Response to referees – ESurf-2019-54

Dear prof. Hovius,

Thank you and the associate editor for the editing advice. We have inc
comments suggested – see correction in the attached revised manuscript.

Regarding the mentioned citation. We agree with reviewers and the assoc
publication (Sinclair et al., 2018; *geology*) is cited (see line 45).

We are happy to submit the final version of the manuscript for publication ir

On behalf of all the authors, I would like to thank the entire editorial staff an
health during these times.

Sincerely,

Michal Ben-Israel

Michal Ben-Israel

Response to Reviewer no. 1: Taylor Schildgen

General comments:

Ben-Israel and co-authors analyze stable (21Ne) and unstable (10Be, 26Al) c
Miocene sediments from the NW Arabian plateau to calculate paleo-erosio
"modern" rates obtained from bedrock outcrops. They interpret an appr
concentrations to result from erosion rates that were 2x faster during the ea
be reasonable considering evidence for a wetter climate in the region at th
this work illustrates the unique ability of the stable cosmogenic nuclide 2
averaged over relatively short time intervals (if we can consider 100s of kyr s
sedimentary deposits; such information cannot be obtained with 10Be or 2
their consideration of various potential complications of their data – post-
elevation through time, and how different types of detrital material (quart
have experienced very different pathways to the final deposition site. I also
types of detrital material to assess the possibility of 21Ne inheritance.

We thank prof. Schieldgen for these comments.

But I see several areas that require improvement. Most concerning for me
history constraints, which I don't find very convincing, but are critical for th
difference in measured 21Ne concentrations between modern and m
explained either by a change in elevation through time or a change in erosi

This is a very good point and one that has been similarly made by the other
this uncertainty in the original manuscript, we agree that the discussion into
rates should have been done more circumspectly. We now include additiona
paleo-elevation and the calculated production rates. In addition to the s
evidence we now also calculate the possible elevation using a moderate co
to account for the uncertainty in paleo-elevation as well as basin scaled pa
consider an elevation uncertainty range of 500-1000 m a.s.l (see lines 250-

with erosion rates mentioned only in the final part of the manuscript. As m hyper-arid environment, even small changes to erosion rates are significar (lines 333-343) and conclusions (lines 377-381).

I'm also concerned by the small number of samples obtained from the possibility that the rates reported are not representative of modern rat outcrops lead to a wide range of erosion-rate estimates). Are there any oth have been reported that can be used to corroborate the results present modern erosion-rate estimate wasn't made from modern detrital sands ir would not be from exactly the same drainage area as the early-mid Miocen

Unfortunately, the area where A. Matmon and Y. Avni collected the moderr to access these days, and it is not possible to collect any more samples. H manuscript, there has is an extensive body of work looking into rates of e surfaces in the hyper-arid Negev desert (e.g., Boroda et al., 2014; Fruchte 2009; Matmon et al., 2016; Matmon and Zilberman, 2017). We now refere (see lines 307-309).

I think the difference between the detrital quartz sand and detrital c emphasized in the final interpretations/conclusions of the paper. It seems th not considered in the final interpretations due to the possibility that the periods of deposition and exposure prior to the last deposition, hence it cor the reason that the erosion rates for the quartz samples are not reported, explicitly rather than leaving it for the readers to infer; still I think the erosi But rather than making it seem as if those samples were just a waste o emphasize how in recycled sediments, inherited 21Ne can be a real probler measuring different types of detrital material to assess this possibility! Tha than hidden.

That was by no means our intention. Inherited cosmogenic 21Ne is one c

l. 36-37: Older landscapes are transient? Odd wording. Also, this sentence
previous ones. You've discussed river systems and sediment archives, now
landscapes themselves? Be more precise and focused.

We have changed the phrasing in this section. See lines 35-46.

l. 38: Okay, so the focus is on quantifying erosion rates from surfaces? This

See previous comment.

l. 41: If the focus is on erosion, don't change the terminology here to
encompasses much more than just erosion.

See previous comment.

l. 43: Now you've explained that the focus is on sedimentary deposits,
suggest rewriting this whole paragraph with a clearer focus on what inform
reader. What is the main problem, why is it difficult to address, how are yo

See previous comment.

l. 51: Wouldn't it be the other way around, i.e., the Afar plume leads to magn
influenced tectonics?

We have changed the phrasing in this section. See lines 56-65.

l. 67-69: This means that the deposition associated with the river started
interpret only the upper part of the Hazeva Formation to be associated with
deposition started after 20 Ma? Please clarify.

The sediments in lower part of the Hazeva formation are local and were not
(unlike the upper part of the section). We have now clarified this in the tex

l. 99-101: How is this history of the quartz sand known? If this history
explaining differences between 21Ne measured in quartz vs. chert, then a

This paragraph has been moved and modified. See lines 75-95.

l. 109: How deeply shielded were the collected samples? Deeply enough
21Ne production?

This question is thoroughly discussed in the discussion section. We now ref
116).

l. 113: I suggest "accumulated cosmogenic nuclides only during exhum
experienced the full sedimentary cycle also accumulated nuclides during ex

We accept this correction. See line 127.

l. 156-157: Is this because you assume the U and Th are equally distributed
reasonable assumption?

U and Th are most likely found in inclusions within the crystal lattice. The U/
is determined by the age of the rock and the environmental conditions
metamorphosis). It is reasonable to assume that is would the same or simil
as they all share the same lithology.

l. 212-217: Don't assume that your readers remember that EJC5 and EJC3
from the "in situ" outcrops, remind us.

Maybe this comment can be clarified as the first part of the paragraph de
246-259).

l. 214-215: This detail concerning the scaling of production rates belon
discussion.

We now include these details in the methods section (see section 3.3, lines

l. 223-224: I don't see the added value of reporting equivalent exposure tim
"simple exposure time"), given that you are mainly interpreting the measur
erosion rates. Or is the goal to give readers a sense of the averaging times

l. 237-239: A bigger overview map that includes the Suez rift in addition to t
mentioned here would be very helpful.

See our revisions to figure 2, and our comments to this there.

l. 237-242: These uplift constraints are crucial for your interpretation of whe
samples show a faster erosion rate compared to today or reflect a similar ero
paleo-production rate. Given their importance, some more details on thes
very helpful. Although I have not checked each of the references in detail,
referenced the Wilson et al. (2014) interpretations. Despite many reasons
uplift histories from river profiles should be considered suspect, their interp
that most of the modern elevation gain occurred since 20 Ma, and it looks
since 10 Ma (see their Fig. 17). For that reason, I don't agree at all with your s
to presume that the western flank of the Arabian Peninsula (or the NW edg
area) reached its current elevation prior to the initiation of the Hazeva fluvi

As is mentioned in our answers to the general comments, we agree with t
regarding the elevation of the Arabian Plateau during the Miocene should h
now provide additional evidence to support our assumption of the paleo-e
significant uncertainty for this (see lines 250-289). Regarding Wilson et al. (2
figure 21, the central part of the Arabian plate appears to be stable ~20 Myr
tip).

l. 255-258: I can guess why you do not mention erosion rates from the quart
it has inherited 21Ne – but it seems like an oversight. I suggest to not "h
emphasize how recycling of quartz sand can lead to incorrect results.

As is mentioned in our answers to the general comments, hiding this aspec
We refer to the possible inheritance in quartz throughout the manuscrip
section). The discussion about the possible effects of it is slightly beyond the
is referenced to (see Ben-Israel et al., 2018 for further reading).

l. 281-287: Mostly I've been able to work out myself whether you are refe
uplift up until now, but in this section in particular I cannot follow your me
ideally throughout the manuscript, specify which one you are referring to

paleo-elevation, still seem very slow. How do rates of 4 to 12 mm/kyr
measured from similar environments today? (Incidentally, I realize I'm assu
is relatively low, but it would be helpful to actually show a slope/relief map

that's the case).

This section has now been revised – see out previous comments and lines 3

Figure 2: As mentioned above, a broader overview map would be very helpf
the bottom? Highlighting or circling him/her in some way would make it eas
this photo. Likewise, in 2C, is that a dog?

Figure 2 has been revised and now includes a more zoomed overview map
additionally now includes clear marking of a human (Dr. Avni) in 2B and dog

Figure 3: Given the overall focus on erosion rates, I find it odd that the ca
shown in this figure. Why not use those instead of the effective exposure a

With the addition of Table 2, figure 3 no longer includes exposure ages (or

Editorial comments:

l. 35: always specify what you mean after "this", e.g., this lack of informatio

Corrected. See line 38.

l. 64: "comprise" rather than "compose"

Corrected. See line 78.

l. 71: I'd suggest "disruption" rather than "dismantlement"

Corrected. See line 71.

l. 210: Please refer to “denudation” or “erosion” rates throughout, not “rate
is unnecessarily vague.

We have corrected this in the referenced line (245) and throughout the ma

l. 221: lots of needless words here, please shorten to “erosion rates betwee

This section has been revised. See lines 307-309.

Response to Reviewer no. 2: Anonymous Referee

Ben-Israel et al. present 10 new in situ-produced 21Ne concentrations from
the pre-Dead Sea rift Hazewa River located in southern Israel. Where possi
26Al concentrations are provided for the same sample material. The data fro
is used to determine Early-mid Miocene erosion rates.

General comments:

The manuscript is generally well written and reads well. However, there a
manuscript which need to be clarified and improved:

We thank the reviwer for these comments.

1. The interpretations of the data are relatively strong given the amou
manuscript stands right now, it is not clear to me if the given interpretation
more data is available. For instance, the nuclide concentrations of the tw
with continuous erosion of a landscape. In order to investigate the probl
analyzed. However, knowing that this is easy to say and that cosmogenic n
a request for more data is not at the right place. Instead a request to tor
made.

As the first reviewer made a similar point, I include here the answer given t
where A. Matmon and Y. Avni collected the modern chert nodules is very
and it is not possible to collect any more samples. However, as we point to i
an extensive body of work looking into rates of erosion of chert and quartz
Negev desert (e.g., Boroda et al., 2014; Fruchter et al., 2011; Matmon et al
Matmon and Zilberman, 2017). We now references rates from these studie

2. The method section needs to be set-up in a logical and rigorous way (se
The different methods applied need to be described in more detail. The
parameters used explained. In general, the order of the presented inform
make understanding easier. Concise wording and details in tables and figur

Concentrations and erosion rates could also be investigated with “banana
nuclides (e.g., Ivy-Ochs and Kober, 2008). Such plots would help to visualiz
1. In addition, the use of erosion rate in combination with the integration
reader.

Unfortunately, applying a ‘banana-plot’ type of diagram will not help in inv
The Miocene sample presented have been buried for extensive per
concentrations of cosmogenic 26Al and 10Be do not represent burial time,
a steady state determined by post-burial (muonic) production. We did in
changes in steady state concentration with time (see fig. 4).

Unfortunately, I am not an expert in the measurements of cosmogenic 21N
reliability of the presented measurements are not assessed in this review. T
another reviewer. For instance, it is not clear to me what happens to 21N
when leached at 150_C (see line 118-9)? This question comes up as just
closure temperature for 21Ne in quartz is mentioned to be 90 - 100_C. As c
used sample preparation may be valid. Clarification is needed.

As the manuscript suggests, 80-90°C is the closure temperature of Ne in quar
The fractional loss of Ne due to diffusion over a 1.5 hour timeframe is insign
we now include a more rigorous examination of possible diffusion from the
made by the third reviewer (see lines 106-112 & 193-203).

Detailed comments:

<u>Abstract</u>

L11-14 The abstract jumps to much into details which are not relevant fo
more sense to give the reader a reason why this study was done and what t

The abstract has been revised (see lines 25-27). However, we think a sh

L21-23 Long sentence not easy to understand. What does the even mean? A
nodules not used for the bedrock erosin? Needs clarification.

This part has been revised. See lines 21-25.

L24-25 From what material are the "rates calculated today"? And what d
today"? As mentioned in the general comments, it might be bette
concentrations rather than erosion rates.

This part has been revised. See lines 21-25.

1 Introduction

L37-40 This sentence is not easy to understand for a reader not familiar
produced cosmogenic nuclides. Can this sentence be extended? What is the
to the half-lives?

The concept of half-lives is well known in the field of Earth Sciences and we
is beyond the scope of this manuscript. Further information can be found in

L44 ": : :parts of the: : :"

Corrected. See line 48.

L46-48 The introduction comes to a quick end. An outline of the study set-up
would be helpful for the reader. What kind of samples do you analyze with
questions to be answered with this study?

The introduction has been revised. See lines 50-54.

2 Geological Background

L49 This chapter would gain a lot if called "Study Area" and start with a ge
and what deposits are present. Then move over to the geologic backgrour
request to change Fig. 2 to Fig. 1 and vice versa.

The methods section has been revised (See section 3.3, lines 152-156). explanation on Neon-21 accumulation in sedimentary cycles (see lines 98-1 parts of this comment have more to do with writing style choices than subs name of this section in its current format.

L90 Now start here: 3.2 Sampling Strategy?

See previous comment.

L134 How is the chemistry blank correction performed? What are the calculations?

Blank correction is a commonly performed procedure and further expla performed is not in the scope of this manuscript. Regarding erosion rates va 156.

4 Results

L143-5 This sentence needs clarification. What is exactly 21Neex?

In addition to the explanation in Table 1, we now include the formula for see lines 166-167.

L160-1 What is about differences in 21Neex in chert and quartz samples? C the 21Necos concentration?

We are not sure what the reviewer meant in this comment. However, if the cosmogenic 21Ne concentrations (or 21NeEx concentrations) between qu presented in Table 1 and explained in the next line below.

L178-9 Difficult sentence to understand. Please clarify.

Al/Be ratios are commonly used for burial ages and as mentioned in the discussed in the Discussion section and is further explained there.

L215 Are these reported values correct? Please cross-check.

The values used for the calculation were correct, and the mistake made in t
lines 152-156).

<u>Figures</u>

Fig. S5 - S11: Please label x- and y axes.

Axes labeled. See appendix.

<u>Tables</u>

Table 1: Please cross-check units.

Units have been checked and corrected. See Table 1.

Response to Reviewer no. 3: Marissa Tremblay

In this discussion paper, Ben-Israel et al. present new neon isotope measur
chert pebbles deposited by the Hazeva River, which drained the Arabian Pe
as well as from modern eroding outcrops where the chert pebbles were
compare apparent erosion rates calculated from cosmogenic 21Ne conc
conclude that the erosion rates recorded by the Miocene fluvial deposits
modern. They attribute higher Miocene erosion rates to higher uplift rate
Arabian Peninsula at that time.

Major comments:

In general, I think the approach taken in this paper to quantify paleo-erosio

We thank Dr. Tremblay for this comment.

However, I am concerned that the uncertainties in the paleo-erosion ra
underestimated, and that therefore the conclusions about higher erosion
overstated. Specifically, the authors assume that the elevation during Mioc
21Ne was 1000 km. It is unclear to me if this is the assumed elevation of th
and that the authors then assume that the majority of cosmogenic 21N
sediment transport? Or is 1000 km accounting for sediment transport and
some catchment-integrated value between where the pebbles we
Furthermore, it appears that the authors do not give this paleo-elevat
calculation of exposure times or minimum erosion rates. I suspect that
reasonable elevation uncertainty of something like ï´C´s 500 m, that their pa
entirely with their modern erosion rates. Because the choice of a paleo-ele
on the calculated paleo-erosion rates, there needs to be (1) a more deta
paleo-elevation the authors use represents, and (2) an uncertainty associ
incorporated into the calculated paleoerosion rates.

This is a very good point and one that we now incorporate along with othe

degassing temperatures in the laboratory for the chert samples than the
suggest that the chert has a lower thermal sensitivity. Altogether, this makes
be contributing to the observation that the chert pebbles have lower cosm
than the quartz sands. Given this, I think a discussion of the potential role
added to the text. C. These seem like high temperatures, but in the Arabia
regularly exceed 40 C in the summer months and rock temperatures can ce
70 C (e.g., McFadden et al., 2005). Additionally, the fact that the auth
temperatures in the laboratory for the chert samples than they do for the qu
chert has a lower thermal sensitivity. Altogether, this makes me think that d
to the observation that the chert pebbles have lower cosmogenic 21Ne co
sands. Given this, I think a discussion of the potential role of neon diffusion

Two very interesting points are made here regarding (1) the 'typical grain
(2) the temperatures reached in the Negev Desert. We have revised the man
role of Ne diffusion, and our answers are as follows:

(1) We do not know with certainty whether or by how much the kinetic pa
that of quartz. This uncertainty and its possible implications are now discus

(2) While it is very true that air temperatures get very high in the desert and
dark rock (such as cherts) can get up to even higher reaching 60-70°C ar
However, it is crucial to remember that the Miocene samples presented ar
likely to be exposed to direct solar radiation for extended periods. In suppo
chert samples did not exhibit any visible cracking or fractures commonly id
(see lines 2198-203).

Minor comments:

Figure 1 should have a box indicating the location of figure 2A.

Lines 255-268: The calculated paleo-erosion rates overlap with the upper end
even without my concerns about the paleo-elevation uncertainty being a
similar statements elsewhere) overstates the significance of the authors find
appropriate to say that the calculated paleo-erosion rates allow for the pos
in the Miocene.

This part has been rephrased. See lines 325-335.

Lines 281-283: Here and elsewhere, do you mean rock uplift or surface uplif

This has been clarified. See lines 345-348.

Supplement: There needs to be some text explaining what is provided in e
tabs as well as a caption provide for each of the supplemental figures. It's
need all of the different neon three isotope plots and why they are in the o
in. This could be cleaned up by having one three isotope plot for the Mioc
modern samples, and using different symbol shapes to represent the differe

We have made corrections to the supplement based on these comments. S

The revised manuscript with the author's changes included

Early-mid Miocene erosion rates ~~measured in~~ Dead Sea rift Hazeva River fluvial che cosmogenic ^{21}Ne ~~in fluvial chert pebbles~~

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Abstract. ~~The Miocene Hazeva River was a large fluvial system >100,000 km^2) that drained the Arabian Plateau and Sinai Peninsula during the Early-Mid Miocene. It was established after rifting of the R Plateau during the Oligocene. Following late Miocene to early Pliocen Sea Rift, the Hazeva drainage system was abandoned and dissected divides on either side of the rift.~~ In this work, ~~W~~we utilize~~d~~ a novel ^{21}Ne measurements in chert to compare

Rift, the Hazeva drainage system was abandoned and dissected, result on either side of the rift. We find that modern erosion rates derived fr and ^{10}Be in exposed *in situ* chert nodules to be extremely slow, betwee between modern and ~~paleo~~ paleo-erosion rates, measured in chert peb as cosmogenic ^{21}Ne was acquired partly during bedrock ~~exhumation~~ transport of these pebbles in the Hazeva River. However, even maintained transport along this big river, ^{21}Ne ~~concentrations~~ exposure in Miocene cherts are generally ~~lower~~ shorter (range between $\mathbf{0}^{+5}_{-0}$ kyr~~.97±1.39x10^6 atoms/g SiO$_2$~~) compared to exposure times calcu ~~measured~~ in the currently eroding chert nodules presented here 378±76~~2.10±2.43x10^6 atoms/g SiO$_2$~~kyr) and other chert surfaces cur environments. Shorter ~~^{21}Ne concentrations~~ exposure times in Miocene ~~minimum~~ paleo-erosion rates, ~~that are at least twice as fast as rates ca~~ attribute ~~these faster erosion rates~~ to a combination of continuous sur wetter climatic conditions during the early-mid Miocene.

1. Introduction

Tectonic and climatic conditions control geomorphological processes

climatic conditions that prevailed. This lack of information is
preservation potential of older sediments landscapesin fluvial systems,
these tend to end up either deeply buried at depositional basins or rec
process (e.g., Anderson et al., 1996; Guralnik et al., 2011; Schaller et a
of transient landscapes.Cosmogenic nuclides have long been applie
diverse geological settings (e.g., Bierman, 1994; von Blanckenburg,
when geological circumstances do allow for the preservation of sl
sediments, erosion rates prior to the Pliocene cannot be quantified wit
cosmogenic radionuclides (^{10}Be and ^{26}Al) due to their half-lives
accordingly; Ivy-Ochs and Kober, 2008). Unlike their radioac
cosmogenic nuclides have the potential to quantify rates of surface pro
Cretaceous of surface processes significantly older than com
radionuclides (Balco et al., 2019; Ben-Israel et al., 2018; Dunai et al.,
Sinclair et al., 2019). Here, we apply stable cosmogenic ^{21}Ne to sedi
early-mid Miocene (~18 Ma) by a massive fluvial system that dra
Peninsula and Sinai into the Mediterranean prior to the subsidence of
Dead Sea transform (Garfunkel and Horowitz, 1966; Zilberman and
the time of exposure during erosion and transport of Miocene cher
Hazeva River and compare it to exposure times of chert that has been
(~10^5 yr). Through this comparison, we compare The erosion rates of
fromduring early-mid -Miocene to those measured today in hyper-arid
examine the possible influence ofriver sediments open a window int

of the Afar plume uplifted the Arabian Peninsula has been uplifting present elevation of ~1km (e.g., Feinstein et al., 2013; Morag et al., 20 a result of this uplift, widespread erosion denudation followed, andfoll truncation surface developed in the northern Red Sea and the south older strata down to Precambrian formations depending on the preexi 2012). Following these events, Dduring the early-mid Miocene, the up a newly established fluvial system, termed the Hazeva River, which f the uplifted eroded terrains towards the Mediterranean Sea, and >100,000 km^2 (Garfunkel and Horowitz, 1966; Zilberman and Calvo, fluvial system operated until the subsidence of the Dead Sea Rift, duri Pliocene, brought on a dramatic change in morphology, which led to th fluvial system, the last of its kind in the region (Garfunkel, 1981). Hazeva River was abandoned, and new independent drainage system the Dead Sea Basin (Avni et al., 2001).

At present, the mostly clastic sedimentary Miocene sequence deposite systemRiver is preserved mainly in structural lows, karstic systems, an in southern Israel, eastern Sinai, and Jordan (Calvo and Bartov, 20 associated with this Miocene fluvial system compose comprise the u formation in southern Israel. This formation is divided into two maj autochthonous conglomerates and lacustrine carbonate units, and the allochthonous clastic sequences typical to fluvial environments (Calvo sand and chert pebbles . Here we focus on the allochthonous upper p onset of the Hazeva River is constrained by the Karak dike (~20 Myr section of the Hazeva formation (Calvo and Bartov, 2001). While clima during the Miocene are believed to have been wetter (e.g., Kolodny region is part of a middle latitude dry warm desert extending from north with the Negev Desert remaining hyperarid at least since the middl 2006).~~The Hazeva fluvial system operated until the subsidence of th late Miocene to early Pliocene brought on a dramatic change in mo dismantlement of this massive fluvial system, the last of its kind in th By the early Pliocene, the Hazeva River was abandoned, and new inc drained the region toward the Dead Sea Basin (Avni et al., 2001).~~

3. Methodology and Analytical Procedures

3.1 Sampling Strategy

Cosmogenic nuclides in sediments accumulate throughout the sedime material is exposed during weathering and ~~exhumation~~ exposure c transport in a specific drainage system, and to a much lesser degree intermediate or final destination. Unlike the more commonly use nuclides, which may decay substantially or even completely over m ^{21}Ne is stable. This means that the concentration of ^{21}Ne measured accumulated over several ~~sedimentary~~ cycles of exposure and deposit reaches the depositional basin, it can be re-exhumed and once again ex new sedimentary cycle. Therefore, the concentration of cosmogenic obtained from two Miocene Hazeva ~~deposits~~ exposures (Fig. 2 B-C samples were collected from deeply shielded locations to minimize production (see section 5.1 for further discussion). The quartz sand a both transported by the Miocene Hazeva system and share an overal However, the quartz sand was exposed in previous sedimentary cycle and Paleozoic, where it accumulated cosmogenic ^{21}Ne. In contrast, the Eocene and then exposed, transported, and buried during the Mio Therefore, while the cosmogenic ^{21}Ne measured in the quartz sand repr cycles, the cosmogenic ^{21}Ne measured in the chert pebbles represents e a single sedimentary cycle in the Miocene Hazeva River.

Additionally, ~~T~~two individual samples of *in situ* chert nodules (EJC3 from exposed bedrock outcrops of the Eocene source rock in central J Miocene samples, which were exposed during at least one full sedim chert nodules accumulated cosmogenic nuclides only during exhumati surface. Therefore, the cosmogenic nuclide ~~These~~ concentrations meas ~~thus~~ represent averaged rates of erosion ~~surface denudation~~ over the la

3.2 Preparation of Chert and Quartz Samples and Analytical Proc

Chert pebbles (ranging 4-14 cm, b axis) were crushed and both chert an to 250-850 μm. Chert and quartz samples were processed to separate c Earth Sciences Cosmogenic Isotope Laboratory, Hebrew Universit standard procedures (Hetzel et al., 2002; Kohl and Nishiizumi, 199 leached in HCl/HNO_3 mixture (3:1) at a temperature of 150°C for 1.5h each temperature step. Ne isotope measurements used the BGC "Ohio described in Balco et al., (2019). 20-30 grams of leached and clea samples and three chert samples were processed to separate Be and Al Nishiizumi (1992) and Bierman and Caffee (2001). These were then $^{26}Al/^{27}Al$ at the Centre for Accelerator Mass Spectrometry, Law Laboratory, and calibrated against house standards and blanks.

3.3 Cosmogenic Scaling and Correction Factors

Exposure and burial times and erosion rates were calculated based o using time-independent scaling (Stone, 2000) and production mechan (2008), given sea-level high-latitude production rates of 4.96 atoms atoms/g SiO_2/year for ^{26}Al (Balco et al., 2008), and ~~Exposure ages, re~~ ~~using production rates scaled for latitude and altitude after Stone (20~~ ~~rate of~~ 18.1 atoms/g SiO_2 year (Borchers et al., 2016; Luna et al., 2018

4. Results

4.1 ^{21}Ne in Quartz Sand and Cherts

For the chert samples, <2% of the total ^{21}Ne and no more than 1% of th released above 950°C (see the Supplementary Tables S1-4). Therefor performed at 450, 700, and 950°C heating steps for chert samples an steps for quartz samples (Table 1). Of the total ^{21}Ne measured, >85 temperature steps, below the 950°C step in the chert samples and be quartz samples (see Supplementary Tables S1-4). Also, low-temperatu calculations, discussion, and interpretations. It is important to note isotopic values of $^{21}Ne/^{20}Ne$ and $^{22}Ne/^{20}Ne$ ratios at the low-temperatu cosmogenic component of $^{21}Ne_{ex}$ from the nucleogenic component, p and Th within the crystal lattice, is not trivial. Nonetheless, as all cl nodules and Miocene chert pebbles) share the same lithology, any concentrations must be due to the cosmogenic component.

The chert pebbles and quartz sands sampled at both Miocene H concentrations of $^{21}Ne_{cos}$ ranging between 0.00±1.88·10^{6} and 8.89±1.8 At both Miocene Hazeva sites, the cosmogenic ^{21}Ne concentrations m similar or lower compared to sand samples. These measured con understanding that the sand samples contain quartz grains that originat that were deposited throughout the Phanerozoic and could have und cycles before they were exhumed and transported by the Miocene flu the sand samples could have higher concentrations of nucleogenic ^{21}N sand is >800 Ma (Kolodner et al., 2009). Conversely, the chert sa relatively young, Eocene, source rock and only participated in one se Miocene. Both chert nodule samples collected from *in situ* Eoce cosmogenic ^{21}Ne concentrations, higher compared to the Miocene che

Diffusion kinetics of Ne in quartz have been examined experimentally and Farley, 2005; Tremblay et al., 2014) but have yet to be tested o unclear what is the diffusion length-scale of chert crystals. While dif likely to be similar to quartz, more work is needed to determine that w

^{10}Be and ^{26}Al concentrations were measured in three Miocene sand sa MHS5), the two Eocene chert nodules (EJC3 and EJC5) and two c MHC6). ^{10}Be results for sample MHC5b and ^{26}Al results for sample MH 1). Miocene sand and chert samples show ^{10}Be and ^{26}Al concentrations with extended periods of burial ($\leq 0.39.\pm 0.03 \cdot 10^5$ atoms/g SiO_2 for atoms/g SiO_2 for ^{26}Al). Currently eroding Eocene nodules show higher ^{26}Al, with sample EJC3 showing ^{26}Al/^{10}Be ratio that is consistent wit and sample EJC5 showing a lower ^{26}Al/^{10}Be ratio, suggesting a more co (see Discussion section).

5. Discussion

5.1 Correcting for Post-Burial Muonic Produced Cosmogenic ^{21}Ne

When examining concentrations of cosmogenic nuclides in sediment extended periods, post-burial production needs to be considered. At or interactions are the main pathway for *in situ* production of cosmoger >95% for ^{26}Al, ^{10}Be, and ^{21}Ne (Dunai, 2010). However, the relative co muon interactions increases with burial depth, and while production ra can be significant when integrated over long periods of time—especia post-burial component does not represent surface processes, and there for its contribution to the measured cosmogenic component. For radioa such as ^{10}Be and ^{26}Al, their initial concentrations (acquired during exp due to radioactive decay, with ^{26}Al decreasing faster than ^{10}Be accor burial depth, only tens of meters below the surface, and the deduced bu of surface erosion that occurred during the last ~2 Myr (Matmon references therein). Additionally, the relatively large uncertainty on could account for some of this discrepancy (Balco, 2017; Balco et a show that the cosmogenic ^{21}Ne produced post-burial over 18 Myr of b 120 m is lower than the $^{21}Ne_{ex}$ measured for in the presented samples (i). The maximal calculated post-burial cosmogenic ^{21}Ne concentration a of ~1.3·10^{6} atoms/g SiO_2,. This which concentration is lower than th all measured Miocene samples except for MHC2, where no cosmo However, sample MHC2 is not considered in the interpretations of consider post-burial cosmogenic ^{21}Ne production to be insignificant exposure times.

5.2 Calculating Modern and Miocene Exposure TimesRates of Su

Exposure times Erosion rates calculated for exposure at the surfa concentrations measured in modern exposed *in situ* chert nodules f Plateau (EJC3 and EJC5) range between a minimum of 193 kyr and a m (correlating to cosmogenic ^{21}Ne concentrations of 8.08±1.48·10^{6} an SiO_2).

Erosion rates calculated from ^{10}Be and ^{26}Al concentration measured 2-4 mm/kyr, with production rates scaled for latitude and altitude production rates of 2.62 and 30.26 atoms/g SiO_2 year for ^{10}Be and ^{26}A erosion rates calculated from ^{10}Be and ^{26}Al concentrations measured

In comparison to the Jordanian samples, Qquantifying rates of surfac samples exposed that occurred during the Miocene using cosmogenic trivial,, most notably due to the challenge in evaluating the local isot rates. The production rate of cosmogenic nuclides increases with altit shielding effect of the atmosphere decreases (Stone, 2000). While t Peninsula during the early Miocene was similar to today (Meulenkar references therein), accounting for the elevation of the Miocene sar cosmogenic ^{21}Ne raises two difficulties. Firstly, it is not possible to d elevation of the Jordanian Central Plateau during the Miocene. It i Cretaceous up until the late Eocene, the Arabian Peninsula was mostly and that during the Oligocene it was uplifted to a sufficient elevati surface erosion (Garfunkel, 1988). During the early Miocene, broad va ~100 m deep) incised the regional truncation surface that develope Hazeva formation was later deposited (Avni et al., 2012). This timeline that significant surface uplift occurred prior to the initiation of the Mio at ~18 Ma. Nevertheless, this stratigraphic evidence is not enough Arabian Peninsula reached its current elevation during the early- additional uplift occurred over the past 20 Myr, and if so how significa on exhumation along the eastern flank of the Dead Sea Rift do not constrain the timing of surface uplift. Surface uplift histories based or al., 2013), and river profiles (Wilson et al., 2014), conclude that du western half of the Arabian Peninsula was uplifted to its current elev mid Miocene. However, another difficulty in calculating paleo-produc elevation of the Central Jordanian Plateau during the time the Hazeva R arises whether it is appropriate to use the elevation of the source calculations or whether a spatially averaged elevation should be used in information about the size and steepness of the catchment area of the H to correct for different elevations and production rates throughout the their core, both possible lower paleo-elevation and a basin-wide uncertainties that decrease the potential paleo-elevation used for s resulting in longer calculated exposure times. Therefore, accountin assume an elevation range of 500-1000 meters above sea level, and calculated Miocene exposure times.

The calculated exposure times of sediments in the Miocene Hazeva and range between a minimum of 0^{+59}_{-0} – 0^{+86}_{-0} kyr measured in sampl of 278±63 – 408±63 kyr measured in sample MHS5 (Table 2). Compari concentrations (and exposure times) of the sand samples are overlapp samples (Fig. 3). This agrees with our understanding that the cosmog Miocene chert pebbles represents the total time of exposure during coupled with transport in the Hazeva River, while the sand samples sedimentary cycles and contain inherited cosmogenic ^{21}Ne. Therefor used to calculate the time sediment were exposed during transport in th to infer erosion rates.

The cosmogenic ^{21}Ne exposure times calculated from the Jordanian c

Central Plateau chert nodules range ~300-400 kyr. It is important exposure times in the Jordanian cherts represent only exposure at the exposure during transport, in contrast to the Miocene chert pebbles. Lastly, when examining ancient exposure times, we must first consider cosmogenic nuclides are averaged. The question arises whether th accurately represent the environmental conditions of a certain peri Miocene) or if the calculated times are the result of episodic oscillation events. For currently exposed *in situ* samples reported here, it is a reas modern exposure times are relatively long and so they integrate hund over which such oscillations or rare catastrophic events would be ave exposure times, samples were collected from two separate sites and fr unlikely that they all represent the exception. We, therefore, consider from Miocene samples to be a good representation for Miocene surfac

5.3 Modern and Miocene Erosion Rates and the Influence of Clim

The calculated exposure times of the Jordanian chert samples are equiv 12 mm/kyr (Table 2), which is consistent with erosion rates measured Zilberman, 2017 and references therein). Calculation of paleo straightforwars, as Miocene samples were sampled post deposition a during erosion from bedrock and transport in the Hazeva River. Howev are either shorter or overlap within uncertainty with those of the *in si* Thus, the actual bedrock erosion rates during the Miocene must have be sediment transport. Erosion rates in fluvial systems also respond to te in base level that increase slope steepness and instability, resulting i more sediment readily available for transport. Here we examine eviden the climatic and tectonic conditions that prevailed in the region durin forcing the deduced ~~rapid~~ increase in erosion rates. ~~However, when rates, we must first consider the time-scales over which cosmogenic question arises whether the reported erosion rates accurately re conditions of a certain period (e.g. the early to mid-Miocene) or if the c of episodic oscillation or catastrophic geomorphic events. For the mo here, it is a reasonably simple answer. The modern erosion rates are integrate hundreds of thousands of years over which such oscillations would be averaged. As for the Miocene erosion rates, samples were c sites and from different depths, so it is unlikely that they all represent th consider the range of rates obtained from Miocene samples to be a good surface processes.~~

Many works which quantify the rates and timing of surface uplift rela Sea are confined to the edges of the Arabian plate and do not intercontinental uplift (Bar et al., 2016; Morag et al., 2019; Omar et al 1995). While s~~Collectively,~~ome of these studies ~~show~~ point to a de during the mid-Miocene (~18 Myr~~).~~; ~~While uplift rates decreased durin~~ 2019), ~~tectonic~~ surface uplift and topographic changes could still c response, manifesting as increased erosion rates and the establishn

We compared the cosmogenic ^{21}Ne measured in chert pebbles an transported during the mid-Miocene (~18 Myr) by the Hazeva River (Eocene chert nodules) currently eroding in the Central Jordanian Plat In addition to tectonic forcing, there is ample evidence for a warme region during the Miocene. Locally, the appearance of mammals in the and grassy vegetation during the early-mid Miocene supports a humid al., 1988; Horowitz, 2002; Tchernov et al., 1987). Tropical to subtropi eastern Arabian Peninsula, as indicated by fossilized mangrove roots 1980). Locally, Kolodny et al. (2009), interpreted the ^{18}O in lacustrin part of the Hazeva unit to be deposited by ^{18}O-depleted paleo-meteori the presence of a warm ocean to the southeast of the region during Miocene resulted in tropical cyclones being more prevalent and increa We successfully established a novel application for measuring cosm Miocene chert samples, expanding the opportunities and settings in nuclides analysis could be used as a tool to quantify geomorphic proc as a viable lithologic target for cosmogenic Ne analysis. In modern cosmogenic nuclides ^{10}Be and ^{26}Al generally agree with ^{21}Ne results cosmogenic ^{21}Ne in quartz sand samples is equal or higher compared agreeing with the geologic understanding that sand has experienced where ^{21}Ne was produced, while chert experienced only one such cy fluvial system.

Exposure times calculated from the measured cosmogenic ^{21}Ne con as faster rates of surface erosion. ~~Furthermore~~In addition, multiple ind in previous studies support wetter climatic conditions in the region dur Increased precipitation would explain the faster rates of bedrock eros higher water discharge needed to maintain transport along the H variability observed in exposure times of Miocene chert pebbles n ~~possible that rates of erosion or it~~ a change~~d~~ ~~significantly~~ in rates Miocene~~,~~. However, this~~e~~ variability in ^{21}Ne concentrations ~~measured~~ ~~are~~ is more likely the result of fluvial transport dynamics, temporary st transport in this large Miocene river.

Data availability

A raw data table including all Ne isotope measurements and three-isot supplement.

Author contribution

MBI and AM designed the study. MBI collected the samples for analys and YA. MBI prepared samples for analyses and measured ^{21}Ne/^{20}N GB, and AJH measured the ^{10}Be/^{9}Be and ^{26}Al/^{27}Al ratios. MBI analy figures, and prepared the manuscript with contributions from all co-au

Competing interests

and administrative staff at the Berkeley Geochronology Center for th This work was performed in part under the auspices of the U.S. Departm Livermore National Laboratory, United States under Contract DE-A LLNL-JRNL-788357.

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Table 1: Sample Description, Sampling Site Locations and Cosmogenic Nuc

Sample	Sample type	Site	Sampling depth below surface (m)	Location Lat (°N)	Long (°E)	Elevation (m.a.s.l)	Be Carrier (mg)	$^{10}Be/^{9}Be$ ($\times10^{-13}$)	$[^{10}Be]$ (10^5 atoms/ g SiO_2)
MHS1	Quartz sand	Paran Valley, Israel	30	30.33296	34.92724	290	176	0.17±0.03	0.14±0.02
MHS3	Quartz sand	Arad Quarry, Israel	90	31.23372	35.20685	570	171	0.36±0.02	0.29±0.02
MHS5	Quartz sand	Arad Quarry, Israel	100	31.23372	35.20685	570	175	0.32±0.02	0.26±0.02
MHC2	Chert pebble	Paran Valley, Israel	20	30.33296	34.92724	290	NA	NA	NA
MHC3	Chert pebble	Arad Quarry, Israel	90	31.23372	35.20685	570	NA	NA	NA
MHC5a	Chert pebble	Arad Quarry, Israel	100	31.23372	35.20685	570	NA	NA	NA
MHC5b	Chert pebble	Arad Quarry, Israel	100	31.23372	35.20685	570	172	NA	NA
MHC6	Chert pebble	Paran Valley, Israel	30	30.33296	34.92724	290	170	0.10±0.01	0.39±0.03
EJC3	In situ chert	Central Jordanian Plateau	Surface	30.97045	36.64469	910	172	0.70±0.03	1.13±0.05
EJC5	In situ chert	Central Jordanian Plateau	Surface	30.87181	36.52129	1000	178	18.43±0.30	29.75±0.49

Note: NA – not available. Samples were either not analyzed, or no result was attained.
*Measurement uncertainties are ~5%.
†Cosmogenic ^{21}Ne is the excess of ^{21}Ne concentrations relative to the atmospheric $^{21}Ne/^{20}Ne$ ratio, calculated for the low-temperature steps (<

Table 2: Exposure times and erosion rates calculated for the modern and Miocene samples

Sample	Sample type	Location	Exposure time (kyr)	Erosion r (mm/kyr
MHS1	Miocene quartz sand	Paran Valley, Southern Negev Desert	114±46 – 166±87	-
MHS3	Miocene quartz sand	Arad Quarry, Northeastern Negev Desert	280±10 – 408±63	-
MHS5	Miocene quartz sand	Arad Quarry, Northeastern Negev Desert	278±17 – 404±83	-
MHC3	Miocene chert pebble	Arad Quarry, Northeastern Negev Desert	167±53 – 242±113	3.0±1.4 –
MHC5a	Miocene chert pebble	Arad Quarry, Northeastern Negev Desert	91±46 – 132±78	5.5±3.3 –
MHC5b	Miocene chert pebble	Arad Quarry, Northeastern Negev Desert	0^{+59}_{-0} – 0^{+85}_{-0}	>8.6 – >
MHC6	Miocene chert pebble	Paran Valley, Southern Negev Desert	121±59 – 176±102	3.0±1.4 –
EJC3*	In situ chert nodule	Central Jordanian Plateau	269±49 / 16±1 / 13±1	2.7±0.5 /
EJC5*	In situ chert nodule	Central Jordanian Plateau	378±76 / 361±6 / 378±3	1.9±0.4 /

Note: Exposure times is the ‘simple exposure time’ calculated for exposure at the surface, calculated cosmogenic ^{21}Ne production rates rangi yr), given an elevation of 500 and 1000 meters above sea level. Erosion rates for sand samples were not calculated as the concentration of cos inherited cosmogenic ^{21}Ne from previous sedimentary cycles.

*Erosion rates calculated using ^{21}Ne / ^{10}Be / ^{26}Al.

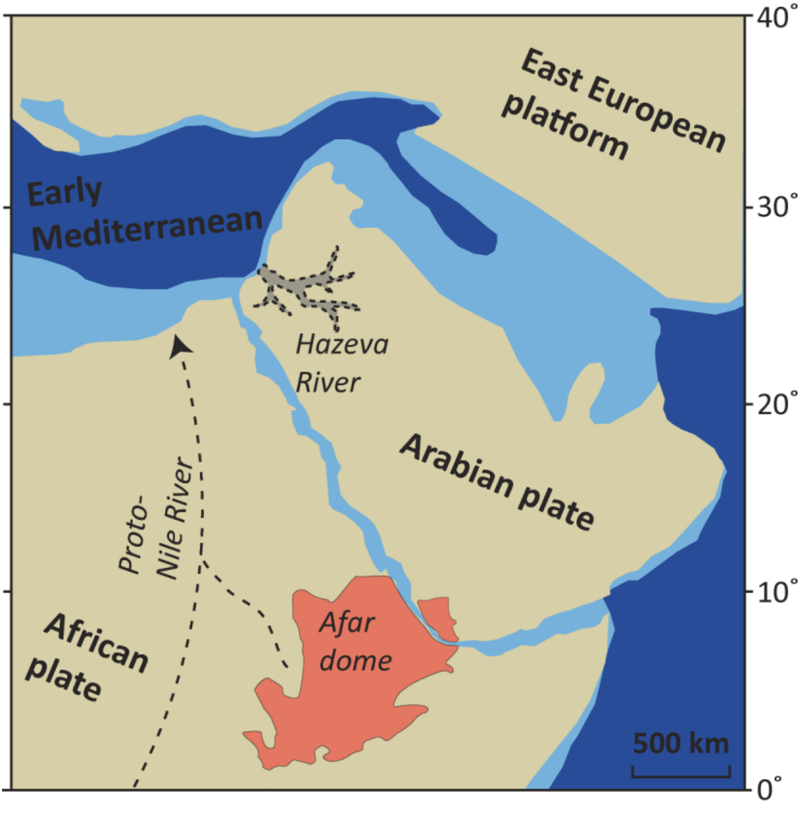

Figure 1. Paleo-geographic map of the eastern Levant during the ear Meulenkamp and Sissingh, 2003) with the approximated extent of the H on Avni et al., 2012; Zilberman and Calvo, 2013).

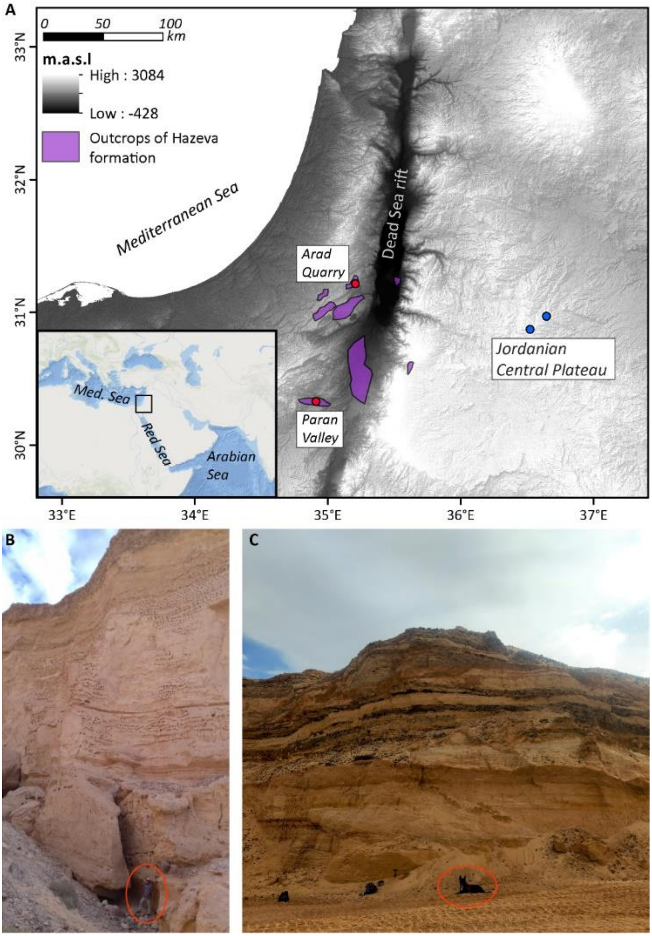

Figure 2. (A) Shaded relief map of the study area with sampling lo sediments sites (red) and in situ Eocene source rock (blue). Hazeva outcr Calvo (2013). Inset map shows regional geographical context. (B) Sampl Sample collected from behind the fallen boulder in a narrow canyon and of ~50 meters of sand and conglomerate. See person for scale marked sampling location at Arad Quarry. Samples collected from underneath an of quartz sand. See dog for scale marked at the bottom.

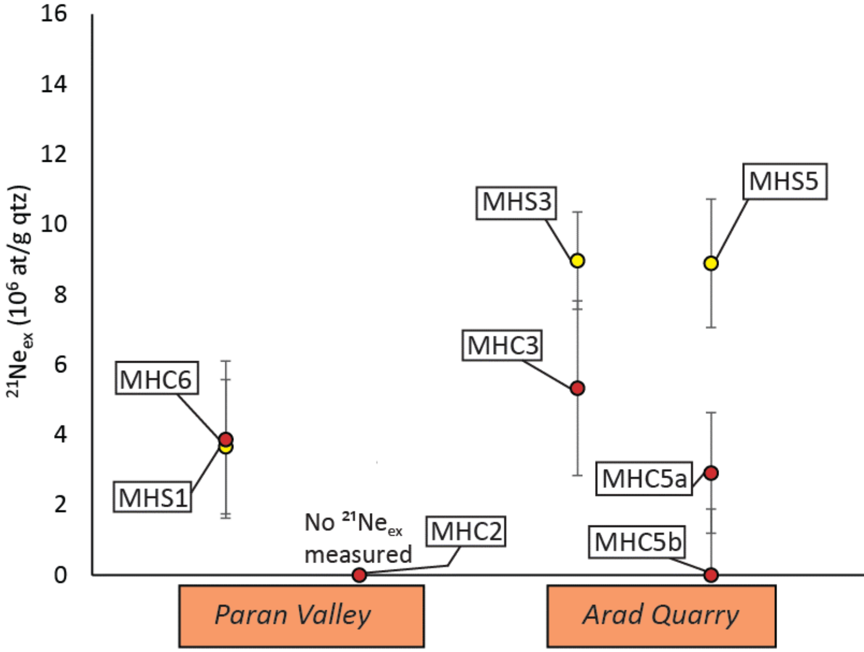

Figure 3. $^{21}Ne_{cos}$ **concentrations in Hazeva sands (yellow), Hazeva che Jordanian Central Plateau chert nodules (blue) with respective un** ~~**reported in kyr, are calculated using production rates scaled for latitu (2000), using** ^{21}**Ne production rate of 18.1 atoms/g** SiO_2 **year (Borchers et**~~

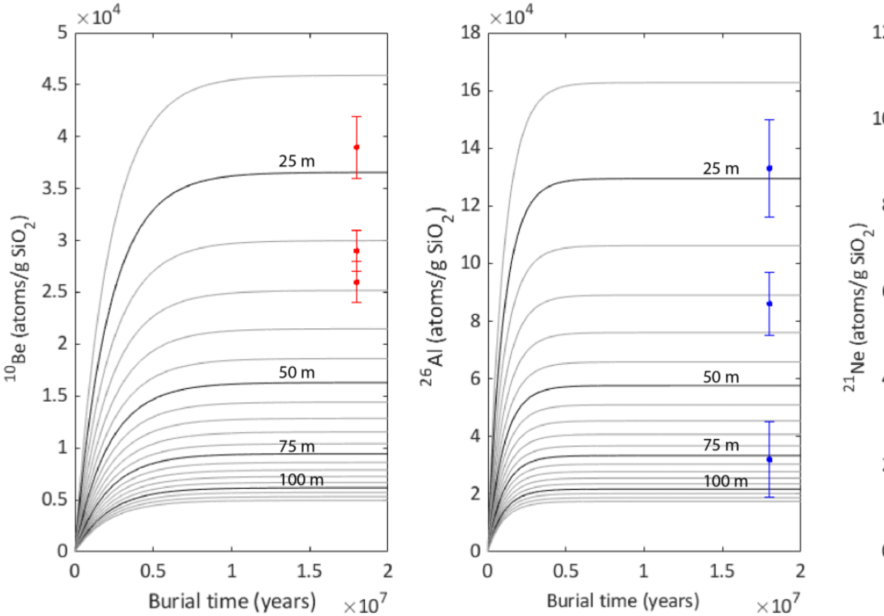

Figure 4. Measured concentrations of ^{10}Be (red), ^{26}Al (blue), and ^{21}Ne MHS5, and MHC6. Grey contour lines show changes in nuclide concentr depths from 20 to 120 m below the surface in 5m increments. For both sar the concentrations of cosmogenic ^{21}Ne are higher than the estimat Production by cosmic-ray muons is calculated with schematics presented rates were calculated at the Arad Quarry site by cosmic-ray muons of (2017) and of ^{21}Ne by fast muons is after Balco et al. (2019). This concentrations can be explained by post-burial production, but ^{21}Ne significant fraction of cosmogenic ^{21}Ne is pre-burial.