AUTHOR RESPONSE TO RC2 (Alexander Schaaf)

We summarize below the referee comments and the authors response, along with the actions and changes done to improve the manuscript.

GENERAL COMMENTS:

"The paper presents an interesting case study of the impact of structural uncertainties on structural geomodels. The authors compare two different approaches of uncertainty parametrization of structural geomodels from seismic data and their impact on gross rock volume estimations. The manuscript is well structured, and both title and abstract are adequate for the content.

The manuscript gives a good introduction to the uncertainties involved in seismic interpretation and subsequent structural geomodeling and clearly states the motivation for and relevance of their work in the context of economic geology.

The methodology section and clarity of the paper would be significantly improved if the authors would elaborate more on the details of how they parametrized the stochastic geomodel. It is not very clear what kind of statistical distributions were used for the Monte Carlo simulation, which is important to interpret the results. More detail on this can be found in the specific comments below.

The results are clearly presented, and the authors give a good visual overview of the effects of uncertainty on the structural geomodel and GRV estimates.

The discussion is overall good but could use some minor improvements outlined in the specific comments below. It could also use a more detailed integration of the results in context of related work. The figures presented are overall good, but the use of a perceptually uniform colormap is recommended (see technical comments below).

Overall, I believe this manuscript to be a good submission for the special issue on uncertainty in the geosciences. The scientific quality of the manuscript is good but should be further improved regarding the stochastic parametrization."

Authors comment: Thank you very much for your comments and suggestions, especially for those regarding the parametrization of the stochastic uncertainty modeling. We have considered your recommendations to try to improve the clarity and the quality of the manuscript.

In the list below, we specify the actions done after each of your comments addressed.

SPECIFIC COMMENTS:

P6L25 – The sentence is not clear to me: what exactly is meant by geophysical data? This should be more specific for the reader.

Authors comment: We agree with the referee and we have changed the text by replacing "geophysical data" by "picking the seismic events (faults and the horizons)". We have combined this sentence with the following sentence (see the P6L25-26 Referee comment just below) to improve in clarity.

P6L25-26 – The sentence is unclear. As I interpret it, the authors use the base case model and modify it using samples from perturbance distributions for faults and horizons to create new structural geomodels. I recommend specifying this.

Authors comment: Following the recommendation of the referee, we have clarified the original sentence as follows (also including the sentence of the comment above):

“The base case model (in time or in depth domain, depending on the modeling workflow) is a reference to subsequently build new structural models using the sampled perturbance distribution for the faults and horizons. Perturbances record the structural uncertainty in picking the seismic events (faults and the horizons).” (P6L28-31).

P7L10-12 – What does “constant envelope” mean in context of the stochastic simulation? A Uniform distribution with the stated bounds? I recommend the authors expand this a bit to clearly state the stochastic parametrization of their uncertainty model.

Authors comment: Constant envelope means that the dimension of the uncertainty zone around each fault or horizon interpretation is set as a constant distance to that interpretation (i.e. constant distance above and below the horizons, and along both sides of the faults), independently of the fact that the uncertainty area in picking the surface varies across the interpreted trace.

We have clarified this in section “3.1 Manual and constant uncertainty workflows” (P6L19-23).

P7L12-13 – How exactly was the envelope adjusted to the seismic quality and what exactly does seismic quality refer to in this context?

Authors comment: The envelope in the manual case was adjusted according to the extent of the uncertainty area (i.e. zone of ambiguity in picking a surface) along the interpreted surface. This has been clarified as follows (P7L20-23):

“In the interpreted case, this envelope was adjusted according to how the uncertainty zone (i.e. zone of ambiguity when picking the fault) varies along each interpreted fault trace. In the study dataset, faults do not produce seismic reflections nor diffractions and their interpretation was mainly based on the distance of the reflector terminations (Fig. 4).”

Additionally, we have modified the text in section “3.1 Manual and constant uncertainty workflows” (P6L14-15) concerning the ambiguity zones in picking horizons and faults. These zones represent the uncertainty in the interpretation of a surface related to low frequency content events, lateral variations of amplitudes along reflectors, diffraction areas or the lack of seismic reflections of faults.

P8L10 – “This sentence needs to be corrected. A stochastic simulation can only create equi-probable realizations if only Uniform distributions were used. The authors used Gaussian Random Fields and Gaussian distributions in their simulation (Fig. 7), and therefore the samples/realizations are not equi-probable. It is also unclear to me what “spans the uncertainty” means. A Monte Carlo simulation (or any stochastic simulation methods) will only ever reproduce the exact uncertainty in limit to infinite samples.

Authors comment: Following the comment of the referee, we have modified the sentence in the revised version of the manuscript as follows (P8L20):

"The stochastic simulation produces multiple realizations of the horizons, which represent the input uncertainty."

P8L24 – Why 200 realizations? Stochastic simulations need to balance computational cost with representative sampling, and the number of samples is critical for an accurate representation of the uncertainty within the results. I recommend the authors elaborate why they chose this number.

Authors comment: We have completed the text in new version of the manuscript explaining why 200 realizations were obtained (P9L1-5): "With this number of realizations, the fluctuations in the predicted GRV stabilizes resulting in the output statistics being enough representative of the uncertainty captured."

P11L7-9 – I recommend comparing Inner Quartile Ranges instead of minimum and maximum values to describe and compare the uncertainty. Minimum and maximum values are not necessarily representative.

Authors comment: Following this comment and according to the statistical data and figures in the paper, we present the ranges corresponding to the difference between the P10 and P90 (instead of between minimum and maximum values) in the revised version of the manuscript. Changes in the text are in section "4.2 GRV in the prediction models and in the simulated realizations" (P10L26-29); and in section "5.1 Manually interpreted versus constant uncertainty cases" (P11L19-20). Additionally, we also comment the percentage differences of P10 and P90 realizations with respect to the base case model instead of maximum and minimum values (see changes in the "Abstract" section in the revised manuscript (P1L31).

P11L15 – Parametrization relies on assumptions, thus the word "accurate" can be misleading here. There is ample room for human bias and error in interpreting uncertainty from seismic data.

Authors comment: We agree with the Referee comment. We have deleted this term from the corresponding sentence in the new version of the manuscript (P11L28-29).

P11L25 – It is unclear to me what exactly is compared here. The mean GRV values of the different simulations?

Authors comment: We compared the difference in percentage between the maximum GRV and the base case, and the minimum GRV and the base case for the three OWC, and separately in the manual and the constant cases. According to the Referee comment of P11L7-9, we use the P10 and P90 values instead of maximum and minimum values in the revised version of the manuscript. Thus, the corresponding percentages presented in the reviewed manuscript have changed (see P1L31 in the "Abstract" section; and P12L5-7 in "5.2 Impact of the structural uncertainty in a small and fractured reservoir").

P12L24 – Why are trend uncertainty values typically up to 10% of the depth of the horizon? Is this a rule of thumb, is there actual data on this? The source of this information should be clarified.

Authors comment: This percentage was provided by Emerson Automation Solutions, but there is no specific reference to document this. A personal communication reference has been added to the revised manuscript.

P12L13 – Why should the variogram range for the residual uncertainty "in general not be more than the half of the reservoir size"? It is unclear if this is a rule of thumb or based on actual studies. This should be clarified.

Authors comment: This is the same case than the comment above. A personal communication reference was used in the revised manuscript.

P13L3-5 – Manual interpretation of seismic data is prone to human error and bias. This should be discussed in this paragraph.

Authors comment: We have added a comment on human error in interpretation in the corresponding paragraph (P14L33-P15L1).

TECHNICAL CORRECTIONS:

Figure 13d – It's really hard to see any differences in this plot due to the small size and scale of the y-axis and use of arrow heads.

Authors comment: Following the comment of the referee, we have modified fig. 13d, and accordingly, also figs. 14d and 15d. We have duplicated the vertical scale to see more easily differences in these plots. The vertical exaggeration (2×) has also been indicated in the corresponding figure captions.

Figures 6, 8, 9, 12 – All figures make us of rainbow color schemes, which is perceptually not uniform. This makes it more difficult for readers to correctly perceive the underlying data. I highly recommend use of a perceptually uniform colormaps which are also more robust to color blindness.

Authors comment: We thank the suggestion of the referee and agree than in some cases using perceptually unifom colormaps is an appropriate choice. However, we have selected the same color scale for some of the maps and images in the commented figures in order to make possible a direct visual comparison of the results.

In the case of fig. 6, the residual map is shown with a specific color table, different from the one for the trend and the simulated horizon, which both show the same range of values.

In fig. 8, we selected different color tables for the manual and for the constant uncertainty cases. Amongst the maps of each case, we use the same color table in order to highlight that for those horizons without well picks available (e.g. Top model, Top upper BTG Lubina, Base model) higher prediction errors are recorded than for those horizons with well picks. This has been also commented in the new version of the manuscript (P11L32-33 in section "5.1 Manually interpreted versus constant uncertainty cases" and in the caption of figure 8). Additionally, using the same color table allows comparing the degree of lateral variation in the prediction error in each horizon and for each modeling case.

In Fig. 9a and b, the color table is showing the depths of all the horizons, so there is no possibility of using perceptually uniform colormaps. In Fig. 12, the color scale is showing the GRV in each modeled cell above the oil-water contact. In this image, we consider that comparing the variation of the oil zone extent amongst the different scenarios shown is the most relevant objective, and that using the same color tables helps in direct comparison of results.