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**Review and assessment of the dissertation of Mr. Sadegh Adineh,
entitled**

**"Structural, petrological, and geochronological analysis of salt diapirs and their caprocks:
Implications for growth dynamics of salt diapirs in Iran"**

I am writing my opinion on Mr. Adineh's dissertation from the point of view of an external reviewer in the field of active tectonics. I am a structural geologist, geochronologist and tectonic geomorphologist. My research expertise lies in linking problems in active tectonics, tectonic geodesy, earthquake studies, sedimentology, and stratigraphy to quantify the variability of deformation, erosion and sedimentation rate of the lithosphere on scales of years to millions of years. I have worked in various mountain and rift regions of the world (North America, Ireland, Germany, Spain, and southern Iran), but so far not in the Iranian Zagros Mountains, apart from an exploratory field trip. Nevertheless, I am familiar with the general structural geologic and petrologic framework of the study area and with the research methods of the present work. I have not contributed to joint publications with the doctoral candidate, although I collaborate remotely with his supervisor. Therefore, I do not consider myself biased in the sense of the DFG guidelines.

In my review, I assess the scientific advancements made in the dissertation and compare them internationally. I evaluate the independent research performance, the originality and quality of the work concerning the problem definition, the methodological approach, and its relevance to addressing current research questions or generating new findings. Additionally, I provide feedback on the specific professional, formal, and linguistic aspects of the dissertation, as outlined in the report guidelines to which I have agreed.

Mr. Adineh's dissertation topic and his research discovery regarding the composition and origin of salt diapir caprocks in the Zagros Mountains are pioneering in his field. He conducted extensive fieldwork and laboratory studies on contemporary research issues in modern field geology, structural geology, petrology, and geochemistry, utilizing numerous samples collected from the salt diapirs, which are notoriously challenging to access. Particularly remarkable is the fieldwork conducted by Sadegh Adineh under extremely difficult conditions, much of which took place during the COVID-19 pandemic, when other members of the research group were unable to enter Iran. Consequently, Mr. Adineh organized his own expedition to the salt diapirs and successfully retrieved significant rock samples, many of which he analyzed independently or in collaboration with his advisors in Prague and Munich.

A significant discovery from Mr. Adineh's research is the realization that the caprocks, previously believed to primarily consist of young reaction products, actually contain substantial amounts of exotic blocks originating from older, deeper layers. Dolomitization, a process involving the conversion of carbonate rocks to dolostones, plays a crucial role in this context. However, distinguishing the origin of these dolostones through optical inspection alone has been challenging, leading scientists to overlook the fact that a considerable portion of the dolostone formed long before the diapirs' formation. Mr. Adineh's keen observations during field mapping revealed sedimentary microstructures within these dolostones resembling stromatolites, along with their association with fine-grained clastic rocks containing large clasts of various rock types. He recognized that such rock formations require specific conditions, akin to glaciers depositing dropstones into fine marine muds. These diamictites, overlain by cap carbonates, are characteristic of several distinct periods in Earth's history. Through the examination of sedimentary microstructures, isotopic, and geochemical analyses, Mr. Adineh determined that these glacial deposits and the overlying cap carbonates likely date back to the late Ediacaran period. This groundbreaking discovery sheds light on the remarkable preservation of Earth's rock record, with gentle structures and rock associations dating back over 600 million years, buried beneath several kilometers of sediment, compacted, and lithified over time. Eventually, as regional tectonic forces compressed the strata and overburden grew sufficiently large, less dense salt rose to the surface, preserved amidst the caprocks, which serve as the reaction residue capturing all materials flushed to the surface through diapirism.

It is likely that this sensational finding will trigger a rush towards mapping of the diapirs' caprocks to find more of these exotic blocks. Analysis of such rocks will result in a better understanding of the tectonic and environmental settings since the latest Proterozoic time, which is not otherwise possible in the region of the Zagros Mountains. The findings also allow the comparison to those previously known in other regions, which increases the significance of Mr. Adineh's work even more.

Originality

Mr. Adineh's dissertation exemplifies modern interdisciplinary research at the intersection of fields that have not traditionally been combined: contemporary structural geology, petrology, geochemistry, and field mapping. His dissertation impressively documents his success in significant methodological advancements at this interface, establishing his work as pioneering in integrating these approaches synergistically and inseparably, resulting in a novel approach. It serves as a prime example of modern geological analysis in uncovering unexpected rock bodies—a crucial step in understanding the complex dynamic behavior within caprocks.

The study region of caprocks in the SE Zagros Mountains of Iran is exceptionally conducive to the application and advancement of new geological methods. This suitability arises from the region's arid climate, which minimizes soil and vegetation cover, and its sparse population. Consequently, the salt diapirs exposed at the surface are shielded by their insoluble caprocks, which persist for extended periods, facilitating comprehensive study using a combination of remote satellite imaging, fieldwork, and laboratory analyses. This favorable initial data situation contrasts with many other regions worldwide, where significant overburden impedes direct caprock study. The unique value of this research lies in the strategic combination of abundant data availability, appropriate methodology, and pertinent research questions within a region that is both accessible and tectonically active. However, accessibility was somewhat constrained due to the main field seasons coinciding with the COVID-19 pandemic and the challenging terrain of some caprock areas, which proved excessively rugged and inaccessible.

The methodological and professional development is documented by...

1. *field mapping and collection of rock samples for quantitative analysis using an array of methods, such as petrological characterization of rocks, major and minor geochemical element analysis, stable and radiogenic isotopic analysis, carbon and oxygen clumped isotope analysis, thin section characterization, construction of maps and profiles, and the integrative interpretation of all data.*

This dissertation demonstrates the successful integration of various datasets to enhance the structural and petrological analysis, leading to a deeper understanding of caprock composition and formation. Traditionally, information on caprock composition relies heavily on drill cores from petroleum wells and limited field inspections. Mr. Adineh's integrated study significantly advances our understanding of the complexity of caprock compositions. Moreover, the application of these integrated methods enables us to gain insight into recent processes and uncover a significant record of Earth's history preserved within the studied rock samples. This work is both clever and inspiring.

2. *a systematic structural, stratigraphic, and sedimentological analysis of the halokinetic series surrounding the salt diapirs. The halokinetic series is a collective term for the erosional products that were redeposited in the surrounding of rising diapirs, and these deposits document the ascent history of salt diapirs.*

This paradigmatic contribution demonstrates the application of previously developed methods, such as lithostratigraphy, field mapping, profile construction, geological remote sensing using satellite imagery, digital terrain analysis, and measurement of bedding plane orientations, to an exceptionally suitable problem. Through a clever combination of these methods applied to the Paskhand salt diapir, Sadeq Adineh successfully determined the activity history of this diapir. This methodology holds great potential for widespread application and could soon provide valuable insights into the activity history of salt diapirs over timescales ranging from tens of thousands to millions of years, which are not accessible by any other method.

3. *a study of hydrothermal processes through petrographic analysis, scanning electron microscopy, isotope geochemistry, and Carbon & oxygen clumped isotope analysis.*

Adineh et al. (in preparation) have introduced a systematic new approach to classify the diverse types of dolomite found in the Paskhand caprock exotics. Extensive studies of these dolomites under various microscopes have unveiled their detailed composition, texture, and various types of cements. Building on this analysis, they have developed a conceptual model for the formation of hydrothermal dolomite. This model is testable and has the potential to be applied by collecting similar data from a variety of present-day and ancient examples worldwide.

4. *a preliminary geochronological study of the carbonate caprock using radiometric Uranium-Lead-dating based on Laser ablation-ICP-MS analysis on calcite textures.*

This innovative method holds significant promise, and Mr. Adineh has tested it by dating 20 samples of calcite and dolomite from the Paskhand caprock carbonate blocks. While the preliminary results present challenges in interpretation, the method shows great potential due to the abundance of calcite and dolomite crystals and cement. Furthermore, if the preliminary ages are confirmed, this work could potentially lead to a revision of the pre-diapir evolution of the Zagros region.

Relevance for solving current research questions

The methodological progress and results documented in all chapters are also important for international experts. In particular, the integration of the methods shown here can lead to a much better assessment of problems in the area of dynamics of the salt diapir-caprock system. For example, this integrated multiple-technique approach can be used to determine the mineral chemistry and petrology of an unlimited number of rocks, from which the formative reactions may be deduced. This advocates for the significance of field-based research. Modelling alone is insufficient. These new results are also relevant for the exploration and exploitation of mineral resources because a better understanding of the processes concentrating minerals in the diapir's ascent and their reaction with the surface waters allows more accurate modeling of the reactive fluid systems of the subsurface.

In the future, these integrated approaches can also be applied to the rest of the diapirs in the Zagros Mountains and those with accessible caprocks in other regions. The caprocks exposed there show the same characteristic composition of caprocks elsewhere, but the study of exotic blocks that may have been carried up by those will yield the own unique geological history of the respective regions. In many parts of the world, however, these rock packages are hidden from direct observation underground, so

that the development and testing of geological caprock dynamic models can be carried out much better in well-exposed, arid regions. The application of the analysis of the origin and evolution of exotic blocks over the entire Zagros Mountains could represent a methodological core area of a priority program. It would lead to a better understanding of additional geological mineral and energy resources.

Independent research work

So how did this research development come about and what role do the co-authors and the supervisor of the work play in this? Sadegh Adineh was already passionately working on the structures of salt diapirs for his Master Thesis work between 2013 and 2015, based out of Shiraz University, Iran. He approached the geologists in Prague and Munich about wanting to pursue his doctoral work under their guidance. His persistent inquiry about research options eventually led to the joint German-Czech collaboration funded to work on better understanding the dynamic behavior of caprocks in the Zagros Mountains — a passion that Drs. Prokop Zavada and Jiri Bruthans also long shared. A look at the previous publications of the members of the working group in Munich (mainly Drs. Anke Friedrich, Soraya Heuss) proves that a large part of the initiative was taken by Mr. Adineh himself, who must have carried out the essential work steps (field work, obtaining permits, sampling, literature work, thin section analysis, some laboratory analysis) himself. Dr Zavada, as the main advisor, provided guidance and instilled the urge of staying focused on the main thesis topic. Nevertheless, the strong, collegial environment in Prague, combined with the support from Dr Soraya Heuss at the LMU Munich certainly contributed to the fact that Mr. Adineh was able to work on his research questions.

Professional, formal and linguistic aspects of the dissertation

The doctoral thesis of Mr Sadegh Adineh consists of a 345-page-long text and 13-page-long appendix containing geochemical results, some textural evidence, and sample locations. The thesis contains a comprehensive introduction and conclusions summarizing each chapter's findings. Additionally, it contains a very brief section stating implications and future work, which reveals the depth of insights gained from the research. The scientific content is structured in six chapters, of which two have been published in international peer-reviewed journals, one has been submitted, and one is in preparation for submission. The text has few spelling errors, but it's notably deficient in references. Several references mentioned in the text are absent from the reference list.

In addition to the stand-alone thesis chapters that have been, or, are intended to be, published, the thesis contains a 52-page-long introduction with 17 figures. This chapter is characterized by a compilation of previously published research findings on the formation of salt diapirs in their tectonic context, caprocks, and the Ediacaran rocks that make up some of the exotic blocks within the caprocks. The narrative builds on claims from the literature which are used in a few cases to build reasoned statements about the current problems in the formation of salt diapirs and caprock. The introduction resembles a comprehensive summary of knowledge rather than critical reasoning about the scientific problems to be addressed, and their relevance, in the stand-alone chapters thereby missing an opportunity to point out the significance of this work. The last portion of the introduction abruptly focuses on motivation and objectives of the thesis.

While providing a helpful overview of previous research, which sets the stage for the broader context of the thesis topic — the formation of caprocks and intriguing discoveries concerning the origin and significance of exotic blocks within them — this type of writing lacks effective evaluation and organization of pertinent information. The comprehensive nature of this approach seems to stem from a patchwork of reasoned claims drawn from various published sources but lacks critical analysis to streamline the thought process. Consequently, it becomes challenging to build upon the reasoning of previous publications to address current issues and identify precisely where further research is needed. This issue manifests in an excessively lengthy reference section, uneven writing style, and in the abrupt appearance of the subsection on motivation and objectives.

An exemplary inspection of the introduction, starting with section 1.9, revealed that the way in which the text is compiled includes lengthy sections (multiple paragraphs) that are adopted from previous

publications. In some cases, a few sparse words appear to have been swapped. The structure of many sentences is identical to that of the original source. The original publication is not credited appropriately, and it is not listed in the reference list at the end of the introduction. The study is cited once at the beginning of the section, but the reader is misguided in thinking that this study ([Wang et al., 2023](#)) was only consulted once and that the rest of the sentence structure is original; the remainder of the text contains references to other articles, and those are identical to the cited sources in the original article.

Example 1:

- (A) Text in thesis (first sentence of section 1.9, p.28): “Understanding the **characteristics** of glaciation throughout Earth history is **crucial**, **since** its waxing and waning dynamics represent one of the most fundamental controls on climate and hence on the evolution of life (Wang et al. 2023).”
- (B) Original in Wang et al. (2023): „Understanding the **nature** of glaciation throughout Earth history is **important**, **as** its waxing and waning dynamics represent one of the most fundamental controls on climate and hence on the evolution of life.“

The practice of substituting just a few words without employing direct quotation marks, especially when the entire sentence structure is clearly lifted from the original source, demonstrates poor writing etiquette. This approach is considered substandard style and should be avoided. It's particularly concerning in this case, as the reference to Wang et al. (2023) has not been included in the reference list, and there are no further mentions of it in the text until the end of page 29, despite the sentences on page 28/29 (section 1.9) of the thesis seemingly being borrowed from their work:

Example 2:

- (A) Text in thesis (second sentence in section 1.9, p.28/29): “Geological **findings** and **climatic simulations** show that **glaciation at low latitudes**, i.e. ice sheets **reaching down to sea level in the tropics**, **happened during the Snowball Earth** (Hyde et al., 2000; Donnadieu et al.,2003) during which Earth’s surface was completely or mostly frozen for tens of millions of years (Haffman et al., 2007).
Note: Haffman et al. 2007 does not exist. It is Hoffman et al. either 1998 or 2017.
- (B) Original next sentence from Wang et al. (2023): Geologic **evidence** and **climate models** indicate that **low**-latitude glaciation, i.e. ice sheets **extending to** sea level in tropics, **occurred** under the Snowball Earth climatic condition [**1,2**], during which Earth's surface was completely or mostly frozen for tens of millions of years [**3,4**].

Note: References: [**1,2**], = Hyde et al., 2000; Donnadieu et al.,2003; [**3,4**] = Hoffman et al. 1998; Hoffman et al. 2017.

These two examples were the first two sentences of section 1.9 but reading on to the main body of page 29, the sentence structure and content are equally nearly identical to the first portion of the introduction of [Wang et al. \(2023\)](#).

Subsequent inspection of the remainder of the introduction, and the chapters that have not yet been published yield numerous additional sentences and paragraphs that appear to have been borrowed from the published literature. In many cases, the original reference from which the text has been copied is not included in the reference list and not credited at the end of such sentences (e.g., the doctoral thesis of [Leonardo Muniz Pichel, 2018](#); e.g., section 1.1 on salt deposition and section 1.17 on the synopsis stem mostly from this source; section 1.4. much text from [Rowan et al. \(2019\)](#), not cited; section 1.5. much text from [Amanda L Labrado, dissertation, 2021](#), not cited; section 1.8 much text from Stewart (2020), cited once, but not sufficiently; sections 1.10 & 1.11 much text & figure 1.13. from Wang et al: (2023), not cited and not in list; section 1.14 much text from [Aftabi et al. 2022](#), cited, but reference not in list; section 1.14 text from [dissertation Marco Snidero](#) and [Hassanpour et al. \(2021\)](#) not cited here, but in reference list; section 1.15 (motivation) much text from [Master thesis Lerer, 2017](#);). In some cases, the reference has been included but not at the location where the sentence structures have been copied. The unpublished other chapters are also affected, while the two published chapters could not be checked. Please refer to the iThenticate report for full details.

The writing style within the introductory section, and in some portions of the manuscripts, is uneven. The original writing style of the thesis candidate might be reflected by these sentences (the text from the end of section 1.8): “...*The southwest margin of the Hormuz evaporite basin deposited in late Ediacaran to early Cambrian sub-basins on the eastern side of Saudi Arabia and in Oman, these are studied here in terms of in which environmental condition the Hormuz Formation were deposited and how it impact structural style, and their relationships with the regional tectonics.* (new paragraph) *In this thesis, we examine the carbonate caprock of the salt diapirs in terms of in which environmental condition the Hormuz Formation were deposited and how it impact structural style, and their relationships with the regional tectonics...*” See section 2.17 for another typical example of the writing style.

So, the authentic text contains typos, slight grammatical mistakes, and a cumbersome style. Yet, I consider this style an acceptable normal writing style for a graduating doctoral candidate whose first language is not English. In contrast, most other sections are written in professional language, containing sentence structures that reflect mature, native-like writing (e.g., Section 1.9). These differences in writing style might indicate incomplete, or inconsistent, levels in proof-reading and revising, or that different capacities crafted the original sentence structures. In summary, the technical state of the introduction reflects an ambitious effort that wasn't fully realized. It should have been boiled down to the essence relevant to this thesis and be rewritten and credited. However, it does reflect on the motivation and level of ability of the doctoral candidate.

Before the thesis is displayed publicly, I strongly recommend revising the introduction, and all other affected text sections, according to mannerism of good scientific practice. This includes always giving proper credit to the sources, listing references completely, using direct quotation where necessary, and obtaining proper copyright of figures or redrawing them as needed. Such a revision of this introduction will result in a more natural flow of the text providing the reasoning, backed up by claims, needed to build the case for motivation and objectives of this thesis. Then, the introduction might be useful to evaluate the scientific capacity of the doctoral candidate.

The original portion of the introductory thesis chapter starts on page 44 with a section on Motivation and Objectives. This section addresses problems in imaging salt structures and the geology beneath them, which are not within the core scope of the thesis. It broadly introduces the topic of caprocks once more and then abruptly states the goals of the thesis. Improving the reasoning regarding which problems need to be tackled and how to tackle them could enhance the clarity of the statements. It would also lead to a slimmer list of references, because priority would be given to the most relevant sources, reflecting a mature state of scientific writing.

The thesis presents seven objectives focused on uncovering the "origin, structure, timing, and evolution of the caprock." Some of these objectives are quite ambitious and could easily form the basis of entire theses on their own. Implicitly assuming that these objectives translate into testable hypotheses and premises, one also acknowledges the methodology employed in this study, which is followed by synoptic abstracts of each stand-alone chapter.

Part VIII, the “comprehensive and detailed conclusion” section, an apparent requirement, provides a summary of each chapter’s findings, but it does not reveal how the seven objectives have been met. There is no critical assessment of the success or failure of these objectives, and the respective reasons for each. I recommend rewriting the conclusion section to better reflect the implications and consequences of the results.

The list of references is long but incomplete. A quick check on the references revealed that least three key references (Wang et al. 2023, Horton et al. 2008, Hoffman et al. etc.) that are mentioned in the introduction are not included in the reference list. Reference Haffman et al. is not in the reference list, and most likely, it should be Hoffman et al. The entire list of references must be checked for consistency with the text prior to public release of the thesis.

Of the 17 figures, 14 are adopted from the literature, but three constitute original contributions (Figs 1.1, 1.10, and 1.16). At least two figures are directly copied from published work without any modification. Prior to release of the thesis, it is essential to assure that copyrights will have been obtained for the figures (e.g., Figures 1.8a., 1.11., 1.12., 1.13, 1.15, and 1.16) or that they do not fall under any copyrights because they have been redrawn.

Minor issues:

The entire document should be checked for formatting, for example, a section heading must be followed by at least two lines of text on the same page, or there should be no paragraph breaks in the middle of sentences (see German abstract).

The German abstract needs to be proof-read by a native speaker to fix the text where it has been auto translated.

The hyphenation is used inconsistently and needs to be improved. Hyphenation usage varies throughout the text, including some hyphens and some en-dashes for the same purpose, indicating a range.

How to spell LES (layered evaporitic sequences) and fold-and-thrust belt versus Fold and Thrust Belt – capital or small letters, at the least be consistent or follow convention.

Please be sure that all coauthors have contributed to each study and only circulate a manuscript after co-authorship-related issues have been clarified.

Summary

This dissertation contains conceptually outstanding, relevant, and modern research methodology and findings that are documented in several chapters, some of which are already published. The above comments and praising of the work have been conducted under the premise that all work is original, also the written work. However, the extensive problems with the writing style, i.e., the leaning on and copying of previously published text without giving proper credit to these sources, significantly blurs the written quality of this dissertation. It is, therefore, difficult to evaluate the ability of the candidate to carry out critical thinking and original reasoning in a written manner.

In addition, specific shortcomings are the heavy introduction that does not lead naturally to a lean derivation of the research objectives. The section on overall conclusions and implications of the work is rudimentary and superficial; it does not evaluate to what degree the research objectives have been met. In addition, the references are incomplete, and several figures may require copyrights prior to their publication. These problems diminish the overall impression, as the importance of the research results and their relevance for the further development of the subject area cannot outweigh the errors.

Under normal circumstances, the problems with the dissertation would need to be fixed prior to the defense. Given the special circumstances, however, and under the premise that the problems with the text, as outlined above, will be fixed prior to publication of this dissertation, I am willing to conditionally recommend this thesis to be defended by Mr. Sadegh Adineh as scheduled on March 27th. If you have any questions, please do not hesitate to contact me.

Yours sincerely,



Professor Dr. Anke Friedrich