Deliverable 1.2: DAS dataset suitable for microseismic and ANI analysis

DigiMon

Digital monitoring of CO_2 storage projects

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DigiMon Deliverable D.1.2 Version 2

November 2020

Revision

Version	Date	Change	Page
1.0	21.08.2020	First version	All
2.0	03.11.2020	Second version, processed comments of DIGIMON review panel	All

Document distribution

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1 Introduction

Deliverable 1.2 concerns a DAS dataset suitable for microseismic and ambient noise interferometry (ANI). For this deliverable the DAS field dataset of FORGE is recommended. FORGE is the Frontier Organization For Research in Geothermal Energy, and is a field laboratory for developing an enhanced geothermal system in hot crystalline rock situated near the town of Milford in Utah, USA (https://utahforge.com/). The FORGE team is led by Joe Moore of Utah (and funded by the US Department of Energy) and is credited for this dataset. The dataset is completely open access, but obviously attribution would be appreciated in any publications.

The FORGE dataset applies for deliverable 1.2, because it provides downhole DAS and geophone recordings of microseismic events, and covers approximately two weeks of continuous DAS recordings that can be used to test the potential of DAS for the ANI method.

In addition to the FORGE dataset, various other DAS datasets have recently become publicly available that are recommended to consider as well for further work in task 1.3 and associated tasks, since they can be valuable in addressing different research aspects of the application of DAS. Table 1.1 gives a summary of the different open access datasets considered for this deliverable. This table also shows whether the datasets are suitable to be used for microseismic and ANI analysis. With this application in mind for deliverable 1.2, and when compared against alternative datasets (see Table 1.1), the FORGE dataset is considered to be especially relevant for this deliverable, since it provides both microseismic event data and continuous DAS recordings from a borehole configuration spanning a relatively long duration (17 days). The borehole configuration is preferable for the purpose of detecting micro-seismicity since it allows measurements close to the reservoir and therefore able to detect weaker events compared to a trenched deployment at the surface. FORGE concerns an enhanced geothermal system and in this setting the mechanism driving seismicity is different compared to the case of CO_2 injection and storage (DIGIMON). However, the performance of the DAS cable with respect to detected seismicity is expected to be similar for the case of monitoring CO_2 injection and storage as in a geothermal setting and therefore the FORGE dataset is expected to be suited for this purpose.

Table 1.1. Overview of open access datasets containing DAS data and relevant for D 1.2.

Dataset	Location	Onshore/offshore	Field operation	DAS configuration	DAS monitoring period	Microseismic/ Earthquake data	Ambient noise data*
POROTOMO	Brady hot springs, Nevada, USA	Onshore	Geothermal, natural lab	Surface/trench	15 days of continuous data	DAS, geophone	DAS, geophone
FORGE	Milford, Utah, USA	Onshore	Enhanced geothermal system	Permanently cemented into monitoring borehole	17 days of continuous data	DAS, geophone (40 microseismic events)	DAS
Antarctica	Antarctica	Onshore (ice)	Passive & Active seismic surveys	At surface (1km cable). Downhole VSP	jan-20	Icequakes	~3 days of continuous DAS data for 3 configurations each
Garner Valley	Garner Valley, CA	Onshore	Natural tectonics	Trenched	8 hours overnight data	No	DAS
Stanford phase 1	Stanford, CA, USA	Onshore	Urban	Telecommunication conduit. OptaSense ODH3	Only snippets of data available	DAS, geophone	No
Richmond Field Station and Fairbanks	Richmond Field Station at Richmond, CA, USA; Farmers Loop Road, Fairbanks, AK, USA	Onshore	Permafrost and geothermal	Trenched in Richmond. Trenched in Fairbanks. Silixa iDAS	Only snippets of data. late 2014 and early 2015 (Richmond), summer 2016 (Fairbanks)	DAS, geophone	No
Belgium DAS array	offshore Zeebrugge, Belgium	Offshore	Teleseismics, ocean noise	Trenched. Chirped pulse DAS	1 hr of raw strain data acquired on August 19, 2018 including the principle body wave phases from the M8.2 Fiji deep earthquake of the same date.	DAS, Teleseismics	No
Monterrey Bay Dark Fiber	Offshore Moss Landing, CA	Offshore	Plate tectonics	Silixa iDAS. Trenched	4 days, continuous	DAS (M=3.4)	Possibly
SAFOD DAS array (San Andreas)	San Andreas Fault, California, USA	Onshore	Plate tectonics	Permanently cemented into monitoring borehole. Optasense H-3	Earthquake events available within period of 22 days	DAS	No

2 Description of dataset

The FORGE dataset is an open dataset where data is acquired by a borehole DAS set-up with 12 co-located geophones, where microseismic events have been recorded on both sensor types. This allows comparison of the response of the two sensor types. The main acquisition parameters are listed in Table 2.1, but more extensive information can be found in the technical reports available on https://utahforge.com/.

The bottom part of the DAS cable is positioned in hard rock and the upper part in weathered granite/alluvium. The DAS data is fairly noisy, and the geophones showed a better signal-to-noise (and recorded many more microseismic earthquakes). However, additional data processing can help to improve the DAS data quality as demonstrated by Lellouch et al. (2020b). An example of a micro-seismic event recorded with the array is shown in Figure 2.1. More information on related background data and instrumentation of the different wells can be found in Appendix A and in the associated FORGE documents.

Table 2.1. Acquisition parameters.

Hardware	iDAS v3 Carina system with constellation fibre
Sampling frequency	2000 Hz
Gauge length	10 m
Channel spacing	1 m
Date of acquisition	19 April 2019 – 03 May 2019
File format	SEGY
Channels per file	1280
Record length	15 sec. per file
Unit	Strain rate

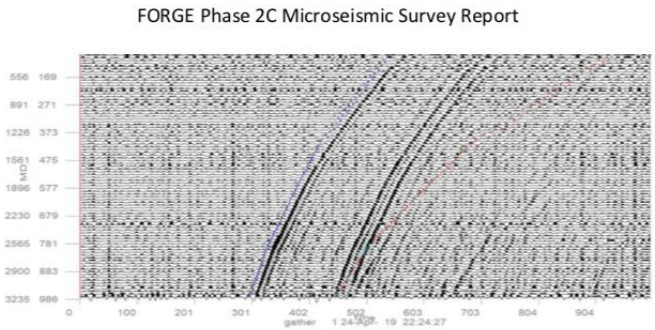

Figure 8. Perf shot waveform with calibrated model times displayed.

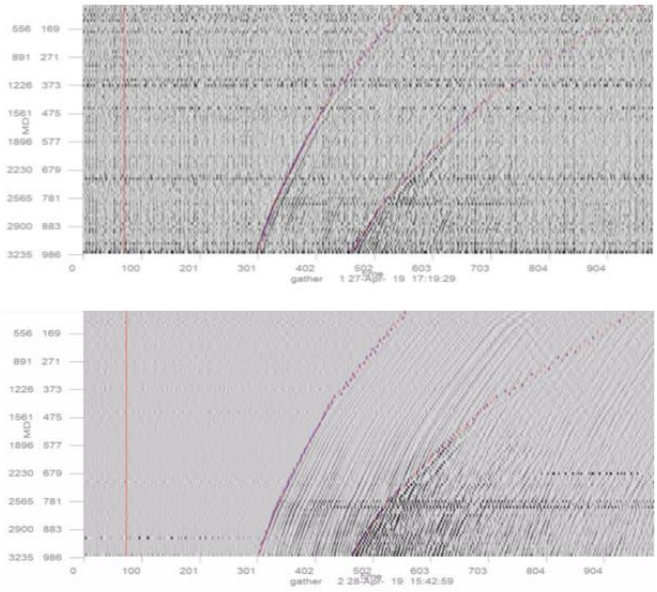

Figure 9. Low quality (above) and high quality (below) events with calibrated model times displayed.

Figure 2.1. From Phase 3C Section II Silixa report. The data for these events were uploaded to the Bristol sharepoint.

3 Data access and background reports

The DAS data and related reports can be accessed on https://gdr.openei.org/submissions/1185. A very useful data analysis tutorial for the FORGE dataset provided by N. Lindsey (Stanford) can be found on https://github.com/eileenrmartin/IntroToDASData/blob/master/Forge.ipynb. This notebook consists of a python workflow for downloading the FORGE dataset and for subsequent data processing.

The DAS-data amounts in total to 13 TB and can be downloaded by running a shell script named get_all_silixa.sh. This shell script is simply a set of wget commands, so it requires wget on your computer, or something similar. For instance the following command:
wget -q https://pando-rgw01.chpc.utah.edu/silixa_das_apr_19_2019/FORGE_78-32_iDASv3-P11_UTC190419001218.sgy

A vast amount of documentation is available online and all data (geology, well logs, stimulation reports). The Phase 2C report can be found at https://gdr.openei.org/submissions/1187. For further DAS data description, the seismic monitoring report (see Report section B, Results III) contains an extensive data report from Silixa.

Other data and documents can be found at https://gdr.openei.org/ under FORGE (use Utah FORGE not Fallon FORGE). The entire microseismic catalog can be found at https://gdr.openei.org/submissions/1151.

The example shown in Figure 2.1 is also available on the sharepoint of Bristol (see *DigiMon/DigiMon-WP1-Share/Task1_3/Data/FORGE_selected_data_info*).

This folder contains the files:

- FORGE_info_scripts.tar.bz2 (~300 mb). This bzipped tarfile contains: Info: copies of FORGE data acquisition reports. Also it provides two scripts (scripts_get_all_data) to download all DAS and geophone data (multiple TB)
- FORGE_events_sac.tar.bz2 and FORGE_events_segy.tar.bz2. This is the same data stored respectively in SAC and SEGY format, each about 370 mb in size. These contain three events in SAC and SEGY file data for events for both geophone and DAS.

4 Relevant Literature

FORGE, 2019, Phase 2C Topical Report Section B: Results III. Seismic Monitoring Report.

Lellouch, A., R. Schultz, N. J. Lindsey, B. Biondi, and W. L. Ellsworth, 2020a, Low-magnitude Seismicity with a Downhole Distributed Acoustic Sensing Array -- examples from the FORGE Geothermal Experiment. https://arxiv.org/abs/2006.15197

Lellouch, A., N. J. Lindsey, B. Biondi, and W. L. Ellsworth, 2020b, Comparison between Distributed Acoustic Sensing and Geophones - Downhole Microseismic Monitoring of the FORGE Geothermal Experiment, Seismological Review Letters, August 1, 2020

5 Appendix A: Background data on FORGE dataset

This section contains some relevant background data of the FORGE site. Please see the associated FORGE reports for a comprehensive overview of this site and associated datasets.

Figure A1. Photo of FORGE site. Currently existing wells are white, planned in yellow. From https://utahforge.com/data-dashboard/current-and-planned-activities/

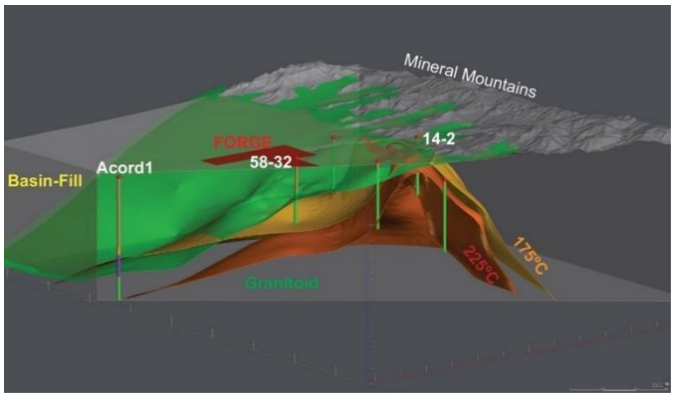

Figure A2. Perspective view of geology showing granite body under alluvium and key wells.

Table A1. FORGE wells (From https://utahforge.com/data-dashboard/current-and-planned-activities/).

Well	Status	Notes	Notes	Depth m (feet)
58-32	Existing	Available		
68-32	Existing	Geophone/accel.	Silicon Audio	281/(920)
58-32	Existing	**Fiber outside casing**	**Silixa Constellation**	**996/(3268)**
16A(78)-32	2020-2021	Vertical/deviated	Partially cased	2585/(8480)
56-32	2020-2021	Fiber	Silixa Constellation	1372/(4500)
Production well	TBD			

A pilot stimulation was conducted in 2019 from April 14 to May 04 2019. 9 cycles of injection at three different depth zones were conducted, which were recorded on DAS. Table A2 shows the conditions of the different depth segments and Figure A3 shows a cross-section of stimulation and bottom of the fiber. The fiber monitoring well has fiber to a depth of roughly 995 meters.

Table A2. Conditions of different depth segments along the well trajectory.

Zone	Type	Approximate depth (m)
1	Uncased	2255/(7400)
2	Cased/perfed	2124/(6970)
3	Cased/perfed	2002/(6570)

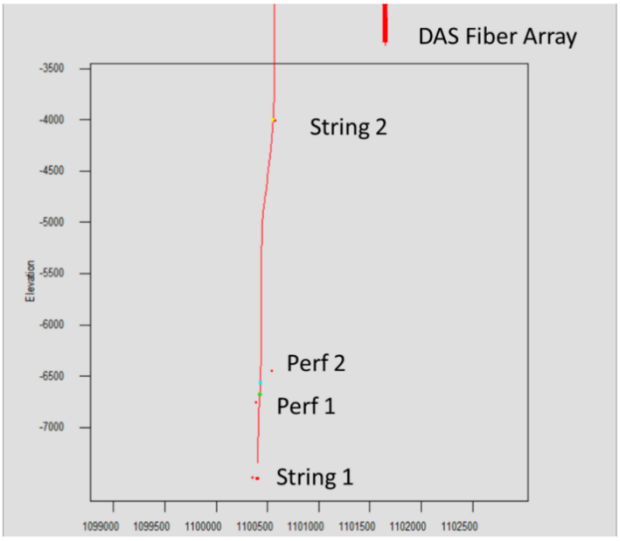

Figure A3. Cross-section of stimulation and bottom of fiber. From Phase 2C report, Section III.