Surface Wave Analysis for Estimating S-wave Velocity

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Outline

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- Surface Wave Analysis:
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Introduction

- **Priddis Survey: Data collected by University of Calgary 2007 Field School and used here includes:**
  - **Well Data (125m deep)**
  - **2-D Seismic Data**

- **Objective: S-Wave velocity model of the near surface**

- **Motivation: Static corrections for S-waves**

Background

- Significant portion (2/3 according to Park et al. 1999) of seismic energy is imparted into Rayleigh waves when using a compressional source
- Dispersion of Rayleigh waves:
  - Isotropic Homogenous Half Space
  - Layered Earth
  - Phase velocity and group velocity:

$$c = v\left[1 - \frac{f}{c}\frac{dc}{df}\right]$$

c: phase velocity   v: group velocity
f: frequency

  - Normal Dispersion
  - Phase velocity: function of frequency and 4 earth parameters (P-wave velocity, S-wave velocity, density, and thickness)

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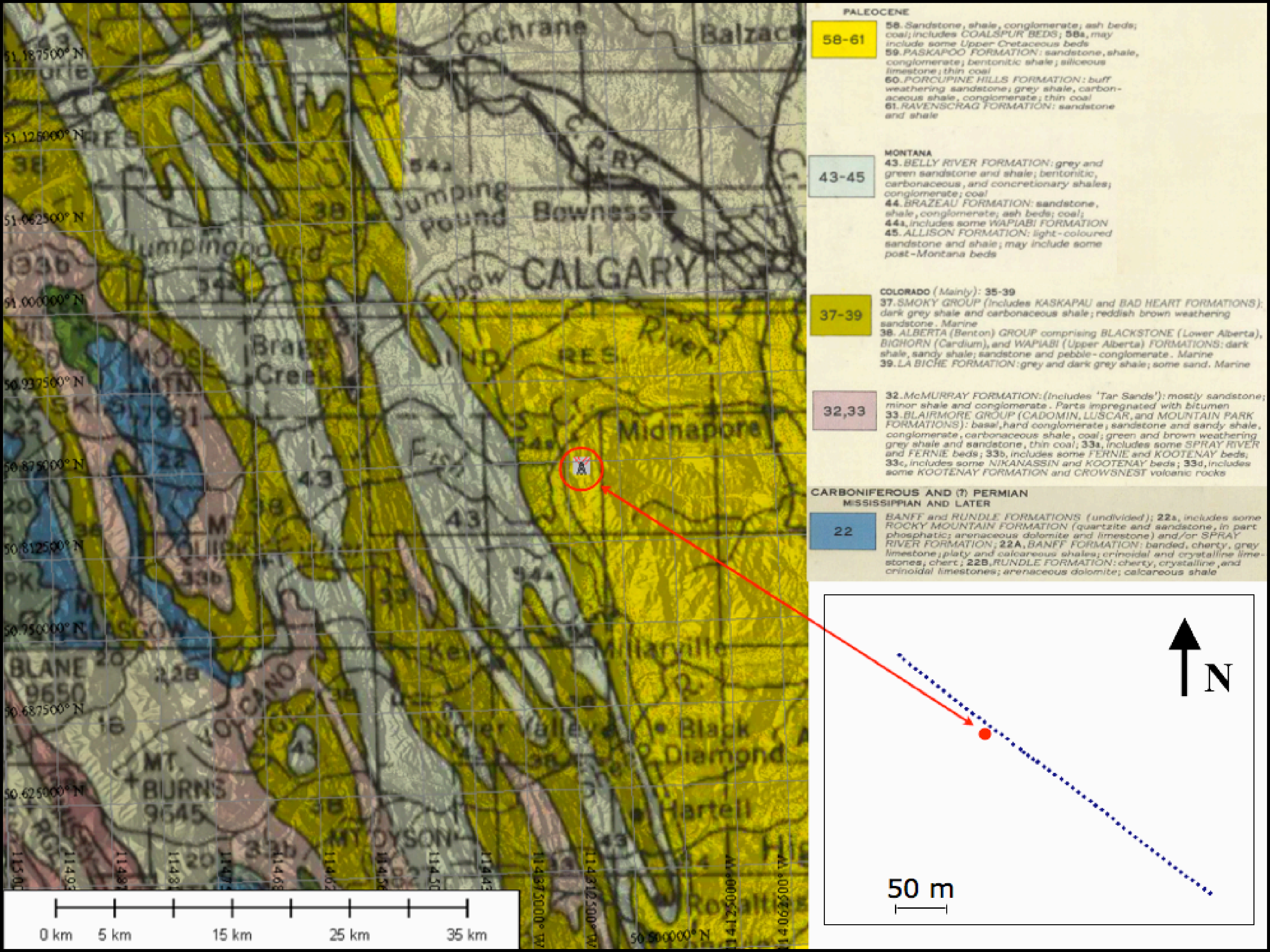
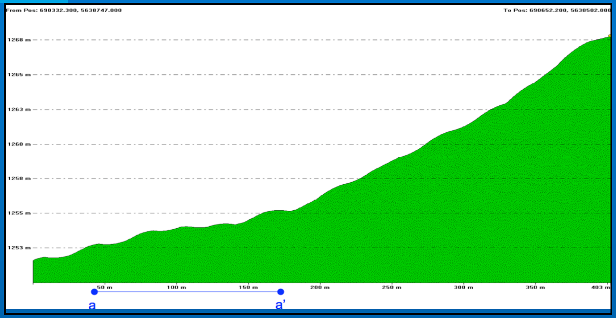
Background

- **Surface wave methods developed for geotechnical engineering and seismology purposes**
- **Current surface wave methods**
- **Multichannel Analysis of Surface Waves (MASW) method (Park et al., 1999)**



Cochrane
Balzac
C.P.R.Y.
Jumping Pound
Bowness
Jumpingpound
CALGARY
Elbow
River
IND. RES
Bragg Creek
MOOSE MTN. 7991
Fish
Midnapore
Millarville
Kew
BLANE 9650
Turner Valley
Black Diamond
MT. BURNS 9545
MT. DYSON
Hartell
51.187500° N
51.125000° N
51.062500° N
51.000000° N
50.937500° N
50.875000° N
50.812500° N
50.750000° N
50.687500° N
50.625000° N
50.500000° N
114.375000° W
114.312500° W
114.125000° W
114.062500° W
0 km
5 km
15 km
25 km
35 km
PALEOCENE
58-61
58. Sandstone, shale, conglomerate; ash beds; coal; includes COALSPUR BEDS; 58a, may include some Upper Cretaceous beds
59. PASKAPOO FORMATION: sandstone, shale, conglomerate; bentonitic shale; siliceous limestone; thin coal
60. PORCUPINE HILLS FORMATION: buff weathering sandstone; grey shale, carbonaceous shale, conglomerate; thin coal
61. RAVENSCRAG FORMATION: sandstone and shale
MONTANA
43-45
43. BELLY RIVER FORMATION: grey and green sandstone and shale; bentonitic, carbonaceous, and concretionary shales; conglomerate; coal
44. BRAZEAU FORMATION: sandstone, shale, conglomerate; ash beds; coal;
44a, includes some WAPIABI FORMATION
45. ALLISON FORMATION: light-coloured sandstone and shale; may include some post-Montana beds
COLORADO (Mainly): 35-39
37-39
37. SMOKY GROUP (Includes KASKAPAU and BAD HEART FORMATIONS): dark grey shale and carbonaceous shale; reddish brown weathering sandstone. Marine
38. ALBERTA (Benton) GROUP comprising BLACKSTONE (Lower Alberta), BIGHORN (Cardium), and WAPIABI (Upper Alberta) FORMATIONS: dark shale, sandy shale; sandstone and pebble-conglomerate. Marine
39. LA BICHE FORMATION: grey and dark grey shale; some sand. Marine
32,33
32. McMURRAY FORMATION: (Includes 'Tar Sands'): mostly sandstone; minor shale and conglomerate. Parts impregnated with bitumen
33. BLAIRMORE GROUP (CADOMIN, LUSCAR, and MOUNTAIN PARK FORMATIONS): basal, hard conglomerate; sandstone and sandy shale, conglomerate, carbonaceous shale, coal; green and brown weathering grey shale and sandstone, thin coal; 33a, includes some SPRAY RIVER and FERNIE beds; 33b, includes some FERNIE and KOOTENAY beds; 33c, includes some NIKANASSIN and KOOTENAY beds; 33d, includes some KOOTENAY FORMATION and CROWSNEST volcanic rocks
CARBONIFEROUS AND (?) PERMIAN
MISSISSIPPIAN AND LATER
22
BANFF and RUNDLE FORMATIONS (undivided); 22a, includes some ROCKY MOUNTAIN FORMATION (quartzite and sandstone, in part phosphatic; arenaceous dolomite and limestone) and/or SPRAY RIVER FORMATION; 22A, BANFF FORMATION: banded, cherty, grey limestone; platy and calcareous shales; crinoidal and crystalline limestones, chert; 22B, RUNDLE FORMATION: cherty, crystalline, and crinoidal limestones; arenaceous dolomite; calcareous shale
N
50 m

Priddis Site



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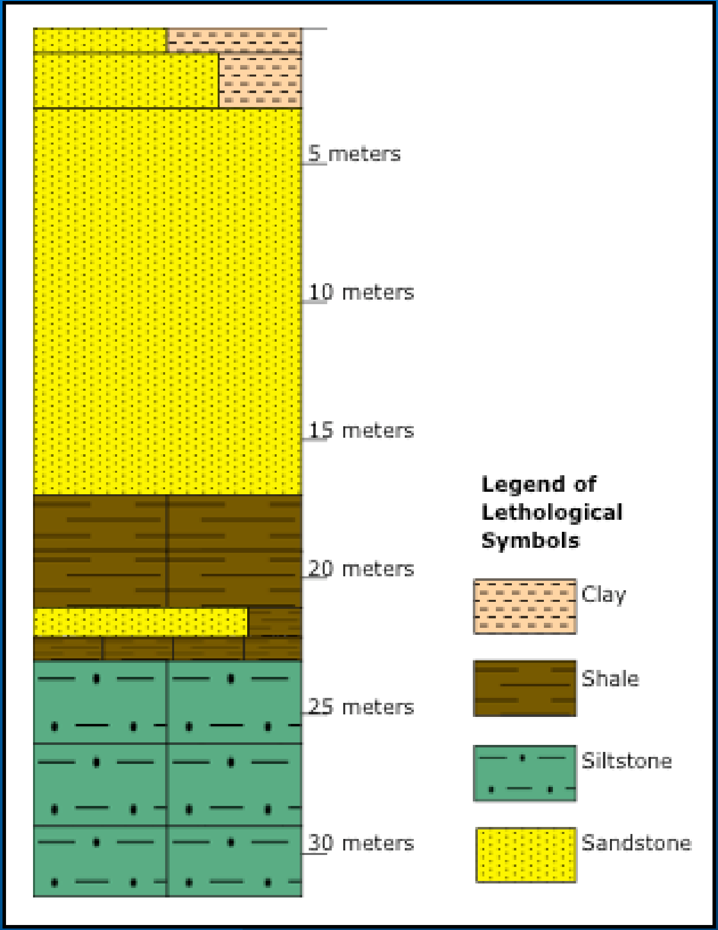
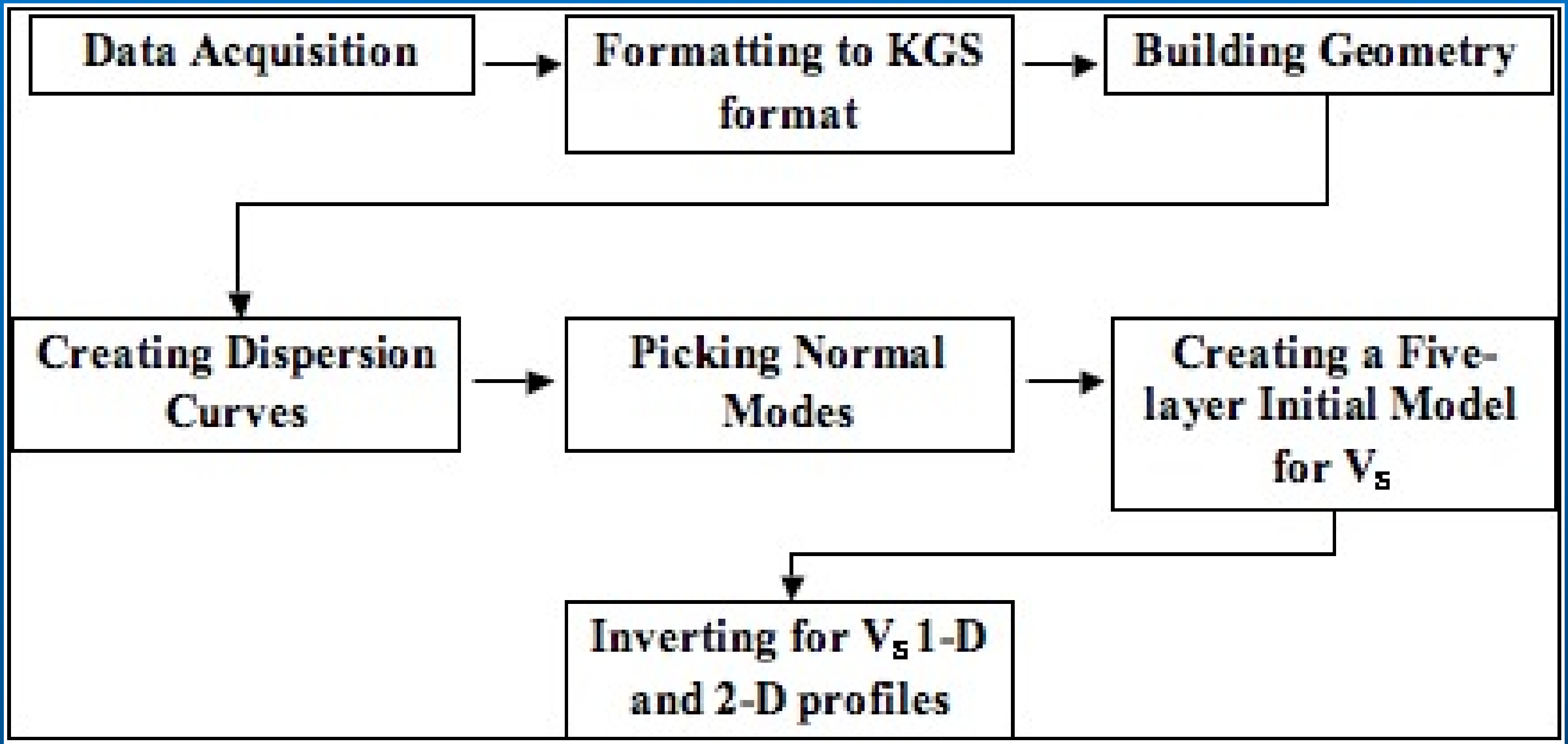
Well Data



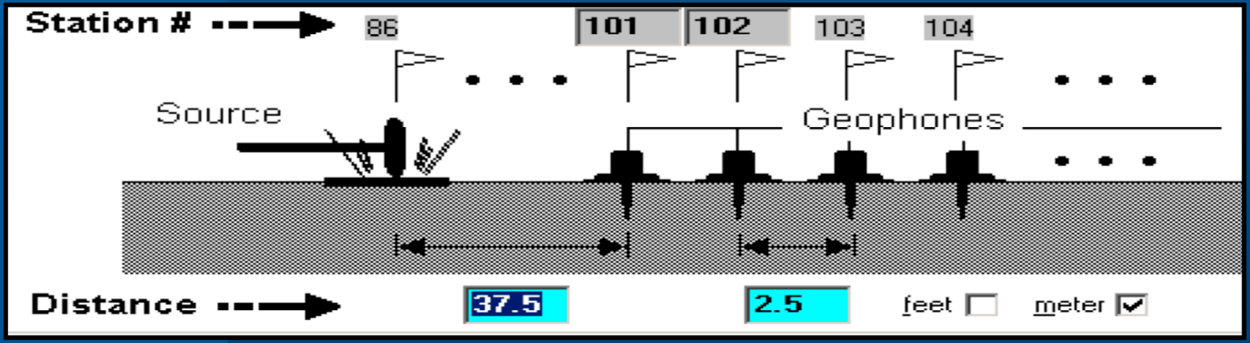
Depth (m)	P-wave velocity (m/s)
0-3.9	600
3.9-17.6	1900
17.6-28.3	2080
28.3-39.3	2250

Surface Wave Analysis Workflow

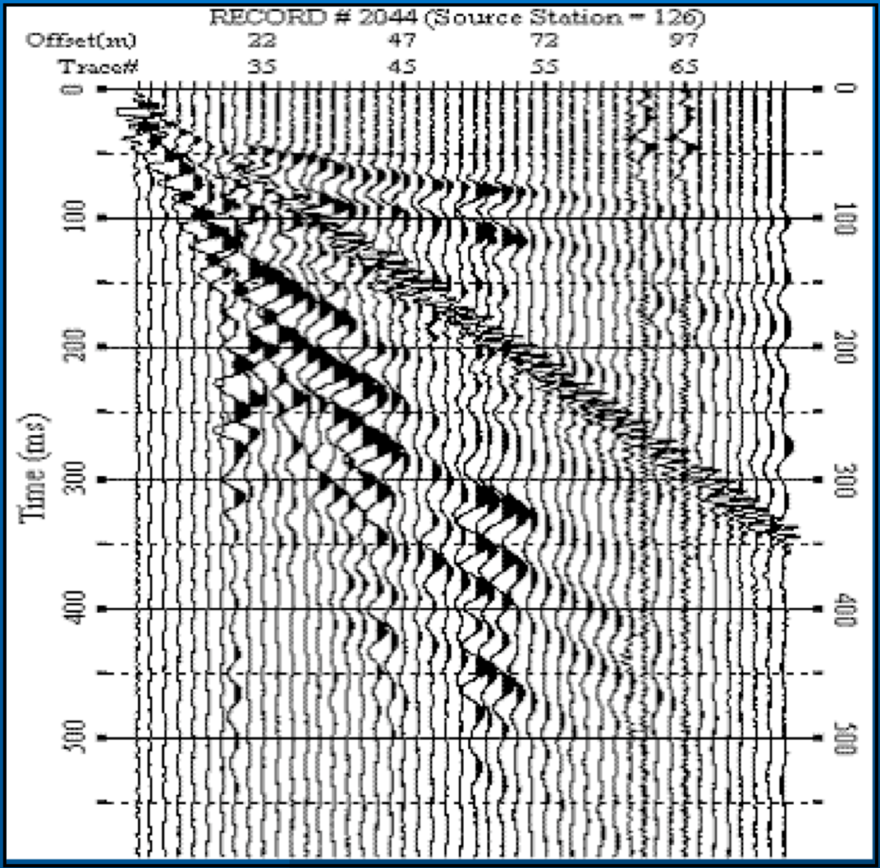


Acquisition Parameters

- A 5-pound sledgehammer source
- 10 Hz vertical geophones
- Receiver spacing~ 2.5 m
- Shot interval~ 12.5 m
- Near offset~ between 0 and 37.5 m
- Record length~ 600 ms
- Sample rate~ 0.125 ms



Shot Gather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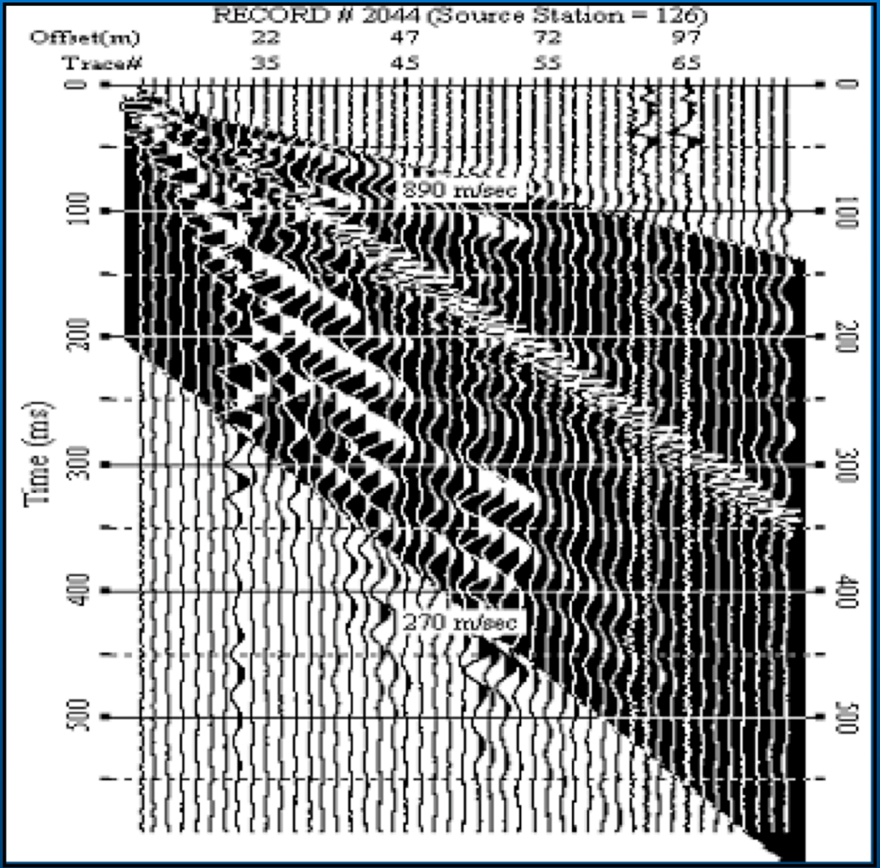
Offset(m) 22 47 72 97
Trace# 35 45 55 65
Time (ms)
0
100
200
300
400
500


RECORD # 2044 (Source Station = 126)
Offset(m) 22 47 72 97
Trace# 35 45 55 65
Time (ms)
890 m/sec
270 m/sec
0
100
200
300
400
500

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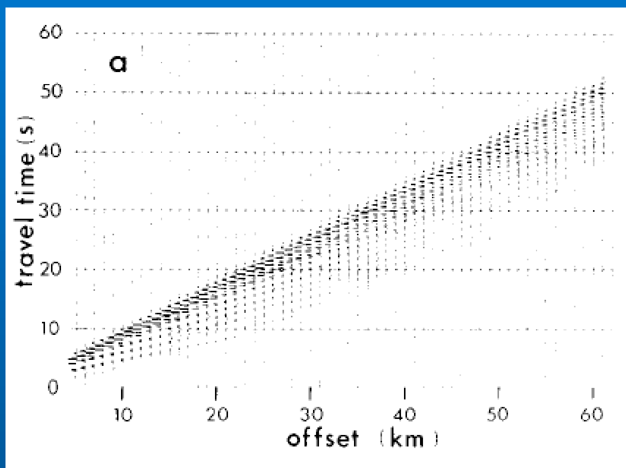
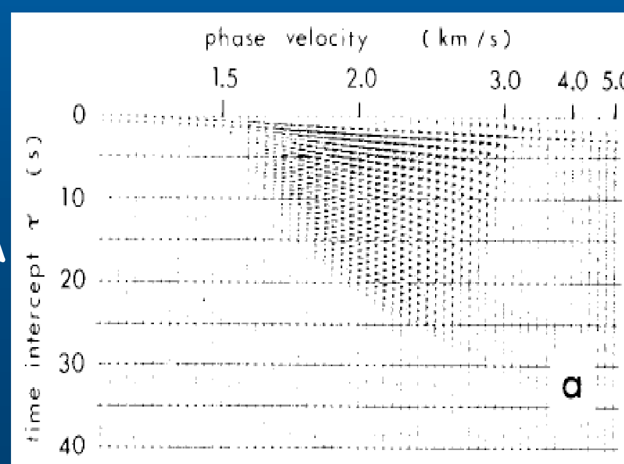
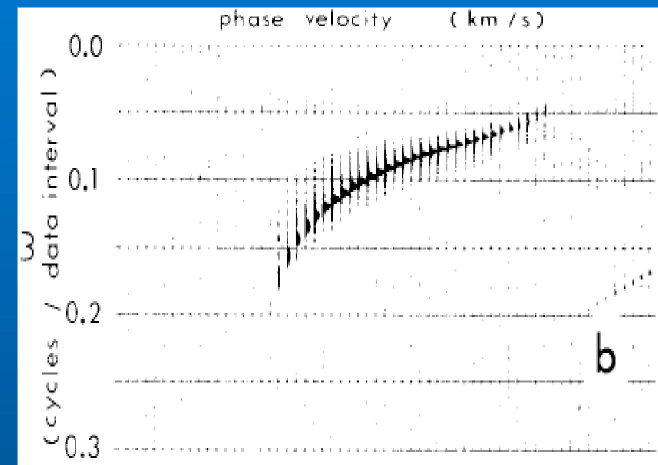
Dispersion Curve Calculation



Slant Stack



1-D Fourier Transform



(After McMechan & Yedlin, 1981)

(1) A shot gather: $u(x,t)$

(2) Fourier Transform: $U(x,\omega) = \int u(x,t)e^{i\omega t}dt$

$U(x,\omega)$ is expressed as the multiplication of the phase spectrum, $P(x,\omega)$, and the amplitude spectrum, $A(x,\omega)$

$$U(x,\omega) = A(x,\omega)P(x,\omega) = A(x,\omega)e^{-i\phi x}$$

where $\phi = \frac{\omega}{c_\omega}$, and c_ω is the phase velocity.

(3) Transformation:

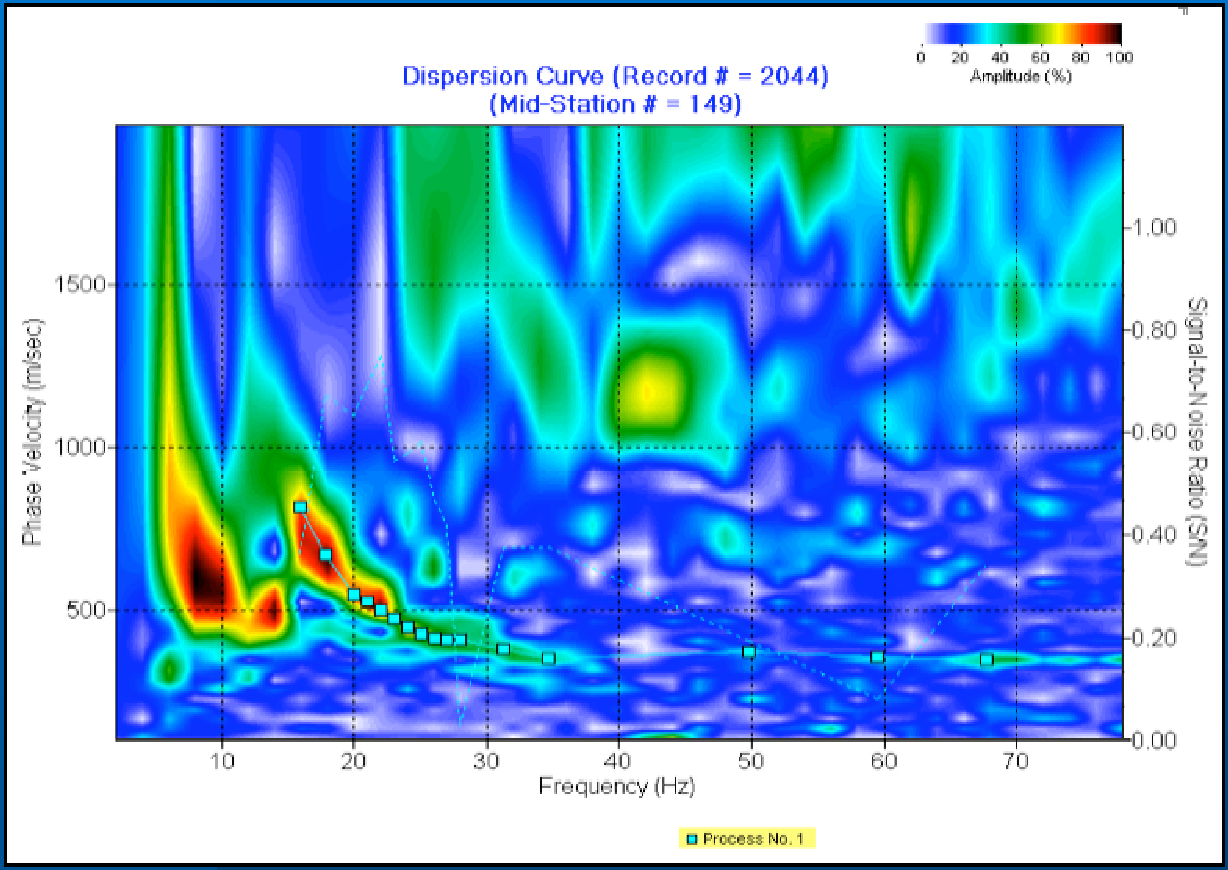
$$E(\omega,\theta) = \int e^{i\theta x}\left[U(x,\omega)/\left|U(x,\omega)\right|\right]dx = \int e^{-i(\phi-\theta)x}\left[A(x,\omega)/\left|A(x,\omega)\right|\right]dx$$

where θ is an offset-dependent phase shift.

This will have a maximum at $\phi = \theta = \frac{\omega}{c_\omega}$. c_ω can be estimated where peak of E occurs.

(Park et al., 1998)

Dispersion Curve



The cutoff frequency, f_{cn}, of the n[th] mode:

$$f_{cn} = \frac{V_s(n + \frac{1}{2})}{2h}$$

, where h is the thickness of the layer

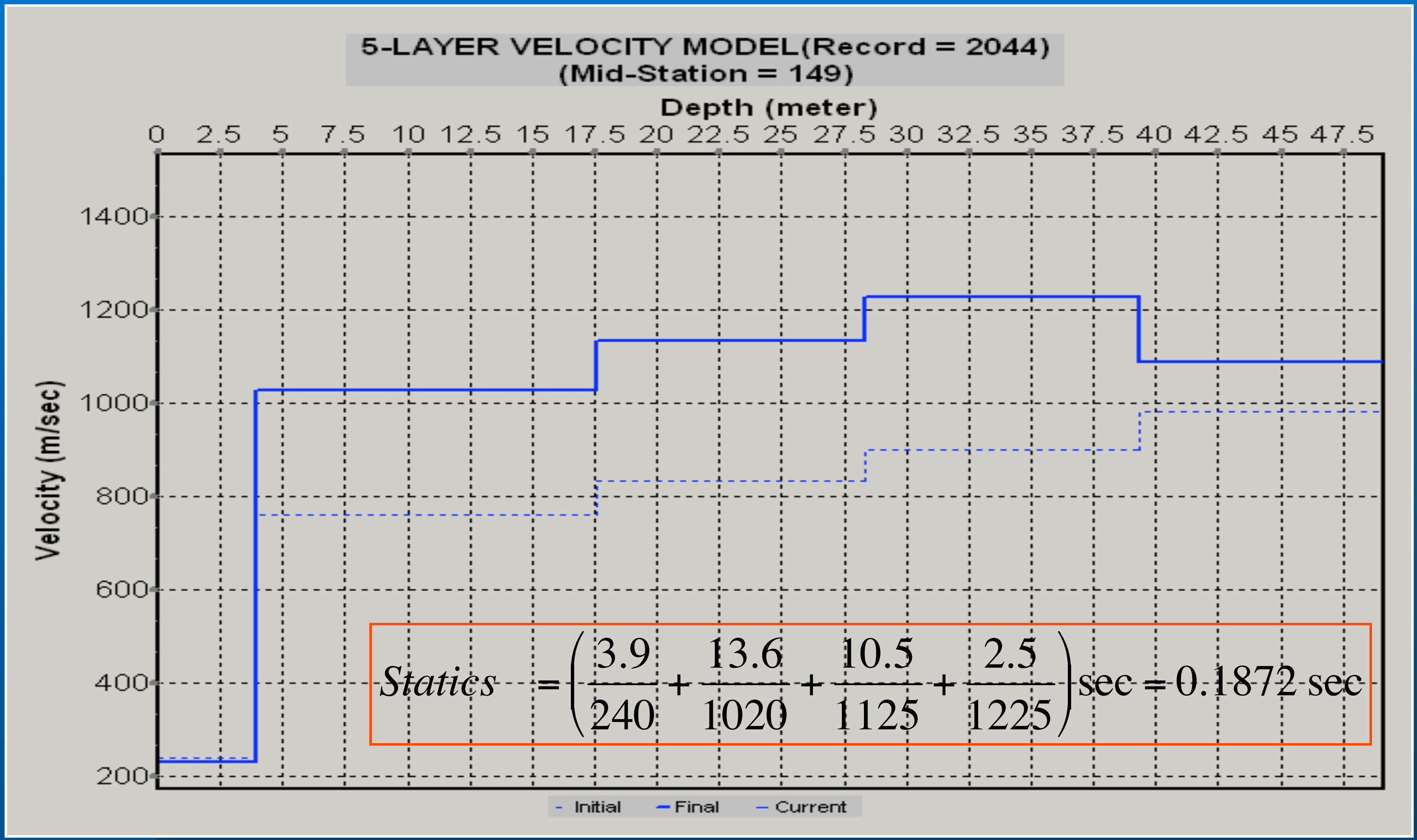
Inversion

- **Initial model:**
  - P-wave velocity and depth from well data
  - Constant Poisson's ratio~ 0.405

Layer	Bottom	Thickness	S-Vel (Vs)	P-Vel (Vp)	POS Ratio
1	3.900	3.900	240	600	0.405
2	17.600	13.700	760	1900	0.405
3	28.300	10.700	832	2080	0.405
4	39.300	11.000	900	2250	0.405
5	Half Space	Infinity	980	2450	0.405

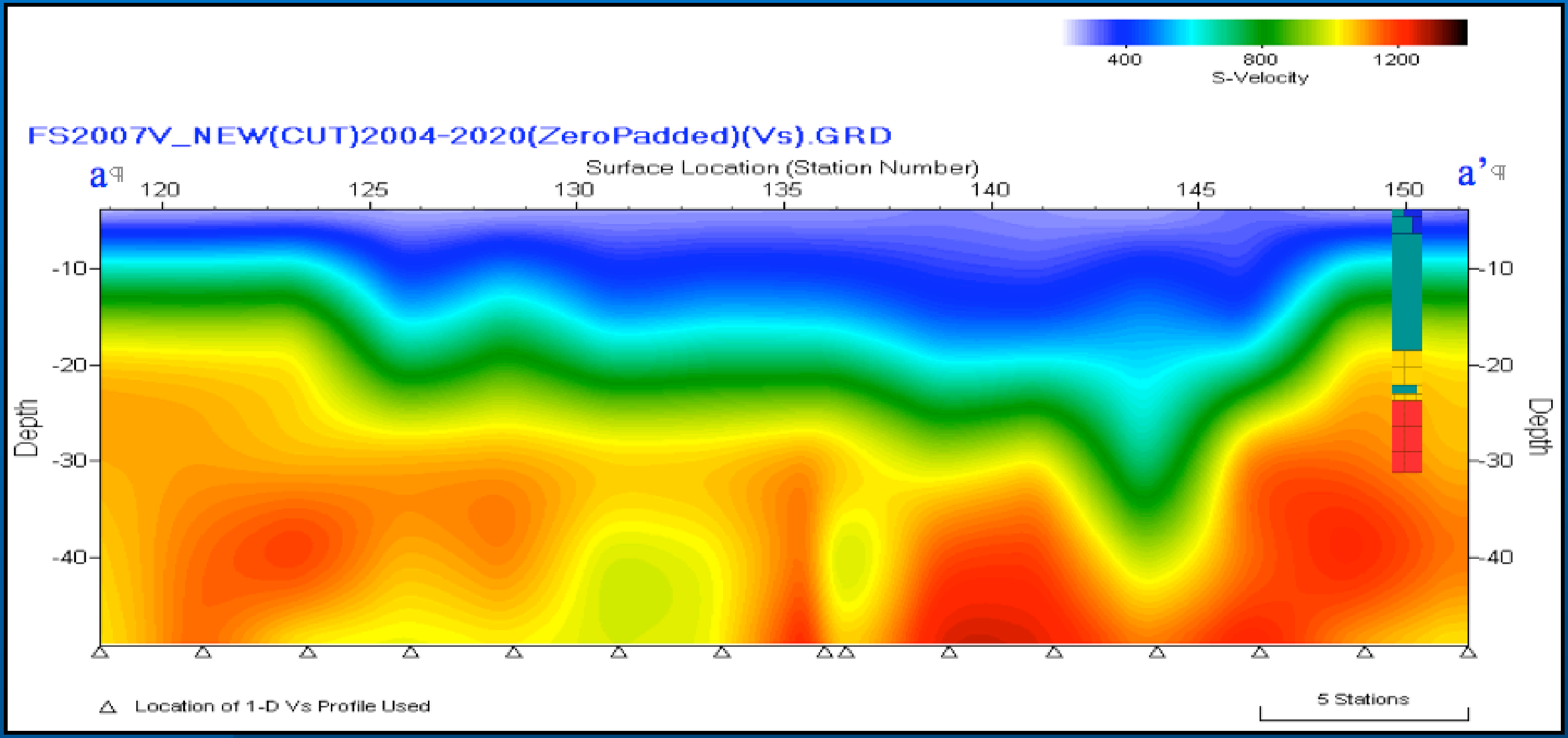
- **Inversion using SurfSeis**

Inverted S-wave Velocity vs. Initial Model



$$Statics = \left(\frac{3.9}{240} + \frac{13.6}{1020} + \frac{10.5}{1125} + \frac{2.5}{1225} \right) \sec = 0.1872 \sec$$

2-D S-wave Velocity Profile



Conclusion

- In a real layered earth, surface waves are dispersive with multiple modes.
- Different modes can be imaged using dispersion curves.
- Dispersion curves can be inverted for S-wave velocity model of the near surface.
- Well data of the near surface were analyzed for Priddis site, and showed good correlation with the surface wave inversion results.

Future Work

- Re-acquiring the seismic data with longer record length, and using a 3 component land streamer.
- Calculate S-wave static correction using surface wave methods.

Acknowledgments

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