Title

Refining alumina from ore: Selective metal oxide extraction using laser heating

Author

Lucas-Brian Christen, Masataka Watanabe, Hiroto Yamakami, Hokuto Sekine, Kimiya Komurasaki, Hiroyuki Koizumi

Affiliation

PhD Student (D1), Komurasaki & Koizumi Lab.
The University of Tokyo

E-mail

christen-lucas-brian@g.ecc.u-tokyo.ac.jp

アルミエネルギーサイクル研究会

2025/02/28

1

Introduction

Green Transformation

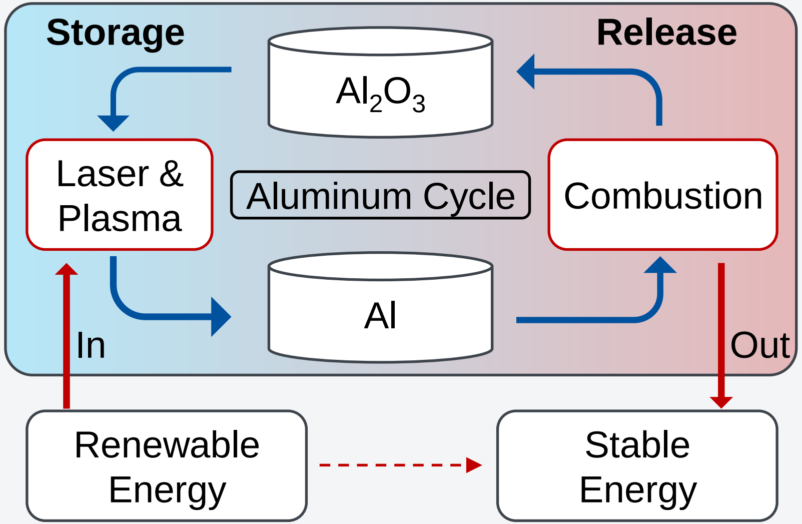
- Aluminum energy cycle was proposed towards a Green Transformation
- Focus of research topics in the aluminum cycle on the Reduction of Alumina
- This presentation: focus on the **Production of Alumina**

Motivation:

- Large amounts of alumina must be produced first
- Alumina production is harmful to the environment

Lead Question

- Are there alternative (green) ways to produce alumina?



Conventional vs. Alternative Alumina Production

Conventional

CO2

Bauxite ore → Bayer process → Alumina

Gibbsite
$Al(OH)_3$

- CO_2 emission through transport
  - Bauxite is unavailable in Japan
- Invasive strip mining
- High waste & pollution: “Red mud”

Green Alternative

Plagioclase Feldspar

Most common minerals inside Earth’s crust

Albite ($NaAlSi_3O_8$) $\rightleftharpoons$ Anorthite ($CaAl_2Si_2O_8$)

→ Laser heating → Alumina

+ Local production
  - Plagioclase 40% of Earth‘s crust
+ No waste

How can we realize this?

Alumina Production from Plagioclase Mineral

Proposal

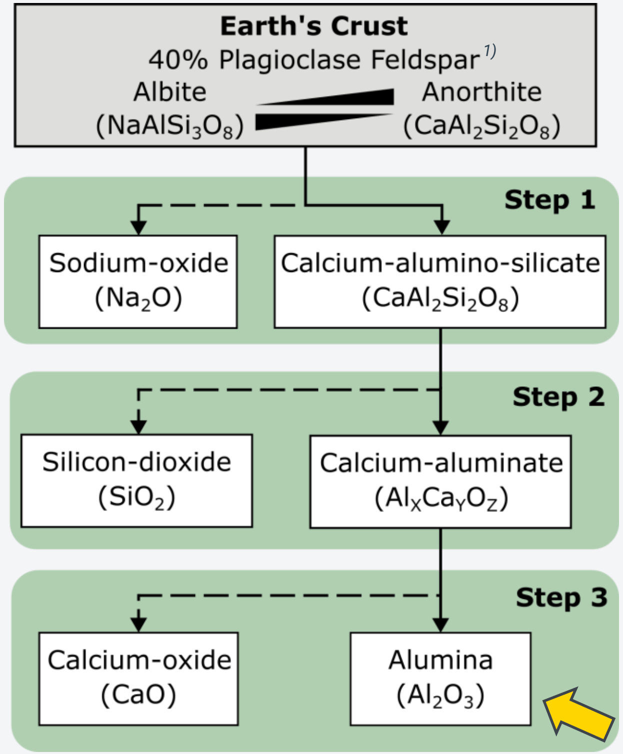
- Selective oxide extraction according to their boiling points by Laser Heating
- **Stepwise extraction** allows refinement of minerals to alumina

Plagioclase Feldspar
$\mathbf{NaAlSi_3O_8 - CaAl_2Si_2O_8}$

Oxide	Boiling Point
K_2O	623 K
Na_2O	2223 K
SiO_2	2503 K
CaO	3123 K
Al_2O_3	3250 K

Objective

- Provide **proof-of-concept** for the oxide extraction



[1)] S. R. Taylor et and S. M. McLennan. "Chemical Composition and Element Distribution in the Earth's Crust." (2003).

2

Experiment

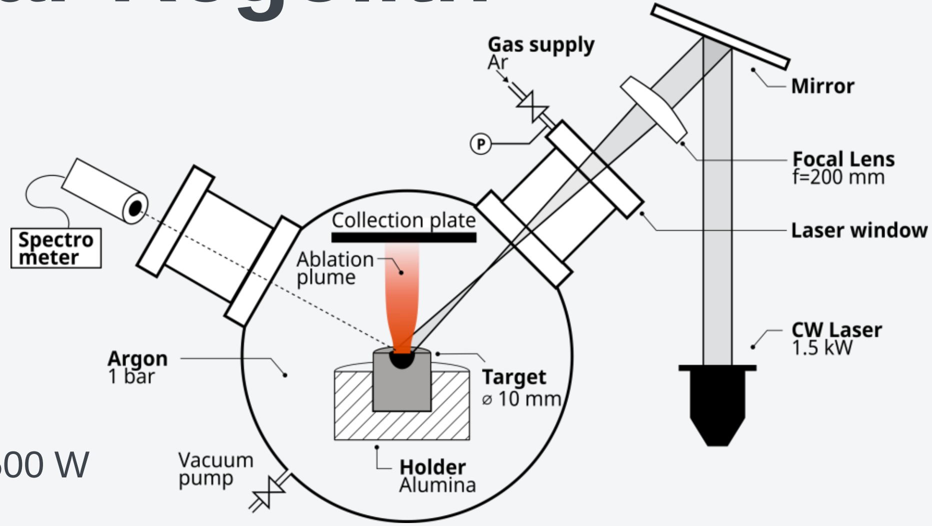
Lunar Regolith (Simulant)

$\downarrow$ Transfer of knowledge

Earth‘s regolith

Experiment on Lunar Regolith

- **Material**: Lunar regolith simulant
  - JSC-2A, FJS-1, EAC-1A
  - Sintered (SPS) with Tokyo City University (TCU)



- **Experiment process**
  - Preheating at 150 W followed by 10 s ablation at 1500 W
    - ➢ To Prevent cracking and maximize temperature[2)]

- **Analysis methods:**

Surface temperature | Emission spectrum | SEM/EDX

SEM/EDX → Sample surface, Collection plate

Parameter	Value
Ambient gas	Argon
Ambient pressure	1 bar
Laser type	Fiber, 1080 nm
Laser power	1.5 kW
Laser spot radius	2.5 mm
Laser intensity (avg.)	80 MW/m^2

[2)] S. Tanaka et al, *JTHT* (2020)

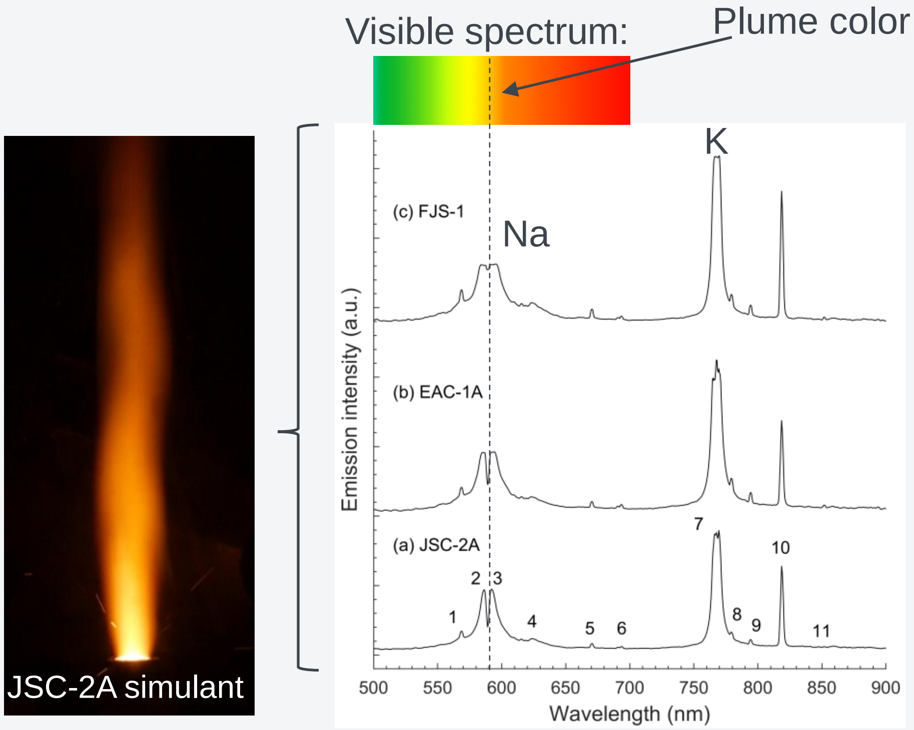
3

Results & Discussion

- Emission spectrum & surface temp.
- SEM/EDX of sample surface
- SEM/EDX of collection plate

Emission Spectrum and Surface Temperature

- **<u>Emission spectrum</u>** reveals the abundance of $\mathbf{Na}$ **and** $\mathbf{K}$ in the plume
  - ➢ Extraction of K_2O and Na_2O
  - ➢ Thermal reduction

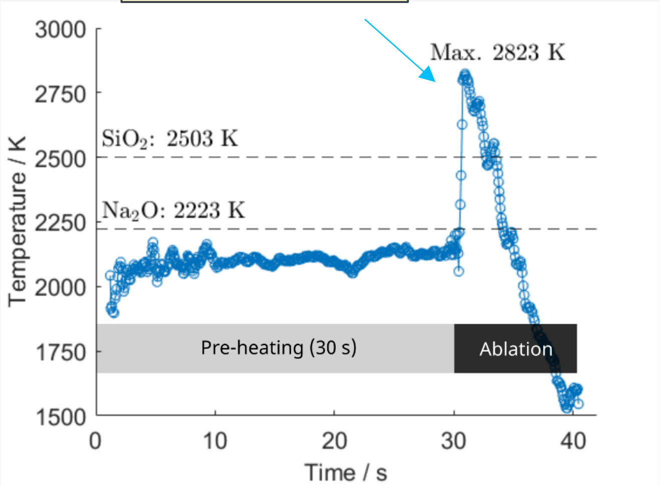


Emission Spectrum and Surface Temperature

- **Emission spectrum** reveals the abundance of **Na and K** in the plume
  - ➢ Extraction of K_2O and Na_2O
  - ➢ Thermal reduction

- **Surface temp.** reached a maximum of **2800 K**
  - ➢ Above boiling point of SiO_2
  - ➢ Was SiO_2 extracted?
    - ➢ Yes! However, not visible in the spectrum
    - ➢ Extraction without reduction

$I = 80\ MW/m^2$



Sample surface temperature

Oxide	Boiling point	Detected
K_2O	623 K	Yes (K)
Na_2O	2223 K	Yes (Na)
SiO_2	2503 K	No
CaO	3123 K	No

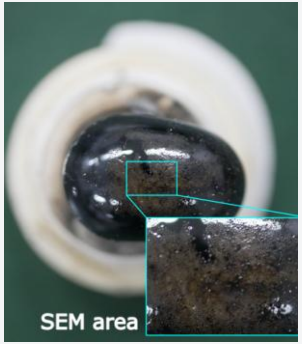
Surface Temp.: 2800 K

SEM / EDX Analysis of the Sample Surface

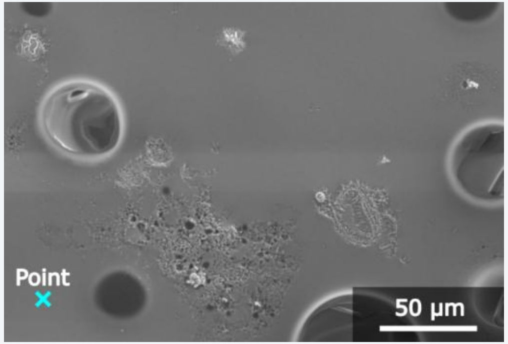
- Scanning electron microscopy (**SEM**) with Energy dispersive X-Ray (**EDX**)
- If oxides are extracted, the relative amount of an element should be decreased → **Deficiency**

Element	Sample surface (EDX)	JSC-2A (unaltered)	Δ
-	wt%	wt%	-
K	0.30	0.68	**-57%**
Na	1.92	2.31	**-17%**
Si	21.31	21.61	**-1%**

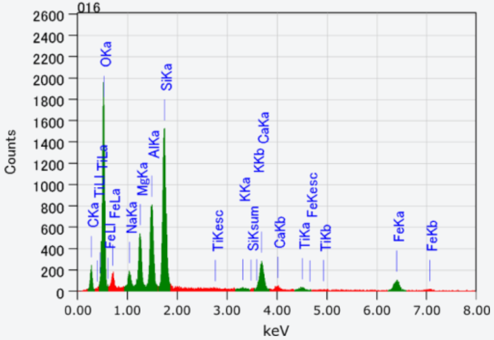
➢ Deficiency of **K, Na & Si** was detected



Sample photograph



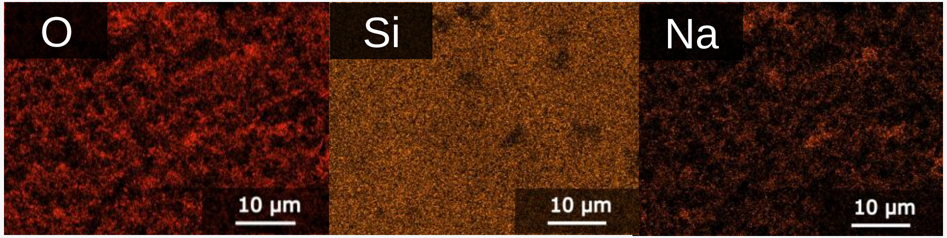
SEM



EDX

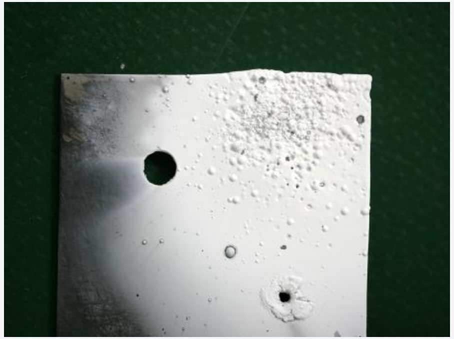
SEM / EDX Analysis of the Collection Plate

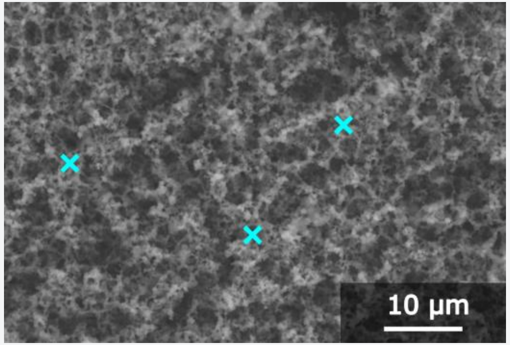
- Ta-plate covered with white material
  - SEM / EDX
- Composition of white material = plume/vapor composition



Collection plate EDX mapping

> ➢ Deposition of mainly **O, Si & Na** was detected
>
> ➢ Extraction of Na_2O (Step 1) and SiO_2 (Step 2)


Collection plate photograph



Collection plate SEM

Collection plate EDX

Element	wt%
O	**40.9 %**
Si	**23.3 %**
Na	**12.5 %**
Fe	5.1 %
K	3.5 %
P	2.7 %

4

Conclusion

Conclusion

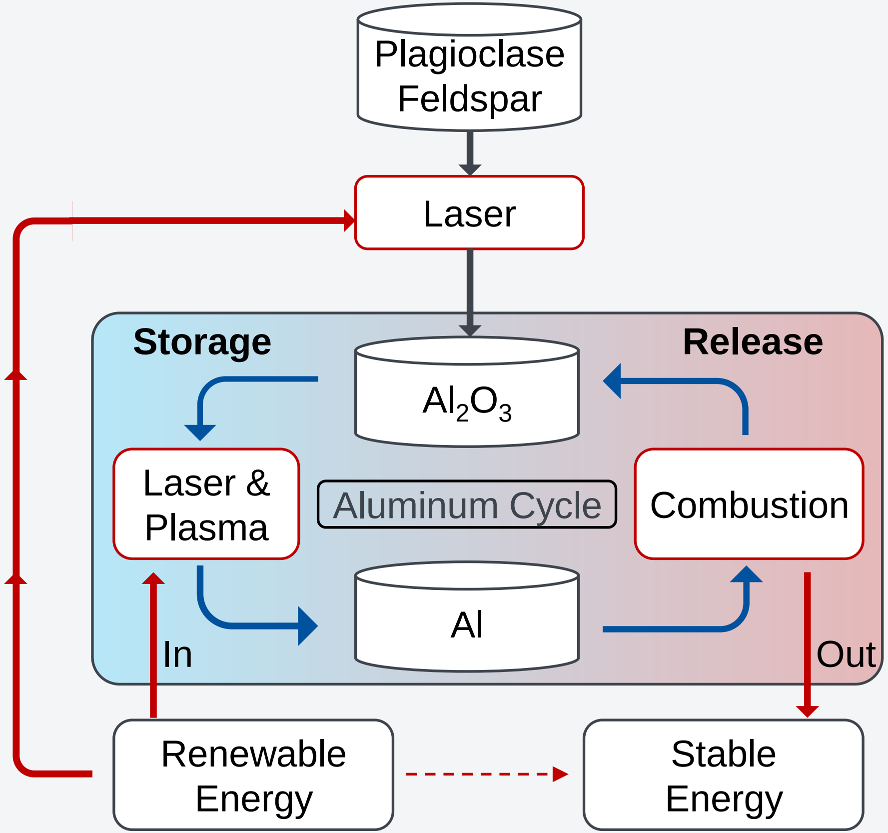
✓ Objective is met

- **Proof-of-concept** for the extraction of Na_2O (**Step 1**) and SiO_2 (**Step 2**)
- Next step: Full **depletion of Na_2O and SiO_2** using Plagioclase Feldspar material

Outlook

- Extension of the aluminum energy cycle
- Waste-free & Carbon-free production of commercially valuable products:

SiO_2 CaO Al_2O_3

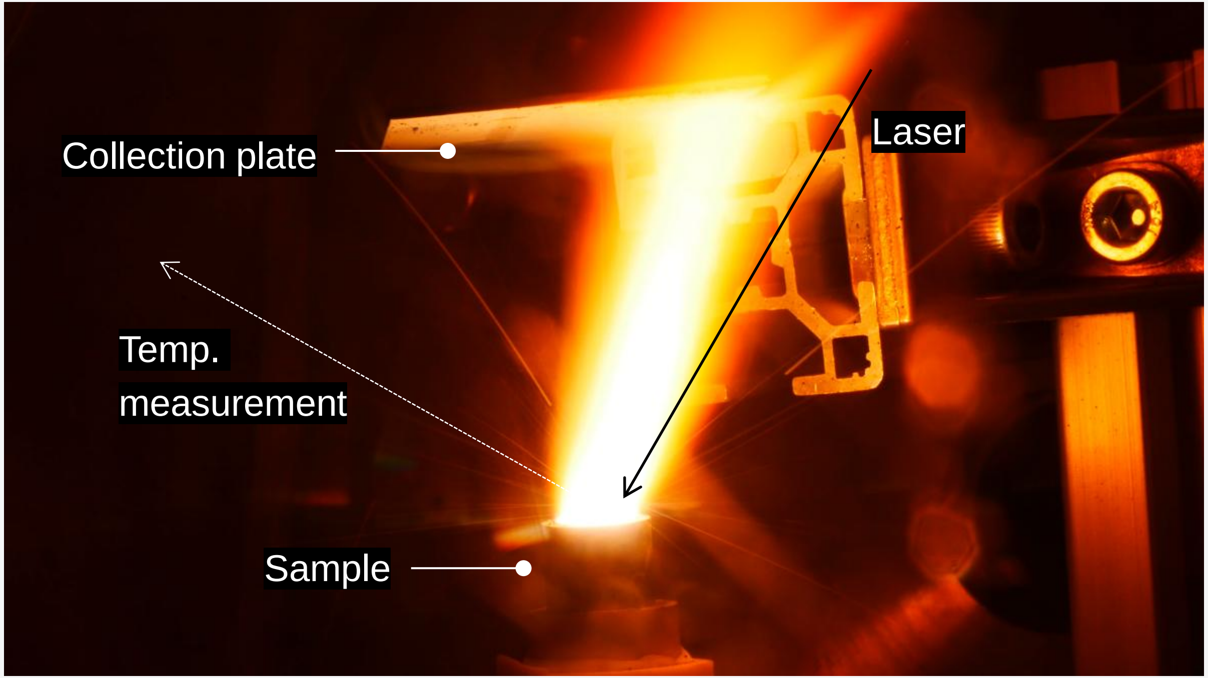


Thank you for your attention!

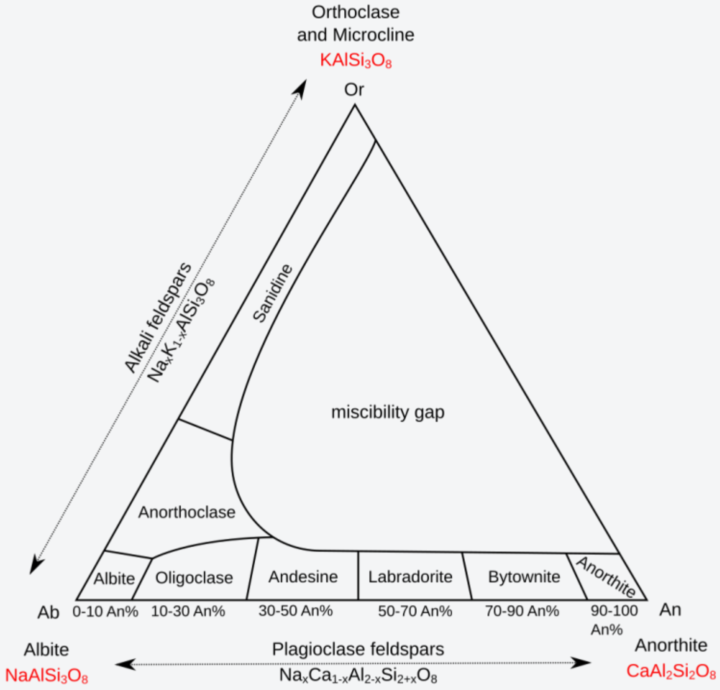
Author	Lucas-Brian Christen, Masataka Watanabe, Hiroto Yamakami, Hokuto Sekine, Kimiya Komurasaki, Hiroyuki Koizumi
Affiliation	PhD Student (D1), Komurasaki & Koizumi Lab. The University of Tokyo
E-mail	christen-lucas-brian@g.ecc.u-tokyo.ac.jp

Appendix

Experiment Set-up



Feldspar Group



Mineral	Alumina content	Aluminum content
Anorthite	35.8 wt%	19.0 wt%
Albite	20.4 wt%	10.8 wt%
Orthoclase	18.3 wt%	9.69 wt%

Mineralogy database, https://webmineral.com/

Lunar regolith & Plagioclase Feldspar

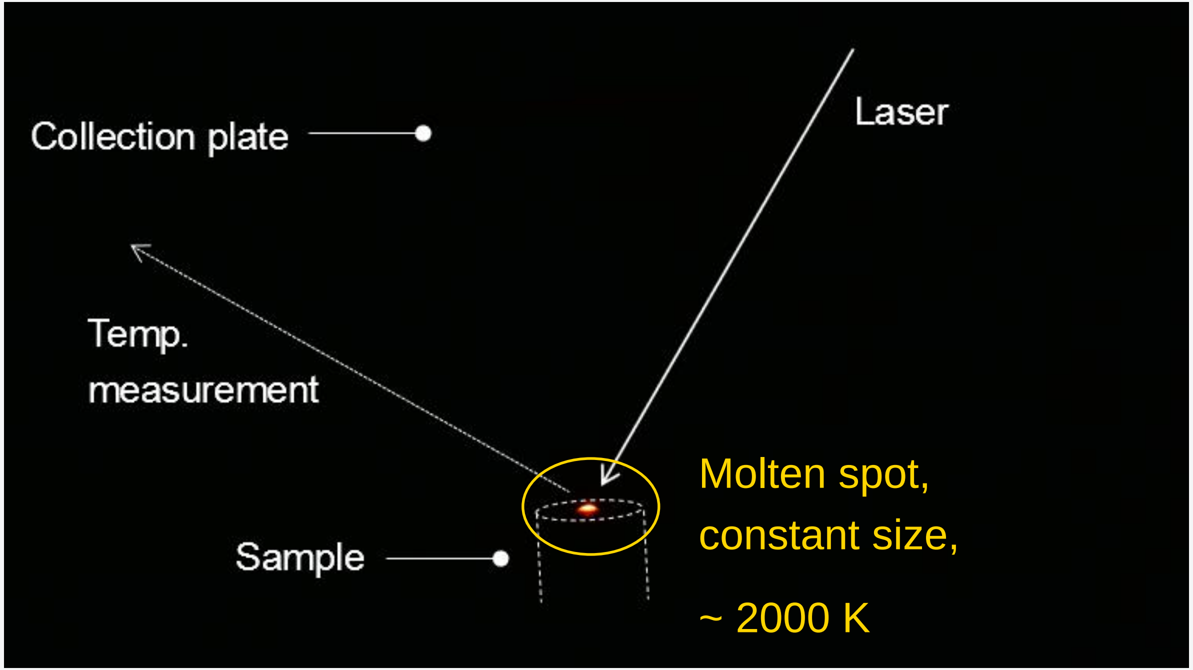
- **JSC-2A**
  - Mare type, low-Ti
- **EAC-1A**
  - Mare type
- **FJS-1**
  - Mare type, low-Ti
- **Albite**
  - $NaAlSi_3O_8$
- **Anorthite**
  - $CaAl_2Si_2O_8$

Table A1: Oxide composition of the regolith simulants JSC-2A, EAC-1A, and FJS-1 along with Albite and Anorthite, and Earth's upper crust

Compound	**JSC-2A**	**EAC-1A**	**FJS-1**	**Albite**	**Anorthite**	**Upper crust**
-	wt%	wt%	wt%	wt%	wt%	wt%
K_2O	0.80	1.30	1.01			2.80
Na_2O	2.75	2.75	2.75	11.91	0.56	3.27
SiO_2	47.50	43.70	49.14	67.39	44.40	66.62
CaO	10.50	10.80	9.13	1.07	19.20	9.79
TiO_2	1.50	2.40	0.19			0.64
Al_2O_3	15.00	12.60	16.23	20.35	35.84	15.40
FeO	7.25	-	8.30			5.04
MgO	9.00	11.90	3.84			2.48

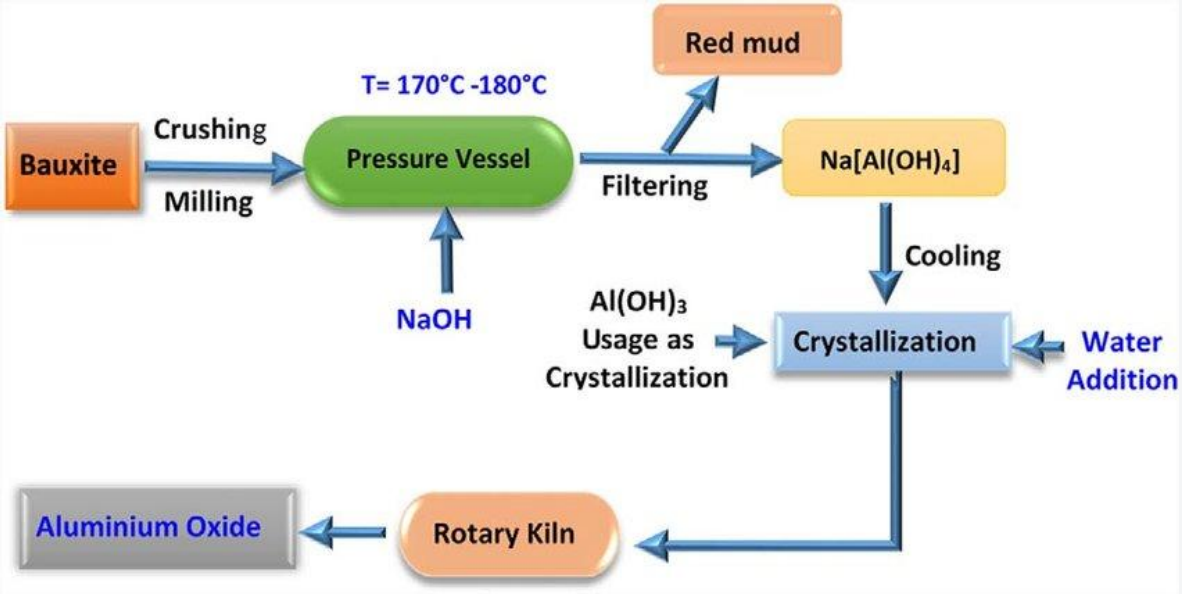
J. Schleppi et al, "Manufacture of glass and mirrors from lunar regolith simulant" (2019);
Mineralogy database, https://webmineral.com/ ;
Rudnick and Gao, "Composition of the continental crust" (2003)

Preheating



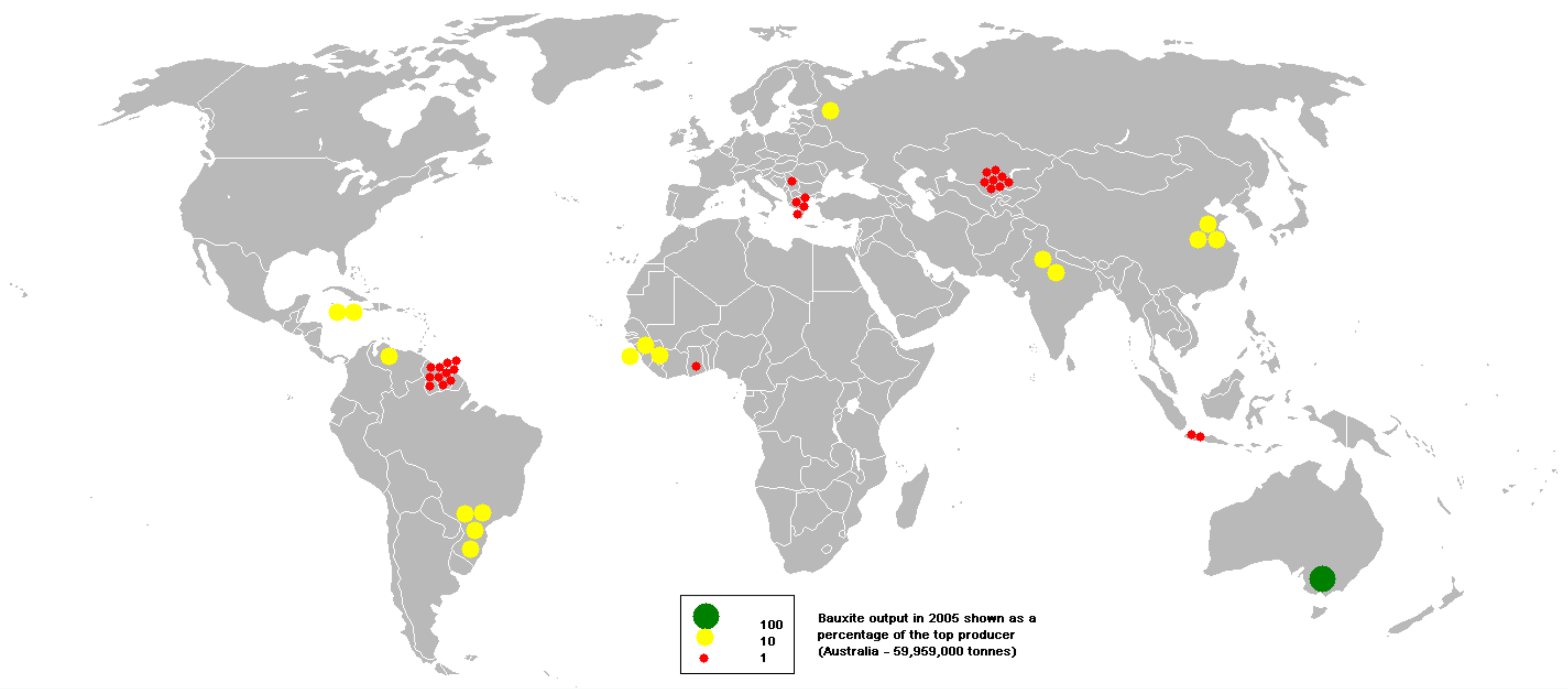
Collection plate
Laser
Temp.
measurement
Sample
Molten spot,
constant size,
~ 2000 K

Bayer Process



Dodoo-Arhin et al, *Case Studies in Construction Materials, (2017)*
http://dx.doi.org/10.1016/j.cscm.2017.05.003

Abundance / Mining sites of Bauxite Ore



British Geological Survey, URL:
http://www.bgs.ac.uk/mineralsuk/commodity/world/home.html, Accessed on Feb. 27th 2025

Sintering Conditions

- The samples were sintered using Spark Plasma Sintering using 4.5 g of simulant
- Max. pressure: **20 MPa**, max. temperature: **950 K**

$$H = 10\ \mathrm{mm}$$

$$\varnothing = 10\ \mathrm{mm}$$

$$\rho = 2.88\,\frac{\mathrm{g}}{\mathrm{cm}^3}$$