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Comments on two Petitions for revised state water quality standards forwarded by The Center for Biological Diversity before The Environmental Protection Agency, 2012 and 2013

OCEAN pH-VARIATIONS, CORALS, AND THE OFFSHORE PETROLEUM INDUSTRY

By

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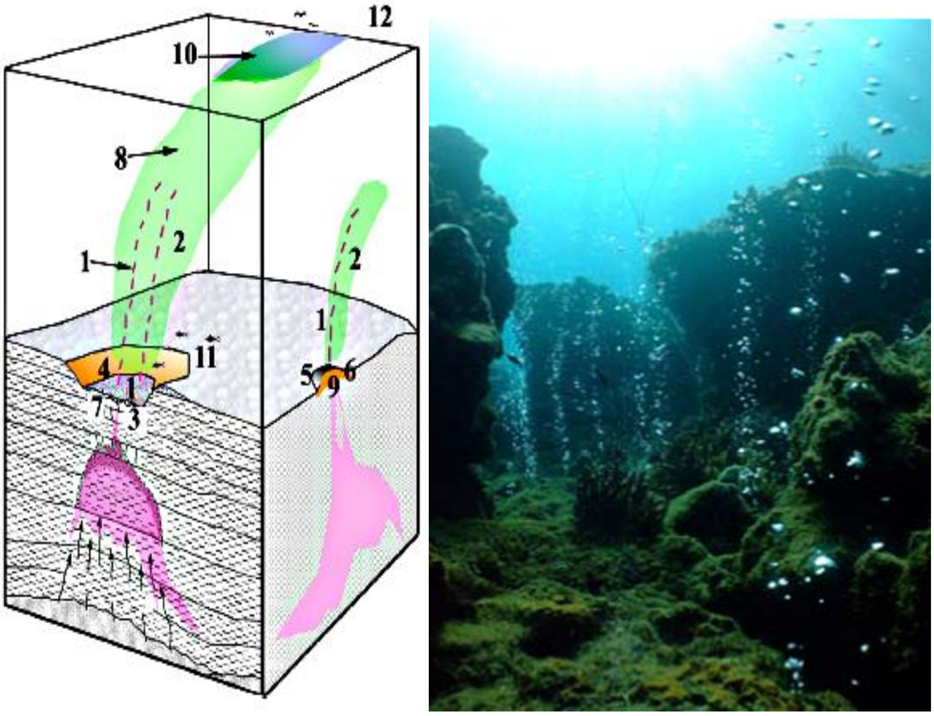

Images: M. Hovland (left), K. Fabricius (right)

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Executive Summary

Despite hundreds of peer-reviewed published articles stating that 'ocean acidification' is occurring and is already affecting marine life, no proper documentation has been presented to date. That the ocean's surface pH-value has been reduced by ~30%, i.e., by ~ -0.1 pH-value is based on numerical modeling (IPCC, 2007). Likewise, that marine life is affected by pH-reductions and disturbances in the aragonite saturation state and calcification has been based on artificially induced aquarium studies and volcanic CO_2-seeps, i.e., on proxy observations, only. The reviewed proxy studies were, thus, found to be invalid on the basis of poor and irrelevant methodology.

Nevertheless, the null hypothesis "*There is, has been, and will be derogatory effects on marine life forms caused by oceanic sequestration of anthropogenic CO_2 to the atmosphere, including a lowering of the ocean surface water pH-value, 'ocean acidification'*" has not been totally disproved, and, therefore, partly merits to be taken seriously. Thus, it is recommended that the petroleum industry, for example, over the next decade supports some of the research that is on-going and planned. In particular, it is recommended to design and support further research into the well-being and nature of tropical and deep-water corals and coral reefs.

"*The seabed is a diverse environment that ranges from the desert-like deep seafloor to the rich oases that are present at seeps, vents, and food falls such as whales, wood or kelp*." (Jørgensen and Boetius, 2007).

1. Introduction

These comments are provided in response to **two petitions** from The Center for Biological Diversity (CBD) presented before The Environmental Protection Agency (EPA). In the following, these two petitions will be referred to as '**CBD-I**', (of October, 2012, discussing "Marine pH"), and '**CBD-II**' (of April, 2013, discussing "Additional Water Quality Criteria and Guidance"). The objectives of the two petitions are to tighten regulations on offshore discharges, in particular tighter pH-range, based on the presumed impact of 'ocean acidification', especially on corals.

This report contains some comments to the two petitions and the referred scientific basis (Ch 2 and 3). In addition, there are two chapters containing some pertinent information about i) the natural variations and current state of lakes and oceans (Ch 4), and, ii) the relatively recent discoveries of deep-water corals (DWCs) and cold seeps (Ch 5). Summary and conclusions are found in Ch 6, and, finally, Ch. 7 contains definitions and abbreviations used in this report.

2. Comments on CBD-I

2.1 The Petition's requests

The CBD bases the Petition on some of the vast, modern literature on the rising atmospheric CO_2-levels, which are presumed to cause a general drop in upper ocean water pH-values. This expected reduction in the ocean's surface alkalinity, is estimated to have reached -0.1 pH-units since the start of the Industrial Revolution (IPCC, 2007). Despite the ocean water being a very strong buffer solution, there are model simulations and tank experiments that suggest a negative impact on marine ecosystems due to the expected pH-reduction, during the coming century. This is in particular expected to be valid for calcifying organisms, such as corals, mainly due to the expected associated decrease in ocean water calcium carbonate super-saturation.

Despite this being a potential global scale problem, the CBD Petition requests that:

"…the EPA promulgate marine pH water quality standards for 15 states and territories whose standards do not adequately protect aquatic life from the effects of ocean acidification…"

CBD mainly base this request on the following categorical statement:

"***pH changes greater than 0.2 units are harmful to aquatic life***"

This statement is the crux of their demand. In the Petition, there is a substantial review of modern literature which apparently supports this notion.

a. Scientific foundation of the request

CBD base the requests partly on peer reviewed information. One of the frequently cited papers (on pages 8 – 10 of CBD-I), is an interesting study recently published by geochemists (Honisch et al., 2012). However, as many other NGOs (Non-Governmental Organizations), also the CBD pick out those particular results and speculations presented in the publications, which seemingly underpin their expectations, but, at the same time CBD tends to ignore (or 'hide') the conditions and statements that don't.

Here is an example: in CBD-I, Honisch et al. (2012, p. 1062) is (wrongly) cited as saying: "…*stand out as capable of driving a combination and magnitude of ocean geological [*wrong word, it shall be 'geochemical'*] changes potentially unparalleled in at least the last 300 million years of Earth history…*", CBD fail to mention that this statement is highly uncertain, as the authors of the paper correctly point out (Honisch et al., 2012). The authors provide the following two cautions:

1) *"Geochemical proxy estimates are not yet available for the Cretaceous and beyond and need to be obtained to verify whether ocean acidification did indeed happen"* (Honisch et al., 2012).
2) *"This includes finding new archives to study the secular evolution of seawater chemistry but also the laboratory study of living proxy carriers under conditions mimicking past seawater chemistry."* (Honisch et al., 2012).

And finally, a third caution, that clearly demonstrates the current lack of general knowledge: 3) "*An unfortunate aspect of the geological record, however, is the lack of deep-sea carbonates in the Early Jurassic and beyond, which further reduces our ability to reconstruct the carbonate chemistry of those older events*." (Honisch et al., 2012).

Therefore, what Honisch et al. (2012) actually write in their (perhaps premature and rather speculative) conclusions, is: *"…the current rate of CO_2 release stands out as* ***capable*** *of driving a combination and magnitude of ocean geochemical change* ***potentially*** *unparalleled in at least the last ~300 million years of Earth history, raising the* ***possibility*** *that we are entering an unknown territory of marine ecosystem change."* (Honisch et al., 2012, my enhancement of words). This 'conclusion' is clearly based on a number of very uncertain presumptions, none of which are mentioned in CBD-I.

This means that CBD is grossly 'over-selling' messages, attempted to be cautiously presented by Honisch et al. (2012) as meager future possibilities.

There is also a valid critique that can be made to Honisch et al. (2012), who, in passing, mention the last ~300 million year period, as if it was well known. Either Honisch et al. (2012) are unaware of the Paleogeologic and Paleoclimatologic reconstructions made for the last 300 million years, or they are grossly exaggerating the current atmospheric CO_2-trend. The last 300 million years of Earth history, namely, includes the Early Triassic period (254 – 245 million years BP), when the mean global temperature was about +10 ^{o} C warmer than at present (Sun et al., 2012). It also includes the more recent and better known Cretaceous period (100 – 65 million years BP), with higher mean temperatures than at present and mass deposits of carbonates in the form of chalk (incl. the White Cliffs of Dover, etc.).

However, the main irony in this exaggeration by Honisch et al. (2012) is that the last 1.5 million years BP had dramatic cooling and warming bursts, i.e., the freezing ice ages and warmer interglacial periods, of which the Holocene (present) is one of many. One has to remember that corals and coral reefs managed to cope with all these events. Even tropical corals and the deep-water corals managed to survive the extreme shifts in atmospheric and seawater temperature, CO_2-concentration, pH-shifts, and sea-level alterations (up to 120 m). This statement, although having been echoed again and again in many peer reviewed articles, must be grossly at fault, and should not be used as it is currently used, also in CBD-I.

b. Natural water pH-ranges and tropical corals

CBD-I contains a lengthy discussion on the possible fate of tropical corals and coral reefs.

Tropical corals grow in regions of the ocean located between 30^o N and 30^o S and are dependent on sunlight as their polyps contain symbiotic algae (zooxanthellae) that harvest CO_2 from the ambient seawater for their photosynthesis. It is well known, that the pH-values alter significantly in shallow ocean waters, over periods of hours, days, weeks, and decades, as this sole parameter is dependent upon many other parameters, such as water temperature, pressure, currents, nutrients, ambient photosynthesis, respiration, and nearby upwelling (see Ch 4). As rainwater has a natural pH-value of around 5, it is clear that surface ocean water must periodically experience low pH-values as torrential rain mixes with surface water and is buffered by seawater. According to Francisco Chavez (at the Monterey Bay Aquarium Research Institution, MBARI), "*These organisms* [tropical corals] *are seeing large swings of pH on a daily basis.*"
http://www.mbari.org/earth/mar_chem/ocean_acid/oa_lesson.html

This means that all tropical corals experience both short-term and long-term (decades) swings in ocean water pH-values and obviously have natural mechanisms to cope with such variations. But, despite hundreds of scientific investigations conducted to date, researchers have not been able to find a proper answer to the most basic questions concerning tropical corals, such as "*Why do they grow only in specific coastal regions of the tropics, and why don't they grow along all coastal regions of the* *tropics?*" Even the largest reef on Earth, The Great Barrier Reef (visible from space), off NE Australia, is an enigma: – "*Why is it there in the first place*?"

What is known, however, is that tropical corals are very sensitive to alterations in ground-water conditions and to local and regional sub-surface hydrological condition. This is also why they are very sensitive to anthropogenic pollution and mechanical disturbance. After the great 1998 ocean warming event, caused by the strong 1998-El Niño, in the eastern Pacific Ocean, it was also clearly demonstrated that tropical coral reefs are highly dependent on ocean water temperature. This El Niño event caused widespread bleaching of tropical corals, both in the Pacific and Indian oceans. It was established that the bleaching occurred as a consequence of the wide-scale exodus of zooxanthellae (symbiont algae) from the tropical coral host polyps, due to thermal stress.

Since around 2003, modern marine biologists have been searching, in vain, for ideal *in situ* locations in the ocean where natural and/or anthropogenically induced atmospheric CO_2-rise has led to a reduction in surface water pH. However, this reduction has so far evaded field documentation. The lack of success has forced marine biologists to turn to other, 'proxy' methods, even though Hall-Spencer et al. (2008) warned of caution, due to the evident time and scale problems of proxy methods.

Apparent proxy locations have been found, especially where under-ground volcanic processes have led to the emitting of exotic CO_2 through the seafloor. These proxies are discussed in CBD-I and used as scientific basis for the key statement: "*pH changes greater than 0.2 units are harmful to aquatic life"* (Fabricius et al., 2011). Although such investigations provide very interesting results on how volcanic CO_2 seepage affects the nearby macrobenthos, including corals, the complex nature of marine seep systems, in general (Hovland et al., 2012), and the uncertainty of the gas composition, in particular, prevent these types of studies to provide valid proxies for the potential effects of 'ocean acidification' on tropical corals. However, they may possibly shed some light on possible effects of leaking anthropogenic CO_2 repositories from underground CCS-plants (CCS: Carbon Capture and Storage).

Therefore, despite Hall-Spencer et al. (2008) and Fabricius et al. (2011) relying on their studies of volcanic seeps to demonstrate the expected effects of 'ocean acidification' on tropical corals, it is premature to utilize these results in the way they are used in CBD-I. The main reason is that the volcanic seeps, for example off Papua New Guinea used by Fabricius et al. (2011) were found to contain only ~99% pure CO_2 gas. A critical question to these authors is: "*what is the composition of the remaining ~1% of the gas?*" From many other studies of volcanically induced cold seeps, both on land (terrestrial) and in the ocean (marine), we know that there is a broad range of possible trace elements and gases, such as: HCl, H_2S, SO_4, Mg, Al, Br, FeS, etc., that could potentially be lethal to corals.

c. Chapter summary and conclusions

The general basis for CBD-I is the scientific 'null hypothesis': "*There is, has been, and will be derogatory effects on marine life forms caused by oceanic sequestration of anthropogenic CO_2 to the atmosphere, including a lowering of the ocean surface water pH-value, 'ocean acidification'* " which is based on peer reviewed literature published over the past decade (2003-2013). Included herein is IPCC (2007) (IPCC: Intergovernmental Panel for Climate Change), who numerically modeled the ocean's surface pH-value to have been reduced by ~30%, i.e., by ~ -0.1 pH-value. Although this null hypothesis has not been proved yet, it has neither been proved wrong, and is therefore still valid.

The main basis for CBD-I is the non-documented statement "*pH changes greater than 0.2 units are harmful to aquatic life".* The proxies used to underpin this statement are found to be of poor and inadequate methodology, as they are based on irrelevant proxy studies and aquarium (tank) experiments.

3. Comments on CBD-II

3.1 The Petition's requests

The most puzzling aspect of this new Petition, from the CBD, is its timing. It is issued to the EPA only 6 months after CBD-I, and parts of its argumentation apparently tears down some of the foundation on which CBD-I was built, i.e., it correctly downgrades the potential effects of pH as a viable measure for the health of the ocean. Thus, the reason for producing a new Petition to the EPA may be that the first one probably received numerous negative comments.

However, CBD-II starts off with underlining the well-known mantra (on p.2): "*Ocean acidification is dramatically transforming the chemistry of our oceans and the health of its ecosystems*." etc…

But, in contrast to CBD-I, which only focuses on pH, CBD-II includes the carbonate equilibrium and solution characteristics of the ocean. Again, despite this being a potential global scale problem, CBD-II requests that:

"…the EPA promulgate water quality criteria for ocean acidification, including but not limited to the following:

1) *Aragonite saturation state (Omega$_{ar}$) shall not fall below 1.0, or for marine waters with tropical corals aragonite saturation state shall not fall below 3.3; and*
2) *Calcification rates for target calcifiers should measurably decline.*

In addition, section 304 mandates that EPA publish information to provide guidance to states…"

CBD-II bases this request on a series of alarmist-type of statements, of which the following are typical: "…***there is a strong scientific consensus that ocean acidification is occurring…***" (CBD-II, p. 3)"…***at a rate faster than anything experienced in the past 300 million years…***" (CBD-II, p. 3)

"***Modeling the oceans' aragonite saturation predicts that by the end of the century up to 75% of ocean volume could be undersaturated…***" (CBD-II, p. 5)

"***Over 90 national academies of science have signed a statement that ocean acidification…***" (CBD-II, p. 14)

"***Hundreds of studies have documented the impacts that will occur…***" (CBD-II, p. 15). It, thus, seems that these non-scientific types of statements are forming the basis for their requests.

Also in this Petition, however, there is a review of modern literature which apparently supports the notions. Only a couple of these will be commented on.

a. Scientific foundation of the requests

CBD-II is partly based on peer reviewed information. One of the scientific reports reviewed as support for the claims is a very recent study by Feely et al. (2012). On p. 9, CBD-II claims there is a dramatic shoaling of aragonite saturation horizon (see Ch. 5 and 6). However, as Feely et al. (2012) also mention, this shoaling may be "…*due in part to changes in ocean circulation as well as atmospheric* CO_2." Their survey also found "…*under-saturated bottom water with pH of < 7.75 units*…" and "…*The upwelled waters in northern California were last at the surface about 50 years ago, when* CO_2 *levels were much lower than they are today*." So, here we have a situation where completely natural effects of changes in ocean circulation, including upwelling of bottom waters are attempted linked to changes in atmospheric CO_2-content. This is highly speculative and unrealistic, as the CCD-gradient is reverse (bottom up) of any effect induced by ‘ocean acidification’ (top down). Therefore, any reference to this scientific article can be ignored in this context.

On p. 17 of CBD-II there is the remarkable claim by De’ath et al. (2012) that “*The Great Barrier Reef (GBR) has lost 50% of its coral cover since 1985 as a result of the combined effects of ocean acidification, global warming, coral bleaching, coral-predation by starfish, and cyclone damage*.” However, this study has now been firmly refuted by J. Marohasy (2013), who has analyzed the basis for this dramatic conclusion (see: http://jennifermarohasy.com/2013/05/). In short, this conclusion was reached by only studying 17% of the reefs of the GBR. The sites being studied had all been damaged severely by bleaching in 1998, or by starfish, or by cyclones, previously. The basis for picking already damaged reefs is given in an earlier paper by Sweatman et al. (2011), who clearly state a note of caution: “*In the early years of the programme, up to 32 reefs spread across the Swains sector were surveyed annually, but only seven reefs in the south of the Swains sector were surveyed regularly 1993-2004. Five of these seven reefs had large and persistent outbreaks of A. planci for most of the survey period, a high incidence of outbreaks that was not representative of reefs across the sector.*” It is these most affected reefs that De’ath et al. (2012) base their study on. Therefore, this dramatic claim cannot be taken seriously, as it is strongly biased by poor methodology.

b. Suggestion that EPA provides guidance

In Chapter 5, CBD-II, however, contains many interesting and sound suggestions on the way forward. For example, on p. 34, the following true statement is given: “*Because there are few baseline data on historical marine pH, it is exceedingly difficult to demonstrate departures from the past range of a particular water-body. Consequently, scientists and policy makers are asking whether alternative forms of water quality standards might better defend existing designated uses. (Kelly and Caldwell, 2012).*”

And, also on p. 44: “*The need for guidance on ocean acidification is clear for many reasons: (1) EPA already determined that ocean acidification guidance is warranted; (2) states rely on EPA for guidance about ocean acidification; (3) new scientific information about ocean acidification must inform state’s water quality protection programs; and (4) long-term water quality monitoring is needed to detect ocean acidification related problems. In order to comply with the Clean Water Act, …*”. It is especially the *Baseline studies* and *Long-term monitoring* that is lacking, in order of properly assessing the status of natural repositories of waste water. Although, these are not specifically mentioned in the concluding chapter of the report (CBD-II, Ch. 6), these are the two main aspects that are needed in order of separating conjectures and speculations from facts.

c. Chapter summary and conclusions

In contrast to CBD-I, CBD-II argues that a tighter regulation of the pH-value of discharge water, alone, may be futile. Therefore, it is more specific, and suggests regulation of the aragonite saturation state and calcification conditions for target calcifiers, such as corals. In addition, CBD-II suggests EPA should provide information and guidance. With regards to the scientific basis for CBD-II, similar comments as given in Ch 2.4 are also valid here. For example, the study of volcanic CO_2-seeps which is not a valid proxy for ‘ocean acidification’ effects on marine life. The main problem with the ‘ocean acidification’ hypothesis is that we know too little about natural variations and biological adaptations to change. CBD-II rightly points out the need for *Baseline studies* and *Long-term monitoring*. This should be supported by the petroleum industry.

“Subsurface fluid flow is a key area of earth science research, because fluids affect almost every physical, chemical, mechanical, and thermal property of upper crust.” (Tryon and Brown, 2001)

4. Natural lake and ocean pH-ranges and variability

The World contains a total of over 220 large surface fresh, alkali, and acid lakes. There is a large database on the web, especially for people interested in keeping fish in aquariums. If there should be a real imminent danger of water (ocean) ‘acidification’ due to increasing concentrations of the atmospheric trace gas CO_2, then it should affect some of the World’s largest freshwater lakes first. This is because such lakes lack the enormous buffer capacity found in the ocean. Strangely, this aspect is rarely (never) discussed in the climate-related scientific literature.

4.1 pH in some of the world’s largest lakes

By volume, the largest lake on Earth, is Lake Baikal in Siberia, it contains about 20% of the World’s surface liquid fresh water. It is 1,673 m deep, and has an average water temperature of 3.6 ^{o}C. Its pH is more or less constant at 7.1 – 7.2 (varying slightly with depth and annual temperature). The lake is located on a tectonically active continental shear zone. It is unique in many ways (Leifer et al., 2011), especially with respect to the occurrence of gas hydrates containing CO_2 and CH_4, in addition to other seep features, such as mud volcano–like structures, and bitumen mounds.

By areal size, the seven largest of the world’s lakes have the following specifics, including surface pH:

Name	Area (sq km)	Depth (m)	pH	comments	
Caspian Sea	371,000	1025	8.4-8.2 (2004)	Contains vents and seeps	
L. Superior	82,100	406	5.0-6.0		
L. Victoria	69,500	82	7.3-8.5		
L. Huron	59,600	229	5.0-6.0		
L. Michigan	57,800	281	5.0-6.0		
L. Tanganyika	32,600	1470	7.3-8.0	Contains vents and seeps	
L. Baikal	31,500	1637	7.1-7.2	Contains vents and seeps	

There is no doubt that there needs to be performed massive measurement campaigns not only in the ocean, but also in some of the World’s largest lakes, to find out if there is any derogatory effects of rising CO_2 in the atmosphere.

4.2 pH in the oceans

The World’s oceans form an interconnected body of saline water containing most of the elements of the periodic table (some in trace amounts only). It covers about 72% of the Earth’s surface and has a mean depth of ~3.6 km. Its surface pH-value varies naturally between ~7.7 and ~8.3 depending on temperature, pressure, nutrient content, and several other parameters. Whereas the most of the surface Pacific water has relatively low pH-values of 7.9 – 8.1, the northern Atlantic Ocean surface water has high pH-values of 8.0 – 8.2 (See Fig. 1).

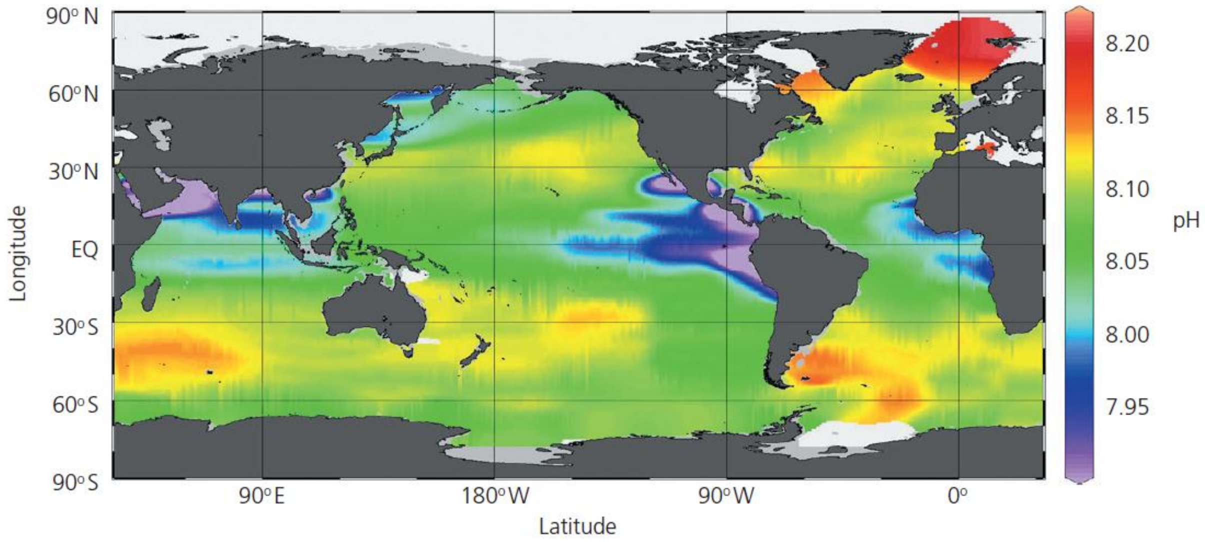

Fig. 1. *Map of mixed surface layer (upper 50 m) pH values in the global oceans for the nominal year 1994. The lowest values are observed in upwelling regions (eg Equatorial Pacific, Arabian Sea) where subsurface waters with lower pH values are brought to the surface. The highest values are observed in regions of high biological production and export. In these regions DIC is fixed by phytoplankton and exported by the biological pump into the deeper layers resulting in higher pH values in the surface waters. Values are calculated from the GLODAP DIC and total alkalinity dataset (Key et al 2004) using the Dickson & Millero refit of the Merbach carbonate dissociation constants (Dickson and Millero 1987). Physical oceanographic modelling is based on Bryan (1969) and Cox (1984).(From Caldeira et al., 2005).*

It should also be kept in mind, that the total ocean water body is rejuvenated by deep-ocean hydrothermal circulation into and out of the underlying ocean crust on a 0.1 to 0.5 million year cycle. The oceanic crust, which is only about 15 km thick (on average) underlies most of the World's oceans, deeper than ~500 m water depth. The seawater circulates into cracks and fissures near the spreading centres and along transform faults where it is heated to boiling and to the supercritical phase, before being guided back to the above ocean through hot and cool vents in the ocean floor. New results from scientific drilling into the oceanic crust performed over the last 15 years (see www.iodp.org) have proved that the crust actually is a worldwide reservoir of saline water contained in cracks, pores, and fissures. The size of this reservoir, which is constantly in motion and connected to the above seawater column, is approximately the same as the total volume of seawater in the oceans.

Acid seawater (i.e., with pH-values of <7) is associated with most deep-ocean hydrothermal systems. The most acid seawater bodies known in the ocean are, therefore, located inside hot, dense brine pools beyond 2 km water depth, in the Red Sea (see for example Ehrhardt et al., 2005) and the eastern Mediterranean Sea. These occurrences ('hot brine pools') may have temperatures of >50 ^{o}C, and have pH-values < 5. (See Fig. 2).

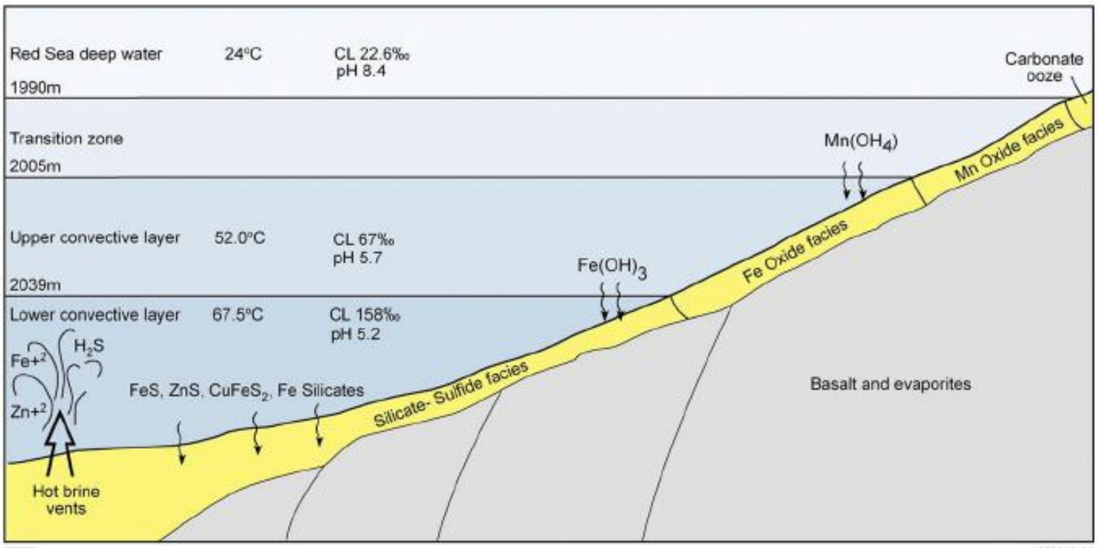

Fig. 2. *Inside the 'Atlantis II Deep' of the Red Sea hot, dense brines (~67°C, 1.2g/cm^3), covers an area of 5 x 14km. The topmost of the two mineralised layers of Atlantis II Deep, one of several in the Red Sea, was evaluated in three dimensions in the early 1980s by the German company, Preussag, on behalf of the Red Sea Commission. Note the very low pH-value in the overlying water mass: 5.2 pH-units…*

See also: http://www.miningmagazine.com/management-in-action/mining-the-oceans?SQ_DESIGN_NAME=print_friendly

4.3 The significance of seeps

Over the last 30 years, or so, it has become evident that the natural seepage of "exotic" fluids (gas and/or liquids) from the substratum may have an important effect on the surrounding organic production. Depending on location, the nature of seeping fluids can be from:

- Fresh water (i.e., artesian groundwater)
- "Cold seeps" of petroliferous and biogenic gases (mainly methane and ethane)
- Mineral liquid oil
- Hot (hydrothermal) vents.

Thus, seeps may occur at all ocean depths and at many different types of geologic settings (Judd and Hovland, 2007; Etiope et al., 2013).

For an illustration of possible effects of seepage on the surrounding environment, see Fig. 3.

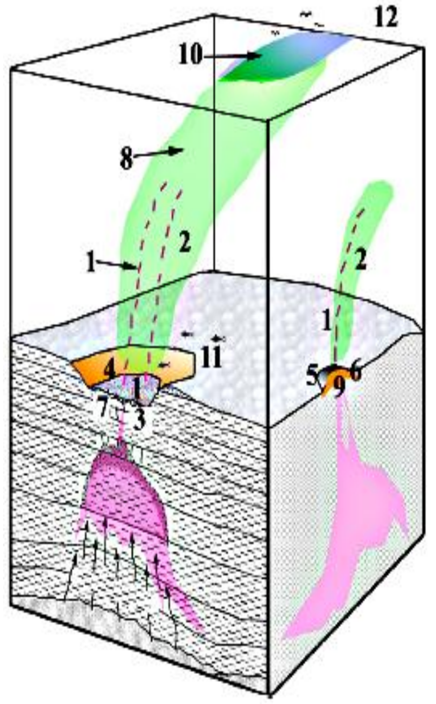

Fig. 3 A conceptual drawing showing some of the characteristics of methane macroseeps: (1) bubble streams (ebullition), (2) hydroacoustic flare, (3) relatively high CH_4 levels in water and porewater, (4) visual and chemical aureole, (5) chemical and temperature anomalies, (6) topographic effects, (7) MDAC (methane derived authigenic carbonate) development, (8) (same location as 1 and 7) bacterial mats and blooms, (9) upwelling seawater, (10) sea-surface slicks, (11) attraction of fish and other macrofauna, (12) nutrients on surface/birds feeding. Not all of the effects occur at all seep locations (based on Hovland et al., 1984 and 2012).

It should be clear by the conceptual illustration in Fig. 3, that we need much more information about the whereabouts of seeps in the ocean and how they affect the adjacent marine life and also the regional environment. Thus, we need more long-term knowledge about the natural conditions at many scales, ranging from meters to kilometers and more.

4.4 Chapter summary and conclusions

This chapter provides examples of the known (great) spatial and temporal variability of pH-values in lakes and the oceans. It demonstrates how seeps affect the near-field water conditions. Thus, it can be concluded that too little is currently known about general natural conditions both in lakes and the oceans to conclude about the validity of current ‘ocean acidification’ fears and warnings.

“*In fact, methane-fuelled microbial communities in anoxic sediments above gas hydrates and gas vents have the highest biomass that is known to occur in marine ecosystems, with up to* 10^{12} *cells per cm*^{3} .”(Jørgensen and Boetius, 2007).

*“*Lophelia *is the coral that breaks all the rules. It is a true hard coral produced by a colony of individual polyps but it is found in deep cold water. Unlike its tropical counterparts,* Lophelia *does not contain zooxanthellae and so does not rely on sunlight.”* (Roberts, 1997)

5. Cold-water Corals, pH, and seeps

Although deep- and cold-water corals have been known to exist, even at high latitudes (particularly off Norway), for over 2 centuries, proper biological and ecological research on these enigmatic organisms never started before the late 1990’s (Freiwald et al., 1997). One of the favoured statements used to induce alarm with respect to deep-water corals and ‘ocean acidification’ is that they may become extinct (due to anthropogenic reasons) before they have even been explored: Such statements demonstrate naivety rather than the reality of the situation.

The irony is, however, that the deep-water corals were first documented and studied properly by their touted ‘worst enemies’, namely the offshore hydrocarbon industry (Fig. 4), as acknowledged in the scientific literature by Armstrong and van der Hove (2007): “The modern re-discovery of the deep-water coral reefs has been very important for the public awareness and also action to protect these seafloor habitats. For several hundreds of years fishers and marine biologists have been pulling scraps of cold water coral up from the depths of the sea. Both groups had theories for how the coral was part of the ecosystems in the ocean, but what these entities even looked like in their full glory was unknown. In 1982 the Norwegian oil company Statoil, took the first ever colour stills, and black and white videos of cold water coral reefs, just off Haltenbanken. The visual image of these cold water corals were to have a profound effect upon the people who observed them, in part determining where the oil company laid gas pipes, and finally leading to protection. The combined efforts of biologists, fishers and NGOs, and the repercussion via media, on public opinion and policy-makers, played an important part in triggering and developing legislation.” (Armstrong and van der Hove, 2007).

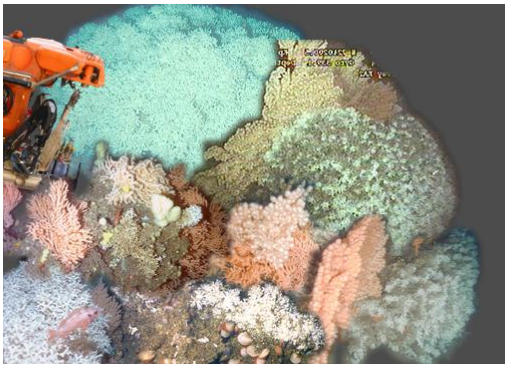

Fig. 4 This collage of images has been assembled from many different Norwegian coral reefs. The artificial image was made in order to provide a ‘wide-angle’ view of the biodensity and biodiverstiy that can be experienced on some Norwegian deep-water coral reefs. It illustrates the abundance of species and prolific life that exists on parts of these reefs. The ROV on the left (Hirov6) is about 1,5 m high (from Hovland, 2008).

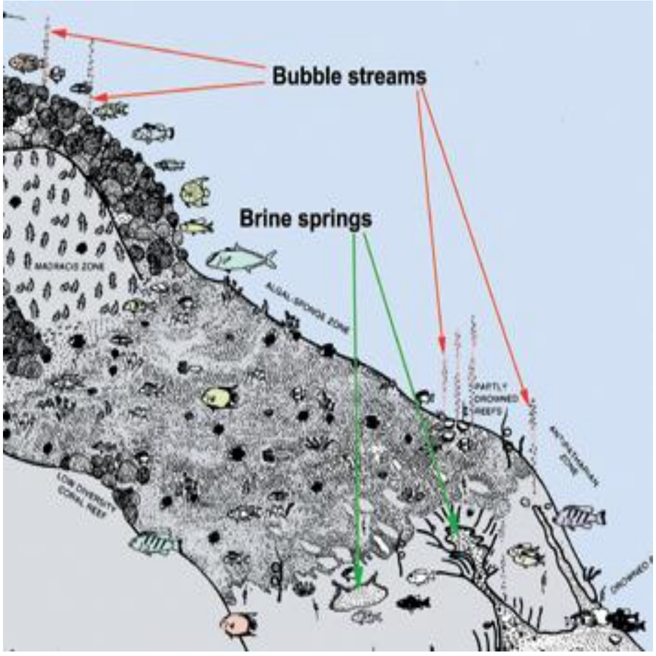

Fig. 5 A detailed drawing of the southeastern part of East Flower Garden Bank, from Rezak et al. (1985). It illustrates zonation, but also shows evidence of seepage, which is not discussed by the authors. There are two types of seepage on both East and West Flower Garden Banks: brine seeps (green arrows) and gas bubble seeps (red arrows). Both these banks and many other in the depth range 70 to 100 m, in the GoM are located on top of buried salt domes (see also next Fig.). From Hovland and Mortensen (1999).

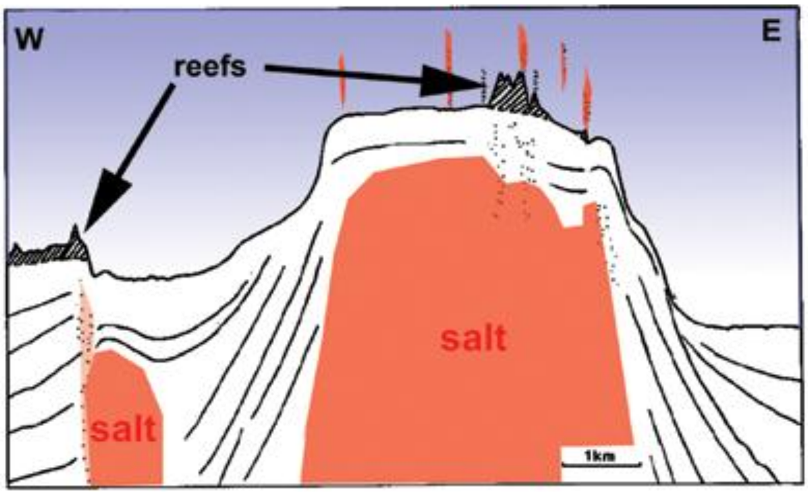

Fig. 6 An interpreted high-resolution shallow seismic section shot across the East Flower Garden Bank, published in Berryhill (1987). The suspected seep-related carbonate reefs (hachured) occur at locations on the seafloor where gas-charged porewater emits through the seafloor. Gas-charged sediments are shown partly in pink (left) and with dots (interpreted from the seismic image). Salt bodies are shown in dark pink, and gas plumes in the water column are shown in red. (From Hovland, 1990).

5.1 *A coral reef with hydrothermal input*

Hirayama et al. (2007) were the first to report on microbial communities associated with a shallow submarine hydrothermal system occurring within a coral reef (Fig. 6): "*The main hydrothermal activi-*

ty occurred in a craterlike basin (depth, ~23 m) on the coral reef seafloor. The vent fluid (maximum temperature, >52^{o}C) contained 175 mM H_2S, and gas bubbles mainly composed of CH_4 (69%) and N_2 (29%). A liquid serial dilution cultivation technique targeting a variety of metabolism types quantified each population in the vent fluid and in a white microbial mat located near the vent. The most abundant microorganisms cultivated from both the fluid and the mat were autotrophic sulfur oxidizers, including mesophilic Thiomicrospira spp. and thermophilic Sulfurivirga caldicuralii. Methane oxidizers were the second most abundant organisms in the fluid; one novel type I methanotroph exhibited optimum growth at 37^{o}C, and another novel type I methanotroph exhibited optimum growth at 45^{o}C." This case is a very good example of how the local environment is modified by input from the substratum. Probably there would be a coral reef in this area, even without the hydrothermal waters seeping through, but would it be as prolific and diverse? At least there would not be any chemosynthtically associated microbes there. Figure 8.13 shows the startling vent site, as imaged by the authors with shaded relief bathymetry.

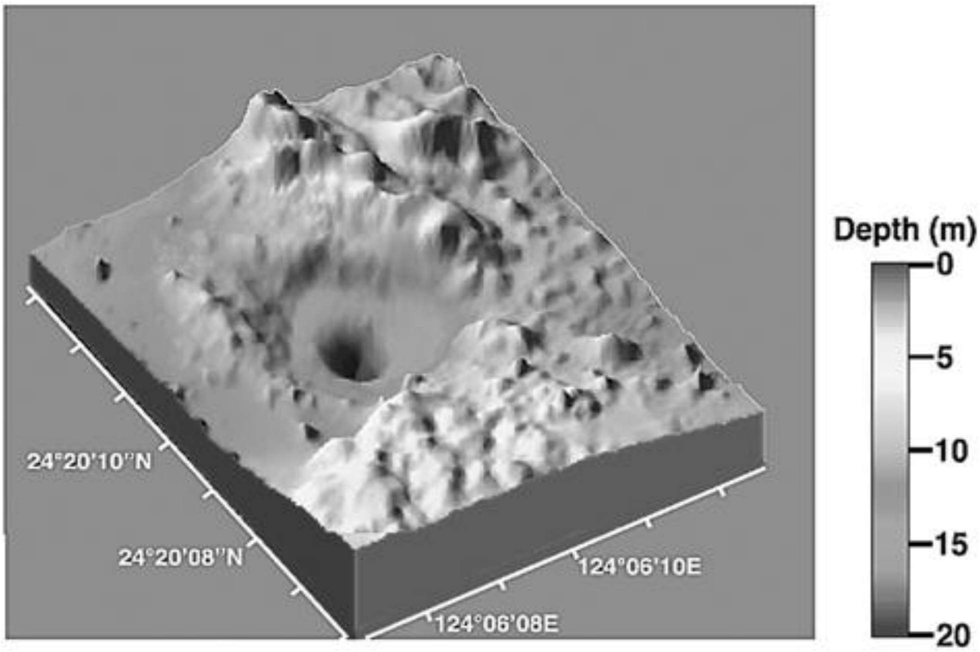

Fig. 7 A 3D-perspective bathymeric map of the shallow hydrothermal system, located on a coral reef off Taketomi Island, Japan (Courtesy of Hisako Hirayama).

5.2 Ocean acidification and deep water corals

There is no lack of uncomforting hints about what may happen in the future. With respect to corals and reduced pH in the ocean due to oceanic CO_2-sequestering, here is a short review of doomsday scenarios up till 2008 (copied from the book: "Deep-Water Coral Reefs, Unique biodiversity hotspots" (Hovland, 2008)):

The main threat when it comes to climate change, is a consequence of the ocean taking up huge amounts of CO_2 from the atmosphere: "*Acidification is the big elephant in the room." "Reef building would grind to a halt, with grievous implications. If CO_2 emissions are not curtailed, we'll eventually see reefs dominated by sea anemones and algae*." (Stone, 2007).

According to J.M. Guinotte et al. (2006) and also to Roberts et al. (2006), human-induced changes in seawater chemistry will alter the distribution of deep-water scleractinian corals. This is mainly because of the acidification of the seawater caused by a higher uptake of CO_2 by the oceans: "*Perhaps the most insidious threat to cold-water coral reef ecosystems is from ocean acidification. There is general consensus that atmospheric carbon dioxide levels are rising sharply, and modeled scenarios suggest that this could cause the greatest increase in ocean acidification over the last 300 million years.*

Current research predicts that tropical coral calcification would be reduced by up to 54% if atmospheric carbon dioxide doubled. In addition to the effect acidification could have on coral calcification, modeling studies predict that the depth at which aragonite dissolves could shallow by several hundred meters, thereby raising the prospect that areas once suitable for cold-water coral growth will become inhospitable." (Roberts et al., 2006). See also Sabine et al. (2004) and Turley et al. (2006).

Carol Turley and her team (2007) looked into this and came with the following disturbing conclusions: "*Increased greenhouse gases are causing the oceans to warm and become more acidic at unprecedented rates. The paleo record tells us that scleractinians have survived several mass extinction events, but in all cases it took several millions of years to recover. It now seems likely that perturbations in the carbon cycle, most likely resulting in ocean acidification, has played a fundamental role in all major mass extinctions of the Scleractinia. However, the extremely rapid release of anthropogenic* CO_2 *from fossil fuel deposits is unprecendented in geological history and risks fundamentally perturbing deep-water coral ecosystems before the scientific community has begun to map and understand them*." (Turley et al., 2007).

Thus, the main question, now, is very urgent: Is acidification of the seawater (from a pH of 8.1 of today, to a pH of 7.8 in one century) going to have any effect on the livelyhood of deep-water coral reefs? The answer to this question is, like most of the processes in nature, very complex and difficult. However, – because the question has been raised, and the answer is not a straight-forward: 'no', – then, we need to seriously look into it and perform some focussed investigations.

We are here, talking about the complex carbonate cycle in a global perspective. According to James Kasting and David Catling (2003): "*The most important part of the carbon cycle in terms of long-term climate is the inorganic carbon cycle, sometimes called the carbonate-silicate cycle.* CO_2 *dissolves in rainwater to form carbonic acid* (H_2CO_3)*, which is a weak acid, but when it acts over long timescales, it is strong enough to dissolve silicate rocks. For illustrative purposes, we use the simplest silicate mineral, wollastonite* ($CaSiO_3$)*, to represent all silicate rocks. The products of silicate weathering, including calcium* (Ca^{2+}) *and bicarbonate* (HCO^-) *ions and dissolved silica* (SiO_2)*, are transported by streams and rivers to the ocean. There, organisms, such as foraminifera, use the products to make shells of calcium carbonate* ($CaCO_3$)*. Limestone is the commonly preserved form of calcium carbonate. Other organisms such as diatoms and radiolarians make shells out of silica. When these organisms die, they fall into the deep ocean. Most of the shells redissolve, but a fraction of them survive and are buried in sediments on the seafloor. The combination of silicate weathering plus carbonate precipitation can be presented chemically by* $CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2$.

If silicate weathering and carbonate precipitation were the only reactions occurring, all of Earth's CO_2 *would eventually wind up in the carbonate rock reservoir and the planet would become uninhabitable. Fortunately, another part of the cycle exists. As we know from the theory of plate tectonics, the seafloor is not static. Rather, it is continuously created at the mid-ocean ridges, and it is subducted at certain plate boundaries when the denser oceanic plate dives beneath the less dense continental plate. When this happens, the overlying carbonate sediments are carried down to depths where the temperatures and pressures are much greater. Under these conditions, carbonate minerals recombine with* SiO_2 *(which by this time is the mineral quartz) to reform silicate minerals, releasing* CO_2 *in the process. This reaction is termed carbonate metamorphism. The* CO_2 *released from carbonate metamorphism makes its way back to the surface and re-enters the atmosphere by way of volcanism, thereby completing the carbonate-silicate cycle. This cycle replenishes all the* CO_2 *in the combined atmosphere-ocean system on a timescale of approximately half a million years*." "*As silicate* *weathering is the loss process for atmospheric CO_2, CO_2 concentrations should tend to fall as T_s [ocean surface temperature] rises and CO_2 should increase as T_s falls. The response time of this feedback loop is that of the carbonate-silicate cycle – hundreds of thousands to millions of years. It is thus too slow to counteract human-induced global warming, but fast enough to have a dominating effect on the billion-year timescale of planetary evolution*." (Kasting and Catling, 2003). So, again, this is a worrying situation with respect to the rising CO_2-accumulation caused by humans – or is it? Why the relatively rare mineral wollastonite was used by Kasting and Catling in this modelling, is uncertain. The iron and magnesiumsilicates kaolinite, pyroxenes and hornblende would be more natural to model. Perhaps there is a 'need' to aggrevate the perceived situation?

5.3 Biological response

To some researchers, the acidification scenario discussed in the previous chapter may well be overly pessimistic. Because we do not really have a proper understanding of the ocean's buffer dynamics when it comes to natural CO_2 sequestration and its balance with carbonate in the ocean, it has been discussed, amongst others, by Chin and Yeston (2007): *"..., prediction of atmospheric CO_2 content several centuries from now is severely hampered by the multitude of poorly understood feedback mechanisms. The most important of these is probably the interaction between atmospheric CO_2 and marine calcification. In a nutshell, the amount of CO_2 absorbed by the ocean depends on the quantity depleted through calcium carbonate incorporation into the skeletons of calcifying organisms such as foraminifera and coccolithophorids. This bioactivity is a function of the alkalinity and the pH of the ocean, which in turn depend largely on the partial pressure of atmospheric CO_2, as well as the type of calcifying organism (E. huxleyi and O. universa). Although the carbonate chemistry of the ocean is well known, the response of different species to changes in pH and alkalinity is incompletely understood, and large differences exist between the species that have been studied. Ridgwell et al. (2007) have performed model calculations for a range of calcifying behaviors. They find that the strength of CO_2 calcification feedback is dominated by the assumption of which species of calcifier contributes most to carbonate production, and that ocean CO_2 sequestration could reduce the atmospheric fossil fuel CO_2 burden by 4 to 13% in the year 3000*." This means that the situation is not as dramatic as stated by others.

There is evidence that the scleractinia corals may have certain feed-back mechanisms by which they can cope with acidification of the ocean by CO_2. Stolarski et al. (2007) recently found that a solitary azooxanthellate scleractinian coral, the *Coelosmilia* sp. had a calcite skeleton which, during evolution turned into an aragonitic skeleton. It resembles the currently common solitary coral *Desmophyllum* sp., which like all other known scleractinian corals have skeletons of aragonite: "*It has been suggested that hypercalcifying organisms, including corals, are sensistive to the Mg/Ca ratio of seawater, which has changed through geologic history in response to variations in the plate tectonic cycle. According to this model, hypercalcifying aragonite-producing organisms (including corals) flourish during periods in which seawater has a Mg/Ca ratio greater than 2, whereas hypercalcifying calcite-producing organisms flourish when the Mg/Ca ratio is less than 2 (in the modern ocean Mg/Ca = 5.2). The Coelosmilia sp. lived in the Late Cretaceous when the inferred Mg/Ca ratio of seawater was below 2. Our findings may thus appear to support the recently proposed idea that seawater composition can even change the skeletal mineraology of scleractinians. However, other aragonitic scleractinians lived at about the same time as the Coelocmilia sp. specimens studied here, and other studies have shown that the chemical and isotopic composition of scleractinian skeletons is under strong biological control. Therefore, it seems more likely that the capability of scleractinians to produce either aragonitic or calcitic skeletons is genetically determined. In any case, skeletal mineralogy can no longer be considered a conservative feature among scleractinians throughout their evolution*." (Stolarski et al., 2007). This could mean that the *Lophelia pertusa* and other reef-building deep-water corals may be robust enough to 'fight back' in case the ocean water slightly changes its composition, including its acidity, or perhaps its Mg/Ca ratio.

5.4 Cold-water coral reefs of Comau Fjord, Chile

Comau Fjord on Chile's northwest coast is a unique research area in two respects. Firstly, the deep-sea coral *Desmophyllum dianthus* grows here both in shallow and deep water. Secondly, in its mid and deep water layers the fjord already has the high acidification values forecast for the oceans in the course of climate change. Scientists thus have the unique opportunity of plunging into a "*journey into the future*". Biologists of the Alfred Wegener Institute (AWI), in Germany take advantage of this opportunity. Prof. Claudio Richter of this institute was recently interviewed on the web about this research. A copy of this interview is provided below, as it highlights some of the aspects, including conjectures of 'ocean acidification':

"Comau Fjord is so interesting because its water displays a pronounced stratification and we have relative acid water in the deeper layers. That means we find living conditions there like those forecast for the future of the oceans in the course of ocean acidification. In Comau Fjord we can thus undertake a journey through time into the depths and, so to speak, take an elevator from the present down to the future. Moreover, we know from pictures recorded by a remotely operated vehicle of salmon farmers that corals of the species Desmophyllum dianthus very definitely occur in these water layers with a low pH value and they are presumably very much in the pink. The intriguing question that now arises for us is: How do they do that? After all, the great concern here is, in fact, that cold-water corals in particular are extremely vulnerable to ocean acidification. But is that true? Are cold-water corals really so sensitive? Are they the canaries of ocean acidification? Or are they so robust because, like "Big Bertha" in our aquarium, they eat a lot and can pump out ions to compensate for these pH gradients?

What circumstances bring about such water layers with a low pH value in the fjord?

That's a very natural process. The fjord is a semi-closed system with a relatively low water exchange. Organic material in it that is brought in naturally, such as via rivers, is decomposed by microorganisms – and in the course of this natural process the oxygen concentration and pH-value of the water drop. [This is a wrong conjecture / speculation – see later on this topic].

Why is it presumed that corals could be especially affected by acidification of the oceans? What processes play a role in these considerations?

Particularly in shallow water and in the tropics seawater is normally three- to four-fold oversaturated with aragonite: the mineral with which corals build their calcareous skeletons. If we now go into colder water or dive into deeper water layers, however, the degree of saturation falls. That means we arrive at the level of aragonite undersaturation there. For corals it becomes more and more difficult under these conditions to build their calcareous skeletons. This is because when they grow close to the saturation limit, they have to expend greater energy to be able to carry out the process of calcification at all. For this reason it is assumed, on the one hand, that cold-water corals existing close to the saturation limit have considerable problems in growing there and, on the other hand, that the problems, of course, increase the closer the water approaches undersaturation.

How should we imagine the process of calcification: Do the corals filter out the aragonite or calcium carbonate from the water?

No, it's not a filtering process. Calcification takes place in a closed space directly below the tissue layers of the coral. A very thin liquid film exists there in which the pH value and all other chemical conditions are completely different than in seawater. And the corals manage that only by virtue of the fact that they have pumps in their membranes that create these conditions using a great deal of energy. That means protons are pumped out, calcium is pumped in. These processes naturally require energy. We therefore presume that a well-fed coral is a happy coral that is certainly able to perform this work and then actually get to the saturation or undersaturation range because it has the right energet-

ic status. However, that's only a presumption. Now we have to show that this is really the case. That's why it's so important to go to the fjord and collect corals precisely from this range of undersaturation and then determine experimentally whether they are, in fact, able to withstand these or even higher pH gradients – or not.

Question: Are there any initial signs yet that this presumption may be correct?

We don't have any quantitative data. There are photos taken by the remotely operated vehicle that was used by the salmon farms and simply took a deeper look. Back then it was very surprising that Desmophyllum existed at all at these depths. Its sheer existence in these layers, which, as we now know, are acidified, indicates that it cannot be so difficult for Desmophyllum to survive there. We mustn't generalise now, however. On the one hand, we know little about Desmophyllum *and, on the other hand, we definitely cannot draw conclusions about other cold-water corals based on this one. But cold-water corals as a whole are considered to be a relatively successful group. They are very widespread and have gone through times of great environmental fluctuations in the past. We therefore assume that the animals are relatively flexible and capable of adapting to changing environmental conditions. However, all of this has to be demonstrated, of course. We may also be in for a surprise or two – for instance, that the corals are perhaps very sensitive after all or that there are genetic differences. At the moment we don't know that."* From the website: (www.oceanacidification.wordpress.com/2013/05/22/occurrence-of-a-cold-water-coral-along-natural-ph-gradients-patagonia-chile/).

Although this is a very interesting summary of their research, Dr Claudio Richer manages to 'hide' a very obvious and important fact about the Comau fjord: The fjord actually contains cool (volcanic) springs along the shores and undoubtedly along its underwater axis. There is little doubt that these hydrothermal springs (seeps) have the same effect on the seawater pH-value as the seeps in the Red Sea, i.e., a bulk lowering of the pH-value. The fish farmers in the fjord from where the ROV was borrowed by the AWI-researchers, know this and also the tourist operators in Chile (see for example: http://www.exchile.com/downloads/Coast_of_fjords_SeaKayak.pdf).

Therefore, it is quite interesting to note the professor's answer on what causes the low pH-values.

Even in a newly published report by Jantzen et al. (2013) on the cold water corals and the strange natural pH-gradients in the fjord, the fact about the springs are not taken very seriously: "*CO_2 and H_2S may degas and further promote the formation of CO_2-rich and low-pH water 'bodies', which ascend to lower depths. Further hints for such a scenario are given by observations of white mats of chemotrophic sulphur bacteria of the Thiooloca- and Beggiatoa-group and 'foul eggs smell' at sites where low density water seeps out of cracks (Gallardo et al., 2005). These bacteria are usually associated with low oxygen environments*." But even so, the authors find excuses for not taking account of the positive effects of the seeps on the corals: "*Nevertheless, the relatively high oxygen situation in deeper water may be indicative of little or no hydrogen sulphide release, low oxygen consumption and sufficient water exchange with oceanic water masses*." And further: "*Variations of pH may therefore be determined by CO_2-rich water production, rather than by a daily cycle (i.e. by photosynthetic production, respiration or tide). Nevertheless, daily fluctuations in pH can reach ~0.2 units within day-and-night cycle*." It seems the possibility of nutrients (minearals) from the seeps feeding into the fjord ecosystem is ignored by Jantzen et al. (2013). But even so, the fact remains that the deep-water corals live in water previously thought to be poisonous to them: "*This suggests a high adaptation potential of* D. dianthus *to adjust its calcification performance to conditions thermodynamically unfavourable for the precipitation of aragonite*." (Jantzen et al., 2013).

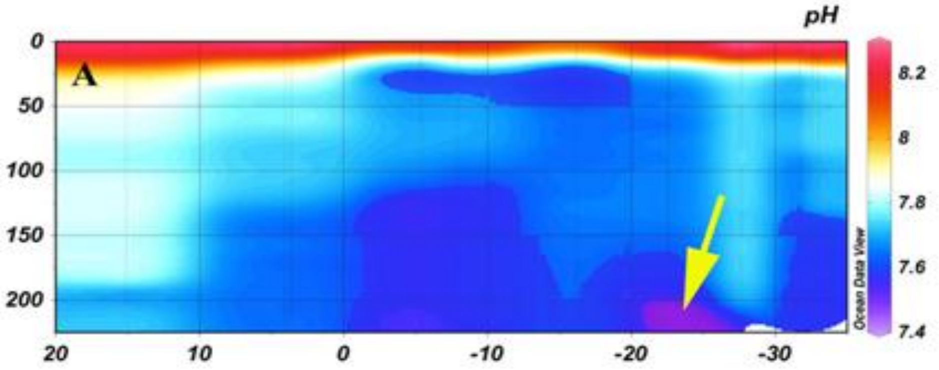

Fig. 8 Illustration of the pH-variations along the Comau fjord in Chile (from Jantzen et al., 2013). It seems evident that there is seepage of low-pH fluids from the bottom of the fjord at around the -23 km mark (yellow arrow), where the colour of the water touches on violet, i.e., a pH-value of 7.4.

5.5 Chapter summary and conclusions

This chapter discusses cold-water corals in particular, as they have been stated to possibly represent the ‘early-warning canary’ of the ocean with respect to ‘ocean acidification’. However, we do not really know how and why cold-water corals, - not only survive, but also proliferate in deep, cold, black ocean waters. Therefore, it is justifiably premature to use them as early-warning organisms.

In the Chilean Comau fjord, cold-water corals actually live and proliferate at pH-values down to 7.4, which clearly disproves the statement made in CBD-I “*pH changes greater than 0.2 units are harmful to aquatic life*” (Hall-Spencer et al., 2008; Fabricius et al., 2011). Furthermore, this fjord probably also demonstrates that both low pH-values and prolific sessile life, including cold-water corals, are dependent on low-temperature hydrothermal venting (seepage).

"As rigs support Lophelia*, a species threatened by fishing activity elsewhere, should old rigs be left in place rather than being decommissioned?"* (Roberts and Gass, 2005)

6. Main summary and conclusions

This report comments some of the statements and scientific bases for two petitions, CBD-I and CBD-II, made by the Center for Biological Diversity before the EPA in 2012 and 2013. In total, this report concludes that there, so far, has been no documented aspects that are unusual, unprecedented, or unnatural with respect to the present near-surface water of large lakes or any of the World's oceans. This is despite numerous peer reviewed scientific reports, cited by CBD, that state contrary views. The null-hypothesis which was presented and tested over the last decade (2003 – 2013), can be stated as:

"*There is, has been, and will be derogatory effects on marine life forms caused by oceanic sequestration of anthropogenic* CO_2 *to the atmosphere, including a lowering of the ocean surface water pH-value, 'ocean acidification'*."

Thus, it has been shown that the two petitions suffer from statements and conclusions mainly based on predictions projected by numerical model calculations, poor and unsuitable (inadequate) methodology, and/or conjectures. However, the null hypothesis has been neither proved nor been totally disproved yet. Therefore, to remove some of the doubt still remaining, as to the truth of the null hypothesis, it is recommended that the petroleum industry over the next decade supports some of the research that is on-going and planned. In particular, it is recommended to design and support further research into the well-being and nature of tropical and deep-water corals.

"*New results show that the response of marine organisms to ocean acidification varies both within and between species*" (Fabry, 2008).

7. Definitions and abbreviations

The following definitions and abbreviations are valid for this report.

Acid: Any solute with a pH-value of 6.99 or lower (NOTE: Surface ocean water is rarely acidic).

Alkalic: Any solute with a pH-value of 7.01 or higher (NOTE: Surface ocean water is alkalic).

pH-value: A measure for the *hydrogen ion concentration* of a liquid. According to Uvarov et al. (1964): it is defined as the: "*Number of grams of hydrogen ions per litre of solution. Useful as a measure of the acidity of a solution and in this context is usually expressed in terms of* $pH = \log_{10} 1/[H^+]$*, where* $[H^+]$ *is the hydrogen ion concentration. As pure water dissociates slightly into hydrogen ions and hydroxyl ions* ($H_2O \rightarrow H^+ + OH^-$)*, the concentration of each type of ion being* 10^{-7} *gram-molecules per litre, the pH-value of pure water is* $\log_{10} 1/10^{-7} = 7$*: This figure is accordingly taken to represent neutrality on the pH-scale. If acid is added to water its hydrogen ion concentration will increase and its pH will therefore decrease*."

'Ocean acidification': A misnomer, coined by environmental scientists around 2005, which has become popular, but misleading slang, also used in scientific literature. According to Wikipedia, the term means: "*…the ongoing decrease in the pH of the Earth's oceans caused by the uptake of anthropogenic* CO_2 *from the atmosphere*." A more scientifically correct term is: *'Ocean pH-reduction'*.

Buffer: A 'Buffer' is a solution with a hydrogen ion concentration that resists a change of pH on the addition of either an acid or alkali solute." (Uvarov et al., 1964) (NOTE: Ocean water is a strong buffer solution).

Carbonate: "Salt of carbonic acid, H_2CO_3" Uvarov et al. (1964) (NOTE: Because ocean water normally contains Ca (Calcium atoms), the salt $CaCO_3$ can form (precipitate) when ocean water absorbs more CO_2).

CCD: Carbonate Compensation Depth: The ocean depth at which the rate of dissolution of $CaCO_3$ equals ('compensates for') the rate of $CaCO_3$ sedimentation. Thus seafloor deeper than the CCD will be devoid of carbonate sediments. The CCD is shallower in the Pacific Ocean (4.2 – 4.5 km) than in the Atlantic Ocean (~5.0 km). (Wikipedia).

Seep: A seep in the ocean is a location where exotic fluids are emanating from the substratum and mixing with the ocean water, through the ocean floor. There are numerous types of seep fluids, the three of which are best known: 1) volcanic and/or hydrothermal seeps; 2) Groundwater seeps; 3) 'Cold seeps' (associated with natural hydrocarbon gas and liquid escape from the ocean floor). Actually, these latter types, "*…have become the most extensively studied seep types in the world…*" (Raggi et al., 2012).

Hydrothermal process: The fluid interaction between ocean, lake, and/or ground water with subsurface high-heatflow locations, such as volcanic magma, or hot sub-surface magma bodies associated with mid-ocean spreading ridges, etc. The best known types are the so-called “black smoker” chimneys on the deep ocean floor, first discovered in the eastern Pacific, in 1977. Acid seawater (i.e., pH-vlues of <7) are associated with most hydrothermal processes and locations. The most acid seawater bodies known in the ocean are the hot, dense brines at depths beyond 2 km in the Red Sea (see for example Ehrhardt et al., 2005). These occurrences have temperatures of >50 ^{o}C, and have pH-values < 5.

PDO: ***Pacific Decadal Oscillation***: The PDO is detected as warm or cool surface waters in the Pacific Ocean, north of 20° N. During a "warm", or "positive", phase, the west Pacific becomes cool and part of the eastern ocean warms; during a "cool" or "negative" phase, the opposite pattern occurs. It shifts phases on inter-decadal time scales, usually about 20 to 30 years. The Pacific (inter-)decadal oscillation was named by Steven R. Hare, who noticed it while studying salmon production pattern results. It also seems to affect upwelling and therefore also surface pH-values.

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