

3D anatomy of the Cretaceous-Paleogene age Nadir Crater

Corresponding Author: Dr Uisdean Alasdair Nicholson

Version 0:

Decision Letter:

**** Please ensure you delete the link to your author home page in this e-mail if you wish to forward it to your coauthors ****

Dear Dr Nicholson,

Your manuscript titled "3D anatomy of the Cretaceous-Paleogene age Nadir Crater" has now been seen by 3 reviewers, and we include their comments at the end of this message. They find your work of significant interest, but have raised some important points that need to be addressed. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

Please submit your point-by-point 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.

Important: The response to reviewers must not include any figures, tables or graphs. If you wish to respond to the reviewer reports with additional data in one of these formats, please add them to the main article or Supplementary Information, and refer to them in the rebuttal. Due to current technical limitations, any figures, tables, or graphs embedded in your rebuttal will not be included in the peer review file, if published.

We are committed to providing a fair and constructive peer-review process. Please don't 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 referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:

Link Redacted

**** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first ****

We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still 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.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

J. Kim Welford, PhD
Editorial Board Member
Communications Earth & Environment
orcid.org/0000-0002-5919-5303

Joe Aslin
Deputy Editor
Communications Earth & Environment

EDITORIAL POLICIES AND FORMATTING

We ask that you ensure your manuscript complies with our editorial policies. Please ensure that the following formatting requirements are met, and any checklist relevant to your research is completed and uploaded as a Related Manuscript file type with the revised article.

Editorial Policy: [Policy requirements](https://www.nature.com/documents/nr-editorial-policy-checklist.pdf) (Download the link to your computer as a PDF.)

For Manuscripts that fall into the following fields:

- Behavioural and social science
- Ecological, evolutionary & environmental sciences
- Life sciences

An updated and completed version of our Reporting Summary must be uploaded with the revised manuscript

You can download the form here:

<https://www.nature.com/documents/nr-reporting-summary.zip>

Furthermore, please align your manuscript with our format requirements, which are summarized on the following checklist: [Communications Earth & Environment formatting checklist](https://www.nature.com/documents/commsj-phys-style-formatting-checklist-article.pdf)

and also in our style and formatting guide [Communications Earth & Environment formatting guide](https://www.nature.com/documents/commsj-phys-style-formatting-guide-accept.pdf).

*** DATA: Communications Earth & Environment endorses the principles of the Enabling FAIR data project (<http://www.copdess.org/enabling-fair-data-project/>). We ask authors to make the data that support their conclusions available in permanent, publically accessible data repositories. (Please contact the editor if you are unable to make your data available).

All Communications Earth & Environment manuscripts must include a section titled "Data Availability" at the end of the Methods section or main text (if no Methods). More information on this policy, is available at <http://www.nature.com/authors/policies/data/data-availability-statements-data-citations.pdf>.

In particular, the Data availability statement should include:

- Unique identifiers (such as DOIs and hyperlinks for datasets in public repositories)
- Accession codes where appropriate
- If applicable, a statement regarding data available with restrictions
- If a dataset has a Digital Object Identifier (DOI) as its unique identifier, we strongly encourage including this in the Reference list and citing the dataset in the Data Availability Statement.

DATA SOURCES: All new data associated with the paper should be placed in a persistent repository where they can be freely and enduringly accessed. We recommend submitting the data to discipline-specific, community-recognized repositories, where possible and a list of recommended repositories is provided at <http://www.nature.com/sdata/policies/repositories>.

If a community resource is unavailable, data can be submitted to generalist repositories such as [figshare](https://figshare.com/) or [Dryad Digital Repository](http://datadryad.org/). Please provide a unique identifier for the data (for example a DOI or a permanent URL) in the data availability statement, if possible. If the repository does not provide identifiers, we encourage authors to supply the search terms that will return the data. For data that have been obtained from publically available sources, please provide a URL and the specific data product name in the data availability statement. Data with a DOI should be further cited in the methods reference section.

Please refer to our data policies at <http://www.nature.com/authors/policies/availability.html>.

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

Summary:

The manuscript presents an analysis of a 3D seismic dataset over the proposed Nadir impact crater, offshore Guinea. The work compiles structural and stratigraphic observations over the impact structure and its surroundings. Based on the data analysis, the authors draw conclusions on the ability of 3D seismic data to: (1) identify unambiguously buried marine impact

craters and its key diagnosis features, (2) provide an approximate age, (3) decipher cratering processes and, (4) assess its environmental consequences.

General appraisal:

All in all I found the paper very interesting, the 3D seismic analysis is outstanding and the observations are crisps. The manuscript is well structured, and the figures and data visualization are clear and appropriate. The conclusions and claims are original and mostly supported by evidence (see minor comments below). To my knowledge, the “sheltered” zone, paleoseabed scars and details of radial faults in the central peak are previously unseen in seismic data.

This work is relevant to international research communities working on terrestrial and planetary impacts, environmental consequences of tsunamis, structural geology and planetary science.

However, I note a major shortcoming related to the unfair treatment of previous literature. Indeed, the authors have omitted all references related to research on the proposed Silverpit impact crater (North Sea) and its alternative interpretations based on 3D seismic data analysis. This corpus of research has been published and debated in Nature letters and other reputable international journals:

Stewart, S. A., and Allen, P. J., 2002, A 20-km-diameter multi-ringed impact structure in the North Sea: *Nature*, v. 418, no. 6897, p. 517-520 DOI: 10.1038/nature00942.

Underhill, J. R., 2004, Earth science: an alternative origin for the 'Silverpit crater': *Nature*, v. 428, no. 6980, p. 1 p following 280; discussion 282 p following 280 DOI: 10.1038/nature02476.

Stewart, S. A., and Allen, P. J., 2005, 3D seismic reflection mapping of the Silverpit multi-ringed crater, North Sea: *Geological Society of America Bulletin*, v. 117, no. 3 DOI: 10.1130/b25591.1.

MOSTYN L.T. WALL, JOE CARTWRIGHT, and DAVIES, R. J., 2008, An Eocene age for the proposed Silverpit Impact Crater: *Journal of the Geological Society* v. 165, p. 781 - 794 DOI: <https://doi.org/10.1144/0016-76492007-138>.

Owen, P., 2009, Discussion on 'An Eocene age for the proposed Silverpit Impact Crater': *Journal of the Geological Society*, v. 166, p. 1159 - 1160 DOI: <https://doi.org/10.1144/0016-76492009-061>.

Based on 3D seismic data analysis, the authors claim that the Nadir structure is due to a hypervelocity impact “beyond reasonable doubt”, which I believe is correct. In the same line of reasoning, the 3D seismic analysis of the Silverpit Crater ticks all the diagnosis features (ring faults, central uplift, radial faults etc.) that the authors identify in 3D seismic data for the Nadir impact crater. Regardless of the author’s opinion on the nature of the Silverpit structure, this controversy is constitutive of the scientific question whether buried impact crater can be unambiguously identified without core drillings. In that sense, Silverpit precedes Nadir and cannot be discarded in this manuscript. However, the superior quality of the 3D seismic imaging at Nadir and the full data coverage over the crater and its surroundings is clearly unprecedented and original.

Therefore, I recommend publication with major revisions. However, on the grounds of fair treatment of previous literature, the publication should be conditioned to reference and comprehensive discussion of the research related the proposed Silverpit impact crater, in both introduction and discussion chapters of the manuscript.

Minor comments:

P1L24: Please remove occurrences of “unprecedented”.

P1L28: Please add “Contemporaneous” or “Paleo” seabed.

P1L31-33: Repetition of “allow us” in two consecutive sentences.

P2L48: Please remove “more” for clarity.

P2L64: It would be helpful for the readers if you can provide references and name of the terrestrial, marine impact craters imaged by conventional and high-resolution seismic.

P3L92: Please remove “unprecedented”.

P3L101: Please add a reference to figure 2 in the paragraph.

P3L103: Do you mean “Granitic basement”?

P3L107: Please add a reference on tectonic history of the Guinea Terrace.

P4L164: I do not see a “clear” link to Aptian fault in Fig.5. This statement is too assertive and not supported by clear evidence in the figures.

P5L179: About "around 82 degrees". Please provide more informations and, if possible, an uncertainty regarding this rather precise measurement.

P5L188-189: The statement is too assertive. From the figures, I cannot see that the negative flower structures are related to underlying normal faults.

P5L196: Remove "unprecedented".

P5L207-208: A reference and paragraph on the Silverpit impact structure could be added in this part of the discussion chapter.

P6L244-246: This "inheritance" is not sufficiently supported by visual evidence in the figures.

P7L277-285: Polygonal faulting is documented in Cretaceous Basins all along the Atlantic margins, especially in the Norwegian and SW Barents Sea. The claim that polygonal faulting is partially linked to the hypervelocity impact is not supported by any evidence and is purely speculative at this stage. This paragraph should be removed.

P8L346-347: Here, it should be mentioned that most buried impact craters (undiscovered or not) have undergone post-impact modification by tectonic forces and/or sedimentary compaction (see references below). For this reason, crater structural relationships would be impossible to apply for most buried craters. Nadir is an exception in that regard!

Corseri, R., Gac, S., Faleide, J. I., and Planke, S., 2020, The tectonized central peak of the Mjølnir Impact Crater, Barents Sea: *Journal of Structural Geology*, v. 131 DOI: 10.1016/j.jsg.2019.103953.

Tsikalas, F., Faleide, J.I., 2007. Postimpact structural crater modification due to sediment loading: an overlooked process. *Meteorit. Planet. Sci.* v42, 2013–2029. <https://doi.org/10.1111/j.1945-5100.2007.tb00557.x>.

Kulpecz, A. A., Miller, K. G., Browning, J. V., Edwards, L. E., Powars, D. S., McLaughlin, P. P., Harris, A. D., and Feigenson, M. D., 2009, Postimpact deposition in the Chesapeake Bay impact structure: Variations in eustasy, compaction, sediment supply, and passive-aggressive tectonism, The ICDP-USGS Deep Drilling Project in the Chesapeake Bay impact structure: Results from the Eyreville Core Holes.

P14L460: In figure 5E, the annotations "A" and "T" on each side of the faults are not explained in the legend nor in the text.

With kind regards,

Romain Corseri

Reviewer #2 (Remarks to the Author):

6/27/2024

Dear Dr. J. Kim Welford,

Thank you for this opportunity to review "3D anatomy of the Cretaceous-Paleogene age Nadir Crater." This manuscript presents exciting new information as a follow-on to the previous Nicholson et. al. (2022) "The Nadir Crater offshore West Africa: A candidate Cretaceous-Paleogene impact structure" published in *Science Advances*.

The 2022 article proposed that the Nadir Crater be considered a candidate hypervelocity impact crater. In short, the author's developed their impact crater hypothesis based on the structure's morphology (after they examined and rejected alternative crater-forming mechanisms) and after they conducted a range of hydrocode marine impact simulations to match dimensions and observations interpreted from the 2D seismic data. I enjoyed reading the 2022 article and only summarize it here to emphasize what is new in the present manuscript submission (Nicholson et. al., 2024), namely 3D seismic data.

The submitted manuscript is well written, and the figures are well thought out. I found their references pertinent to their interpretations and discussion. There is a good balance between cross section views and plan views provided. Moreover, there is a wealth of detail provided by the different lines chosen and appropriate surfaces (depth maps and stratigraphic horizons).

The authors have accomplished much more than just adding 3D seismic data to their previous work. I am not an expert when it comes to structural geology in marine sediments and environments, but I find their interpretations to be compelling and worthy of dissemination to the scientific community. For example, their section on reconstructing impact angle connecting results from oblique impact experiments with structural asymmetries observed in the new 3D data appears to be an important link between the laboratory and nature.

Finally, I appreciate the author's presented position that it is highly likely that the Nadir crater does in fact represent an

impact crater but until hard evidence from drill core is obtained it should remain a proposed candidate – as mentioned in the abstract, introduction, and elsewhere. I wish the authors well with their ocean drilling proposal for the structure.

I support publication of this manuscript in its current form and only found a few minor grammatical questions below.

Kind regards,
Marc Biren, Ph.D.

INTRODUCTION

Page 2, Line 61: suggest "...fluid-saturated sediments..."

RESULTS

Page 4, Line 130: looks like this reference number was supposed to be 18 instead of 1?

DISCUSSION

Page 6, Line 223: suggest adding a comma "...on other planets, morphology..."

Page 8, Lines 332 - 336: These sentences are a bit confusing to me – you state that the crater depth (immediately at the end of the crater modification stage) is shallower than what has been typically observed for impact craters of this size, but I am not sure of the why after reading the paragraph. Is it because of ground hugging flows, or resurge, or do both mechanisms cause the even more shallow final crater depth and not the earlier post modification shallow depth?

Reviewer #3 (Remarks to the Author):

Dear Editor and Authors,

I read with great interest the work titled "3D anatomy of the Cretaceous-Paleogene age Nadir Crater" by Dr Nicholson and colleagues, which has been submitted for publication in Communications Earth & Environment.

This work constitutes a follow-up to a previous work published in Science (The Nadir Crater offshore West Africa: A candidate Cretaceous-Paleogene impact structure, Science Advances, 17 Aug 2022, Vol 8, Issue 33, DOI: 10.1126/sciadv.abn3096), which hypothesized the presence of a large impact crater on the African continental shelf off the coast of Guinea, dated around the K-T boundary.

In this new work, 3D seismic reflection data are presented and described, which confirm the initial hypothesis, allowing for a more precise description of the morphological and stratigraphic characteristics of the presumed crater, and formulating formation models based on available numerical codes.

I must say that I enjoyed the reading, because this is a well-written paper that presents spectacular and well-illustrated data, and it certainly deserves to be published for its importance, both in terms of the local situation (the size of the event and a possible connection with Chicxulub, etc.), and because it allows us to verify and "tune" with a real example the dynamics of impacts in a particular environment, such as the seabed and oceans, which however cover most of the Earth's surface, and are therefore probabilistically very important for the research of past impacts and the verification of what could happen in a future event.

That said, I would like to draw attention to some "details," which in my opinion can improve the impact of the work:

1. Why weren't magnetic and gravity data included in the description, which are generally available in the datasets of oil exploration? I checked the exploration company's website and it seems that these data have indeed been acquired...

(<https://www.pgs.com/data-library/map/amec/africa/north-west-africa/republic-of-guinea/?lat=9.346092468658036&long=-16.92306518556926&zoom=8>).

These are complementary and important evidence to seismic reflection images, and allow for better discuss (and eventually rule out) alternative mechanisms for the crater formation. As described by some of the authors in the previous work, we are not too far from salt diapir fields rising from Jurassic formations, but we are also close to a major transform fault where serpentinization phenomena and diapir formation have been documented, which potentially have the ability to form circular or sub-circular features (see for example Polonia et al., 2017). This aspect should be included, if not by adding new data, which I do not know if they are available, at least to reinforce the actual, preferred interpretation. It is not enough to write, as it appears in the abstract: "Here we present 3D seismic data that image this crater in exceptional detail, unprecedented for any such structure, which demonstrates beyond reasonable doubt that the crater-forming mechanism was a hypervelocity impact." It is important instead to try to demonstrate it as convincingly as possible. Doubts are always reasonable and the essence of scientific research. I would change that sentence....

2. There are few details about the velocity analyses of the seismic reflection dataset: how were they performed? What is the associated error-bars in the absence of direct sampling and stratigraphic logs in the study area? How can these eventually affect the correction of the pull-up effect that was evident from the 2D seismic data published in the previous paper? This is an important point because seismic processing, especially depth-migration, has significant margins of subjectivity, and in this case constitutes a crucial point. In fact, if the reflectors below the alleged crater are not undisturbed, this might weaken the impact hypothesis.

3. Is recommend to publish (perhaps as supplementary material, as was done for the Science paper) the uninterpreted seismic reflection profiles. This aspect is important because the presence of faults (especially normal faults, but most probably with a strike-slip component), not necessarily related to the presumed impact complicate the interpretative models interfering with faults and fractures eventually created by the impact.

Finally, I acknowledge that the interpretation made by the authors appears convincing and supported by an exceptional set

of data. But the discovery of an impact crater, such as the Nadir crater, very close in age (within error bars) to the famous Chicxulub crater, is an important discovery, and will probably guide and give a new impetus in the coming years to the underestimated problem of extraterrestrial impacts, particularly those which occurred underwater, a peculiarity of the Earth surface. For this reason, rather than focusing on detailed models and descriptions of the alleged phenomenon, it would be better in my opinion to concentrate as much as possible on objective evidence, bringing as much data as possible to support a very strong and extremely interesting hypothesis.
My final opinion is publishing this paper with minor revisions.

Polonia, A., Torelli, L., Gasperini, L. et al. Lower plate serpentinite diapirism in the Calabrian Arc subduction complex. *Nat Commun* 8, 2172 (2017). <https://doi.org/10.1038/s41467-017-02273-x>

Submitted by Luca Gasperini

** Visit Nature Research's author and referees' website at <http://www.nature.com/authors> for information about policies, services and author benefits**

Communications Earth & Environment is committed to improving transparency in authorship. As part of our efforts in this direction, we are now requesting that all authors identified as 'corresponding author' create and link their Open Researcher and Contributor Identifier (ORCID) with their account on the Manuscript Tracking System prior to acceptance. ORCID helps the scientific community achieve unambiguous attribution of all scholarly contributions. You can create and link your ORCID from the home page of the Manuscript Tracking System by clicking on 'Modify my Springer Nature account' and following the instructions in the link below. Please also inform all co-authors that they can add their ORCIDs to their accounts and that they must do so prior to acceptance.
<https://www.springernature.com/gp/researchers/orcid/orcid-for-nature-research>

For more information please visit <http://www.springernature.com/orcid>

If you experience problems in linking your ORCID, please contact the [Platform Support Helpdesk](http://platformsupport.nature.com/).

Author Rebuttal letter: The author's response to these comments can be found at the end of this file.

Version 1:

Decision Letter:

** Please ensure you delete the link to your author home page in this e-mail if you wish to forward it to your coauthors **

Dear Dr Nicholson,

Your manuscript titled "3D anatomy of the Cretaceous-Paleogene age Nadir Crater" 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 revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

EDITORIAL REQUESTS:

Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table".

*****Please take care to match our formatting and policy requirements. We will check revised manuscript and return manuscripts that do not comply. Such requests will lead to delays. *****

Please outline your response to each request in the right hand column. Please upload the completed table with your manuscript files as a Related Manuscript file.

If you have any questions or concerns about any of our requests, please do not hesitate to contact me.

SUBMISSION INFORMATION:

In order to accept your paper, we require the files listed at the end of the Editorial Requests Table; the list of required files is also available at <https://www.nature.com/documents/commsj-file-checklist.pdf>.

OPEN ACCESS:

Communications Earth & Environment is a fully open access journal. Articles are made freely accessible on publication. For further information about article processing charges, open access funding, and advice and support from Nature Research, please visit <https://www.nature.com/commsenv/open-access>

At acceptance, you will be provided with instructions for completing the open access licence agreement on behalf of all authors. This grants us the necessary permissions to publish your paper. Additionally, you will be asked to declare that all required third party permissions have been obtained, and to provide billing information in order to pay the article-processing charge (APC).

Please use the following link to submit the above items:

Link Redacted

**** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first ****

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

Best regards,

Kim Welford
Editorial Board Member
Communications Earth & Environment

Joe Aslin
Deputy Editor,
Communications Earth & Environment
<https://www.nature.com/commsenv/>
Twitter: @CommsEarth

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

Dear authors,

Thank you for the revised version of this manuscript and taking into account my review.
I have no further comments and recommend publication of the revised manuscript as is.

Good luck with disseminating those fascinating data and results!

Kind regards,

Romain Corseri

Reviewer #3 (Remarks to the Author):

I see that all suggestion were included in the manuscript, which is ready for publication.

Best Regards,
Luca Gasperini

**** Visit Nature Research's author and referees' website at <[a href="http://www.nature.com/authors">www.nature.com/authors](http://www.nature.com/authors)> for information about policies, services and author benefits****

Open Access This Peer Review File is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

In cases where reviewers are anonymous, credit should be given to 'Anonymous Referee' and the source.

The images or other third party material in this Peer Review File are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

To view a copy of this license, visit <https://creativecommons.org/licenses/by/4.0/>

Point-by-point response

We provide point-by-point responses to each comment by the three reviewers below. Reviewers' comments are in black and our responses are in blue.

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

General appraisal:

All in all I found the paper very interesting, the 3D seismic analysis is outstanding and the observations are crisp. The manuscript is well structured, and the figures and data visualization are clear and appropriate. The conclusions and claims are original and mostly supported by evidence (see minor comments below). To my knowledge, the “sheltered” zone, paleoseabed scars and details of radial faults in the central peak are previously unseen in seismic data.

This work is relevant to international research communities working on terrestrial and planetary impacts, environmental consequences of tsunamis, structural geology and planetary science.

[We thank the reviewer for their positive appraisal of our manuscript.](#)

However, I note a major shortcoming related to the unfair treatment of previous literature. Indeed, the authors have omitted all references related to research on the proposed Silverpit impact crater (North Sea) and its alternative interpretations based on 3D seismic data analysis. This corpus of research has been published and debated in Nature letters and other reputable international journals:

[We appreciate this point and agree that this should be included in the manuscript. We note that the lack of reference to, or discussion of, Silverpit Crater was partly because of the limited word limit available for the originally submitted manuscript. However, in this version we note this in both the introduction and the discussion, as suggested by the reviewer. We include references to the key papers below.](#)

Stewart, S. A., and Allen, P. J., 2002, A 20-km-diameter multi-ringed impact structure in the North Sea: Nature, v. 418, no. 6897, p. 517-520 DOI: 10.1038/nature00942.

Underhill, J. R., 2004, Earth science: an alternative origin for the 'Silverpit crater': Nature, v. 428, no. 6980, p. 1 p following 280; discussion 282 p following 280 DOI: 10.1038/nature02476.

Stewart, S. A., and Allen, P. J., 2005, 3D seismic reflection mapping of the Silverpit multi-ringed crater, North Sea: Geological Society of America Bulletin, v. 117, no. 3 DOI: 10.1130/b25591.1.

MOSTYN L.T. WALL, JOE CARTWRIGHT, and DAVIES, R. J., 2008, An Eocene age for the proposed Silverpit Impact Crater: Journal of the Geological Society v. 165, p. 781 - 794 DOI: <https://doi.org/10.1144/0016-76492007-138>.

Owen, P., 2009, Discussion on 'An Eocene age for the proposed Silverpit Impact Crater': Journal of the Geological Society, v. 166, p. 1159 - 1160 DOI: <https://doi.org/10.1144/0016-76492009-061>.

Based on 3D seismic data analysis, the authors claim that the Nadir structure is due to a hypervelocity impact “beyond reasonable doubt”, which I believe is correct. In the same line of reasoning, the 3D seismic analysis of the Silverpit Crater ticks all the diagnosis features (ring faults, central uplift, radial faults etc.) that the authors identify in 3D seismic data for the Nadir impact crater. Regardless of the author’s opinion on the nature of the Silverpit structure, this controversy is constitutive of the scientific question whether buried impact crater can be unambiguously identified without core drillings. In that sense, Silverpit precedes Nadir and cannot be discarded in this manuscript. However, the superior quality of the 3D seismic imaging at Nadir and the full data coverage over the crater and its surroundings is clearly unprecedented and original.

We agree that these criteria are also relevant to Silverpit. The high-resolution PSDM data for Nadir is clearly of significantly higher quality than that currently published for Silverpit, but that does suggest that Silverpit could be more definitively categorized as an impact structure (or not) with improved seismic data, and coverage.

Therefore, I recommend publication with major revisions. However, on the grounds of fair treatment of previous literature, the publication should be conditioned to reference and comprehensive discussion of the research related the proposed Silverpit impact crater, in both introduction and discussion chapters of the manuscript.

This has been done.

Minor comments:

P1L24: Please remove occurrences of “unprecedented”. Although we think the term is generally appropriate (in that there are no other published datasets like this that reveal the 3D anatomy of any impact structure), the term has been removed or replaced here and elsewhere.

P1L28: Please add “Contemporaneous” or “Paleo” seabed. “paleo” added

P1L31-33: Repetition of “allow us” in two consecutive sentences. The second one is changed to “are used to”

P2L48: Please remove “more” for clarity. Removed

P2L64: It would be helpful for the readers if you can provide references and name of the terrestrial, marine impact craters imaged by conventional and high-resolution seismic. References to Mjølner, Montagnais and Chesapeake now included as the most well-known examples.

P3L92: Please remove “unprecedented”. “Replaced with unique”

P3L101: Please add a reference to figure 2 in the paragraph. This paragraph refers entirely to previous work, based on the references cited. We prefer not to refer to Figure 2 until the start of the Results section, later on page 3.

P3L103: Do you mean “Granitic basement”? No, the basement here, at least below the Guinea Terrace, consists of a sequence of seaward-dipping reflections – volcanic (extrusive) in origin.

P3L107: Please add a reference on tectonic history of the Guinea Terrace. Two references are already cited for the break up sequence, and then three additional reference also for the stratigraphic and tectonic evolution of the plateau. The text has been amended to highlight the tectonic evolution as well as simply the stratigraphic age.

P4L164: I do not see a “clear” link to Aptian fault in Fig.5. This statement is too assertive and not supported by clear evidence in the figures. The word clearly has been removed, and an additional reference added to Figure 3, where this link is more evident in profile A-A’.

P5L179: About "around 82 degrees". Please provide more informations and, if possible, an uncertainty regarding this rather precise measurement. We have amended this to ‘around 80 degrees’ to avoid over-precision. The angle is simply measured from our best estimate of the bilateral axis of symmetry (separating concave-uprange reverse faults), which is explained in the text.

P5L188-189: The statement is too assertive. From the figures, I cannot see that the negative flower structures are related to underlying normal faults. We softened this to ‘we interpret these as...’ and ‘these appear to be rooted in older normal faults’. We also call out the specific figure where this is illustrated.

P5L196: Remove “unprecedented”. Removed

P5L207-208: A reference and paragraph on the Silverpit impact structure could be added in this part of the discussion chapter. A new short section on the implications for Silverpit is added to the end of this section.

P6L244-246: This “inheritance” is not sufficiently supported by visual evidence in the figures. In a longer format paper, it would be easier to show this structural inheritance more clearly. We don’t have the space to present more figures to show this point more clearly here, but these faults are shown on Figure 5 and more clearly on the video file in the Supplementary materials. We also add a couple of citations for the NW-SE structural fabric below the Albian unconformity.

P7L277-285: Polygonal faulting is documented in Cretaceous Basins all along the Atlantic margins, especially in the Norwegian and SW Barents Sea. The claim that polygonal faulting is partially linked to the hypervelocity impact is not supported by any evidence and is purely speculative at this stage. This paragraph should be removed.

We have replaced the term ‘polygonal-style faulting’ with ‘rectangular fault blocks’ as we feel that this is a better description of the structural style, and is not confused with the main mechanism for polygonal faulting - dewatering and diagenesis. We used the term polygonal faulting initially as not all of the fault blocks are rectangular in nature; however, this appears to have caused some confusion. The main point here is not the presence of polygonal faults *per se* – as the reviewer points out, these are a very common feature of many marine basins and are even observed in the shallower Eocene strata of the Guinea Terrace (Aduomahor et al., 2024). However, the distribution and character of the fault blocks to the SW of the crater (they are not actually perfectly polygonal) at the K-Pg are not typical of those that form from diagenesis and dewatering alone. The faults bounding the structures are asymmetric, with a longer NW-SE axis, and with more offset on SW to W-dipping faults (as described in the Results section), and these faults only occur to the southwest and west (downrange) of the crater itself. The equivalent faults to the north (adjacent to the crater) or to the east (uprange) are not polygonal or rectangular in character, showing that these are clearly not just related to lithology and diagenesis but to the impact process itself. We have added some additional sentences to the paragraph to explain this more clearly. We recognize that this could benefit from some more detailed structural analysis, and potentially numerical modelling, but that is beyond the scope of this first paper documenting the broad set of structural features evident for this crater.

P8L346-347: Here, it should be mentioned that most buried impact craters (undiscovered or not) have undergone post-impact modification by tectonic forces and/or sedimentary compaction (see

references below). For this reason, crater structural relationships would be impossible to apply for most buried craters. Nadir is an exception in that regard!

We have now extended the last paragraph to capture this point – that Nadir is a pristine crater in terms of a lack of post-impact deformation, as well as exceptional imaging. We have also included the citations suggested below as these nicely demonstrate that most other marine impact craters are not pristine – we thank the reviewer for highlighting these.

Corseri, R., Gac, S., Faleide, J. I., and Planke, S., 2020, The tectonized central peak of the Mjølnir Impact Crater, Barents Sea: *Journal of Structural Geology*, v. 131 DOI: 10.1016/j.jsg.2019.103953.

Tsikalas, F., Faleide, J.I., 2007. Postimpact structural crater modification due to sediment loading: an overlooked process. *Meteorit. Planet. Sci.* v42, 2013–2029. <https://doi.org/10.1111/j.1945-5100.2007.tb00557.x>.

Kulpecz, A. A., Miller, K. G., Browning, J. V., Edwards, L. E., Powars, D. S., McLaughlin, P. P., Harris, A. D., and Feigenson, M. D., 2009, Postimpact deposition in the Chesapeake Bay impact structure: Variations in eustasy, compaction, sediment supply, and passive-aggressive tectonism, The ICDP-USGS Deep Drilling Project in the Chesapeake Bay impact structure: Results from the Eyreville Core Holes.

P14L460: In figure 5E, the annotations “A” and “T” on each side of the faults are not explained in the legend nor in the text. [These are now referred to in the figure caption. The strike-slip symbols in Figure 6 are also modified to A and T as well, for simplicity and for a more general audience.](#)

With kind regards,

Romain Corseri

Reviewer #2 (Remarks to the Author):

6/27/2024

Dear Dr. J. Kim Welford,

Thank you for this opportunity to review “3D anatomy of the Cretaceous-Paleogene age Nadir Crater.” This manuscript presents exciting new information as a follow-on to the previous Nicholson et. al. (2022) “The Nadir Crater offshore West Africa: A candidate Cretaceous-Paleogene impact structure” published in *Science Advances*.

The 2022 article proposed that the Nadir Crater be considered a candidate hypervelocity impact crater. In short, the author’s developed their impact crater hypothesis based on the structure’s morphology (after they examined and rejected alternative crater-forming mechanisms) and after they conducted a range of hydrocode marine impact simulations to match dimensions and observations interpreted from the 2D seismic data. I enjoyed reading the 2022 article and only summarize it here to emphasize what is new in the present manuscript submission (Nicholson et. al., 2024), namely 3D seismic data.

The submitted manuscript is well written, and the figures are well thought out. I found their references pertinent to their interpretations and discussion. There is a good balance between cross section views and plan views provided. Moreover, there is a wealth of detail provided by the different lines chosen and appropriate surfaces (depth maps and stratigraphic horizons).

The authors have accomplished much more than just adding 3D seismic data to their previous work. I am not an expert when it comes to structural geology in marine sediments and environments, but I find their interpretations to be compelling and worthy of dissemination to the scientific community. For example, their section on reconstructing impact angle connecting results from oblique impact experiments with structural asymmetries observed in the new 3D data appears to be an important link between the laboratory and nature.

Finally, I appreciate the author's presented position that it is highly likely that the Nadir crater does in fact represent an impact crater but until hard evidence from drill core is obtained it should remain a proposed candidate – as mentioned in the abstract, introduction, and elsewhere. I wish the authors well with their ocean drilling proposal for the structure.

I support publication of this manuscript in its current form and only found a few minor grammatical questions below.

Kind regards,

Marc Biren, Ph.D.

INTRODUCTION

Page 2, Line 61: suggest "...fluid-saturated sediments..." [Modified as suggested.](#)

RESULTS

Page 4, Line 130: looks like this reference number was supposed to be 18 instead of 1? [Correct, modified.](#)

DISCUSSION

Page 6, Line 223: suggest adding a comma "...on other planets, morphology..." [Modified](#)

Page 8, Lines 332 - 336: These sentences are a bit confusing to me – you state that the crater depth (immediately at the end of the crater modification stage) is shallower than what has been typically observed for impact craters of this size, but I am not sure of the why after reading the paragraph. Is it because of ground hugging flows, or resurge, or do both mechanisms cause the even more shallow final crater depth and not the earlier post modification shallow depth? [The last paragraph of this section has been revised to improve the clarify, and emphasise that resurge in particular suppresses crater morphology \(depth\).](#)

Reviewer #3 (Remarks to the Author):

Dear Editor and Authors,

I read with great interest the work titled "3D anatomy of the Cretaceous-Paleogene age Nadir Crater" by Dr Nicholson and colleagues, which has been submitted for publication in Communications Earth & Environment.

This work constitutes a follow-up to a previous work published in Science (The Nadir Crater offshore West Africa: A candidate Cretaceous-Paleogene impact structure, Science Advances, 17 Aug 2022,

Vol 8, Issue 33, DOI: 10.1126/sciadv.abn3096), which hypothesized the presence of a large impact crater on the African continental shelf off the coast of Guinea, dated around the K-T boundary.

In this new work, 3D seismic reflection data are presented and described, which confirm the initial hypothesis, allowing for a more precise description of the morphological and stratigraphic characteristics of the presumed crater, and formulating formation models based on available numerical codes.

I must say that I enjoyed the reading, because this is a well-written paper that presents spectacular and well-illustrated data, and it certainly deserves to be published for its importance, both in terms of the local situation (the size of the event and a possible connection with Chicxulub, etc.), and because it allows us to verify and "tune" with a real example the dynamics of impacts in a particular environment, such as the seabed and oceans, which however cover most of the Earth's surface, and are therefore probabilistically very important for the research of past impacts and the verification of what could happen in a future event.

We thank the reviewer for these positive comments and their recognition of the importance of the paper.

That said, I would like to draw attention to some "details," which in my opinion can improve the impact of the work:

1. Why weren't magnetic and gravity data included in the description, which are generally available in the datasets of oil exploration? I checked the exploration company's website and it seems that these data have indeed been acquired... (<https://www.pgs.com/data-library/map/amec/africa/north-west-africa/republic-of-guinea/?lat=9.346092468658036&long=-16.92306518556926&zoom=8>). These are complementary and important evidence to seismic reflection images, and allow for better discussion (and eventually rule out) alternative mechanisms for the crater formation. As described by some of the authors in the previous work, we are not too far from salt diapir fields rising from Jurassic formations, but we are also close to a major transform fault where serpentinization phenomena and diapir formation have been documented, which potentially have the ability to form circular or sub-circular features (see for example Polonia et al., 2017). This aspect should be included, if not by adding new data, which I do not know if they are available, at least to reinforce the actual, preferred interpretation. It is not enough to write, as it appears in the abstract: "Here we present 3D seismic data that image this crater in exceptional detail, unprecedented for any such structure, which demonstrates beyond reasonable doubt that the crater-forming mechanism was a hypervelocity impact." It is important instead to try to demonstrate it as convincingly as possible. Doubts are always reasonable and the essence of scientific research. I would change that sentence....

These data (gravity and magnetic survey) would make an excellent addition to this dataset but these were simply not available to us for this initial work. A shipboard gravity survey has indeed been acquired by PGS but was not part of the data package available for this work, which included only a subset of the larger data package acquired as part of the 3D seismic survey. A magnetic survey was not acquired, based on our discussion with PGS.

We thank the reviewer for highlighting the paper documenting serpentine diapirs in Calabria. These are very interesting features to consider. However, as with salt diapirs or maars, gas escape features, etc., this genetic mechanism is not plausible for Nadir, based both on the regional geological context and the local observations from the 3D survey and more regional 2D seismic data documented in Nicholson et al., 2022. This is dealt with in more detail in our previous paper. We have, however, added reference to other magmatic features and to the Polonia paper in the first Discussion section

on the '3D seismic evidence for a hypervelocity impact origin' to show that this mechanism has also been considered.

Regarding the expression 'beyond reasonable doubt', this expression means that, based on the evidence presented, there is no other reasonable (consistent) explanation for this feature. We do not say beyond *any* doubt, or any similar expression, that would completely rule out any other explanation, nor are we discouraging further tests of this hypothesis – rather we are proposing that this feature should be drilled for final confirmation. We note that Reviewer 1 also explicitly states their agreement with this statement, based on the evidence provided, and all reviewers are convinced by the evidence. Even this reviewer 3 states that the new data “confirm this hypothesis”. We prefer to keep this expression as it supports that such craters (with Nadir being perhaps the only example, or the most convincing example, at the moment) should be included in impact crater databases, etc.

2. There are few details about the velocity analyses of the seismic reflection dataset: how were they performed? What is the associated error-bars in the absence of direct sampling and stratigraphic logs in the study area? How can these eventually affect the correction of the pull-up effect that was evident from the 2D seismic data published in the previous paper? This is an important point because seismic processing, especially depth-migration, has significant margins of subjectivity, and in this case constitutes a crucial point. In fact, if the reflectors below the alleged crater are not undisturbed, this might weaken the impact hypothesis.

The depth velocity model building was entirely data driven using 3D tomography driven by depth-migrated gathers to create the final velocity model from the initial. This reduces the uncertainty considerably as the primary driver in assessing the quality of the velocity model is purely the gamma (flatness) of the gathers.

Also, far field well velocity profiles were used as a starting point for the initial velocities, so there is little human subjectivity in the model building. The main uncertainty would be with the direct under-burden of the crater but, given the long offsets of the data collection, there was more than enough angle to tomographically derive the velocity without passing through the crater itself. It isn't possible to put an error bar on the velocity uncertainty but we think that this explanation is sufficient justify that the velocity model is robust. We have modified and expanded the *Material and Methods* section to explain this.

Regarding the reflectors below the crater, “if the reflectors below the alleged crater are not undisturbed, this might weaken the impact hypothesis”. we disagree with this last point. The reflectors below the crater floor *are* significantly affected by the impact, but only down to a depth of ~1.5 km, as shown in Figure 1 (both in terms of the seismic velocities and the depth structure. The fact that the reflectors deeper than 1.5 km below the crater floor are not affected is consistent with what would be expected for a crater of this size (see for example Kenkmann, 2021), and with impact modelling (Nicholson et al., 2022).

3. Is recommend to publish (perhaps as supplementary material, as was done for the Science paper) the uninterpreted seismic reflection profiles. This aspect is important because the presence of faults (especially normal faults, but most probably with a strike-slip component), not necessarily related to the presumed impact complicate the interpretative models interfering with faults and fractures eventually created by the impact.

This has now been added in the supplementary materials, as suggested.

Finally, I acknowledge that the interpretation made by the authors appears convincing and supported by an exceptional set of data. But the discovery of an impact crater, such as the Nadir crater, very close in age (within error bars) to the famous Chicxulub crater, is an important discovery, and will probably guide and give a new impetus in the coming years to the underestimated problem of extraterrestrial impacts, particularly those which occurred underwater, a peculiarity of the Earth surface. For this reason, rather than focusing on detailed models and descriptions of the alleged phenomenon, it would be better in my opinion to concentrate as much as possible on objective evidence, bringing as much data as possible to support a very strong and extremely interesting hypothesis.

We thank the reviewer for this point. Indeed, we plan in future to expand this work to do further seismic structural and stratigraphic analysis of the crater to expand the set of observations that we can make, but also trying to test some of the hypothesis that we lay out here using numerical modelling. This is beyond the scope of this first (short-format) paper documenting the first set of observations of the 3D data, giving an overview of the crater morphology both at the palaeo-seabed and in the subsurface. As stated above, we do not have further geophysical data (gravity, magnetics) that can add further objective evidence to this at the moment.

My final opinion is publishing this paper with minor revisions.

Polonia, A., Torelli, L., Gasperini, L. et al. Lower plate serpentinite diapirism in the Calabrian Arc subduction complex. *Nat Commun* 8, 2172 (2017). <https://doi.org/10.1038/s41467-017-02273-x>

Submitted by Luca Gasperini