Full review report

Duffy et al., The Role of Salt Tectonics in the Energy Transition: An Overview and Future Challenges, TEKTONIKA, 2023.

Index:

1st round decision letters by the executive and associate editors, followed by the 2 reviews.

Subject: [тєкτоніка] Editor Decision

Oliver Duffy, Michael Hudec, Frank Peel, Gillian Apps, Alex Bump, Lorena Moscardelli, Tim Dooley, Shuvajit Bhattacharya, Kenneth Wisian, Mark Shuster:

We have reached a decision regarding your submission to тєкτоніка, "The Role of Salt Tectonics in the Energy Transition: An Overview and Future Challenges: Salt Tectonics and the Energy Transition".

Our decision is: Revisions Required

Frank Zwaan (section editor):

Dear authors,

Many thanks for submitting your manuscript to Tektonika.

We had received quite positive comments from two reviewers, including some suggestions on what can be improved. Please find these comments below and in the attachment of this email. We invite you to revise the manuscript for resubmission, and to prepare a reply to all reviewer comments (also those in the annotated PDF).

Next to that, please find some additional comment from my side below:

_____

Intro (line 46): a basic point --> what is the definition of salt here? It may be good to define this at the start of the text.

End of intro (Line 86-89): perhaps clearly number the 3 main topics to make them stand out, to prepare the reader for the 3 main sections of the paper.

Line 199: a “C” is missing (should be ˚C)

Line 239: perhaps specify that this salt flow is on short (human) time-scales?

Line 245: use “modelling” instead of “to model”?

Line 330: only shortening? Or also extension (or other types of deformation)?

Line 364: perhaps explain what “salt quality” means (“salt impermeability” might be better?)

Line 373-374: please check grammar, seems a bit off here.

Line 389: lots of “that”, consider rephrasing

Line 446: perhaps use “economy” instead of “ecosystem”

Line 467-469: this sentence is not 100% clear to me

Line 576: suggestion to use “salt-bearing basins” instead of "salt basins"

Line 605: consider having a new paragraph starting here, same for line 619

Line 664-666: consider removing, as the focus of the paper is on salt, not carbonates. This last sentence therefore seems out of place.

Line 671: not clear what “this salt related structure” is

Line 733: start with “an ultimate goal”?

Line 760: by using “intra-continental settings”, it seems like the whole world is basically covered. Perhaps use “intra-continental rift basins” or so

Line 771: “geothermal resources” would be clearer

Line 949: there is no Fig. 22?

Figure 2: what does CCUS stand for? Please specify in the caption.

Figure 4b: perhaps add in the caption that this is offshore Brazil

Figure 9: please specify in the caption where this is (I assume in the US)?

Figure 16 and 17: the colour scale goes from blue to red, where white seems to suggest the null-point. But the temperatures represent a continuous range. It may be better to use a colour scale that goes from light to dark blue (or light to dark red). This will also help colour-blind readers and make things clearer when printed in black and white. This may also be a consideration for the other figures. Please check the figure guidelines for more info: https://tektonika.online/index.php/home/figure_guidelines

Table 1: third column: should be post-depositional

Note: please check for UK/US English, it seems not always consistent (e.g. color/colour)

Practical concerns:

Figures: some figures are split in different parts (e.g. 3a, 3b). Please organize these in one figure, or split figures and renumber them accordingly. There is also a Fig. 4 and a Fig. 4b, but no Fig. 4a. Please double-check.

Figures: A large number of the figures are derived from previous publications. Please make sure that you have secured the right to reproduce these figures (See also Tektonika figure guidelines: https://tektonika.online/index.php/home/figure_guidelines). Failure to do so may cause issues down the line (e.g. the paper may have to be withdrawn due to copyright infringement).

Looking forward to receiving your revised manuscript,

Kind regards,

Frank Zwaan

We have reached a decision regarding your submission to тектоnika, "The Role of Salt Tectonics in the Energy Transition: An Overview and Future Challenges: Salt Tectonics and the Energy Transition".

Our decision is: Revisions Required

Reviewer 1 Comments - Leonardo Pichel

Recommendation: Revisions Required

For author and editor

The paper offers a comprehensive review of the technical and economic needs and goals for the energy transition and the associated reduction of CO2 emissions; and how salt tectonics structures and concepts can play a fundamental role in achieving these goals. The paper is also exceptionally well-written and of great value to the salt community and society. The illustrations are also good, simple, and easy to follow. In sum, it is a very inspiring and exciting paper.

As a researcher on salt tectonics, I found great pleasure and renewed optimism in reading this manuscript, especially by acquiring an improved understanding of the importance and applications of salt tectonics to the energy transition. Furthermore, as one of the associate editors of *Tektonika,* I am also glad to have a paper of such academic and societal relevance published in our journal.

I also learned a lot about the technicalities and broader economic aspects of CO2 and H2 storage; and geothermal exploration. That said, I am no expert on these topics, so I cannot fully evaluate their related technical aspects in the paper.

I have added only a few minor suggestions throughout the paper (see annotated pdf). My two main, albeit minor issues/suggestions are:

- The examples are very US-EU-centric (e.g., Gulf of Mexico and Zechstein salt basins). This is understandable given the greater availability of infrastructure, data, and perhaps economic potential in these areas, but I was left wondering about the potential in other parts of the world (e.g., the Middle East, East Asia, South America, Africa, etc.).
- What about mining? I see that the authors refer already, albeit briefly to Lithium mining, but I was curious about other mining applications worldwide. I think that, if possible, having an additional, brief sub-section about this would be a significant improvement to this already excellent paper. I understand this may be beyond the scope and, thus, I leave it to the authors' and editor's discretion.

If the authors have any queries and would like to discuss my comments, please do not hesitate to contact me: Leonardo.m.pichel@uib.no

Yours sincerely,

Leonardo M. Pichel

_____

Tektonika review form - reviewer 1

Tektonika peer-review form

Section A: Overview of manuscript

A1) Overall evaluation, general comments & summary

A1.1) Reviewer's comments

A1.1.1) General evaluation and publication suggestion – Required:
Please use this space to describe, in your own words, the core subject of the submission and your overall assessment of its suitability for publication.

The paper offers a comprehensive review of the technical and economic aspects and goals for the energy transition and the associated reduction of CO2 emissions; and how the concepts of salt tectonics and its related geological structures can play a fundamental role in achieving these goals. The paper is also exceptionally well-written and of great value to the salt community and society. The illustrations are also good, simple, and easy to follow. In sum, it is a very inspiring and exciting paper and I recommend it for publication after minor revision.

Being a researcher on salt tectonics, I found great pleasure and a renewed optimism by reading it, in particular, by acquiring an improved understanding on the importance and applications of salt tectonics concepts to the energy transition, and ultimately, how this can be used to help society. Furthermore, as one of the associate editors of Tektonika, I am also very glad to have a paper of such academic and societal relevance published in our journal.

I learned a lot about the technicalities and broader economic aspects of CO2 and H2 storage, and geothermal exploration. That said, I am no expert on these topics so I cannot fully evaluate their related technical aspects in the paper.

I have added only a few minor suggestions throughout the paper (see annotated pdf). My two main, albeit minor issues/suggestions are:

1) The examples are very US-EU-centric (e.g., Gulf of Mexico and Zechstein salt basins). This is understandable given the greater availability of infra-structure, data, and perhaps economic potential in these areas, but I was left wondering about the potential in other parts of the world (e.g., Middle East, East Asia, South America, Africa, etc.)?

2) What about mining? I see that the authors refer already, albeit briefly to Lithium mining, but I was curious about other mining applications worldwide. I think that, if possible, to have an additional, brief sub-section about this would be a significant improvement to this already excellent paper. I understand this may be beyond the scope and, thus, I leave it to the authors' and editor's discretion.

A1.1.2) What does the submission need to be publishable? (select as needed; comment for all cases)

- ☐ No changes required
- ☐ Rewriting
- ☐ Reorganising
- ☐ More data/figures
- ☐ Condensing
- ☐ Reinterpretation
- ☒ Other

Comments:

Small changes in the text and possible some additions to the discussion regarding mining and more worldwide example/applications

A1.1.3) Can the submission be improved by reducing/adding any of the following? (select as needed; comment for all cases)

- ☒ Text
- ☐ Table
- ☐ Figures
- ☐ Supplementary material

Comments:

[See comment above]

A1.1.4) Please complete the following section if you recommend that the submission is NOT appropriate for publication (select as needed; comment if a box is selected)

- ☐ Quality is poor
- ☐ Research is not reproducible
- ☐ Other

Comments:

[Free form box]

A1.2) Author(s) Responses:

A2) Summary of main merits and main points of improvement

A2.1) Reviewer's comments

Please describe below in a few sentences (100 to 300 words) the main merits of the submission and suggestions for improvements.

The main merits I have found are...

The text is very well written and nicely illustrated. It has also great value for the scientific community and society in general.

The main points of improvement I have found are...

A few text additions, in particular to the discussion would significantly strength the manuscript, but are not strictly necessary.

A2.2) Author's responses:

[Free form box]

Section B: Detailed evaluation of manuscript

B1) Title and abstract

B1.1) Reviewer's comments

*These statements are a **guide** to what good* Titles *and* Abstracts include*. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Title* describes the main topic of the manuscript **accurately** — [**YES**] / [NO]

The *Title* describes the main topic of the manuscript **succinctly** — [**YES**] / [NO]

The *Title* includes **appropriate key terms** — [**YES**] / [NO]

The *Abstract* includes a **clear aim and rationale** — [**YES**] / [NO]

The *Abstract* supports the rationale with **sufficient background information** — [**YES**] / [NO]

The *Abstract* includes a **well-balanced description of the methods** — [YES] / [**NO**]

The *Abstract* describes the **main results sufficiently and adequately** — [**YES**] / [NO]

The *Abstract* clearly describes the **importance/impact of the study** — [**YES**] / [NO]

The *Abstract* clearly states the **conclusions of the study** — [**YES**] / [NO]

The *Abstract* is **clear** and **well structured** — [**YES**] / [NO]

Comments:

My only "NO" comment is related to the lack of information on methods as the manuscript does not have a methods section. This is however completely understandable given it fits more into a "review" type of manuscript, although with many novel insights on the new applications of relatively mature concepts of salt tectonics.

B1.2) Author's responses

[Free form box]

B2) Introduction

B2.1) Reviewer's comments

*These statements are a **guide** to what good* Introductions *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Introduction* provides **sufficient background and context** for the study — [**YES**] / [NO]

The *Introduction* describes the **aim/hypothesis/rationale** clearly, providing **sufficient context** — [**YES**] / [NO]

The *objective/hypothesis/rationale* **flows logically from the background** information — [**YES**] / [NO]

The *Introduction* describes the study's **objective and approach** (last paragraph) — [**YES**] / [NO]

The *Introduction* contains **relevant, suitable citations** — [**YES**] / [NO]

The *Introduction* is **organized effectively** — [**YES**] / [NO]

Comments:

[Free form box]

B2.2) Author's responses

[Free form box]

B3) Data and methods

B3.1) Reviewer's comments

*These statements are a **guide** to what good* Method *sections include and good practices for* Dataset *accessibility. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Methods* are described **concisely and with enough detail** for reproducibility — [YES] / [NO]

Necessary information about **data sources/acquisition/processing** is included — [YES] / [NO]

Data used are accessible via either supplementary files or links in the data availability statement — [YES] / [NO]

The *Dataset and/or Methods* are **organized effectively** — [YES] / [NO]

Comments:

Not applicable in my opinion (see comment on section B1)

B3.2) Author's responses

[Free form box]

B4) Results

B4.1) Reviewer's comments

*These statements are a **guide** to what good* Result sections *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Results* findings are **supported by data** — [**YES**] / [NO]

The *Results* findings are presented **clearly and succinctly** — [**YES**] / [NO]

The text in the *Result* section **cites tables and figures appropriately** — [**YES**] / [NO]

The *Results* directly **relate to the study objectives** — [**YES**] / [NO]

The *Results* present **data for all the approaches** described in the *Methods* section — [YES] / [**NO**]

The *Results* **text belongs to the Results section**, not to *Introduction*, *Methods*, or *Discussion.* — [**YES**] / [NO]

The *Results* section is **organised effectively** — [**YES**] / [NO]

Comments:

[Free form box]

B4.2) Author's responses

[Free form box]

B5) Discussion and conclusions

B5.1) Reviewer's comments

*These statements are a **guide** to what good* Discussions *and* Conclusions *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Discussion* is **focused on the objectives** of the study — [YES] / [NO]

The *Discussion* **addresses all major results** of this study, which are shown in *Results* — [YES] / [NO]

The *Discussion* section makes **comparisons with other studies** that are relevant and informative — [YES] / [NO]

The *Discussion* section properly identifies all **speculative statements** — [YES] / [NO]

The *Discussion* section presents the **implications of the study** persuasively — [YES] / [NO]

The *Discussion* section **highlights novel contributions** appropriately — [YES] / [NO]

The *Discussion* section **addresses the limitations** of the study appropriately — [YES] / [NO]

The *Discussion* section is **organised effectively** — [YES] / [NO]

The *Conclusions* are **consistent** with and **summarise** the rest of the manuscript — [**YES**] / [NO]

The *Conclusions* are **supported by the data** in *Results* and **follow logically** from the *Discussion* — [**YES**] / [NO]

The *Conclusions* are **clear and concise** — [**YES**] / [NO]

Comments:

There is no discussion section as the results sections already comprise an overview and discussion of established concepts and its new applications.

B5.2) Author's responses

[Free form box]

B6) Figures, tables and citations

B6.1) Reviewer's comments

*These statements are a **guide** to what good* Figures *and* Tables *include and how they are presented. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

Tables and *Figures* are **ordered logically** and **numbered sequentially** — [**YES**] / [NO]

Tables and *Figures* have **captions that explain** all their major features — [**YES**] / [NO]

Tables and *Figures* have **captions that complement** the information in the main text — [**YES**] / [NO]

Tables and *Figures* present data that **relate** to the study objective — [**YES**] / [NO]

Tables and *Figures* present data that are **consistent** with and support the description of results — [**YES**] / [NO]

Tables and *Figures* have **succinct and informative titles** — [**YES**] / [NO]

Figures are **accessible** (elements are clearly labelled, accessible colour palettes, colour contrasts, font size legible, etc.…) — [**YES**] / [NO]

Please, check our [Figure guidelines]

Figures with **maps or cross-sections** contain all **elements to be understood** (north arrow orientation, scale, visible coordinates, sufficient coordinate grid intercepts) — [**YES**] / [NO]

Figures with **maps** have **sufficient location information** (in the map or caption) — [YES] / [NO]

Cross-sections have clear labels for **scale and coordinates** at ends and within-section kinks — [YES] / [NO]

All georeferenced elements are provided in common format (.shp, .geotiff, .kml) [in an open-access repository] — [YES] / [NO]

Citations throughout are relevant, suitable, and comprehensive — [YES] / [NO]

Comments:

[Free form box]

B6.2) Author's responses

[Free form box]

Section C: Additional comments

C1) Minor/line-numbered comments

C1.1) Reviewer's comments

[Free form box]

C1.2) Author's responses

[Free form box]

C2) Other remarks

C2.1) Reviewer's comments

[Free form box]

C2.2) Author's responses

[Free form box]

_____

Reviewer 2 Comments - Sian Evans

Recommendation: Revisions Required

For author and editor

Please see the Tektonika review form attached.

Tektonika review form - reviewer 2

Tektonika peer-review form

Section A: Overview of manuscript

A1) Overall evaluation, general comments & summary

A1.1) Reviewer's comments

A1.1.1) General evaluation and publication suggestion – Required:
Please use this space to describe, in your own words, the core subject of the submission and your overall assessment of its suitability for publication.

This manuscript is a forward-looking review in the field of salt tectonics, with a firm focus on how the knowledge we have accrued thus far, principally due to its applications in the oil and gas industry, may be repurposed for emerging technologies related to the energy transition. Following the introduction, the paper is divided into 3 key sections that each tackle a different energy transition technology where salt tectonics could play a key role, namely: short-term gas storage in

salt caverns, permanent sequestration of CO2 in salt basins, and geothermal exploitation around salt structures. The aim of the paper is not to present new knowledge, but to highlight the transferrable knowledge and key areas of research that would help to advance these novel applications, which are still in their relative infancy. The manuscript draws on the vast experience of the authors in this field, with clear text and highly informative supporting figures. The focus on energy transition applications gives the paper a particularly topical theme, and I expect this will be seminal paper used to steer the direction of research in the field of salt tectonics in the years to come. The manuscript will be of great interest to those working in the energy industry and especially to those hoping to redirect their research toward accelerating the energy transition.

A1.1.2) What does the submission need to be publishable? (select as needed; comment for all cases)

- ☐ **No changes required**
- ☐ **Rewriting**
- ☐ **Reorganising**
- ☐ **More data/figures**
- ☐ **Condensing**
- ☐ **Reinterpretation**
- ☒ **Other**

Comments:

The manuscript is well organised and well written with excellent supporting figures to illustrate important concepts. No major changes are needed to make the manuscript publishable, though some minor to moderate improvements should be addressed to ensure the high quality of the publication (see sections A2 and B).

A1.1.3) Can the submission be improved by reducing/adding any of the following? (select as needed; comment for all cases)

- ☐ **Text**
- ☐ **Table**
- ☐ **Figures**
- ☐ **Supplementary material**

Comments:

I believe that the length of text and number of tables/figures is well balanced and appropriate for the content presented.

A1.1.4) Please complete the following section if you recommend that the submission is NOT appropriate for publication (select as needed; comment if a box is selected)

- ☐ **Quality is poor**
- ☐ **Research is not reproducible**
- ☐ **Other**

Comments:

[Free form box]

A1.2) Author(s) Responses:

A2) Summary of main merits and main points of improvement

A2.1) Reviewer's comments

Please describe below in a few sentences (100 to 300 words) the main merits of the submission and suggestions for improvements.

The main merits I have found are...

The principal strength of the paper is the clarity and brevity with which the authors communicate the value of salt tectonics research in a rapidly changing landscape, and define specific research questions that will drive further progression in the 3 highlighted energy transition applications. The manuscript is structured logically, guiding the reader from basic concepts in salt tectonics to the relevant challenges and opportunities within each application, as well as giving a succinct research outlook. This overview covers significant ground and though it does not explore any single aspect of research in huge depth, it provides a valuable cross-disciplinary perspective on the future direction of salt tectonics research.

The main points of improvement I have found are...

My only general recommendation for improvement is to add supporting citations where they are lacking. There are some points discussed in the text that derive from previous work but are stated with insufficient supporting references, and may therefore be read as if they are described for the

first time in this manuscript. For example, L508-517 describes downdip injection strategy and importance of pressure dissipation – only one (very recent) reference is cited in this paragraph yet many previous authors have discussed this (e.g. Bergmo et al., 2009; Williams et al., 2013; Sundal et al., 2015; Ringrose et al., 2020, 2021). Similarly for L522-527 on the risk of CO2 leakage via borehole penetrations in depleted hydrocarbon fields (no refs), for L741-748 on residual trapping over long distances (1 ref), and for L775-784 on technological advances in geothermal exploitation (1 ref). Some technical details related to salt tectonics concepts are also stated without supporting references, e.g. L621-627 concerning differences between reservoir distribution in shallow vs deepwater settings. Such statements may be considered common knowledge by the authors but it is important for readers, in particular those new to the field, to be directed towards relevant supporting literature. This also ensures the high scientific quality of the manuscript is maintained throughout.

Additionally, some assertions made by the authors are speculative and/or subjective, reflecting the opinions of the authors. There is no problem with the authors speculating or expressing their opinions on these topics, indeed it is a strength of the paper, but such statements should use language that clearly distinguishes this from the objective factual content. Some examples include: 'CCS is the multi-tool of climate change mitigation – flexible, available immediately, proven and permanent.' (L476); 'injected CO2 is unlikely to migrate far' (L499); 'it may not be necessary to know the precise migration path' (L647); 'CCS is likely to simply avoid such geology' (L729); 'the era of CO2 storage is only just beginning' (L751).

A2.2) Author's responses:

[Free form box]

Section B: Detailed evaluation of manuscript

B1) Title and abstract

B1.1) Reviewer's comments

These statements are a guide to what good* Titles *and* Abstracts include*. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.

The *Title* describes the main topic of the manuscript accurately — YES

The *Title* describes the main topic of the manuscript succinctly — YES

The *Title* includes appropriate key terms — YES

The *Abstract* includes a clear aim and rationale — YES

The *Abstract* supports the rationale with sufficient background information — YES

The *Abstract* includes a well-balanced description of the methods — N/A

The *Abstract* describes the main results sufficiently and adequately — N/A

The *Abstract* clearly describes the importance/impact of the study — YES

The *Abstract* clearly states the conclusions of the study — YES

The *Abstract* is clear and well structured — YES

Comments:

The abstract clearly and concisely sets up the premise of the manuscript and summarises the main points.

B1.2) Author's responses

[Free form box]

B2) Introduction

B2.1) Reviewer's comments

These statements are a guide to what good* Introductions *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.

The *Introduction* provides sufficient background and context for the study — YES

The *Introduction* describes the aim/hypothesis/rationale clearly, providing sufficient context — YES

The *objective/hypothesis/rationale* flows logically from the background information — YES

The *Introduction* describes the study's objective and approach (last paragraph) — YES

The *Introduction* contains relevant, suitable citations — YES

The *Introduction* is organized effectively — YES

Comments:

The introduction is brief but sufficient, giving just enough context to the history of salt tectonics research and current drive towards the energy transition. Its concise nature helps keep the flow of text focussed and streamlined.

B2.2) Author's responses

[Free form box]

B3) Data and methods

B3.1) Reviewer's comments

These statements are a guide to what good* Method *sections include and good practices for* Dataset *accessibility. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.

The *Methods* are described concisely and with enough detail for reproducibility — N/A

Necessary information about data sources/acquisition/processing is included — N/A

Data used are accessible via either supplementary files or links in the data availability statement — N/A

The *Dataset and/or Methods* are organized effectively — N/A

Comments:

N/A – this is a review paper, thus no new data or methods are presented.

B3.2) Author's responses

[Free form box]

B4) Results

B4.1) Reviewer's comments

These statements are a guide to what good* Result sections *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.

The *Results* findings are supported by data — N/A

The *Results* findings are presented clearly and succinctly — N/A

The text in the *Result* section cites tables and figures appropriately — N/A

The *Results* directly relate to the study objectives — N/A

The *Results* present data for all the approaches described in the *Methods* section — N/A

The *Results* text belongs to the Results section, not to *Introduction*, *Methods*, or *Discussion.* — N/A

The *Results* section is organised effectively — N/A

Comments:

This is a review paper, thus no new results are presented.

B4.2) Author's responses

[Free form box]

B5) Discussion and conclusions

B5.1) Reviewer's comments

These statements are a guide to what good* Discussions *and* Conclusions *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.

The *Discussion* is focused on the objectives of the study — YES

The *Discussion* addresses all major results of this study, which are shown in *Results* — N/A

The *Discussion* section makes comparisons with other studies that are relevant and informative — YES

The *Discussion* section properly identifies all speculative statements — YES

The *Discussion* section presents the implications of the study persuasively — YES

The *Discussion* section highlights novel contributions appropriately — N/A

The *Discussion* section addresses the limitations of the study appropriately — N/A

The *Discussion* section is organised effectively — YES

The *Conclusions* are consistent with and summarise the rest of the manuscript — YES

The *Conclusions* are supported by the data in *Results* and follow logically from the *Discussion* — YES

The *Conclusions* are clear and concise — YES

Comments:

There is no section titled Discussion as this is a review paper but I have instead listed here my specific comments pertaining to the main body of the manuscript (chapters 2-4).

1) Depositional vs. non-depositional heterogeneities:
In section 2.2.2 on salt cavern formation, the authors define two types of heterogeneities in salt diapirs: depositional and non-depositional. This is a useful way to think about the origins of these heterogeneities, but also left me with a few questions. Firstly, is it always possible to distinguish between depositional and non-depositional heterogeneities in reality? And how important is it to do so? For example, it may not always be possible to conclude definitively whether clastic material identified within a diapir is derived from interbedded intra-salt layers or entrained country rock during deformation. Also, 'coarse-grained' textures are classified as non-depositional heterogeneities (L401) – but some salt units are depositionally coarse, and can't non-depositional fine-grained textures be created during deformation? Finally, the authors classify 'fluids and gases trapped *during salt deposition*' (L398) as a *non-depositional* heterogeneity – which seems counter-intuitive.

2) CO2 storage in salt basins:
This is a nice overview of the key considerations associated with CO2 storage in salt basins, I only note here a few points on which the authors may wish to elaborate. Firstly, the authors

note pressure dissipation and avoidance of pressure build up several times as a key factor in both storage site selection and injection strategy, and allude to trap failure due to overpressure, but never explicitly discuss the potential for fault reactivation or fracture dilation/propagation/nucleation. The long-term stability of faults/fractures in areas of mobile salt may also be considered a key research question in this context. Secondly, when reasoning why salt caverns are unsuitable for long-term CO2 sequestration, it would also be pertinent to note the lack of opportunity for dissolution and eventual mineral trapping, i.e. the mechanisms that eventually make the storage permanent in porous media. In fact, there is no mention of mineral trapping anywhere in the main body of the text as far as I can see, only in the caption for figure 11. Finally, in the discussion of halokinetic sequences and associated traps where CO2-rich fluids are directly in contact with the salt, the authors may also wish to consider whether dissolution or other physical/chemical reactions may compromise the long-term stability of the trap.

B5.2) Author's responses

[Free form box]

B6) Figures, tables and citations

B6.1) Reviewer's comments

These statements are a guide to what good* Figures *and* Tables *include and how they are presented. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.

***Tables* and *Figures* are ordered logically and numbered sequentially — YES**

***Tables* and *Figures* have captions that explain all their major features — YES**

***Tables* and *Figures* have captions that complement the information in the main text — YES**

***Tables* and *Figures* present data that relate to the study objective — YES**

***Tables* and *Figures* present data that are consistent with and support the description of results — YES**

***Tables* and *Figures* have succinct and informative titles — YES**

***Figures* are accessible (elements are clearly labelled, accessible colour palettes, colour contrasts, font size legible, etc.…) — YES**

Please, check our [Figure guidelines]

Figures **with maps or cross-sections contain all elements to be understood (north arrow orientation, scale, visible coordinates, sufficient coordinate grid intercepts) — YES**

Figures **with maps have sufficient location information (in the map or caption) — YES**

Cross-sections **have clear labels for scale and coordinates at ends and within-section kinks — YES**

All georeferenced elements are provided in common format (.shp, .geotiff, .kml) [in an open-access repository] — Not sure

Citations **throughout are relevant, suitable, and comprehensive — Could be more comprehensive in some places**

Comments:

Figures are very clear and informative.

B6.2) Author's responses

[Free form box]

Section C: Additional comments

C1) Minor/line-numbered comments

C1.1) Reviewer's comments

L169 – '(monthly ? seasonal ?)' – seems to be a note-to-self for authors to double check the frequency

L364-L366 – it would be good to cite some cases where fluid leakage at or near non-depositional heterogeneities has been observed and specify for what types of heterogeneities this is a risk

L375 – for the uninitiated reader it would be good to briefly describe the properties of shear zones in salt bodies, i.e. how they are recognised and distinguished from the typical salt mass

L389-390 – 'salt spines that move independently in an upward piston-like manner' – I think this requires some elaboration

L415 - One of the key research questions for salt caverns is 'how and where do inclusions become incorporated into salt diapirs' but there is little said about this subject in the prior text

L497 – 'The counterpoints are that…' – it is not clear to me how the following statements are counterpoints to the previous sentence (that pressure buildup is the ultimate limit on injection rates).

L501-502 – isn't pore throat trapping a type of capillary trapping? Why specify separately?

L555 – typo, 'fulling' should be 'filling'

L665 – typo, may *be* developed?

L810-813 – this sentence doesn't quite work, add punctuation or rephrase

C1.2) Author's responses

[Free form box]

C2) Other remarks

C2.1) Reviewer's comments

C2.2) Author's responses

[Free form box]

_____

Author's response to review comments

Dear Dr Zwaan,

Below is our reply to the comments of editor and reviewers for our manuscript ('The Role of Salt Tectonics in the Energy Transition: An Overview and Future Challenges') submitted to Tektonika.

Key points to note:

1) Naiara Fernandez has been added as a co-author to this manuscript (please ensure this is in the metadata of final publication if accepted).
2) If this manuscript is accepted and passes into the copyediting stage the graphics files for the figures are available for the copyeditor to download at: (*link removed*).

I will be away on paternity leave soon after this resubmission so it would be great if those can be accessed from that link to ensure progress is not halted.

Response to Editor Comments

Intro (line 46): a basic point --> what is the definition of salt here? It may be good to define this at the start of the text.

Definition of salt added 'the term *'salt'* refers to rocks composed mainly of evaporite minerals, especially halite'.

End of intro (Line 86-89): perhaps clearly number the 3 main topics to make them stand out, to prepare the reader for the 3 main sections of the paper.

Numbered as suggested.

Line 199: a "C" is missing (should be ˚C)

Added as requested.

Line 239: perhaps specify that this salt flow is on short (human) time-scales?

Added text ‘(which occur on human timescales)’ as suggested.

Line 245: use “modelling” instead of “to model”?

Changed as requested.

Line 330: only shortening? Or also extension (or other types of deformation)?

This bullet has been removed as it is covered by the previous bullet.

Line 364: perhaps explain what “salt quality” means (“salt impermeability” might be better?)

(e.g. increased permeability) added.

Line 373-374: please check grammar, seems a bit off here.

Sentence has been split and rephrased to clarify.

Line 389: lots of “that”, consider rephrasing

Removed one use of ‘that’ so it is less repetitive.

Line 446: perhaps use “economy” instead of “ecosystem”

Changed as requested.

Line 467-469: this sentence is not 100% clear to me

Comma added, otherwise, this seems to make sense.

Line 576: suggestion to use “salt-bearing basins” instead of "salt basins"

Changed as requested and applied throughout.

Line 605: consider having a new paragraph starting here, same for line 619

Changed as requested.

Line 664-666: consider removing, as the focus of the paper is on salt, not carbonates. This last sentence therefore seems out of place.

We have left this text in – it is referring to carbonate reservoirs developed above salt diapirs, and is thus relevant.

Line 671: not clear what “this salt related structure” is

Clarified

Line 733: start with “an ultimate goal”?

Changed as requested

Line 760: by using “intra-continental settings”, it seems like the whole world is basically covered. Perhaps use “intra-continental rift basins” or so

Changed as requested

Line 771: “geothermal resources” would be clearer

Changed as requested

Line 949: there is no Fig. 22?

Changed to cite correct figure

Figure 2: what does CCUS stand for? Please specify in the caption.

Changed in figure - ‘carbon capture, utilization and storage’

Figure 4b: perhaps add in the caption that this is offshore Brazil

Added to caption

Figure 9: please specify in the caption where this is (I assume in the US)?

Louisiana, USA – Added to caption.

Figure 16 and 17: the colour scale goes from blue to red, where white seems to suggest the null-point. But the temperatures represent a continuous range. It may be better to use a colour scale that goes from light to dark blue (or light to dark red). This will also help colour-blind readers and make things clearer when printed in black and white. This may also be a consideration for the other figures. Please check the figure guidelines for more info: https://tektonika.online/index.php/home/figure_guidelines

Figure 16 and 17 changed to suitable color bars. The color bars now run from dark red (hottest) to white, coolest. There is now no null point which we agree did not help matters.

Table 1: third column: should be post-depositional

Changed as requested

Note: please check for UK/US English, it seems not always consistent (e.g. color/colour)

Changed as requested

Practical concerns:

Figures: some figures are split in different parts (e.g. 3a, 3b). Please organize these in one figure, or split figures and renumber them accordingly. There is also a Fig. 4 and a Fig. 4b, but no Fig. 4a. Please double-check.

Figure numbers modified accordingly.

Figures: A large number of the figures are derived from previous publications. Please make sure that you have secured the right to reproduce these figures (See also Tektonika figure guidelines: https://tektonika.online/index.php/home/figure_guidelines). Failure to do so may cause issues down the line (e.g. the paper may have to be withdrawn due to copyright infringement).

Copyright licences and key info can be downloaded here:
https://utexas.box.com/s/drgbgceszty19eqtxk8y1ogesgmn1o7u

Fig 1: Copyright from Cambridge University Press requires us to add: 'Reproduced with permission of Cambridge University Press through PLSclear' to the caption – we have done this.

Fig 2: We have sent 3 emails sent to NPC council with no response. Given this lack of response, the fact that we cite the publication and data source, and the fact this is a rather general graph I do not see any issue with reproducing this.

Fig 3. Copyright fees paid to Springer eBook – see license. 'Reproduced with permission from Springer Nature' added to caption.

Fig 4: we have email from Solution Mining Research Institute stating we are fine to use this figure with simple citation and reference

Fig 5: We will cite and reference accordingly. Two emails sent with no response to mail@schweizerbart.de. This figure has been shown and reproduced by other authors without issue so that, coupled with the lack of response seems reason for publishing.

Fig 6: Available to reuse under Creative Commons CC BY-NC-ND 4.0

Fig. 7: we have email from Solution Mining Research Institute stating we are fine to use this figure with simple citation and reference

Fig 8: Original work is by Richter-Bernburg, G. (1972). *Geology of Saline Deposits: Géologie Des Dépôts Salins*: Unesco. This document is unavailable online so there is no-one obvious to contact. Figure has been reused and published by others so again, see no issue in using this with a simple citation and reference.

Fig 9: Some elements of this figure are published in SMRI and therefore can be used with a simple citation and reference. The part from Ratigan, 2009 (Ratigan, J. (2009). Liquefied Gas Storage in Salt Caverns at Mont Belvieu, Texas, USA. 9th World Salt Symposium, Bejing, China, 9p) is from a somewhat obscure conference proceedings. I

have emailed info@chinascientificbooks.com three times with no response and so again, I see no issue using this with a simple citation and reference, especially as it is reproduced in Solution Mining Research Institute literature.

Fig 10: Available to reuse under Creative Commons CC BY 4.0

Fig 11: Available to reuse under Creative Commons CC BY 4.0

Fig 13: approval email states: ‘We request that usage include a statement as part of the figure citation to the effect of something like "... (citation, reproduced with permission of the Gulf Coast Association of Geological Societies)" or a similar statement in the Acknowledgments--". We have added this in caption: ‘Reproduced with permission of the Gulf Coast Association of Geological Societies.’

Fig: 14: Available to reuse under Creative Commons (CC BY-NC-ND 4.0)

Fig 15: Gained approval through Copyright Clearance Center: simply requires us to state: ‘Reprinted (adapted with colours modified) with permission from (Bourg et al. 2015). Copyright 2015 American Chemical Society’. We have done this.

Fig 19: Copyright fees paid to Springer Nature - see license. ‘Reproduced with permission from Springer Nature’ added to caption.

Fig. 20: Available to reuse under Creative Commons (CC BY-NC-ND 4.0)

Fig 21: approval email states: ‘We request that usage include a statement as part of the figure citation to the effect of something like "... (citation, reproduced with permission of the Gulf Coast Association of Geological Societies)" or a similar statement in the Acknowledgments--". We have added this in caption: ‘Reproduced with permission of the Gulf Coast Association of Geological Societies.’

Response to Reviewer 1 – Dr Leonardo Pichel

Comments from PDF:

Line 60 - I would be interested to read about/see a few examples of locations of underground salt caverns used for storage

We do not want to disrupt the flow in the introduction with examples (in our view a citation is sufficient here to direct reader to key literature). We do already discuss perhaps the most famous example of the US Strategic Petroleum Reserve (lines 127-132).

Line 110 – we now explicitly state that some solution mining is done to recover salt.

Line 210 – Reviewer asks if the ‘colour’ of salt is important when identifying intra-salt heterogeneities.

The colour may be useful as a first pass indicator of chemical composition or impurity content, or salt of different ages etc and a property that has been recorded by salt mine geologists that can be useful in some circumstances.

Line 243 - we use the term anomalous salt a few paragraphs after saying we would not.

Good spot, we have simplified the sentence and removed this issue.

Line 404 - clarify ‘stems vs overhangs’ for non-expert readers

We have changed this as requested by reviewer to ‘sub-vertical stems versus sub-horizontal overhangs’.

Line 417 - To be honest, I am a bit confused of what that means? Does it refer to intra-salt diapirs of more mobile salt surrounded by non-mobile salt and/or shear-zones? Maybe this could be explained up-ahead in this section?

This issue was raised by both reviewers. We have modified the text earlier (lines 392-394) to simplify. In general, it should be noted that the concept of salt spines are poorly defined in the literature and is not widely used outside of the salt mining and solution mining communities. We have used and modified the description summarized in Hudec and Jackson 2017.

Line 636 – reviewer suggests adding in a wider variety of references

We agree with the reviewer comment and have added in extra references (Rowan et al., 2006; Callot et al., 2016; Pichel et al, 2018).

Line 648 – could we schematically show how contamination of aquifers and producing hydrocarbon fields is avoided in fig 16

We feel the point in the text suffices and would be too much detail/annotation on the figure.

Line 727 - I think another requirement is ‘additional and more advance modelling (numerical and physical) that can help predict the often poorly imaged near- and/or sub-salt geomeries’

We have modified the text in line 735 to add that numerical modelling will be required. We feel the point the reviewer makes is addressed in the text.

Line 739 - I think it would be important to add what we need to do to develop this updated models, something along the lines of:"*And this will require an inter-disciplinary approach and integration of seismic, field-, well-data, modelling, etc.*

We agree and have added the following text – line 747: ‘This will require an interdisciplinary approach and integration of seismic, field data, well data, and insights from modelling approaches.’

Line 753 – add ‘salt properties and dynamics’

Added as requested.

Figure – reviewer asks if this is US only or global (if not, add in a global graph)

The graph is global – see caption. No change required. Plus minor figure edits where required (e.g. splitting figure 4 into part a and b)

Fig 18/22 ‘I wonder if these bullet-points nicely illustrated here should be also briefly summarized in the conclusions?

We do not deem this necessary as we would like to keep the conclusions concise.

The examples are very US-EU-centric (e.g., Gulf of Mexico and Zechstein salt basins). This is understandable given the greater availability of infrastructure, data, and perhaps economic potential in these areas, but I was left wondering about the potential in other parts of the world (e.g., the Middle East, East Asia, South America, Africa, etc.).

We agree. This is simply a result of where key examples are located, where the infrastructure is best developed, and where emissions are highest (in the case of CO2

storage). We draw examples from offshore Brazil, Oman and Kazakhstan (particularly when discussing layered evaporites), as well as cite literature from a diverse range of salt basins. Thus, in our opinion we feel many of the concepts are equally applicable to other salt basins around the world.

What about mining? I see that the authors refer already, albeit briefly to Lithium mining, but I was curious about other mining applications worldwide. I think that, if possible, having an additional, brief sub-section about this would be a significant improvement to this already excellent paper. I understand this may be beyond the scope and, thus, I leave it to the authors' and editor's discretion.

This is an interesting point, as some critical minerals/metals can be associated with salt domes. However, as an authorship team we have no experience on this topic. Thus we feel it is beyond the scope of this manuscript. We end the article with a paragraph that aims to encourage those with other perspectives to contribute.

Response to Reviewer 2 – Dr Sian Evans

L169 – '(monthly ? seasonal ?)' – seems to be a note-to-self for authors to double check the frequency

Removed from text.

L364-L366 – it would be good to cite some cases where fluid leakage at or near non-depositional heterogeneities has been observed and specify for what types of heterogeneities this is a risk

We reference Warren et al 2016 and 2017 and feel this suffices. – he documents x…. A look over that work will show the depth of work that has been conducted and which is difficult to summarise in a way that fits neatly into our manuscript here.

L375 – for the uninitiated reader it would be good to briefly describe the properties of shear zones in salt bodies, i.e. how they are recognised and distinguished from the typical salt mass

This is a contentious issue in the literature and we comment on this (lines 383-388) – the evidence of shearing is elusive. This is lengthy and complicated topic that we do not deem it viable to go into in this paper. The citation of Warren et al. 2017 and the work of Donald Kupfer will direct readers to this issue.

L389-390 – ‘salt spines that move independently in an upward piston-like manner’ – I think this requires some elaboration

This issue was raised by both reviewers. We have modified the text earlier (lines 392-394) to simplify. In general, it should be noted that the concept of salt spines are poorly defined in the literature and is not widely used outside of the salt mining and solution mining communities. We have used and modified the description summarized in Hudec and Jackson 2017

L415 - One of the key research questions for salt caverns is ‘how and where do inclusions become incorporated into salt diapirs’ but there is little said about this subject in the prior text

Lines 394-401 touches on this and cites the key literature. Given the breadth of topics raised and the need to remain concise we cannot expand deeply on each point and so we do not deem extra explanation necessary.

L497 – ‘The counterpoints are that…’ – it is not clear to me how the following statements are counterpoints to the previous sentence (that pressure buildup is the ultimate limit on injection rates).

Paragraph has been clarified as requested mainly with the addition of this text:’ Other contrasts between CO_2 storage and petroleum systems are…’.

L501-502 – isn’t pore throat trapping a type of capillary trapping? Why specify separately?

Yes, we have changed text accordingly to ‘Dissolution, capillary trapping, mineral trapping…’.

L555 – typo, ‘fulling’ should be ‘filling’

Typo corrected.

L665 – typo, may *be* developed?

Typo corrected.

L810-813 – this sentence doesn't quite work, add punctuation or rephrase

Sentence shortened.

My only general recommendation for improvement is to add supporting citations where they are lacking. There are some points discussed in the text that derive from previous work but are stated with insufficient supporting references, and may therefore be read as if they are described for the first time in this manuscript. For example, L508-517 describes downdip injection strategy and importance of pressure dissipation – only one (very recent) reference is cited in this paragraph yet many previous authors have discussed this (e.g. Bergmo et al., 2009; Williams et al., 2013; Sundal et al., 2015; Ringrose et al., 2020, 2021). Similarly for L522-527 on the risk of CO2 leakage via borehole penetrations in depleted hydrocarbon fields (no refs), for L741-748 on residual trapping over long distances (1 ref), and for L775-784 on technological advances in geothermal exploitation (1 ref). Some technical details related to salt tectonics concepts are also stated without supporting references, e.g. L621-627 concerning differences between reservoir distribution in shallow vs deepwater settings. Such statements may be considered common knowledge by the authors but it is important for readers, in particular those new to the field, to be directed towards relevant supporting literature. This also ensures the high scientific quality of the manuscript is maintained throughout.

We agree with the reviewer and have cited a number of extra references.

Additionally, some assertions made by the authors are speculative and/or subjective, reflecting the opinions of the authors. There is no problem with the authors speculating or expressing their opinions on these topics, indeed it is a strength of the paper, but such statements should use language that clearly distinguishes this from the objective factual content. Some examples include: 'CCS is the multi-tool of climate change mitigation – flexible, available immediately, proven and permanent.' (L476); 'injected CO2 is unlikely to migrate far' (L499); 'it may not be necessary to know the precise migration path' (L647); 'CCS is likely to simply avoid such geology' (L729); 'the era of CO2 storage is only just beginning' (L751).

We have modified the text in these cases and added 'in our view'/'would seem' (or equivalent phrases) to make it clear this is subjective/speculative.

Depositional vs. non-depositional heterogeneities: In section 2.2.2 on salt cavern formation, the authors define two types of heterogeneities in salt diapirs: depositional and non-depositional. This is a useful way to think about the origins of these heterogeneities, but also left me with a few questions. Firstly, is it always possible to distinguish between depositional and non-depositional heterogeneities in reality? This is true, it is not always going to be possible to distinguish depositional and non-depositional heterogeneities – this will depend on data type and availability in a given location. And how important is it to do so? If we want to get to a point where we can predict the likely distribution of heterogeneities, we first need to classify them and then systematically work through developing understanding of salt tectonic processes that may influence the distribution of each of them in the salt body. For example, it may not always be possible to conclude definitively whether clastic material identified within a diapir is derived from interbedded intra-salt layers or entrained country rock during deformation. This is true, but the key point here is that research will explore if interbedded intra-salt layers experience different processes and deformation styles than entrained country rocks or tend to end up in different locations within the diapir. Therefore we may be able to determine what the likely hazards may be in different parts of the diapir. Also, 'coarse-grained' textures are classified as non-depositional heterogeneities (L401) – but some salt units are depositionally coarse, and can't non-depositional fine-grained textures be created during deformation? True. We have simplified the classification scheme and have removed reference to coarse/fine textures as this was an unnecessary complication. Finally, the authors classify 'fluids and gases trapped *during salt deposition*' (L398) as a *non-depositional* heterogeneity – which seems counter-intuitive. We agree and have removed the reference to 'during salt deposition' in the text. We have also modified the Table 1 and added 'fluids and gases trapped during deposition' to the depositional heterogeneities column.

CO2 storage in salt basins: This is a nice overview of the key considerations associated with CO2 storage in salt basins, I only note here a few points on which the authors may wish to elaborate. Firstly, the authors note pressure dissipation and avoidance of pressure build up several times as a key factor in both storage site selection and injection strategy, and allude to trap failure due to overpressure, but never explicitly discuss the potential for fault reactivation or fracture dilation/propagation/nucleation. The long-term stability of faults/fractures in areas of mobile salt may also be considered a key research question in this context. These points are now mentioned or emphasized in lines 720-736. Secondly, when reasoning why salt caverns are unsuitable for long-term CO2 sequestration, it would also be pertinent to note the lack of opportunity for dissolution and eventual mineral trapping, i.e. the mechanisms that eventually make the storage permanent in porous media. In fact, there is no mention of mineral trapping anywhere in the main body of the text as far as I can see, only in the caption for figure

11. We have added this point (line 568) and mentioned mineral trapping (line 507). Finally, in the discussion of halokinetic sequences and associated traps where CO2-rich fluids are directly in contact with the salt, the authors may also wish to consider whether dissolution or other physical/chemical reactions may compromise the long-term stability of the trap. Nice point. We have added this to the list of research questions (lines 736-737).

We look forward to hearing from you in due course,

Kind regards,

Oliver Duffy (on behalf of all co-authors)

Final editor's response

Dear Oliver et al.,

Good news: We have accepted your manuscript for publication! The revised manuscript will make a very nice contribution to the Tektonika paper collection, congratulations. It was a pleasure to edit your submission, and we are looking forward to seeing the final version online.

Kind regards,

Frank Zwaan (handling editor) and Tony Doré (executive editor)

Oliver Duffy, Michael Hudec, Frank Peel, Gillian Apps, Alex Bump, Lorena Moscardelli, Tim Dooley, Shuvajit Bhattacharya, Kenneth Wisian, Mark Shuster:

We have reached a decision regarding your submission to тєкτоніка, "The Role of Salt Tectonics in the Energy Transition: An Overview and Future Challenges: Salt Tectonics and the Energy Transition".

Our decision is to: Accept Submission