Climate & Earth Systems | Dec 14, 2025 | 7 min read | By Bryan White

The Abyssal Carbon Sponge: How the Ocean Floor Protects the Planet

Environment * Climate Change * Conservation

Introduction: The Missing Sink in the Geological Carbon Cycle

Earth's long-term habitability depends on the geological carbon cycle, which balances mantle degassing of carbon dioxide (CO2) against mineral sequestration to prevent a runaway greenhouse effect.[1] For decades, geochemists attributed the primary removal of this greenhouse gas to continental silicate weathering, which flushes calcium and bicarbonate ions into the oceans to precipitate as limestone. Yet global carbon budget models persistently revealed a discrepancy between volcanic CO2 inputs (~0.08-0.1 GtC/yr) and known weathering outputs.[1][2]

In late 2025, an international team led by Rosalind Coggon at the University of Southampton published a landmark Nature Geoscience study from the International Ocean Discovery Program (IODP) South Atlantic Transect that resolves this missing sink.[3][4] Drilling into 61-million-year-old crust on the Mid-Atlantic Ridge flank, the researchers discovered that porous piles of fault-shattered volcanic rubble -- talus breccia -- sequester 2 to 40 times more CO2 per unit volume than standard intact seafloor basalts, acting as a planetary carbon sponge with major implications for paleoclimate evolution, engineered carbon storage, and climate change policy.[3][5][6]

Mid-Ocean Ridge Tectonics and the Genesis of Talus Breccia

Stretching over 60,000 kilometers, the global mid-ocean ridge system generates new oceanic lithosphere through divergent plate tectonics, yet crustal architecture varies sharply with spreading rate.[7] While fast-spreading centers like the East Pacific Rise (>80 mm/yr) receive continuous magma supply and form smooth lava plains, slow-spreading ridges such as the Mid-Atlantic Ridge (20-55 mm/yr) are magma-starved and dominated by mechanical extension.[3]

| Ridge Regime | | Full Spreading Rate | | Representative System | | Axial Morphology & Faulting | | Talus Breccia & Carbon Sink Capacity |

| Fast-Spreading | | >80 mm/yr | | East Pacific Rise | | Smooth axial dome; continuous sheet/pillow lavas | | Low breccia volume; low bulk CO2 uptake (~0.02 GtC/yr baseline) |

| Intermediate | | 55-80 mm/yr | | Juan de Fuca Ridge | | Transitional relief; cyclic magma chambers | | Moderate faulting and localized talus wedges |

| Slow-Spreading | | 20-55 mm/yr | | Mid-Atlantic Ridge | | Deep rift valley (1-2 km); steep normal fault scarps | | High talus breccia volume; 2-40x CO2 sequestration density |

| Ultra-Slow | | <20 mm/yr | | Gakkel & SW Indian Ridges | | Extreme tectonic relief; detachment faults | | Extensive tectonic rubble and serpentinite/carbonate

alteration |

In submarine geology, as normal faults tear the slow-spreading rift valley apart, 1- to 2-kilometer-high basaltic fault scarps repeatedly collapse during seismic mass-wasting events, shedding angular boulders and cobbles into massive wedge-shaped aprons of talus breccia.[3][6] Unlike massive lava flows with low interior permeability, these rubble piles possess immense open pore space and stay permeable for tens of millions of years as they are rafted off-axis and buried beneath pelagic sediment.[3][5]

IODP Site U1557 and the Geochemistry of Mineral Carbonation

During IODP Expeditions 390 and 393 aboard the drillship JOIDES Resolution, scientists cored a crustal aging transect at ~31 deg S across 7- to 61-million-year-old Mid-Atlantic Ridge crust, probing hydrothermal circulation, the deep microbial biosphere, and carbon uptake.[8][9] At Site U1557 (61 Ma Paleocene crust), drilling beneath 560 meters of sediment recovered basement cores of dark basaltic talus fragments thoroughly cemented by brilliant white calcium carbonate.[8][10]

Driven by chemical thermodynamics, anhydrous mantle silicates -- plagioclase ($CaAl_2Si_2O_8$), pyroxene, and olivine -- are unstable when exposed to cold (2-4 deg C) oxygenated seawater containing Dissolved Inorganic Carbon (DIC).[11] As seawater percolates through the fractured rubble, silicate dissolution consumes protons (H^+), elevates fluid pH, and liberates Ca^{2+} and Mg^{2+} cations, precipitating secondary clays (saponite), microporous zeolites, and abundant calcite/aragonite ($CaCO_3$) within the low-temperature (10-60 deg C) off-axis window.[12][13]

Because shattered breccia provides orders-of-magnitude greater Reactive Surface Area (RSA) than intact lava flows, Site U1557 breccia cores locked away 2 to 40 times more CO_2 per unit volume.[3][5] Furthermore, isotopic fingerprinting confirmed the marine provenance of the carbon: carbonate cements yielded Paleocene seawater strontium ratios ($^{87}Sr/^{86}Sr \sim 0.7078$ vs. mantle ~0.7028) and marine DIC carbon isotope values ($\delta^{13}C \sim 0$ vs. mantle 5 to 7), proving that the rubble directly scrubs oceanic and atmospheric carbon.[3][14]

Global Extrapolation, Cenozoic Cooling, and Deep-Sea Mining Risks

Integrating core measurements with seismic reflection profiles across the global ridge network -- where slow-spreading centers comprise 50-60% of total ridge length and tectonic faulting accommodates >10-20% of plate separation -- Coggon et al. demonstrated that talus breccias can sequester a CO_2 flux comparable to a large fraction of the magmatic CO_2 degassed during crustal accretion.[3][6] Alongside continental silicate weathering, the expansion of slow-spreading Atlantic and Indian Ocean ridges during the Cenozoic Era likely accelerated seafloor carbonation, contributing to Earth's transition from the Early Eocene hothouse to the Oligocene icehouse.[3][14]

For engineered Carbon Dioxide Removal (CDR) initiatives such as CarbFix and Solid Carbon, the U1557 cores provide natural proof-of-concept that sub-seafloor basaltic breccias possess the permeability, pore volume, and 60-million-year mineral stability required to store hundreds of gigatons of injected CO_2.[15][16]

Conversely, these findings highlight an acute environmental risk from commercial Deep-Sea Mining (DSM) targeting cobalt-rich ferromanganese crusts on ridge flanks and seamounts.[17][18] Because ferromanganese crusts accrete directly atop talus breccia substrates, strip-mining and sediment plumes risk crushing pore networks, suffocating fluid circulation, and destroying fragile benthic coral and sponge communities.[19]

Conclusion: Protecting the Breathing Seafloor

The discovery of the abyssal talus breccia carbon sponge at IODP Site U1557 transforms our view of the oceanic crust from an inert volcanic floor into a self-regulating geochemical filter.[3][4] By converting fault-shattered basalt rubble into permanent carbonate stone over tens of millions of years, slow-spreading mid-ocean ridges provide both a foundational stabilizer of Earth's past climate and a natural blueprint for durable carbon sequestration -- provided humanity safeguards these deep-sea formations from industrial disruption.[3][19]

Works Cited

* Gerlach, T. (Jun 14, 2011). Volcanic versus anthropogenic carbon dioxide. Eos, Transactions American Geophysical Union, 92(24), 201-202. https://doi.org/10.1029/2011EO240001

* Potsdam Institute for Climate Impact Research (PIK) (2025). Land and ocean carbon sinks weakening, and other new insights from climate science. https://www.pik-potsdam.de/en/news/latest-news/land-and-ocean-carbon-sinks-weakening-and-other-new-insights-from-climate-scie

* Coggon, R. M., Carter, E. J., Grant, L. J. C., et al. (Nov 24, 2025). A geological carbon cycle sink hosted by ocean crust talus breccias. Nature Geoscience, 18, 1280-1286. https://doi.org/10.1038/s41561-025-01839-5

* University of Southampton (Nov 25, 2025). Ancient rocks reveal themselves as 'carbon sponges'. https://www.southampton.ac.uk/news/2025/11/ancient-rocks-reveal-themselves-as-carbon-sponges.page

* ScienceDaily (Dec 11, 2025). Scientists find a massive hidden CO2 sponge beneath the ocean floor. https://www.sciencedaily.com/releases/2025/12/251211100631.htm

* Springer Nature Research Communities (Nov 24, 2025). How we discovered a giant geological sponge for carbon in rocks deep below the seafloor. https://communities.springernature.com/posts/how-we-discovered-a-giant-geological-sponge-for-co2-in-rocks-deep-below-the-seaflo

* Le Voyer, M., Hauri, E. H., Cottrell, E., Kelley, K. A., Salters, V. J. M., Langmuir, C. H., Hilton, D. R., Barry, P. H., & F ri, E. (Mar 2019). Carbon Fluxes and Primary Magma CO2 Contents Along the Global Mid-Ocean Ridge System. Geochemistry, Geophysics, Geosystems, 20(3), 1387-1424. https://doi.org/10.1029/2018GC007630

* Coggon, R. M., Sylvan, J. B., Estes, E. R., Teagle, D. A. H., et al. (Jan 23, 2024). Site U1557. Proceedings of the International Ocean Discovery Program, 390/393. https://doi.org/10.14379/iodp.proc.390393.105.2024

* Coggon, R. M., Teagle, D. A. H., Sylvan, J. B., et al. (Jan 23, 2024). Expedition 390/393 summary. Proceedings of the International Ocean Discovery Program, 390/393.

https://doi.org/10.14379/iodp.proc.390393.101.2024

* Phys.org (Nov 2025). Ancient seafloor lava rubble stores vast amounts of carbon dioxide, researchers discover. https://phys.org/visualstories/2025-11-ancient-seafloor-lava-rubble-vast.amp

* Picazo, S., Malvoisin, B., Baumgartner, L., et al. (Feb 18, 2020). Low Temperature Serpentinite Replacement by Carbonates during Seawater Influx in the Newfoundland Margin. Minerals, 10(2), 184. https://doi.org/10.3390/min10020184

* Alt, J. C., & Teagle, D. A. H. (May 1999). The uptake of carbon during alteration of ocean crust. Geochimica et Cosmochimica Acta, 63(10), 1527-1535. https://doi.org/10.1016/S0016-7037(99)00123-4

* Seyfried, W. E., Jr., & Bischoff, J. L. (1979). Low temperature basalt alteration by sea water: an experimental study at 70 deg C and 150 deg C. U.S. Geological Survey / Geochimica et Cosmochimica Acta. https://pubs.usgs.gov/publication/70012505

* Borrelli, C., Lowery, C. M., et al. (May 2, 2024). Data report: early Eocene-early Oligocene carbon and oxygen stable isotope data of bulk carbonates, IODP Expedition 390/393 Sites U1557 and U1558. Proceedings of the International Ocean Discovery Program, 390/393. https://doi.org/10.14379/iodp.proc.390393.208.2024

* University of Victoria (Sep 8, 2021). Ocean basalt may store gigatons of CO2. https://uvic.ca/news/topics/2021+co2-ocean-basalt+media-release

* Goldberg, D. S., Takahashi, T., & Slagle, A. L. (Jul 22, 2008). Carbon dioxide sequestration in deep-sea basalt. Proceedings of the National Academy of Sciences, 105(29), 9920-9925. https://doi.org/10.1073/pnas.0804397105

* Zawadzki, D., Maci g, ., Abramowski, T., et al. (Apr 26, 2022). Geochemistry and Mineralogy of Ferromanganese Crusts from the Western Cocos-Nazca Spreading Centre, Pacific. Minerals, 12(5), 538. https://doi.org/10.3390/min12050538

* Jauhari, P. / International Seabed Authority (ISA) (Dec 2022). Marine Mineral Resources of the AREA (with an emphasis on the Mid-Atlantic Ridge and south Indian Ridge). https://www.isa.org.jm/wp-content/uploads/2022/12/Jauhari.pdf

* Radziejewska, T., B a ewicz, M., W odarska-Kowalczuk, M., et al. (Oct 26, 2022). Benthic biology in the Polish exploration contract area of the Mid-Atlantic Ridge: The knowns and the unknowns. A review. Frontiers in Marine Science, 9, 898828. https://doi.org/10.3389/fmars.2022.898828