Active-source seismology & OK Wavefields

Marianne Karplus

U.S. Array short course

August 2017

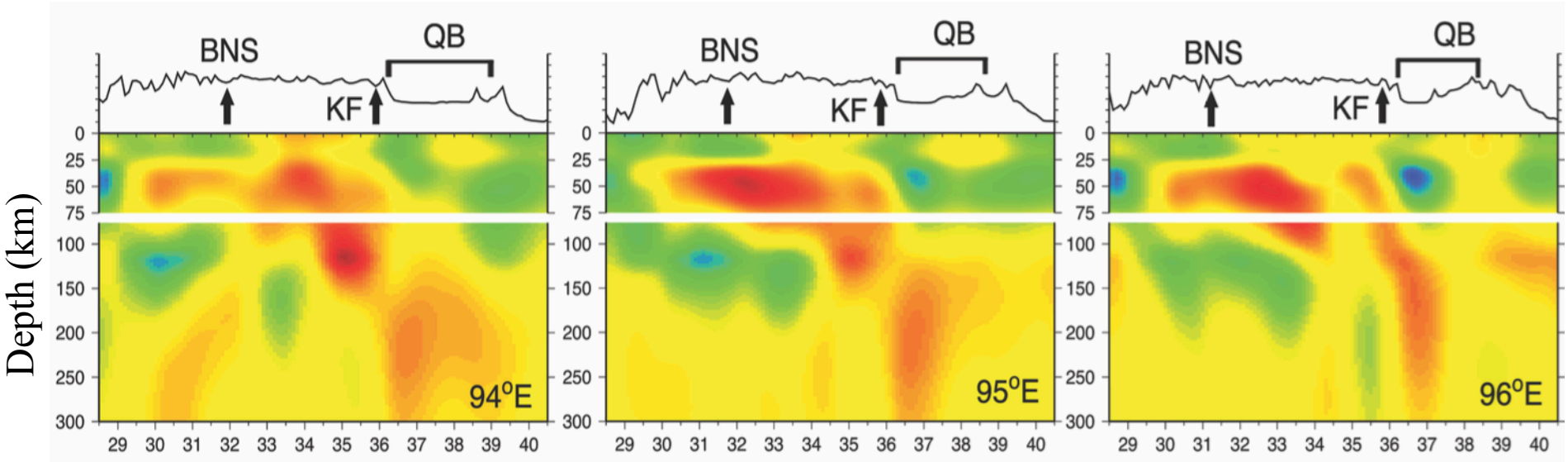
Bats do it… dolphins do it...

- Seismologists do it… glaciologists do it... Hydrologists do it...
- Basic idea: Make a sound and listen for an echo.
- How long did it take for the echo? (velocity)
  - Tells us about composition/ layer thickness
- Echos from layers within the earth/ ice
  - Tells us about rock properties/ presence of fluids

After Sridhar Anandakrishnan, Penn State

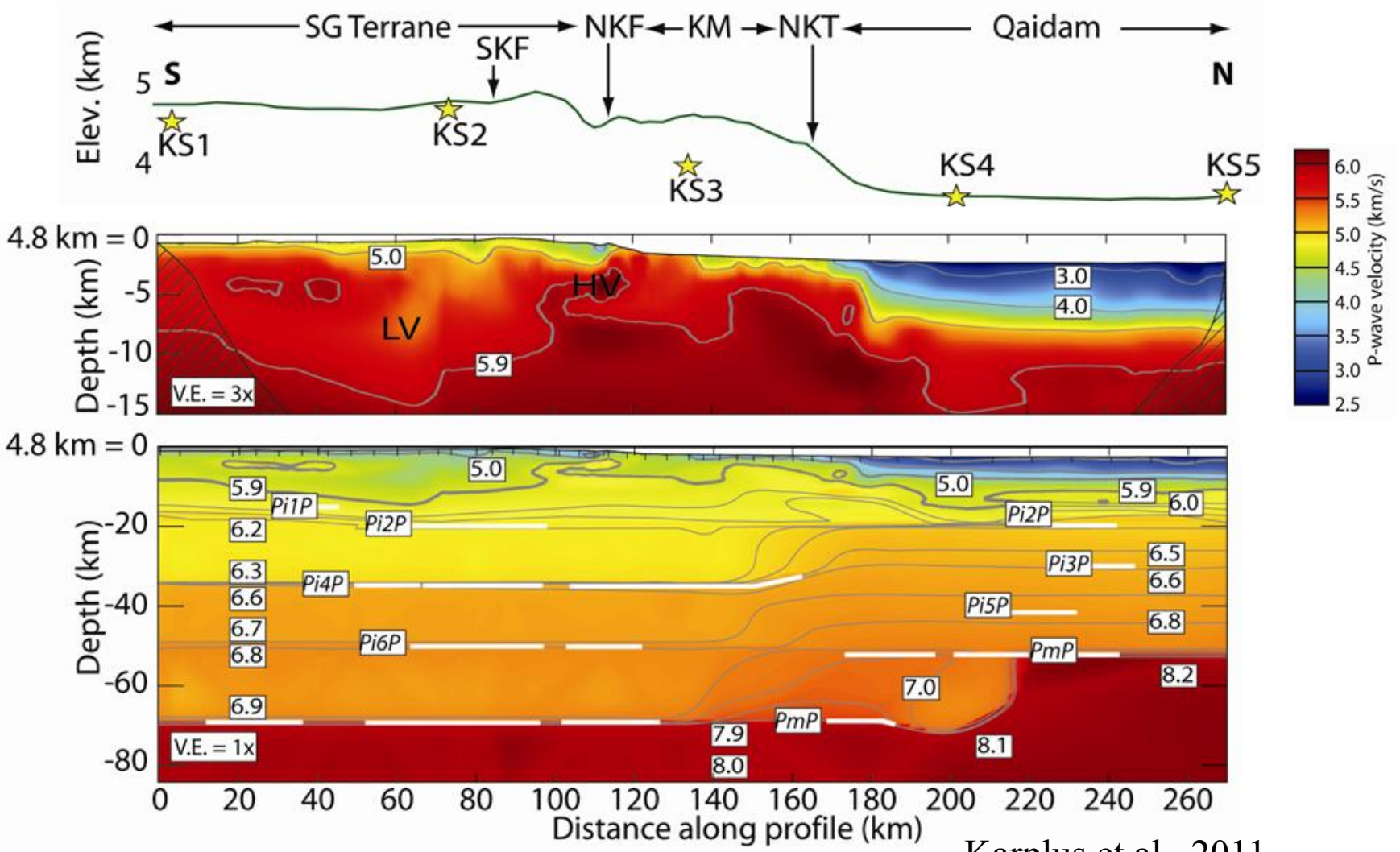
If you don't have many local sources… passive-source seismology has limited-resolution for subsurface imaging

One example of Vs velocity models from N. Tibet
Fundamental mode Rayleigh waves (2 plane wave tomography)



Ceylan et al., 2012

If you don't have many local sources… active-source seismology allows much higher resolution subsurface imaging



Karplus et al., 2011

Active-source seismology: key concepts

Overview: Acquisition & Processing
Physics: Rock physics, velocities, amplitudes, reflection / refraction raypaths
Mathematics: Time & frequency domains, Fourier transforms, amplitude & phase spectra, digital filtering, convolution, correlation

Sources & Receivers: dynamite, vibroseis, airguns; geophones & hydrophones

Arrays: surface sampling, surface ghosts, frequency effects CMP (common-midpoint) method, Stacking charts, Survey design

Velocity: measuring interval, rms, stacking, NMO & apparent velocities
Statics: refraction statics, automatic statics

Migration and DMO: migration equation; effects on stack data; wavefront, Kirchhoff, f-k, & finite-difference methods; time vs. depth migration

VSP (vertical seismic profiling), *3D seismics, S-waves, AVO* (amplitude-vs-offset)

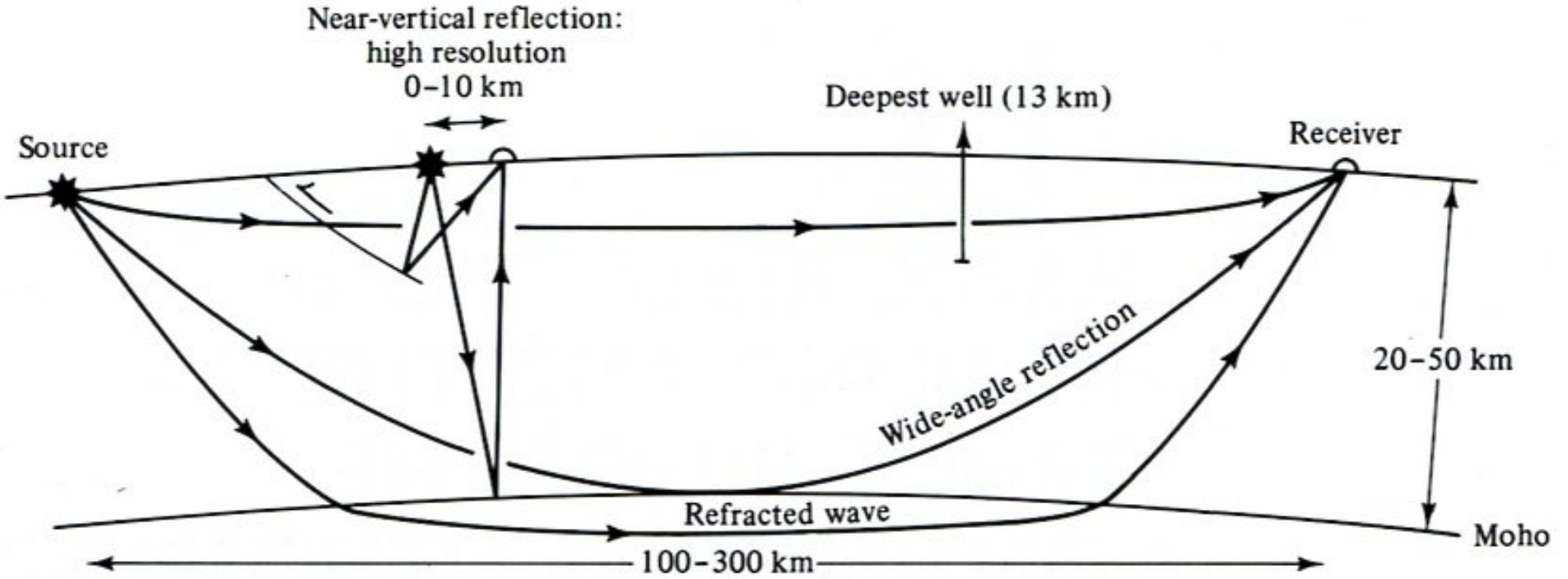
Historical development of active-source

Year	Acquisition	Processing
1849	First controlled-source seismic experiment (Robert Mallet exploded a barrel of gunpowder near Dublin)	
1919	First reflection experiment (quarry near DC, 4/12/1919, Clarence Karcher)	
1925	First oil discovered by refraction (Orchard Dome, SW of Houston using fan-shooting to spot fast velocities through shallow salt domes)	
1928	First oil discovered by reflection (Maud field, Oklahoma)	
1930s		Automatic gain control (AGC)
1940s	First marine profiles	
1950s	Analog magnetic recording	Common midpoint method (CMP) Trace stacking
1960s	Digital recording Vibroseis source (on land) Airgun source (at sea)	Deconvolution

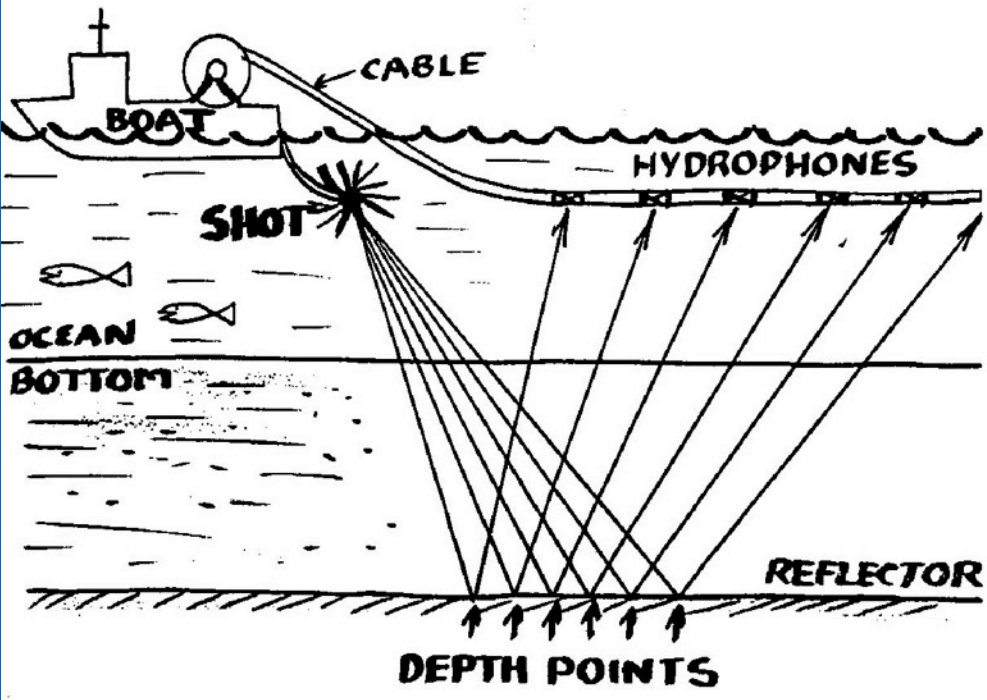
Reflection (near-vertical; offset ≤ penetration)

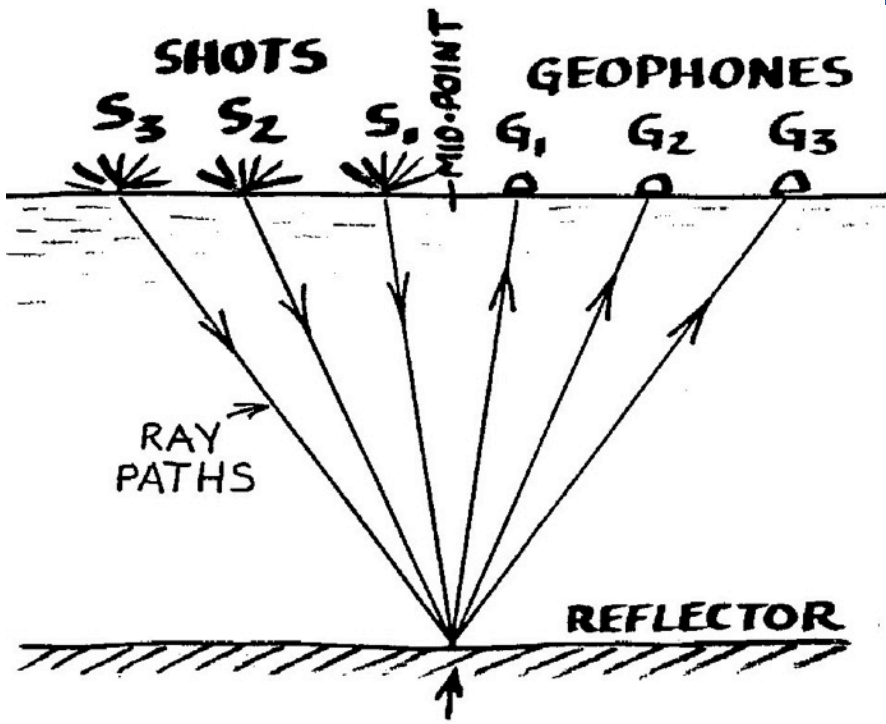
vs.

Refraction (wide-angle; penetration ≤offset)



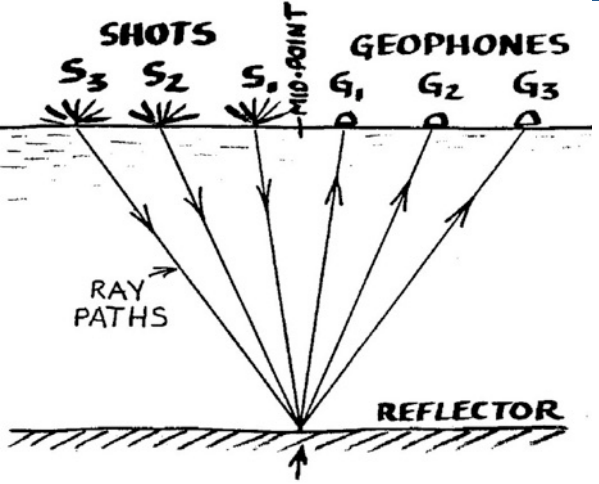
Refraction/wide-angle reflection: rays average crustal properties



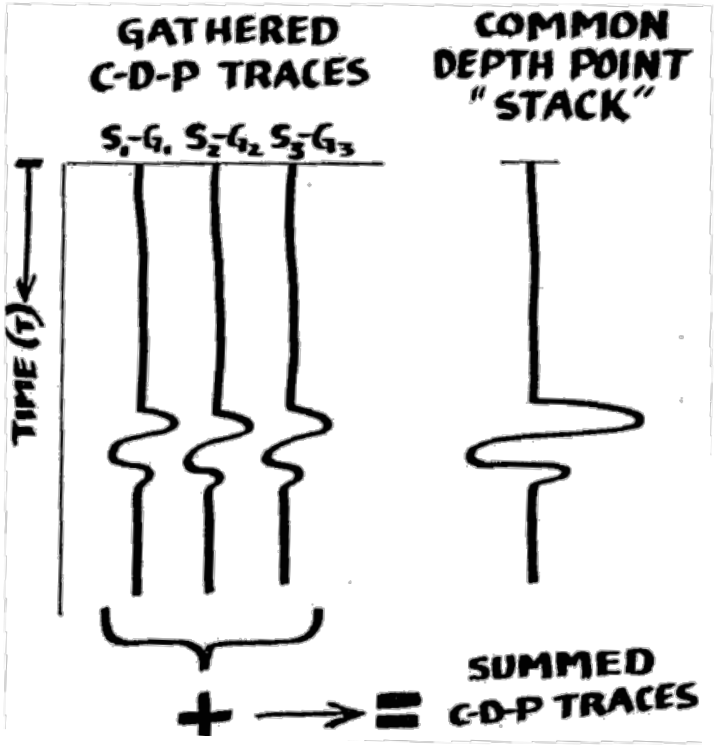


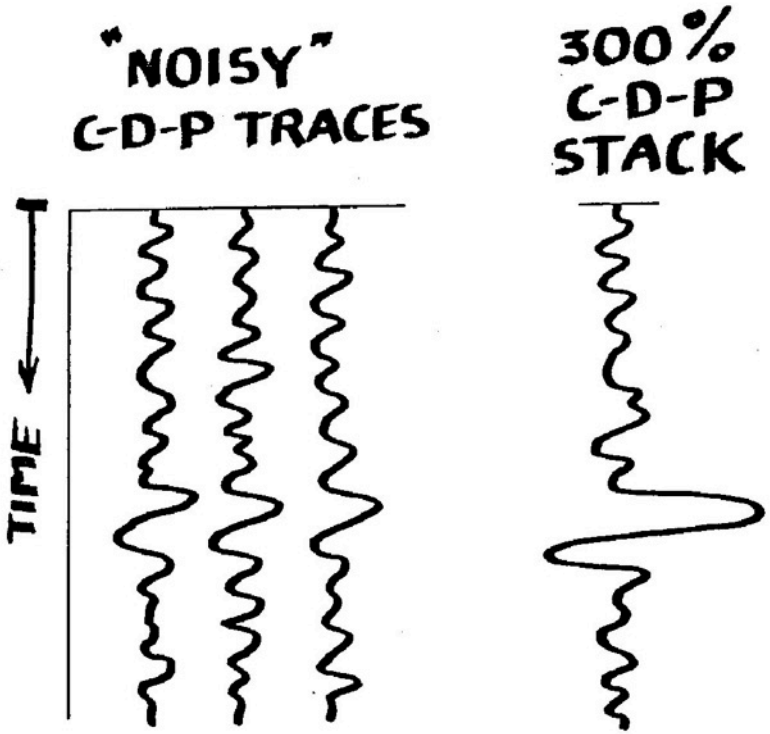
Single shot geometry:
all traces share a common source; the ensemble of recordings (traces) is a "common-source gather" or "shot gather"

CMP geometry:
all traces share a common surface source-receiver mid-point; for 1D geology, all traces share a common depth point (CDP)



Trace stacking enhances signal, and reduces noise





summing 3 traces provides a "stacking fold" of 3

Sources: hammer on aluminum plate

Xia, 2006

Sources: Betsy seis gun

Sources: accelerated weight drop

Sources: vibroseis

Sources: explosions

IRIS active seismic source facility at UTEP

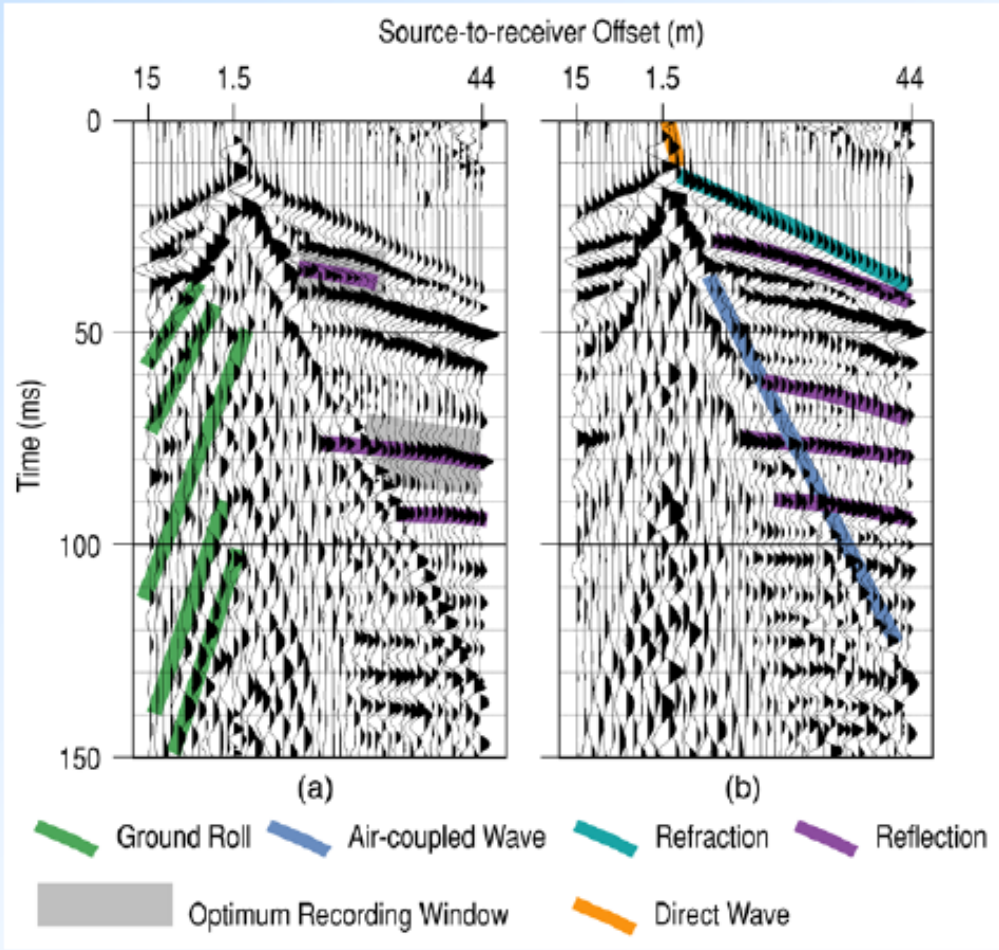
- Contact: Galen Kaip (gkaip@utep.edu) or Steve Harder at UTEP (harder@utep.edu)
- Resources, training opportunities, support for experiments
- UTEP ENAM project team (minus Steve Harder):

IRIS PASSCAL active-source equipment

- ~1200 “Texan” recorders w/ geophones – 1 component (includes ~320 UTEP Texans) – no longer supported
- L28 and L22 short period geophones
- 14+ Geodes – 24 channels (1-3 component)
- 3 Stratavisors – 60 channels
- 63 Fairfield 3C 5-Hz nodes
- 1 PEG-40 weight drop

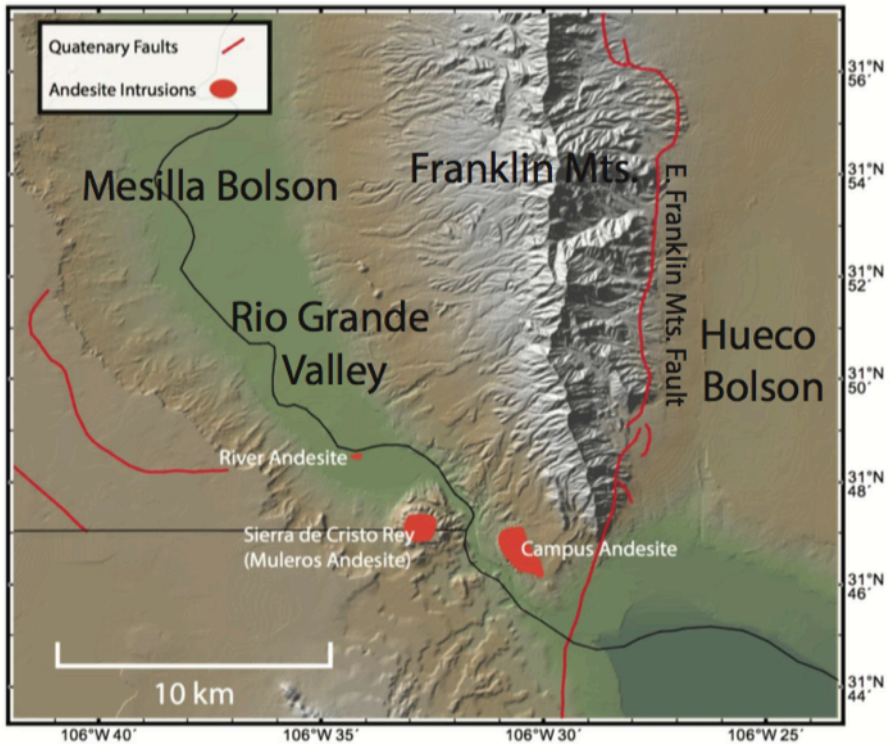
Seismic wavefield: interpreting shot gathers

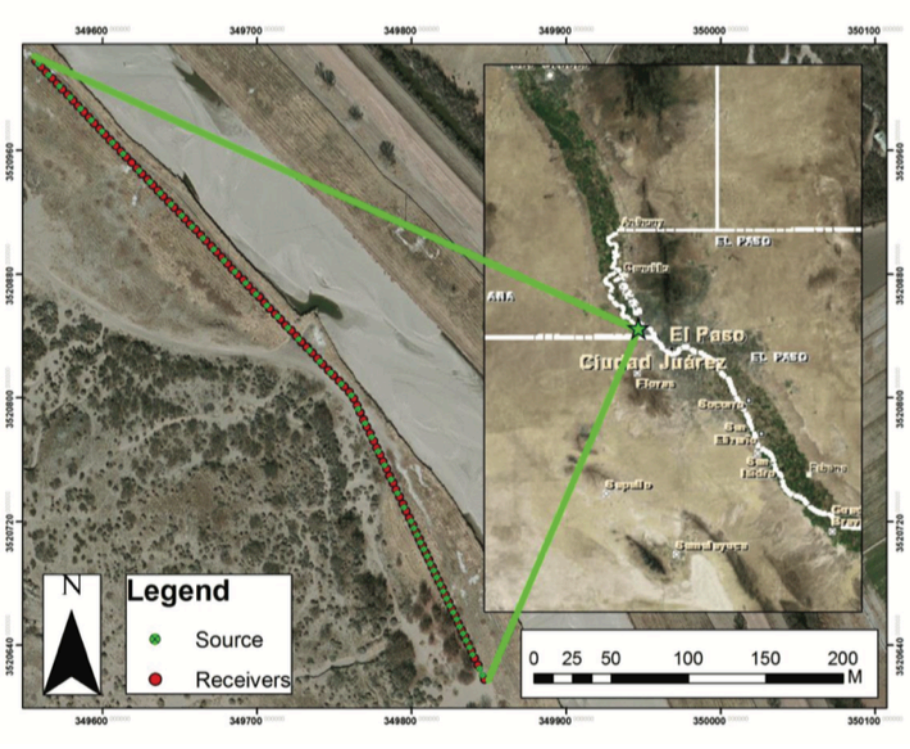
- Compressional and Shear
  - Body Waves
    - direct
    - refracted
    - reflected
    - diffracted
  - Surface Waves
    - Rayleigh
    - Love
- Air-Coupled Waves



Adapted from Lee Liberty

Research example: 500-m shallow seismic line, NM





Research example: 500-m shallow seismic line, NM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andesite outcrop
Rio Grande riverbed
© 2015 Google
© 2015 INEGI
111 m
Google earth
Tour Guide
1991
Imagery Date: 5/2/2014 lat 31.813704° lon -106.585699° elev 1142 m eye alt 1.65 km

Active-source survey geometry

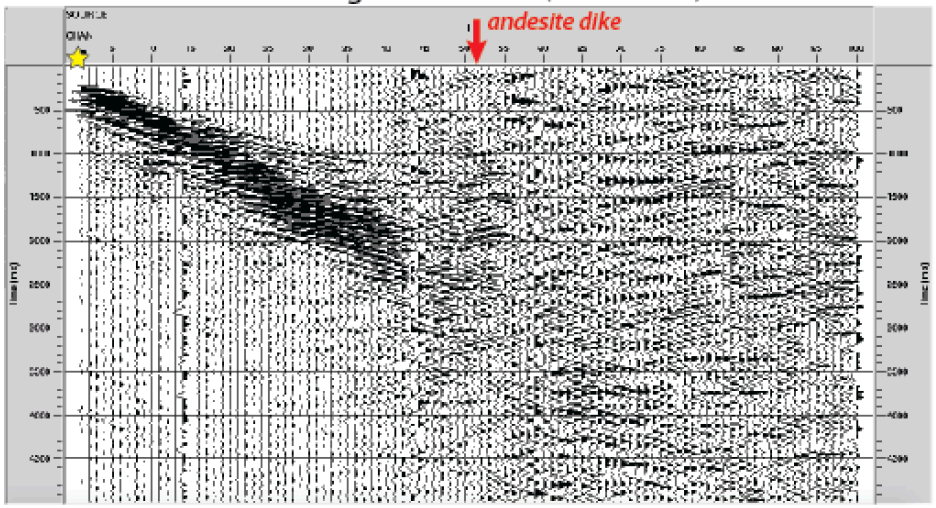
- 500 m long line
- Shots: Betsy seis gun: 5-10 m spacing
- Reftek Texans & 4.5 Hz geophones: 5 m spacing (100 1-C stations)
- Fairfield nodes: 10 m spacing (47 3-C stations)

Goals of shallow seismic survey

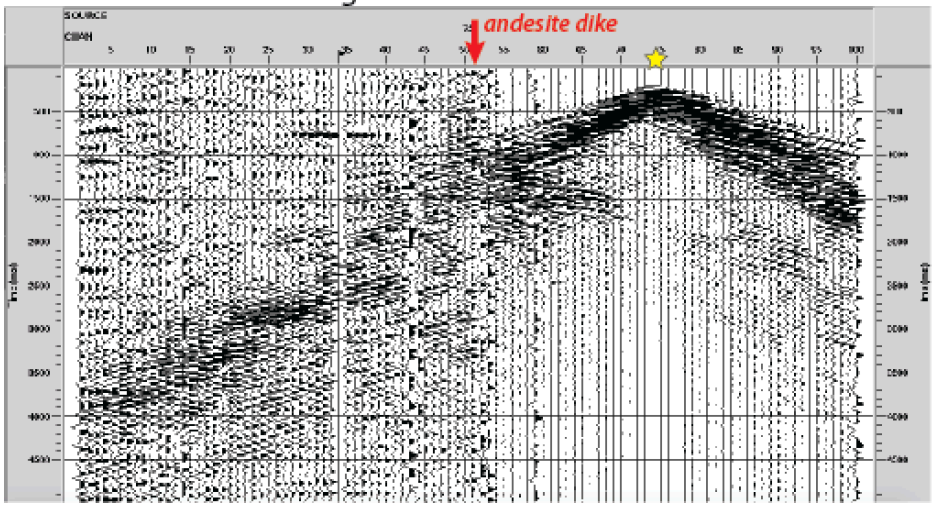
- Determine subsurface lithologies for top ~100 m based on velocity
- Determine depth of water table
- Determine depth extents and geometry of andesite
- Look at contact relationships between andesite and surrounding lithologies/ sediments
- Build on existing subsurface models of this region from gravity, electromagnetics, ground penetrating radar
- Test the Fairfield 5-Hz nodes compared to the Reftek Texans with a 4.5 Hz geophone

River dataset: shot gather examples (SEG-Y)

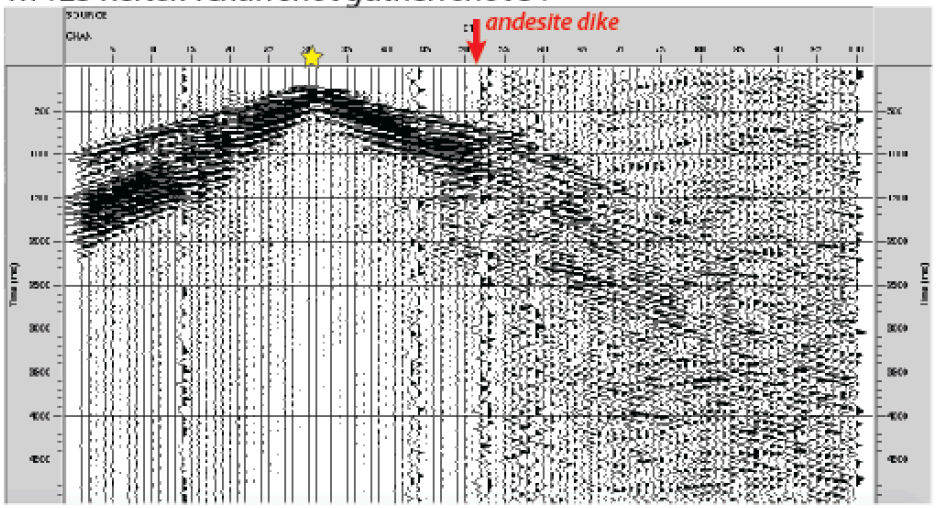
RT125 Reftek Texan shot gather: shot 1 (unstacked)



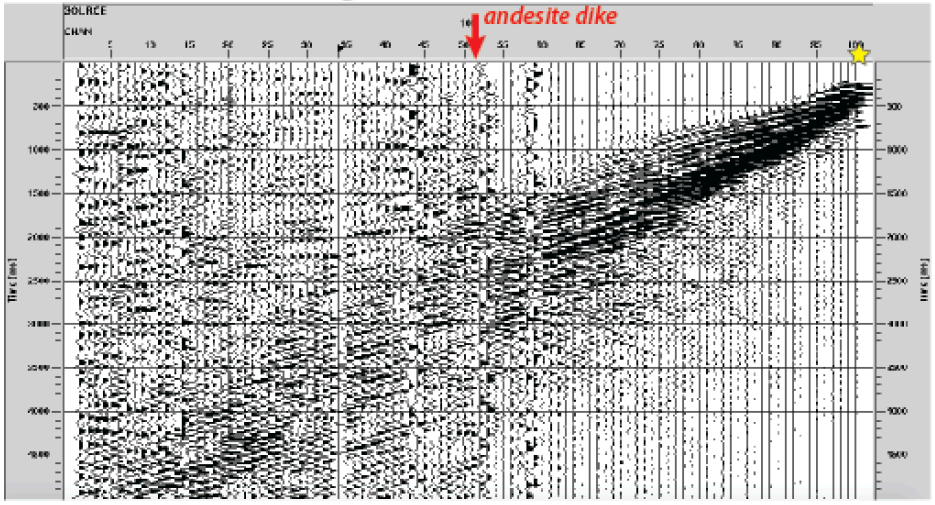
RT125 Reftek Texan shot gather: shot 75



RT125 Reftek Texan shot gather: shot 31



RT125 Reftek Texan shot gather: shot 101 (unstacked)



First arrival Vp~1.8-2.0 km/s.

P-waves, S-waves, "ground roll" (surface waves)

Velocity modeling, CMP stacking, reflection analysis, attenuation, etc.

Seismic data processing software

- Seismic Unix
- Landmark ProMAX
- Paradigm Focus
- Dolphin Geophysical OpenCPS (free for academic institutions)

Refraction velocity modeling

- Colin Zelt: RAYINVR, ZP, …
  http://terra.rice.edu/department/faculty/zelt/rayinvr.html
- John Hole: FAST 2D, FAST 3D, …
  http://www.geophys.geos.vt.edu/hole/software.html
- Cerveny SEIS81, …
  talk to Europeans (or me…)
- MATLAB options exist, but I don't know how robust they are
- SAC and earthquake tomography tools (e.g., Cliff Thurber at UW Madison)
- Full waveform inversion (e.g., Joanna Morgan, Mike Warner at Imperial in UK, John Hole at Virginia Tech, Stanford Exploration Project, UTIG - Austin, others…)

Reflection seismic interpretation

- IHS Kingdom

http://www.ihs.com/products/oil-gas-information/analysis-software/kingdom-seismic-interpretation/index.aspx

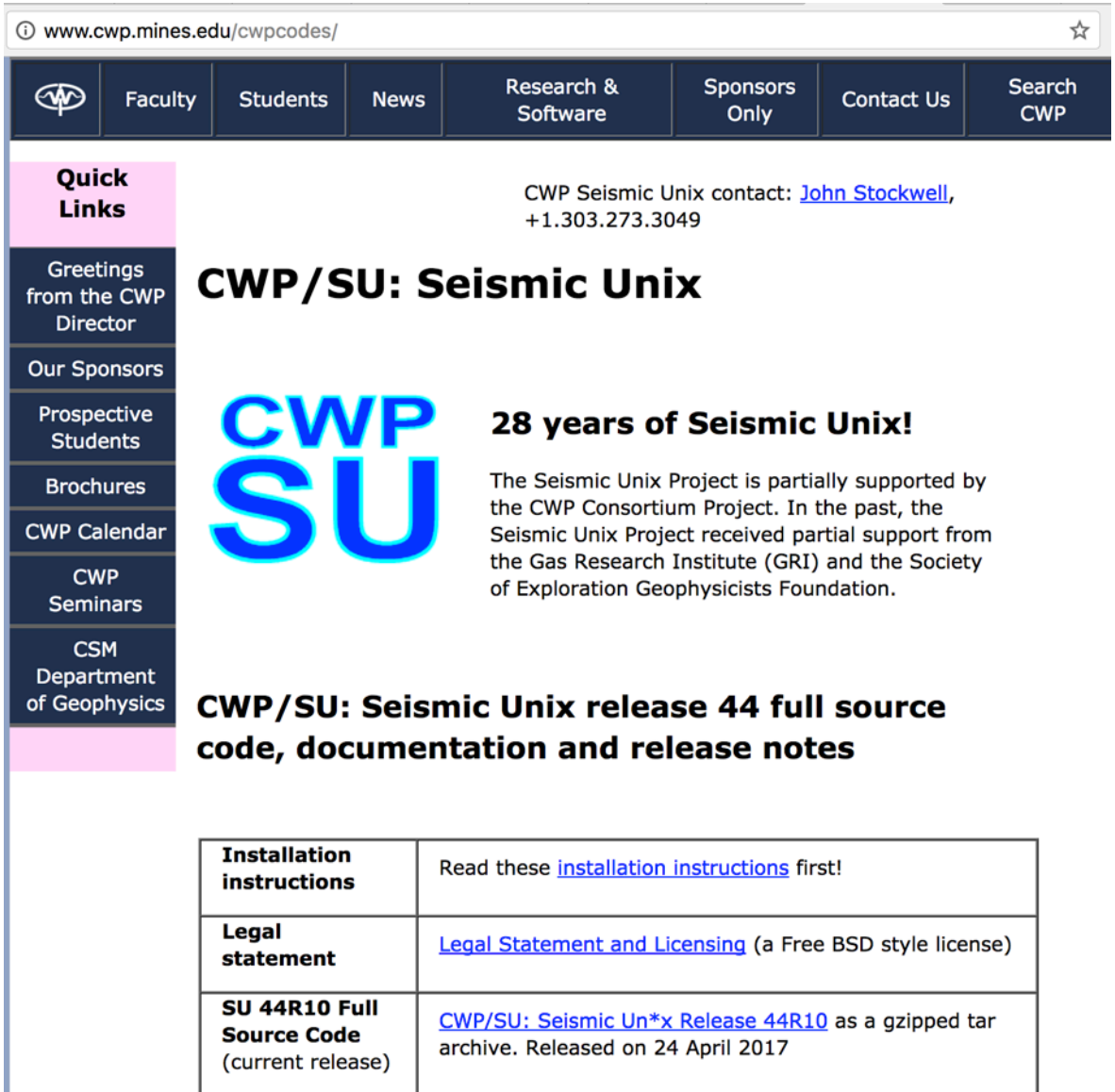
- Opendtect – Open Source seismic interpretation

http://www.opendtect.org/

- SeisWorks – Landmark/Haliburton
- Petrel – Schlumberger
- MATLAB options exist, but I don't know how robust they are

Processing the data: Seismic Unix – home page

http://www.cwp.mines.edu/cwpcodes/

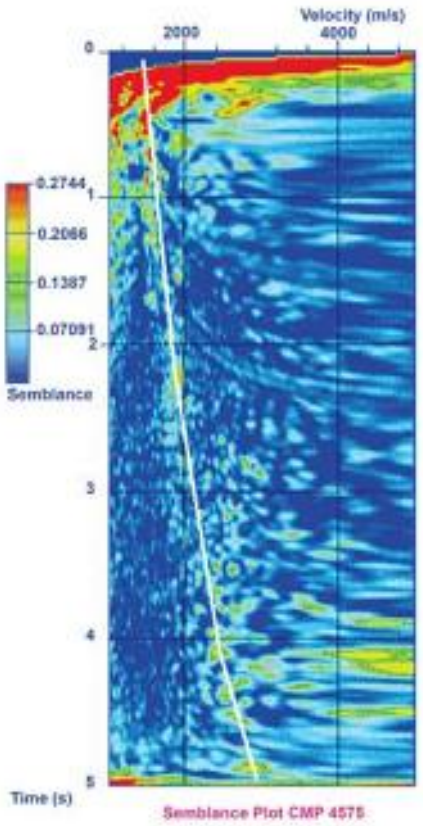


Online tutorial resource: http://library.seg.org/doi/book/10.1190/1.9781560801948

Seismic Data Processing with Seismic Un*x

A 2D Seismic Data Processing Primer

David Forel, Thomas Benz,
and Wayne D. Pennington



Course Notes Series No. 12
Lawrence M. Gochioco, Series Editor

SEG

Society of Exploration Geophysicists

Tips for setting up Seismic Unix

- Login to your account on karst:
- ssh -Y hpstrnXX@karst.uits.iu.edu
- Set environment variables in your bash shell.

- For example:

export CWPROOT=/N/u/hpstrn60/Karst/SeisUnix
export PATH=$PATH:$CWPROOT/bin

/N/u/hpstrn60/Karst/docs/PresentationFiles
Karplus.ActiveSource+Wavefields.v2.pdf

Seismic Unix help

- suhelp – list all available SU programs
- suname <program> – list SU programs with short description
- sudoc <program> – program documentation
- sufind <keyword> – search sudoc for keyword
- sukeyword –o – list header variables

Pipe (|), redirect out (>), redirect in (<)

- $ suplane | suxwigb (pipe)
- $ suplane > test.su (redirect out)
- $ suxwigb < test.su (redirect in)
- $ suplane | suxwigb & (ampersand)

(& frees up the terminal and runs the process in the background)

Basic examples with Seismic Unix

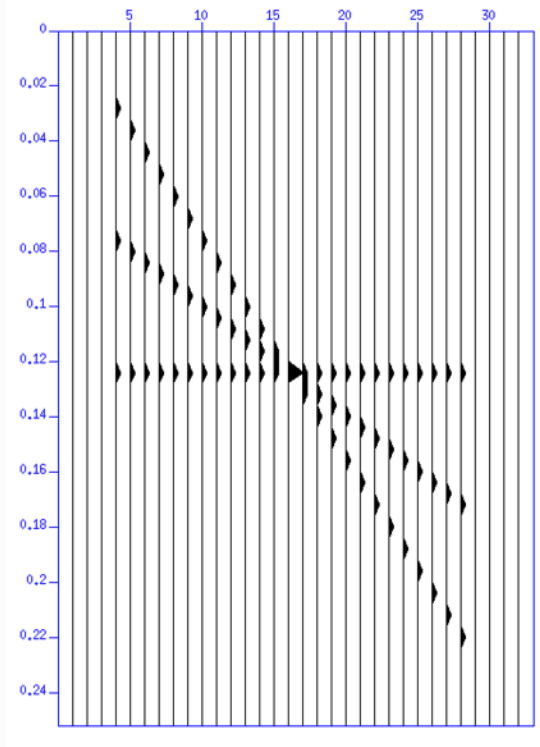
> suplane | suxwigb (Create 32 traces with 3 planes)

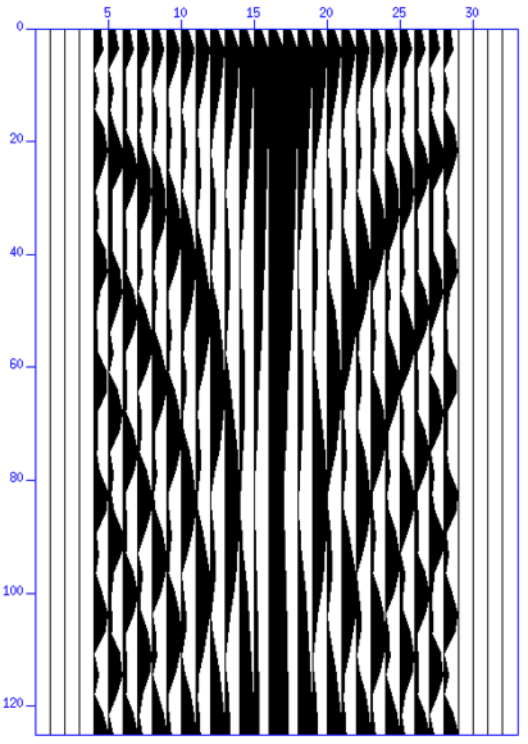
> suplane | suspecfx | suxwigb

> suplane > test.su

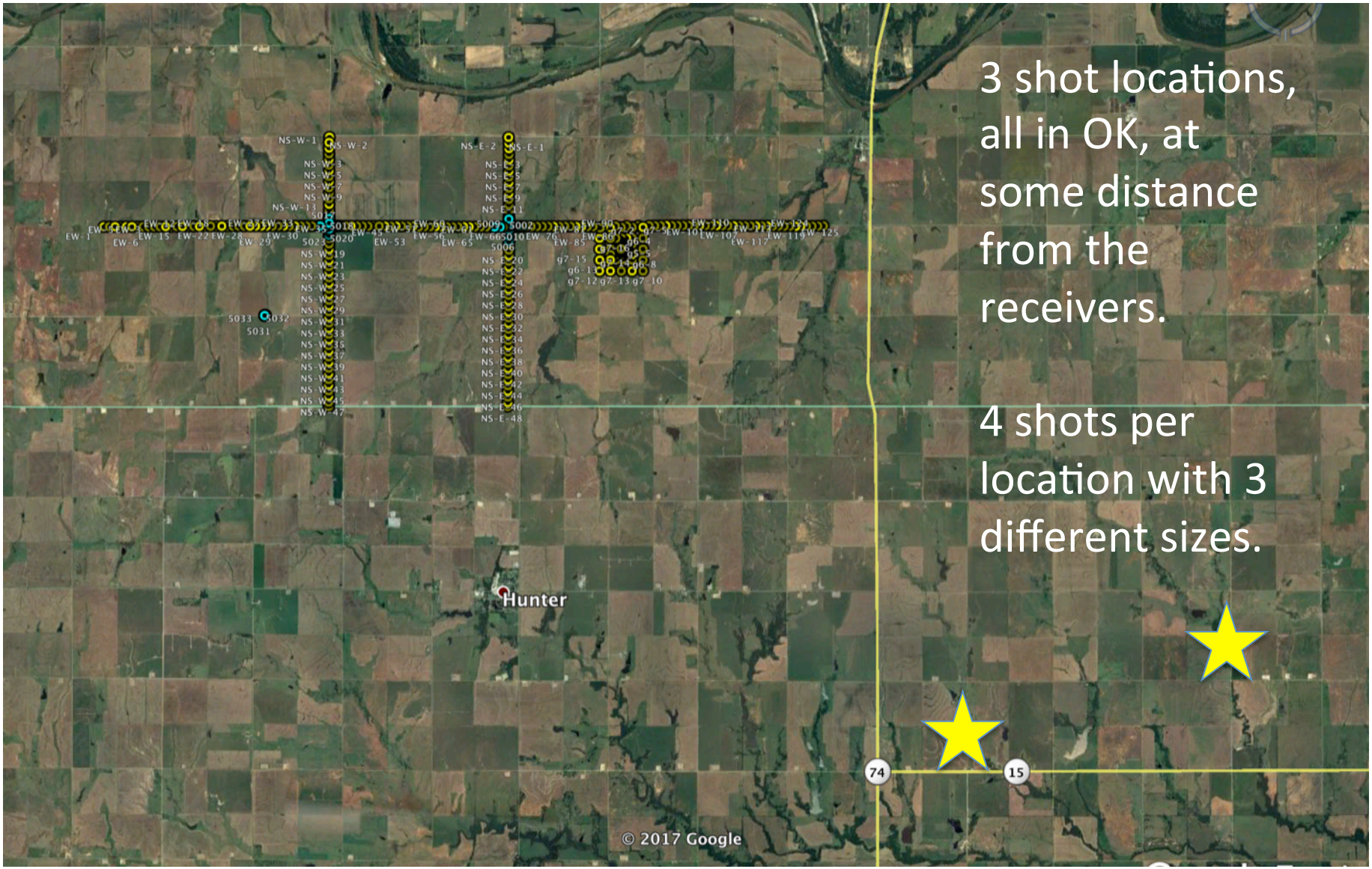
> suspecfx < test.su > test2.su

> suxwigb < test2.su label1='freq (Hz)' label2='trace number' title='Amplitude Spectrum' &

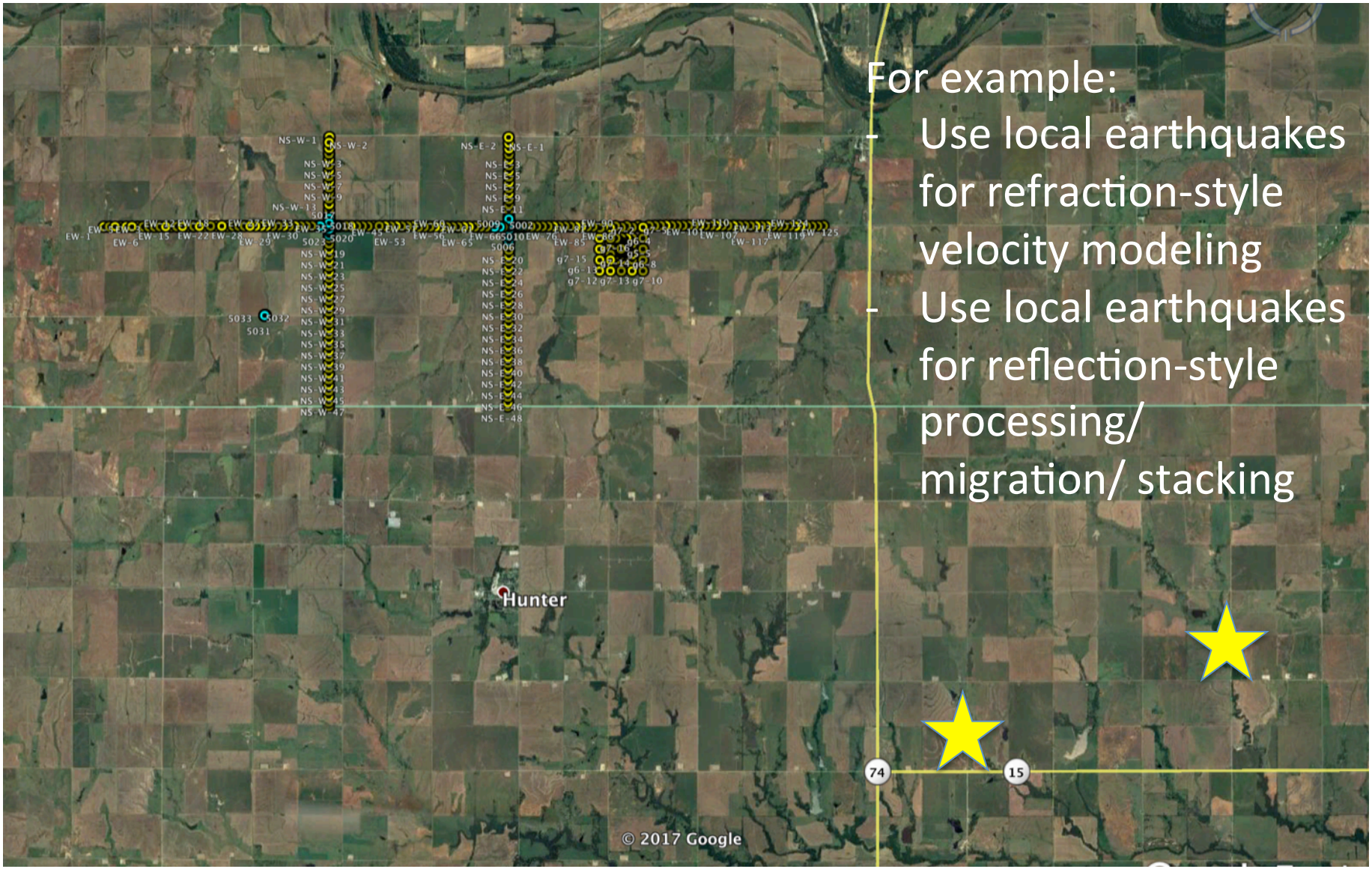




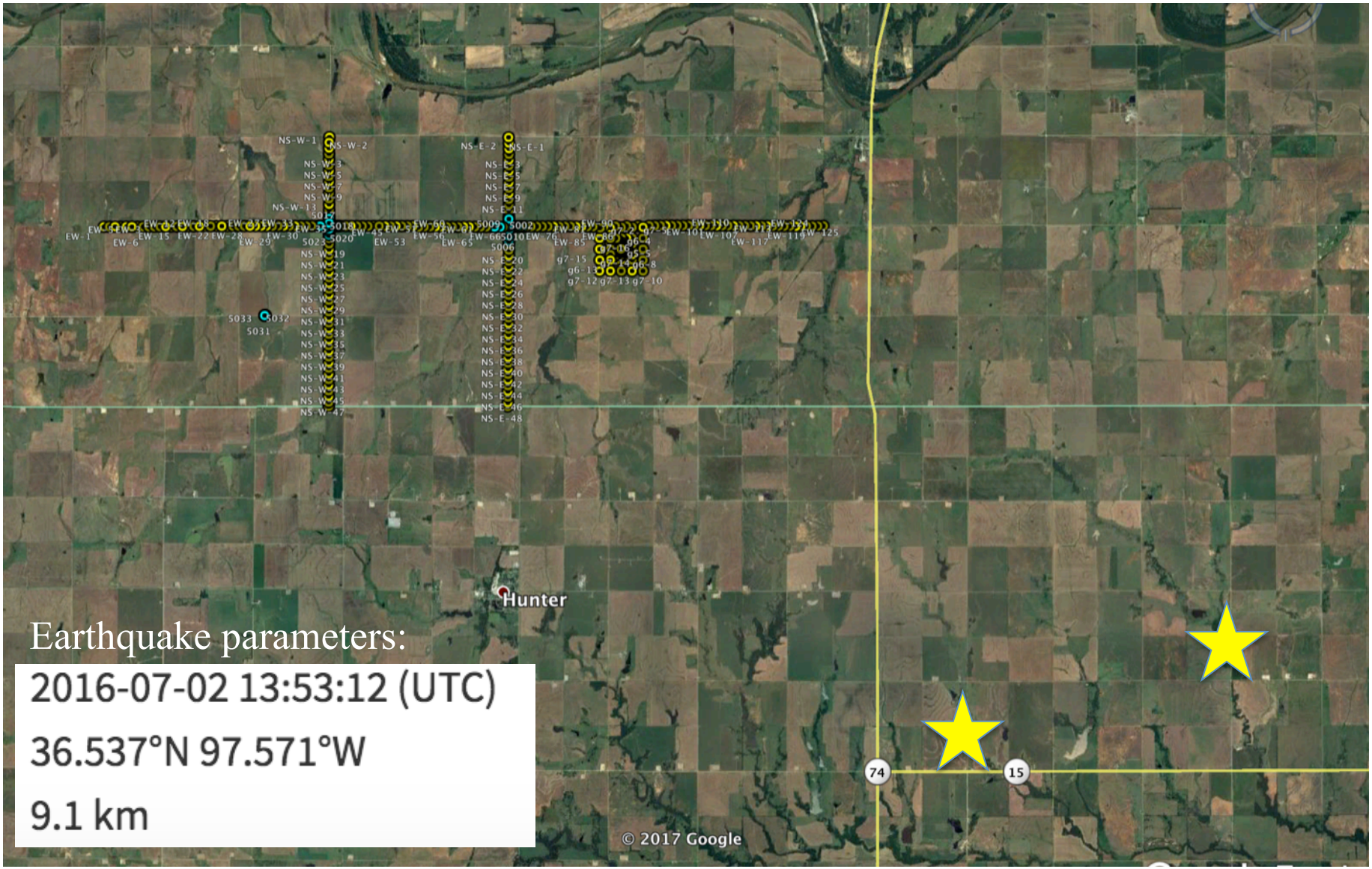
IRIS Wavefields active-source component



IRIS Wavefields active-source-style processing



Seismic Unix: looking at a Wavefields record section



Seismic Unix: looking at a Wavefields record section

> segyread - read SEG-Y standard files

> segywrite - write SEG-Y standard files

> sukeyword –o - prints a complete list of header values

> surange - provides the range of header values for a dataset

Copy data file eq.segy to your workspace:

cp /N/u/hpstrn60/Karst/karplus/eq.segy .

Now we want to read that file into SU. Create a text file called read_data.bash, and type the following into that file:

segyread tape=eq.segy conv=1 endian=0 | segyclean > eq.su

Seismic Unix: exploring the data

That file includes all 3 components of data in one SEG-Y file. We want to create individual files for the 3 different components.

susort < eq.su fldr offset > eq_sort.su
susplit < eq_sort.su key=fldr stem=eq_ middle=fldr suffix=.su numlength=1 verbose=1 close=1

This creates eq_fldr1.su, eq_fldr2.su, eq_fldr3.su.

surange < eq_fldr1.su
sugethw < eq_fldr1.su key=sx | more
sukeyword sx

>sugethw - gets the header values from each trace
>sushw - sets a new header value for each trace
>suwind - window trace data by keyword

http://www.seismicunix.com/w/Seismic_Unix_data_format

Seismic Unix – trace display

suximage - X windows image plot

suwigb - X windows bit-mapped wiggle plot

supsimage - postscript image plot

supswigb - postscript bit-mapped wiggle plot

supswigp - postscript polygon-filled wiggle plot

spsplot - plot postscript velocity models

ximage - uniformly sampled X image plot

Seismic Unix – trace display

Write another script file to read in the *.su file and display it in the x windows.

suxwigb < eq_fldr1.su

suxwigb/suximage

X Functionality:

Button 1	Zoom with rubberband box
Button 2	Show mouse (x1,x2) coordinates while pressed
q or Q key	Quit
s key	Save current mouse (x1,x2) location to file
p or P key	Plot current window with pswigb (only from disk files)
a or page up keys	enhance clipping by 10%
c or page down keys	reduce clipping by 10%
up,down,left,right keys	move zoom window by half width/height
i or +(keypad)	zoom in by factor 2
o or -(keypad)	zoom out by factor 2
l	lock the zoom while moving the coursor
u	unlock the zoom
1,2,...9	Zoom/Move factor of the window size

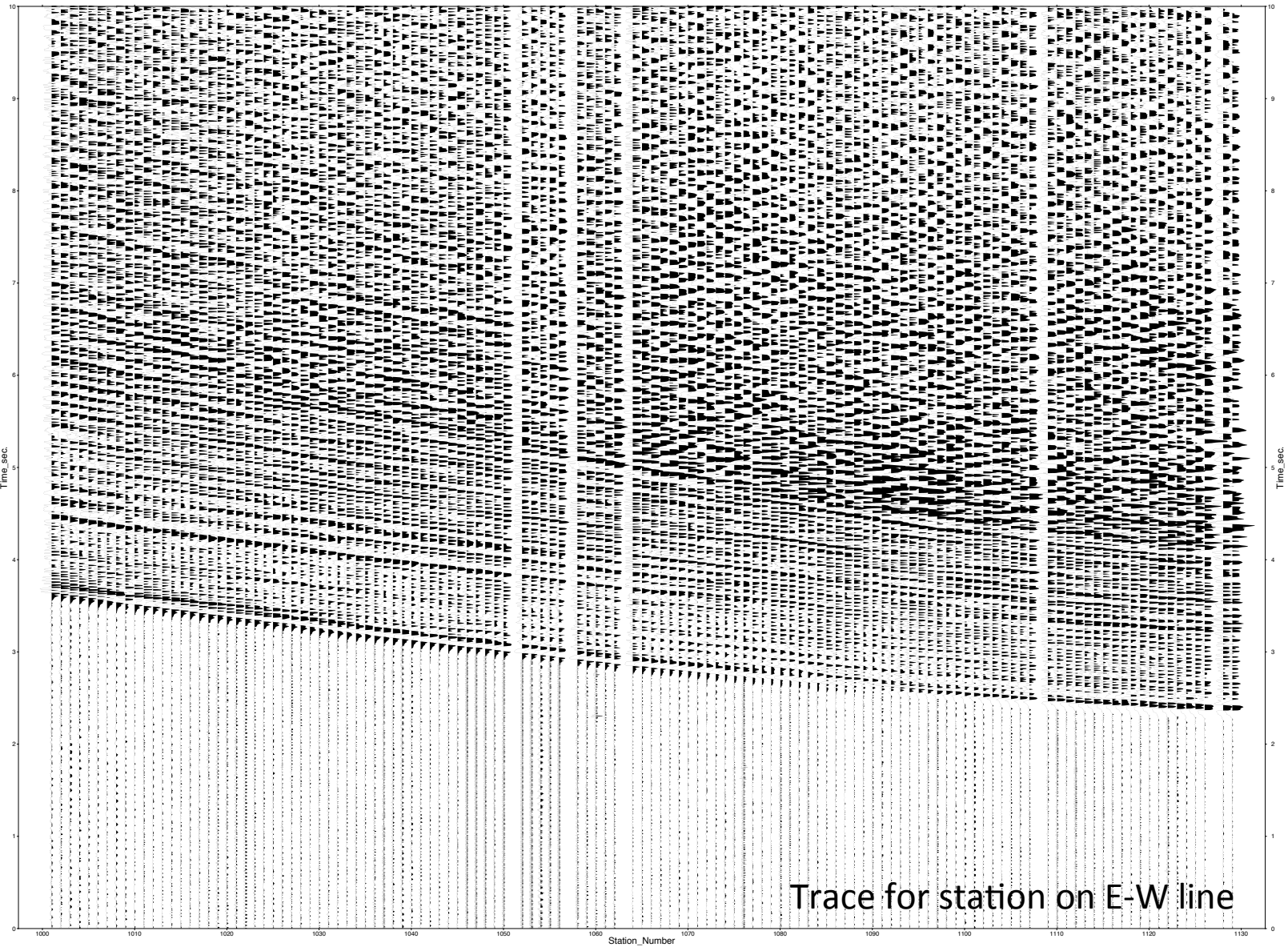
Seismic Unix – trace display

Write another script file to read in the *.su file and create a postscript display of it.

sufilter f=2,4,16,32 < eq_fldr1.su | suwind tmin=0 tmax=8 | suxwigb

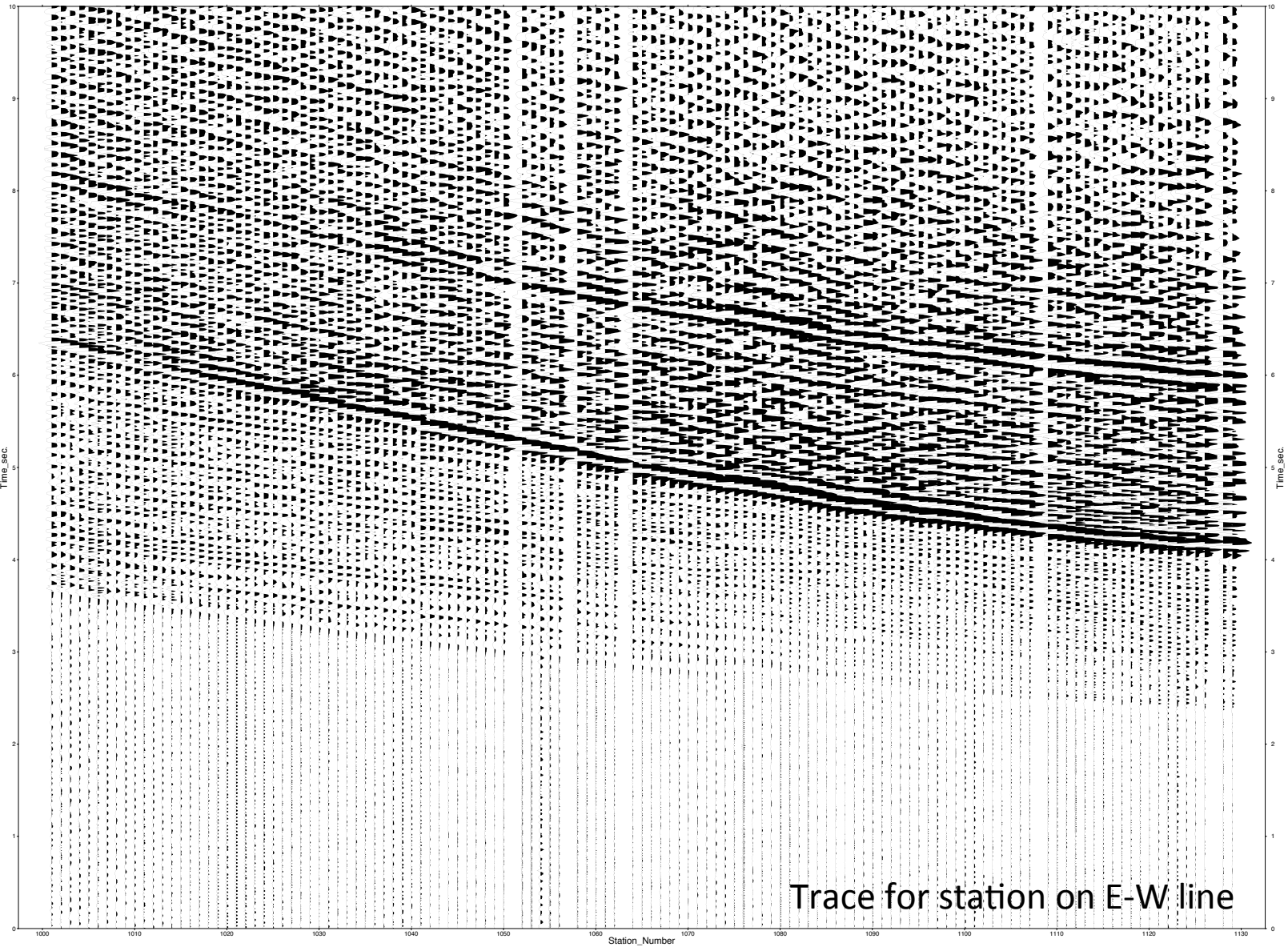
Try changing the window and filter parameters and see what happens.

E-W record section: earthquake vertical



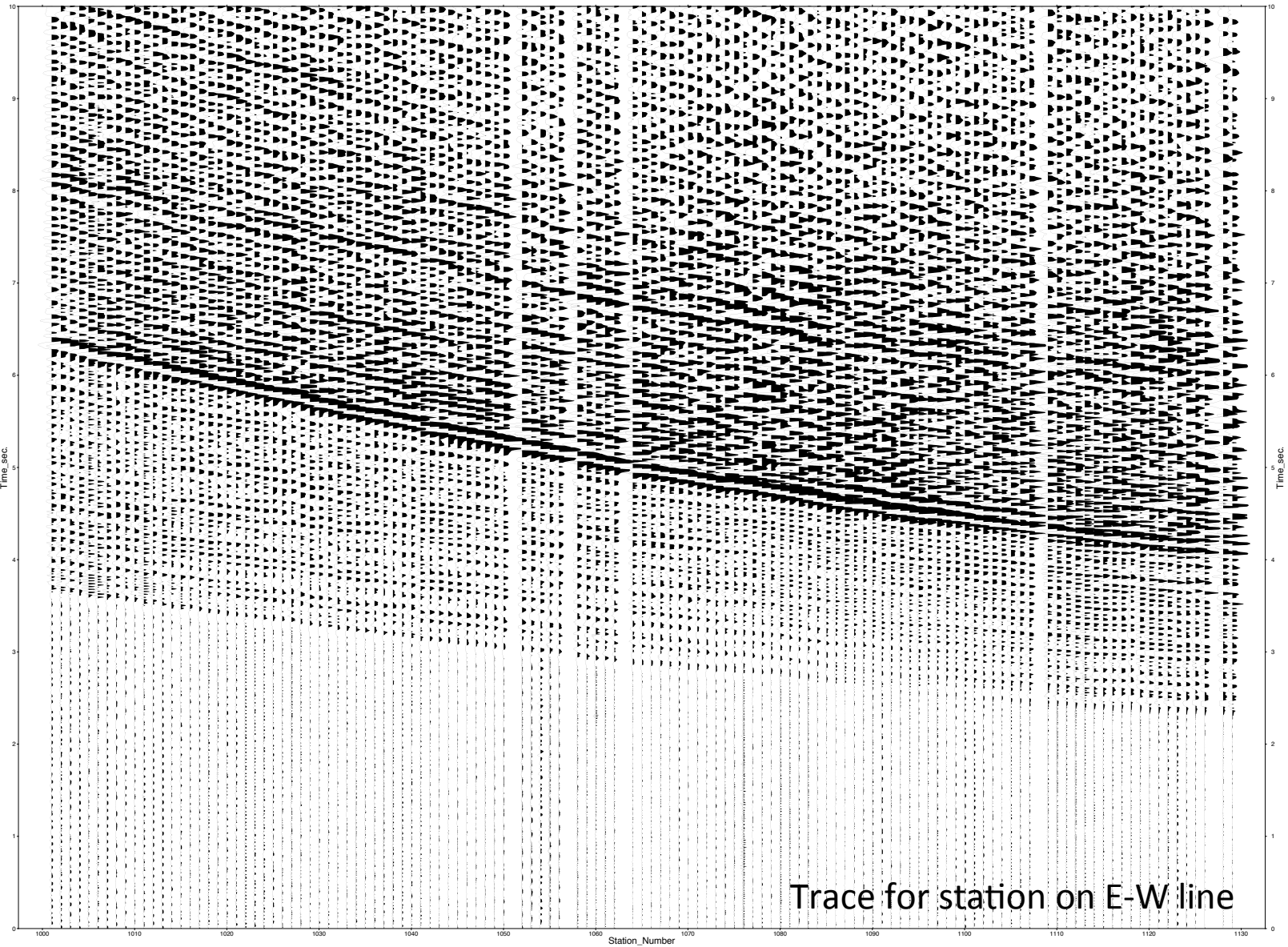
Time (s), Range is 0-10 s

E-W record section: earthquake E-W horizontal



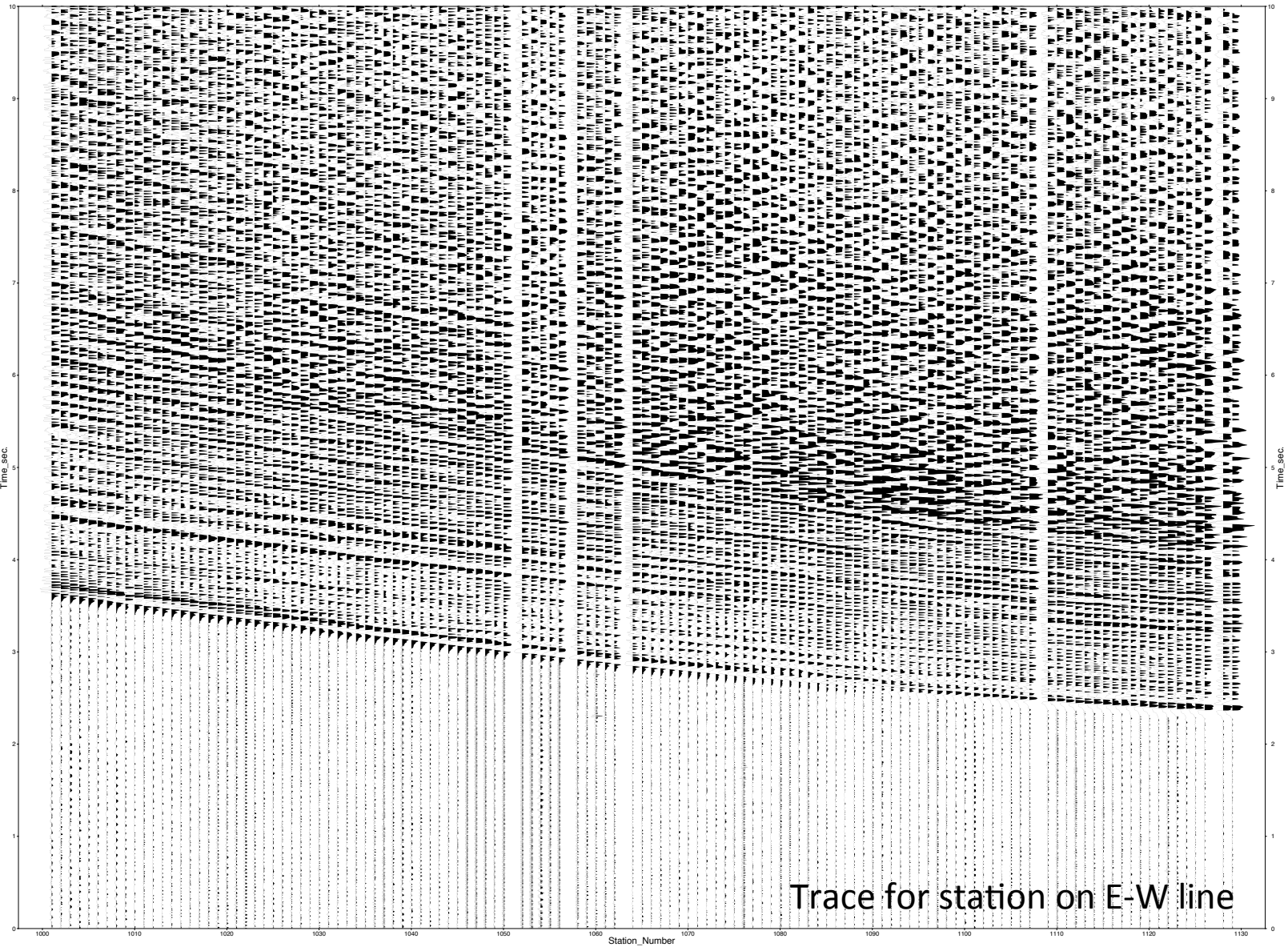
Time (s), Range is 0-10 s

E-W record section: earthquake N-S horizontal



Time (s), Range is 0-10 s

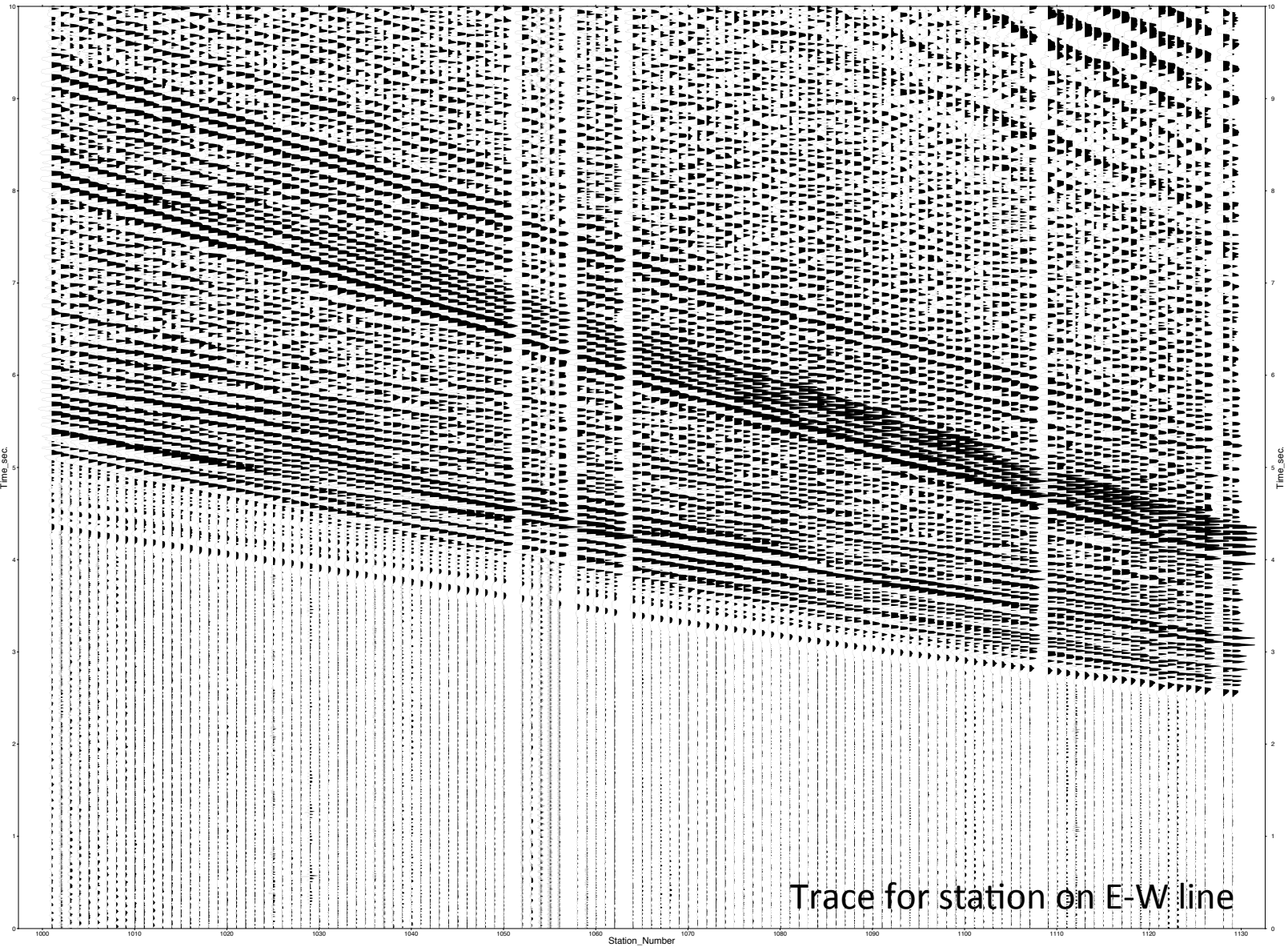
E-W record section: earthquake vertical



Time (s), Range is 0-10 s

Trace for station on E-W line

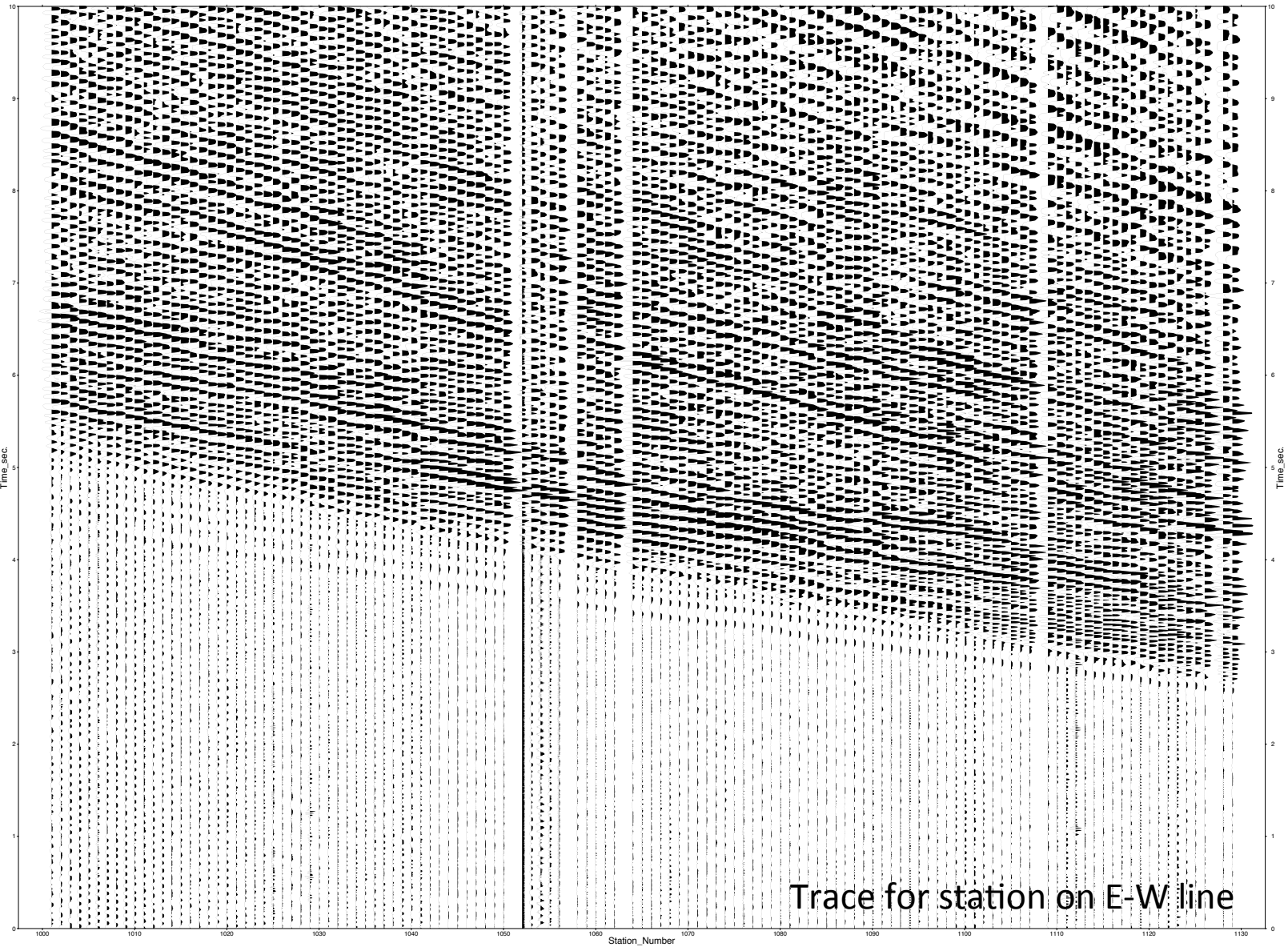
E-W record section: explosion vertical



Time (s), Range is 0-10 s

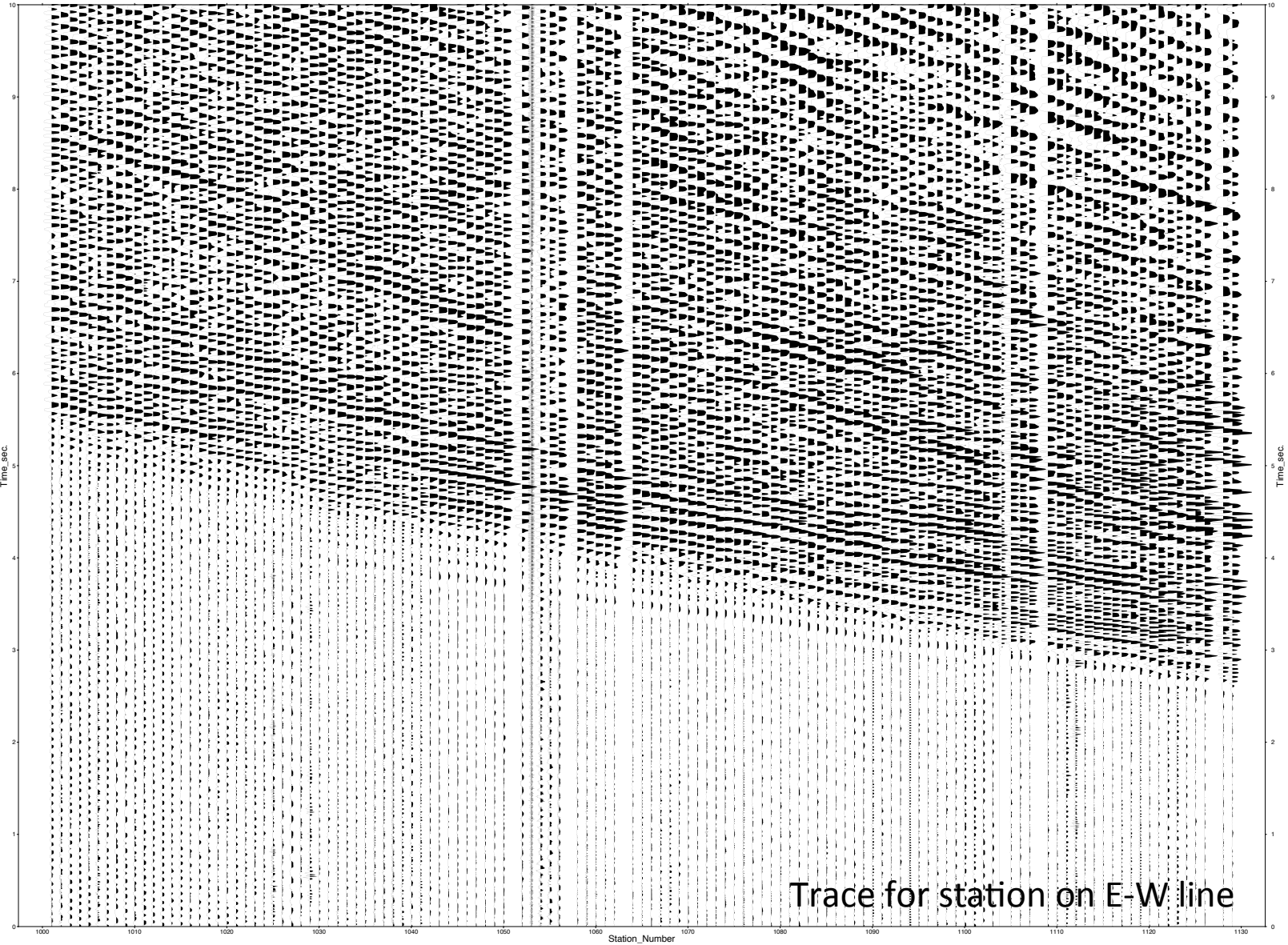
Trace for station on E-W line

E-W record section: explosion E-W horizontal



Time (s), Range is 0-10 s

E-W record section: explosion N-S horizontal



Time (s), Range is 0-10 s

Additional processing for single channel data

- sufilter → bandpass filter – 1-d operation
- sumix → trace mixing
- sushw → set header word
- sustack → stack on header word
- suop → arithmetic operations
- suop2 → arithmetic operations between 2 datasets
- sugain → trace gain (AGC, amplitude recovery)
- sukill → kill traces

Picking first arriving refractions

> sufbpickw < *.su window=.01 | suximage perc=99

Use sumax to get the values

> sufbpickw < *.su window=.01 | sumax mode=max verbose=1

SU velocity models

- makevel - make a velocity function
- triseis - generate Gaussian beam synthetic seismograms
- sufdmod2 (sufdmod1) – finite difference modelling
- suea2df - (an) **e**lastic **a**nisotropic **2D** **f**inite difference forward modeling, 4th order in space

Setting up geometry in su

sushw - Set one or more header word using trace number, mod and integer divide to compute the header word values or input the header word values from a file

key=cdp,... header key word(s) to set

a=0,... value(s) on first trace

b=0,... increment(s) within group

c=0,... group increment(s)

d=0,... trace number shift(s)

j=ULONG_MAX,ULONG_MAX,... number of elements in group

The value of each header word key is computed using the formula:

- i = itr + d
- val(key) = a + b * (i % j) + c * (int(i / j))
- where itr is the trace number (first trace has itr=0, NOT 1)

Setting up geometry in su

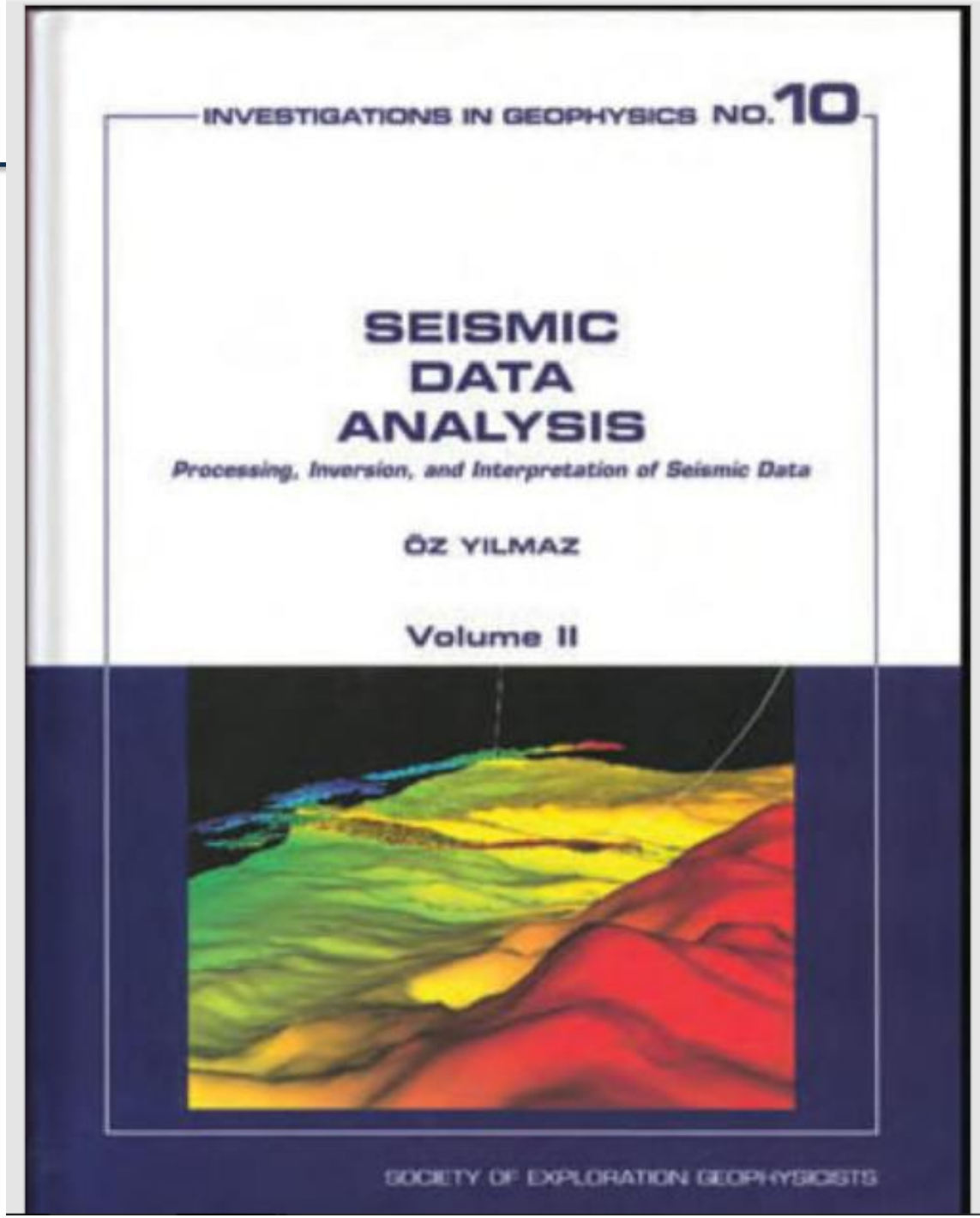
suchw- Change Header Word using one or two header word fields

key1=cdp,...	output key(s)
key2=cdp,...	input key(s)
key3=cdp,...	input key(s)
a=0,...	overall shift(s)
b=1,...	scale(s) on first input key(s)
c=0,...	scale on second input key(s)
d=1,...	overall scale(s)
e=1,...	exponent on first input key(s)
f=1,...	exponent on second input key(s)

The value of header word key1 is computed from the values of key2 and key3 by:

val(key1) = (a + b * val(key2)^e + c * val(key3)^f) / d

Processing resource



Also, Sheriff & Geldart, 1995
Exploration Seismology

Finding a dataset

- If you are doing passive data processing, maybe there is an active-source dataset nearby?
- What kind of analysis will you do?
  - Reflection?
  - Refraction?
  - Other processing?
- What hypotheses do you want to test?

Finding a dataset – nodes

- Sweetwater, Texas data
- http://ds.iris.edu/mda/XB?timewindow=2014-2014
- http://ds.iris.edu/gmap/XB?timewindow=2014-2014

- Oklahoma IRIS wavefields experiment

Finding a dataset

- Search IRIS for assembled SEGY datasets: http://ds.iris.edu/SeismiQuery/assembled.phtml

- Search UTIG or LDEO Academic seismic portals:

http://www.ig.utexas.edu/sdc/

http://www.marine-geo.org/portals/seismic/