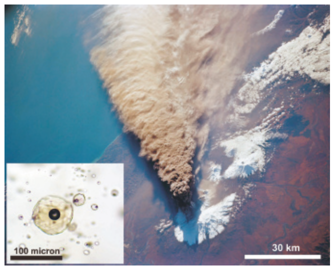
# Fertilising the surface ocean – the role of volcanoes




The oceans are by far the largest global reservoir of carbon that is available on climate relevant timescales (< 1000 yrs). A fraction of this oceanic carbon pool, comparable in magnitude with the $CO_2$ inventory of today's atmosphere, is transformed via biological assimilation of inorganic carbon into dissolved or particulate organic material within the sun-lit surface ocean. Subsequently this material can be respired, returning to the ocean as $CO_2$, or it can sink to the sediments and this forms the basis of the 'biological pump'. The efficiency of this pump is limited by the availability of nutrients, which are essential prerequisites for the growth of phytoplankton. We now know that vast areas of the surface ocean have extremely low nutrient concentrations limiting productivity. For instance, in the subtropical oceanic gyres, which comprise more than 40% of the Earth's surface, the macronutrients nitrate, nitrite, ammonia and phosphate are depleted to trace levels which limit phytoplankton abundance so strongly such that the term "oceanic desert" was coined for these regions.

In other regions such as the Southern Ocean and the equatorial Pacific, iron is the growth-limiting element. Natural and artificial addition of iron to these oceanic areas can cause massive phytoplankton blooms with an enhanced export of carbon. This process of intentional iron addition has been proposed as a mechanism for sequestering anthropogenic carbon emissions from the atmosphere into the deep ocean. Although this idea is still highly controversial it highlights the need to improve our understanding of the role of natural sources of nutrients and in particular iron in the surface ocean in the Earth's history. Aeolian dust has been studied extensively for almost two decades now for its critical role in supplying iron to the ocean, however other forms of atmospheric iron sources are currently poorly studied. The potential of volcanic eruptions for the surface ocean nutrients inventory has only very recently attracted the attention of scientists. This is surprising at first sight since the fertilising potential of volcanic soils has been known for hundreds of years and volcanoes are known to be capable of depositing airborne material as e.g. volcanic ash and pumice (during major volcanic eruptions) into even the remotest oceanic areas. While iron concentrations are at the ultra-trace level in open ocean seawater, it is a major element (up to several percentages) in volcanic material. Interaction of relatively iron-rich volcanic material with ultralow-iron surface ocean water could therefore increase iron concentrations and drive considerable phytoplankton growth.

Previously it was not known how much nor how fast volcanic material may release iron and other nutrients upon contact with seawater. Thus we set out to investigate the following questions: (1) does volcanic material release its nutrients in the upper sun-lit (above 200m depth) ocean where the algae thrive or in the darkness of the sea where they cannot have any influence on phytoplankton growth? (2) Will the nutrient release be sufficient and can phytoplankton use these nutrients, so that significant growth can be fuelled? Or are there any processes inhibiting the utilisation of nutrients released from volcanic material? (3) Is there any natural evidence confirming a causal connection between volcanic

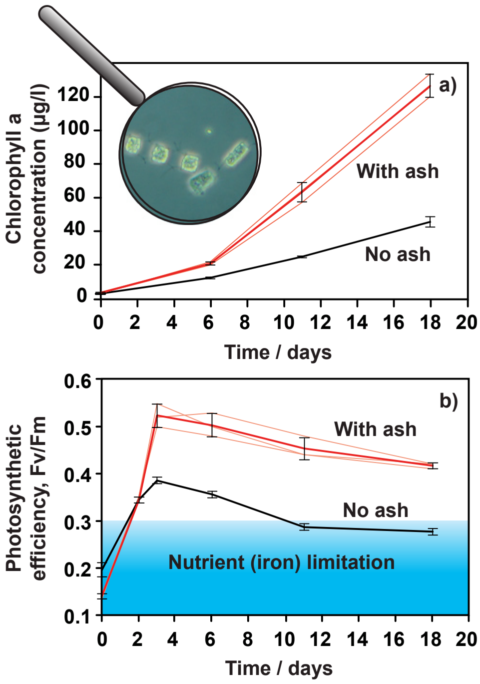



*Fig. 1: Results from bio-incubation experiments in marine biology laboratories with/without volcanic ash and the diatom Chaetoceros dichaeta in natural seawater, showing the increase of (a) chlorophyll a and (b) photosynthetic efficiency through time. Modified rom Duggen et al. (2007) Geophysical Research Letters*

eruptions and enhancement of phytoplankton growth? And what is the relative importance of different types of volcanoes and their products, compared to other natural nutrient sources for the surface ocean? To answer these questions a young researcher group NOVUM (Nutrients Originating in Volcanoes and their effect on the euphotic zone of the Marine ecosystem) was formed in 2007 with funding from IFM-GEOMAR. NOVUM initiated this new research field in marine sciences in Germany and several young researchers from different divisions at IFM-GEOMAR combine their expertise in chemical oceanography, igneous geology, marine biogeochemistry, ocean modelling, marine biology and volcanology in order to find the answers to the aforementioned questions.

In our first paper we focussed on volcanic ash for experiments with natural seawater and phytoplankton. The volcanic ash we used should not have had contact with water after deposition (e.g. rain), because very fresh (or unhydrated) volcanic ash particles are covered by salt coatings (formed during the volcanic eruption) that contain nutrients and are easily soluble in water.

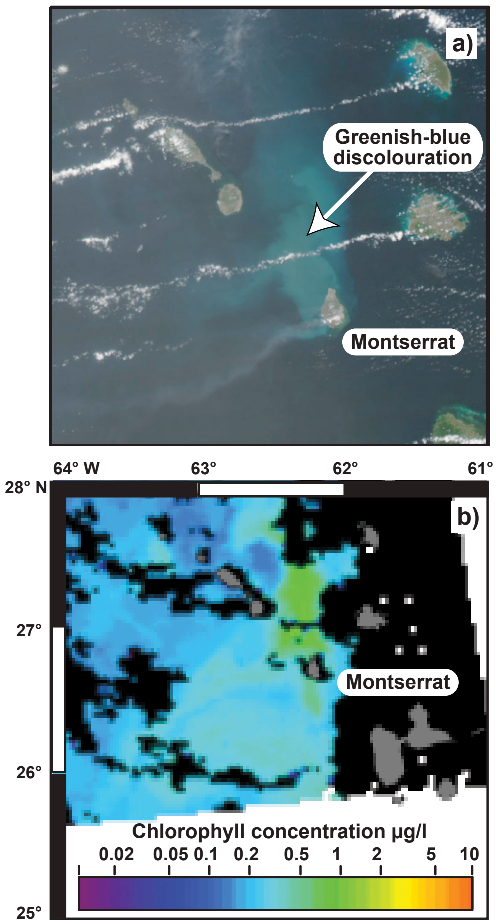



*Fig. 2: True colour satellite images showing a greenish-blue seawater discolouration (a) and processed satellite data displaying chlorophyll concentrations in seawater (b), suggesting a phytoplankton bloom around erupting Soufrière Hills volcano on Montserrat (July 2003, Lesser Antilles) Modified from Duggen et al. (2007) in Geophysical Research Letters.*

Such ash material is rare but our group has a considerable collection available from numerous volcanoes worldwide and in different tectonic settings. Our geochemical experiments with unhydrated ash and natural seawater show that volcanic ash can release an array of nutrients, including nitrate, nitrite, ammonia, phosphate, silica, iron, zinc and copper. The ash mobilised fixed nitrogen mainly as ammonia, appealing knowledge for marine biologists, as phytoplankton can more easily incorporate ammonia than nitrate and nitrite. We were the first to examine the nutrient mobilisation behaviour of volcanic ash on the minute-scale showing that the strongest release occurs within the first twenty minutes after contact with seawater. These results illustrate that volcanic ash rapidly releases nutrients in the sun-lit surface ocean where phytoplankton exist.

As a next step bio-incubation experiments were designed to examine the phytoplankton response to oceanic volcanic ash fertilisation. We used a diatom species (*Chaetoceros dichaeta*) common in the Southern Ocean, where algae growth is limited by low iron concentrations. After pre-culturing in the marine biology laboratories at IFM-GEOMAR, the diatom culture was split up into two sets of parallel experiments – one in which the diatoms continued to grow under iron-limited conditions and another where the seawater was briefly, for twenty minutes, brought in contact with volcanic ash. In the experiments with volcanic ash fertilisation, compared to those without, the phytoplankton reacts positively with an increase of two biotic parameters: chlorophyll a as a measure for biomass and the photosynthetic efficiency as a measure of how good the algae are to use sunlight for their metabolism (Fig. 1). These are the first experiments showing that marine phytoplankton in iron-limited oceanic areas is able to utilise iron from volcanic sources. Natural evidence comes from true colour satellite images (only available in the NASA archives for the past few years). Pictures from July 2003 show the brownish haze of a volcanic ash plume during the eruption of Souffriere Hills volcano on Montserrat, associated with a large area of greenish-blue seawater discolouration (Fig. 2). Processed satellite data suggest that the discolouration arises from an increase in chlorophyll and thus a phytoplankton bloom.

Our research activities gained considerable attention by the German press (e.g. Die Welt, Hamburger Abendblatt, Kieler Nachrichten). During an evaluation of the Research Division 4 "Dynamics of the Ocean Floor" our multi-disciplinary study was highlighted by the reviewing committee as an important contribution to improve our understanding of global carbon-cycles. Some important answers have been found by NOVUM in 2007, yet many question as to the significance of volcanoes for the surface ocean nutrient budget, the marine primary productivity, carbon-cycles and eventually climate development are still subject to ongoing and future multi- disciplinary research activities.

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