University of Glasgow | UK Research and Innovation | BREEDON | TARMAC A CRH COMPANY

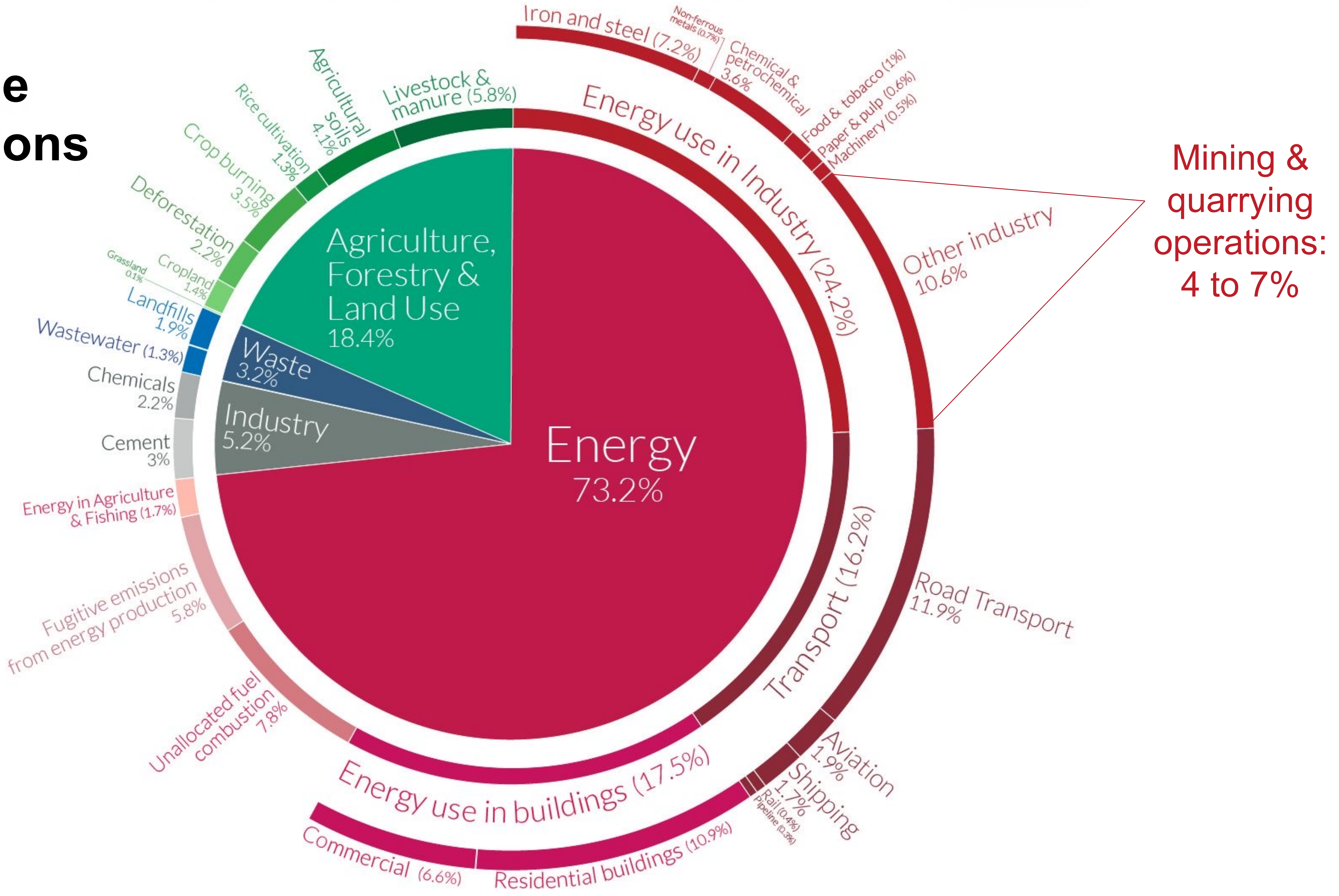
Potential for atmospheric CO_2 removal in mafic quarries via enhanced weathering of basalt fines

Amanda Stubbs (a.stubbs.1@research.gla.ac.uk), Faisal Khudhur, John MacDonald, Linzi McDade, and Mark Friel

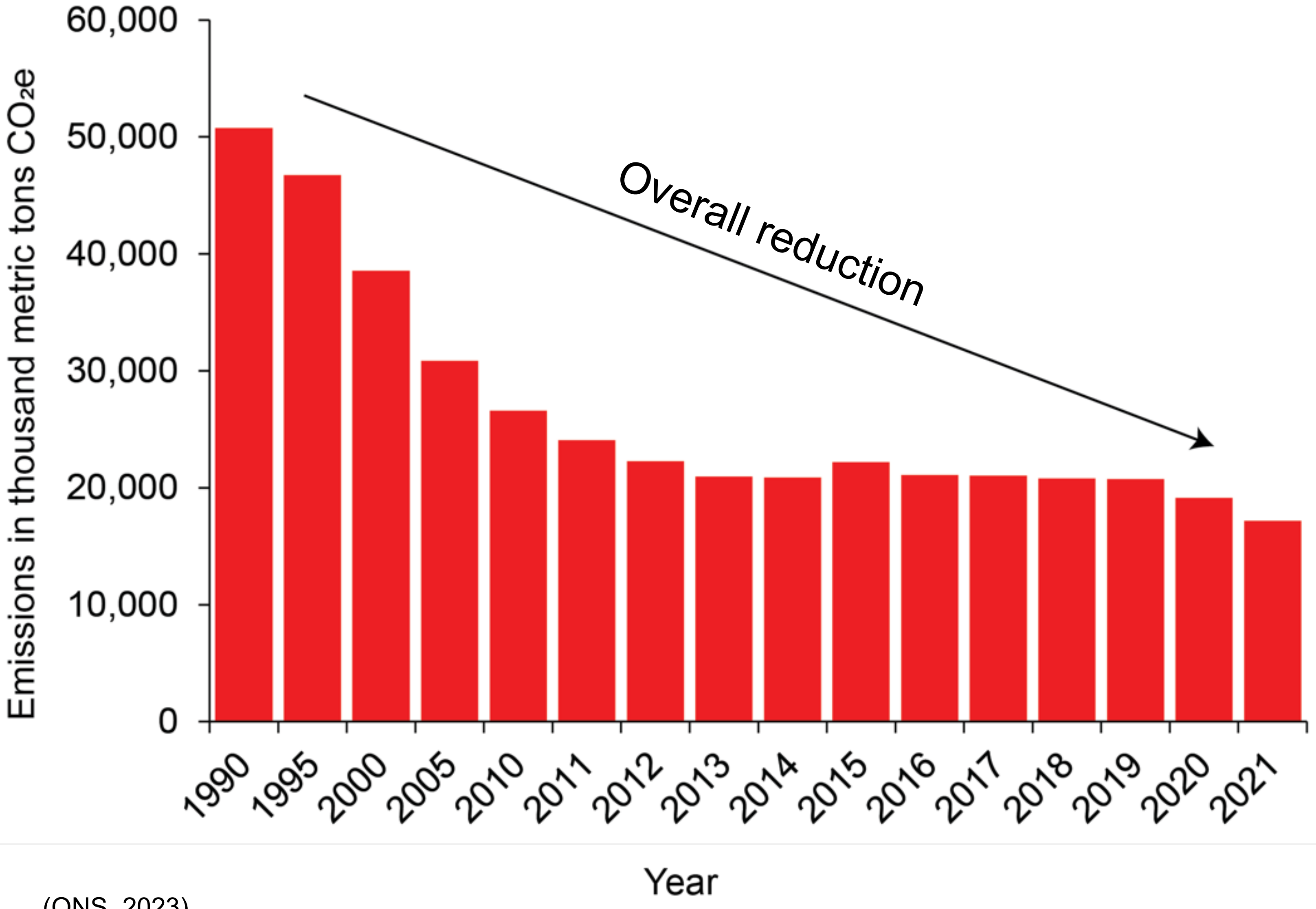
IAPETUS2 Doctoral Training Partnership

Global greenhouse gas emissions by sector

Climate Watch, the World Resource Institute. (2020)



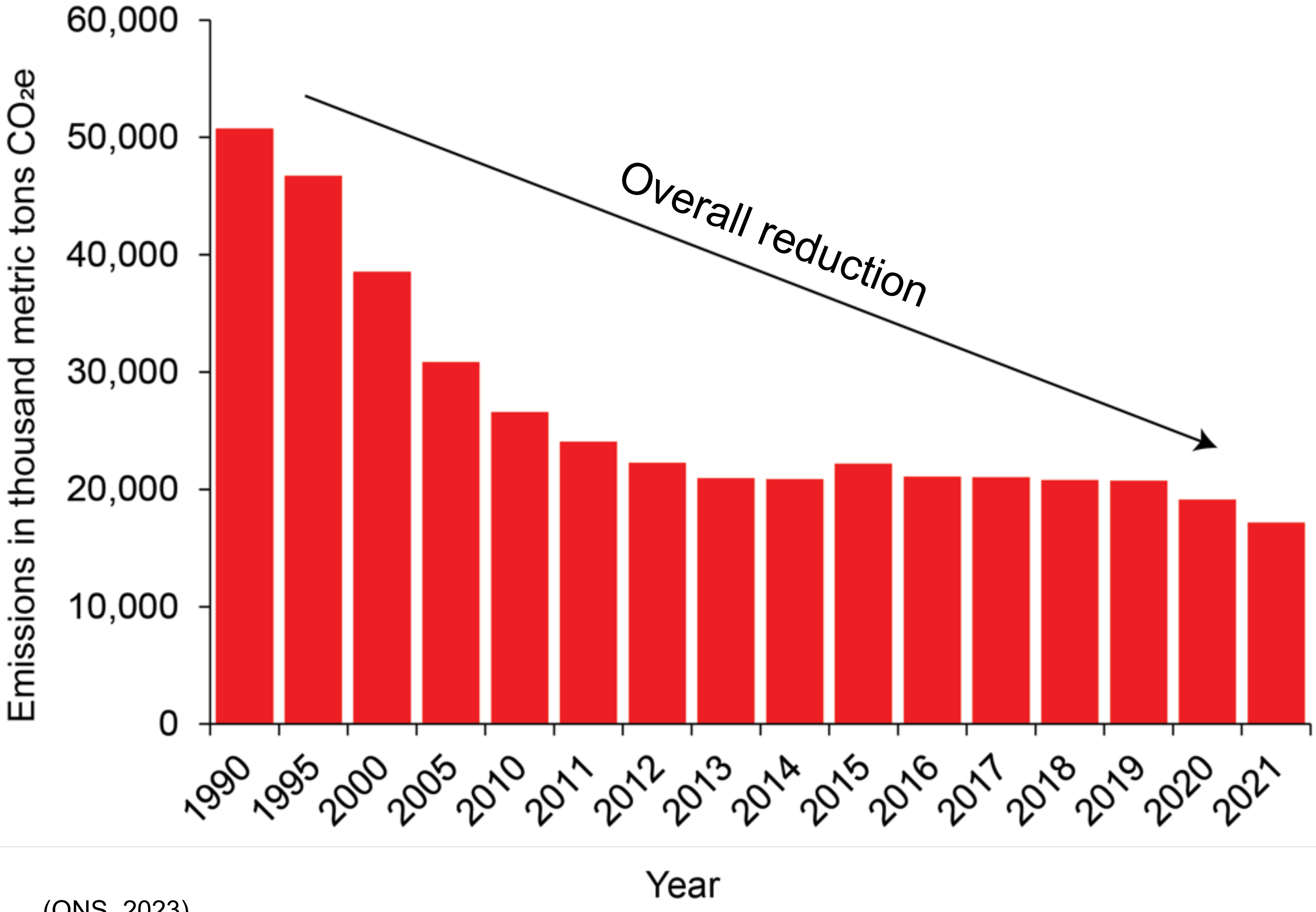
UK greenhouse gas emissions in the mining and quarrying industry



(ONS, 2023)

- Since the turn of the century, over a 40% reduction
- CO_2 accounted for more than 90% of greenhouse gas emissions (ONS, 2023)

UK greenhouse gas emissions in the mining and quarrying industry



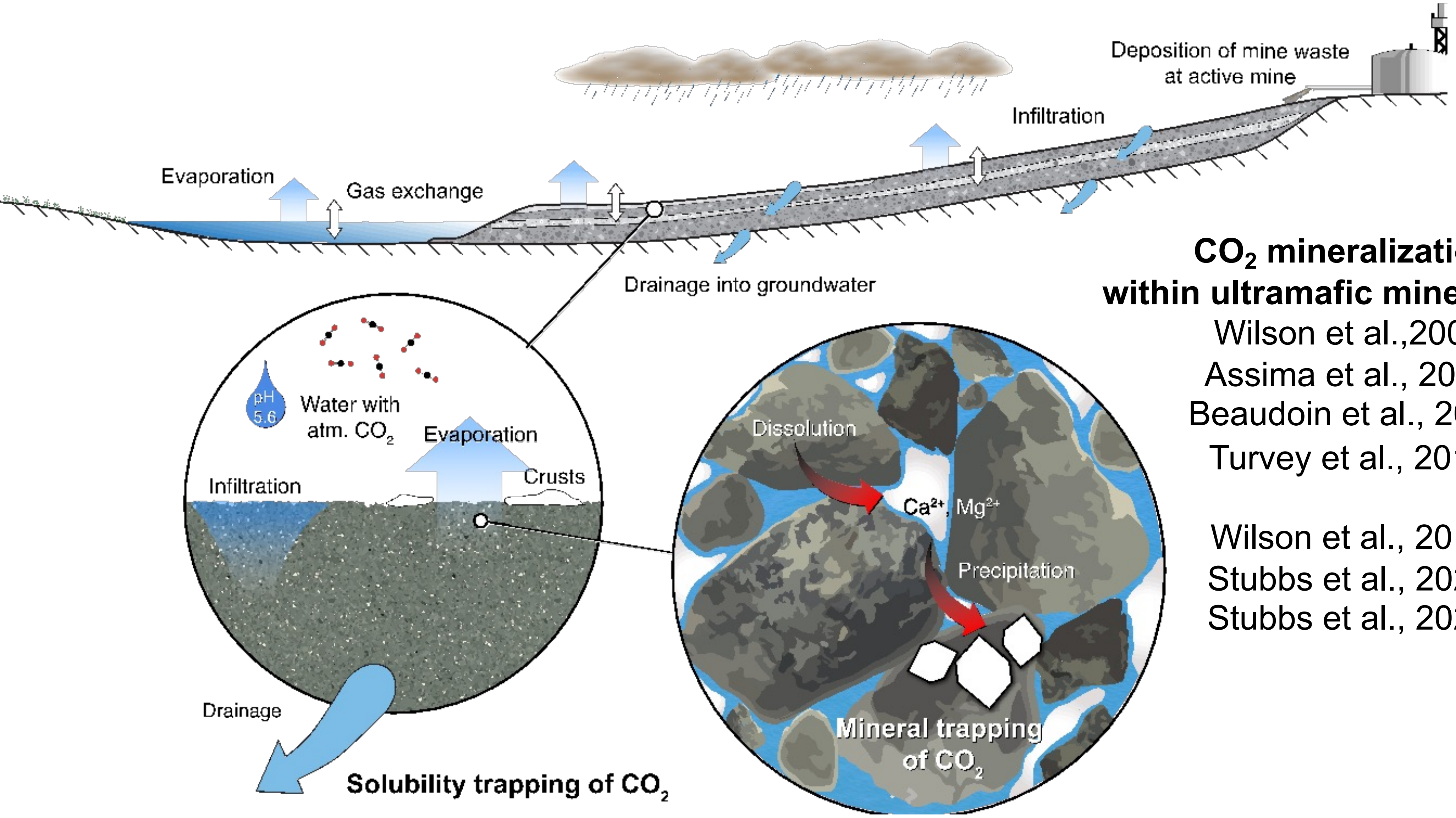
(ONS, 2023)

- Since the turn of the century, over a 40% reduction
- CO_2 accounted for more than 90% of greenhouse gas emissions (ONS, 2023)

More sustainable practices

- Modifying equipment design
- Optimising resource use
- Using renewable resources

Negative emission technologies: Enhanced weathering of quarry fines



CO_2 mineralization within ultramafic mine wastes:

Chrysotile:
- Wilson et al.,2009
- Assima et al., 2012
- Beaudoin et al., 2017
- Turvey et al., 2018

Kimberlite:
- Wilson et al., 2011
- Stubbs et al., 2022
- Stubbs et al., 2023

Advantages and disadvantages of utilising quarry fines

Strengths

- In 2018, the UK produced 80.4 million tonnes of mineral waste (Department of environment, food, and rural affairs, 2023)
- Quarries have the capability to move waste around sites
- Primarily fine-grained material
- Desirable geochemical composition
- Financial backing

Advantages and disadvantages of utilising quarry fines

Strengths

- In 2018, the UK produced 80.4 million tonnes of mineral waste (Department of environment, food, and rural affairs, 2023)
- Quarries have the capability to move waste around sites
- Primarily fine-grained material
- Desirable geochemical composition
- Financial backing

Opportunities

- 1750 active quarries in the UK, many extract mafic rock (Cameron et al., 2020)
- In Scotland alone there are 37 mafic quarries
  - Basalt, dolerite, and/ or gabbro (Cameron et al., 2020)
- Industry interest/ and expertise available

Advantages and disadvantages of utilising quarry fines

Strengths

- In 2018, the UK produced 80.4 million tonnes of mineral waste (Department of environment, food, and rural affairs, 2023)
- Quarries have the capability to move waste around sites
- Primarily fine-grained material
- Desirable geochemical composition
- Financial backing

Weaknesses

- Local UK climate may be inhibiting
- Currently no management practices in place
- Limited research/ knowledge about on-site removal

Opportunities

- 1750 active quarries in the UK, many extract mafic rock (Cameron et al., 2020)
- In Scotland alone there are 37 mafic quarries
  - Basalt, dolerite, and/ or gabbro (Cameron et al., 2020)
- Industry interest/ and expertise available

Advantages and disadvantages of utilising quarry fines

Strengths

- In 2018, the UK produced 80.4 million tonnes of mineral waste (Department of environment, food, and rural affairs, 2023)
- Quarries have the capability to move waste around sites
- Primarily fine-grained material
- Desirable geochemical composition
- Financial backing

Weaknesses

- Local UK climate may be inhibiting
- Currently no management practices in place
- Limited research/ knowledge about on-site removal

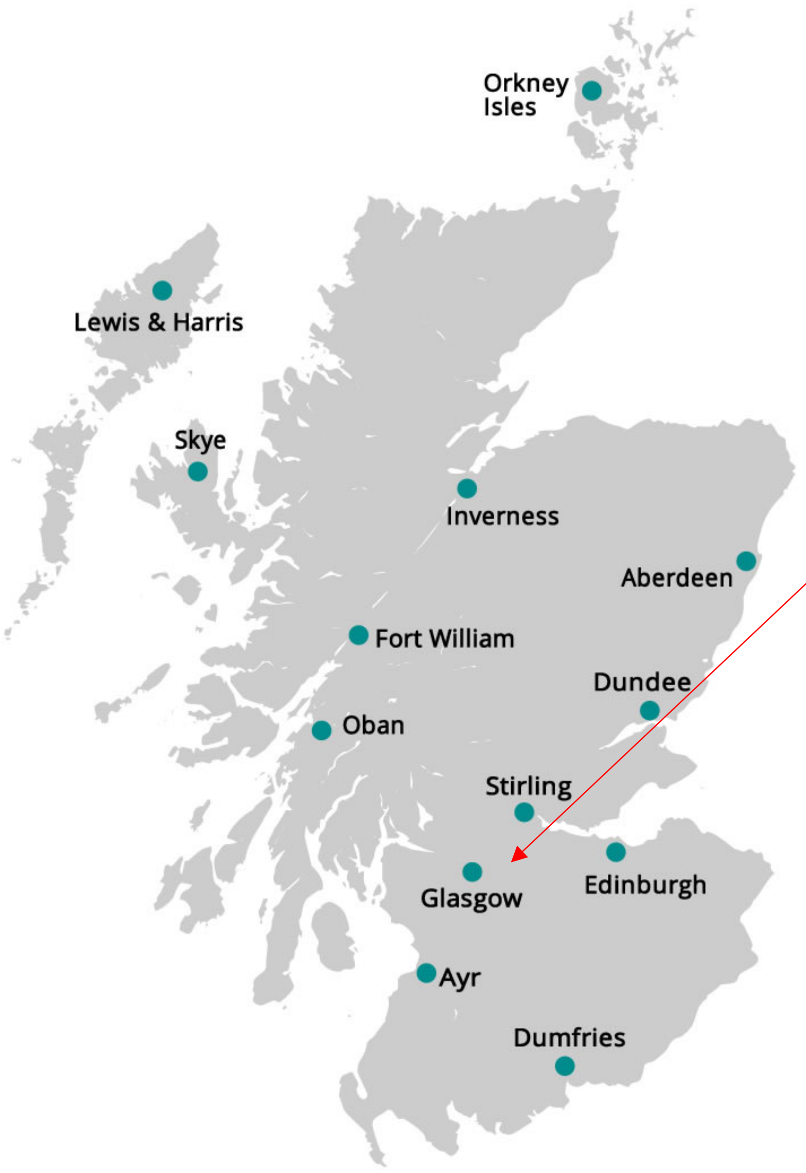
Opportunities

- 1750 active quarries in the UK, many extract mafic rock (Cameron et al., 2020)
- In Scotland alone there are 37 mafic quarries
  - Basalt, dolerite, and/ or gabbro (Cameron et al., 2020)
- Industry interest/ and expertise available

Threats

- Release of ecotoxic elements
- More time and resources researching traditional mine waste as a feedstock
  - Tailings from active and historical:
    - Diamond mines
    - Nickel mines
    - Asbestos mines

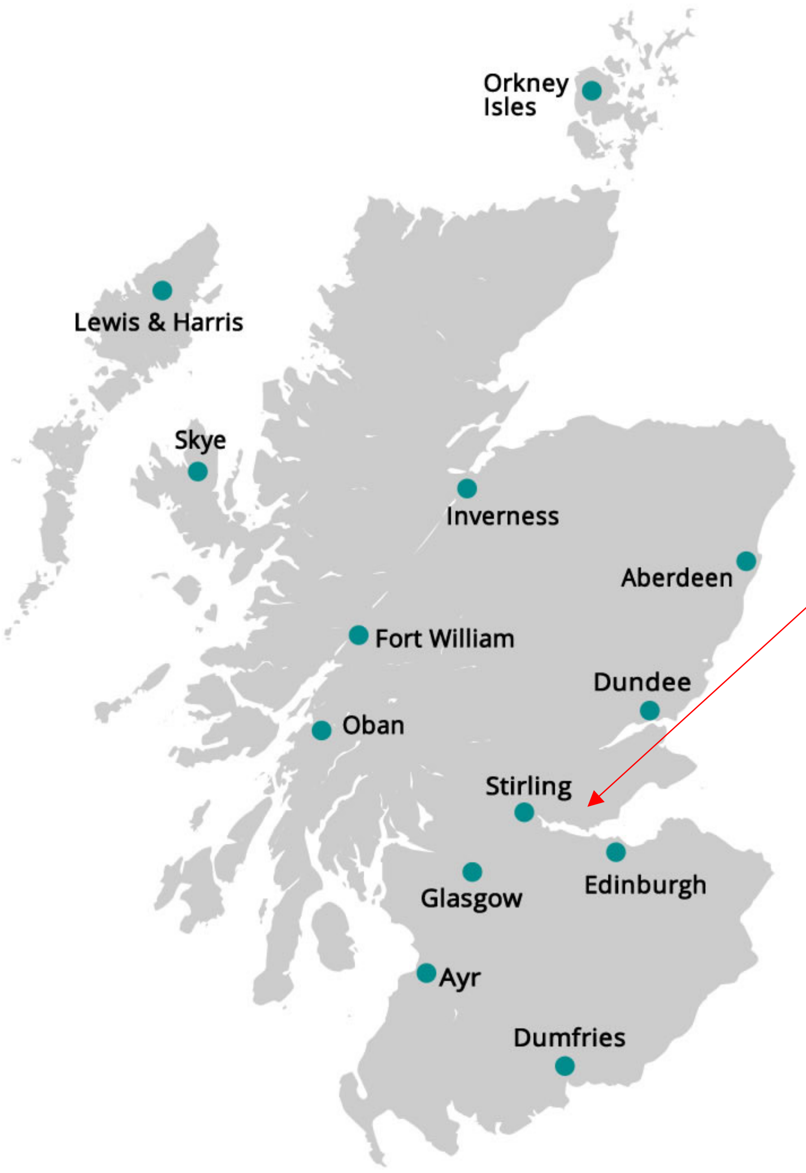
Fieldwork and sampling: Cairneyhill Quarry



TARMAC
A CRH COMPANY

- Established in the 1950s
- Asphalt production for road building and construction
- Exploiting large microgabbro/ dolerite
- More than 83,100 tonnes of available fines

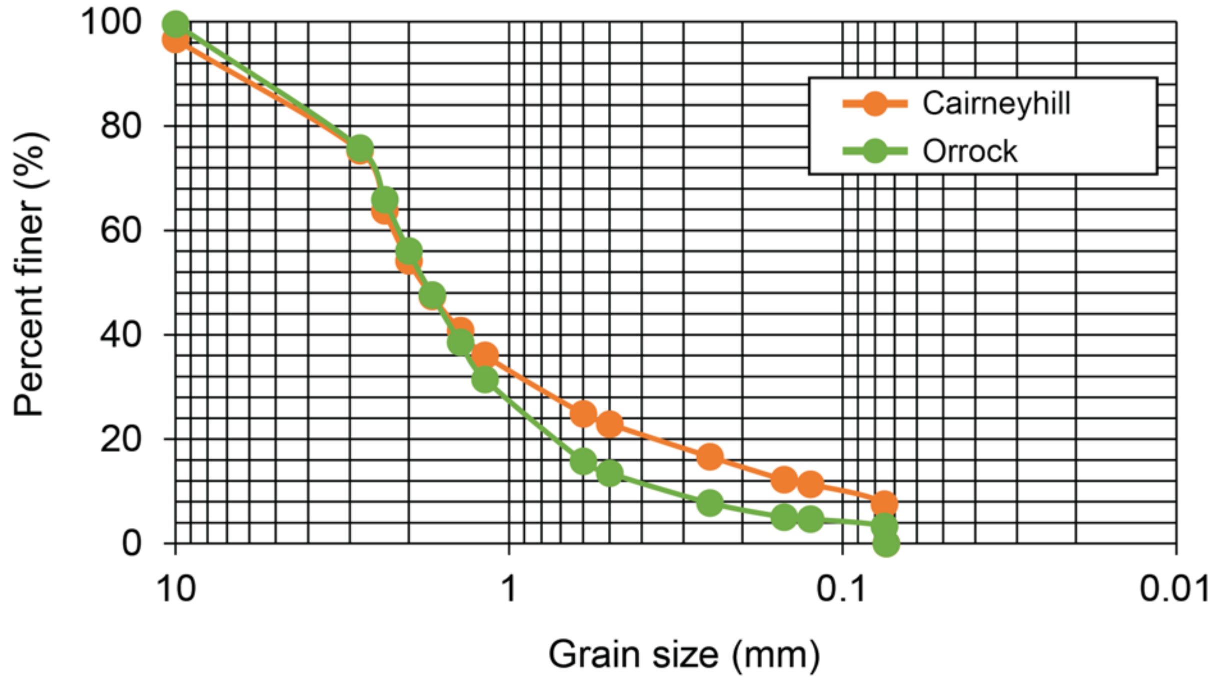
Fieldwork and sampling: Orrock Quarry



- Established in the 1950s
- Asphalt and aggregate production
- Exploiting basalt
- 42,000 to 56,000 tonnes of fines annually

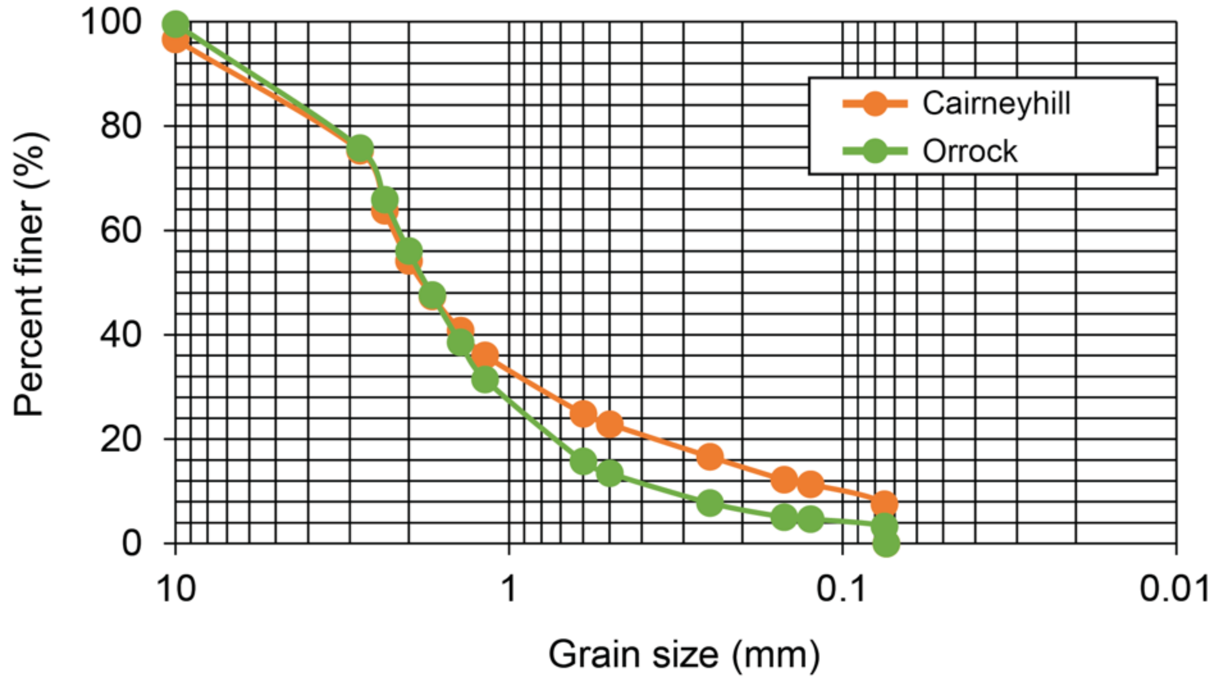
BREEDON

Initial characterisation: Physical properties



Both fines are dominated by sand sized particles

Initial characterisation: Physical properties



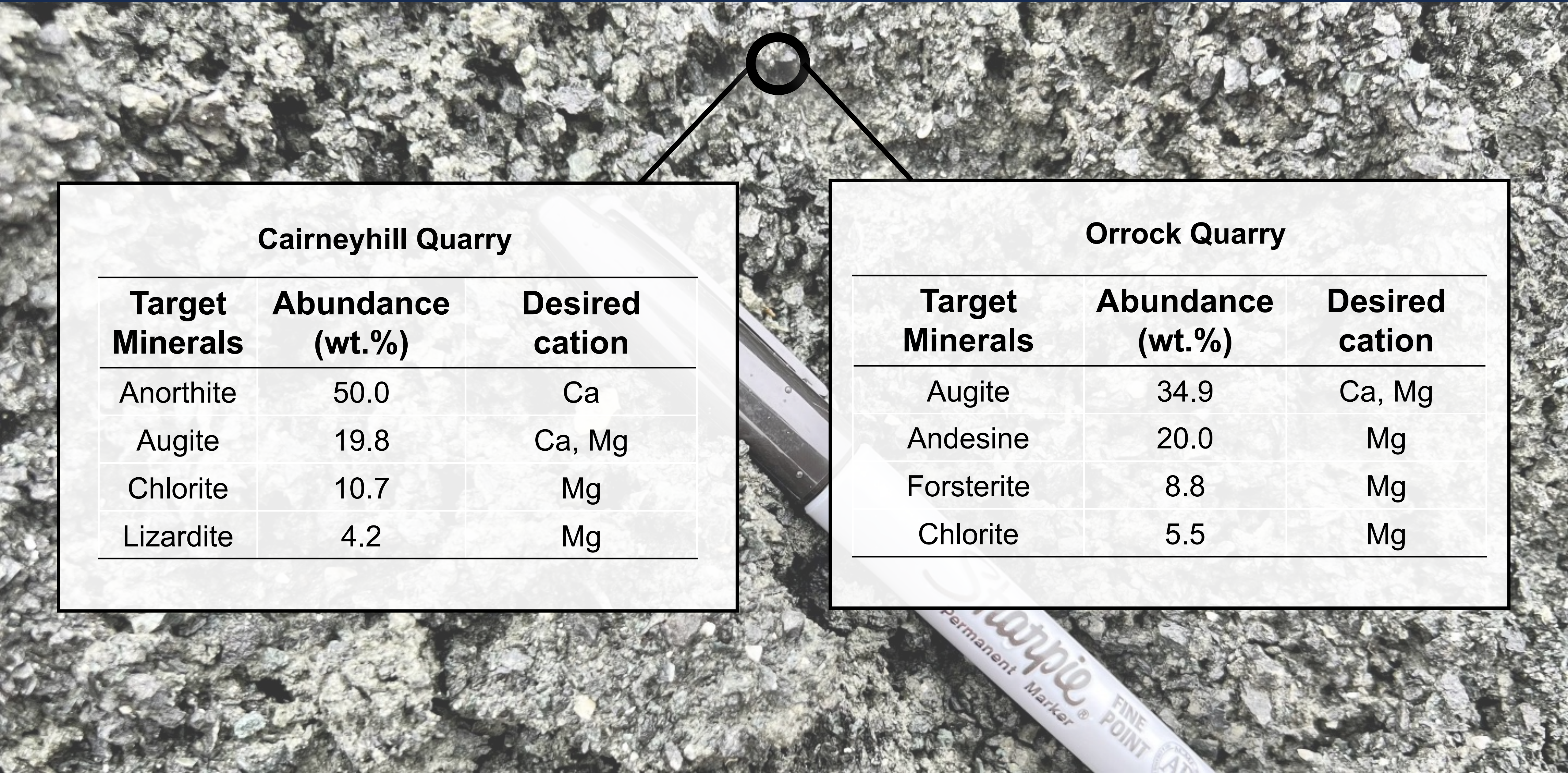
Both fines are dominated by sand sized particles

BET surface area

Cairneyhill = 3.05 m^2/g

Orrock = 5.82 m^2/g

Initial characterisation: Mineralogical properties



Cairneyhill Quarry

Target Minerals	Abundance (wt.%)	Desired cation
Anorthite	50.0	Ca
Augite	19.8	Ca, Mg
Chlorite	10.7	Mg
Lizardite	4.2	Mg

Orrock Quarry

Target Minerals	Abundance (wt.%)	Desired cation
Augite	34.9	Ca, Mg
Andesine	20.0	Mg
Forsterite	8.8	Mg
Chlorite	5.5	Mg

Initial characterisation: Geochemical properties (XRF)

Cairneyhill Quarry:
- CaO = 8.5%
- MgO = 8.7%
- P_2O_5 = 0.2%

Orrock Quarry:
- CaO = 9.7%
- MgO = 10.3%
- P_2O_5 = 0.6%

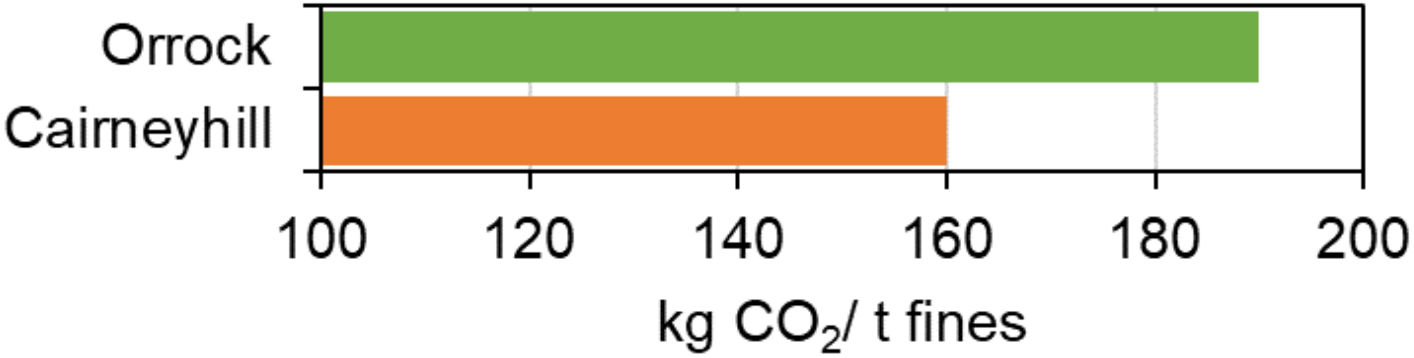
Carbonation potential calculated based on Steinour formula from Gunning et al., 2010 and Renforth 2019

Initial characterisation: Geochemical properties (XRF)

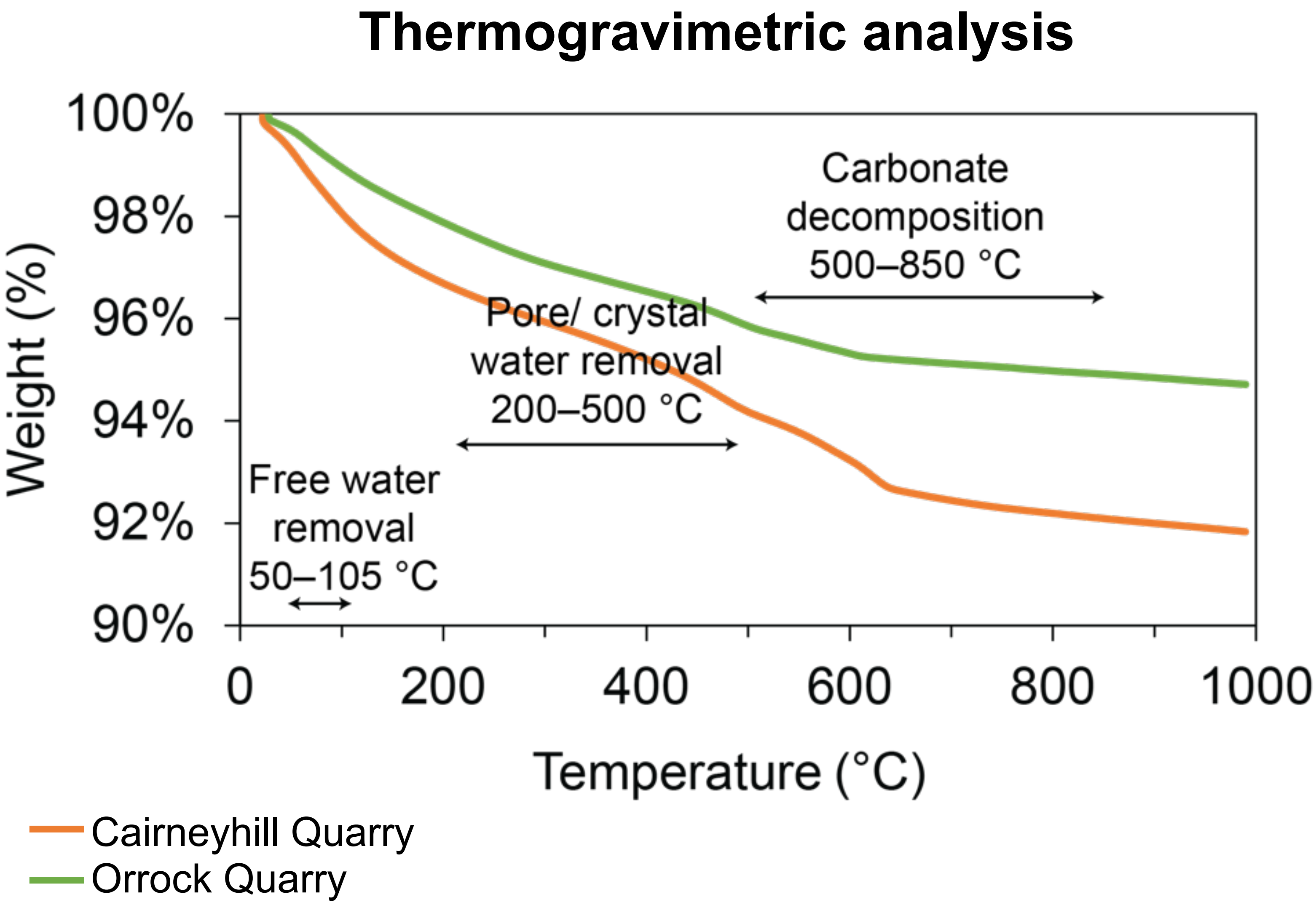
Cairneyhill Quarry:
- CaO = 8.5%
- MgO = 8.7%
- P_2O_5 = 0.2%

Orrock Quarry:
- CaO = 9.7%
- MgO = 10.3%
- P_2O_5 = 0.6%

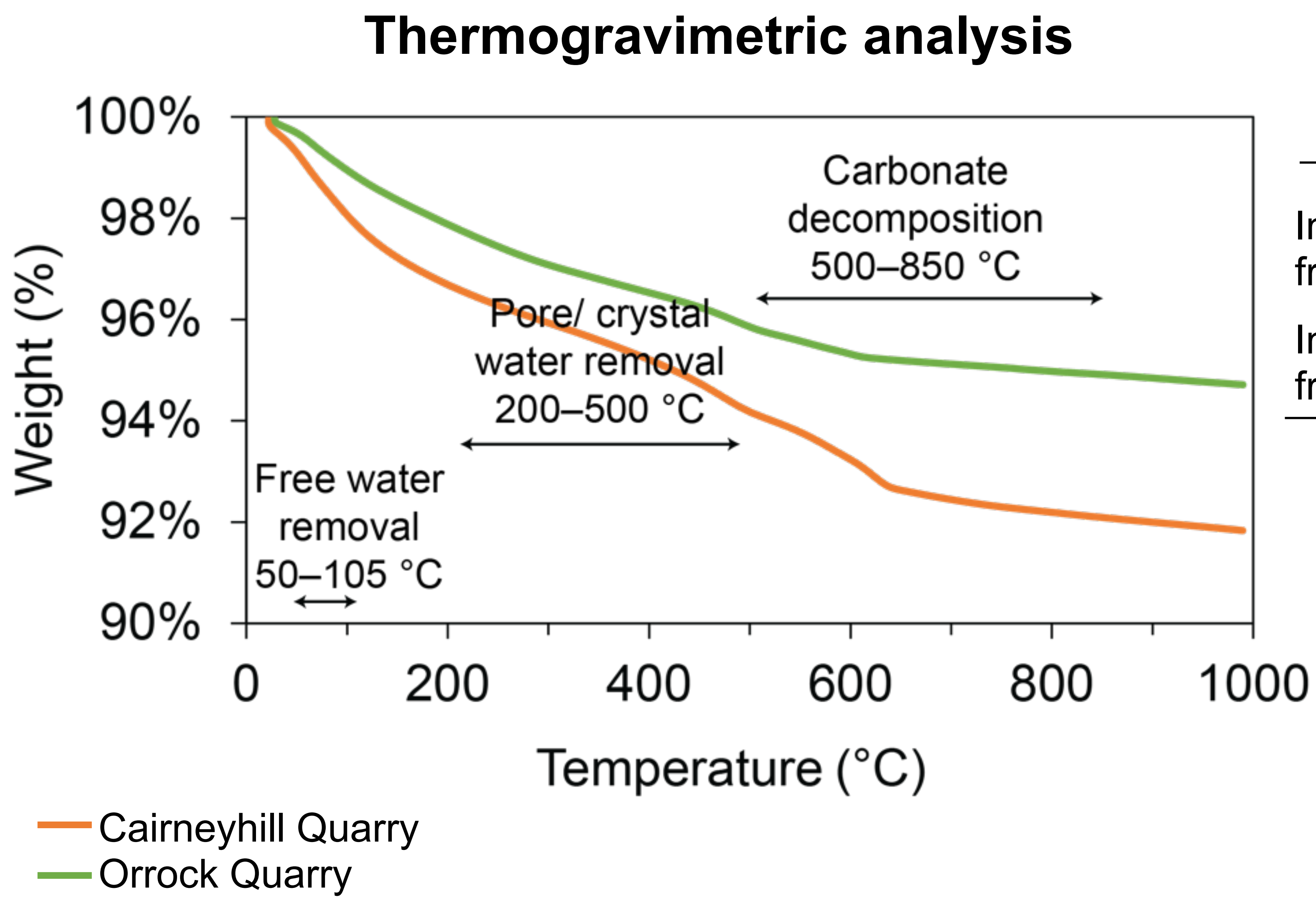
Carbonation potential calculated based on Steinour formula from Gunning et al., 2010 and Renforth 2019



Initial characterisation: Geochemical properties

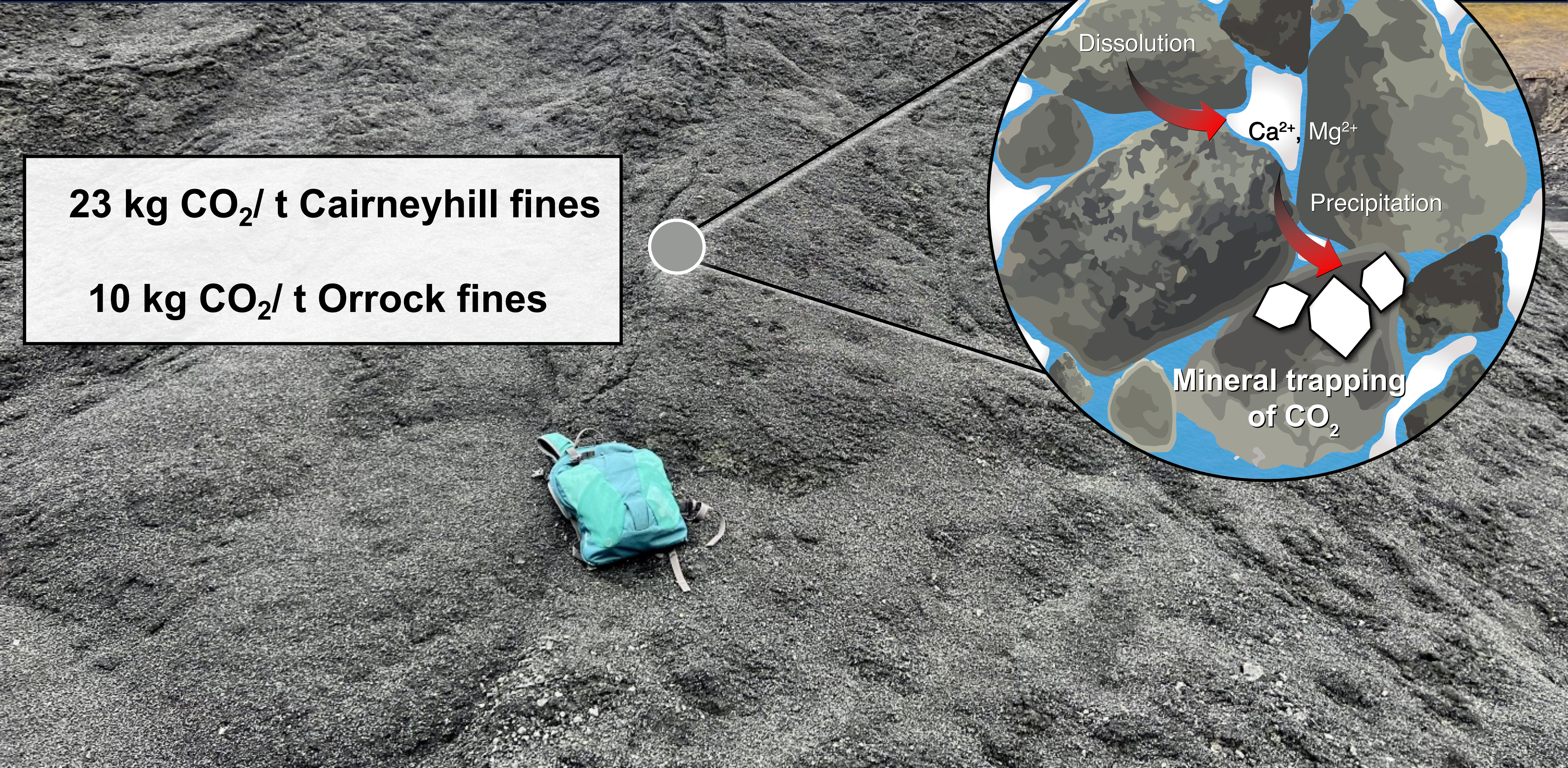


Initial characterisation: Geochemical properties



	Cairneyhill	Orrock
Initial CO_2 (%) from TGA	2.22	1.02
Initial CO_2 (%) from TIC	1.17	0.22

Estimation of passive CO_2 sequestration




How can the management of quarry fines be optimised for on-site CO_2 removal?

Basalt carbonation experiments

- **Comparative analysis to assess limiting carbonation factors**
- Two carbonation conditions:
  1. Ambient UK conditions
  2. Engineered approach to accelerate weathering
- Two different grain sizes:
  1. Bulk fines (no modifications made)
  2. <75 μm
- Two different depths:
  1. 1 cm
  2. 5 cm

Basalt carbonation experiments

- Comparative analysis to assess limiting carbonation factors
- **Two carbonation conditions:**
  1. **Ambient UK conditions**
  2. **Engineered approach to accelerate weathering**
- Two different grain sizes:
  1. Bulk fines (no modifications made)
  2. <75 μm
- Two different depths:
  1. 1 cm
  2. 5 cm

Basalt carbonation experiments

MMM Medcenter Climacell EVO Climate Chamber

- 10 °C (average annual UK temperature)
- 0.04% CO_2 (ambient conditions)
- 80% relative humidity (average annual UK RH)

Thermo Fisher Scientific Series 8000 Direct-Heat CO_2 Incubator

- 50 °C (very high end of ambient conditions)
- 20% CO_2 (engineered approaches)
- 80% relative humidity (average annual UK RH)

Basalt carbonation experiments

- Comparative analysis to assess limiting carbonation factors
- Two carbonation conditions:
  1. Ambient UK conditions
  2. Engineered approach to accelerate weathering
- **Two different grain sizes:**
  1. **Bulk fines (no modifications made)**
  2. **<75 μm**
- Two different depths:
  1. 1 cm
  2. 5 cm

Basalt carbonation experiments

- Bulk fines (no human modifications made)
  - Benefits: Less time, energy and cost on further processing
  - Drawbacks: Generally, has a lower reactive surface area

BET surface area

3.06 m^2/g

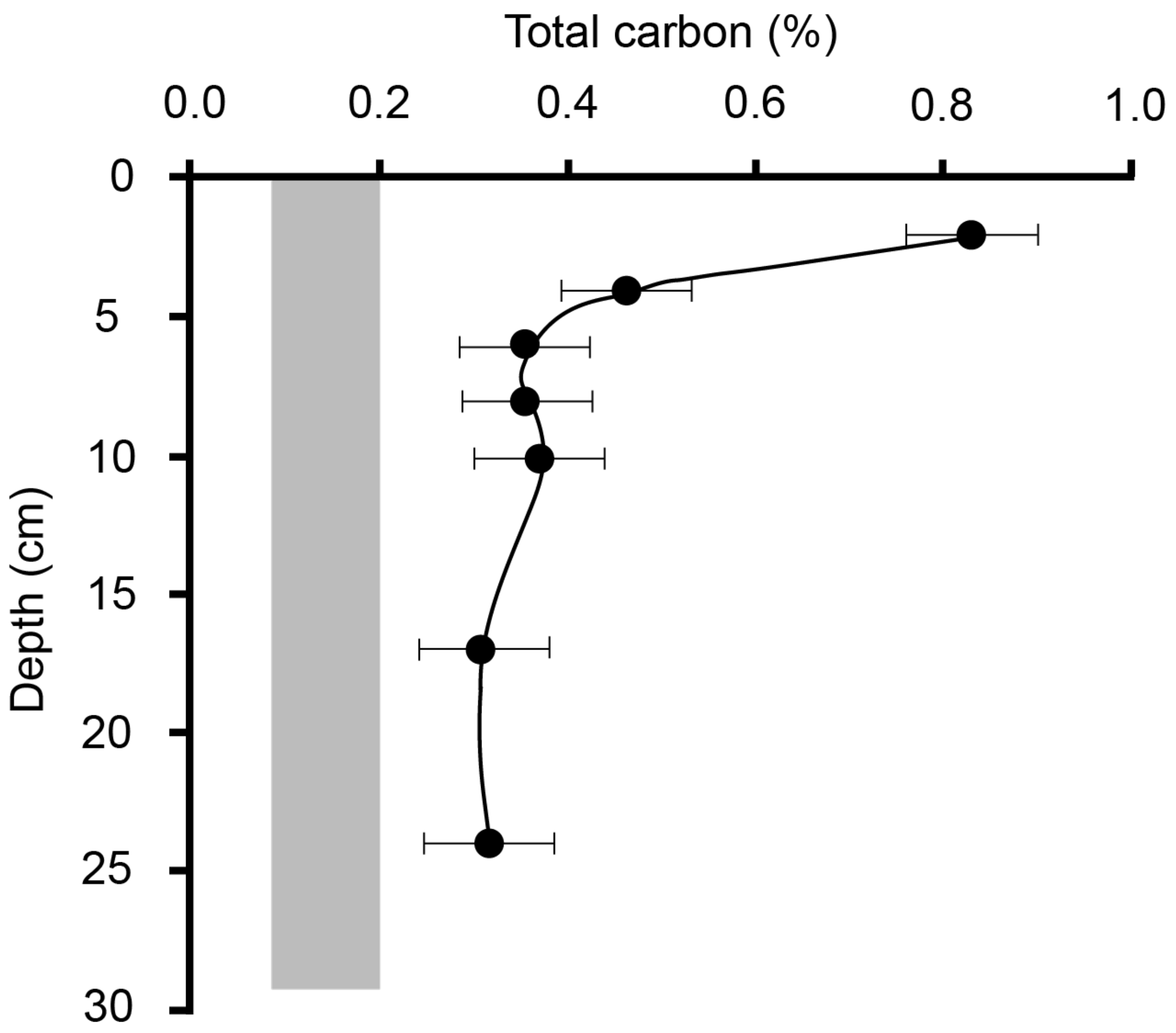
- Sieved fines (<75 µm)
  - Benefits: Increased reactive surface area
  - Drawbacks: Further processing is required, therefore greater emissions output

18.39 m^2/g

Basalt carbonation experiments

- Comparative analysis to assess limiting carbonation factors
- Two carbonation conditions:
  1. Ambient UK conditions
  2. Engineered approach to accelerate weathering
- Two different grain sizes:
  1. Bulk fines (no modifications made)
  2. <75 μm
- **Two different depths:**
  1. **1 cm**
  2. **5 cm**

Basalt carbonation experiments



1 cm depth:

- Greater carbonation in the top surface of tailings
- CO_2 diffusion may not be a limiting factor

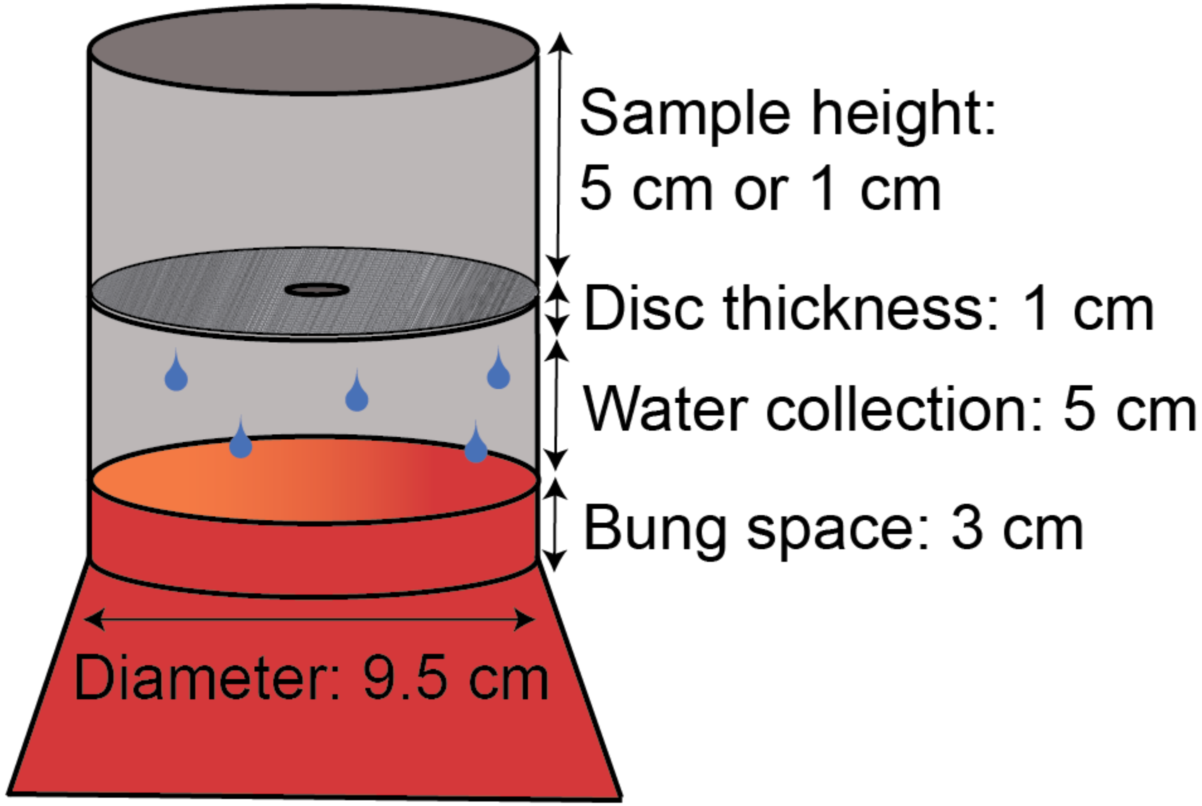
5 cm depth:

- Generally, carbonation rates decrease after this depth

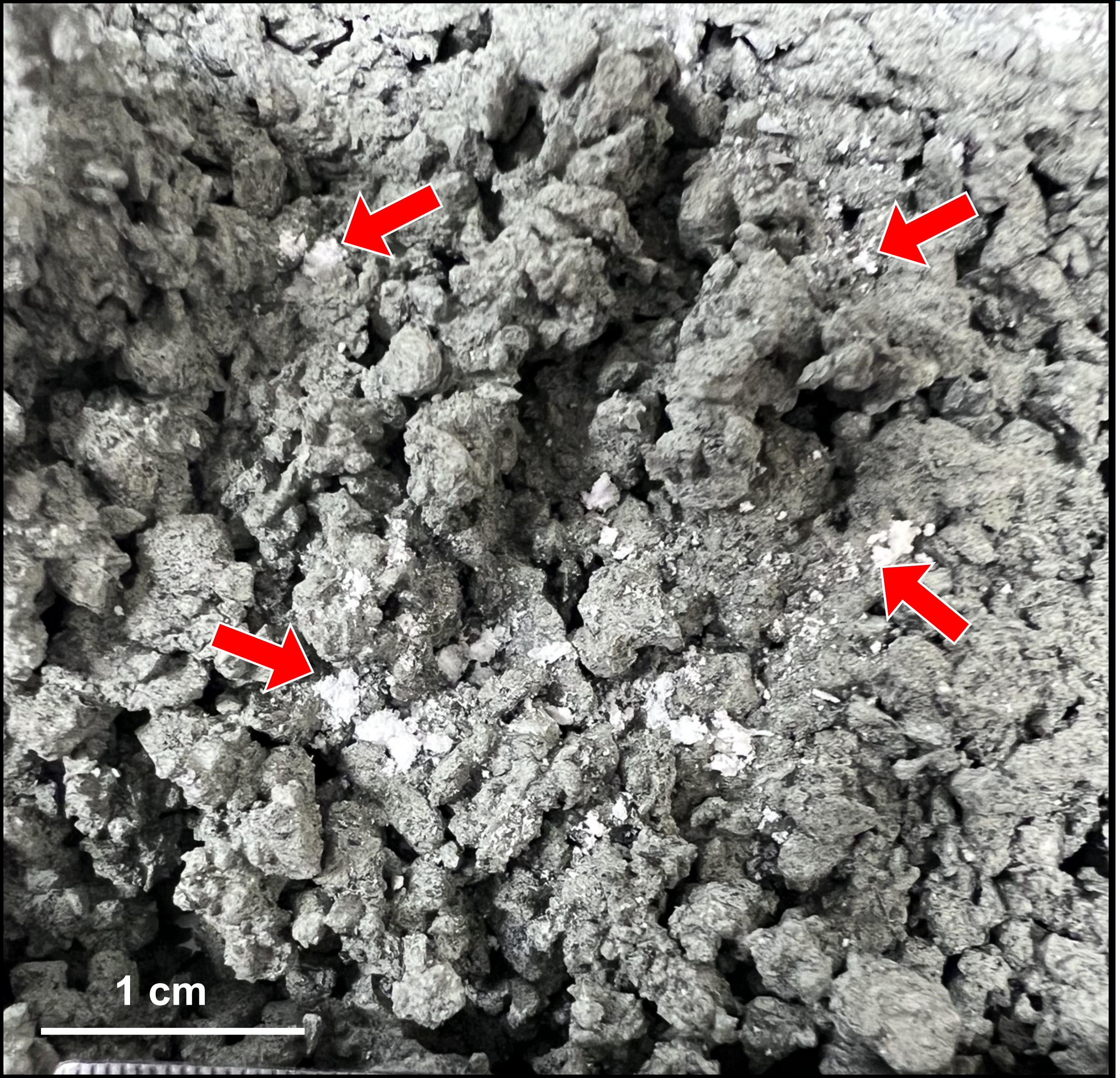
(Kandji et al., 2017)

Basalt carbonation experiments

- Column experiments
  - Bulk fines:
    - 1 cm = 100 g
    - 5 cm = 500 g
  - <75 µm fines:
    - 1 cm = 70 g
    - 5 cm = 500 g
- Monthly water addition equivalent to 60% pore water saturation
- Disc with 25 µm nylon mesh in the middle of the column to separate fines from water
- 3 months total

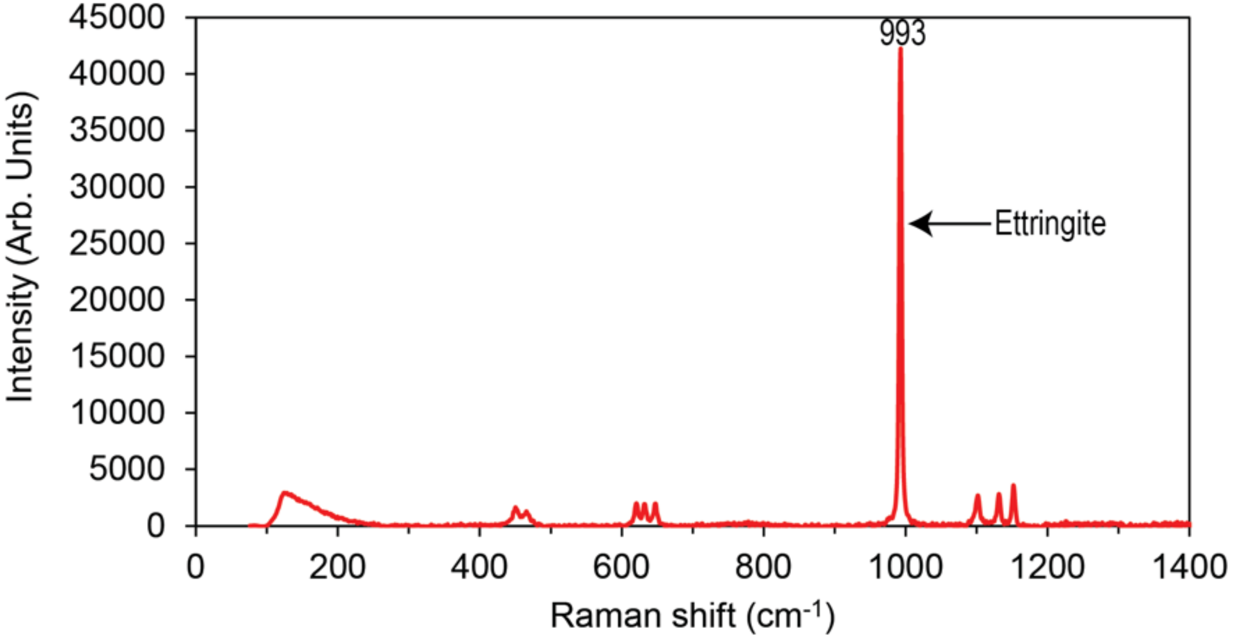


Preliminary results



White efflorescence's observed on the surface during initial drying

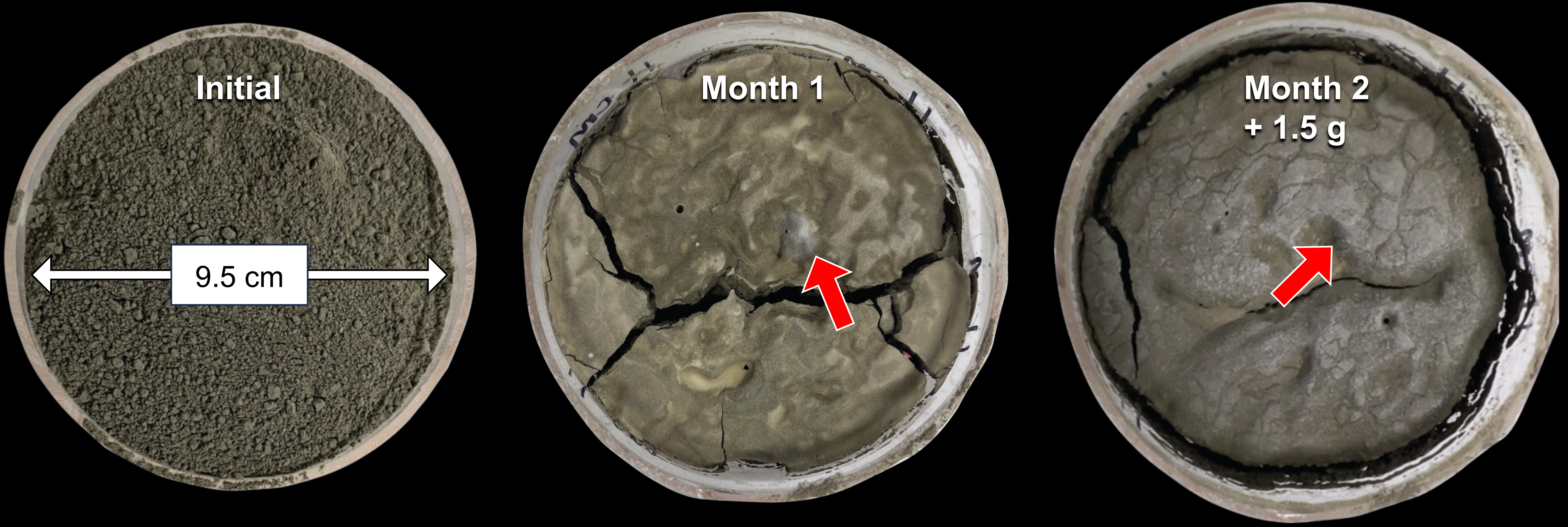
- Fizzed with dilute HCl
- Raman spectroscopy suggests these are Ca-bearing sulphates (i.e., Ettringite)



Preliminary results: Bulk fines – Ambient UK conditions

Orrock Quarry bulk fines (5 cm depth) – 4 kg CO_2/ t Orrock fines/ yr

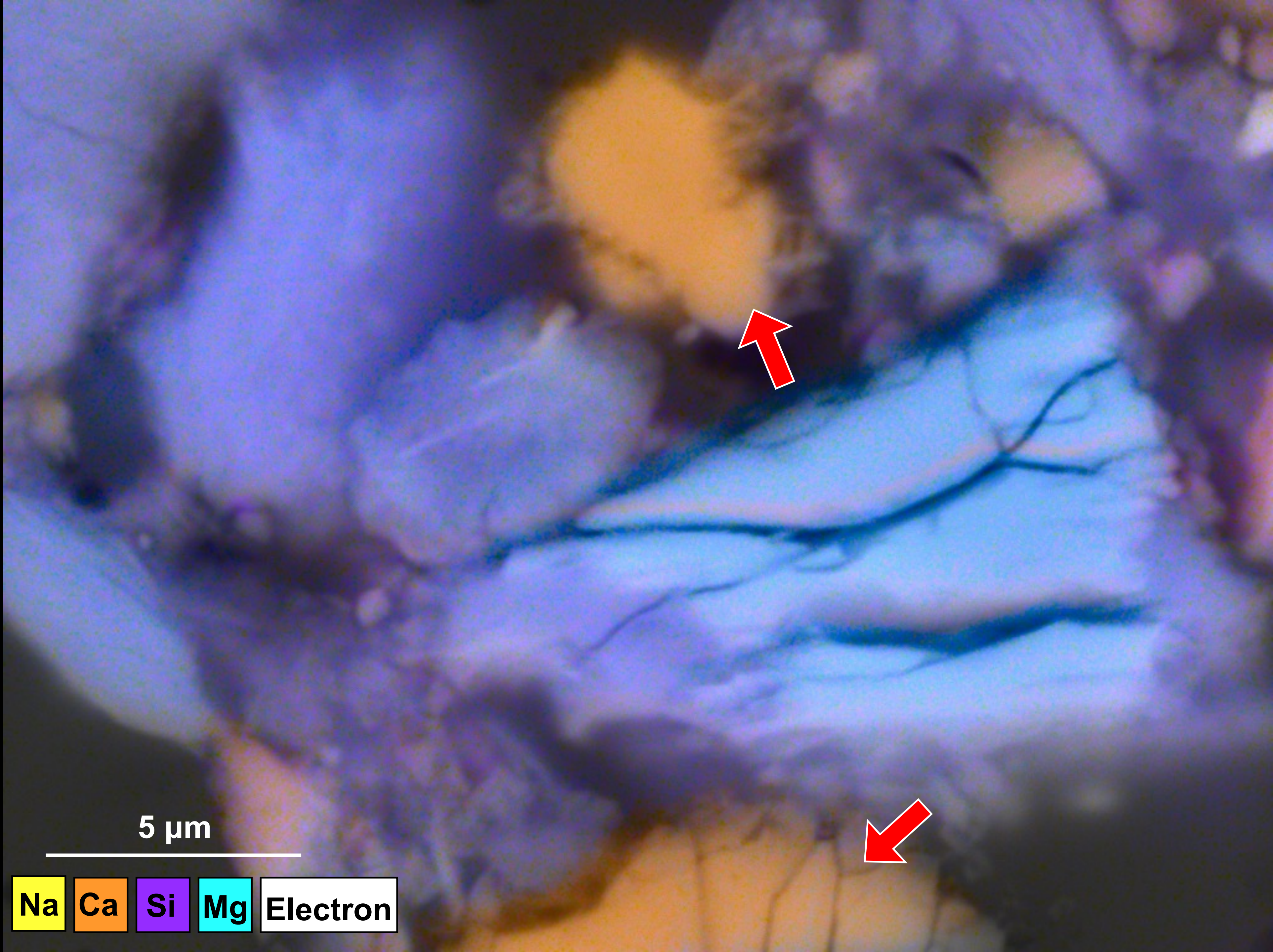
Preliminary results: <75 µm fines – Engineered approach



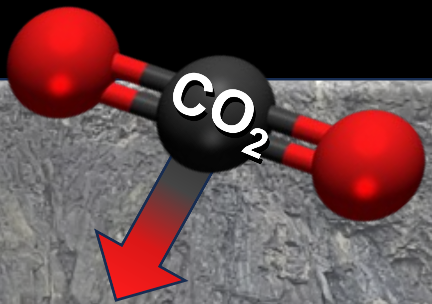
Orrock Quarry <75 µm fines (5 cm depth) – 17 kg CO_2/ t Orrock fines/ yr

Preliminary results: <75 μm fines – Engineered approach

Calcium carbonates



Implications for CO_2 sequestration



- **Potential for quarries to offset their CO_2 emissions**

- **Engineered approach (<75 μm fines):**
  - 840 g CO_2/ m^2/ yr

- **Ambient UK conditions (Bulk fines):**
  - 276 g CO_2/ m^2/ yr
  - Considering total fines production (42,000 t) and operation time remaining at Orrock (6 yrs):
    - 1006 t CO_2/ yr

Acknowledgements

Email: a.stubbs.1@research.gla.ac.uk

Acknowledgements: Carla Comadran Casas, Andrew Monaghan

UKRI Natural Environment Research Council

IAPETUS2 Doctoral Training Partnership

SAGES Scottish Alliance for Geoscience, Environment and Society

SCAN ME

Follow my research on X