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Coupled controls of climate, geology, and biota on late Pleistocene alluvial fan morphodynamics along the coast of the hyperarid Atacama Desert

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Explanations: Click on for audio comments (requires *Adobe Flash Player®*)

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Department of Geography | RWTH AACHEN UNIVERSITY | A B C/J geoverbund aachen bonn cologne jülich | University of Cologne | DFG | Earth – Evolution at the dry limit

Coastal alluvial fans (CAF) as geo-archives

Allogenic (environmental) controls

Biota

Geology

Climate

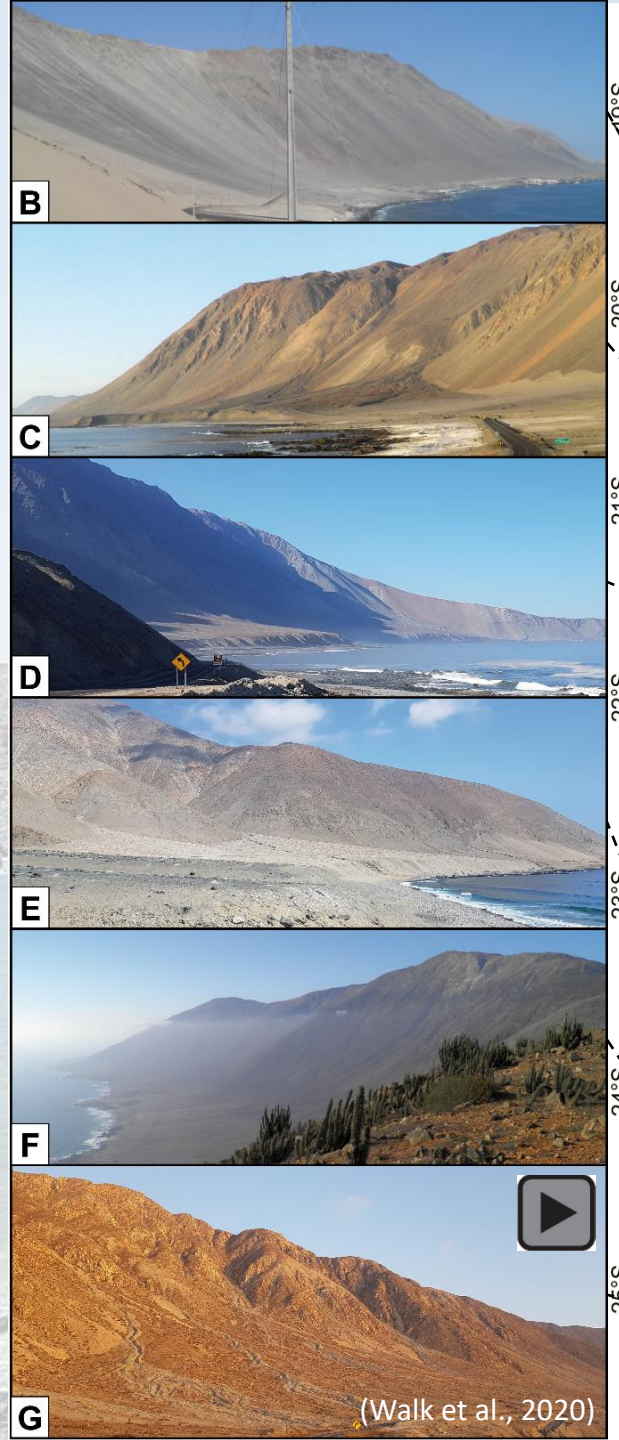
Characteristics

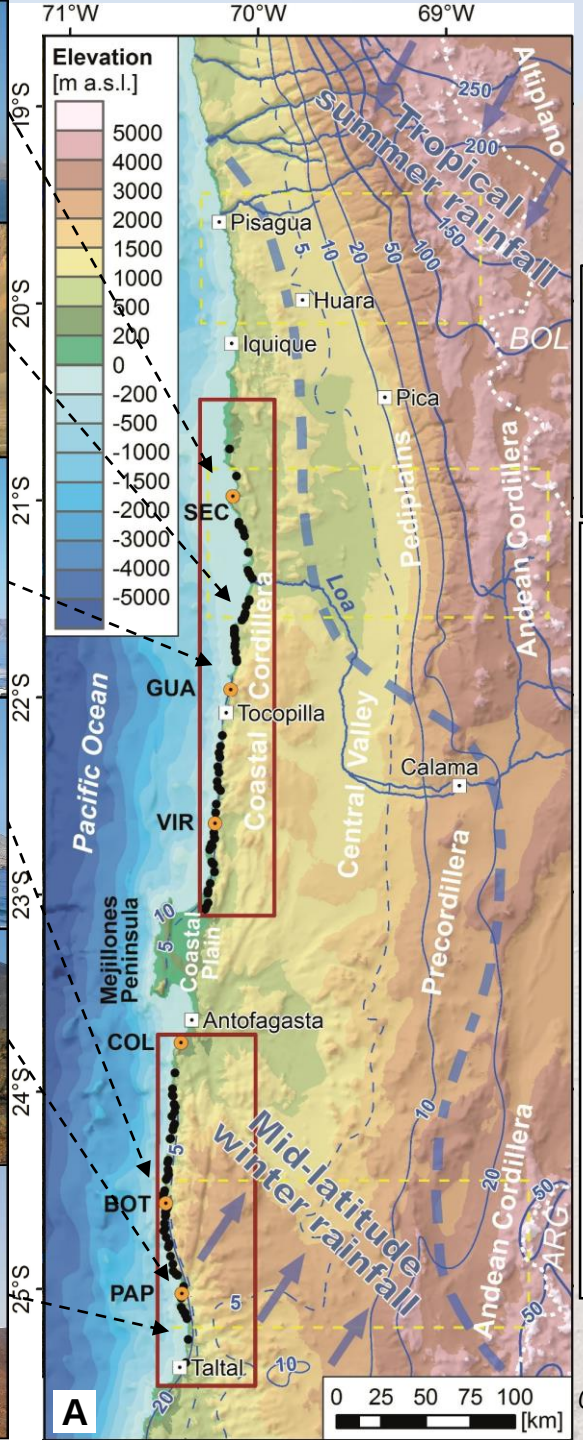
- CAF surface morphology
- CAF stratigraphy
- Catchment hydro-morphometry
- Spatial trends

Archive functions

- Magnitude, frequency, and types of primary processes
- Secondary processes
- Timing of fan development
- Coastal tectonic uplift

Autogenic (intrinsic) controls





Study area

CAF studied (catchment area >1 km²)

CAF key site

CRC 1211 focus area

National border

Stream

City / town

Climatic setting
(Houston, 2006)

Dry diagonal

Major seasonal rainfall source

MAP [mm/a]
(Fick and Hijmans, 2017)
Isohyet interval
5 10 50

(Walk et al., subm., mod.)

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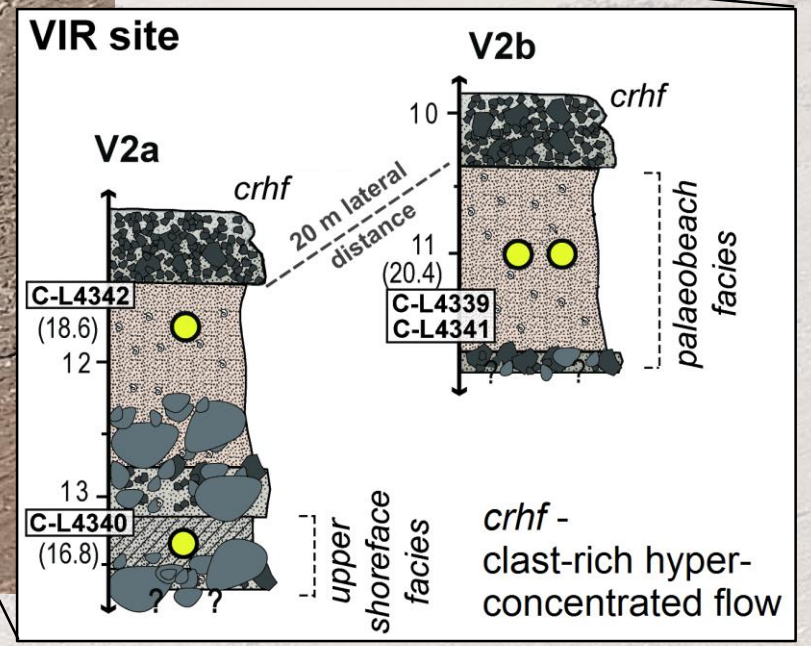
CAF as geo-archives in the hyperarid Atacama Desert – Caleta El Fierro (VIR)



(Bartz et al., 2020a, mod.)

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Material and methods

TanDEM-X World DEM™
(DLR, 2017)

Regional Weather Research and Forecasting (WRF) climate model (Reyers, 2019)

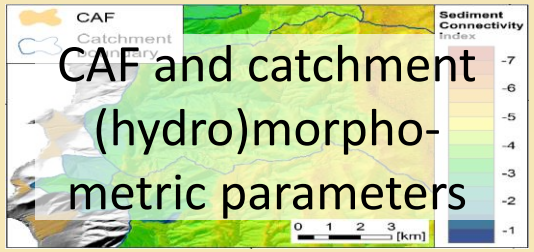
Regional geological maps
(diverse sources, cf. slide 7)

(Uplift rates derived from dated marine terraces)
(Regard et al. 2010; Bartz et al., 2020a)

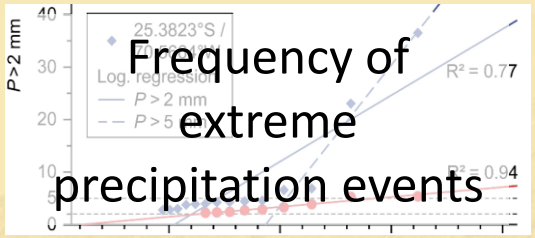
(Geobotanic studies on Loma vegetation)
(Schulz et al., 2011)

Gradient analysis

(Walk et al., 2020)



CAF and catchment (hydro)morpho-metric parameters



Frequency of extreme precipitation events

Source-area lithology and fault density

(Regional tectonic uplift)

(Vegetation density)

Geochronology

^{10}Be surface exposure dating
(Bartz et al., 2020a; Walk et al., in prep.)

^{14}C dating
(Vargas et al., 2006; Vásquez et al., 2018; Walk et al., in prep.)

Luminescence (pIR-IRSL) (and quartz ESR) dating
(Bartz et al., 2020a, b; Walk et al., in prep.)

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CAF and catchment (hydro)morphometric parameters

CAF morphometry

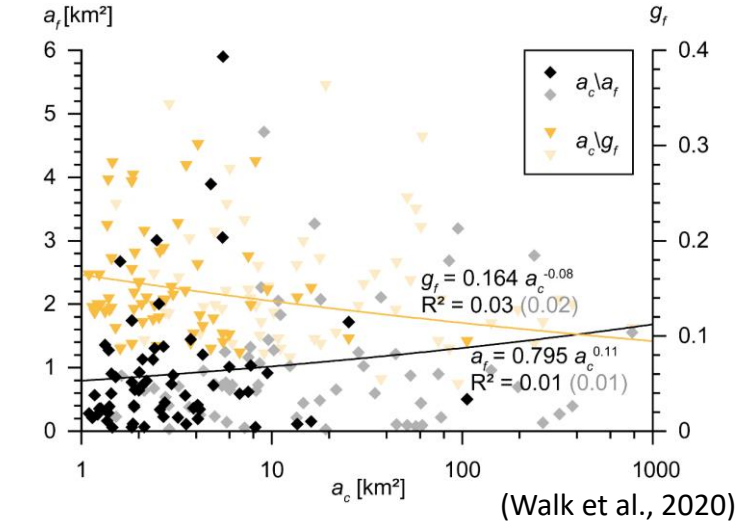
a_f –Area
$VRM_f(3)$ – Mean vector ruggedness measure (3 x 3 kernel)
g_f – Mean gradient
R_f – Relief

For details on parameters see Walk et al. (2020)

Catchment hydromorphometry

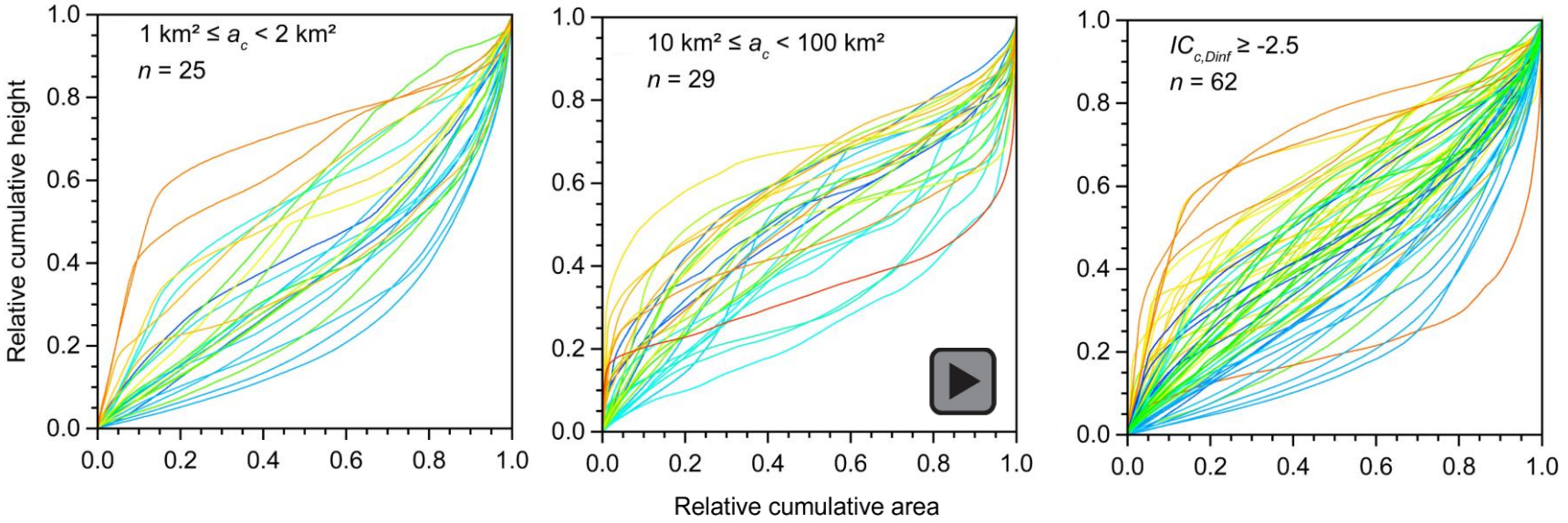
a_c – Area
g_c – Gradient
$h_{c,min}$ – Minimum elevation
HI_c – Hypsometric index
rr_c – Basin relief ratio
$StdCTI_c$ – Mean standardized compound topographic index
$VRM_c(5)$ – Mean vector ruggedness measure (5 x 5 kernel)
CI_c – Circularity index
$IC_{c,Dinf}$ – Mean index of sediment connectivity
kzd_{25} – Knickzone density (d interval = 25 m)
dd – Drainage density

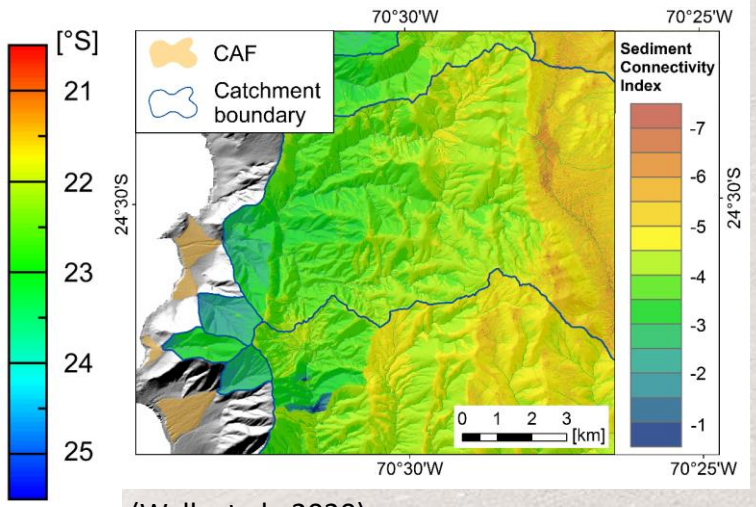
CAF-catchment relationships



(Walk et al., 2020)

Catchment hypsometry





(Walk et al., 2020)

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Climatic control: Frequency of extreme precipitation events

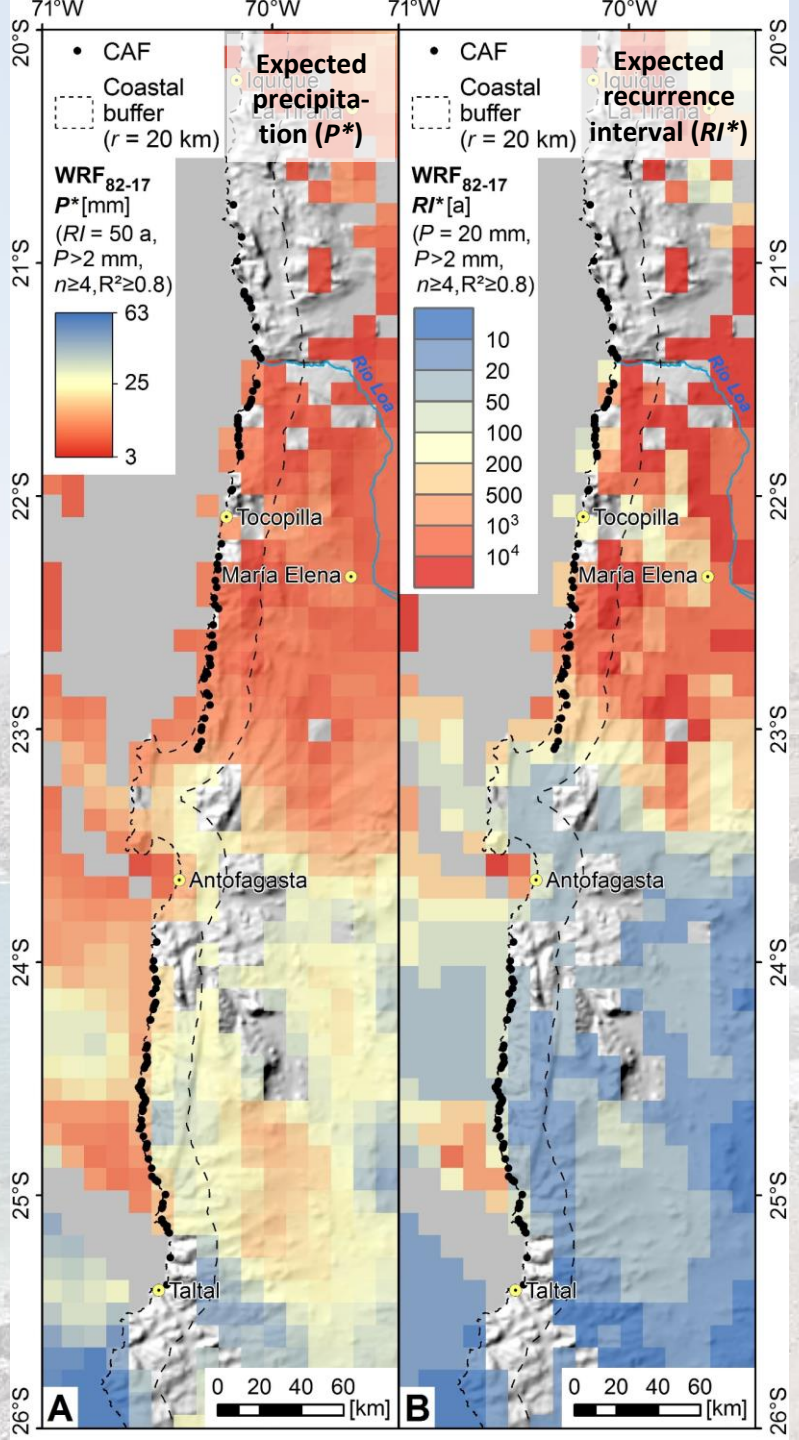
Climatic parameters

- Based on frequency analysis of 36 a WRF precipitation time series (Reyers, 2019)
  - Temporal resolution: daily
  - Spatial resolution: 10 km

  P – Precipitation (event)
  RI – Recurrence interval
  P^* – Expected precipitation
  RI^* – Expected recurrence interval
  MAP – Mean annual precipitation
  $n_{>20mm}$ – Number of events with P > 20 mm (in WRF time series)

- For statistical analysis:

  $p^+_{30a,10mm}$ – Distribution-free occurrence probability of an event with P > 10 mm in 30 a



(Walk et al., 2020)

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Geologic control: Source-area lithology and fault density

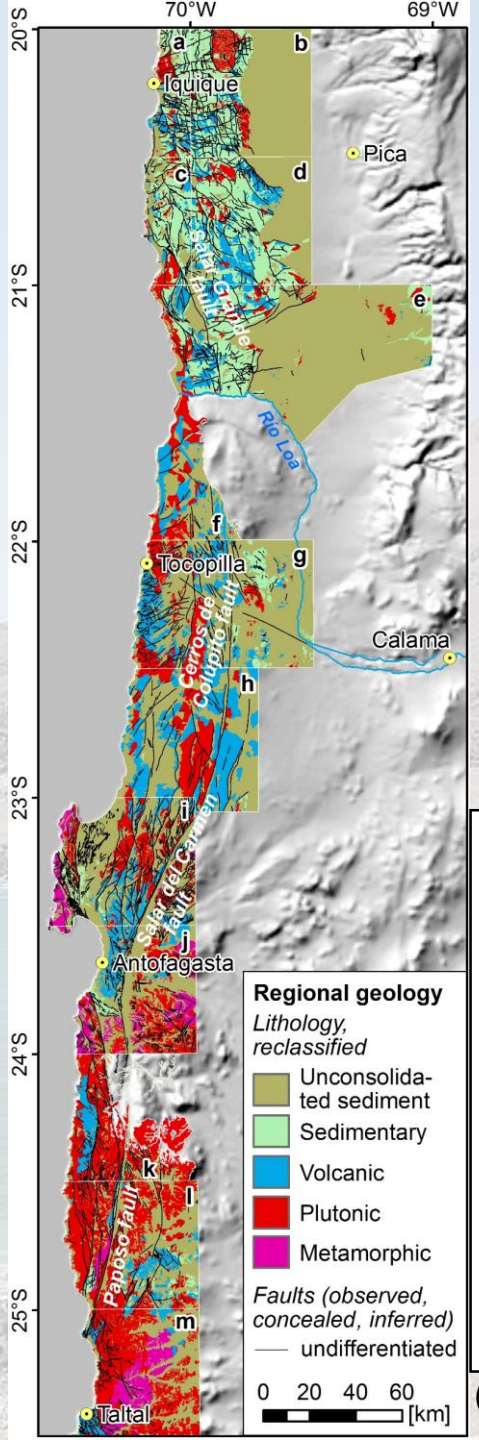
Geologic parameters

- Based on compilation of 13 regional geological maps (1:100k, 1:250k)
- Reclassification of catchment bedrock lithology (proportions)

  g(1_) – Unconsolidated sediments
  g(2+3) – Sedimentary rocks
  g(4_) – Volcanic rocks
  g(5) – Plutonic rocks
  g(6) – Metamorphic rocks

- Degree of faulting in catchments

  fd – fault density



References

a – Sepúlveda and Vásquez (2012)
b – Vásquez and Sepúlveda (2012a)
c – Vásquez and Sepúlveda (2012b)
d – Sepúlveda et al. (2012)
e – Quezada et al. (2012)
f – Skarmeta and Marinovic (1981)
g – Medina et al. (2012)
h - Mpodozis et al. (2015)
i – Cortés et al. (2007)
j – González and Niemeyer (2005)
k – Domagala et al. (2016)
l – Álvarez et al. (2016)
m – Escribano et al. (2013)

(Walk et al., 2020)

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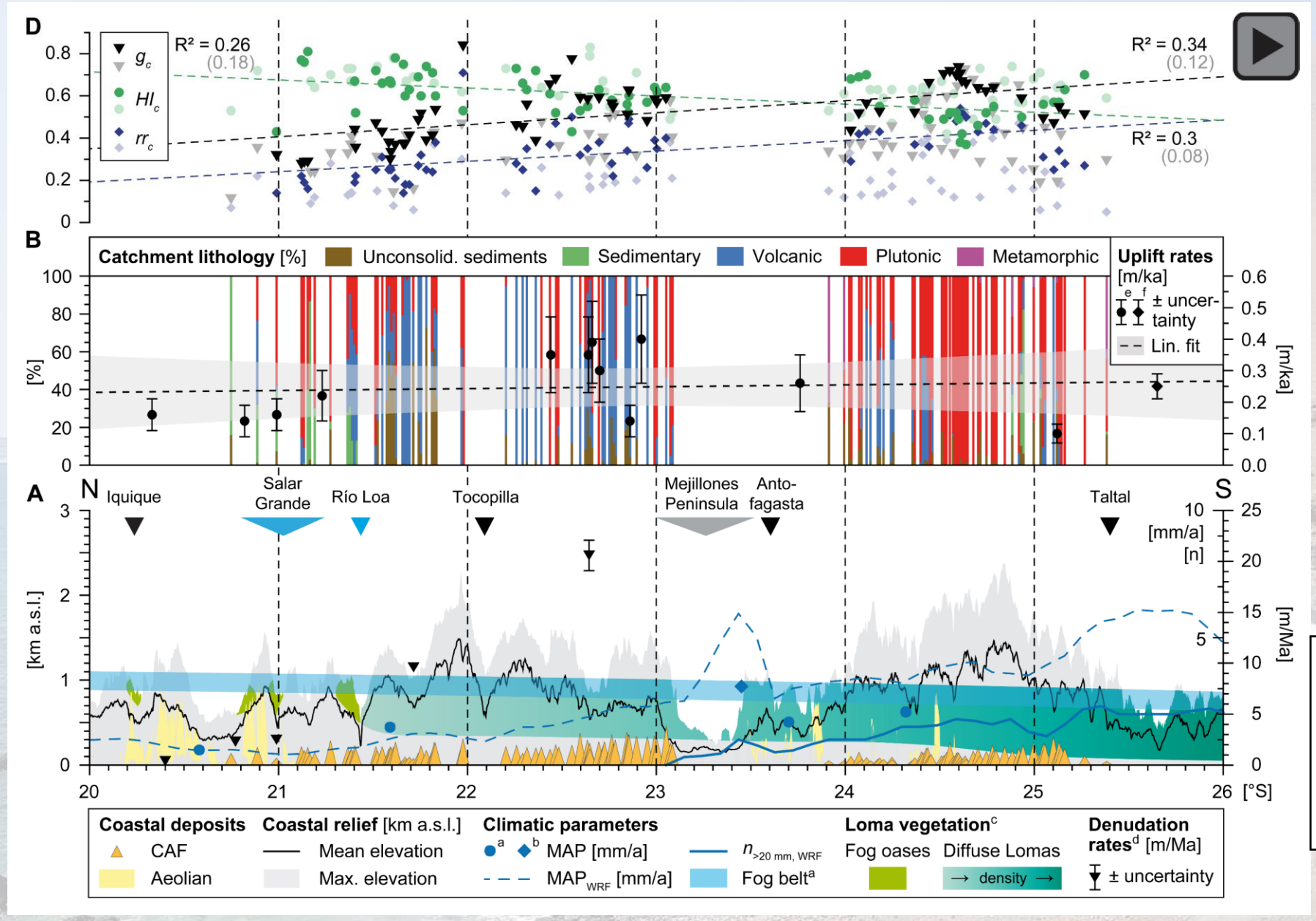
Results: Controls on CAF morphodynamics – Spatial gradient analysis



References

a – Garreaud et al. (2008)
b – Houston (2006)
c – Schulz et al. (2011)
d – Starke et al. (2017)
e – Bartz et al. (in press a)
f – Regard et al. (2010)

(Walk et al., 2020)

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Results: Controls on CAF morphodynamics – Factor analysis

$IC_{c,Dinf} \geq -2.5$	$n = 62$	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
	Explained variance	0.24	0.16	0.10	0.07	0.06
CAF morphometric parameter	log a_f	0.16	**0.98**	0.08	-0.03	0.07
	$VRM_f(3)$	0.02	-0.52	0.02	0.01	0.04
	g_f	-0.05	**-0.77**	0.22	0.02	-0.06
	log R_f	0.07	**0.72**	0.31	0.06	-0.02
Catchment morphometric and hydrographic parameter	log a_c	-0.50	0.14	-0.01	0.12	0.29
	g_c	**0.95**	0.12	-0.05	0.01	-0.01
	log $h_{c,min}$	0.09	**0.68**	0.31	0.10	-0.01
	HI_c	**-0.67**	-0.05	-0.06	0.22	-0.03
	rr_c	**0.95**	-0.08	0.00	-0.04	-0.04
	$StdCTI_c$	-0.47	-0.35	-0.04	-0.13	0.08
	$VRM_c(5)$	-0.24	0.18	0.18	0.02	-0.06
	CI_c	**0.59**	0.05	-0.16	0.02	0.19
	kzd_{25}	**0.83**	0.20	0.00	-0.05	-0.06
	dd	**-0.64**	-0.16	0.22	-0.14	-0.12
Catchment geology	fd	0.02	0.02	-0.13	0.29	0.12
	$g(1\_)^*$	-0.14	0.12	**0.83**	-0.53	-0.07
	$g(2+3)^*$	0.05	-0.04	0.02	0.00	**1.00**
	$g(4\_)^*$	-0.09	0.05	0.20	**0.95**	-0.19
	$g(5)^*$	0.18	-0.14	**-0.96**	-0.15	-0.07
$WRF_{82\text{-}17}$	$p^{+}_{30a,10mm}$	**0.60**	0.00	-0.19	0.24	0.03

* – centred log-ratio transformation applied prior to analysis
Bold type – factor loading value ≥ 0.59 or ≤ -0.59
(= components of factor)
(Walk et al., 2020)

CAF hydro-morphometry & frequency of extreme *P*

Interrelated CAF morphometry

Source-area lithology

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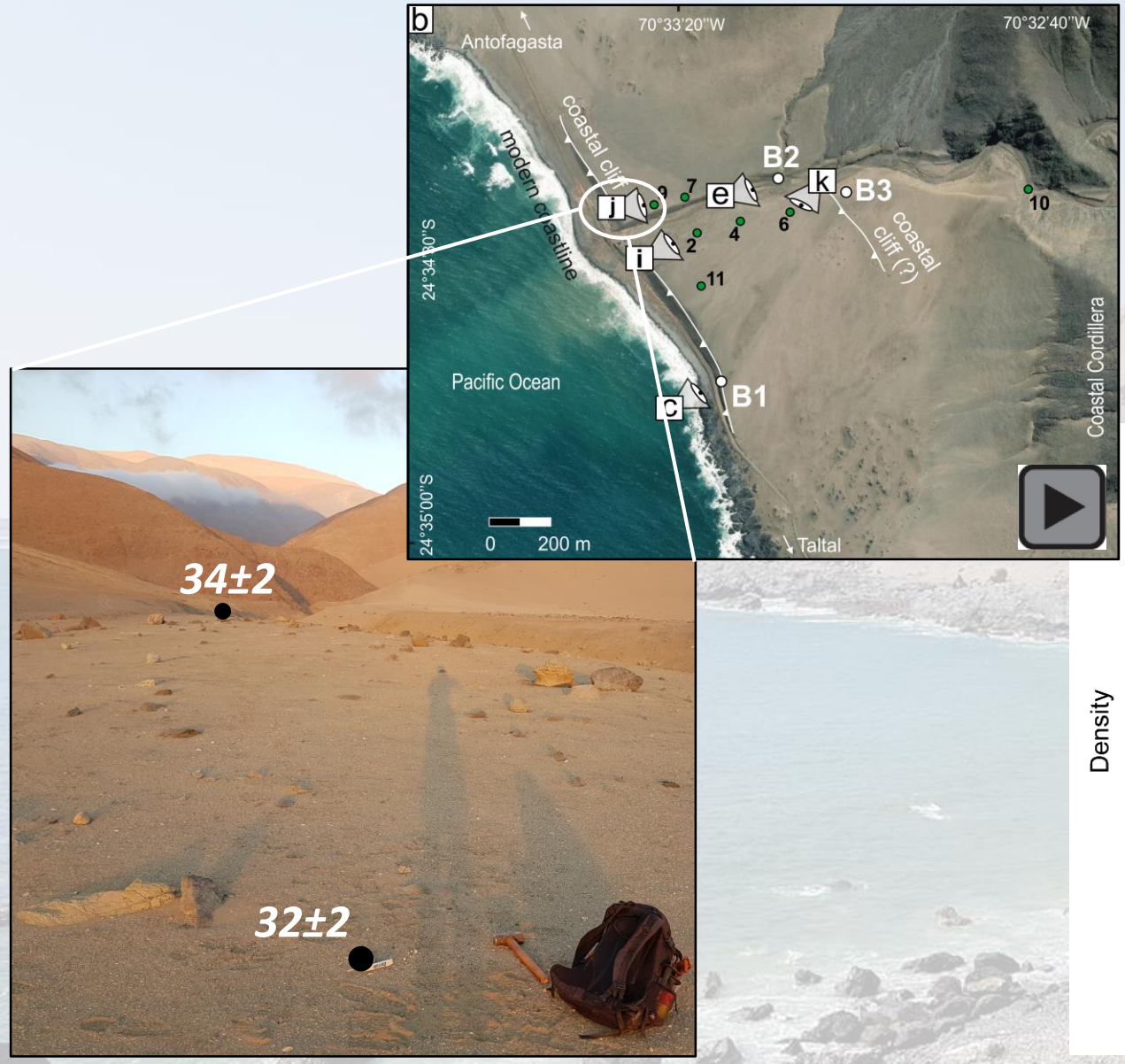
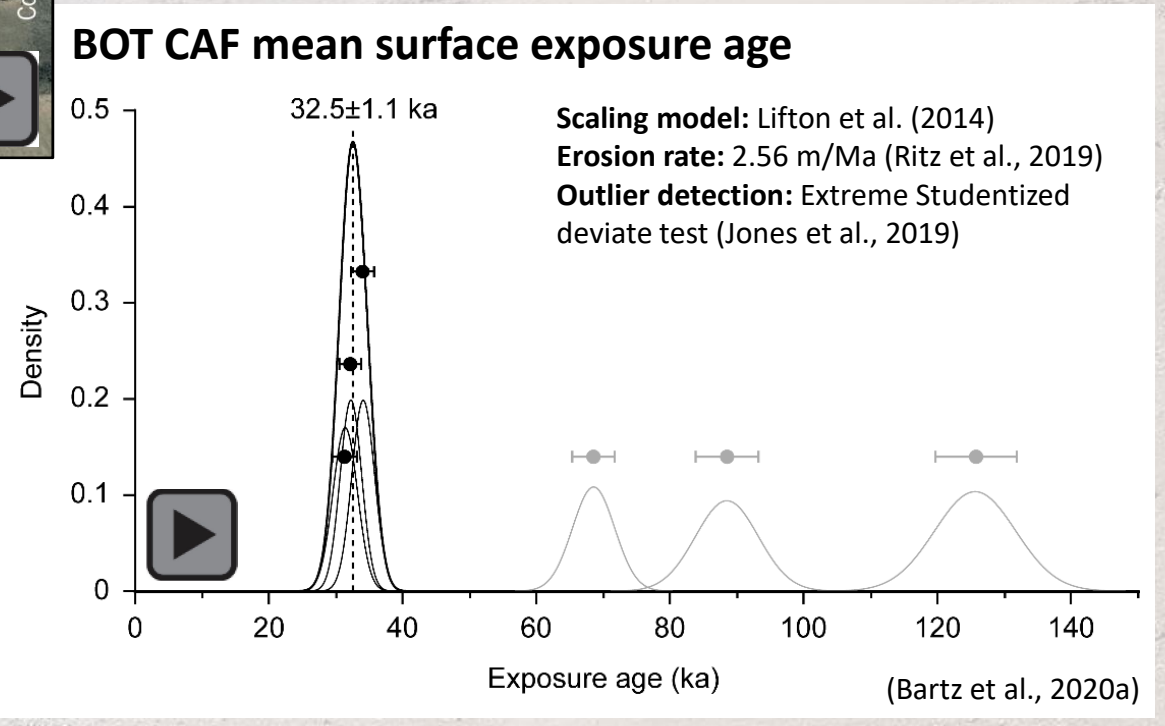
Results: Geochronology – ^{10}Be surface exposure dating (BOT – Botija)





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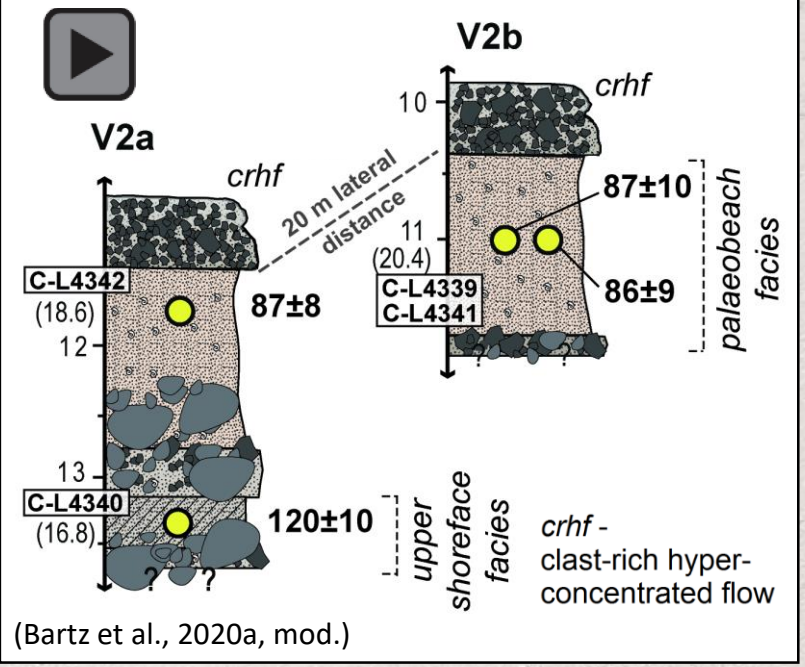
Results: Geochronology – Luminescence dating (VIR – Caleta El Fierro)

VIR site

Protocol: pIR-IRSL$_{225}$ (Thomsen et al., 2008)
Fading correction: Huntley and Lamothe (2001), Auclair et al. (2003)
Central age model: Galbraith et al. (1999)



(Bartz et al., 2020a, mod.)

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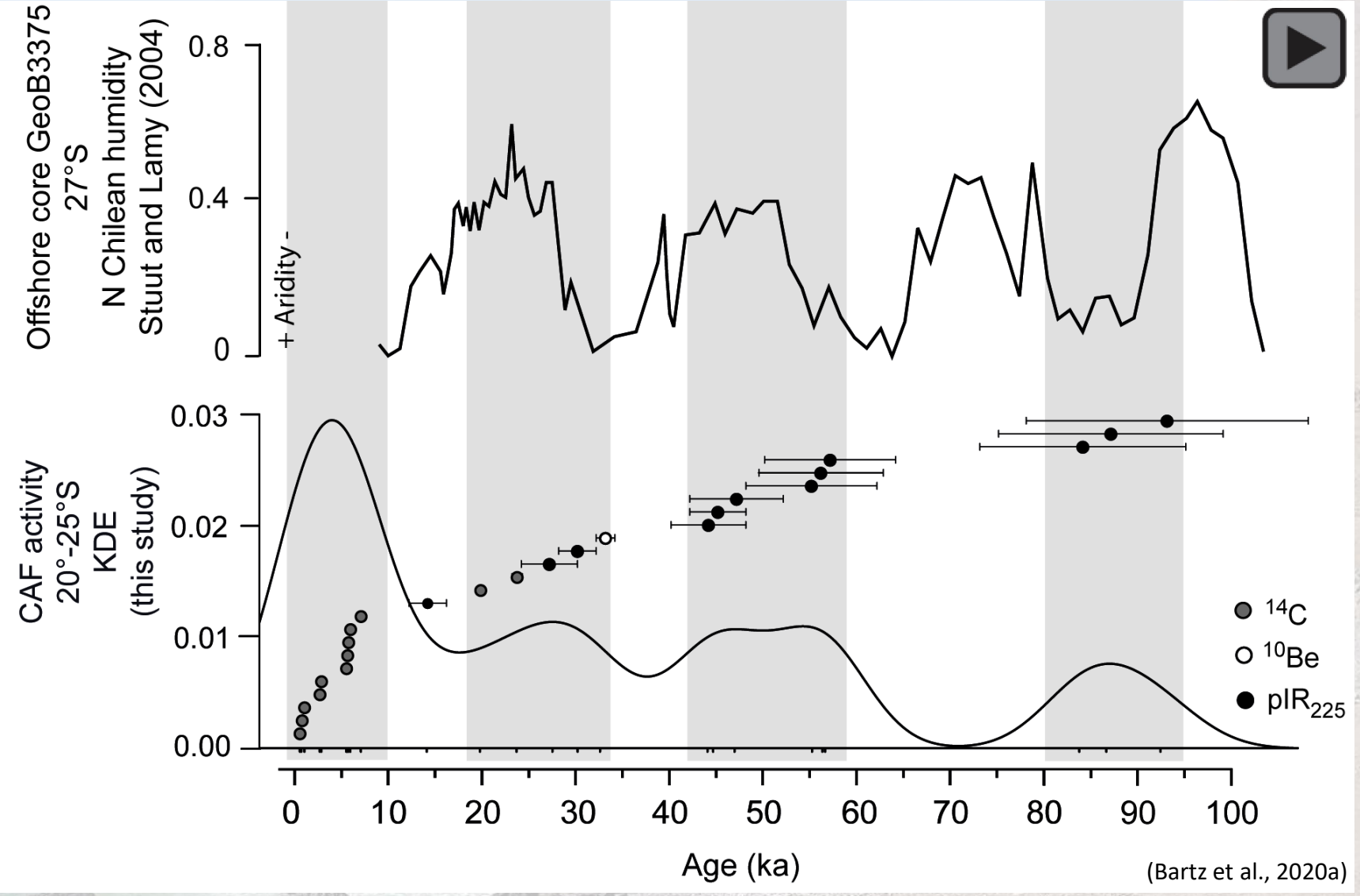
Results: Geochronology – Synthesis and palaeoenvironmental interpretation



(Bartz et al., 2020a)

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Conclusions

Allogenic controls

Climate
- Frequency of strong *P* events: **dominant**

Geology
- Source-area lithology: **negligible**
- Tectonics: **indirect**

Biota
- Positive feedback mechanisms: **indicated** (future work)

Autogenic controls

- Significance for specific CAF systems as yet unknown
- Future studies to discriminate case-specific from systematic regional geomorphic responses

Geo-archive functions – CAF of the Atacama Desert

- Magnitude, frequency, and types of primary processes
- Secondary processes
- Timing of fan development
- Coastal tectonic uplift

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Thank you for your attention!

We are looking forward to questions, comments, and a fruitful discussion during the live chat session (Tuesday, 5 May 2020, 10:45–12:30)!

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