Baseline 3D seismic imaging for the CO_2SINK project in the Ketzin area, Germany

C. Juhlin[1] , C. Cosma[2] , A. Förster[3] , R. Giese[3], N. Juhojuntti[1], H. Kazemeini[1], B. Norden[3], K. Zink-Jørgensen[4]

[1]Uppsala University, Sweden

[2]Vibrometric Oy, Finland

[3] GeoForschungsZentrum Potsdam, Germany

[4]GEUS, Geological Survey of Denmark and Greenland

Abstract

Baseline 3D seismic data over the Ketzin area were acquired in the autumn of 2005. Main objectives of the survey were to (1) provide an understanding of the structural geometry for flow pathways within the reservoir, (2) provide a baseline for later evaluation of the time evolution of rock properties as CO_2 is injected into the reservoir, and (3) provide detailed sub-surface images near the injection borehole for planning of the drilling operations. Processing of these data began in early 2006 with final stacked and migrated volumes expected to be ready in June 2006. Results from a sub-volume near the planned injection site show that most prominent reflections are generally laterally continuous, with no clear indications of faulting near the injection site.

Keywords: CO_2 storage, seismic, borehole, acquisition, migration

Introduction

Since April 2004, preparatory work prior to CO_2 injection is being conducted for the CO_2SINK project, the European Union's first research and development activity on in situ testing of geological storage of CO_2 near the town of Ketzin, Germany (Figure 1). Drilling into the saline aquifer of the Upper Triassic Stuttgart Formation, in an anticlinal structure of the Northeast German basin, will begin in the autumn of 2006. The preparatory phase has focused on investigating the site in order to fully understand the geological setting, the risks associated with leakage, and how to effectively monitor and control the injection activities. The Stuttgart Formation is lithologically heterogeneous. It comprises muddy flood-plain-facies rocks of poor reservoir quality (forming also the about 200 m thick cap rock of the CO_2SINK reservoir) alternating with sandy string-facies rocks of good reservoir properties that may attain a thickness of several tens of meters where sub-channels are stacked.

The site selected near Berlin,Germany includes industrial land and some infra-structure, which makes it suitable as a testing ground for a small scale demonstration of CO_2 injection. Three boreholes, one injection well and two observation wells, will be drilled, about 50–100 m apart, into the anticlinal structure. A total of up to 100 tons/day of CO_2, in gaseous state at the well head, will be injected at about 600 m depth into the saline sandstone aquifer component of the Stuttgart Formation. Injection will last for approximately two years, during which the distribution and fate of the injected gas will be monitored by surface geophysical surveys and by downhole instrumentation.

An extensive collection of data from previous and ongoing exploration has been screened and interpreted in detail and is available online to the project participants. This data collection includes seismic profiles and stratigraphic and lithological information from 36 boreholes, which have been used to develop a first structural and lithological model of the CO_2SINK storage site at Ketzin to be verified during the project. The data also constitute a basis for selecting the preliminary location of the injection well and the two observation wells and was used to initiate the permitting process for the baseline 3D seismic survey, as well as the drilling operations.

The baseline 3D seismic survey, covering an area of about 12 km^2, is the spearhead for the seismic imaging aspect of the project. Main objectives of the survey are (1) to provide an understanding of the structural geometry for flow pathways within the sandstone aquifer at about 600 m depth, (2) to evaluate the time evolution of the reservoir properties as CO_2 is injected, and (3) provide detailed sub-surface images near the injection borehole for planning of the drilling operations. In this paper we present a summary of the seismic data acquisition and results from initial processing of the data.

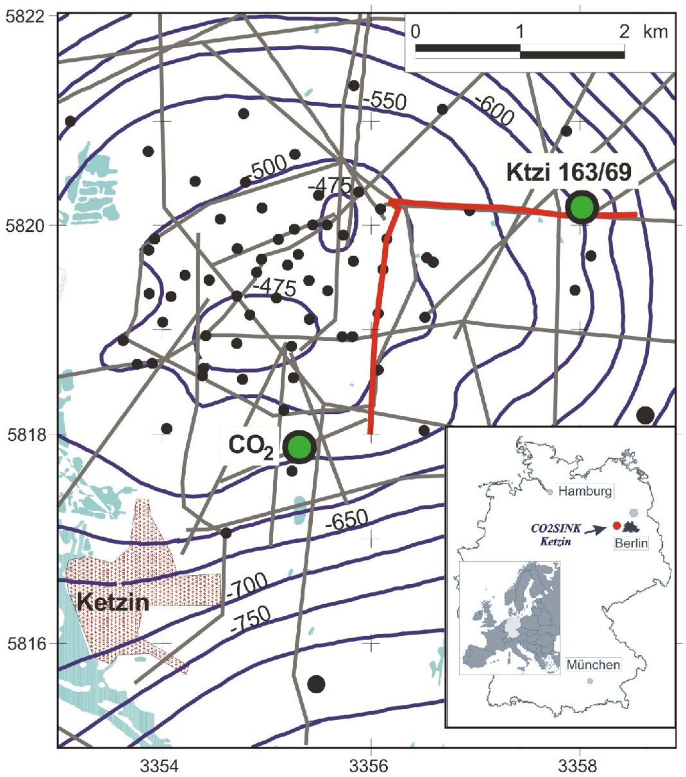

Figure 1. Isolines showing the depth to the K2 seismic reflector at the Ketzin anticline located NW of Berlin delineated from former seismic profiles (straight lines) and from former exploration boreholes (dots). The top of the Stuttgart Formation is located about 80 m below the K2 reflector. Injection well is indicated by CO_2, and a previously drilled well that penetrated the Stuttgart Formation is indicated by Ktzi 163/69. The two lines of a seismic pilot survey are shown in red. Coordinates are in km in the UTM system.

Acquisition

The baseline seismic survey contained two components, a full 3D survey of the entire area using a weight drop source and a focused pseudo-3D survey near the injection site using a VIBSIST source [3, 4] with a “star” geometry (Figure 2). The latter seismic survey will be repeated within the project framework to add a surface time-lapse component to the project.

Prior to the full 3D survey, a pilot study (Figure 1) was performed in September 2004 in order to (1) test different seismic sources, (2) test different geophone setups, and (3) define optimal acquisition parameters. Based on the pilot survey, economics and logistical considerations; a weight drop source was chosen for the full 3D survey.

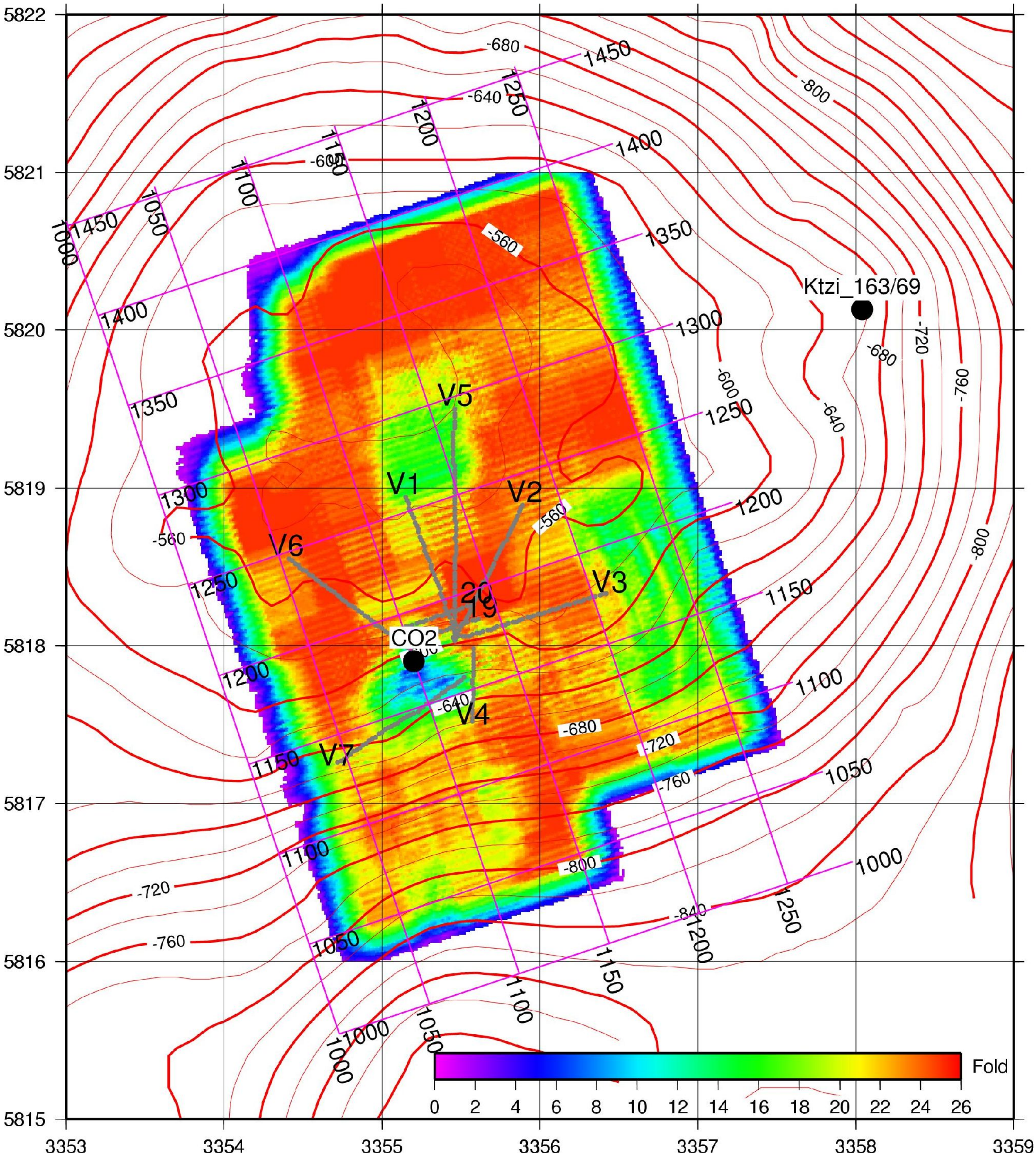

Figure 2. Color-coded fold for the full 3D survey with cross-line and in-line locations indicated by purple lines. Source and receiver lines for the "star" VIBSIST acquisition are show in gray. Isolines show the elevation relative to M.A.S.L. of the top of the Stuttgart Formation. Injection well is indicated by CO2. Coordinates are in km in the UTM system.

For the full 3D survey, acquisition was carried out using a template scheme, with the aim of having the same acquisition geometry for each template. The template geometry was a modified version of that used by ETH Zurich in their 3D high resolution seismic surveys [6]. Source points and recording stations overlapped from template to template to give an even nominal fold of 25 over the area, which was considered sufficient for imaging down depths of 1000 m based on results from elsewhere [2]. Each template consisted of 5 west-east running receiver lines with 48 stations. Station spacing was 24 m and the receiver lines were spaced at 96 m. Up to two hundred source points were activated along 12 source lines running in the north-south direction in each template. Templates were shifted 24 stations in the west-east direction along the receiver lines and half the shot line length in the north-south direction, providing an even distribution of offsets and azimuths for each 12 m x 12 m CDP bin.

Acquisition of the full 3D survey began on 1 September 2005, proceeded in a snaking manner through the 3D area, and ended on 20 November 2005. About 7500 source points were recorded during the 72 days of active acquisition. In general, each source point consisted of 8 hits with the weight drop. Aside from days that it was necessary to jump swaths, it was possible to activate about 130 source points per day.

Time-lapse seismic surveys are an important component of any CO_2 sequestration project [1, 5]. Within the present project framework, time-lapse cross-hole, vertical seismic profiling (VSP) and moving source profiling (MSP) will be carried out. The latter two will utilize a VIBSIST source. Therefore, it was considered advantageous to acquire surface seismic data in the vicinity of the injection site with the VIBSIST source (Figure 2), allowing time-lapse surface seismic studies to be conducted. In particular, it was considered important to have the possibility of tracking movement of CO_2 up towards the top of the Ketzin anticline (Figure 2). In addition, the VIBSIST component of the surface seismic baseline survey provides pseudo 3D coverage near the injection site. In order to achieve these goals, the VIBSIST source was activated along 7 separate lines running radially out from the borehole (Figure 2) in the “star” geometry. The location of the lines was governed partly by logistics, but also with an aim to have greater sub-surface coverage towards the top of the anticline.

Processing

Geometry was extracted from the field SEGD file headers and the data were binned into 12 m x 12 m CDP bins. Fold is generally close to 25, but there exist some areas where fold is low due to (1) the gas works at the injection site (in-line 1175, cross-line 1100), (2) nature preserves (in-line 1275, cross-line 1150), and (3) the village of Neu Falkenrehde (in-line 1100 to 1225, cross-line 1225) (Figure 2).

In order to obtain results more quickly from data near the injection site a sub-volume was initially processed that contains swaths 3, 4, and 5, corresponding to the the area between in-lines 1110 and 1244 (Figure 2).

Processing steps were kept relatively simple to allow the processing to be carried out quickly and minimize the potential for introducing artifacts into the processed volumes. Statics, both refraction and residual, and velocity analysis had the greatest influence on the processed stack. Two passes of velocity analysis were carried out, one before residual statics and one after. The velocity field was visually inspected to ensure that there were no sharp jumps in it. Surface consistent deconvolution and filter panel tests were carried out to determine the optimum parameters for these steps. After stacking, 3D migration, using a 45 degree finite difference code, was applied using the stacking velocity field.

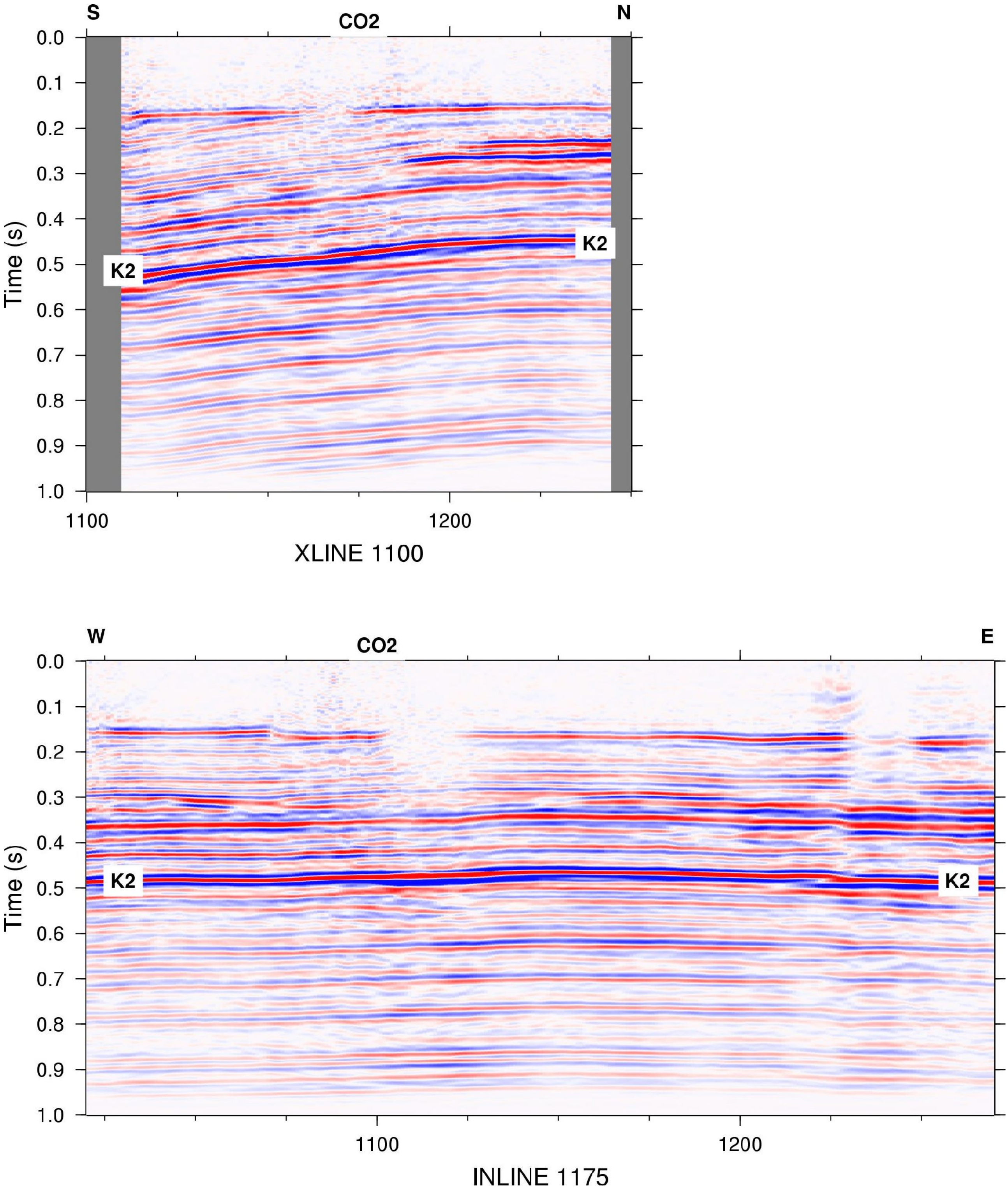

Figure 3. Migrated slices from the sub-volume showing in-line 1175 (bottom) and cross-line 1100 (top). CO2 marks the location of the injection site on the slices. The village of Neu Falkenrehde is located from about cross-line 1230 to 1245 on the in-line section.

Preliminary results

Figures 3 shows migrated slices from in-line 1175 and cross-line 1100 from the full 3D stacked sub-volume. In-line 1175 runs nearly over the planned injection site, as does cross-line 1100 (Figure 2). The image in the vicinity of the injection site and below the village of Neu Falkenrehde are disturbed somewhat on the in-line 1175 due to the lack of near-offset traces in the CDP bins and lower fold. The geometry of the reflections in the in-line direction is nearly sub-horizontal with the base of the Tertiary corresponding to the uppermost clear reflection at about 150 ms and the K2 horizon to the strong reflection at about 460 ms. Clear lateral variations in the reflectivity is observed below the K2 horizon at the injection site, suggesting the Stuttgart Formation is heterogeneous here.

In the cross-line direction more structural dip is present below the base of the Tertiary at about 150 ms (Figure 3), at least to the south of the planned injection site. North of the site, the K2 horizon becomes more sub-horizontal at about 450 ms (Figure 3).

Most reflections are fairly constant in amplitude in the sub-volume, except for the reflections between 200 ms and 300 ms. These increase in amplitude towards the north-central part of the sub-volume. No obvious faults are observed in the data at this point. However, there may be minor faults present that may be detected by a more thorough analysis. The depth to the base of the Tertiary changes rather abruptly within the sub-volume at some locations (Figure 3), indicating possible faulting.

Conclusions

Preliminary processing shows that data quality are generally of good quality. Stacked and migrated sub-volumes of the full 3D show that the K2 horizon is well imaged in the vicinity of the injection site. Reflections are observed down to the processing limit of 1 s. Inspection of shot gathers from areas not included in the sub-volume indicates that similar results may be expected for the entire full 3D area.

Inspection of VIBSIST shot gathers from the “star” survey shows that these are also generally of good quality. They can be expected to form an important baseline for surface time-lapse studies within the CO_2SINK project.

List of References

[1] Arts R, Eiken O, Chadwick A, Zweigel P, van der Meer L, Zinszner B. Monitoring of CO2 injected at Sleipner using time-lapse seismic data. Energy 2004; 29:1383-1392.

[2] Birkhaüser P, Graf R. 3D Seismics in Zürcher Weinland: Methodology, planning and performances of the field work. Nagra Bulletin 2000; 33: 8-17.

[3] Cosma C, Enescu N. Characterization of fractured rock in the vicinity of tunnels by the swept impact seismic technique. International Journal of Rock Mechanics and Mining Sciences 2001; 38: 815-821.

[4] Park CB, Miller RD, Steeples DW, Black RA. Swept impact seismic technique (SIST): Geophysics 1996; 61: 1789-1803.

[5] Sakai A. Monitoring of the Carbon Dioxide sequestration by time-lapse 3D seismic survey in Japan. Paper presented at the 7th International Conference on Greenhouse Gas Control Technologies, Vancouver, Canada. 5-9 September, 2004.

[6] Spitzer R, Nitsche FO, Green AG. Minimizing field operations in shallow 3-D seismic reflection surveying: Geophysics 2001; 66: 1761-1773.