Silicon isotopes as tracers of paleoenvironmental conditions during laterite formation in the Amazon Basin

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Lateritic soils: composition and occurrence on Earth

- 1/3 of emerged land but 85 % of soil volume on Earth
- Composition: kaolinite clay and Fe/Al (oxi)hydroxides
- Formation under tropical rainy climate

Laterite developed on sedimentary Alter do Chão Formation

Nahon 2003

Credit: Z. Fekiacova
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Parent rock or sediment
Here: sedimentary Alter do Chão formation (Sandy and kaolinite-rich sediment)

Credit: Z. Fekiacova

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Mottled zone
Differentiation between whitish (kaolinite) and reddish (Fe/Al oxides) sequences

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"Iron crust" - Pisolitic horizon

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**Red latosol**
Iron and kaolinite-rich level

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**Yellow latosol**
Iron and kaolinite-rich level

**Red latosol**
Iron and kaolinite-rich level

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Lateritic soil formation

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- Composition: kaolinite clay and Fe/Al (oxy)hydroxides
- Formation under tropical rainy climate
- Laterites formed by successive weathering episodes (based on dating techniques)

Does a geochemical tracer exist to identify the paleoenvironmental conditions during these successive episodes of formation?

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Use of Si isotopes in the weathering zone

Si isotopes: fractionation of kinetic origin during chemical weathering process (Oelze et al. 2014, 2015)

Enrichment of solution in heavy isotopes

\[
\delta^{30}\text{Si} = \left( \frac{^{30}\text{Si}}{^{28}\text{Si}} \right)_{\text{sample}} / \left( \frac{^{30}\text{Si}}{^{28}\text{Si}} \right)_{\text{std}} - 1 \times 1000
\]

Frings et al. 2016

Si isotope fractionation expected during lateritization

Control of climatic conditions on recorded Si isotope signal

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Lateritic profile developed on Alter do Chão (65-45 Ma) sedimentary formation

Already studied for dating and kaolinite crystallinity (Balan et al. 2005)

Do Si isotopes record a similar evolution over the lateritic profile?
Do Si isotopes record distinct conditions for the formation of the two kaolinite populations?

Modified from Eyrolle et al. 1996 and Balan et al. 2005
Elemental transfer through the profile

- **Focus on the clay fraction** (<2 µm after CBD removal of iron oxides)
- \( \tau_{X,Nb} = \frac{(X_{\text{soil}} \times N_{\text{UCC}})}{(X_{\text{UCC}} \times N_{\text{soil}})} - 1 \)

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**Graphs**

**Immobile elements**
- \( \tau_{X,Nb} \) plotted against depth (m)

**Rare earth elements**
- Rare earth elements plotted against \( \tau_{X,Nb} \)

**Si-like elements**
- Silicon isotopes plotted against \( \tau_{X,Nb} \)

**Al-like elements**
- Al-like elements plotted against \( \tau_{X,Nb} \)

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1st episode: weathering of Alter do Chão sediment


1/ Limited Si isotope fractionation ($\Delta^{30}Si_{\text{sediment-UCC}} = -0.40 \text{‰}$) compared with fractionation reported in literature for kaolinite formation (ca. $\Delta^{30}Si_{\text{clay-parent rock}} = -2 \text{‰}$)

2/ Silicon isotope recording kinetic fractionation (Oelze et al. 2014)

- Slow kaolinite precipitation

3/ Post-Oligocene weathering phase (25-30 Ma) under climatic conditions enabling the slow precipitation of kaolinite mineral

- Limited water infiltration
Desilication of the clay fraction associated with strong enrichment in light Si isotopes

fastest kaolinite formation

\[ \delta^{30}\text{Si} \%_o \]

 Depth (m)

-3.0  -2.0  -1.0  0.0

6 Ma
9 Ma
14 Ma
19 Ma
22 Ma
37 Ma
2nd episode: lateritization process

- Desilication of the clay fraction associated with strong enrichment in light Si isotopes
  fastest kaolinite formation

- Two possible scenarios to explain Si isotope evolution during laterite formation
  
  - Progressive lateritization process between 22 Ma and 6 Ma
  - Binary mixing with a short-term episode around 6-8 Ma
2nd episode: lateritization process

- Desilication of the clay fraction associated with strong enrichment in light Si isotopes
  fastest kaolinite formation
- Two possible scenarios to explain Si isotope evolution during laterite formation
  - Progressive lateritization process between 22 Ma and 6 Ma
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❖ Leaching of light REE: persistence of similar chemical conditions over 14 Ma unlikely
Two possible scenarios to explain Si isotope evolution during laterite formation

- Progressive lateritization process between 22 Ma and 6 Ma
- **Binary mixing with a short-term episode around 6-8 Ma**
Environmental conditions during the lateritization process? How to explain it?

- Desilication of the clay fraction associated with strong enrichment in light Si isotopes, **fastest kaolinite formation than during the first weathering episode**

- Lateritization prone to occur with a persistent rainy season (Beauvais et al. 1999)

- Massive changes in paleogeography and water drainage during early Miocene (8-10 Ma) may have caused important changes in seasonality and water drainage in the Amazon Basin

✦ Onset of transcontinental Amazon River between 8 and 10 Ma (Hoorn et al. 2010)
Conclusions and future steps

✧ Si isotopes: a powerful tool to identify weathering episodes

➢ Two distinct weathering periods with distinct climatic conditions
➢ Current development: use of a transport reactive model
   ❖ Constraints on water flow dynamics during Alter do Chão weathering and lateritization process

✧ Use of Si isotopes at a larger scale

➢ On lateritic soils with various ages
➢ On lateritic soils developed on crystalline rocks

Thank you

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Cited references in the presentation

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Thank you

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