

Swiss Centre of Competence
for Deep Geothermal Energy
for power and heat production



GES Microseismic Monitoring of 16A and 16B Stimulations at Utah FORGE, April 2024

Ben Dyer 24th August 2024

Team:

Ben Dyer, Dimitrios Karvounis, Peter Meier, Remi Fiori – GES.
Paul Jaques – Geoware. Consultant Logging Engineer.

Acknowledgement: Jim Rutledge, Kris Pankow and Joe Moore



Site Overview



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Monitoring Configuration

Microseismic Sensor Network

56 – PSS 3C geophone tool

78B

a) Geochain eight level, 3C digital string

b) PSS 3C geophone

58

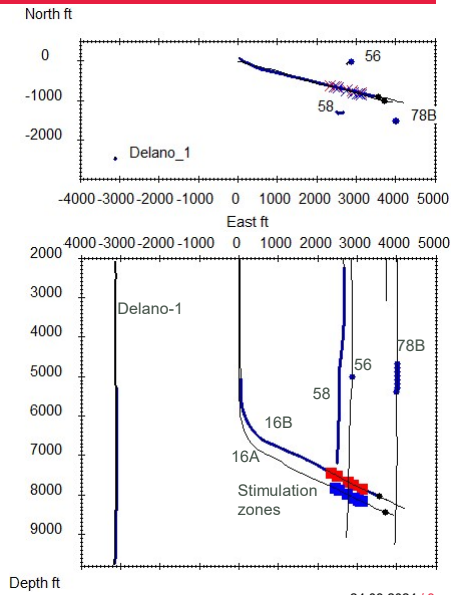
a) VSI twelve level 3C geophone string, failed then

b) Wireline DAS, 491 traces at 3m intervals

16B – DAS 499 traces at 3m intervals

Delano-1 – DAS 439 traces at 3m intervals

All DAS acquisition was at 1m trace interval, 1m Gauge Length and 1m Spatial Resolution



Single Level, PSS 3C Geophone at 56-32



Outline Specification

3C, 1 sensor per axis,
damped. x500 downhole gain
23,500 V/m/s overall sensitivity



Deployment History

SN005 deployed 25/03 to 5/04, 11 days.
Electronic component failure.

SN001 deployed 7/04. No further
problems.



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Geochain 3C String in 78B and Later PSS

Deployment History

Geochain 28/03 to 18/04, 21 days.
Downhole data acquisition failure.
PSS deployed 19-25/04. Recovered working.



Outline Specification

Geochain. 8 levels x 3C, 4 sensors per axis. Downhole digitisation, 208 V/m/s overall sensitivity. No damping
3C, 4 sensors per axis, damped.
x500 downhole gain 88,400 V/m/s overall sensitivity



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DAS – Behind Casing 16B/Delano and Wireline



16B behind casing
Shell/Prysmian 2xSM
and 2xMM flat pack.
Installed in 7/2023
UT Austin/Shell
project
Delano-1 - Fervo

GES fibre optic wireline
terminator and clamping arm
4xSM and 2xMM 250°C
wireline.



Deployment by crane and
T bar "hand over hand"



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Divine, Realtime Microseismic Processing

Two Instances of Divine

- ATLS – Monitoring the 3C data only. Approximate locations for Mw only. Most sensitive.
- Intense – Monitoring 3C and DAS. Much higher data volumes for auto-location and location accuracy. Reported here.

Location Parameters – ATLS and Intense Instances, Except No DAS for ATLS

- Reference is ground level at the 16A wellhead
- Trigger is STA/LTA>5, 5/50ms windows, HP 20Hz on 3C tools
- Vp 19.1ft/ms, Vs 11.2ft/ms, same as April 2022.
- Search grid is 100ft coarse followed by 10ft fine grid.
- Bootstrap auto-location using group rms of 3C tools and trace rms of 16B DAS sensors at 100 ft intervals. Location by triangulation.
- Visually checked larger events and re-picked traces as necessary, particularly the furthest offset sensors in Delano-1.



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Event History vs Hydraulic Program. 16A

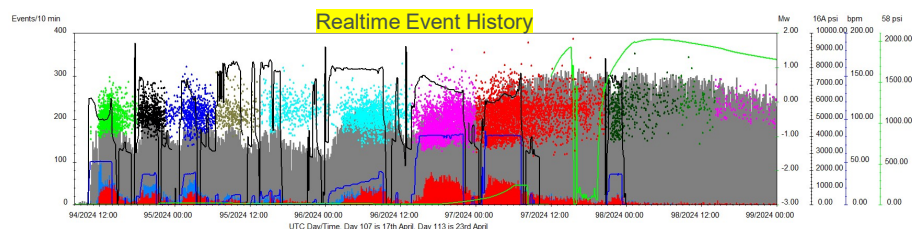
16A. Three stages previously stimulated in April 2022 and seven new stages stimulated through perforations

Event rates >1800 triggers/hour. Coloured symbols are a mix of auto located and checked locations

Injection rate up to 80 bpm (212 l/s) and 8,200psi (56 Mpa)

171,345 triggers, 9,995 realtime auto-locations. 1046 field checked locations

Histogram bins: Grey – triggers, Red - located events and Blue – noise.



16A Stimulations of stages 1-3 (3R), 4, 5, 6, 7, 8, 9 and 10



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Checked Events vs Hydraulic Program. 16A

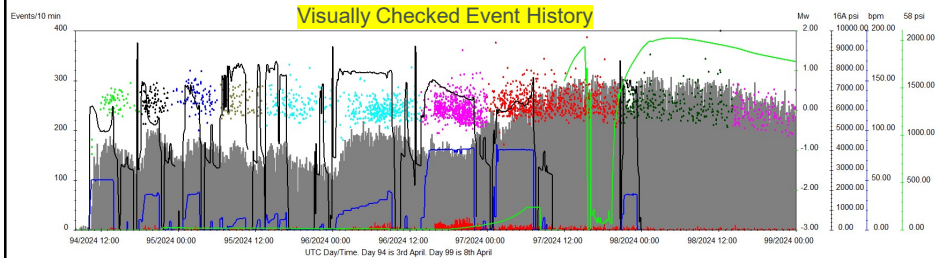
Post stimulation, 2680 events were visually checked and located.

Each of the checked events had at least one of P or S interpreted on Delano, the furthest sensors. Checked event magnitudes > -0.5 typically.

16A. Three stages previously stimulated in April 2022 and seven new stages stimulated through perforations

Injection rate up to 80 bpm (212 l/s) and 8,200psi (56 Mpa)

Histogram bins: Grey – triggers, Red – checked and located events



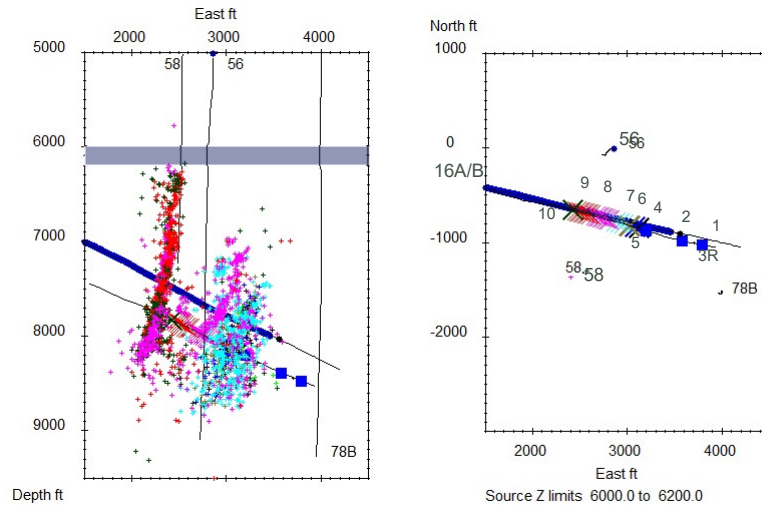
16A Stimulations of stages 1-3 (3R), 4, 5, 6, 7, 8, 9 and 10



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16A 200ft Depth Slices. Checked Locations

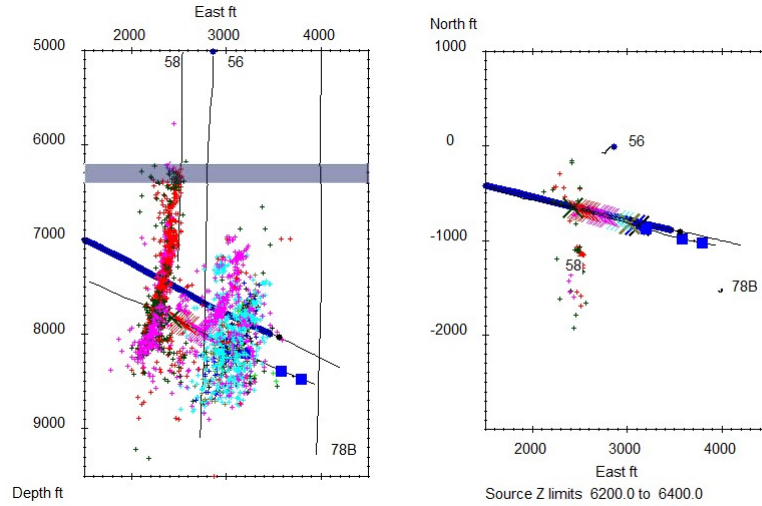
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



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16A 200ft Depth Slices. Checked Locations

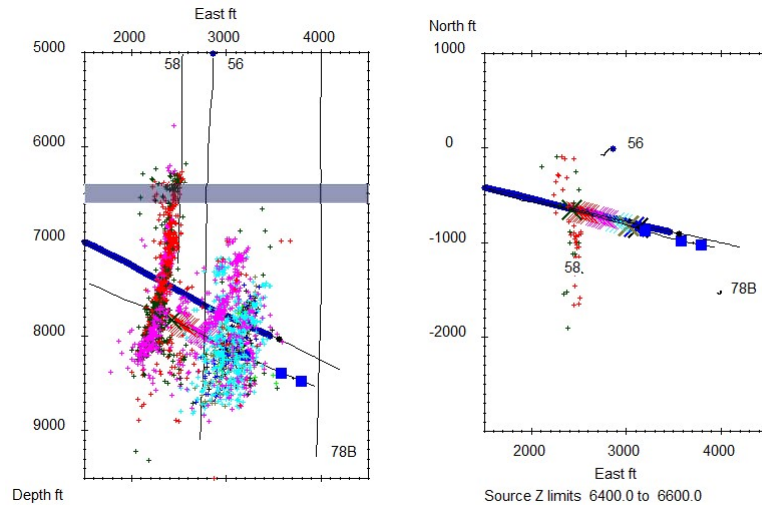
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



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16A 200ft Depth Slices . Checked Locations

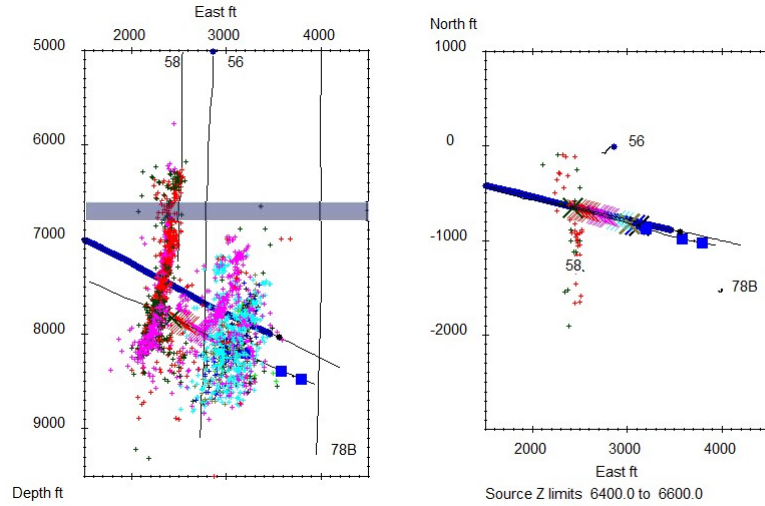
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



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16A 200ft Depth Slices

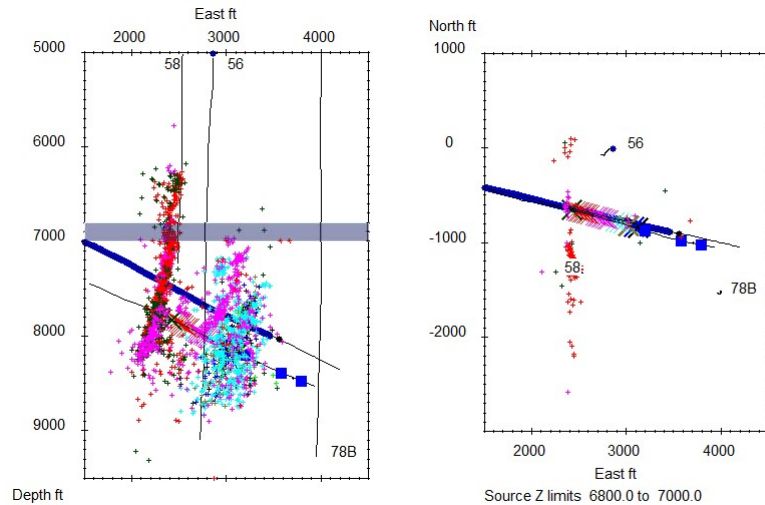
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



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16A 200ft Depth Slices . Checked Locations

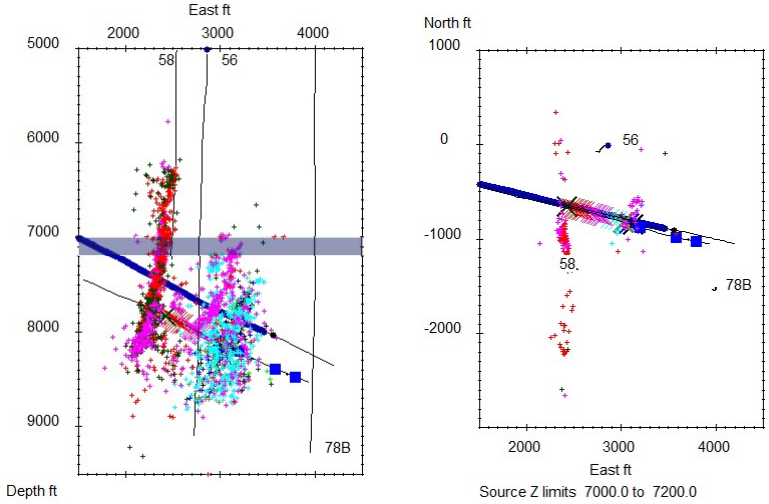
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



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16A 200ft Depth Slices . Checked Locations

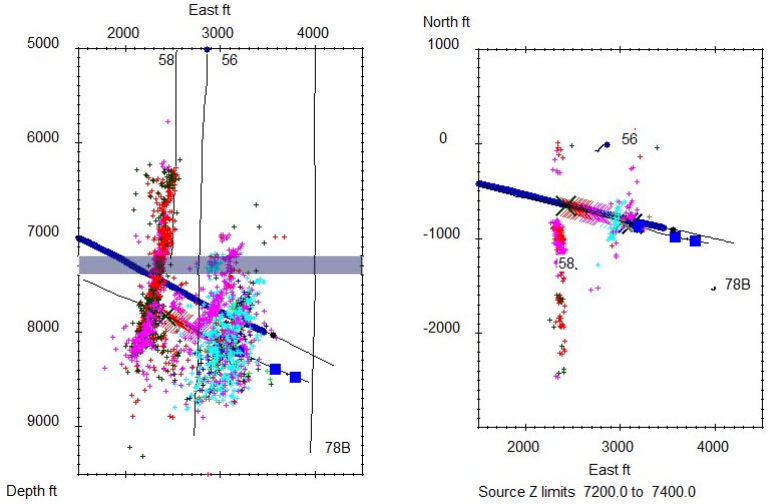
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



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16A 200ft Depth Slices . Checked Locations

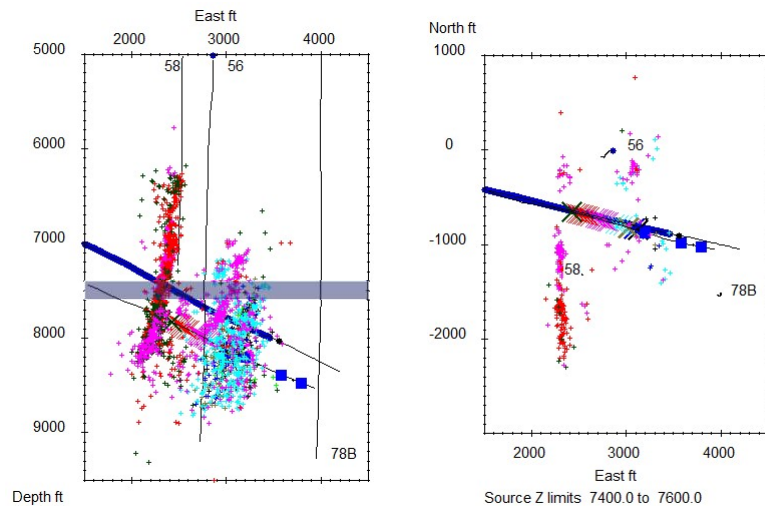
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



24.08.2024 / 16

16A 200ft Depth Slices . Checked Locations

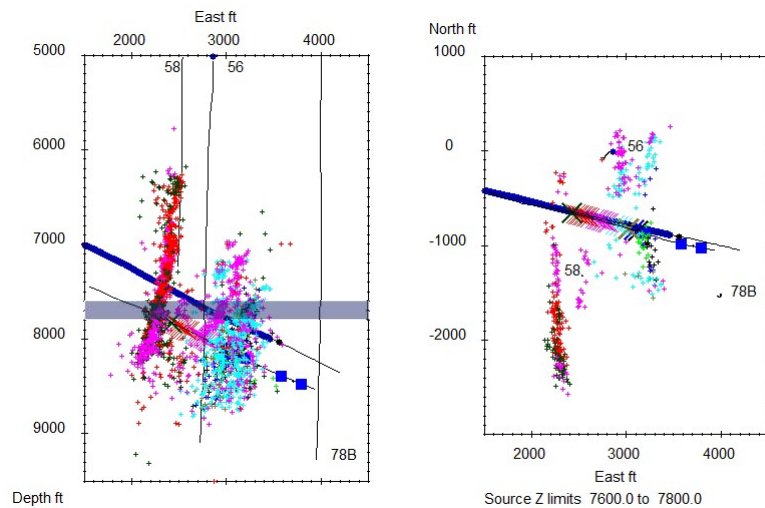
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



24.08.2024 / 17

16A 200ft Depth Slices . Checked Locations

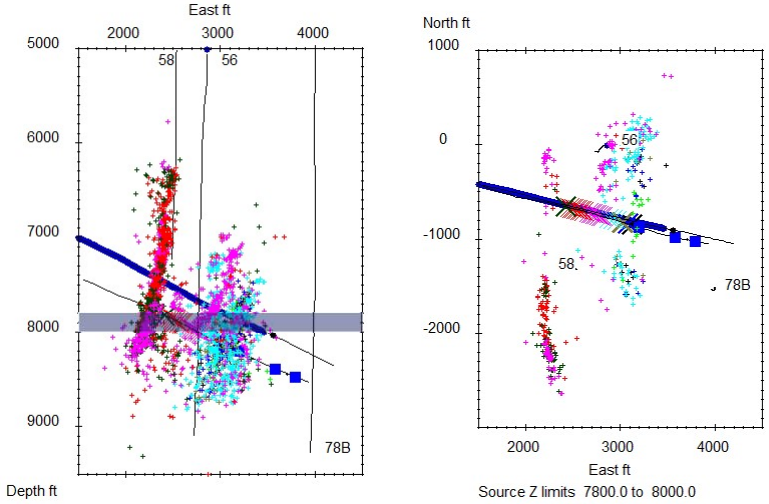
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



24.08.2024 / 18

16A 200ft Depth Slices. Checked Locations

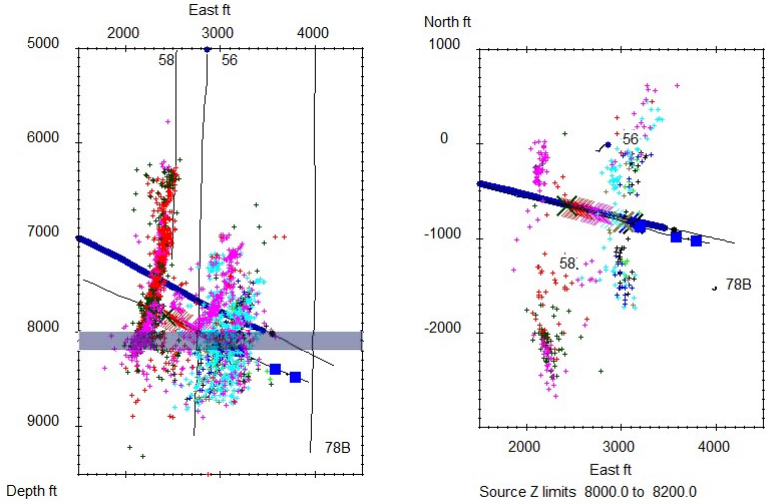
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



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16A 200ft Depth Slices . Checked Locations

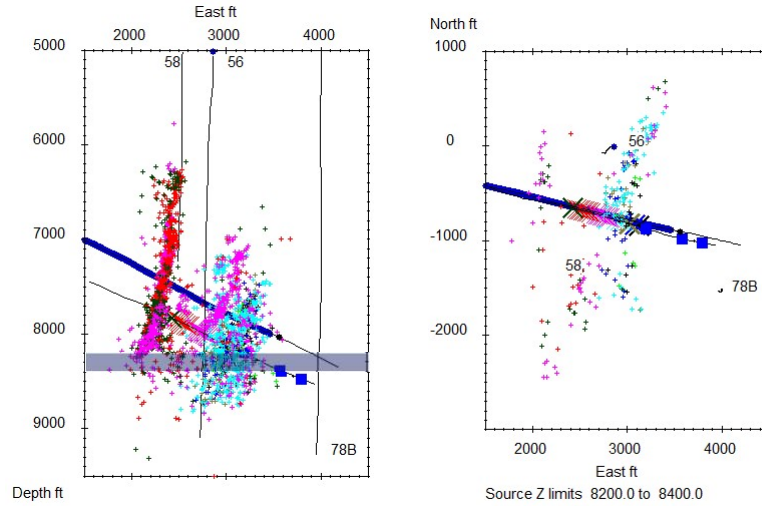
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



13.05.2024 / 20

16A 200ft Depth Slices . Checked Locations

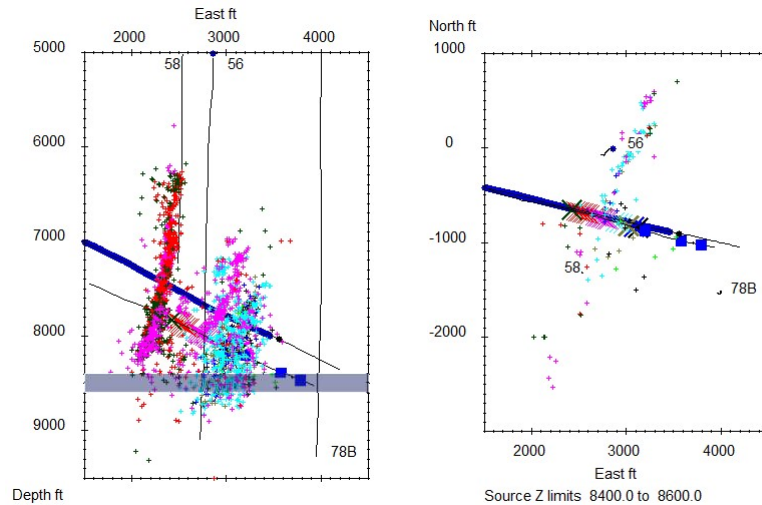
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



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16A 200ft Depth Slices . Checked Locations

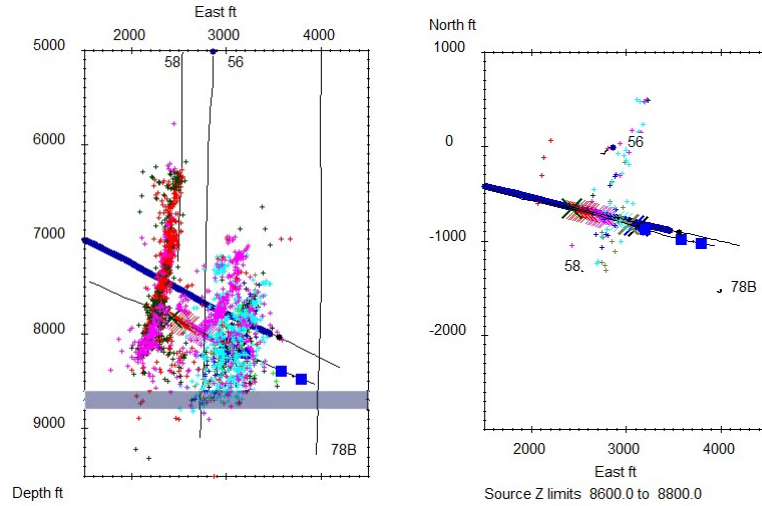
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



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16A 200ft Depth Slices . Checked Locations

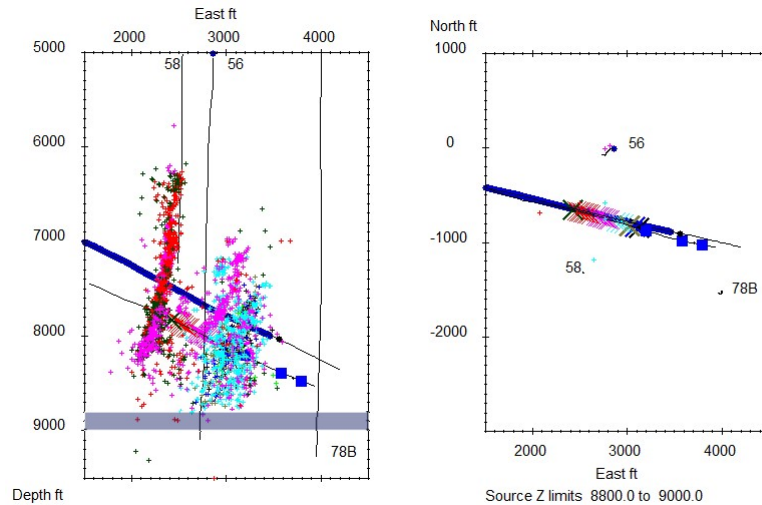
Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



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16A 200ft Depth Slices . Checked Locations

Stage: 3R green, 4 black, 5 blue, 6 khaki, 7 turquoise, 8 pink, 9 red and 10 black



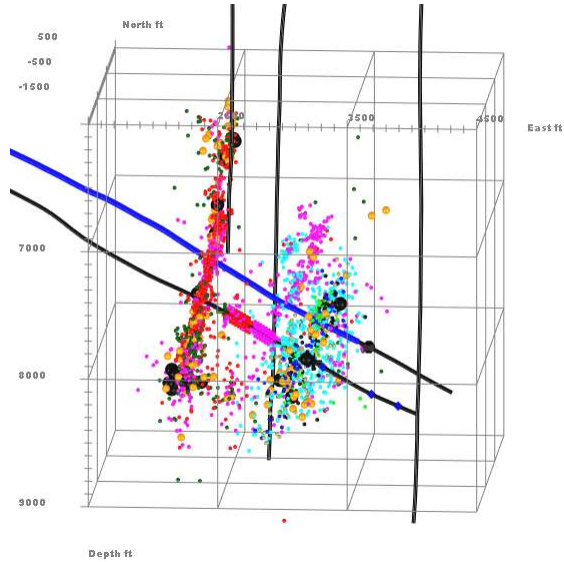
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3D View of Checked Stimulation Locations

Orange spheres
>0.6Mw

Black spheres
>1.0Mw

Coloured spheres,
events coloured by
stimulation stage.



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Event History vs Hydraulic Program. 16B

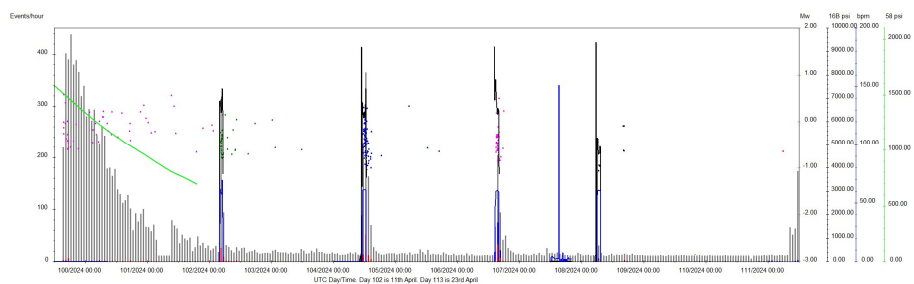
16B. Four new stages stimulated through perforations and a fifth perforated but not stimulated individually.

Event rates up >350 triggers/hour, but only briefly.

Injection rate up to 60 bpm (160 l/s) and 9,500psi (65 Mpa)

16,074 triggers (events), 4 auto-locations. 240checked locations

Histogram bins: Grey – triggers, Red - located events

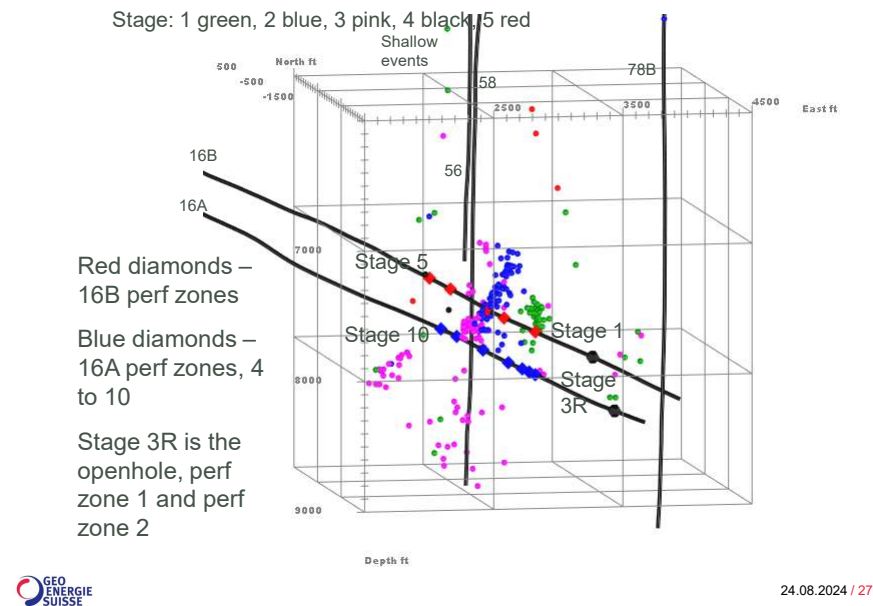


16B Stimulations of stages 1, 2, 3, and 4 (no stage 5 stimulation)

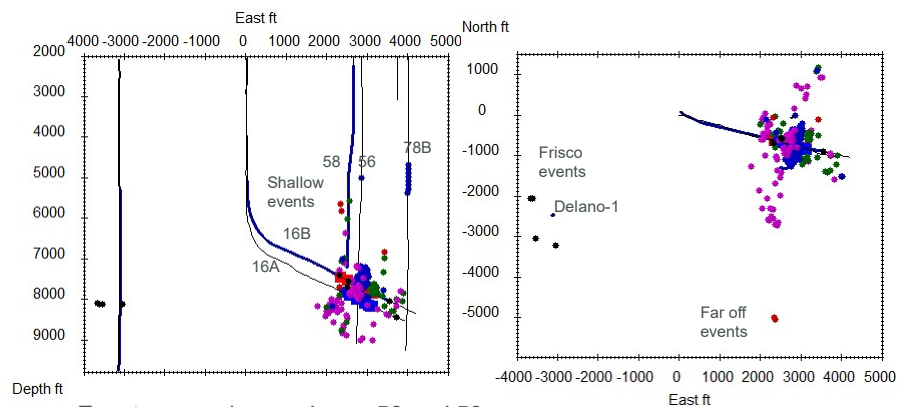


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16B Distribution



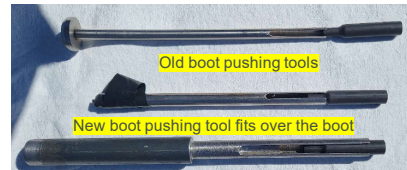
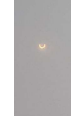
16B Stimulation and Far Offset Events



2023/2024 Developments - PSS

October 2023 PSS 3C Tool Tests – Annular Eclipse Time

- ▣ Strict tool preparation and cablehead assembly procedure applied
- ▣ Consultant wireline engineer oversight
- ▣ Baked tools to drive off moisture
- ▣ Argon filled - inert
- ▣ Sealed in the workshop
- ▣ New insulator boot fitting tool

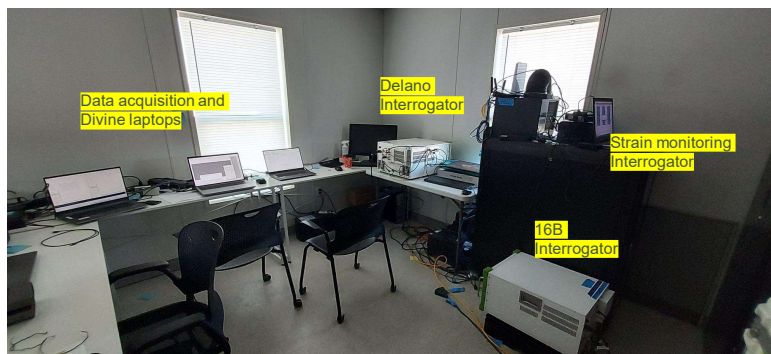


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2024 Developments – Frisco Monitoring

DAS Integration into Divine, Merger and first application of DASSei

- ▣ Fast, reliable auto-locations using a mix of DAS and 3C for Mw
- ▣ Developed in February monitoring Fervo stimulations :
 Frisco-1: 1x3C in 78B-32, 16B DAS
 Frisco-3 and part of Frisco-2: 1x3C in 78B-32, 16B DAS and Delano DAS
 (proprietary data of Fervo that is not for public release)



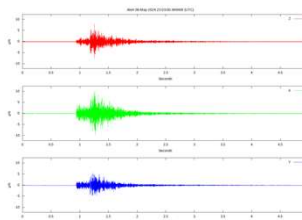
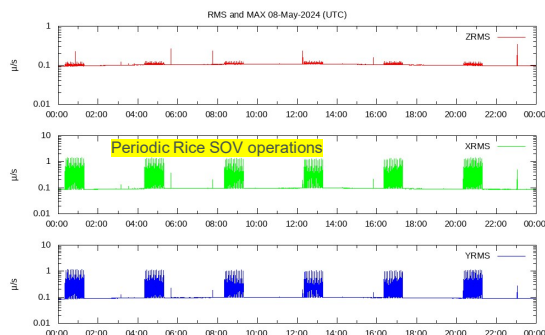
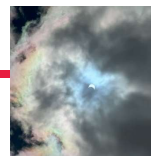
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2023/2024 Developments - PSS

A new Raspberry Pi/Guralp based acquisition system for the PSS tools

Continuous, gapless acquisition at up to 5000Hz x 8 channels (two x 3C tools in a string)

Remote access, daily reports and email alerts for trace levels and events above a threshold



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2024 Developments. Data Management

All Seismic Systems - Data Flow					
	Three component			DAS	
Traces	PSS 56-32 (1 x 3C=3)	Geochain 78-32 (8 x 3C=24)	VSI 58-32 (12 x 3C=36)	DAS 16B-32 (1x1496)	DAS Delano/58 (1x1317)
Raw File	12 second, sg2 at 4kHz	12 second, rcd at 4kHz	1.5 second ldf at 2kHz	12 second, H5 at 10 kHz	12 second, h5 at 10 kHz
Daily folder size	3.87 GB	30.5 GB	-	4.7 TB	4.1 TB
First Step	Merge into a continuous sequence of synchronous 12 second sg2 files of 27 traces at 4 kHz (used for ATLS processing)			DASSei: H5 conversion to 12 second sgy at 4 kHz (anti-alias)	DASSei: H5 conversion to 12 second sgy at 4 kHz (anti-alias)
Size of daily folder (kept)	34.8 GB			1.88 TB	1.65 TB
Second Step	Merge into a continuous sequence of synchronous 12 second sg2 files of 27 geophone traces and 499/439/491 (16B/Delano/58) DAS traces (every third DAS trace) at 4 kHz				
Divine processing	Real time Trigger and Auto-Locate using P and S arrivals from >200 traces to derive a seismic catalog and database of microseismic event and trace data.				



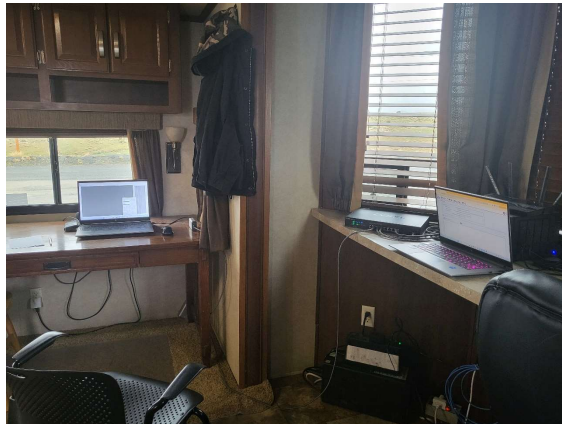
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Efficient Laptop Based Processing

Right hand laptop – DASSei DAS to SegY conversion

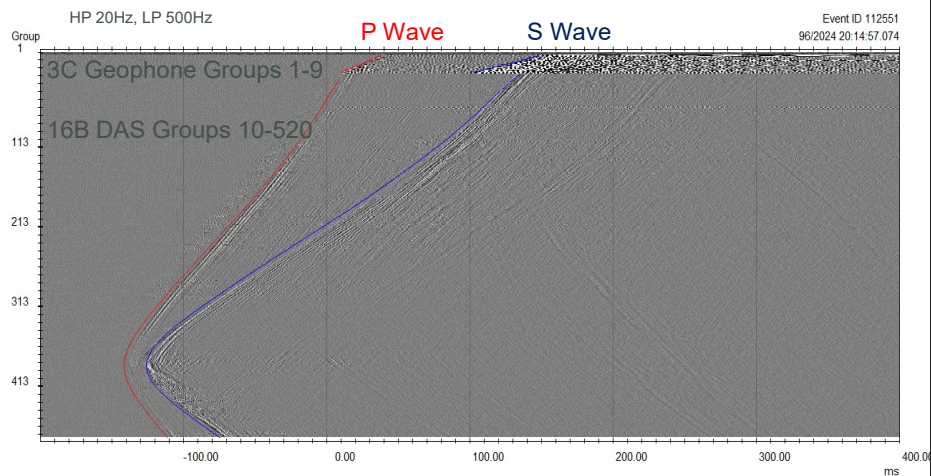
Left hand laptop –

- Merging SegY from 3C and DAS into a single sequence of Seg2 files
- Divine triggering, auto-location (3D migration) and visual QC



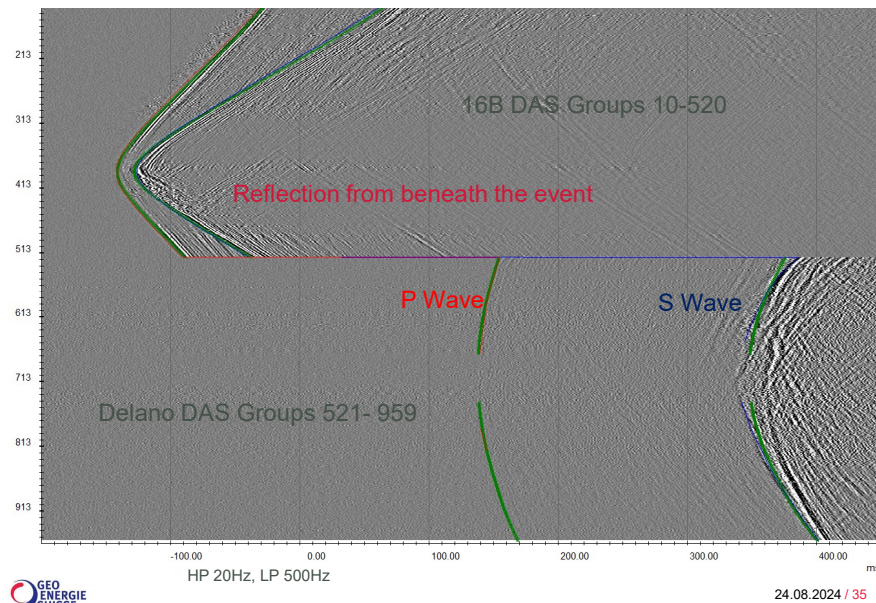
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16B DAS Data at 3m Trace Intervals, 1.5Mw

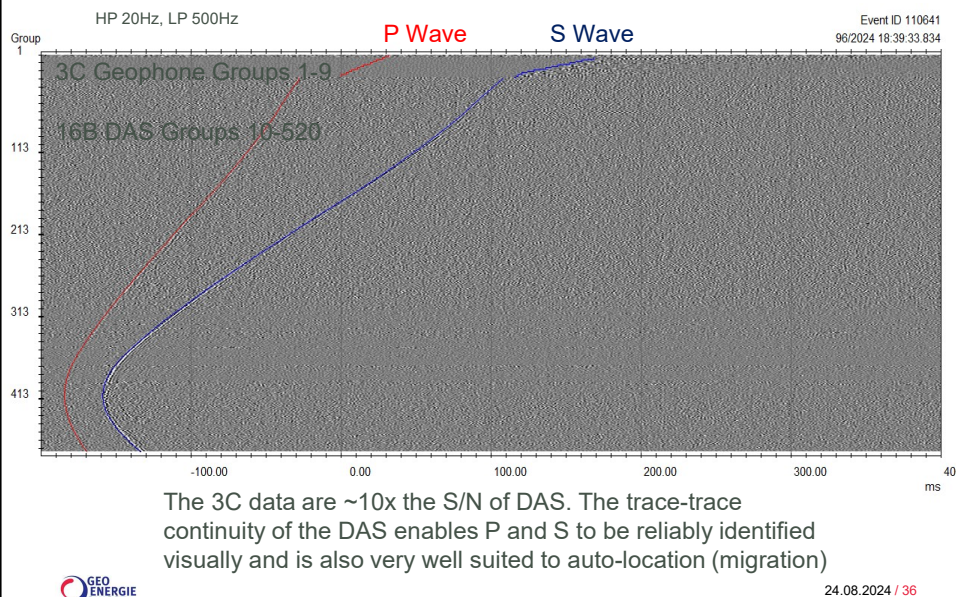


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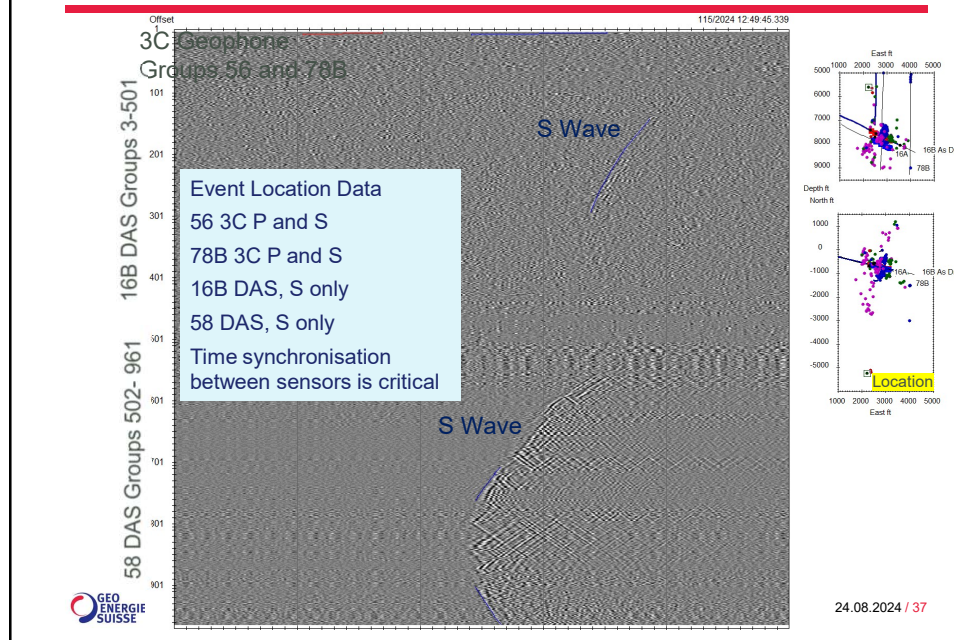
16B DAS Data at 3m Trace Intervals, 1.5Mw



16B DAS Data at 3m Trace Intervals, -1.4Mw



16B Behind Casing of Wireline DAS



Coming Up at Utah FORGE

At FORGE

- Monitoring Fervo stimulation in early June
 - a) wireline DAS in 58
 - b) behind casing DAS in 16B and Fervo Delano
 - c) PSS in 56 and dual level PSS on test in 78B
- Specify an hybrid wireline, DAS and electric for Haute-Sorne for deployment of a geophone string with wireline DAS
- 16A to 16B circulation monitoring, mid-July coinciding with Fervo circulation

16A/B April Stimulation Post Acquisition Processing

- Visual QC of April stimulation events
- Velocity model calibration check
- Evaluate the hodogram accuracy of the Geochain and PSS tools
- Cluster analysis
- Plane fitting
- Migration

Summary

- Preparatory visits to FORGE in October (tools) and February (DAS) were critical. 7 weeks of preparation on site.
- Good progress on the reliability of downhole 3C tools
- Produced new acquisition systems for the PSS tools
- Integration of DAS into Divine
- Developments of DAS_{Sei} – H5 to SegY and Merger – time synchronisation and trace merging
- Proven capability of realtime processing of 1017 traces (27, 3C and 990 DAS). Data handling ~4TB day
- Initial testing of a wireline DAS in 58 appears to show similar sensitivity to the behind casing DAS in 16B
- Realtime catalogue for ATLS



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