Discussion on the Direct Ocean Disposal of CO₂

Organized and edited by
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Ishitani:
I think it is not possible to evaluate the environmental effects on living creatures. What do we think about the environmental effects on creatures on the sea floor?

Tietze:
I am neither an oceanographer, a biologist, nor a geologist. However, because clathrate is in the same form as many sediments (just as we have found here clathrate from carbon dioxide), and also because there may be the other sites where clathrates have been formed, I believe that clathrate is a very good disposal technique.

Ishitani:
I have heard about methane, natural methane clathrate. However, it is difficult to extract such methane clathrate. So do you have some idea about how to form clathrate beneath the sediment, at this time?

Tietze:
That is an engineering problem. The present method is very primitive and it consists of high-speed disturbance of the sediment, so that when we disturb the sediment only in a limited region, not a large region, but a small region. When the sediment is disturbed, it falls and rises repeatedly, so that I think it will take a little time, maybe some days or some weeks, to form the clathrate.

Ishitani:
I am thinking from a practical point of view. If we build some equipment for dumping or injecting CO₂ from a power plant, the CO₂ flow rate is quite fast and large. In such a case, I am not sure that we would have enough time to form a clathrate.
Tietze:

Yes, I think we therefore have to solve all sorts of primitive problems, that we must ensure that the liquid carbon dioxide which we put into the water be broken into small drops, and if we have small drops, then we think that a crust of hydrate will be built and there will perhaps be a little liquid inside. However, the drops should be very small, so that we have a very high efficiency of building clathrates. Experiments might be the answer. One separate basin, a small basin in the Gulf of Mexico, would be a possible one. I think it is too warm there for such disposal. You are asking about several possible other small basins suitable for the experiment you are describing. This basin has a very strong density stratification similar to the Red Sea. However, I think the topography of that basin is not very good. I will look for and maybe find some basins which may be possible for experimentation. Also, I think I know of some others which may be useable.

Chen:

Relative to disposal, we have to be concerned about whether we are talking about a stable compound. If it is a stable compound, we would like it to stay in an isolated basin. If we want it to be dispersed, then we need to have it in an unstable form. We probably want it to be dissolved in seawater: then in that case, we do not want an isolated basin. We would like to be dispersed into a large area, maybe even into the entire North Pacific Ocean. So first we have to decide whether we are talking about a stable form or not.

Koike:

Relating to this question, is anyone on this panel able to give me an answer about the size or dimension of a $2 \times 10^{15}$ gram mass of carbon dumped as a liquid into the deep sea. What are the dimensions of this block?

Ishitani:

It depends on the extent to which we can recover the total amount of CO$_2$. According to my calculation, I only calculated an estimate of the total amount of CO$_2$ recovered from flue gas in the Kanto Area. In such a case, we would need to dispose of 3 tons of CO$_2$ per second. So it depends on the quantities under consideration. But I think this is quite a large amount of CO$_2$ if we think about dispersion time. I am not sure, but what do you think about this?

Koike:

My question is about the maximum quantity. Dr. Nozake mentioned that a $2 \times 10^{15}$ gram of carbon is the maximum. So if we must dump this maximum amount each year, how large an area, or how much volume must we occupy in the deep sea? That is my question.
Ishtani:

Professor Nozaki is thinking about the total amount of CO$_2$ generated by power plants in the world, so that is quite different. But I am not sure whether it is practicable or not.

Nozaki:

I think that is true. And that figure gives only the maximum of what we should considered. However, I do not think any tanker can bring the waste material at one time. So the tanker would probably have to make quite a few trips to bring it to the sea. It depends on how the real operation would be designed.

Ohsumi:

Two billion tonnes that Dr. Nozaki mentioned is a carbon basis figure, so if we take one third of the total anthropogenic emission on a carbon dioxide basis, it is around 6 billion tonnes. Since liquid CO$_2$ has a density of only one, it means each year, 10 km by 10 km and the thickness is 60 meters. ... About 15 years ago, Dr. Marchetti made a proposal about disposing one third of the total emission from human activity could be put into the Strait of Gibraltar in the North Atlantic. Alternatively we would make such a big lake constantly; maybe a 60 m deep $\times$ 10 km $\times$ 10 km lake would be formed every year.

Sakai:

I think there are two approaches being raised. One is regarding the dumping of CO$_2$ into the ocean, to dump it into a basin-like structure to keep it there as long as possible. The other way is to dump it into the ocean so that it is dispersed as quickly as possible. The first method includes neutralization of the carbon dioxide into bicarbonate, which means that carbon dioxide would have less chance to go back to the atmosphere than with the second method. But the first method causes some damage to the environment. With the second way, we do not have to think about the neutralization of carbon dioxide, using the bottom sediment and in that way we might have a greater chance of having the CO$_2$ return there. However, the second way has less risk of damaging the sea floor environment.

Ohsumi:

I have a question to Dr. Miyake. If you put CO$_2$ in mid-ocean, then I think some part could also go down to the bottom to react with the sediment. Maybe in the Pacific Ocean there is no carbonate (in the sea floor sediment), but if we put CO$_2$ into south Pacific Ocean, then some parts would also react with calcium carbonates. If CO$_2$ is just dissolved in a deep ocean, some stratified structures could be changed because of the solution of CO$_2$, and then could it be more easily reacted at the bottom?
Miyake:

I think Dr. Kajiwara is referring to the more common kind of bottom current boundary effect of deep water. However, I think that one way or the other, if a cloud (of suspended CO$_2$) is formed in mid-water, it will slowly migrate and will inevitably reach the boundary, either at the bottom or the side boundary of the ocean. There I think the waste material will possibly have a chance to go through a chemical reaction after coming into contact with different substances than (those occurring) in mid-ocean water. But during this migration period, it will go through a chemical change, I think, if I am not mistaken, to become a completely hydrate material. Chemistry has to be built into the proper diffusion equations, and none of us has the proper notion of that at the moment. We need a chemical reaction time equation with the mixture.

The sinking velocity would be proportional to the dilution amount. Thus, the lower the concentration of these materials, the lower the sinking velocity. As you went further downstream, the less sinking would occur, almost becoming neutral.

Kimoto:

I would like to ask about one possibility to the biologists. There is a very big ocean desert in the Pacific Ocean. If we fertilize that ocean desert biologically, I am not sure if this is possible or not, but could it become a good carbon dioxide sink or not?

Takahashi:

I would like to partly answer that question. The ocean is limited mostly by nutrients. So if you want to accelerate biological production, you have to find some way to add nutrients. That requires more energy. And I am thinking as a biologist: is anybody looking for a way to accelerate carbon dioxide absorption by seawater. Could it be possible to introduce carbon dioxide directly into the seawater in quantities which would not be harmful to the organisms, and to then introduce this mixture into the Kuroshio Current and disperse it over the large basin of the Pacific Ocean?

Sakai:

So are you suggesting that we should dump CO$_2$ directly into surface water, or into mid-water, as Dr. Miyake suggested before? Or are you thinking about some biological ways to accelerate the absorption of carbon dioxide as Prof. Nozaki discussed?

Takahashi:

We could simply use chemical absorption. Dumping. Speaking as a biologist, we would like to have as little harmful effect on the biological environment.
Saiki:

Central Research Institute of Electric Power Industry is now doing research on iron fertilization, as you know already. Prof. Nozaki has already said that we think iron fertilization is almost the same idea as dumping carbon dioxide into the deep ocean. However, whereas dumping carbon dioxide is an artificial means of disposal, iron fertilization uses biological pumping. We biologist think the latter way is safer, cheaper, and easier than the former concept.

Sakai:

I have a question about this iron fertilizing method. You can absorb carbon dioxide into the surface water zone, but is (that method) effective enough to carry this fixed carbon to the bottom of the ocean? My understanding is that it is rather difficult to have them descend to the bottom.

Koike:

It depends on the structure of the food chain. If the consumers are large diatoms, it is quite easy to bring the material down to the deep sea in about two to three weeks. So if you have large diatoms, or other large organisms, it is quite easy. But if you have very small phytoplanktons, the material will never sink. So you must be very careful to control the community structures.

Sakai:

And you can be optimistic about that?

Koike:

In controlled systems, I am optimistic. But in natural systems, we cannot predict what will happen, because we do not know many of the processes in natural food webs.

Handa:

One little comment about the biological pump; 40 to 72 percent of the body of the phytoplankton is made of protein. It is very easily decomposed. So if you enhance their production, in the Antarctic, if they settle out at the bottom, they will be decomposed and during that process it will require or consume oxygen. So, the ideal thing is to find a way to keep the phytoplanktons from decomposing, to involve cellulose or something before those organisms go below the euphotic zone. Otherwise, the deep water become anoxic, and anoxic conditions can be formed as in Black Sea.

Chen:

Another angle from which to look at this problem is that for ocean dumping, for deep water dumping, we essentially isolate this CO₂ from the atmosphere on the order of 1000 years. But for this nutrient of iron enrichment method, we
produce phytoplankton, most of which would decompose in the top 1000 meters of so. Thus, it would be in contact with the atmosphere very quickly.

Aoki:

From the standpoint of chemistry, I want to ask the biologists. In the iron fertilization, Fe$^{3+}$ reacts with phosphate to form a very insoluble compound, iron phosphate. Is iron phosphate readily available for biological being such as phytoplankton and so on?

Saiki:

How to feed iron? Well, let’s compare with land plants. I do not think the growth of land plants is limited by iron, because a lot of iron exists in the soil. But in the case of the ocean, the iron is very reactive and has a very short residence time in surface water. I do not know much about the technological aspect, but the significant problem is that even if we disperse the iron, it will be absorbed on particles and will settle very quickly. That may be a significant problem: to create the efficient fertilization of phytoplankton.

Horikoshi:

Dr. Nozaki, you mentioned the presence of organisms just around the emission area of CO$_2$ observed by Professor Sakai and the other JAMSTEC people. However, I think it is a slightly different problem, because the disposal of liquid CO$_2$ should be within a deep sea depression, or some similar place. However, in that place the liquid CO$_2$ should stay a very long time. I do not know about the matter of exchange between ambient seawater and liquid CO$_2$, I do not know, but in the case of the Okinawa Trough, I observed that the liquid CO$_2$ begins to float up immediately; that means it leaves the bottom very rapidly, not staying there, so it has very little time to react with the ambient water. Furthermore, I also noticed that whenever there is a bubbling place just around that bubbling place organisms are very prolific and they seem to be not sea anemones, but rather sponge-like creatures. Anyway, we noticed that even if the organisms touch such liquid CO$_2$, it has no influence on them. Nonetheless, that is a very short term phenomenon, whereas the disposal of liquid CO$_2$ on the ocean bottom is a quite long term phenomenon. So that is a quite different thing, I think.

Nozaki:

My assumption is that if the liquid is injected into the depth of 3000 m, that will cause liquid CO$_2$ bubbles like that to form. However, the CO$_2$ will mix with ambient seawater relatively rapidly. That is my assumption. Thus, there is no longer pure liquid CO$_2$. I do not know whether that assumption is right or not, but my impression is that, when we put the liquid CO$_2$ by sending it through a tube, it diffuses into the ambient seawater in a relatively short time, I think.
Horikoshi:
You mean that (there would be) no deposit on the sea floor, but (rather) in the seawater?

Nozaki:
I am not quite sure. Even if you put it into the bottom, but it stays in liquid form by forming a clathrate on the surface.

Sakai:
I think there are two types of questions here. One is a sort of global effect, as he mentioned. If they assume that the oceans homogenize dumped carbon dioxide, that is the effect he discussed. But I think people are generally more worried about the local effect. But I think people have to discuss the issue by creating theoretical models and conducting experiments.

Horikoshi:
And one more thing is that I brought a rather precise map of submarine topography made by the Japanese Hydrographic Office. Thus, if you want to deposit the CO\textsubscript{2} into a deep sea basin, it would be quite difficult to find a suitable place. If you are hoping to dump it into a basin, I would like to suggest that you should study a detailed submarine topography map (such as this) very carefully.

Ohsumi:
Professor Nozaki, you said that the alkalinity will be increased, when all the CO\textsubscript{2} reacted with calcium carbonate, making it into bicarbonate ion. After 1000 years such a water mass would come to the surface. In that water mass, the alkalinity would be increased so that we could expect more CO\textsubscript{2} to be dissolved into the ocean surface, thus causing the next glacial age to come more quickly.

Nozaki:
I think that the key to the relationship between the ocean surface and atmospheric $p$CO\textsubscript{2} is based on the ratio between alkalinity and total carbon dioxide. Alkalinity is determined by calcium carbonate formation and also determined by the river input, and to a very slight extent, by photosynthesis. However, the total CO\textsubscript{2} is exchanged into the atmosphere during photosynthesis. Thus, those are not completely, but essentially independent parameters. So, if you increase the alkalinity and keep the total carbon dioxide constant, the atmospheric CO\textsubscript{2} will be sucked up (absorbed). That is one of the model output by Boyle.

Kitazato: (comments)
My name is Hiroshi Kitazato, from Shizuoka University. I am a paleontologist, but this time I will talk about living benthic foraminifera which lives in great abundance in the deep sea area. Benthic foraminifera dominates the bathyal and
the abyss of the deep sea. In the Pacific Ocean, benthic foraminifera composes about fifty percent or more of the total biomass at the ocean bottom, so they are also abundant in the Atlantic Ocean. Thus, when we discuss benthic activity in the bathyal or the abyss of the deep sea, I think it is important to understand the ecology of the benthic foraminifera. First I would like to introduce the role of benthic foraminifera in the deep sea. A recent study in the Atlantic Ocean shows that benthic foraminifera covers the sea floor during the spring season. Before the spring season, the ocean floor is not covered, but after the spring season the floor is thickly covered by a feed detritus layer. So, after the descent of feed detritus, small benthic foraminifera are quite abundant on the sea floor. European scientists have long thought that benthic foraminifera were consuming this feed detritus. However, in the Pacific we have had little data concerning this phenomenon.

This year I started to observe the seasonal occurrence of deep sea benthic foraminifera at a fixed station in the Sagami Bay near Tokyo. Preliminary results show that the standing crop of benthic foraminifera varies with the season. It can be seen that in April and March, numbers of benthic foraminifera increase a great deal. Thus, the change of the standing crop is closely related to the blooming of the surface plankton. The number of coccolith flux increased in May. So the increase of the benthic foraminifera population is very concordant with such changes in the flux population. So in the laboratory I cultivated benthic foraminifera. This species reacted sensitively to the feed detritus that I gave them during the culture experiment. I then put in the feed detritus, and one day after, very small foraminifera gathered on the feed detritus. It seems that they have green colored cytoplasm. Judging from their color this species perhaps consumed feed detritus. This result suggests that some benthic foraminifera actively consume free detritus on the sea floor.

Next I will talk a little about the microhabitat of deep benthic foraminifera. Deep-sea benthic foraminifera have different kinds of microhabitats around sediment water interfaces. There is an epifaunal group, with shallow infaunal and deep infaunal species. Regarding the shallow infaunal (species), the epifaunal benthic foraminifera stands on the sea bottom like a tree, so they cannot move. A shallow infaunal species makes complex networks like plant roots. They also cannot move. The deep infaunal species have the most mobile mode of living. If some layer like turbidite suddenly covers the sea bottom, deep infaunal benthic foraminifera can escape by making burrows through the layer. However, epifaunal and shallow infaunal benthic foraminifera cannot move through the turbidite layer, so they die out.

Next, I will try to show how benthic foraminifera tolerate various environments in the sea. Since benthic foraminifera is a primitive animal, some benthic foraminifera can survive under extreme environments. I will show four examples. The first one is acidic water. In the bay head area of Kagoshima Bay, Southwest Japan, low pH waters of about 6.5 occupy the bay bottom. The dissolved carbon dioxide content is extraordinarily high in the bottom water. Here volcanogenic
carbon dioxide is supplied from the sea bottom. Agglutinated foraminifera species are dominant in this area. The next case is anoxic of disaerobic water. An enclosed brackish bay like Hamana Lake in central Japan, where a disaerobic bottom environment occurs in the summer season, is an example. The dissolved oxygen content in the bottom water is zero and there is a strong smell of hydrogen sulfide. Large benthic animals could not survive in this water. However, a soft shell foraminifera can survive in this environment. The next case is interstitial salt water. In the ground water of the Karakoram desert of the Soviet Union, there is a sea-covered area from the Pliocene Age dating from about 3 or 4 million years ago. The species with small, thin-walled protoplasm exist in the ground water. The last case is hydrothermal vents and cold seeps. Large animals have been reported in both hydrothermal vents and cold seeps. Several species of benthic foraminifera were reported in the vent areas. These were mostly agglutinated foraminifera.

As stated now, some foraminifera are actually living in such a hostile marine environment. However, most other benthic foraminifera species cannot live in such environments. Thus, the ecological balance of benthic foraminifera may break down when waste material is disposed on the ocean bottom. Waste disposal has the potential of seriously modifying the ecology of deep sea organisms. However, at present we do not have much knowledge of deep sea animals, especially, their activity and their ecology. So we should accumulate fundamental knowledge concerning biological activity on the deep sea floor. I think culture experiments in both the laboratory and in the sea are useful methods of advancing our understanding of this problem. Just one week ago, I started an in situ culture experiment in Sagami Bay using a submersible Shinkai 2000 (JAMSTEC). The purpose of the experiment was to find out how benthic foraminifera repopulate on the substrate. I prepared different substrates: an artificial substrate made of very small silt size glass beads and a substrate composed of normal sediment I collected from the experimental field one month ago (I killed all the animals by the deep-freezing method). The third one is an enriched substrate. To the normal sediment, I added dried chlorella in the mat. And I set these substrates into trays and brought the trays into the deep sea where the depth is 1500 meters. Through this experiment we can learn the rate of repopulation of benthic foraminifera in the new substrate. I think if I retrieve these instruments next year, the results may be useful for waste disposal problem.

Koike: (comments)

During the presentations and discussions in this workshop, we have several options or scenarios for how to use the ocean to decrease carbon dioxide in the atmosphere. I assume, there are three cases for using the ocean to decrease carbon dioxide. Cases 1 and 2 are so called “carbon dioxide dumping”. Case 3 is the use of additional nutrients like iron fertilization to produce organic materials to use carbon dioxide in the atmosphere. So first, I will consider Cases 1 and 2, then try
to move to Case 3.

Dr. Nozaki assumed the very homogenous distribution of anthropogenic carbon dioxide in the ocean. If it is possible to achieve, it is the best way to do it. Because as he mentioned, the change introduced by these conditions will have minimal impact on the whole ocean (Case 1). In Case 2, there are some big tankers and pipes going down and dropping a big pile of carbon dioxide pellets on the bottom. The actual scenario for carbon dioxide dumping may possibly be like this. So what we should consider is what will happen in the deposition site and what will be the effect of this unusual environment on the whole ocean.

Then, I would like to present one example for showing the effects of this carbon dioxide dumping, that is the process of denitrification. There are several places which may be very significant for denitrification. One of the places is the water column. Eastern tropical South Pacific and North Pacific are also important, and also there are several other locations, such as near Saudi Arabia i.e. the Arabian Sea. The water column is anoxic and nitrogen is reduced to nitrogen gas. So the water column is one of the important areas of denitrification in the ocean. In sediment areas, for example estuary sediments and coastal and shallow coastal sediments, a quite large scale denitrification can also occur. Most deep sea denitrification estimations are very difficult to do. So mostly what we use is the profile in a sediment. So I will show you some of the profiles we obtained from the sediments. The profile of nitrate and nitrate from the Sagami Bay at about a 1,000 meter depth shows quick consumption in the top layer of sediment. It disappears at a depth of a few centimeters. So this means there is rapid consumption of nitrates which are probably changed to nitrogen gas. Another fact is that there are high concentration of organic materials. Thus, a coastal sediment has a very high denitrification activity. Then if you go to the open sea, e.g., the Ogasawara Trench (core sampled at an 8,000 meter depth), still you can see that the profile of nitrate plus nitrite, on the top, say, 5 cm, is a bit greater. Then it starts to decrease. This means, in reality, I would say that on the (very) top 5 meters (layer), the surface is oxic, so the increase of nitrate and nitrite means nitrification ... that there is still nitrification, even in this area. Then this produced nitrate is consumed which means that denitrification has occurred here, even in this really deep basin. I think this is because in this basin there is not only vertical transport but also horizontal transport, which is very important. Then if you go far beyond to the east from the Japan side, there is a 4,000 meter depth, and then the profile of nitrate shows steady increases. That means there is no more apparent denitrification. So the most active site of these biological activities in ... at least in a sediment (except for the thermally active site) is shallow coastal sediment.

In terms of denitrification, even if we put a 10 km × 10 km × 60 m block of liquid carbon dioxide, it is very easy to find negligible impact. If it stays there, it is very inert relative to the nearby environment. However, I have not mentioned for the organisms like the foraminifera sitting in exactly the same site. The effects are very serious. Relative to the geochemical cycle of elements, if you can find
some technique to isolate this carbon dioxide block from the environment, I think the impact will not be so serious. It depends on the technique, of course.

I would like to go back to Case 3, which is to introduce nutrients. It is another option we can consider. There are also two ways for this trial. One way is to put a limited number of nutrients like iron in not too concentrated amounts, spreading them, for example in the Southern Ocean or the Equatorial Pacific. Then their effect would not be so large. Again, it is a very difficult process. Technically it is not so easy to get a very homogenous distribution of these enrichments. Also, this kind of enrichment increases POM, which is another source of oxygen consumption. And these may be found all the way down to the bottom, so this decomposition must be quick enough not to produce anoxic or deleterious conditions for benthic organisms. But we could consider one more scenario, which is to try to concentrate these organic materials in some small basin, I do not know where. Furthermore, this scenario could present another future possibility: that of finding oil reserves, because today what we are burning is the marine organisms of long years ago which gradually accumulated and then changed to oil. Although I do not know how to change these organisms into oil, if we try to create an organic material, this could additionally be a potential source of future energy resources. My conclusion is that we should consider many aspects of the situation. Thus, we do not need to hurry to do more practical things. Basic science is much more important at this point.

**Handa:**

That might be the conclusion of this meeting. Dr. Koike talked of three methods for removing carbon dioxide from the atmosphere. He has given us a nice summary.

**Sakai:**

One thing I can imagine. If you have a layer of liquid carbon dioxide over the area of a limited basin, you have no supply of oxygen to the underlying sediment. So my question is, what effects would it cause in the long term? You showed that nitrification is not occurring, does that mean that there are no biological activities there?

**Koike:**

No, I am not saying that. The limitation is the supply of organic materials in most cases. Or oxygen, of course. In pelagic cases what is limited is the supply of oxygen from the interface of sediments. And also the supply is enough for the demands of organic matter decomposition. So the sediment itself is still oxic, and the increase of the levels of nitrate or nitrite means that the process of nitrification, which is the oxidation of ammonia to nitrate or nitrite, is going on. It is an aerobic process. So if we covered it with liquid carbon dioxide, I can imagine that since the supply of oxygen is really limited, nitrite would be reduced, using the organic
materials in the sediment. But that would occur only in exactly the place where you put the liquid carbon dioxide. So, the really important thing is whether this affects the surrounding area, or if it is really limited to the 10 km × 10 km site.

Jannasch:

On the oil formation, it has already been realized in the Gulf of California, but it requires high temperature. There the diatoms have been accumulating over the last, maybe, ten thousand years only. It is a very quick deposition of organic material from the overlying very rich water of the Gulf of California. The water is about 2000 meters deep and the sedimentation rate is very high. The hot water penetrates up and collects the lipids of diatoms into hydrocarbons. It is still spread in the sediment. It has not accumulated in layers. It will take another few million years. Then it will be accumulating. However, there is a lot of oil produced in that area, but it requires the cracking of lipids of diatoms into useful hydrocarbons. So, that is an area where rich phytoplankton production is indeed resulting in oil production in very recent times, that means only the last million years or so.

Shirayama: (comments)

I would like to read some comments on Cases 1 and 2, given by Dr. Koike. First, if Case 1 or Case 2 were carried out, what would happen to the benthic community? Then the second, if indeed disturbed the benthic community, would people agree to that policy or not. I do not want you to think I am a soldier of Green Peace, but I still would like to say of course that it can disturb the ecological balance. I would like to say that we should take a moment to learn well about the benthic community.

Let me start with the beginning with what happens, with the possible scenario, to the basic communities if we dump CO2 onto the deep sea floors. First of all, as Dr. Nozaki said, the pH of seawater will decrease. I do not know to what extent it would happen, but if it came to a level of 6.5, it could dissolve foraminifera, and so on. That would be very serious for these organisms. As Dr. Kitazato pointed out, the natural environment of the 6.5 pH for the foraminifera is not calcareous. It is only agglutinated, or collects only sandy sediment in that area. And if we release CO2 into carbonate sediment, then the carbonate will dissolve and that means the properties of the sediment will change. And I would like to emphasize one thing about that. The organisms living within the sediment use the interstitial spaces made of grains. Usually these large particles are made of calcareous material. If they emerge when CO2 has been released into the sediment, they might be in trouble.

As for the second part, the increase of P CO2 in seawater may affect the efficiency of their exchange or excretion of CO2 gases as their respiratory waste. I do not know for certain, but it is possible. At the start, I suspect that if we dump liquid CO2 into the environment, the temperature might be affected. If the temperature were affected, it would disturb the biology of organisms living in the
deep sea. And first of all, as Dr. Jannasch introduced to us, the organisms, especially the deep water organisms, are rather sensitive to changes of temperature. Also, on the basis of my experience, if we bring up deep sea organisms from the depth of the ocean and if they are exposed to 20°C, they will instantly die at these high temperatures. Second, some people say the deep water animals are still seasonal in their reproductive cycle. There are many arguments about these seasonalities, especially for reproduction. However, someone says there would be a very, very small change of temperature (as a result of the dumping of CO₂). I cannot agree to these opinions, but we cannot prove it right now. In other words, we can not say no to that. I would like to add something to these possibilities. One is that deep sea organisms are more sensitive than shallow water species to environmental changes. This is especially true if we see the results of the so-called DISCOL experiment. The DISCOL experiment is designed for manganese nodule mining. In that case, they disturbed the deep sea floor mechanically and made plumes of sediment from about 4,000 meters deep. After that happened, a few millimeters of sediment was deposited around the experimental site. Then they analyzed the benthic organisms around there. And they found a significant decrease in copepods and nematodes.

If we return to the discussion of yesterday, we dumped 10 km × 10 km × 60 m thick of CO₂. If the global effect of liquid CO₂ is the same as the local effect on the sediment deposit, then such experimental dumping must be spread more than a thousand km to assure the effect of CO₂ is negligible. The second thing I would like to point out is that once benthic fauna is disturbed, it is very difficult to recover. There are several experiments that Dr. Kitazato introduced just before. They put an abiotic sediment on the deep sea floor and tracked what happened after that. One example of such experimentation shows that about 140 days after the setting of the substrates their number was obviously much smaller than the ambient density of organisms.

There have been many other experiments so far. In these, even 25 months later, their density is only about 900, which is much less than the ambient density of about 5000 individuals per square meter. There was, however, one exception right here. In that experiment, their numbers rose steadily to five thousand after only 6 months. This was carried out by French people, and they argued that French cuisine is much better than other foods and even deep sea organisms prefer to eat it. Anyway, this experiment is not easy to replicate. Also, it is not easy to detect what happens in the deep sea, because the biological processes in the deep sea are very slow. Only a few millimeters, about a 10 millimeters mollusk requires on the order of 10 years to grow.

Let us go to the second part which means whether we can accept the disturbance or not. On this point, I would first like to say two things: one is that deep sea organisms provide good gene pools. I mean they are good sources of DNA. We do not know very well about these diverse organisms yet and if we cause the extinction of certain species, we may lose very good gene sources. Also, from
the biological point of view, the many so-called "living fossils" are found in the deep sea areas and we biologists are always eager to know the evolutionary scenario and we want to study there much more before the previously discussed disturbance. On that point, I would like to emphasize three things.

One is that the deep sea communities are very, very diverse; they are as diverse as coral reef faunas. Consequently, each species has only a few individuals, so it is very easy to make them extinct. If we want to avoid such an outcome, then we must dump in a very low diversity area where biomasses are rather high, which would mean that you could not hide the disturbance. For example, relative to species diversity, I mean that if you collect 15 individuals of 100 individuals, the number of species you can find is very high in the San Diego Trough of the Central North Pacific, down the Aleutian Trench area or in the St. Catania Basin. These two differences are mainly only whether the habitat is stable or not. These two are rather more stable than in other areas and there are some theories for explaining this. There is a tendency that the diversity of these species will increase with depth at first and then decrease. This species diversity will be determined in balance with how frequently disturbances of the habitat occur and how severe the disturbances are. The balance of these two factors, the best balance, is achieved here at about 3,000 meters depth, as far as we know. So species diversity is the highest right here. On the other hand, the biomass of organisms will at first decrease with depth. Perhaps any organism goes down like this (under the same circumstances). But in the trench area the biomass will suddenly increase again, for usually the trough biomasses are higher than those of the flat ocean basin. Thus, these two factors are always in discordance. And so, in conclusion, we want to learn much more.

**Handa:**

Thank you very much Dr. Shirayama. I think he elucidated two points. One is what carbon dioxide dumping does, how the carbon dioxide dumping disturbs benthic communities, and also, he discussed whether we can accept those disturbances. It is a very important review from a biological standpoint. Do you have any questions or comments.

**Nozaki:**

Let me ask you a very drastic question. If we kill all of the benthic organisms, what will the problem be? In other words, is there any connection, ecologically, is there any effect there? For fish or something?

**Shirayama:**

I do not think so. Maybe the connection is not so serious. But from a purely scientific point of view, we wish to know more about the biology of these organisms. And they may give us significant breakthroughs in some biological arguments which we cannot solve using surface organisms.
Jannasch:

I would like to comment on this last point a little bit. Because if we exclude the deep sea from the recycling of organic matter, we exclude all of the upwellings from the replenishment of surface water of the nutrients. Fish stocks will be horrendously diminished all over the world. We will have, say, an increase of pH in deep water and a decrease of microbial decomposition. We would have accumulation of organic matter in this area. That would immediately be shown, not immediately, but there would be a lag time. There would be a tremendous change of the recycling rate of nutrients. The turnover into organic nutrients is very important. You cannot grow fish or phytoplankton on organic matter. So organic matter has to be decomposed into an organic form. So that would be the main effect. I will really propose an experimental work on it. I am an experimentalist. I cannot think of other ways of doing it. And this is very easy: by having pressure chambers and low temperature, having the seawater and adding CO₂ and seeing what is the rate of microbial decomposition of certain compounds. That could be done immediately and would answer one question.

Shirayama:

Yes, I perfectly agree, and we want to have the chance to carry out the experiments right here.

Koike:

Regarding the DNA diversities, do you have any idea, if we take an area of 100 km × 100 km, and if we eliminate all the, not macrobentic, but microbentic or bacteria from this area, will you lose any quite unique organisms from this area or not?

Shirayama:

I guess we will lose certain species, there is no doubt, because if you see trenches from the Aleutian, to the Japan, to the Ogasawara Trenches, and each trench is, only a portion of these innate fauna is overlapping. Much of the innate fauna of each trench is unique to each other. So the gene pools between these two area is very small. So once you eliminate everything in certain places, I think it is easy to lose a gene pool.

Tietze:

I think the question before was put as a joke ... but to many people who were asked such a question, it is not a joke. Therefore, I think it is important from the standpoint of principle that we do not neglect the fact that organisms could be removed from our planet, and it is also the standpoint on many that organisms are lost each day or each year, hundreds of organisms, so I think it is very important that we have species diversity. (That means) we should not work with the whole ocean. We should not allow the disposal of carbon dioxide in the whole ocean, but
only in very limited areas where we have barriers so that the carbon dioxide will not come out quickly into the ocean, but rather, slowly, after about several hundred or thousand years, so that the ocean is not disturbed in a large area.

Furthermore, even if we must stop disturbing such a small area, it is necessary not to disturb the atmosphere so much because the greenhouse effect is increased, and many fish and other animals will die because the temperature of the ocean will rise, and the birds will not be able to pick up fish or other things. So we must make a compromise by this. But the principle must be to work in such a direction that no animal species will be lost or will be allowed to be lost in the world. So that I think that although this question was meant as a joke.

**Handa:**

However, the biological effect of the carbon dioxide dumping, I think, is the most important thing if we really conduct ocean dumping.

**Horikoshi:**

Prof. Jannasch indicated the final catastrophe, but I think that before that the most affected organisms would be benthic organisms. And if the benthic organisms are destroyed in a very wide area like the whole Pacific Basin, still the surface area is healthy, so the surface production must be going on like today. There must be a rain of organic matter every day, every hour, which must be accumulating on the deserted sea floor. And also, there are some other flux or sinking of organic matter, that is, larger organisms like whales, dolphin, tuna fish and so on. And they sink down to the bottom, and as Dr. Jannasch touched upon this morning, many Archepose and many Macouridiae and other brotulid fish will accumulate, or will gather around such nice carcasses, such large fish and whales. And if they come after the ocean floor has become so deteriorated, such fish and so on will also be damaged very much. That in turn will cause an accumulation or deposition of organic matter, not eutrophication by hypertrophication. And I think that an anoxic environment can be established all over the Pacific Ocean, or something like that. So I am afraid of that.

**Jannasch:**

You mentioned that deep sea trenches are particularly rich and I did not really know that. There might be the idea that the deep sea or the whole ocean might be a very good place where CO$_2$ cannot be dispersed from, to fill it up with CO$_2$, if it is a dead area anyway. But you are saying that deep trenches are rich, so they must be a part of the nutrient circulation pattern of the ocean in general. Do you have any comments on that? I do not know much about deep sea trenches.

**Shirayama:**

The data of Dr. Koike will give us some insight that denitrification is occurring, even at eight thousand meters just like at 1500 meters. And on the basis
of the biomass point of view, it is that the richness is close to about 1500 to 200 meters, and we had so many trace fossils from sediments collected from the trenches. So their activity seems also very fast. I mean, the biomass does not mean the biological activity as a whole, but still, under extreme pressure they seem to be very active. And even some strange animals are concentrated into these subsurface areas and they may disturb the distribution of trace metals and so the trench area, I think the trench area is a very active place, even more active than the ordinary red clay deep sea floors.

Handa:

I think that the organic carbon concentration of the trench areas, I mean, in deep sediment, is usually a little bit higher than the ordinary sediment of ocean floors. So it seems to me that the biological activities in these trench areas, especially at the bottom of the trench, might be much higher than that in open oceans. So I think that trench areas are sometimes very important for biological beings.

Horikoshi:

About the trench area, the trench is, it seems, a kind of trap. And anything, organic matter, particulate organic matter, can come down but cannot go out. And there are many waste products, too. We tried deep sea trawling two times along the axis of the Japan Trench. And each time we picked up so many plastic bags. Yes, that is one example of how the trench is quite a good trap of everything.

Shirayama:

What I would really like to know is whether for Case 1, the carbon dioxide can be piled up to 60 meters, or will they disperse to a very thin layer and cover a very wide area of the sea floor. Or can they be stacked up in a very high, towerlike structure?

Ohsumi:

While the coffee break, Dr. Soh and I were just discussing about my scheme of liquid CO₂ deposition in a carbonate covered area. He said that we possibly have such depression suitable for deposition and that because the carbonate sediment is quite porous, at the bottom of the deposit of the block, there are some parts where the neutralization or dissolution of carbonate may happen. In that case, automatically at the bottom of the deposit liquid CO₂ percolates or permeates into the sediment. Anyway, we should know more about what is the best place to deposit or how we can dissipate the CO₂ quickly. Maybe this is the first occasion for every participant to make this kind of thought experiments, I think.

Sakai:

I think there are many things we do not know yet. For instance, from the
chemical point of view, people are talking about the reaction between liquid carbon dioxide and calcium carbonate. But liquid carbon dioxide would not react with calcium carbonate. We need water. So what dissolves calcium carbonate is the carbon dioxide rich water, not liquid carbon dioxide. However, there must be water in the existing sediment, so as long as we have water, the reaction will go on. The important thing is how far the mass of water which contains sufficient amounts of carbon dioxide will spread laterally or vertically.

_Jannasch_:  
If I understand that correctly, I am not a chemist, that the the solid phase of the carbon i.e. carbon dioxide hydrate, is in equilibrium with the aqueous phase. So if the aqueous phase is constantly removed in a small way by currents and so on, the deposit will slowly disappear. And it will still be a part of the water column. Or it will be transported to somewhere else and will eventually come back to the surface. So that means there is no way to deposit carbon dioxide forever on the deep sea floor.

_Tietze_:  
Before we make an experiment, I think we can make a thought experiment. That is the normal working method for physicists. And if we look here to such a depression, where we have a liquid lake of carbon dioxide, what will happen there? What will happen is that water will dissolve in carbon dioxide. There will be a layer of carbon dioxide which contains water, and also carbon dioxide will dissolve in water. And it will reach saturation level. That means that no more carbon dioxide could be dissolved in the water. And when we are in a region where the temperature is very low, carbon dioxide cannot go into the gaseous phase. We will have an exchange with the open ocean, and the ocean current will take that carbon dioxide which comes out by eddy diffusion. And it will be at a relatively low rate. That means that such a liquid lake could really exist a longer time. If there were not many disturbances in that areas, and if we filled the depression do not fill it more than 50 percent so that there exists the region with carbon dioxide saturated water could build up, then we would have here a relatively slow exchange. And also this would migrate to sediment in the other direction, and possibly disappear after several years, ten years, or a hundred years.

_Nozaki_:  
I just want to get back to the question about what the final fate of the excess CO₂ in the ocean will be: probably, dissolution of calcium carbonate, neutralization with the solution of calcium carbonate, and result in the increase of the alkalinity. So once it happens, the CO₂ will not come back to the atmosphere again.
Grove:

Right now I know there is a reference, it appears, you know, in 1983 talks about a two meter layer of hydrates on the sea bottom near Guatemala, on the Pacific side of Guatemala. I do not know whether this is common, but this was discovered in a Deep Sea Drilling Program and the way it was discerned that there was a complete layer of hydrate is with electrical resistivity. So from the drilling program, they could discern the presence of hydrates and maybe there is a record you could go back to and look at the resistivity data and find out and start mapping where some hydrates occur naturally and thickness and then maybe you could do some biology studies, some observation in these areas. When you do that, well, you could try to decide whether hydrates that would be put down by man are going to disperse or going to settle in the layers. So I think there might be some observational studies possible here.

Jannasch:

I would like to repeat that my preference is on the experimental work and I think for future meeting and plans, one should design already some work that should be done. This might be very good in looking for funds to do it. That is anyway the way it is done in the United States. You cannot do anything without money to do it. So a meeting like this might be very conducive for plan, certain experimental approaches to the problem besides the theoretical and the environmental considerations and so on. And I agree probably the separation between the scientists and the engineers is good, because the engineers would not be interested in this and we often do not use the feasibility studies of the engineers. There are some proposals I would include in such an experimental work. We have not only a CO₂ problem but we also have a hydrogen sulfide problem in this world. We are pumping hydrogen sulfide that is coming from all our mining work into the atmosphere. We are pumping it out and we get the acid rain problem. Now we have seen from the deep sea vent work, that hydrogen sulfide and CO₂ go together very nicely. They are producing organic matter. CO₂ is removed by oxidizing hydrogen sulfide with CO₂. And that is the chemosynthesis that I mentioned in this meeting. Now what one can do experimentally and possibly on a fairly large scale is to use all the hydrogen sulfide we have, not all of it but that which is available from the power industry, and to bring it together with CO₂ in a marine aqueous environment, and produce bacterial biomass. This material is excellent because the composition can be kept very constant. It is a carbohydrate that is good for two things, and we have already done some preliminary work in that. One is in aquaculture. We can feed it to mussels. Mussels are particular animals that pick up smallest particles of the size of 1 micron. So they eat pick up bacterial biomass as food. We have done ¹⁴C work where we label the ¹⁴C and CO₂ as it passes through microorganisms into mussels, and we can show that bacteria as food are almost as good as the phytoplankton that mussels live on, the detritus of phytoplankton. So mussels could be grown in small mussel ... colonies or in
mussel farms underground in pipes. After CO$_2$ and H$_2$S are mixed with seawater in a bacterial biomass generator it goes extremely fast. We get very small generator that is a container of about 3 or 4 liters. We get half a gram of dry weight which is a lot of material in wet weight in one day to produce. And we have grown mussels on material. All this has to be upscaled into large pilot plants. I think that could be very feasible. Its second application or use of this biomass can be for the fermentation industry. This carbohydrate is excellent for making propanol and ethanol for synfuels. This is one way. Of course, then it goes back into CO$_2$ as it is burned off. The other way is rubber making. So this is a material that can be produced from hydrogen sulfide in the marine environment because the waste product would be sulfate. That sulfate would go as the only waste material back into the seawater. And that increase would be very, very small. So this is a proposal that might not take a tremendously large amount of CO$_2$ but would take away hydrogen sulfide. So these two incentives are very important. And there may be a product that can be sold, as aquaculture or in the fermentation industry.