Imaging the CarbFix2 Reinjection Reservoir at Hellisheiði, Iceland, with Body-wave Seismic Interferometry

Hassing, S.; Draganov, D.; Barnhoorn, A.; Janssen, M.

DOI
10.3997/2214-4609.202285008

Publication date
2022

Document Version
Final published version

Published in
2nd EAGE Conference on Near Surface in Latin America

Citation (APA)
Hassing, S., Draganov, D., Barnhoorn, A., & Janssen, M. (2022). Imaging the CarbFix2 Reinjection Reservoir at Hellisheiði, Iceland, with Body-wave Seismic Interferometry. In *2nd EAGE Conference on Near Surface in Latin America* (pp. 1-5). (2nd EAGE Conference on Near Surface in Latin America). EAGE. https://doi.org/10.3997/2214-4609.202285008

D1-5

Imaging the CarbFix2 Reinjection Reservoir at Hellisheiði, Iceland, with Body-wave Seismic Interferometry

S. Hassing[1], D. Draganov[1], A. Barnhoorn[1], M. Janssen[1]

Tu Delft[1]

Summary

In July 2021, passive seismic data has been recorded on a network of geophones at the CarbFix2 injection site at Hellisheiði, Iceland. This data is processed using seismic interferometry to get an image of the injection reservoir. The data is split up into noise panels. Panels dominated by body-wave energy are selected using an illumination analysis. In panels where the dominant event has a (near) vertical incidence, each trace is autocorrelated to get a zero-offset section. In panels where the dominant event is recognized as a body-wave event, all the traces are crosscorrelated, obtaining virtual common-shot gathers. This is processed with a reflection-seismology workflow to obtain a stacked section. Comparing the two final sections shows that similar reflectors are imaged. The zero-offset section shows a higher frequency content, while the stacked section shows more continuous reflectors. Comparison with a local geological model shows that the results are plausible, but that a better interpretation has to wait for more results of the same survey to be processed.

Introduction

The Hellisheiði geothermal power plant in Iceland is the location of the original pilot wells for the CarbFix project. The aim of this project was to find a reinjection method for CO_2 and H_2S that would allow for mineralization to occur more quickly compared to other methods in use at the time (Matter et al. 2016). After the success of the project, it was expanded by adding a second injection field at Hellisheiði in the CarbFix2 project (Gunnarsson et al. 2018).

The Hellisheiði power plant works together with the SUCCEED project. This project was established to investigate the injected CO_2 and test new instruments for the monitoring of CO_2 (Durucan et al. 2021). Therefore, two seismic surveys were conducted at the CarbFix2 injection site in July 2021 and June 2022. During both surveys, an active-source campaign was conducted with a seismic-vibrator source and recorded on a Distributed Acoustic Sensing (DAS) fiber-optical cable.

During the 2021 survey, an extra network of geophones was deployed. A 148-station-network of SmartSOLO geophones recorded ambient noise for a week. The geophones were set up in two lines – one along the DAS cable, the inline, and one perpendicular to the DAS cable, the crossline. The exact location of the stations and the location of the power plant are shown in figure 1.

As the geophone network was not used in the 2022 survey, the passively recorded data cannot be used for monitoring. It can, however, be used to image the reservoir into which CO_2 is injected. The aim of this work is to use seismic interferometry to process the data recorded passively with the SmartSOLO stations during the 2021 survey.

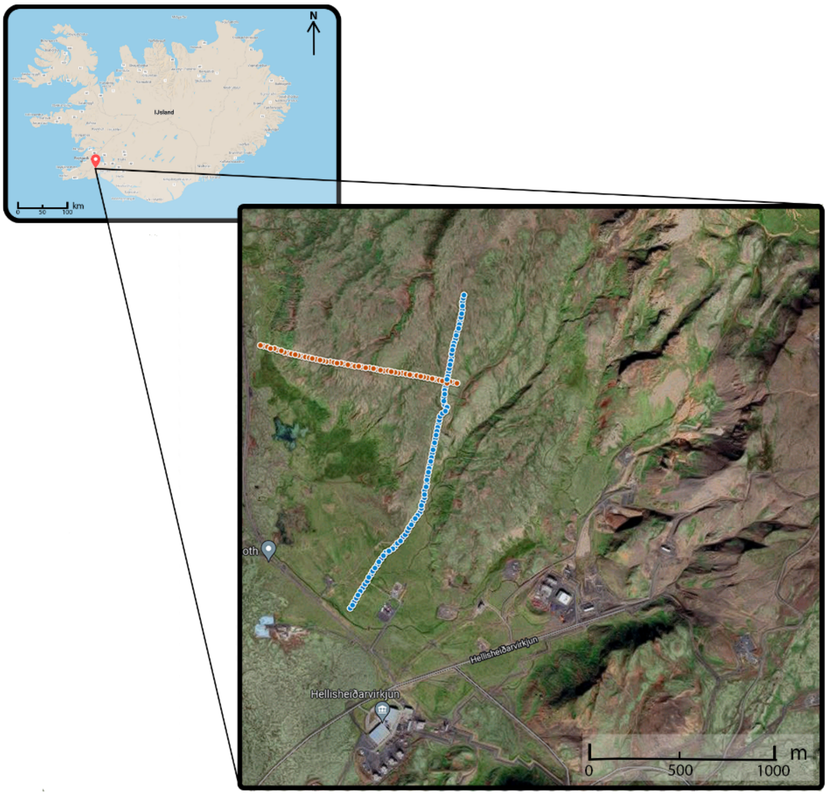

Figure 1 *A map showing the SmartSOLO stations in the 2021 survey. The inline is shown with blue circles, while the crossline is shown with red circles. The various buildings are part of the power plant with the main building lying south of the inline.*
Background image from Google, ©2022, CNES / Airbus, Maxar Technologies.

The Hellisheiði area is part of the Hengill volcanic system. Under the CarbFix2 injection site, the succession is dominated by horizontal formations of hyaloclastic material and lava flows. Injection happens to roughly 1900 m below the surface, while the base of the Hengill volcano is located around 1700 m below the surface (Snæbjörnsdóttir et al. 2018).

Theory and methods

Seismic interferometry is a method that can retrieve a virtual seismic response at a certain receiver location caused by a virtual source at a second receiver location by crosscorrelating the seismic records as measured at the two receiver locations. This requires that the ray path of the recorded event reaches the second receiver location before reaching the first receiver location. The result is that the path between the original source location and the second receiver location is effectively eliminated, placing the source at the virtual source position. For a comprehensive overview of the derivation and the limitations of the method, see for example Wapenaar and Fokkema (2006) and Wapenaar et al. (2010).

With passively recorded data that contains recordings of local seismicity, the method can be applied to retrieve virtual common-shot gathers at each receiver location. Most of the data, however, is dominated by surface-wave energy. To improve the results, only the parts of the data that are dominated by body-wave noise are selected. This is done with an illumination analysis, similar to Almagro Vidal et al. (2014).

For this, the data is split up into noise panels of 10 s. The illumination analysis finds the slowness – the inverse of the apparent velocity – of the dominant event in each panel. The dominant slowness gives an indication of the angle of incidence of the dominant event. A low slowness indicates an incidence close to vertical. This is used to select panels used to retrieve the virtual common-shot gather. The set of virtual common-shot gathers is processed with a standard reflection seismological processing workflow to obtain a subsurface image. With more strict selection criteria, only dominant events with a (close to) vertical incidence can be selected. This means that each trace can be autocorrelated to directly retrieve a virtual zero-offset section.

The illumination analysis is performed by performing a Tau-P transform to each crosscorrelated noise panel. After seeing the results, the process is repeated with a bandpass filter between 5 and 40 Hz that is applied to the panel before the Tau-P transform. The results of the illumination analysis are used to select panels that are dominated by body-wave noise. The limit for this is set as a maximum slowness of 0.0002 s/m. For the virtual zero-offset section from autocorrelations, the limit is set as a maximum slowness of 0.0001 s/m.

Each selected panel is first normalized by dividing each trace by its root-mean-square value. Then, the same bandpass filter as for the illumination analysis is applied. Then, for the virtual zero-offset section, each trace in the panel is autocorrelated and added to a summed section. Afterwards the filter is reapplied, low times are dampened and automatic gain control is applied to visualize the final image. For the retrieved virtual common-shot gathers, each trace is crosscorrelated with all the traces. Then, Wiener deconvolution is applied. The result is then resorted into common-midpoint gathers, a normal moveout correction is applied, and the result is stacked to obtain a final stacked section.

Results and discussion

The final sections that are obtained along the main line using autocorrelation and crosscorrelation are shown in figures 2 and 3, respectively. The main difference between the two sections is that the frequency content in figure 2 is higher and the reflectors appear more horizontal. The imaged reflectors are, though, more continuous in figure 3. A possible explanation is that the autocorrelation method has difficulty imaging dipping reflectors, due to the requirement for vertical incidence. The most prominent reflectors shown in both sections correspond to each other.

Due to the limited spatial extent of the geophone lines, creating a velocity model is difficult. This means that no time-to-depth conversion is possible. The results fit with the knowledge of the local geology, but where the base of the Hengill volcano and the deepest injection occur needs to be estimated. A first estimate would be to place the base of the Hengill volcano around 0.6 s two-way traveltime.

The data from the active campaign has not been processed, so no comparison with other data can be made. This could also provide a velocity model for the sections, to make interpretations easier.

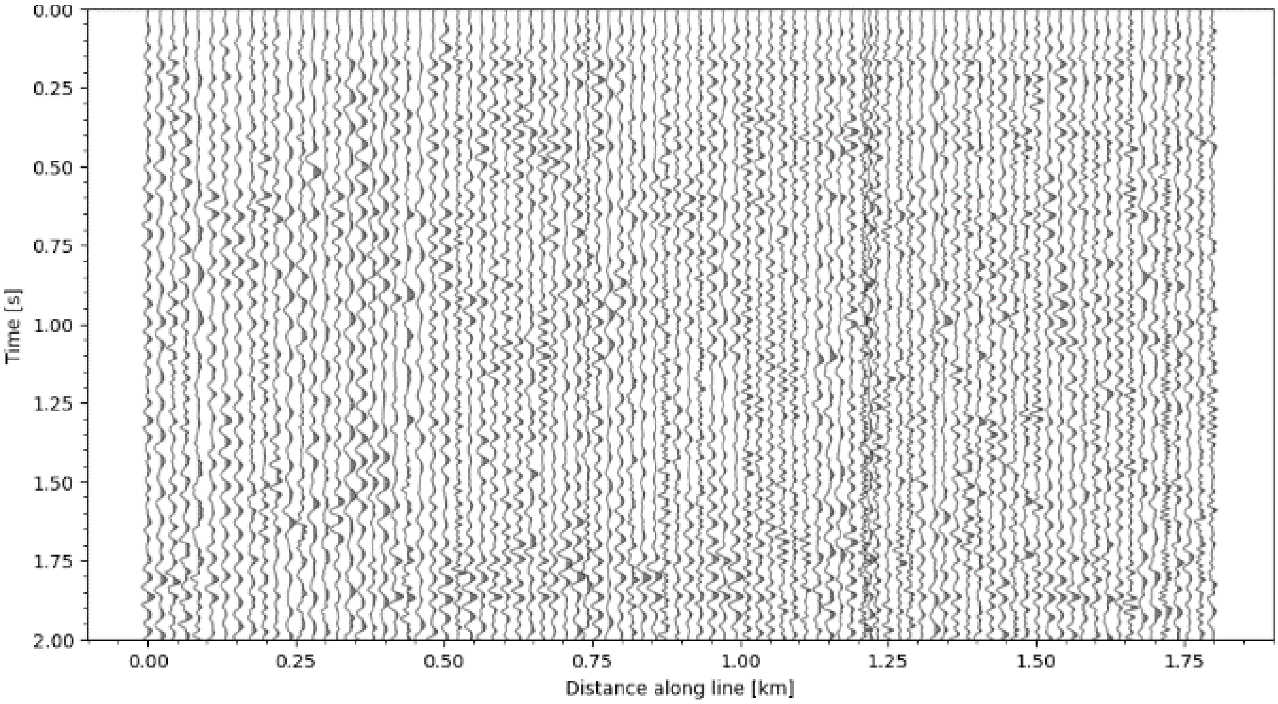

Figure 2 *The inline virtual zero-offset section obtained from autocorrelating each trace in each selected panel.*

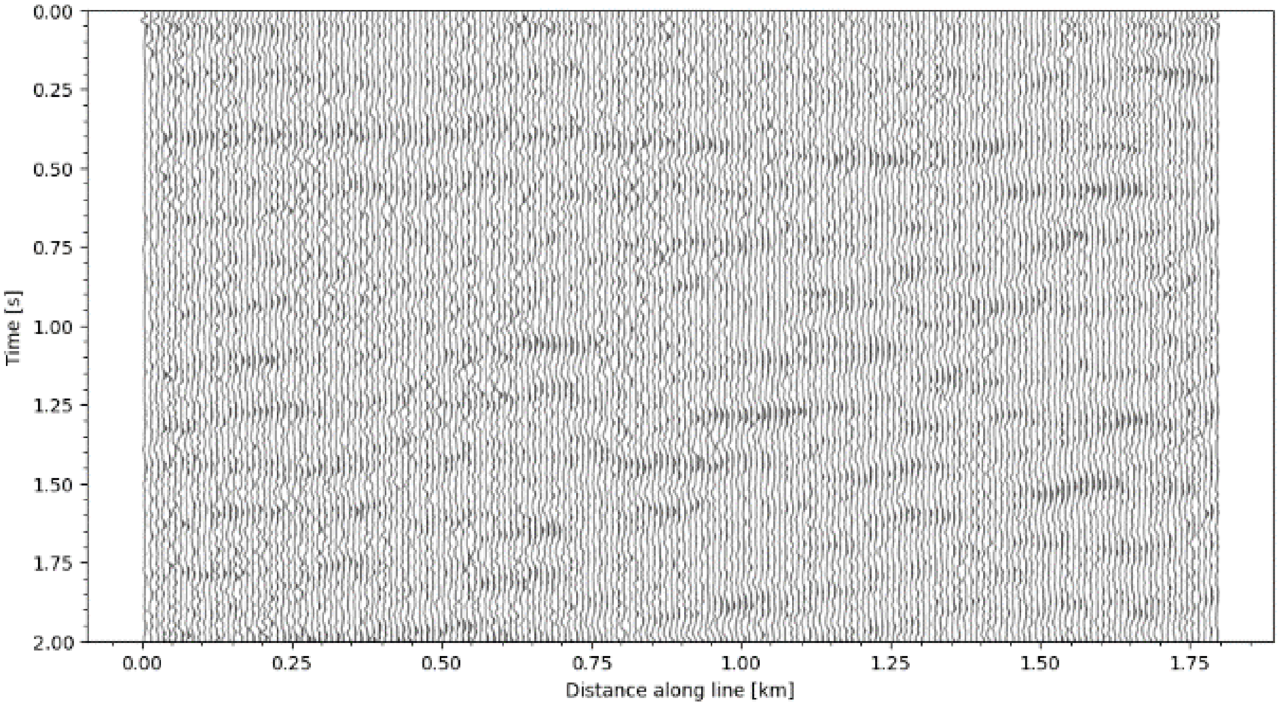

Figure 3 *The inline stacked section obtained by crosscorrelating the traces in each selected panel and then applying a reflection-seismology processing workflow.*

Conclusions

Passive seismic data recorded in July 2021 at the CarbFix2 injection site at Hellisheiði was processed using seismic interferometry. This resulted in two images of the subsurface structures: one obtained by autocorrelating each trace in selected noise panels, the other by crosscorrelating the traces in the selected noise panels and using concepts from reflection seismology to obtain an image.

The two sections appear very different to the eye, with a higher frequency content in the zero-offset section from autocorrelations and more continuous reflectors in the section from crosscorrelations. However, the main reflectors correspond between the two sections.

A comparison with the local geology shows that the results are plausible and the reservoir itself has been imaged. Further verification of the results would be possible when the results of the active-source campaign, conducted during the same week, become available.

References

Almagro Vidal, C., Draganov, D., van der Neut, J., Drijkoningen, G. and Wapenaar, K. [2014] Retrieval of reflections from ambient noise using illumination diagnosis. *Geophysical Journal International*, **198**(3), 1572–1584.

Durucan, Ş, Korre, A., Parlaktuna, M., Şentürk, E., Wolf, K, Chalari, A., Stork, A., Nikolov, S., de Kunder, R., Sigfússon, B., Hjörleifsdóttir, V., Andersen, N. and Poletto, F. [2021] SUCCEED: A CO_2 storage and utilization project aimed at mitigating against greenhouse gas emissions from geothermal power production. *Proceedings of the 15th International Conference on Greenhouse Gas Control Techniques Conference 15-18 March 2021.*

Gunnarsson, I., Aradóttir, E.S., Oelkers, E.H., Clark, D.E., Arnarson, M.Þ., Sigfússon, B., Snæbjörnsdóttir, S.Ó., Matter, J.M., Stute, M., Júlíusson, B.M. and Gíslason, S.R. [2018] The rapid and cost-effective capture and subsurface mineral storage of carbon and sulfur at the CarbFix2 site. *International Journal of Greenhouse Gas Control*, **79**, 117-126.

Matter, J., Broecker, W., Gislason, S., Gunnlaugsson, E., Oelkers, E., Stute, M., Sigurdardóttir, H., Stefansson, A., Alfreðsson, H., Aradóttir, E., Axelsson, G, Sigfússon, B. and Wolff-Boenisch, D. [2011] The CarbFix pilot project – storing carbon dioxide in basalt. *Energy Procedia*, **4**, 5579–5585.

Snæbjörnsdóttir, S. Ó., Tómasdóttir, S., Sigfússon, B., Aradóttir, E. S., Gunnarsson, G., Niemi, A., Basirat, F., Dessirier, B., Gislason, S. R., Oelkers, E. H. and Franzson, H. [2018] The geology and hydrology of the CarbFix2 site, SW-Iceland. *Energy Procedia*, **146**, 146–157.

Wapenaar, K., Draganov, D., Snieder, R., Campman, X. and Verdel, A. [2010] Tutorial on seismic interferometry: Part 1 - basic principles and applications. *Geophysics*, **75**(5), 195–209.

Wapenaar, K. and Fokkema, J. [2006] Green's functions representations for seismic interferometry. *Geophysics*, **71**(4), 33–46.