SCIENCE FOCUS: Sulfur Eruptions

A Bloom by Any Other Name...Might Never Be a Bloom at All

Highly reflective feature photographed from the Space Shuttle in December 1985 off the coast of Namibia. Walvis Bay is on the coast at lower right.

The primary mission of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) was to accurately determine the concentration of chlorophyll *a* in the surface waters of the Earth's oceans. Chlorophyll is the photosynthetic pigment found in **phytoplankton**, the cellular, usually microscopic, plants that float near the surface of the ocean. When conditions are favorable to the growth of phytoplankton (which usually means that there is an adequate amount of sunlight and sufficient concentrations of the basic nutrients that foster plant growth), the phytoplankton will tend to multiply very fast, creating a *phytoplankton bloom*.

To set the scene, previous *Science Focus!* articles, **The North Atlantic Bloom,** and **Convergence Zones: Where the Action Is** described the seasonal occurrence of the large-scale bloom in the North Atlantic in spring and the high-productivity zones that occur when oceanic currents interact.

A **Classic CZCS Scenes** section, **The Benguela Upwelling Zone**, describes one of the most productive areas in the world ocean, which is found off the western coast of South Africa and Namibia. The *Classic CZCS Scenes* section on the Benguela Upwelling Zone features the same photograph as the one above, which was taken by astronauts on the Space Shuttle in 1985. For many years this image has been described as a phytoplankton bloom, perhaps a bloom of coccolithophorids [see **The Bering Sea: Seasons and Cycles of Change** for more on coccolithophorid blooms and what they look like].

The problem is...based on an examination of SeaWiFS images and research in this area, the cloudy-white feature in the photograph is more likely something quite different from a phytoplankton bloom: it appears to be an image of a unique phenomenon that is related to high rates of phytoplankton growth and high productivity found in the Benguela upwelling zone, but it isn't literally an image of a phytoplankton bloom.

So if it's not a phytoplankton bloom, what is it?

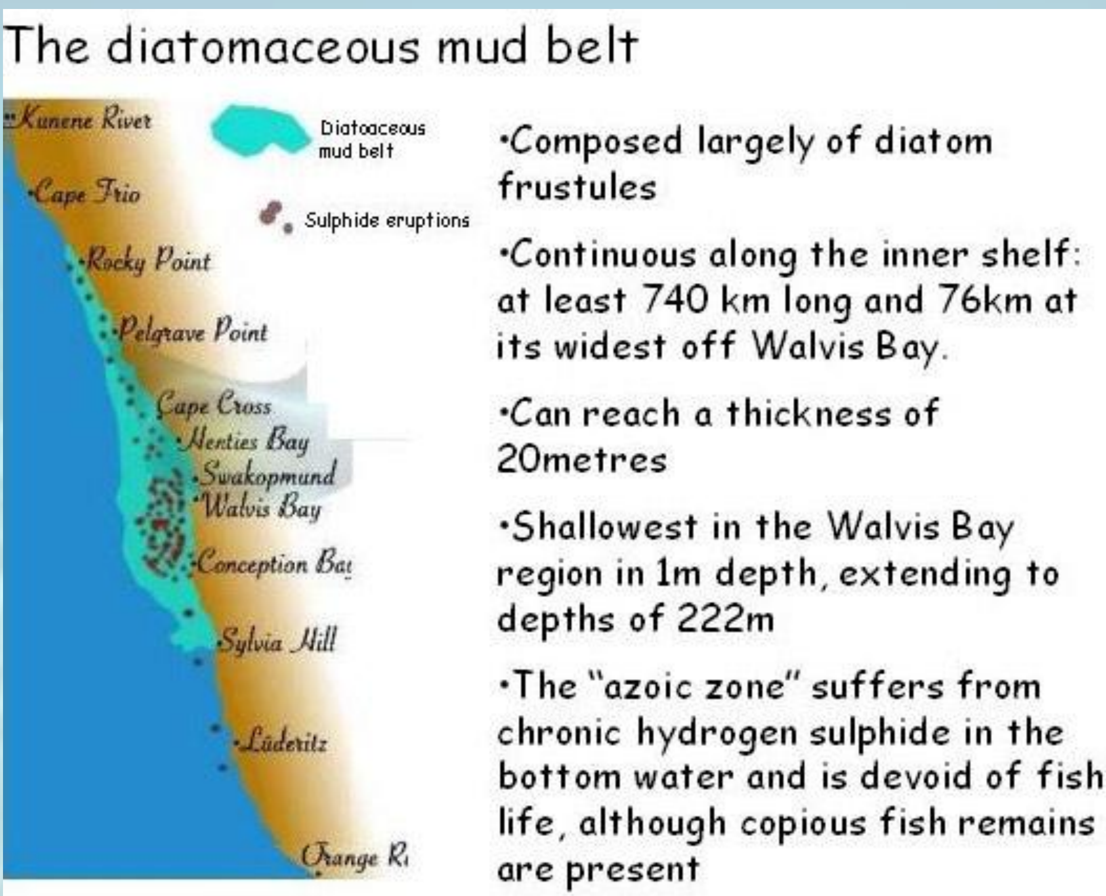
Most likely, it is an occurrence of the phenomenon that is also shown in the SeaWiFS images below:



SeaWiFS images of the Namibian coast and northern Benguela upwelling zone obtained on March 18 (left), March 29 (center) and April 3, 2001 (right), of the generation and evolution of a highly reflective optical feature similar to the one at the top of the page. In the April 3 image, it appears that another event is commencing along the coast.

In January 2002, a paper published in the noted science journal *Nature* described the occurrence of highly-visible surface features that were observed by SeaWiFS. These features consist of microcrystalline particles of sulfur. They are formed when a large amount of hydrogen sulphide (H_2S) gas erupts from the *diatomaceous* (mainly composed of the shells* of diatoms) sediments underlying the highly productive waters of the northern Benguela upwelling zone. In these areas, oxygen in the bottom waters (the water just above the sediment layer at the sea floor) is used up by the bacterial respiration of organic matter. I.e., the bacteria consume the dead cells of the phytoplankton that fall to the seafloor, using oxygen as they do so. The bacteria actually "oxidize" the organic carbon back to the dissolved inorganic carbon that is commonly found in seawater. (Another *Science Focus!* feature, **Creeping Dead Zones**, discusses this at length).

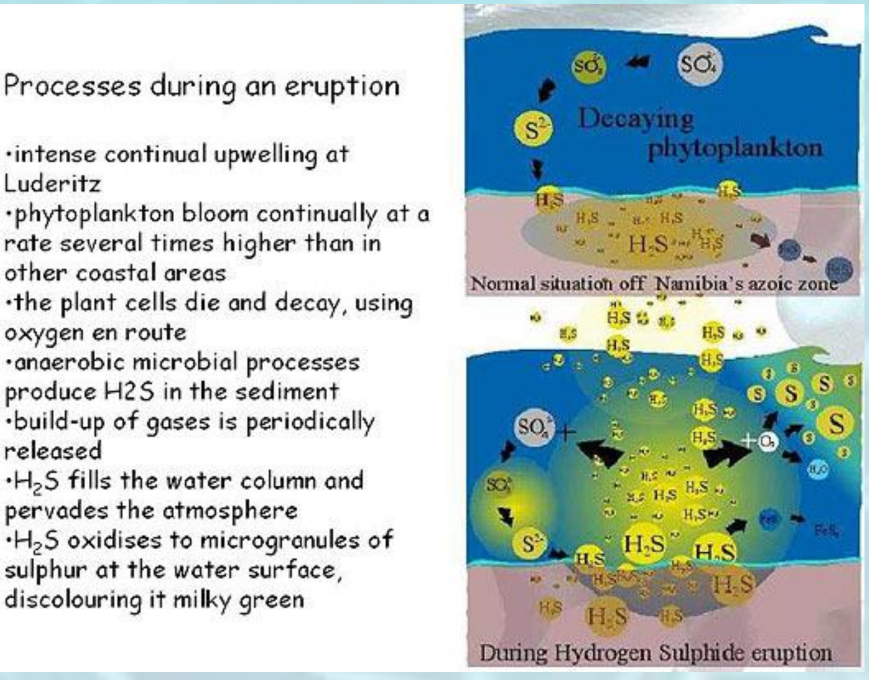
***** also called *frustules*



When the oxygen is used up, bacteria that don't require oxygen to digest the organic matter take over. These bacteria are called *anaerobic* bacteria. When there is little or no oxygen present, these bacteria utilize the sulphate (SO_4^{2-}) ions in seawater to oxidize the organic matter. In the process, the sulfur atoms in the sulphate ion are reduced to sulphide (S^{2-}), which combines with hydrogen to form H_2S.

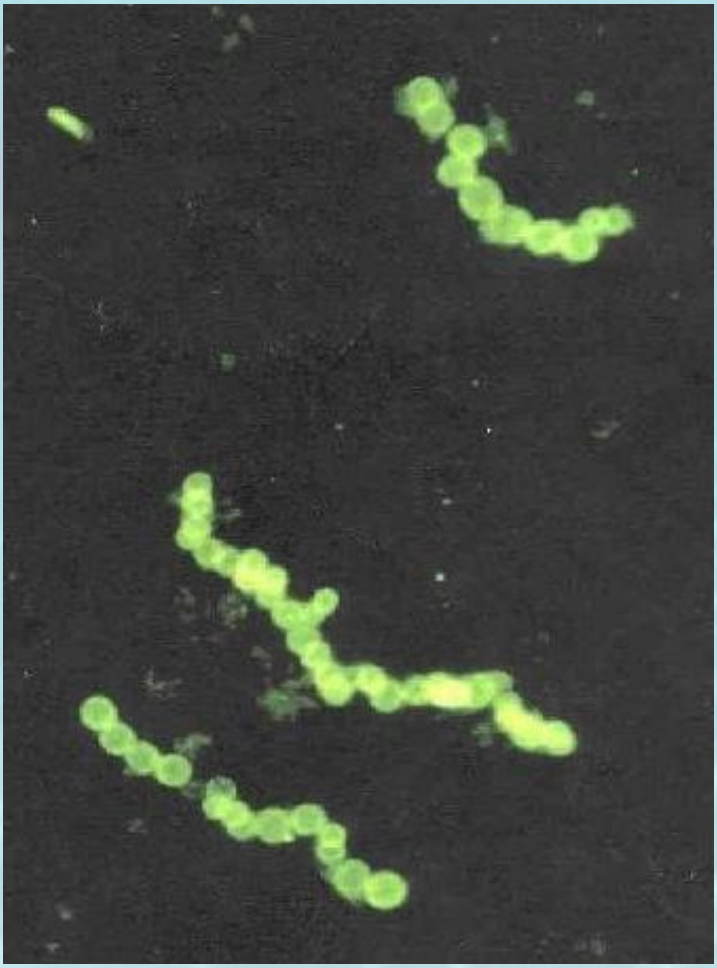
In the northern Benguela upwelling zone, the high productivity of the surface waters means that large amounts of organic matter fall to the sea floor, where they are oxidized, and the bottom waters are frequently hypoxic (with low oxygen concentrations) or anoxic (zero oxygen concentrations). These conditions allow anaerobic bacteria to do their work. Over time, enough H_2S builds up in the sediments to form a large enough volume of gas to release from the sea floor and rise to the surface.

When it gets to the surface waters, where oxygen is present, the sulphide is oxidized to elemental sulfur, and the resulting mass of particles is seen as the turquoise waters along the coast in the left (March 18) image. These SeaWiFS images actually capture the chemical transition state between the sulphide and sulfur, when the particles are initially whitish. But then they oxidize completely to elemental sulfur, which is yellow, and in the blue waters of the ocean (blue because of Rayleigh light scattering, of course), the cloud of sulfur particles appears to turn greenish as it floats out to sea and as the particles sink.



H_2S is poisonous, and it also smells really bad, an odor called "rotten eggs". By the way, if you ever smell H_2S near an industrial site where it could be leaking, be very careful. Humans can smell H_2S at low concentrations, but at higher concentrations we can't -- and at those concentrations breathing H_2S is lethal.

H_2S concentrations in the diatomaceous sediments off of Namibia are likely the highest concentrations found in seafloor sediments anywhere in the world. One of the reasons is the activity of the bacterial species *Thiomargarita namibiensis*, the largest bacteria in the world, also called "the sulfur pearl of Namibia". "Thio" is derived from the Greek word for sulfur.



Stained microphotograph of *Thiomargarita namibiensis* bacteria

In Namibia, the local population near the coast has gotten used to the occasional bad smells that occur when hydrogen sulphide gas is released from the sediments. But the organisms that inhabit the sea floor, particularly the rock lobsters (called *kreef* in that region), don't like it very much. When massive eruptions of H_2S gas take place, the rock lobsters flee the area, sometimes even crawling onto the beach to avoid the poisonous gas in the water. Dead fish will also be seen floating in the water and washing up on shore. Both sulphide poisoning and low oxygen concentrations in the water column caused by sulphide oxidation can cause fish kills. In fact, the seagulls living on the coast seem to be on the lookout for a sulphide eruption, because it means that a lot of seafood will be available!

Images of sulfur-laden water offshore (top) and aggregation of seagulls foraging for lobster and fish affected by the sulphide eruption (bottom)

As the *Nature* article states, due to their noxiousness and the escape of lobsters to the beach, eruptions of H_2S are hard to miss. However, the dry desert coast of Namibia is very sparsely populated, and many of these events are not observed. SeaWiFS therefore provided invaluable data on the frequency, duration, and spatial extent of the phenomenon, indicating it was more common, longer-lasting, and significantly larger than had been suspected from observer reports. H_2S eruptions occur only in the northern part of the Benguela upwelling zone, not in the southern part, where more people would be present to observe them.

The feature photographed from the Space Shuttle was observed north of the SeaWiFS images shown here (Walvis Bay is the small bay seen on the coast at the bottom of the photograph). According to Scarla Weeks, the lead author of the article in *Nature*, the zone of anoxic sediments is widest just off of Walvis Bay (see the map), and sulfur eruptions occur here frequently. So while it might be a photograph of a phytoplankton bloom, it seems likelier that the Space Shuttle astronauts happened to see the results of a sulfur eruption.

Weeks and her colleagues expect to analyze more images of these events to produce a better understanding of their frequency of occurrence and their spatial extent. One of the key questions to be answered is what conditions are required to initiate a sulphide eruption.

Water column anoxia in the southern Benguela upwelling zone

The southern Benguela upwelling zone is considerably more productive than the northern Benguela, but the sediments do not contain as much H_2S. However, low oxygen concentrations due to bacterial respiration of organic matter will cause rock lobsters to flee to the shallow waters near the shore, where they can be stranded at low tide. In one case, some of the nearly 900 tons of stranded rock lobster were rescued by the government and military of South Africa and moved back to friendlier waters.

Image of massive rock lobster "walk-out" on a beach in South Africa near Elands Bay, caused by water column anoxia. This picture was taken by G. Pitcher.

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Reference:

Scarla J. Weeks, Bronwen Currie, and Andrew Bakun, 2002: Massive emissions of toxic gas in the Atlantic. *Nature*, **415**, 493-494 (January 31, 2002 issue).