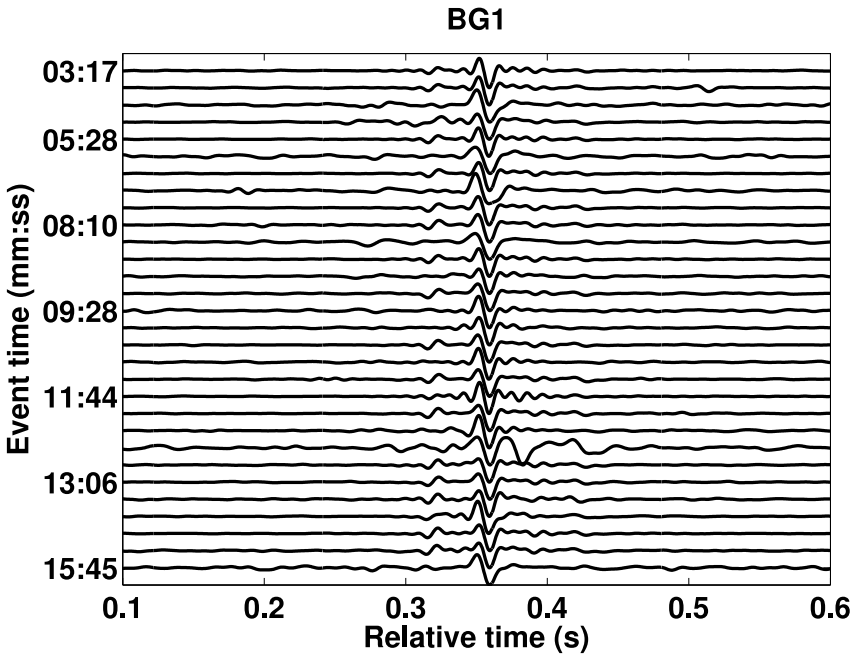


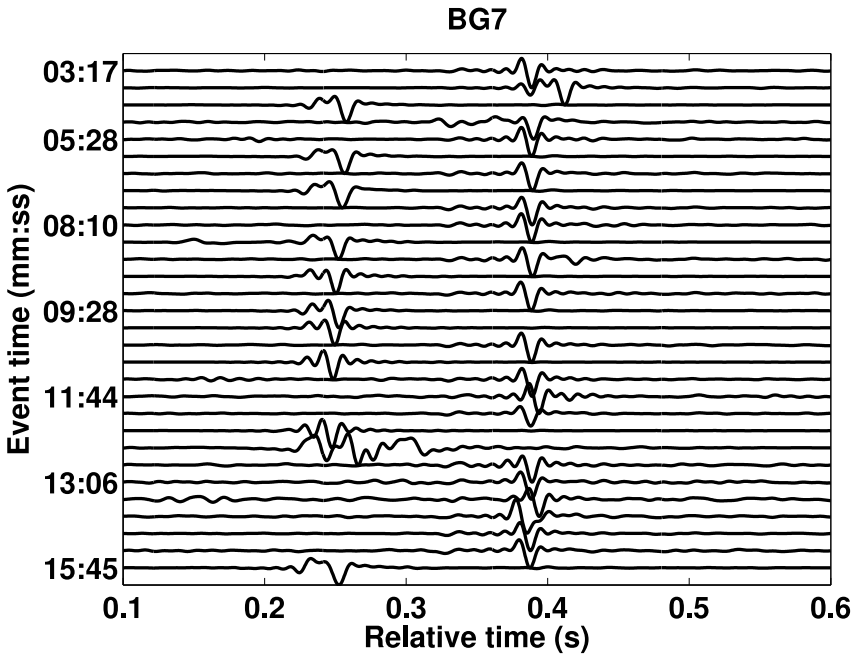
Step 2: cluster identification





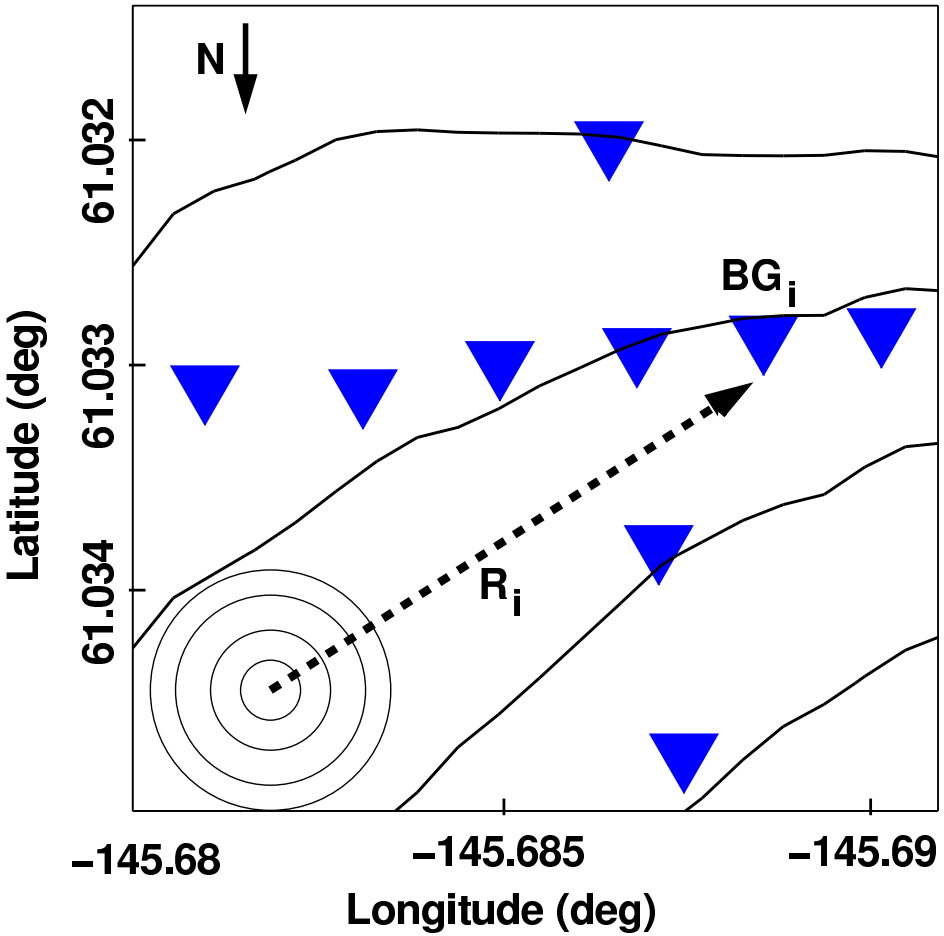
Source mechanism similarity





Icequake location estimation

$$d_i = t + \frac{R_i}{V} = t + \left(\sqrt{(x_i - x)^2 + (y_i - y)^2} \right) / V$$



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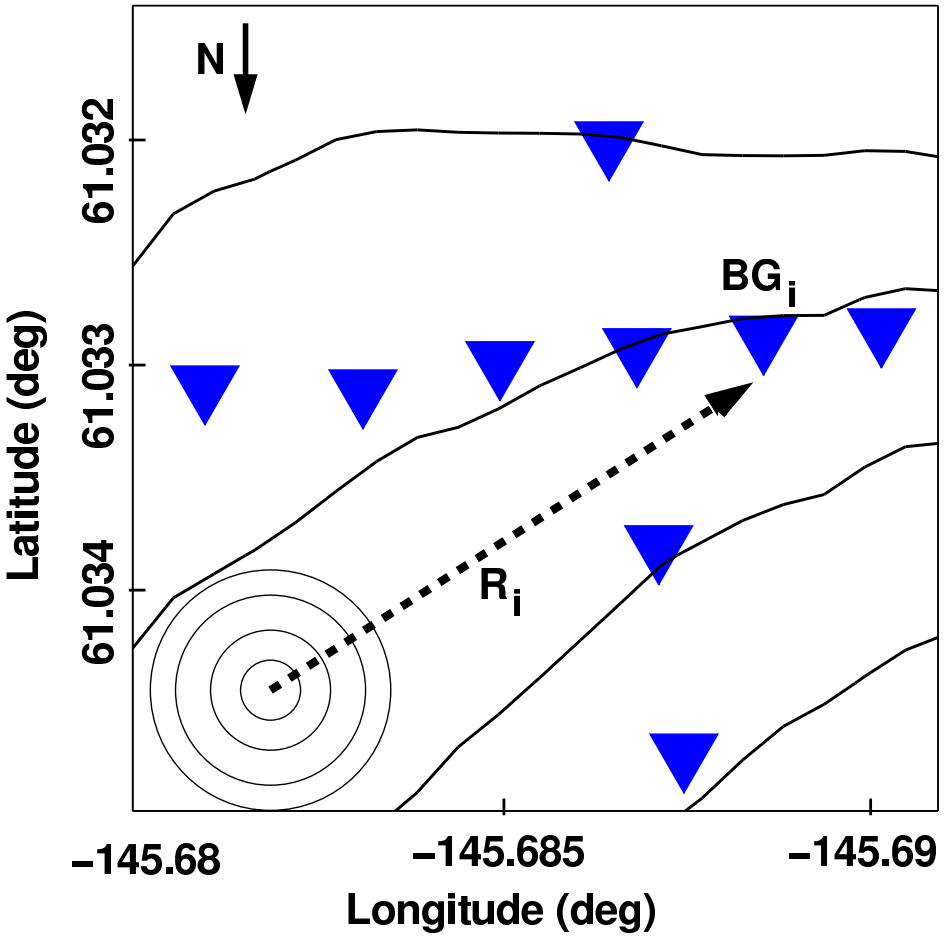


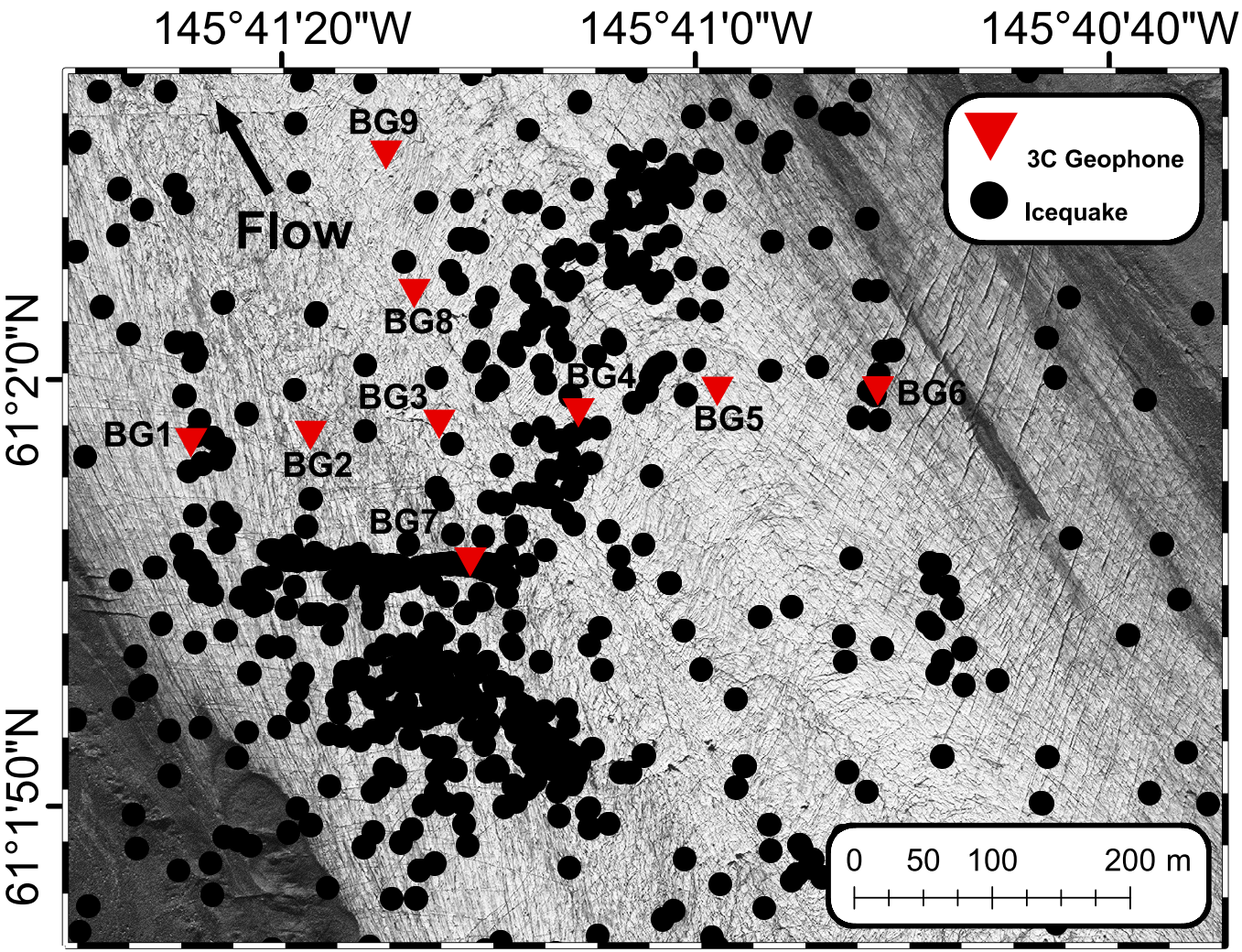
$$\mathbf{m} = \begin{bmatrix} t \\ x \\ y \end{bmatrix}$$

$$\mathbf{d(m)} = \begin{bmatrix} d_1 \\ . \\ . \\ . \\ d_9 \end{bmatrix}$$

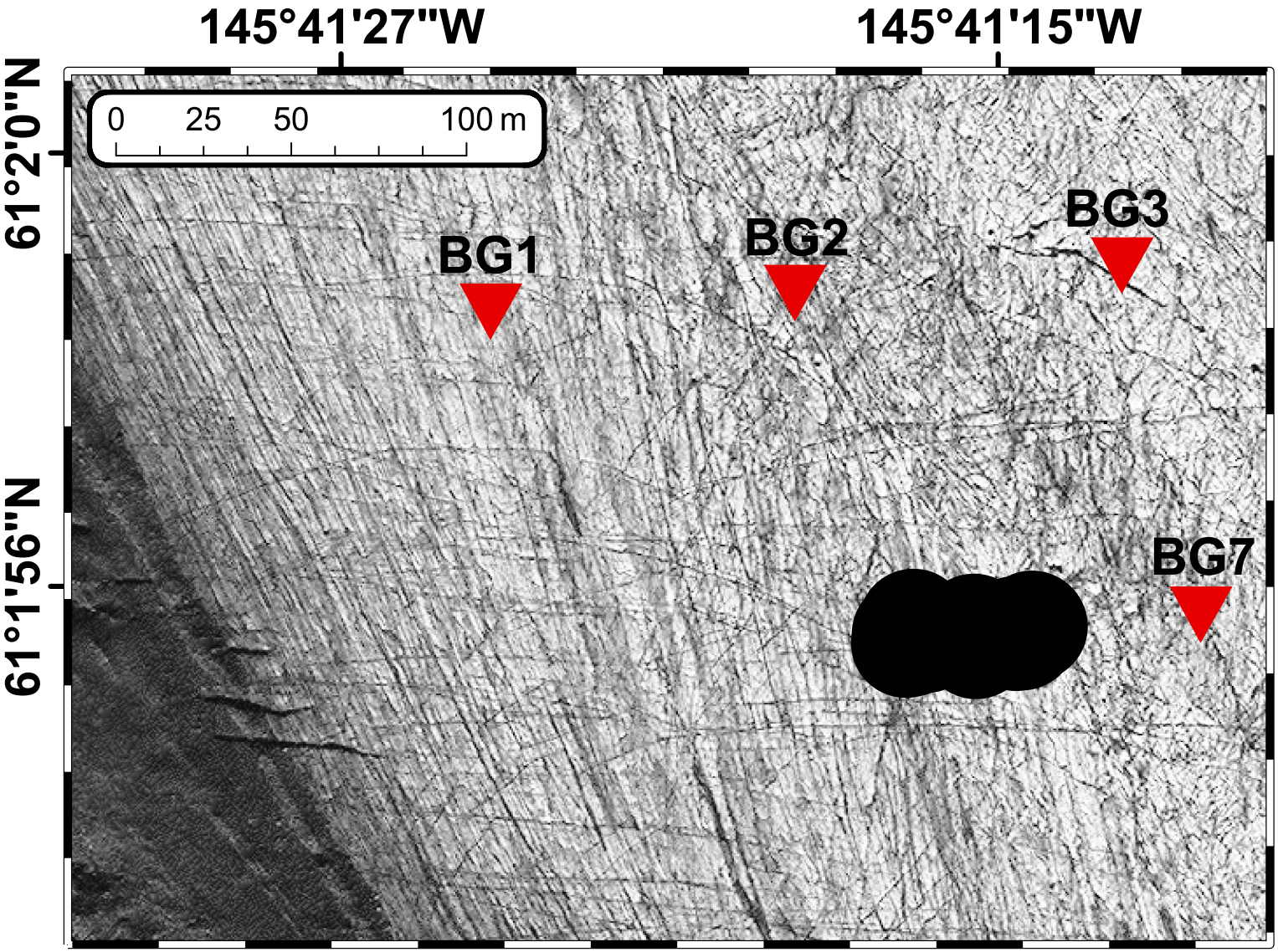
$$\mathbf{\Delta d} = G\mathbf{\Delta m}$$

$$\mathbf{\Delta m} = G^{\dagger}\mathbf{\Delta d}$$

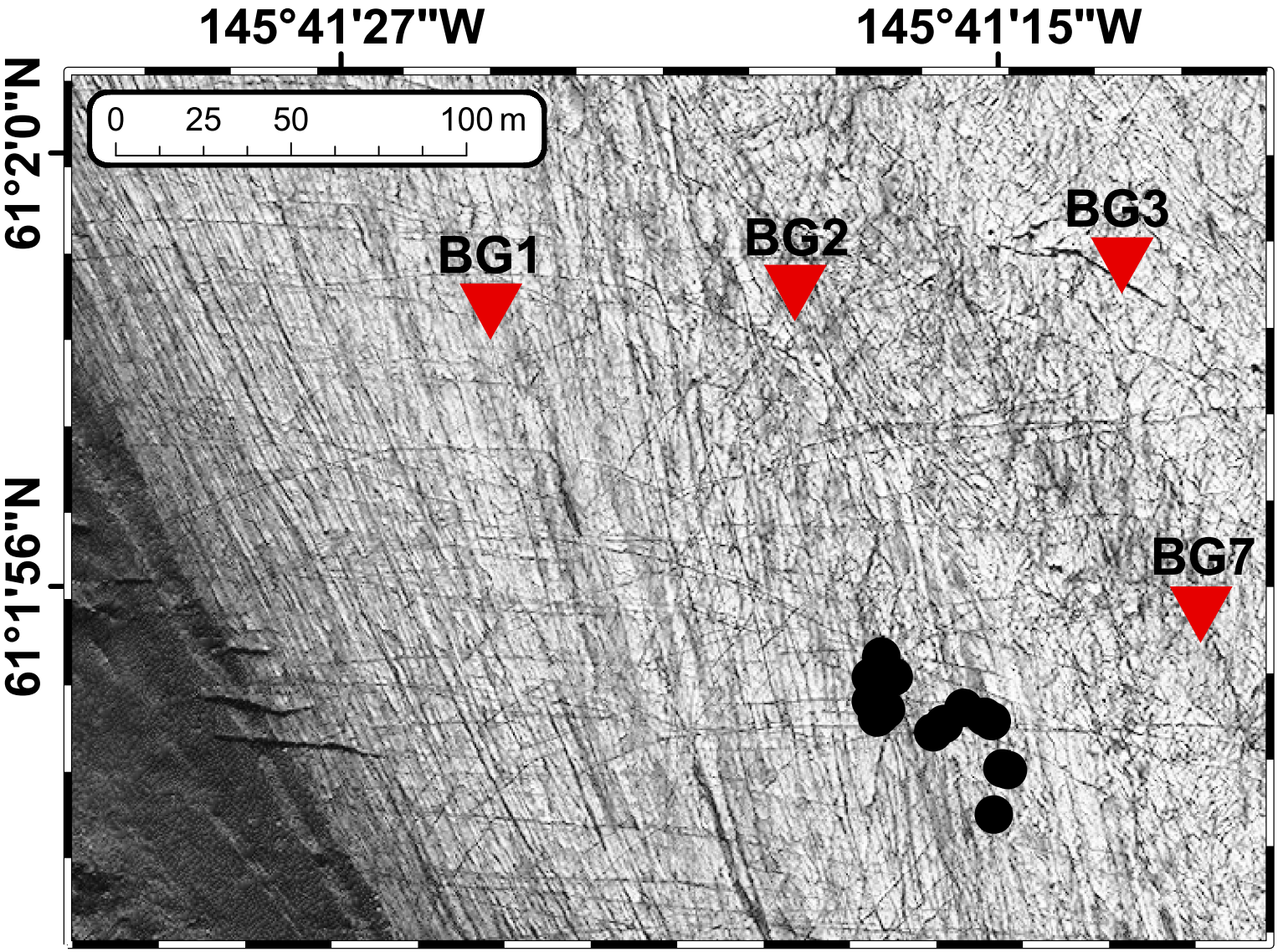
Rayleigh wave epicenter location



Improving source location resolution



P, S, & Rayleigh wave epicenter location



Error estimates

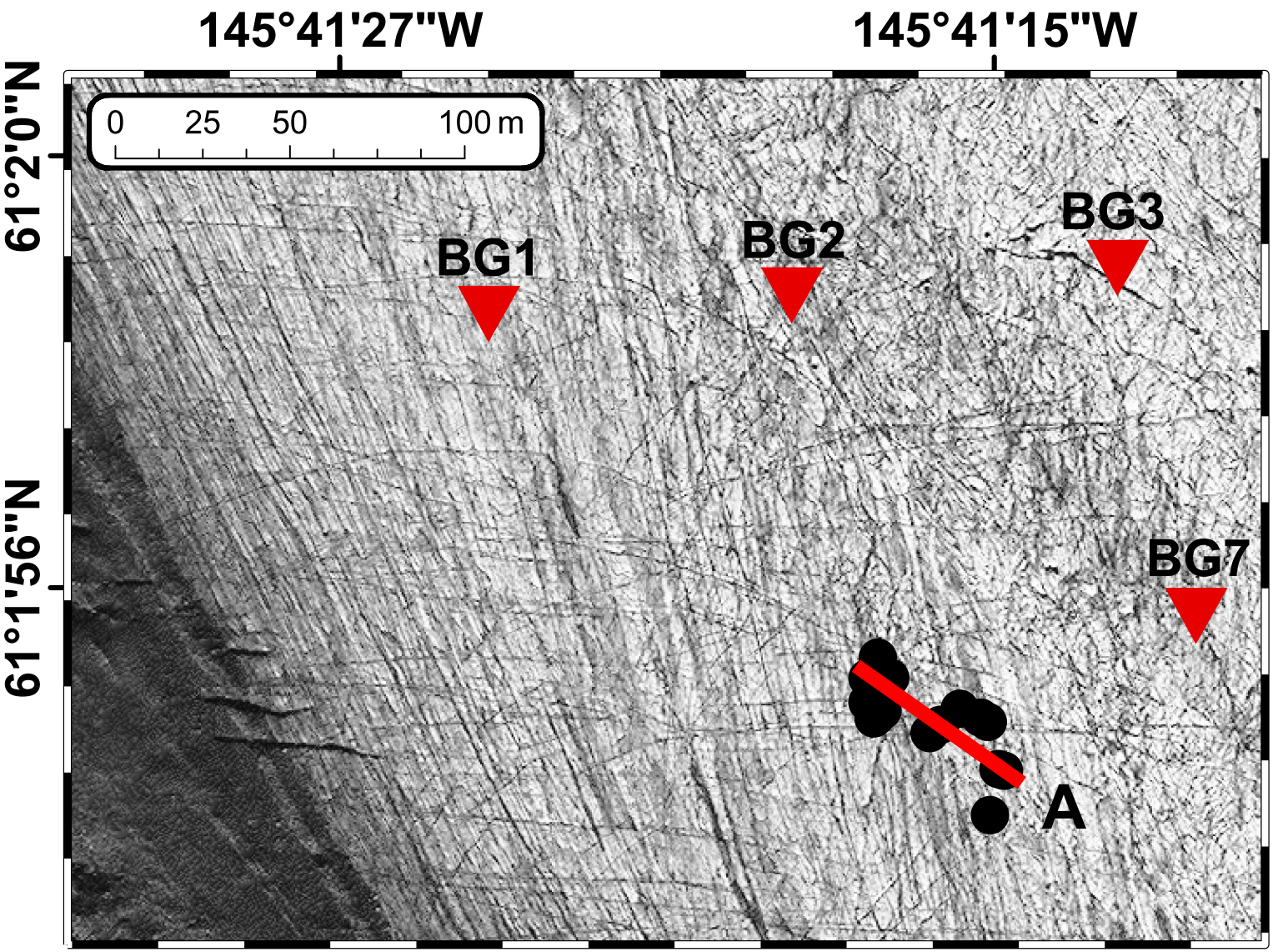
Using **only** the **Rayleigh** wave

$$\sigma_{\mathbf{m}} = \begin{bmatrix} t = 9ms \\ x = 10m \\ y = 11m \end{bmatrix}$$

Using **P, S, & Rayleigh** waves

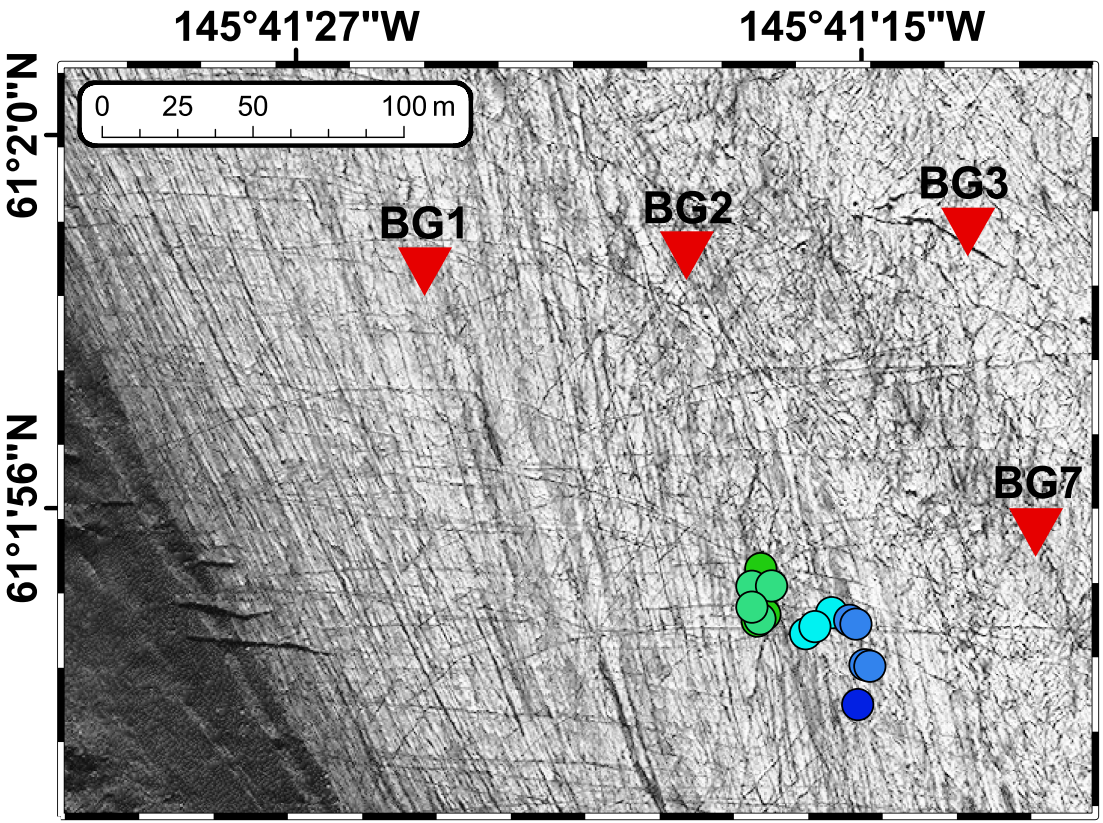
$$\sigma_{\mathbf{m}} = \begin{bmatrix} t = 2ms \\ x = 4m \\ y = 6m \\ z = 43m \end{bmatrix}$$

Fracture properties

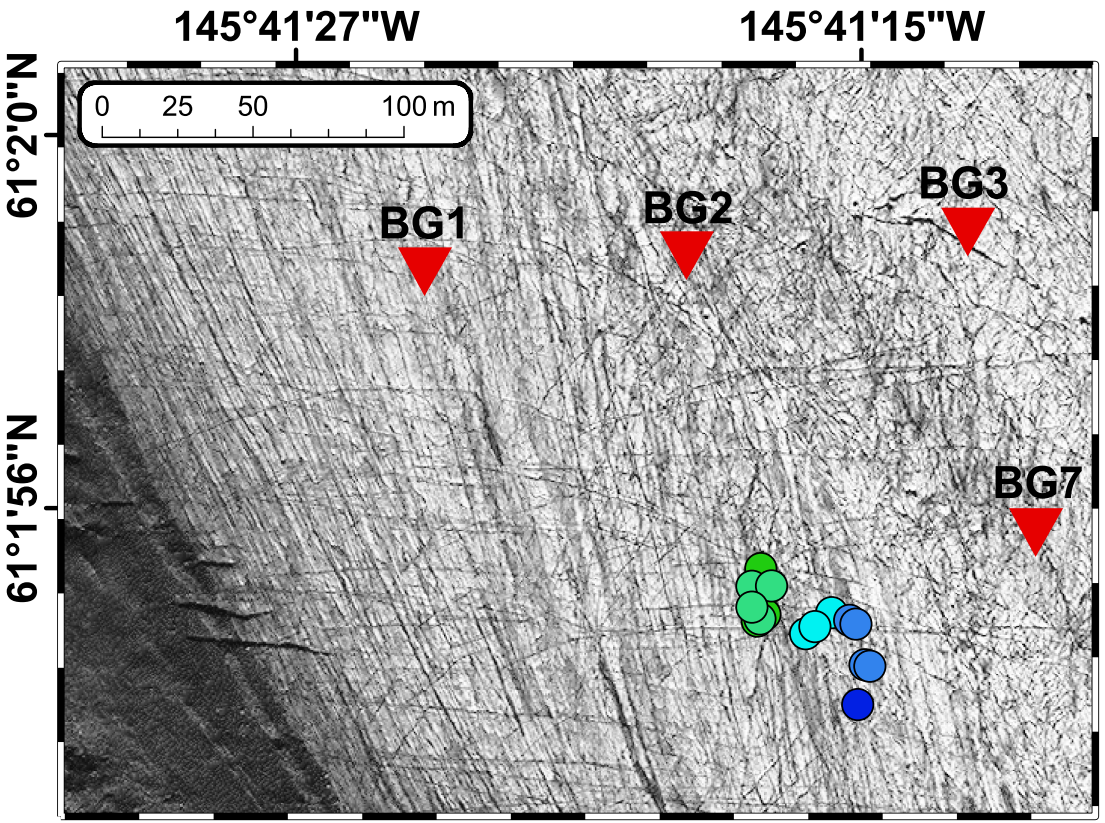


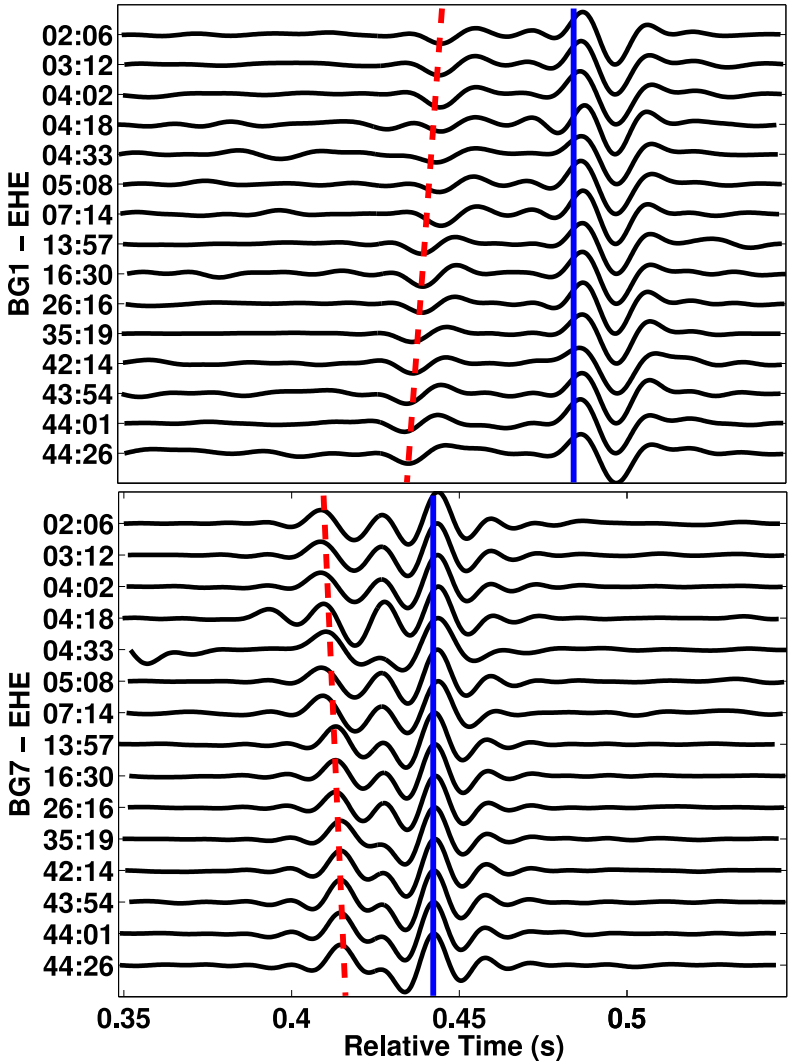
50 $m/42\ min = 2\ cm/s$

Monitoring fracture propagation

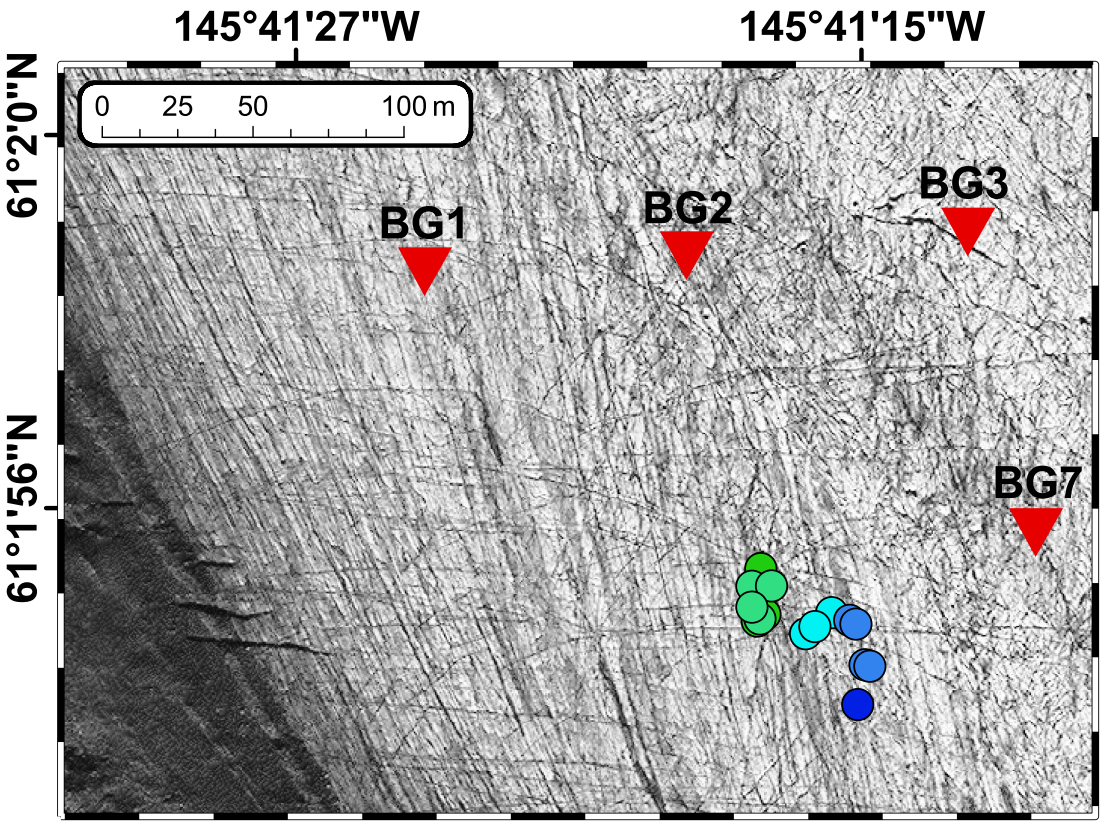


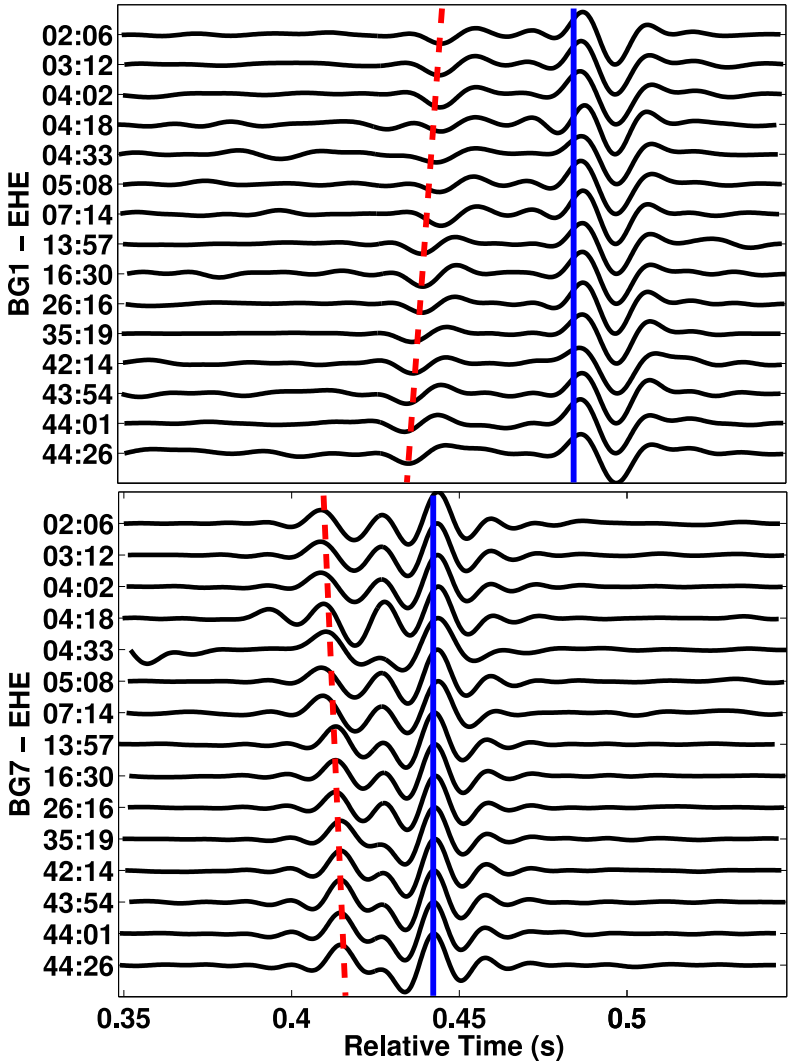
Monitoring fracture propagation





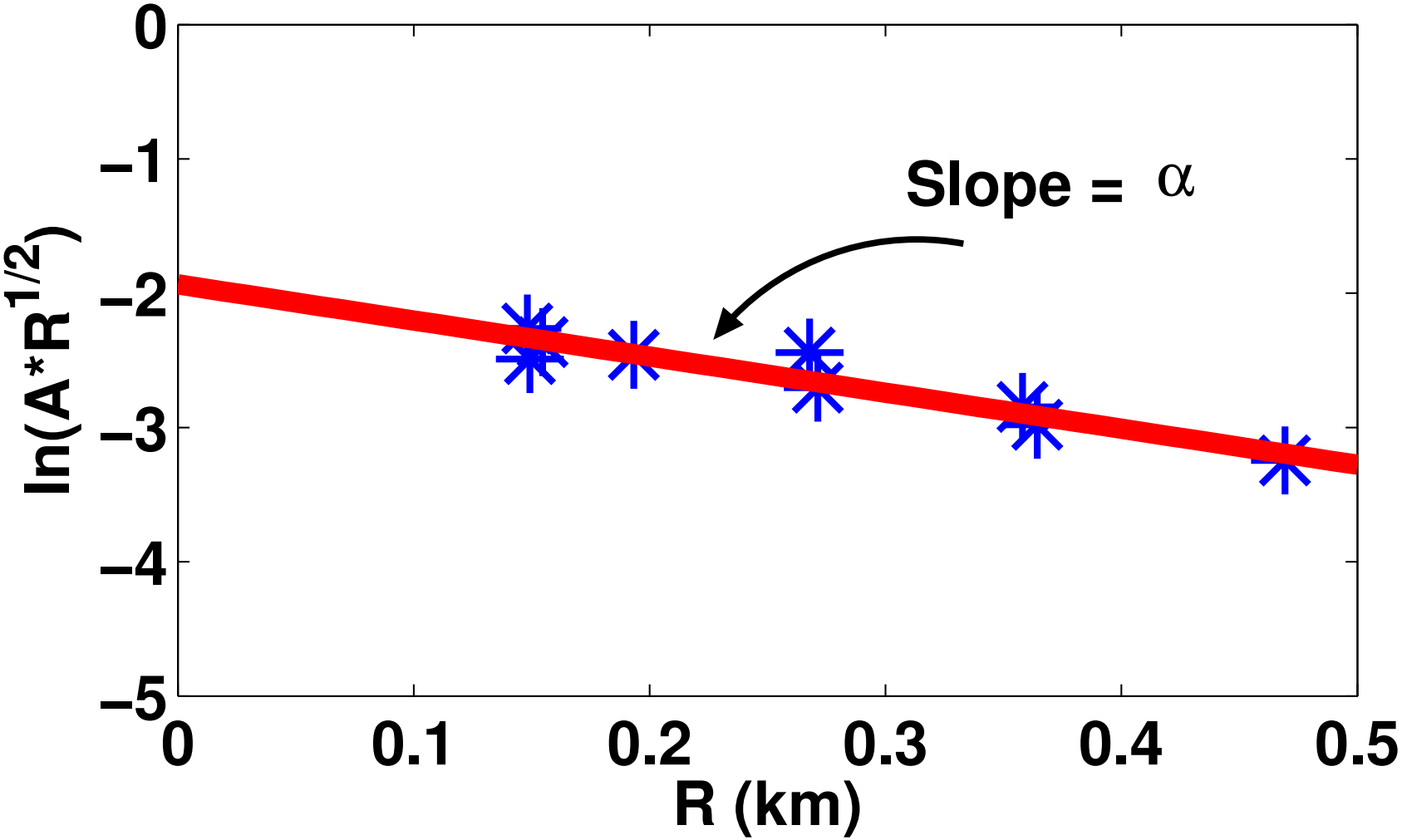
Monitoring fracture propagation



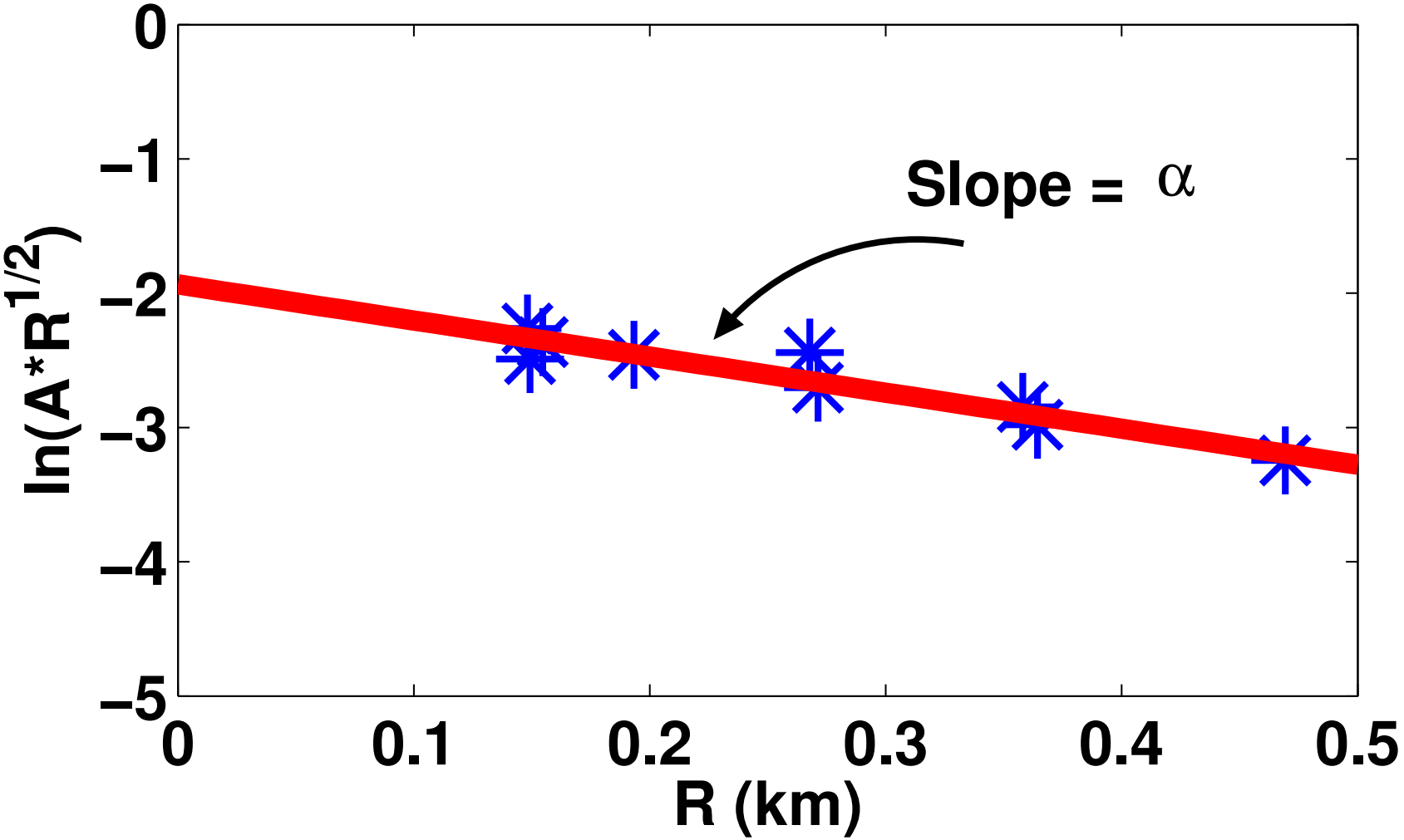


$$0.013\ s \times 3650\ m/s \approx 47\ m$$

Using amplitude information

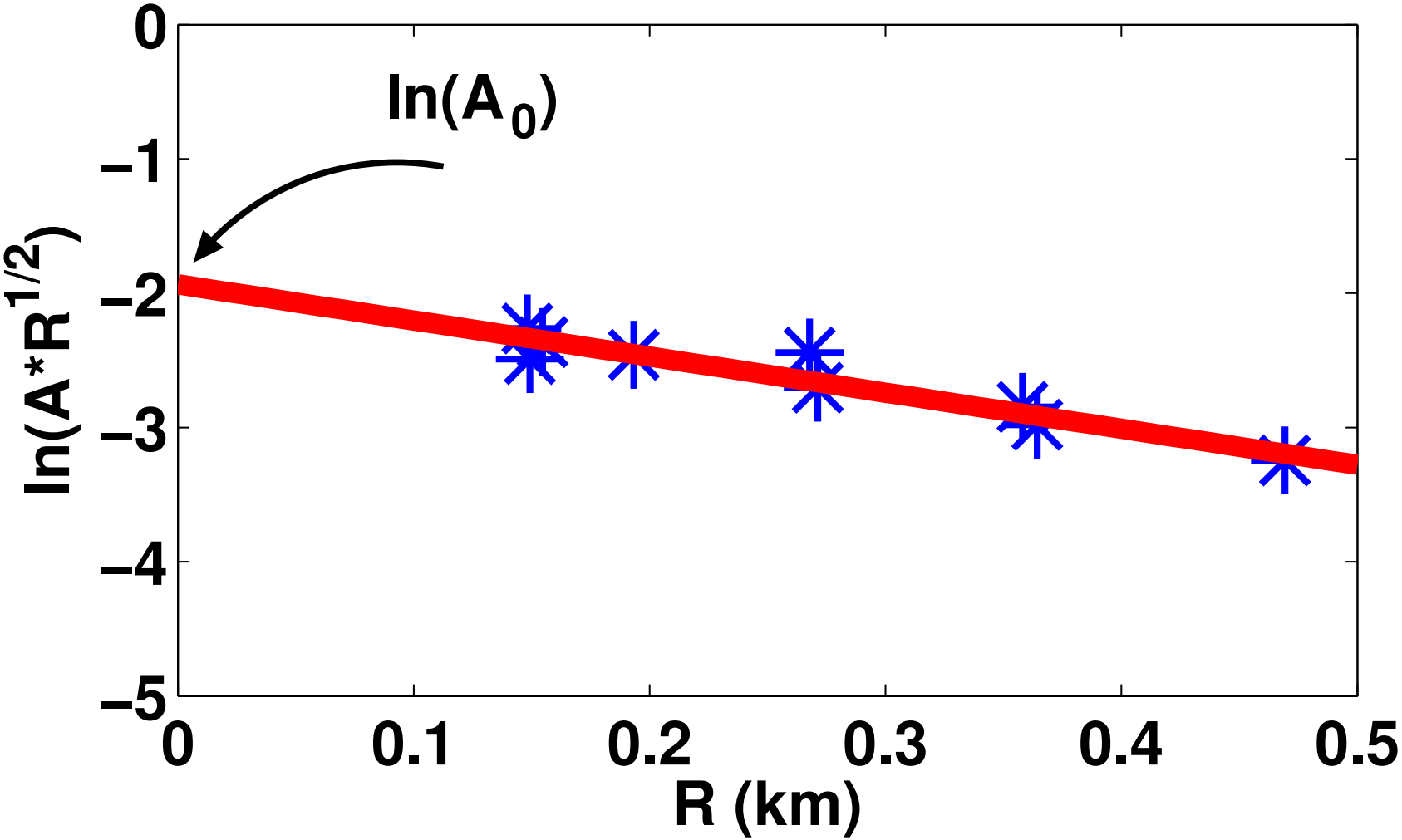


Using amplitude information



- $\bar{Q}_{ice} = 53 \pm 14$

Using amplitude information



- $\bar{Q}_{ice} = 53 \pm 14$

Amplitude

Rayleigh wave amplitude:

$$A_{obs} = \frac{A_0}{\sqrt{R}} e^{-R\alpha}$$

Amplitude $\rightarrow M_s$

Rayleigh wave amplitude:

$$A_{obs} = \frac{A_0}{\sqrt{R}} e^{-R\alpha}$$

Richter magnitude:

$$M_s = \log_{10}(A_{obs}) + f(R, Z)$$

Amplitude $\rightarrow M_s \rightarrow M_o$

Rayleigh wave amplitude:

$$A_{obs} = \frac{A_0}{\sqrt{R}} e^{-R\alpha}$$

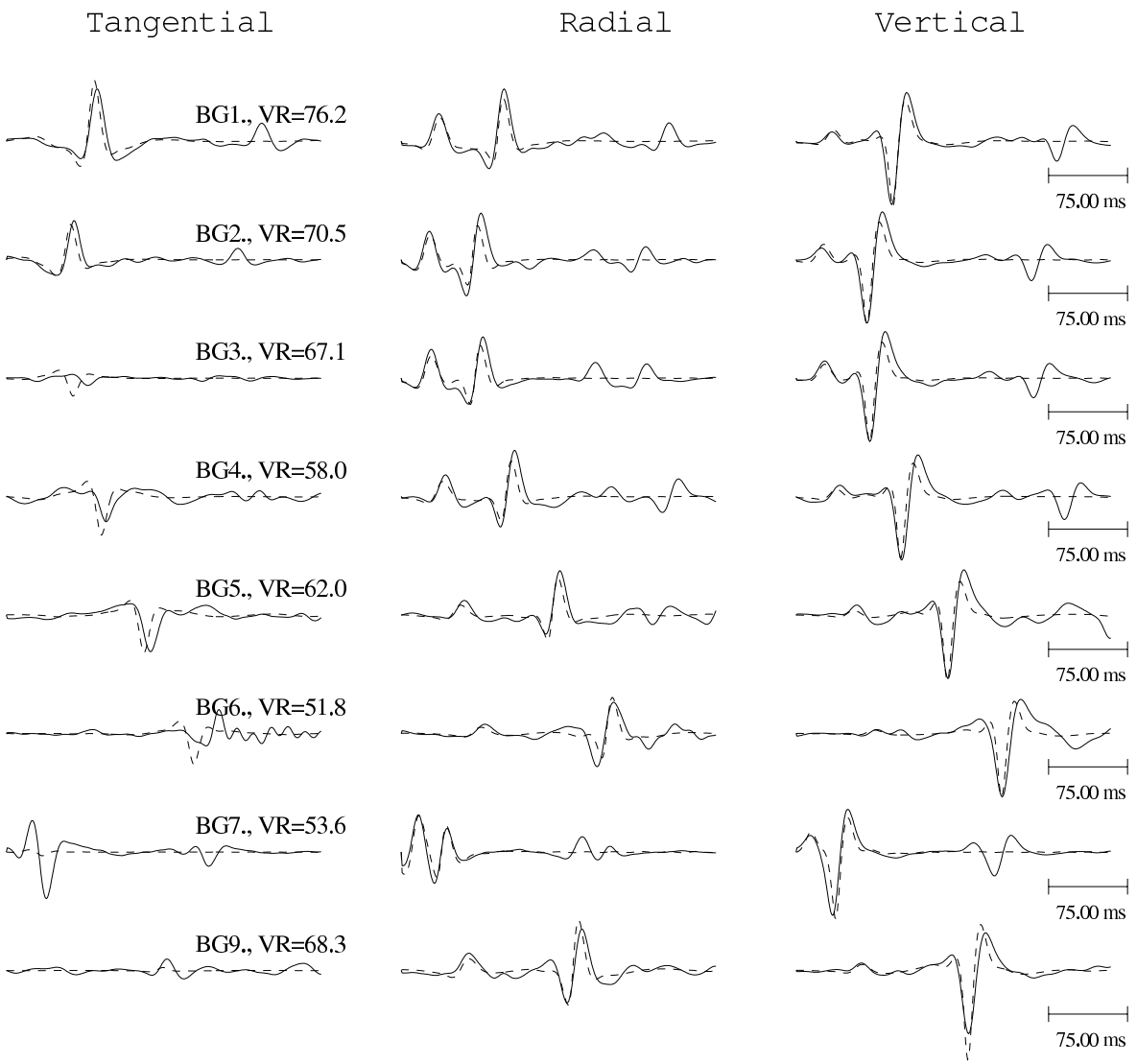
Richter magnitude:

$$M_s = \log_{10}(A_{obs}) + f(R, Z)$$

Empirical seismic moment:

$$\log_{10}(M_0) = 1.5 M_s + 16.1$$

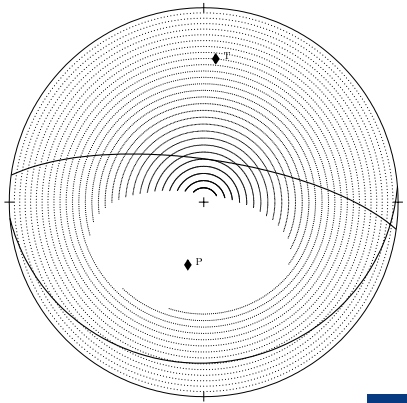
Moment Calibration



Mw = -1.96
Mo = 1.14e+06 Nm

Mxx = 9.49e+05 Nm
Myy = 3.15e+05 Nm
Mzz = -6.47e+04 Nm
Mxy = 4.32e+04 Nm
Mxz = 4.76e+05 Nm
Myz = 8.19e+04 Nm

Strike = 278 ; 278 deg
Rake = -86 ; -86 deg
Dip = 72 ; 72 deg
Var. Red = 6.34e+01



Conclusion

- Improved source location resolution
- Estimate Q_{ice} (fractures and water content)
- Amplitude $\rightarrow M_S \rightarrow M_0 \rightarrow \mu \times A \times D$

Acknowledgments

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