Active source Seismology

A way to look into glaciers and what lies beneath using ``sound''

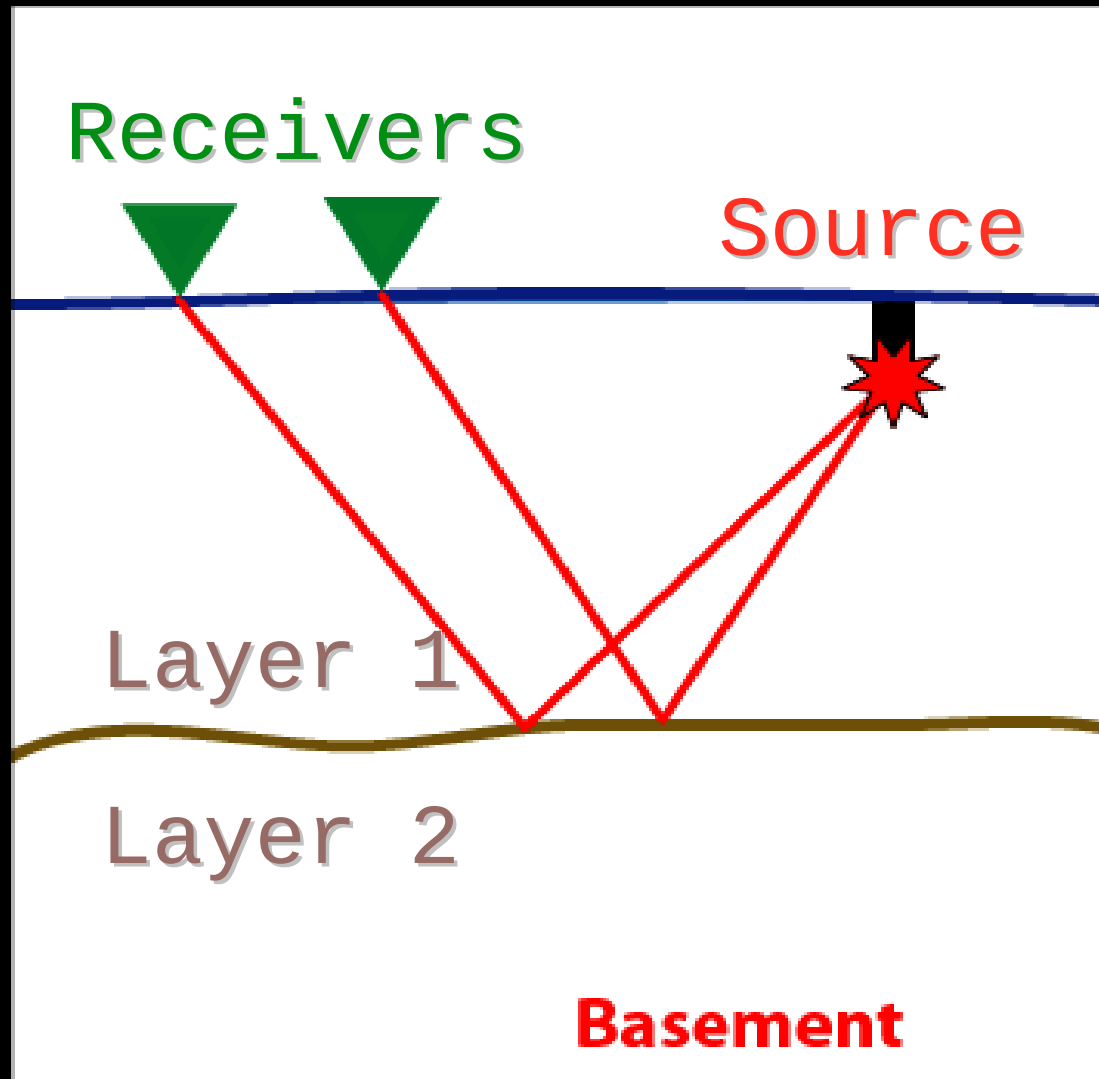
Leo E Peters and Sridhar Anandakrishnan
Pennsylvania State University
Dept. of Geosciences
PSICE (Penn State Ice & Climate Exploration)

Outline

- Introduction to active source seismology
- Applications in glaciated regions
- A little on seismic waves
- CReSIS and active source seismology

Bats do it...

Seismologists do it...



Seismology

- Use of energy waves to image the interior of the earth
- “CAT Scanning” the subsurface
- Passive source -- record earthquakes and use their energy to answer geologic questions
- Active source -- produce sound waves to target specific subsurface regions to study

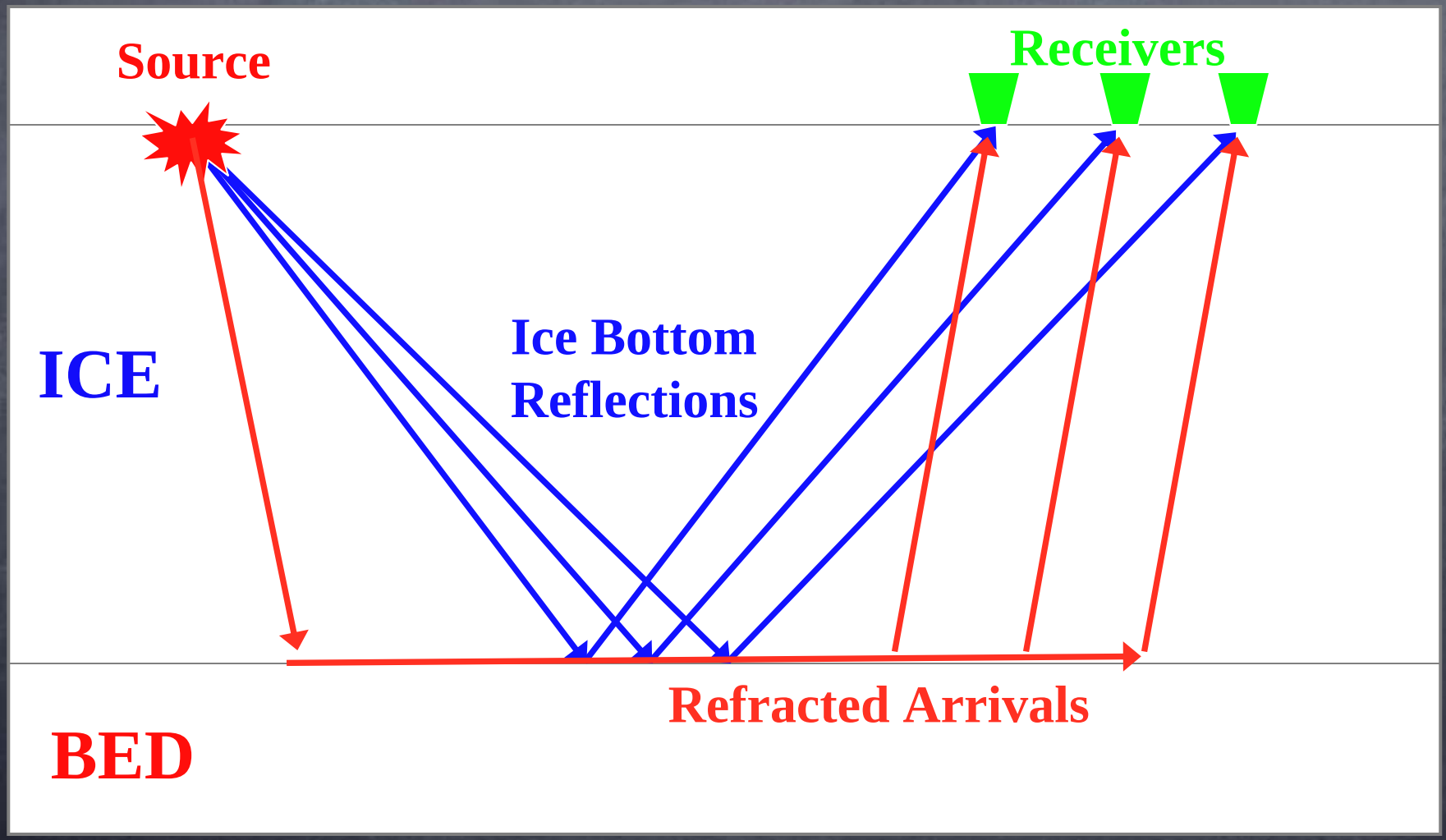
Active Source Seismology

- Produce a sound and record the echo
- How long until echo received?
  - Distance to subsurface layer
- How strong is echo?
  - Subsurface layer properties

Seismic Reflection & Refraction -- I

- Reflection: Sound wave reflects at layer(s) of interest
  - High-resolution at depth
  - Constraints on subsurface properties
- Refraction: Sound wave bends along a layer boundary of interest
  - Can cover large regions more easily
  - Cheaper and faster

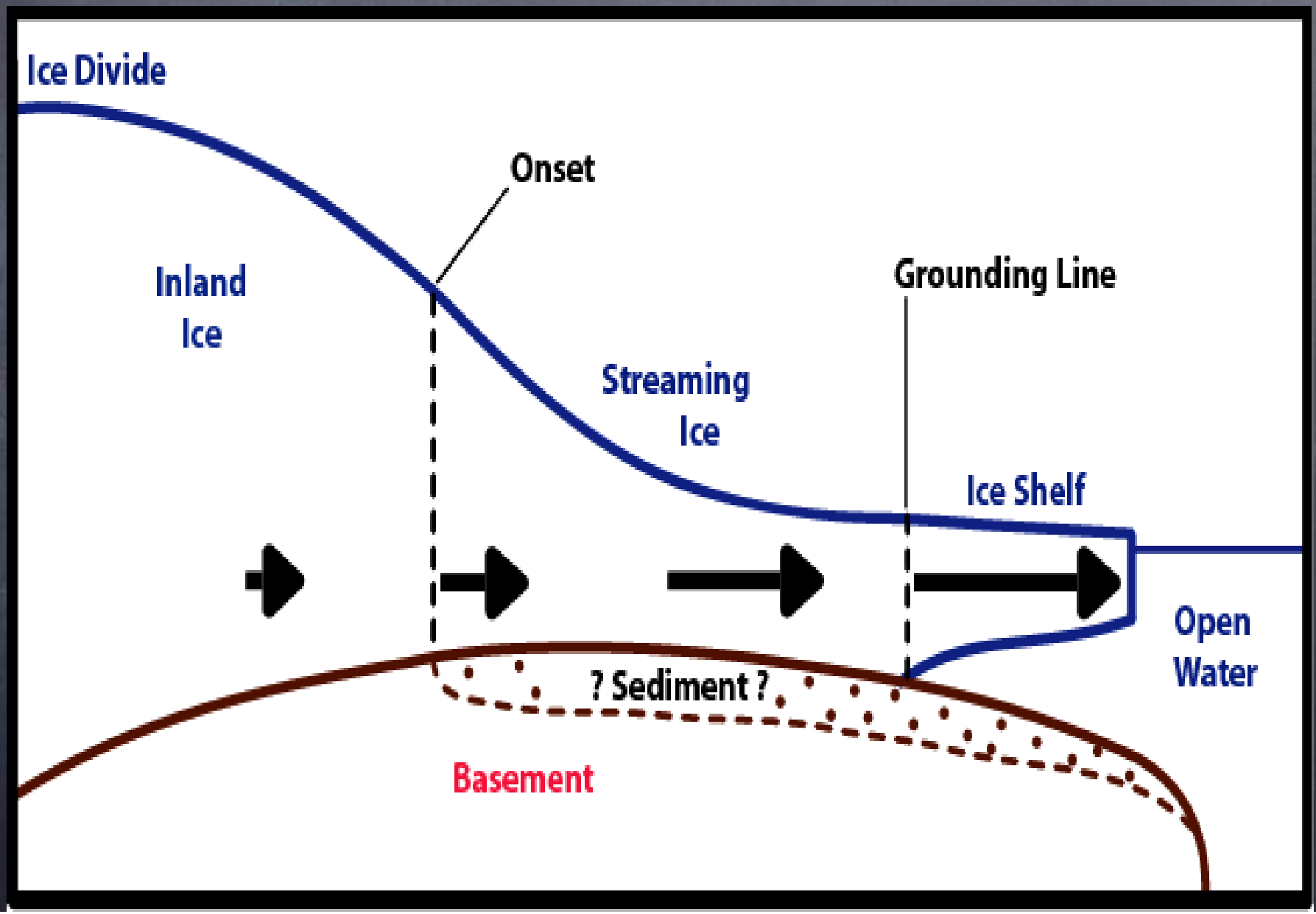
Seismic Reflection & Refraction -- II



Why Apply to Ice Sheets?

- Determine ice thickness (radar too)
- Englacial layers (ice fabric)
- Presence of water
- Glacier bed properties
  - Bedrock vs. Till vs. Water
  - Soft vs. Hard Till
- Deeper subglacial structures
  - Sedimentary basins, faults, crustal

Glaciology 101: Geology and Ice Flow



Obtaining Active Seismic Data

- Survey Seismic Line
- Drill Shot Holes
- Lay out Seismic Cables
- Shoot
- Record Data

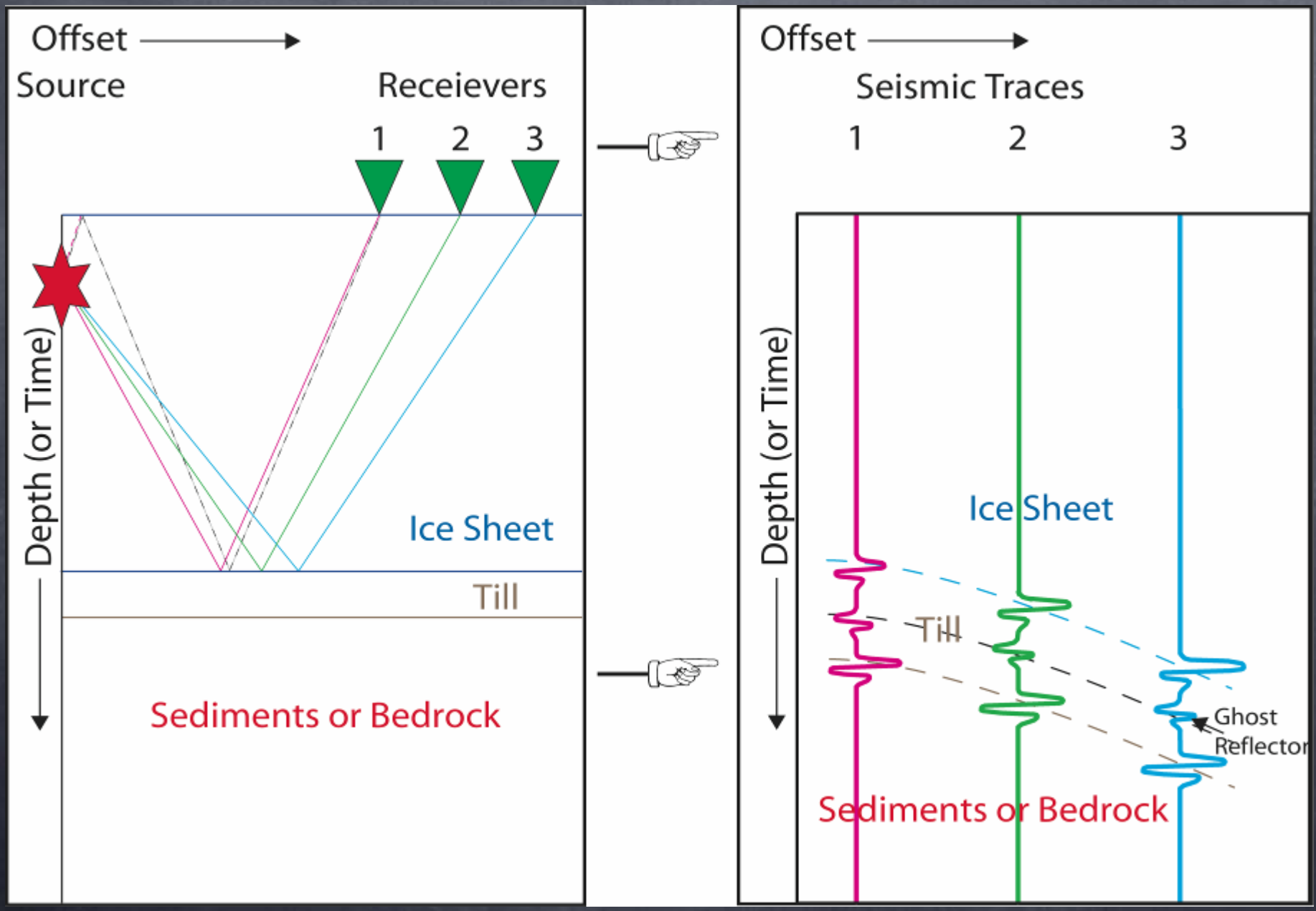
Obtaining Active Seismic Data

Seismic Sources…

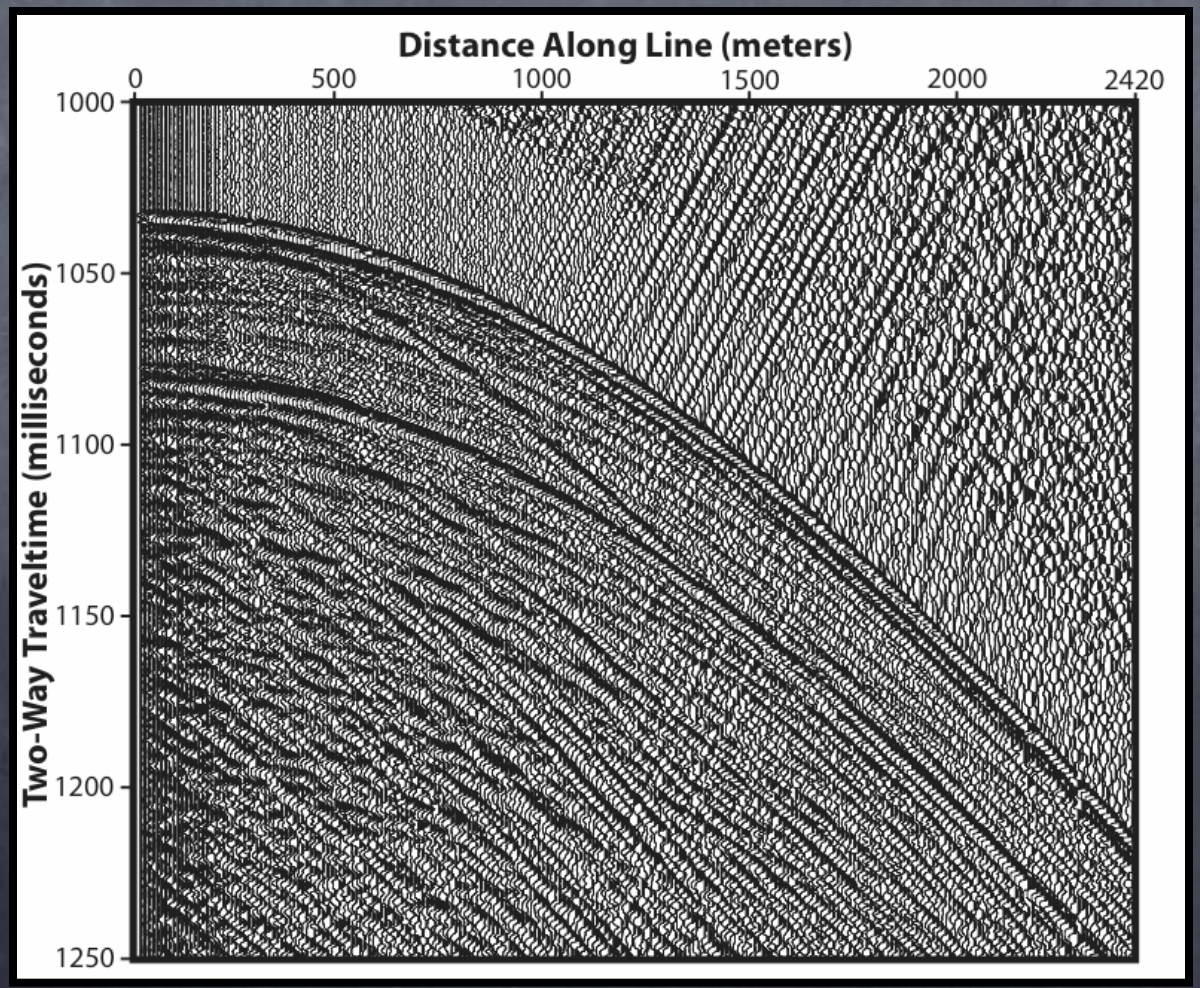
- Explosives
- Sledgehammer
- Vibroseis
- Compressed-air gun
- …

…in Glaciated Regions -- Explosives

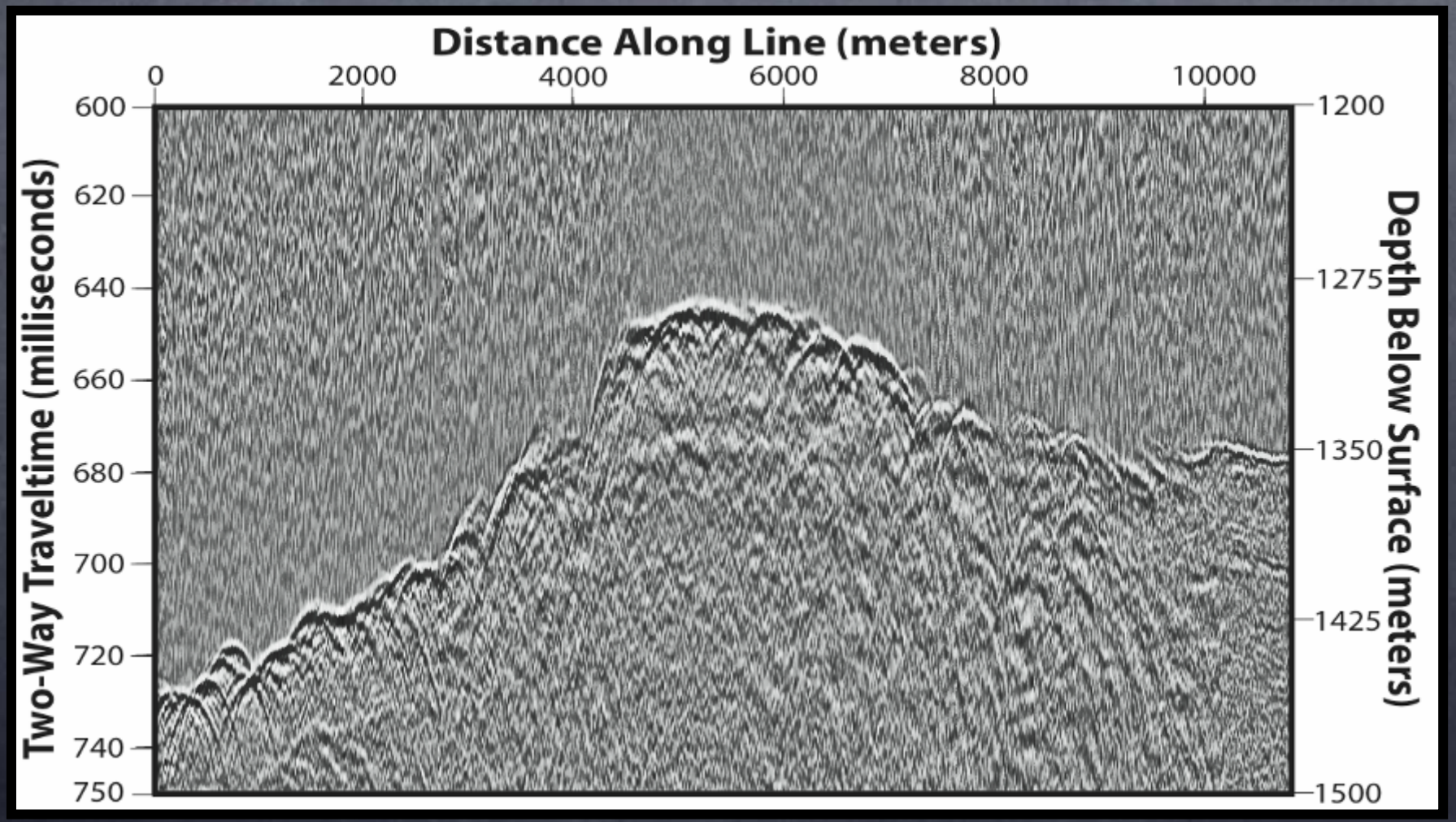
Obtaining Active Seismic Data



Shot Record from Bindschadler Ice Stream, WA

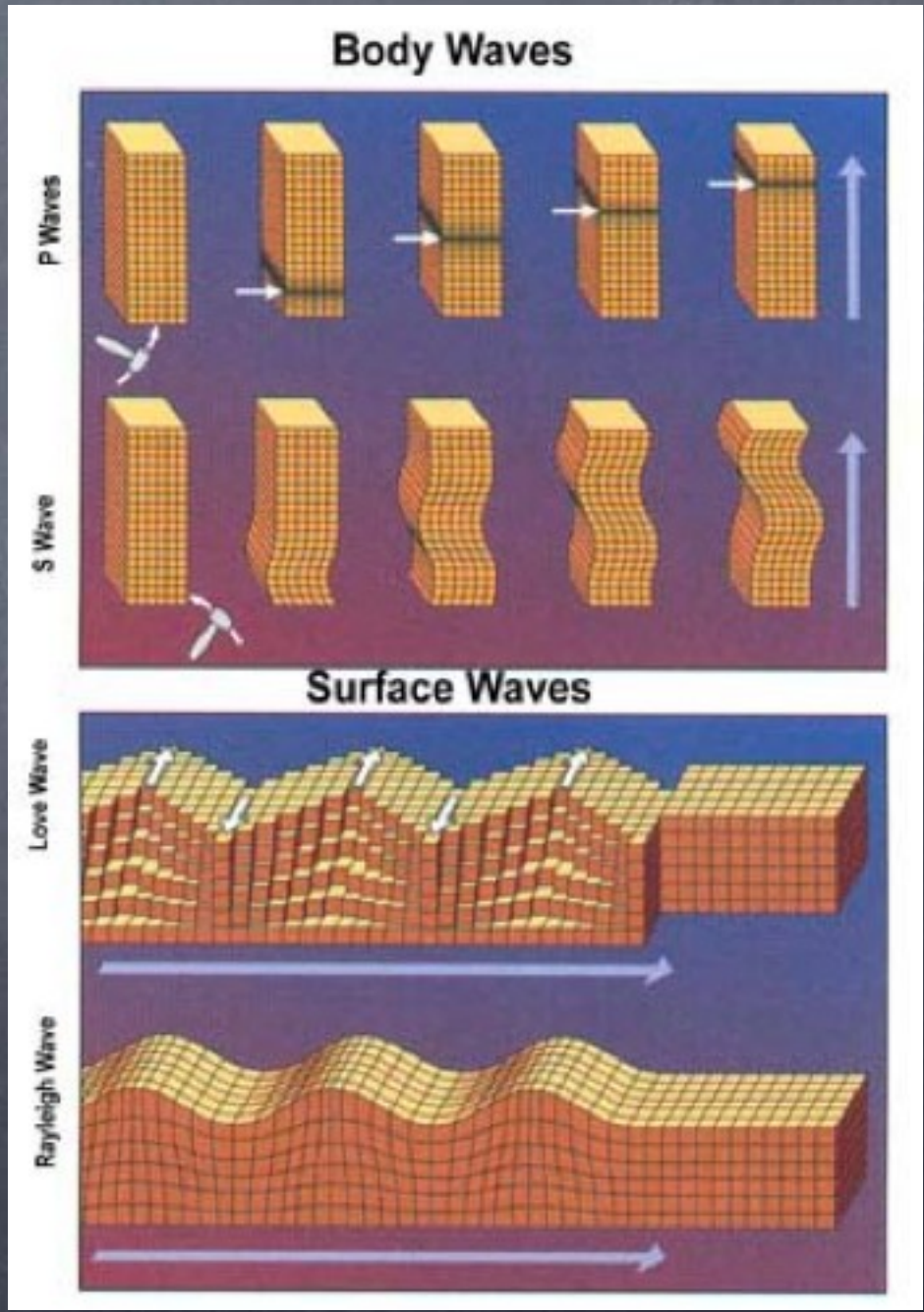


Seismic Profile Along Kamb Ice Stream, West Antarctica



Types of Seismic Waves

- Body Waves
  - Compressional or P-wave is fastest
  - Shear or S-wave is slower
- Surface Waves: Raleigh waves, Love waves, “air blast”, “ground roll”



Seismic Velocity of Body Waves

- Velocity = function of elastic properties
- Reflection character is related to seismic velocity and density
- Gives subsurface lithology

Ice and Seismology

- Firn: Vp = 1-3 km/s, density=.4-.8 g/cc
- Ice: Vp = 3.9 km/s, Vs = 1.9 km/s
  - Highly anisotropic, small temperature dependence
  - Water: Vp=1.5 km/s, Vs = 0
- Tills: Vp = 2.1-2.4 km/s, Vs = ??, depends on porosity - important for fast flow
- Sediments vs. crystalline rocks: roughness, erosion potential, fracture potential, water transport...

Seismic body wave velocity

$$V_p = \sqrt{\frac{\left(\frac{4}{3}\mu + k\right)}{\rho}}$$

$$V_s = \sqrt{\frac{\mu}{\rho}}$$

μ = shear modulus (rigidity)
k = bulk modulus (incompressibil
ρ = density

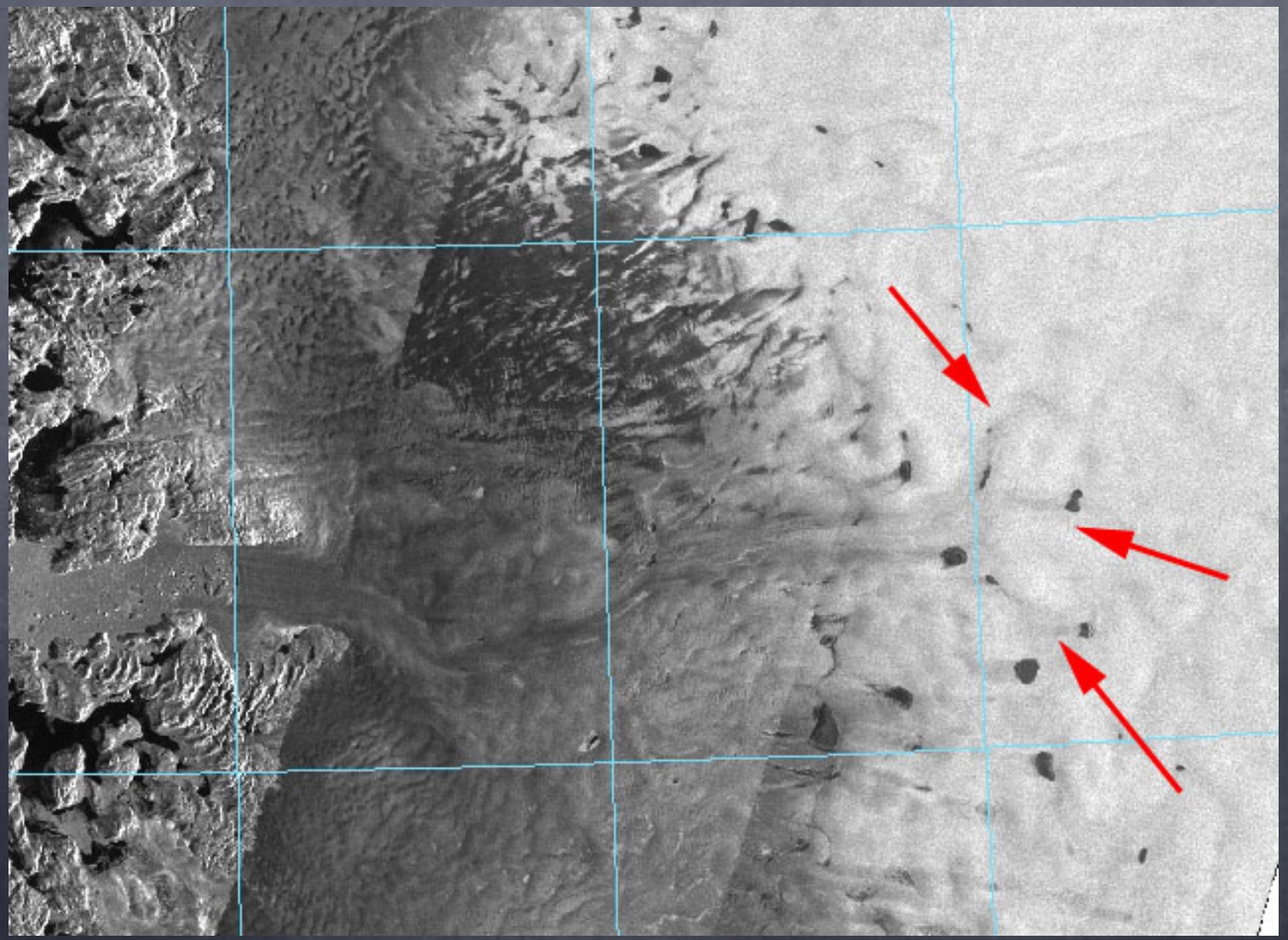
Influences of μ, k, Density on Velocity

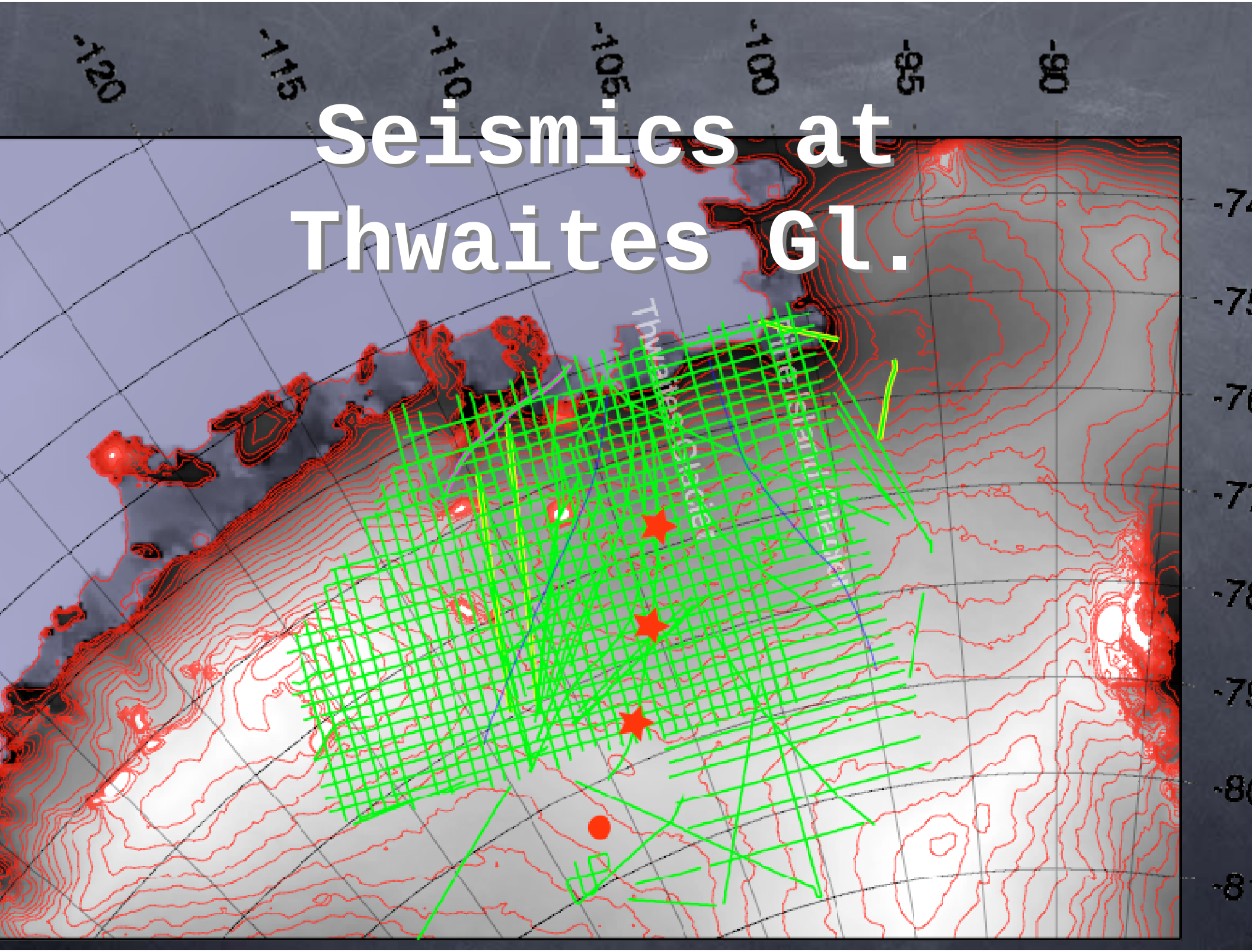
- Rock type, porosity
  - Till vs. basement; water content; deformation rate
- Fluid presence and type
  - Water
- Temperature, microcracks, fabric, ...
  - Flow law of ice

CReSIS and Seismics

- Subglacial imaging of Jakobshavn Isbrae (Greenland) and Thwaites Glacier (West Antarctica)
- Both are among the largest dischargers of ice in the world
- Both are changing rapidly (decadal)
- Neither has good (any?) basal data

Seismics in Greenland




Seismics at
Thwaites Gl.

Summary

- Active source seismology is a powerful tool in subglacial imaging
- Seismic energy is sensitive to changes in elastic properties
- Reflection seismic profiling can image at & below the base of the ice sheet
- For fast-flowing glaciers (and rapidly-changing glaciers), conditions at the base & below the base are extremely important