First round of revision

Dear reviewers

Thank you for your time, effort and comments. I hope you find my corrections to be improving.

I have gone through all of your comments, requests and questions and implemented all of them - you find short to long answers in the text below or in the attached pdf in the form of comments. The overall article structure was perturbed by adding three (sub)chapters and transferring some paragraphs - a file with differences might lead you.

I understand that the major clarity issues came from unclear distinctions of introduction, methodology, results and discussion. I did my best to restructure the text accordingly. The other issues came from a single waveform used for thousands of events, varying in magnitudes. It is now pointed at more places, hopefully not overdone. Another issue is the usage of two 1D models, only one presented in the paper. The second velocity model is not representative of any real vertical profile, it just reflects the velocities a very specific ray would encounter; but is it useful for creating additional waveform complexity for PEPiN performance testing. I am not publishing it to prevent anyone from re-using it.

Some figures were completely redrawn, others just little adjusted based on your comments, many were resized (but the final size depends on the Seismica typesetter). The article was proof-read to improve my English.

We hope you find our article satisfying this time.

Best regards, Eva Káldy & Tomáš Fischer

---------- Reviewer A:

Dear editor and authors,
I reviewed the manuscript titled "Performance of Automatic Detector & Locator Tested on Synthetic Seismograms," which presents a significant contribution to the assessment of seismic network sensitivity and event detection performance, particularly in regions prone to induced seismicity. The study focuses on the Litoměřice region of the Czech Republic, where a geothermal project is ongoing, and no seismicity has been recorded over years of monitoring. By utilizing synthetic seismograms to simulate a potential earthquake in the geothermal well, the authors evaluate the detection and location efficiency of the network in the most exposed area. The results are promising, and this work provides valuable insights into the capabilities of seismic monitoring systems in similar settings with low seismicity.

However, there are several areas where improvements could enhance the clarity and impact of the paper. The manuscript is somewhat wordy and could benefit from more concise language. Additionally, it lacks citations in key sections, as highlighted in the attached PDF. The figures require touch-ups to improve their clarity and presentation. It is also unclear which parts of the work are based on the authors' previous studies and what constitutes new contributions. The use of vague terms like "sufficient" should be replaced with more precise

language, and the overall organization of the text could be improved for better readability. Detailed comments and suggestions are provided in the attached document.

Recommendation: Resubmit for Review

---------- Reviewer B:

Dear authors and editor,
You will find below my comments for Eva Káldy and Tomáš Fischer paper.
Best regards.

Reviews: Performance of automatic detector and locator tested on synthetic seismograms by Eva Káldy and Tomáš Fischer.
Resume and opinion:
The authors investigated the capability of a seismic network to detect seismicity induced by a geothermal project in an inactive region (Litoměřice, Czech Republic). Induced or triggered seismicity caused by industrial operations can lead to damage, making seismic monitoring essential to assess any seismic activity increasing. This paper is therefore well-justified and addresses a gap in research, as no similar study has been conducted in this region before.

The description of the 1D velocity models used lacks clarity, suggesting inconsistencies and insufficient explanation regarding 3D vs. 1D models. It is recommended to clearly differentiate how the sedimentary and baserock models vary in terms of structure, parameters, and applications. If both use the same 1D model, the justification for this choice and its implications should be provided, along with a clear definition of the scope and limitations of each model.

I have tried to clarify these 1D models with 3D effects formulations in the text in several places. In short, I am using two 1D velocity models, first representing the expected 1D Earth profile at the place of EGS and the second represents the Earth parameters likely encountered by the seismic signal emitted at this particular source and received by stations at base-rocks.

It is unclear when the authors test one characteristic event or a set of events with various characteristics. There is confusion between the methodology and results sections. The merging of synthetic events with real background noise seismograms should be introduced in the methodology section, as it is mentioned for the first time in the results section. I recommend a major redesign and clarification, as well as a correction of the English, before the article can be published. Moreover, lines must be numbered for reviewers' ease of correction.

I am really sorry for converting to pdf without the line numbers. It is correct now.

Remarks:

1. Lines are not numbered, making it difficult to add comments on used vocabulary or to highlight some typo. I highly recommend line numbering to fully review the manuscript.

I am sorry the pdf document went out without the numbering - line numbers were in the original document. The revised version will have it.

2. “The sensitivity of the network depends on factors such as station geometry”: do you mean station network geometry?

yes. Added “network”

3. “PEPiN, originally tailored for the West Bohemia region (Fischer, 2003), where it demonstrates detection capabilities with Mc-0.7 at 6 km depth and Mc-0.3 at 11 km depth”: you precise here the depth detection capabilities, but what about the distance to the station? An event could be at 6 km depth but 15 km of distance.

added “for 8 stations of the WEBNET seismic network (epicentral distance 0 - 15 km)”

4. “GRSN”: what’s the acronym?

Geothermal Research Seismic Network - placed to the first GRSN

5. “RICC and NSNC”: I supposed this is station names, this should be precise.

Not sure how you meant, but now it is like: (stations RICC and NSNC in shallow underground)

6. Same for GLT1 and GLT2.

now: (station GLT1 at 1500 m and station GLT2 at 190 m below the surface)

7. “The Litoměřice region is geologically segmented by the Eger fault system”: a fault is mentioned, and seismometers as well, but they are not reported on figure 1.

It seems I complicated it by using the Eger fault as separation between the sedimentary and base-rock stations. I have reformulated some parts of the text so it highlights the important part of it - that some stations are located at the hard-rock base-rock and not on horizontally layered sediments - which influences the velocities and densities encountered by seismic waves.

8. Page 4 “This article extends the previous research (Fig 1 right)”: Do you mean Fig 1c? What do you mean by previous research? Is there a paper related to it? What was about the previous research? Are you talking about Káldy and Fischer (2023)?

Corrected figure label and extended the explanation of the previous research: “This article extends the previous research on GRSN network sensitivity (Káldy & Fischer, 2023) by conducting reliability tests using synthetic earthquakes overlaid onto real seismic records. The theoretical network sensitivity from the preceding study is shown in terms of M_c variation in depth of 2 km in Fig 1c: only the stations noted by black triangles were considered for the detection, assuming an event is detected when a minimum of four stations will receive the S-wave signal exceeding (3 times representative) noise. The light blue color west of the well (white diamond) represents the area of greatest network sensitivity in the depth where water is likely to be injected during the EGS, meaning the weakest earthquake confidently detectable at depth of 2 km is M_L-0.85, respectively M_L-0.7 at the well location.”

9. 1: text should be bigger and country names should be reported into the Fig 1.a) inset. A name should be given to the figure before (a), (b) and (c) descriptions (same to all figures).

Country names added, the (a) figure can be made bigger. A name given to all figures.

10. 1: “lie within the brownish area above the 250 m isoline, representing the footwall block of the Eger fault system”: But where is the Eger fault system? This should be indicated.

viz point 7

11. 1: “Broad-band receivers are operational at KAM, RICC, TER, PLO, and SKAC as of Autumn 2023, while short-period receivers are deployed at LMP, MHR, NSNC, and GTCLT”: it should be easier if the stations (red triangles) were color coded by broad-band and short-period criteria and if you remove this sentence to make the legend shorter. Red triangles should also be bigger.

Triangles colored black for downhole receivers. Distinguishing the broad-band and short-period receivers shifted to major text only. Whole figure was made bigger.

12. 1: “latitude 50.5344286, longitude 14.1537447”: this should be illustrated into the figure and not into the legend. “magnitude 1”: should be change by: M = 1.

reformulated

13. “the variation of elastic parameters and density in all three dimensions”: does this mean that you may have the three components (E, N and Z)?

changed to: “Seismogram modeling can address the variation of Earth’s elastic parameters and density in all three dimensions,”

14. “most seismic stations in Litoměřice are situated atop the sedimentary Bohemian Cretaceous Basin […] a 1D velocity model is adequate”: most means not all. Did you adapt for those stations that are not concerned? Did you try with a 3D velocity model? What this will change?

I have made my point more clear in the text, biz general answer.. I did not try a 3D velocity model. 2D active seismics will be conducted in the future.

15. I would like to understand the reasoning behind using a 1D velocity Earth model for the sedimentary layers but not for the bedrock. Given that this region is influenced by a fault system that could significantly deform the area, would a 3D velocity model potentially provide more accurate insights? Additionally, considering the relatively small size of the region, would calculating a 3D velocity model for part or all of it require significantly more effort than the current approach? Should I understand that GLT1, GLT2, GTCLT, LTM, NSNC, PLO and TER stations will have the same 1D velocity model and that KAM, MHR, RICC and SKAC will have a 1D velocity model adapted to each of them and extracted from a 3D velocity model? If yes, this could be more precise. The mention of "the previously described sedimentary basin model" for baserock implies that there may not be distinct models for different geological regions as initially suggested.

KAM, MHR, RICC and SKAC have the same 1D velocity model, which is not presented in this study in order to prevent others using it without understanding the very specific purpose it was created for (to introduce different waveforms and arrival times to test PePin detector).

16. “The resulting P-wave velocity model”: Does this mean that the Vp profile in Fig.2.a) is not the same that the Vp profile in Fig.2.b) (red curves)? In a), the profiles are direct measurements in the region and in b) the profile is readjusted to fit with local measurement (VSP, acoustic logs etc.)?

It is the same. I have reformulated the text of the figure label. Fig. 2 Velocity profile at EGS location. (a) 1D P and S wave velocity profile of Bohemian Cretaceous Basin (sedimentary area) in Litoměřice: V_p [km/s] in red, V_s [km/s] in blue; corresponding to Table 1.. (b) Various P wave velocities from local measurements utilized or tested for creating the final 1D earth model (red line - similar to Vp in (a)). Gray lines represent some of the tested velocity profiles.

17. “P and S wave velocities is maintained throughout the profile, validated by laboratory measurements”: Did the measurement was made during this study? This is not clear. Is it in agreement with literature?

“ The standard 1.7 ratio between P and S wave velocities is maintained throughout the profile, validated by previously conducted laboratory measurements”

18. “The elastic model uncertainties are not quantified but the variations in experienced and tested velocities are shown in Fig. 2b.”: You should precise how many profiles did you test in the text.

I am sorry, but I am not sure the number of tested profiles has any meaning here. It was a single VSP, single gneiss velocity laboratory measurements and a single sonic log that I was trying to fit with the velocity model.

19. It could be nice to have the sedimentary layer velocity profiles and the baserock velocity profiles on the same figure to compare them.

The base rock velocity profile is not presented in this study in order to prevent others using it without understanding the very specific thing it displays (velocities along the expected ray path for base-rock stations) and the limited purpose it was created for (to introduce different waveforms and arrival times to test PePin detector).

20. “For seismic stations situated on baserock, the 1D earth model is based on the previously described sedimentary basin model, optimized for a seismic source at a depth of two kilometers”: I finally do not understand the difference between your two earth model, it seems that you use the same for both region (sedimentary layers and baserock) as they both referred to Fig.2.a) while you justify previously that a 3D model is required for the baserock region. This is not clear.

The base-rock reference to Fig.2a refers only to the formation named in the first velocity model. I am removing this reference. The difference is described and clarified at few places like: “For seismic stations situated on baserock, the 1D earth model is representing velocities and densities along the expected ray path from the synthetic source to the baserock stations. It is based on the previously described sedimentary basin model, …”

21. “Built up on GF, Pyrocko allows simulation of multiple types of point and finite seismic sources and various source time functions; moment magnitude is used.”: This should be two sentences or words are missing (yellow).

“Built up on GF, Pyrocko allows simulation of multiple types of point and finite seismic sources and various source time functions. For scaling the amplitudes moment magnitude

$$MW=2/3\log M0 - 9.1 \quad (1)$$

(M0 in Nm, Hanks & Kanamori, 1979) is used.”

22. “The resulting synthetic seismograms” to “detection and location algorithms.”: should it be in the result part instead of methodology?

The overall structure was changed a bit to make clearer parts of introduction, methodology and results.

23. Equation (2): you did not precise what sigma means. I supposed that it is covariance matric values.

Thank you for this note. Yes, sigma is covariance - we added it in the text.

24. “This way the horizontal eigenvalue CFNE and the vertical eigenvalue CFZNE = 1/2 (CFZN+CFZE) are obtained”: why CFZNE is precise and not CFNE?

CFZNE includes the vertical component, so Z should appear in the index.

25. 4: text should be bigger. Do you mean local maxima instead of “local minima”?

The text is bigger and the figure represents data from GRSN now. The b) figure removed. Yes, it was supposed to be maxima, thank you.

26. “The mean RMS residuals of the locations obtained at these seismic networks are smaller than 0.1 s”: May you also precise longitude, latitude and depth mean errors in km?

We do not evaluate location errors for these preliminary locations - the location uncertainties are a different quantity than location RMS. While RMS is clearly defined and is used to assess the quality of the data, there are several approaches for estimation the location error. And it is usually the task for the final location step, which is usually done by special programs like NonLinLoc or others. When Pepin is applied in Iceland, we get location errors in few hundreds of meters.

27. “In our study, synthetic seismograms representing a hypothetical induced earthquake scenario in Litoměřice […] Synthetic events were introduced into the real seismic records at intervals of every half-minute, resulting in a total of 2880 events per day.”: I do not understand. Did you test one hypothetical induced earthquake or 2880 events per day? If you test several events, this should be introduced into the methodology part and not in the result part. If not, the message is unclear.

I have restructured the text to address your point 22 and the following sentences are the opening of section Results: Performance test on synthetics: “Performance of PePin is tested on real noise records overlaid by synthetic events of similar location and focal mechanism, but various magnitudes. It is evaluated in terms of detection and location efficiency.” Many texts are removed from this paragraph.

28. “MW0 to MW2.0 (tests on 8 stations), MW-0.2 to MW1.8 (tests on 11 stations)”: Why you did not test MW-0.2 to 2.0 for every station? “The span of magnitudes is set to conveniently represent the detection results”: Do you mean completeness?

If I chose the span MW-0.2 to 2.0 for every station set, it would not show such clear minimal detectable magnitude for the test on 8 stations. I have layered teh text by: “...represent the detection results in terms of minimal detectable magnitude”

29. “utilizing eight surface GRSN stations”: I do not understand. What do you mean by surface?

None has a borehole receiver. They are the same as during the preceding study, which I highlighted newly in the following sentence: “Subsequently, the detection results were compared to the predicted network sensitivity as outlined by Káldy & Fischer (2023), which is referring to similar eight stations.”

30. “while respecting the station constant Ci (refer to Table 1)”: you did not explain what is the station constant for you. Are you talking about station corrections? You refer to Table 1 but there is not information on Ci on it.

Yes, it is station correction, my error. Corrected.

31. “As the detected events are characterized by two distinct magnitude scales (MW and ML)”: which events are you talking about? Detected means not synthetic? But you said that no events are recorded in the region. You should said picked synthetic events but not detected.

I hope the reformulation makes it clear: “Nature of this project is that every synthetic event detected (and located) is characterized by two distinct magnitude scales (M_w and M_L). M_W is assigned when generating synthetic seismograms. M_L is determined by PEPiN from the maximum S-wave amplitude according to Jakoubková (2018), utilizing station corrections in Table 1 and hypocentral distance.”

32. “and consistent with observations e.g. by Abd El-Aal (2020) in Egypt.”: How may you compare scaling low from Egypt to Czech Republic? Scaling law are local, not global. Is there similarity between these two areas to justify a comparison?

Finding scaling laws is very rare and most are vague and it was a great surprise to find a similar relation already published. But I agree that it is not justified to present it here. I remove it. Thank you for your comment.

33. 5: Police should be bigger. “(b) Effect of ML and Mw on the magnitude”: I am not sure that “effect” is the right term.

I hope the labels are a better size now. Description of fig b) reformulated.

34. “PEPiN is set up to declare an event when at least 4 S waves coincide”: Why P min waves are not considered, why only S?

Because the S-wave is more pronounced in these local case scenarios and PEPiN uses only one phase for the primary association. I am adding more intro and an additional paragraph with PEPiN setting in GRSN in the chapter “Methodology: PEPiN - ..”

35. “event detection and event localization are synonymous in the following text”: I would say co-dependent but not synonymous.

Thank you, I gladly use your suggestions.

36. “The synthetic dataset is varied for tests conducted with either 8 or 11 GRSN stations”: If you need only 4 S, why you did not choose GRSN station number vary from 4 to 11?

In the previous study, I have tested various stations’ groups and their effect on network sensitivity. Here I chose 8 stations to make the recent observations comparable to the most described setting of the previous study. It is explained at the beginning of chapter “Results: Performance test on synthetics”.

37. “akin to the approach employed in the study of network sensitivity.”: If this is not this study, a reference must be given.

Referenced.

38. Did you induce noise during the day to disturb detection? This will influence Mc which should be different between night and day. It seems you add noise during working hours but you did not introduce that in the method section, did you?

The noise is a real seismic record of the stations - from a working day. Noted at the end of chapter “Synthetic Seismograms”, where the overlay of synthetic events with real seismogram is discussed.

39. 6: Several events with M>-0.5 are not detected. However, you choose this value to be Mc, but Mc is the minimum magnitude above which all earthquakes within a certain region are reliably recorded. Mc should be 0.5 and not -0.5

Mc is derived as if you did not know the real concentration of events, purely from Gutenberg - Richter relation. Knowledge of the real synthetic seismicity allows us to evaluate such Mc validity, which cannot be done in real detection cases.

40. “would still be detected even if only the SKAC, NSNC, MHR, and KAM stations were available”: the station efficiency is not the only factor, network geometry and station combination are important (Aiken et al., (2021) – doi: 10.1016/j.jvolgeores.2021.107322), this should be discussed. It is well illustrated by the fact that the stations that contribute the most are not the same between the two tests (8 or 11 stations).

The reason why different stations are the most contributing for 8/11 station setup is the 4 trigger requirement. Also the greatest effect on contribution at GRSN is the noise level and station correction (Kaldy & Fischer, 2023). I am aware that the geometry of triggering stations should affect the location's RMS and so reduce the detectability (high RMS events are removed from detection). But the RMS as calculated does not incorporate the error due to velocity model or poor geometry. The poor geometry of the most efficient stations plays a significant role in case the focal mechanism would cause the S-wave signal to be weak at that location…

I have placed an additional explanation in the discussion part. Thank you!

41. 7: Bigger text. You inform about the P+S detection but you did not discuss about it in the text.

Bigger text, also similar scale of a and b figure and not-tilted station names. I have highlighted the importance of P(+S) wave detection at the beginning of the chapter "Location efficiency" . Thank you.

42. "two events with magnitudes ML 1.5 and ML 0.8 were missed by PEPiN": Why?

Additional explanation: "The reason for two detections instead of a single strong event is that the first, stronger detection consisted of 11 correct picks on 6 stations, while the second, smaller incorporated 4 correct picks on 2 different stations plus 3 noise-triggers recognized as S picks (one at GLT1). The latter has the RMS residual of the location of 0.3 s. Note, constraining the RMS residual to 0.1 s (94% of events) significantly affects the stronger events detectability."

43. "Overall, PEPiN is missing 0% at ML 5" wrong, you missed ML 1.5 and ML

It's correct for 8 surface stations. I pointed more clearly: "Overall, PEPiN utilizing 8 surface stations is missing 0% at ML0.5, 7% at ML0.0, 33% at ML-0.5 and 40% at Mc.The overall efficiency of detection above Mc-0.7 is calculated to be 78%."

44. "localization we display only events with at least one P wave pick assigned, which lowers the uncertainty of the resulting event location": How you are supposed to located event with only one P when at least a minimum of 3 stations in theoretically needed? Of course, with only one pick the uncertainty will be low, it does not mean that the result is good.

You are right. But the result is better than if you have only four S-wave picks. It means that for a successful localization the event must have at least 1 P pick and 4 S picks. This topic is reformulated in text, hopefully for better.

45. Location efficiency part: it is really not clear if you are talking about one unique synthetic event and that fig.10 illustrates location inversions for only ONE synthetic event or if fig.10 illustrates all the 1276 located events. This part is very difficult to understand and need huge reshaping.

I have tried to clarify this topic of a single waveform shape (location), but various magnitudes, at multiple previous locations in text.. This chapter “Location efficiency” is also reformulated. Intro as follows: “Over a thousand events were detected by PEPiN in both 8 and 11 station scenarios. If the station providing P and S picks would be surrounding the well of planned EGS, the PEPiN location of detected events would be expected to cluster around the zero (local) coordinate and 2 km depth, because the synthetic events represent a single event in terms of waveform shape and arrival time. In this chapter, the locations of PEPiN with 8 surface and 9 surface + 2 borehole stations are discussed gradually. ”.

46. 10: it could be easier to understand the figure if depth always represent the Z or Y axis but not X. It also will be easier with real longitude and latitude values. A figure with original synthetic locations is clearly mandatory.

The original synthetic location is the black diamond. In the figure description I have added: “ Origin [0, 0] of local coordinates is 50.5345N, 14.1535E and it is similar to synthetic event horizontal coordinates.”

Recommendation: Revisions Required ----------

Secound round of revision

Dear reviewer A

In the text below, I am addressing your main concern regarding publishing the 1D velocity model. I hope it also clarifies some of your uncertainties pointed independently. Also the rest of your remarks is addressed both in the text and with some comments further on in this document. I hope it makes the article more understandable also for others.

Thank you for your time and energy you invested to give me your feedback.

Best regards, Eva Kaldy

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The overall 3D effect is approximated using two 1D velocity models. If a comprehensive 3D model were available, it would have been utilized. However, at the time of the study, no active seismic surveys had been conducted to provide detailed insights into the 3D structure of the region. The available information was limited to broader geological studies referenced in the article. The baserock velocity model and its corresponding ray path are included in the article. Additionally, the following change is reflected in the corresponding paragraph in the Section: 1D Velocity Models:

“”””

For seismic stations situated on baserock, the baserock 1D velocity model represents velocities and densities along the expected ray path from the synthetic source to the baserock stations. It is based on the previously described sedimentary velocity model, optimized for the seismic source at a depth of two kilometers. It is anticipated that the seismic wave originates at a depth of 2 km in the Proterozoic gneiss, where it travels horizontally, encounters the brittle Litoměřice Fault Zone (Šafanda et al., 2020), passes through the high velocities of a volcanic body or limestone, and finally traverses an eroded layer, volcaniclastic material, and upper sedimentary layers (Cajz et al., 2009, https://mapy.geology.cz/geocr50/), see the red ray-path in Fig. 3. The uncertainty associated with seismic rays encountering volcanic structures is addressed by incorporating parameters that exhibit gradient increases with depth for base-rock and that are decreasing with depth for the fault zone (Table 2.). Although this baserock velocity model is a reasonable approximation of the geology likely to be encountered by the seismic signal between the source at GLT1 at 2 km and receivers at baserocks, it does not represent any real vertical geological profile (no basalts over sediments in the Litoměřice region). While this 1D baserock model serves as a valuable tool for testing detection-location algorithms by adding variation in waveform shape and complexity, its applicability is primarily within the scope of this project.

Table 2: The baserock 1D velocity model represents the velocities encountered by the seismic ray originating at a depth of 2 km in the Bohemian Cretaceous Basin (sedimentary area) and arriving at a station located atop the Central Bohemian Volcanic Complex (baserock area). Refer to the red ray path in Fig. 3.

Formation	Depth [km]	V_p [km/s]	V_s [km/s]	Density [g/cm^3]	Q_p	Q_s
Base rock	-0.31	4	2.4	2	500	222
Fractured zone	0.95	6.4	3.8	3	500	222
Proterozoic gneiss	1.1	6	3.5	2.82	500	222
	2.7	6.1	3.6	2.82	500	222
Granite	2.7	6.2	3.6	2.66	1000	444
	8	6.3	3.7	2.82	1100	489

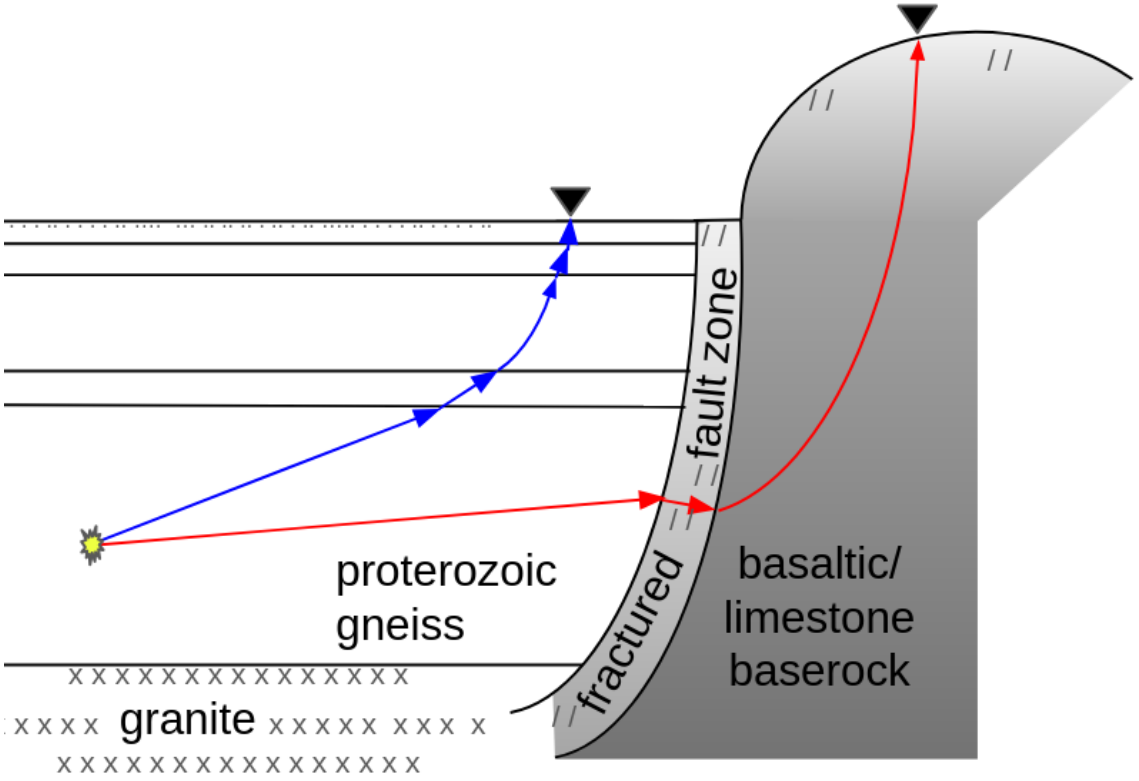

Fig. 3: Sketch of the geological structure in the Litoměřice region. The sedimentary area, shown on the left, is separated from the baserock area on the right by a regional fault. The seismic source (yellow) is located at a depth of 2 km within Proterozoic gneiss. The red line with arrows depicts the seismic ray path from the source to a seismic station atop the baserock formation, corresponding to the 1D baserock velocity model outlined in Table 2. The blue line represents the seismic ray path from the source to a station above the sedimentary layers, corresponding to the velocity model described in Table 1.

“”””

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Remarks:

1. Everywhere: “velocity model” should be used instead of “model” as this may induce confusion.

   Changed everywhere. Also earth model → velocity model

2. l.91: by “cross-section at depth 2km” I supposed you mean horizontal cross-section?

   cross-section at depth 2km →horizontal cross-section at depth 2km

3. l.108: by “real seismic records” do you mean recorded noise? As you do not have any earthquake records, how could you know that the recorded noise has a seismic origin?

   Yes, I mean noise recorded by seismic stations. real seismic records → recorded noise is overlaid

4. l.108: precise the “synthetic seismograms” number. 3 is not the same as 3,000 in term of statistic that you may perform after.

   →recorded noise is overlaid by **2880** synthetic seismograms of various magnitudes, but **of** a similar location **and focal mechanism**.

5. l.108: “are incorporated in order to …”, how it is incorporated? Through the velocity model?

   l.114 Bold text added to clarify: Changes in the underground geology (sediment vs. hardrock) are incorporated **via two 1D velocity models** in order to provide some variation in the expected arrival times in an inhomogeneous environment.

6. l.152: “An additional 1D baserock velocity model …”, Even if this is definitely clearer now, I still do not understand why in l.150 you introduce the need of a 3D model for these 4 stations and then, tell us that you are using 1D velocity model, and said that 1D velocity model provides a 3D effect to the study. 1D cannot produce 3D effect, isn't it? Or did you calculate 1D velocity model per station for these 4 stations? If yes, you should write "Additional 1D baserock velocity models [...]"

   For the network sensitivity assessment the synthetic seismograms do not need to be realistic, but they need to be reflecting that the arrival time to different stations cannot be easily explained by a single homogeneous or 1D velocity model. The 3D effect is obtained by two 1D velocity models, see change L.144 pointed above. Also I have little rephrased the following text in l.150. “Such a geological setting makes the use of a single 1D velocity model unjustifiable, and if realistic synthetic seismograms should be calculated, a 3D velocity model would be more beneficial. But for testing the detection reliability in a 3D environment it is sufficient that the synthetic waveforms

vary in wave arrival times (not explainable by single homogeneous or 1D model) and also in the waveform shape and complexity."

Also added to l.142 "At the beginning of this study, there were no active seismic or other geophysical profiles providing a closer insight into the 3D velocity structure of the Litoměřice region, but it is clearly divided by a regional fault system into sedimentary and baserock part (Myslil et al., 2007 & 2012)."

7. l.155: "baserock model is limited", do you mean baserock velocity model? Why is it limited?

   I hope it is clarified later in the text: l. 203: "The uncertainty associated with seismic rays encountering volcanic structures is addressed by incorporating parameters that exhibit gradient increases with depth for base-rock and that are decreasing with depth for the fault zone (Table 2.). Although this baserock velocity model is a reasonable approximation of the geology likely to be encountered by the seismic signal between the source at GLT1 at 2 km and receivers at baserocks, it does not represent any real vertical geological profile (no basalts over sediments in the Litoměřice region)"

8. Always use the same name: sedimentary area model l.164 "sedimentary area model", l.166 "earth model, l.166 "Litomerice earth model", l.192 "sedimentary basin model" ➔ only choose one and use it, several names could be confusing. In the same way; you cannot use the same name for the sedimentary velocity model and for the baserock velocity model (l.190 "earth model").

   I have changed the velocity model names to be consistent. Also left out the "earth model" reference totally.

9. l.186: "The standard 1.7 ratio between P and S wave velocities is maintained throughout the profile, validated by previously conducted laboratory measurements"; did you conduct this measurement? If yes, this is not clear, if not, you should give the referee.

   I added the citation, (T. Lokajíček, personal communication), which is similar as for the laboratory measurements in the preceding sentence.

10. l.198: "by incorporating parameters that exhibit gradient increases with depth", which parameters? Vp, Vs, Density, Qp and Qs? You should be more precise.

    Since I am publishing the velocity model, I resolve this point by referencing the table with the baserock velocity model.

11. l.203: "its applicability is primarily within the scope of this project and is therefore not presented here.", as you use it to create synthetic, you cannot say you'll not present it.

It is presented now.

12. l.215: “The resulting GFs …”, I suggest to move this sentence in the acknowledgement part.

    Information about data is in the Data and Code Availability section, therefore I have shortened the sentence and kept it here.

13. l.235: “The mean RMS residuals …”, I am not sure of the importance of this information. The RMS will depend on several factors different in each area and cannot be the only factor that determines software reliability.

    You are right, the RMS information does not play an important role in it. Therefore the info about location RMS is removed through the article, in order to avoid further confusement.

14. l.261: “various kinematic criteria”, what various means? Be more precise.

    We agree that various was confusing. In fact, the main criteria are given below, in the same paragraph. So we removed the word ‘various’.

15. l.276: “are obtained using a non-linear grid-search optimization similar to NonLinLoc (Lomax et al., 2009).”, do you mean that you did not use NonLinLoc? If yes, the nonlinear grid-search is part of PEPIN software? If yes, I think there is no need to talk about NonLinLoc here.

    Thank you for this point. Pepin never uses NonLinLoc, the location algorithm was developed prior to NonLinLoc. So we modified the text to “are obtained using a non-linear grid-search optimization (Fischer, 2003b).”

16. l.281: use 4 or four but not both, keep consistency.
    Change: Digits used for nr of stations and picks. Thank you.

17. l.284: “Location is performed with a homogeneous velocity model of P wave velocity 5.9 m/s”, why did you choose this value for P wave velocity? Is it the Vp mean present in your 1D sedimentary velocity model? Is it consistent with the baserock velocity model? The Vp homogeneous value is applied till which depth? Till 3 km depth? Why you did not use your 1D velocity model (sedimentary or baserock)?

    The reason is that for the sake of detection it proved sufficient to use a homogeneous velocity model. More advanced location approaches are used for analysis of the whole datasets in applications of Pepin for analysis of the West Bohemia and Iceland seismicity.

18. l.302: “by synthetic events at similar locations and focal mechanisms”, please, refer to fig.1.

Done, thank you.

19. l.305: suggestion ➔ “[…] was tested on eight surface GRSN stations to compare with the predicted network sensitivity as outlined by [REF]”.
    Done, thank you.

20. l.320: “Similar results are seen at the second borehole receiver GLT2.”, please, refer to fig.4.
    Done, thank you.

21. l.347: “aligned with the theoretical scaling”, are you talking about equation3? If yes, refer to it.
    Done, thank you.

22. l.348: “consistency with previous studies”, add referees.
    Done (Káldy & Fischer, 2023, Jakoubková, 2018), thank you.

23. l.375: “revealing 0% detections missing above M L 0.5”, but you wrote l.370 “multiple stronger events (up to M L 0.5) remaining undetected during working hours (6:00 - 15:00)”. So, your 0% is still wrong.
    I have slightly reformulated the sentence: “ multiple stronger events (ML < 0.5) remaining undetected during working hours (6:00 - 15:00)”

24. l.383: “1303 out of 1317”, you should precise if it is for 8 or 11 stations (I guess 8, but it could be nice to remember it for clarity).

    It is actually just 4 stations, as noted later in that sentence: “Upon closer examination of the GRSN efficiency, it becomes evident that all events (1303 out of 1317) would still be detected even if only the SKAC, NSNC, MHR, and KAM stations were available,...”

25. Fig.7: It seems that there is more detected event when using 8 stations instead of 11. This is right clear for the NSNC station. How do you explain that?

    I have added little to the figure description: “Efficiency of GRSN surface seismic stations, **when 4 S waves are required to trigger:** The rate at which individual stations contribute to event detection, when PEPiN utilizes 8 surface GRSN stations (a) or all 11 GRSN stations (b).”

    Also I hope it is pointed in the paragraph at l.425 where the 11 station scenario is discussed closely. I have reformulated a sentence here: “Additionally, the other 2 most beneficial stations, NSNC and KAM, play substantial but interchangeable roles by contributing to 70% and 55% of detections, respectively; which is a decline to their irreplaceable contribution in the 8 station setup, where they had to fully contribute to the requirement of 4 triggers”

    In other words: The setting requires at least 4 S waves triggering. It is the effect of station RICC, that is not present in the 8 station setting, and plays a major role in

detection in case of 11 stations. If you should rate the station “quality” you might end up with following: MHR = 100, RICC= 95, SKAC = 80, NSNC = 60, KAM = 55, GLT2 = 20, TER = 10, (LMP , PLO, GLT1) = 5. That makes the stations NSNC & KAM play substantial but interchangeable roles for 11 station scenario, but irreplaceable for 8 station scenario.

26. Fig.9: how do you explain that P and S arrival times are not always coherent with the epicentral distance, as for the MHR station here?

    That is actually the aim of introducing the second velocity model. Also in reality P can arrive at a further station earlier if the velocities are faster in the direction of that station.

    Added a comment to l.442: “Also note that the P and S arrivals in Fig. 10 do not fully correlate with the epicentral distance: the wave arrivals at sedimentary stations (red waveforms) are later to wave arrivals on baserock stations (black waveforms). It is due to the greater velocities in the baserock velocity model which is used to create the synthetic seismograms of baserock stations.”

27. l.453: “1317 events” add “over 2880”
    Done, thank you.

28. l.453: “the remaining are outside the area”, what is the width of your cross-section? This should be precise.

    The sections show all the events within the 3D cube, so the width is the coordinate interval in the direction perpendicular to the section. We changed “the remaining are outside the area” to “the remaining are outside the displayed volume”

29. l.460: “The medium PEPiN location”, do you mean median?
    Yes, changed, thank you.

30. l.486: “Ithis study showed…”, typo ➔ “This study”
    Thank you.

31. l.488: “exceeding the role of distance from the source”, you are not evaluating the distance from source here, as you use the same location. So, how can you evaluate that the impact of station correction and noise is greater?

    It refers to the 2023 study. I have connect this sentence to the previous, so it it more clear that I am referring to the 2023 study.

32. l.490: “empirically test the network sensitivity” ➔ on magnitude detection.
    Thank you, done.

33. l.501: typo “then” instead of “that”.
    Thank you, done.

34. l.518: “elongated in a form of a fault system.”, It is important to discuss the fact that this should be considered for future seismic monitoring to not made confusion between real fault and false fault.
    Yes, I have stated it there in brackets. Thank you.

35. l.532: “installing additional borehole sensors and by updating the phase associator”,
    Yes, but in your study you're better detecting events with 8 stations than 11.

    The decrease in performance for 11 stations was caused by phase association, therefore if we update it, the additional borehole station will play a role.