An overview of geohemical trapping system for CO$_2$ sequestration study in the ultramafic rock from Sulawesi, Indonesia

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One of the biggest environmental problems in the world nowadays is the anthropogenically induced climate change which has contributed intimately to the increasing of CO$_2$ level in the atmosphere. This situation has influenced the global climate, leading to warmer temperature, increased sea melts and rise in sea level. One of the most environmentally-friendly methods to tackle the CO$_2$ increasing is the CO$_2$ storage in geological formation method or CO$_2$ sequestration storage (CSS). Among CO$_2$ storage sequestration model that have been developed, the geochemical trapping system in ultramafic rocks offer a promising result. However, despite its environmentally-friendly and economically-cost, the study on this is still lack.

The ultramafic rocks in Sulawesi occur as a dismembered ophiolite body covering largely from central to the south eastern portion of the island. The composition of the rocks is ranging from peridotite to clinopyroxenite which contain Mg and Fe rich mineral and Ca- and Mg-rich minerals, respectively. The basic principal in this method is the acceleration of weathering/alteration process occurring in nature by producing reaction between CO$_2$ with ultramafic rocks in which Mg-, Fe-, and Ca-bearing minerals are abundant. Theses minerals will act as a sink to sequester CO$_2$ in the form of magnesium and calcium carbonates.

In this study, geochemical character and approximate amount of CO$_2$ than can be sequestered in ultramafic rocks from Sulawesi will be overviewed and estimated using standard equation. Approximately 780 mt and 34.9 mt of CO$_2$ can be sequester in the ultramafic rocks from ESO and South Sulawesi Ultramafic rocks, respectively.

Introduction
Carbon dioxide (CO$_2$) is the most common greenhouse gas found in the atmosphere. The emission of CO$_2$ can be produced largely by the excessive burning of fossil fuels (coal, oil and natural gas) from power plant, industrial boilers and heaters and other kind of fuels such as wood, solid waste, ethanol, and biodiesel. This situation has influenced the global climate, leading to warmer temperature, increased sea melts and rise in sea level.
There are at least three primary methods for reducing the amount of carbon dioxide in the atmosphere: employing energy efficiency and conservation practices; using carbon-free and reduced-carbon energy sources; and capturing and storing carbon to the underground or what so called carbon capture storage. Carbon capture and storage is a technology that can capture up to 90% of the CO2 emissions produced from the use of fossil fuels in electricity generation and industrial processes, preventing the CO2 from entering the atmosphere. This method is also known as carbon capture sequestration or CCS method. Among CO2 storage sequestration model that have been developed, the geochemical trapping system in ultramafic rocks offer a promising result (Voormeij & Simandl, 2004; Huijgen et al. 2006). Over the past several years some papers have been published which discuss the advantages of CO2 injection into ultramafic rocks formations (Hansen & Dipple, 2005; Oelkers et al., 2008). A survey of the global carbon reservoirs suggests that the most stable, long-term storage mechanism for atmospheric CO2 is the formation of carbonate mineral such as calcite, dolomite and magnesite (Oelkers et al., 2008) which has been also known as carbonation method. However, despite its environmentally-friendly and economically-cost, the study on geochemical trapping system in ultramafic rocks is still lack.

The ultramafic rocks in Sulawesi occur as a dismembered ophiolite body covering largely from central to the south eastern portion of the island (Kadarusman et al., 2000; Maulana et al., 2013). The composition of the rocks is ranging from peridotite to clinopyroxenite which contain Mg and Fe rich mineral and Ca- and Mg-rich minerals, respectively. The basic principal in this method is the acceleration of weathering/alteration process occurring in nature by producing reaction between CO2 with ultramafic rocks in which Mg-, Fe-, and Ca-bearing minerals are abundant. Theses minerals will act as a sink to sequester CO2 in the form of magnesium and calcium carbonates. In this study, geochemical character and approximate amount of CO2 than can be sequestered in ultramafic rocks from Sulawesi will be overviewed and estimated using standard equation. This result will shed the light on using geochemical trapping system for CO2 storage potential in the ultramafic rock from Sulawesi, Indonesia. As the ultramafic rocks are widely distributed in Sulawesi, a potential future utilization is highly demanded.

**Carbon dioxide storage in geological formation**

According to Mani et al (2008), there are three different ways for CO2 sequestration in geologic formation i.e. hydrodynamic trapping, solubility and mineral trapping.

1. Hydrodynamic trapping
It involves the storage of free CO2 as gas or supercritical CO2 in the pore spaces of sedimentary layers overlying oil and gas reservoirs, unmineable coal seams and deep saline reservoirs.

2. Solubility
In this type of trapping, CO2 is dissolved in fluid phase comprising of aqueous brines and oils. The solution has density greater than brine in order to prevent buoyant escape of CO2 (Weir et al., 1995).

3. Mineral carbonation trapping
It is a permanent mechanism of sequestration in which silicate minerals are converted to secondary carbonates due to reaction with CO2 (Mani et al., 2008). Detailed background of this method is given below.

**Mineral CO2 sequestration: brief review**
The primary requisite for using mineral carbonation method for CO2 sequestration is availability of suitable ultramafic rocks containing Mg, Ca dan Fe silicate minerals e.g olivine. Olivine is a common constituent of dunites and peridotite. These rocks are typically abundant in mantle, exposed on Earth’s surface as ophiolites. In crustal setting, they form as a part of layered complexes formed in deep-seated basaltic magma chamber as cumulates and are exposed to surface through tectonic exhumation process.

The basic principle of mineral CO2 sequestration in ultramafic rock is the acceleration of weathering/alteration processes occurring in nature, wherein CO2 reacts with Ca, Fe, or Mg containing minerals, especially silicates. The permanent sequestration of CO2 in the form of carbonates is shown by this reaction.

\[(\text{Ca, Mg})\text{O} + \text{CO}_2 \rightarrow (\text{Ca, Mg})\text{CO}_3\]
\[(\text{Ca, Mg})\text{SiO}_4 + \text{CO}_2 \rightarrow (\text{Ca, Mg})\text{CO}_3 + \text{SiO}_2\]

Nature stores CO2 predominantly in carbonates, mainly limestone, dolomite. Litswanite (carbonated serpentinite) represents a fossil mineral carbonation system, serving as a repository of CO2 in the form of carbonates during the reaction of serpentine with CO2-rich fluids (Klump et al., 2000; Kojima et al., 1997). CO2 is made to react with mafic/ultramafic rocks which are the most common source of magnesium, iron or calcium-bearing silicate minerals present in nature (Goff and Lackner, 1998). Example of such a carbonation reaction with suitable magnesium minerals (Mani et al. 2008) are:
Mg$_3$SiO$_5$(OH)$_4$ + 3CO$_2$ $\rightarrow$ 3MgCO$_3$ + SiO$_2$ + H$_2$O
Serpentine       Magnesite       Silica

MgSiO$_4$ + 2CO$_2$ $\rightarrow$ 2MgCO$_3$ + SiO$_2$
(Olivine)       Magnesite       Silica

Potential of usage of ultramafic rocks for CO2 for carbon sequestration in Sulawesi

South Sulawesi is famous for its tectonic evolution as a continent-island arc-continent collision zone involving opening of Makassar Strait and collision between the Sundaland and Australian-derived microcontinent. Ultramafic rocks in Sulawesi occur as dismembered ophiolite. In the following we briefly review the occurrence of ultramafic rocks in South Sulawesi for their possible usage in CO2 sequestration.

**East Sulawesi Ophiolite**
Ultramafic rocks in Sulawesi occur as dismembered ophiolite body in some areas e.g. south, southeast, east and central part (Kadarusman et al., 2004; Maulana et al., 2015). In the east, southeast and central part of Sulawesi forming some segmented ophiolite body which later known as East Sulawesi Ophiolite (Kadarusman et al., 2004). The ESO grades upward from residual mantle peridoite, and mafic-ultramafic cumulate, through layered to isotropic gabbro, to sheeted dolerite and basaltic volcanics. The ultramafic rocks composed of peridotite which consists mainly of lherzolite and Cpx-rich harzburgite, with minor dunite, pyroxenite dan Cpx-free harzburgite.

**South Sulawesi Ultramafic Rocks**
In South Sulawesi, the ultramafic rocks occur in two separated basement blocks, namely Bantimala and Barru Block (Maulana et al., 2015). The rocks of both blocks show strong serpentinization of original anhydrous silicates. The Bantimala ultramafic consists mainly of peridotite (harzburgite and dunite) and clinopyroxenite, with lenses of podiform chromitite. They have undergone metamorphism as shown by the occurrences of amphibolite-facies tremolitic schist. In contrast, the Barru ultramafic rocks consist of harzburgite peridotite and podiform chromitite and have been metamorphosed to amphibolite-facies condition.
Quantification of Sulawesi ultramafic rocks for CO2 sequestration

Carbon storage capacity of various ultramafic rocks from Sulawesi will be tentatively quantified by using their MgO content (Goff and Lackner, 1998; Kohmann and Zevenhoven, 2001; Tahirkheli et al., 2012). General information about the geology and structure of ultramafic rocks and data on their distribution, approximate thickness, chemical composition and mineralogy are used to calculate the volume of ultramafic rocks in Sulawesi. The volume thus calculated and then multiplied by the wt% of MgO to assess the quantity of ultramafic rocks needed to sequester CO2 in these areas using the formula given by Zevenhoven and Kohlman (2001).

\[ T = 1 \times \rho \times a \times t \times d \times (1 - \phi). \]

Where \( T \) is the amount of CO2 that can be sequestered, \( \rho \) is the wt% of MgO in ultramafic, \( a \) is the area, \( t \) is the thickness, \( d \) is the average density and \( \phi \) is the average porosity of ultramafics.

1. East Sulawesi Ophiolite

For East Sulawesi Ophiolite, an effective sequestration of about 20% at a depth of 1 km is calculated as:

Volume of the complex = 15.000 km\(^2\) (Kadarusman et al., 2004) x 1 km = 15.000 km\(^3\)

Effective volume of the complex for sequestration = 20% of 15.000 km\(^3\) = 3000 km\(^3\) = 3000 \times 10^6 m\(^3\)

Average density = 3197 km/m\(^3\)

Mass of ultramafic = volume \times density = 3000 \times 10^6 m^3 \times 3197 km/m^3 = 9591 \times 10^9 m^3.

Average % MgO in ultramafic rocks of ESO = 8.3 wt%

Total MgO in ultramafic rocks of ESO = 8.3 wt% \times 9591 \times 10^9 m^3 = 796 million tons (mt)

Since 1 ton of MgO can dispose of approximately 1 ton of CO2 (Zevenhoven & Kohlman, 2001), with an average porosity of 2% in ultramafic rocks, 796 mt of MgO in ESO can sequester 1 \times 796 \times (1 - 0.02) = 780.08 mt of CO\(^2\) in the form of magnesium carbonate.

2. South Sulawesi Ultramafic Complex

For South Sulawesi Ultramafic Complex, an effective sequestration of about 20% at a depth of 1 km is calculated as:

Volume of the complex = 420 km\(^2\) (Maulana et al., 2015) x 1 km = 420 km\(^3\)

Effective volume of the complex for sequestration = 20% of 420 km\(^3\) = 84 km\(^3\) = 84 \times 10^6
m³
Average density = 3197 km/m³
Mass of ultramafic = volume x density = 84 x 10⁶ m³ x 3197 km/m³ = 26 x 10⁹ m³.
Average % MgO in ultramafic rocks of ESO = 13.7 wt%
Total MgO in ultramafic rocks of ESO = 13.7 wt% x 26 x 10⁹ m³ = 35 million tons (mt)

Since 1 ton of MgO can dispose of approximately 1 ton of CO₂ (Zevenhoven & Kohlman, 2001), with an average porosity of 2% in ultramafic rocks, 35 mt of MgO in ESO can sequester 1 x 35 x (1-0.02) = 34.9 mt of CO₂ in the form of magnesium carbonate.

Conclusion

This study outlines the tentative amounts of CO₂ that can be stored as mineral carbonates in ultramafic rocks from Sulawesi Island. We assumed 20% of the total ultramafic volume can be utilized as sequestration. Approximately 780 mt and 34.9 mt of CO₂ can be sequestered in the ultramafic rocks from ESO and South Sulawesi Ultramafic rocks, respectively.

Reference


magnesium Silicates in Finland. Processing of 11th International Conference on Coal Science, San Francisco, California.


Zevenhoven, R., Kohlmann, J. 2001. CO2 sequestration by magnesium silicate mineral carbonation in Finland: Second Nordic Minisymposium on Carbon Dioxide Capture and Storage, 26 October, Goteborg.