Reviewer 1 (John Hooker)

John Hooker: *"These mostly concern the orientation of the fractures in the quarries, and their inferred orientations in the subsurface. As well, the conclusions are fairly scant and qualitative, especially in terms of what type of fracture patterns are predicted to be in the subsurface and why. Lastly, and relatedly, I think the authors have the data to weigh in on some long-standing debates about fractures at the surface versus those in the subsurface, the implications of which have important consequences for the hypothetical geothermal capacity. I think to make their study broadly applicable to similar problems elsewhere, and thus to warrant publication in the scientific literature, the authors need to be firmer in their conclusions and explain the implications for their findings on natural fracture patterns in general."*

Authors' reply: We agree with you that the results of our fracture orientations were not sufficiently clear in the original version. Thank you for pointing out that you consider our study an important contribution to the long-standing debate on fractures on the surface compared to those underground. Nevertheless, we believe that our results are not universally applicable to all other geothermal sites due to the complex geological structures. However, our data and findings are particularly interesting for geothermal case studies that will also be conducted in the vicinity of an anticline. This is an important finding from the investigation of the fractures orientation in relation to the outcrops along the regional Remscheid-Altena anticline. By including the additional distinction between fracture orientation and fracture filling, we were able to formulate our conclusion more clearly (please see conclusion section 5). Furthermore, we now distinguish more clearly between the individual outcrops.

John Hooker: *"Importantly, the fracture strikes in the three quarries do not match one another. Is this because bedding is in a different orientation, accounting for a clockwise rotation at Hönnetal? It is not clear. If so, it may mean the fractures pre-date the folds. The best way to show that is to restore bedding and see what the fracture orientations do."*

Authors' reply: Thank you for that important remark, which mentions a point that we must emphasise more dominantly in the text. Yes, the fracture strikes in the three quarries do not match one another. We have the same explanation as you for this observation, namely that these differences are due to the formation of the anticline. We have now added this to the text (line 469):

> "All studied outcrops are located in the large scaled fold formation Remscheid-Altena anticline. However, there is a disagreement between the three outcrop results which might be an effect of the formation of the regional Remscheid-Altena anticline, different stress states, or different time of origin (Table 3). Due to the anticline formation, the strike directions of the present fractures in this region exhibit a rotation from the northern limb (Wuppertal) towards the tip of the anticline (Hönnetal). Fractures striking NE−SW are highly related to folding mechanism and are parallel oriented to fold axes which have been studied within the Rhine-Ruhr area (Drozdzewski, 1985; Brix *et al.*, 1988; DEKORP Research Group, 1990; Drozdzewski and Wrede, 1994)."

Besides, we have added this paragraph to refer more precisely to the chronological development of the fractures in Hagen Hohenlimburg and Hönnetal (line 480):

> "The observed strong scattering of the fracture strike directions in the dolomitic carbonates exposed in Hagen Hohenlimburg is due to their formation by hydrothermal veins during the Hercynian Orogney (Gillhaus et al., 2003). Furthermore, Gillhaus et al. (2003) explain that the existing NNW−SSE striking fractures are of post-Hercynian Orogeny origin. The cause of the slightly different fault strike directions in Hönnetal cannot be clearly specified according to the current state of scientific knowledge. Most likely, the fracture formation can be explained by various local and temporal stress anomalies and different formation times."

The study of chronological bedding and fracture formations and its restoration is a widely studied topic with different approaches. In many cases these investigations show a very simplified model based on single formations (e.g., Maerten and Maerten, AAPG Bull., 2006; Caumon *et al.*, Math. Geosci., 2009). Unfortunately, we could not sufficiently address this point, because it exceeds the scope of our study. But we would like to take up this point in the following studies, that are already scheduled to be published by the end of this year (for more details see Gonzalez de Lucio *et al.*, EGU General Assembly Conference Abstracts, 2020; Kruszewski *et al.*, EGU General Assembly Conference Abstracts, 2020).

John Hooker: *"But furthermore, the authors note a correspondence between the observed fracture orientations and the World Stress Map, but that map, in western Germany, has SHmax indicators in many directions. I would agree that NNW is probably the dominant one, but I see several trending NE, WNW, and NNE. So the wide scatter in the outcrop data, combined with that in the map, makes questionable any correspondence between the two. And in any case, it is claimed that the dominant fracture orientations in quarry exposures are NNW and NE, and I suggest that is only true for one of the three quarries (Wuppertal)."*
Authors' reply: Thank you for pointing out that our conclusion is not sufficiently explained. We have adapted our reasoning and added another important reference (Rummel & Weber, 1993). The new paragraph about the geological subsurface model of the carbonate reservoir, the predominant stress directions in western Germany, and the influence of the prominent Remscheid-Altena anticline reads as (line 475):

> "The dominant fracture strike directions NNW−SSE in Wuppertal agree with the structure of the regional Remscheid-Altena anticline (Fig. 1b) and the overall assumed mean principle stress direction according to the World Stress Map (Heidbach *et al.*, 2016) and additional available stress data (Rummel and Weber, 1993). In western Germany, or to be more precise in North Rhine-Westphalia, the World Stress Map contains a wide variability of mean principle stress directions (Heidbach *et al.*, 2016), that can be explained by shallow stress measurements, local anomalies which can be attributed to weak coal-seems, or regional NE−SW thrusts."

John Hooker: *"Again, in Hönnetal it is unclear whether a third fracture set is present, judging by orientation; we might be able to objectively discriminate sets based on filling, but it is not clear which orientations are filled with what mineral. Fill type is an excellent way to discriminate between fracture relative ages and origins, and of course will have large implications on permeability. As well, partial cementation is a way to keep fractures open in the subsurface, regardless of the current state of stress (Laubach et al., EPSL, 2004)."*
Authors' reply: We consider your commentary to be very appropriate and have accordingly added another figure to the manuscript (see Fig. 7). The new Figure 7 shows rose diagrams of all measured discontinuity sets as a function of their fracture filling, that is, whether the fractures are filled with (a) calcite or (b) debris. From our point of view, Figure 7 emphasizes the idea of focusing on discontinuities that are oriented towards NNW-SSE. Figure 7 shows that the NNW-SSE-striking faults are mainly filled with calcite. It can be found, that debris filled fractures do not show a distinct strike direction. In the text we refer to the figure as follows (e.g., line 540):

> "In addition, we present fracture orientations versus filling materials, these are, calcite or debris. The orientation of the recorded veins allows us to conclude, that many of the discontinuities studied on the outcrop scale can be related to residual stress and stress release during unloading regimes (cf. Nickelsen and Hough, 1967; Roberts,1974, Fig. 7)."

The quoted paper was very helpful and appropriate. Based on Laubach et al (2004), we expect at least partially open fractures in the direction of NNW-SSE, independent of the current stress state (line 550):

"In addition to the relative orientation of the fractures to the direction of the main principal stress, the filling is also decisive for whether the fractures are potentially open or closed in the subsurface (Laubach *et al.*, 2004). Thus, there might be open fractures that are not necessarily aligned in the direction of the principal stress and are still open. This is particularly true for fractures that are filled, for example, with cement (Laubach *et al.*, 2004)."

John Hooker: *"Assuming the authors are correct and more-or-less N-S striking fractures would dominate the subsurface permeability, can we extrapolate any key parameters of the fracture patterns (length distributions, connectivity, intensity) based on the quarry exposures? These are only discussed very qualitatively. Are the N-S (or thereabouts) striking fractures more porous? Entirely sealed?"*

Authors' reply: Yes, it is true that our results are primarily discussed qualitatively. But this can be explained by a number of reasons. First of all, the present manuscript is a preliminary study on which a comprehensive geomechanical model and further intensive laboratory measurements will be based. The aim of this manuscript is that we characterize the complex geological conditions and existing fracture orientations at the surface. In order to fulfill the requirements of a comprehensive publication, we explicitly address how potential underground reservoir conditions could be addressed by near-surface geological features in North Rhine-Westphalia, more precisely in the Rhine-Ruhr area. These investigations have not been covered to date for this highly complex geological environment. We expect that by answering the further comments, the question about the specificity of the N-S striking fractures has now been clarified in detail. N-S striking fractures are mainly calcite-filled. However, if we look at discontinuities that are oriented parallel to the main normal stress direction and exhibit a slightly different striking from N-S striking calcite-filled fractures, we assume that this open fractures may significantly compensate for the poor matrix permeability in the reservoir rock. Nevertheless, you are absolutely right that with the results in this manuscript we can only state an upper or possible lower limit regarding the fracture network and the associated fracture permeability. For this reason the present sentence in line 492is decisive:

„This assumption allows us to predict local DFN in the deep Devonian limestone (i.e., naturally fractured carbonate reservoir), whose exact depth and characteristics should be verified by additional geophysical prospecting techniques to further describe the geothermal potential of this reservoir (e.g., Hirschberg *et al.*, 2015)."

John Hooker: *"The quarry fractures dip 80 to 90 degrees, and yet the beds dip 30 to 40 degrees toward north. This implies a distinct non-orthogonality between the fractures and the beds. Is this true of all fractures of all fill types? All else being equal, I would assume opening mode fractures would form with either a vertical or horizontal attitude. Does the near-vertical attitude of fractures, and the significant dip of beds, mean that the fractures post-date the folding of the beds? Is that true of mineral-filled fractures (perhaps earlier) and clay- or debris-filled fractures (perhaps later-formed)? If so, presumably my above conjecture that the fractures pre-date the folds is wrong. Why then do the strikes in different quarries not match up? It could be any number of reasons (different stress states, different timings) but with a more thorough description of the observations, particularly documenting fracture orientation versus fill type, we could make more sense of the variation of the pattern from quarry to quarry. This is seemingly a prerequisite to understanding the variation from quarries to subsurface."*

Authors' reply: Yes, the observation you made applies to all fractures of all filling types. To answer this basic question of whether the fractures occurred after the beds were folded, we have included a new reference in the manuscript (see Gillhaus *et al.*, 2003). In addition, we have visualized the different strike directions of mineral-filled and debris-filled fractures in Figure 7. This helped us considerably to explain the variation from each quarry. In the results section 3.1 we have added the following sentences (line 311):

"By further differentiating the strike directions of the classified discontinuity sets further according to their filling material differences between calcite and debris-filled fractures can be identified (Fig. 7). Our data tend to show a slight strike rotation between paleo-filled and debris-filled discontinuities in NNW−SSE direction."

We have added the following information to the description of the results of the Wuppertal outcrop (line 320):

"No significant difference in the strike direction of the paleo and debris-filled discontinuities can be detected (Fig. 7a,b). The average paleo-filled and debris-filled fracture strike directions are 177°and 178°, respectively."

The description of the results of the Hagen Hohenlimburg outcrop was extended by two sentences (line 342):

"Here, the disagreement between the average calcite-filled fracture strikedirection and that with debris becomes more apparent (Fig. 7c,d). The average paleo-filled and debris-filled fracture strike directions are 135° and 154°, respectively."

For the Hönnetal digestion we have summarized the results of the filling material differentiation in one sentence (line 361):

"The difference between the striking of calcite and debris-filled fractures is about 34° (Fig. 7e,f)."

In the discussion section 4.2.2 we discuss the new results of the filling material differentiation (line 565):

"The observed slight fracture rotation between paleo and recent or debris-filled discontinuities strongly suggests that the fill material may serve as an indication of their different tectonic origins. It is also remarkably that the average orientation of the recently filled cracks of the set 1 corresponds very well with the orientations of the main principal stress according to the World Stress Map (Heidbach *et al.*, 2016) and additionally available stress data (Rummel and Weber, 1993). The unfilled fractures might be interpreted as open or closed in the subsurface. If the fractures appear to be open, fracture roughness is the next property which should be considered in deriving a proper geothermal model of the area."

Line-by-line comments:

John Hooker: *"14, also 567. Can omit "shallow" because that is a relative term, and you have already quantified it."*

Authors' reply: Thank you, we adjusted the sentence accordingly and removed the word "shallow".

John Hooker: *"18. See general comment above: why do you focus on N-S fractures and not the other orientations? Especially since the stress map has a variety of SHmax orientations. Is your inferred insufficience of permeability ameliorated any if more fractures are present in the subsurface?"*

Authors' reply: On re-reading our sentence, we realized that it was not formulated precisely enough. We thank you for bringing this to our attention. The corrected sentences read (line 18):

"We proposed to focus on prominent discontinuities striking in NNW-SSE for upcoming geothermal applications, as these (1) are the most common, (2) strike in the direction of the main principal stress, (3) the fracture permeability significantly exceeds that of the reservoir rock matrix, and (4) because some of them are filled. Hence, the filled fractures bear the potential to be reopened by, for example, hydrochemical dissolution to create even better fluid efficiencies."

John Hooker: *"20-1. Is karstification only related to the facies fabric, or does it have anything to do with fracturing? Is there dissolution porosity associated with fractures?"*

Authors' reply: Thank you for the hint. In fact, we have recorded karstification related to hydrothermal process in Hagen Hohenlimburg. The corrected sentence reads (line 22):

"Our results indicate that even higher permeability can be expected for karstified formations related to the reef facies and hydrothermal processes."

John Hooker: *"38. "can be" for "be can"."*
Authors' reply: Thank you very much. We have corrected the sentence accordingly.

John Hooker: *"75. "right-handed side" awkward/un-specific."*
Authors' reply: You're absolutely right. We've improved the expression: "Three outcrop analogues on the eastern side of the northern Rhenohercynian Massif have been chosen for field survey and sample collection."

John Hooker: *"127-9. Please clarify: there is a 150 m thick "carbonate layer" on top of dolomitic carbonates (which of course are also carbonates. Then the limestone beds have 1-5m thickness? The carbonate layer is composed of limestone beds? What are the bed boundaries like – is there fracture stratigraphy?"*
Authors' reply: After reading it several times it became clear that the noted sentences are not conclusive. Many thanks for the hint. We have now clarified the description (line 129):

> "The studied limestone layers with a mean thickness of 1 to 5 m showed grayish, compacted layers of well-bedded carbonates with corals, stromatoporoidea, and bioclastic materials. This approximately 150 m thick horizon sits on top of dolomitic carbonates and is either related to the brachiopoda- and coral rich series of stromatopora series. The limestone bed boundaries show mechanical and fracture stratigraphy."

John Hooker: *"145. Again, awkward distinction between "dolomite" and "carbonate"–dolomite is a carbonate mineral."*
Authors' reply: Very good point. Accordingly, we have introduced the term "dolomitic carbonate" to distinguish it more clearly from the mineral "dolomite". We have made this change for the whole document.

John Hooker: *"200. Can you describe your method of establishing/categorizing the roughness more? How did you observe them at two scales? It's fine to just have three qualitative categories of roughness, but please take this opportunity to describe the roughness more. Is it imparted by stylolitization, branching, hooking?"*
Authors' reply: Thank you for the comment. We are happy to explain our qualitative measuring technique to determine fracture roughness on the meso- and field scale. We added the following sentence (line 207):

> "On the mesoscopic scale, the fracture surfaces were analysed for mineral steps, stylotites, or plumose structures. On the field scale, the fracture roughness was determined by wavelength measurements with a tape line."

John Hooker: *"213. Are any fractures filled by quartz? Looks like zero in Table 2-3."*
Authors' reply: Your observation is correct. We have not observed any quartz fillings and have accordingly deleted this term from the manuscript. This was a textual relic. The corrected sentence in line 208 reads:

> "In our study, typical filling materials are calcite, clay or debris."

John Hooker: *"213. What is the "true" spacing between two fractures that are not parallel? Better to ust use the apparent spacing?"*
Authors' reply: It is important to mention that we classify the recorded fracture networks as spatially homogeneous. Therefore, it is also possible to calculate the true spacing from the apparent spacing. You are absolutely right that in case of non-parallel fractures this calculation is not correct. For this reason, we have included the following sentence in the text (line 183):

> “Based on our field observations, we make the simplified assumption that spatially homogeneous fracture networks are dominant in the outcrops, whereby this depends on the spatial scale of observation. In regions with spatially heterogeneous fracture networks, however, more complex methods than the scanline sampling technique are required for fracture characterization (Watkins *et al.*, 2015).”

We have also adjusted the sentence in line 221:

> “Further, the true angle δ and the apparent spacing χ_s between two discontinuities were used to calculate the true spacing assuming a homogeneous fracture pattern $\chi_r = \cos(\delta)\, \chi_s$.”

John Hooker: *“229. A negative exponential function is not, I don’t think, the same as a power law. Exponential is y = ab^x whereas power law is y = ax^b.”*
Authors' reply: You're absolutely right. This is a power-law relationship and we have adapted the sentence accordingly. Thank you for the remark.

John Hooker: *“408. Why does tectonic motion favor the growth of reefs?”*
Authors' reply: Thanks. In fact, the sentence was not particularly revealing. For a better understanding we have expanded this sentence, provided more detailed information, and added an additional reference (line 452):

> “An overall NW-movement reduced clastic sedimentation within the sea and enabled the formation of reef carbonates on the clastic shelf. Beside those clastic shelf carbonates, other reef deposits formed on volcanic mounds within the hemipelagic realm and is the geothermal horizon of interest in this study (Franke *et al.*, 2017; Salamon & Königshof, 2010).”

John Hooker: *“417, also 566. Why is the modeled layer 300 m thick? Why not 150, as in Line 127? Without quantifying predicted fracture attributes, what is the purpose of specifying a layer thickness?”*
Authors' reply: Thanks, a mistake has crept in here. The modeled layer is 150 m and not 300 m thick. The error is due to the fact that in the literature the term carbonate horizons refers to the limestones and dolomitic layers studied (see Jansen *et al.*, 1986; Drozdzewski *et al.*, 2007). The complex of limestones and dolomitic carbonates is about 300 m thick. In the investigated outcrops, however, only the first 150 m, that is, the limestone layers, were exposed. Based on the previous investigations (e.g. DEKORP Research Group, 1990), we mention the layer thickness to bundle all information on the target horizon. We corrected the remarked all text passages accordingly.

John Hooker: *“429-31. I don’t understand this sentence.”*
Authors' reply: With this sentence we would like to state that if we extrapolate the carbonate layers exposed in the quarries in their direction of incidence, these carbonates are located approximately below the cities of Essen, Bochum, and Dortmund. These deep carbonates, which are located below these three cities, represent the target reservoir of this study. This extrapolation of the carbonates in the direction of incidence of the layers corresponds in this case approximately to the direction of the main principal stress (Heidbach *et al.*, 2016; Rummel & Weber, 1993). It should be noted that this extrapolation is based on the simplified geological model (Fig. 1a). We have like to adapt the sentence, so that our statement is now more understandable (line 487):

> “However, if the carbonate layers exposed in the investigated opencast mines are extrapolated in dip direction of bedding, the carbonate reservoir of interest is approximately located below the cities Essen, Bochum, and Dortmund at depth of 4000 to 6000 m (Fig. 2). This extrapolation of the carbonatesin dip direction corresponds in this case approximately to the direction of the main principal stress (Heidbach *et al.*, 2016; Rummel and Weber, 1993) with respect to the simplified geological setting (Fig. 1a).”

John Hooker: *"480. Unloading stress regimes–yes, highly possible. To determine whether this occurred, some discernment of fracture orientation versus fill would be useful."*
Authors' reply: Thank you for pointing out that we need to address the different filling material in order to support our assumption. Therefore, a new Figure 7, which shows two rose diagrams with calcite or debris filling, can be found accordingly (line 540):

> "In addition, we present fracture orientations versus filling materials, these are, calcite or debris. The orientation of the recorded veins allows us to conclude, that many of the discontinuities studied on the outcrop scale can be related to residual stress and stress release during unloading regimes (cf. Nickelsen and Hough, 1967; Roberts, 1974; Fig. 7)."

The orientation of the calcite-filled fractures supports our hypothesis that the NNW-SSE-striking fractures are particularly interesting for future geothermal applications. (line 545):

> "When comparing the recorded discontinuity orientations with the orientation of the maximum horizontalstress (Heidbach *et al.*, 2016), we propose to focus on discontinuities that are oriented NNW-SSE for future geothermal applications, which are highly probable filled by calcite."

John Hooker: *"487. This is very approximate usage of orientations when discussing potential for openness. Is the difference between "NNW" and N-S" significant?"*
Authors' reply: Due to the general agreement with you that the fracture strike orientation N-S does not reflect the measured average strike direction of the fractures of interest accurately enough, we have adjusted this sentence and others accordingly (e.g., line 549):

> "It can therefore be assumed that higher fracture permeability can be expected in the NNW-SSE direction, which can lead to the application of hydraulic stimulation."

John Hooker: *"497. Slickensides a filling material?"*
Authors' reply: You are right, slickensides are no filling material. We corrected the sentence accordingly (line 564):

> "More than half of all observations showed paleo filling materials like calcite beside calcite enriched slickensides on the fracture surface, approx. 58 % and 17 %, respectively."

John Hooker: *"534-5: P-waves more sensitive to pore spaces and unfilled cracks? I thought it was precisely because S-waves only travel through the solid rock that S-waves are more sensitive."*
Authors' reply: In fact, the sensitivity of P- and S-waves to unfilled pore space and crack volume cannot easily be generalized, since many factors (e.g. the crack geometry) have to be considered. However, if we were to consider a change in the saturation state, P-waves would provide more insight into the state of the rock than S-waves. Since the sentence mentioned is not important for the core statement of the paragraph, the sentence is deleted from the manuscript.

John Hooker: *"589. "comparable" any two numbers are comparable; you mean similar? How similar? Can you quantify intersection probabilities, if I drilled a hole at Dortmund?"*
Authors' reply: Indeed, the intersection probabilities could not be clearly quantified from the original manuscript submitted. Therefore, we have now added a simple method for estimating 2D fracture connectivity according to Ozkaya (2011) to the manuscript. This method allows to estimate the average number of discontinuity intersections per discontinuity in a 2D plane parallel to the exposed outcrop wall. We have added this paragraph to the methodology section (line 235):

> "In addition, the simplified 2D fracture connectivity of fractures aligned parallel to the examined outcrop face, that is, the average number of discontinuity intersections per discontinuity P, was estimated for each opencast mine according to Ozkaya et al. (2011)

$$P = \sum^{n}_{k} d_k^{-1} \sum^{n}_{k} d_k \sum^{n}_{j\neq k} d_j L_j \sin(\Delta\theta_{jk}), \quad (3)$$

where $\Delta\theta_{jk}$, d_j, L_j denote the angle between the average striking directions of two discontinuity sets *j* and *k*, the number of discontinuities per total scanline length (i.e., fracture density), and the mean discontinuity length of each discontinuity set, respectively. In each outcrop we encountered three sets of fractures (n = 3) in the respective investigated carbonate layers. Therefore, the average fracture connectivity *P* of each exposed carbonate layer was estimated on the basis of three average fracture densities and mean discontinuity lengths."

The results of the evaluation of the Wuppertal discontinuity data set are described starting at line 326:

"The 461 recorded discontinuities can be divided into three sets according to their orientations (Fig. 4b), whereby set 1, 2, and 3 could be assigned 181, 142, and 138 discontinuities, respectively. On average 2.71, 2.13, and 2.07 discontinuities or fractures were recorded per scanline meter in the sets 1, 2, and 3, respectively, corresponding to the average fracture density of the corresponding sets. For the sets 1, 2 and 3 the average discontinuity lengths amount to 7.01, 4.07 and 11.43 m, respectively. The angles between the average striking direction of set 1 and 2, set 1 and 3, and set 2 and 3 were derived as 112°, 62°and 50°, respectively. This results in an average number of discontinuity intersections per discontinuity of 21.42, that is, the estimated 2D fracture connectivity according to Ozkaya et al. (2011). The identified fracture interconnection in this outcrop is about 6 to 8 times higher than in the other outcrops Hönnetal and Hagen Hohenlimburg."

The results of the discontinuity data set of Hagen Hohenlimburg are described as from line 349:

The discontinuities recorded in this outcrop show three different strike directions (Fig. 5b) and were therefore divided into three sets with 134, 95, and 132 discontinuities. The fracture densities of set 1 to 3 were calculated as 1.76, 1.25, and 1.24 m^{-1}, respectively. The mean discontinuity length of the discontinuity set 1, 2, and 3 amounts to 1.24, 0.96, and 1.46 m, respectively. The discontinuity lengths determined here are the smallest of all recorded discontinuity sets of all quarries. The average strike difference direction between the sets $\theta_{1,2}$,$\theta_{2,3}$, and $\theta_{1,3}$ were calculate as 122°, 63°, and 59°, respectively. The value of fracture connectivity P determined for Hagen Hohenlimburg is 2.49 and corresponds to the smallest value of all examined quarries.

The results of the 2D fracture connectivity evaluation for the data from Hönnetal are given from line 368:

"In Hönnetal, too, the over 200 recorded discontinuities occur in three clusters or sets of striking directions. The sets 1 to 3 could be assigned 140, 24, and 82 discontinuities, respectively. The mean discontinuity length of the discontinuity sets L_1, L_2, and L_3 are 4.51, 5.57, and 2.85 m, respectively. The fracture densities d_1, d_2, and d_3 were derived as 2.23, 0.38, and 1.31 m^{-1}, respectively. Although the fracture density of set 2 is very low compared to the other sets, the mean discontinuity length is relatively high and reaches 5.57 m. The angles between the strike directions of sets 1 and 2, 1 and 3, and 2 and 3 are 115°, 87°, and 28°. The identified fracture properties of the sets result in an average number of discontinuity intersections per discontinuity of 3.71 for the exposed carbonate layer in Hagen Hohenlimburg.

In discussion chapter 4.2.3 the data are discussed and it is also apparent from these data that the reservoir exposed in Wuppertal is the most interesting carbonate reservoir for a deep geothermal project (line 593):

"However, our results of the 2D fracture connectivity analysis clearly show that the reservoir in Wuppertal has the highest average 2D fractureconnectivity. Both the fracture density and the mean discontinuity length of each discontinuity set are significantly higher in Wuppertal than in the other outcrops. Accordingly, we can assume that this reservoir probably has considerable geothermalpotential. For the Hönnetal reservoir a low number of discontinuity intersections per discontinuity was determined. One reason for this relatively low value is the location of the reservoir on the anticline axis and the associated tectonics. Although the recorded fractures in Hagen Hohenlimburg exhibit the greatest variety of strike directions, the estimated 2D fracture connectivity is thelowest at this location, which is due to the short discontinuity lengths and the associated low fracture densities. Nevertheless, based on the observations of many karst formations and altered host rocks by hydrothermal veins in Hagen Hohenlimburg, we conclude that there might be a higher permeability in the Hagen Hohenlimburg reservoir and in the surrounding areas than in the other studied areas. But, the distribution of this reservoir in the subsurface is still under debatte (e.g., Salamon and Königshof, 2010) and its conditions due to karstification still have to be proven."

In conclusion, we now state that in the target horizon, which is located below the major cities of Essen, Bochum, and Dormund, we expect similar fracture connectivity as in the investigated quarries. This expectation is based on the combined evaluation of the complete data set of the manuscript. The corresponding sentence in the conclusions reads (line 670):
"Besides, taking all measurements into account, we expect similar probabilities for interconnecting fracture networks in the deep reservoir. From this it follows that the recorded field surveys (Wuppertal, Hagen Hohenlimburg, and Hönnetal) can be assigned representatively for the reservoir of interest below the cities Essen, Bochum, and Dortmund."