RAFFLES INSTITUTION
2021 YEAR 6 PRELIMINARY EXAMINATION
Higher 3

CHEMISTRY
9813/01

Paper 1
INSERT

28 September 2021

2 hours 30 minutes

READ THESE INSTRUCTIONS FIRST

This insert contains information for Question 1. **Do not write your answers on the insert**.

This document consists of **4** printed pages.

Information for Question 1

An important strategy in mitigating climate change is to manage CO_2 levels in the atmosphere. Low emission targets have been set but are difficult to meet, hence, negative emissions or carbon dioxide removal has to form part of the overall strategy. Geochemical reactions such as weathering of minerals to accomplish this have been widely studied, and even commercially applied in some countries such as the Carbfix project in Iceland. A review paper published in the journal *Frontier in Climate* examines the application of such strategies and their possible impact to oceans. Another paper examines the kinetics of weathering reactions and the implications in their effectiveness in CO_2 capture.

For the interpretation of the information in Abstract 1, the following definitions are relevant.

- Calcite saturation (Ω) refers to the saturation levels of $CaCO_3$ in the ocean.
- Calcification refers to the rate of growth of calcifying shelled organisms that incorporate $CaCO_3$ into their growth.
- pCO_2 represents the partial pressure of atmospheric CO_2.
- Alkalinity refers to the total *excess* concentrations of all ions which are proton accepting over those which are proton donating, including, but not limited to, the following: $H_3SiO_3^-$, HCO_3^-, CO_3^{2-}.
- OAE refers to Ocean Alkalinity Enhancement, through the addition of minerals that would weather and increase alkalinity, such as silicates.
- Air-equilibrated OAE means that CO_2 in air and dissolved in water are able to equilibrate, so that any shift in aqueous CO_2 concentrations due to OAE are compensated by the transfer of CO_2 with the atmosphere.
- Non-equilibrated OAE means that aqueous CO_2 concentration shifts are not able to equilibrate with atmospheric CO_2.

Abstract 1 (*Front. Clim., 2019, 1, 7*)

One of the most important global concern is climate change due to global warming. In fact, to meet a < 2 °C global warming goal, negative emission technologies (NETs) are needed to remove carbon dioxide in the range of 600 gigatons (Gt) by the end of the 21st century. Carbon dioxide removal (CDR) via enhanced weathering (EW) of minerals containing silicates and oxides is a widely recognised idea. The desired consumption of atmospheric CO_2 during weathering and dissolution would inevitably be accompanied by a release of mineral products (alkalinity, Si, Ca, Mg, Fe, Ni and others) into the soil and sea. EW of minerals also does not require special land or water resources to be set aside for it. Thus in contrast to other NETs, EW of minerals do not compete with other Sustainable Development goals, but are potentially beneficial for them, for example, in food security.

A way to implement EW is by using the minerals to bring about ocean alkalinity enhancement (OAE).

Fig. 1 shows how certain ocean chemistry parameters change with and without OAE.

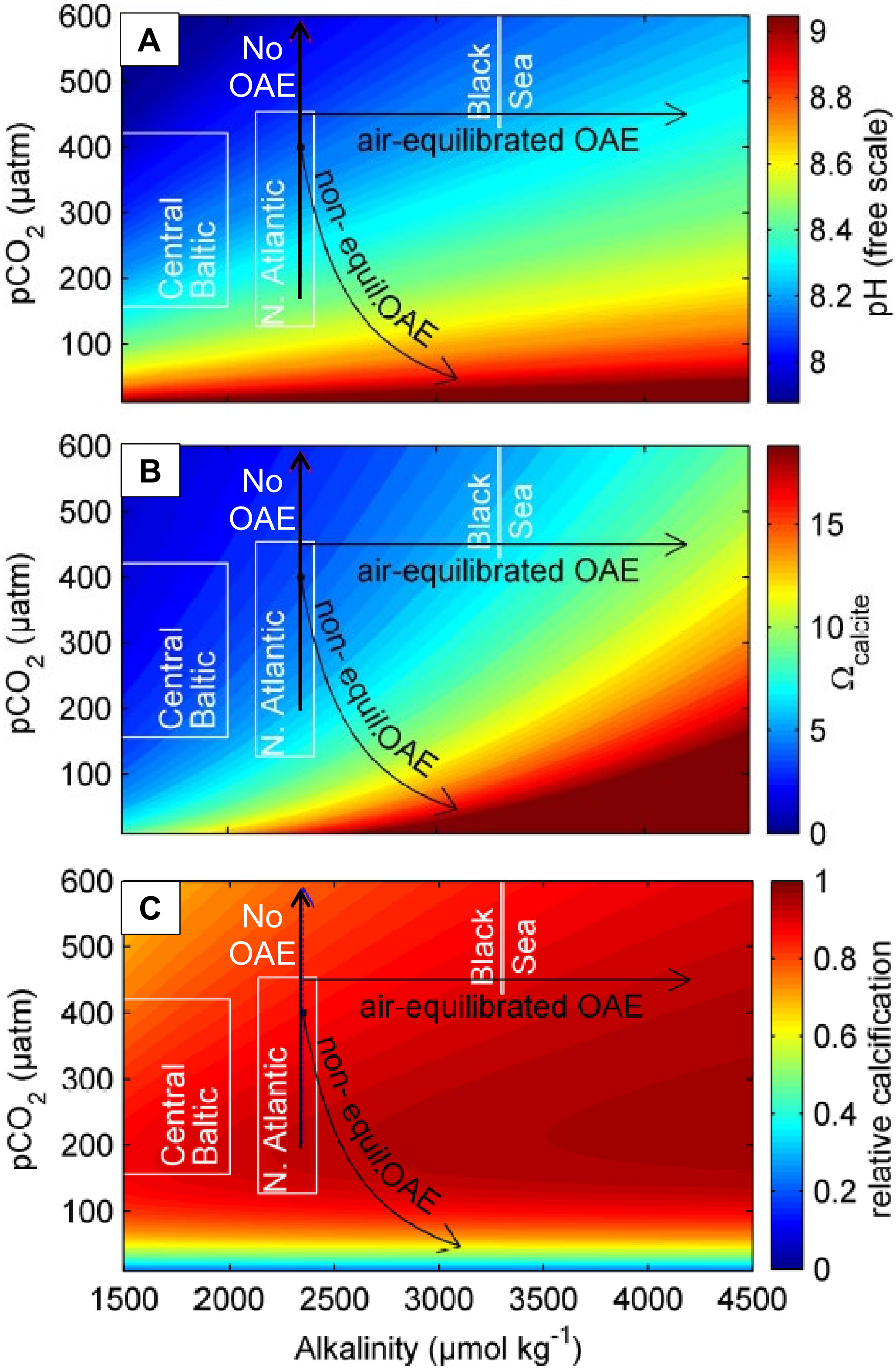

Fig. 1 Carbonate chemistry perturbation through EW/OAE. **(A)** Proton concentration, **(B)** Ω of the $CaCO_3$ mineral calcite, and **(C)** relative calcification rates of the coccolithophore *Gephyrocapsa oceanica*, as a function of alkalinity and pCO_2. The arrows show the trajectories of ocean acidification with no OAE, air-equilibrated OAE, and non-equilibrated OAE. Approximate carbonate chemistry conditions of the Baltic Sea, Black Sea, and North Atlantic (0-100m depth) are show in white boxes (data from Goyet et al., 1991; Key et al., 2004; Müller et al., 2015).

Abstract 2 (*Geology, 1993, 21, 1059*)

Estimation of the temperature dependence of natural feldspar weathering in two catchments at different elevations yields an apparent Arrhenius activation energy of 77.0 kJ mol^{-1}, much higher than most laboratory values (lowest estimate around 29.7 kJ mol^{-1}). This finding supports recent suggestions that hydrolytic weathering of silicate minerals may consume carbonic acid and thereby remove atmospheric carbon dioxide more rapidly with increasing temperature than previously thought. This result provides a stronger negative feedback on long-term greenhouse warming than has been assumed in most models of global carbon cycling.

Copyright Acknowledgements:

Question 1 Abstract 1	© Bach LT, Gill SJ, Rickaby REM, Gore S and Renforth P (2019) CO_2 Removal With Enhanced Weathering and Ocean Alkalinity Enhancement: Potential Risks and Co-benefits for Marine Pelagic Ecosystems. Front. Clim. 1:7.
Question 1 Abstract 2	© Velbel MA (1993) Temperature dependence of silicate weathering in nature: How strong a negative feedback on long-term accumulation of atmospheric CO_2 and global greenhouse warming? *Geology* 21, 12, 1059.
Question 2	© Field LD, Sternhell S, and Wilton HV (1999) Electrophilic Substitution in Naphthalene: Kinetic vs Thermodynamic Control. Journal of Chemical Education 76, 9, 1246.