

**Innovation for Cool Earth Forum (ICEF)  
9th Annual Meeting**



**REE-rich mud:  
An innovative seafloor resource  
for Sustainable Development Goals**

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School of Engineering, The University of Tokyo

# Rare-earth elements (REE) as a key material for SDGs

## SUSTAINABLE DEVELOPMENT GOALS



World Business Legal Markets

### COP26

## U.N. climate agreement clinched after late drama over coal

By Valerie Volcovici and Kate Abnett, William James



Reuters  
(2021.11.14)

## France to uphold ban on sale of fossil fuel cars by 2040

By Reuters Staff

Reuters  
(2019.7.11)

PARIS (Reuters) - The French government's new law on mobility will uphold a planned ban on fossil fuel-powered cars by 2040, Transport Minister Elizabeth Borne said on Tuesday.

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### Bloomberg Green

Subscriber Only

Bloomberg  
(2020.9.24)

Hyperdrive

## California to Ban New Gasoline Cars by 2035, a First in U.S.

By David R Baker, Emily C Dooley, and Keith Naughton  
2020年9月24日 2:31 JST Updated on 2020年9月24日 5:23 JST

## Electrification of vehicles

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### NEWS

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## China looks at plans to ban petrol and diesel cars

10 September 2017

BBC NEWS  
(2017.9.10)

## Japan may ban sale of new gasoline-powered vehicles in mid-2030s: media

By Reuters Staff

Reuters  
(2020.12.3)

TOKYO (Reuters) - Japan may ban sales of new gasoline-engine cars by the mid-2030s in favour of hybrid or electric vehicles, public broadcaster NHK reported on Thursday, aligning it with other countries and regions that are imposing curbs on fossil fuel vehicles.

### CLIMATE CHANGE

## EU Green Deal seeks to force shift to electric vehicles in 2035

Ambitious emissions plan also targets steel and cement with carbon border tax



A charging station in Ruesselsheim, Germany. A European Union proposal would in effect ban the sale of new gasoline and diesel cars in 2035. © Reuters

YASUO TAKEUCHI and KOSEI FUKAO, Nikkei staff writers  
July 15, 2021 03:08 JST

NIKKEI Asia  
(2021.7.15)

## Rapid growth of wind power generation

ENVIRONMENT 2020年11月19日 / 9:05 午後 / 1年前更新

## European Union plans mammoth expansion of offshore wind farms

Kate Abnett

Reuters  
(2020.11.29)

BRUSSELS (Reuters) - The European Union unveiled plans on Thursday to transform its electricity system to rely mostly on renewables within a decade and increase its offshore wind energy capacity 25-fold by 2050.



### the japan times

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## Japan aims to be world's No. 3 offshore wind power producer in 2040



An offshore commercial wind power plant in Taiwan | KYODO

The Japan Times  
(2020.12.16)

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March 31, 2022  
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Last Updated 5 months ago

Environment Clean Energy Climate Change Energy

## Global wind and solar growth on track to meet climate targets

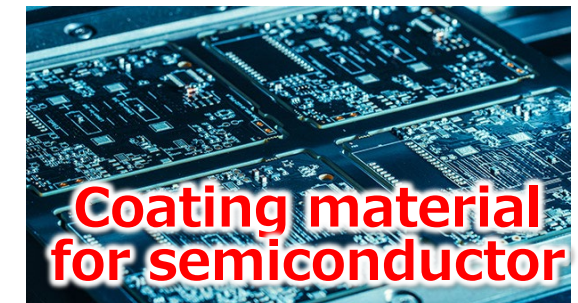
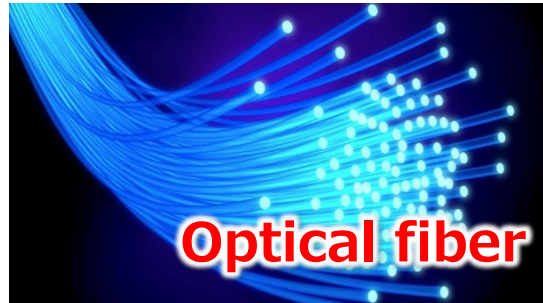
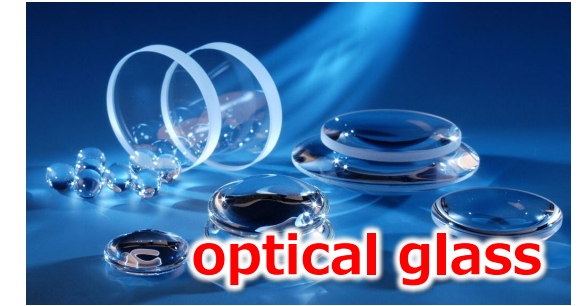
Reuters

3 minute read



Reuters  
(2022.3.21)

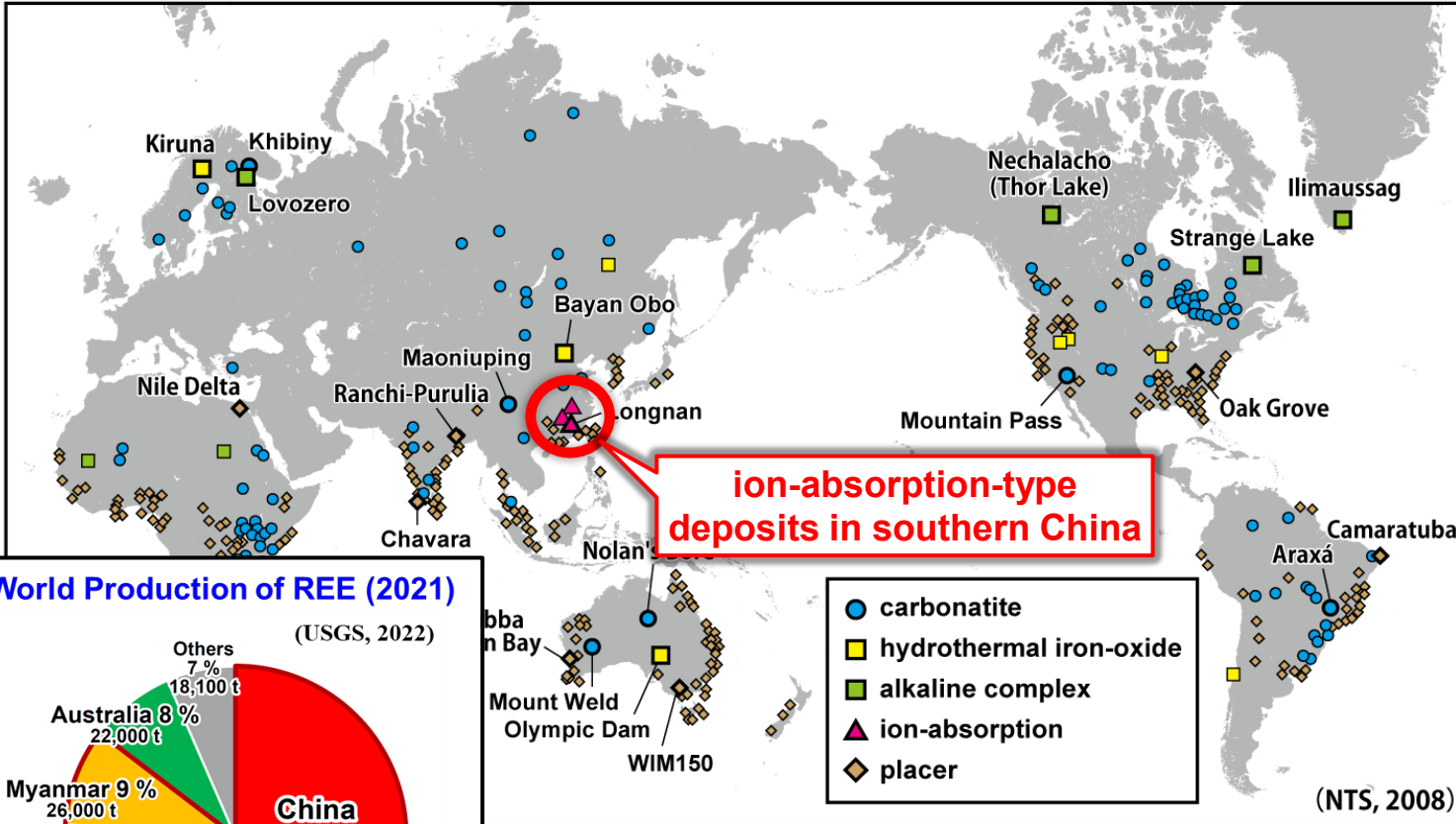
# Principal uses of REE



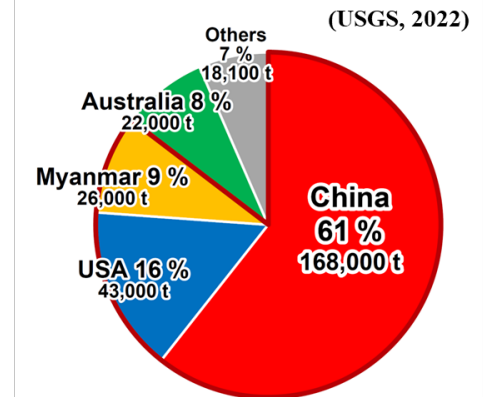
**REE are strategic materials crucial for**

- *Green-energy technologies*
- *Novel electronic equipment*
- *Aerospace instruments etc...*

# Problems on the current REE resources



World Production of REE (2021)

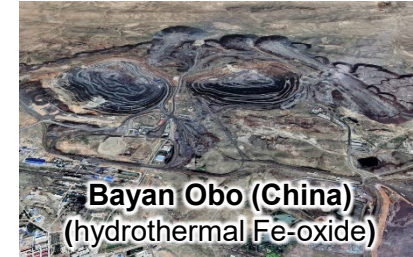


- ❖ Mt. Pass mine (US) is partly funded by a **Chinese company** and its ores are **smelted in China**
- ❖ Ores from Myanmar are **smelted in China**

- **Almost all deposits are of LREE**
- **Industrially critical HREE are exclusively produced by ion-absorption-type deposits in southern China**

## Serious environmental problems with onshore REE deposits

### LREE deposits



High Th and U concentrations cause serious problems of radioactive waste

### HREE deposit



Outflowing of the leaching acids causes a severe environmental pollution

**The most important problem to be solved**

# “The rare-earth crisis”



## China ready to hit back on rare earths: newspapers

BEIJING (Reuters) - China is ready to use its rare earth exports to hit back at the United States, Chinese newspapers warn in commentaries on a move that would escalate the trade war between the two economies.

## China Stokes Rare Earth Export Controls

Bloomberg News  
2019年6月4日 23:41 JST  
▶ Experts suggested a mechanism for tracking, approving exports  
▶ NDRC met with experts focused on promoting the industry

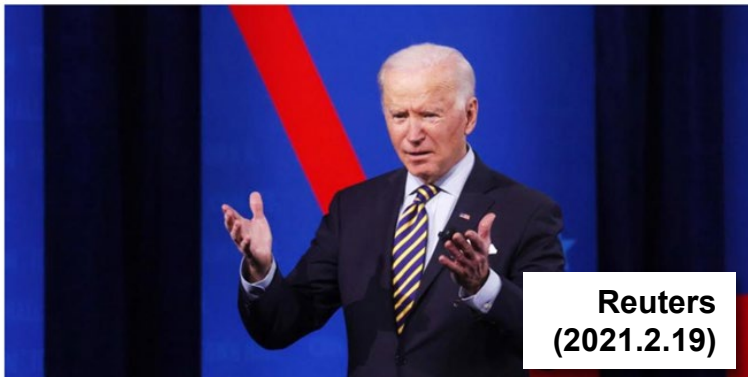


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## Biden to order review of U.S. reliance on overseas supply chains for semiconductors, rare earths - CNBC

By Reuters Staff

2 MIN READ



Reuters (2021.2.19)



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Politics

## F-35s All Contain Banned China-Made Alloy Pentagon Says

- Alloy in magnet poses no risk to security or flight safety
- Security waiver needed to resume deliveries, avoid retrofits



Lockheed Martin F-35A Photographer: George Frey/Bloomberg

Bloomberg (2022.9.10)

Bloomberg

## U.S. to Ensure Rare-Earth Supply Amid Trade War With China

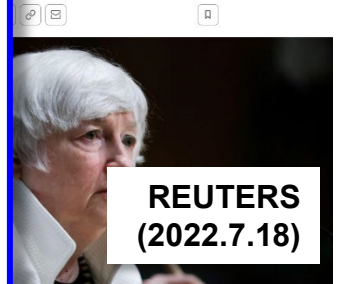
on 2019年6月5日 6:47 JST

mitting, U.S. exploration

of rare earths

Bloomberg (2019.6.5)

ants to end dependence on rare earths, Yellen



Reuters (2022.7.18)



The U.S. is seeking a way to strengthen its supply chain by getting rare-earths from sources other than China, but is not successful until now...

# Discovery of a new REE resource

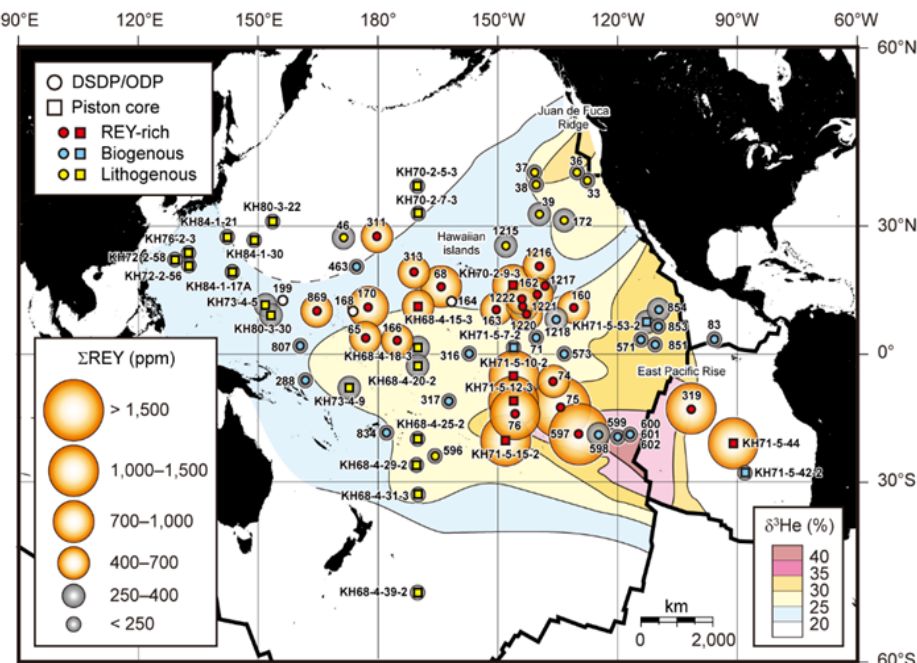


nature geoscience LETTERS  
PUBLISHED ONLINE 3 JULY 2011 | DOI: 10.1038/NATURE10186

## Deep-sea mud in the Pacific Ocean as a potential resource for rare-earth elements

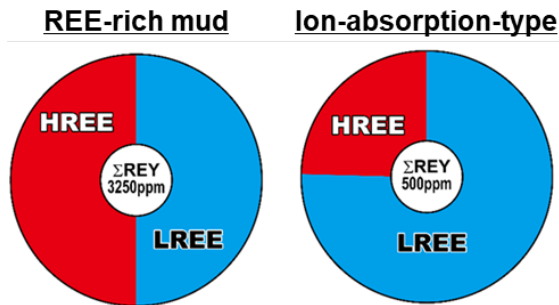
Yasuhiro Kato<sup>1\*</sup>, Koichiro Fujinaga<sup>1</sup>, Kentaro Nakamura<sup>2</sup>, Yutaro Takaya<sup>3</sup>, Kenichi Kitamura<sup>4</sup>, Junichiro Ohta<sup>1</sup>, Ryuichi Toda<sup>1</sup>, Takuya Nakashima<sup>1</sup> and Hikaru Iwamoto<sup>1</sup>

World demand for rare-earth elements and the metal yttrium—which are crucial for novel electronic equipment and greenenergy technologies—is increasing rapidly<sup>1,2</sup>. Several types of seafloor sediment harbour high concentrations of these elements<sup>3,4</sup>. However, seafloor sediments have not been regarded as a rare-earth element and yttrium resource, because data on the spatial distribution of these deposits are insufficient. Here, we report measurements of the elemental composition of over 2,000 seafloor sediments, sampled at depth intervals of around one metre, at 78 sites that cover a large part of the Pacific Ocean. We show that deep-sea mud contains high concentrations of rare-earth elements and yttrium at numerous sites throughout the eastern South and central North Pacific. We estimate that an area of just one square kilometre, surrounding one of the sampling sites, could provide one-fifth of the current annual world consumption of these elements. Uplifts of rare-earth elements and yttrium by mineral phases such as hydrothermal iron-oxides and pillajite seems to be responsible for their high concentration. We show that rare-earth elements and yttrium are readily recovered from the mud by simple acid leaching, and suggest that deep-sea mud constitutes a highly promising huge resource for these elements. At present, 97% of the world's production of rare-earth elements and yttrium (REY) is accounted for by China, although China has only one-third of global reserves and the Commonwealth of Independent States, the United States, and Australia together have another one-third of reserves<sup>5</sup>. China's dominance certifies to



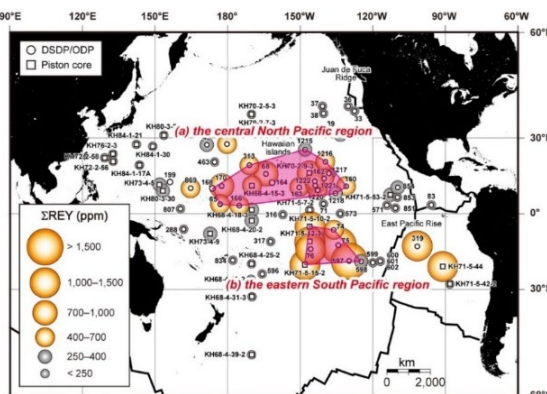
Kato et al. (2011 Nature Geoscience)

## 1. High REE (HREE) contents



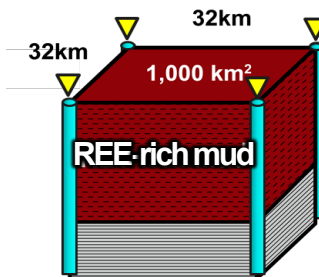
50% of REE in the mud are HREE, which is highly profitable as a mineral resource

## 2. Enormous resource potential



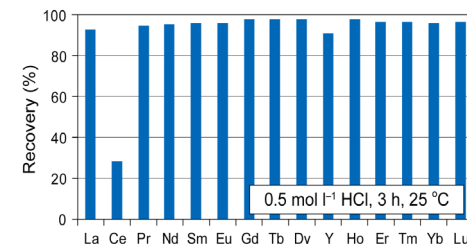
~1,000 times larger than the world's current land reserves of REE

## 3. Easy exploration



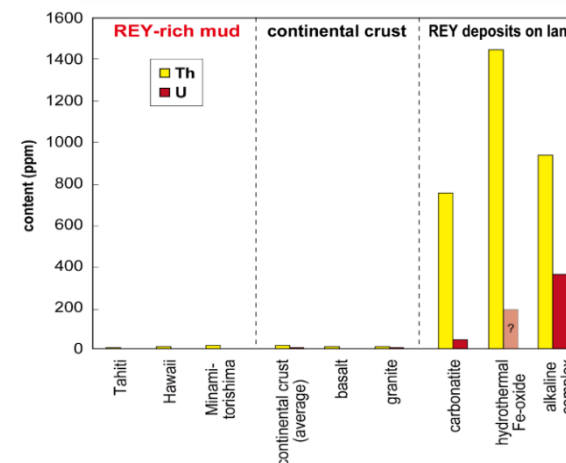
REE resource can be simply estimated by taking piston cores from the four corners of the area

## 4. Easy leaching by dilute acids



>97% of REE are easily extracted by dilute acids under a room temperature within 1–3 hours

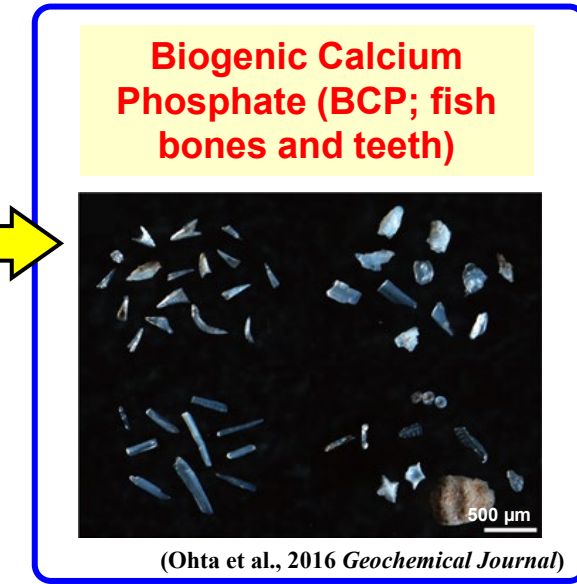
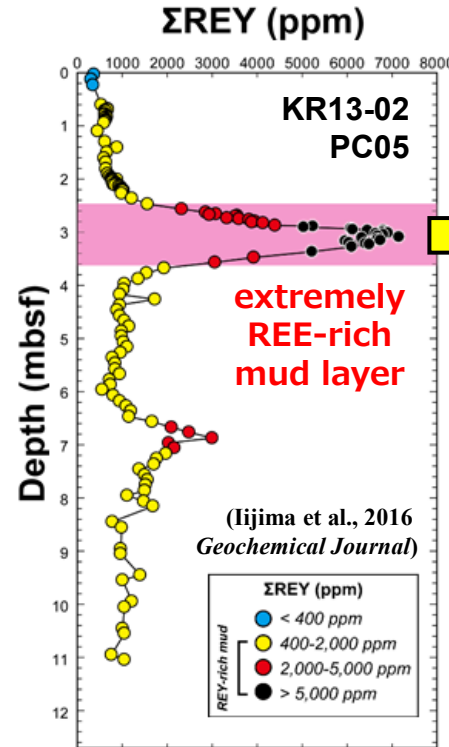
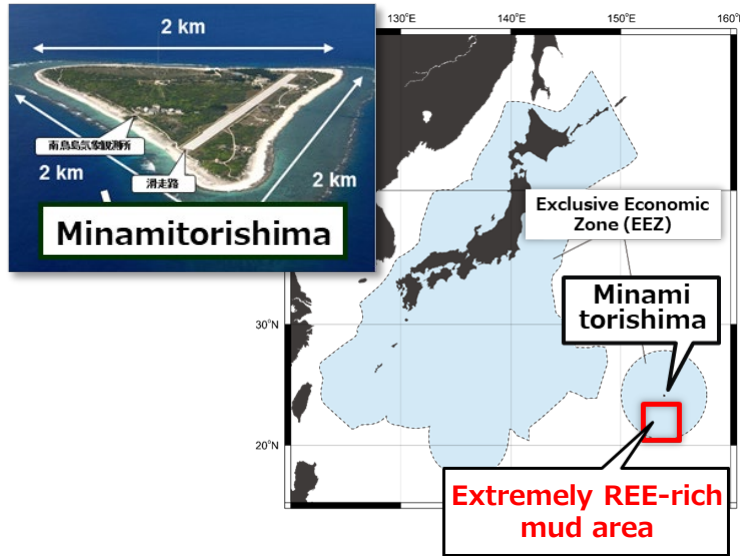
## 5. Low contents of radioactive elements (Th & U)



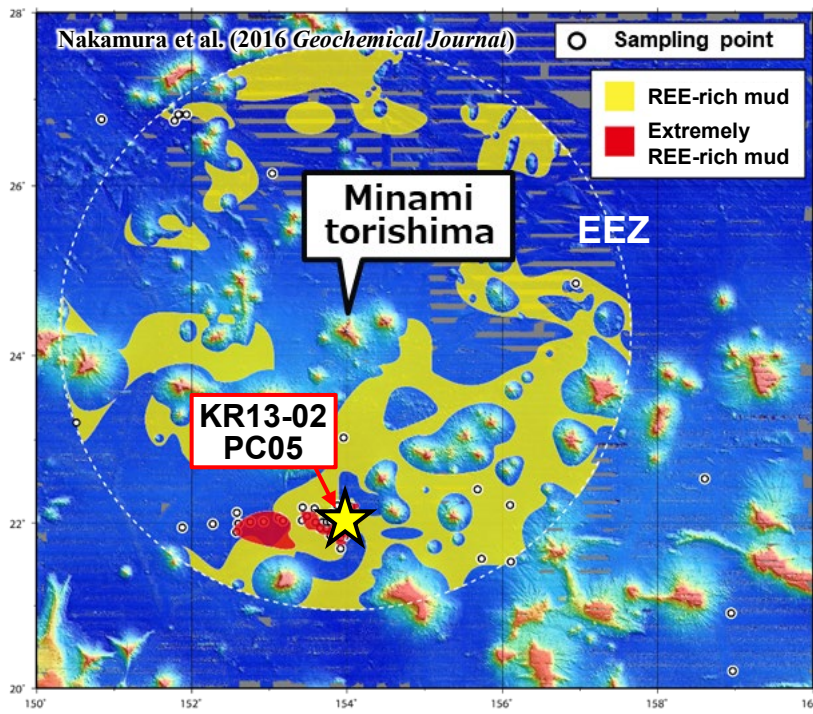
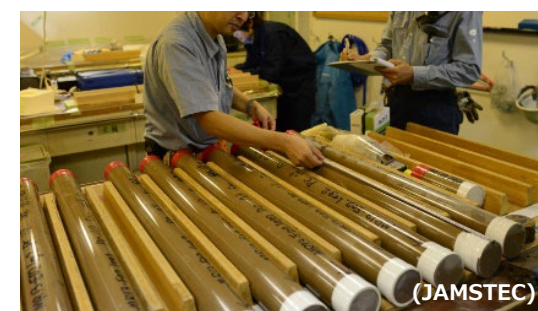
On-land deposits show very high contents of radioactive elements  
REE-rich mud has very low Th & U

REE-rich mud is a clean and harmless resource

# Discovery of extremely REE-rich mud in the Minamitorishima EEZ



**>7,000 ppm of total REE in bulk sediment**  
(~20 times higher than on-land deposits in southern China)

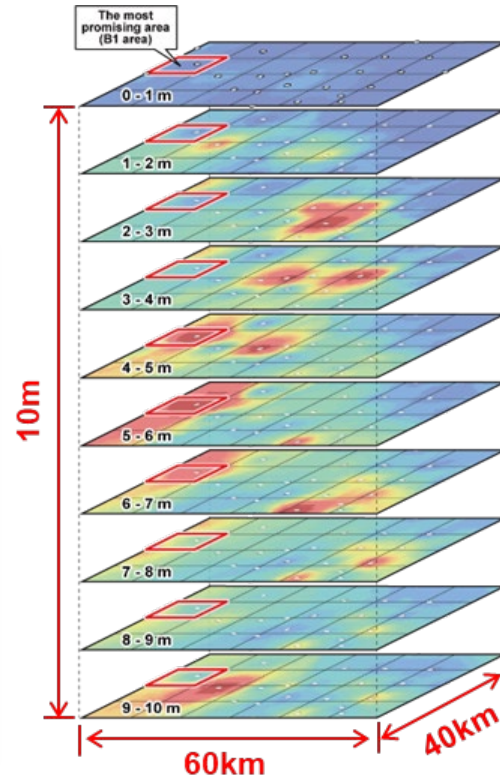
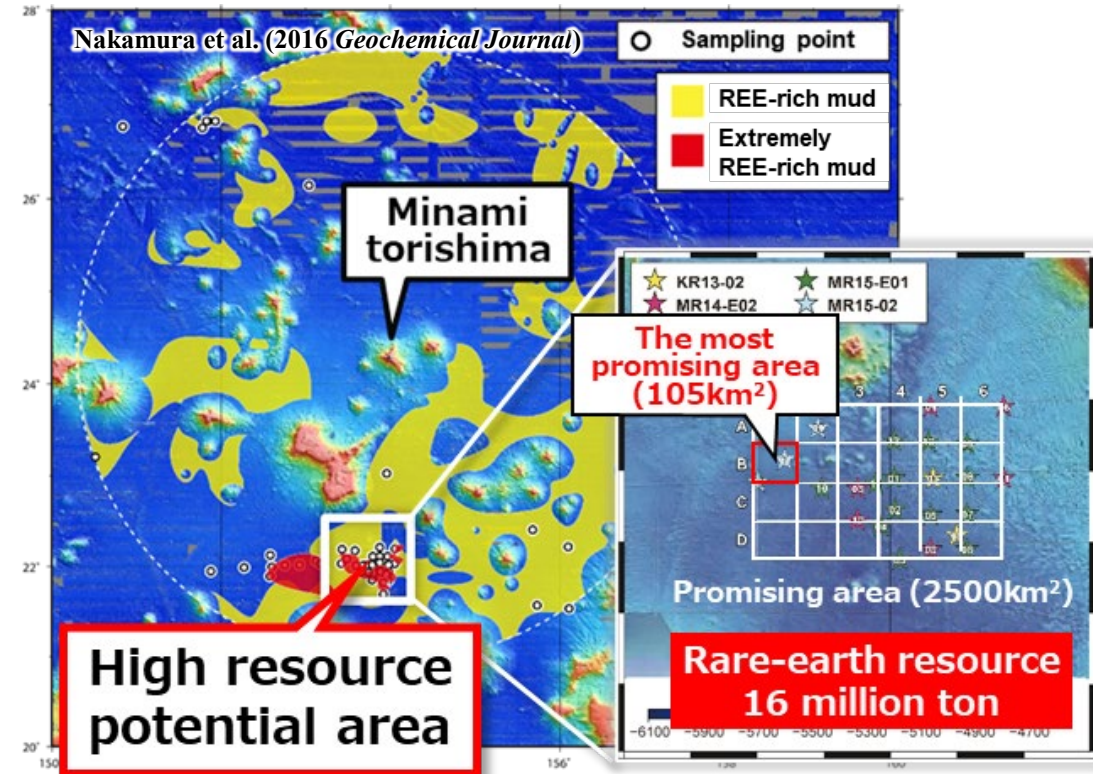


**Extremely REE-rich mud is also enriched in scandium**

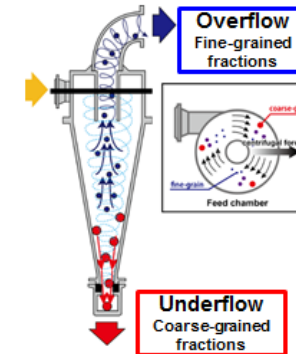
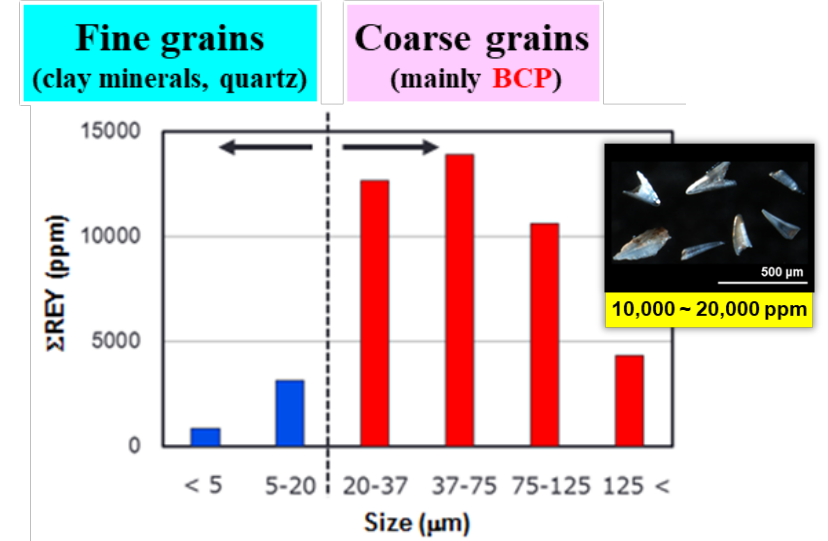


# Resource potential of REE in the Minamitorishima EEZ

(Takaya et al., 2018 *Scientific Reports*)



## Effective separation by hydrocyclone



❖ The most promising area (105 km<sup>2</sup>) can provide

- 50 to 800 times of the Japanese annual REE demand
- 1,400 to 2,400 times of the global annual supply (15–25 t) of Sc

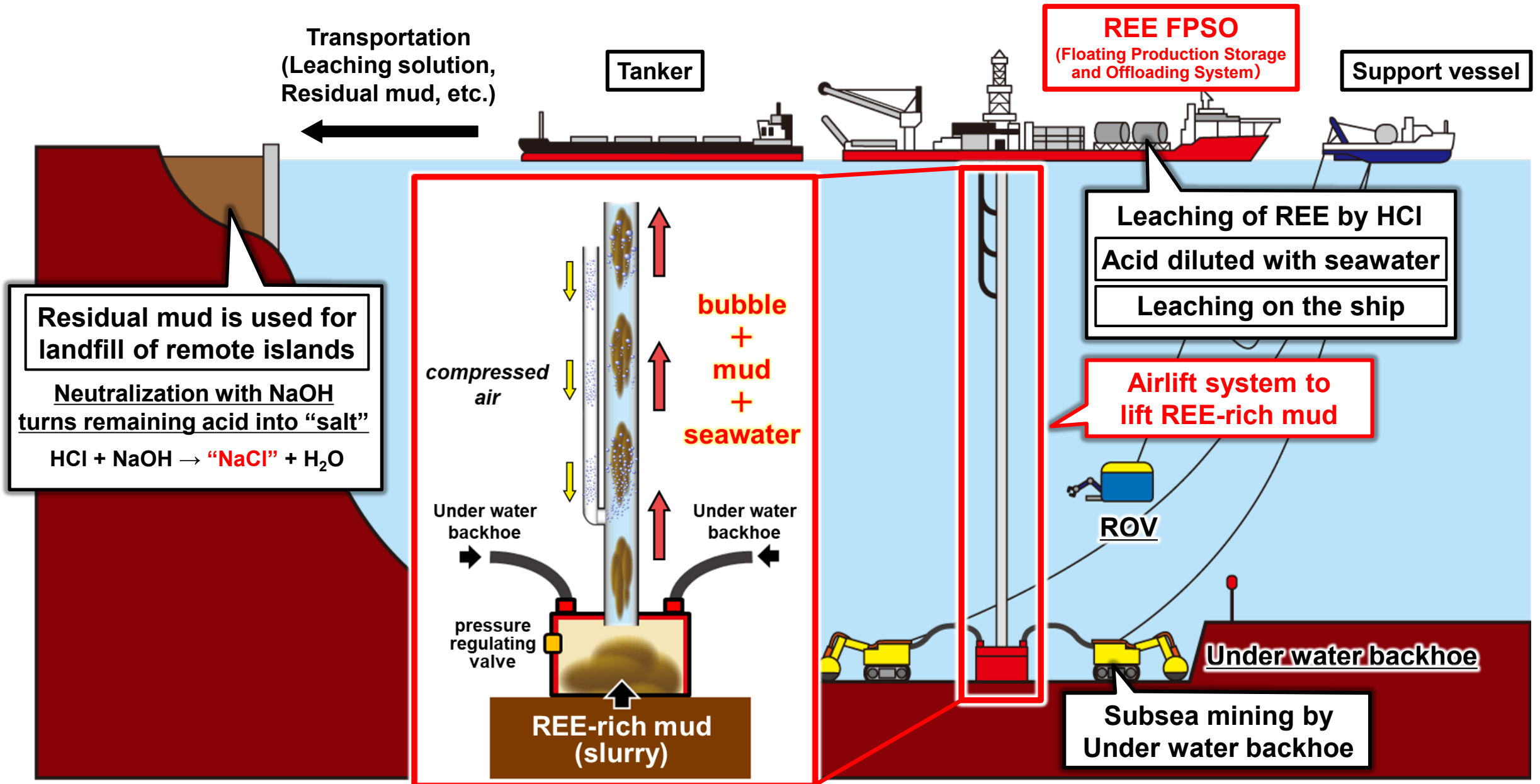
REE-rich mud is a unique resource that can serve both HREE and Sc

Grain-size separation enables

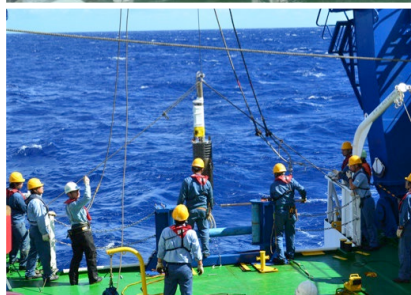
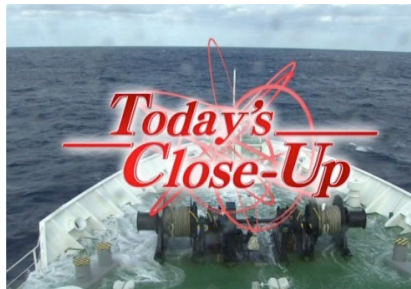
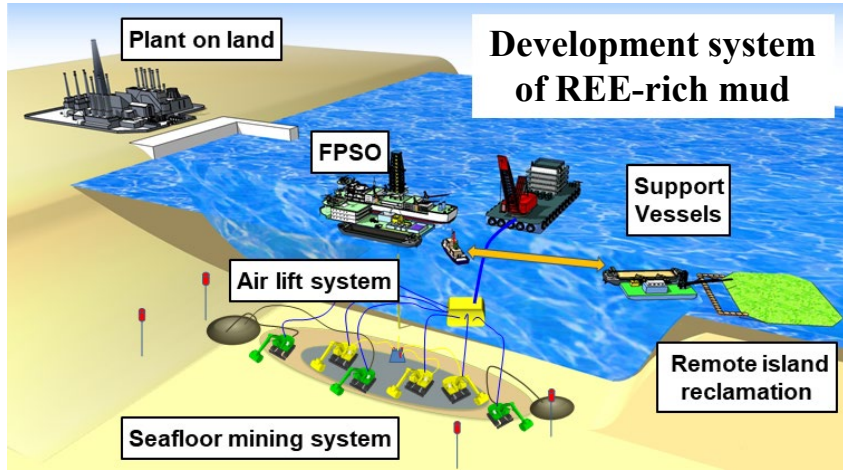
- to improve REE grade by 2.6 times
- to reduce mud volume to 20–50%



# Development system of REE-rich mud



# Consortium for promotion of REE-rich mud development




 The University of Tokyo	 MODEC Mitsui Ocean Development & Engineering	 SANTOKU	 Shin-Etsu Chemical	 TOA Corporation	 IHI	 Mitsui Mining & Smelting	 FURUKAWA
 Nippon Yusen Kaisha LINE	 Komatsu	 Showa Denko	 TOYOTA MOTOR	 Mitsui O.S.K. Lines	 KAWASAKI KISEN KAISHA	 FUKADA Salvage & Marine Works	 Sumitomo Mitsui Construction
 KAJIMA Corporation	 Taiheiyo Cement	 JX Nippon Mining & Metals/ENEOS	 JAPAN NUS	 Industrial Growth Platform	 Nippon Steel Research Institute	 PwC	 The Japan Research and development Center for Metals
 UACJ	 AGC	 TDK	 NEMOTO	 YAMAGIWA	 Mitsubishi Heavy Industries	 applause	 The Ota City Industrial Promotion Organization
 Office of Designated Remote Island Ports, MLIT	 Chiba Institute of Technology	 Tokyo Institute of Technology	 Aoyama Gakuin University	 Japan Agency for Marine-Earth Science and Technology	 National Maritime Research Institute [Observer]	 Japan Oil, Gas and Metals National Corporation [Observer]	 Development Bank of Japan [Observer]

40 Japanese major companies and agencies join with great expectations toward the first development of deep-sea mineral resources in the world

# Toward a “truly” sustainable development of mineral resources

On-land deposits can be easily mined by anyone  
⇒ **Illegal and unregulated mining has occurred**

## Environmental pollution

Amazon gold rush: illegal mining threatens Brazil's last major isolated tribe  REUTERS



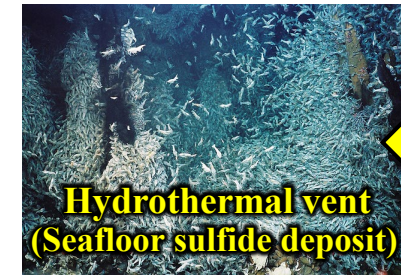
## Human rights violation (Child labor)

Tesla, Apple among firms accused of aiding child labor in Congo  REUTERS



Seafloor resources can be developed **only by national agencies and/or companies with high-level technologies and compliance**

## Low environmental impact of REE-rich mud development



- ❖ Common species (probably no endemic species) live in pelagic areas  
⇒ **Ecosystem can recover after mining**
- ❖ **The mud itself is harmless**, in contrast to deep-sea oil, methane hydrate, or seafloor sulfide deposits
- ❖ **Effective airlift system can inhibit spreading mud** into surrounding seawater

**Development of REE-rich mud is in line with the direction of the international community and the SDGs**

# Advanced REE materials will open the way to the future



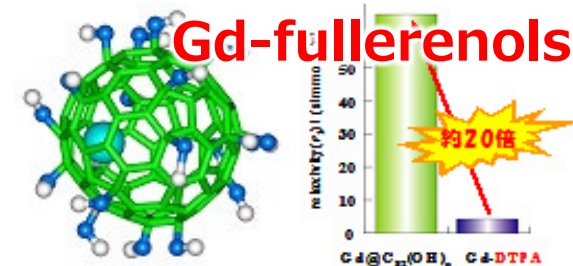
**Al-Sc alloy**



**SOFC**



**Luminescent REE complexes**



**3D printed bike by Al-Sc-Mg alloy**



**High-luminance long afterglow phosphorescent pigment**



**Polarized luminescence film**



**Oxide Scintillator**

## Toward a sustainable future with REE-rich mud

