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SILIXA

Testing and Calibration of HT Wide-bandwidth Seismic Sensors for EGS Applications and Collaboration with IPGT Program

Project Officer: Jay Nathwani, Lauren Boyd, Bill Vandermeer

Total Project Funding $ 50K

May 12, 2015

Ernest L. Majer

LBNL

Track 3 EGS 1

- Objectives:
  - Evaluate current and near term technology that could be deployed in high temperature boreholes (200C to 350C) to monitor and record passive and active seismic data.
  - Collaborate and leverage knowledge with IPGT (International Program for Geothermal Technology) members (Japan).

Relevance/Impact of Research

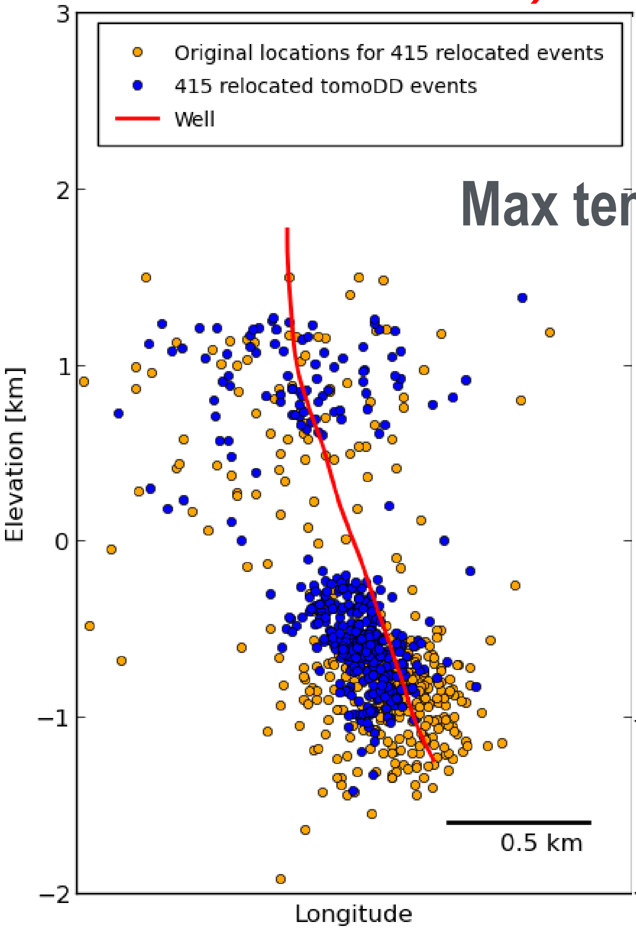
- Challenges, barriers, knowledge gaps, or problems being address by this project.
  - High temperature instrumentation(200C – 350C) is currently very rare.
  - Permanent (long term) deployment even rarer (may work for a while).
  - High temperature instrumentation is needed for not only sensors, but cable/wire lines, clamping mechanisms and data transmission electronics (digitizers, motors, pressure lines. etc.).
    - The entire deployment system must be addressed, not just the sensors (for example, multi size boreholes, borehole coupling, etc.).
  - Many sensors are being developed for oil and gas but few if any are solely for the Geothermal (not for geothermal budgets).
  - Time from initial design to deployment is years.

Relevance/Impact of Research

- Impact on costs, performance, applications, markets, or other factors in geothermal energy development.
  - Seismic data are critical for EGS development
    - Accurate MEQ data for well targets, stimulated reservoir volume, hazard evaluation, fracture behavior, (source mechanisms (mode I versus mode II)), impact on estimates of long term power production.
    - Active Seismic (VSP and crosswell) for fracture imaging , time lapse measurements, permeability estimates.
  - Surface data (non borehole, or shallow borehole) data are not adequate to meet needs because:
    - I.e., often poorer signal to noise ratio, lack of bandwidth and detection capability, lack of 3-D spatial coverage
  - High temp seismic deployments will be critical for success of FORGE.

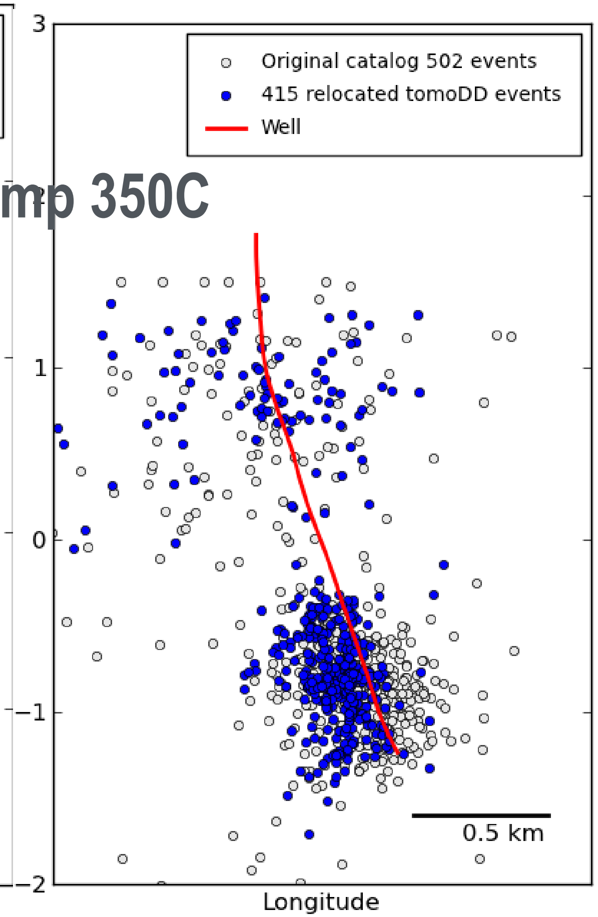
Relevance/Impact of Research

– Example of Importance (drilling targets and stress direction)

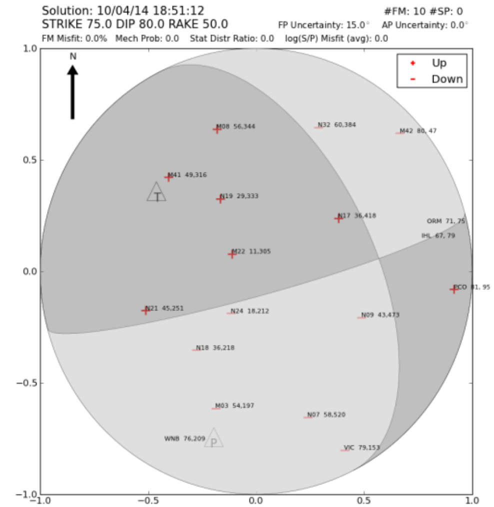


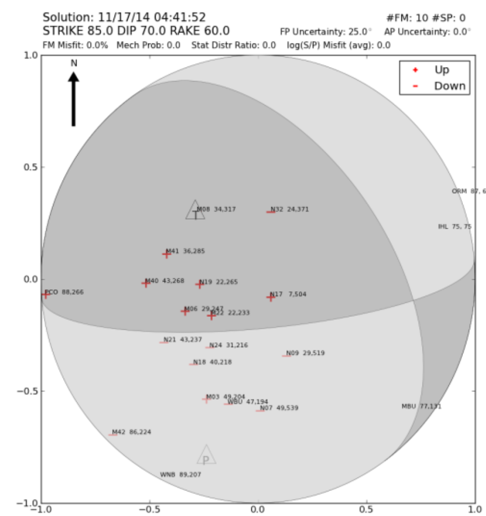
Vp/Vs = 1.75

Max temp 350C



Vp/Vs = 1.70





Relevance/Impact of Research

- Innovative aspects of project
  - Highly leveraged with industry involvement
  - International collaboration
  - Examined from user point of view as well an instrumentation point of view.
- Success will lead to utilization of the most promising high temperature instrumentation for the Geothermal Technologies Office's projects for:
  - High resolution of EGS reservoirs and permeability paths
  - Well bore targeting
  - Reservoir performance monitoring
  - Reservoir volume analysis
  - Implementation at FORGE
  - International projects

Scientific/Technical Approach

- Identify key attributes and technical needs required of high temperature instrumentation (by both U.S. and other IPGT countries)
  - 200C to 350C. (Iceland up to 400 C)
  - Wide bandwidth: 0.1 hertz to 1000 hertz.
  - Low noise (wide band <50 nanoV/ root hertz), high sensitivity
  - Three component, multilevel deployment
  - Deploy in bore holes from 3 inches to 13.5 inches
  - Depths to over 10,000 feet
  - Easy to deploy (clamping force to allow full vector fidelity)
  - Survive from months to years
  - Affordable for geothermal applications

Scientific/Technical Approach

- Search for instrumentation that may meet criteria in:
  - Industry manufacturers (ION, Calidus, Lumedyne, MagiQ, LINE, OptaSense, OYO, PI, Sercel, Silicon Audio, Silixa, US-SI)
  - Service companies
  - Federal Labs (Sandia, USGS,)
  - Geothermal companies (AltaRock, Calpine, Ormat)
  - IPGT members (Japan)
  - Oil and gas companies (Conoco-Phillips, Chevron)
- Obtain/observe field test data from different systems
  - Partner with companies and ongoing EGS projects
- Perform limited bench and field tests

Accomplishments results and progress

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- Examined three different classes of sensors
  - Conventional “exploration” and industrial sensors (geophones and accelerometers)
    - Advantages – Available, low cost , proven technology rugged
    - Negatives - low temp, lack low frequency (bore hole deployment), mostly for short time deployments
  - MEMS
    - Advantages - Low cost, easily deployed, meet desired specs
    - Negatives – most low cost versions lack sensitivity and bandwidth, desired sensors not available or lack temp requirements , and /or expensive
  - Fiber based
    - Advantages- most meet temp requirements, some easy to deploy,(some not),some meet bandwidth and sensitivity, most are not temp tested in field
    - Negatives, some only single component, some difficult to deploy, can be expensive, very expensive at very high temp, some still in development

Accomplishments, Results and Progress

Deployment of Calidus 200 C, 3-C Tool at Raft River (Japanese tool and LBNL wireline truck)

Specification	Standard ASR downhole geophone tool	ASR/Calidus accelerometer GERD2011 modification
Locking arm range	4” to 12” (101 to 305mm)	5” to 13” (127 to 330mm)
Maximum well pressure	20,000 psi / 1400 bar	1450 psi / 100 bar / 10MPa, maximum well depth 1200m
Max operating temperature	390F / 200C	302F / 150C for 72 hours max (minimum 0C for 72 hours)
Sensor	Geophone SM-4 HT 10Hz high sensitivity high pressure	Accelerometer Endevco 7703A-1000 high sensitivity
Mounting	3-component self-aligning gimaballed orthogonal	3-component fixed orthogonal
Well deviation	0 – 95 degrees from vertical	Not applicable, accelerometers fixed in cartridge
Amplifier gain	54dB gain at 70% damping downhole; total differential gain 60dB, total single-ended system gain 54dB	Fixed 40dB gain downhole, 0dB at uphole controller, total 40dB system gain. (Modified from GERD-03 cartridge.) Dynamic range 100ug to 100mg
Uphole controller	DCP for single-tool, DCP-2 for dual tool	DCP-2 for single tool only (dual tool controller is required to run second amplifier set)

Accomplishments results and progress

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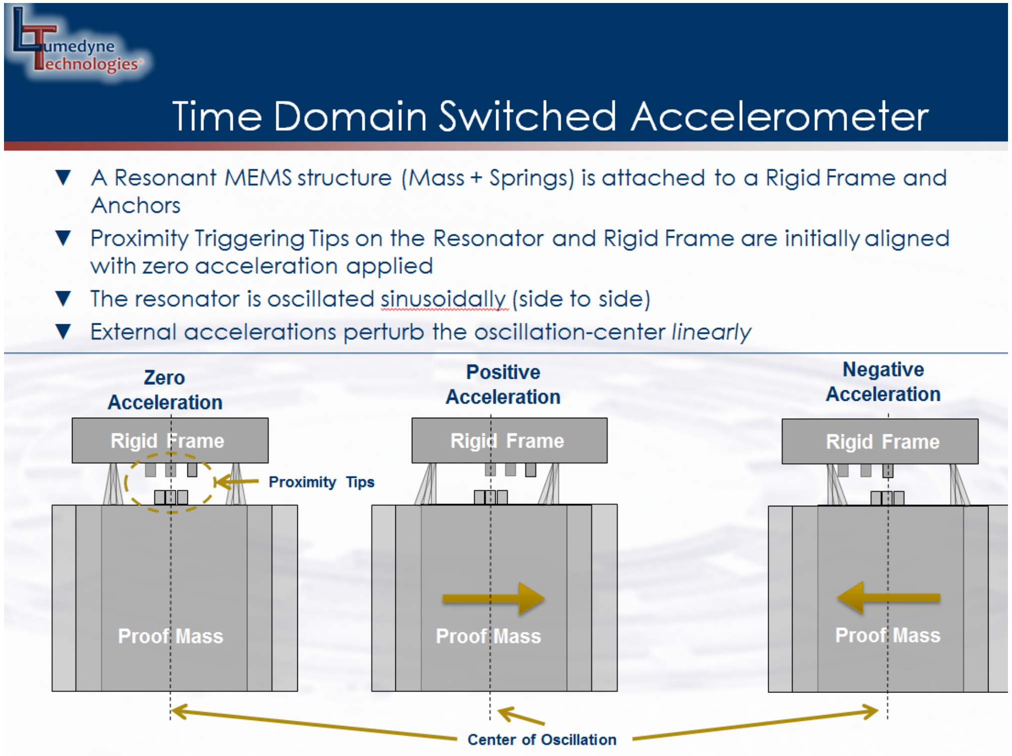
Example: Some sensors meet tech specs, but not yet packaged for deep, high pressure, and/or not yet available.



Accomplishments results and progress

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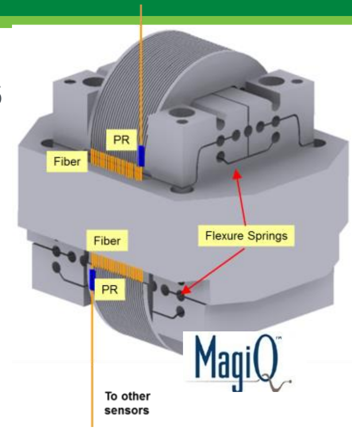
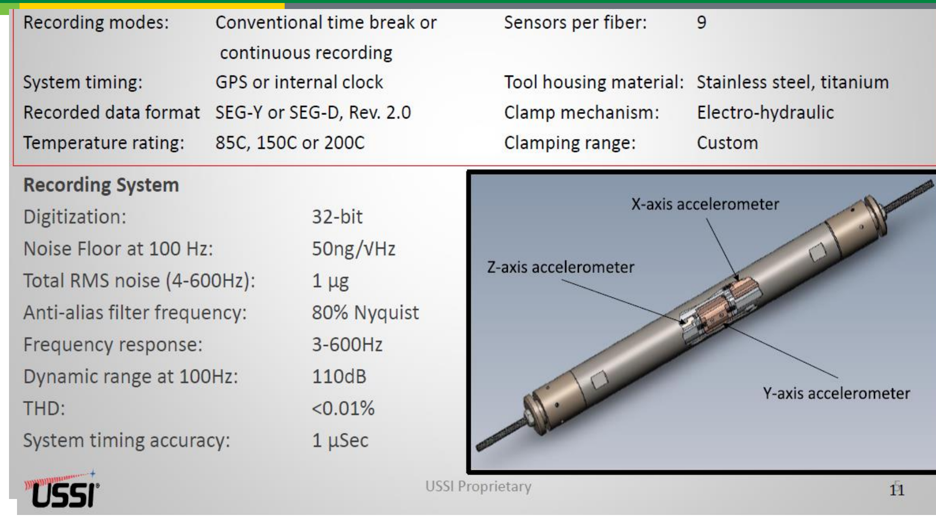
Discrete fiber based sensors

- USS-SI
- PI
- MagiQ
- LINE (future)





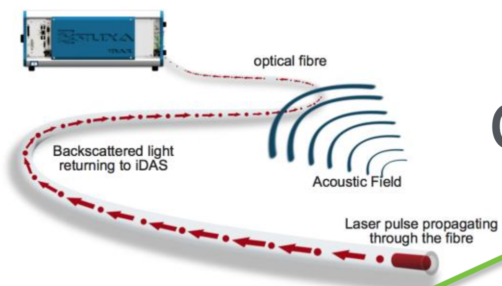
Recording modes:	Conventional time break or continuous recording	Sensors per fiber:	9
System timing:	GPS or internal clock	Tool housing material:	Stainless steel, titanium
Recorded data format	SEG-Y or SEG-D, Rev. 2.0	Clamp mechanism:	Electro-hydraulic
Temperature rating:	85C, 150C or 200C	Clamping range:	Custom

Recording System

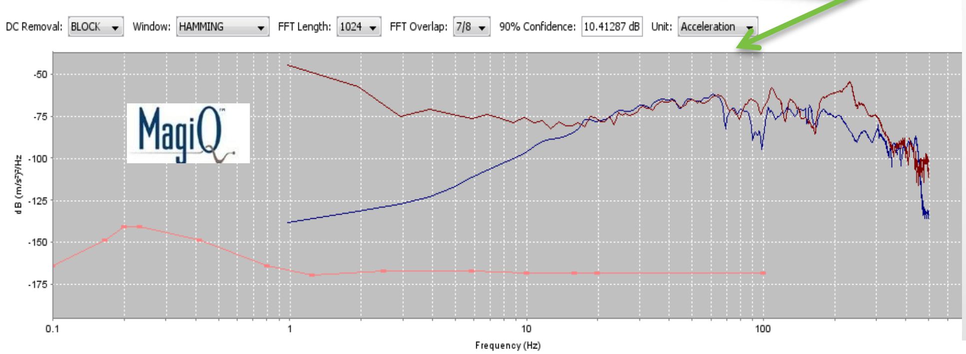
Digitization:	32-bit
Noise Floor at 100 Hz:	50ng/√Hz
Total RMS noise (4-600Hz):	1 µg
Anti-alias filter frequency:	80% Nyquist
Frequency response:	3-600Hz
Dynamic range at 100Hz:	110dB
THD:	<0.01%
System timing accuracy:	1 µSec

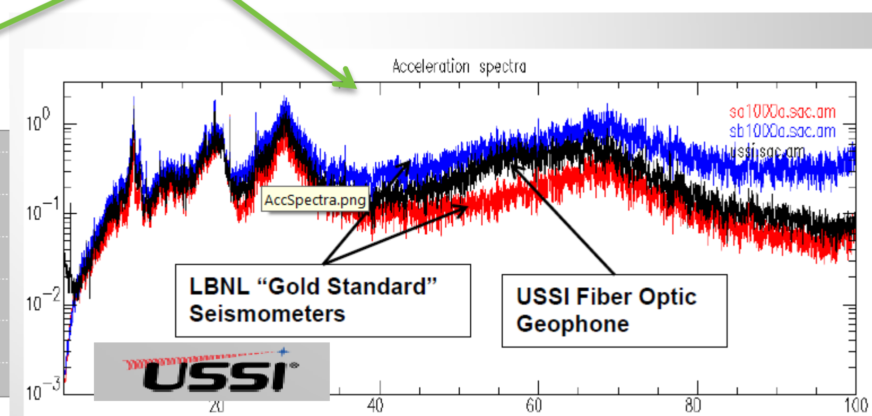
DAS (Distributed Acoustic Sensors)

- Silixa
- Optasense



GS-13 Standard





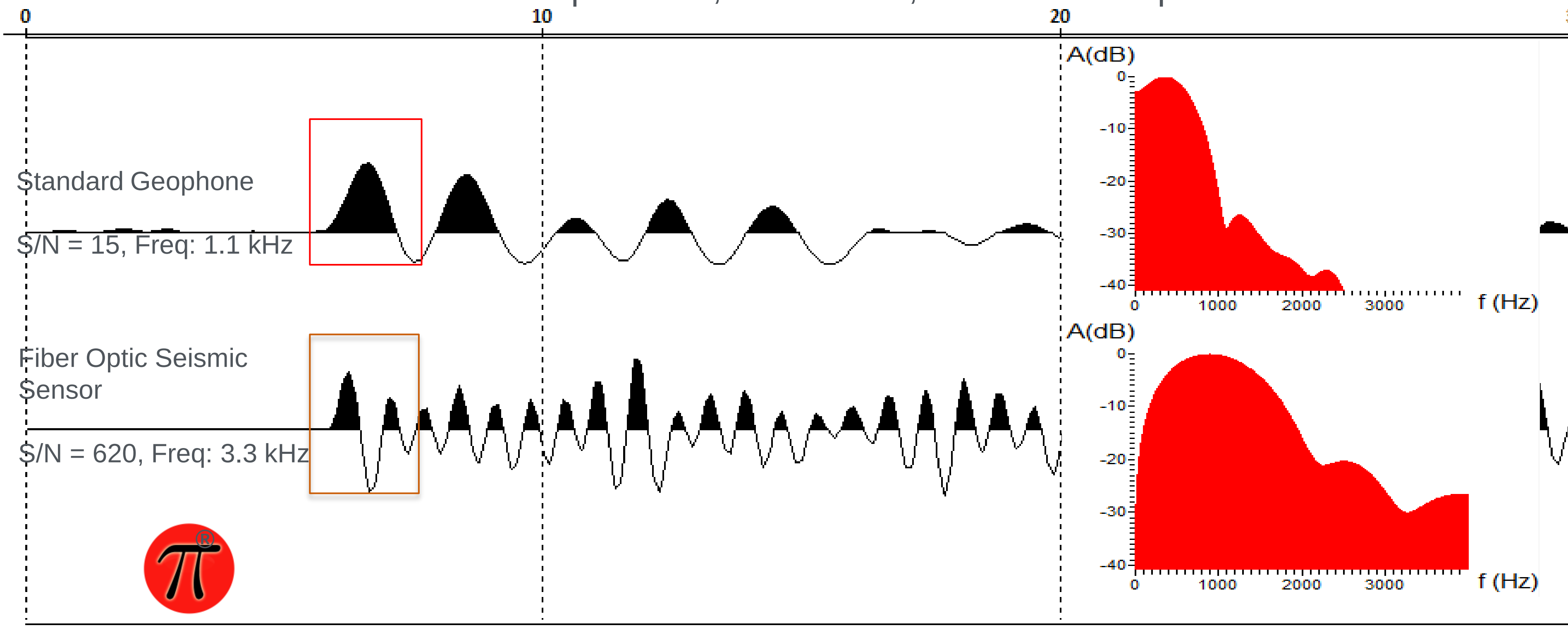
Accomplishments results and progress

Fiber Optic Seismic Sensor (FOSS)™ (PI) vs. Standard Geophone

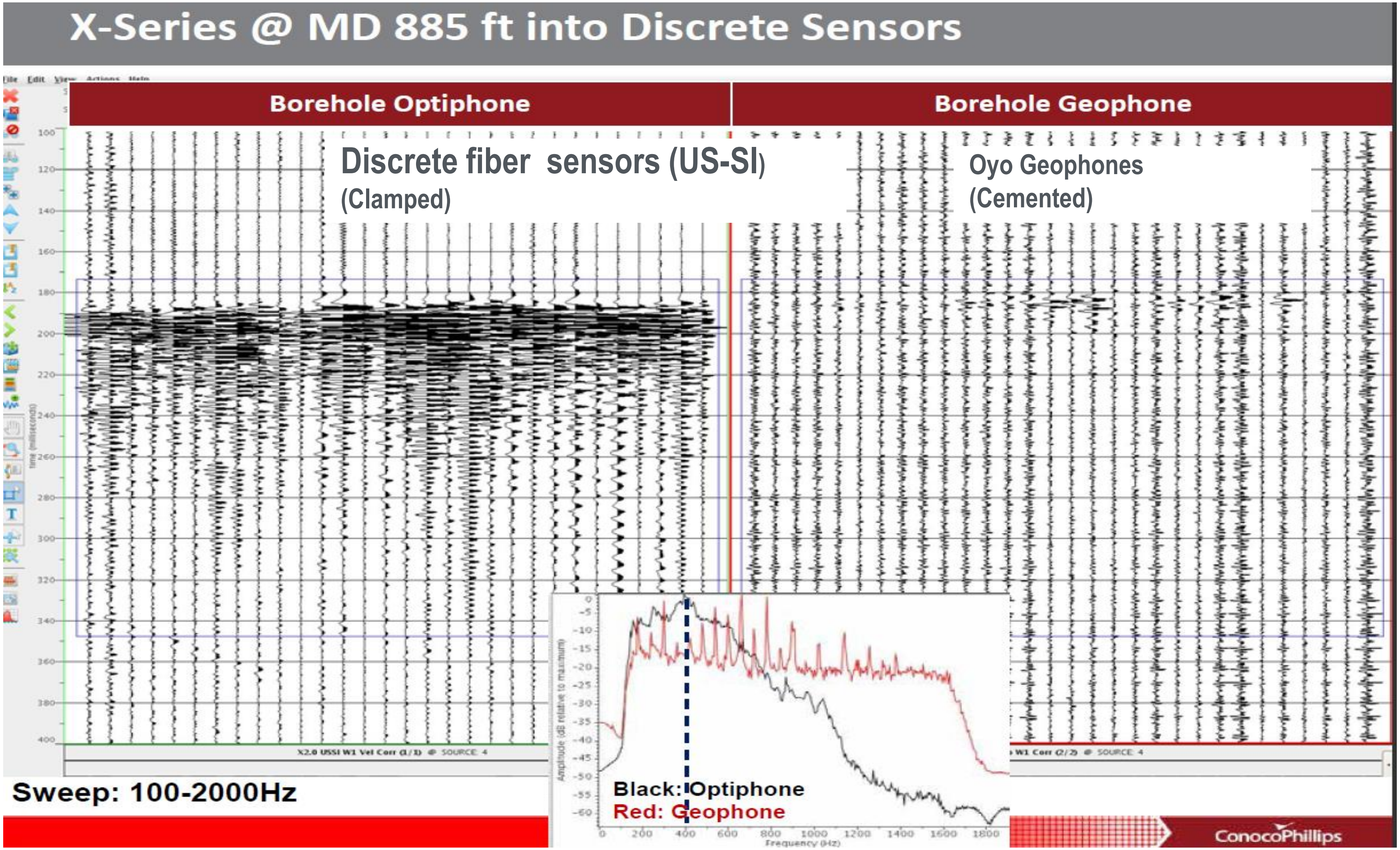
Data recorded simultaneously from a single tap test

Sampling rate: 8,000 Hz. High cut filter at 2,500 Hz.

- FOSS S/N ratio is 41 times higher than S/N for Geophone
- FOSS -30 dB point is 3,300 Hz vs 1,100 Hz for Geophone

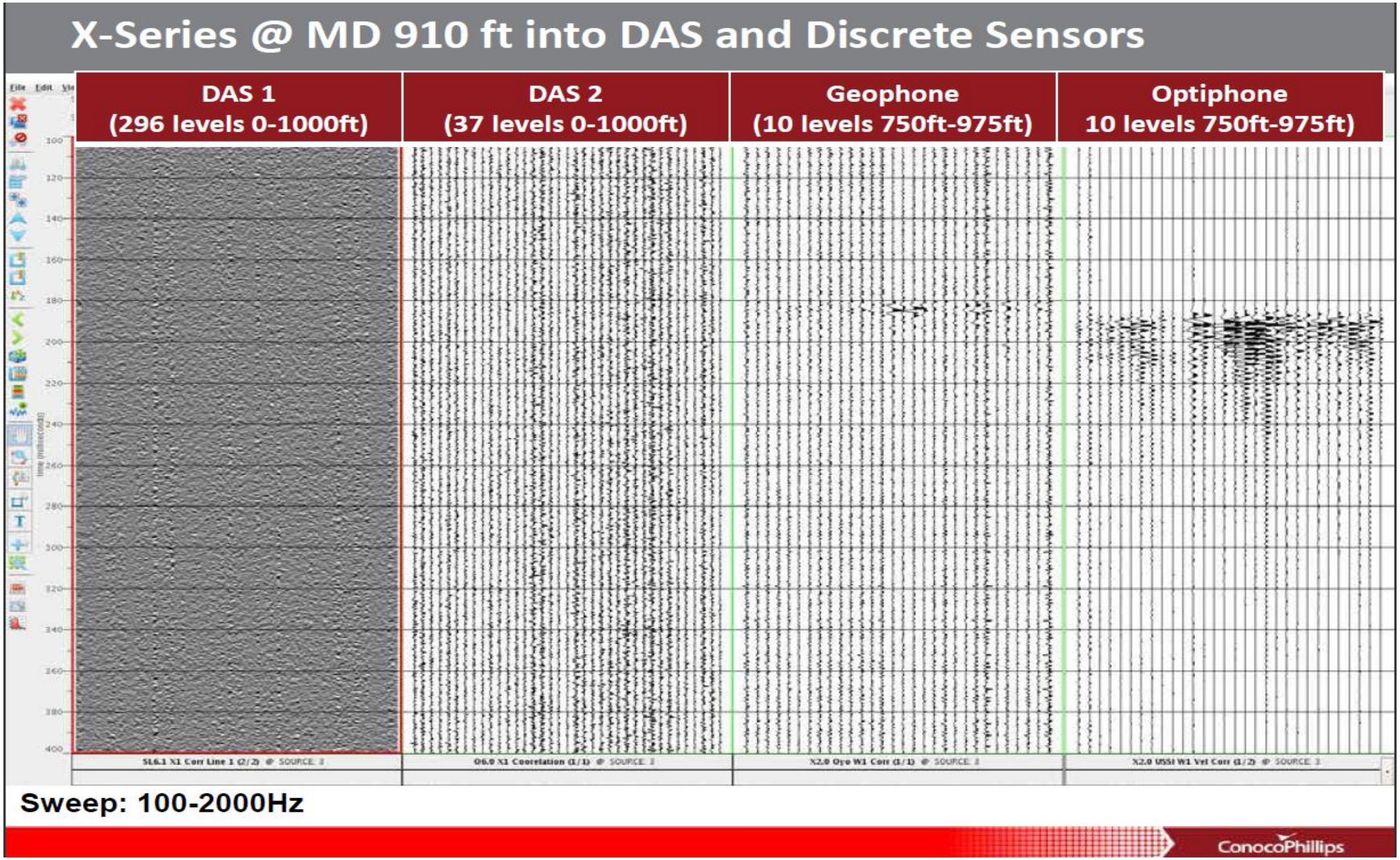


Accomplishments results and progress



From Eike et al., 2014 SEG Annual Meeting

Accomplishments results and progress



From Eike et al., 2014 SEG Annual Meeting

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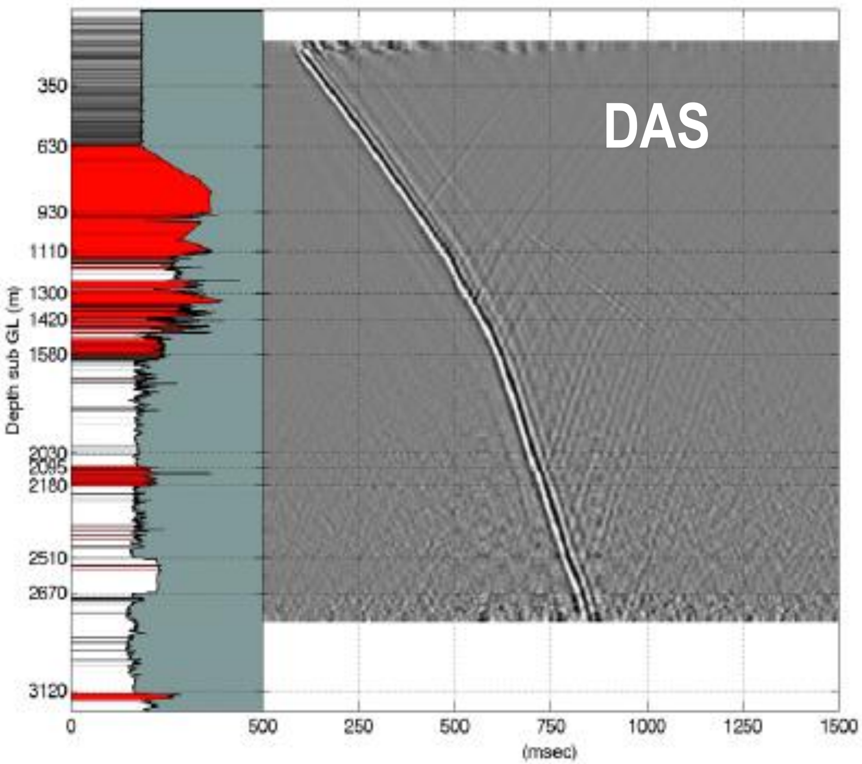
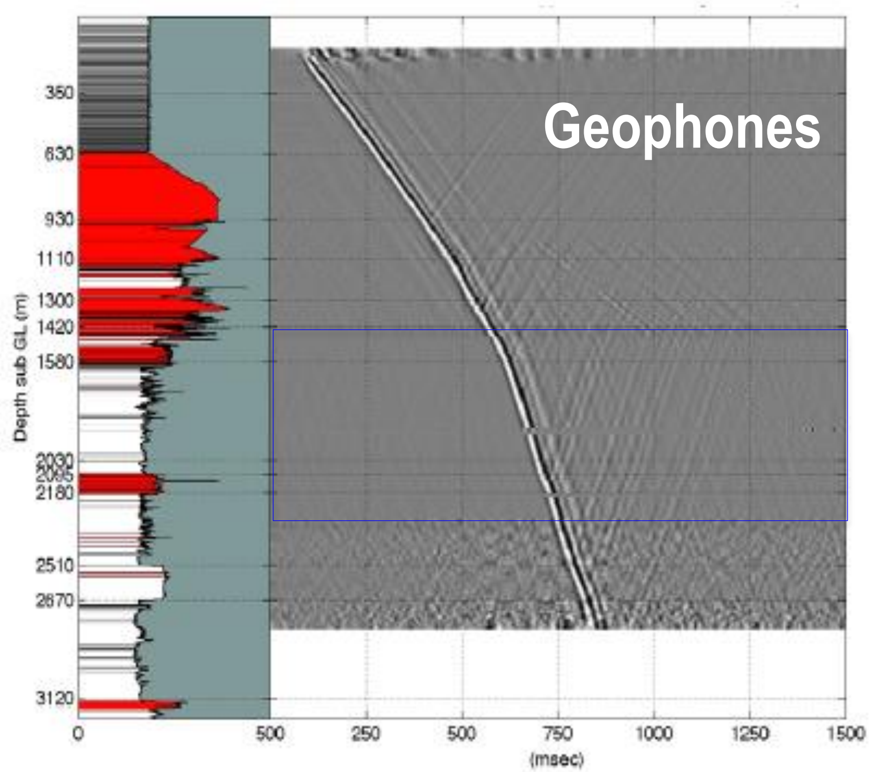
DAS vs Geophone (all depths) (DAS Cemented behind casing, clamped MAXIwave Sercel Geophones)





TM Daley et al., SEG Annual meeting 2014

Accomplishments, Results and Progress

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- **Challenges to Date:** The Almost all developers of high temp instrumentation are mainly catering to oil and gas, especially larger companies. Development and testing is taking longer than anticipated. Recent down turn in oil prices are having an impact on development and deployment. Very few are tested in high temp environments. Few are fully commercialized for high temp (> 200C). Field results are dependent on others not directly involved in this project.

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date to be Completed
Sign MOU with Japan 2013	2014	2014
Field test Japanese tool 2013	2013	Done
Survey Industry 2013- 2015	Same milestone/on-going	09/30/2015
Final report	Same milestone/on-going	01/31/2016

Future Directions

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- Next tasks will focus on field testing in Geothermal areas (not funded by this project but by the state of California and other DOE projects) and industry projects
  - Calpine Inc. (California Geothermal Energy Research and Development (GERDA)) (PI, US-SI)
  - Brady's Ormat EGS project for VSP (US-SI)
  - Newberry (DAS) with Alta Rock
- As new sensors become available they will be evaluated

Milestone or Go/No-Go	Status & Expected Completion Date
Field testing (Brady's , AltaRock, Geysers)	In planning, end of 2015
New sensor evaluation	2016
Final Report	2016

Mandatory Summary Slide

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- High temp borehole seismic instrumentation is critical to EGS Success.
- Fiber optic based sensors show the most promise
  - Discrete sensors
    - Broad bandwidth, good sensitivity, low noise, (10 to 50 Nano V/root hertz) up to 250C to 300C, multicomponent, multilevel, future holds promise
    - However, expensive for geothermal, some may have clamping issues
    - Only one field tested in 200C plus geothermal wells
    - MEQ best application ,VSP for fracture detection, still in development
  - DAS
    - Potential up to 350C, routine 285C, easy to deploy, (open hole and behind casing), lower cost, high spatial resolution, commercially available and tested.
    - Higher noise levels (20 dB), single component
    - Best for VSP and imaging, less so for MEQ
- Once fiber is in hole one could do DAS as well as discrete (and other things)
- Conventional sensors and MEMS, if adapted for high temp, could also play a role
- Need to design for specific conditions and needs