

GEORG-AUGUST-UNIVERSITÄT

# Ignimbrite flare-ups in the Central Andes: Crustal sources and processes of magma generation

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### Layout:

- 1. Geological setting (review, maybe skipped)
- 2. Ignimbrite compositions: AIDA data base: (review, maybe skipped) Ages, volume and composition through time and space
- 3. Evidence for large crustal contributions (review, maybe skipped)
- 4. Zircon U/Pb dating combined with O-isotope and Hfisotope analyses (new data)

### Results (in a nutshell)

- -> Contributions of large volume ignimbrite magmas increase from 20 to 70% with thermal maturation of increasingly thickened Andean crust
- -> Individual ignimbrite units are isotopically heterogeneous and are amalgamations of crustal melts from distinct Proterozoic sources w/r to age and composition

### **Ignimbrites:**



"Google

### message from thickening crust at Andean-type active continental margins

40

-<u>60</u> -80

L100 km

**Brazilian Shield** 

Moho

Large-volume, plateau-forming ignimbrites on the western margin of the Central Andean orogen...

over 30 Ma and 1500 km N-S extension

900 m

Valle de Azapa 18°S

### Cuno Cuno Section

with > 24 Ma old marine sediments at 1900 m (S. Peru)

22 Ma Ignimbrites

# Uplift, erosion and sedimentation prior to "ignimbrite flares"

**Jurassic Sediments** 



## 1700 m

# What is the source of these voluminous ignimbrites ?

### Our tools: GIS-Data base mapping

Volumes Sr-O-isotopes O-Hf-U/Pb analyses in zircons

Peru

# Ignimbrites

Bolivia

Chile





Oxaya-lg 19.38±20<sup>(1)</sup> 19.71±0.04<sup>(2)</sup>

-Molinos-Ig

sediments

Cardones-Ig 21.92±0.17<sup>(2)</sup>

sediments Poconchile (Willi)-Ig 22.72±0.15 San Ar-Ar<sup>(1)</sup> 22.74±0.02 Zr U-Pb<sup>(2)</sup>

Race not exposed

### Diablo Fmt

(16-6 Ma, volcaniclastic conglomerates, sands, lacustrine deposits)

### Oxaya Fmt

(rhyolitic ignimbrites > 3000 km<sup>2</sup> with few intercalated sediments)

### Azapa Fmt

(35-22 Ma: conglomerates, sandsones, mudstones, sheet-flow deposits)

- Oxaya-lg 19.38±20 <sup>(1)</sup> 19.71±0.04<sup>(2)</sup> Molinos-lg

### Diablo Fmt

(16-6 Ma, volcaniclastic conglomerates, sands, lacustrine deposits)

# U-Pb zircon ages and Ar-Ar sanidine ages perfectly overlap !!



21.92±0.17<sup>(2)</sup>

sediments Poconchile (Willi)-Ig 22.72±0.15 San Ar-Ar<sup>(1)</sup> 22.74±0.02 Zr U-Pb<sup>(2)</sup>

### Azapa Fmt

(35-22 Ma: conglomerates, sandsones, mudstones, sheet-flow deposits)

Race not exposed

## Temporal and compositional evolution of "ignimbrite flares"

# Based on our Andes Ignimbrite Database

More than 200 ignimbrite sheets GIS-mapped,

(AIDA)

more than 1600 samples with geochemical, isotopic, and many with age data

APVC, 3-10 Ma, 23°S

#### ...La Pacana caldera...as an AIDA - example

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#### Andes Ignimbrite Database





#### Brandmeier and Wörner AIDA Website

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#### Andes Ignimbrite Database





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#### Ignimbrite mapping





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#### Brandmeier and Wörner AIDA Website

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#### Example Lauca and Oxaya ignimbrites : 2. Ignimbrite compositions Edit and update the database by authorized users Firefox 🔻 🖸 2014 IEEE International Geoscience an... 🛪 🎯 ArcGIS - Andes Ignimbrite Database (... 🚿 🎯 Andes Ignimbrite Database WHISPERS 2014, Switzerland : 6th Wo... 🚿 1 = C S + Google P 🖸 - 🕂 🗲 ) 🖀 https://uni-goe.maps.arcgis.com/apps/OnePane/basicviewer/index.html?appid=47038ddc0628473f9f0ce67aa2eff8be# Andes Ignimbrite Database 🖊 Editor 📲 Dethils 🧮 🖺 Layer 🔻 👫 Grundkarte 🔻 🚋 Messen 🔟 Lesezeichen 🔻 😁 Freigeben 🔻 🔍 Adresse oder Ort suchen 🖶 Drucken 🔻 × Structures Samples • 0,0 - 2,0 Ma ● 2,1 - 4,0 Ma O 4,1 - 7,0 Ma O 7,1 - 11,0 Ma O 11,1 - 16,0 Ma O 16,1 - 18,0 Ma Lauca-Perez Ignimbrite 18,1 - 23,0 Ma NAME Lauca-Perez Ignimbrite Description 23,1 - 24,0 Ma 2,73 Age (Ma) No age data Comment Reference from SERNAGEOMIN, 2003. Mapa Ignimbrite mapping Geológico de Chile Caldera 0,20 - 2,00 Further references Wörner et al. (2000) 2,01 - 4,00 Thickness 4,01 - 7,00 2.405.09 Area (km2) Calculated volume 90.19 7,01 - 12,00 12,01 - 15,00 Reference for volume own source calculations 15,01 - 17,00 17,01 - 19,00 Zoomen auf

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19,01 - 24,00 Undated ignimbrite

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### Age migration of Central Andean Ignimbrites



Freymuth et al (2015)

### Age migration of Central Andean Ignimbrites



Freymuth et al (2015)

### 2. Ignimbrite compositions Age migration of Central Andean Ignimbrites



### Magmatic compositions

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after Wörner et al (2018)

2. Ignimbrite compositions Systematic temporal changes in trace element patterns through time during crustal thickening in the Central Andes



Mamani et al. (2011) Geol Soc Am Bull

2. Ignimbrite compositions Systematic temporal changes in trace element patterns through time during crustal thickening in the Central Andes



Mamani et al. (2011) Geol Soc Am Bull

2. Ignimbrite compositions Systematic temporal changes in trace element patterns through time during crustal thickening in the Central Andes



### Compositional variation related to crustal thickening





This study applies cluster analysis (CA) and linear discriminant analysis (LDA) on log-ratio transformed data.

Brandmeier and Wörner (1916)

### Compositional variation related to crustal thickening





This study applies cluster analysis (CA) and linear discriminant analysis (LDA) on log-ratio transformed data.

Brandmeier and Wörner (1916)

### Peru

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### How much crustal recycling during ignimbrite volcanism? Bolivia

Chile











4. Zircon U/Pb dating combined with O-isotope and Hf- isotope analyses

## Are zircons the solution ?



### Zircon phenocrysts from Oxaya Fmt Ignimbrites (19 – 22 Ma): Shapes



4. Zircon U/Pb dating combined with O-isotope and Hf- isotope analyses

### Zircon phenocrysts from Oxaya Fmt. Ignimbrites Zonation : inherited zircons ?



# Reference data for potential crustal components in ignimbrite magmas



4. Zircon U/Pb dating combined with O-isotope and Hf- isotope analyses

basement data from Pankurst et al (2016) Earth Sci Rev 152:88-105

# Reference data for potential crustal components in ignimbrite magmas



4. Zircon U/Pb dating combined with O-isotope and Hf- isotope analyses

basement data from Pankurst et al (2016) Earth Sci Rev 152:88-105

# Reference data for potential crustal components in ignimbrite magmas: basement rocks



4. Zircon U/Pb dating combined with O-isotope and Hf- isotope analyses

basement data from Pankurst et al (2016) Earth Sci Rev 152:88-105

### Reference data for potential crustal components in





### Reference data for potential crustal components in



Detrital zircons ("Toquepala arc" and "Mesozoic") from Wotzlaw et al (2011)

Belen zircons from the Arequipa metamorphic basement from Pankhurst et al (2016)

### Zircons in ignimbrites



Belen zircons from the Arequipa metamorphic basement from Pankhurst et al (2016)

### Reference data for potential crustal components in



Detrital zircons ("Toquepala arc" and "Mesozoic") from Wotzlaw et al (2011) Belen zircons from the Arequipa metamorphic basement from Pankhurst et al (2016)  $T_{DM(crustal)} \text{ calculated with} \\ \lambda^{176}Lu = 1.865 \times 10^{-11} \text{ (Scherer et al., 2001)} \\ {}^{176}Lu/{}^{177}\text{Hf (crust)} = 0.015 \\ {}^{176}\text{Hf}/{}^{177}\text{Hf (crust)} = 0.0384 \\ \end{array}$ 

### Old crustal components in ignimbrite magmas



4. Zircon U/Pb dating combined with O-isotope and Hf- isotope analyses

### Old crustal components in ignimbrite magmas



4. Zircon U/Pb dating combined with O-isotope and Hf- isotope analyses



# Relations between tectonic shortening and ignimbrite volume and composition Bolivia

Chile







### Summary Origin of ignimbrite magmas

Ignimbrite "flare-ups" migrate from N to S and evolve after the passage of the Juan Fernandez-Ridge ("flat slab")

....related to subsequent steepening/roll-back of the slab

Ignimbrite are 20/80 to 70/30 mixtures of crustal melt and magmas derived from the mantle wedge.

Variable compositions and crustal contribution reflect thickness and thermal maturity of the continental crust

Additional ignimbrite-related arc magma flux are 30-70 km<sup>3</sup>Ma<sup>-1</sup> km<sup>-1</sup> and occur after crustal thickening and slab steepening