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Short Communication

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Accelerating Climate Resilience: A Geologically Integrated Framework for Rapid CO_2 Mineralization and Extreme Heatwave Mitigation

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This study establishes a unified geological framework to enable efficient, scalable responses to two interconnected dimensions of the climate crisis:

a. Accelerated mineralization of atmospheric and industrial CO_2, and

b. Targeted mitigation of the rising frequency and intensity of extreme heatwave events.

The framework strategically integrates specific geological conditions with engineering interventions to address both urgent challenges concurrently. The Tibetan Plateau, which was formed by the continuous collision between the Indian and Eurasian continental plates, is marked by its extensive geographic extent and high average elevation. It acts as a huge heat source that induces monsoon development and modulates global atmospheric circulation patterns. Under the current context of continuous global warming, this thermal forcing significantly contributes to the formation and persistence of extreme heatwave events in downstream regions, particularly in Europe and North America during summer. To mitigate this effect, we propose the deployment of large-scale photovoltaic arrays across the plateau, which generates four coordinated benefits:

a. Utility-scale renewable energy production,

b. Additional large-scale agricultural output,

c. Increased carbon sequestration capacity, and

d. Elevation of regional surface albedo.

Consequently, a larger proportion of incident solar radiation is directly reflected back to outer space at the plateau's average elevation of 4,000 meters above sea level, where the impact on tropospheric thermal conditions is the most pronounced. At the same time, the shaded microclimate formed under elevated photovoltaic panels provides appropriate growth environments for herbaceous vegetation on the plateau's sparsely vegetated land largely due to much water provided for cleaning the solar panels, generating substantial additional agricultural output. More importantly, this vegetation promotes the sequestration of large volumes of atmospheric CO_2 via accelerated deep silicate weathering on the tectonic-active Tibetan regions. This process is driven by the combined action of physiologically active plant roots and active tectonics associated with the ongoing Indo-Eurasian continental collision (Figure 1). As a result, the subsurface fractured silicate minerals beneath the photovoltaic panels are rapidly converted into stable carbonate and clay minerals,

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consuming tremendous amounts of atmospheric CO_2 (Figure 2). A representative stoichiometric reaction for this process is:

$CaAl_2Si_2O_8$ (anorthite) + $3H_2O$ + $2CO_2$ → $CaCO_3$ (calcite) + $Al_2Si_2O_5(OH)_4$ (kaolinite)+ CH_2O (organic matter) + O_2.

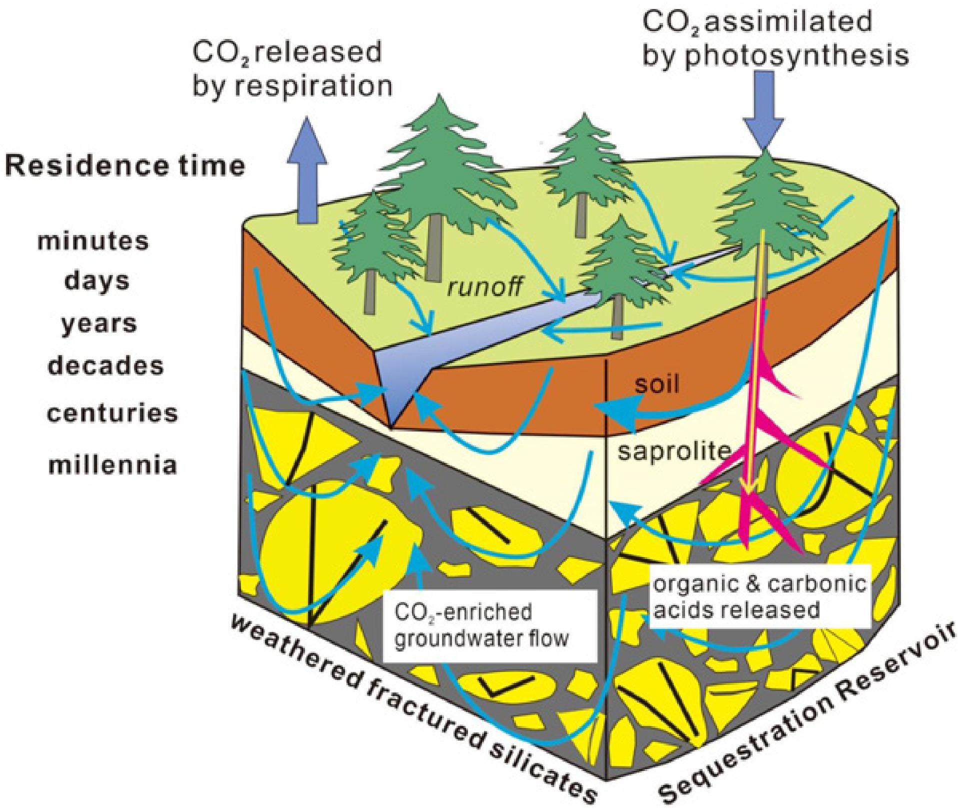

Figure 1: A schematic diagram illustrating the enhancement of deep silicate weathering driven by the coupling between physiologically active plant roots and deeply fractured silicate minerals formed by sustained continental collision between the Indian and Eurasian plates. This weathering process occurs via acid-promoted silicate decomposition within fine-grained, three-dimensional deep reactive environments. As plant roots grow vertically downward, they locally increase the concentrations of organic acids (including oxalate and citrate) and inorganic acids (including carbonic acid), which triggers the decomposition of deeply fractured silicate minerals. Active tectonic activity further increases the fracture density, aperture, and hydraulic connectivity of these silicate minerals.

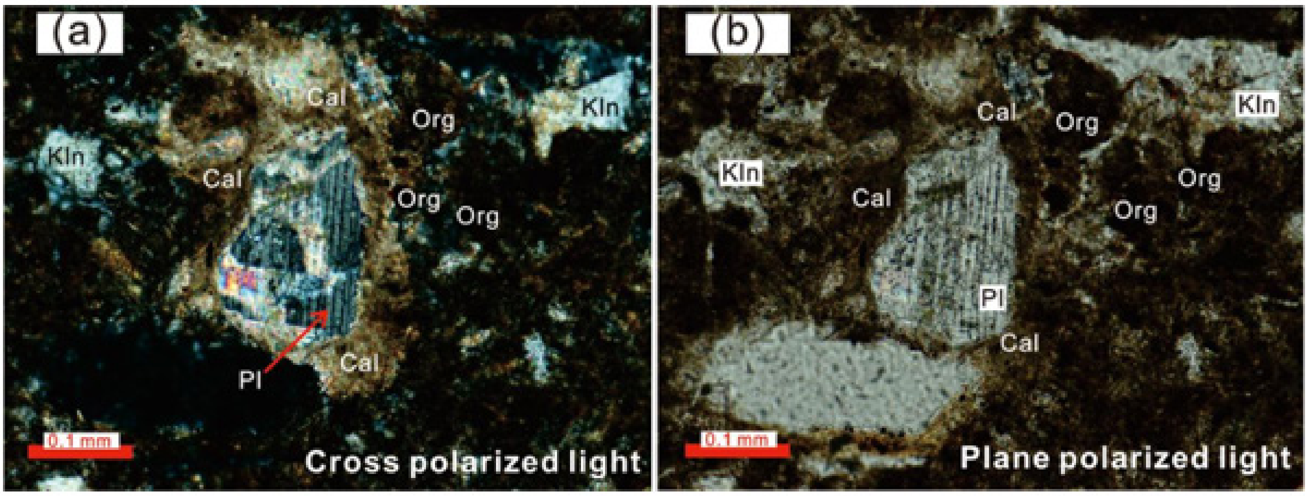

Figure 2: Photomicrographs demonstrate that fractured plagioclase (Pl) has undergone partial alteration to form calcite (Cal) and kaolinite (Kln), with concomitant occurrence of organic matter (Org). This alteration is induced by the coupling effect between physiologically active plant roots and active tectonic processes.

Through the integrated geophysical and biogeochemical effects of albedo regulation and enhanced carbon sequestration, the anomalous thermal output of the Tibetan Plateau heat source will be significantly reduced. This reduction directly weakens a core driving factor of continental heatwaves, thereby substantially decreasing the frequency and intensity of these extreme meteorological events. As an auxiliary engineering method, this framework addresses point-source CO_2 emissions through further integration of established research on the coupling interaction between physiologically active root systems and the aforementioned active tectonic processes. When industrial CO_2, or concentrated CO_2 captured directly from the atmosphere, is injected into a closed, transparent engineered system configured as a water-filled bioreactor charged with mechanically pulverized silicate minerals (Figure 3), the gas undergoes rapid conversion. This process produces two final products: stable subsurface carbonate minerals that enable long-term CO_2 storage, and incrementally large-scale agricultural output. The conversion is propelled by the coupling interaction between C3 plant photosynthesis and accelerated subsurface silicate weathering (Figure 3), both of which are amplified under the system's optimized and controlled operational parameters. By directly extracting CO_2 from industrial emission streams, this method generates both additional environmental and economic gains, and realizes the complete carbon capture and utilization cycle.

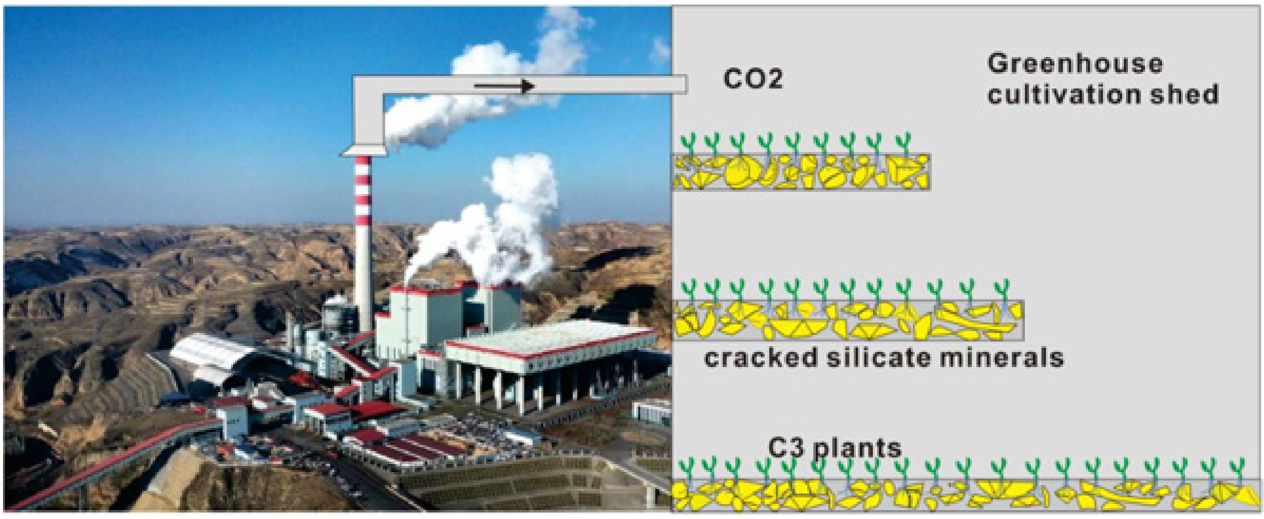

Figure 3: A sketch map showing the process wherein CO_2 originating from point-source carbon emissions is delivered into a closed transparent engineered system containing mechanically crushed silicate minerals, C3 plants and water. Within this system, the gaseous CO_2 is largely converted into stable carbonate minerals stored in the subsurface, along with large-volume agricultural products.