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Tales Set in Stone

40 Years of the International Geoscience Programme (IGCP)

Palaeozoic metamorphic rocks, Belle-Ile, France.
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Scientists discussing in the field, Japan.
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40 Years of the International Geoscience Programme (IGCP)

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Cover photo: Acidic lake of Mount Aso active volcano, Kyushu, Japan. © Aloé Schlagenhauf

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Table of contents

Prefaces

Irina Bokova
Director-General of UNESCO

© UNESCO/Michel Ravassard

We must understand the Earth better. This is essential for the diversity of life and the future of human society. The Earth sciences hold key answers to the challenges we must overcome to preserve our environment and develop sustainably. At this time of global environmental change, UNESCO's *International Geoscience Programme* has never been so important.

The Earth's 4.6 billion year history is rich in dramatic climatic variations, recorded in rocks, sediments, ice and landscapes. Change has been minor at times, but also catastrophic. We must capture this experience to grasp how the Earth's climate has evolved and how biodiversity has fluctuated. We must understand better the mass extinctions of the past as well as the diversification and morphological change that have occurred in organisms. Unlocking the past will open up the future for better anticipation today.

Developments in human culture are inextricably linked to geology, as revealed in the names by which we frame our past – the Stone Age, the Iron Age and the Bronze Age. As some say, we live today in the Silicon Age; we must recognize fully the role of the Earth sciences for the development of 'greener' societies in the century ahead, for green technology and innovation.

For forty years, UNESCO has worked with the *International Union of Geological Sciences* to mobilize global cooperation in the Earth sciences through the *International Geoscience Programme*. This Programme has provided a platform for scientists from across the world to push the frontiers of knowledge forward through concrete projects.

In the early years, the Programme enhanced scientific exchange through the correlation of geological strata and research data, focusing on basic geoscientific research and on making connections between events throughout the Earth's history. The focus has evolved. In 2011, the Programme supported work on five themes – global change, geohazards, hydrogeology, earth resources and the deep earth. Throughout this evolution, the Programme has always built bridges between disciplines and between scientists, including young ones, with the aims of stimulating cutting-edge research and sharing scientific knowledge for the benefit of all. UNESCO is the only United Nations organization with a mandate to support research and capacity in geology and geophysics, and the *International Geoscience Programme* is our flagship.

On the occasion of this 40th anniversary, I congratulate the scientific community for its engagement and the *International Union of Geological Sciences* for its partnership. This unique model of global collaboration is vital for releasing the power of science for international collaboration and sustainable development. Stone, indeed, has many wonderful tales to share – about our past and about our future. The *International Geoscience Programme* helps us capture this wisdom and understand it better.

Alberto C. Riccardi
President of the International Union of Geological Sciences

Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata, Argentina

I welcome this volume celebrating the 40th Anniversary of the International Geoscience Programme (IGCP), an outstanding and unique cooperative enterprise between UNESCO and the International Union of Geological Sciences (IUGS).

Rock arch, Arches National Park, Utah, USA.
© Lin Wareham-Morris

Since its inception in 1972, the IGCP has been a research programme designed to attain globally-homogeneous advancement of the geosciences so as to improve the prosperity of nations and the quality of human life. Over 300 projects in about 150 countries with the participation of thousands of Earth scientists, and a continuous flow of published results, attest to the scientific and applied quality of this programme.

All these initiatives have been enriched by high-quality scientific supervision aimed at obtaining maximum efficiency through better coordination of efforts in interdisciplinary approaches, international cooperation, evidence-based decision-making on national and international levels, and sharing of scientific knowledge.

The success of the programme, however, has not only been due to the projects carried out throughout these years, but also to the flexibility of a programme that could be adapted to the changing circumstances and needs of human society. Thus the IGCP changed through time to become a programme in which special focus is given to projects related to societal needs, such as a safer environment, the relations between natural geological factors and health problems, biodiversity, climate change, protection from and mitigation of geohazards, and water resources.

Moreover, the IGCP is also becoming a forum for the analysis of other Earth science issues of relevance to society, such as the creation of international research centres, the promotion of Earth education in developing countries and regions, and the development of initiatives in Geoparks and geoheritage. All this comes under the subtitle of the IGCP - “Geoscience in the Service of Society”.

The IUGS makes every effort to supplement the IGCP through the work of several commissions and task groups involved in specific fields, such as standards in the geosciences, management and application of geoscience information, geological education and training enhancing technology transfer, and geoscience in environmental management. The ultimate goal is to contribute to the main and perhaps unique component of the IGCP, i.e. its cooperative character, which crosses natural, political, economic, and knowledge boundaries at a grass-roots level. In that way, IGCP projects are international in the broadest sense. They facilitate cooperation and understanding between geoscientists of different ages, from various regions, countries, cultures and with diverse educational backgrounds.

It is clear that the IGCP projects are fundamental to the growth of geoscientific education and capacity-building, and make possible an enormous transference of knowledge across the many remaining boundaries. Thus, the IGCP contributes to filling existing gaps in geoscience education and the management and application of information around the world. There is no doubt that education and information are basic to social, political and economic development and of fundamental importance in the building of a safer, healthier and wealthier society.

IGCP: a unique global platform for Earth sciences research and education

Vivi Vajda
IGCP Chair, Department of Earth and Ecosystem Sciences, Lund University, Sweden

In the light of the 40th anniversary of the International Geoscience Programme (IGCP), I would like to take the opportunity to present an overview on the work carried out by the Scientific Board during my time as ICGP Chair from 2009–2012, also adding some future perspectives. However, let me start with some brief background information.

IGCP provides several thousand scientists from about 150 countries with a multi-disciplinary platform to exchange knowledge and methodologies on Earth

Arclusaz perched syncline, Massif des Bauges Geopark, France. © Denis Vidalie

sciences-related problems of global importance. The Programme promotes collaborative projects with a special emphasis on the benefit provided to society, capacity-building, and the advancement and sharing of knowledge between developed and developing nations. IGCP primarily focuses on applied geosciences, including mitigation of geohazards. Special emphasis is given to projects related to environmental issues, medical geology, and mineral and groundwater resource extraction. Climate research is a prioritized area, as climate change is a global issue that can be addressed only through international cooperation. The temperature rise that occurred during the last century and the extent of future global warming are constant topics for discussion as we lack complete knowledge of the complexity and functions of the Earth's climate system. Climate modelling is an essential tool for the understanding of climatological processes but can only be successful when integrated with an understanding of living organisms and their diversity on a geological time scale, with the fossil plants and animals providing information on evolution and ecosystems through time.

The objectives of IGCP are met through individual projects. The strength of IGCP lies in the grass-roots origins of its projects, in their limited lifespan, in their regular and rigorous peer-review assessment and in IGCP's ability to add legitimacy. This legitimacy enables projects to attract additional widespread, well-funded international support. The number of active projects depends on the current priorities of UNESCO and IUGS, the availability of funds provided by IUGS and some external stakeholders, the success and progress of existing projects, and the quality and merit of newly submitted proposals. The success of the Programme and individual projects is the result of the dedication of project leaders and the enthusiasm, support and participation of geoscientists globally. Projects often build upon existing activities with participating countries, and attract additional funds from governmental and other agencies.

The Scientific Board is responsible for evaluating project proposals, for annual quality assessment of projects that are in progress and for projects in the final year of completion. A Chairperson and five Theme Leaders are appointed to manage the annual review of project proposals and reports. During my time as Chair, I had the great pleasure to work together with a group of outstanding scientists serving as Theme Leaders. We met once a year in Paris at UNESCO Headquarters to carry out the final rankings. Each theme has additional corresponding Board Members (about 10 per theme, all highly qualified scientists) assisting their respective Theme Leader.

IGCP projects that are active in 2011 focus on key geological issues for the people of today and are divided among the following five themes:

Global Change and evolution of life

Geohazards: Mitigating the risks

Hydrogeology: Geoscience of the water cycle

Earth Resources: Sustaining our society

Deep Earth: How it controls our environment

This means that IGCP has a peer-reviewing infrastructure involving about 50 specialists who are charged with the technical reviews. These Board Members represent specific fields in the Earth sciences, and jointly reflect a worldwide geographic distribution. In addition, the professional guidance provided by the Secretariat at

UNESCO – which is charged with the overall management of the IGCP, handling both project and financial administration, the preparation of the annual meetings, the website, and the outreach activities of IGCP – is invaluable.

Looking back into the past of IGCP, the number of project proposals submitted to the Scientific Board has increased over the years showing that the IGCP is held in high regard by the scientific community. At present there are about 40 ongoing IGCP projects; each project runs for four to five years and about 200 participants from all over the world are active within each project. The projects cover a wide range of topics from the formation of the early Earth and the study of its biota through the Palaeozoic (540 to 250 million years ago) and Mesozoic (250 to 65 my ago) marine and terrestrial ecosystems to climate changes and extinction events. There are projects investigating the deep Earth, the processes related to plate tectonics and the genesis of minerals. Other projects focus on natural hazards and the study of volcanic processes, earthquakes and the mitigation of their consequences. Hydrogeology is yet another important topic; karst systems are one of the more important aquifers on Earth, providing drinking water for Earth's population. Other important natural resources projects concern hydrocarbon and mineral resources, their extraction and sustainability through mitigation of the consequences of mining activities on the environment.

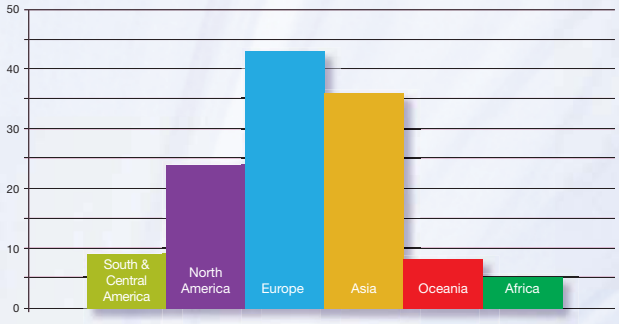
Looking back into the past of IGCP, the number of project proposals submitted to the Scientific Board has increased over the years showing that the IGCP is held in high regard by the scientific community.

The active projects are, without exception, very successful and have not only served as a link between scientists from all over the globe but have also generated thousands of scientific peer-reviewed papers, a large number of popular science publications and documentaries for television and other media. They have generated impressive maps, databases and material for school children. It is my view that these projects have generated massive amounts of important data and have both provided knowledge to society and shared it between research groups in the most cost-efficient way.

However, it is important not to rest on our laurels and maintain the status quo, but to enhance and develop the management and efficiency of the Programme. This is just as true for individual learning as for managing large enterprises or scientific programmes such as IGCP. The major difficulty during the three days of IGCP Board meetings in Paris from the Theme Leaders' point of view has been the lack of time, with every minute spent together being precious and used efficiently. From our first meeting we decided to set a few hours aside (away from evaluations, rankings and open meetings) for brainstorming of identified problems with the aim of finding creative solutions for the benefit of the IGCP. We used the priorities set out in UNESCO's Medium-Term Strategy for 2008-2013, expressed as follows: "UNESCO shall accord priority to Africa and to gender equality in all its fields of competence throughout the duration of the Medium-Term Strategy."

One very important question that has been raised from year to year by project leaders primarily from Africa and the Middle Eastern countries was the low acceptance rate

of projects from these regions. We investigated the history of applications and indeed found that the involvement of Africa in the UNESCO-IUGS IGCP since its launch in 1972 has remained very marginal, both in terms of number of projects devoted to the continent (only 7%) and in terms of number of project leaders from the continent (5%). We also found that their submitted applications sometimes showed weaknesses concerning infrastructure of the proposed projects even though the central scientific idea was interesting and worth developing. However, instead of repeatedly advising the project leaders to improve the application for the coming year we recognized a key-point that was failing in the system. The low participation of members from certain geographical regions within the project-leader groups was identified to be the point to attack in the system, a statistic that indeed could be turned around and used instead as a very efficient tool in a new mentoring system. It was also noted that, even though participation by women within the projects is relatively high considering it is a natural science programme, the participation of women in the project leader groups is appallingly low and not in line with either UNESCO's policy or the expectations of a modern scientific society.



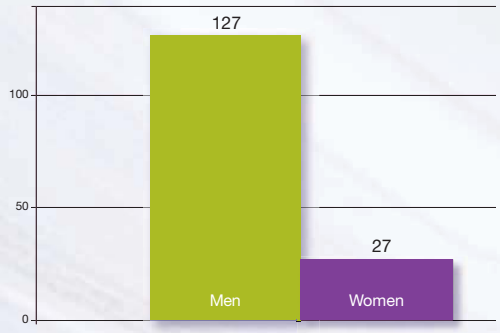
Geographic distribution of recent IGCP project leaders

We decided that ear-marked funding would be used to support scientists from selected developing countries. It was decided that such funding could be used to integrate project leaders from developing countries into at least six excellent projects with the aim of integrating these new leaders into the whole working process of applications, annual reporting, organization of workshops, participation in business meetings, etc. Additionally, a number of weak project applications that, nevertheless, contained a promising scientific background could be selected and mentored by experienced scientific leaders. It is important to emphasize that only by participating in the decision-making group, learning the process of application and other administrative issues connected to a project leadership, hosting conferences and editing conference volumes can these under-represented regions gain sufficient knowledge and experience to submit future, high-quality applications and manage large projects, such as those of the IGCP. Given that the normal evaluation processing of applications cannot be set aside, extrabudgetary ear-marked funding is required if these extraordinary measures are to be sustained.

Once the idea was formulated, we had to locate funding agencies to elicit support for this novel idea. In 2009 the Swedish National Commission to UNESCO and the Swedish International Development Cooperation Agency (SIDA) were approached and the main benefits of investing in IGCP were presented as one of the most cost-effective ways of transferring knowledge at a high level. Those benefits include the following facts: an infrastructure is already set up, including networks of international scientists experienced in running IGCP projects; there is an experienced scientific board carrying out the evaluation of the projects and scrutinizing the yearly progress of the

active projects based on annual reports; and a professional administrative apparatus is in place within UNESCO, which is in charge of handling of applications and working with an organised management system.

The application to SIDA was submitted and, to our great satisfaction, it was accepted, bringing in extra-budgetary funding of US$100,000 per year over four years. In 2011, this funding was allocated to six new projects; we eagerly await the outcome. Other parts of the funding were allocated to UNESCO field offices with a focus on the Nairobi office, Kenya, as an initiative to target the local scientific communities by training young scientists, and women in particular, in the skills of scientific proposal preparations. A first "Workshop on Skills Development in Preparing Project Applications" was held in Nairobi in July 2011, led by the Earth Science programme specialist in the Nairobi Field Office Sadrack Felix Toteu, a former IGCP project leader, and one of the Theme Leaders, Dilek Yildirim. An important message carried from this workshop is the very strong desire for African scientists to break out of their isolation and to move from individual and local research projects to those of a regional and international scale.



Distribution of project leaders by gender

The IGCP is the only worldwide network involving international cooperation in the geological sciences. The increased demand for resources, such as groundwater, rare earth elements and heavy metals, have shown that science must operate in an environmentally-aware manner if it is to mitigate the effects of exploration and extraction of these resources. Our science programmes have specifically supported others with these objectives, especially within Africa and developing countries, a policy that will continue with the same priorities. A global knowledge of Earth sciences is also increasingly needed in the study of climate change, which poses the greatest threat humankind has ever faced; by studying past climatic conditions we can provide decision-makers with important tools with which to mitigate the impact of global warming. The scientific activity within the IGCP projects generates a vast amount of research data resulting in several thousand scientific publications, maps and databases and last, but by no means least, outreach to society through popular scientific publications and television documentary productions. However, all this has been achieved with very limited resources. Further support for the IGCP will provide a basis for improved equilibrium between human society and our planet, given that our knowledge of the Earth system is our insurance policy for the future of planet Earth.

Geologists in the field in Democratic Republic of the Congo.
© S. Felix Toteu

Gournier cave, Vercors, France. © Association spéléologique du Sud Est

Introduction

The International Geoscience Programme: a brief history

Edward Derbyshire
IGCP Chair 1996-2001

IGCP project 429: Postgraduate Training Course during GEOCHEM 2000, Czech Republic. © Jan Pašava

IGCP: pre-history and birth

The International Geoscience Programme (IGCP) is celebrating its 40th anniversary in 2012, but the roots of the IGCP can be traced some eight years further back in time. In 1964, a young Australian geologist (H.J. Harrington) single-handedly took the initiative of writing a persuasive letter to 50 leading international Earth scientists suggesting the setting up of an international Gondwana Project to facilitate and test geological correlations between the southern continents. During Earth's history from approximately 510 to 180 million years ago, Gondwana was the southernmost of two supercontinents. Gondwana is a fascinating topic for geoscientific studies as this supercontinent included most of the landmasses in the Southern Hemisphere, including Antarctica, South America, Africa, Madagascar and the Australian continent, as well as the Arabian Peninsula and the Indian subcontinent, which have now moved entirely into the Northern Hemisphere.

Despite the advice given to Harrington to avoid the word "Gondwana" and any mention of continental drift, his proposal attracted much attention and, in fact, led to strong pressure to broaden itself so as to include the nations of the northern hemisphere. A committee of young but established Australian geologists was set up in 1965, following the formal creation of the IUGS in 1961. The early leaders of this new geological union proved to be innovative, perceptive and encouraging. In fact, the title 'International Geological Correlation Programme' was an IUGS creation arising from the union's awareness of the evident need to aid interaction and exchange of ideas between the East-West divided Europe of that time in addition to meeting the global ambitions set out in the Australian initiative. A formal proposal for the establishment of the IGCP was drafted for approval at the International Geological Congress in Prague, Czech Republic, in 1968 but the political events of 'the Prague Spring' disrupted that Congress. Thus, the formal process had to await a meeting in Budapest, Hungary, at which an international panel launched the Programme. A few successful projects were launched by this fledgling organisation but it was not until 1972 that UNESCO agreed to formal involvement.

The IGCP was widely examined and discussed by UNESCO's governing bodies over several years, including consideration by the General Conference on several occasions. In line with General Conference resolution 2.321, adopted by the General Conference at its 16th session in 1970, an Intergovernmental Conference of Experts for preparing an International Geological Correlation Programme was organized at UNESCO Headquarters from 17 to 28 October 1971. Fifty-two Member States, one Associate Member, and 11 international NGOs were represented by experts at this meeting, which defined objectives and the content of a formal Programme. The Statutes of the IGCP obtained their final official approval from UNESCO's General Conference at its 17th session in Paris in 1972 (document 17 C/66), which now marks the official birth date of the IGCP. The Programme was launched in 1972 during the 24th International Geological Congress in Montreal. Thus, the IGCP's gestation period lasted for at least eight years.

The establishment and guidance of the novel international programme in geology coincided with the final year as IUGS President of Sir Kingsley Dunham (Director of the British Geological Survey at that time). The main business of the London meeting of the IUGS Executive Committee in

Sir Kingsley Dunham, late Director of the British Geological Survey and first Chairman of the Scientific Board of the IGCP. © Photograph courtesy of Helen Dunham (special thanks to Joe Cann who provided this photo)

1972 involved setting up the IGCP as a major international framework for geological research with the encouragement of two UNESCO programme specialists (Michel Batisse and Felix Ronner), whose intervention was crucial at that stage in the Programme's planning. Continuing as an ordinary member of the IUGS Executive Committee, Sir Kingsley Dunham was 'ambushed' at an Executive meeting in Prague in February 1973 and was, after much argument, pressed to take on the four-year duty of first Chairman of the IGCP. As he later wrote "I returned to London… as honorary chairman of a programme that was to contain many cooperative projects; the total had reached 67 by the end of my term in 1977, with implications all over the world."

© Jacques Malavieille

The years of transformation and growth

The development and growth of the IGCP as a joint venture of the IUGS and UNESCO was distinctly positive following the initial approval of a number of projects in the 1973-74 academic year. The IGCP's administrative base at UNESCO headquarters in Paris was well placed for researchers on both sides of the 'Iron Curtain' to seek support to enable them to advance knowledge of the geology of continental Europe and, in particular, to address the challenging subject of trans-national stratigraphical correlation (hence the 'Geological Correlation' of the new programme's name).

With the eventual changes in European political history in the following decade, the IGCP began to expand its scope from continental to global. Thus, by the early 1990s, the Programme was secure largely due to the novel combination of its 'grass roots' nature, its peer-review quality control, and the ability of its dedicated leaders and co-leaders to raise funds, largely from national sources, that were often orders of magnitude higher than the IUGS-UNESCO 'seed money'. With this rise in diversity and scale, the IGCP was increasingly concerned to ensure the involvement of geoscientists, and especially the younger and less-privileged ones, from developing countries. Steady growth during this 20-year period is well documented in several publications, but the 1992 account by B.J. Skinner is perhaps the most succinct and readily accessible.

Consolidation, application and diversion

From its inception, the IGCP Scientific Board's assessment of project proposals and annual reports was managed by four Working Groups covering the main specialist components recognised at that time:

Working Group 1 – Stratigraphy, Palaeontology, Sedimentology, Fossil Fuels

Working Group 2 – Quaternary, Environmental and Engineering Geosciences

Working Group 3 – Mineral Deposits, Petrology, Volcanology, Geochemistry

Working Group 4 – Geophysics, Tectonics, Structural Geology

This structure served the Programme well. A fifth Working Group was added for Hydrogeology, which made its first appearance at the IGCP Scientific Board in February 2004, thus constituting the first formal interdisciplinary action within the IGCP since its foundation.

There then followed a series of events that, slowly at first, progressively remoulded the aims, content and mode of operation of the Programme.

UNESCO commissioned an independent review of the IGCP in 1997. The subsequent report identified the key features of the IGCP and recommended a more deliberate pursuit of the core values of UNESCO by encouraging more applied geological projects with clear societal relevance, an action that led to the IGCP's current sub-title "Earth Science in the Service of Society". The response to this substantial change

The first IGCP Scientific Board, Paris, 1973. Members, from left to right are R. Said (Egypt), F. Kabbanni (Saudi Arabia), J. Marçais (France), C, Nishiwaki (Japan), M. Oyawoye (Nigeria), D. McLaren (Canada), R. Chowhury (India: Vice-Chair), K. Dunham (UK: Chair), G. Salas (Mexico: Vice-Chair), H. Erban (Germany), J. Reinemunde (USA), J. Bigarella (Brazil), J. Petránek (former Czechoslovakia) and M. Glaessner (USA). V. Menner (former USSR) did not attend.

can be clearly seen by comparing projects in their major groups between 1995 and 2001. A full list of IGCP projects can be found at the end of this book.

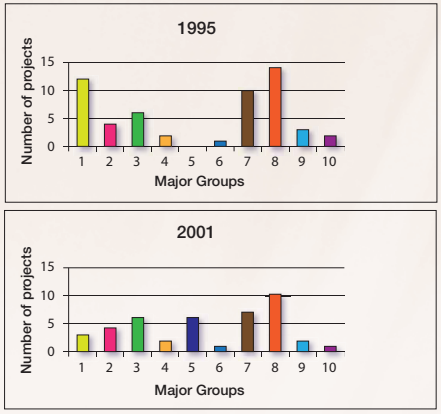
The 1997 review reinforced the UNESCO priority of education within the programmes of the Sciences Sector. In this case, the IGCP was well ahead of the 'game'; its projects were effectively exchanging expertise, experience and information between geologists around the world, many of these making a substantive contribution to capacity-building in less-developed countries. Even so, this important trend increased further, in proportional terms, even after 1998.

(Many UNESCO priorities appeared later in the 2001 Strategic Action Plan of the IUGS as IGCP's co-sponsor; the IUGS Mission Statement placed great emphasis on education, applied Earth science, interdisciplinarity and capacity-building in less-developed countries.)

The influential UNESCO-International Council for Science (ICSU) World Conference on Science (Budapest 1999) declared that UNESCO's programmes must "recognise the need to treat the Earth's environment as a single complex system that must be observed globally and in an integrated way in order to predict its variability and probable impacts of human activities thereon". This statement clearly implied a need for certain changes in the management of the Natural Sciences Sector's programmes, including the elevation of scientific interdisciplinarity.

Despite much positive rhetoric, certain decisions were made during 2004 at the highest levels in UNESCO that, being driven by budgetary considerations rather than the performance level of the IGCP, reduced the profile of the Programme. The Division of Earth Sciences, which included IGCP together with Geoparks, Earth Observation and Capacity-Building, was combined with the Division of Ecology to form the Division of Ecological and Earth Sciences, and all budgets were considerably reduced. The disaster reduction elements of the former Division of Earth Sciences were moved to the Division of Basic and Engineering Sciences.

1. Stratigraphy
2. Coastal, Marine & Limnology
3. Climate change & Drylands
4. Biodiversity
5. Disaster reduction
6. Mountains
7. Ores, Minerals & Metals
8. Structure, Tectonics & Drifting Continents
9. Palaeontology
10. Weathering



IGCP projects by Major Groups

Substantial shape-shifting from 2004 to 2008

This restructuring of the IGCP was followed by a series of actions designed to attempt a re-balancing of the Programme in the light of the changes to structure, range and financial support.

In my former position as Chairman of the IGCP Scientific Board, I wrote to the Assistant Director-General for the Natural Sciences Sector in November 2004 with suggestions designed to bring down the costs of running the IGCP such that the funds released would be used to sustain the scientific projects at the core of the Programme. The letter contained the following points.

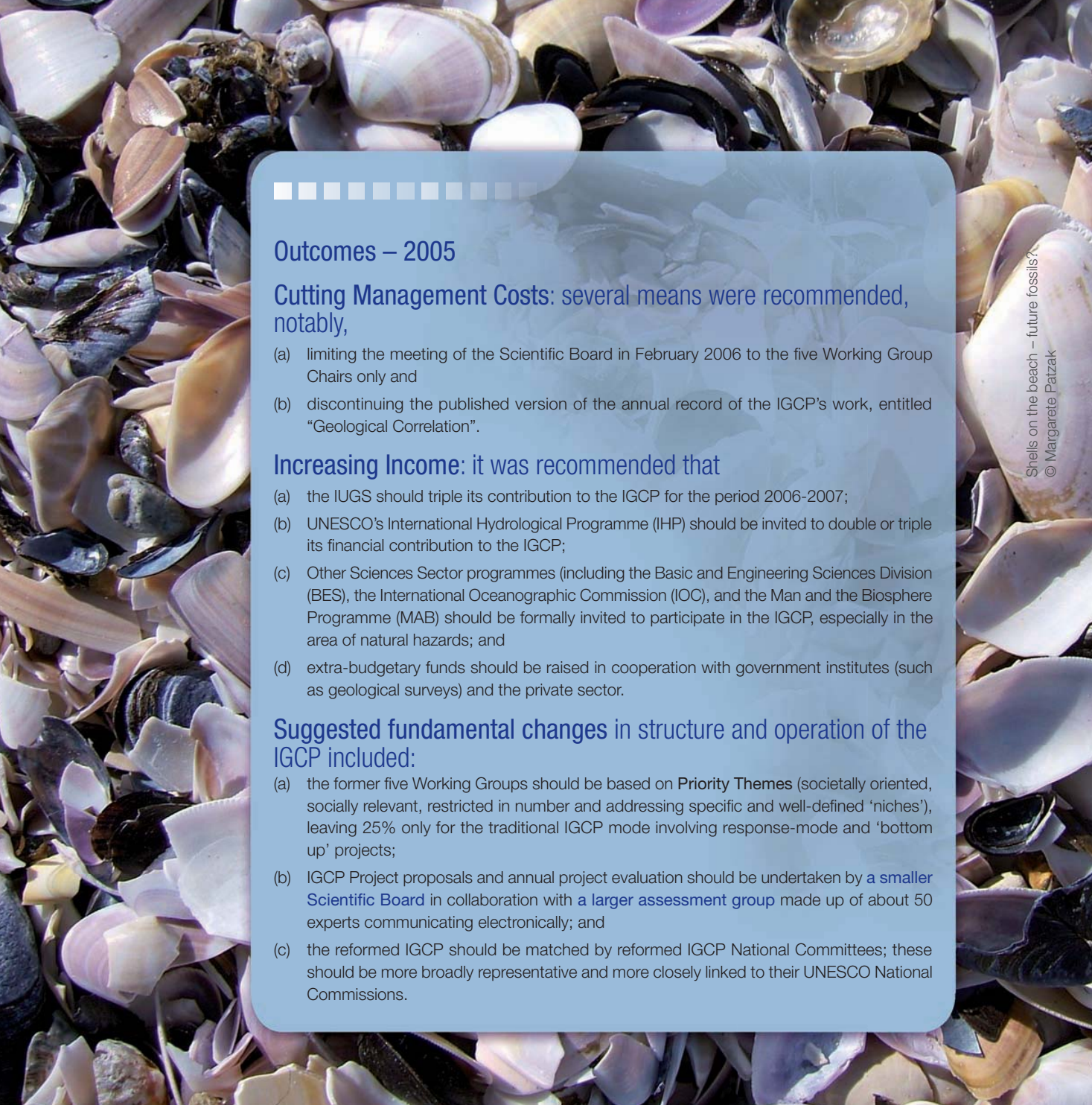
1. The annual meetings of the IGCP Scientific Board should be retained, with coverage of all established items of discussion, but meetings should be attended by the Chairpersons of the five Working Groups only, and the use of electronic communication for project assessment should be favoured.

2. Special efforts should be made to attract sponsorship from nations and industries that obtain particular benefits from a healthy and vigorous global Earth science community.

3. Discussions should be entered into, as soon as possible, with the IUGS as UNESCO's scientific partner in the IGCP.

The letter was used to convince the Director-General that 'Earth Sciences and IGCP' should be retained as a discrete programme within UNESCO's Science Sector. It was also used in subsequent discussions with IUGS and other partner organisations, with the following outcomes.

A background paper by the Director-General ("The Earth Sciences Programme in UNESCO's Natural Sciences Sector" that stated the Director-General's position at the UNESCO's Executive Board meeting in April 2005) was followed by a meeting on 17 June 2005 of the "Joint IUGS/UNESCO Task Group on the reform of IGCP". This meeting focused on structural reform and changes in IGCP's mode of operation. Some of the Task Group's proposed changes lie close to proposals that had already been suggested by a number of bodies including the UK National Commission for UNESCO. Outcomes included cutting management costs, increasing income and, importantly, a recommendation that several fundamental and wide-ranging changes of a structural and operational nature should be introduced, as well as some shorter-term actions (see box next page).



Shells on the beach – future fossils?
© Margarete Patzak

Outcomes – 2005

Cutting Management Costs: several means were recommended, notably,

(a) limiting the meeting of the Scientific Board in February 2006 to the five Working Group Chairs only and

(b) discontinuing the published version of the annual record of the IGCP's work, entitled "Geological Correlation".

Increasing Income: it was recommended that

(a) the IUGS should triple its contribution to the IGCP for the period 2006-2007;

(b) UNESCO's International Hydrological Programme (IHP) should be invited to double or triple its financial contribution to the IGCP;

(c) Other Sciences Sector programmes (including the Basic and Engineering Sciences Division (BES), the International Oceanographic Commission (IOC), and the Man and the Biosphere Programme (MAB) should be formally invited to participate in the IGCP, especially in the area of natural hazards; and

(d) extra-budgetary funds should be raised in cooperation with government institutes (such as geological surveys) and the private sector.

Suggested fundamental changes in structure and operation of the IGCP included:

(a) the former five Working Groups should be based on Priority Themes (societally oriented, socially relevant, restricted in number and addressing specific and well-defined 'niches'), leaving 25% only for the traditional IGCP mode involving response-mode and 'bottom up' projects;

(b) IGCP Project proposals and annual project evaluation should be undertaken by a smaller Scientific Board in collaboration with a larger assessment group made up of about 50 experts communicating electronically; and

(c) the reformed IGCP should be matched by reformed IGCP National Committees; these should be more broadly representative and more closely linked to their UNESCO National Commissions.

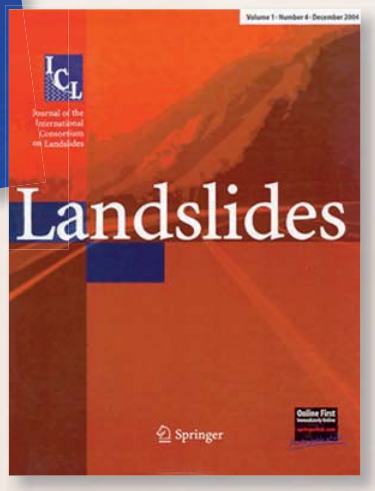
As the IGCP's history shows, for most of its 40 years the Programme has attracted an impressively wide range of projects, increasingly bringing in scientists from the less-developed countries by providing opportunities for them to work together with others from many nations on some key problems in a way that could not have been undertaken by any other means. Many projects provided training workshops before or following annual scientific conferences. These actions, which enhanced capacity-building in staff and postgraduate students at tertiary education level in less-developed countries, frequently inspired higher standards.

Given this capacity-building role and the importance of field-based discussion and analysis in Earth science, approved projects have often been regional in scope, although the record of global projects has been impressive, as is illustrated in a number of projects that have led to permanent, free-standing legacies such as the following selected examples:

- the Global Geochemical Database (IGCP 259: 1995);
- the International Consortium on Landslides (IGCP 425: 2002);
- the International Medical Geology Association (IGCP 454: 2005);
- the establishment of the International Research Centre on Karst, People's Republic of China in 2008, following more than 20 years of IGCP projects on international karst research (IGCP 299, 379, 448, 598); and
- a proposed International Research Centre on Global Geochemical Mapping

A Global Geochemical Database (publication 1995)

IGCP 259 (1988-1992) & IGCP 360 (1993-1997)



International Consortium on Landslides (publication 2002)

Journal supported by – UNESCO, WMO, Japanese Ministry of Education and Kyoto University

IGCP 425 (1998-2002)

Two examples of permanent legacies drawn from, or stimulated by the IGCP Projects

From 2008 to 2012

Notwithstanding the magnitude of the changes that culminated in 2008, there are some who believe that the process did not go far enough. In the same year, during a meeting of the Chairpersons of the four Intergovernmental/ International Science Programmes (ISPs) within the UK National Commission for UNESCO, I made the following statement.

"…I believe that the effort involved in the changes (recently) made to the Programme by UNESCO and IUGS would have been more effective and rewarding had it been re-shaped so as to dovetail UNESCO Earth sciences into parts of some established global environmental programmes… and… failure to guide it [IGCP] towards a more adaptable structure in an era of global problems requiring the coming-together of many disciplines in pursuit of solutions has weakened the Programme."

With the acceleration of the need for complementary interaction between the sciences in response to environmental problems of a global scale, scrutiny of project proposals of a discrete nature will be needed if the Programme is to retain its relevance, flexibility and innovation potential. Many former IGCP projects have indeed operated on a global scale. Continental-scale projects, too, have always figured in the Programme, some having been ahead of their time, such as IGCP 475 (2003-2007 – DELTAMAP: Deltas in the Monsoon Asia-Pacific region). This project was closely linked to the Asia-Pacific Network for Global Change Research programme on "Mega Deltas of Asia" and was led by Chinese scientists with successive annual meetings in Bangladesh, Brunei, China, Thailand and Viet Nam.

My brief history is trespassing into the future and should go no further except, perhaps, to say that it would be sound practice if the Scientific Board and officers of the Programme were to keep a wary eye on the nature and practicality of potential further changes in the operational characteristics of the IGCP with a view to meeting key future needs, recognising that the classic disciplinary boundaries should yield to the pressure posed by increasingly global and multi-disciplinary challenges. The IGCP, given the sustained encouragement in the use of novel management approaches by UNESCO and the IUGS, is surely well placed to take full advantage of this growing trend in the years ahead.

Edward Derbyshire
IGCP Chair 1996-2001
Visiting Professor,
Royal Holloway, University of London

Rivers, Russia. © Aloé Schlagenhauf

Selected IGCP project examples

The International Geoscience Programme, formerly the International Geological Correlation Programme (IGCP), provides an international platform for Earth scientists to collaborate on projects aimed at understanding the Earth, its resources, and the role of the geosciences in sustaining society. A major strength of the IGCP is a worldwide network of research infrastructure and well-trained human resources which provides a platform for partnerships and training across political boundaries. The IGCP welcomes proposals by multinational teams of scientists on topics of particular interest to IGCP, occasional annually-defined topics, and other relevant topics in basic and applied geoscience. All proposals are assessed by the IGCP Scientific Board, a process that is based on scientific quality, with added emphasis on the goals of IGCP.

A few examples of excellent IGCP projects which were conducted during the four decades of the Programme are summarised in the following pages.

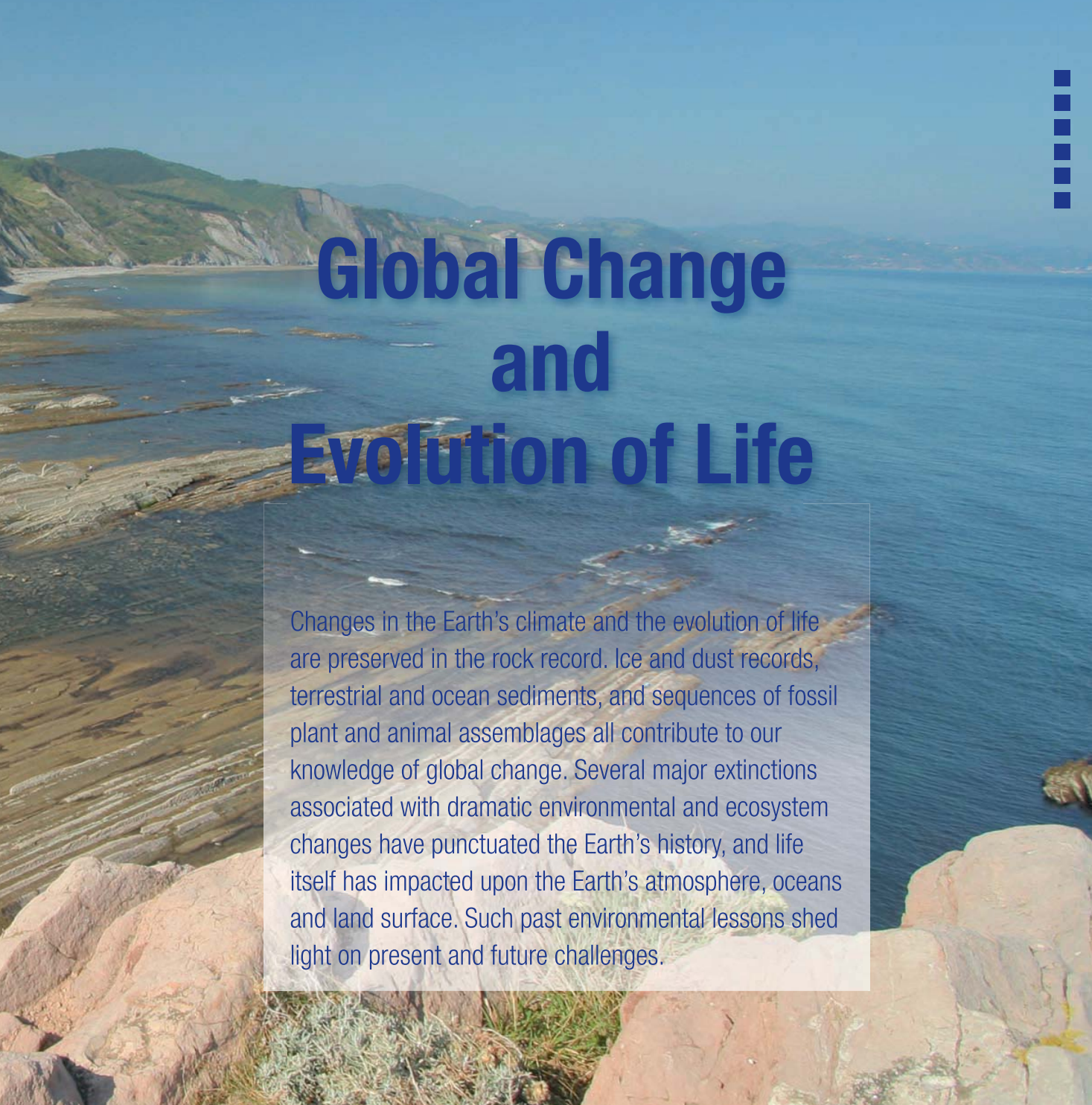
A list of all projects is included in the Annex. They are presented as representatives of the major themes introduced by the Scientific Board in 2007 and in the following sequence:

- Global change and evolution of life
- Geohazards: Mitigating the risks
- Hydrogeology: Geoscience of the water cycle
- Earth Resources: Sustaining our society
- Deep Earth: How it controls our environment

An example project supported under the 'Young Scientists' scheme is also presented.

A fossil coral reef in the mountains.
© Madonie Geopark

65 million year old sedimentary layers from the mass extinction at the Cretaceous/Tertiary boundary, Basque Coast Geopark, Spain. © Jon Paul Llordés



Global Change and Evolution of Life

Changes in the Earth's climate and the evolution of life are preserved in the rock record. Ice and dust records, terrestrial and ocean sediments, and sequences of fossil plant and animal assemblages all contribute to our knowledge of global change. Several major extinctions associated with dramatic environmental and ecosystem changes have punctuated the Earth's history, and life itself has impacted upon the Earth's atmosphere, oceans and land surface. Such past environmental lessons shed light on present and future challenges.

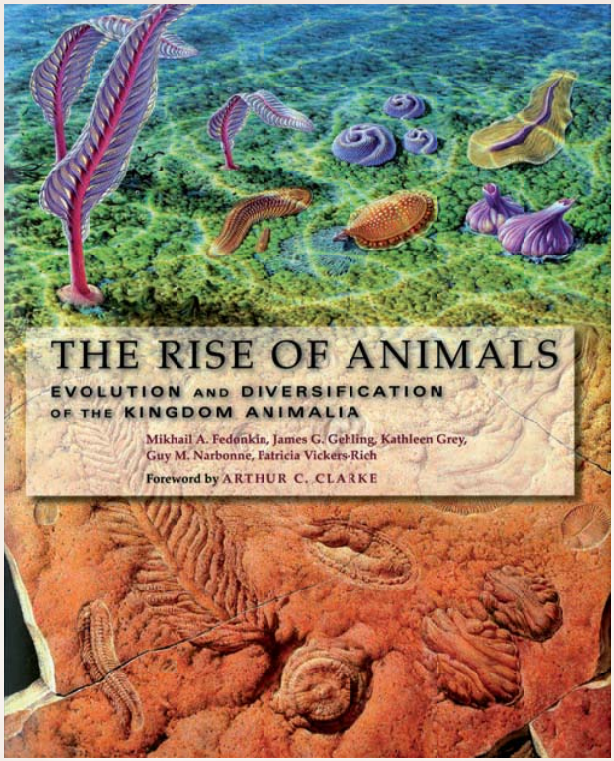
IGCP 493 and 587: The Rise and Fall of the Vendian Biota (2003-2007 and 2010-2014)

IGCP 493, which evolved into IGCP 587, dealt with the precise timing of global events during the late Proterozoic (older than about 543 million years) and the effects changing environments of that time (climates, global ocean and atmospheric chemistry and palaeogeography) had on the development and diversification of the Earth's first animals, culminating in the spectacular and globally-recognised Ediacaran or Vendian faunas. These fauna did not look like modern animals. Some looked like a cross between an animal and a plant, others looked like frisbies and others like worms, although they were not. Some were smaller than a fingernail, others larger than a metre. After these fauna went extinct, animals we are more familiar with (equipped with shells and eyes) arrived with the 'Cambrian explosion' (542 million years ago).

Ediacaran or Vendian biotas are best represented along the Winter Coast of the White Sea in the Russian Federation, in the Flinders Range of South Australia, in the southern deserts of Namibia, along the Yangtze River in China and in the coastal outcrops of Newfoundland in Canada. Other less biodiverse faunas from NW Canada, Siberia, the Ural Mountains of the central Russian Federation and the Ukraine, Mongolia, NW Argentina and central Brazil and the Middle East have been investigated and they, along with the better known locales, have provided and continue to provide significant new information on the rise and demise of this unique Neoproterozoic metazoan assemblage (multicellular animals), which blossomed and prospered from around 600 to 543 million years ago. Then, it disappeared rather abruptly, giving rise to only a few of the animal groups we know today. Working out what controlled the precise make-up of this globally-distributed multicellular assemblage (environments, time or both?) has been, and continues to be, central to the activities of the researchers involved in studying these two multidisciplinary projects. Pushing the boundaries, both in expanding the known age-span of this Ediacaran or Vendian assemblage, as well as understanding the detail of the morphology and functioning of the unique architecture of these strange first animals, has been a major theme of these two IGCP projects.

Over the years, more than 110 researchers have been involved in IGCP 493 and 587 from a wide range of countries: Argentina, Australia, Brazil, Canada, China, the Czech Republic, Germany, India, Iran, Iraq, Ireland, Italy, Japan, Namibia, the Netherlands, Poland, Russian Federation, Saudi Arabia, Spain, Sweden, South Africa, Taiwan of China, the UK, the USA, and Uruguay. These projects involved a multidisciplinary team of sedimentologists and stratigraphers, geochemists, geochronologists, structural geologists, palaeontologists, biochemists and functional morphologists, as well as a reconstruction artist, a significant number of undergraduate and graduate students, children, teachers and media documentary producers.

The last Ediacarans: Pteridinium fossils counterpointed against the modern landscape formed by Neoproterozoic marine sediments, southern Namibia. This is the last occurrence of diverse assemblages of these first animals on planet Earth. Art by reconstruction artist, Peter Trusler.
© Peter Trusler

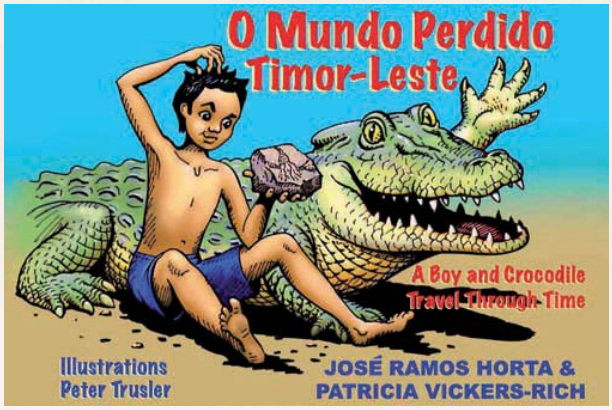


Publication by Johns Hopkins University Press, USA for the general public that summarized results of IGCP 493, including much original art work commissioned by this project, undertaken by reconstruction artist Peter Trusler. It has been used as a catalogue for several exhibitions organized as part of IGCP 493 shown in Asia and Australia. Winner of the prestigious Victorian Premier's Prize (Australia) for the best popular science book published during the 2005-2007 period.

Meetings organized and sponsored by these projects have been both field-oriented (e.g. White Sea and Siberia in the Russian Federation, Namibia, Argentina) and also conference-presentation oriented, allied with International Geological Congress meetings in Italy (2004) and Norway (2008), with Australia to come in 2012. Some meetings have resulted in significant publications such as The Rise and Fall of the Ediacaran (Vendian) Biota, produced by the Geological Society of London in 2007 as Special Publication 287, as well as both research and popular news items in Argentina, Australia, China, Japan, the Russian Federation and Taiwan of China. A deliberate attempt has been made to popularize research results through exhibitions including Wildlife of Gondwana, The First Animals and The Artist and the Scientists, which have travelled worldwide; to produce teaching materials and popular books such as The Rise of Animals by M. A. Fedonkin; to generate stamps in both Australia and Namibia accompanied by teaching materials; to set up an active and broad-user website (www.geosci.monash.edu.au/precsite.html); and to initiate and assist in the production of documentaries by media production companies in Australia, Japan, Spain, the UK, Uruguay and the USA. The most recent of these, initiated and strongly supported by participants in IGCP 493 and IGCP 587, was First Life, the final in the Attenborough Life Series, honoured with three Emmy Awards in September 2011.

One of the outstanding accomplishments of this project was a three-year campaign to secure over US$70,000 with which to lodge the 50-cabinet Vendian collection in a dedicated room in the Palaeontological Institute of the Russian Academy of Sciences in Moscow, and to appoint four curatorial assistants.

Imaginary Yorgia rising in the clouds above Zimnii Gory on the White Sea coast of northern Russia, one of the locales intensively worked by members of the Precambrian Laboratory of the Palaeontological Institute, Russian Academy of Sciences who were participants in IGCP 493. Art crafted for use in both publications and exhibitions.
© Peter Trusler



Popular book co-authored by Patricia Vickers-Rich, one of the co-leaders of IGCP 493/587 with Nobel laureate José Ramos-Horta, President of Timor-Leste, aimed at primary school-aged children, and concerning geological history, including the Ediacarans/Vendians. This book has been translated into 14 languages.
© Peter Trusler

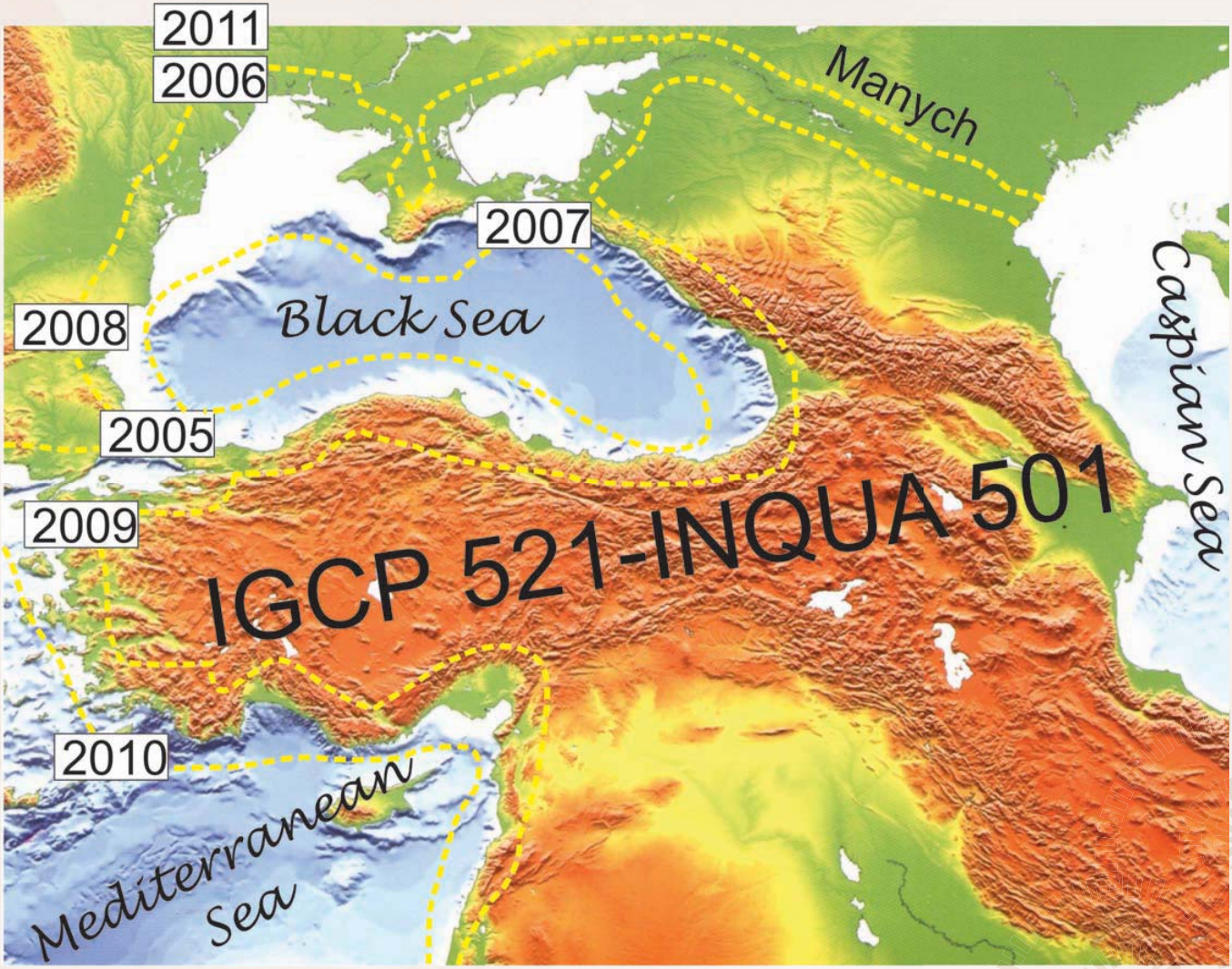
By understanding the sequence and the rate of occurrence of such major biotic events in the past, in this case the rise and fall of a diverse biota in the late Proterozoic, and throwing light on the drivers of such evolutionary events, wisdom concerning future predictions of climate and environmental changes and what forces are driving such changes, will be enhanced. Only then will our decisions concerning our own behaviour be informed, realistic and perhaps less fanciful.

***Patricia Vickers-Rich**, Palaeontology, School of Geosciences, Monash University, Melbourne, Victoria, Australia; **Mikhail Fedonkin**, Precambrian Laboratory, Palaeontological Institute and Director, Geological Institute, Russian Academy of Sciences, Moscow, Russia; **Jim Gehling**, Senior Research Scientist, Palaeontology, South Australian Museum, Adelaide, South Australia, Australia (IGCP 493 and 587); **Guy Narbonne**, Geological Sciences and Geological Engineering, Queen's University, Kingston, Ontario, Canada (IGCP 587)*


エディアカラの不思議な生き物たち

Great interest was shown in the Precambrian Exhibition mounted in the Fukui Dino Museum, Japan.
© Fukui Prefectural Dinosaur Museum

IGCP 521: The Black Sea-Mediterranean Corridor during the last 30,000 years: Sea Level Change and Human Adaptation (2005-2009)



The Black Sea-Mediterranean Corridor is an integrated oceanographic system defined as the area covering the Manych-Kerch Gateway (consisting of Manych Valley, Sea of Azov, and Kerch Strait), the Black Sea, the Marmara Gateway (consisting of the Bosphorus Strait, Sea of Marmara, and Dardanelles), the Aegean Sea, the Eastern Mediterranean, and their coasts. During the Late Pleistocene (126,000 years ago), the Corridor was connected to the Caspian Sea via the Manych Gateway. The Corridor has strategic importance, not only for its coastal countries but also for at least 17 others that share its drainage basin, which is one-third the size of Europe. The Corridor acts as a sensitive recorder and amplifier of past climatic events, sea-level variations, and coastline migration, which are especially pronounced in the Black Sea owing to its geographical location and semi-isolation from the open ocean.

Over the past 30,000 years, the Corridor underwent a complicated history that remains hotly debated. This region has attracted tremendous international interest over the last decade as a possible location for the origin of the biblical story of the Great Flood. This connection encouraged new and controversial research on the hydrological regime within the connecting straits and the transition from lacustrine to marine conditions, as well as the past, present and future adaptation of humans to environmental change.

The Corridor (marked by yellow dotted line) and the location of IGCP 521-INQUA 501 Plenary Meetings for the years 2005–2011: 2005 – Istanbul, Turkey (Marmara coast); 2006 – Odessa, Ukraine (Dniester-Pivdennyi Bug region); 2007 – Gelendzhik, Russia-Kerch, Ukraine; 2008 – Bucharest, Romania-Varna, Bulgaria; 2009 – Izmir-Çanakkale, Turkey (Aegean coast); 2010 – Rhodes, Greece; 2011 – the Lower Dniester and Ukrainian part of the Lower Danube region.

Before the launch of the IGCP 521 project (2005-2010), no study had explored the 30,000 year time span and evolution of the Corridor as a single entity, despite much isolated geological and archaeological research by various investigators. These data remained as individual pieces of a large puzzle waiting to be assembled by the joint efforts of the global community. The main goal of IGCP 521, which went hand-in-hand with an International Union for Quaternary Research Project INQUA 501 (Caspian-Black Sea-Mediterranean Corridor during the last 30,000 years: sea level change and human adaptive strategies (2005-2011), was to bring the diverse research groups together to provide cross-disciplinary and cross-regional correlation of geological, geochemical, geophysical, palaeontological, archaeological, and historical records for the entire Corridor and thereby evaluate the influence of sea-level change and coastline migration on human adaptation during the last 30,000 years.

Project activities enabled the international community of multidisciplinary scientists to correlate their results, present new findings at annual plenary meetings, topical sessions, symposia, and workshops, and publish results in various journals and books (www.avalon-institute.org/IGCP/index.html). Field trips carried out after plenary sessions allowed participants to visit significant sites within the Corridor (see map), which would otherwise have been difficult to access, in order to observe relevant features under the guidance of local experts and discuss important scientific issues at the sites. About 400 specialists from 31 countries participated, bypassing language and political boundaries and encouraging East-West dialogue.

Achievements were presented at conferences and published in seven peer-reviewed volumes of extended

The term “mud volcano” generally applies to a surface extrusion of watery mud or clay which is almost invariably accompanied by methane gas. Fossil mud volcanoes can be used for reconstructing climate and sea-level changes and show that at the Last Glacial Maximum (ca. 26,500-19,000 years ago) the level of the Black Sea was about 100 m below present.

abstracts, three special volumes of the journal *Quaternary International* and three books. The projects' activities were also disseminated through three regularly-updated websites: www.avalon-institute.org/IGCP, www.black.sealevel.ca, and www.bridge.bris.ac.uk/projects/EMBSECBIO. This information contributed to a spin-off of educational reform in the Earth, behavioural, and atmospheric sciences, thus improving competitiveness among young Eastern scientists and enhancing their employment opportunities.

The project established a database of radiocarbon (^{14}C) assays for the Black Sea; reference collections of Quaternary benthic foraminifera (an important component of the deep-sea biomass) and molluscs from the Black Sea, Sea of Azov, and Eastern Mediterranean (the combination of these two outcomes helping to improve the stratigraphical scale for the last 30,000 years and providing correlation of various geological settings); pollen data sets for about 100 sites that expanded upon biomization (global vegetation) models at selected time intervals; a standardized system of marine palynology (pollen) preparation methods and taxonomy (science of identifying and naming species) for studying Corridor sediments and palynomorphs (microscopic acid-insoluble organic material) to allow future interpretations to be based on the same types of assemblages and using updated nomenclature; a new approach to investigating amino acid racemization (a biological dating method used on bone and shell) and AMS (Accelerator Mass Spectrometry) radiocarbon dating of Holocene Black Sea core sediments, and exploring the possible extent of time-averaging; and Black Sea level curves in radiocarbon and calendar time-scales for the last 12,000 years.

The project helped to reveal the influence of active tectonics on sea-level change and coastal processes within the Corridor. It described palaeo-oceanographic evolution in terms of palaeo-temperature, palaeo-salinities, palaeo-productivity, circulation patterns, and efficiency of the Manych and Marmara Gateways for certain time-intervals. It traced the evolution of water masses in space and time, identifying their possible sources, and it reconstructed vegetation and climate dynamics since the Last Glacial Maximum (between about 26,500 and 19,000 years ago). The project also examined transmigrations as a mechanism of living space exploration in the NW Black Sea at the Pleistocene-Holocene boundary (between 12,000 and 11,000 years ago) and the cultural sequences, the emergence of food-producing economies in SE Europe, and the collection of various rocks used during prehistory in different parts of the Corridor.

The project also elaborated several mathematical models of the Late Pleistocene and Holocene Black Sea transgressions; extreme Black Sea and Caspian Sea levels since the Last Glacial Maximum; sedimentation on the NW Black Sea shelf that reveals significant periodicities of sedimentation related to sea-level change and hydrodynamic activity. Other mathematical models shed light upon the dynamics of ecological crises and adaptive reaction of ancient people to changing environmental conditions of the Late Pleistocene-Holocene boundary, thus providing a quantitative assessment of the impact of environmental changes on the spread of early farming and the transition from the Mesolithic to Neolithic, contributing to a better understanding of the Neolithic way of life in Europe.

Kerch active mud volcanoes. © Valentina Yanko-Hombach

The Eltigen neostratotype, Kerch Peninsula, Crimea. This neostratotype contains the most complete and well preserved marine sequence in the Corridor. It overlays continental deposits, indicating Black Sea transgression (relative sea level rise).
© Valentina Yanko-Hombach

The ruins of Ephesus, on the west coast of Asia Minor, Turkey. The ruins of Ephesus, which was an ancient Greek city, and later a major Roman city, have been excavated and reveal that many parts of the later city were erected on formerly shallow marine and lagoonal sedimentary deposits indicating the growth of the river deltas of Küçük Menderes in the surrounding area of the city of Ephesus.

With regard to theoretical science, the project yielded fundamental new knowledge about the driving mechanisms influencing human adaptation in the region; it also enhanced our knowledge of linear and non-linear geological processes and concepts through correlative studies of a wide range of sites throughout the Corridor. In addition, it improved understanding of the influence of global climate change and/or active tectonics on regional sea-level fluctuations, coastline evolution, transformation from lacustrine to marine environments, ecosystems and sedimentary systems, as well as the prehistory and history of human adaptation.

The project improved standards of research methods in applied science (e.g. the quantitative modelling of sea-level change with detailed identification of environmental factors involved and their behaviour). Its strongest applied component is directly relevant to the work of coastal managers who assess the environmental risk and sustainable development of the Corridor under the global climate change expected to take full effect during this century.

As to benefits to society, the project enhanced our understanding of the links between environmental change and human adaptation, contributing to an improvement in human living conditions and promoting the wise use of the Earth as a human habitat.

***V. Yanko-Hombach**, Avalon Institute of Applied Science, Winnipeg, Canada;*
***Y. Yilmaz**, Kadir Has University, Turkey;*
***P. Dolukhanov** (Deceased)*

Istanbul today.
© Sarah Gaines

New Zealand. © Aloé Schlagenhauf

IGCP 588: Preparing for Coastal Change (2010-2014)

IGCP 588 focuses on coastal evolution at different temporal and spatial scales and builds on a research legacy of previous IGCP coastal programmes that have continued for more than three decades (Projects 61, 200, 274, 437 and 495). This project brings together scientists and practitioners who study the contemporary processes, impacts and responses of coastal environments to changes in sea level and extreme events with an overarching focus on human influences and reactions to coastal processes. A primary aim of the project is not only to examine the past and present coastal dynamics and evolution, but also to incorporate predictive modelling of the coastal response to changing climates, anthropogenic impacts and natural hazards. Thus, this project brings together researchers assessing coastal dynamics and vulnerability at timescales from minutes to millennia that are immediately relevant to a variety of stakeholders interested in the future of coastal communities globally.

Coastal change

It is well know that, through human history, changes in relative sea level, coastal evolution and extreme coastal hazard events such as storms and tsunamis have hindered individual well-being and intensified or enhanced environmental degradation. An increased public awareness of predicted future sea-level rise combined with recent

Normandy coast line, France.
© Margarete Patzak

devastatingly extreme events has placed significant socio-economic relevance on the understanding of human-land-ocean interaction and coastal dynamics. More than ever, the impending threat of sea-level rise to large low-lying coastal cities such as New Orleans, Shanghai, Venice, and island communities such as the Maldives, Kiribati and Tavaru has served to highlight the importance of understanding relative sea-level change in the past in order to predict the future with more confidence. Similarly, extreme events such as Hurricane Katrina, Cyclone Nargis and the 2004 Indian Ocean and 2011 Japan tsunamis have demonstrated the vulnerability of coastal communities all over the world. Coastal communities continue to grow at unprecedented rates and, as a consequence, such growing populations are vulnerable to coastal flooding associated with sea-level rise, storm surges, tsunamis and river flooding.

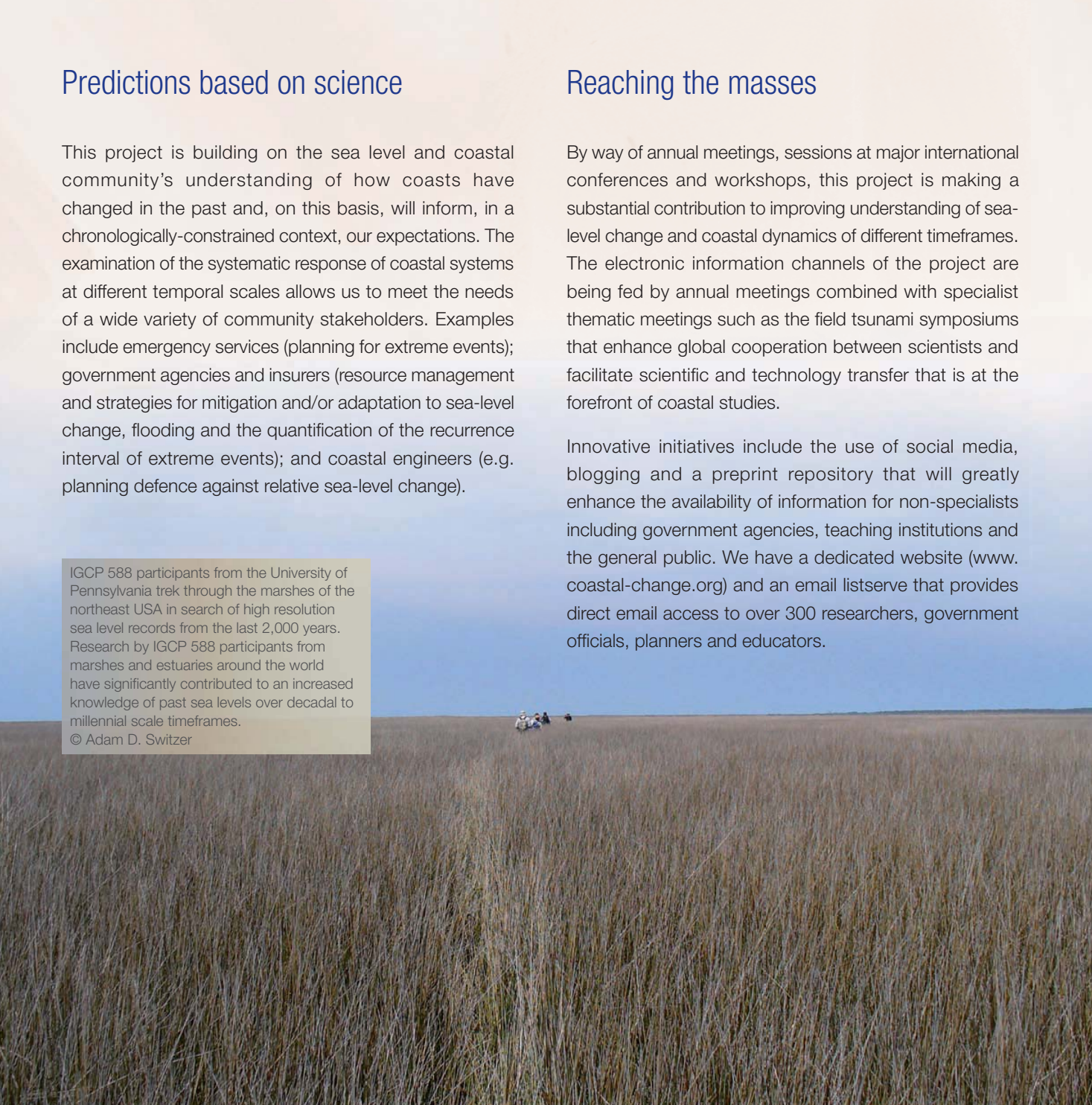
Time is of the essence

The themes of this project are linked by the cross-cutting themes of time and the impact of human communities on past and the future coastal landscapes. This project looks at records that will assist in assessing human interactions, coastal dynamics and vulnerability at different timescales, which are immediately relevant to a variety of stakeholders interested in the future of coastal communities. The overlapping time scales include catastrophic or instantaneous events (minutes to hours); measurable and predictable changes (hours to years) for planning-scale decisions (years-decades); and geological-scale changes (centuries to millennia).

IGCP 588 participants Simon Engelhart (University of Pennsylvania) and Andrew Kemp (Yale University) take cores in the marshes of the outer banks of North Carolina, USA. Research from this area has highlighted a definitive and marked increase and inflection in the rate of relative sea-level rise on the US eastern seaboard. © Adam D. Switzer

Predictions based on science

This project is building on the sea level and coastal community's understanding of how coasts have changed in the past and, on this basis, will inform, in a chronologically-constrained context, our expectations. The examination of the systematic response of coastal systems at different temporal scales allows us to meet the needs of a wide variety of community stakeholders. Examples include emergency services (planning for extreme events); government agencies and insurers (resource management and strategies for mitigation and/or adaptation to sea-level change, flooding and the quantification of the recurrence interval of extreme events); and coastal engineers (e.g. planning defence against relative sea-level change).



IGCP 588 participants from the University of Pennsylvania trek through the marshes of the northeast USA in search of high resolution sea level records from the last 2,000 years. Research by IGCP 588 participants from marshes and estuaries around the world have significantly contributed to an increased knowledge of past sea levels over decadal to millennial scale timeframes.

Reaching the masses

By way of annual meetings, sessions at major international conferences and workshops, this project is making a substantial contribution to improving understanding of sea-level change and coastal dynamics of different timeframes. The electronic information channels of the project are being fed by annual meetings combined with specialist thematic meetings such as the field tsunami symposiums that enhance global cooperation between scientists and facilitate scientific and technology transfer that is at the forefront of coastal studies.

Innovative initiatives include the use of social media, blogging and a preprint repository that will greatly enhance the availability of information for non-specialists including government agencies, teaching institutions and the general public. We have a dedicated website (www.coastal-change.org) and an email listserve that provides direct email access to over 300 researchers, government officials, planners and educators.

Feeding the IPCC

Several key research questions tackled by this project will be particularly relevant to the upcoming reports of the Intergovernmental Panel on Climate Change (IPCC) regarding future sea level. In particular, these include trends in sea level during the last few centuries to millennia; mass balance changes in the Greenland Ice Sheet; the influence of sediment and topography during the Holocene (approximately the last 11,000 years) in controlling current coastal dynamics; and spatially-variable trends in past and future sea-level rise due to gravity changes. The IPCC recently re-emphasized the importance of sea level as a barometer of climate and drew attention to the potentially devastating consequences of future climate change as experienced through sea-level rise. However, the IPCC also highlighted the uncertainty with which the driving mechanisms of recent sea-level change are understood and the disconnection between long-term geological and recent observational trends. In essence, this IGCP project is designed to fill this important gap in knowledge.

***Adam D. Switzer**, Tectonics Group, Earth Observatory of Singapore, Nanyang Technological University, Singapore; **Benjamin P. Horton**, Sea Level Research Laboratory, Department of Earth and Environmental Science, University of Pennsylvania, USA*

'Today, coastal issues, once the prerogative of esoteric geological and geomorphological disciplines, are a major focus in the debate about climate change, its impacts, and the need for adaptation on the most vulnerable shorelines.'

Colin Woodroffe, IPCC lead-author of the Fourth Assessment Report and former IGCP leader (IGCP 274)

Palaeoseismologic trench showing the 6 metre vertical offset of the ground surface created by the Mw8.0 Nobi earthquake in 1891, Motosu city museum, Japan. © Aloé Schlagenhauf

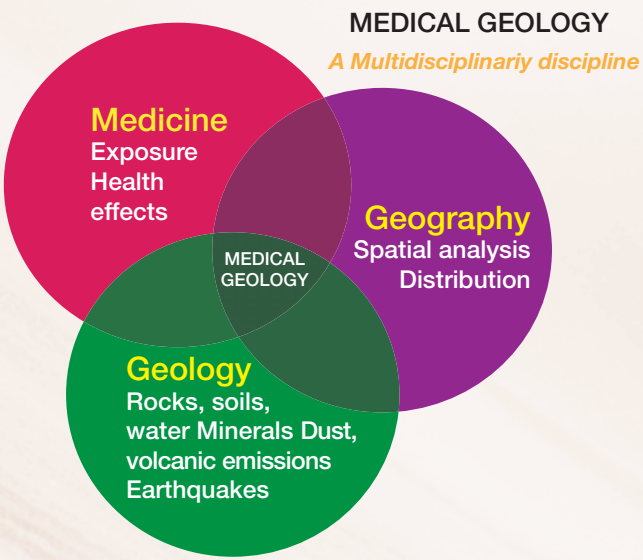
Geohazards: Mitigating the Risks

Geohazards include earthquakes, volcanic activity, landslides, tsunamis, floods, meteorite impacts and the health hazards posed by geological materials. Geohazards range from local events such as debris slides and coastal erosion to those that threaten the whole of humankind, such as supervolcano eruption and meteorite impact. Research by Earth scientists improves our understanding of such hazards and contributes to risk mitigation.

IGCP 454: Medical Geology: a New Tool for Public Health (2000-2004)

Medical geology is the science that deals with the impact of our natural environment and geology on both human and animal health. The modern version of this discipline brings together geoscientists with biomedical and public health researchers to address a range of environmental health problems. For example, serious global health problems arise from intake of arsenic, heavy metals, radiation such as radon, global dust, iodine and fluorine. All these are derived from the natural environment, that is geology, and almost all people on Earth are affected in some way and to some degree, either from an excess or lack of these elements and natural processes.

The foresight of the IGCP: the start of Medical Geology



Although geologic factors play a key role in a range of environmental health issues for billions of people worldwide, for many years there was a general lack of understanding among the general public, the biomedical and public health community, and even within the geoscience community, of the importance of these factors concerning human and animal health. In response to this situation, in 1996 the International Union of Geological Sciences (IUGS), by way of its former Commission on Geologic Sciences for Environmental Planning (COGEOENVIRONMENT), established an International Working Group on Medical Geology under the leadership of Olle Selinus of the Geological Survey of Sweden (SGU). The primary aim of this Working Group was to launch an international campaign to raise awareness of this issue among geoscientists, medical specialists, and the general public.

In 2000, the IGCP established a new project "IGCP 454 Medical Geology", co-chaired by the authors of this article. The primary aim of the IGCP project was to bring together scientists in developing countries working on medical geology issues with colleagues who shared their interest but who were located elsewhere. This initiative provided, for the first time, the opportunity for scientists and clinicians (geoscientists, physicians, geographers, veterinarians, etc.) from developed and developing countries to come together in a coherent international and inter-disciplinary forum in order to identify and tackle significant environmental health problems.

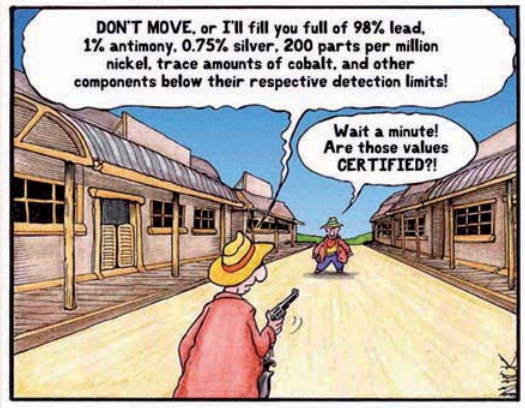
Medical geology is the science that deals with the impact of our natural environment and geology on both human and animal health.

In 2000, Bob Finkelman, a geoscientist, then with the US Geological Survey (USGS), and José Centeno, a chemical toxicologist with the US Armed Forces Institute of Pathology (AFIP), joined the IGCP 454 project. They delivered a one-day short course at the 2001 COGEOENVIRONMENT meeting in Lusaka, Zambia. The excitement generated during this event was a convincing demonstration that the medical geology short course would eventually become a powerful tool with which to advance the objectives of the IGCP project and the original IUGS Working Group. A proposal was then developed to bring this short course to other developing countries which were also experiencing critical medical geology problems. This was approved by the International Council for Science (ICSU), which provided a substantial grant to support the delivery of medical geology short courses around the world.

Short course in Medical Geology in Lithuania, April 2006. © Olle Selinus

With the support of IGCP, IUGS, COGEOENVIRONMENT, USGS, AFIP, SGU and host countries, the ICSU grant was used to fund many more short courses than had originally been proposed. So far, courses have been presented at more than 60 events around the world and have attracted the participation of several thousand students and professionals. As part of

the scientific programme for these short courses, local scientists are invited to describe medical geology work going on in their regions and students are encouraged to present their work as posters. The courses, ranging in length from a few to several days, are intended for anyone interested in the effects of natural materials and natural geological events on animal and human health. An important objective of the courses is to provide an opportunity to develop and enhance contacts and networks between professionals working in different countries and on different aspects of environmental health issues. The use of the course material by participants to conduct their own regional courses in medical geology is strongly encouraged. Information and news on the results of the IGCP project have been published in many journals, including popular literature such as *Scientific American.*



Medical Geology draws attention to the dangers of failing to check the content of ingested materials. We acknowledge, with thanks, the following site: http://img.moonbuggy.org/analytical-chemists-in-the-wild-west.

Toxic elements in soil, rocks and the atmosphere, arising from both natural (owing to rock chemistry) and human pollution may impact upon human health. In some parts of the world, fine-grained natural mineral dust in the atmosphere may reach concentrations comparable to those found in some extraction industries. Densely populated areas, such as eastern China, can suffer palls of dust from the western drylands at any time in the year but particularly in spring and autumn, as shown here in Lanzhou, western China, as follows: (left) onset on 28 April 2011, (centre) peak condition on 29 April 2011 and (right) after the event on 30 April 2011. The density on 29 April was the most intense for nine years. View towards the Guolan Shan, a mountain on the south wall of the Lanzhou graben.

Global Impact

The activities originating from IGCP 454 have had, and will continue to have, profound positive impacts around the world. The United Nations appointed UNESCO as the lead agency for the implementation of the International Year of Planet Earth (IYPE). Of the several key IYPE issues, one of the topics was *Earth and Health: Medical Geology.*

A textbook entitled *Essentials of Medical Geology* (800 pages, with colour illustrations) was published by Elsevier (Academic Press) in 2005 by Chief Editor O. Selinus and six associate editors. Approximately 60 distinguished specialists from all around the world contributed to the volume, about half being geoscientists and the other half medical, veterinarian and other types of specialists. The book was aimed at junior to senior undergraduates and decision-makers. In November 2005 the volume was recognized as a "Highly Commended" title in the Public Health category by the British Medical Association. It also won a second prestigious reward in January 2006 from the Association of American Publishers and was one of two winners in the "Geology/Geography" category of the 2005 Awards for Excellence in Professional and Scholarly Publishing. In 2007, a third award was announced by 'Choice', an annual list of Outstanding Academic Titles reviewed in the previous calendar year. The book has since been translated into Mandarin and a new, revised edition is in progress.

This initiative has led to the publication of many other textbooks, proceedings and reports on medical geology.

International Medical Geology Association (IMGA) and the future

As a direct result of the IGCP 454 project, the International Medical Geology Association was launched in 2006 (www.medicalgeology.org). This serves as an umbrella body for many regional chapters and groups around the world. Membership continues to grow by the week as regular international conferences are held, and several new books and papers are published every year. One of the most exciting current developments is the establishment of centres of excellence in medical geology. These centres will address education and research at the regional level; the first three are now under way in Puerto Rico, South Africa and Turkey.

It is never easy to anticipate what the future holds, but we are confident that the future of medical geology is bright. IMGA, a direct outcome of IGCP 454, will continue to provide a stable platform for the exchange of ideas and dissemination of information, and the many other medical geology activities mentioned above will continue to stimulate enthusiasm and momentum. Medical geologists will continue to demonstrate that what they have to offer will materially benefit society by helping to improve quality of life for both people and animals around the globe. Most importantly, the medical geology 'revolution' illustrates the leadership, foresight and importance of the IGCP. By recognizing the need for this sub-discipline and

by providing critical financial and moral support during its formative years, the IGCP helped to foster this multi-disciplinary outcome and to contribute to its evolution.

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Girl pumping water in Cambodia.
© UNESCO/Tang Chhin, Sothy

Group of Bangladeshi people using UNESCO-IHE Arsenic Removal Family Filter.
© UNESCO/IHE/Fred Kruis

IGCP 490: The Role of Holocene Environmental Catastrophes in Human History (2003-2007)

The inter-disciplinary investigation of Holocene geological catastrophes (the last 11,000 years) is relevant to future civilizations and ecosystems. The project combined three approaches: instrumental records, written documents and sedimentary records. It also examined how quickly ecosystems and civilizations were able to recover from catastrophic events. With the growing recognition that major natural events can have abrupt global impacts, this project provided a timely opportunity to assess the sensitivity of modern society to extreme natural threats. The project not only involved the geoscience community but also biologists, archaeologists, historians and meteorologists.

An inaugural workshop took place in early 2004 in Mauritania. This workshop addressed the transition between the 'green' and the 'yellow' Sahara that existed some 5,000 years ago. At that time, an important fauna of large animals, including giraffes, hippopotami, elephants, zebras, cattle and horses lived in what is now a desert. As the climate changed, people left the centre of the Sahara and emigrated to the coast or to the Nile valley. At the same time, we examined the changes in the extension of the Sahel (immediately south of the Sahara) over the last 50 years, including the precipitation crisis in the 1970s. The IGCP scientists wished to impart the following messages: it is necessary to study the past and, in so doing, the geosciences can provide information at a very high time resolution (societal scale) as well as identifying the key indicators of future changes; multidisciplinary studies have already made clear the impact of rapid and catastrophic changes on past societies; and nature (in addition to people and independently from them) may have negative effects that should not be minimized.

The inter-disciplinary investigation of Holocene geological catastrophes (the last 11,000 years) is relevant to future civilizations and ecosystems.

The second workshop, held in late 2004 in Mozambique, focused chiefly on recent and past floods in equatorial east Africa and southeast Africa, comparing Holocene floods with those of recent years. A declaration mainly based on the African experience and prepared by the participants was posted on the internet. It declared that floods are the most frequent of all natural catastrophes; they affect almost every part of the World and a great part of the World's population because so many people live along rivers and on flood-plains, and the catastrophic effects of floods are closely linked to human transformation of natural systems.

In May 2005 a conference on rapid sea level change, held in northern Iran, focused on the very rapid water level changes that occurred in the Caspian Sea in past centuries, when changes occurred 100 times faster than that of the global ocean. Many 'end users' attended, including people from the Harbours organisation (concerned with the rapid siltation that occurs when the sea level is going down) and from the Fisheries organisation (especially those in the caviar industry). Petroleum companies also had an interest

Mosque flooded by the Caspian high stand in 2005.
© Suzanne Leroy

Blown sand invading the old inland town of Chinguetti, Mauritania.
© Suzanne Leroy

not only in the northern basin which is very shallow and allows the development of offshore infrastructure, but also elsewhere in the Caspian Sea, due to the increase in geohazards such as landslides, mud volcanoes, and methane release.

In the same year, a field excursion was conducted in the Pampa of Argentina along the shores of Mar Chiquita. This is a large lake whose level has risen extremely rapidly in past decades. This was also noticed in other Pampean lakes and was clearly linked to increased periods of precipitation. The villagers, on having to relocate their village, followed the advice of a geologist who had studied Holocene lake levels. The information transfer was especially successful as the scientist was from such a village and therefore trust was easily established.

In June 2005, the Canadian Arctic meeting saw the presence of physical and social scientists and representatives from the humanities, local communities, and First Nations. One of the main topics of discussion was the impact of global warming on local communities. This was presented in the framework of historical and archaeological studies focused on past rapid changes. The stories of the First Nations and their culture indicate that, as conditions on land and sea changed, the early peoples of the North adapted their migration and living patterns. Northern peoples have today maintained cultural continuity and creativity in the face of marked environmental and social change. A declaration was prepared by the attendants, posted on the internet, and addressed to the governments and environmental authorities, researchers, and funding agencies.

The meeting in September 2005 in the Italian Alps was held at the tip of the very deep Lake Como. The field excursion took participants to a huge landslide that occurred in 1618 and destroyed the rich village of Piuro. The merchant diaspora, having earlier emigrated throughout Europe, wrote abundantly about this event, making it well known. Also, the modern town of Como is built on an unstable flood plain that poses serious risks of subsidence and tsunami as shown by two recent underwater landslides. However, despite the efforts of local scientists to sensitise the community to this natural hazard and the need to have evacuation plans, the risk is perceived as too remote to be taken seriously. This kind of reaction is recognised as one of the main difficulties encountered by Earth scientists when they transfer information to local politicians and decision-makers.

In September 2006, the Louisiana workshop focused on the past record of ancient hurricanes. The field excursion included a visit to New Orleans to see the damage inflicted by Hurricane Katrina a year earlier. A geologist also demonstrated ‘concrete’ evidence of the lack of knowledge of the underlying sediment and the poor engineering work. One of the organisers, whose family had been evacuated from the city, led the participants to the house of her parents-in-law. This dwelling, as was the case with so many other areas of the city, was still without basic amenities a year after the event. The great challenges faced by the US government in helping the recovery were self evident.

The last meeting took IGCP 490 scientists to Java and Sumatra in August 2007. Participants had the opportunity to climb what is left of Krakatau after its eruption of 1883 and the associated tsunami. The organisers showed us the amazing level of the monitoring system for seismic activity,

as well as the mitigation plans for tsunamis put in place in this region by the Indonesian government.

In conclusion, rapid environmental changes that have occurred in the past, some of them catastrophic, have seen the end of some ancient civilizations, for example the abandonment of Greenland by the Norse 600 years ago and the Maya decline about 1,100 years ago in Central America. However, rapid environmental changes have not always led to collapse of ancient civilizations. On the contrary, it may be argued that this led to the rise of some civilizations, for example the drying of the Sahara leading to the emergence of the Egyptian dynastic civilization, and the droughts in Mesopotamia about 5,000 years ago that encouraged the development of urban centres. It has been argued that the earliest complex and highly organised state-level societies emerged at a time of increasing aridity throughout the global monsoon belt.

It is clear that we live in an ever-changing world, and that recovery takes place if a society is capable of adapting to the changes. Nowadays, the accelerating rate of urbanisation around the world is forcing society to concentrate increasingly on mitigating the effects of the changes. Unfortunately, we do not always learn from past lessons and too often aim at recovering from the situation before the disaster has occurred. It is sometimes necessary to modify some core societal values if we want to become more resilient to natural hazards.

The succession of several negative environmental and societal factors will decrease the resilience of a society. The lack of societal flexibility and the 'ratchet' effect of cumulative disasters are key components in a catastrophic societal collapse.

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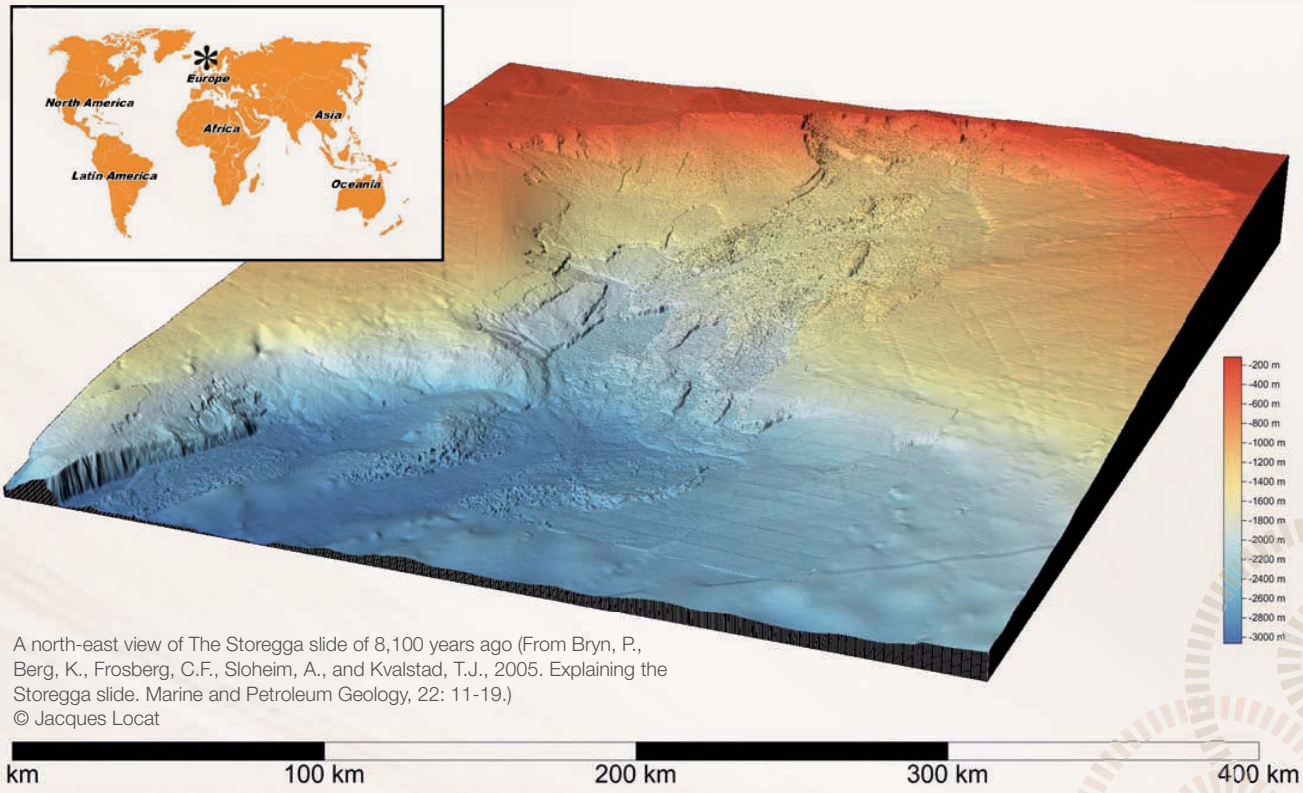
Large boulder-size blocks of coral ripped off a reef and transported to the beach by the Krakatau tsunami in 1883.
© Charlotte Miller

IGCP 511: Submarine Mass Movements and their Consequences (2005-2009)

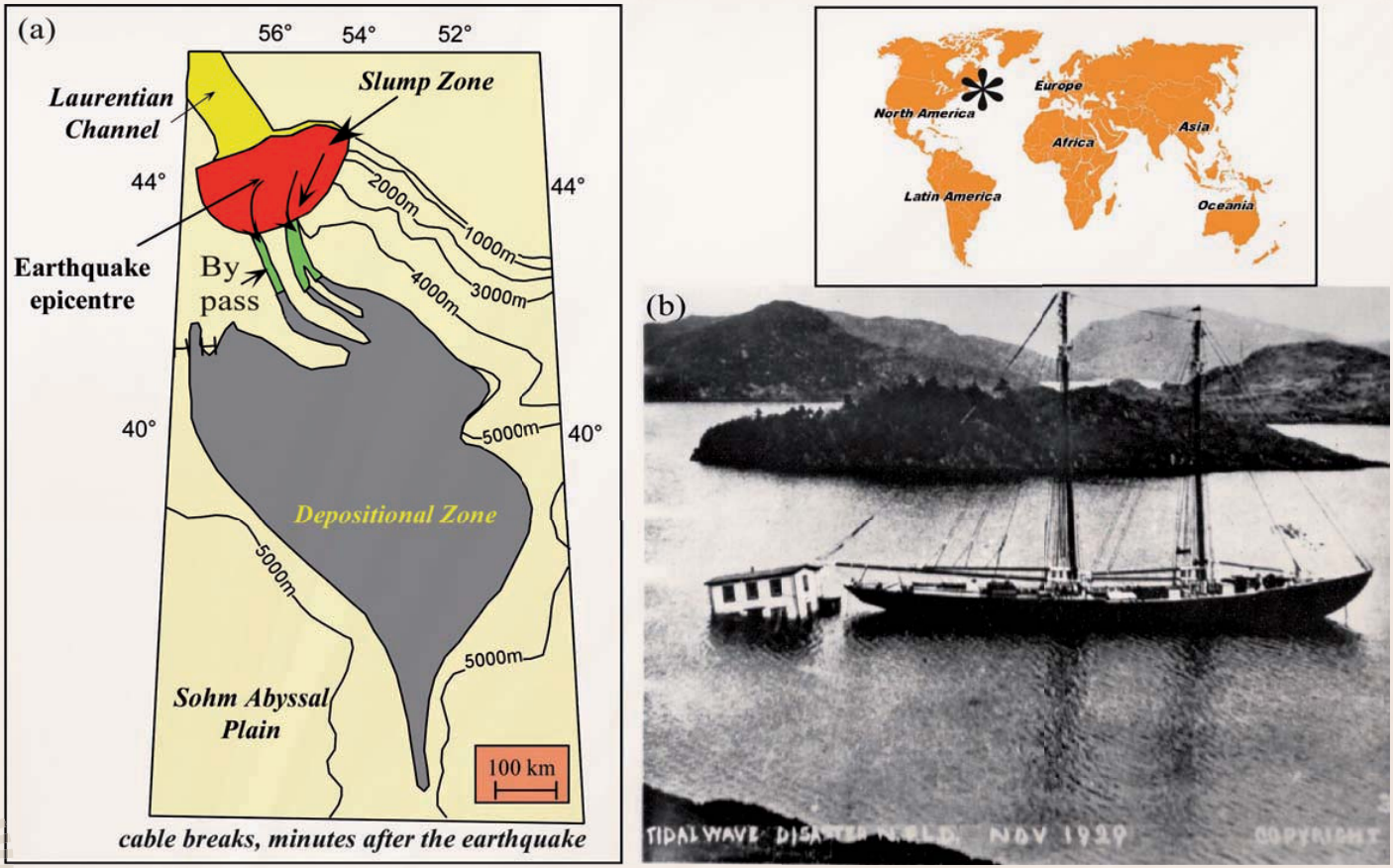
Subaqueous mass movements occur in almost all environments in the ocean and lakes, in fjords and along the coastline. They can have volumes of up to several hundred cubic kilometres and are typically at least one order of magnitude larger than their counterparts on land. They are found throughout the geological record right up to the present and are caused by various triggering mechanisms including earthquake, erosion, gas hydrate dissociation, diapirism (a sharply upward fold in rock) and wave action. Like their counterparts on land, subaqueous



A north-east view of The Storegga slide of 8,100 years ago (From Bryn, P., Berg, K., Frosberg, C.F., Sloheim, A., and Kvalstad, T.J., 2005. Explaining the Storegga slide. Marine and Petroleum Geology, 22: 11-19.)

mass movements result from a disequilbrium between resisting forces and stresses. Damage can be huge, extending over more than 1,000 km and threatening underwater communication cables and infrastructure (pipelines, wellheads, fishing habitats, coastal infrastructure and communities). They are also responsible for about 10% of observed tsunamis.

Submarine mass movements of various sizes and styles have shaped the sea floor through geological time; their



The Grand Banks slide and tsunami, off the Newfoundland coast of Canada. (a) Map of slide showing location of the breakage point of the Transatlantic cable within the slump zone (red); (b) a large schooner at anchor with a tsunami-born two-storey house (and an attached shed behind it), in Little Burin Harbour, floating directly astern of the schooner (A. Ruffman, pers. com.; photo by Father James Anthony Miller). (From Heezen, B.C., and Ewing, M., 1952. Turbidity currents and submarine slumps, and the 1929 Grand Banks earthquake. American Journal of Science, 250: 849-873). © Jacques Locat

Participants of the 3rd symposium of IGCP 511 (Santorini, Greece).
© Jacques Locat

deposits now play an important role in controlling the location of hydrocarbon reservoirs. In developing our understanding of submarine mass movements and their consequences, there are two milestone examples: the Grand Banks slide of 1929 and the Storegga slide which took place 8,100 years ago.

On November 18th 1929, a M7.2 earthquake shocked the Grand Banks to the southeast of Newfoundland, Canada, triggering a huge (~150 km^3 in volume) submarine mass movement; it generated a tsunami which devastated a small village in Newfoundland, killing 27 people. The turbidity current generated by the slide broke submarine cables over a distance of up to 1,000 km. A similar event occurred in Papua New Guinea in 1998 with more than 2,000 casualties.

The large and much older Storegga slide involved a total volume of 2,500 km^3 and removed about 300 km of the Norwegian continental margin. Such a massive failure generated a tsunami, evidence of which has been recorded as far south as the eastern coast of Scotland and north-eastern England. Located above one of the major gas reservoirs in the Norwegian Sea, the Storegga slide was the subject of a comprehensive investigation involving a multidisciplinary approach from Earth sciences to engineering.

These milestone cases illustrate clearly that research on subaqueous mass movements has clear societal implications. Such mass movements represent a major geohazard because of their potential destruction of near-shore structures, coastal facilities, seafloor life and offshore seabed structures. Submarine slides can trigger tsunamis and are capable of methane gas release into the seawater and the atmosphere.

IGCP 511 was initiated as a community effort originating from the 1st International Symposium on Submarine Mass Movements and Their Consequences (ISSMMTC) held in Nice, France in 2003; it coincided with the conclusion of the COSTA project (COntinental Slope sTAbility), an international investigation of submarine mass movements. Since then, IGCP 511 has promoted many workshops and conferences, including the continuation of the ISSMMTC series, as well as its biennial conferences in Oslo, Norway (2005), Santorini, Greece (2007) and Austin, Texas, USA (2009). On the basis of these conferences alone, more than 220 peer-reviewed papers have been published (also available in electronic format). The ISSMMTC conference series has continued under the IGCP 585 E-MARSHAL project. The various IGCP 511 symposia were in many ways strongly supported by various industrial, governmental and non-governmental organizations.

This IGCP project has brought a worldwide perspective to submarine mass movements and their consequences. The project attracted a broad range of research, covering fundamental as well as site-specific studies from many parts of the world including the Atlantic and Pacific oceans, inner seas like the Mediterranean, fjords and lakes using the most recent technologies from multi-beam sonar imaging and 3D seismic imaging to modelling of slope stability to post-failure evolution and tsunami generation, propagation and run-up. It has also acted as a unique forum to showcase the diversity and complexity of the geomorphology and geology of the subaqueous environment.

One of the main goals of IGCP 511 was to advance science through networking of scientists and engineers from around the world by supporting meetings and

conferences in particular with a large proportion of its budget dedicated to the active participation of students. This goal was achieved by bringing together more than 150 scientists from 17 countries as well as financially supporting a number of students and researchers from developing countries. IGCP 511 was instrumental in securing the inclusion of marine geohazards in the Integrated Ocean Drilling Program (IODP) science plan. It also supported IODP projects aimed at understanding the role of groundwater flow on submarine mass movement initiation.

On the basis of our five years of cooperation on submarine mass movements within the framework of IGCP 511, significant advances have been made on a number of important topics, including groundwater flow along continental margins and slope instabilities, landslides and tsunamis, 3D seismic imagery revealing palaeo-submarine landslides, and mechanisms of transition from slope failure to post-failure evolution.

In conclusion, the advancement in our knowledge of submarine mass movements and their consequences has been greatly enhanced by the sustained support of UNESCO and IUGS. Such support has provided an exceptional framework with which to establish a strong research network for the benefit of society.

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IGCP 567: Ancient Earthquakes (2008-2012)

Damaging earthquakes along faults typically recur at intervals of centuries to millennia, but the instruments that can register them have only been available for about a hundred years. To reduce the threat from earthquakes, we need a longer record of them than what has been provided by such instruments. Archaeological evidence has the potential to reveal earthquake activity over millennial time spans, especially when integrated with

Typical earthquake-related structural damage pattern: displaced drums of a column keystone in the Temple of Aphrodite in the Roman city of Aphrodisias in southwest Turkey, near the modern town of Geyre, west of Denizli. © Manuel Sintubin

Typical earthquake-related structural damage pattern: a dropped keystone in a doorway near the Byzantine Gate in the Roman city of Hierapolis in southwest Turkey, near the modern town of Pamukkale, northeast of Denizli.
© Manuel Sintubin

Typical earthquake-related structural damage pattern: dropped keystones in an arch in the medieval Nimrod Fortress, or Kal'at Al-Subayba on the Golan Heights. © Manuel Sintubin

historical documents and geological evidence. The international geosciences programme IGCP 567 on earthquake archaeology is intended to demonstrate that archaeological evidence can make a valuable contribution to long-term seismic-hazard assessments in earthquake-prone regions where there is a long and lasting cultural heritage.

Although archaeoseismology (the study of ancient earthquakes through indicators left in the archaeological record) has a lineage that extends back to the pioneering excavations of Schliemann at Troy, Evans at Knossos and Schaeffer at Ugarit in the late 19th and early 20th centuries, it is essentially a young and burgeoning discipline that has met with much reservation from some earthquake scientists. Many of them question whether cultural

phenomena, including destruction layers, cultural-piercing features (man-made structures displaced by surface-rupturing, e.g. viaducts), structural damage to buildings, indications of repairs, historical accounts and myths can be reliably used as earthquake indicators.

The problem seismic-hazard practitioners face, however, is that the instrumental record of earthquakes is too short and the historical record too incomplete. Historical catalogues record only a tiny proportion of the sizeable shocks that have struck a region over centuries and millennia; such missing 'populations' in the earthquake records temper reliable seismic-hazard assessments, but the archaeological record can bolster and augment that historical archive. What is more, in extending the earthquake record beyond the written sources, archaeoseismology serves as a bridge between instrumental and historical seismology, on the one hand, and palaeoseismology and earthquake geology, on the other. Only the integration of all potential evidence for past earthquakes enables us to advance our understanding of the complex earthquake history of a region. Archaeoseismology could be a legitimate and complementary source of seismic-hazard information.

What holds archaeoseismology back from being a mature scientific discipline is its lack of a rigorous and transparent methodology. To date, many practitioners have proposed procedural schemes for archaeoseismological investigations but, in most cases, these schemes

IGCP 567 visiting the Nabatean city of Petra in Jordan; posing on top of the imbricated drums of a fallen column of the Great Temple, probably caused by an ancient earthquake.

are designed from within a single scientific discipline, revealing archaeoseismology's principal hubris, namely the interdisciplinary nature of the evidence that confronts it. Archaeoseismology calls upon the expertise of historians, anthropologists, archaeologists, geologists, seismologists, geophysicists, architects and structural engineers. Integrating the principles and practices of such a wide range of disciplines is archaeoseismology's greatest challenge and its foremost attraction.

IGCP 567 took up this challenge not only by bringing together the world's principal practitioners in archaeoseismology, but also by expanding this nucleus with young and emerging scientists, and by integrating our activities with practitioners in palaeoseismology as well as with historical and instrumental seismology. Together with our colleagues of the INQUA (International Union for Quaternary Research) focus area group on palaeoseismology and active tectonics, IGCP 567 started a new tradition of joint field workshops. The initial workshop was organized in 2009 at the archaeological site of Baelo Claudia in southern Spain; the second took place in 2011 in Corinth, Greece; a third is planned for 2012 in Morelia, Mexico; and a fourth in 2013 in Aachen, Germany.

The confrontation of ideas at these workshops has definitively advanced the discipline to a level that archaeoseismological evidence is now considered as a complementary source of earthquake data in the whole range of approaches in earthquake science. During the period of IGCP 567, the archaeoseismological principles and practices have further matured in pursuing an intimate relationship with other disciplines of earthquake science. These integration efforts are clearly expressed in published work, offering a taste of the complexity confronting archaeoseismologists. A new textbook on archaeoseismology is planned for 2012, guaranteeing a lasting legacy for IGCP 567. The strength of this new community (active in the social media as www.paleoseismicity.org) has also increased the visibility of our work, not only in the scientific community but also across a wide public audience. IGCP 567 turned out to be an incentive for an active engagement from our community in geosciences communication and outreach activities for local communities at each of the field workshops, but also for various international media.

We have identified the Alpine-Himalayan region as the ideal laboratory. The Alpine-Himalayan belt is of particular interest because it is home to some of the most ancient civilizations in the world. Thus, it might be expected to have the clearest cultural evidence of ancient earthquake catastrophes. Archaeoseismological developments were originally grafted on to investigations in the Eastern Mediterranean and the Middle East, with a strong dependence on identifying structural damage to monumental buildings. We succeeded in taking archaeoseismology out of its 'Mediterranean cradle', extending our focus to 'new territories' that share a comparable seismotectonic setting and a contiguous cultural and historical context. New 'seed points' for future archaeoseismological research were promoted by IGCP 567 in China, India and the Republic of Korea, and other countries in central and southeast Asia, opening new opportunities for the use of already excavated archaeological sites as ancient 'seismoscopes'.

Typical earthquake-related structural damage pattern: aligned series of fallen columns in the Byzantine Cathedral (South-East Church) in the Greco-Roman city of Hippos (Sussita), overlooking the Sea of Galilee (Golan Heights).

There is a wider remit for our activities, because they clearly have important societal benefits. As illustrated by the collapse of the magnificent antique citadel at Bam, the largest sun dried bricks (adobe) building in the world and a World Heritage Site, during the devastating earthquake that struck this ancient Iranian city, cultural heritage sites themselves are threatened by earthquake destruction. Clearly, there is a growing need to understand how ancient structures and monuments respond to faulting and ground shaking. Our work also contributes to our understanding of ancient history, elucidating why some cities were abandoned or why mature societies suffered decline; we also study the enduring attraction of fault lines in luring peoples, ancient and modern, to settle along persistent danger zones. By highlighting how their ancestors coped with earthquakes, archaeoseismology should play a key role in fostering better earthquake preparedness in modern communities that are equally threatened.

In this respect, the legacy of IGCP 567 will be a strong community of practitioners who are well disposed towards archaeoseismology, advocating a holistic approach that will eventually contribute to the establishment of an essential earthquake culture in the Alpine-Himalayan region, occasionally confronted with the inevitable earthquake catastrophe.

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Hydrogeology: Geoscience of the Water Cycle

Life on Earth depends on water, and its sustainable use is crucial for continued human existence. Earth's water resources include surface and groundwater, ocean water, and ice. The study of the Earth's water involves understanding and managing both surface and groundwater systems, including sources, contamination, vulnerability and the history of water systems.

IGCP 415: The GRAND Project – Glaciation and Reorganization of Asia's Network of Drainage (1997-2001)

Extensive glaciations in the past 2.6 million years, during the Earth's Quaternary Period, not only repeatedly buried landscapes at high latitudes and high elevations under ice for thousands of years, but dramatically impacted on continental drainage systems, damming north-flowing rivers and impounding lakes along their southern margins. Glaciers in High Asia also expanded and contracted, influencing continental weather patterns and regional climate, as well as valleys beyond the mountains. An understanding of these past glacial events may help us to assess the possible impact that melting modern glaciers will have on future climate in a globally warming world because it is known that freshwaters can impact on palaeo-ocean circulation and, in turn, on climate. With this in mind, a project was designed to investigate past glaciations and drainage in Asia.

The scale of the proposed project demanded an international and multidisciplinary effort. Leading scholars of the Quaternary in Europe and Asia were contacted, together with expert researchers in North America who had studied, mapped, and modelled comparable situations. The resulting proposal, "Glaciation and Reorganization of Asia's Network of Drainage" (GRAND) was accepted as IGCP project 415 and launched in 1997; the project was led by the author, together with Rein Vaikmae (Estonia) and Nat Rutter (Canada) as project secretary.

The main objectives of the GRAND project were to study the extent and timing of late Quaternary glaciation in Asia and the impact that this had on the continent's drainage system. This was identified as one of the most important unresolved questions related to global change, because coupled ocean-atmosphere (GCM) models have shown how influential extensive ice cover on continents can be to atmospheric circulation, and how freshwater from melting ice sheets can influence ocean circulation and climate. If, as had happened in North America, the northward-flowing river systems that drained to the Arctic Ocean had been dammed by ice sheets, the Asian rivers would have been forced to seek new routes southward through the Aral, Caspian, Black, and Mediterranean seas. Such a shift would have resulted in a large part of Asia's runoff entering the world's oceans by way of the Atlantic Ocean, rather than into the Arctic Ocean as it is today.

Seven Working Groups (with leaders) were set up as follows: Glaciation in the Tibet Plateau (Lewis Owen, USA); Drainage off the Tibetan Plateau (Frank Lehmkuhl, Germany); Eurasian Arctic Ocean Record (Leonid Polyak, USA); Permafrost and Ground Ice in Asia (Nikolai Romanovsky, Russian Federation); Glaciation in Asia (Valery Astakhov, Russian Federation; Julie Brigham-Grette, USA); Proglacial Lakes and Drainage Systems of Siberia (Vic Baker, USA); and Modelling Ice Sheets, Oceans, and Climate (Andrew Bush, Canada). The following eighteen countries participated in the GRAND project: Brazil,

Ice pinnacle and supraglacial meltwater channel on Baltoro glacier in the Karakoram Mountains, Northern Pakistan. At about 58 km in length, Baltoro is one of the longest glaciers outside of the polar regions. It advances from the slopes of four of the world's fourteen 8,000 m peaks (K2 at 8,611 m above sea level, Gasherbrum 1 at 8,068 m asl, Broad Peak at 8,047m asl and Gasherbrum II at 8,035 m asl); its meltwaters feed into the Braldu and Shigar river before eventually reaching the Indus River and the Arabian Sea.

Canada, China, Estonia, France, Germany, India, Italy, Japan, Latvia, Mexico, Mongolia, Norway, Poland, Russian Federation, Sweden, the UK, and the USA. All Working Groups met together annually with venues in Estonia (1997), India (1998), USA (1999), Russian Federation (2000) and Germany (2001); many other meetings were convened by individual Working Groups.

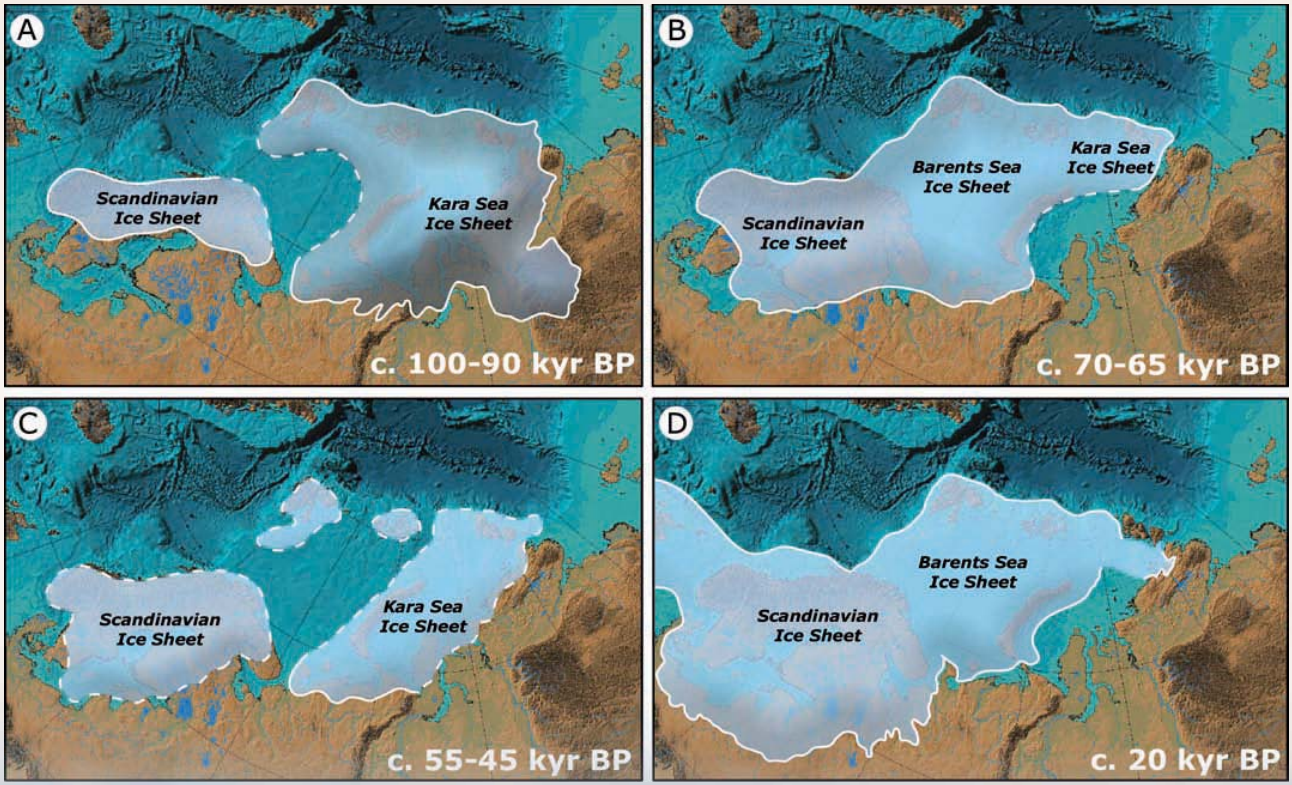
During the life of the project, IGCP 415 interacted with QUEEN (Quaternary Environment of the Eurasian North, with Astakhov as Liaison Scientist); RAISE (Russian-American Initiative on Shelf-Land Glacial Maximum, with Brigham-Grette as Liaison Scientist); GLOCOPH (Global Continental Paleohydrology); APARD (Arctic Palaeo-River Discharge); IGCP 396 (Continental Shelves in the Quaternary); IGCP 464 (Continental Shelves During the Last Glacial Cycle): and the International Permafrost Commission, convening a number of joint meetings and holding special sessions at some of their meetings. These collaborative links between IGCP 415 and other projects were invaluable, and are a common feature in this distinctive UNESCO-IUGS Programme.

GRAND studies, including those on the genesis, palaeo-fauna, and palaeo-flora in depressions in melting permafrost, distinctive cryogenic (freeze-thaw) features, and isotope and chemical composition of ice, confirmed the results of QUEEN that the last period of glaciation did not cover the Arctic Ocean shelf and coastal lowlands east of the Ural Mountains, and that Asia's rivers continued to drain into the Arctic Ocean during that glacial period. Offshore cores and seismic records in the Arctic Ocean basin, studied by the IGCP 415 Working Group on Eurasian Arctic Ocean Record, in combination with continental records, also suggest a somewhat limited extent of the last glaciation; however, they indicate that earlier glaciation was more extensive and probably dammed and diverted the flow of Siberian rivers southward into the Aral, Caspian, and Black Seas. The Working Group on Proglacial Lakes and Drainage Systems of Siberia studied large valleys across central Asia that once carried meltwater from the northern glaciated regions to these southern seas, in the opposite direction from that seen today. Evidence that the flow of northward-draining rivers across Asia was not reversed by the last period of Quaternary glaciation led us to conclude that freshwater from this region did not impact on ocean circulation nor did it play a major role in climate change at that time.

A major thrust of the IGCP 415 project was toward the extent and timing of glaciation in High Asia (Himalayas and Tibet) and was carried out by three Working Groups. The records in China and northern India provided especially long and high quality palaeoclimatic proxies for change and also reflect both orbital controls on climate and other more regional influences such as the uplift of the Tibetan Plateau. Global ocean circulation at this time was impacted by differences in rainfall and by freshwater infusions from melting glaciers in the Himalayas. Coupled atmosphere-ice sheet modelling, which includes radiative models and the role played by topography, was integrated into a global circulation model (GCM). The IGCP 415 project provided a clearer understanding of the role of glaciation in High Asia in controlling precipitation through changes in the monsoon belt.

Data, analyses and conclusions from Project 415 have been published as dozens of journal papers, hundreds of abstracts, and several special issues of scientific journals.

***James Teller**, Department of Geological Sciences, University of Manitoba, Manitoba, Canada*



Field excursion, Krossfjorden, Svalbard.

IGCP 299, 379, 448, 513, 598: Global Efforts to Understand the Nature of Karst Systems: over two Decades with the IGCP (1990-2015)

Karst landscape and aquifer systems are formed within especially soluble bedrock such as limestone, dolomite and gypsum in which large underground rivers flow through caves that have been dissolved by groundwater. Karst systems have formed within these rocks over roughly 15% of the world's land surface and display spectacular landforms. Karst landscapes range from the bare, flat pavements of western Ireland's Burren to the rolling plains of bowl-like depressions called sinkholes and to the dramatic karst peaks that line southwest China's Li River in a landscape so iconic that it appears on China's 20 RMB currency notes.

The term karst is derived from a Slavic word *krs* or *kras* (meaning barren land) coming from the border of present-day Slovenia and Italy, where the caves, underground rivers and large closed depressions are spectacular. Modern karst geomorphology was born here with the work of Serbian geographer Jovan Cvijić early in the twentieth century, and the term karst eventually gained international recognition as a generic, descriptive term for such landscapes throughout the world.

Serious environmental problems occur in karst regions. An estimated 20-25% of the world's people obtain drinking water either directly or indirectly from karst aquifers, yet there are problems with water quality and with water access because, typically, the water flows underground and thus is limited at the surface. Collapse of subsurface voids can cause structural damage and, on occasion, loss of life.

Given the beauty, complexity, challenges and global breadth of karst systems, it was to be expected that scientists from around the world would come together to organize projects under the 'umbrella' of the IGCP. In 1990 the first of the five projects was initiated as IGCP 299: Geology, Climate, Hydrology and Karst Formation. This work greatly enhanced international communication among the world's karst scientists, and synthesized progress in the spirit of IGCP's original goal, namely to establish global correlations not just between scientists but between the landscapes and systems themselves. In the sixteen chapters of the final report of IGCP 299, written by authors from 15 countries and entitled *Global Karst Correlation*, the evolution, structure and behaviour of karst systems are described for arctic, temperate, tropical, Mediterranean and other climates impacted upon by a wide range of geological conditions.

Scientific results obtained under the auspices of UNESCO and IUGS are described herein; they include those established by the five related IGCP projects, as well as a substantial outgrowth from these projects in the form of the establishment in 2008 of the UNESCO Category II International Research Center on Karst (IRCK), hosted within the Institute of Karst Geology of the Chinese Academy of Sciences.

Gournier cave, Vercors, France. © Association spéléologique du Sud Est

Project	Title	Duration
IGCP 299	Geology, Climate, Hydrology and Karst Formation	1990-1994
IGCP 379	Karst Processes and the Global Carbon Cycle	1995-1999
IGCP 448	Global Correlation of Karst Hydrogeology and Relevant Ecosystems	2000-2004
IGCP 513	Global Study of Karst Aquifers and Water Resources	2005-2010
IGCP/SIDA 598	Environmental Change and Sustainability in Karst Systems	2011-2015

How has IGCP made a difference in the advancement of Karst research?

As with other IGCP projects, the work described here has been initiated and implemented by individual scientists and laboratories around the world. Its impact has been greatly enhanced, however, through the intervention of the IGCP. First, remarkable synergy has been generated through individual interaction between scientists (some planned, some by chance) during some 30 conferences throughout the world that benefited from support from the IGCP karst projects. While any such conference is bound to concentrate on technical presentations of new results, another inevitable result occurs when individual scientists meet during field excursions, at meal times and during coffee breaks. This collaboration is what IGCP does best; many new ideas or promising opportunities have emerged during such informal discussions.

Very many field excursions in the world's greatest karst sites organized through the IGCP have also had a synergistic effect. By travelling through (and in this case, sometimes underneath) these iconic landscapes, led by the leading local experts, we have learned about karst systems by comparing them, adding to our experience, and noting the common features and differences. When carefully examined, the knowledge derived from such differences improves our understanding of the similarities and common features that can be seen in karst terrain around the world; thus, we gain a deeper appreciation of the basic, fundamental nature of karst systems.

Scientific and societal contributions from the Karst IGCP projects

We highlight here the principal technical contributions that have arisen from the work of the IGCP projects on karst. Significant advances have been made in our understanding and quantification of the processes of the *Karst Dynamic System*, a conceptual framework useful for understanding how karst systems function, and how the water, chemical, biological and human systems interact within them.

Improved Interpretation of the Records Contained within Karst Systems

In karst regions, cave passages, sediments and other features are preserved deep in the bedrock for long periods and may thus be protected (and preserved for later interpretation by scientists) for millions of years.

Measuring past climates is a key to understanding the dynamics of climate change; this is especially relevant now because of the clear human impact and potential costs. For several decades now, a search has been under way to identify records of past climate contained within natural systems. Such records are found in caves in several forms. For example, minerals in stalactites (the stone "icicles" that hang from cave ceilings) and other similar formations contain chemical information that records the past climates of the region around the cave. A fine example was published in the journal *Science* by an international team during IGCP 448; they interpreted records of the Asian monsoon over a period of 160,000 years from stalagmite records collected from Dongge Cave in China's Guizhou Province.

The IGCP has enhanced this work by fostering international coordination of the interpretation of this information. Of course, climate records within a cave represent conditions at that location only, and not until many such records are synthesized can both the spatial and temporal patterns of past climate change be understood.

Geochemistry of Karst Systems and its broader significance

The Study of the evolution of karst systems is based on understanding details of the interactions between natural waters and the rocks they dissolve. The chemistry has been intensely studied and data published and reported at IGCP-sponsored conferences, allowing scientists to make great progress in understanding how karst landscapes and aquifers form.

An extension of this work, in which IGCP-affiliated scientists have made particularly significant contributions, first came into focus in Project 379: Karst Processes and the Global Carbon Cycle. When limestone is dissolved in karst regions, CO_2 gas is removed from the atmosphere. The resulting atmospheric CO_2 sink (the term used here as opposed to a source) impacts upon global atmospheric CO_2 concentrations, which have been implicated in human-induced climate change. The details of these water-rock interactions have received relatively little attention because of a chemically related source in the oceans that, over long periods, has been assumed to balance out. However, these processes may or may not balance out over the relevant timescales of decades to centuries, particularly with rapid global environmental change under way. Project 379 produced the book Karst Processes and the Carbon Cycle and progress along this line continues under Project 598. Chinese scientists at the IRCK in Guilin are now collaborating with colleagues around the world to establish a global network of monitoring sites that will measure this carbon sink more precisely and show how it may vary with geological and climatic conditions.

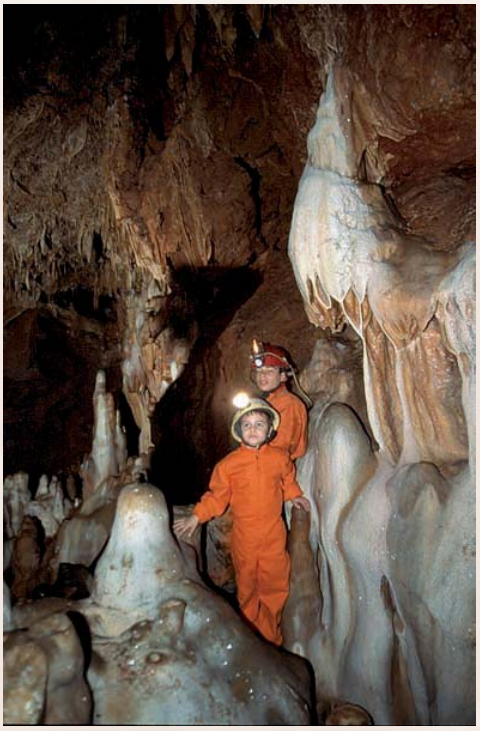
Cheran river, Massif des Bauges Geopark, France. © Gilles Lansard

Water resources and environmental problems in Karst

The greatest societal contribution to karst science within the framework of the IGCP has come by way of study and training efforts in the development and protection of karst water resources, with both ecological (IGCP 448: Global Correlation of Karst Hydrogeology and Relevant Ecosystems) and human (IGCP 513: Global Study of Karst Aquifers and Water Resources) dimensions. With over one billion people relying to some degree on water from karst aquifers, serious challenges exist. Because of the great permeability of karst aquifers, the flow of water underground, rather than on the surface, limits its accessibility for human needs. This creates especially severe problems in places where monsoonal climates include a prolonged dry season. Groundwater in karst areas is often contaminated. In contrast to the frequently high quality well or spring water found in other geological settings, contaminants can quickly infiltrate the ground with little filtration, travelling rapidly through underground river systems to join the water supply from springs or wells. Exploitation of karst water resources sometimes demands special techniques. Numerous contributions have been made through the years by scientists working and reporting under the auspices of these IGCP projects, including advancements in groundwater tracing, geophysics, methods for mapping underground river courses, and in a major effort (primarily driven by Spanish and other European participants) to develop groundwater vulnerability mapping methods.

Partnerships and capacity-building

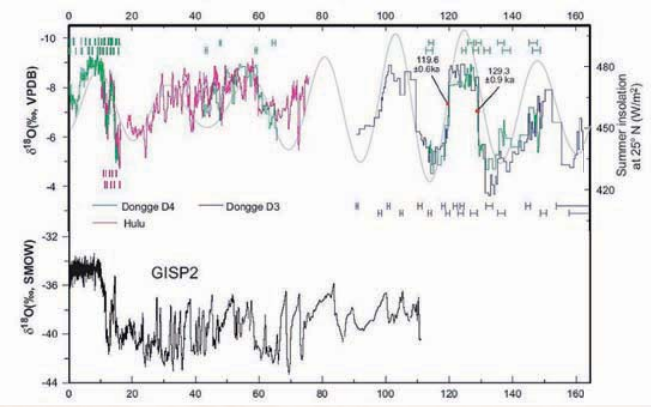
Perhaps the most tangible outcomes have come from partnerships and training. The IGCP karst projects have organized joint publications and conferences with the karst commissions of the International Association of Hydrogeologists, the International Geographical Union, and the Commission on Speleogenesis and Hydrogeology of the International Union of Speleology. These have not only created countless opportunities for the exchange of ideas, experience and opportunities, they have raised efficiency by identifying common goals and working to eliminate redundant efforts.



Children at Doxa cave, Psiloritis Geopark, Greece. © K. Paragamian

Many countries with developing economies have well-developed karst regions that present environmental challenges, and numerous scientists from these regions have benefitted both directly from IGCP funding to participate in international conferences and, indirectly, by participating in training opportunities organized under the auspices of IGCP and UNESCO programs. Two outstanding examples are noted here.

First, the China Environmental Health Project, with funding from multiple sources including the US Agency for International Development along with China's Ministry of Land and Resources and Ministry of Technology, has a karst-related capacity-building component that has established laboratories for Geographic Information Systems and underground water tracing in China. This project alone has provided training for more than 1,500 Chinese scientists, students, local and provincial government officials, and members of the public.



Oxygen isotope changes of stalagmite D3 and D4 from Libo, Guizhou Province, China, and comparison with summer insolation at 25°N.
© Yuan Daoxian

A tremendous outgrowth from the long history of the IGCP karst projects is the International Research Center on Karst (IRCK). This was established following an agreement between the Government of the People's Republic of China and UNESCO in December 2008. Situated in Guilin, the IRCK is the first Category II Centre for the geosciences to be established; and, under the auspices of UNESCO and within the IGCP framework, it is the only international centre for interdisciplinary research on karst in the UN system. The aims of the IRCK are to improve understanding of karst systems on a global scale, to keep the fragile karst environment ecologically sound, and to promote sustainable socio-economic development in karst regions as one of the world's most fragile environmental systems. The IRCK will advance karst dynamics through scientific research, publications and international cooperation; it will promote international communication and provide a platform for the exchange of scientific information about karst dynamics and sustainable utilization of karst resources as well as eco-environmental protection; and, finally, it will provide advisory activities, technical information, education and training as a basis for development and implementation of novel integrated methods of rehabilitation of rocky desertification and ecological restoration of karst regions.

A major emphasis of the Center, in addition to pure and applied scientific research to improve understanding of karst resources, is placed on the provision of international karst training courses. Successful courses were implemented in 2009 and 2010 with numerous students attending from around the world, primarily from countries with karst resources that included Brazil, India, Indonesia, Peru and Uganda. A continuing annual series of such courses is planned for the foreseeable future.

Karstic surface, Burren and Cliffs of Moher Geopark, Ireland. © Ronan Hennessy

Looking Ahead

The future continues to look bright for karst research; much has been learned but questions remain. UNESCO and IUGS partnerships will continue to serve as a leading platform for international communication in karst science, both by way of IGCP 598: Environmental Change and Sustainability in Karst Systems (2011-2015) and the International Research Center on Karst (IRCK). While the countries that have most strongly supported the IGCP karst projects (including China, Slovenia, Spain, and the USA) and continue to do so, interest continues to grow. IGCP 513, which ended in 2010, attracted active participation from 44 countries, and IGCP 598 has co-leaders from Asia, Europe, and North America and, for the first time, the southern hemisphere (Brazil). IGCP 598 has also been awarded supplementary support from the Swedish International Development Agency (SIDA) in recognition of its training courses.

The IRCK also continues to grow as it meets 21st century challenges with excellent facilities at the Institute of Karst Geology in Guilin. Principal financial support comes from the Chinese government so that Chinese administrative leadership comes together with international scientific leadership; present members of the academic committee of the IRCK represent 13 countries. Current plans envisage a rise in the staff of the IRCK to 60 by 2020.

We and our successors expect to be able to report additional successes at IGCP's 50th and perhaps even its 75th anniversary celebrations!

Chris Groves, *Hoffman Environmental Research Institute, Western Kentucky University, USA;*
Yuan Daoxian *and* ***Zhang Cheng****, International Research Center on Karst under the Auspices of UNESCO, China and Institute of Karst Geology, Chinese Academy of Geological Sciences, China*

Earth Resources: Sustaining our Society

The sustainable use of earth resources, including minerals,hydrocarbons, rare earth elements, geothermal energy, air and water, is vital for the future well-being of society. Environmentally responsible exploitation of these resources is a challenge for geoscience research; advances in technological development are equally bound by this premise.

Salt mine, Petralia Soprana, Madonie Geopark, Italy.

IGCP 357: Organics and Mineral Deposits (1993-1997)

View of Muruntau, Uzbekistan, the world's largest open-cast gold mine, 3 by 2 km and 330 m deep.

Almost every area of human activity, including agriculture, construction, manufacturing, transportation, electronics, art and science, depends on minerals and, therefore, mineral extraction. Precious metals (gold, silver and the platinum-group elements) and other metals such as copper, lead, zinc, tin and uranium fundamentally underpin the quality of life enjoyed in a world with increasingly high technology, as well as advancing the future development of global human society. In order to identify sufficient sources of such industrial metals, it is important to understand how they were formed. It has been known for a long time that organic matter is often associated with a range of metal accumulations. In setting up a dedicated correlation study in 1993, IGCP 357 brought together a group of about 200 geoscientists representing the following 31 countries: Argentina, Australia, Bulgaria, Canada, Cuba, China, Czech Republic, Ecuador, Estonia, Finland, France, Germany, Guinea, Hungary, India, Italy, Japan, Kazakhstan, Mongolia, Nigeria, Pakistan, Poland, Romania, Russian Federation, Slovakia, South Africa, Spain, Switzerland, Tunisia, UK and the USA. The prime aim of this initiative was to improve our understanding of the different roles played by organic matter in the origin of various ore deposits and so facilitate more effective exploration and extraction of metals so vital to modern human society. The work of IGCP 357 has shown that organic matter can act as an important control of the precipitation of metals and also as an important agent in the transport of metals to the sites of deposition. We have also shown that organic matter-rich metasedimentary rocks (black shale) can often serve as a source of metals for various ore deposits. Examples of some organically-hosted metals, including many in everyday use, are described below.

Precious metal deposits (gold, silver and platinoids)

Historically, precious metals have commanded much higher prices than common industrial metals because they were important as currency, but are now regarded mainly as investment and industrial commodities.

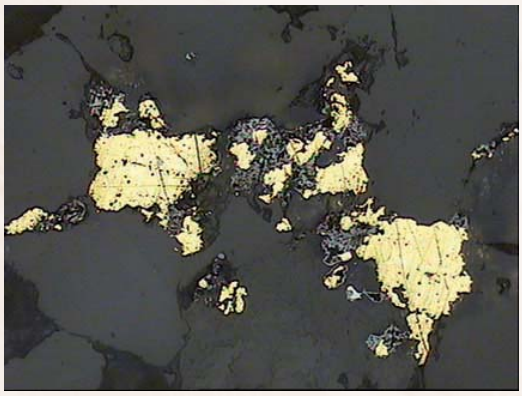
It should be noted that 65% of the total gold reserves of the former USSR is bound to gold deposits hosted by metasediments rich in organic matter. One of the world's largest gold deposits (the Muruntau deposit with over 100 million ounces of gold) is located in the Kyzyl Kum desert in Uzbekistan. Work by Russian scientists within IGCP 357 showed that, besides granite intrusion, rocks rich in organic matter acted as an important source of the metal, a result that will help to direct more effective exploration for similar types of giant gold deposits in other parts of the world.

A major discovery of a new source of precious metals in the south-western part of the Kupferschiefer-type copper deposit in Poland was made by Polish and German scientists in IGCP 357. They were able to show that this mineralization formed because of the key role played by organic matter reduction, which facilitated precipitation of gold and platinoids (metals associated with platinum) from metal-bearing fluids. This discovery will make possible more effective exploration for similar types of gold-platinum-palladium ores in other parts of the world.

Copper deposits

Copper is widely used in numerous everyday activities. Approximately 65% of the copper produced is used for electrical applications. For example, copper has a key role to play in energy efficiency; the judicious use of 1 tonne of copper in the energy sector makes it possible to reduce CO_2 emissions by an average of 200 tonnes per year. One quarter of all the copper extracted from the Earth is used in buildings, while use in transportation accounts for about 7%. The remaining 3% is used for coins, sculptures, musical instruments and cookware.

Substantial results from strata-bound (ore laid down in specific rock layers) copper deposits, a major source of the metal, arose from work by IGCP 357 on one of the world's major copper sources in Chile and also in southern North America. This work demonstrated that the involvement of organic matter is probably a critical component in the formation of economic deposits of this type, providing a valuable new tool for future prospecting.



New type of precious metal mineralization associated with sediment-hosted copper ores discovered in Poland (yellow grains of gold with grey iron oxide-hematite). Photo by kind permission of A. Piestrzynski. © Jan Pašava

IGCP 357 research on sediment-hosted copper deposits in Poland, which belong to one of the world's leading copper sources, showed the importance of organic matter in metal accumulation, as well as helping to improve genetic modelling work and enhancing exploration activities.

Lead-zinc sulphide deposits

People have used zinc-bearing mineral compounds for more than 2,500 years. Almost 50% of the world's current zinc is used in the construction, automotive and white goods industries, where its primary use is as a protective galvanized coating on steel and iron. Approximately 70% of the world's lead is used in the manufacture of batteries, predominantly for the automotive industry.

One of the most important industrial sources of zinc and lead are carbonate-hosted Mississippi Valley Type deposits (MVT), in which bitumen and petroleum liquids are known to occur. No single genetic model existed for this category of deposits until a critical assessment of the role of organic matter in the formation of MVT deposits was carried out by IGCP 357. Project scientists from the USA and the UK succeeded in developing a new model for the origin of these deposits in which organic matter is the key to the location of metal accumulations (transport of metals by way of organic complexes and various oxidation-reduction reactions). These results will greatly assist future exploration of similar type zinc-lead resources.

Tin Deposits

The most important engineering use of tin is in alloys. Tin is also used as an anti-corrosion coating on other metals. Some tin organic compounds have several applications as fungicides and insecticides in agriculture. Other tin compounds are used in high technology equipment.

A joint Czech-Chinese-Canadian study within the IGCP 357 study of tin deposits in the Dachang tin field, the biggest Chinese tin producer, showed that organic matter played a key role in the determination of the ore-forming capacity of the magmatic system; this is important for further exploration of similar types of tin sources worldwide

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Uranium deposits

Uranium is a radioactive element; its main use is the generation of nuclear power, but an important issue arising from such use of the metal is the safe disposal of high-level and long-living radioactive waste. Significant progress on this issue was achieved in a cooperative study within IGCP 357 that involved Canada, France, Gabon, the UK and the USA, based on natural fission reactors rich in solid bitumen in Oklo, Gabon. It was found that the organic matter in the uranium ore played a key role in the immobilization and accumulation of radionuclides. This constraint serves to promote a crucial analogue for the engineered long-term containment of anthropogenic nuclear waste.

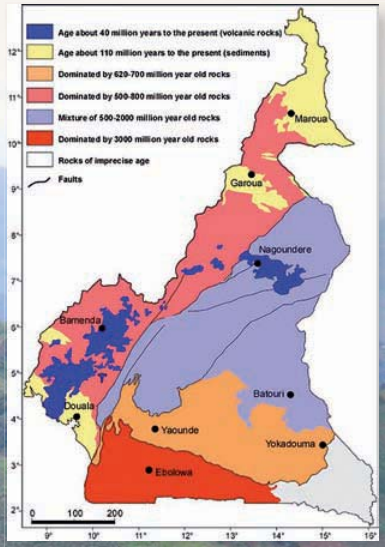
***Jan Pašava**, Czech Geological Survey, Czech Republic*

Calcite with sulfur crystals, Rocca di Cerere Geopark, Italy.
© Gino Fabio

IGCP 470: The Neoproterozoic Pan-African Belt of Central Africa (2002-2006)

A typical landscape in the highlands of the Cameroon Volcanic Line. Here, in the Dschang region of Cameroon, the struggle to sustain agriculture is clearly evident.

Geological map of Cameroon.
© S. Felix Toteu



In recent years, the geoscience sector in Africa has benefited from important international investment to meet a significant global increase in demand for mineral and energy resources. As a consequence, many African countries have now launched new national geological mapping programmes.

From a geological perspective, one of the most enigmatic regions of the continent is central Africa, which includes Cameroon, the Central African Republic (CAR), Chad, Congo, the Democratic Republic of Congo (DRC), Equatorial Guinea and Gabon, although some progress has been made in the latter two countries, probably because of their currently high level of oil and mineral exploration.

IGCP 470 was the first IGCP project to be implemented in this region. At the time of IGCP 470's launch in 2002, geoscience research in Central Africa was facing many difficulties including limited modern data, outdated geological maps of the colonial era or by-products of mineral prospecting projects of the 1980s, and unequal distribution of surveys, as well as a lack of inter-project communication, particularly across international boundaries. As a consequence, trans-border correlations, which would have benefited from regional treatment, were difficult to establish.

The objectives of IGCP 470 were to address these shortcomings. The project focused on the Precambrian rocks, i.e. those older than 570 million years, because they underlie the greater part of the region and host most of the mineral resources. Geologically, the region comprises two

major units. These are the northern edge of the Congo craton (a large portion of continental plate that has been relatively undisturbed for 2,000 million years or more), which cover most of southern Cameroon, Gabon and Equatorial Guinea; and the Pan-African belt which, as part of a network of collisional belts surrounding the major African cratons, covers central and northern Cameroon, Chad and the CAR. These belts formed as a result of convergence about 600 million years ago to form Western Gondwana, an ancient southern 'supercontinent' that split primarily into what we recognize today as Africa and South America.

During its activities, the project established a network of cooperation with researchers in Africa, Europe, and North and South America. Annual field workshops were organised in the concerned countries in central Africa, and new data were obtained in various laboratories of the network. For the first time in decades, foreign geoscientists had the opportunity to carry out fieldwork in the CAR and Chad. The University of Kinshasa also hosted its first geological meeting since the independence of the DRC in1960.

IGCP 470 also achieved the important objective of breaking down the isolation facing many researchers in the region. Besides field excursions, during which young scientists were provided with opportunities to learn from more experienced colleagues, the careers of many have been boosted and five of them have since completed doctoral degrees thanks to cooperative research between universities and research institutions in the region and their counterparts in Europe. The most active institutions were the Universities of Yaoundé (Cameroon); N'Djaména (Chad); Bangui (CAR); Kinshasa (DRC); Kiel (Germany); Orleans and Toulouse (France); Kansas (USA); the Institute for Geological and Mining Research (Cameroon); the CRPG-CNRS Nancy (France); the Geological Survey of Denmark and Greenland; the Bureau de Recherches Géologiques et Minières (France); and the Royal Museum of Central Africa (Belgium). Through these institutions, the development of an important regional database now provides us with a better understanding of the geological architecture of the region. Furthermore, a new trans-boundary geological and ore deposit map has been published for the central African region; the colonial era map of Cameroon has been updated and the chronology of the evolution of the Precambrian basement rocks has been more accurately defined (see map). Such age differentiation assists the interpretation of the geology and thus helps to guide mineral exploration. The outputs from IGCP 470 have also contributed to current international geological mapping projects. The new data gathered were crucial to finalising the central African part of the 2nd edition of the Tectonic Map of Africa published in 2011. In 2008, Cameroon was among the first African countries to contribute to the OneGeology initiative, which aims to make a single trans-national geological world map accessible online.

The project completed its activities at the end of 2006 but, like the aftershocks of a major earthquake, its influence is still being felt. IGCP 470 has continued to be active through publication of project results. The project also gave new impetus to cooperative efforts that have been inactive for many years, such as those between the Royal Museum of Central Africa and the University of Kinshasa; new regional-scale studies such as the collaborative project between the Universities of Ngaoundéré (Cameroon), N'Djaména (Chad) and Orleans (France), sponsored by the Agence Universitaire de la Francophonie (2006-2008);

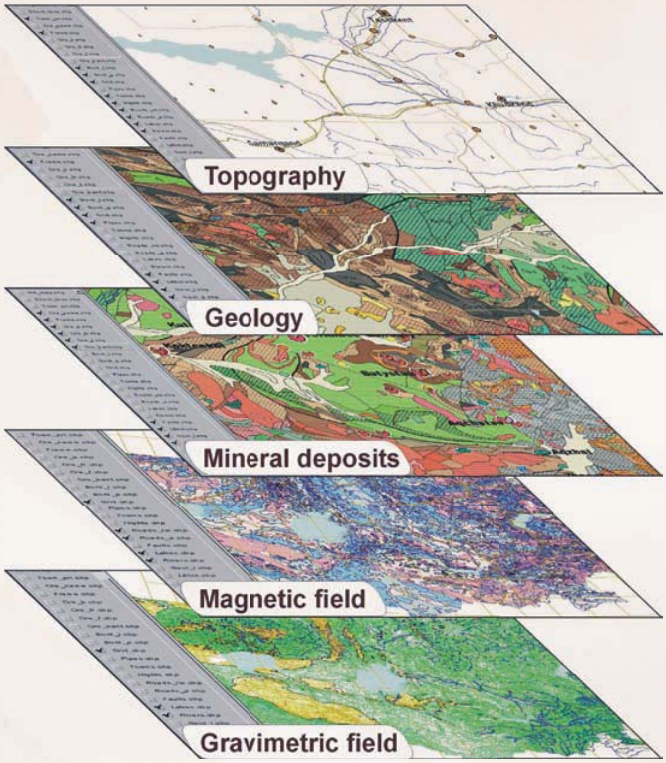
Field research involves much long-distance travel, as shown here during an IGCP field excursion in the Democratic Republic of Congo. The low hills in the distance are made of resilient rock (quartzite), which serves as a mapping reference for the region. © S. Felix Toteu

and the involvement in 2009 of the IGCP 470 project leader in the African Alive Corridors initiative at the African Earth Observatory Network (AEON) of the University of Cape Town (South Africa).

Experience gained from implementing IGCP in Africa shows that the success of a project largely relies on the motivation of a small number of participants forming the core of the project and on the political, logistical and financial support from institutions in the region, starting with the home institution of the project leader. This support, even if modest, is important for the visibility of both the institutions and the IGCP. This experience has also revealed some of the important points that need to be addressed if the IGCP is to be promoted successfully in Africa. They include the revitalisation or creation of IGCP National Committees (thus far, only 35% of African countries possess such a committee, whether or not they are active). National Committees provide a key to improving the involvement of Africans in the IGCP in a situation in which only 7% of IGCP global science projects have been devoted to Africa, with only 7% of project leaders being Africans. However, there are signs of hope; the African geoscience community through the Geological Society of Africa is engaged in promoting awareness of the IGCP and its benefits and directing these to African Earth science leaders and institutions. The Swedish International Development Agency (SIDA) is currently funding a four-year programme to boost the development of the IGCP in Africa through training workshops and direct support for individual projects.

***S. Felix Toteu**, Earth Sciences Unit, UNESCO Nairobi Office, Kenya*

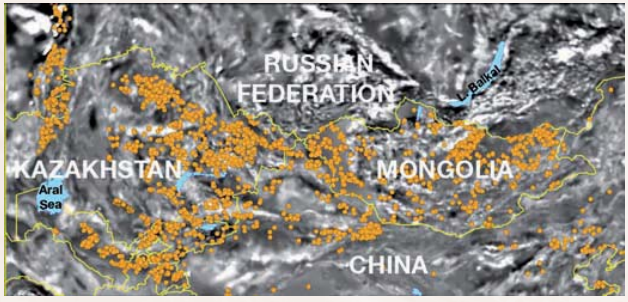
IGCP 473: GIS Metallogeny of Central Asia (2002-2007)



Scheme showing composition of traditional GIS with thematic map layers. © Reimar Seltmann

Central Asia is one of the world's richest mineral provinces and is considered to be one of the commodity baskets of the future where vast resources in hydrocarbons, strategic metals and raw materials are still undeveloped and even underexplored.

The IGCP 473 project developed out of its precursor IGCP 373 project "Ore-bearing granites of Eurasia" (1997-2002) and benefited largely from an existing research infrastructure with an established international network (about 300 scientists from 30 countries, organised in 20 core teams), coordinated by the Centre for Russian and Central EurAsian Mineral Studies (CERCAMS) hosted by the Natural History Museum, London (UK). The project was initially prepared as a pilot proposal for a Young Scientist Project before developing into a full IGCP project. The research aimed to develop available expertise in the region, to utilise modern techniques of Geographic Information Systems (GIS), and to bridge the gap between superseded knowledge and assessments regarded as incompatible with international standards. Project funding from the involved international mining industry was exceptionally high (close to 1 million USD over the six-year project term); such a funding level was essential if the ambitious goal of building a publicly-available mineral deposits database of the region and linking it to thematic geoscientific maps was to be achieved. The project research led to a



Distribution of gold deposits and occurrences (golden dots) of central Asia from Kazakhstan through China to Mongolia overlain on "Magnetic Anomaly Map of the World" (UNESCO, CGMW 2007) © Reimar Seltmann

Tian-Shan field trip (People's Republic of China), 2007. © Stéphane Dominguez

View of the open pit of the Kounrad porphyry copper deposit Kazakistan. © London Natural History Museum – Robin Armstrong

better understanding of the formation controls of mineral deposits, and of catalysed prospecting and sustainable exploitation of mineral resources in Central Asia.

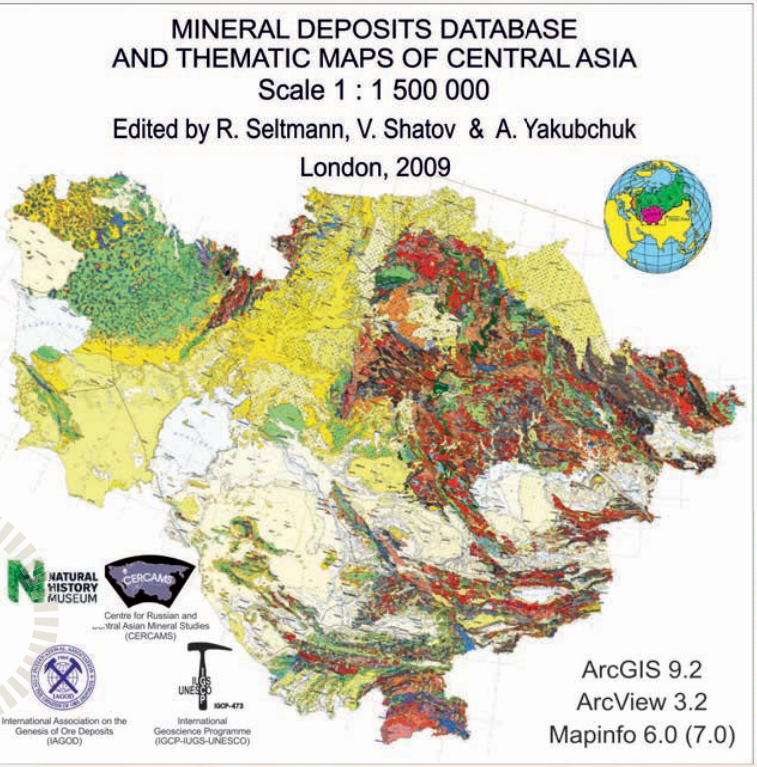
The research framework benefited from successful negotiation concerning the involvement of Central Asian partners, including access to unpublished local and Russian language reports, maps and data sets. Governmental institutional support was secured from Kazakhstan, Kyrgyzstan and Uzbekistan, as well as the Russian Federation, Mongolia and China, to cover the involved countries' research contribution and their assistance in sharing labour and travelling expenses. During the pilot stage of the research, the *New geological base map of Central Asia* was completed (scale 1:1,500,000, ArcView GIS format) in partnership with the Commission for the Geologic Map of the World and UNESCO, and geophysical and topographical layers were added. The GIS database was built and distributed to the project teams for recurrent updating. Research on mineral potential, prospective metallogenic belts and on unconventional deposit types has led to the identification of key problems focused on case studies throughout the project's term. The study integrated available and new data in order to combine the geotectonic units of Central Asia and its mineral inventory. Such an approach allows comparison of the metallogenic evolution and a background of continental crustal growth during mountain-building processes, and aims to develop a unified metallogenic–geodynamic model of Central Asia. Selected mineral deposit sites were studied by local partners jointly with foreign visitors in the field, using modern laboratory methods.

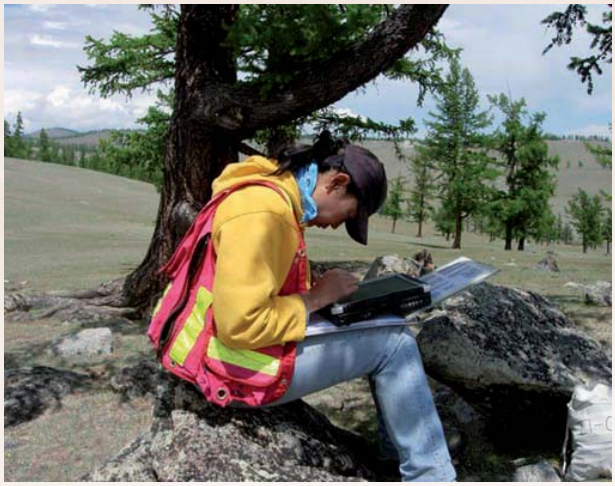
In order to obtain data on the geochemistry of ores, mineralized rocks, wall-rock alteration and country rocks for each deposit type suitable case study objects were

selected (including Muruntau, Kumtor, Verkhnee Kairakty, Jubilejnoe, Kalmakyr, Kounrad and Dzhezkazgan). The case studies aimed to develop genetic models of the major mineral deposits and were published in international peer-reviewed journals (see www.nhm.ac.uk/cercams). Interdisciplinary research included the classification and data-basing with processing of about 1,800 deposits within the hosting terrains according to their age, deposits type, and metallogenic framework. Complex research and correlation was carried out by complementary teams with technical-methodological skills in GIS techniques and geodynamic-metallogenic expertise. This resulted in the compilation of a set of GIS-based geological, geodynamic and metallogenic maps of Central Asia, at a scale 1:1,500,000, aimed at assessing the mineral potential of the study area.

Based on the initial ArcView pilot version, the basic components of a more professional ArcInfo/ArcMap GIS package on the Mineral Deposits of Central Asia had been assembled and, as the main research outcome, the completed package was released upon project completion

CD cover of the project's key product acquired by more than 40 mining companies and research institutions for mineral assessment and academic studies. © Reimar Seltmann





Mongolian post-doctoral student during field documentation training.
© London Natural History Museum – Robin Armstrong

in 2007, together with an annual update and upgrade service. A data model was developed by the project team, and a template of the database was re-structured and passed on for further input to local experts. Thematic map layers were digitized and linked to the deposits database. For the first time in that region, a topographical layer was linked to a newly developed geological map for which the project holds copyright, and was further combined with mineral deposits, gravity and magnetic layers. This constituted a prerequisite to the carrying out *of technical queries* (formulating questions to utilise the GIS platform) and the feasibility of spatial analysis, both tools characterizing modern GIS as requested by 'end-users'. Assessment and processing of satellite imagery was also undertaken. The project leader obtained official approval from the Chinese, Kazakh, Kyrgyz, Mongolian, Russian, Uzbekistan and Tajik authorities to involve national experts in the project research. Additional cooperation was achieved with Chinese, Mongolian and Russian teams who have also proposed to extend the GIS metallogeny study to their neighbouring regions in Central Asia.

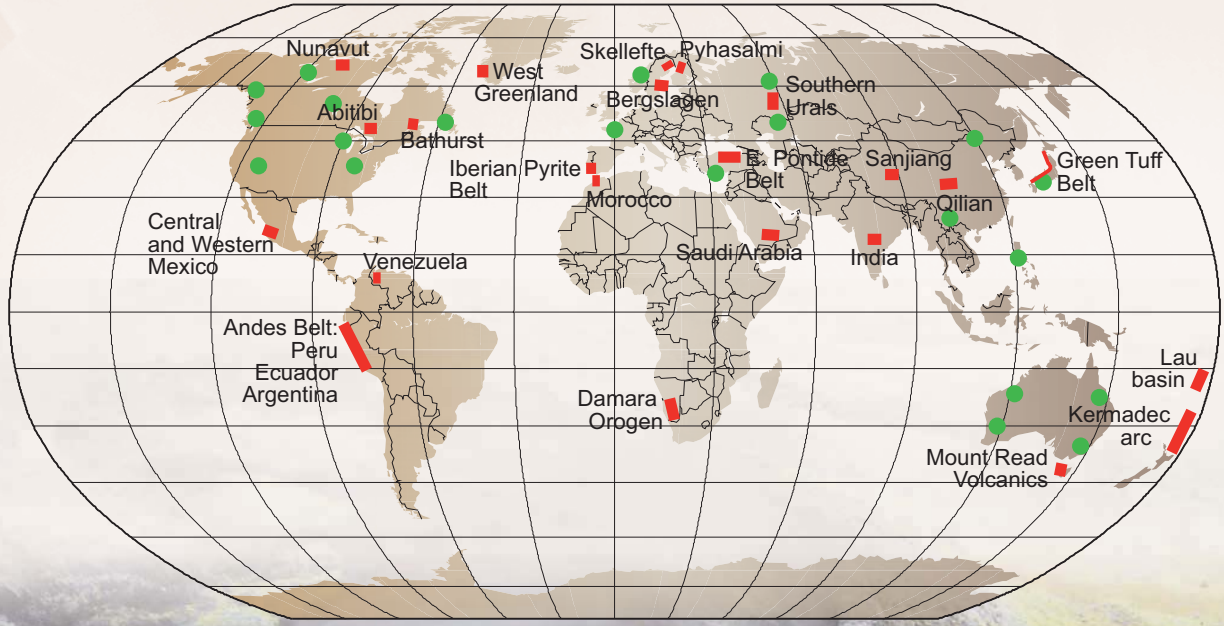
In addition to the Central Asia GIS platform as the main project deliverable, and now available on CD-ROM in ArcGIS format including MS Access database linked to thematic layered vector maps, the case studies have produced, within their five-year term, more than 200 publications (including 50 original papers in peer-reviewed journals, annual reference guidebooks and peer-reviewed monographs). From 2002 to 2007 more than 100 expert and training visits from the study region took place in European research facilities, half of which were focused on postgraduates and postdoctoral fellows. The research network contributed to development, training and knowledge exchange, mainly through the CERCAMS host programme. This included grant-in-aid support for education and laboratory training fellowships for young scientists (50% being female) from less-developed countries and knowledge transfer by way of joint project cooperation. These provided hard- and software to facilitate the research project by using a joint platform, developing e-learning modules, training in GIS techniques at the Natural History Museum in London and the All-Russian Geological Research Institute (VSEGEI) in St Petersburg, as well as short courses and expert excursions in mineral deposit types, predictive exploration models and alteration studies.

IGCP 473 contributed to the *International Year of Planet Earth (IYPE)* and worked jointly with the International Association on the Genesis of Ore Deposits (IAGOD); the Society for Geology Applied to Mineral Deposits (SGA); the Society of Economic Geologists (SEG); other IGCP projects (486, 502); the IUGS-UNESCO Mineral Resource Sustainability Programme (MRSP, the former Deposit Modelling Program - DMP); and the International Association on Volcanology and Chemistry of the Earth's Interior (IAVCEI). These efforts culminated in the compilation of a DVD entitled "Promoting responsible mineral resource management on planet Earth".

***Reimar Seltmann**, Centre for Russian and Central EurAsian Mineral Studies, Natural History Museum, Mineralogy Department, UK*

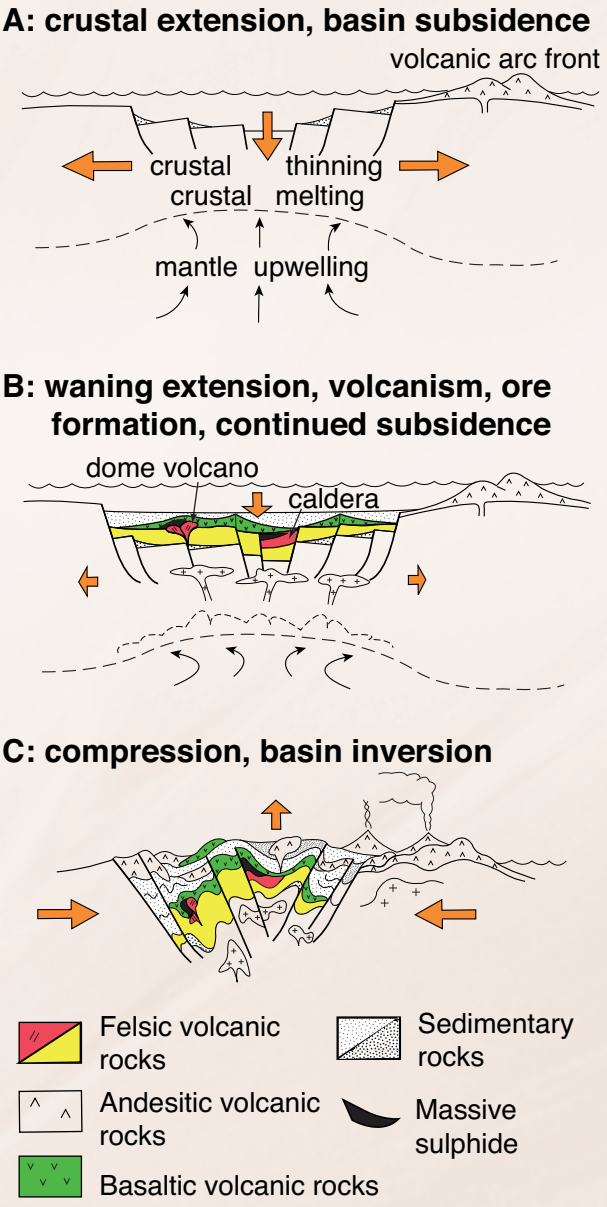
Field mapping.
© Marble Arch Caves Geopark

IGCP 502: Global Comparison of Volcanic-Hosted Massive Sulphide (VMS) Districts (2004-2009)



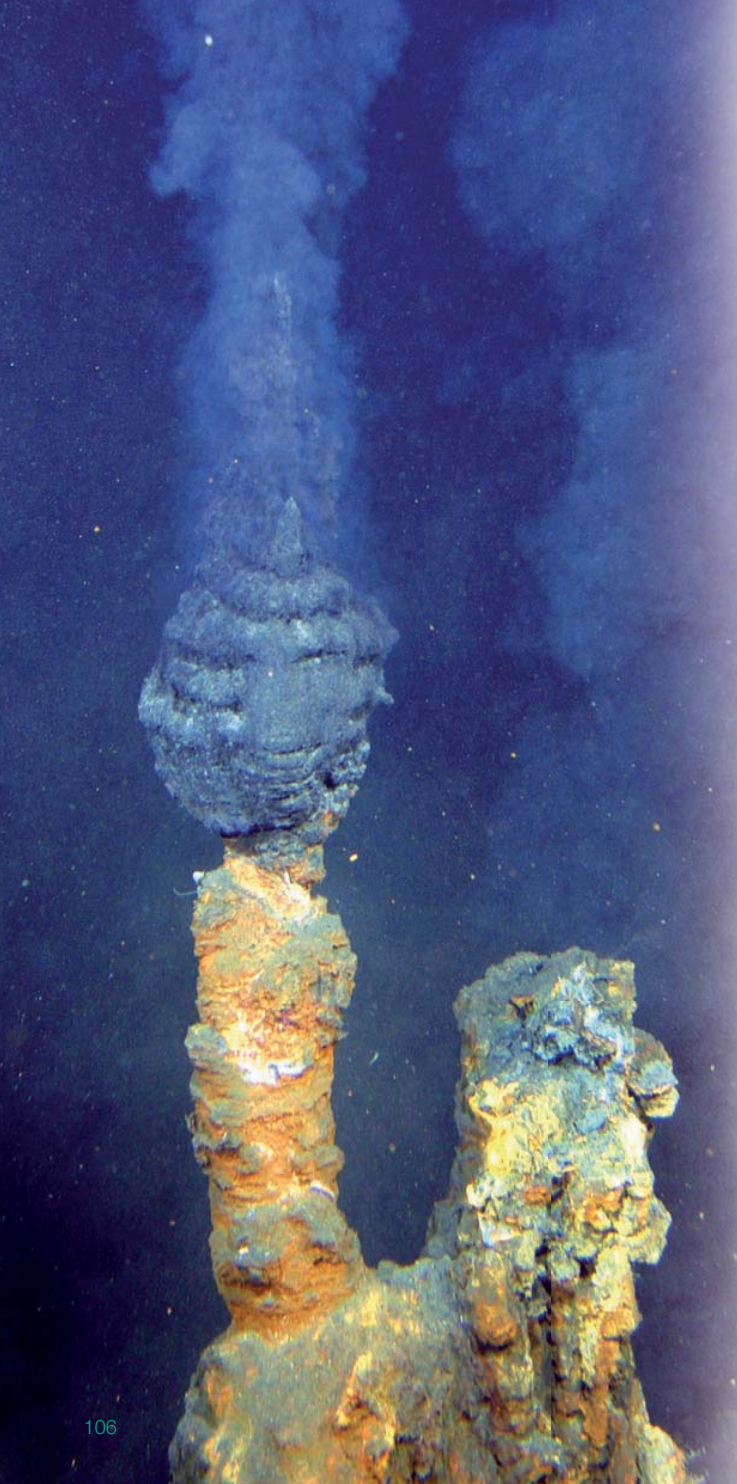
Volcanic-hosted massive sulphide (VMS) deposits are accumulations of metal sulphide minerals that precipitated at, or just below, the sea floor in association with volcanism. The ore deposits occur in clusters referred to as mining camps or districts, and are located in marine basin successions that formed as a consequence of extension of the crust adjacent to the Earth's plate margins. The ore deposits occur in strata from several billion years old to those of recent age and are also actively forming at present-day hydrothermal vent sites (black smokers) on the modern sea floor. They are typically disc-shaped bodies, 10-50m thick and 100-1,000m in diameter. The average metal content of a VMS deposit is one million tons of massive sulphide ore, but very large deposits may contain 300 million tonnes of ore. The deposits occur in many countries and are one of the world's most important sources of zinc, copper, lead, silver and gold.

The goal of IGCP project 502, which became known as the "Global VMS project", was to create an international network of scientists interested in VMS deposits and together make a major step forward in understanding where, when and how VMS deposits form during the evolution of extensional plate margin terranes. Our hypothesis and strategy was that, in order to make this step forward, it is essential to compare and contrast the geology of the world's major VMS districts so that the critical common features can be distinguished from the myriad of other less important features. Apart from creating databases of the geology of each VMS district, our strategy was to run field workshops in as many of the world's major VMS districts as possible, which would enable members of the IGCP 502 network to compare the various VMS districts, and also promote the transfer of ideas, results and new technology between scientists and research



The evolution cycle of many VMS districts. © Rodney Allen

New Zealand volcano © Sarah Gaines



groups in the best possible environment, both on site in the field and in the laboratory. This knowledge could then be used to improve exploration for these ore deposits and lead to new mining operations in both developing nations and established mining regions.

The scientific network was built steadily throughout the duration of the project. We engaged researchers, PhD students and also scientists involved in mineral exploration and mining, including scientists from well established research institutions and mining regions, as well as scientists from developing nations. By the final year of the project, a network of 221 geoscientists from 43 nations had been created. A regional co-ordinator was selected for each of about 20 VMS districts and a local scientific team of 5-20 scientists interested in VMS deposits was identified and engaged for each mining district. These local teams were encouraged to propose, plan and organize a one to two-week field workshop in their country and VMS district, with help from the IGCP project leaders. During the course of the project, field workshops were held in 11 of the world's major VMS mining regions: Skellefte, Sweden; Iberian Pyrite Belt, Spain and Portugal; East Pontide Belt, Turkey; Bathurst, Canada; Damara orogen, South Africa and Namibia; NE Honshu Arc, Japan; Central Ural Mountains, Russian Federation; Caledonian belt, UK and Ireland; Bergslagen, Sweden; Rudny Altai, Kazakhstan and Russian Federation; and the Hercynian fold belt, Morocco. For many participants, these field workshops

Hydrothermal vents (black smokers) forming a massive sulphide deposit on the sea floor at Brothers Volcano, Kermadec Arc (photograph courtesy of GNS Science, New Zealand). © Cornel de Ronde

Workshop participants study drill cores with mining geologists at the Hajjar mine, Morocco, 2009. © Rodney Allen

were the highlight of the IGCP project. The workshops brought together local scientists, mining industry staff, students and experts from many countries and were the breeding ground for many new ideas, enhanced scientific collaboration and personal friendships. Project participants also benefited greatly from experiencing the different social cultures of the diverse group of nations in which the workshops were held. Most of these workshops were held directly following an international conference in which IGCP project 502 organized a scientific session on VMS ore deposits, or following our own project symposiums.

In total, the project organized 29 scientific meetings, workshops and short courses in the five-year duration of the project. Funding from UNESCO and IUGS was used to support four to six PhD students and scientists from developing nations to attend each field workshop and meeting. Additional funding was attracted from national organizations, universities and mining industry sources, and was used for research costs and running the field workshops and meetings.

IGCP project 502 produced a number of scientific publications, culminating in 2011 with the publication of a thematic issue of the Mineralium Deposita Journal on key issues and controversies in the geological setting and genesis of VMS deposits. Less obvious, but probably even more important, outcomes include new collaboration and increased interaction between scientists interested in VMS ore deposits in developing and developed nations, and the experience that students and scientists from developing nations have gained from visiting some of the world's famous mining regions. The ultimate benefit is to society in those nations where an increased knowledge of VMS ore deposits and increased expertise in exploration for the deposits will result in new mining operations that create wealth, employment and higher living standards.

***Rodney Allen**, Lulea University of Technology, Sweden and Boliden Mineral, Sweden; **Fernando Tornos**, Instituto Geológico y Minero de España, Spain; **Jan Peter**, Geological Survey of Canada, Canada; **Namik Çagatay**, Istanbul Technical University, Turkey*

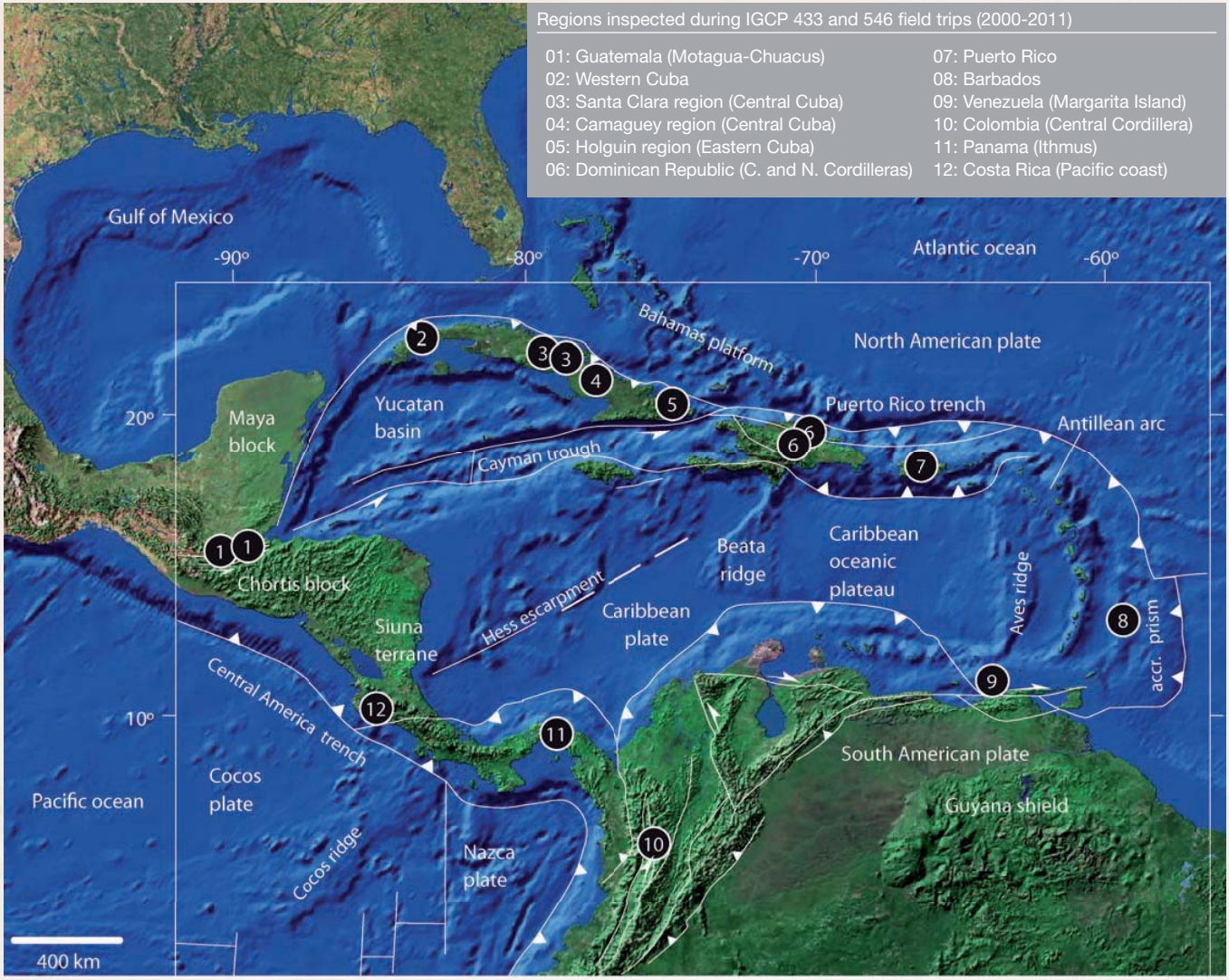
Potential beneficiaries of new metal mines in Morocco.

Deep Earth: how it Controls our Environment

Our habitable environment at the Earth's surface is linked and controlled by processes occurring deep within the Earth. Earth scientists use, among others, geophysical techniques to study deep Earth processes, ranging from changes in the Earth's magnetic field to plate tectonics, to better understand the Earth as a dynamic planet. Those processes are also relevant to natural resource exploration, distribution and management of groundwater resources and the study and mitigation of natural hazards such as earthquakes.

Tanzanian beach. © Sarah Gaines

IGCP 433: Caribbean Plate Tectonics (2000-2004) and IGCP 546: Subduction Zones of the Caribbean (2007-2011)



IGCP 433 and 546 field excursion locations (2000-2011).
© Antonio Garcia-Casco

From 2000 to 2005 and from 2007 to 2011 two successive IGCP projects were undertaken in order to encourage and support geological investigations in the Caribbean region. After this decade of multidisciplinary research, the knowledge obtained by these projects represents a step forward for scientific and academic development in the region, for prospecting natural resources of the territory and, especially, in providing society with a more accurate framework for geohazard prevention.

The two projects organized some 30 meetings and field workshops in Barbados, Brazil, Colombia, Costa Rica, Cuba, Dominican Republic, Germany, Guatemala, Italy, Panama, Spain, UK, USA and Venezuela. Participants of these projects included researchers and students from Argentina, Australia, Austria, Barbados, Brazil, Canada, Chile, China, Colombia, Costa Rica, Cuba, Dominican Republic, France, Germany, Guatemala, Hungary, Italy, Jamaica, Japan, Mexico, Netherlands, New Zealand, Nicaragua, Panama, Peru, Poland, Puerto Rico, Spain, Switzerland, Trinidad and Tobago, UK, USA and Venezuela. The project results are available at www.ig.utexas.edu/CaribPlate/CaribPlate.html and www.ugr.es/~agcasco/igcp546/.

From 2000 to 2005 and from 2007 to 2011 two successive IGCP projects were undertaken in order to encourage and support geological investigations in the Caribbean region.

The primary goal of the projects was to generate discussion and pursue a consensus approach to plate tectonic models of the origin and evolution of the Caribbean plate. Major progress was made in terms of clarifying and refining models and in understanding critical details of regional and local geology, natural resources and potentially catastrophic geological events. While some scientists continue to favour the hypothesis that the Caribbean plate originated in-situ (i.e. in the inter-Americas gap created during the Jurassic break-up of the Permian-Triassic supercontinent known as Pangea) others - probably a majority of scientists - consider that it formed in the Pacific and drifted towards the east relative to the Americas from the mid-Cretaceous onwards (ca.120 million years ago) until it reached its present position between North and South America. This drift was possible because an ocean basin (the Proto-Caribbean or American Tethys, occupying the inter-Americas gap formed during the break-up of Pangea) was consumed by the subduction process. This drift continues today, as indicated by Global Positioning System (GPS) measurements and active geological processes such as volcanism of the Lesser Antilles arc and intense earthquakes like the catastrophic events of 1976 in Guatemala (magnitude 7.5, 23,000 fatalities) and 2010 in Haiti (magnitude 7.0, 316,000 fatalities).

Both projects contributed a long list of scientific publications including two special volumes dedicated to the Caribbean, published in the journal Geologica Acta. In these volumes and other papers published by project members, authors have compiled current views on the origin and evolution of the Caribbean and adjacent regions. The questions and answers presented in these papers at the beginning of the 21st century provide a useful forum to guide and encourage further research.

Another essential achievement was the creation of a platform for geoscientists and students interested in diverse aspects of Caribbean Earth systems to communicate and interact as a community. Teaching local researchers and students the tools for the analysis of rock complexes and geological risk was a key aspect of both projects. For example, courses were taught in the Universidad de San Carlos de Guatemala, in Granada University, Spain, in the Escuela de Cuadros del Ministerio de la Industria Básica in Havana, in Stanford University, USA and in the Universidad Pedagógica y Tecnológica de Colombia.

Participants of the 2010 Panama field excursion crossing a river to gain access to sampling sites.

Additional products include field-excursion guides containing valuable basic geological information, photographs, maps and cross-sections of key areas of the Caribbean and adjacent regions. These field guides have been made available to the scientific and non-specialized community in the web sites of both projects.

Fieldguides were produced for – Western Cuba; Santa Clara region; Central Cuba; Camaguey region, Central Cuba; Dominican Republic Central Cordillera; Dominican Republic Median Belt and northern Cordillera; Guatemalan Motagua valley and Chuacus regions; Panama Isthmus, Venezuelan Margarita Island; and the Colombian Central Cordillera.

The scientific achievements of IGCP projects 433 and 546 represent a significant advance in the understanding of the complex geological history of the Caribbean and, especially, of the geological processes that took place in the past and shaped the present and future evolution of the territory. Such research has encouraged new local and regional investigations that extend beyond Caribbean tectonics into more fundamental questions of plate tectonics, natural resources and geohazard prevention.

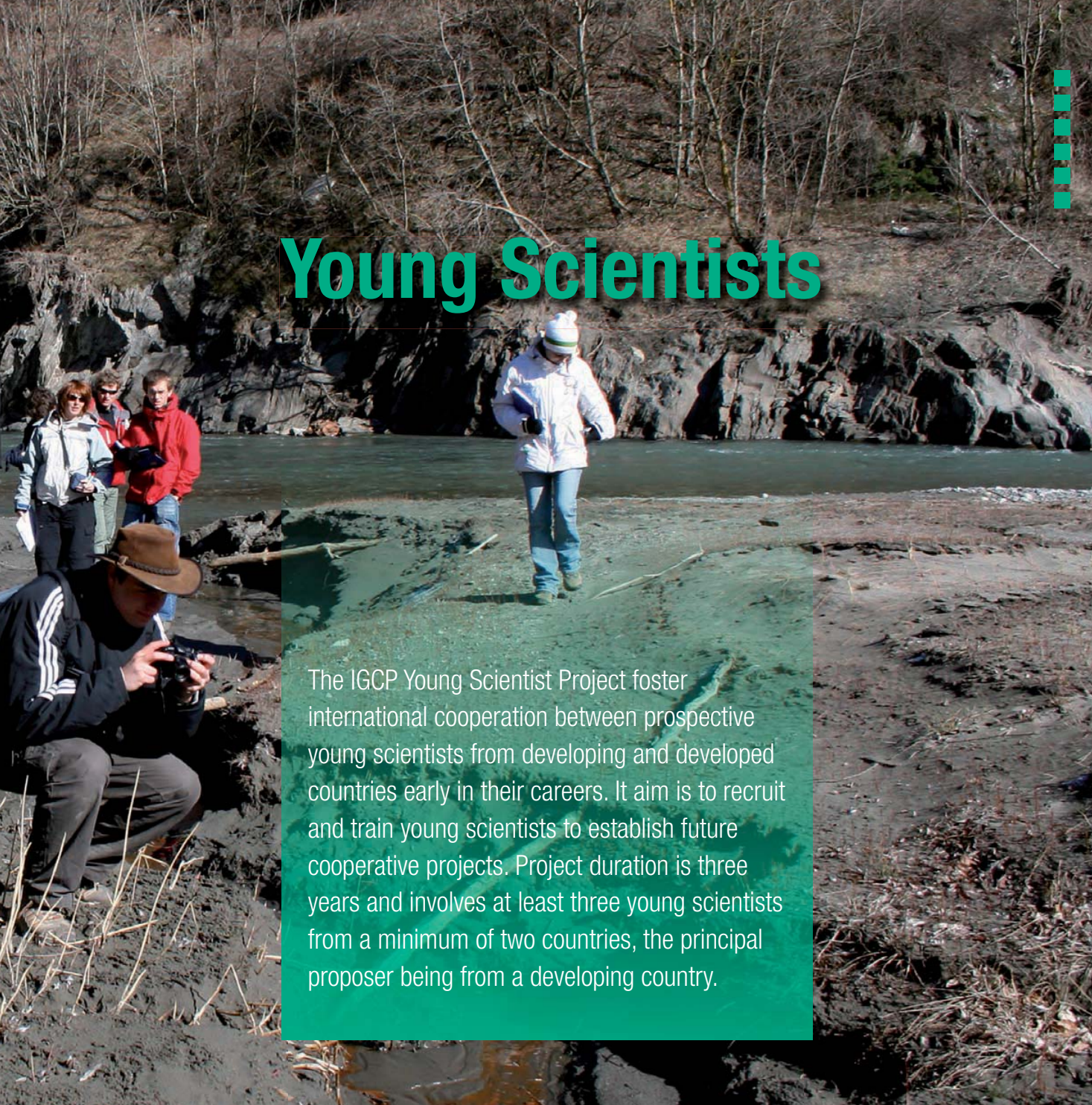
***Manuel A. Iturralde-Vinent**, Museo Nacional de Historia Natural, Cuba; **Antonio García-Casco**, Departamento de Mineralogía y Petrología, Universidad de Granada, Spain and Instituto Andaluz de Ciencias de la Tierra, CSIC-Universidad de Granada, Spain; **Uwe Martens**, Tectonic Analysis Ltd., Walnut Creek CA, USA; **Edward G. Lidiak**, Department of Geology and Planetary Science, University of Pittsburgh, USA*

Cape Cod beach cobbles, USA.
© Sarah Gaines

Students of the Escuela Centroamericana de Geologia, Costa Rica, in the field excursion “High-pressure belts of Central Guatemala: The Motagua Suture and the Chuacús Complex”, Guatemala (2007). © Antonio Garcia-Casco

Learning how present sediments form to understand past conditions of sedimentation.
© Aloé Schlagenhauf

Young Scientists



The IGCP Young Scientist Project foster international cooperation between prospective young scientists from developing and developed countries early in their careers. It aim is to recruit and train young scientists to establish future cooperative projects. Project duration is three years and involves at least three young scientists from a minimum of two countries, the principal proposer being from a developing country.

IGCP 586Y: Geodynamic Processes in the Andes 32° to 34°S – Interplay between Short-term and Long-term Processes (2010-2012)

This Young Scientist Project is a multinational, multi-disciplinary and regional-scale research effort, which brings together young researchers from developing and developed countries. It also serves to stimulate interaction and research ties between different scientific institutions in the Americas and Europe. The participating institutions are the University of Chile, Chile; Argentinean Institute of Snow, Glaciology and Environmental Research, Argentina; University of Comahue, Argentina; International Center of Earthquake Research Montessus de Ballore, Chile; Syracuse University, USA; Institut de Recherche pour le Developpement and Toulouse University, France.

The project evaluates the interplay between the mechanisms that build the Andes, and those that sculpt its landscape. Convergent continental margins and subduction zones are first-order features of Earth's plate tectonics. The stresses generated at these boundaries drive internal deformation of the lithosphere, resulting in topographic uplift, and a concomitant surface process response that is intimately related and often governed by feedback mechanisms. The complex interactions of deformation and surface processes in the Andean subduction-related orogen (a belt of deformed rocks) represent the principal focus of our research project.

Climbing Aconcagua Mountain (Camp 2) during the IGCP 586Y summer field season along the 32°40′S transect in 2010.
© Laura Giambiagi

Although the period of time over which the Andean range formed is tightly constrained, this is not the case with respect to the magnitudes and rates that govern how the Andes grew. The multidisciplinary research of IGCP 586Y aims to investigate the interplay between tectonics (in what way and how rapidly did the Cordillera form) and surface processes (mass movements, fluvial erosion and weathering) from the Miocene (about 23 million years ago) to the present as a means of improving our understanding of evolution of the Andes of Chile and Argentina in the zone between 32° and 34°S. Specifically, it aims to improve our understanding of the mutual relationship between endogenic (inside the Earth) and exogenic (at or near the Earth's surface) mechanisms in mountain building, topographic evolution, basin development, and mega-landslide occurrences across this segment of the Andean orogen.

Our research integrates the geodynamic processes affecting this sector of the Andes using a multi-faceted approach involving incorporation of field and analytical studies of structural geology, geomorphology, geophysics, geotechnics, geochronology, basin analysis, petrology, seismology, mineralogy and isotopic analysis. This will improve our understanding of how the Andes are being constructed and how they are evolving as a dynamic system. Additionally, seismological data will provide insights about the present-day state of rock structures, and their probable link with landslides will be geotechnically analyzed.

The specific goals include understanding of the interactions between tectonics, erosion, sedimentation and climate in the southern Central Andes and their feedback mechanisms; understanding geomorphic-tectonic evolution of the southern Central Andes during the Pliocene-Quaternary (the last 5.3 million years); illuminating the relationship between the spatial-temporal distribution of landslides and neotectonic activity; and addressing both seismic and landslide hazards in the region.

The Andes constitute a spectacular field laboratory of modern mountain building and an ideal place to study the relationship between tectonic and geomorphic processes, and the Andean range provides a unique opportunity to study the dynamics of a mountain belt and the interaction of geodynamics and surface processes.

This project draws upon the results and experience of several actively funded or pending projects to create an integrated view of Andean geodynamics between 32º and 34°S latitude. In addition, the close relationships between active deformation and uplift, associated crustal growth, seismic activity and a great climatic transition that controls erosional processes make this subduction orogenic belt an important natural laboratory where the influence of climate and tectonics in mountain building can be studied.

Fundamental to the project is the integration of disparate yet related studies, requiring contact and dialogue among the group members both in the field and around the table.

Studies of this nature are unusual in the Andes, but a joint effort by Argentinean, Chilean, French and US geoscientists is just beginning, and the preliminary results of this initiative already point to the importance of this collaborative work.

Aconcagua peak 32°40´S transect 2010.

The IGCP 586Y team working along the Río Blanco transect.
© Laura Giambiagi

Vertical beds resulting from tectonic deformation in the Cajón del Maipo area, Chile, along the 33°40´S transect. © Laura Giambiagi

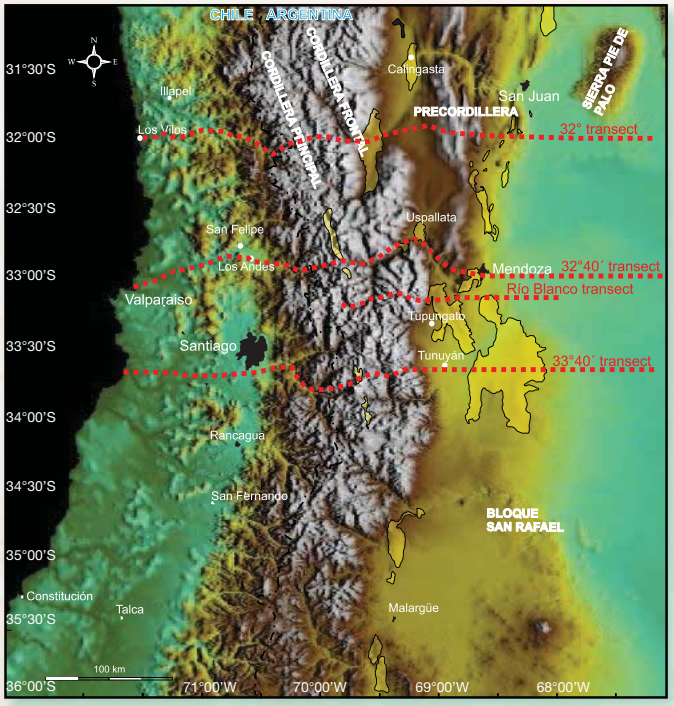
View of the mega-landslide close to the town of Las Cuevas, Argentina, near the Argentinean-Chilean border, along the 32°40′S transect.
© Laura Giambiagi

In order to fulfil this project we are focusing on four transects across the Andean orogen:

- At 32°S along the Blanco and Patos rivers (Argentina)
- At 32º40´S along the valleys of the Aconcagua (Chile) and Mendoza rivers (Argentina)
- At 33ºS along the Rio Blanco River (Cordón del Plata, Argentina)
- At 33º40´S along the valleys of the Maipo (Chile) and Tunuyán rivers (Argentina)

Along these transects, different and integrated studies have been completed and others are in progress, including structural geology and tectonic geomorphology; geomorphology and Quaternary stratigraphy; landslide analysis; petrography and provenance analysis; and seismicity analysis. On each transect the result of several studies will be integrated and discussed.

Several of the expected results relate to the scientific aspects of the project but one related directly to benefits to society is the detection of places susceptible to geohazards. A direct impact of this project will provide both governments and society with the basic knowledge of geohazards that will help them to make informed and optimally constrained decisions.



© Laura Giambiagi

__Luisa Pinto__, Departamento de Geología, Universidad de Chile, Chile; __Laura Giambiagi__, IANIGLA CCT Mendoza, Argentina; __Maisa Tunik__, Departamento de Geologia y Petróleo, Universidad Nacional del Comahue, Argentina; __Sergio Sepúlveda__, Departamento de Geología, Universidad de Chile, Chile; __Stella Maris Moreiras__, IANIGLA CCT Mendoza, Argentina; __Marcelo Farías__, Departamento de Geología, Universidad de Chile, Chile; __Greg Hoke__, Department of Earth Sciences, Syracuse University, USA

Ordovician fossil trilobites and school carnival parade with children dressed as trilobites. © Arouca Geopark Association

Annex

Scientific Index of IGCP Projects

List of IGCP Projects – 1974 to 2011 (335 Projects out of 606 proposals)

No.
Title
Project Leader(s)
Duration

1 **Accuracy in Time**
C.W. Drooger (Netherlands)
1974-1979

2 **Correlation of the Precambrian in Mobile Zones**
G. Choubert, A. Faure-Muret, (France)
1974-1980, O.E.T. (1 year prolongation without funding)

3 **Ore Deposists Separated by Continental Drift**
W.E. Petrascheck and F. Hermann, (Austria)
1974-1978

4 **Upper Triassic of the Tethys Realm**
H. Zapfe (Austria)
1974-1982, O.E.T.

5 **Correlation of Prevariscan and Variscan Events of the Alpine-Mediterranean Mountain Belt**
H.Flugel (Austria) and F. Sassi (Italy), C. Spassov (Bulgaria)
1976-1986, O.E.T. 1987-1988

6 **Correlation of Diagnostic Features in Ore Occurrences of Base Metals in Dolomites and Limestones**
L. Kostelka (Austria)
1974-1979

7 **South West Pacific Basement Correlation**
R.A. Cooper and G.W. Grindley (New Zealand)
1974-1978

8 **Mesozoic Chronostratigraphy, New Zealand-New Caledonia**
J.A. Grant Mackie (New Zealand)
1974-1979

22 **Precambrian in Younger Fold Belts**
V. Zoubek (former Czechoslovakia)
1974-1980, O.E.T.

23 **Genesis of Kaolins**
M. Kuzvart (former Czechoslovakia)
1974-1980

24 **Quaternary Glaciations in the Northern Hemisphere**
V. Šibrava (former Czechoslovakia)
1974-1983

25 **Stratigraphic Correlation of the Tethys-Paratethys Neogene**
J. Seneš (former Czechoslovakia)
1974-1983

26 **Mineralization Associated with Acid Magmatism**
M. Štemprok (former Czechoslovakia)
1974-1980

27 **The Caledonide Orogen**
B.A. Sturt (Norway)
1974-1985

28 **Terminalogía Geocientífica en América Latina: ALEGEO**
C. Petzall (Venezuela)
1974-1980

29 **Precambrian-Cambrian Boundary**
J.W. Cowie (UK)
1974-1984, O.E.T. 1985-87

30 **Circum Pacific Plutonism**
P.C. Bateman (USA)
1974-1981

32 **Stratigraphic correlations between sedimentary basins in the ESCAP region: Mineral Resources Section**
ESCAP (Thailand)
1974-1982, O.E.T.

38 **Pre-Pleistocene Tillites**
W.B. Harland, (UK)
1974-1978

39 **Ophiolites**
N.A. Bogdanov, (former USSR)
1974-1980

41 **Neogene-Quaternary Boundary**
K.V. Nikiforova (former USSR)
1974-1984

42 **Upper Palaeozoic of South America**
A.C. Rocha-Campos (Brazil)
1974-1982

44 **Lower Palaeozoic of South America**
J.C.M. Turner (Argentina)
1976-1982

53 **Ecostratigraphy**
A.J. Boucot (USA)
1974-1984, O.E.T. 1985-1986

58 **Mid-Cretaceous Events**
R.A. Reyment (Sweden)
1974-1982, O.E.T.1983-1985

60 **Caledonian Stratabound Sulphides**
F.M. Vokes (Norway)
1974-1983, O.E.T.1984-1985

61 **Holocene Sea-level Changes**
A.L. Bloom (USA)
1974-1982, O.E.T.

86 **Eastern European Platform (S.W. Border)**
K.B. Jubitz (former German Democratic Republic)
1974-1985

91 **Metallogeny of the Precambrian**
A.V. Sidorenko (former USSR)
1974-1985

92 **Archaean Geochemistry**
A.M. Goodwin (Canada)
1974-1983

96 Messinian Correlation
M.B. Cita (Italy)
1975-1979

98 Standards for Computer Applications in Resource Studies
A.L. Clark (USA)
1975-1980

99 Geochronological Correlation of Precambrian Sequences in Stable Zones
M. Bonhomme (France)
1975-1979

100 International Tectonic Lexicon
F. Delany (France)
1975

105 Continental Margins in the Alps
D. Bernoulli (Switzerland)
1975-1980

106 Permo-Triassic Stage of Geological Evolution
D.L. Stepanov, (former USSR)
1975-1985

107 Global Correlation Epochs of Tectogenesis
V.E. Khain (former USSR)
1975-1980

108/144 Precambrian of West Africa and its correlation with Eastern Brazil
Y. Yacé, (Côte d'Ivoire)
1975-1983, O.E.T. 1984-1985

110 Evolution of the South West Pacific Plate Boundaries
G.H. Packham (Australia)
1975-1980

111 Genesis of Manganese Ore Deposits
G. Grasselly (Hungary)
1975-1985

114 Biostratigraphic Datum-Planes of the Pacific Neogene
N. Ikebe (Japan)
1976-1982

115 Siliceous Deposits in the Pacific Region
J.R. Hein (USA)
1975-1981

116 Circum-Pacific Turbidites
H. Okada (Japan)
1976

117 Geological Events at the Mio-Pliocene Boundary
J. Aubouin, J.J. Bizon, J.P. Rampnoux and J. Sigal (France)
1976-1986

118/99 Upper Precambrian Correlations
R. Trompette (France)
1975-1980

120 Magmatic Evolution of the Andes
U. Cordani (Brazil) ; E. Linares (Argentina)
1975-1985

124 North-West European Tertiary Basin
H. Tobien (Germany)
1975-1982

126 Optimum Estimation of Reserves
M. David (USA)
1976

127 Revision of the "Continental terminal" Concept in Africa
F. Tessier (France)
1975-1980

128 Late Cenozoic Magnetostratigraphy
G. Kukla (USA)
1976-1982, O.E.T.

129 Lateritization Processes
Geological Survey of India
1975-1983

132 Basins of iron formation deposition
A.F. Trendall (Australia)
1975-1980

133/89 Geochronology of Mesozoic and Cenozoic Deposits of Europe
Calibration of stratigraphic methods
G.S. Odin (France), I. Wendt (Germany)
1975-1979/1978

142 Palaeomagnetic Studies in the Permo-Triassic of the "Gondwana" Continent
IGCP National Committee, Madagascar
1976

143 Remote Sensing and Mineral Exploration
W.D. Carter and L.C. Rowan (USA)
1976-1982

144 Precambrian of West Africa (accepted for merger with N° 108)
P. Tapsoba (Burkina Faso)
1976

145 West African Biostratigraphy and its Correlations
O.S. Adegoke, I. De Klasz (Nigeria), and M. Moullade (France)
1976-1981

146 River Food and lake-level Changes
R. Paepe and L. de Meyer (Belgium)
1976-1984

148 Quantative Stratigraphic Correlation Techniques
J. M. Cubitt, J.C. Brower and J.E. Robinson (USA)
1976-1983, O.E.T. 1984-1986

154 Global Exchange and Processing of Information in Geochemistry
H. de la Roche, J.M. Stussi and Ph. Grandclaude (France)
1977-1983

156 Phosphorites of the Proterozoic-Cambrian
P.J. Cook and J.H. Shergold (Australia)
1977-1988

157 Early Organic Evolution and Mineral and Energy Resources
P.A. Trudinger, M.R.Walter and D.M. Mckirdy (Australia)
1977-1988

158 Palaeohydrology of the Temperate Zone
L. Starkel (Poland) and B. Berglund (Sweden)
1977-1988

160 Precambrian Exogenic Processes
J. Veizer (Canada)
1977-1986

161 Sulfide Deposits in Mafic and Ultramafic Rocks
A.J. Naldrett (Canada)
1977-1987

163 Design and Generation of a World Data Base for Igneous Petrology
F. Chayes (USA)
1977-1984

164 Pan-African Crustal Evolution
A. Al-Shanti (Saudi Arabia)
1978-1984

165 Regional Stratigraphic Correlation of the Caribbean
J.L. Yparraguirre (Cuba)
1983-1989; O.E.T. 1990

166 Correlation of Coal-bearing Formations
P.P. Timofeev (former USSR)
1978-1987

169 Geotectonic Evolution and Metallogeny in the Eastern Mediterranean and Western Asia
S. Jankovic (former Yugoslavia) and W.E. Petrascheck (Austria)
1979-1984, O.E.T. 1985

171 Circum-Pacific Jurassic
G.E.G. Westermann (Canada)
1981-1985, O.E.T. 1986-1987

174 Geological Events at the Eocene-Oligocene Boundary
Ch. Pomerol (France)
1980-1985

175 Chronostratigraphic Precision
N.F. Hughes (UK)
1981-1983 , O.E.T. 1984-1985

179 Stratigraphic methods as applied to the Proterozoic record
J. Fabre, J. Sarfati, N. Clauer (France) and G.M. Young
1981-1986

183 West, African Mesozoic and Cenozoic Correlation
M. Moullade (France), O.S. Adegoke (Nigeria), B. Peybernes (France)
1981-1985, O.E.T. 1986-1987

184 Palaeohydrology of Low Latitude Deserts
C.R. Lawrence (Australia)
1981-1985

185 Peri-Aegean Blue Schists
I. Godfriaux (Belgium)
1981-1985

187 Sliceous Deposits
J.R. Hein (USA)
1982-1986

191 Cretaceous Palaeoclimatology
E.J. Barron (USA)
1982-1986

192 Cambro-Ordovician Development in Latin America
B. Baldis and G. Aceñolaza (Argentina)
1982-1986

193 Siluro-Devonian of Latin America
M.A. Hünicken (Argentina)
1982-1986

195 Ophiolites and Lithosphere of Marginal Seas
L. Beccaluva (Italy) and N. Bogdanov (former USSR)
1982-1986

196 Calibration of the Phanaerozoic Time Scale
G.S. Odin and N.H. Gale (France)
1983-1983

197 Metallogeny of Ophiolites
S. Karamata (former Yugoslavia)
1982-1986; O.E.T. 1987-1988

198 Evolution of the Northern Margin of the Tethys
M. Rakús (former Czechoslovakia)
1983-1988

199 Rare Events in Geology
K.J. Hsü (Switzerland)
1983-1988

200 Sea-level Correlation and Applications
P.A. Pirazzoli (France)
1983-1987

201 Quaternary of South America
H.H. Camacho (Argentina)
1983-1987

202 Megafaults of South America
F. Hervé (Chile)
1983-1986, O.E.T. 1987

203 Permo-Triassic Events of Eastern Tethys Region and their Intercontinental Correlation
Z.Y. Yang (China)
1983-1987

204 Precambrian Evolution of the Amazonian Region
W. Teixeira and C.C.G. Tassinari (Brazil)
1983-1987

206 Comparison of Active Faults
R.C. Buckman (USA), G.Y. Ding and Y.M. Zhang , and Y.M. Zhang (China)
1983-1988

210 Continental Sediments in Africa
C.A. Kogbe, (France) E. Klitzsch (Germany) and J. Lang (France)
1983-1987 O.E.T. 1988

211 Late Palaeozoic of South America
A.J. Amos and S. Archangelsky (Argentina)
1984-1988; O.E.T. 1990

215 Proterozoic Fold Belts
R. Caby (France)
1984-1989; O.E.T. 1990

216 Global Biological Events in Earth History
O.H. Walliser (Germany)
1984-1991

217 Proterozoic Geochemistry
K.C. Condie (USA)
1984-1990

218 Quaternary Processes and Events in South-East Asia
N. Thiramongkol (Thailand), B.K. Tan (Malaysia) and H.M.S. Hartono (Indonesia)
1984-1988

219 Comparative Lacustrine Sedimentology through Space and Time
K. Kelts (Switzerland)
1984-1990

220 Correlation and Resource Evaluation of Tin and Tungsten Granites in South-East Asia and the Western Pacific Region
S. Suensilpong (Thailand) and T. Nozawa (Japan)
1984-1988

224 **Pre-Jurassic Evolution of Eastern Asia**
K. Ichikawa (Japan)
1985-1990

226 **Correlation of Manganese Sedimentation to Palaeoenvironments**
B. Bolton (Australia), S. Roy (India)
1986-1990, O.E.T. in 1991

227 **Magmatism and Evolution of Extensional Regions of the African plate**
A.B. Kampunzu (former Zaire) and R.T. Lubala (France)
1985-1989; O.E.T. 1990

233 **Terranes in the Circum-Atlantic Palaeozoic Orogens**
J.D. Keppie (Canada) and R.D. Dallmeyer (USA)
1985-1990, O.E.T. in 1991

234 **Precambrian Volcano-Sedimentary Complexes in West Africa**
I. Yace (Cote d'Ivoire), M.A. Rahaman (Nigeria)
1989-1994

235 **Metamorphism and Geodynamics**
L.L. Perchuk (former USSR) and M. Brown (UK)
1985-1989; O.E.T. 1990

236 **Precambrian Events in the Gondwana Fragments**
D.J. Ellis (Australia)
1986-1990, O.E.T. in 1991

237 **Floras of the Gondwanic Continents**
O. Rösler (Brazil)
1985-1990, O.E.T. in 1991

239 **Exploitation of IGBADAT**
F. Chayes (USA)
1985-1989

242 **Cretaceous of Latin America**
W. Volkheimer, J.A. Salfity (Argentina)
1986-1990

245 **Non-Marine Cretaceous Correlation**
N.J. Mateer (USA), Chen Pei-ji (China)
1986-1991

246 **Pacific Neogene Events in Time and Space**
R. Tsuchi (Japan)
1985-1991, O.E.T. 1992

247 **Precambrian Ore Deposits related to Tectonic Styles**
G. Gaál (Finland), Zhang Yixia (China)
1986-1991, O.E.T. 1992

249 **Andean Magmatism and its Tectonic Settings**
M.A. Parada (Chile), C. Rapela (Argentina)
1986-1990, O.E.T. 1991

250 **Regional Crustal Stability and Geological Hazards**
Chen Qingxuan (China)
1986-1987; O.E.T. 1990

252 **The Past and Future Evolution of Deserts**
N. Petit-Maire (France)
1987-1991

253 **Termination of the Pleistocene**
J. Lundgvist (Sweden)
1989-1994

254 **Metalliferous Black Shales**
J. Pašava (Czech Republic)
1987-1991, O.E.T. in 1992

255 **Kibaran Metallogeny**
W. Pohl (Germany), A. Ntungicimpaye (Burundi), D.P.M. Hadoto (Uganda)
1987-1991

256 **Ophiolite Genesis and Evolution of Oceanic Lithosphere**
N. Bogdanov (former USSR), L. Beccaluva (Italy)
1988-1992

257 **Precambrian Dyke Swarms**
H.C. Halls (Canada)
1987-1991

259 **International Geochemical Mapping**
A.G. Darnley (Canada)
1988-1992

260 **Earth Glacial Record**
M. Deynoux (France)
1987-1991

261 **Stromatolites**
S. Awramik (USA)
1987-1991, O.E.T. 1992

262 **Tethyan Cretaceous Correlation**
G. Császár (Hungary), H. Kollmann (Austria)
1987-1991, O.E.T. 1992

264 **Remote Sensing Spectral Properties**
G.L. Raines, M.H. Podwisocki (USA)
1987-1991

267 **Palaeozoic Terranes in the Circum-Pacific Orogens**
M.J. Rickard (Australia), Guo Lingzhai (China)
1989-1993

269 **A Global Data Base in Sedimentary Petrology**
N. Nishiwaki-Nakajima (Japan)
1988-1992

270 **Early Palaeozoic Events in Latin America**
F.G. Aceñolaza, O.L. Bordonaro (Argentina)
1988-1992

271 **South American Palaeozoic Conodontology**
M.A. Hünicken (Argentina), M. Suarez Riglos (Bolivia)
1988-1992, O.E.T. 1993

272 **Late Palaeozoic and Early Mesozoic Circum-Pacific Events**
J.M. Dickins (Australia), Yang Zunyi (P.R. of China)
1988-1992

273 **Achaean Cratonic Rocks of Kasaï**
B.T. Rumyegeri, D. Kapenda (former Zaire)
1988-1992, O.E.T. 1993

274 **Coastal Evolution in the Quaternary**
O. Van de Plassche (Netherlands)
1988-1992, O.E.T. 1993

275 **Deep Geology of the Baltic Shield**
R. Gorbatschev (Sweden), F.P. Mitrofanov (former USSR)
1989-1993

276 **Palaeozoic of the Tethys**
D. Papanikolaou (Greece), P. Sassi (Italy), A.K. Sinha (India) from 1991
1988-1992, O.E.T. 1993-1994

277 Phanerozoic Oolitic Ironstones
J. Petránek (former Czechoslovakia)
1988-1992

279 Terranes in Latin America
G.F. Toussaint (Colombia), F. Herve (Chile)
1988-1992, O.E.T. 1993

280 The Oldest Rocks on Earth
A. Kröner (Germany)
1988-1992, O.E.T. 1993

281 Quaternary Climates of South America
J. Argollo Bautista (Bolivia)
1989-1993

282 Rare Metal Granitoids
Zhu Jinchu (China), P.J. Pollard (Australia)
1989-1993

283 Evolution of the Palaeoasian Ocean
Xiao Xuchang (China), N.L. Dobretsov (former USSR), R.G. Coleman (USA)
1989-1993

285 Metamorphism in Eastern Asia
Cheng Yuqi, Dong Shenbao (China)
Provisionally for 1990

286 Early Palaeogene Benthos
L. Hottinger (Switzerland), E. Caus (Spain)
1990-1994

287 Tethyan Bauxites
A. Dangić (former Yugoslavia), A. Mindszenty (Hungary), L. Simone (Italy)
1989-1993, O.E.T. in 1994

288 Gondwanaland Sutures and Fold Belts
R. Unrug (USA), G.R. Sadowski (Brazil)
1990-1995, O.E.T. in 1996

290 Anorthosites and Related Rocks
M. Higgins (Canada), J.-C. Duchesne (Belgium)
1990-1994

291 Metamorphic Fluids and Mineral Deposits
W. Frank, W. Prochaska (Austria)
1989-1993

293 Geochemmical Event Markers in the Phanerozoic
H.H.J. Geldsetzer (Canada), Xu Dao-Yi (China)
1990-1993

294 Very Low Grade Metamorphism
R.E. Bevins, D. Robinson (UK)
1989-1993

296 Quaternary in the Asia/Pacific Region
J.L. Rau (Thailand), V. Šibrava (Czech Republic)
1989-1993

297 Geocryology of the Americas
A.E. Corte (Argentina), Cui Zhijiu (China)
1989-1993

299 Geology, Climate, Hydrology and Karst Formation
Yuan Daoxian (China), H. Hotzl (Germany), J.W. Hess (USA)
1990-1994

301 Palaeogene of South America
N. Malumián (Argentina), S. Benitez (Ecuador)
1991-1995, O.E.T. in 1996

302 The Structure and Metallogenesis of Central African Late Proterozoic Belts
M. Wendorff (Botswana), W.M. Katekesha (former Zaire)
1990-1994

303 Precambrian/Cambrian Event Stratigraphy
M. Brasier (UK), K.J. Hsü (Switzerland)
1990-1993

304 Lower Crustal Processes
B.J. Hensen (Australia), L.Ya. Aranovich (Russian Federation)
1990-1994

306 Stratigraphic Correlation in South-East Asia
Dang Vu Khuc (Vietnam), H. Fontaine (France)
1992-1995, O.E.T. in 1996

308 Palaeocene/Eocene Boundary Events
M.-P. Aubry (France)
1990-1994, O.E.T. in 1995

314 Alkaline and Carbonatitic Magmatism
L. Kogarko (Russian Federation), J. Keller (Germany), K. Bell (Canada)
1991-1995

315 Rapakivi Granites and Related Rocks
I. Haapala (Finland), R.F. Emslie (Canada)
1991-1995, O.E.T. in 1996

317 Palaeoweathering Records and Palaeosurfaces
M. Thiry, J.-M. Schmitt (France)
1991-1995, O.E.T. in 1996

318 Marine Polymetallic Oxides
J.R. Hein (USA), Dasgupta (India)
1991-1995

319 Global Palaeogeography of the Late Precambrian and Early Palaeozoic
K.B. Seslavinsky (Russian Federation), T.P. Crimes (UK)
1992-1996, O.E.T. in 1997

320 Neoproterozoic Events and Resources
N. Christie-Blick (USA), M. Semikhatov (Russian Federation)
1991-1996

321 Gondwana Dispersion and Asian Accretion
Ren Jishun (China), J. Charvet (France), S. Hada (Japan), I. Metcalfe (Australia)
1991-1995, O.E.T. in 1996

322 Jurassic Events in South America
A.C. Riccardi (Argentina), J. Mojica (Colombia)
1992-1996, O.E.T. in 1997

324 GLOPALS: Global Limnogeology
L. Cabrera, P. Anadon (Spain)
1991-1995

325 Palaeogeography and Authigenic Minerals
J. Lucas, L. Prévôt (France)
1991-1995

326 Oligocene-Miocene Transition in the Northern Hemisphere
M.A. Akhmetiev (Russian Federation), S. Lucas (USA), F. Steininger (Austria)
1992-1996

328 Palaeozoic Microvertebrates
S. Turner (Australia), A. Blieck (France)
1991-1995, O.E.T. in 1996

329 Neogene of the Paratethys
N. Krstić (former Yugoslavia), F. Marinescu

(Romania)
1992-1996, O.E.T. in 1997

335 **Biotic Recovery from Mass Extinctions**
D.H. Ervin, E.G. Kauffman (USA)
1993-1997

336 **Intraplate Magmatism and Metallogeny**
M.L. Zientek (USA)
1992-1996

339 **Geomagnetic Equator**
Nguyen Thi Kim Thoa (Viet Nam)
1992-1995

341 **Southern Hemisphere Palaeo- and Neoclimates**
W. Volkheimer (Argentina), P.P. Smolka (Germany)
1993-1997, O.E.T. in 1998

342 **Age and Isotopes of South American Ores**
M. Zentilli (Canada), C. Dtassinari (Brazil), F. Munizaga (Chile)
1992-1996, O.E.T. in 1997

343 **Stratigraphic Analysis of Peritethyan Basins**
J. Cavalier (France), E. Dudich (Hungary)
1992-1996

344 **Biosedimentology and Correlation Microbial Buildups**
J. Cavalier (France), E. Dudich (Hungary)
1992-1996

345 **Andean Lithospheric Evolution**
M.C. Gardeweg (Chile), R. Pankhurst (UK), C. Rapela (Argentina)
1993-1997

346 **Neogeodynamica Baltica**
R.G. Garetsky, E.A. Levkov (Belarus), G. Schwab (Germany)
1994-1997, O.E.T. in 1998

347 **Correlation of Ganges-Brahmaputra Sediments**
Md. Hussain Monsur (Bangladesh)
1995-1999, O.E.T. in 2000

348 **The Mozambique and Related Belts**
S. Muhongo (Tanzania), S. Berhe (USA)
1993-1997

349 **Desert Margins and Palaeomonsoons since 135 kys BP**
A.K. Singhvi (India), An Zhisheng (China), E. Derbyshire (UK)
1993-1997

350 **Cretaceous Environmental Change in E & S Asia**
H. Okada (Japan)
1993-1997, O.E.T. in 1998

351 **Early Palaeozoic Evolution in NW Gondwana**
B.A. Baldis, F. G. Aceñolaza (Argentina)
1993-1997, O.E.T. in 1998

353 **The Last Interglacial Period in the Circum-Arctic**
J.V. Matthews Jr. and A. de Vernal (Canada)
1993-1997

354 **Economic Superaccumulations of Metals in Lithosphere**
Pei Rongfu (China), P. Laznicka (Canada), J. Kutina (USA), D.V. Rundquist (Russian Federation), I. Plimer (Australia), T. Nakajima (Japan)
1995-1999, O.E.T. in 2000

355 **Neogene Evolution of Pacific Ocean Gateways**
S. Nishimura (Japan), J. Sopaheluwakan (Indonesia)
1993-1997

356 **Carpatho-Balkan Plate Tectonics and Metallogeny**
E. Véto-Ákos (Hungary), J. Lexa (Slovakia), S.N. Vlad (Romania)
1993-1997, O.E.T. in 1998

357 **Organics and Mineral Deposits**
J. Pašava (Czech Republic)
1993-1997

359 **Correlation of Tethyan, Circum-Pacific and Marginal Gondwanan Permo-Triassic**
Yin Hongfu (China), J.M. Dickins (Australia), A. Baud (Switzerland), Yang Zunyi (China)
1993-1997

360 **Global Geochemical Baselines**
A.G. Darnley (Canada), J.A. Plant (UK), A.J. Bjørklund (Finland)
1993-1997

361 **East Asia Activated Zones**
R. Barsbold, O. Gerel (Mongolia)
1993-1997, O.E.T. in 1998

362 **Tethyan and Boreal Cretaceous**
J. Michalík (Slovakia), H. Leereveld (Netherlands)
1993-1997, O.E.T. in 1998

363 **Lower Proterozoic of Sub-Equatorial Africa**
M. Kanika (former Zaire), S. Master (Zimbabwe)
1994-1998

364 **Caribbean Volcanic Arcs and Ophiolites**
G. Draper (USA)
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A. Zhuravlev, R. Riding (UK)
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D.P. Scott (Canada)
1994-1998

368 **Proterozoic Events in East Gondwana Deposits**
M. Yoshida (Japan), M. Santosh (India), C.R. Dissnayake (Sri Lanka)
1995-1999, O.E.T. in 2000

369 **Peritethyan Rift Basins**
W. Cavazza (Italy), A. Robertson (UK), P. Ziegler (Switzerland)
1994-1998; O.E.T. in 1999

371 **North Atlantic Precambrian (COPENA)**
R.P. Gorbatschev (Sweden), C.F. Gower (Canada)
1994-1998, O.E.T. in 1999

373 **Correlation, Anatomy and Magmatic-Hydrothermal Evolution of Ore-Bearing Felsic Igneous Systems in Eurasia**
R. Seltmann (Germany), R. Grauch (USA), A.A. Kremenetsky (Russian Federation)
1997-2001, O.E.T. in 2002

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A.E.S. Kemp (UK)
1994-1998

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V.A. Ramos (Argentina), F. Hervé (Chile), J.D. Keppie (Mexico)
1994-1998, O.E.T. in 1999

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C. Schlüchter (Switzerland), N.J. Vivic (Slovenia)
1994-1997, O.E.T. in 1998

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Yuan Daoxian (China)
1995-1999

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C. Monty (France)
1995-1999, O.E.T. in 2000

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E.A.M. Koutsoukos (Brazil), P. Bengtson (Germany)
1995-1999, O.E.T. in 2000

382 **Seismotectonics and Seismic Hazard Assessment of the Mediterranean Basin**
D. Giardini (Italy), K. Makropoulos (Greece), J. Mezcua (Spain), S. Riad (Egypt)
1996-2000

383 **Palaeostress, Neotectonics, Geodynamics and Natural Hazards in West Pacific/Asia**
R.H. Findlay (Papua New Guinea)
1996-2000

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C.H. Detre (Hungary), A. Bevan (Australia), B.P. Glass (USA), K. Jakabská (Slovakia), Z. Ouyang (China), E. Papp (Australia), A. Raukas (Estonia), G. Udubasa (Romania)
1996-2000

386 **Response of the Ocean/Atmosphere System to Past Global Changes**
H.H.J. Geldsetzer (Canada), D.M. Banerjee (India), L.R. Kump (USA)
Z. Sawlowicz (Poland), H. Strauss (Germany)
1996-2000, O.E.T. in 2001

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Z.M. Zaghloul, Ferial El-Bedewy (Egypt)
1995-1999

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Farouk El-Baz (USA), Ibrahim Himida (Egypt)
1995-1999

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E. Caus (Spain)
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W. W.-S. Yim (China), P.J. Davies (Australia)
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D. Delvaux (Belgium), A. Khan (UK)
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H. Faure (France), A. Velichko (Russian Federation)
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P. Sulovsky, J. Zeman (Czech Republic)
1996-2000, O.E.T. in 2001

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M.V.H. Wilson (Canada), T. Märss, P. Männik (Estonia)
1996-2000, O.E.T. in 2001

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F.P. Mitrofanov (Russian Federation), D.M. Guberman (Russian Federation), H.-J. Kümpel (Germany)
1998-2002

410 **The Great Ordovician Biodiversification Event**
B.D. Webby (Australia), F. Paris (France), M.L. Droser (USA)
1997-2001, O.E.T. in 2002

411 **Geodynamics of Gondwanaland-derived Terranes in E & S Asia**
S. Hada (Japan), I. Metcalfe (Australia), J.H. Kim (Korea), Tran Van Tri (Vietnam), Jin Xiouchi (China)
1998-2002, O.E.T in 2003

413 **Understanding Future Dryland Changes from Past Dynamics**
D. Thomas (UK), A.K. Singhvi (India)
1998-2002, O.E.T. in 2003

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