Carbon Sequestration Potential in the Propylitic Alteration Zone of a Porphyry Copper Deposit

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Introduction

Global climate change, triggered by rising atmospheric CO_2 concentrations, demands the development of geology-based mitigation technologies, one of which is carbon mineralization. This approach is gaining scientific interest due to its highly stable and long-term storage properties (Kelemen & Matter, 2008). In various Mg-, Ca-, and Fe-rich silicate rocks, carbonation reactions are known to proceed effectively, particularly under hydrothermal conditions or in open environments that facilitate rock–fluid–gas interactions (Power et al., 2013; McCutcheon et al., 2019).

Research on mineral carbonation has predominantly focused on ultramafic rocks such as peridotite and serpentinite (Hansen et al., 2005); however, few studies have examined mineral carbonation within the propylitic zone of porphyry copper deposits, which are abundant in magmatic belts such as Indonesia (Lowell & Guilbert, 1970; Sillitoe, 2010; Maryono, A., et al., 2018). Therefore, investigation and evaluation of mineral carbonation in this alteration zone are needed in relation to temperature, pressure, pH, and kinetics reaction.

Keyword: Propylitic alteration, Porphyry copper, Carbon Mineralization and Sequestration

Geological Carbon Storage

Geological carbon storage is plays a crucial role and gaining recognition in climate mitigation by capturing and permanently injecting CO_2 deep underground into secure geological formations, including depleted oil and gas reservoirs, deep saline formations (both onshore and offshore), and coal beds (IPCC 2005). These diverse storage options not only effectively reduce greenhouse gas emissions into the atmosphere, but some methods can also be utilized to support enhanced oil, gas, and coal bed methane recovery (Fig.1). The alternative geological storage is propylitic zone in porphyry copper deposit (PCD) where the the propylitic zone is one of the most extensive alteration zones in porphyry systems, spatially occupying greater than 40% of the area (Lowell & Guilbert, 1970; Sillitoe, 2010), and is associated with geochemical changes that reflect the addition of Ca, Mg, and Fe in the form of alteration minerals that are highly relevant for mineral carbonation.

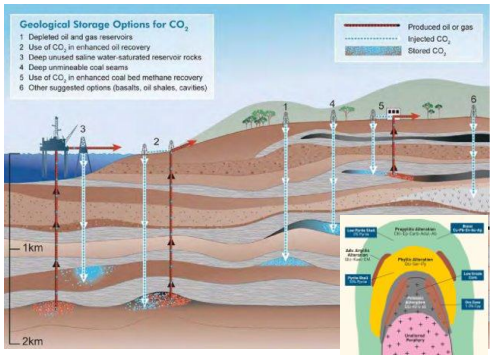


Fig 1. Options for the geological storage of carbon dioxide including the alteration zone of PCD

Experimental Set-up and Analytical Methods

Crushed sample of propylithic alterated rock was used as starting material. Inside batch-type autoclave made of SUS pipe, with an internal volume of 7.85 mL, was used for the hydrothermal experiments (Fig. 2). The apparatus filled with 200mg of sample and NaCl with 40% filling ratio. The experiments was performed at 250 °C and 4 MPa (vapor-saturated pressure) for 72 hour (Uno, M., et al., 2022; Amarbayar, N., et al., 2023). After the experiment the solid and liquid was separated using filter. The solid sample was prepared as thin section and analyzed using EPMA. Excess solution after experiment was analyzed using ICP-OES.

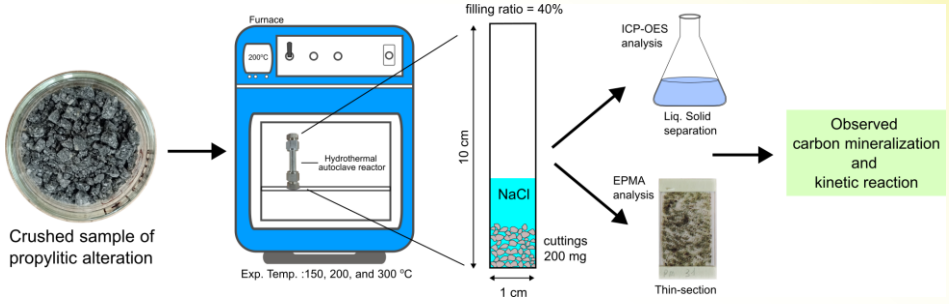
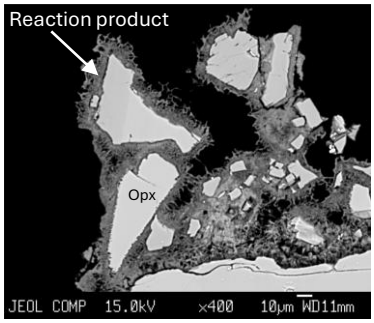
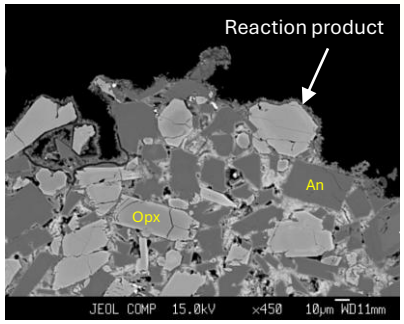


Figure 2. Experimental Set-up

Result

- Reaction product propagate outward from the phenocrysts and rock pores.
- Reaction kinetics are slow in the NaCl solution.
- A small amount of Ca precipitates as a silicate mineral (possibly chlorite?).
- Divalent cations remain available in the excess solution, ready to react with carbonic acid under varying temperature conditions.
- The pH decreased below 4 after the experiment.





EPMA Result

	Opx	An	Reaction
SiO2	53.67	54.22	28.47
Na2O	0.07	4.87	1.03
FeO	21.10	1.00	24.22
CaO	4.94	11.95	0.97
Cr2O3	0.02	0.04	0.00
Al2O3	0.58	28.37	5.98
MgO	20.83	0.00	4.56
MnO	0.47	0.00	0.08
K2O	0.00	0.07	0.20
TiO2	0.00	0.00	0.00
Total	101.67	100.53	65.51

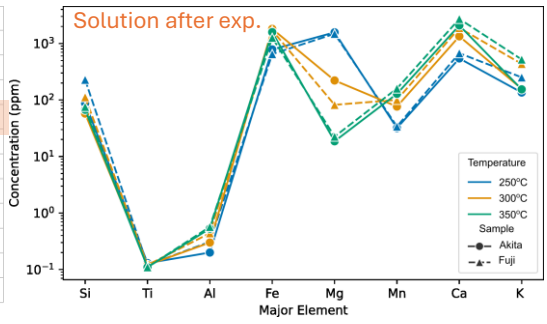


Figure 3. Observed reaction product and its composition and the dissolved element available in the excess water after experiment

The Potential of Propylitic zone as Carbon Reservoir through Carbon Mineralization

The propylitic halo is the outermost alteration zone of porphyry Cu systems and extends laterally for kilometres (Fig. 4a) from the potassic core (Sillitoe, 2010; Cooke et al., 2014a). The carbon mineralization can be achieved by two scenario first insitu carbon injection at temperature 25-100 °C (Marieni et al., 2020) allow epidote to react and precipitate carbonate minerals (Fig. 4b). Second is from Mine tailings, notably from mafic and ultramafic rock-hosted operations and high-tonnage Cu-hosting deposits, have the potential to capture ~1.1–4.5 Gt CO_2 annually (Bullock et al., 2021)

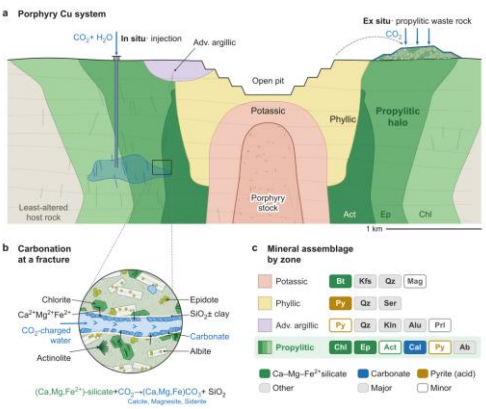


Fig 4. Schematic figure of carbon mineralization mechanism in propylitic zone of PCD.

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