

# **The Winners of the Blue Planet Prize**

**2005**

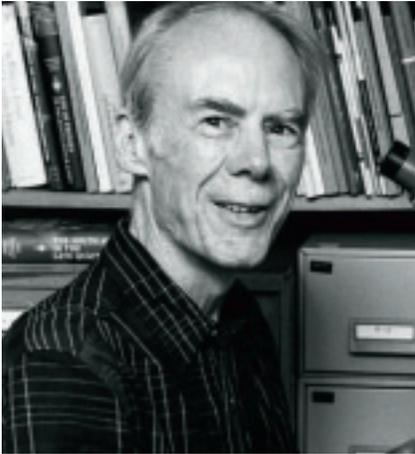


2005

## Blue Planet Prize

### Professor Sir Nicholas Shackleton (U.K.)

Emeritus Professor, Department of Earth Sciences, University of Cambridge  
Former Head of Godwin Laboratory for Quaternary Research



### Dr. Gordon Hisashi Sato (U.S.A.)

Director Emeritus, W. Alton Jones Cell Science Center, Inc.  
Chairman of the Board, A&G Pharmaceutical, Inc.  
President, Manzanar Project Corporation



#### **The Sign:**

The earth is engraved with the wisdom of nature, leaving its impression in the changes of the weather, and in the behavior of animals giving them life. Humans have forgotten to listen to the suffering earth, or to notice the state of living creatures. The 2005 opening film touched on the signs in the earth's history that pointed towards the future and the creatures that live there.



His Imperial Highness Prince Akishino congratulates the laureates



Their Imperial Highnesses Prince and Princess Akishino congratulate the laureates at the Congratulatory Party

The prizewinners receive their trophies from Chairman Seya



Dr. Gordon Hisashi Sato



Prof. Sir Nicholas Shackleton



Dr. Jiro Kondo, chairman of the Presentation Committee makes a toast at the Congratulatory Party



J. Thomas Schieffer, Ambassador of the United States of America to Japan and Graham Fry, Ambassador of the United Kingdom to Japan, congratulate the laureates



Blue Planet Prize Commemorative Lectures

## Profile

# Professor Sir Nicholas Shackleton

Emeritus Professor, Department of Earth Sciences, University of Cambridge  
Former Head of Godwin Laboratory for Quaternary Research

### Education and Academic and Professional Activities

- 1937 Born on June 23, in London
- 1961 B.A. University of Cambridge
- 1965-1972 Senior Assistant in Research, University of Cambridge
- 1967 Ph.D., University of Cambridge
- 1972-1987 Assistant Director of Research, Sub-department of Quaternary Research, Cambridge
- 1974-1975 Senior Visiting Research Fellow, Lamont-Doherty Geological Observatory, Columbia University
- 1975-2004 Senior Research Associate, Lamont-Doherty
- 1985 Fellow of The Royal Society
- 1987-1991 Reader, University of Cambridge
- 1988-1994 Director, Sub-department of Quaternary Research, Cambridge
- 1990 Fellow, American Geophysical Union
- 1991-2004 *Ad hominem* Professor, University of Cambridge
- 1995 Crafoord Prize, Royal Swedish Academy of Science
- 1995-2004 Director, Godwin Institute of Quaternary Research, Cambridge
- 1998 Knighthood (for services to the Earth Science)
- 2000 Foreign Associate, US National Academy of Sciences
- 2002 Ewing Medal, American Geophysical Union
- 2003 Urey Medal, European Association of Geochemistry
- 2003 Royal Medal (Royal Society of London)
- 2004 Vetlesen Prize, Columbia University
- 2004 Emeritus Professor, University of Cambridge
- 2005 Founder's Medal, Royal Geographical Society
- 2006 Deceased, January 24

It is important to know and understand climatic change over the past in order to simulate future climate change more reliably.

After graduating from Cambridge University with a B.A. in physics, Professor Shackleton received a Ph.D. with a thesis titled "The Measurement of Palaeotemperatures in the Quaternary Era" in 1967, and focused his attention on the geologically most recent period

in the earth's history, the Quaternary which covers about the last 1.8 million years.

During the ice age when ice sheets up to 3 km thick covered North America and Scandinavia, lighter oxygen isotope  $^{16}\text{O}$  was trapped in the ice sheets and the remaining ocean water have been enriched in  $^{18}\text{O}$  by a measurable amount. He developed a high-resolution analysis method for oxygen isotope ratios in the tiny fossil shells of foraminifera from the oceans globally and devised a method to analyse more accurately the fluctuations in size of ice sheets which developed many times during the period, and made contributions to palaeoclimatology.

In 1973, he analysed a core from the western tropical Pacific that contained evidence of the most recent reversal of the Earth's magnetic field that occurred about 780,000 years ago. It was obvious that the ice-volume cycles that he reconstructed occurred roughly every 100,000 years, and he established a method for assigning an age scale for a core, based on the 100,000-year cycles from the core.

Further work on the cyclicity in the sediment cores revealed that the major cyclice was in sync with the major changes in the eccentricity of the earth's orbit, and a paper was published in 1976 together with Drs. J. D. Hays and J. Imbrie, which validated the "Milankovitch hypothesis" that hypothesized the idea that cyclical changes in the three elements, earth orbit eccentricity, angle of its rotational axis (obliquity) and precessional changes, caused the glaciation that had occurred during that time.

In the 1990s, after French and Swiss scientists measured the carbon dioxide in air bubbles trapped in ice from the Vostok ice core in central Antarctica and revealed the atmospheric carbon dioxide concentration for the last 420,000 years, he used the carbon isotope ratios in fossil foraminifera to reconstruct past carbon dioxide concentrations. His reconstruction was surprisingly similar to the first record obtained by French and Swiss scientists. In a later study he showed that carbon dioxide was a major contributor to past global climate change during the period and that in fact the main features of climatic variability over the past million years can be explained taking account of earth's orbital changes as well as natural carbon dioxide changes.

Recently he worked on the detailed record of the last glacial cycle. He showed that a drastic warming and cooling, such as, temperature difference of 10 degree within 30 years which the earth had experienced known from the study of ice cores from Greenland can also be found in sediment cores from the North Atlantic.

Professor Shackleton had major influence on the development of Palaeoceanography and Palaeoclimatology, and served central roles in several international research projects. He published more than 200 papers including highly renowned ones, taught and brought up many young researchers, and was major thrust in these field with his highly positive attitude. Besides serving as Director of the Godwin Institute for Quaternary Research, he served many key positions such as the President of the International Union for Quaternary Research.

Professor Shackleton had an idea that by knowing the past global climate and eventually the earth's environment through the research in geology, this would enable us to find a way to tackle the issue of global environmental change in the future, and thus contribute to society. He poured in his enthusiasm into understanding global climate change during the Quaternary

which was also considered as the human era, and he sounded a warning that we should be aware that increase in global warming gas may possibly trigger a rapid climate change that had happened in the past again in the future, and urged that the human race must make efforts to control the release of greenhouse gases.

Professor Sir Nicholas Shackleton passed away on 24 January, 2006. May he rest in peace.

## Lecture

# Geological Deposits, Geological Time and Natural Changes in Climate

Professor Sir Nicholas Shackleton

### What are geological deposits?

A geologist who is examining material hundreds of millions of years old with the aid of a geological hammer, might use the expression 'geological deposits' as synonymous with 'rocks'. However as one becomes interested in younger material one has to consider deposits which have not yet experienced sufficient time, pressure and temperature to be converted to rocks. In addition, one can consider deposits such as the ice in the Greenland ice cap that remains a geological deposit until such time as it melts. In my interpretation, even the bubbles of air that are trapped in this ice constitute geological deposits. The annually ringed trunk of an ancient tree may be thought of as a geological deposit, whether or not the tree is living today.

Two very important descriptors of a geological deposit are accumulation rate and time resolution. On a cut cross-section of a tree, one can see every yearly increment so the resolution is described as annual. The accumulation rate, or radial growth rate, may be of the order 1mm/year. In reality it may be possible to distinguish spring growth from summer growth but it is not possible to extract monthly information. On the other hand, a mollusc might accumulate a similar thickness per year but might preserve a weekly resolution provided a suitable sampling method is used. On the other hand a muddy, estuarine sediment might accumulate at a similar rate but might only offer a resolution of a hundred to a thousand years due to the prevailing mixing by burrowing organisms on the sea floor (bioturbation) and mixing by bottom currents.

If funding and time permits, I believe that a scientist should sample a geological section at close enough depth intervals to achieve the temporal resolution required for his/her project, or as close as the resolution of the deposits allows, whichever is the smaller. People often ask me what are the secrets of my success, and I believe one of them is that I have always preferred to sample as closely as circumstances permit. In contrast, many of my friends would prefer to sample as long a record as possible, sacrificing resolution. It could be argued that the benefit of my approach is purely aesthetic; the closely-sampled record looks nicer. But undoubtedly the densely sampled record gives the reader greater confidence in the data, because it is easier to see just how reliable the measurements are.

### What have I measured? stable isotope ratios

The Chicago scientist Harold Urey was awarded the 1934 Nobel Prize for discovering Deuterium, the heavier isotope of hydrogen. In 1947 he published a seminal paper<sup>1</sup> on fractionation between the stable isotopes of a variety of elements. Here "fractionation" refers to a

process in which some matter is separated in such a manner that one fraction contains proportionately more of the heavy isotope, while the remainder has proportionately more of the light isotope. For example, in nature it is observed that when water evaporates the water vapour is depleted in the heavy isotope of oxygen  $^{18}\text{O}$  and the remaining liquid is slightly enriched in  $^{18}\text{O}$ . The reason is that it requires slightly more energy to hold a heavier water molecule in the vapour phase. In his 1947 paper Urey calculated the magnitude of this effect both for the case of the evaporation of water and for many other phase transitions and chemical reactions. One example involves the crystallization of calcite (calcium carbonate) from water, and here not only did Urey calculate the  $^{18}\text{O}$  fractionation between the water and the calcite, but he also calculated the effect of temperature on this fractionation. He then suggested that if this fractionation could be measured at different times in the geological past, it would be possible to estimate the palaeotemperature at the time of crystallization.

Together with a team of brilliant colleagues Urey set about developing this idea into a viable tool. This entailed: 1. developing a sufficiently precise mass spectrometer for measuring the isotope ratios; 2. developing a method for extracting  $\text{CO}_2$  from carbonate without introducing additional fractionation; 3. demonstrating that the fractionation exhibited during calcite crystallization is as predicted by theory; 4. demonstrating that biogenic calcite undergoes the same  $^{18}\text{O}$  fractionation during shell growth as does calcite that grows inorganically; and 5. demonstrating that the method does actually give reasonable results for fossils. All this was achieved in a remarkable series of papers published in the early 1950's<sup>2</sup>.

One additional scientist was needed to set the scene for my entry into the field. Cesare Emiliani came to Chicago already fortified by a PhD in micropalaeontology (the study of microscopic fossils) from the University of Bologna in Italy. Using the techniques that Urey's team had developed he set out to measure palaeotemperatures in a range of deep-sea sediment cores and rock outcrops. His outstanding publication (1955)<sup>3</sup> was entitled "Pleistocene Palaeotemperatures". In this paper Emiliani gave palaeotemperature measurements in cores that covered over half a million years (as we now know) in cores from the deep Caribbean, equatorial Atlantic, and North Atlantic.

After the second World War Dr (later Sir Harry) Godwin formed a Sub-Department of Quaternary Research as a small research unit within the Botany School in Cambridge. He was an all-round botanist and the founder of pollen analysis in Britain. He set up this group because together with the archaeologist Graeme Clarke he was working on vegetational change in Britain in relation to the prehistoric humans. Godwin set up the first radiocarbon dating laboratory in Britain in the 1950's and so was able to put the human and vegetational changes in a reliable time frame for the first time. About 1960 Dr (later Sir Edward) Bullard suggested that Godwin should seek funding to set up a laboratory for stable isotope analysis. The idea was that in Eastern England marine deposits exist that contain pollen from the nearby land mass as well as marine fossils; Bullard suggested that the combination of palaeotemperature analysis using  $^{18}\text{O}$ , and pollen analysis would make a unique contribution. Godwin's grant application was successful and through a series of random events I was the person who he selected to get the project under way.

Urey's team had not been limited as regards sample size because they worked with rel-

atively large fossils. Emiliani worked with the same equipment – indeed when he moved to a permanent position in the University of Miami he took one of the Chicago mass spectrometers with him. He was obliged to pick up to 400 foraminifera for each analysis in order to make up the 5 mg of carbonate that was needed. I soon realised that if I was to set up a successful laboratory without the need to rely on a team of assistants, it would be necessary to have a mass spectrometer that was about ten times more sensitive than this. The means by which I accomplished this are only of historic interest today<sup>4</sup>. However it is important to realise that at the time this was a considerable achievement and for many years my reputation was mainly as “the person who can analyse <sup>18</sup>O in tiny samples of foraminifera.” I had devoted the last year of my undergraduate studies to physics, absolutely essential training given that my first task was to rebuild a commercial mass spectrometer such that it could attain the specifications that I needed. Over the next years I learned a great deal about the disciplines with which I would interact as well as keeping up with Emiliani’s work, and one of the areas that I covered was glaciology (aided by the existence in Cambridge of the Scott Polar Research Institute). Hence I discovered a fatal weakness in Emiliani’s brilliant papers. Emiliani had appreciated that it was necessary to make a correction for changes in the isotopic composition of the ocean when huge ice sheets accumulated on North America and Fennoscandia. This is because the removal of isotopically depleted water to form the ice sheets must have left the ocean slightly enriched in <sup>18</sup>O. However when I started to calculate this effect more carefully I realized that Emiliani had seriously underestimated it and indeed that it must have been the dominant cause of the variations in <sup>18</sup>O in many of the cores that he analysed<sup>5</sup>.

At first sight this discovery appeared to weaken the attraction of the field, but I was able to see it in a different light and to offer two entirely new contributions. First, it would be extremely valuable to be able to generate a record of global ice volume through time. By selecting cores from areas where temperature variability might be small, I could optimise the value of the measurements from the ice volume point of view. Second, subject to the limitations of each individual core, I could use the <sup>18</sup>O record to correlate any core to a master curve. As it happens the second contribution gained me a large group of high-level colleagues and this enabled me to achieve the first. John Imbrie, Andrew McIntyre and a number of others had embarked on an ambitious project named CLIMAP, to generate a map of the surface temperature of the ocean at the time of the last glacial maximum. They had already achieved one task that would be needed for this endeavour; they had found a means for mathematically analyzing quantitative faunal data from each sample going down the core so as to estimate a record of changing sea surface temperature. However they were stymied by the other problem: how to locate the horizon in each core that corresponded to glacial maximum. When I said that that would be easy with my method they were amazed and immediately invited me to join the CLIMAP team (which up to that point was an exclusively American venture). The publication in 1976 of the CLIMAP map of sea-surface temperature during the last ice age maximum<sup>6</sup> was huge accomplishment for the reason (among others) that it provided sufficient data for numerical atmospheric modellers to reconstruct atmospheric circulation in glacial times. One of the many scientists who was stimulated by this opportunity was Syukuro Manabe, winner of the first Blue Planet Prize.

Working with the CLIMAP community, and spending many months in the USA, gave me access to two incredibly exciting ventures. First, I wanted to analyse a long Pacific core. My friend Jim Hays taught me to look at deep-sea sediment cores and showed me the cores from the East Pacific that he had worked on with Neil Opdyke and others. However the pattern of cyclic carbonate dissolution that he had worked on was a disadvantage from my point of view, because I wanted to analyse calcite Foraminifera that had not been subject to dissolution on the sea floor. I then turned to the West Pacific and with the assistance of Neil Opdyke I found what I wanted; a core that appeared uniform from top to bottom. Its reference number is V28-238; number 238 of the cores collected during the 28<sup>th</sup> cruise of the Vema. Neil Opdyke had already located a reversal in the direction of magnetization of the sediment at twelve metres in the sediment; the last time the direction of the Earth magnetic field reversed was about 730 (now known to be 780) thousand years ago. This is known as the Brunhes-Matuyama boundary. With Mike Hall to assist me, we worked steadily down the core (Mike Hall has worked with me for forty years starting as a junior technician). Each day I plotted the measurements on graph paper, gluing on extra pieces when necessary. Any suspect measurement I would try to replicate three more times. The excitement was palpable as we saw all the features of the Caribbean records published by Emiliani, and then continued into unknown territory. I could see nothing wrong with the core (Though I looked forward to being the first person to replicate it). I could also see that with the benefit of the Brunhes-Matuyama boundary fixed at 12 metres in what I called Isotope Stage 19, the time scale that Emiliani has set up, extrapolating from very shaky dates near the top of his cores, was too short. There were many important conclusions to be drawn and I wrote what has proved to be a very influential paper<sup>7</sup> that has been cited well over a thousand times.

Soon after that I saw the opportunity to analyse another long core. An Englishman named David Parkin had developed a method for estimating changes in the vigour of the wind that blows dust out into the Atlantic Ocean from the Sahara Desert. He had a long record that included the Brunhes-Matuyama boundary and since the data showed most vigorous winds near the top of the core he concluded that winds were weaker during glacial times. I persuaded him to delay publishing his conclusions until I could develop an oxygen isotope record and establish whether greater wind vigour was consistently associated with lighter <sup>18</sup>O values. It turned out that David Parkin had missed the very short Holocene and that in general more vigorous winds were consistently associated with the glacials. This study<sup>8</sup> confirmed the importance of my oxygen isotope stratigraphy; suddenly a method existed by means of which a record of variations in an important palaeoclimate parameter (in this case, wind) could be directly linked to a standard stratigraphy and associated time scale. Soon after this, Neil Opdyke suggested that I should work on another core V28-239 that extended about two million years into the past. The accumulation rate of this core was lower but by analysing it every 5cm instead of every 10cm I was able to obtain a nice record of the whole Pleistocene<sup>9</sup>.

When I first showed the data from core V28-238, my colleague John Imbrie immediately wanted to perform a spectral analysis of the data, in order to test the long-standing "Milankovitch Hypothesis". In the 1920's Milutin Milankovitch has hypothesised that the ice ages were caused by changes in the distribution of the sun's energy over the earth, which in

turn arise due to changes in the geometry of the earth-sun system. It had never been possible to test this because continuous records of changing climate were not available until Emiliani published his  $^{18}\text{O}$  records, and because these could not be used because of the lack of age control. We started working of the spectral analysis but then it emerged that Jim Hays was working on cores from the subantarctic Indian Ocean that had several advantages over my core. Most important, they had twice the accumulation rate of core V28-238. Jim Hays generated records of sea-surface temperature in the Southern hemisphere, while I generated a Northern hemisphere record from the  $^{18}\text{O}$  measurements, since the fluctuating ice sheets accumulated on the Northern hemisphere continents. We showed<sup>10</sup> that the three periodicities with which the orbit changes (100,000 years, 40,000 years and 21,000 years) were all present in the data, just as Milankovitch theory predicted.

We realised while finalising the publication that it was possible to fine-tune the time scale by aligning the cycles in a core with those calculated by astronomical theory, by the early 1980's we had constructed an astronomically tuned and averaged stable isotope record known as the SPECMAP stack<sup>11</sup>, which has been incredibly valuable as a template for workers to place their data on a highly detailed common time scale. In 1991 I improved this with new data and was able to show that the age of the Brunhes-Matuyama reversal was 780,000 years rather than 730,000 years as had been believed<sup>12</sup>; I also recalibrated several earlier reversals. Surprisingly, these recalibrations were very soon accepted because new laboratory measurements also suggested that the published ages required correction. I was able to carry the work further back in time, ultimately calibrating the geological time scale back to about 30 million years<sup>13</sup>.

In 1975 I was invited to a meeting in Hawaii concerned with carbon dioxide, and I decided to think about the isotopes of carbon. Every day that I collected  $^{18}\text{O}$  data I also collected  $^{13}\text{C}$  data but up to that time I had only used them to make a small correction to the  $^{18}\text{O}$  measurements. The most important process that gives rise to variations in  $^{13}\text{C}$  in nature is photosynthesis; plants, and organic matter that derives from them, contain about two percent less  $^{13}\text{C}$  than the  $\text{CO}_2$  from which they grew. When I saw in my collection of  $^{13}\text{C}$  data that the ocean has undergone systematic variations in the  $^{13}\text{C}$  content I reasoned that the only plausible explanation had to be was that the mass of organic matter on planet Earth had fluctuated on a glacial-interglacial time scale. Investigating the literature I found that the area that is covered by tropical rainforest was reduced during glacial times because it was drier. At the same time large areas of terrain that are now vegetated, were then covered by ice sheets. It seemed that I had stumbled across a method for estimating changes in the mass of organic matter covering the continents. When the continental biomass (including soil) diminished, the organic carbon that was released must have oxidised and ended up in the ocean<sup>14</sup>.

Soon after this, two reports appeared claiming that the concentration of carbon dioxide in "fossil" air bubbles from the glacial part of the Antarctic ice sheet is less than that of pre-industrial air. Wallace Broecker (another past Blue Planet Prize winner) gave a talk which I was lucky enough to hear before he published it<sup>15</sup>. He explained that the only mechanism capable of reducing the carbon dioxide in the atmosphere from 280 to 200 parts per million by volume was one that transferred it to the deep ocean, and he described the working of the "bio-

logical pump” that controls the equilibrium pressure of carbon dioxide over the ocean. In the ocean surface layer photosynthesis removes some of the dissolved carbon dioxide by converting it to organic matter, which sinks to the deep ocean and oxidises there. The proportion that can be photosynthesised is limited by the concentration of nutrients in the surface water. This process leads to an enrichment in  $^{13}\text{C}$  in the remaining dissolved carbon dioxide that is available for Foraminifera to build their calcite shells with. Meanwhile the rare genera of Foraminifera that live on the sea floor build their shells from average ocean carbon dioxide, so that the strength of the “biological pump” can be monitored by the  $^{13}\text{C}$  difference between the shells of the planktonic (floating near the surface) foraminifera and the benthonic (living on the sea floor) foraminifera. I sought a suitable core and carefully selected benthonic and planktonic specimens to get the best record. Sure enough there was a larger  $^{13}\text{C}$  difference between surface water and bottom water in the glacial part of the core, consistent with the published data from the ice cores that showed a lower carbon dioxide concentration in the air bubbles from glacial times. I continued and obtained a record that predicted similar values to today in the last interglacial. My glaciologist friends in France were shocked when they saw this record published in the journal *Nature*<sup>16</sup> because they had already analysed ice from the Antarctic ice core at Vostok, and saw at once the similarities between their real carbon dioxide record and my reconstruction.

I have reviewed for you some of the work I have done which may give you an idea why I have been selected for this wonderful award. Each publication was based on a lot of new analytical data, and indeed much of my success has depended on the fact that I and my assistant Mike Hall have always had the philosophy that to justify the support of my funding agents, the lab ought to be generating data all the time. However five years ago I wrote a paper that contains no new data and instead is based on combining data from my lab with different data published by Robert Petit and his colleagues in the French ice core community. In some ways I regard it as my best paper<sup>17</sup> and of course it is far too complicated to explain to a general audience. Nevertheless I will explain some of its importance. The key was the fact that there is a record from the Vostok ice core of the changing isotopic composition of the atmospheric oxygen that is trapped in bubbles in the ice. The trapping occurs at the point where that accumulating snow on the ice surface becomes sufficiently packed down that the air can no longer exchange with the overlying atmosphere (this trapping happens tens of metres below the surface). Now atmospheric oxygen equilibrates with ocean water through global photosynthesis with many complex steps, but if everything else is assumed not to change, the atmospheric oxygen would follow changes in the isotopic composition of the ocean with a lag of about a thousand years. By comparing this record with the deep-sea oxygen isotope record from carbonate microfossils, I was able to separate the ice-volume component of the many deep-sea records I had published from the temperature component, something that we have never previously been able to do. Thus I found that the ice volume component does indeed lag (i.e. it responds with a delay) behind the carbon dioxide record. Some people have argued that changes in the ice sheets caused the changes in atmospheric carbon dioxide; I believe these data show the reverse; carbon dioxide was a major player in causing the glacial cycles.

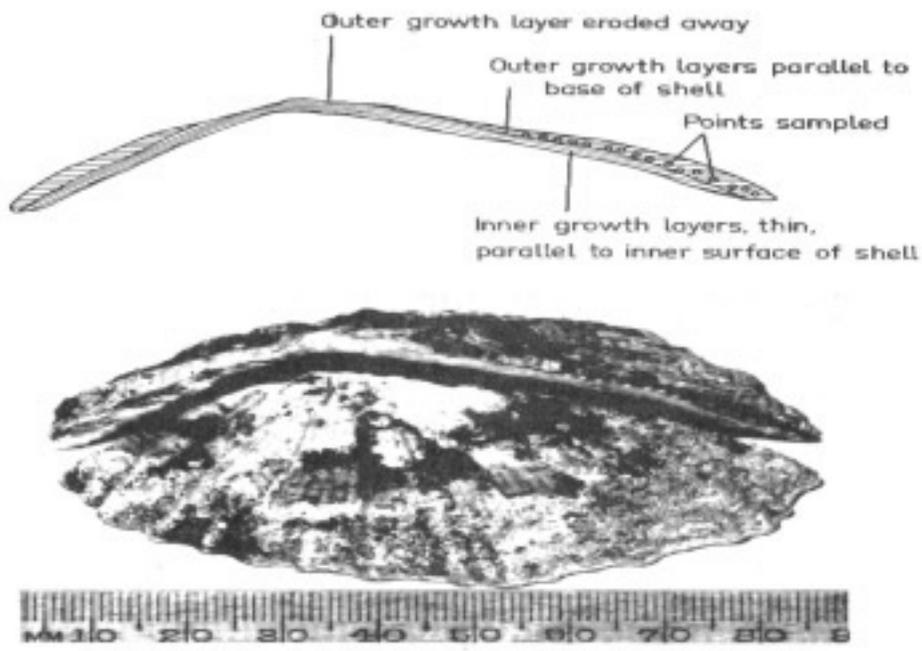
Ultimately if we claim to be able to explain past climate, we want to be able to take the

carbon dioxide record and the orbital variations and model the resulting climate record, and to compare this model result with the geological observations. I believe that at the very simplest level we can actually do that.

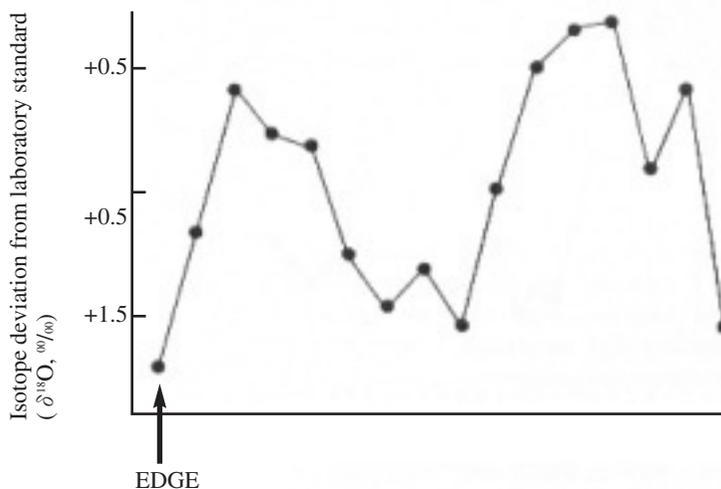
The natural range of variation in atmospheric carbon dioxide during the ice ages, which had such a dramatic effect on the earth's climate, was about 80 parts per million by volume. This range has already been exceeded by the man-made increase over the past century. The geological record is very important in ramming home the message, that it is imperative that we stop the carbon dioxide rise that is causing global warming.

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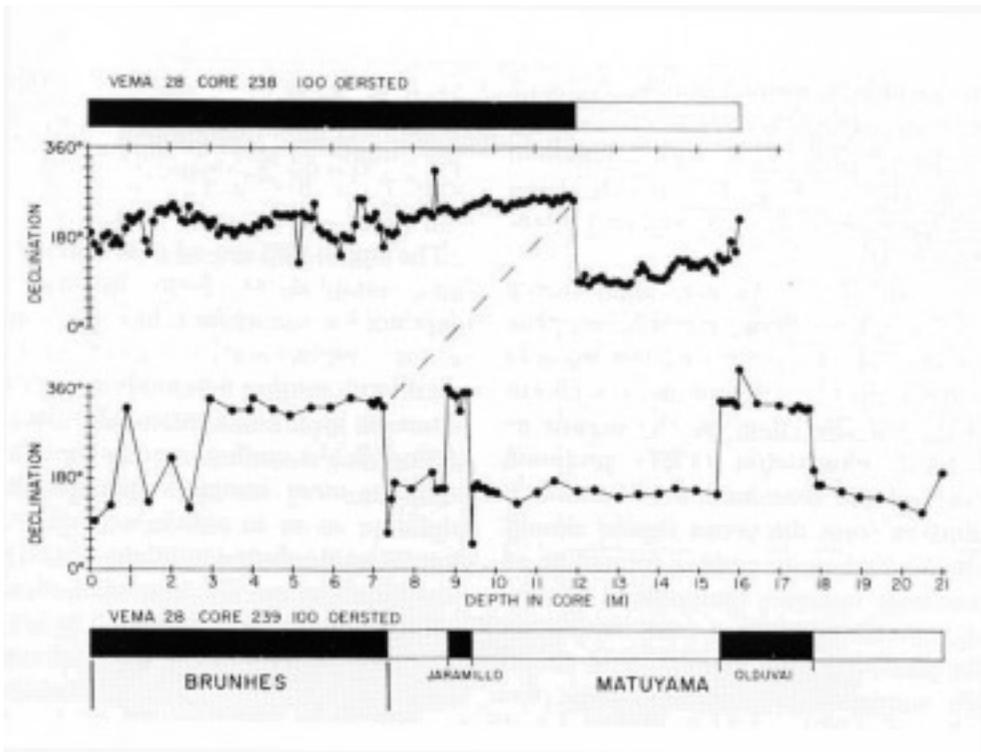
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**Figure 1.** Photograph of a limpet from the South African coast, cut in half and sampled with a small drill for oxygen isotope analysis.

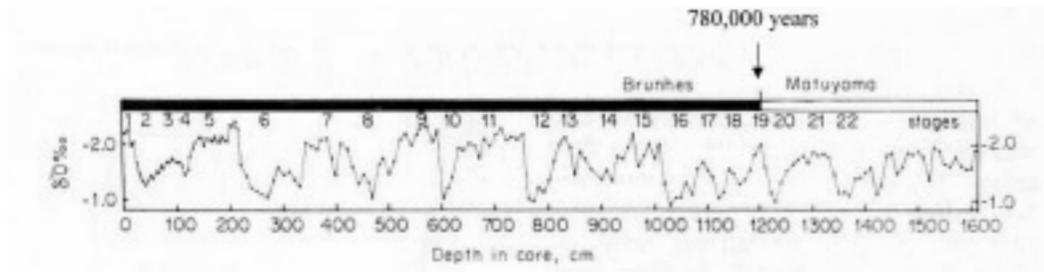


**Figure 2.** Oxygen isotope record for shell in Fig. 1, covering two years of growth. This crude sampling is good enough to determine the season during which prehistoric people were eating shellfish (winter), but it would be technically possible with modern methods to sample at weekly intervals. This is an example of geological measurements on a very fine time scale.



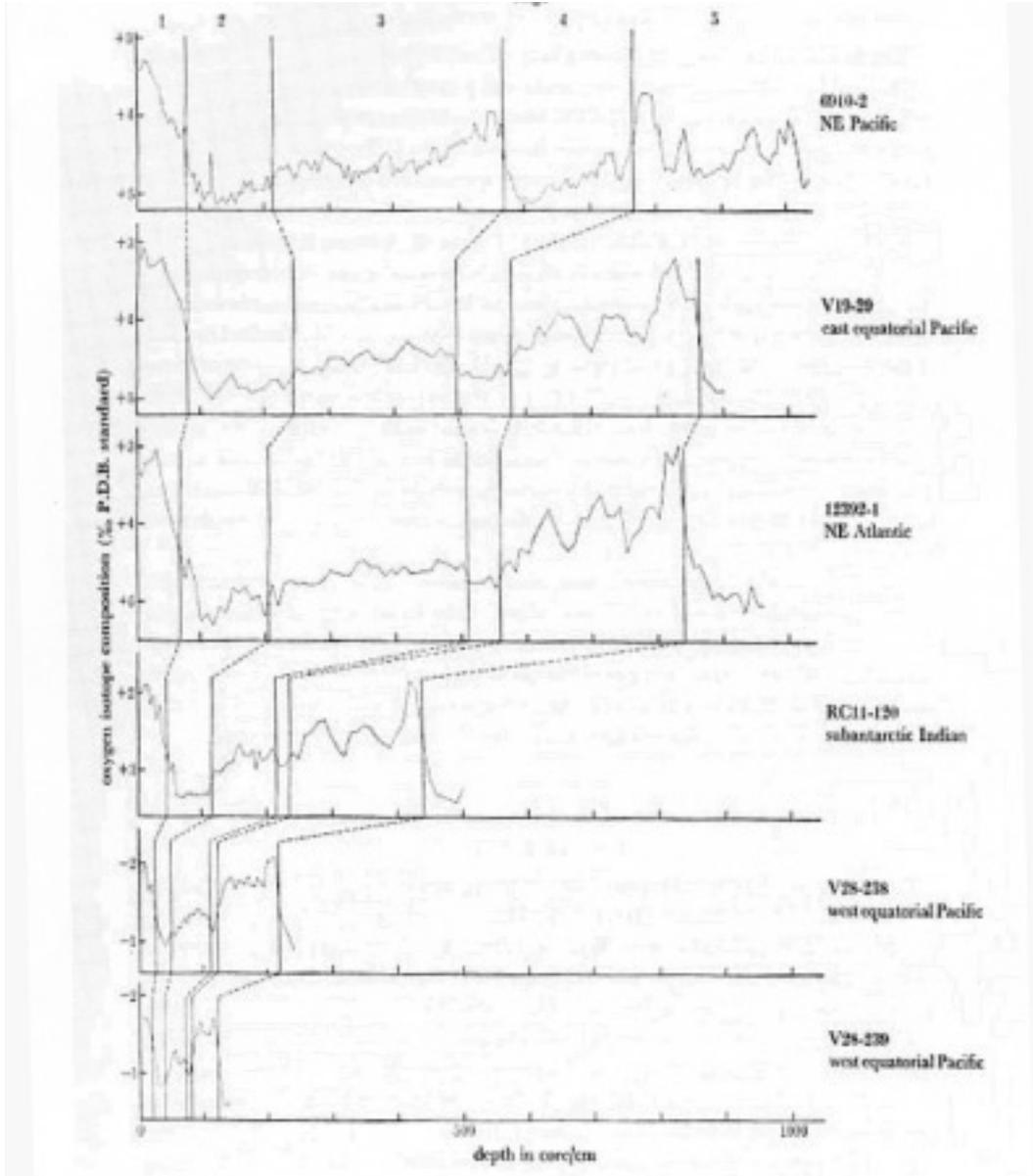
**Figure 3.** The magnetic measurements that were carried out by Neil Opdyke in core V28-238 (upper part of figure) before I sampled the core. It is apparent that the direction of magnetization of the sediment switches by 180 degrees at 12 meters depth in the core. We know that the last time the field was consistently oriented in the reverse direction was about 780,000 years ago.

#### SHACKLET ON AND OPDYKE



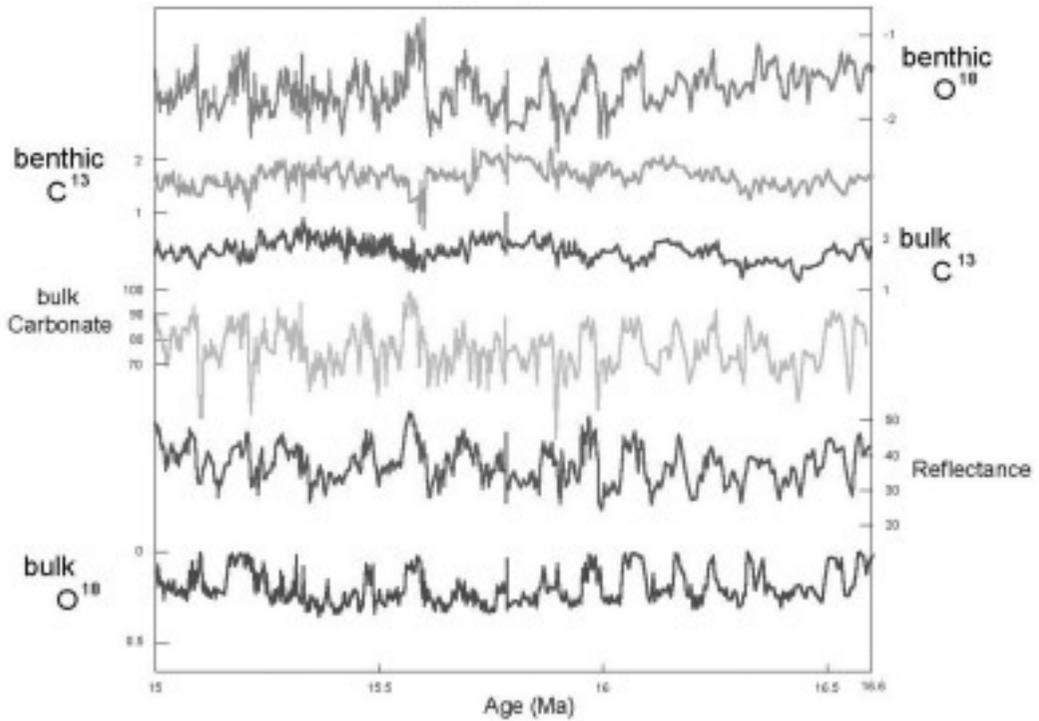
**Figure 4.** The oxygen isotope measurements in core V28-238. This figure, published in 1973, demonstrated for the first time the existence of 100,000-year cyclicality of glaciations over the past million years and has been described as a “Rosetta Stone” for the ice ages.

## OXYGEN ISOTOPE RECORD OF LATE OLEISTOCENE



**Figure 5.** This figure illustrates the effect of sediment accumulation rate on the character of the record obtained by oxygen isotope analysis. At the bottom 100,000 years is compressed into only a meter of sediment and all the fine detail is lost. As the accumulation rate increases in cores toward the top of the figure the last 100,000 years are revealed in four to ten meters and the important details of the last glacial cycle are reproducibly revealed.

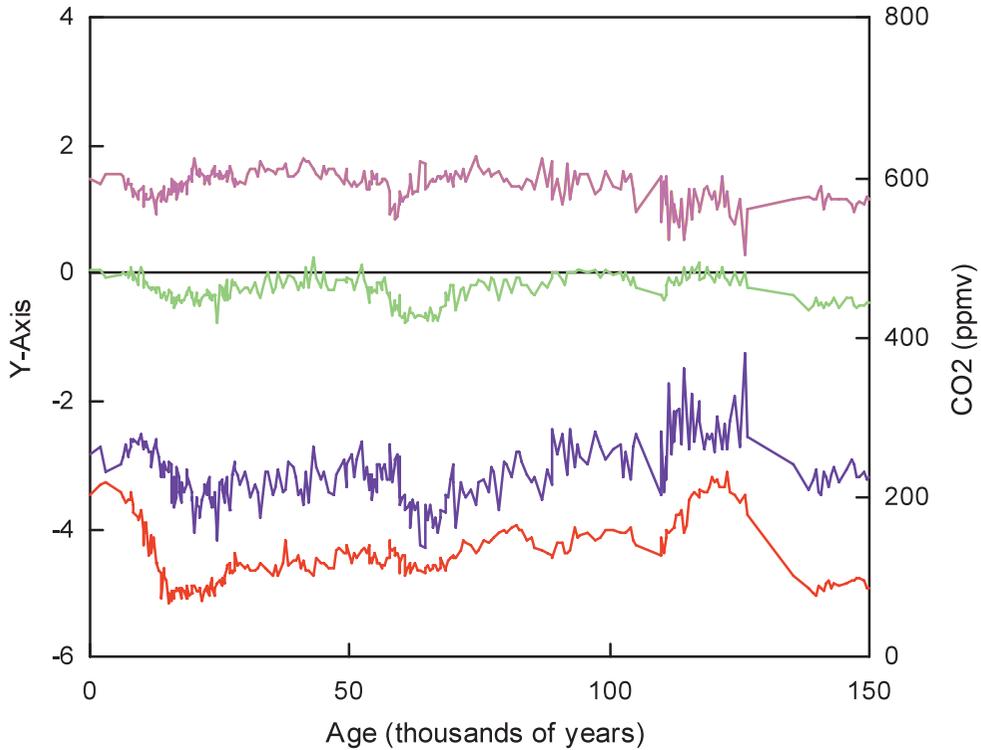
## ODP Log 154, Site 925



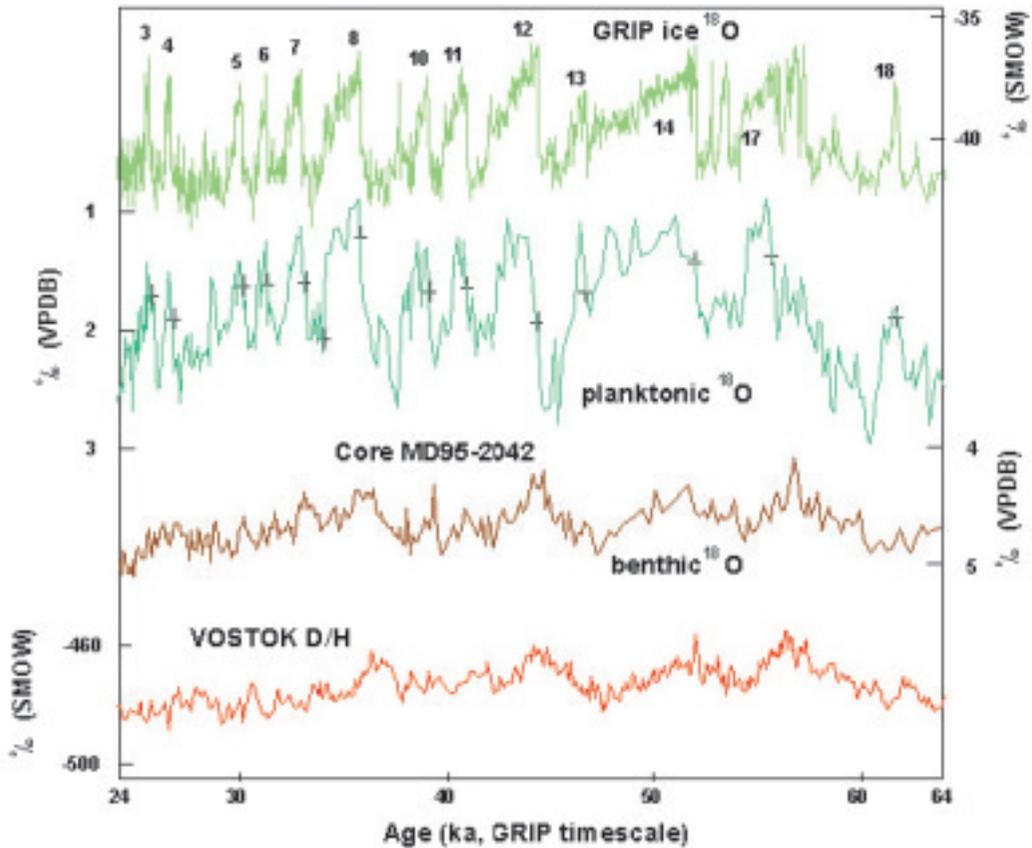
**Figure 6.** Climate cycles (probably including cyclic appearance and disappearance of the Antarctic ice sheet) between 15 million and 16.6 million years ago are illustrated. Many different climate-sensitive parameters were measured, and it is apparent that all display approximately the same cyclicity.

## Core V19-30

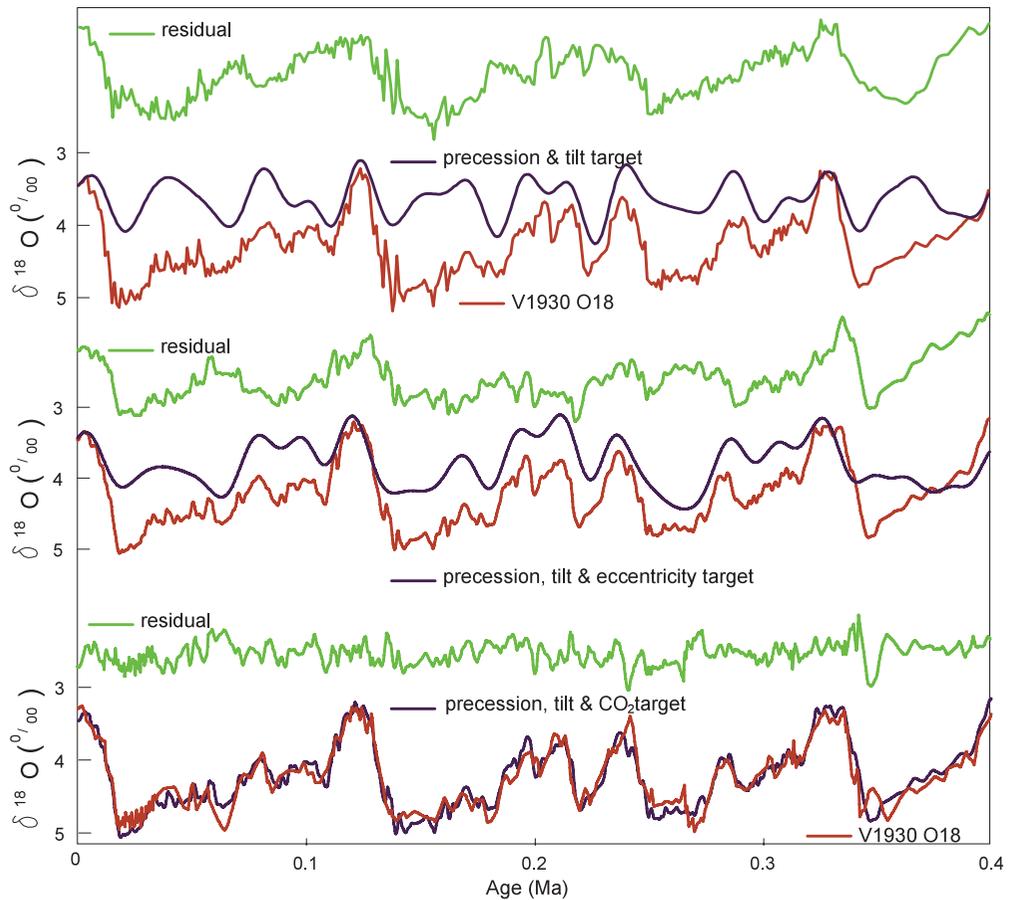
### Atmospheric CO<sub>2</sub> from C-13



**Figure 7.** The top two records in this figure show carbon isotope records from the surface waters, and from the water bathing the sea floor, in the Eastern equatorial Pacific. The next record shows the carbon isotope gradient between the surface and deep water as a function of time (obtained by subtracting the second record from the first). To a first approximation this provides an estimate of changing carbon dioxide in the atmosphere. The bottom record shows the oxygen isotope record of the core. From this it can be concluded that carbon dioxide was higher during interglacials and lower during glacials.



**Figure 8.** The top and bottom records on this figure show stable isotope records (roughly proportional to air temperature when the snow was falling) from Greenland ice (measured by Johnsen and co-workers in Copenhagen) and from Antarctic ice (measured by Petit and co-workers in Grenoble). The middle two records are stable isotope records (proxies for water temperature) in surface water and in deep (3000 m) water near Portugal, both measured in the same samples. All four records are on a consistent age scale covering the interval from 25,000 to 65,000 years ago during the last ice age. On the scale of rapid events during the last ice age it appears that while the temperature of the surface of the North Atlantic changed in synchrony with Greenland, the temperature of the deep waters varied in synchrony with the high southern latitudes.



**Figure 9.** Each panel includes the same oxygen isotope record from a deep-sea core, superimposed on a model that partly simulates the record; each covers 400,000 years. Above each pair is a plot of the residual (obtained by subtracting the model from the data). The upper two panels use different versions of a model using only data for the variations in the Earth's orbital parameters and have quite a large-amplitude residual. The model for the lowest panel incorporates the record of atmospheric carbon dioxide concentration as measured in bubbles from the Vostok Antarctic ice core (from Petit and colleagues) and has a much smaller residual.

## Major Publications

### Professor Sir Nicholas Shackleton

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## Profile

# Dr. Gordon Hisashi Sato

Director Emeritus, W. Alton Jones Cell Science Center, Inc.

Chairman of the Board, A&G Pharmaceutical, Inc.

President, Manzanar Project Corporation

### Education and Academic and Professional Activities

- 1927 Born on December 17, in Los Angeles
- 1944 Graduated from Manzanar High School
- 1951 B.A., Biochemistry, University of Southern California
- 1953-1955 Teaching Assistant, Microbiology, California Institute of Technology
- 1955 Ph.D., Biophysics, California Institute of Technology
- 1958-1963 Assistant Professor, Graduate Department of Biochemistry, Brandeis University
- 1963-1968 Associate Professor, Graduate Department of Biochemistry, Brandeis University
- 1968-1969 Professor, Graduate Department of Biochemistry, Brandeis University
- 1969-1983 Professor, Biology Department, University of California, San Diego
- 1982 Rosentiel Award, Brandeis University
- 1983-1992 Director, W. Alton Jones Cell Science Center, Inc.
- 1984 Member, National Academy of Sciences
- 1987-present Distinguished Research Professor & Director of the Laboratory of Molecular Biology, Clarkson University
- 1992-present Director Emeritus, W. Alton Jones Cell Science Center, Inc.
- 2002 The Rolex Awards for Enterprise
- 2002 Lifetime Achievement Award, Society for In Vitro Biology
- 2005 Distinguished Alumni Award of the California Institute of Technology

Dr. Sato has long dealt with the task of trying to cultivate food in a harsh environment, such as a desert, from his past experience of being relocated during World War II in a relocation camp in the California desert for those of Japanese descent.

Dr. Sato was born on December 17, 1927 in Los Angeles as a child between a first-generation Japanese immigrant father and a second-generation mother. From his upbringing, he grew up with traditional Japanese values such as social obligations and respect for human feelings. During World War II, he was relocated to Manzanar Relocation Camp in the California desert with his family and this made a significant influence on his future way of life.

After the war, he studied biochemistry at University of Southern California and later studied at California Institute of Technology under Max Delbruck who later received the Nobel Prize in Physiology or Medicine. Max Delbruck not only taught him academically but also

supported him economically, which changed Dr. Sato's life dramatically and he never forgot the indebtedness he owed and nourished an idea that education was fundamental to bringing up people, and he himself also provided opportunities for young people to get an education.

After doing research under Max Delbruck and earning a PhD in biophysics in 1955, he further carried out research at University of California at Berkley and University of Colorado Medical School. In 1958, he became assistant professor of Graduate Department of Biochemistry at Brandeis University in Massachusetts. He served as associate professor and professor at Brandeis till 1969, and moved to University of California San Diego (UCSD) and was professor of biology there till 1983. There he succeeded in cell culturing in hormonally defined medium devoid of serum and clarified that a specific hormone and a growth factor are necessary for cells and made a significant contribution, scientifically mainly in mammalian cell culture.

While at UCSD in the early 1980s, he began to work on how to produce food in a severe environment such as a desert, and started the research of growing algae in the desert with aquaculture utilizing the food chain in mind. In 1983, he moved from UCSD to the W. Alton Jones Cell Science Center in Lake Placid, New York and began to work in earnest on the Manzanar Project, which targeted to realize a healthy sustainable life even for those people suffering hunger in a severe environment. After testing at production facilities built in the Atacama Desert in Chile and in Fujian Province in China in the mid-1980s, a new location was sought and found Eritrea. Eritrea was under Ethiopian rule at that time and the people were oppressed and suffered from starvation and Dr. Sato felt sympathy in its resemblance to those Japanese Americans during World War II. He began practicing aquaculture in the Northern Eritrean coastline in 1986.

After Eritrea became independent, watching the camels eat mangrove leaves gave a hint and led to an idea that by utilizing mangroves as fodder, it will eventually be a more positive approach in enabling people to raise livestock and making them economically self-sustaining.

Mangroves only grew on 15% of Eritrean coastline. By disclosing that the seawater lacked nitrogen, phosphorous and iron among the nutritional elements necessary for the mangrove to grow, he devised the basic technique to provide these elements slowly to the mangrove and enabled the mangroves to be grown easily at low cost in areas where it was difficult to grow in the past. With this method, he succeeded in growing more than 800,000 mangrove trees.

What Manzanar Project is aiming to do is to allow people living in a harsh environment like a desert become self-sustaining by creating a sustainable economy. Dr. Sato's activities are different from the previous aids from developed countries to Africa by not giving goods but providing a mean of food production together with a mean for people to become self-sustaining, which indicates how future aids should be. His achievements which have proved a practical measure to enable economic self-sustainability in the poorest area of the world are significant and are demonstrating to the world the importance of a way of living which regularly uses the technology of environmental conservation and humanity.

## Essay

# Creation of Mangrove Forests Where None Existed before to Combat Hunger, Poverty and Global Warming

**Dr. Gordon Hisashi Sato**

An event of great importance to those interested in efforts to make the world a better place is the contribution of a great deal of the fortune of Warren Buffet to the Bill and Melinda Gates Foundation. Spending money effectively for humanitarian causes is a complicated and difficult process. In my experience, solving the technological problems is much simpler than addressing the problems that arise from cultural and political considerations. Warren Buffet realized this and he is to be commended for acting rationally on this realization. The Gates Foundation is an exceptionally well managed organization. This event has given me great pause to reconsider what I and countless others are trying to do to correct the many ills of this world by relatively small individual efforts.

I had previously applied for funding from the Gates Foundation, and was told that the foundation did not support efforts to combat hunger and poverty. A large foundation must have policy guidelines and this makes them too inflexible to pursue unexpected opportunities as they arise. In addition, the solutions to many of the world's ills will come from unpredictable sources that will not fit in any conventional framework. I believe that I and many others of my ilk must continue to try to solve the many problems of this world and that collectively we are an important part of the effort and will synergize with the large scale efforts of organizations like the Gates Foundation.

Let me now summarize what we have done and what we hope to do in the future. We have shown that mangrove trees can be grown in desert inter tidal areas where they do not normally grow by providing them with phosphorus, nitrogen, and iron. This is because sea water is deficient in these elements, and mangroves only grow where these elements are provided by fresh water runoff from land. Though obvious, this fact is not generally understood by mangrove specialists. In addition, we have developed ways to deliver the fertilizer in the correct needed amount so as to avoid waste and minimize the danger of fertilizer runoff. We have learned to sun dry the seeds of *Avicennia marina* to produce a stable grain-like product that can serve as animal food several months after harvesting. We have learned that mangrove foliage and seeds is an inadequate diet for sheep because they are able to produce lambs but cannot produce the milk to feed them. By supplementing the mangrove material with a small amount of fish meal produced from fish wastes the sheep are able to produce lambs and milk. Thus with simple experiments we are able to produce food and money for poor people where it did not seem possible. We can convert barren mud flats into mangrove forests and use these to provide the bulk of food for livestock. To date, we have grown about 800,000 mangrove trees and potentially can grow many millions more in the country of Eritrea. This technology can

reduce regional poverty in many parts of the world, and our present plan is to extend this work to many impoverished regions of the world. In the next few months we will apply this technology in Haiti. Poverty and over population are two parts of the same problem. The solution of one will be the solution of the other. In poor countries, people have many children to provide them support in their old age. This makes the prospect of a long term solution more difficult. In countries with a high standard of living such as Italy and Japan, population growth is negative

We have developed a second way of producing food and wealth in poor coastal countries. The bottom of the food chain in the ocean is micro-organisms—mainly algae. They grow very slowly by depending on sunlight for photosynthesis—about one doubling per day. From our mangrove experience, we add nitrogen, phosphorus and iron to sea water and then add sugar. We get rapid growth of *bacillus megatherium* or the heterotrophic algae, *tetraselma chui*, and these in turn fed to filter feeders such as brine shrimp or shell fish. The brine shrimp are then fed to fish. Thus we are able to convert a low cost commodity like sugar to a nutritious food with high economic value.

Global warming is on the minds of many people with apparent increased frequency and intensity of hurricanes. Some climatologist argue that there is insufficient evidence that this is the result of increased output of green house gases by human activity. I respect their professional opinion, but I am sure if the CO<sub>2</sub> content of the atmosphere continues to increase at the present rate it will eventually be the cause of catastrophe. We can only expect the output of greenhouse gases to increase as developing countries such as India, and China assume their rightful places as nations with advanced industrialization and reasonable standards of living for their inhabitants. To fix the amount of CO<sub>2</sub> produced from fossil fuels will require several hundred million hectares of new forests. I propose that we begin to convert the great deserts of the world to mangrove forests with sea water irrigation. I believe our work has shown that this can be technologically and economically feasible.

The work I have described is highly individualistic and unconventional. It is not the kind of work done by large organizations. It is too risky. Therefore I encourage people like myself to continue to seek solutions to the ills of the world, and when these are well established, leave the large scale implementation to foundations such as the Gates Foundation.

## Lecture

# Sea Water is Deficient in Nitrogen, Phosphorus and Iron

**Dr. Gordon Hisashi Sato**

**The Manzanar Project, Ministry of Fisheries, State of Eritrea, Massawa, Eritrea**

My scientific career was spent predominantly on laboratory research in cell biology. My goal was to gain knowledge of whole animal physiology by studying the basic elements of the body (the cell) in isolation under defined, controllable conditions which might be achievable in tissue culture. The trouble with this simple minded concept, in 1957, when I began work on tissue culture, was that cells in culture did not display the differentiated properties of the tissue of origin. Apparently cells in culture were different from cells in the animal. It was generally believed that cells in culture underwent “dedifferentiation” to become a common tissue culture type cell. In the only experiment to address this issue, we showed that when liver tissue is put into culture, the small amount of fibroblasts in the tissue selectively grow, and the liver parenchyma die<sup>1</sup>. The problem with lack of tissue specific properties in culture was selection not “dedifferentiation.” The next step was to develop enrichment culture techniques to favor tissue specific cells over fibroblasts<sup>2</sup>. This resulted in a number of tissue cultures which retained differentiated properties, and the “dedifferentiation” hypothesis, virtually unnoticed, died a quiet death<sup>3</sup>. The next step was to devise defined, controllable conditions in culture. Traditionally, tissue culture media consisted of a nutrient solution of defined composition supplemented with serum. I was led to believe that the serum could be replaced by hormones because cell growth in the animal is stimulated by hormones<sup>4</sup>. Izumi Hayashi and I devised a system of nutrient medium supplemented with a complex of hormones that was different for each cell type<sup>5</sup>. This eliminated fibroblastic over growth in primary cultures, and made it possible to culture cell types never before successfully grown in culture. This method allows one to discover hormone responses by different cell types discoverable in no other way, and I proposed that this catalogues the vulnerability of cancer cells and opens up a general approach to cancer therapy<sup>6</sup>. A case in point, we developed a monoclonal antibody to EGF receptor<sup>7</sup>. I was led to try this approach from the knowledge of the existence of LATS, long acting thyroid stimulator, an antibody to the TSH receptor, which mimics the action of TSH. The antibody to the EGF receptor has proven to be an effective anti cancer agent and is a harbinger of future anti cancer agents<sup>8</sup>. I believe that my long experience with laboratory, experimental research enabled me to approach applied, field research differently from established workers in the field.

Let me now define the problem that has occupied me for the last twenty years. Hunger and poverty is one of the problems that the human race must solve before it reaches a catastrophic, irreversible state. Eritrea is one of the poorest nations in the world with a per capita gross domestic product of approximately 50 USD per year. Its conventional agriculture in its

highlands is insufficient to feed the nation because of frequent and unpredictable droughts. In periods of drought Eritrea would suffer widespread famine were it not for international food aid. How could we produce food and a profitable, sustainable agriculture under such conditions? On its desert shores on the Red sea, I noticed patches of mangrove trees, and watched camels eating the foliage. Could this be a possible solution? But first we had to consider the conditions that limit the growth of mangroves. Sea water is deficient in nitrogen, phosphorus, and iron, elements that are required by all living creatures including plants, animals and microorganisms. While this fact has been generally known, it has been ignored by those who are concerned about the productivity of the sea and the inter tidal areas. I will try to show how attention to this fact can help alleviate poverty and hunger by making the marine environment more productive. Sea water contains all the elements in sufficient quantity that are essential for life except for nitrogen, phosphorus and iron. So in the following discussion of the importance of nitrogen, phosphorus, and iron, the term fertilizer will refer to these three elements. At the bottom of the food chain in the ocean are microscopic algae. They grow near the ocean surface where they are exposed to sunlight and capture the fertilizer. They sink to the bottom and die from lack of light and the fertilizer is trapped. If upwelling currents bring up the fertilizer, the sea is rich in fish. In the arctic and antarctic, water freezes and the saltier and heavier unfrozen water sinks and stirs up the bottom. The polar regions are rich in fish life. Seas are rich in fish where rivers enter the sea because the fresh water is bringing fertilizer from land. The Red sea has neither upwelling currents nor rivers. Consequently it is poor in fish life.

Eritrea has approximately 1,500 kilometers of desert sea coast along the Red Sea (counting islands). Mangroves grow in only about 15% of the coastal inter tidal zone, and where they grow they form a narrow fringe, usually no more than 100 meters wide. We observed that mangroves typically occur in areas called “mersas” where the seasonal rains are channeled to enter the sea each year. The conventional explanation is that fresh water per se is required<sup>9</sup>. This explanation is untenable because the amount of fresh water and the duration of flow are too short to affect salinity to any extent. Our explanation, which is a radical departure from conventional belief, is that the fresh water is bringing nitrogen, phosphorus, and iron from land, and the fringes are no more than 100 meters wide because the fresh water may not be able to carry these minerals in sufficient quantity more than 100 meters from the high tide line. We predicted that the treeless, inter tidal areas of Eritrea, which occupy 85% of the coast, could be successfully planted with mangroves if nitrogen, phosphorus, and iron were provided, and that the mangrove fringes could be widened if the trees were provided with these elements.

Both of these predictions have proven true. Methods were developed to deliver fertilizer at a controlled rate that greatly reduces the possibility of runoff. Experiments were carried out to find ways of rendering mangrove foliage and seeds a complete food for livestock.

### **Materials and Methods**

We use predominately the mangrove, *Avicennia marina*, and to a much lesser extent *Rhizophora mucronata*. Both plants are indigenous to the area. *Rhizophora* are almost extinct in Eritrea because of their value as construction timber. Our plantings will contribute to its

preservation. *Avicennia* seeds are planted in their final site by placing them in a tin can cylinder constructed by removing the top and bottom of the tin can. The can is embedded in the soil with a centimeter or so above the ground and is held in place with an iron rod. The top of the can is covered with a wire mesh to prevent the seeds from being washed away by wave action. Planting seeds in the final site saves considerably in time and effort by avoiding the necessity of transplantation. To prevent encircling wrasse and wave action from uprooting young seedlings, we build concrete blocks with upwardly protruding iron rods. The dimensions of the blocks are 1 meter long, about 25 centimeters high and about 5 centimeters wide with the protruding iron rods about 60 centimeters above the blocks. A continuous wall of blocks is placed sea ward of the area of planting. The iron rods prevent wrasse from entering the planting area, and the concrete blocks allow the buildup of low lying soil so that adequate drainage can allow air to get to the roots. This allows the extension of the usable planting area.

Our method of providing a slow release fertilizer to trees growing in an area continually awash in sea water is to place 500 gms of a 3:1 mixture of urea and diammonium phosphate in a polyethylene bag, tie the bag so it is sealed shut, and puncture one surface three times with a 0.2 cm diameter nail. The bag is buried next to the tree with its upper surface and the nail hole punctures about 10.0 cm below the soil surface. This arrangement allows the fertilizer to exit the bag by slow diffusion - fast enough to nourish the tree but slow enough not to be wasteful. By digging up bags after various times, we estimated that the bags deliver all their fertilizer in about three years. From the density of planting, 5000 trees per hectare, we estimate that the fertilizer is delivered at a rate of about one ton per hectare per year. This is approximately the desired rate. The desired rate is calculated as follows: a hectare of *Avicennia* drops about 10 tons of litter per year which is about 19% protein, or two tons of protein. We assume that the trees synthesize three tons of protein per hectare per year. To synthesize three tons of protein requires about one ton of fertilizer.

A barbed wire fence is erected around the trees and guards are employed to prevent camels from destroying the trees.

To measure possible fertilizer runoff, water was collected a few meters offshore from our plantings and from a natural mangrove forest about a half hour before the tide reached its lowest level. The water was analysed for nitrogen and phosphorus content by the analytical laboratory of the Ministry of Fisheries by the method of Parsons et al<sup>10</sup>.

*Avicennia* seeds are soaked in sea water for three days to remove the cover and facilitate drying. They are then placed in the sun to dry resulting in a grain-like material that is avidly eaten by animals up to a year after drying.

## Results

Figure 1 shows a planting that is about 1 year old. No trees grew in this area before we planted it. Before we realized the need for fertilizer, over a hundred trees were planted in this area and all died. After the need for fertilizer was understood, virtually all trees grew successfully with our method of fertilization.

Figure 2 shows the same area about two years later. Growth is rapid.

Table 1 shows the measurement of nitrogen and phosphorus offshore from our planti-

ngs and offshore from a natural mangrove forest which was not fertilized by us compared to the fertilizer content of water from the open sea. It can be seen that offshore from our plantings where three tons of fertilizer is applied per hectare no evidence of nitrogen or phosphorus runoff is found. Offshore from a natural mangrove forest, nitrogen and phosphorus levels are appreciably higher than the open sea. This tends to support our assumption that natural mangrove forests are provided with fertilizer by the seasonal rains.

Figure 3 shows the concrete blocks with their protruding iron rods. They prevent wrasse from entering the planting area and cause the build up of soil. Waves bring sand over the blocks and the sand is prevented by the blocks from returning seaward. By building up low lying soil the usable planting area can be extended seaward.

Figure 4 shows our method of drying mangrove seeds to make a stable grain-like product that can serve as animal food several months after drying.

Figure 5 shows the drying of fish wastes to form fish meal that is an essential supplement to mangrove foliage and seeds for the feeding of livestock.

Figure 6 shows sheep eating mangrove foliage. They are also fed mangrove seeds and fish meal. They have been kept on such a diet for 8 months and produce babies and milk to feed them. When the fish meal is omitted, they produce lambs but not the milk to feed them.

Figure 7 Camel lusting after mangrove trees.

Figure 8 A grove of trees in the village of Hargigo, our principal site of work. We have planted over 800,000 trees mainly in areas where trees had not grown before.

Figure 9 Typical housing in Hargigo reflective of the poverty in the region.

Figure 10 The water supply of the village which is shared with animals. One of our most urgent needs is a supply of healthy water.

Figure 11 Passengers from the Japanese peace boat visiting our work site in Hargigo

## **Discussion**

Sea water is deficient in nitrogen, phosphorus, and iron . It follows that plants growing in the inter tidal area must have a source of these minerals. This is almost always furnished by fresh water from land. In arid countries, areas where fresh water enters the inter tidal area are limited. It is in these areas where mangroves grow naturally. We have developed new ways of substantially increasing the mangrove forests in tropical coastal deserts by making it possible to grow mangroves in the tree less mud flats by artificially providing these elements. Such mud flats make up the greater part of the inter tidal area of these coastal deserts. Even in tropical countries with plentiful rain, we can increase mangrove forests by widening the growth area by fertilization and the use of concrete blocks. This can potentially reduce the damage due to tsunamis, and hurricanes. We have also shown that mangroves can provide the bulk of the food for sheep with small and inexpensive supplementation of fish meal. This last finding renders mangrove planting a technically feasible and commercially profitable business. We estimate that a hectare of mangroves can produce a metric ton of meat per year. This compares favorably with pasture land in temperate climates. This should provide the economic incentive to plant mangroves as well as the disincentive to destroy them. Each of these findings is very simple but new and original. We believe that our approach has the potential to create a cost effective

tive sea water agriculture and eliminate hunger and poverty in many regions of the world.

We believe that discoveries made in Africa can help solve problems in the developed world, such as in Japan which produces only forty percent of its food. Algae in the ocean divides about once a day. Simon Tecleab Gebrekiros and I discovered, in Eritrea, that we could add nitrogen, phosphorus, iron, and sugar to sea water and get micro-organisms, bacteria or algae, to divide every half hour. These micro-organisms were consumed by brine shrimp which could then be fed to fish. By this method, we could make the coastal waters of any nation rich in fish by essentially converting sugar to fish. Japan, for instance, could be made self sufficient for fish. The coastal, inter tidal zones of Japan's southern islands is nearly bereft of plants, and their fish catch is declining. Japanese control their fresh water so well that natural flows into the sea is diminished. We can grow native plants in these inter tidal areas with fertilization and increase fish life.

Mangroves seem to be limited by latitude. This fact is not well understood<sup>6</sup>. In north Africa and southern Europe mangroves cannot grow because the tidal variation in the Mediterranean and Aegan sea is too small to provide drainage and air to the roots. This raises the possibility that mangroves could be grown inland, the Sahara desert for instance. Some crop plants like millet and barley can grow with sea water irrigation, but the value of the crop is less than the cost of fertilizer and pumping water. Our trees have economic value, and we have solved the problem of economic use of fertilizer. Can we pump sea water economically with for instance wind mill pumps. If so it is thinkable to convert the deserts of the world to mangrove forests. It is time to consider such far out solutions. Glacial ice is breaking off the polar ice caps, the arctic tundra is melting, and typhoons and hurricanes are increasing in frequency and intensity. At present we add about four billion tons of CO<sub>2</sub> to the atmosphere each year. As developing nations, such as India and China, assume their rightful positions as nations with advanced industrialization and a high standard of living for their inhabitants, this will only get worse. I believe converting the worlds deserts to forests is a necessary step to buy us time before we can develop alternate forms of energy.

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**Figure 1.** Mangrove planting in area where mangroves had not grown before. About a year after planting.



**Figure 2.** Same scene as in previous slide, but three years after planting



**Figure 3.** Concrete blocks with protruding iron bars. In final position they build up soil on landward side.



**Figure 4.** Peeled *Avicennia* seeds drying in the sun



**Figure 5.** Fish wastes being sun dried after brief boiling.



**Figure 6.** Sheep eating mangrove foliage.



**Figure 7.** Camel lusting after mangrove trees.



**Figure 8.** Mangrove grove in village of Hargigo.



**Figure 9.** Typical housing in Hargigo



**Figure 10.** Source of village water.



**Figure 11.** Passengers from Japanese Peace Boat visiting the work site in Hargigo.

**Table 1.** Analysis of fertilizer content of seawater offshore from our plantings, offshore from a natural mangrove forest, and from the open sea.

	Nitrogen content	Inorganic phosphate
Area A in Hargigo with 3 tons of fertilizer per hectare	Not detectable	.04 mg/liter
Area B in Hargigo with 3 tons of fertilizer per hectare	Not detectable	.03 mg/liter
Natural mangrove forest unfertilized	.02 mg NH <sub>3</sub> /liter .01 mg NO <sub>3</sub> /liter	.04 mg/liter
Water from open sea	not detectable	.06 mg/liter

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\*deceased



## **Follow-up Essay Contributed in June, 2013**



# Seawater Agriculture Can Solve Many of the World's Problems

**Dr. Gordon Hisashi Sato**

First we have to examine algae medium. All plants require all the elements in algae medium, from the tallest pine tree to the smallest seaweed to food crops such as corn and wheat. All plants require all the elements found in algae medium and do not require any elements not found in algae medium. There are exceptions to this generalization but they are very rare and do not require our attention.

All food derives from plants. Lions and tigers eat grass but the grass must first be eaten by deer and antelope.

Seawater contains all the elements in algae medium in sufficient quantities except for phosphorous, iron, and nitrogen. If these elements are added to seawater then any plant that can grow in seawater can be successfully grown in this fortified seawater; eg, one million mangrove trees in Eritrea.

This fact presents an immediate solution to the problems of the Middle East. Unrest in the Middle East is caused by poverty and unemployment. Even a country such as Saudi Arabia with immense oil wealth has 30 to 40 percent unemployment.

The deserts of the Middle East could be fertilized with fortified seawater and crops such as mangrove trees, *spartina*, and *nitraria retusa* could be grown for animal fodder. Land based agriculture was first found to be feasible where fresh water naturally occurred. This area was greatly expanded by digging trenches, and by using water pumps and animal dung.

Some of the areas of the seas are very rich with the growth of seawater plants. Fertile seabeds have developed where there is rain and as the rain moves over the land the streams of fresh water dissolve needed minerals and deposit them in the ocean. No attempt was made to increase the area of fertile seabeds. This is because the application of fertilizer was also found to promote the growth of toxic algae such as red tide and microscopic algae which blocks the sun from reaching useful plants, such as eelgrass, on the seabottom.

But toxic algae and useful seaplants both require the same nutrients. Therefore, withholding fertilizer is not the solution to the problem because beneficial seaplants are also discouraged.

We have developed a method of fertilizing useful plants to produce fertile seawater in such a way that algae are discouraged and useful plants are supported. We make bricks of 1 lb of cement, 2 lb of gypsum, 1 lb of urea and 1 lb of phosphate. These bricks are placed on the ocean bottom where some seaweed is growing and a small amount of iron is placed nearby. The slowly dissolving bricks preferentially fertilize the ocean plants attached on the bottom and the fertilizer which rises above the seabed are absorbed by the leaves and stems of the

seaweed.

Algae typically has a 24 hour differentiation time. After division algae must accumulate mineral nutrients and biosynthesize many components. Since algae are easily moved by water currents and since the area of fertilizer is restricted near the ocean bottom the algae are not likely to find themselves in a nutrient rich area and, therefore, massive growth of algae does not occur.

We have observed that this method of fertilizing seawater brings about the growth of eelgrass and brown, green and red seaweed and does not support the growth of algae. This expansion of seaplants greatly increases fish and crabs.

The creation of wealth in poor countries with high unemployment and extreme poverty can bring about the best solution for managing the expanding population of the world. The most humane way to manage population growth is to increase the wealth of all its citizens.

Each year the world produces more than 32 billion tons of CO<sub>2</sub> by burning fossil fuels. It is very unrealistic to think that China and India will stop building coal fired power plants. Land based plants can only fix about 60 percent of this CO<sub>2</sub> and all arable land is already utilized.

Seawater plants in coastal seabeds can absorb all the CO<sub>2</sub> produced by fossil fuels which then helps us to focus on the critical problem; methane gas produced by the melting tundra.

In addition, ponds of seawater fertilized by phosphorous, iron, and nitrogen can produce immense quantities of algae which can be pumped into depleted oil fields and replenish the oil supply.