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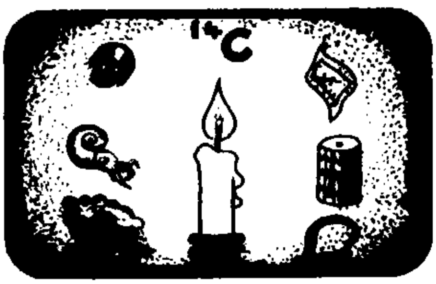
Conference Report



The Earth System: Geology Lessons for Our Future[1]

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> The task of the Future is to build knowledge and understanding among and between citizens and scientists, so that the distinction between the two groups disappears, so that both become citizen scientists, potentially able to solve our problems together.
>
> Ursula Franklin

BACKGROUND

So began the preamble to a three-day extravaganza held 5-7 December 1996 at the Ontario Science Centre in North York, Metropolitan Toronto. Inspired by the "Colloque Geoprospective – Time in Geology: From Past to Future," held in Paris in April 1994, the meeting was intended to explain in simplistic terms two critical questions facing the inhabitants of planet Earth: 1) What lessons are to be concluded from the 4.5 billion year history of the Earth system? and 2) What are the impacts on the Earth system of humans, estimated by 2020 AD to be twice the number of the present 5+ billion population?

A stellar cast of individuals, mentioned in more detail below, was mustered to explain these concepts, and most succeeded admirably, although unfortunately, to an audience of converts! I am not sure just what happened in the planning for this meeting, but for one of the best casts assembled for a geoscience meeting, the anticipated fusion between "citizens" and "scientists" was limited and the media proved to be singularly disinterested.

This lack of participation is really tragic. For a profession that has a particularly important — more than that — a *crucial* role to play in what happens on this world of ours over the next several centuries, the lack of awareness of the part that the geosciences *will* play is particularly disturbing. More on this below; but just what had been missed by the news media and good citizens of southern Ontario?

The Earth System Symposium (which honored J. Tuzo Wilson, first Director of the Ontario Science Centre and a driving force behind aspects of the plate tectonic theory, and Harry Thode, a renowned isotope geochemist and former President of McMaster University) had an outstanding organizing committee. Bill Fyfe (Chair and Past President of the International Union of Geological Sciences) had gathered Bernard Beaudoin (School of Mines, Paris), Jim Franklin (Geological Survey of Canada, Ottawa), Kathryn Hough, J. Fraser Mustard and Dorothy McKinnon (Canadian Institute for Advanced Research, Toronto), Emlyn Koster (former Director, Ontario Science Centre), and Jan Veizer (Canadian Institute for Advanced Research, Ottawa). Veizer in turn chaired the Scientific Program Committee which had as members Claude Allègre (University of Paris), Chris Barnes (University of Victoria), Michael McElroy (Harvard University), Keith O'Nions (University of Oxford), Brian Skinner (Yale University), and Jörn Thiede (Geomar, Kiel). The support for the meeting came from the Geological Association of Canada (GAC), the Geological Survey of Canada, the International Union of Geological Sciences, the Ontario Science Centre, the Royal Society of Canada (Global Change Program), the Royal Society of London, UNESCO and the University of Toronto.

The program was arranged into seven blocks. Each block had a chair and three invited speakers and time for a few questions. Two public lectures were also given in the evenings.

The conference began with an **Introduction** by **J. Fraser Mustard**, who commented briefly on concerns about anthropogenic changes in the biosphere with increasing levels of CO_2, and with remarks on geosphere–biosphere interactions. He discussed the background of the meeting, and mentioned the public lectures and the honorary scientists (Wilson and Thode) who had inspired aspects of the research which was to be discussed. Mustard was followed by **Debra Feldman,** who explained the background to the Ontario Science Centre and **Emlyn Koster**, President of the GAC, who gave a short address on "Planet Earth" mentioning that earth scientists fell short on agreement about the questions and solutions which face us, and putting this symposium in the context of GAC's developing long-term strategy to promote new kinds of inter-disciplinary dialogue. **Wolfgang Eder** (Earth Sciences Division of UNESCO, Paris) conveyed greetings from the Director-General of UNESCO and described

[1] *Editor's Note: Although it is a break with* Geoscience Canada *tradition to publish a conference report as long as this one, we are doing so because of the importance of this Earth system symposium. Readers and potential conference report preparers should be aware that our normal conference report guideline of 1000-3000 words remains in effect* (Geoscience Canada, *June 1996, Instructions to Authors).*

some of the UNESCO programs which were relevant to the conference. He was followed by **Robert Haynes** (Royal Society of Canada) who presented a short, but interesting, background on the Royal Society and its much later Canadian counterpart and the role that some of the earlier "natural historians" (Hutton, Lyell, Darwin) made on the evolution of interactivity within the sciences. The introductions ended with a brief presentation by J. Stefan Dupré, President and CEO, Canadian Institute for Advanced Research.

BLOCK I — THE PLANET: ORIGIN AND NATURE was introduced by the Chair, **Derek York** (University of Toronto), who took us through the history of the planet with specific reference to the problems of its age. He explained that humans had always been fascinated by time and used the example of Stonehenge to illustrate an early preoccupation with time and space. He also pointed out that Bishop Ussher had successfully improved on earlier estimates of the age of the Earth by predicting that it had commenced at 4004 BC! More scientific estimates had gradually pushed the age back. Buffon's estimate in the late 1700s was 75 ka; Charles Lyell had merely (and probably sensibly) suggested "indefinite," while Charles Darwin suggested about 300 Ma, based on erosion rates. Lord Kelvin came a long way in a short time with estimates of 32 ka in 1854, to less than 500 Ma in 1862 and finally to "between 20 and 400 Ma" in 1881. All these dates were incorrect, because they had not taken radioactivity into account. Once Henri Becquerel had recognized radioactive decay, the door was open for more accurate assessments, and some of the fundamental work was conducted by Ernest Rutherford at McGill University. Fifty years ago the estimated age of the Earth had been pushed back to 3.35 Ga by Holmes and 3.29 Ga by Bullard, and by 1956 Claire Patterson had reached the presently accepted age of 4.5 Ga.

York also pointed out that radiometric age assessment has allowed dating of not just the age of the Earth, but major events in its history: from mountain building to continental breakup, from meteorite impacts to the extinction of the dinosaurs, to the timing of continental glaciations, and more. It sets the stage for the framework of humanity on planet Earth.

R. Keith O'Nions (University of Oxford) presented a fascinating talk on "**The Early Development of the Earth.**" He explained that dates obtained from Ca–Al inclusions in carbonaceous chondrites were 4.567 Ga, and observed that the crystallization age of the planet was estimated at 4.558±.005 Ga. In his discussion on the very early planetary history he suggested that atmospheric losses of terrestrial rare gases such as heavy Xe ceased approximately 150 Ma after aggregation at *ca.* 4.4 Ga. Atmospheric closure seems to have been complete by 4.36 Ga, and there was clear potential for the formation of oceans after this date. Furthermore, the differentiation of various "shells" of the Earth had also taken place. The SiO_4 "depleted" upper mantle was distinct from the Perovskite (SiO_6) lower mantle, and the core formation was also complete. Recent deep Earth studies suggest that thermal plumes continue to rise from the core–mantle interface, but the upper mantle (to a depth of *ca.* 670 km) stays cool, and deep mantle plumes stop largely at this contact. Some occasionally penetrate this level and continue to rise to the surface.

Richard Grieve (Geological Survey of Canada, Ottawa) presented the next talk on "**Extraterrestrial Impacts.**" This was a fascinating summary of "things that go bump" on Earth. Recalling that barely a few years ago we, on Earth, had been able to witness a fragmented comet impacting Jupiter, Grieve pointed out that if "Fragment G" of Shoemaker-Levy 9, had struck our world, it would have initiated a "nuclear winter." He commented that it is fortunate to have Jupiter in our system since this giant planet acts as a cosmic "magnet" for small asteroids and comets which otherwise would make Earth practically uninhabitable. Without Jupiter, Earth would have one large impact every million years, making advanced life forms impossible. Because Earth is a very active planet, most craters have been obliterated with the passage of time. However, we are aware of about 160 craters on Earth, most concentrated on old cratons in Canada, Fennoscandia and in Australia, and about 3-5 new craters are discovered each year. Grieve went on to comment on several different craters and the associated ages, body size, energy releases, and phenomena. These included the Barringer Crater, a recent (50 ka) structure created by a small (50-60 m) body impacting with a 60 megaton force and creating a crater 1.2 km in diameter. Other examples are the Sudbury Basin, an impact at 1.85 Ga affecting 250 km^2, and, of course, the infamous Chicxulub crater of Yucatan at the Cretaceous Tertiary boundary.

Grieve concluded his talk by comments on the scale of these events (energy release from Mt. St. Helens, 10^{16} joules; Santorini, 10^{20} joules; and the K–T impact, 10^{24} joules); on event frequency (K–T, hundreds of millions of years; and Tunguska, a 10-megaton event, on the scale of hundreds of years); on "near misses" (one at 700,000 km in 1989, or, put in a different way, a collision missed by 6 hours!); and on our good fortune that the major bombardment stopped relatively early in Earth's history at 3.9 Ga. His final comment that "We are only here until the next large one" left many in the audience glancing over their shoulders!

Kurt Lambeck of the Australian National University talked on the "**Changing Shape of the Earth: Ice Sheets, Sea level and the Shape of the Earth.**" This was a lecture that dealt with scales: on the speed of events from seismicity (seconds) to tides and rotation (hours, days, to years) to glacial rebound (thousands of years) to sedimentary and volcanic loading (tens to hundreds of millions of years) and to mantle convection (hundreds of millions of years). Lambeck pointed out that it is possible to detect changes in the shape of the Earth by using satellite altimetry. Phenomena such as tide heights and even atmospheric loading can be seen by oscillations in satellite orbits. He spent some time discussing geoid warping as a result of recent ice accumulation and melting, with the associated interactions of sea-level drawdown and subsequent rise, and adjustments in mantle rheology. These interlinked phenomena allow calculations on the size of ice sheets, and time constraints on glacial fluctuations, as well as providing clues about sea-level rise in various parts of the Earth. The last element has obvious implications for human movements and settlement patterns, particularly over the past 30,000 years.

BLOCK II — PLANET DYNAMICS: CONTROLS AND RESPONSES was chaired by **Paul F. Hoffman** (Harvard University, Massachusetts). Paul provided a quick overview of planetary comparisons between Venus, Earth and Mars. He pointed out that small planets like Mars have cooled very rapidly, but Earth and Venus still remain hot. However, either because of the differences in distance from the sun, or for internal differences within the planetary system, the two bodies have reacted in different ways. Earth with a mean surface temperature of 15°C is a relatively cool planet and the plate tectonic processes that take place effectively cool the earth's interior on a more or less continuous basis. Venus, with a surface temperature of 427°C, is a planet with a runaway greenhouse effect. It appears that the cooling mechanism on Venus is somewhat unstable, which prevents the lithospheric crust from subsiding on a regular basis. Because of this, the heat loss from Venus is convulsive, and takes place at discrete intervals with time spans of several hundreds of millions of years. He also pointed out that Venus lacks liquid water and this plays an exceptionally important role in the effects of both erosion, sedimentation and plate tectonism.

The second speaker in the session was **Richard G. Gordon** (Rice University, Texas). The title of Gordon's presentation was **"Plate Tectonics from Satellites"** and he provided an interesting overview of the various Earth-orbiting satellites which have provided a lot of recent information about the configuration of our planet. Movements of the various plates can now be detected by using some of the sophisticated techniques that were set up for military purposes. These include Satellite Laser Ranging (SLR), Global Positioning Systems (GPS) and Very Long Baseline Inferometry (VLBI). These various techniques provide extremely accurate estimates of the changes between various reference points on the earth's surface. Furthermore, these space-borne platforms also provide a secondary check against the types of movements inferred from conventional plate tectonic motions. These include marine magnetic anomalies and other data which provide averages of the rate of plate movement. The view from space indicates that plate motion is very steady, with geologically averaged rates over millions of years agreeing within a few millimetres per year with the satellite-observed rates over a period of several years. Space Geodesy also permits precise mapping of marine gravity fields with very high resolution. These types of observations can be used to locate fracture zones with great precision. From this, it has been observed that 80-85% of plate boundaries are extremely narrow; while only 15-20% of boundaries are wide plate junctions. The North American plate rotation has been shown to be centred around the Cochrane–Val D'Or Region.

The third presentation, **"Mountains, Landscapes and Climate - Interactions between Tectonics and Surface Processes"** was presented by **Chris Beaumont** of Dalhousie University, Nova Scotia. Chris's contribution was to show how computer models could be used to try to link the relatively slow scale "deeper" motions involved with the lithosphere with smaller, and much faster, "surface" modifications provided by the hydrosphere, the atmosphere, and the biosphere. He pointed out that models can simulate the system but, although they are incomplete, they can serve as "intuition enhancers." He commented on the various views of the great geomorphologists: William Davis on erosion, Walter Penck on slopes, and John Hack on dynamical equilibrium. (Hack had made the point that landscapes are forced to react by the changing status of processes.) Beaumont illustrated this by a number of computer models which had incorporated smoothing coefficients, efficiencies of transport, and the nature of bedrock on the area being examined. He illustrated a number of interesting areas, including the Lammerlaw Range in Otago in New Zealand, which has a very interesting and complex pattern of streams which have interacted with the soft bedrock and regional uplift. One of his more interesting examples was that of an escarpment which he likened to a reaction front, retreating under the various effects of a number of variables. These included the rock substrate composition (the properties of the bedrock), the climate (relative aridity), and other factors (tectonics, isostasy and antecedent drainage) which may be superimposed on this.

The fourth and final speaker of the afternoon was **Hans-Ulrich Schmincke** (Geomar, Kiel, Germany). Schmincke's talk was entitled **"Volcano-magma systems: Climate, Hazards and Prediction"**. Schmincke pointed out that volcanic eruptions have direct benefits to humanity but also pose serious hazards in the form of major natural disasters. He spent some time discussing the various linkages between volcanic systems, the athsthenosphere, the lithosphere, and also the atmosphere. He mentioned that ocean ridges produce more than 20 cubic kilometres of fresh lava per year. Schmincke stated that there are a number of benefits associated with volcanic activity and cited geothermal power plants as one example. Volcanism is also of crucial importance in terms of producing different types of ore deposits, and much national wealth is due to former submarine volcanic island arcs. There are some major hazards associated with volcanoes, however, including very large eruptions with eruption columns rising to 20-30 kms. These produce glowing avalanche deposits and base-surge deposits. There is also the inherent risk of tsunamis and ignimbrite sheets affecting wide regions close to volcanic centres. He pointed out that the Boeing airfield at Tacoma–Seattle is situated on top of a lahar deposit that is 6000 years old.

Schmincke went on to discuss some of the big disasters that have affected humanity, such as Mont Pelée at St. Pierre in Martinique, and the more recent eruption at Nevada Del Ruiz, which destroyed the town of Armero on 13 November 1985. The tragedy behind this particular disaster, in which more than 20,000 people were killed, was that in the last century and 200 years prior to that, the former Armero had also been wiped out by lahar flows. Scientists now are coming to grips with a degree of predictive capability of volcanoes by studying the various types of eruptions. There are precursors in terms of earthquake activity: expansion of the volcanic dome, tremors which are due to gas bubbles, degassing events (particularly of sulphides), and general increase in regional heat. It is of interest to observe that many of these have been seen in the vicinity of Popocatapetl, Mexico, where more than 60,000 tonnes of sulphur dioxide per day have been ejected recently from the volcano.

Former large eruptions have been noted in historic times. For example, in 1816, Turner, the English landscape artist, changed his style of painting as a result of the 1815 eruption of Tambora in Indonesia. The interesting colours that are reflected in Turner's landscapes are due to sulphuric acids which were injected at high atmospheric levels. In 1983, El Chichon also erupted with high-altitude injections of sulphuric acid. Still more recently (21 August 1991), Nimbus 7 TOMS satellite data illustrated the same phenomenon from Mt. Pinatubo.

There is a direct correlation between high-altitude ash insertion, which lasts for a matter of months, and high-altitude sulphur dioxide injection, which has a very pronounced back-scattering effect and falls out as sulphuric acid with an accompanying temperature decrease. For example, between August 1991 and August 1993, Pinatubo had a world-wide cooling effect of about 0.5°C. The injection of high-altitude aerosols also has some serious effects on the ozone budget alterations in the polar regions. Finally, Schmincke commented on the K–T boundary in Haiti, which has an extremely sulphur-rich horizon. This layer is believed to have been deposited as a result of a bolide impact in sulphur-rich shallow water sediments in what is now the nearby Yucatan at 65 Ma. It has been calculated that the injection of 1.2×10^{17} grams of sulphur into the atmosphere may have led to a six-month cooling of the planet to -20°C.

Although the formal sessions closed at 5:00 p.m., there was a public lecture on the origin and nature of the solar system by **Claude Jean Allègre** of the University of Paris. Professor Allègre is a recipient of the Crafoord Prize awarded by the Royal Swedish Academy of Sciences (the equivalent of a Nobel Prize in the disciplines of mathematics, astronomy, geosciences and ecology). His presentation was titled "**Origin, and Nature of the Solar System**." In it, Allègre discussed the timing, duration and sequence of events that led to the creation of our solar system and the formation of our sun and the associated planets. Much of this information was gathered as a result of chemical and isotope analyses of meteorites and terrestrial materials. The evening wrapped up with a very entertaining session chaired by Derek York in honour of J. Tuzo Wilson.

The Friday morning session began at 8:30 to an enthusiastic bunch of die-hard scientists, although it was obvious that student numbers had dwindled somewhat.

BLOCK III — LIFE: ORIGIN, DIVERSITY AND EXTINCTION was chaired by **Chris Barnes** (University of Victoria, British Columbia). In his ten-minute introduction, Chris started with the origins of life on Earth (perhaps 3.8 Ga "ish"): undoubted bacteria at 3.5 Ga, the eukaryotes at 2.2 Ga, and "higher" animals at *ca.* 0.6 Ga. He pointed out that although the changes of life on the planet were slow at first, they gathered momentum through time, and increasing biomass and diversity have had profound effects on the planet. These include atmospheric modification, nutrient fluxes (both terrestrial and oceanic), the accumulation of fossil fuels, and many economic sedimentary rock types. Extinction events, which are well documented in the Phanerozoic record, have created pronounced perturbations in the continuum of life on Earth, and he concluded that the newly recognized fragility of modern ecosystems places a special responsibility on humanity, from both ethical and scientific viewpoints.

The second speaker was **Andrew Knoll** (Harvard University, Massachusetts) who discussed "**Earth as a Biological Planet: Infancy and Maturation.**" He pointed out that life is extremely ancient and, within our solar system, is confined to Earth. Life has not evolved independently and the tectonic and biochemical events are extremely important. It would appear that the earliest life forms consisted of chemosynthetically supported communities, and that these were probably restricted to hydrothermal springs, volcanoes and areas associated with crustal rifting. These early organisms did not use oxygen, but if one looks at a tree of life through time, the middle levels of the tree allow the use of oxygen, and the higher levels depend on oxygen. Rocks in Greenland dated at 3.9 Ga appear to contain traces of the earliest life detected on the planet. The cyanobacteria are dated between 2 Ga and 1.8 Ga: the eucaryotes really got going between 1.2 Ga and 1 Ga (typified by red algae of *Porphyra* type). By 1 Ga to 900 Ma, larger branching filamentous algae of *Vaucheria* type were in existence, and the green algae (*Cladophora* type) are confined to late Precambrian time. Knoll concluded by pointing out that the late Precambrian "explosion" of life was a function of genetic possibility combining with environmental opportunity.

The third speaker was **Douglas H. Erwin** of the National Museum of Natural History at the Smithsonian Institute in Washington. The title of his talk was "**Extensions and Renewals.**" The thrust of the discourse was on episodic mass extinctions and the biotic recoveries that followed. Early geologists recognized that mass extinctions help to break the geological column into a series of subdivisions. Exceptionally large extinctions, such as those which followed the Permian and that of the Cretaceous, led John Phillips (in 1841) to suggest the divisions of the Paleozoic, Mesozoic and Cenozoic. Other larger mass extinction events have taken place at the end of the Ordovician, toward the end of the Devonian, and at the end of the Triassic periods. The Permo–Triassic extinction event at 251 Ma coincides approximately with the break up of the Pangaean "Super-Continent." The Paleozoic termination caused the demise of more than 85% of all the marine species at the end of Permian time. The succeeding Triassic faunas are highly depauperate in species diversity but very high in numbers of individuals. Erwin concluded by pointing out that extinction events are probably a good thing for the planet but they are quite catastrophic in terms of species diversity. Barren zones may be present for up to 3 m.y. following one of these natural catastrophes. In this time frame, very simple ecosystems are present, dominated by a small number of widespread species. Finally, the "survival interval" gives way to more normal ecosystems, producing faunas which are as diverse as those which preceded the extinction event.

The fourth speaker was **Christopher J. Humphries** of the Natural History Museum in London. Humphries lectured on "**Biodiversity: Form, Space and Time.**" The principal thrust of the talk was on hypotheses derived over the course of the last three decades as systematists have taken into consideration the new concepts of continental drift. He pointed out that the British Museum of Natural History has 81 million species on record which date back as far as 1610 A.D. There is an estimate that approximately 10-15 million organisms exist on the planet, of which 1.8 million have been described so far. Humphries spent some time discussing biodiversity within distinct geographic regions of Western Europe, illustrating that the modern distribution patterns of plants and animals are providing new insights into taxonomic richness, and discussing endemism and aerial relationships. These factors are obviously of crucial importance in the case of the present biodiversity crisis, a problem which will only increase in seriousness as we enter the next century.

BLOCK IV – ANCIENT OCEANS AND ATMOSPHERES: GREENHOUSES AND ICEHOUSES. This session began with an introduction by **Jörn Thiede** of Geomar, Kiel, Germany. Thiede made the case that there is an impending crisis which we will have to face over the course of the next 100 years. Paleoceanographers are well equipped to provide scientific advice to both the public at large and to politicians about the rapid changes that have taken place in the Earth's environment in the recent past. The geological record preserved in ocean floor sediments provides interesting insights into some of the rapidly changing conditions of the past. These include the extreme greenhouse climates of the late Mesozoic and early Cenozoic when ice cover did not exist in the polar regions of either hemisphere, to the rapid transitions seen after Eocene–Oligocene time when the Antarctic Ice Sheet first developed. He spent time explaining the periodicity inherent within the Milankovich cycles and more time dealing with the recent climatic fluctuations in the North Atlantic created by ice advances and retreats and the deposition of ice-rafted debris. These iceberg deposits known as "Heinrich levels" appear to be related to major instability in the Laurentide Ice Sheet that produce large numbers of icebergs which subsequently deposit sediment in the North Atlantic during melt. He concluded his introduction by discussing the challenges in trying to define anthropogenically induced warming effects and their interaction with the natural climate system.

The second presentation in this session was **"Ancient Oceans, Atmosphere and Climate"** by **Jan Veizer** of the Ottawa-Carleton Geoscience Centre and the Ruhr University in Bochum, Germany. Veizer began by pointing out that oceans have an average life of about 55 m.y. The oldest sections of modern oceans date back to approximately 190 Ma. Because of this relatively short residency time, the bulk of global sediments are recycled fairly frequently: a process that has gone on over the last 2.5 Ga. The isotopic composition of early oceans resulted from the interaction of early ocean waters with oceanic crust coupled with injections of material from ridge-spreading centres. This portion of the planet's history probably ceased some 2.5 Ga ago at the Archean–Proterozoic Transition. Veizer noted that the earliest known sedimentary rocks contain a carbon isotope record and, when the isotopic record is examined through time, the ancient carbon biospheric interactions appear not to be too much different from those of today. Veizer made the point that the early life forms of as long ago as 4 Ga probably produced abundant oxygen, but the oxygen levels were subdued largely because of excessive volcanism and intense CO_2 output. The $\delta^{13}C$ record appears to indicate that there was as much life then as there is today. Veizer concluded by suggesting that anthropogenic variations superimposed on an already largely chaotic system will not be amenable to prediction by modelling. The only advantage in attempting such models is to produce a range of likely scenarios.

The third talk was by **Larry Mayer** of the University of New Brunswick, and was entitled **"Unravelling the History of Oceanic Variability."** Mayer pointed out that recent advances in computing have allowed models that permit insights into potential climatic variations. These models are based on the laws of physics, together with observational and experimental experiences. Unfortunately, natural variation is too complex to model easily and observational experiences are too limited to provide a full understanding of natural variability. Earth scientists can look at the geological record to understand longer term fluctuations in various parts of the climate system. The deep ocean basins contain an excellent fossil record that is relatively undisturbed in terms of erosional breaks, and that reflects the long recycling time within the oceans. Oceans are globally distributed and the analysis of microfossils allows a widespread climate record for the recent geological past. The microfossils produce a marine paleoclimatic proxy record, and, since the early 1970s, researchers have realized that there is a cyclicity in this record. The cycles appear to be a function of eccentricity, obliquity and precession in the earth's orbit, and lend strong support to an hypothesis of orbital variation put forward by Milankovitch earlier in the century. Milankovitch had suggested that expansion and contraction of ice sheets are a function of long-term changes in insolation. The microfossil record has allowed a latitudinal analysis of insolation over the last 10 m.y. Mayer illustrated, by means of a video, that these paleoclimatic proxy records can be placed into a sequence that allows the analysis of orbital parameters over 10 m.y. with a resolution of about 1 k.y. The "cosmic clock" illustrated in the video can be stopped in any time frame and an analysis can be made of the various forcing factors that prevailed at that time. Mayer concluded by stating that while orbitally controlled, long-term, climate trends indicate global cooling over the next 10 ka, there is a very important question about the role that anthropogenic warming may have over a shorter time frame.

The final speaker of the morning session was **Richard Fairbanks** (Lamont–Doherty, Columbia University, New York) who talked on the **"Oceanic Record in Hominid Times."** He explained that recent research and the recovery of arctic and antarctic ice cores has helped to link climatic fluctuations to orbital variations. Furthermore, these changes have been verified by deep-sea cores which can also be tied to the same phenomenon. Fairbanks outlined the rapid sea-level change caused by the melting (10^{21} joules) of the northern ice sheets, illustrated by the drowned Barbados reefs, and discussed the problems of correlating ^{14}C and U–Th dates. He was able to use these points to explain that there are conflicting hypotheses over whether the tropical regions have remained constant in temperature over the last sets of glaciations or whether there have been temperature fluctuations. One school of thought claims that tropical sea-surface temperatures had remained fairly constant, while the most recent observations from chemo-thermometers from coral reefs and other proxies seem to indicate that tropical ocean temperatures had dropped by up to 5°C during the last glaciation. These observations have led to modifications in global circulation models which will have interesting implications in terms of forecasts for global warming.

BLOCK V — GLOBAL CHANGE AND NATURAL VARIABILITY was chaired by **Lawrence Mysak** (McGill University, Quebec) who pointed out that the extremely equable climates of the Late Cretaceous and Early Tertiary gradually deteriorated in Late Tertiary and Quaternary times. These major shifts in climate appear to be controlled by variations in CO_2, coupled with fluctuations in oceanic circulation. Changes in climate can occur extremely rapidly, in time scales as short as centuries or decades. Recent examples can be seen in the cooling trends of the Late Pleistocene "Younger Dryas" and the Holocene "Little Ice Age" (1250-1850 A.D.). Although the causes of this very rapid variation in climate are unknown, it appears that they might be caused by changes in deep water oceanic circulation, especially in the North Atlantic Ocean and perhaps also in the North Pacific. It is extremely important to understand these processes and the feedback mechanisms in order to develop sensible climate models for future prediction.

The second presentation was by **Ralph Keeling** (Scripps Institute of Oceanography, La Jolla, California), who gave a paper on "**Global Change and the Carbon Cycle from an Atmospheric Perspective.**" Keeling pointed out that atmospheric monitoring of CO_2 in the recent past has led to a number of predictive models. Atmospheric CO_2 has been measured at Mauna Loa for the past 40 years. Recently, it has been observed that the amplitude of the fluctuations has been gradually increasing through this time frame. Keeling spent some time discussing the balance of CO_2, explaining that fossil fuel burning and tropical land use amount to a release of approximately 7.1 Giga-tonnes (Gt) of CO_2 in anthropogenic releases each year. The sinks for the planet include the northern forests, the atmosphere, and the oceans, which account for approximately 5.7 Gt of $CO_2 \cdot a^{-1}$. The big question is what is happening to the missing CO_2? In order to explain this, Keeling suggested that the amplitude change seen in the Mauna Loa record may be due to a longer growing season in the northern hemisphere, probably caused by climate warming. The draw-down of CO_2 is occurring earlier in the year. This might be due to a longer growing season, and is a function of spring growth starting earlier in the year. He stated that these points were conjectural but they fit the data quite well. He concluded that our overall understanding of CO_2 balances is inadequate in terms of ecological processes.

The third talk was by **Hans Oeschger** (University of Bern, Switzerland) on the "**Polar Ice Record.**" Oeschger's talk did not present much new information, but it was a pleasure for those of us interested in the Quaternary to see one of the principal researchers in person. Much of his talk revolved around the now famous Siple and Vostok ice cores in Antarctica and the more recent cores obtained at DYE-3, Summit and the GISP2 and GRIP cores in Greenland. Oeschger's talk took the audience through the causes of variation in the oxygen isotopic signatures in ice, and also through the mechanism of bubble inclusion in glacial ice as it is transformed from snow crystals to névé. He examined the fluctuations of CO_2 and CH_4 in several ice cores, explaining that CH_4 variations are highly correlated with climatic variations and seem to be slaved by them, while the CO_2 variations are far more complex. One of the characteristic oscillation forms appears to record abrupt warming trends and longer-term cooling trends. The most recent initiation of a cooling trend seems to have taken place at 8200 ka in the Holocene. He spent time linking ice core and oceanic records, suggesting that there is a linkage between atmospheric gas records and fluctuations in North Atlantic deep water circulation. Oeschger also mentioned the results from the recently drilled GRIP and GISP2 ice cores, which appear to have revealed extremely rapid fluctuations in the last interglacial (Eemian–Ipswichian–Sangamon). He suggested that these might be alternatively interpreted as rheological variations in basal ice.

The fourth talk was by **Lonnie G. Thompson** of Ohio State University at Columbus, and was entitled "**Record of Mountain Glaciers.**" Thompson commenced his talk by pointing out that tropical regions contain 75% of the world's population, 80% of new births, and 20% of the world's agricultural production. Little is known about the historical variations in climate; even the longer northern hemisphere meteorological records extending back over the last 150 years cannot be applied to this region. The polar ice cores which have been studied in some detail do not reflect the tropical climate fluctuations generated by such important phenomena as tropical cyclones, monsoons and ENSO effects. However, there is a record contained in tropical ice caps. His research has looked at two tropical ice caps at Huascarán in Peruvian Andes, where 85% of precipitation (>$3 m \cdot a^{-1}$) comes in the wet season, and at Guliya in Tibet. Both of these ice caps cover the last glacial cycle (>20 ka) and both illustrate a cooling of about 8°C. The ice cores have revealed much environmental data including ^{18}O, the chemistry of bubbles in the ice, and net accumulation and precipitation rates. These data have been supplemented by wind speed analyses, high-level vegetation records (preserved in pollen), and volcanic records. The latter are seen as tephra and sulphates. In addition, anthropogenic inputs can be observed. Thompson pointed out that one matter of grave concern was the increasing ablation of these tropical ice caps. Some were retreating at rates of about $4 m \cdot a^{-1}$ several decades ago and they are now melting at more than $30 m \cdot a^{-1}$ (1995). The exponential increase in rate of retreat started in the mid 1970s. These ice caps must be examined rapidly and comprehensively or we risk losing the record. One of the most interesting aspects of the talk was the explanation of the considerable logistic difficulties encountered in trying to sample these high-altitude tropical ice caps. These ranged from teams of mules and porters bringing supplies to the edge of the glaciers, to the innovation of solar panels to assist in drilling, and to new attempts to look at hot-air balloons to ferry supplies and samples.

Thompson's talk concluded the second day's sessions, but the second evening public lecture was given by **William (Bill) Fyfe** (University of Western Ontario, London) on "**Environmental Science and Policy: Issues, Questions and Answers.**" The talk was attended by about 60 participants. Fyfe's talk explained that there will be between 10 and 20 billion humans on the planet by 2050 and this incredible population growth will require new technologies for energy, food production, transport, material resources, water and air quality as well as the management of wastes. These points were not lost on the audience, but it was extremely unfortunate that more members of the public, and particularly our political task masters, were not present to hear these words of wisdom coming from such an erudite scientist.

Saturday morning's lectures started again at 8:30 to a faithful group of devotees. A casual glance around the audience showed that high school participants had dropped to a few, and as far as I am aware, only one news media person was present in the auditorium.

BLOCK VI — OUR PREDICTIVE CAPACITY AND EARTH SYSTEM MODELS was chaired by **Antonio C. Lasaga** of Yale University, who pointed out that the new observations on the Earth system have produced great masses of information ranging from small-scale, atomic interactions to large-scale continental or plate size movements. When these are coupled with other forms of measurements, such as atmospheric chemistry or isotopic analyses, scientists have been encouraged to create models to try to explain the data gathered. He pointed out that a good predictive capacity really depends on continued refinement of these models and we have found out that these refinements require the integration of many different sciences. Such integrations, which, ideally, should be global in scale, also encompass a time factor. Fortunately, geoscientists can check these against "real" observations in the geological record. He cited a number of examples: at the close of the Cretaceous, CO_2 levels were 18 times greater than those of today, and the average global temperature was at least 12°C higher than modern values. This led Lasaga into a short and interesting discourse on the sequestering of CO_2 and the "lifetime" of certain minerals of varying chemical composition (Albite at 575,000 years *versus* Anorthite at 112 years). Improvements in these models will require an understanding of the dynamic coupling between the many different parts which make up the Earth system.

The second speaker of the session was **Karl Turekian** of Yale University, Connecticut, who presented a talk on "**Models and Experimental Records**." Turekian's thesis was that Earth system models do not necessarily involve computer models, but may also result purely from observation and experimental methodologies. He illustrated such a model by talking about osmium leaching from crustal rocks, giving various values from different river systems in various parts of the world and pointing out that $^{187}Os/^{186}Os$ is principally derived from ultramafic rocks which have a high Os content. Turekian went on to comment on Os/Ir ratios in rocks associated with the K–T boundary impact, and then, by incorporating ^3He variations, he attempted to decipher some of the tectonic and climatic history of the last 65 m.y. He noted that there are various theories that might explain atmospheric cooling (dust in the atmosphere) or reduction of CO_2 by weathering of obducted ultramafic complexes.

The third talk was by **Susan W. Kieffer** who addressed the subject of "**Volcanoes, Floods and Landscapes: Our Predictive Capacity**." Kieffer talked about medium–rare events in the geological records: infrequent with respect to political time scales, but important to society since they take place in the range of hundreds to thousands of years. She illustrated her talk by using examples of volcanic and flood activity. Kieffer pointed out that certain volcanic eruptions can be relatively frequent, but quiescent and predictable, as in the case of Hawai'i. Alternatively, there are very rare, extremely violent and relatively unpredictable volcanic events, such as the eruption of Pinatubo. Because these large events are relatively rare and infrequently documented, geologists have to be able to work with past events, by mapping the areal distribution of materials from past eruptions. Kieffer used the example of the 1980 eruption of Mt. St. Helens, where a high-pressure magma reservoir flowed to a low-pressure atmospheric reservoir outside the volcano. This produced an "ash blast" or an "ash hurricane," which, in the case of Mt. St. Helens, was equivalent to a nuclear blast of 24 megatons: 7 megatons in the blast and 17 megatons as heat energy in the magma. She illustrated some computer simulations of massive caldera-type eruptions, and, in one of the highlights of the session, summarized a set of analyses which involved 16 simultaneous equations by a single slide with a large "16" in the centre! (An excellent example of keeping the science at a level which can be understood by the public at large!) Kieffer went on to talk about river floods, particularly the recent controlled release of water into the Grand Canyon of the Colorado River from the Glen Canyon Dam. Here she presented a fascinating analysis of fluvial debris trains left in the Colorado Valley. These reflect the largest floods that have moved through the region before humans impeded the regular flow of the Colorado. She suggested that the largest floods were around $400{,}000^3 ft \cdot s^{-1}$, about four times the largest flood observed in modern times. She pointed out that geoscientists should learn to read these landscapes and apply fluid-dynamics models to try to quantify the rates at which these various processes take place.

The fourth talk was by **James C.G. Walker**, of the University of Michigan, entitled "**Can We Predict Climate?**". Walker gave one of the most thought-provoking presentations of the conference. The "bottom-line" is that caution is called for when certain scientists claim to be able to provide reasonably accurate predictions of future climate. He pointed out that our predictive capabilities can be tested against the past; however, if we moved back in time one hundred years and knowing what we know now, could we have predicted the changes in climate that took place within the last century? His emphatic answer was "no," since we still do not understand the mechanisms of climate changes, and we can only understand changes by using hindsight. Weather can be predicted a few days in advance by observations that can be updated and by predictive equations. However, climate is weather averaged over decades and it cannot be predicted; there are lots of unknown variables. His talk was punctuated by questions thrown to the audience for discussion. He concluded by stating that science can alert us about the possible consequences of various actions that we might take, but it cannot predict the behaviors and complexities well enough to tell us what actions or alternatives might be most cost effective. Science cannot relieve humankind of the responsibility of choices to be made or avoided in face of uncertainty. These choices should be based on an understanding of right and wrong and not the best scientific calculations of relative advantage.

BLOCK VII — HUMAN IMPACTS ON THE ENVIRONMENT: FRAMING THE QUESTION was chaired by **Brian J. Skinner** of Yale University. Skinner began his presentation by taking the audience to Easter Island, the most remote island in the Pacific. He pointed out that a group of Polynesians settled the island about 300-500 A.D., and commenced exploitation of the island and surrounding seas. The population gradually grew to about 10,000-12,000 by 1650, but at the environmental price of complete deforestation, severe soil degradation, and the disappearance of fauna on land and in the surrounding seas. The inhabitants finally had no trees to allow boat building (to move elsewhere), or to fish, and warfare broke out. One hundred years later in 1755 when the Dutch discovered the island, there were less than 2000 malnourished survivors. The Easter Island scenario is a distinct possibility for humanity should population growth continue unabated. Human numbers are now 6 billion and are increasing at 100 million per year. Each human uses, on average, 8 metric tonnes of material, especially aggregates and minerals. When one compares this rate of exploitation to natural forces, humanity is rivalling nature. For example, all the rivers of the world carry 16.5 billion tonnes of material per year. Human exploitation of materials averages 2-20 tonnes per capita (about 50 billion tonnes per year for all human activity). He went further by illustrating individual "human ownership" of a square of the planet's surface. This currently amounts to 86m^2 of forest, 52m^2 of arable land, 76m^2 of pasture and range land, 13m^2 of mining land, and 30m^2 of occupation land. He pointed out that approximately 15% of world arable land has been lost, and that water and wind erosion are becoming serious problems. He suggested that the next critical problem to face humanity will arise from pollution of water supplies as well as the problem of soil contamination and erosion.

The second speaker of the session was **Carroll Ann Hodges** of Woodside, CA, who talked on "**Nonrenewable Resources: Club of Rome Revisited.**" In my opinion, this was probably one of the best-illustrated and presented papers of the conference. Hodges made the case that despite Malthusian "doom and gloom" scenarios about the natural resource shortages which would face humanity as numbers increased, these have not, so far, materialized. The increasing demands of an exploding population have been met by efficiencies in mining discoveries, (bauxite reserves in 1940 were 2 billion tonnes, and in 1995, 256 billion tonnes); mining practices, increased recycling (of all the gold ever mined 85% is still in circulation), and technological innovation and substitution (fibre-optic cables instead of copper). The reality is that real prices of metals have been stable or declining since 1900, even though the rate of mineral consumption has been increasing faster than population growth. She suggested that current reserves of most metals can support the current population at least through the next century. Although North America is still one of the largest producing regions of the world, exploration has turned to the developing nations where 95% of the population growth is taking place and where consumption is rising markedly. She noted that the Middle East has 50% of the world's oil reserves, China 50% of the tungsten; Zaire 50% of the cobalt and South Africa 90% of the platinum, 70% of the chromium, and 45% of the gold. The United States has 50% of molybdenum supplies and Canada and Russia combined have 85% of the world's potash supplies. This availability of raw materials is extremely relevant to policy decisions on mineral development, land use, and other environmental concerns. She noted that historically the social costs of mining have not been incorporated in commodity prices, but as environmental ethics are growing there are demands that environmental accountability be included in the pricing of raw materials. Furthermore, there are demands that environmental concerns be addressed (see the Whitehorse Mining Initiative, published in 1995). These high standards for mining protection are being applied, not only in the developed world, but also in the developing nations. Hodges suggested that although there appears to be no immediate shortage of raw materials, we will need to continue research into technological advances in the extraction, treatment, fabrication and substitution of various ore supplies. The rationale is that if essential minerals are perceived to be in short supply, but are located in an environmentally sensitive region, then the environment will be sacrificed. She concluded by stating that the loss of soils, freshwater, forests, fisheries and biodiversity are a lot more serious than the exhaustion of non-renewable minerals.

The third talk, "**Water**," was by **M. Gordon Wolman** of The Johns Hopkins University, Maryland. Wolman pointed out that fresh water is a very small part of water on the globe, and the first part of his talk was spent explaining the various pathways involved in the hydrologic cycle. Approximately 70% of the total precipitation on the continents is evaporated or transpired and the remaining 30% is available for use. Very little of this is consumed in industrial and household use, although a moderate amount is applied in irrigation agriculture. The remainder (*ca.* 80%) is returned via surface runoff and sub-surface flow. Wolman said that human activities have adversely affected the quality and quantity of fresh water in the world, particularly by the building of dams and reservoirs. This has seriously affected the flow rate of rivers and has curtailed the transport of sediment to tectonically active margins of continents in many parts of the world. For example, run-off in world river systems has been reduced by 25% during the past 300 years as a result of dam construction. Reservoir construction has increased dramatically in the last 100 years with approximately 5,525^3 km in use today. Agricultural, industrial and household pollution has severely degraded freshwater availability for many parts of the world. Even in areas far removed from industrial activity few freshwater sources can be regarded as pristine because of pollutants, such as chlorinated organic contaminants, which have been transported by atmospheric transport. He explained that studies of past civilizations, particularly those of the Middle East, have shown a relationship between development and prosperity and the amount of water available to them. Models of population growth suggest that there will be far greater stresses on water demand, and, as human numbers expand, these stresses will intensify. In some parts of the world climatic variation suggested by GCM's will exacerbate the problems of water supply and human well being.

The final paper, "**Energy and Waste Disposal**," was presented by **M.G.K. Menon** of New Delhi, India. Menon was the only non-European, non-North American speaker at the conference and brought an interesting perspective to comments made by earlier speakers. He too, mentioned world population, pointing out that it is currently at 5.8 billion and is expected to rise to 10 billion by 2050 and 12 billion by 2100. He pointed out that the reason for so many children in the developing nations is sociological; they are there to look after animals, to gather wood (the "lops and tops" as he described them), to bring freshwater, to look after siblings, and also as a degree of old-age security. Ideally, it would be advantageous to stabilize world population at 10 billion, or less, but reality dictates that this is not likely to happen. The developing countries of Asia, Africa and Latin America will see 90% of the world's population growth, and in these areas the energy use per capita is very low. On the other hand, the developed countries have reached levels of over-consumption of energy and it seemed that time had come to address some of these imbalances. The developing countries will have to make significant efforts to reduce pollution associated with coal use and there are established technological "fixes" which can be applied to this problem. He concluded his talk by a discussion of the advantages and disadvantages of using conventional energy resources, for example, the rise in greenhouse gases, the environmental pollution problems caused by trace elements in conventional fuels, the problems of hydro-electric power, and the potential catastrophic effects of accidents within the nuclear industry. It is clear that we are faced with complex and difficult decisions and long-term and unorthodox opportunities will need to be explored.

Menon's talk completed the formal presentations, but a large "public forum" was held on the Saturday afternoon. The forum was entitled **"Debates on Public Issues"** and was chaired by **J. Fraser Mustard** with **William Fyfe** and **Bernard Beaudoin** as co-chairs.

The question posed was "Given what we know about the planet and how it works, what do you think the effects of mankind's changes will be?". A large panel of experts addressed topics such as Time (Bernard Beaudoin); Energy and the Environment (Gordon McBain, ADM, Environment Canada) and M.K. Menon; Waste Management (Bill Fyfe); Groundwater (John Cherry) Predictability (Keith O'Nions); World food (Wolfgang Eder) Earth System Education (Robert Haynes and Godfrey Nowlan); Mineral Resources (Charles Ferguson and Hugh Morris) and "Reflections" (Christine Williams, a student from Pickering High School) and Ursula Franklin. The panel of experts notably lacked females. Ursula Franklin made her usual knowledgeable comments on the relationships of science and society: "Science is not always a benefactor of society, for example, when used in warfare". She stressed that science has to have a point to show its worth to society and the taxpayer. In the case of the earth sciences, there is a need to bring geological timescales and processes to the level of human timescales and actions. Christine Williams bravely attempted to synthesize her thoughts from the perspective of a student at the symposium.

The symposium closed with a delightful dinner at the Ontario Association of Architects building, chaired by John M. Hayes (Woods Hole Oceanographic Institution) to honour H.G. Thode.

SOME CLOSING OBSERVATIONS

The symposium had a total of 320 attendees made up of paid registrants, speakers and panellists, and high school students. The participants came from 11 countries, including Australia, Hong-Kong, India and Czech Republic. Approximately 75% of the audience were Canadians, with the vast majority from Ontario, although some came from British Columbia, others from the Maritimes, and still more from points in between. A further 10% were from the United States. A minimum of 52% of the registered audience had doctoral degrees. A number of government representatives were present, including one Assistant Deputy Minister, and several science writers were also registered.

A three-day meeting of this sort is a major undertaking for speakers and participants alike. Generally, the talks were excellent, marred by a few poorly prepared visuals and upside down, backwards and reversed slides. These, however, were definitely in the minority and most speakers came across at "the right level." Those who stuck through the full three days gained interesting insights into many aspects of the way in which our planet works, and what we, as a species are doing to it. They might also have learned how earth scientists go about trying to understand it. However, the underlying question is "Was it worthwhile?". From a scientist's perspective and as teacher of first-year courses in earth sciences my answer is yes; however, it was obvious that this gathering had missed its mark. The conference had a large number of distinguished speakers pulled in from various parts of the developed world. This was reflected in a long list of donors, and a relatively healthy registration fee. I am unsure whether the greatly reduced registration fee for "the public" was a deterrent, whether the topics might have sounded too esoteric, or whether the conference was not adequately advertised, but I regretfully conclude that it failed. If one wishes to have scientists interact with the populace to put across some of these important ideas, several things must happen. The conference must be free or really nominal in cost. It must be aggressively advertised. The speakers must be superb communicators, and used to talking to large audiences at the appropriate knowledge level. Some speakers were truly excellent, but others had not moved too far from the level of addressing graduate students within their fields of specialization. But perhaps all of this is futile. I was struck by the fact that had the panel of experts consisted of basketball players, ice hockey and football stars, the news media would have been there in force and it would have been standing room only for the general public. Perhaps I am too cynical, but it appears that we (earth scientists) have a lot to do to improve public interest in our subject area. We know it is important; why is it that we fail to communicate our knowledge and interest to the public at large? I suggest that a few individual trans-Canada lecture tours, properly advertised and sponsored, would certainly have attracted a far larger audience, and probably would not have been any more expensive. I know that this was not the purpose of this venture; it was an attempt to pull a theme and speakers together in one location. Unfortunately, our desire to see and hear distinguished fellow scientists must be pushed aside to put these speakers where they will do most good, that is, among the general public. An audience of 200, which might represent the absolute maximum number of public participants at the conference, is simply not good enough.

Not to close on a negative note, I am aware that all presentations were videotaped, that the tapes can be purchased, and that a book is being prepared summarizing the papers presented at this meeting. It might be a last chance to transmit the wealth of knowledge presented at The Earth System Symposium to the public at large. I would like to express my thanks (and I am certain from all other participants) to the Ontario Science Centre and its staff, and especially Vic Tyrer, for hosting this meeting; to the donors for contributing funds which probably kept our registration fees below $500; to the organizing committee for arranging one of the most interesting "show and tells" on planet Earth that has been arranged for a long time; and to the speakers for engaging us in three days of appropriate and intriguing thoughts on the third planet from the sun.