NEDO

Advanced enhanced rock weathering (A-ERW) technology actively combined with site characteristics

PJ partners

WASEDA University
北海道大学 HOKKAIDO UNIVERSITY
京都府立大学 Kyoto Prefectural University
三菱重工エンジニアリング

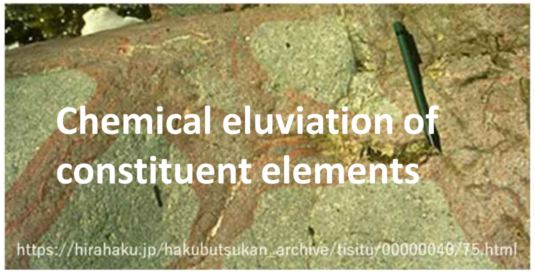
Subcontractors

ソブエクレー株式会社
国土防災技術株式会社
QJ Science
地方独立行政法人 北海道立総合研究機構（道総研）
国立研究開発法人 森林研究・整備機構 森林総合研究所 Forestry and Forest Products Research Institute
NARO 農研機構
東京大学 THE UNIVERSITY OF TOKYO
JIRCAS 国際農研
琉球大学 UNIVERSITY OF THE RYUKYUS
三菱重工パワー環境ソリューション

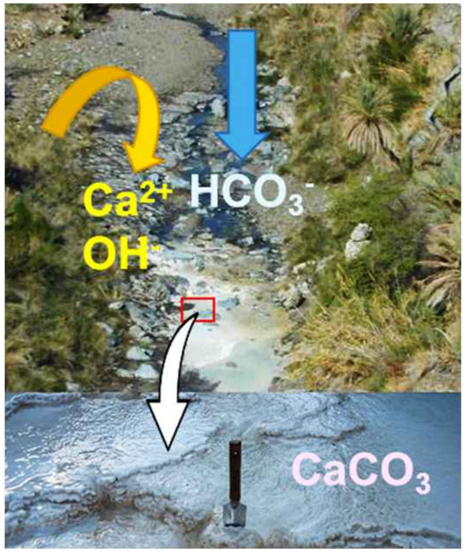
PM：Professor Takao NAKAGAKI
Waseda University

Overview: Enhanced rock weathering (ERW)

Weathering：Natural fracturing and eluviation of rocks for 1,000~10,000 years and precipitating new compounds



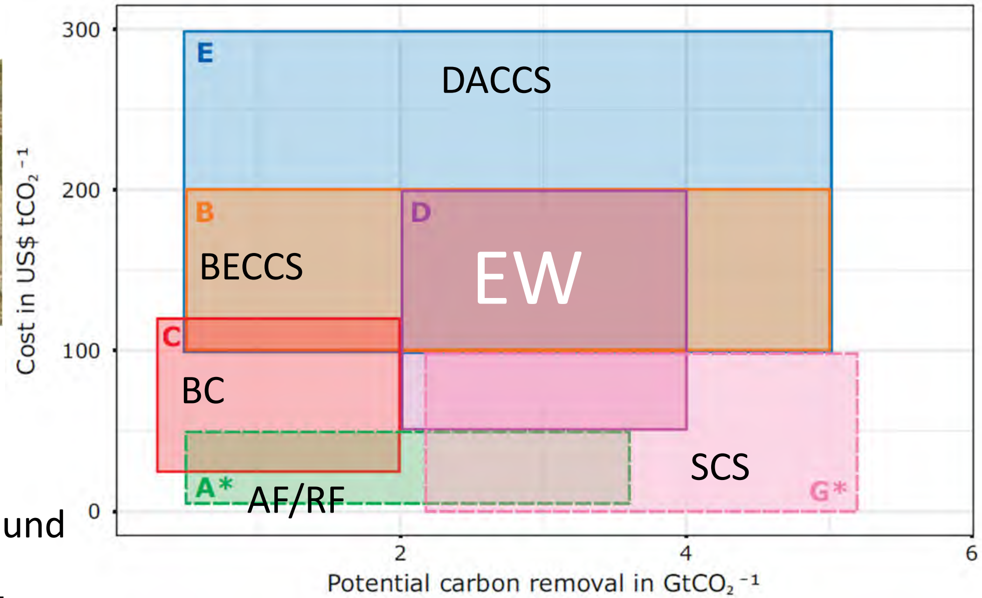
CO_2 mineralization：Sequestration of CO_2 as carbonates by silicate minerals containing Ca/Mg



Natural precipitation of calcium carbonate in a river

Carbfix project, Iceland CO_2 underground injection into basaltic formation

Cost and potential of CDR by NETs



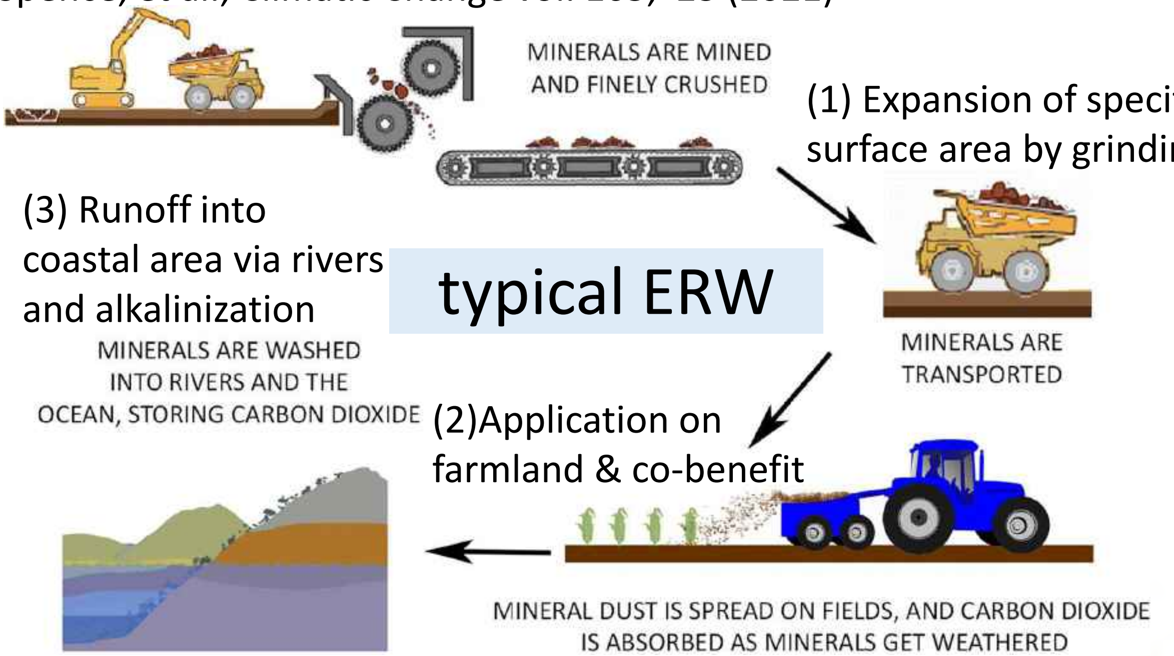
Pros&Cons of EW as a NETs (Water usage of biological NETs is another Cons.)

NETs (TRL)	Landuse $m^2/t\text{-}CO_2/y$	Net reduction	Suitability for Japan
EW(4)	**29**	**Under validation**	◎
DACCS(6)	4	Confirmed	△
BECCS(7)	379	Confirmed	△
AF/RF(9)	978	Confirmed	○
SCS(7)	0	Under validation	○
BC(6)	580	Confirmed	○

This R&D PJ targets a novel ERW technology accelerating weathering x CO_2 mineralization of natural rock and clarifying net CDR effect (carbon accounting method).

ERW: current status & common problem in the world

Spence, et al., Climatic Change vol. 165, 23 (2021)



(1) Expansion of specific surface area by grinding

typical ERW

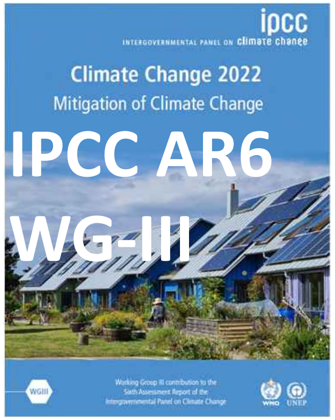
(3) Runoff into coastal area via rivers and alkalinization

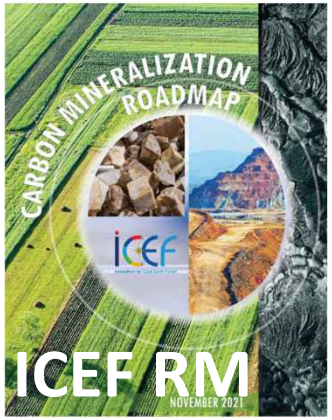
(2)Application on farmland & co-benefit

(2) Limited application except farmland

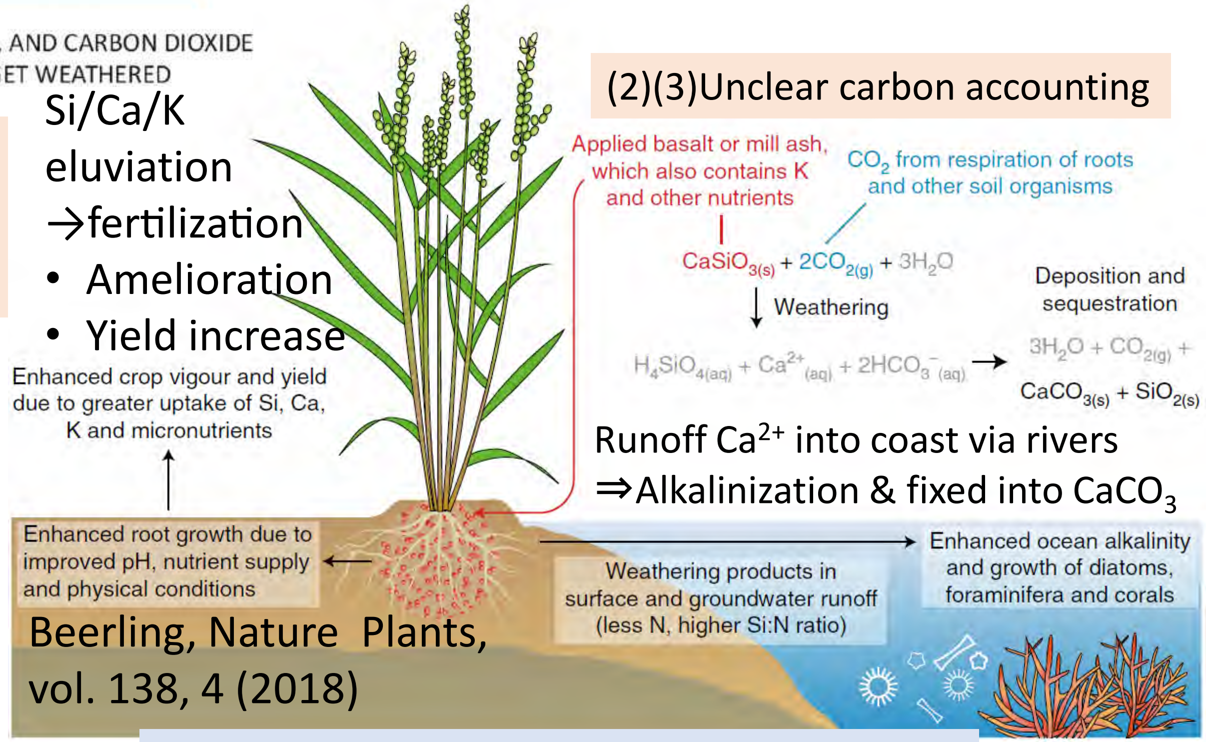
Carbon accounting MUST be established

(1) Evaluation of pretreatment energy depending on rocks
(2) Quantification carbon storage depending on soils





Great expectation found in these report, but…



(2)Basalt only? (2) Side effect on soil?

Common / A-ERW's specific problems

Common problem：Carbon accounting method MUST be established

Evaluation of pretreatment energy depending on rocks + development of energy saving process

Quantification carbon storage depending on soils + sophisticated natural carbon cycle model and consolidating information database of accurate carbon accounting

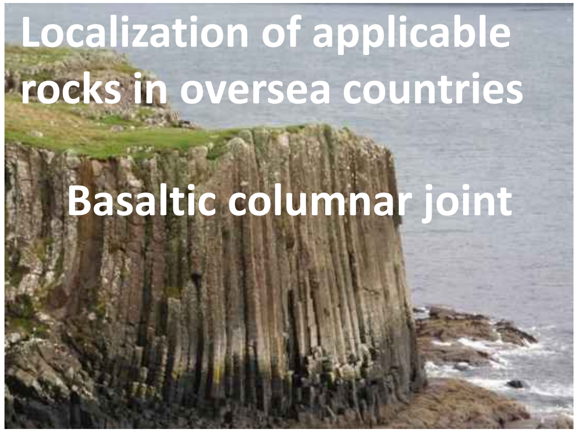
Furthermore

A-ERW's specific problems and challenges

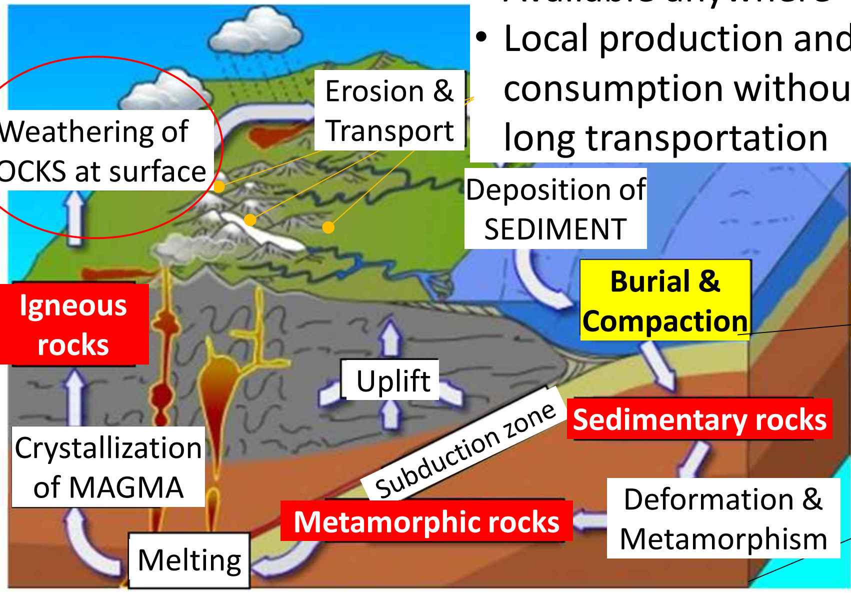
A) Expanding availability of rocks utilizing geological characteristics of Japan

B) Acceleration of weathering and new co-benefits creation by utilizing site characteristics

C) Development of cultivation and soil management aiming at enhancement of weathering and maximizing co-benefits

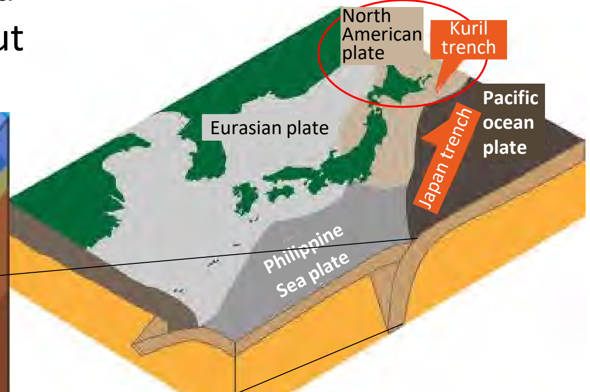


- Available anywhere
- Local production and consumption without long transportation



Practical study in Hokkaido

Philippine Seaplate



Geological characteristics in Japan

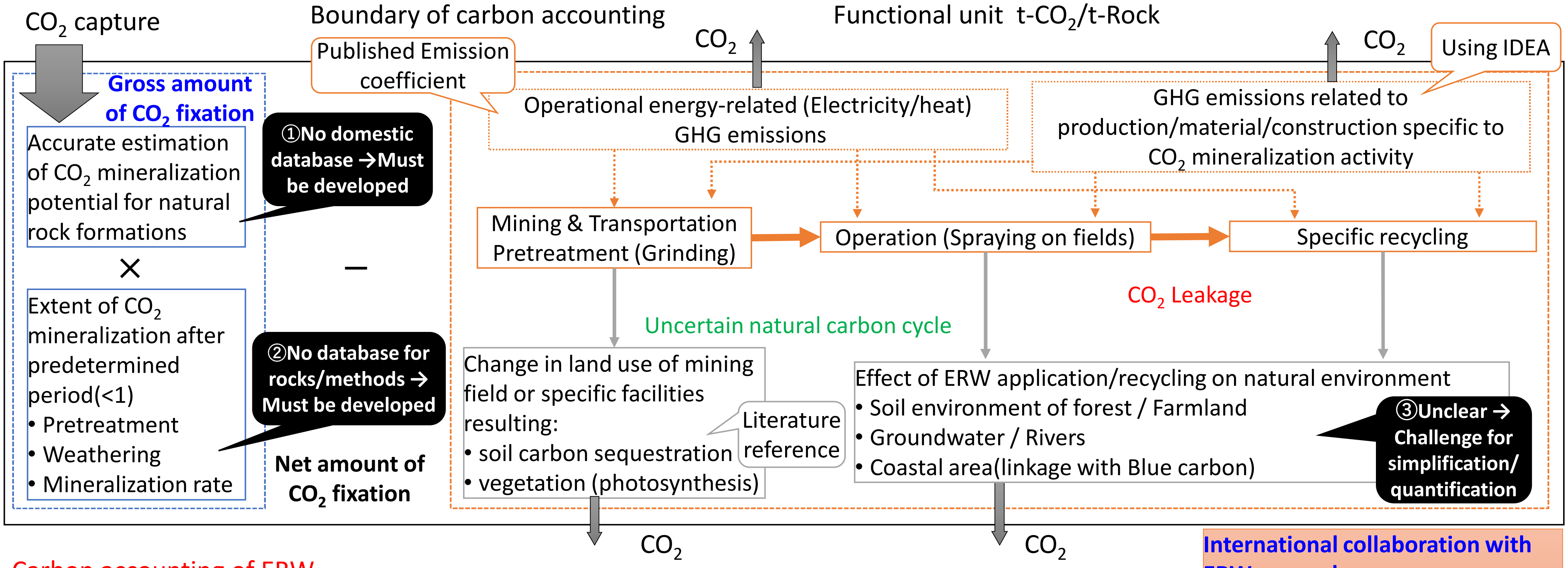
Various and extensive rock resources due to location at subduction zone of plates

Accelerated
Accurate Accounting
Advanced
Active
Agro-industrial
Advantageous

"A-ERW" PJ aims to:

- accelerate artificial weathering and CO_2 mineralization by utilizing characteristics of Japanese rocks and application sites
- consolidate information database of accurate carbon accounting including natural carbon cycle

Concept of accurate carbon accounting



Carbon accounting of ERW

⇒Collecting data for engineering different from each rock: **Consolidating information database**

International collaboration with ERW researchers

Fostering international consensus of carbon accounting methodology under initiative of Japan

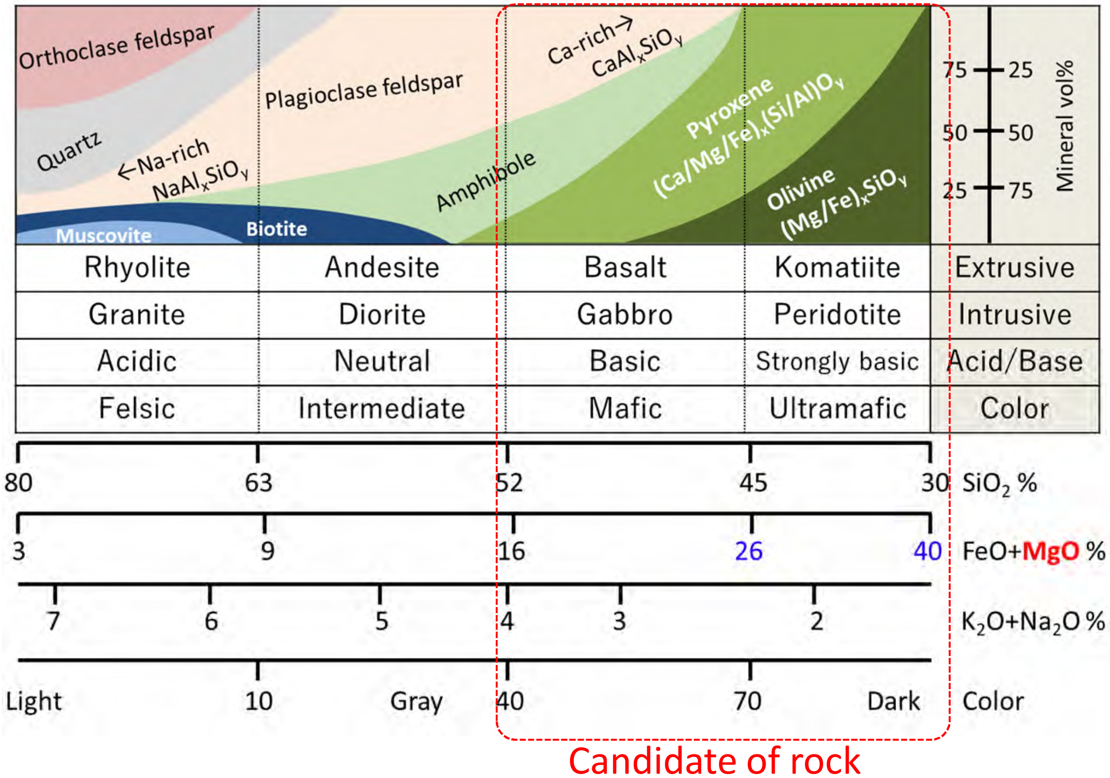
Clarifying problems from previously reported literatures: Solve all problems

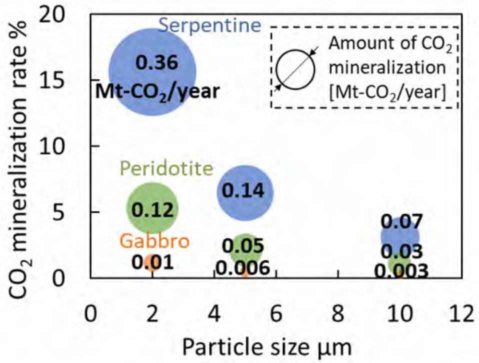
① While geological distribution database for domestic stratums/rocks has been developed, there is no database for CO_2 mineralization potential (No recognition for: weak weathering-proof ≠ fast CO_2 mineralization)

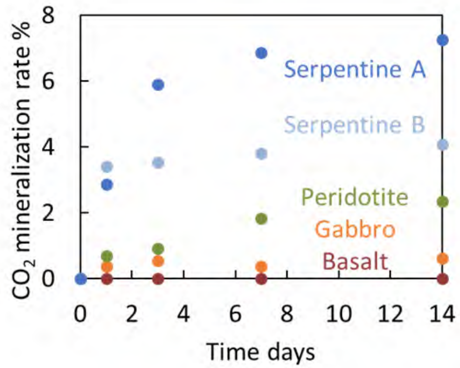
② While mathematical models are proposed, extent of CO_2 mineralization depending on mineral species of rocks/pretreatment/weathering is unclear. (Basic mechanism is party know. However, modeling for multi-pathway mineralization, such as combination of transportation and dissolving process of CO_2, and reaction with Ca/Mg through gas-solid/gas-liquid interfaces is incomplete.)

③ Effect of application on farmland and recycling on natural environment and change in carbon balance is unknown. Monitoring method has not been developed yet. (Glowing environment = law of change in carbon balance and quantity depending on combination of local climate/type of soils/clop species are unexplained. Moreover, other GHGs, such as N_2O/methane, have not been considered.)

(1) Expanding availability of rocks utilizing geological characteristics of Japan







ERW process condition depends on the type of rock
A simple gas-solid contactor is available for serpentine and olivine? (if so, it can:)

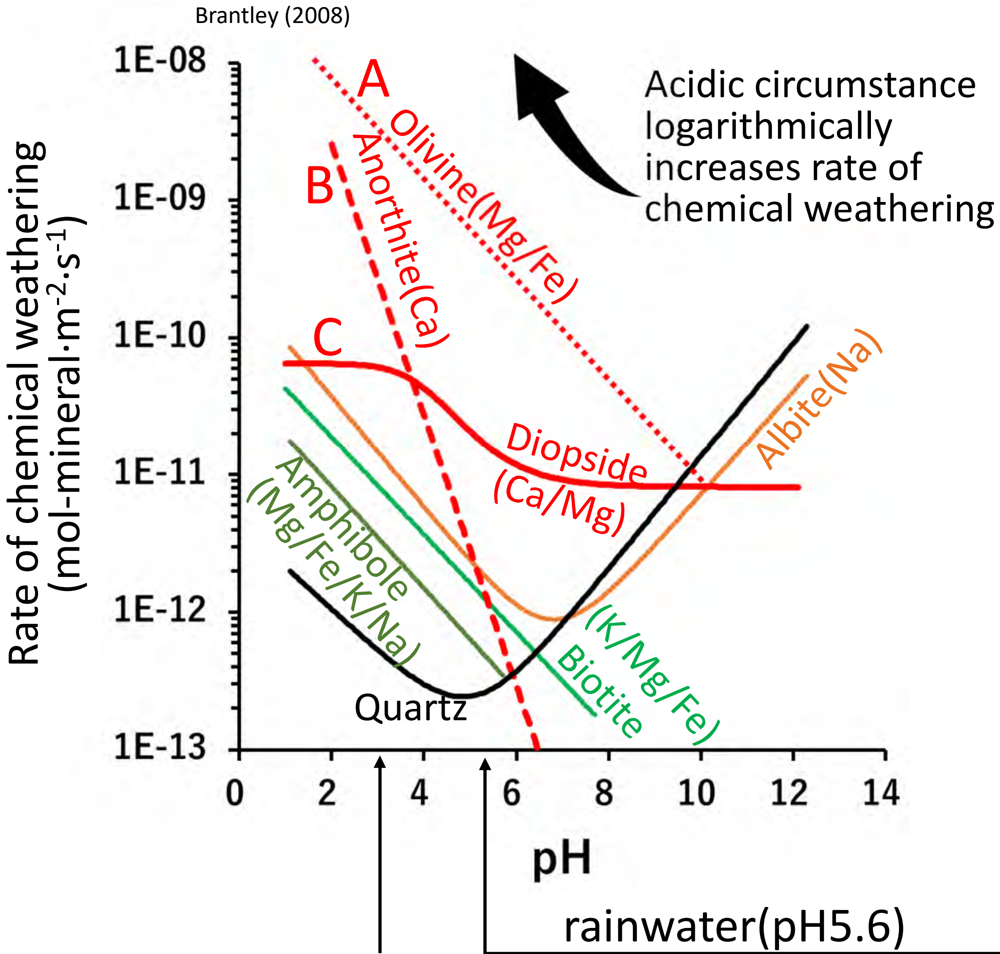
- ✓ simplify accounting inventory
- ✓ shorten mineralization time by rock selection & proper comminution process

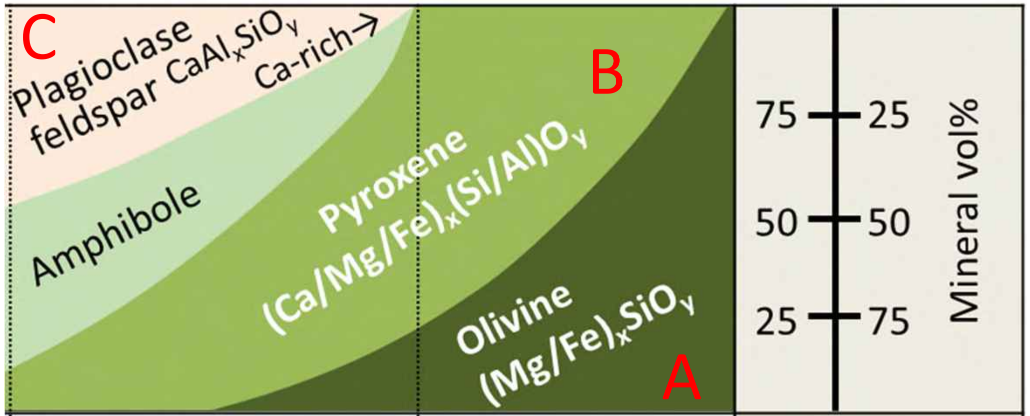
Furthermore…

- *exploring usage of the mineralized rock powder*
- *availability assessment of volcanic ash*

Rock	Weathering (amorphous, weathering-proof)	CO_2 mineralization potential (Ca/Mg content)	CO_2 mineralization rate (basicity, high-pH)	Temporal evaluation
Basalt	Good	Excellent	Good	Better than average, suitable for farmland application Frequently reported due to overseas exposed stratum? Unsuitable for gas-solid contactors?
Olivine	Good	Good	Excellent	Sufficient potential, but limited geological distribution Unsuitable for farmland application
Gabbro	Fair	Excellent	Good	Suitable for farmland application next to olivine and basalt
Serpentine	Fair	Fair ~ Good	Good ~ Excellent	Metamorphic rock found in subduction zones Brittle rock: less grinding energy? Wider variation in CO_2 mineralization? Unsuitable for farmland application (Ni, Cr or other elements)

(2) Acceleration of weathering and new co-benefits creation by utilizing site characteristics

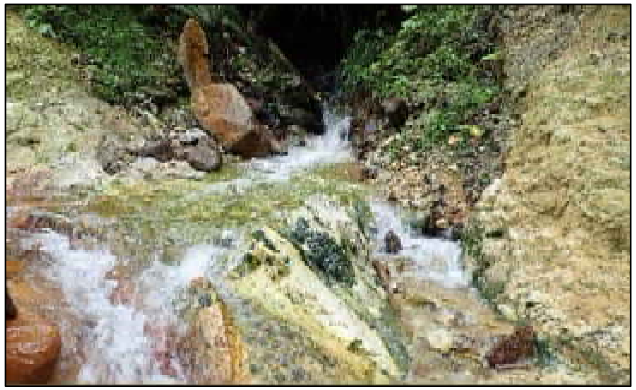




Basalt	Komatiite	Extrusive
Gabbro	Peridotite	Intrusive
Basic	Strongly basic	Acid/Base
Mafic	Ultramafic	Color

Application to acidic (< pH≈6) circumstance sites

(1) Acidic mine effluent (pH<3)



Reduction of limestone usage for effluent treatment

Co-benefit to mining industry

(2) Forest slope with high eluviation

- Forest soil amelioration
- Landslide prevention

Co-benefit to forestry

(3) Development of cultivation and soil management aiming at enhancement of weathering and maximizing co-benefits

CDR by basalt application on farmland

Requirements for implementation	• Yield/Quality increase • Maintaining organic soil carbon • GHG emission reduction

For these requirements…

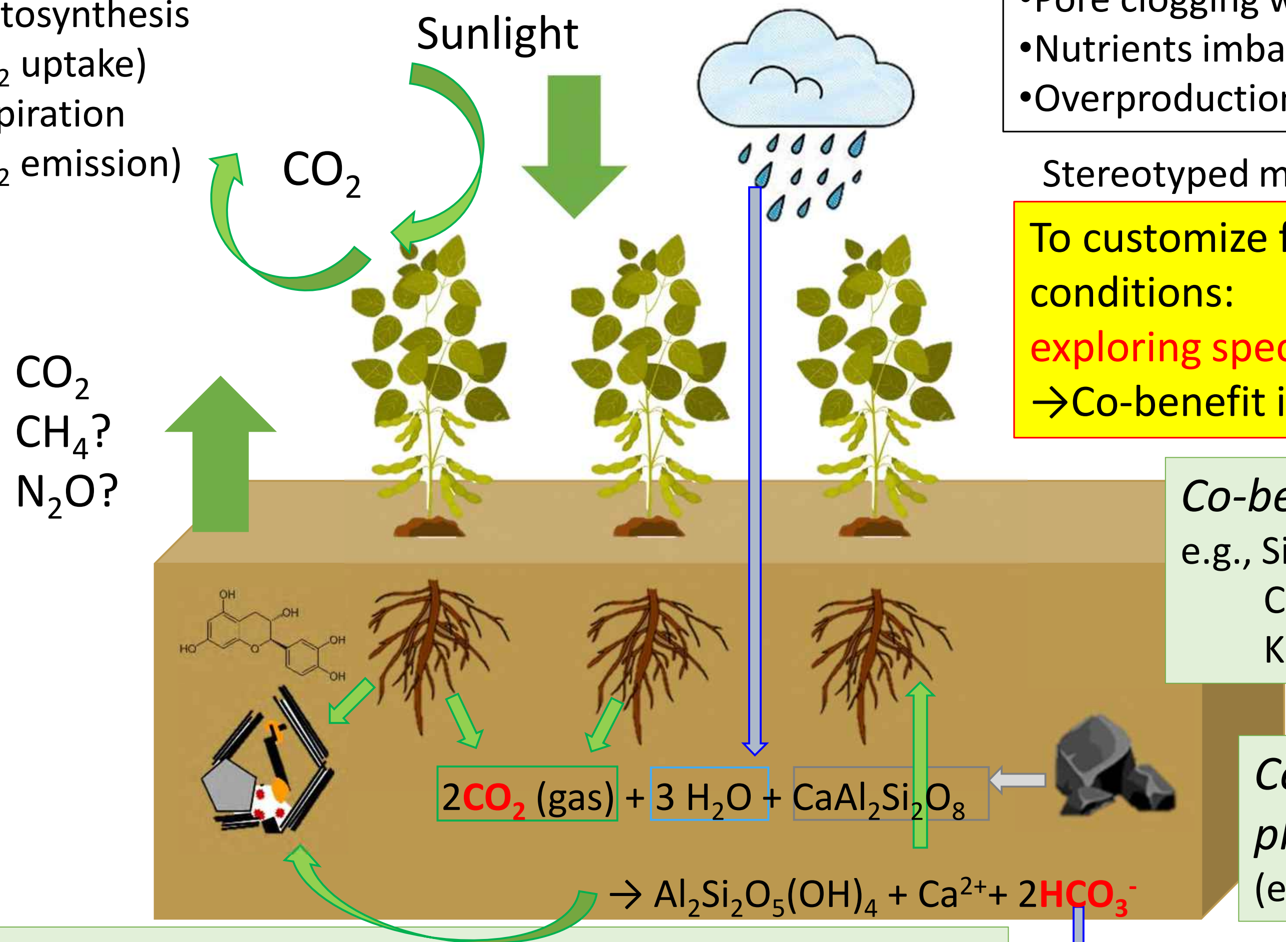
Essential evaluation for complex soil system
Climatic dependency/diverse interaction among soil/crop/rock depending on each specie or type

Evaluation of side effects ever overlooked
- Pore clogging with rock powders: decrease in permeance
- Nutrients imbalance due to excess application
- Overproduction of amorphous minerals: lack of P

Stereotyped method cannot be viable →Customizing!

To customize for Japanese climate/soils/cultivation conditions:
exploring specific suitable package is necessary!
→Co-benefit is different from each farmland

Photosynthesis (CO_2 uptake)
Respiration (CO_2 emission)



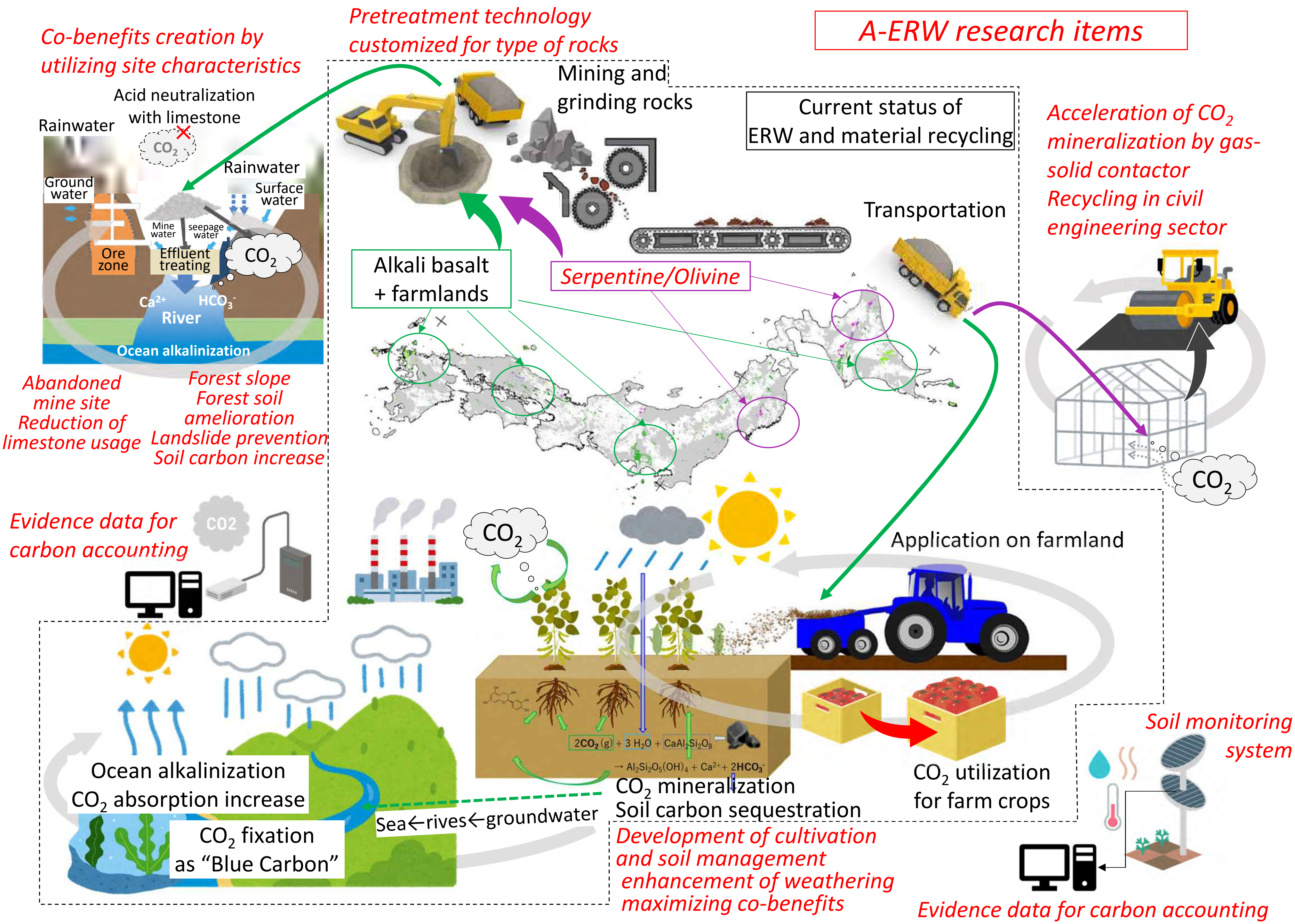
Co-benefit 1: Nutrients supply
e.g., Si: highly weathered soil in SW islands
Ca: tropic high acidity soil
K: andosol

Co-benefit 2: Improvement of physical properties
(e.g., highly viscous soil in Hokkaido)

Co-benefit 3: Increase in soil carbon sequestration
(Combination with calcium and other minerals derived from rock)

Precipitating in the soil as $CaCO_3$
Eluviation→runoff to coastal area and the same effect

Overview of A-ERW associated with resource recycling



A-ERW's Team structure　Period: Sep. 2022 ~ Mar.2025

PD　Dr. K. Yamaji
(President, RITE)

NEDO　Dept. of Moonshot

PM　T. Nakagaki

Waseda Univ.
Prof. T. Nakagaki

①Site suitability assessment(2)
②Mining and grinding test/assay evaluation(1)(2)(3)
③Acceleration of ERW(1)
⑤Information database of accurate carbon accounting(1)

(Subcontract)
Sobueclay, LTD.
②-(1)(2)(3)

MHI engineering, LTD.
Decarbonization Business Dept.

④Field testing under real environment & development of effective monitoring(1)
⑤Consolidation of information database of accurate carbon accounting(1)
⑥Conceptual design of pilot-scale demonstration(1)

(Joint implementation)
MHI Power Environmental Solutions, Ltd.
①-(1), ①-(1), ②-(1)

Hokkaido Univ.
Prof. T. Sato

①Site suitability assessment(1)(2)
②Mining and grinding test/assay evaluation(1)(2)(3)
③Acceleration of ERW(2)
④Field testing under real environment & development of effective monitoring(2)(3)
⑤Information database of accurate carbon accounting(2)
⑥Conceptual design of pilot-scale demonstration(2)

(Subcontract)
QJ Science, LTD.
①-(1),② -(3),②-(2)
Japan Conservation Engineers & Co.,LTD.
①-(2),②-(1),④-(2),⑥-(2)
NARO ③-(2),④-(3)
HRO ②-(1),④-(2)
FFPRI ④-(2)

Kyoto Prefectural Univ.
Prof. A. Nakao

①Site suitability assessment(2)
③Acceleration of ERW(2)
④Field testing under real environment & development of effective monitoring(3)
⑤Information database of accurate carbon accounting(2)
⑥Conceptual design of pilot-scale demonstration(2)

(Subcontract)
The U. of Tokyo ③-(2), ②-(2)
JIRCAS ④-(3)
Ryukyu U. ④-(3)

Regarding carbon accounting, we collaborate with Dr. Morimoto PM team, and will invite oversea advisors.

NARO: National Agriculture and Food Research Organization
HRO: Hokkaido Research Organization
FFPRI: Forestry and Forest Products Research Institute
JIRCAS: Japan International Research Center for Agricultural Sciences

Research items & sharing (subcontractors): At a glance

Items	Subitems	Waseda U.	MHI Eng.	Hokkaido U.	Kyoto P. U.
①Site suitability assessment	(1)Geological assessment			○ (QJ Science/HRO)	
	(2)Business environment assessment	○		○ (JCE)	○
②Mining & grinding test/ assay evaluation	(1)Candidate site of sampling	○ (Sobueclay)		○ (HRO/JCE)	
	(2)Grinding test & assay evaluation of mineral phase	○ (Sobueclay)		○Dept. of Env. (JCE)	
	(3)Prediction of Pretreatment energy	○ (Sobueclay)		○ (QJ Science)	
③Acceleration of ERW	(1) CO_2 mineralization by industrial methods	○			
	(2)ERW application on open sites			○Dept. of Env.&Agri. (NARO)	○ (The U. of Tokyo)
④Field testing under real environment & development of effective monitoring	(1)Gas-solid contactor		○ (MHI PES)		
	(2)Application on forest slop / abandoned mine site			○Dept. of Env. (HRO/JCE/FFPRI)	
	(3)Application on farmland			○Dept. of Agri. (NARO)	○ (JIRCAS/Ryukyu U.)
⑤Information database of accurate carbon accounting	(1)Carbon accounting for industrial CO_2 mineralization	○	○		
	(2)Carbon accounting including natural carbon cycle			○ (QJ Science)	○ (The U. of Tokyo)
⑥Conceptual design of pilot-scale demonstration	(1)Conceptual design of industrial ERW		○ (MHI PES)		
	(2)Conceptual design of ERW application on open sites			○Dept. of Env. (JCE)	○