Response to interactive comment on “Vertical seismic profiling with distributed acoustic sensing images the Rotliegend geothermal reservoir in the North German Basin down to 4.2 km depth” by Anonymous Referee #1

Dear reviewer,
thank you for your constructive comments and suggestions, which helped us to work out several important aspects of our manuscript more clearly. In the following, we have listed the individual comments, followed by our answers in italic font. After this, the revised manuscript text with the changes highlighted is appended.
Thank you and best regards,
Jan Henninges (on behalf of all authors)

-Page 1, lines 23-25: Consider rephrasing. Do you mean that the top and base of the volcanic rocks can not be inferred from the seismic data due to insufficient reflected energy from these interfaces?

Response: Yes, the top of the Carboniferous which we had referred to here is equivalent to the base of the volcanic rocks, and we have rephrased the sentence accordingly to make this clearer: “The top of the volcanic rocks has a somewhat different seismic response, and no stronger reflection event is obvious at the postulated base of the volcanic rocks.”

-Page 1, line31-32: Consider rephrasing . For instance: ’This technique allows for rapid seismic data acquisition, because DAS provides continuous point measurements along the cable and therefore does not require vertical repositioning of the cable during VSP campaigns, opposed to conventional geophone borehole strings’

Response: We have rephrased the sentence accordingly.

-Page 2, line72-73: Please elaborate on how the source positions were optimized using ray tracing.

Response: We have added the sentence “Based on the ray tracing, reflection point fold maps for representative layers at target depth and incidence angles of upgoing reflected waves at the sensor cables were calculated and compared for different source point distributions.” And the following sentence, lines 73-75, was changed to: “The most suitable source point distribution was then selected, and individual source point locations were further adjusted according to the conditions within the survey area (...).”

-Page 3: line 77-78: Is it correct that this hybrid borehole measurement system includes the interrogator? And could you add the specifications of the fiber-optic cables in table 1?

Response: In this case the Schlumberger hDVS interrogator was connected to the hybrid borehole measurement system, as described in the text (p. 3, lines 87-88). The specifications of a hybrid wireline logging cable include many parameters, which would be too much information to be included in Table 1. Within the text on p. 3, we have referred to the publications of Henninges et al. (2011) and Hartog et al. (2014), where descriptions of the individual cables can be found.

-Page 3, line 88: I presume that the hDVS is an optical interrogator, please mention this in the text as well.

Response: We have added “optical interrogator” in this sentence.

-Page 4, line 123: Please specify ground units for the different parameters from the equation.

Response: We have added the units in parentheses after the definition of the individual

parameters for the equations 1 and 2 within the text.

-Page 4, line 133-134: Consider to provide the equation for converting strain to strain rate. Also, does the mentioned 90 ◦ phase shift relate to the 180 ◦ phase shift mentioned in Table 2, or are these not related to each other?

Response: The conversion from strain to strain rate by differentiation in time is already described at the specified position in the text (Page 4, line 133-134). So we think that providing an additional equation would be redundant. The 180° phase shift listed in Table 2 has been applied in order to match the polarity of conventional geophone data, as described on p. 8 line 254-256 (we have added a reference to Table 2 at this position for clarity), and is therefore not related to the 90° phase shift referred to here, which results from the differentiation in time.

-Page 5, table 5: Please clarify what is meant in the row ''Interval velocities → Correct times to vertical"

Response: The correction to vertical travel times is required because of the deviation of the borehole trajectory, along which the VSP data was recorded, from vertical. It is a standard practice in zero-offset VSP processing, and is briefly described in Section 4.3 "Time depth relationships and interval velocities" on p. 7-8, lines 241-243.

-Page 5, line 144-145: Could you comment what the possible cause for the observed zigzag noise pattern is?

Response: A detailed description of our hypothesis for the origin of this "ringing noise" is contained in Section 4 "Results and discussion" on p. 6, lines 171-178.

-Page 6, line 166-167: Please mention that a comparison between normalized trace amplitudes is made.

Response: We have added "The recorded amplitudes have been normalized to the absolute maximum first break amplitude of the individual traces." in the captions of Figures 5 and 6.

-Page 6, line 182: Consider rephrasing, since this is what one would actually expect with DAS data. As for instance Mateeva et al. (2014) state: "Since DAS measures only differential displacement, the polarity of its response is determined by whether a fiber was shortened or elongated over a gauge length, not by the direction of travel of the corresponding seismic wave. "

Response: We first describe the data we have recorded, and then make references to three earlier studies, including the one of Mateeva et al. (2014), where a similar observation has been made. We think the observed polarity reversal for upgoing reflected waves compared to geophone data is worthwhile to be pointed out, and therefore prefer to keep the text as it is.

-Page 6, line 189 with respect to the comparison in Figure 6. The amplitudes of two datatypes seem to be normalized based on their own maximum to [-1,1]. Please mention this. And how do the true unscaled acceleration values actually compare against one another?

Response: Yes, the amplitudes in Figure 6 have also been normalized to the maximum of the first break arrival. We have added "The recorded amplitudes have been normalized to the maximum first break amplitude of the individual traces." in the caption of Figure 6 (also see response to earlier comment on amplitude normalization above, Figure 5).

-Page 7, line 211-212: And what did their study conclude? Do their modeling outcomes match the observations made in this study? Overall it could be that the effect of the degree of slack is hard to control and largely depends on the well geometry. Maybe certain depth intervals favor

from extra slack where coupling is increased, while at other depth intervals the opposite holds depending on trajectory. With this determining optimal slack length could be a matter of trial and error depending partially on well geometry and depth interval/formations of interest for imaging.

Response: The study of Schilke et al. (2016) is from the same group as the one from Constantinou et al. (2016), and it describes the numerical simulations referred to in Constantinou et al. (2016) in more detail. The results of this modeling study explain some of the observations, i.e. the constant pitch region, gradually building up from the bottom of the well when further cable slack is introduced. Nevertheless, what the modeling study does not explain, is the decrease of the signal amplitude within this zone, which is observed in our study, similar to the Rittershoffen data set described in Constantinou et al. (2016). So, as noted, it explains parts of the observations but not all, and we have included it as a further reference for the interested reader. With respect to the required slack length, Schilke et al. (2016) note: "The amount of extra cable necessary to be lowered depends on the total length and diameter of the borehole, the dimensions of the cable and its elastic properties, which determine the stiffness."

-Page 7, line 226-228: Interesting observation. Out of curiosity; did the energy in the noise window increase, or did the energy in the signal window decrease for those intervals?

Response: Predominantly the energy in the signal window decreased. This is described in the following text already, p. 7, lines 230-231: "The observed signal drop at 3400 m after day 1 seems to be similar to the effect of reduced signal amplitudes observed during the slack test." A common shot gather for a record showing this effect is displayed in Fig. 3, panels j, k, and l. Here we noted, that the number of this VP in the figure caption was erroneous, and we have corrected it accordingly ("17" changed to "76").

-Page 8, line 250 regarding section 4.4: Now this section starts with a processing step and continues with the interpretation of the processed data, although the data processing and interpretation phases should typically be separated. I would therefore recommend to split this in two sections consisting of 4.4 Corridor stack and 4.5 Seismic interpretation.

Response: This is correct, and we agree that the data processing and interpretation should usually be separated. In general, we also have followed this practice, and the processing is described in section 3.2 where Table 2 with an overview of the applied processing steps is placed. Nevertheless, as these sections are several pages apart, we think that is helpful for the understanding of the displayed results and our interpretation, if a brief textual description of the related processing steps is given at the beginning of this section here. As this description is rather short (one paragraph with four sentences), we feel that introducing a separate section for this is not justified.

-Page 10, line 352: Can you comment approximately how much faster DAS-VSP is compared to conventional VSP?

Response: This is strongly dependent on a number of factors, but in order to give a rough estimate, we have included the following sentence at this position at the end of the text: "Such savings depend on the specific targets and conditions of an individual survey, as well as on the available technologies and performance of the equipment used. But for a VSP survey similar to this study, we would roughly estimate the operational effort to be reduced around a factor of 5 to 10."

-Page 14, figure 1. Highlight the source positions in the left panel that are further shown in figures 3 and 4 (positions 10, 25, 66 and 17). Please increase the size of the legend in the right panel.

Response: We have increased the font size of the legend in Figure 1 and marked the respective

source point positions with crosses and printed the numbers with bold type. We have added a corresponding explanation in the Figure caption.

-Page 17, caption of figure 5: Please state that these are normalized amplitudes.

Response: We have added "The recorded amplitudes have been normalized to the maximum first break amplitude of the individual traces." in the captions of Figures 5 and 6.

-(Page) 18, caption of figure 6. Please state that these are normalized amplitudes. And consider to show and compare non-normalized amplitudes.

Response: We have added "The recorded amplitudes have been normalized to the maximum first break amplitude of the individual traces." in the captions of Figures 5 and 6. In our opinion it is not very meaningful to directly compare true amplitudes recorded with different sensors having different sensitivity, characteristics, coupling etc. Trace normalization to the same reference is an appropriate way for a comparison with respect to relative amplitude and S/N ratio.

Technical corrections:
-Page 8, line 244: Please rephrase the sentence part "For a close to the receiver wells situated zero-offset position, VSP..."

Response: We have changed this part of the sentence to "For the VP 10 zero-offset position, VSP..."

-Page 10, line 398: Regarding the reference to Daley et al. please check the year, because this work seems to date from 2015 instead of 2016.

Response: We have checked the publication date: the work is from 2016.