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Title:

Late Neogene terrestrial climate reconstruction of the Central Namib Desert derived by the combination of U-Pb silcrete and TCN exposure dating

Journal: Geochronology

Status:

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To whom it may concern,

thank you very much for your work. In the following I will outline every change made, based on the comments of the reviewer and where appropriate provide suitable rebuttals. The line numbers we note in our attached responses refer to the revised version of our manuscript, now attached. Minor spelling and grammatical mistakes were corrected and not specifically marked in the manuscript.

Kind regards,

Benedikt Ritter

University of Cologne – Institute of Geology

Reviewer #1 (Remarks to the Author):

General comments

The manuscript addresses an interesting topic using a combination of (novel) methods and adds significantly to the understanding of the paleoclimate of the late Cenozoic of the Namib desert.

The methods section should be restricted to the machinery and samples used. General discussions on the area and the deficiencies of previously used methods should be moved elsewhere (see specific comments below).

→correct accordingly. For details see modification explained below.

The authors might want to investigate the (potential) correlations between the paleo-climatic and erosional events in the Namib and the Kalahari in a bit more detail. One of the co-authors of this manuscript (Gerdes) was a co-author of a 2020 paper on the Kalahari paleo-climate, so this should be feasible (see specific comments below).

→We added further information and potential correlations to the Kalahari Desert. For details see modification explained below.

For each photograph, the name of the photographer should be added to the figure caption.

→ corrected accordingly

General assessment: minor revisions needed

We want to thank the anonymous reviewer for the review and comments on our manuscript. In the following we outline all changes made, in response on the comments of the reviewer, where appropriate we provide suitable rebuttals.

Specific comments

Line 18: delete "so called" → corrected accordingly

L18-19: the chronology is not poor, it might be poorly understood

→Line 18-19 changed to: "... is rather poorly understood and lacks direct radiometric dating."

L20: what about mouse teeth? I think they were also used in this context

→Also mouth teeth (primitive pedetid teeth) were used/found along specific ostrich shells (aepyornithoid) according to Pickford and Senut (2000). However, these fossils have been rarely found in the Namib along with ostrich shells. They are used for cross-calibration and the relative ostrich shell biostratigraphy. Further information can be found in Pickford and Senut (2000/1999) and references therein. For the relative biostratigrapy numerous different mammals have been used to 'calibrate' the ostrich shell stratigraphy (see for further information also Pickford et al. 1995, for example for the Early Miocene Gomphotheriidae (extinct group of proboscideans related to modern elephants), Macroscelidea (Elephant shrews, also called jumping shrews or sengis)).

Pickford, M., Senut, B., & Dauphin, Y. (1995). Biostratigraphyof the Tsondab sandstone (Namibia) based on gigantic avian eggshells. Geobios, 28(1), 85-98.

We added in Line 89-93:

"In general, the ostrich shell biostratigraphy is linked to intracontinental correlations derived from fossil mammals (Pickford and Senut, 2000). The catch is that only the oldest shells are 'dated' to 16-20 Ma (Aepyonithoid, Senut, 2000; Pickford et al., 1999; Pickford et al., 1995), whereas the ensuing eight ostrich species are arbitrarily assigned to 2 to 3 Myr long periods (Senut, 2000) without any direct age control."

Unfortunately, one must acknowledge that the detailed description of the dating or relative dating and the 'dating' behind it are only very inadequately presented and carried forward by many references.

L20-24: please connect the sentences to show that it is U/Pb laser ablation that now allows to date the calcretes/silcretes

→We corrected and modified these two sentences to: Line 20-23 "The widespread occurrence of calcretes and silcretes in the Namib Desert and the novel application of U-Pb laser ablation dating technique on sil- and calcretes makes it possible to date important phases of landscape stability and to retrieve critical paleoclimatic and -environmental information on desertification and its paleoclimatic variability."

L28: surely calcretes did not only occur in the Pliocene?

→We added: "... at our sampling site"

L32-34: repetition of desert and arid environments. Delete one of them.

→ corrected accordingly

L40-41: Rephrase: the calcretes are not only present in the incised valleys, this is just where they are exposed. The few drillholes found them everywhere in the Namib/Kalahari

→We corrected to: " ...surface cover and are outcropping along deeply...."

L53-55: "One of ..." and then you mention two calcretes. Confusing! Please rephrase

→We corrected to – Line 53-55: "Most prominent calcrete formations are related to calcretes capping the Karpfenkliff Conglomerate of the Kuiseb Canyon in the Central Namib and the Kamberg Calcrete Formation (Fig. 1, Ward, 1987)."

L58: delete "within this formation"

→ corrected accordingly

L65: replace "Etosha Pan" by Kalahari Group sediments

→ corrected accordingly

L67/68: the growth rate of the calcrete maybe small but often it will be faster than the temporal resolution of the U/Pb method (as you correctly state later in L71-73)

→We corrected to Line 67-68: "The variable growth rate makes it difficult to obtain individual ages from multiple generations of..."

L68: replace "is" by "can be"

→ corrected accordingly

L82: again, the calcretes do not form in the valleys, they are everywhere, they are only nicely exposed in the valleys

→corrected to: ".... landscape features (i.e., cliffs) outcropping along..."

L96: define acronym TCN at first use

→ corrected accordingly

L144: The order seems odd: should the Precambrian basement not be mentioned first (as the oldest part)?

→We corrected and modified to – Line 147-148: "..sedimentary units (Fig. 2) resting on the Namib Unconformity Surface of Precambrian age (NUS, Ward, 1987; Miller, 2008), consisting of basal breccias from Precambrian basement,…."

L180: delete "occurring"

→ corrected accordingly

L193: please explain in more detail what Diamantornis is

→ As mentioned in brackets, Diamantornis corbetti is a specific fossil ostrich shell which was used by Pickord and Senut (2000) to assign a relative age to the Tsondab Aeolianites (based on their biostratigraphy) which they and Miller (2008) correlated to the Karpfenkliff Conglomerate formation. For further details we provided references to the ostrich shell biostratigraphy. We added Line 198: " …(fossil ostrich shell)…"

L236: delete "and forcing"

→ corrected accordingly

L268-269: how? by drilling?

→As mentioned in the manuscript Line 271-276: "DWA98008 and DWA980021 (Site 7 and 19) are located next to small gullies running from the north side of the Carp Cliff mesa. At these sites, Van Der Wateren and Dunai (2001) collected shielded samples 5 m below the terrace surface. Van Der Wateren and Dunai (2001) sampled rounded pebbles from the ceilings of overhangs to ensure that the measured 21Ne concentrations were derived only during hillslope and fluvial transport to their present site and not from subsequent exposure at the sampling site."

We added an extra citation (Van der Wateren… instead of we) to avoid misunderstanding. Van der Wateren & Dunai (2001) sampled shielded samples from ceilings of overhangs which are located 5m below the terrace surface at the canyon rim/wall.

L281-304: nice description of calcrete formation but some of it was already discussed above. Maybe delete there

→We checked both paragraphs and slightly shortened information on calcrete formation in the introduction paragraph, which was more or less identical with information given in the respective Calcrete Formation paragraph. We delete from the introduction (former Line 48-50 "The formation of calcretes is largely dependent on the local climate and the availability of calcium and carbonate ions in the system, produced by weathering and leaching in the catchment.". The other information in the introduction are necessary to introduce the reader to the main topic and supply them with short but significant information on calcrete formation in general.

L305-321: the dissolution of silicon is also aided by higher pH, as common in carbonate-rich environments

→We added the following to Line 316-318: "Additional silica may be enriched in the groundwater due to increased pH (favours the precipitation of calcite and the solution of silica, Goudie 1983, Nash & Shaw 1998)."

L324: add an introductory statement for what analysis Raman was used

→We added Line 367-368: "We use Raman spectroscopy to obtain high resolution images of silcretes and to better characterise the mineralogical composition."

L334-374: most of this description does not belong here. In a methods section, only the method actually used and the sampling techniques should be described, not the problems and limits of other methods. Move this elsewhere, maybe to the introduction/motivation (and shorten it, too)

→We created a new chapter (4. Dating of Sil-Calcretes) and relocated the mentioned parts. Now this chapter introduces general dating techniques and why we use U-Pb laser ablation dating. We additionally shortened this part. Now Line 329-363.

"Quantifying the timing and duration of calcrete formation is quite difficult. Clear stratigraphic relationships with the overlying and underlying sediments are not straightforward, as groundwater calcrete, for example, forms within sediments deposited close to the surface. Numerous studies propose only relative age controls and estimates of the formation time, such as the application of the ostrich shell biochronostratigraphy used for the Namib Group (Pickford and Senut, 2000; Senut, 2000; Miller, 2008). Many attempts have been made to date this type of deposits using radiocarbon 14C (e.g. Geyh and Eitel, 1997), U/Th (Kelly et al., 2000; Candy et al., 2004; Candy and Black, 2009) or U-Pb dating (Rasbury and Cole, 2009; Houben et al., 2020).

Silcretes are enriched in U relative to calcretes and occur in most soils in arid and semi arid environments. Uranium decays to Pb isotopes through a chain of intermediate daughter isotopes, and ages of thousands- to millions-of-years-old samples can be estimated using parent-daughter pairs 238U-206Pb, 235U-207Pb, 234U-230Th, and 238U-234U. The use of a particular isotope pair depends on how old the sample is compared to the half-life of the selected radioactive isotope within the U decay chain (Neymark, 2011; Neymark et al., 2002, 2000). Considering that the samples are 2.85 Ma old or older (Van Der Wateren and Dunai, 2001), the U-Pb method using the parent-daughter pairs 238U-206Pb and 235U-207Pb was chosen to date the samples in this work.

Many studies attempting to date massive cal-/silcretes are hampered by the dilution or averaging effect of bulk analysis and by bias from non-carbonate detrital minerals or secondary reprecipitated carbonate due to diagenesis. The "limestone dilution effect" (as a result of contamination with detrital carbonate components of the host rock, Alonso-Zarza, 2003) or the "averaging effect" (averaging of different phases of mineral precipitation, Candy and Black, 2009; Neymark et al., 2000) are minimised (or even avoided) by the higher spatial resolution of laser ablation compared to bulk analysis techniques. The possible effect of detrital components (e.g. Zircon or clay minerals) on the U-Pb analyses is also neglected, as the signals from these inclusions can be filtered out of the time-resolved analyses.

The conventional method of calculating U–Pb isotope dates assumes that all intermediate daughter isotopes in the 238U and 235U decay chains were in secular equilibrium at the time of formation (Neymark, 2014). This is not necessarily true for calcretes and silcretes due to differences in the geochemical behaviour of parent and daughter elements. The silcretes dated in this study are sufficiently old (> c. 2.85 Ma) to have achieved secular equilibrium (at present), and therefore (almost) all its initial excess of daughter isotopes to decay, or their initial depletion to replenish (i.e. their activity ratios to be equal to 1) ergo a direct measurement of these deviations is not feasible. Therefore, the values needed to correct for these disequilibriums were estimated from previous works (see methodology chapter)."

L408: describe type of equipment (type, manufacturer etc.)

→We added Line 412-413: *"..new noble gas mass spectrometer at the University of Cologne (Helix MC Plus from Thermo Fisher Scientific, further information see Ritter et al. (2021)). "*

L552-554: repetition, delete or shorten

→We delete these two sentences, as they are already mentioned in the text before.

L562-577: are there any correlations between your paleoclimatic events and those discussed by Houben et al. for this period of time? You later discuss the onset of higher aridity at 3 or 3.8 Ma but for the older events, a correlation between what was going on in the Namib and the Kalahari would be interesting, too.

→The paleoclimate reconstruction and discussion of the retrieved record from Houben et al. (2020), reveals unfortunately no detailed information for the Late Miocene and Pliocene time period. Nevertheless, we added the following information to our manuscript – Line 563-564: *"Age information from the Kalahari Basin by Houben et al. (2020) indicated a shift towards more arid conditions since ~12 Ma, which intensified at ~4 Ma (Houben et al., 2020; Miller et al., 2010)."*

L609-611: why should a decrease of precipitation lead to a deeper incision of the river? Sounds illogical! Please rethink! Same applies to L654-655 in conclusions

→According to Molnar (2001), increased aridity leads to different flood frequency with larger magnitude, this change will in turn lead to increased bed-load transport and as such accelerate incision and erosion. Although reduced precipitation and increased aridity sounds counter-intuitive for river or canyon incision, a shift towards intensified aridity could enhance incision and erosion despite decreasing river discharge. Base-level lowering (for example decreasing sea-level) or rock uplift during the shift to more arid climate conditions, will lead to river steepening and incision to adapt the either decreasing base-level or existing rock uplift (Bonnet and Crave, 2003, Cooper et al. 2016).

Cooper, F. J., Adams, B. A., Blundy, J. D., Farley, K. A., McKeon, R. E., & Ruggiero, A. (2016). Aridity-induced Miocene canyon incision in the Central Andes. Geology, 44(8), 675-678.

We added Molnar (2001) and Cooper et al. (2016) as reference to the manuscript.

Reviewer #2 (Remarks to the Author):

General comments

This paper presents an interesting application of the U-Pb LA-ICPMS method to secondary silica within soil from arid to semi-arid environment. This method and application developments could contribute to future studies on these material for the reconstruction of paleoclimate conditions in areas where biostratigraphy is limited. The paper could be improved by discussing some of the complicated issues associated with dating of this kind of material such as: open-system behaviour (uranium mostly), mixing of different generations, mixing of different fluids, disequilibrium correction, and matrix-matched reference material. Each of these issues introduce uncertainties to the final age determination and a discussion on these issues could provide an honest evaluation of the accuracy of the dated material. I therefore recommend the following:

Discuss open system behaviour and potential mixing of different generations by looking at all spot analysis of samples from the same location together on a TW plots (see image below). This can help to highlight samples with either characteristic open system behaviour (shifting to the left) or mixing (wedge-like plot). It could also highlight potential difference in source material or fluids (dissolution source etc.) by looking at initial common-lead composition.

We consider that discussing these issues by combining all analysis in a TW plot and discussing these shifts is only useful if the analysis considered are from a texturally homogeneous and therefore cogenetic domain. This is not the case. Each age obtained and reported was calculated from a group of spot analysis that are parallel to the main layering of the silcrete, and therefore considered to represent one event of silcrete layer formation. As these layers formed at different time, the combined data set looks wedge-like. However, mixing and/or open system behaviour can be only considered if the data points within those discrete layers show scatter or “wedge-like” behaviour.

Concerning the discussion about different source fluids, we agree that evaluating the initial isotope Pb compositions would be very useful. The problem is that only one sample (DWA98008-Silc4 Black Crack) gave a spread in the TW plot where we could actually calculate this value. As this value is in line with a Stacey & Kramers (1975) Phanerozoic common Pb, we find it justified to use this value as an assumed common Pb composition to anchor the regression lines for the rest of the samples. This is explained in the manuscript, lines 396-398. We are dealing with a weathering horizon in the water table over a relatively short period of time. There is no reason to assume that the Pb composition changes measurably. Further, since the measurement points are relatively close to Concordia, a 10% change in initial Pb, for example, would only marginally change the calculated age (within error).

The problems related to different source of fluids and/or mixing of different generations could also be resolved by looking at spot analysis with cathodoluminescence imaging, different generations have distinct luminescence (even with gray scale SEM CL). This is essential step before dating of such texturally complex material, but it can also be done after analysis is done and will be convincing to see for each sample where the spots where analyzed. Is it possible to show the area with spot analysis in Figure 4A with CL imaging? See for example paper by Paces et al., 2010 (Figure 2).

We used images from a digital microscope, in which we could see the fine layering, to choose the locations of spot analyses, so we are quite confident about our textural control. The Raman mapping imaging that we report already shows what you suggest by performing SEM Cl imaging. In the Raman maps we can see that the discrete silcrete layers are approx. 2 to 10 µm wide. We tested and checked how small we could go with our laser spot sizes and we considered that the lowest size we were comfortable with was the size we used, 50 µm. This necessarily means that our ages are mixed ages of several layers, but we consider that the data gathered this way is still meaningful and useful. We have added digital microscope images with spot locations of several samples as supplementary material.

The problem of disequilibrium correction is the most problematic in my opinion. It is not appropriate to use some value (e.g. 1.75) that was used in other arid environment for the correction. Did the authors tried to do high-precision analysis of 234U/238U of the material? LA-ICPMS of the 234U/238U ratio is very difficult and it may look like it is in secular equilibrium… It is also possible to analyze younger sample from the area and use it as representative (see Chaldekas et al 2021). Another option is to take a range, between 1 and 2 and report the age range or the uncertainties on the age as a result of that range.

We do agree that the problem of disequilibrium correction is the a problematic one but not a huge one, as a deviation of 1 in the $[^{234}U/^{238}U]_0$ (e.g: from 1 to 2) would imply in total an age shift of 0.354 Ma (calculated with following Wendt and Carl 1975). But still, as accuracy is compromised it needs to be addressed. We did not try to do high precision analysis of the $^{234}U/^{238}U$ because our youngest sample is 2.85 Ma. As 234U half-live is c. 0.245 My we consider that too much time has passed (almost 12 half-lives) to be able to detect (with the techniques at hand) any traceable excess or depletion of ^{234}U. We also thought about Chaldekas et al. 2021 approach, but again, our youngest sample is 2.85 Ma… We consider that the last option that you proposed is what we actually did. As far as I understand, you are proposing to consider an $[^{234}U/^{238}U]_0$ of 1.5 ± 0.5 and consider this uncertainty into the final ages. This is what we did, but with a value of 1.75 ± 0.32, which we think is a more realistic value and uncertainty, and added this extra uncertainty to the systematic uncertainties of the reported ages. It's true that this value is an average on several works (3 actually), but the data from where it is averaged is from similar materials in similar environmental conditions.

In addition, I have several suggestions for improving the text:

Line 18-21 – first paragraph of abstract is very generic and does not provide the context for the main issue of this paper to provide a methodological approach for dating material associated with landscape stability.

→ We corrected and modified the abstract according to the reviewers comment and the comment of the associated editor. Reply and changes see below at the associated editor comment and reply section.

Line 25 – what is the range in size of these structures?

→We added the following in Line 24*: "Microscale silcrete (max 8 mm) …."*

Line 28 – explain TCN

→We added the following Line 28: *"Terrestrial Cosmogenic Nuclide (TCN).."*

Line 32-38 – maybe also add "discuss several important issues associated with LA-ICPMS U-Pb dating of secondary silica…."

→We added/modified lines 31-34: *"This study shows the feasibility of applying U-Pb laser ablation to groundwater sil- and calcretes, discusses several important issues associated to this technique and opens up the possibility of dating numerous sedimentary sequences containing sil- and calcretes in arid environments."*

Line 44-45 – it is unclear why these "sil- and calcretes indicate relatively long periods of landscape and climate stability during their formation"

→We modified Line 43-45: "*these sil- and calcretes are also thought to indicate relatively long periods of landscape and climate stability during their formation (Goudie et al., 2015)."*

We also added an additional reference stating that calcrete formation is thought to be indicative for relatively long periods of landscape stability. Further below we explain more in detail and support this hypothesis of relative long periods of stability with our dataset.

According to Goudie 2015: "The calcrete formed under semi-arid conditions over a long period of relative landscape stability, perhaps half a million years in length."

Line 52 – can you explain in a few words what is "per-ascensum hypothesis" exactly?

→We added the following Line 52-53: *"…., which are formed mainly by evaporation from the capillary fringe or below the water table due to changing CO_2 level (Goudie et al., 2015)."* More detailed information on the formation processes is given in Chapter 3 Formation of Calcretes and microscale Silcretes (Line 286-327).

Line 56 – how do we know that the secondary Si is synchronous with calcrete formation in the Karpfenkliff conglomerates? Could it form after conglomerate deposition by fluid infiltration?

→Silcretes can also formed by infiltration after calcrete formation, however, much wetter climates are necessary. Under these conditions most of the calcrete would have been eroded and or leached. Due to the occurrence of silcretes as small shells or as crack fillings and not as silcretes as described for regions in Australia, we interpret the microscale silcretes as being derived from pressure solution and reprecipitation processes during calcrete formation. Further information can be found below in the manuscript Chapter 3 Formation of Calcretes and microscale Silcretes (Line 286-327).

Line 61-63 seems to be important context for this paper…could be extended to include a bit more details?

→We added Line 63-64: *"The first two dating methods are limited to ~45 kyr or 500 kyr, respectively."*

Line 69 – based on the results of this study it is not really "clearly pre-dating" the major canyon incision…five dated samples have ages that overlap with TCN ages. Following that, is it possible that they represent fluid infiltration during incision?

→ We modified and deleted 'clearly' Line 70: *"Although calcrete formation pre dates the.."*

Line 317-318 could be nice to see these observations with thin-section images of your samples.

→ We have added digital microscope images with spot locations of several samples as supplementary material. See answer on comment above.

Line 365-366 this is not necessarily true, especially if initial 234/238 activity ratios are high.

→ We modified the manuscript to Line 360-361: *"…and therefore (almost) all its initial excess of daughter isotopes to decay, or their initial depletion to replenish…"*

Line 383 it seems like you are using NIST glass as your primary and secondary reference material? It is important to discuss issues related to differences between your samples and these reference material... Could you evaluate uncertainties related to downhole fractionation and/or plasma related fractionation between your material and NIST? This is another potential issue to discuss related to the methodological development of these type of analysis.

In recent years, we have extensively studied the effects of matrix dependence - plasma and laser related in Frankfurt. A synthesis of these results is in progress, but the lack of well characterized reference material and the complexity of the subject, delays this. However, we have data from the matrix effect between carbonates and NIST glass (Montano et al. 2022) showing that this is in the range for 206U/238U at 1-3%. (optimized tuning of the plasma, ablation at low fluence). It can therefore be assumed that the matrix effect for $^{206}Pb/^{238}U$ between silcrete and NIST glass is less than 2%.

We checked the ablated spot depths from which we conclude that the drill speed of the laser was similar between silcrete and NIST. So, we not assume measureable differences in downhole fraction.

Line 395-405 see comment above. It is not appropriate to use this value to correct for disequilibrium of your samples.

→See answers to these comments above

Associate editor decision: Publish subject to minor revisions (further review by editor)

by Daniela Rubatto

Public justification (visible to the public if the article is accepted and published):

Dear Dr Ritter and co-authors,

I have read your response and I am satisfied that most of the reviewers' comments have been addressed and the manuscript improved accordingly.

From an editorial point of view, I have a few more comments:

- The abstract is rather repetitive and not factual, especially the first part. Please improve by reorganising with a short introduction to state the significance of the work, samples and methods, main results (report actual data) and interpretations, wider implications.

- Please add a table listing sample names, GPS location, field observations, petrography.

- You analysed 4 samples and obtained 12 dates, please explain better the different textures dated and show them in figures if possible.

Please proceed to the revision addressing all comments.

Kind regards

Daniela Rubatto

Associate Editor

Dear Prof. Daniela Rubatto

thank you very much for your work, processing the entire review process. In the following we will outline every change made, based on your comments and where appropriate provide suitable rebuttals. The line numbers we note in our attached responses refer to the revised version of our manuscript, now attached. Minor spelling and grammatical mistakes were corrected and not specifically marked in the manuscript.

Kind regards,

Benedikt Ritter

University of Cologne – Institute of Geology

Abstract:

We modified the abstract according to the comments of the associated editor as follows:

"The chronology of the Cenozoic 'Namib Group' of the Namib Desert is rather poorly understood and lacks direct radiometric dating. Thus, the paleoclimate and landscape evolution of the Central Namib Desert remains imprecise, complicating the detailed search for global and/or local forcing factors for the aridification of the Namib. The widespread occurrence of calcretes and silcretes in the Namib Desert allows to apply the novel application of the U-Pb laser ablation dating technique on sil- and calcretes, to date important phases of landscape stability and to retrieve critical paleoclimatic and environmental information on desertification and its paleoclimatic variability. Microscale silcrete formation (max. 8 mm) due to pressure solution by expanding calcrete cementation provides the opportunity to date multiple phases (multiple generation of silcrete as growing layers or shells) of silcrete formation. Groundwater sil- and calcrete formation occurred at our study site during the Pliocene, a period of relatively stable climate and landscape conditions under semi-arid to arid conditions. Terrestrial Cosmogenic Nuclide (TCN) exposure ages from flat canyon rim surfaces indicate the cessation of groundwater calcrete formation due to incision during the Late Pliocene/Early Pleistocene and mark a large-scale landscape rejuvenation due to climate shifts towards more arid conditions in the Pleistocene, which can be connected to global climate patterns. This study demonstrates the feasibility of applying U-Pb laser ablation to groundwater sil- and calcretes, discusses several important issues associated with this technique and opens up the possibility of dating numerous sedimentary sequences containing sil- and calcretes in arid environments. In particular, the use of silcretes (as described above) reduces potential effects of detrital components and bulk-signal measurements by using massive calcretes. Our study redefines and improves the generally accepted Late Cenozoic chronostratigraphy of the Namib Desert (Miller, 2008)."

Table:

We added a table with sample data, including Sample ID, Locality, Type of Sample, Long., Lat., and additional remarks. Note that more detailed information about the sampling sites and the samples are given in the supporting information.

TCN Exposure Dating

Sample ID	Locality	Type	Longitude [°]	Latitude [°]	Remark
DWA98006Etch2	Carp Cliff	Quartz clasts	-23.339	15.744	amalgamated sample of 40 clasts
DWA98007Etch	Carp Cliff	Quartz clasts	-23.339	15.744	amalgamated sample of 40 clasts
DWA98008Etch2	Carp Cliff	Quartz clasts	-23.331	15.746	amalgamated sample of 40 clasts
DWA98021Etch	Carp Cliff	Quartz clasts	-23.332	15.745	amalgamated sample of 40 clasts
DWA98013Etch2	Kamberg Cliff	Quartz clasts	-23.608	15.580	amalgamated sample of 40 clasts
DWA98014Etch	Kamberg Cliff	Quartz clasts	-23.608	15.580	amalgamated sample of 40 clasts

U-Pb LA-ICP-MS Dating

Sample ID	Locality	Type	Longitude	Latitude	Remark
DWA98008- Silc3	Carp Cliff	Silcrete on clast	-23.331	15.746	Silcrete with distinct layering
DWA98008- Silc4	Carp Cliff	Silcrete on clast	-23.331	15.746	Silcrete with distinct layering
DWA98008- Silc7	Carp Cliff	Silcrete on clast	-23.331	15.746	Silcrete with distinct layering
DWA98008- Silc8	Carp Cliff	Silcrete on clast	-23.331	15.746	Silcrete with distinct layering

Sample Description:

We additionally provide a pdf with microscope images and U-Pb LA-ICP-MS spots in the supporting information showing the different dated silcrete layers. This data was mentioned in the response to the reviewers but not uploaded. Please find it attached to the upload of the revised version (including supporting information).

We added in Line 445: "…from various silcrete layers".