Isotopes in global change science: from isotope analytics to Earth system research

Les isotopes pour l'étude du changement du système Terre

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ABSTRACT – The aim of this paper is to emphasize some of the studies of Jean-Charles Fontes and his role in our scientific community.
Isotopes represent a powerful tool for the understanding of the Earth's past environment and defining the envelope of natural environmental variability within which we can assess anthropogenic impact on the Earth's biosphere, geosphere and atmosphere. The reconstruction impacts of past climatic change on the Earth's system are a basis to validate models of the possible impacts of future climate change. Oceanic sediments, polar ice caps, continental sedimentary sequences and groundwater are archives of past climate. Their quantitative study is developed within the IGBP (International Geosphere-Biosphere Program) – Pages project, which strongly emphasizes an optimum use of isotope tools.

Keywords: past global changes, isotopes, polar ice, ocean, continent, atmosphere

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RÉSUMÉ – Je souhaite illustrer ici quelques études réalisées par Jean-Charles Fontes et souligner le rôle qu'il a tenu dans notre communauté scientifique. Les isotopes représentent un outil puissant pour comprendre l'évolution naturelle de l'atmosphère, de la biosphère et de la géosphère, et estimer l'impact de l'activité anthropique sur le système Terre. L'étude de la variabilité climatique sur des périodes de temps plus longues que celles recouvertes par les enregistrements instrumentaux est indispensable pour valider les modèles prédictifs du climat. Les sédiments océaniques, les glaces polaires, les séquences sédimentaires continentales et les eaux souterraines détiennent les

archives du passé. Leur analyse quantitative fait l'objet du programme international Géosphère-Biosphère PIGB-PAGES dans lequel l'outil isotopique doit être optimisé.

Mots clés : changement global dans le passé, isotopes, glace polaire, océan, continent, atmosphère.

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INTRODUCTION

Some decades ago a number of physicists and chemists, involved in isotope analysis, realized the great potential of the application of natural and cosmic ray produced isotopes to Earth system studies. Indeed, many discoveries in this field have only been possible thanks to the use of these techniques. Important knowledge on Earth system processes we owe to studies of high resolution records from the polar ice caps, from sea and lake sediments, but also other natural continental archives. Jean-Charles Fontes belonged to this group of scientists. He was especially interested in studying the continental aspects of the water cycle which are an important factor the Earth system, but also for the living conditions of the population in great parts of the globe.

He found considerable changes in the water cycle through time, often in connection with global climatic change. This knowledge provides an important basis for projections of changes in the water cycle into the future, as a consequence of the human induced global warming.

In the frame of Global Change science, it is not sufficient to know what happened during the 150 year period of instrumental measurements. Many phenomena which might become important in the future did only show up during much longer periods of time, as the ones which J.-Ch. Fontes and his collaborators studied.

For this reason, the IGBP decided to conduct a Core Project Past Global Changes (Pages). Paleo-research provided invaluable and often unexpected information on Earth system processes. Of special value for these studies in many cases are the isotope results. Since several years, a group of paleo-scientists, among which the new Director of the IAEA Isotope Laboratory, J.-Ch. Fontes, had the opinion that in Global Change science in general the use of the isotopes is by far not fully exploited. Together with J.-Ch., a meeting was planned, to stimulate the use of the isotopes in the water cycle and after the death of J.-Ch. Fontes, a meeting on this topic was successfully conducted in January, 1995, close to Bern, the meeting was organized by WMO, IAEA, PAGES and IAHS, with observers of WCRP and IGBP. A team has been formed which aims at up-dating and extending the Global Network for Isotopes in

Precipitation (GNIP) and inspiring a more intensive use of isotopes information in Global Change science.

The aim of this paper is to emphasize some of the studies of Jean-Charles Fontes which I remember especially well and also to show that both of us independently tried to develop a concept of Earth System Research based on new analytical tools and modeling experiments. Jean-Charles passed away exactly during the period when we jointly intended to give to this field of science a new momentum basing on methods and ideas which promise to produce exciting scientific results, but have not been fully recognized and exploited by the large scientific community involved in Earth System and Global Change Research.

^{14}C AND ^{39}Ar AGES OF GROUNDWATER

Jean-Charles Fontes was a good friend of mine and of my collaborators at the Physics Institute of the University of Bern. In 1992 I had to retire as director of the Laboratory for Climate and Environmental Physics and I was moved when I heard that Jean-Charles contemplated being my successor.

I believe that J.-Ch. and myself had a somewhat similar career. He started as a chemist, I as a physicist. We both were initially interested in analytics, in measuring natural radioactivity at very low concentrations. He used and perfected liquid scintillation counting for natural ^{14}C measurements, whereas I tried to construct proportional gas counters with as low as possible backgrounds.

I remember an interesting event on the occasion of the IAEA Conference on "Isotope Techniques in Groundwater Hydrology" in 1974 in Vienna. At the end of the 60ies my collaborator H.H. Loosli succeeded to measure ^{39}Ar in atmospheric Ar and also in Ar extracted from groundwater. Until then many age determinations on groundwater based on ^{14}C had already been made and the ages were considered to be very close to the mixing ages of the groundwater and not afflicted with problems. At this conference H.H. Loosli showed a set of ^{39}Ar groundwater ages which mostly were much younger than the corresponding ^{14}C ages. I mentioned in the discussion that one should really look into the problem of a possible artificial ageing of $^{14}C/C$ in groundwater due to the interaction of the dissolved carbon with the surface of the aquifer.

Several laboratories began to look deeper into these questions raised. J.-Ch. tried to resolve the problem by developing quantitative models for the interaction of the dissolved carbon with carbonate on the surface of the aquifer and the effects on ^{14}C and ^{13}C. This enabled to estimate possible deviations of the ^{14}C ages. I was very much impressed by J.-Ch. attempts to tackle this problem. Simultaneously H.H. Loosli continued his ^{39}Ar measurements and to our surprise he also determined ^{39}Ar ages younger than zero, in spite of the

fact that only negligeable amounts of ^{39}Ar were produced by the nuclear weapon tests, not enough to influence the atmospheric $^{39}Ar/Ar$ ratio.

The problem was resolved: indeed the original $^{14}C/C$ in groundwaters often gets diluted by "older" carbon, but also ^{39}Ar ages can differ from the real groundwater ages due to the admixture of ^{39}Ar produced underground by (n,a) and (n,p) reactions.

This was a typical event in science: from initial consternation about the discrepancy of scientific results to a real step forward.

PALEOSTUDIES IN THE OCEANS, ON THE POLAR ICE CAPS AND ON THE CONTINENTS

Whereas J.-Ch. Fontes was interested in hydrological and in general more continental applications of isotopes, I early was confronted with the CO_2 problem.

In 1958 I had the chance to measure the ^{14}C age of the bicarbonate extracted from deep water of the Pacific Ocean and together with Hans E. Suess and G. Bien in their laboratory in La Jolla, California. We obtained values of the order of 1 500 yrs for the difference between the apparent ages of the deep Pacific Water and that of the mixed surface layer. This information we used in 1974 when we developed the Box-Diffusion-Model (Oeschger et al., 1975) for the uptake of excess CO_2 by the ocean. We had a strong confidence in the validity of this model and were already at that time convinced that due to the rising greenhouse effect mankind would one day be confronted with a drastic climatic change in the next century. Indeed, if the emissions of CO_2 and other greenhouse gases would follow the Business as Usual Scenario of the IPCC Report (1990), the greenhouse forcing in the next century would increase to ca. 10 W/m^2 with the consequence of a global warming of ca. 4 to 5 °C, i.e. of the order of a glacial to interglacial transition. A decrease of the emissions by a factor of 2 until the middle of next century (similar to scenario D in IPCC 1990) would lead to a stabilisation of the greenhouse forcing at the level of 4 W/m^2 corresponding to a global temperature increase of 2 °C. This appeared to us as the best still possible limitation of the greenhouse excursion of the Earth.

Our laboratory in the late 50ies and early 60ies became interested in extracting the Earth system information contained in natural ice from the Alps and from the polar ice caps. Indeed many interesting observations were obtained from studies of ice and ocean sediments. From the ocean sediment information it was possible to study the reaction of the system to the orbital forcing. The ice core studies, thanks to the high resolution, enabled the detection of

unexpected high frequency climatic events and changes in the atmospheric composition related to climatic changes.

These and other information indicated that beside the physical processes also chemical and biological processes play an important role in the behavior of the Earth System (E.S.). In 1986 the International Council of Scientific Unions (ICSU) decided to conduct the International Geosphere-Biosphere Programme (IGBP) to supplement the World Climate Research Programme (WCRP) which essentially concentrates on the physical processes in the E.S. Since the beginning of the IGBP I had the chance to be a member of its committees and the possibility to emphasize the need to conduct a paleo programme. Around 1990 the Special Committee of the IGBP then decided to conduct a core project Past Global Changes (Pages)

J.-Ch. Fontes and his colleagues studied the water cycle, chemical processes (solution, paragenesis and diagenesis) and fundamentals regarding production and behavior of radionuclides (Fontes, 1994). In the following a short overview on his results and visions is given.

Of special interest for him was the water cycle: he studied the isotopic tracing of meteoric water in Europe, Africa and South America and analysed the relation to the origin of the water. Particular emphasis he gave to the interaction of water with the soil, especially also in arid areas. These studies were often linked to problems of water resources. Very important are his studies related to the evaporation and evapotranspiration of water. In Atmospheric General Circulation Models a weak point is the behavior of water over the continent. The question may be posed whether in these models use is made of the information obtained by isotope studies, like those by J.-Ch. and his collaborators. They provide results which often could not have been obtained by any other method.

In the past years J.-Ch. became very much interested in paleo-hydrology and attempted to link his results to the evolution of global climate. In one of his papers (Gasse *et al.*, 1994) an evidence regarding the arid-humid transition in the Sahara and the Sahel during the last deglaciation is discussed. At the time of the Last Glacial Maximum, the Sahara and Sahel regions of North Africa were extremely dry. Records of rainfall show that, during the subsequent deglaciation, the transition from arid to humid conditions in these regions occurred synchronously in two main steps. Comparison with other records of paleoclimate in Europe and the North Atlantic Ocean shows that common factors controlled changes in ocean and atmosphere dynamics during the deglaciation. Impressive in this paper is the broad use of mineralogical and biological parameters, including if possible isotopic measurements.

This paper illustrates the link between ocean ice and continental paleo-records. Only if PAGES succeeds to coordinate the information from those different paleo-records an optimum contributions to Global Change Research will be possible.

WHY ARE STUDIES OF THE PAST SO IMPORTANT FOR GLOBAL CHANGE SCIENCE?

In the following a few examples are given, why the Pages core project is so important in the frame of Global Change Science:

— The present Earth' system is already in a deviated state compared to pre-industrial conditions, due to human emissions which became effective in the 19th century. Continuous, high precision measurements of CO_2 started only in 1958 and of the other gases even a dozen years later; earlier sporadic measurements are difficult to interpret. The reconstruction of the pre-industrial concentrations and the early increases of these gases was possible by the measurement of the gas composition of the air occluded in natural ice of known age.

— Climate shows a natural variability consisting of red noise, but also of internal quasi-oscillations like the ENSO events, the North Atlantic and the Monsoonal variations. How are these phenomena influenced by climatic change? To answer this question one needs to study the climate variability during longer time periods which also cover larger natural climate changes, than those offered by the instrumental records.

— Reconstructions of external forcings, like those due to solar variability and volcanic eruptions, together with their effects on climate enable the study of climate sensitivity over large periods of time and the build up of confidence in our understanding of the climate system.

— Based on results from such studies, one can, within some limits, estimate how climate would have developed during the industrial time without the human impact. This then would enable to disentangle from the actual evaluation of climate the effects of the human impact on the system.

The reconstructed impacts of past climatic change on ecosystems and on fluvial systems, as well as on sea level, are a basis to validate models of the possible impacts of future climate change.

— In the past there have been natural greenhouse gas variations which constituted a feedback during climatic changes, like the glacial-interglacial transitions. The data show that these variations of the greenhouse effect probably contributed to the climatic coupling between the hemispheres during the glacial cycles. To understand the greenhouse gas climate variations, i.e. the full physical-chemical-biological interplay during these fluctuations, is one of the big challenges of Global Change Science.

— In the records of the past unexpected events have been found. As an example, during the last glacial and perhaps also during the Eemian interglacial a bistable climatic system dominated the processes in the North Atlantic region. These events had drastic impacts on large regions of the globe. This discovery could means that in order not to induce climatic changes with immense consequences one not only needs to keep the rate of increase of the greenhouse forcing below a certain limit. Also the absolute value of the forcing should remain below a threshold value above which the system would switch into another state.

INITIATIVES TO ENLARGE THE USE OF ISOTOPES IN GLOBAL CHANGE RESEARCH

PAGES is charged with providing a quantitative understanding of the Earth's past environment and defining the envelope of natural environmental variability within which we can assess anthropogenic impact on the Earth's biosphere, geosphere and atmosphere (Pages, 1994). Fig. 1 gives an overview on the Pages Project Organization.

In the frame of FOCI 1 and 2 the history of the variability of the global climate and environment will be reconstructed, aiming at an integrated high resolution description of the Earth system during the past 2000 years and with lower resolution during the past few glacial-interglacial cycles. The work performed by J.-Ch. Fontes and his collleagues will be of a special value for the Afro-European transect PEP – 3, but methods he developed during the past decades will in general help to increase the standard of continental paleoreconstructions.

In all these projects we emphasize an optimum use of isotope tools. Especially in Focus 5 Pages hopes for a strong collaboration with the Isotope Hydrology Section of the IAEA and started early contacts with their team.

In April 1993 a meeting on "Isotope Techniques in the Study of Past and Current Environmental Changes in the Hydrosphere and the Atmosphere" was held in Vienna. Many papers presented at this conference demonstrate the great potential of environmental isotope studies to investigate past and present Earths system changes. A more formal integration of the IAEA / WMO network on Isotopes in Precipitation and of the most valuable work of the Isotope Hydrology Section of the IAEA into the Global Change Research became a must.

On December 13 and 14, 1993 a planning meeting for PEP III, directed by F. Gasse was hold at the Pages CPO in Bern. J.-Ch. Fontes the new director of the Isotope Hydrology Section of the IAEA attended this meeting and demonstrated much interest. He made valuable suggestions and gave an excellent

presentation on the use of natural isotopes in the frame of this project. He had to leave early, I brought him to the elevator, we expressed our satisfaction about the fledgling collaboration.

A few weeks later Jean-Charles Fontes died. We all were shocked but felt strongly that we have to continue this work in his spirit.

Soon after the funeral planning of a "Workshop on Tracing Isotopic Composition of Past and Present Precipitations - Opportunities for Climate and Water Studies" began. The workshop was successfully held on January 23 to 25, 1995 near Bern, organized by the WMO, IAEA, PAGES and IAHS. Recommendations, aimed at strengthening the operation of the IAEA / WMO Global Network "Isotopes in Precipitations" (GNIP), and a wider and more efficient use of the existing set of isotope data were made.

We believe that Jean-Charles Fontes would have been satisfied with this activity and as a dedicated group we will do our best to help isotope science lead to the so badly needed rapid progress in Earth system science.

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PAGES PROJECT ORGANISATION

FOCUS 1 Global Paleoclimate and Environmental Variability

Activity 1.1: PEP – 1 The Americas transect
Activity 1.2: PEP – 2 Austral-Asian transect
Activity 1.3: PEP – 3 Afro-European transect
Activity 1.4: The Oceans

FOCUS 2 Paleoclimate and Environmental Variability in Polar Regions

Activity 2.1: Arctic Programme
Activity 2.2: Antarctic Programme

FOCUS 3 Human Impacts on Past Environments

Activity 3.1: Human Impacts on Fluvial Systems
Activity 3.2: Human Impacts on Terrestrial Ecosystems

FOCUS 4 Climate Sensitivity and Modelling

Activity 4.1: Climate Forcing and Feedbacks
Activity 4.2: Climate Model – Data Intercomparisons

FOCUS 5 Cross – Project Analytical and Interpretative Activities

Activity 5.1: Chronological Advances
Activity 5.2: Development of New Climatics or Environmental Proxies
Activity 5.3: International Paleodata System (w/WDC-A)
Activity 5.4: Regional, Educational and Infrastructure Efforts (w/START, IAI)