Enabling Cost Effective High Quality Seismic Monitoring of Unconventional Reservoirs with Fiber Optics

DOE contract DE-FE0031780

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U.S. Department of Energy

National Energy Technology Laboratory

2021 Carbon Management and Oil and Gas Research Project Review Meeting

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Presentation Outline

- Program overview
- Background: Optical borehole seismometers
- Technology: Product and Field Results
- Achievements and Developments

Program Overview

– DOE Funding: $2.5M
– Cost Share total: $625k
– Performance Period: 10/1/2019 – 9/31/2021
  - Extended to 04/30/2022
– Project Participants:
  - MagiQ Technologies, Inc. (prime)
  - HighPeak Energy – field operator
  - Microseismic, Inc. – deployment/acquisition

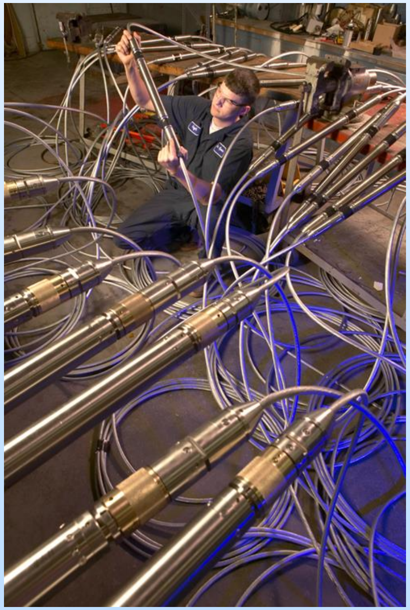
Program Overview

– Overall Project Objectives

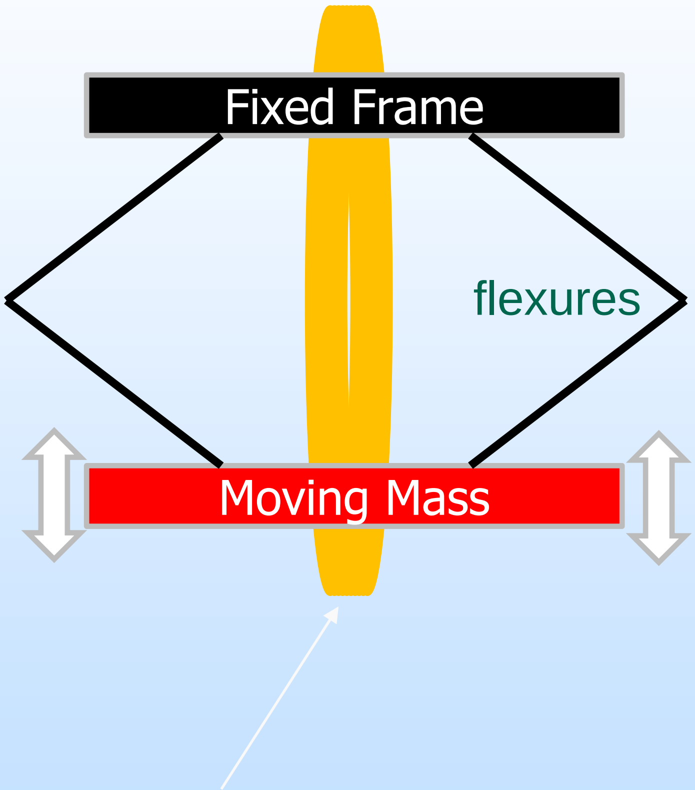
- produce a narrow diameter, high temperature, reliable optical seismic sensor system and demonstrate it in a field test an unconventional basin
- perform a suite of data acquisition activities which will be analyzed to provide information on the reservoir and well operations including active surveys and passive seismic and microseismic monitoring
- demonstrate the ability to cost-effectively provide useful data in a challenging environment

Background: Industry Need

- Accurate geophysical data with reliable, transparent analyses are essential for profit and safety.
- DOE pushing for better understanding of well dynamics in fractured wells to improve safety and efficiency.
- State of the art seismic wireline tools are bulky and require maintenance, so downhole sensor deployments are temporary, labor intensive, and disrupt production operations.
- DEPLOYMENT COST > HARDWARE COST



Background: optical accelerometers

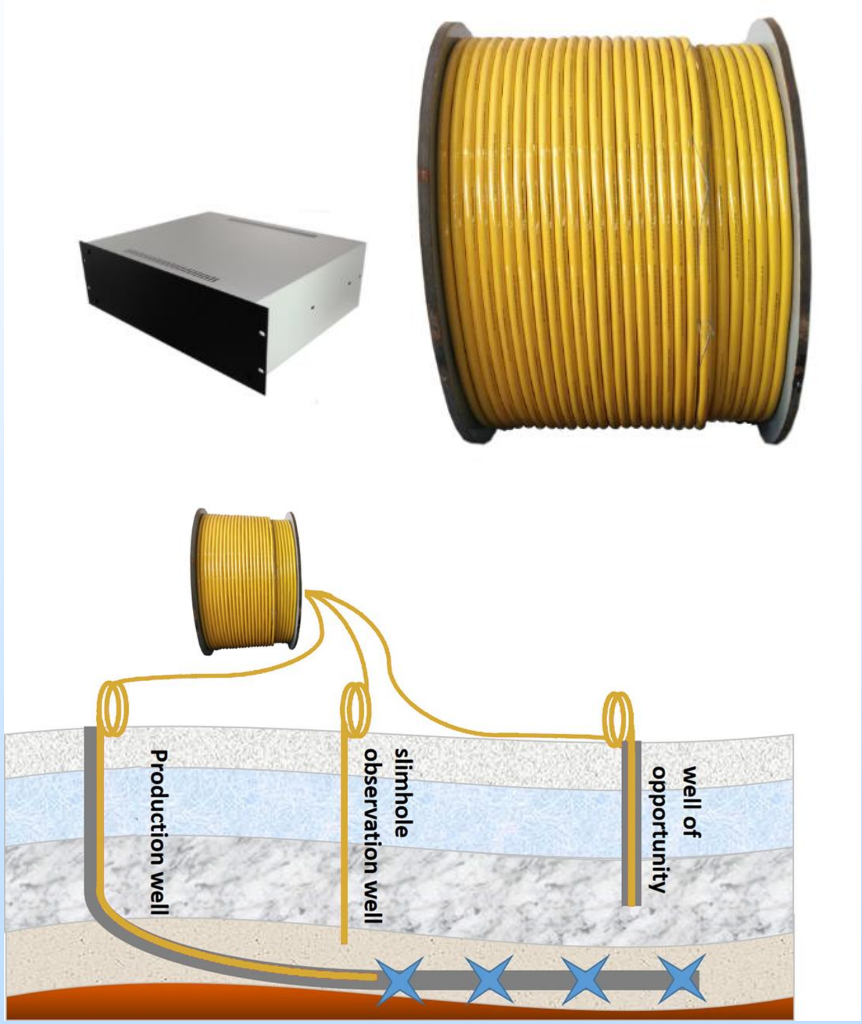


Fiber Coils stretch and contract as mass moves with acceleration

- 'Mass on a spring' design moves under acceleration, stretching optical fibers
- Flexure offers high directionality (>30dB below 100 Hz), high linear dynamic range
- Multiple designs with different specs have been field tested and verified by comparison to geophones and accelerometers.
- All parts are passive and survive decades at high temperatures

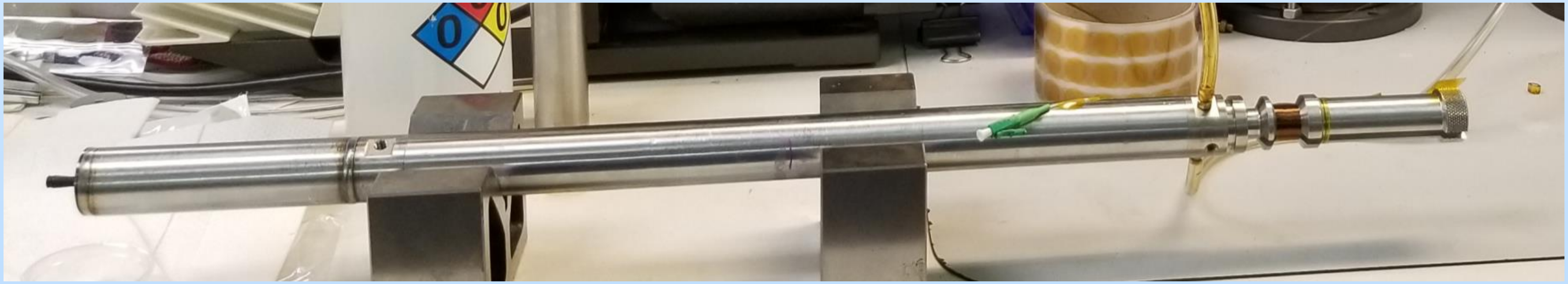
Background: MagiQ Sensor System

- The interrogator includes all electronics, while sensors can be kilometers away, connected by rugged optical cables
- Supports 10 3C sondes per fiber, many fibers per cable.
- Field tested to be robust against laser noise and transmission line pickup.

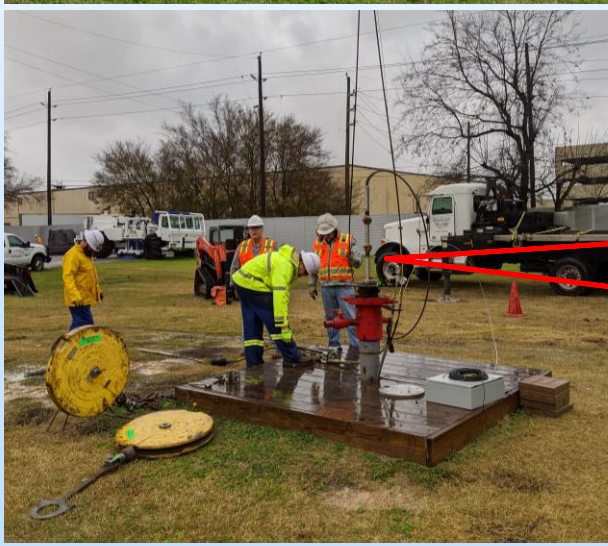


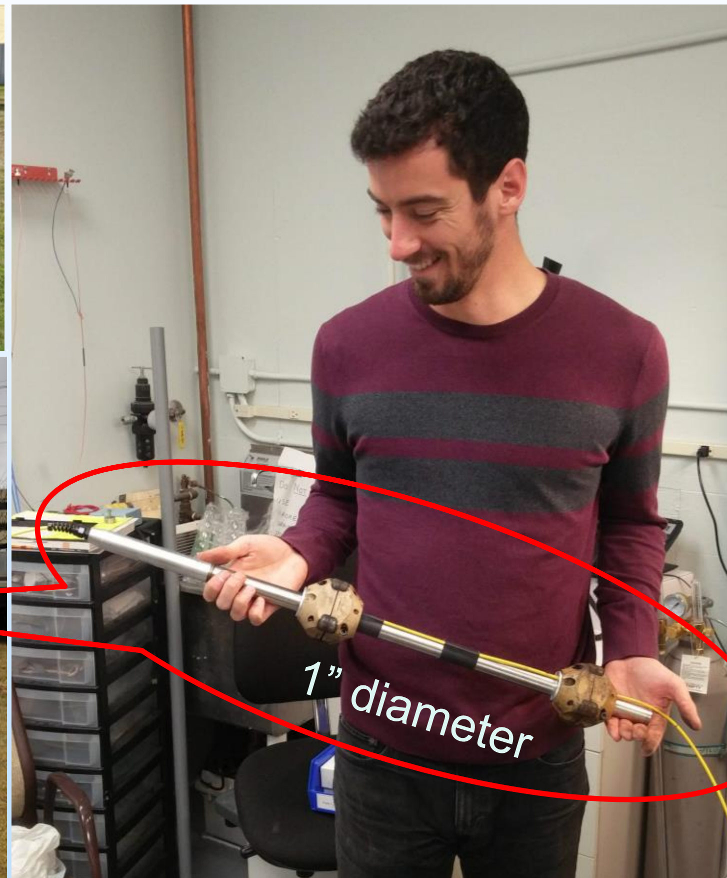
Sensor assembly

- Sensor “core” elements are machined from tungsten (now steel) and wound with fiber.
- The cores are assembled and enclosed in a tube with welded or threaded flanges.
- The sensors are fluid filled for pressure balance and damping.
- Response testing occurs at each step



Completed Sonde





Magnetic clamps

6-Fiber cable, intended to be strapped to a DS-150 toolstring

Issues with cable attachment

Required repairs, changed to a “piggyback” config

Field test performed in Jan. 2020

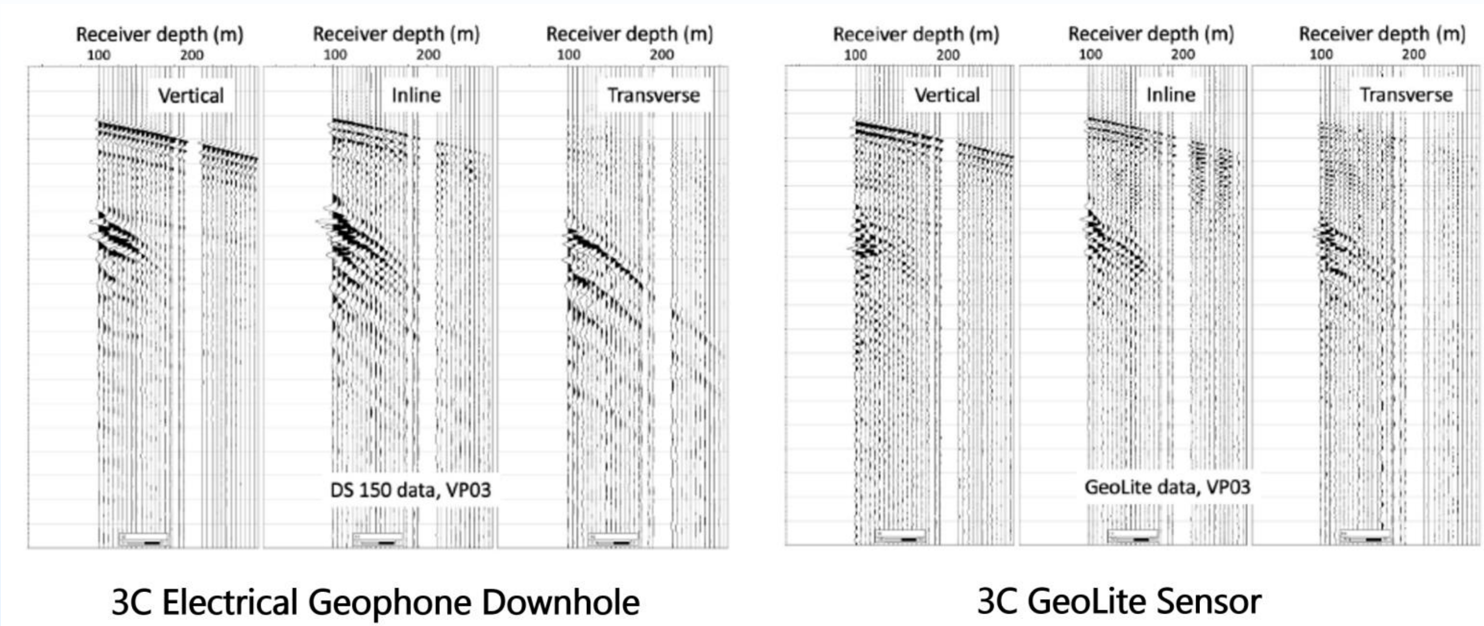
Field test in collaboration with MSI, Aramaco Services Co, and Total SA, partly funded by Phase II SBIR DESC0015781

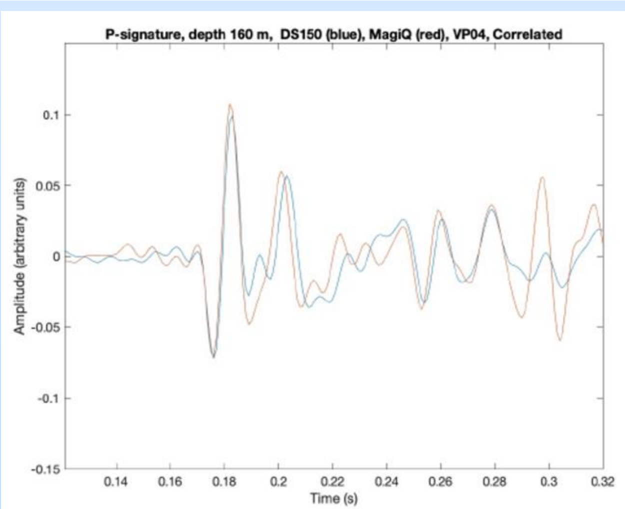
MagiQ produced and tested 4 sonde prototypes (1 Flexible Sonde and 3 Rigid Sondes).
-Narrow diameter, broadband sondes with response comparable to GeoSpace DS-150s

We also delivered an interrogation system with proprietary control software which interfaced with MSI's commercial seismic QA and analysis workflow.

We used the data to generate a variety of seismic analyses and visualizations

Comparison to DS-150 string





Test concluded that the sensors are a more than suitable replacements for electrical 3C geophones, since the GeoLite sensors provide extended coverage to <1Hz, for permanent long-term monitoring in geothermal and storage sites.

Geospace DS-150 3C geophone sondes were used as reference sensors and to support the sensors in the well.

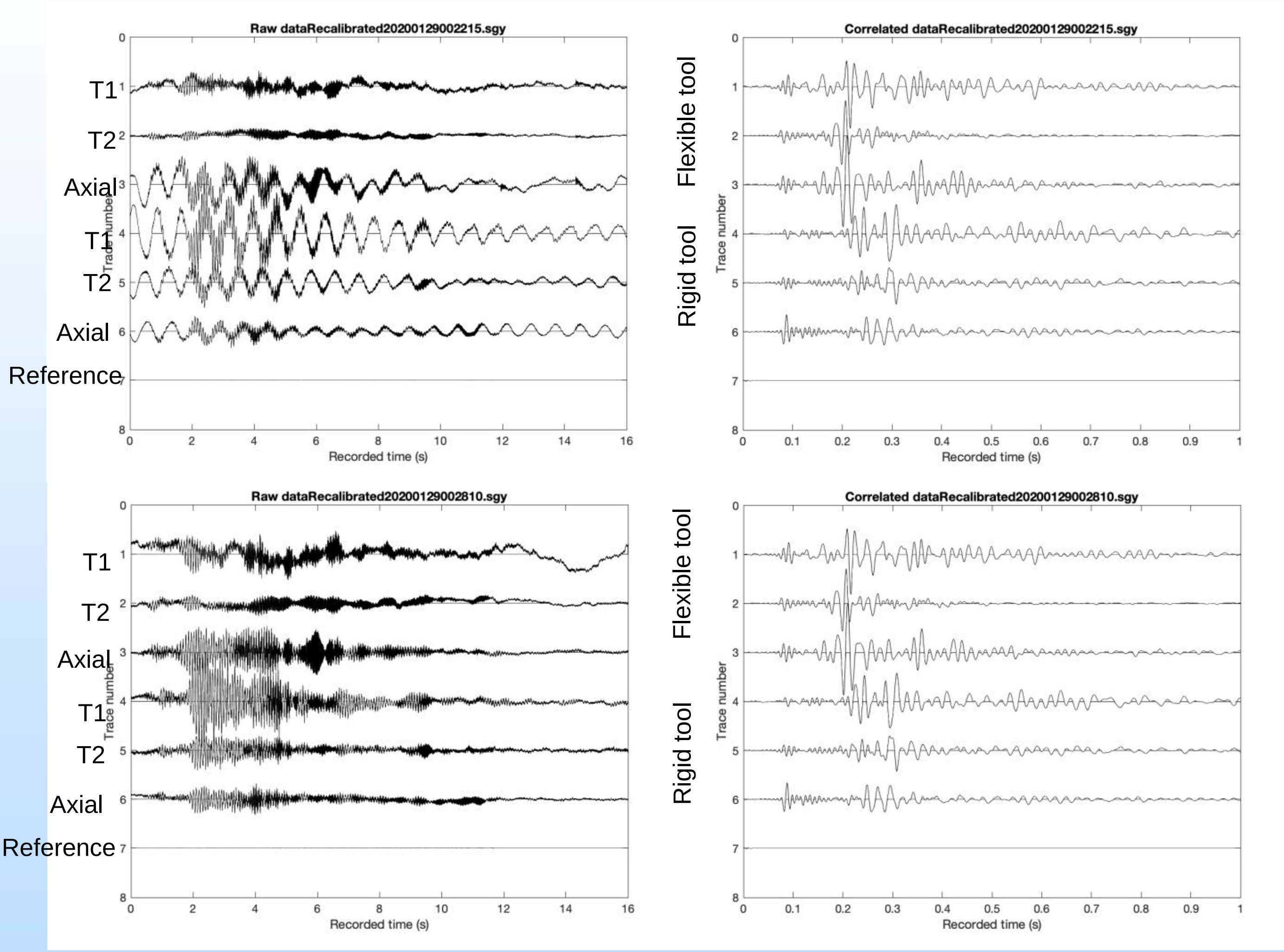
Low-F data (<1 Hz)

Substantial low-f content in test
- Geophones don't pick it up (3Hz HPF)
- Dominant frequencies match tube wave harmonics
- Metro environment with complex infrasound background

With filtering and correlation, vibroseis data was unaffected

16 s, uncorrelated data

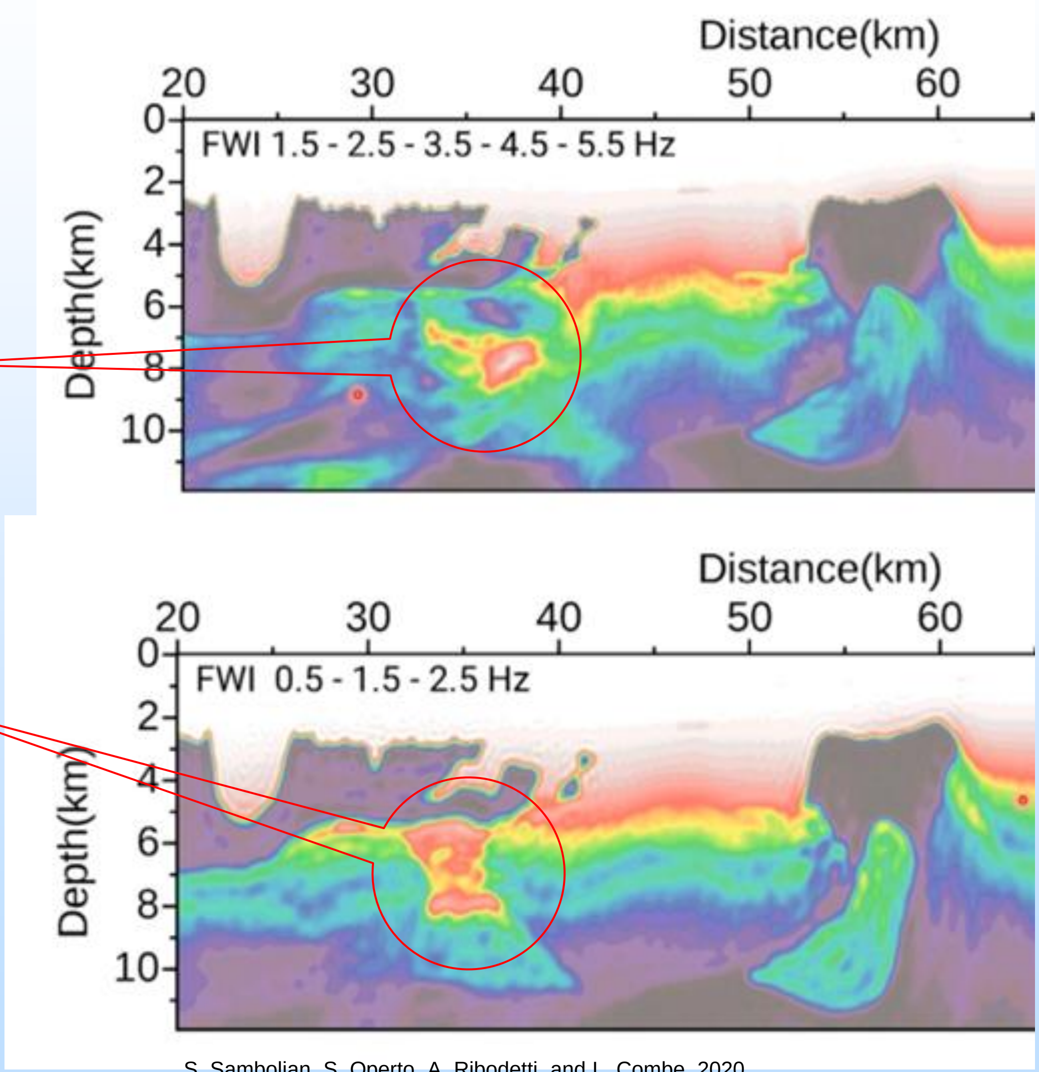
1 s, correlated data



Value of low frequencies

Before:
1.5-5.0 Hz

After:
0.5-2.5 Hz



S. Sambolian, S. Operto, A. Ribodetti, and L. Combe, 2020, From slope tomography to FWI: Is the conventional workflow viable in complex settings? SEG meeting 2020, https://doi.org/10.1190/segam2020-3428063.1

Accomplishments to Date

– Field test complete January 2020 (funded by DESC0015781);

– Advanced latest design for efficient manufacturing, reliable cable/fiber attachments, and optimized sensor response

– Received materials; assembly and testing is underway – delayed

– Finalizing plans for field test in Q1/Q2 of 2022 - delayed

– Pursuing applications and deployments in other sectors (geothermal, CO2 storage, defense)

Lessons Learned

- Integration to toolstring is critical; late changes prevented testing and led to failures

- Data workflow must be fully tested; this delayed fieldwork

- Tungsten was great "on paper", but with a limited ecosystem; this caused poor tolerances, delays, and no-bids

- The pandemic was rough on everybody, especially in this industry. Patience, networking, and diverse applications are essential to develop technology!

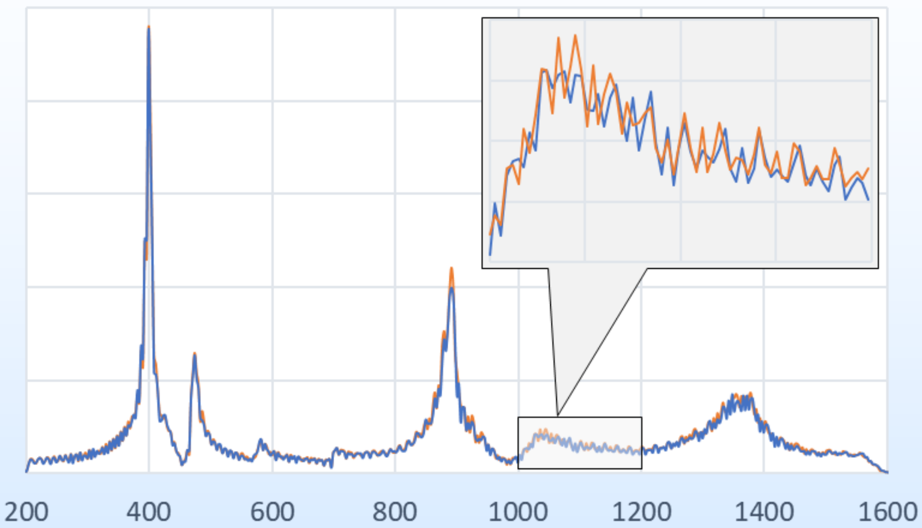
Synergy Opportunities

- We are seeking future partners and customers with unique monitoring needs!

- A small number of wide bandwidth vector seismic sensors could be supplemented with DAS cable to provide low-cost wide area coverage of infrastructure and surrounding formations.

- Permanent seismic/acoustic monitoring of operational gas or oil could be correlated with other continuous datasets regarding resource production, well integrity, and the environment.

Added value: hydrophones



Same interrogator, but broadband acoustic (includes <1 Hz)

Towed/floating sensor for defense apps

Adaptable to 4C borehole or ocean bottom

Tested in Navy labs and at sea, calibrated against H48 Navy developed reference

Project Summary

- High performance optical sensors work very well, providing the capabilities of geophone strings with additional bandwidth and longer expected lifetime.
- Lessons from field tests with prior designs are informing ongoing work, reducing costs and improving manufacturability
- After some delays due to industry recession during pandemic, we expect to perform field tests in early 2022.
- Field test goals are to demonstrate advanced imaging and analysis methods in an unconventional well which benefit from bandwidth and time-lapse.

MagiQ

Appendix

– These slides will not be discussed during the presentation, but are mandatory.

Benefit to the Program

- Project Benefits statement:
  - The research project is designing and fabricating a novel optical seismic sensor system, deploying the system in an unconventional fossil energy reservoir, and performing advanced analyses which take advantage of the long-term deployment capabilities, wide bandwidth, and high SNR of the sensor system. The technology, if successful, can <u>reduce costs for real-time monitoring in long-term or permanent deployment of high performance seismic sensors</u>, while delivering better signal quality at low frequencies and high frequencies compared to state of the art geophone systems. The analysis methods specifically take advantage of the broadband vector information to <u>improve subsurface characterization, visualization, and diagnostics.</u>

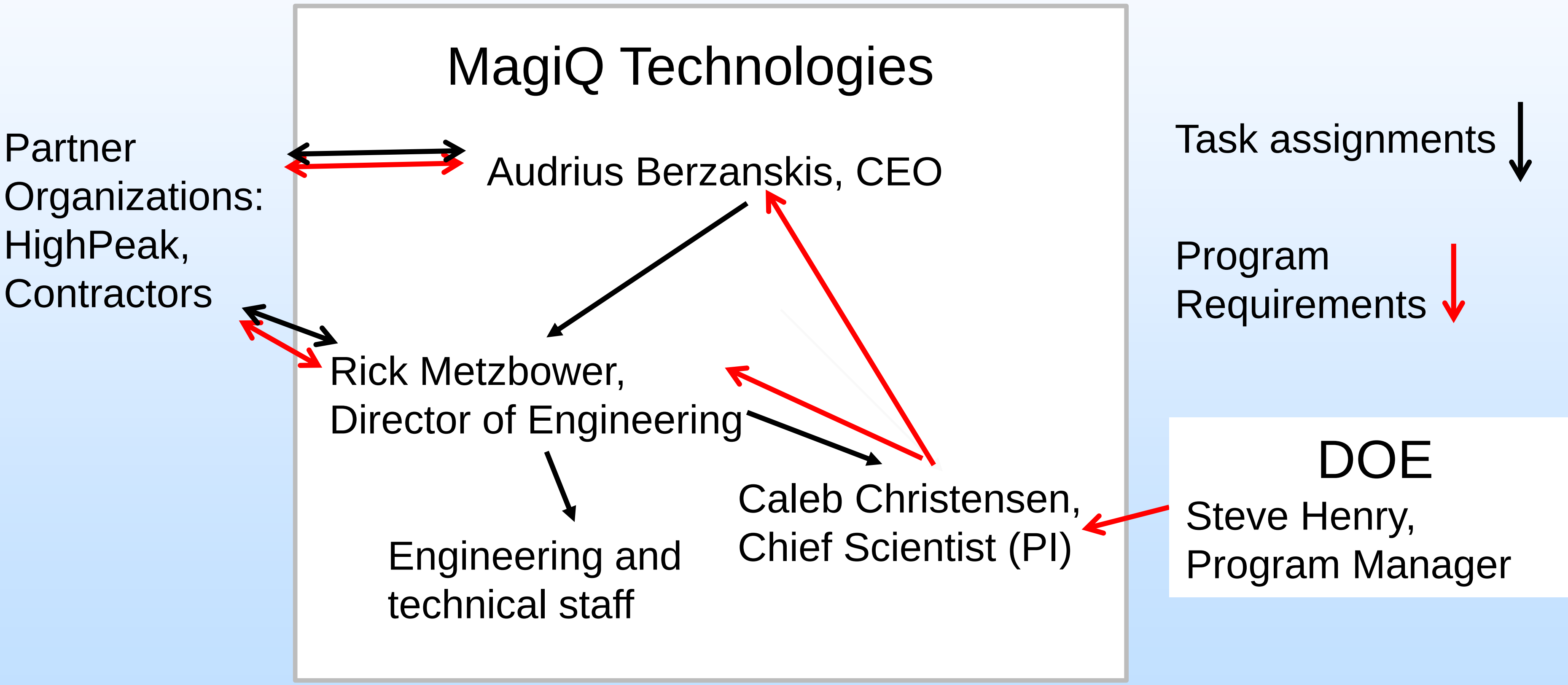
Project Overview

Goals and Objectives

- Describe the project goals and objectives in the SOPO:
  - produce a narrow diameter, high temperature, reliable optical seismic sensor system and demonstrate it in a field test in an unconventional basin success = field test commenced
  - perform a suite of data acquisition activities which will be analyzed to provide information on the reservoir and well operations including active surveys and passive seismic and microseismic monitoring success = data acquisition complete
  - demonstrate the ability to cost-effectively provide useful data in a challenging environment

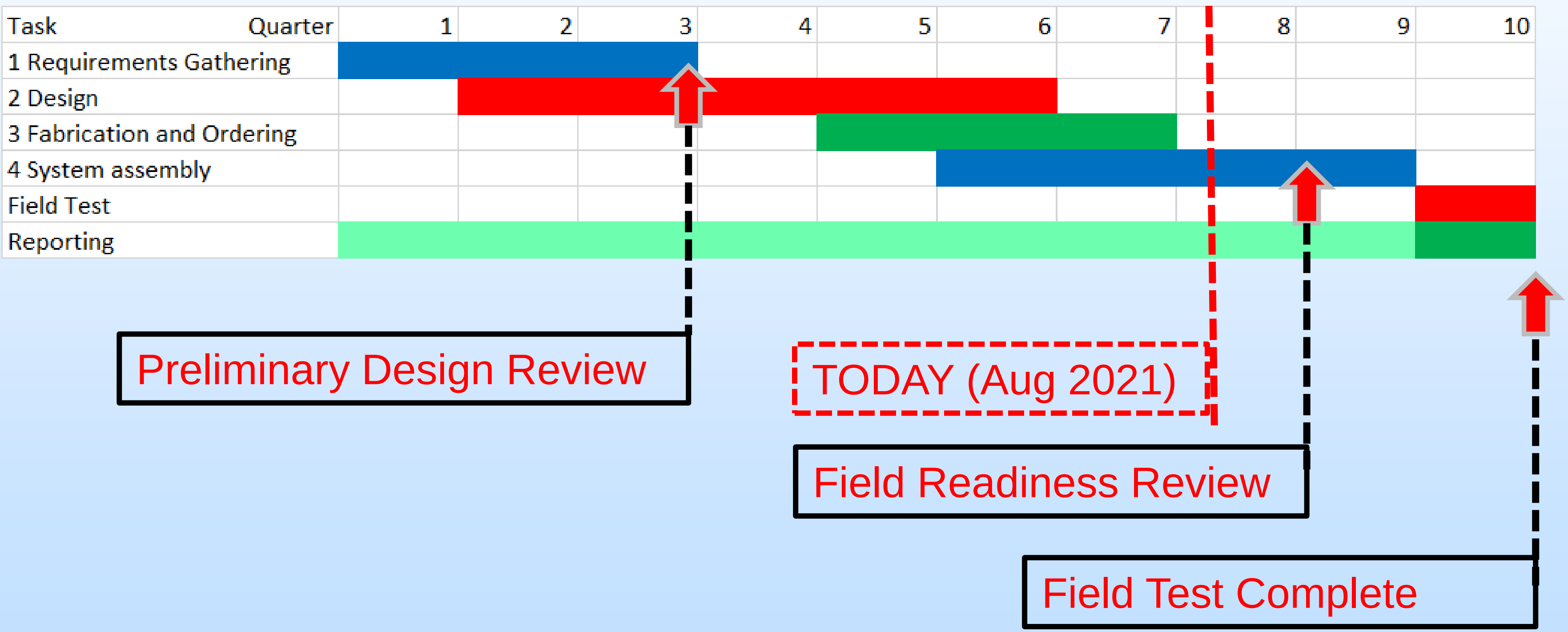
    Success = High Peak, DOE find interpretation and analysis results useful and interesting for O&G development

Organization Chart



Gantt Chart

Start: Oct. 1, 2019 End: Apr 30, 2022



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– Peer reviewed publications and conference proceedings:

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- C. Christensen, R. Metzbower, A. Berzanskis, J. Haldorsen, G. Bergery, V. Lesnikov, M. Verliac, 2021, A Fully Optical Three-Component Accelerometer for Borehole Applications, EAGE Geotech 2021, DAS Workshop. https://doi.org/10.3997/2214-4609.202131033

- Upcoming: Haldorsen J.B.U., C. Christensen, D. R. Metzbower, and A. Berzanskis, 2021, Fiberoptic Wide-Band Acoustic Multi-Component Sensors: Oceans Conference and Exhibition, San Diego, 20-23 September 2021.