nature portfolio

Peer Review File

Fluids from deep subducted sediments control the seismic behavior of the Lesser Antilles megathrust

Corresponding Author: Dr Yaocen Pan

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Version 0:

Decision Letter:

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Dear Mr Pan,

Please allow us to sincerely apologise for the long delay in sending a decision on your manuscript titled "Fluids from deep subducted sediments control the seismic behavior of the Lesser Antilles megathrust". It has now been seen by 2 reviewers, whose comments are appended below. You will see that they find your work of interest to the subduction zone tectonics and seismogenesis communities, as well as natural hazards. However, they have raised quite substantial concerns that must be addressed. In light of these comments, we cannot accept the manuscript for publication, but would be interested in considering a revised version that fully addresses these serious concerns.

We hope you will find the reviewers' comments useful as you decide how to proceed. Should additional work allow you to address these criticisms, we would be happy to look at a substantially revised manuscript. If you choose to take up this option, please either highlight all changes in the manuscript text file, or provide a list of the changes to the manuscript with your responses to the reviewers.

Specifically, there are some points of concern around data processing (and comparison with previous analyses), and robustness of certain key features (R3 reflector, polarity/orientation of reflectors), which are crucial for the interpretation of subducted sediments and fluid pathways.

Therefore, we ask you to address all the reviewers' concerns and ensure that the revised manuscript meets the following editorial thresholds:

- detailed documentation of MCS profile analysis (in context of previous work)
- address robustness of the resolution of reflectors (especially those that have bearing on the interpretation of subducted sediments and fluid pathways), inclusion of resolution tests
- improved image quality
- comparison with along strike structure of the Lesser Antilles subduction zone plate interface.

When resubmitting, please provide a point-by-point response to the reviewers' comments. Please submit your responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

Please bear in mind that we will be reluctant to approach the reviewers again in the absence of substantial revisions.

If the revision process takes significantly longer than three months, we will be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

We are committed to providing a fair and constructive peer-review process. Please do not hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the reviewers' comments with a list of your changes to the manuscript text (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and any completed checklist:

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Please do not hesitate to contact us if you have any questions or would like to discuss the required revisions further. Thank you for the opportunity to review your work.

Best regards,

Derya Gürer, PhD
Editorial Board Member
Communications Earth & Environment
orcid.org/0000-0001-5884-9160

Joe Aslin
Deputy Editor
Communications Earth & Environment

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REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

Pan et al. reprocessed a MCS profile in the forearc offshore Lesser Antilles. The MCS profile reveals several reflectors that are of interest. Particularly, the reflector R3 as shown in Figs 2 and 3 is interpreted as a fluid-rich decollement under which lies sediments. They combine the MCS with seismicity distribution and seismic velocity models to propose that the existence of an aseismic corridor on the leading edge of the Tiburon ridge. They propose that fluids expelled from smectite in the subducted sediments facilitate such aseismic behaviour.

Overall, the article is well written and presented. The figures are of good quality and to the point. References are thorough and correctly used. The findings are of interest to the subduction zone research community but also to the general public in terms of its geohazards implications. I'd recommend the paper being accepted after minor tweaks. Below are some points I'd like the authors to address.

1. How does the reprocessing differ from the previous analysis of the MCS profile? Are those reflectors observed before, particularly the R3 reflectors? This has to be clearly stated in the text, as what counts as “new” and “first (Line 390)” observations is important.

2. How well can you resolve the R3 reflectors? Can they be processing errors or uncertainties in the observations? Can you include some resolution tests? Considering the short distance between R3 and R1, for example at ~160 km in Fig.2, it is critical to know how well the thickness of the sediment layer is resolved.

3. How do you define “seismically quiet” zone as stated in Line 344-346? Fig.1b shows plenty of seismicity in the area with yellow dashed lines. Additionally, the seismicity you plotted are for a given period, therefore may well miss seismic activities. It would help if you can outline the seismically quiet area in Fig.1b, although the area may not be quiet depending on the time scale.

4. Line 390-392 states that “a significant volume of subducted sediments” was driven by the subduction of the Tiburon ridge. And fluid rich forearc is associated with it. Given there is no comparison between the subducted sediments near Tiburon ridge and any other, nor quantification of the volume, how do you define “significant”? Another observation is that the subducted Marathon and Mercurius Fracture zones overlap with the sediments imaged by the MCS profle in this location, how can we know which contributes more fluids to the upper plate?

5. Does similar sedimentary layer exist at the leading edge of the Barracuda ridge at similar depth? How about the other edge of the Tiburon ridge? In other words, is the aseismic behaviour unique to the location found in this study or is it widespread along the Lesser Antilles slab interface? Rijsingen et al., (2020) found low seismic coupling along almost the entire plate interface.

Reviewer #2 (Remarks to the Author):

This manuscript presented a reprocessed seismic reflection profile in the Lesser Antilles subduction zone and discussed the relationship between the imaged structure and the megathrust seismic process. It includes the seamount (or ridge) subduction, subducted sediments, fluid, and their link to the megathrust process, which should interest the science community in the subduction zone tectonics and seismogenesis.
Discussions are interesting, and those on the fluid are new. The interpretation of the seismic profile is key in this paper, and enlarged figures are great to look at in detail. However, the interpretation of the critical features is not convincing, especially on the negative polarity reflectors. In Figure 3a, the “red-black-red” reflections seem to be positive polarity (subsets 1-2). Authors picked up 7 locations where authors argued about the negative polarity reflectors, but, except for subset 7, they are difficult to interpret as negative polarity reflectors from the figures shown here. Subsets 3-5 and 8 show a set of reflectors with large amplitude, and it is impossible to infer the polarity of the reflector. Subset 6 has two (or three) relatively clear reflectors, but neither of them is uniquely interpreted as negative polarity. I am not sure which reflector in subset 9 authors want to interpret as a negative reflector, a dipping one, or a horizontal one. It is crucial to show negative polarity reflectors clearly for discussing the subducted sediments and fluid process. I strongly recommend that the authors clarify this so that readers agree with the authors’ interpretation. Changing the color scheme may work in some locations.
Similarly, the R3 reflector in Figure 2b, especially around 170 km or westward, is unclear. I also recommend that the authors improve the image quality in this area.
In addition, the reflectors around 190 km, interpreted to be related to the Kalanina fault, are steeply dipping, probably steeper than 60°. I suspect these could be remaining refractions or other noises. Authors should carefully examine whether these reflectors are meaningful to interpret.

Other minor points are as follows.

Line 234: Does “the K fault” mean the Kalanina fault?

Does “m” in Figure 2b denote the moho? Please state it in the figure caption.

I suppose Figure 3 is taken from Figure 2b? If so, why are the deeper parts of Figures 3a and 3b muted? Did authors mute the seafloor multiple and below in Figures 3a and 3b?

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Version 1:

Decision Letter:

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Dear Dr Pan,

Your manuscript titled "Fluids from deep subducted sediments control the seismic behavior of the Lesser Antilles megathrust" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Joe Aslin

Deputy Editor,
Communications Earth & Environment
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REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

The authors' revisions are satisfying. No further comments.

Reviewer #2 (Remarks to the Author):

The authors revised the manuscript following my comments. I appreciate that they improved the quality of the seismic profile by processing the data further. The main concerns in the previous version of the manuscript were the negative polarity reflector and the interpretation of stacked reflectors, which are now clarified. I think the manuscript is now ready for publication.

REVIEWER COMMENTS:

Below we reply to each point. Our response is in **blue** and comments from reviewers are in **black**.

Reviewer #1 (Remarks to the Author):

Pan et al. reprocessed a MCS profile in the forearc offshore Lesser Antilles. The MCS profile reveals several reflectors that are of interest. Particularly, the reflector R3 as shown in Figs 2 and 3 is interpreted as a fluid-rich decollement under which lies sediments. They combine the MCS with seismicity distribution and seismic velocity models to propose that the existence of an aseismic corridor on the leading edge of the Tiburon ridge. They propose that fluids expelled from smectite in the subducted sediments facilitate such aseismic behaviour.

Overall, the article is well written and presented. The figures are of good quality and to the point. References are thorough and correctly used. The findings are of interest to the subduction zone research community but also to the general public in terms of its geohazards implications. I’d recommend the paper being accepted after minor tweaks. Below are some points I’d like the authors to address.

We thank the reviewer for the positive remarks.

1. How does the reprocessing differ from the previous analysis of the MCS profile? Are those reflectors observed before, particularly the R3 reflectors? This has to be clearly stated in the text, as what counts as “new” and “first (Line 390)” observations is important.

Laigle et al., (2013a) is the only paper that shows this profile. It is a review article that presents comprehensive results from integrated reflection and refraction data. The previous analysis of the MCS profiles (Figure. R01) were based on on-board processing result, which did not perform sufficient denoising and signal enhancement in the deep domain of the inner forearc. Those reflectors, i.e., R3, deep part of the R1, and the abundant reflective anomalies in the inner forearc basement, have not been observed by authors. The R1, TOC here, was only observed until the distance of 110 km from the trench. The extent of the subducted Tiburon ridge was inferred only until OBS D5. We made changes in Section of Seismic reflection image and stated that these features are the new and first observations (now stated in Lines 137-140, Lines 149-151, Lines 159-167 in the version with tracked changes). We made changes in the method section for a more detailed description of our processing flow (now stated in Lines 442-458), and we included image from PSDM processing (Supplementary Fig.5). In Line 436, we corrected the bandpass filtering width from 3-6-100-125Hz to 3-6-32-35Hz as the latter is the final one applied to the data. In Lines 45-47 and Line 163, we made changes for more appropriate description of the R3.

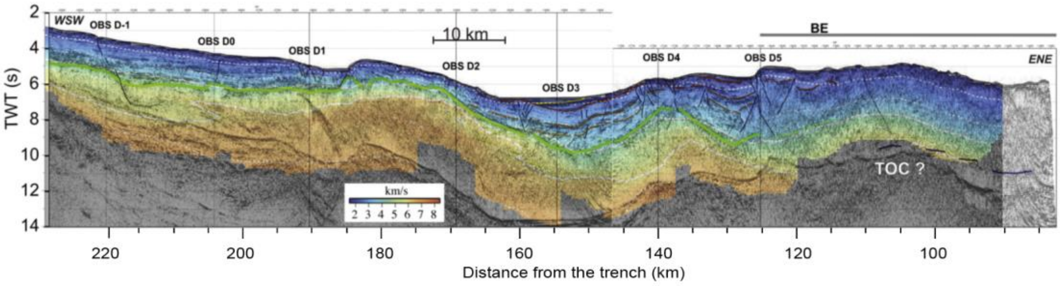

Figure R01: Previously processed MCS profile D in two-way travel time (TWT) (modified from Laigle et al., 2013a). Superimposed in colors on the MCS section is the P-velocity field extracted from the shot tomographical 3D model (Evain et al., 2013), converted into TWT. On the trenchward side, a discontinuous reflector (blue horizon) is interpreted as corresponding to the top of the subducting oceanic crust (TOC). The locally shallower position of the acoustic basement beneath sea-bottom at its trenchward tip is in the prolongation of the southern flank of the subducting Tiburon Rise. The gray thick line on the top indicates the expected location of the subducting Tiburon Rise crossed by the MCS line.

2. How well can you resolve the R3 reflectors? Can they be processing errors or uncertainties in the observations? Can you include some resolution tests? Considering the short distance between R3 and R1, for example at ~160 km in Fig.2, it is critical to know how well the thickness of the sediment layer is resolved.

Firstly, we can clarify that the R3, at 11 s TWT, and the R1, at 12 s TWT is not caused by multiple, as the shallowest multiple from seafloor, is at 13.5 s TWT (Supplementary Fig.1). Further, the strong amplitude reflection R3 does not correspond to any theoretical peg-leg multiple.

Secondly, we observe that the R3 has frequency range from 5-20Hz (Figure.R02). We applied bandpass filter with varying bandwidth and present the results in supplementary Figure 6. The R3 are visible as low as 15 Hz. Commonly, deep structures in the crust can be resolved in low frequency (0.5 to 20 Hz). Taking the image filtered with 3-6-15-20 Hz for example, the vertical resolution corresponds to 75 m (considering the velocity of 6.0 km/s). The R3 appears thin, but more than 75 m thick. This means that the R3 represents true signal from deep structures, instead of being caused by any high frequency artefacts during data processing. Neither it is an artefact from the Bandpass filtering, as we adopted gentle slopes in the Bandpass filter to prevent phase reversals.

We also added a figure of raw shot gathers (Supplementary Fig. 7). The phase reversal of R3 if compared with the sea floor reflection is clearly seen. We included an image of PSDM result (Supplementary Fig. 5) using tomographic velocity. It shows the R3 as well.

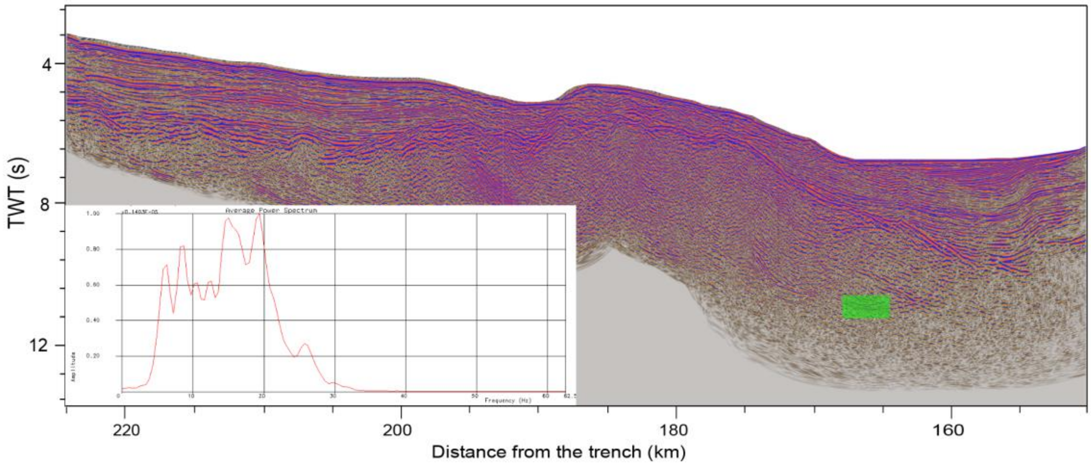

Figure R02: Spectral of the R3 in the post-stack time migrated image. Green area that covers the R3 is selected for spectral analysis.

However, there can be uncertainties in observations. In particular, variations of the depth of R3 and R1 and the thickness between R3 and R1 depend on the velocity used for depth conversion and depth migration. If a +-0.5 km/s error bar is given in velocity of the basement below 8 s TWT (we assume not much changes in velocity of the water column and sedimentary cover), the R3 would vary in depth for about +- 1.5 km. So does the thickness between R1 and R3.

Indeed, the interval between R3 and R1 shows a wedge shape trenchward thinning. In our depth image (Fig.2-3, Supplementary Fig.4), R3 is only resolved at the location of 165-173 km. Further trenchward and arcward, we put dashed line for speculation of continuation of R3.

We concluded a 4-5 km thickness of the R1-R3 interval based on Figures 2c, 3d, the post-time migrated image using tomographic velocity, which was converted to depth domain also using tomographic velocity. Although the R1 dims below the R3, maybe due to reduced fluid content, it can be traced until the distance of 160 km (Fig.3c). In the time-domain (Supplementary Fig. 1), we can clearly observe that the R3 is located in a shallower depth, above 11 s TWT, than the R1, below 12 s TWT where the blue arrow points to. The manually picked velocities and their adjustment for post-stack time migration (result shown in Fig. 3a, Supplementary Fig. 4) would have little influence on the thickness variation of the R1-R3 interval, as the depths of R1 and R3 in s TWT are determined during stacking of cdp gathers. As the vertical resolution is as high as 75 m in image filtered by 3-6-15-20 HZ, the distance between R3 and R1, ~4 km at the 160 km, can be considered relatively large compared to the vertical seismic resolution. However, further downdip, the thickness of the subducted sediments can be larger, where we have no data to constrain.

3. How do you define “seismically quiet” zone as stated in Line 344-346? Fig.1b shows plenty of seismicity in the area with yellow dashed lines. Additionally, the seismicity you plotted are for a given period, therefore may well miss seismic activities. It would help if you can outline the seismically quiet area in Fig.1b, although the area may not be quiet depending on the time scale.

Thank you for pointing out this. It’s probably not appropriate to call it seismically quiet, strictly speaking. We changed into “low spatial density of seismicity” in the text (now stated in Line 352 and Line 365). The period for the recorded seismicity, plotted in Figure 1b (also Figure R03), is 8 months during 2007, and this is what we have in this region regarded as a fairly large amount of high-resolution data for interpretation. Based on these data, Ruiz et al., (2013) first noted an aseismic area (area with dashed line, red arrow) (Figure R03) and the authors attributed it to thick sediments on top of the inner forearc.

Indeed, there are quite a bit of seismicities in the area with yellow dashed lines in our Figure 1b. Many of these seismicities are upper plate events, not in the plate interface (orange events in Fig.1b). We added a solid thick line in Figure 1b to indicate the zone of low density of earthquakes. The data in 1950-1978 from Dorel, (1981) (black dots) also show a low density of seismicities in the area that we outlined as a possible seismic gap inferred from 2007 data (purple colored, in Figure R04).

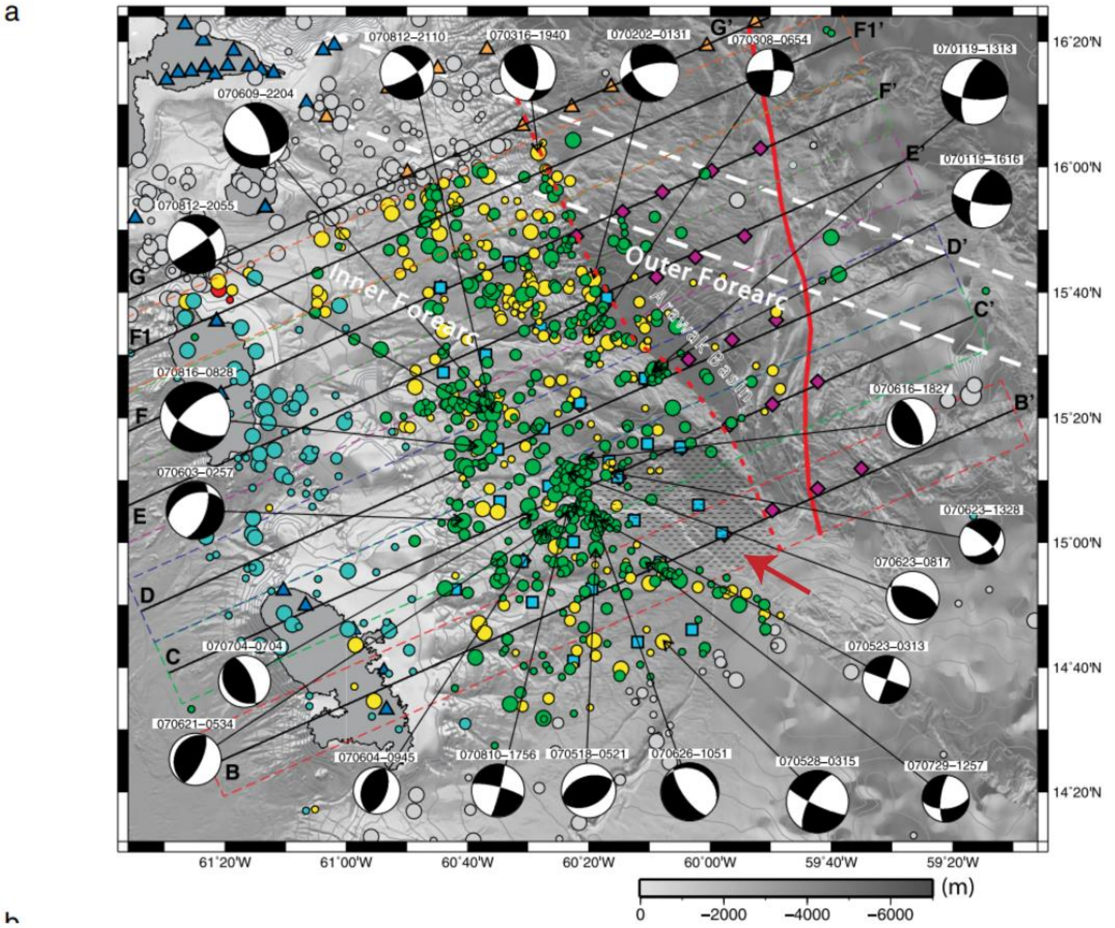

Figure R03: Hypocentral locations during a 8-months experiment in 2007 (modified based on Ruiz et al., 2013). Red arrow pointed to the seismic gap identified by Ruiz et al., (2013).

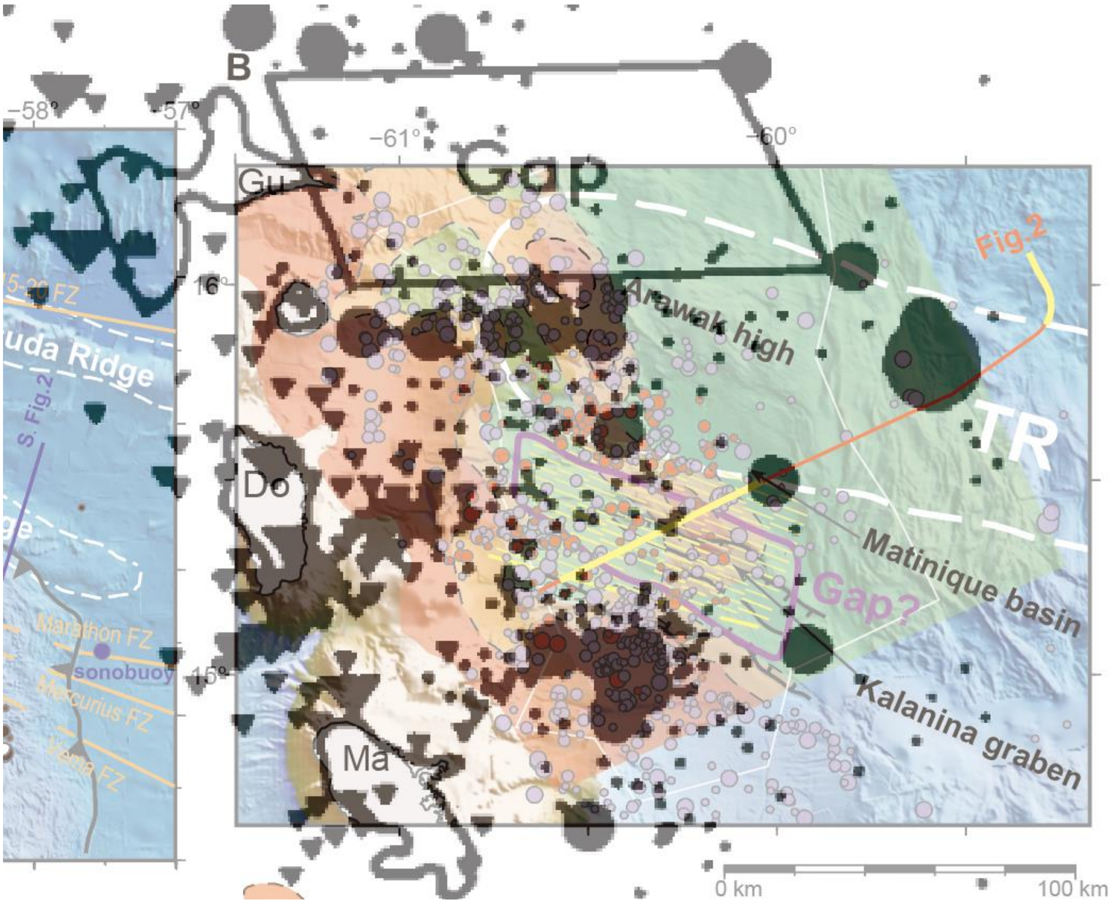

Figure R04: Superposition of our outlined seismic gap on the distribution of earthquake epicentres in the period 1950-1978 (modified based on Dorel, 1981). Note that the inferred seismic gap from 2007 data is consistent with seismicity distribution in 1950-1978.

4. Line 390-392 states that "a significant volume of subducted sediments" was driven by the subduction of the Tiburon ridge. And fluid rich forearc is associated with it. Given there is no comparison between the subducted sediments near Tiburon ridge and any other, nor quantification of the volume, how do you define "significant"? Another observation is that the subducted Marathon and Mercurius Fracture zones overlap with the sediments imaged by the MCS profle in this location, how can we know which contributes more fluids to the upper plate?

We agree that it is not appropriate to state "a significant volume of subducted sediments", although it might be true as it correlates with the largest offset at the trench along strike and also an embayment in the inner forearc (Evain et al., 2013). The southward transition from steep to gentle forearc slope offshore Martinique (Seibert et al., 2020) may be related to strong subduction erosion by the Tiburon ridge which contributed to the subducted sediments. But this needs further constrains, so we do not discuss this in the manuscript. We deleted "significant" as we do not provide comparison with neighboring regions. We changed it to "subduction of 4-5 km thick sediments" (now stated in Lines 397-

398), considering this value is based on our depth image using tomographic velocity.

Yes, the subducted Marathon and Mercurius Fracture zones overlap with the subducted sediments, which is a very interesting aspect, as a number of studies show anomalies at such locality. In the text we discussed that the sources of the fluids can be both. We cannot answer the question of which contributes more to the upper plate fluids. Quantitative distinction of their contribution is beyond the scope of this work. Further studies are needed.

5. Does similar sedimentary layer exist at the leading edge of the Barracuda ridge at similar depth? How about the other edge of the Tiburon ridge? In other words, is the aseismic behaviour unique to the location found in this study or is it widespread along the Lesser Antilles slab interface? Rijsingen et al., (2020) found low seismic coupling along almost the entire plate interface.

Yes, a similar sedimentary layer exists at the leading edge of the Barracuda ridge beneath the accretionary wedge, which has 1km thickness (Laigle et al., 2013b). However, at the depth of 20-30 km farther arcward in the inner forearc domain, there is no data to confirm this. According to Laigle et al., (2013b), the thick sediments may exist all along the ridge beneath the accretionary wedge and the inner forearc domain. The other edge of the Tiburon ridge corresponds to the Tiburon Basin in the oceanic plate, which has sediments of 0.8 s TWT thickness (Pichot et al., 2012), corresponding to 1.2 km thick (assuming average 3km/s velocity). This area between the Barracuda ridge and the Tiburon ridge is associated with a seismic gap (Figure R04 and Figure R05) (Dorel, 1981), probably related to fluid-rich sediments.

The aseismic behavior can be widespread along the Lesser Antilles slab interface, as fluid-rich sediments may widely exist at the slab interface. The low seismic coupling of the entire plate interface from Rijsingen et al., (2020) are based on data from GNSS stations that has generally sparse distribution, only close to the arc islands onshore, and covers a geologically short period of time. The plate-wide seismic behaviour needs more detailed constrains.

Based on studies of coral microatoll paleogeodesy (Weil-Accardo et al., 2022) and sedimentary samples in the forearc basins (Seibert et al., 2024), a portion of the megathrust east of the forearc islands has been found locked and possibly responsible for megathrust earthquakes. The variation of the thickness of the subducting sediments and the presence of the oceanic topographic highs can lead to variation of coupling. High coupling asperities may form where there is less sediments or consolidated sediments.

On the other hand, the location found in this study can be relatively unique, considering that the 4-5 thick subducted sediments are likely thicker than other locations along strike and also that the contribution of fluids from the underlying Marathon and Mercurius Fracture zones is unique. However, further constrains are needed.

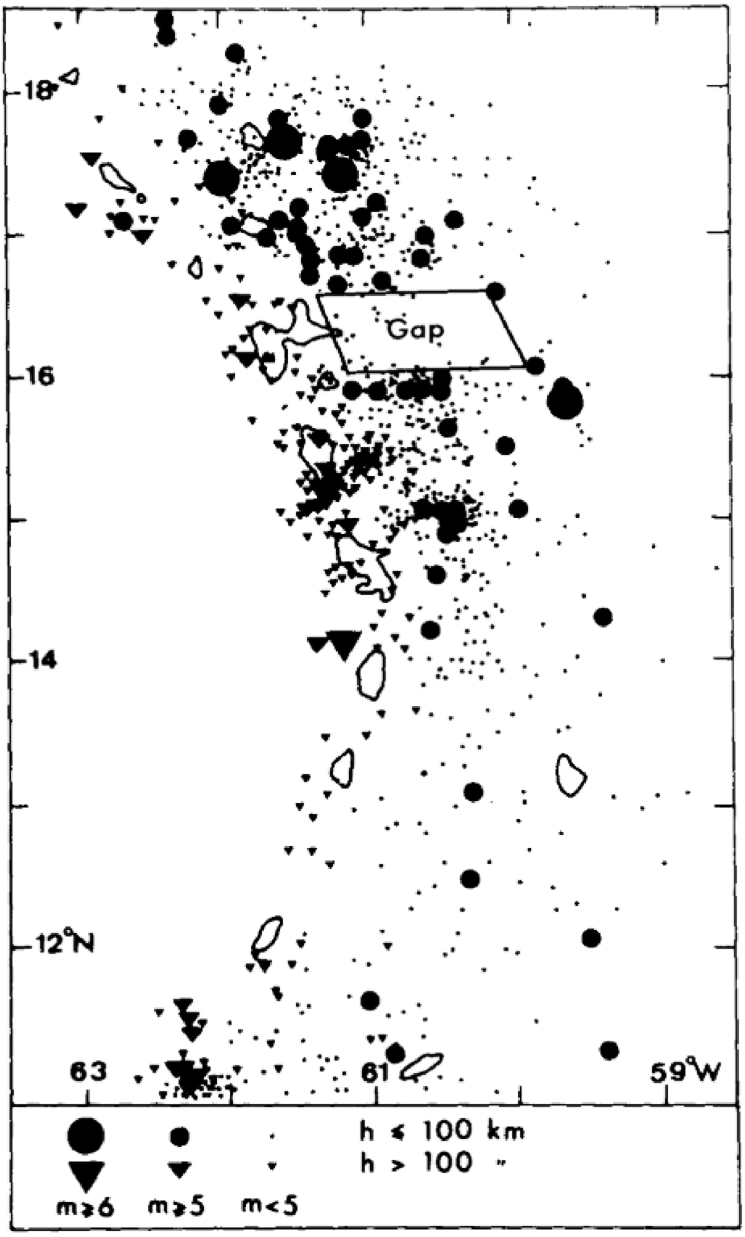

Figure R05: A seismic gap at the east of Guadeloupe during the period 1950-1978 (from Dorel, 1981).

Reviewer #2 (Remarks to the Author):

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We thank the reviewer for the positive remarks.

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In addition, the reflectors around 190 km, interpreted to be related to the Kalanina fault, are steeply dipping, probably steeper than 60°. I suspect these could be remaining refractions or other noises. Authors should carefully examine whether these reflectors are meaningful to interpret.

We enlarged the subsets in Figure 3a, and show 5 Subsets. The enlarged subsets at the Kalanina fault are shown in Supplementary Figure 5. We made changes in the text correspondingly (now in Lines 151, 165). In Figure 3a, subset 1 and 2 represent seafloor and top of basement and they show positive polarity as the first coherent reflection (first break) is in red. Subset 3 shows the R3 with a set of reflections and it starts with black from top, indicating negative polarity with respect to the seafloor. It can be due to thin heterogeneities associated with fluid accumulation within deep-seated fractures. Similar bright spots documented in deep crust show negative polarity at its first break (Brown et al., 1996).

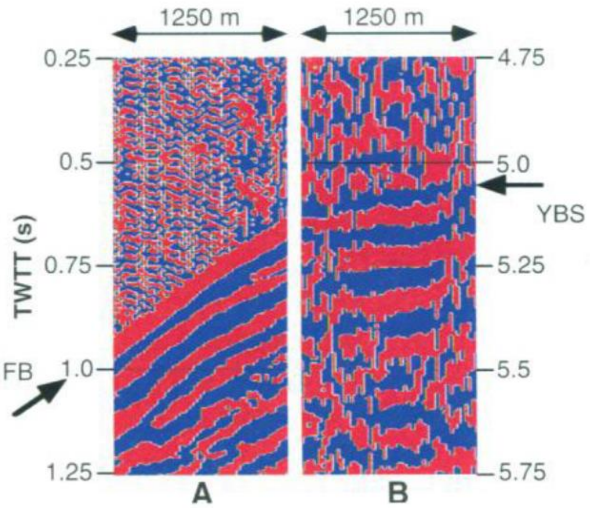


Figure R06: Example bright spot of negative polarity in deep crust (from Brown et al., 1996).

We cannot tell the polarity in Subset 4; however, we show it because it is interesting to note that the R3 shows stacked reflectors of ~1 km thickness.

We clarify that the Figure 2b was processed using tomographic velocity for post-time migration and depth conversion. We made changes of the label of the R3 only where the image is clear. We processed the inner arc domain of the profile for improved image quality by manually adjusting the migration velocity. This area of improved quality is shown in Figure 3a, Supplementary Figure 4 and 6.

Thank you for the suggestion of changing color scheme. In supplementary materials, we added figures shown in color scheme of amplitude scale. We removed the vertical exaggerations, and in Supplementary Figure 4, the steeply dipping reflections can be related to fractures in the basement, as some of them can be traced up as reflective fault planes in the Martinique basin. The fault planes in the basin were resolved in pre-stack depth migration (PSDM) (Supplementary Fig.5).

We agree that some energy of the reflections along the Kalanina fault may come from remaining diffractions. In the PSDM image (Supplementary Fig. 5), there is reduced effect of diffractions and it confirms the existence of the reflective features beneath the Kalanina fault. The Subset 2 and 3 in Supplementary Figure 5 show a set of reflections, starting with blue-red-blue from the top, in contrast to red-blue-red at the seafloor, indicating negative polarities. Such pattern of ringing reflections may be explained by relatively small-scale heterogeneities associated with fluid accumulation. Such features were commonly observed in sedimentary basin, where fluids led to washout or caving along faults and fractures, also called “string-of-beads” phenomenon (see Figure R07-R09 in below). Figure R09 also show that the fluids cause negative polarity.

In the Martinique basin, the subset 4 in the PSDM image shows clearly negative polarity of the arcward dipping reflectors (Supplementary Fig.5b). Such arcward dipping reflectors of small offsets may be related to forearc collapse commonly associated with subduction erosion (von Huene and Ranero, 2003; Straub et al., 2020), where fluids were expelled upwards.

Also, we verified the polarity of R3 in shot gathers (Supplementary Fig.7) and the first break shows negative polarity.

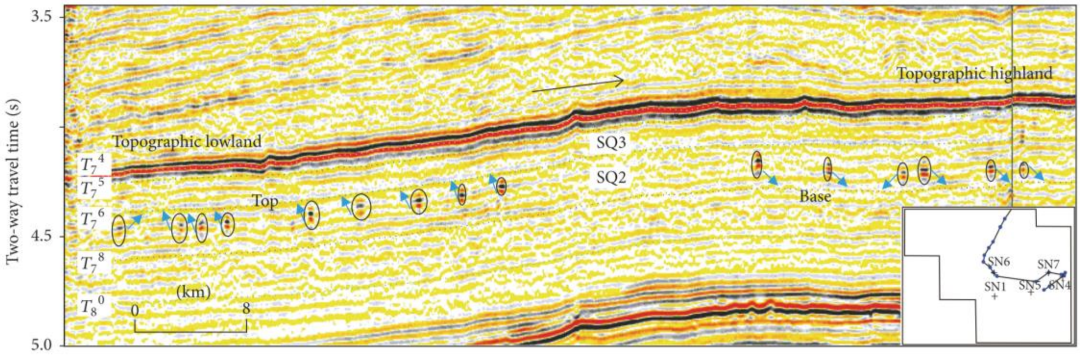
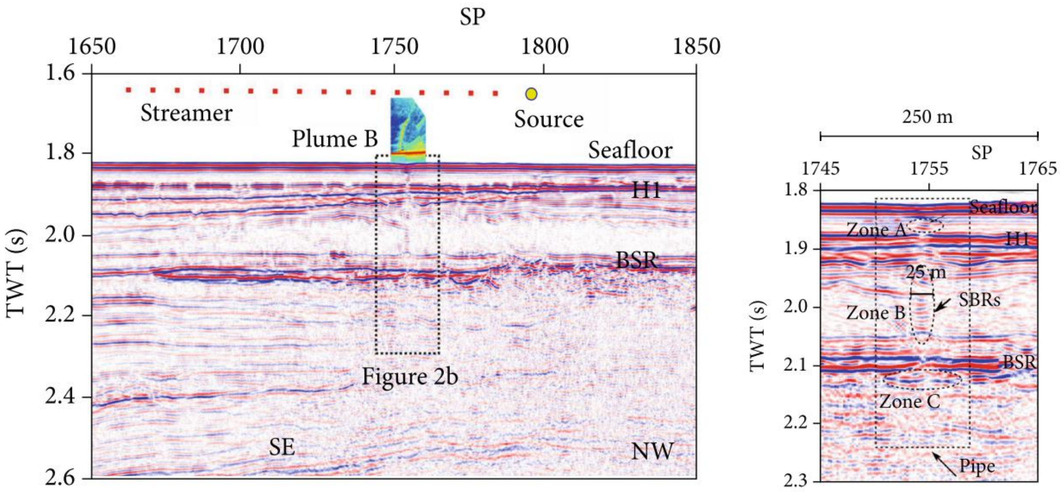
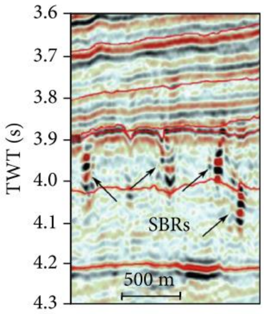


Figure R07: Example of fluid-induced string-beads-like seismic reflections in sedimentary rocks (from Zhu et al., 2017).



(a) Seismic profile passing through the pipe structure

(b) Zoomed image of the pipe



(c) String of bead reflections

Figure R8: Example of fluid-induced string-beads-like seismic reflections in sedimentary rocks (from Liu et al., 2021).

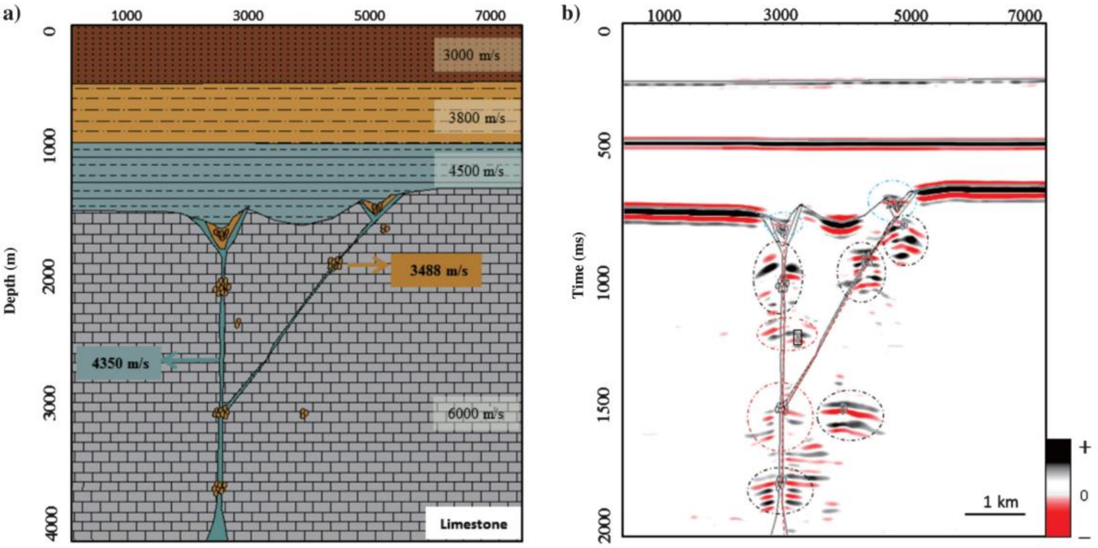


Figure R9: Example of string-beads-like seismic reflections from seismic modeling of the faulted karst reservoir (from Wang et al., 2021).

Other minor points are as follows.

Line 234: Does “the K fault” mean the Kalanina fault?

Yes, it means the Kalanina fault. Thanks,

Does “m” in Figure 2b denote the moho? Please state it in the figure caption.

Well, “m” indicates the multiple of the seafloor. We clarified this now in the caption. Thanks.

I suppose Figure 3 is taken from Figure 2b? If so, why are the deeper parts of Figures 3a and 3b muted? Did authors mute the seafloor multiple and below in Figures 3a and 3b?

Well, the Figure 3c and Figure 3d are taken from the Figure 2b. The Figure 3a and Supplementary Figure 4, 6 are the inner domain of the profile that we improved the image quality by adjusting the migration velocity. We muted the seafloor multiple and below because the seafloor of the inner domain is shallower and the smiling effect of migration can mask the signals from real structures.

We thank again the reviewer for time and effort on the reviewing of this manuscript.

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