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Permit Application for Scientific Research

Leading Institution: Project Vesta
Permit Type: Scientific Research
Thematic Areas: Climate Change, Carbon Sequestration, Ocean Acidification, Coral Reef Ecology

Title: Quantifying the effects and rates of beach enrichment using olivine weathering for climate change mitigation.

Abstract

Given current trajectories of emissions and political will, the Intergovernmental Panel on Climate Change (IPCC) has stated that it is no longer enough to simply reduce carbon dioxide emissions to avoid catastrophic effects of climate change to life on Earth. Carbon dioxide removal methods will be necessary and will need to be employed on large scales, and the IPCC estimates that humans must remove hundreds of gigatons of carbon dioxide by the end of the 21st century. Coastal Enhanced Weathering (CEW) refers to a natural geochemical process wherein silicate minerals like the mineral olivine consume protons as they weather and dissolve, sequestering carbon dioxide into the aqueous medium where they are placed. Coastal processes, such as wave action and biological activity, are expected to accelerate the dissolution rate of this process, and therefore the carbon sequestration rate. There is currently a strong proof-of-principle for this mechanism in modeling, laboratory and mesocosm studies. However, this approach cannot be employed as a means to combat climate change without a rigorous, multi-scale, multi-disciplinary research program that assesses the positive and negative effects of coastal enhanced weathering with olivine. The proposed research program comprises two phases, with the overarching aim to assess coastal enhanced weathering of olivine in the real world at a variety of scales, from a variety of perspectives. In Phase 1, we propose to gain a comprehensive, high resolution environmental assessment about the study sites as the ‘Before’ and ‘Control’ portion of the ‘Before After Control Impact’ study design; the best practice approach to environmental impact assessment. In Phase 2, we propose to apply olivine to the treatment beach, and conduct a comprehensive assessment of the effects of olivine weathering. This permit application refers exclusively to Phase 1 research. This research is of international urgency and significance for humanity’s efforts to slow the harmful effects of climate change on the planet.

PROJECT OVERVIEW

General Project Background

To avoid the worst effects of climate change, we must remove billions of tons of carbon dioxide (CO_2) from the atmosphere, starting as soon as possible (IPCC, 2019). There are currently no proven methods for doing so. There is an incalculably large benefit to humanity in identifying a carbon dioxide removal (CDR) method that is scalable, economical, and permanent. Project Vesta's vision is to help reverse climate change by turning a trillion tons of CO_2 into rock. Coastal Enhanced Weathering (CEW) can do this by harnessing the power of wave energy to accelerate the natural process of rock weathering, which has captured CO_2 on earth for billions of years (see Hartmann et al., 2013; Kelemen et al., 2020; Montserrat et al., 2017).

It is possible to accelerate the Earth's natural carbon removal method of rock weathering, by extracting the volcanic mineral olivine, grinding it into sand, and transporting it to coastlines. There, wave energy causes the olivine particles to collide, grind down and dissolve, and dramatically increases the rate of weathering. Carbon dioxide is removed from the atmosphere as the olivine breaks down. In the earth's natural long-term carbonate-silicate cycle, rain falling on exposed volcanic rock causes it to weather, which removes CO_2 from the atmosphere as bicarbonate dissolved in water (Hangx et al., 2009; Hartmann et al., 2013; Montserrat et al., 2017). This water flows to the oceans, where marine calcifying organisms incorporate the CO_2 into their shells and skeletons. When they die, they form ocean sediment, ultimately becoming limestone. This is how our planet has naturally captured the CO_2 emitted by volcanoes over geological time. As a result, the vast majority of the carbon on our planet is locked up in rock. Along with the carbon removal benefit, CEW de-acidifies the water, which may benefit local marine ecosystems (Bach et al., 2019).

Project Vesta is a 501(c)(3) non-profit organization whose mission is to advance the science of coastal enhanced weathering to galvanize global deployment. This means carrying out the necessary research and creating the protocols and tools needed to establish it as a mature methodology for permanent, cheap, and scalable CDR. If we can do this, we can deliver to the planet a carbon dioxide removal method that captures 50% of annual human emissions every year, using an area consisting of 1% of global shelf seas (0.0016% of the total area of the oceans). This could cost as little as $200B per year, which is a small fraction of the cost of other permanent methods of CDR. We believe that cost-effective, gigaton or greater scale CDR using CEW is possible within a decade, which is the timeframe laid out by the IPCC for taking action at this scale.

General Study Introduction

As introduced above, one of the most promising approaches to climate change mitigation is enhancing the natural weathering process of volcanic silicates by placing these on beaches where the minerals can be exposed to higher energy than where they naturally occur (Montserrat et al., 2017). Our long-term, multi-phase study aims to generate a comprehensive assessment of the carbon dioxide removal process, and in order to study these parameters in a rigorous way, we must study the basic environmental conditions of our study sites as they are. The whole project aims to study the effects of olivine in a field setting. Existing studies have investigated olivine in natural green sand beaches, and in laboratory and small-scale studies. A field experiment is the next step to determine whether coastal enhanced weathering of olivine is a viable option for climate change mitigation. The study will continue the existing large body of research on olivine weathering, and will perform essential toxicology studies in a lab, followed by a rigorous impact assessment of experimental olivine in the field during Phase 2.

This proposal refers to Phase 1 of research. Each of the two phases will have separate proposals.

Phase 1: Baseline environmental assessment
Phase 2: Environmental assessment after the application of olivine to the treatment beach

In Phase 1, we propose to sample the local environment at two beaches that will act as control and treatment sites for Phase 2, in order to understand the natural conditions and variability there. There will be no experiments or application of material to the sites as part of Phase 1 research.

PHASE 1 TECHNICAL STUDY

Technical Background

Enhanced silicate weathering (ESW) uses sand particle-sized silicate minerals that increase the reactive surface area, spread out over a large area either on land or at sea, to accelerate a chemical reaction that removes carbon dioxide from the atmosphere via the weathering process (Hartmann et al., 2013; Kelemen et al., 2020; Montserrat et al., 2017). Olivine weathering consumes protons from the aqueous environment, thereby increasing alkalinity and increasing the CO_2 uptake capacity of the medium (at pH 4.5 and higher), and thus facilitating CO_2 removal from the atmosphere (Montserrat et al., 2017).

Coastal Enhanced Weathering (CEW) refers specifically to ESW in coastal ocean environments (beaches to continental shelves), to accelerate the weathering rates of silicate minerals like olivine. Olivine is the fastest-weathering silicate mineral, typical of ultramafic rocks. Coastal environments are a favorable site for enhanced weathering by providing geochemical and environmental benefits. The continuous movement of waves and currents will cause mechanical impacts between particles that break them down to smaller particle sizes. In turn, smaller particles, because of their larger surface-to-volume ratio, will weather faster. Additionally, biotic effects, such as the processing of sediment material by benthic macrofauna called bioturbation, and microbial respiration producing elevated CO_2 concentrations in sediment porewater also called metabolic dissolution, are expected to enhance the weathering rate in coastal environments (Montserrat et al., 2017).

That coastal ocean water is always well-mixed by wind and waves causes it to be in chemical equilibrium with the atmosphere. That is, the partial CO_2 pressure (p CO_2) in the air is the same as that in the surface waters of the coastal ocean. Whenever CO_2 is "consumed" in the surface waters, the air-water mixing facilitates CO_2 invasion into the water phase. When olivine dissolution consumes CO_2 in the seawater, the p CO_2 in the seawater becomes lower than that of the air. The mixing processes of wind and waves causes the CO_2 to enter the seawater, thereby re-establishing the p CO_2 equilibrium between air and water.

Coastal environments are ideal for ESW, because of the physical, chemical and biological effects on the weathering process, and also because of the almost immediate effect it will have on atmospheric CO_2. However, until now, a field trial has not been undertaken to assess ESW in a natural coastal setting, and the effects need to be investigated.

Olivine dissolution will cause chemical effects in the aqueous medium in which the weathering takes place. The ecosystem impacts of coastal ESW are poorly understood at present, and therefore, a thorough evaluation is crucial to gain societal acceptance (Meysman and Montserrat, 2017). Insights can be gained by analogy with other impacts (e.g. selective Si fertilization of coastal ecosystems by glacial meltwater). However, marine ecosystem functioning is a complex process, and the ecosystem impacts will depend on the scale of olivine application, the local olivine dissolution rate, the characteristics of the coastal water body (e.g. residence time) and the biota present.

Potential Impacts from Study

Phase 1

Phase 1 of the proposed study involves some minimally invasive methods of sample collection that will have a very small and very localized impact on the site of extraction from the actual removal of materials.

Phase 2

Phase 2 involves the experimental application of olivine to the beach area, and has the potential for greater impacts. These will be described in greater detail in the permit application for Phase 2, but the following is a summary of expected chemical effects:

1. Ocean alkalinization: The process of olivine dissolution consumes hydrogen ions or protons from the aqueous medium, following the stoichiometric formula in eq. 1

$$(Mg,Fe)_2SiO_4 + 4H^+ \rightarrow 2(Mg,Fe)^{2+} + H_4SiO_4 \quad \textbf{[Eq. 1]}$$

By consuming protons (H+) from the aqueous environment, the excess of protons is diminished, and thus the alkalinity is increased. The stoichiometry, the ratio with which molecules react with one another in chemical reactions, is one molecule olivine dissolving consuming nominally four protons. The consumption of protons is the same as creation of alkalinity, therefore, per mol olivine dissolved, nominally four mol alkalinity are created.

Following the air-water equilibrium, increasing atmospheric CO_2 concentration (pCO_2) will lead to increased pCO_2 in surface (sea)waters. Dissolving CO_2 in water causes the proton concentration to rise, following eq. 2. As CO_2 dissolves in water (H_2O), it forms carbonic acid (H_2CO_3), which dissociates immediately into bicarbonate (HCO_3^-) and a proton (H^+). The bicarbonate may dissociate further into carbonate and another proton. The free protons from CO_2 dissolving into water cause the acidity to increase (increase [H^+] = decrease pH).

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+ \leftrightarrow CO_3^{2-} + H^+ \quad \textbf{[Eq. 2]}$$

A higher proton concentration means a lower pH. The p in pH stands for the negative natural logarithm, or -ln, so the lower the pH, the higher the H^+ concentration [pH^+] and the stronger the acidity. Concerns about cascading effects of ocean acidification on marine organisms and ecosystems have risen sharply over the past decade. Because the higher the pCO_2 in seawater, the stronger the (seawater) system will tend towards dissolution of minerals, such as calcium carbonate, which is the skeleton material of coral reefs and shellfish. Olivine dissolution increases the alkalinity of seawater (Montserrat et al., 2017) and has the potential to (at least partially) counteract the effect of ocean acidification (Taylor et al., 2015). The exact rate and efficiency of olivine dissolution in the field (in nature) is one of the most important points to be investigated in this pilot project.

2. Fertilization: Olivine is a silicate mineral and thus releases dissolved silicon (DSi) upon dissolution (Eq. 1). Silicon occurs normally in surface seawater in concentration of between 1-10 micromolar (uM), and increases with (great) depth. In surface waters, DSi is usually low, due to biological utilization. Si is an important building block for DSi is a limiting nutrient for diatoms in large parts of the ocean, and functions as a key building block in the skeleton of sponges and other marine organisms.

Diatoms are responsible for a significant portion of the marine primary production and play a key role in the biological carbon pump, which stores CO_2 in the deep sea through export of particulate organic matter. Accordingly, ESW could not only impact the carbon cycle through CO2 sequestration induced by increased alkalinity (see point (1)), but the silicon fertilization effect and stimulation of the biological carbon pump may cause additive effects.

3. Trace metal release: Olivine is a strong candidate in the development of Carbon Dioxide Removal methodologies to combat climate change. However, olivine also contains trace metals, among which Nickel and Chromium. Model simulations have shown that the bio-available portion of trace metals, released from dissolving olivine, do not approach environmentally dangerous levels, but this is yet to be confirmed within an experimental framework. At present, it is unclear what the fate of these trace metals is upon dissolution (Meysman and Montserrat, 2017). Are these trace metals sequestered into the seafloor, or are they released to the seawater? And if they are released, to what levels do they accumulate in the overlying water column, and does this have any (adverse) impacts on the local biota and ecosystem?

Phase 1 Study Objectives

The research project has the following objectives:

1. Develop a high-resolution baseline of environmental conditions at both beaches
2. Determine the natural variation of each parameter that is part of the regular sampling protocol
3. Verify temporal and spatial scale of sampling are appropriate for detecting effects
4. Verify all methods are functional and appropriate for testing the study hypotheses

Technical Study Introduction

The experimental setup of the field pilot study for coastal enhanced weathering of olivine has been designed to exceed best practices for impact assessment and monitoring. The experiment will follow the Before-After-Control-Impact protocol of monitoring, where each parameter is measured prior to and after the treatment, in this case the application of olivine to the beach, at both a control site and the impact site (Smith, 2014).

During Phase 1 sampling, the parameters will be monitored at both study sites with no experimental treatment. The data will be collected via a combination of observation, passive sampling using sensors, and collecting small volumes of seawater and sediments. The procedures for these are described in detail in the 'Materials and Methods' section below.

Baseline Sampling

Prior to the 'Before' phase of the regular sampling protocol, monitoring of all parameters will take place using daily sampling and continuous data loggers to estimate natural variation and identify any time-explicit cycles that could affect the monitoring temporal scale selected. Baseline sampling will be conducted for 7 days, after which the study will proceed as described below.

Phase 1 Sampling

Monitoring of all parameters will be conducted weekly for a minimum of three months prior to the treatment in order to establish the environmental conditions present at the control and treatment sites, and determine if there is significant difference in any parameter between the two sites. Laboratory toxicology studies will be conducted at the same time as the phase 2 field sampling. Phase 3 will not proceed unless toxicology studies verify that olivine does not pose a significant threat to local marine life.

Phase 1 Ecotoxicology Studies

Two separate ecotoxicology studies will be conducted during the Phase 1 sampling: a model organism study program that is based in North America, and local organism tissue analysis described here that will take place in the Dominican Republic. Only the 'local organism' study will utilize resources from the Dominican Republic, and therefore, only the local organism study of the two ecotoxicology studies is included in the permit request.

MATERIALS AND METHODS

Sampling Parameters
Data will be collected on the following parameters, the methods of collection and analysis are described in detail below.

Water Column
Salinity
Temperature
Turbidity
Atmospheric CO_2 (in air)
pH
Dissolved Inorganic Carbon
Total Alkalinity
Oxygen Saturation
Photosynthetic Pigments
Total Suspended Solids
Dissolved Abundant Metals
Dissolved Trace Metals
Nutrients

Sediment
Organic Matter
Solid Calcium
Mineral Composition
Particle analysis - physical
Particle analysis - chemical
Infauna diversity
Infauna abundance

Sediment Porewater
Salinity
pH
Dissolved Inorganic Carbon
Total Alkalinity
Oxygen Saturation
Photosynthetic Pigments
Total Suspended Solids
Dissolved Abundant Metals
Dissolved Trace Metals
Nutrients

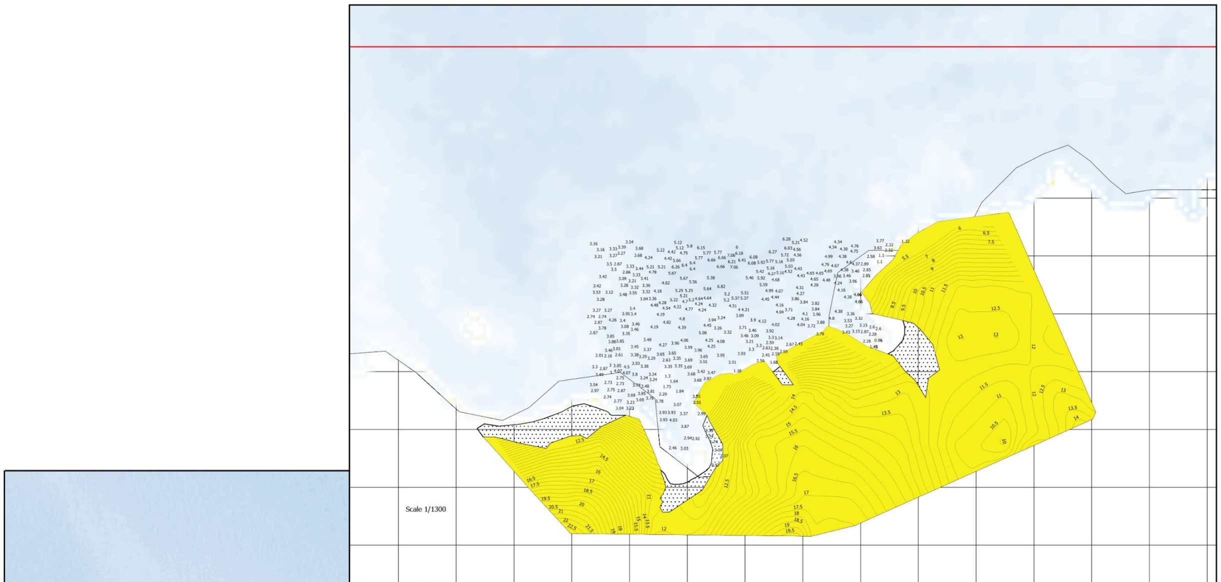
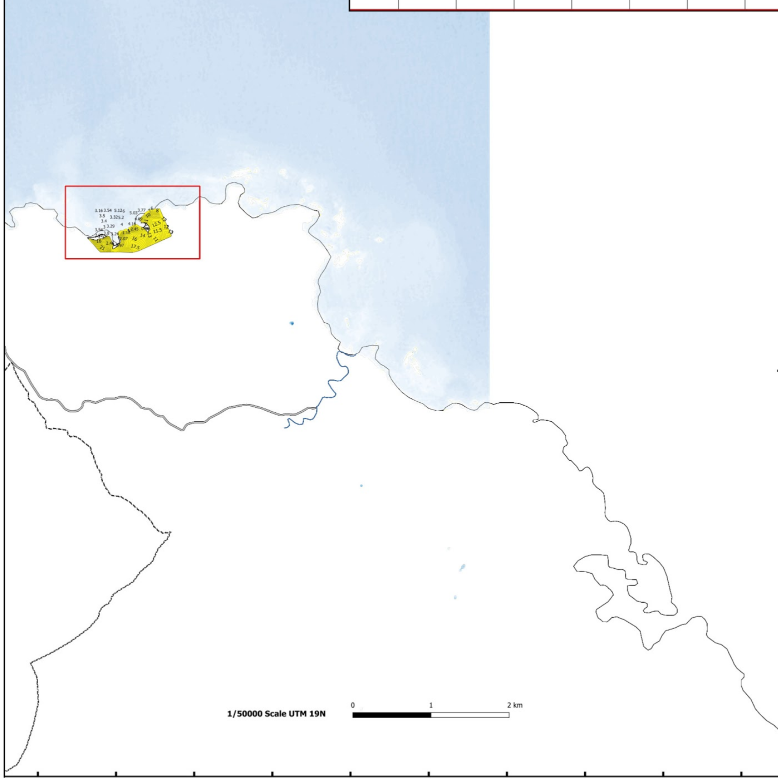
Tissue Toxicology
Marine Flowering Plants

Macroalgae
Microalgae
Macroinvertebrates
Larval invertebrates
Larval fish
Fish

Ecology
Fish diversity
Fish abundance
Fish demography
Macroinvertebrate diversity
Macroinvertebrate abundance
Macroinvertebrate demography
Macroinvertebrate disease/bleaching
Phytoplankton diversity
Phytoplankton abundance
Zooplankton diversity
Zooplankton abundance
Benthic microorganism diversity
Benthic microorganism abundance
Macroalgae diversity
Macroalgae abundance
Seagrass Abundance
Benthic Composition
Mangrove Abundance
Mangrove Demography
Remote Sensing Landscape Analysis

Geographic Location
The two proposed study sites are located on the North Coast of the Puerto Plata area of the Dominican Republic at the following beaches.

Playa Viejo Oscar; lat/long 19.9011037,-70.8645385 [control beach]
Playa Cala Madiana; lat/long 19.9011037,-70.8645385 [treatment beach]

WGS 84 / UTM zone 19N

WKT

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Proj4

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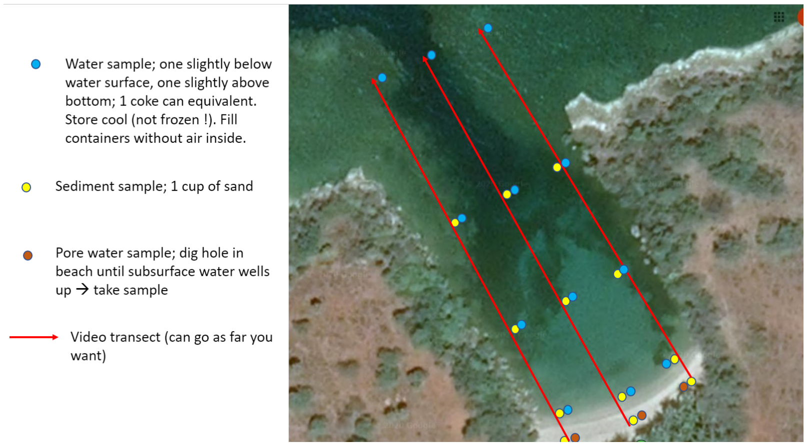
Extent

-72.00, 0.00, -66.00, 84.00

The coves are situated approximately 500m apart and are similar in geomorphology, ecology, and environmental conditions. Sampling will be conducted in a 3x4 grid array according to the following diagram:



Sampling Regime
For all parameters except ecotoxicology:
Two beaches
9 sites per beach
3 heights in the water column per site
Daily sample total: 36

Each 36 sample set will be collected daily for 7 days, then weekly for 3 months, then monthly for 3 months. The total duration of the Phase 1 study will be 6 months.

Equipment List
Microscope
Flow Injection Analyzer
Inductively Coupled Plasma Mass Spectrometer (ICPMS)
Spectrophotometer
High Performance Liquid Chromatography (HPLC)
Dissolved Oxygen (DO) meter
Digital Titrator
pH Meter
Carbon Coulometer
Underwater Camera
Sediment Cores (10cm)
Atmospheric CO2 Monitor
Conductivity Temperature and Depth (CTD) plus pH Sensor and Data Logger
Particle Analyzer
X-Ray Diffraction Analyzer

Observational data will be collected by scuba divers, who will record information on a handheld dive slate and will capture imagery with cameras that will be analyzed on a computer. The parameters and specific equipment used in their analysis is described below.

Parameters of Interest
The following describes each proposed parameter of interest and the method of sampling that is required to collect the data for each parameter. Most parameters are collected via passive probe, passive observation, or water sample collection.

Some parameters require small sediment cores to be collected, and the tissue toxicology assessment requires specimen collection (three organisms of each organism type for the duration of the study). There are multiple sizes of sediment core that remove a minimal amount of sediment from the substrate: a 1cm diameter (8 cm cubed) core and a 10cm diameter (8000 cm cubed volume) core. Organism collection will be conducted at the bare minimum to assess latent tissue toxicology in local organisms, and all animals will be humanely euthanized immediately after collection.

Water Column
Salinity: handheld sensor; *in situ*
Temperature: handheld sensor; *in situ*
Turbidity: handheld sensor; *in situ*
Atmospheric CO2 (in air): handheld sensor; *in situ*
pH: handheld sensor; *in situ*

Bottle 1 500mL – all analytes derived from shared source material
Dissolved Inorganic Carbon: 500mL water sample; analysis by carbon coulometer; lab
Total Alkalinity: 500mL water sample; analysis by digital titration and pH meter; lab
Oxygen Saturation: 500mL water sample; analysis by DO meter; lab

Bottle 2 500mL – all analytes derived from shared source material
Photosynthetic Pigments: 500mL water sample; analysis by HPLC; lab
Total Suspended Solids: 500mL water sample; analysis by spectrophotometer; lab
Nutrients: 500mL water sample; analysis by Flow Injection Analyzer;

Bottle 3 500mL – all analytes derived from shared source material
Dissolved Abundant Metals: 500mL water sample; analysis by ICPMS; lab
Dissolved Trace Metals: 500mL water sample; analysis by ICPMS; lab
lab

Sediment – three 10cm sediment cores per location, all analytes derived from shared source material
Organic Matter: 10cm core sediment sample; analysis by HPLC; lab
Solid Calcium: 10cm core sediment sample; analysis by ICPMS; lab
Mineral Composition: 10cm core sediment sample; analysis by XRD; lab

Particle analysis – physical: 10cm core sediment sample, analysis by particle analyzer; lab
Particle analysis – chemical: 10cm core sediment sample; analysis by ICPMS; lab
Infauna diversity: 10cm core sediment sample; analysis by microscope; lab
Infauna abundance: 10cm core sediment sample; analysis by microscope; lab

Sediment Porewater - three sediment cores per location, all analytes derived from shared source material.
Salinity: 10cm core sediment sample; analysis by handheld sensor; lab
pH: 10cm core sediment sample; analysis by handheld sensor; lab
Dissolved Inorganic Carbon: 10cm core sediment sample; analysis by carbon coulometer; lab
Total Alkalinity: 10cm core sediment sample; analysis by digital titration and pH meter; lab
Oxygen Saturation: 10cm core sediment sample; analysis by DO meter; lab
Photosynthetic Pigments: 10cm core sediment sample; analysis by HPLC; lab
Total Suspended Solids: 10cm core sediment sample; analysis by spectrophotometer; lab
Dissolved Abundant Metals: 10cm core sediment sample; analysis by ICPMS; lab
Dissolved Trace Metals: 10cm core sediment sample; analysis by ICPMS; lab
Nutrients: 10cm core sediment sample; analysis by Flow Injection Analyzer; lab

Tissue Toxicology
Marine Flowering Plants
Macroalgae
Microalgae
Macroinvertebrates
Larval invertebrates
Larval fish
Fish

Ecology - microorganism/phytoplankton/zooplankton data derived from one collection bottle

Fish diversity: observation; analysis by observation and imagery; *in situ*
Fish abundance: observation; analysis by observation and imagery; *in situ*
Fish demography: observation; analysis by observation and imagery; *in situ*
Macroinvertebrate diversity: observation; analysis by observation and imagery; *in situ*
Macroinvertebrate abundance: observation; analysis by observation and imagery; *in situ*
Macroinvertebrate demography: observation; analysis by observation and imagery; *in situ*
Macroinvertebrate disease/bleaching: observation; analysis by observation and imagery; *in situ*
Macroalgae diversity: observation; analysis by observation and imagery; *in situ*
Macroalgae abundance: observation; analysis by observation and imagery; *in situ*
Seagrass Abundance: observation; analysis by observation and imagery; *in situ*
Benthic Composition: observation; analysis by observation and imagery; *in situ*
Mangrove Abundance: observation; analysis by observation and imagery; *in situ*
Mangrove Demography: observation; analysis by observation and imagery; *in situ*
Remote Sensing Landscape Analysis: imagery; analysis by imagery; *in situ*

Phytoplankton diversity: observation; analysis by observation and imagery; *in situ*
Phytoplankton abundance: 500mL water sample; analysis by microscope; lab
Zooplankton diversity: 500mL water sample; analysis by microscope; lab
Zooplankton abundance: 500mL water sample; analysis by microscope; lab
Benthic microorganism diversity: 500mL water sample; analysis by microscope; lab
Benthic microorganism abundance: 500mL water sample; analysis by microscope; lab

Live organism handling
Different organism types will be collected using the minimum possible number of individuals to assess the potential harmful impacts to a diversity of body plans and physiologies represented in local waters. No organisms with vulnerable populations, or that are threatened or endangered according to any local or global jurisdiction will be collected for use in this study.

The ecotoxicology studies will be conducted---- in a controlled aquarium facility with closed circulation. For microscopic organisms, three 150mL water samples will be collected, transferred into 1 litre bottles of fresh saltwater to reduce predator-prey interactions, and monospecific cultures will be grown in the lab to produce a large number of individuals to use to test for development, functional health, and longevity. Three of the most abundant and two of the least abundant microscopic organisms from each group (microorganisms, zooplankton, and phytoplankton) will be selected for culturing. All organisms will be humanely euthanized at the end of the study.

For macroscopic organisms, three individuals of each representative taxa will be collected alive, placed in tanks, and subjected to three varying levels of olivine exposure, for a total of 9 individuals per treatment, per taxonomic group. The taxonomic groups of interest are as follows:

Microscopic (100+ individuals per treatment):
Microorganisms
Zooplankton
Phytoplankton

Macroscopic (9 individuals per treatment):
Algae
Sponges
Echinoderms
Cnidarians
Crustaceans
Vertebrate Fishes

The organisms will be observed for a period of one month, after which time they will be humanely euthanized, and their muscle, organ, and reproductive tissues will be analyzed for contamination and reduced function.

Project Timeline
The proposed timeline of key aspects of the study are described as follows. Task items denoted with a double asterisk (**) are essential research questions related to the study but will not be completed in the Dominican Republic.

Project Budget
This project will make a significant financial investment into the Dominican Republic, and is committed to making purchases locally and hiring local employees as much as possible.

Item	**Local or Foreign**	**Amount (USD)**
Facility Rental	Local	75,000
Staff	Local	75,000
Laboratory	Foreign	420,000
Laboratory Maintenance	Local	45,000
Aquarium Facility Construction	Local	10,000
Sampling Equipment Purchases	Foreign	70,000
Educational Events and Materials	Local	5,000
Transportation	Local	22,000
Other miscellaneous costs	Local	55,000
Total		777,000

Outcomes
Completing the proposed research will produce many types of benefits at all scales, from the communities around the proposed study beaches to the planet as a whole. All ecological assessments and raw data from this study will be made publicly available. All efforts will be made to conduct sampling in a similar manner and using comparable methods to other scientific research in the Dominican Republic, so that this work may be used by other scientists and the

government of the Dominican Republic in their own studies and for local environmental decision-making. A final report summarizing the results will be prepared and made publicly available upon completion of this study.

We expect the following outcomes from the proposed work:

Scientific Outcomes

1. This study will produce a comprehensive assessment of natural resources from geologic, chemical, physical and biological perspectives for the two proposed beaches
2. The results from Phase 1 research will inform the scientific team about the natural variability in the environment and organisms of the proposed study beaches
3. The results from Phase 1 research will determine the appropriate scales of observation in space and time for detecting the effects of olivine on the environment
4. The results from Phase 1 ecotoxicology research will determine the potential impacts of olivine application on organisms
5. Upon completion of Phase 1 of the proposed study, all collected data, as well as analyses, reports and models produced during the study will be made publicly available to scientists and resource managers in the Dominican Republic and throughout the world
6. The proposed research will build significant scientific community in the Dominican Republic, with scientist collaborators from around the world coming to Puerto Plata to analyze the data we collect from this study
7. The proposed research will create a scientific foundation from which to rigorously assess the effects of olivine weathering, a topic of international urgency and significance in climate change reversal research

Community Outcomes

1. Approximately 165,000USD spent on local housing, infrastructure, and wages in the Puerto Plata region over the life of the project
2. More job opportunities for scientists and students from the Dominican Republic to work directly on climate change research
3. Opportunities for scientists and student to collaborate with a global network of researchers working on climate change research
4. Potential for an increase in tourism to the area to visit the olivine beaches and research facilities

Scientific Team

Shanee Stopnitzky is the Principal Scientist for Project Vesta and this study. She is a marine ecologist whose past research investigated the simple rules that govern complex ecological systems, in order to predict the ways ecosystems will respond to a changing future. Her work has focused on coral reef ecosystems and integrating multiple time scales to detect how marine organisms deal with climate change in the short- and long-term. Shanee's early research looked at historical carbonate dynamics on coral reefs in the context of various climates. Shanee has worked in a variety of sectors on environmental impact assessment, marine mitigation technology, and ecological forecasting.

Francesc Montserrat is a marine biologist with over 15 years of research into the functional ecology of bottom organisms and their relationship with the environment, focusing on benthic ecosystems. Francesc has focused on experimental marine ecology, including environmental impact studies and marine habitat monitoring projects. He has conducted fieldwork studies on the natural green sand olivine beach in Hawaii (Papakōlea) including sampling corals there. Francesc has published and contributed to numerous papers on olivine weathering in coastal environments and has spent years exploring methodologies to increase natural marine carbon sinks.

Stephen Romaniello is the Gerald D. Sisk Associate Professor of Isotope Geochemistry at the University of Tennessee Knoxville and the Director of the UT ICP-MS and Trace Metal Analysis Laboratory. Dr. Romaniello has published more than 40 peer-reviewed scientific papers in internationally recognized journals including Geology, Science Advances, Nature Geoscience, and the Proceedings of the National Academies of Science of the United States, and conducts research funded by the US National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA). His research specialties include geochemistry, isotope geochemistry, biogeochemistry, oceanography, and climate science.

Pol Knops is an applied physicist with research interests in sustainable energy projects, including a wide variety of approaches to carbon mineralization. Pol is an author on numerous papers related to olivine weathering and is an expert in the field of olivine dissolution kinetics. He is currently the CTO at Green Minerals, where he works to explore industrial and commercial uses for olivine.

Independent Scientific Review Board

An external scientific review board with no relationship to Project Vesta will be assembled by Will Burns, a climate policy researcher and full professor at American University. This group will be comprised of 5-7 prominent scientists with expertise in areas of direct relevance to olivine weathering and its potential impacts. The board will conduct an independent analysis and peer review of the findings and conclusions from the research that is being proposed in order to exceed the best ethical scientific practices for novel research.

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