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CO_2 Mineralization Potential in the Basalts of Deccan Volcanic Provinces (DVP) India: Case Study on Geochemical and Geo-mechanical Properties

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Abstract

The urgency to mitigate global climate changes caused by the increased greenhouse gas emissions especially from the large amount of CO_2 greenhouse gases released from burning the fossil fuels and industrial process has highlighted the interest in a developing study of Carbon Capture, Utilization, and Storage (CCUS) technologies to reduce atmospheric CO_2 levels around the world (Bachu, 2000; Singh et al., 2024). Approach for CO_2 Storage through various geological formations such as Depleted hydrocarbon Fields, Deep Saline Aquifers, Coal Seams, and Basalt formations hold the potential for geological sequestration of CO_2. CO_2 Mineralization is an one such techniques for the sequestration of CO_2 through mineral carbonation processes via various mineralization methods especially In-situ, Surficial and Ex-situ CO_2 Mineralization which has the potential to store CO_2 gases as Carbon storage for long-term stability in the Geological conditions (Bhavsar et al., 2023; Kirmani et al., 2024). The CO_2 Storage through the Igneous Mafic Basaltic rocks offers a particular promising pathway among geological storage options due to their ability to convert CO_2 into stable, solid carbonates through mineral carbonation and due to their fast reaction rate with the other minerals. The Presence of divalent cations especially the $Mg^{2+,}$ $Fe^{2+,}$ Al^{2+} and Ca^{2+} in the Basalts hold the potential for rapid CO_2 Mineralization compared to the Sedimentary rocks (Ajayi et al., 2019; Kim et al., 2023; Kirmani et al., 2024; Raza et al., 2022; Singh et al., 2024). The study targets the India's Deccan Traps, one of the world's largest continentals flooded volcanic provinces, has an immense potential capacity—estimated at several hundreds of gigatons—for permanent CO_2 Storage. Yet, despite this potential, there are currently no pilot or commercial-scale CCUS projects targeting Deccan basalt formations. For CO_2 storage as a supercritical fluid, target formations must exceed CO_2's critical pressure and temperature (7.4 MPa, 31.1°C), requiring injection depths over 750 m. Only 28% of Deccan basalt meets this, limiting suitable injection locations. Imposing significant geographical constraints on available injection locations. Also, Dike swarms in the Deccan Traps form vertical barriers, limiting horizontal connectivity. Regions with basalt at suitable CCS depths align with high dike prevalence, challenging the feasibility of sustained CO_2 injection (Prasad et al., 2009; Rani et al., 2013; Raza et al., 2022; Singh et al., 2024). This study aims to assess the feasibility of CO_2 storage in Deccan basalt by investigating the favorable sites, establishing the reaction kinetics, trapping mechanisms specifically focusing on the carbonation rate of basaltic minerals like calcium and magnesium silicates under varied temperature, pressure, and fluid saturation conditions. The influence of CO_2 Mineralization through chemical trapping mechanisms especially a.) Solubility and b.) Mineral trapping hold the potential for injection of CO_2 gases in the Basaltic rocks as carbon storage for long-term stability (Kim et al., 2023; Lu et al., 2024; Massarweh & Abushaikha, 2024; Matter & Kelemen, 2009; Rani et al., 2013; Raza et al., 2022; Zhang & Song, 2014). The methodology of the study includes selecting suitable sites and locations through geological field scale observations, geological

mapping, collection of rock samples from a particular location and examining them with Laboratory experiments such as rock characterization (XRD, SEM, ICP-OES) analysis with Stubbs and powdered rock samples; petrophysical properties (porosity & permeability) with cored rock samples; rock strength/integrity (UCS & BTS & TTS) with cored rock samples will be studied by the cycle of pre and post injection of CO_2 gases in the rock and brines using Core flooding experiments and batch reactor experiments where appropriate temperature, pressure and conc. of CO_2 conditions is maintained to evaluate the changes in the petrophysical properties, dissolution and precipitation rates, carbonation rates of calcium and magnesium silicates in basalts and quantify CO_2 trapping rates (Hellevang et al., 2013; Hellmann & Tisserand, 2006; Jiang, 2011; Kwon et al., 2011; Maskell et al., 2015; Pham et al., 2011; Steefel et al., 2005; Wilkinson et al., 2009). Transforming CO_2into solid minerals forms the structural integrity of resulting carbonate formations, which can prevent leakage. Expected outcomes of the study include establishing geochemical & geo-mechanical parameters such as rock characterization, injection rates, mineralization, geochemical reactions, strength & integrity, petrophysical properties, stress/strain rates using acoustic emissions & pulse wave velocity, establishing a scalable storage model such as Reactive Transport Modelling, which will enhance to generate scalable protocols for CO_2 injection and developing a robust monitoring framework in the Basalt rock formations for upscaling into pilot-scale projects. The anticipated outcomes include identifying suitable injection sites, possible mineralization potential of CO_2 & developing protocols for scalable storage and providing a framework for the development of India's future CCUS projects, advancing India's commitment to climate action and sustainable resource management industry standards. In the long term, effective implementation will require comprehensive monitoring of CO_2 storage sites to ensure environmental safety, assess containment integrity, and refine storage methodologies. This research will establish protocols for long-term monitoring, setting the foundation for India's transition toward sustainable carbon management and positioning the Deccan Traps as a critical asset in global climate mitigation efforts.

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