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Cover

Front: Sculptures at the outside wall of Halebeedu temple in Karnataka state, southern India built during the beginning of 12th century by Hoysala King. These sculptures were carved using talc-serpentine-tremolite bearing ultramafic rocks from nearby Archean greenstone belts.

Back: New Cathedral (Salamanca, Spain. UNESCO World Heritage site), of late-Gothic and Baroque style, was constructed between the XVIth and the XVIIIth centuries. Piedra Pajarilla granite was used for the base course, Villamayor sandstone for the superstructure.

by Ian Lambert[1] and Phil McFadden[2]

Scientific advice underpinning decisions on major challenges

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It is important that scientific advice is taken into account in making decisions directed at meeting the needs of the rapidly increasing global population and the aspirations of developing nations, while sustaining Earth systems. However, this has not commonly been the case – it is an all too frequent complaint of scientists, that their advice has not been sought, or has been ignored.

Better community education and ubiquitous rapid communication are resulting in increasing questioning of what are perceived as poor decisions and policies. As a consequence, many governments and other key decision makers are now more amenable to supporting constructive proposals for provision of authoritative scientific and technical advice to guide their responses to major challenges.

This paper discusses how effective mechanisms can be developed for provision of authoritative scientific and technical advice to decision and policy makers and illustrates this in relation to Australia where scientific inputs are now routine. It also emphasizes the need to ensure that all of the information and monitoring required for authoritative advice is available.

The new global program, Future Earth, will provide an excellent platform for international coordination and action to drive consideration of scientific advice, tempered by social and economic considerations, in addressing major challenges.

Introduction

Addressing some of the major challenges facing humankind requires geoscience inputs. For example, geoscience and geospatial information underpins the solutions to challenges associated with finding mineral and energy supplies to sustain a growing population; understanding and managing groundwater systems; minimizing soil degradation and loss; decisions on competing land uses; pollution and environmental health; addressing the impacts of climate change/variability; building megacities and major infrastructure; mitigating the impacts of geohazards and better emergency management.

The opportunities for scientists to influence important policies and decisions have been limited and fraught with difficulties. They have been brought into the international spotlight in the last few years as some serious questions have been asked, such as:

- Why was the existence of major paleo-tsunami deposits along the east coast of northeastern Honshu not factored into risk scenarios in this region, with disastrous consequences for the Fukushima nuclear power plant and coastal communities in the region more broadly?
- What are the ramifications of the conviction of Italian scientists and engineers for manslaughter, stemming from public statements preceding the L'Aquila earthquake?

There are at least two principal requirements for achieving routine consideration of scientific and technical inputs before decisions and policies are made on major contemporary and emerging issues:

1. Establishing effective lines of communication for providing advice into government and other decision makers, including flexible, interactive approaches and an economic and social basis for the acceptance of advice.
2. Enhancing the information base for decision-making through international coordination and support for approaches using high-quality multidisciplinary systems-science that takes advantage of ongoing advances in computing power and in data management and access.

This paper succinctly discusses how these requirements can be achieved. It covers in order government funding and expectations of research, developing effective mechanisms for advising governments, and enhancing the information base to underpin advice. Three Appendices provide more examples and further information: Appendix 1 provides an example of economic and social considerations; Appendix 2 provides an example, from Australia, of effective arrangements in place for routine provision of geoscientific and technical advice to guide important decisions; and Appendix 3 illustrates the value of looking into what needs more attention in current international initiatives to underpin good decision-making, based on mitigating the impacts of tsunami.

Scientific research and governments

Scientific research is, to a large extent, government-funded. Governments provide this funding because they have the expectation that this investment in knowledge generation will enrich the social and economic fabric of the nation. Yet it is a persistent and frequent complaint from scientists, particularly those in the Earth and

Earth-Systems sciences, that their advice is ignored by government.

Clearly there is a clash of cultures and expectations. Scientists tend to see their hard-won knowledge as an absolute because it is knowledge about how the natural system works and that system cannot be changed by opinion polls or political ideologies. Consequently, many scientists feel that their advice should be accepted as given and that it should be paramount in any decision-making process. Conversely, governments consider the (often short-term) economic, legal and social impacts of their policies and the scientific advice, if considered at all, becomes merely one of a mélange of factors contributing to the decision-making process. This is not unreasonable, because the electorate expects their government to make decisions that the electorate considers to be economically and socially responsible. This means it is commonly necessary for scientists to work with economists and social scientists to develop messages that can be appreciated by decision-makers.

For contentious, recurring issues, governments appreciate formally agreed guidelines developed by experts in consultation with interested parties, which can be used in responding promptly when such issues arise.

Establishing effective mechanisms for providing advice

China is unique in having a strong geoscience profile in government. The Geological Society of China is well organized and many senior government officials are members – from Wen Jiabao to various Ministers – because they were trained in the geosciences.

In other countries, the geosciences have variably lower visibility. It is common at scientific meetings to hear leading scientists calling for governments to heed their advice and to provide more funding for research. But more proactive approaches are needed. Putting effective lines of communication in place for evidence-based decisions takes strategic planning, high-level networking, good powers of persuasion, persistence and demonstration projects. In many cases, the mechanisms developed will involve groups of broadly-based scientists working in government who are willing to focus on practical applications of scientific data and research, can see "the big picture", are good communicators, are attuned to the work of academic and other research groups across all relevant disciplines.

Advisory groups need to keep abreast of all relevant research, data and issues; be aware of any limitations in data or knowledge; prepare authoritative papers on trends, options and opportunities; organize projects to demonstrate capabilities; and communicate regularly in appropriate ways with key decision makers. They should be prepared to have their advice subjected to peer review. Where appropriate they should be leading participants in formal processes to develop national approaches, guidelines and standards.

Economic and social basis for acceptance of the advice

Scientists typically deal with developing the knowledge necessary to understand how natural (usually complex rather than just complicated) systems operate. Governments typically deal with developing policy to achieve appropriate economic and social outcomes.

For there to be an effective communication it is usually necessary for the consequences of actions, as elucidated by scientific endeavour, to be articulated in terms of economic and social impact so that governments have an understanding of the actual social and financial commitments that they might be making by putting in place policies that respond to the scientific advice. This is discussed further in Appendix 1.

Flexible, interactive approaches to provision of advice

Because of the pervasive influence of politics, decisions are more often than not about careful compromise rather than bold, decisive policy action. The science community has to recognise that decision-makers take into account a wide range of issues and interests and that the scientific advice is, unfortunately, often in competition with these other issues and interests.

Hence, even when there is a suitable platform for supporting decisions, it is necessary to avoid providing advice in an absolute way. This makes it difficult to find a suitable compromise and so the scientific advice often gets left out entirely, leading scientists to complain bitterly. It is often a better outcome to get a scientific foot in the door through initial compromise and then gradually grow the influence of the scientific advice.

In order to get their knowledge to have an impact on high-level decisions, scientists should strive to acknowledge any shortfalls in information and provide the knowledge system that will allow a decision-maker to ask questions of the form "What will be the consequences if I make such and such a decision?" and "What would be the likely consequences if I make the decision with these compromises?" The answers to such questions can allow all the knowledge, different competing interests and the consequences to be taken into account in reaching an effective decision.

The costs of engaging governments

Putting the above into place does not come for free; there is a cost in time, resources and actual financial commitment. Not surprisingly, governments are often more willing to fund areas of knowledge generation where there is evident social impact. Experience shows that if scientists put in the effort and resource to build effective communication with government then their advice has a far higher likelihood of being accepted, then being manifest in policy and then in having positive social impact. Governments then tend to look positively at providing more funding into that area of scientific endeavour.

Hence, scientists should recognise the building of effective communication channels as a strategic investment in their own future. They should also be arguing for funding to help build those channels. Agencies providing scientific advice should ensure that their scientists are rewarded for impact first and scientific publications second.

Australia has been unusually successful in achieving an effective system for injecting science into major decisions and policies. This example is described in Appendix 2.

Enhancing the information base for decision-making through international coordination

As many of the challenges and approaches are global, it is

important that there be authoritative international coordination and support for enhancing the information base for decision-making, through comprehensive approaches employing high-quality multidisciplinary systems-science which takes advantage of ongoing advances in computing power and in data management and access.

The International Council for Science (ICSU; http://www.icsu.org) acts as the main representative and facilitator of international science, across disciplinary boundaries in order to encourage research and scholarship in those areas that require a multidisciplinary approach. Further it issues positions on topics that are controversial to some, but in which scientists have a firm opinion. Further ICSU is playing a leading role in the alliance implementing the major new global framework initiative, Future Earth.

Accordingly, ICSU and its Unions are well positioned to play pivotal roles in ensuring that: (i) holistic approaches are applied increasingly to achieve real progress in addressing major challenges; (ii) all important data are being collected and are available; and (iii) there are up-to-date authoritative statements available in relation to dealing with global challenges. Cross-disciplinary collaboration is important - the expertise and research needed generally require geoscientists working with mathematicians, computer scientists, chemists, physicists, environmental and social scientists, and economists. Further, data and infrastructure for managing, modeling and simulation must be readily available to those who need them.

Future Earth (http://www.icsu.org/future-earth) offers an ideal opportunity for ICSU to entrench its role in international facilitation and coordination roles in enhancing knowledge and understanding to underpin important decisions aimed at meeting societal needs while maintaining Earth systems.

The importance of taking stock of what is happening globally and identifying important gaps in information that are limiting the effectiveness of advice is illustrated with regard to tsunami in Appendix 3.

Concluding remarks

Earth scientists often complain that governments are averse to accepting their advice. This does not have to be the case. When a sensible, coordinated approach is developed, governments will take account of advice that is presented in a way that is understandable and useful for policy creation, and may be willing to fund the scientific work necessary to create that advice. This will normally involve advisory groups working with government, comprising broadly-based scientists, who consult with social scientists and economists.

There should be international coordination and support for multidisciplinary systems-science addressing major global issues. ICSU is uniquely well-placed to achieve this through its Unions and member states, particularly in developing and implementing its Future Earth program. This would minimize duplication, set priorities, ensure that the information base for decision making is comprehensive and facilitate authoritative position statements. The time is right, given increasing public concern about poor decisions, and the advances in computing power, data management and access which make it possible to use and integrate data in ways that were not previously possible.

Appendices: Additional Information and Examples

Appendix 1: Exemplifying the economic and social basis for acceptance of advice

As scientists we have to accept that there are many instances - for example, the location of radioactive waste stores - where governments have accepted and acted upon scientific advice only to have those actions become electorally toxic because the public-at-large had not accepted the scientific advice. Politicians often respond quickly to this kind of negative feedback and rapidly learn to treat such scientific advice with caution.

Another example of the need for the consequences of actions, as elucidated by scientific endeavour, to be articulated in terms of economic and social impact, is afforded by the influence that the Stern Review on the Economics of Climate Change (Britain; http://webarchive.nationalarchives.gov.uk/+/http:/www.hm-treasury.gov.uk/sternreview_index.htm) and the Garnaut Climate Change Review (Australia; http://www.garnautreview.org.au/update-2011/garnaut-review-2011.html) had on the acceptance of the science of climate change and on the responses of governments to that science.

Further, the consequences of social impact are starkly illustrated by the differential response to scientific advice about the ozone hole and about climate change. Addressing the ozone hole issue seemed to require that a relatively small number of industries (dominantly refrigeration and air-conditioning) change the chemicals they used with little flow-on social impact; hence it was relatively easy to get global action through the Montreal Protocol (http://ozone.unep.org/new_site/en/montreal_protocol.php) to ban the production of halocarbon refrigerants.

Addressing the climate change issue effectively means moving away from carbon-based energy sources, requiring large changes to lifestyle and quality of life for most in the developed world and threatening the aspirations of most in the developing world for much higher quality of life. For the ozone hole issue it was relatively easy to sell the message that the social impact of not taking action would be substantially worse than the social impact of taking action. For climate change it has been much harder to articulate this message in such a way that it is genuinely accepted by the community-at-large. Hence it has been much harder to get effective global policy action on climate change than it was on the ozone hole.

Appendix 2: Example of effective mechanisms for scientific advice - Geoscience underpinning approaches to major challenges in Australia

The Australian Academy of Science's National Committee for Earth Sciences produced a *National Strategy for Earth Sciences* in 2003 (http://www.science.org.au/natcoms/nc-es/documents/nc-es-strategic.pdf), which emphasized the key underpinning role of the geosciences in approaches to a wide range of major issues. In many cases decision-making processes require: (i) information on surface

features, including through remote sensing; (ii) information on subsurface materials and processes, including through collation of information from direct sampling and integration of geological and geophysical data; (iii) systematic monitoring as required to track important trends and events; and (iv) strategic analyses involving integrated consideration and modeling of all relevant data and information. It also identified the need for integration of the efforts of academic researchers and government agencies and collaborative approaches to sharing expertise and infrastructure needed for major research programs. This national strategy was influential in achieving wider appreciation of, and increased funding for, the vital underpinning roles of the Earth Sciences, as well as in developing important new roles for the national geological and geospatial agency, Geoscience Australia (GA: http://www.ga.gov.au/) .

GA is currently a vibrant government agency with a strong public profile. It is a primary source of scientific and technical advice in support of policy development and major decisions on a wide range of issues. But this was not always the case. Two decades ago its predecessor organization, the Bureau of Mineral Resources was underfunded, much-reviewed and under pressure - struggling to be seen as relevant to the government that was funding it. This motivated the agency to transform in an effort to reverse this perception, involving it contributing to and implementing the national strategy.

In changing its attitude and culture, GA transformed from an introverted agency with poor communication channels into the main body of government to a vibrant agency with a culture that said its job is "to apply geoscience to Australia's most important challenges" and with effective communication channels to ensure that its work is recognised, relevant, and used.

The success of the transformation from the beleaguered Bureau of Mineral Resources to the present-day GA is evidenced by a 2010 review by the Department of Finance and the Department of Resources and Energy (http://www.finance.gov.au/publications/strategic-reviews/docs/strategic_review_ga.pdf). That review recognized the importance of the agency's work to many major issues facing the nation and recommended that its funding be increased to (i) strengthen capabilities for collection of regional-scale data and for monitoring, (ii) invest in custodianship of Australia's exponentially increasing geoscientific and geospatial data, and (iii) enable continuation of fundamental capabilities in areas such as groundwater, natural hazards, and clean energy. This was a unique outcome for a review involving the Department of Finance, particularly at a time when the focus is on reducing government expenditure.

Australia is a major supplier of a wide range of mineral and energy commodities to world markets. The strength of its economy is linked to its considerable mineral endowment. In 2010, recognising the falling success rate of mineral exploration in Australia as a consequence of deep cover across about 80% of the continent, the Australian Academy of Science ran a Think Tank for young scientists to try to develop a fresh approach. The Academy then drew together a representative group, now known as the UNCOVER group, from across the spectrum of academia, government agencies, and industry to develop from this Think Tank an appropriate research and data-acquisition vision and to improve collaboration and coordination across the sector. In 2012, UNCOVER released the document *Searching the Deep Earth: A Vision for Exploration Geoscience in Australia* (http://www.science.org.au/policy/uncover.html/) . This vision, which includes enhanced information on the subsurface through comprehensive integration and modeling of geological information and a range of geophysical datasets, has now informed strategic planning for the state geological surveys and for Geoscience Australia.

Amongst the numerous other important geoscience contributions to high profile government policies and decisions are

- Improved water management through better knowledge of groundwater systems and their links with surface waters.
- Addressing community concerns about the rapidly growing coal seam gas sector, particularly centred on potential impacts on ground and surface waters.
- National guidelines to facilitate decisions on proposed uranium mines.
- Enhanced monitoring of environmental health and vegetation cover through developing improved remote sensing approaches.
- Establishing links between geology and bioregions.
- Reinforcing Australia's leadership role in mitigating the impacts of geohazards in its region by building fit-for-purpose tsunami warning systems, and developing a web application for non-experts to conduct inundation modeling to assess their own tsunami risk.

Appendix 3: Example of ensuring everything needed to facilitate decisions is being done – Mega-earthquakes and tsunami

There is increasing acceptance that currently available information is not adequate to rule out any subduction zone hosting a magnitude 9 or greater earthquake. Therefore, it is important that there is considerable activity aimed at providing relevant information as to where major tsunamigenic earthquakes are most likely to occur and as to what the societal impacts are most likely to be. Geologists, seismologists, oceanographers, and geodesists are working together to understand the physics of the processes and complexity of the lithosphere that lead to catastrophic events. This has been a "hot" topic since the disastrous Boxing Day tsunami of 2004 and it is widely believed that enough is presently being done on this topic to achieve this aim – but we should critically appraise whether everything that is needed is in fact being covered adequately. Also, it is important to finesse how these different bits of information should be marshalled to get government to listen to and act upon the scientific knowledge – an important component of this may well be easily understood decision support systems to display data, analyses and options on a laptop. This link to decision makers was clearly not strong enough in Japan.

There has been huge investment in tsunami warning systems, which many see as a quick technological fix. Unfortunately, one of the best warning systems in the world didn't save the many Japanese who died in Tohoku. Does this mean that the scientific advice to develop such warning systems was flawed? The answer is no, but having made significant investments governments will require assurance on this and carefully reasoned and supported advice on what else should be done to protect their peoples.

Considerable relevant scientific activity is underway, as outlined

in the next section. Clearly, future advice will have to be developed from these activities and a substantial effort should be put in to prepare governments for the advice and to ensure that it is appropriately articulated and packaged.

Major current and recent activities directed at mega-earthquakes and tsunami

The following summary of activities has been compiled with assistance of Alik Ismail-Sadeh (IUGG), and Phil Cummins and John Schneider (both of Geoscience Australia)

- There is ongoing compilation and analyses of historical records of earthquakes and tsunamis. Japan has by far the best historical records in the world, but this wasn't enough to expect a magnitude 9. The basic problem is that historical records are very short in geological timescales.
- An Intergovernmental Oceanographic Commission (IOC, UNESCO) committee is tasked with identifying the subduction zones around the world that can produce giant earthquakes and tsunamis, as well as tsunami earthquakes (events that are dangerous because their slow ruptures can be misread by warning systems and coastal populations). Understandably, the IOC is very much dominated by oceanographers and meteorologists and yet the bulk of the evidence for past events is geologic in nature.
- The Global Earthquake Model (GEM) is developing global databases and global scientific consensus on the state of knowledge. This work is being done through a series of Global Components studies that will be underpinned by a computational modelling framework and tools: http://www.globalquakemodel.org/global-components. In particular, it is intended that the Global Active Faults and Seismic Source Database will represent the authoritative source for information on active earthquake sources, including the world's subduction zones. However, GEM is not directly addressing tsunamis and is certainly not doing paleo-seismic or paleo-tsunami studies to increase the knowledge base. GEM's work will, however, provide an excellent baseline from which to identify knowledge gaps and to expose the risks associated with them. GEM is trying to develop a global scientific consensus on Mmax for earthquake hazard calculations. This will at least help establish the state of play from a hazard/risk assessment perspective.
- The Extreme Natural Hazards and Societal Implications Project (ENHANS; http://www.iugg.org/programmes/enhans.php) of the International Union of Geodesy and Geophysics (IUGG) launched in 2010 is supported by several ICSU bodies including the ICSU Regional Office for Asia and the Pacific. It aims (i) to improve understanding of critical phenomena associated with extreme natural events and to analyse impacts of the natural hazards on sustainable development of society; (ii) to promote studies on prediction of extreme events reducing predictive uncertainty and on natural hazards mitigation; to bring the issues into the political and economic policies; (iii) to disseminate knowledge and data on natural hazards for the advancement of research and education in general and especially in developing countries.
- Paleo-tsunami research (including trenching etc.) is one of the essential tools in tsunami research and is covered under the umbrella of ICSU, which established a new 10-year program dedicated to disaster risk research, Integrated Research on Disaster Risk (IRDR, http://www.irdrinternational.org/). IRDR tries to bridge natural and social sciences, engineers and policy makers etc. to mitigate, if not fully prevent, disasters.
- In 2011, the Geological Survey of Japan (GSJ) initiated a project related to Asia-Pacific region global earthquake and volcanic eruption risk management (G-EVER, http://g-ever.org/index.html). The first workshop was held in Tsukuba in Feb. 2012 (http://g-ever.org/en/gever1/index.html) and co-sponsored by IUGG and two IUGG associations dealing with seismology (IASPEI) and volcanology (IAVCEI). One of the major topics was earthquake- and volcano-generated tsunamis.
- The first bilateral symposium on geohazards and disaster risk under the US–Russian Presidential Commission on Science and Technology was held in Moscow in July 2012. One of the important topics was joint paleo-tsunami studies. Further two Natural Hazards sessions at the AGU Fall meeting in San Francisco December 2012 were dedicated to two new initiatives: NH13B. Asia-Pacific Region Global Earthquake and Volcanic Eruption Risk Management (G-EVER); and NH14A. Geohazards and Disaster Risks in the North Pacific Region.
- In a good example of harnessing advances in information and computing power, Geoscience Australia has developed and rolled out TSUDat, which is a web application for increasing the capacity of non-experts to conduct inundation modeling to assess their own tsunami risk (http://eresearchau.files.wordpress.com/2011/11/jeff-johnson.pdf). The web-server and tsunami simulations are hosted in the Cloud giving scalable computing resources. The application is underpinned by, and provides access to, a pre-computed data base of 70,000 tsunami events from all sources in Pacific and Indian oceans. All data is Open Geospatial Consortium compliant and all software is open-source. For each event a 24 hour time series of the tsunami was saved to a database, allowing the TsuDAT application to draw rapidly on a database of offshore waveforms, which means that only the inundation component needs to be modelled.

What is important but not happening systematically?

The above list of the considerable number of major earthquake and tsunami activities under way begs the question as to whether there are other important things that are not happening systematically.

It is submitted that there is scope for better links between various activities already in place and to fill important gaps. It is suggested that the main needs are for:

- More coordination of research, analyses and modeling of data.
- Improving coverage and coordination of geodetic and seismic monitoring networks.
- Integrated systematic geological inputs, particularly **identifying paleo-tsunami deposits in the recent geological records** to establish the occurrence, magnitude and frequency of tsunami **in all regions with significant populations at risk.** This needs an internationally coordinated effort involving government geoscience groups.
- Systems analysis to understand concatenated events, e.g., mega-thrust earthquake - tsunami - flooding - technological accidents or volcanic eruption - lava flooding - volcanic ash clouds - health issue - aviation problems.

- Finally, and of crucial importance, is the need to develop formal mechanisms for gathering and communicating authoritative scientific and technical advice to governments and other decision makers, as exemplified in Appendix 2.

Many Governments and some international funding agencies would likely be interested in supporting internationally agreed priorities for filling knowledge gaps and achieving more effective communication of advice to guide decisions and policies. The sort of message that they can appreciate is: "This region has had three major tsunami events over the last 2.2 million years. The last was approximately 650,000 years ago. This means that, in terms of the proposed major new infrastructure ....." Such information resonates more with decision makers than something like "Geologists, seismologists, oceanographers, geodesists are working together to understand the physics of the processes and complexity of the lithosphere that lead to catastrophic events. Major meetings will be held to discuss the current status."

There is a need to have broad agreement on:

(i) additional activities and programs that are most important for increasing our capability to predict and mitigate tsunami; (ii) appropriate mechanisms for managing and communicating authoritative information to underpin short to longer term decision making at international and national levels; and (iii) funding opportunities.

Addressing gaps

With this in mind, the International Union of Geological Sciences (IUGS) has agreed to support a workshop in conjunction with the Geological Society of Japan meeting in September 2013, in Sendai – which suffered so much devastation from the tragic tsunami of March 2011. This will have the objective of achieving widespread collaboration and support by bringing together leading tsunami researchers, appropriate government and international funding agency representatives, and ICSU and its Unions.

IUGS has provided funding to support the participation by key experts, who will be central in workshopping what is needed for (i) effective mechanisms for advice into decision makers in different circumstances; (ii) collaboration between academic and government scientists to fill important gaps in knowledge; (ii) international coordination; and (iv) securing funding for the most crucial activities.

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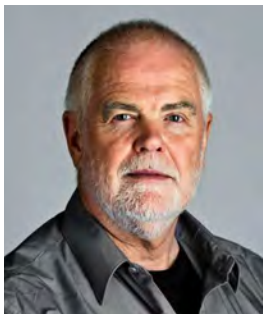

Phil McFadden *is a Fellow of the Academy of Science. He was Chief Scientist at Geoscience Australia until 2009. Following the 2004 Boxing Day tsunami he led the team that obtained funding from the Australian government to build the Australian Tsunami Warning System. He is a past Chairman of the Academy of Science's National Committee for Earth Sciences and in that role developed a national strategic plan for Australian geoscience. He currently provides strategic advice to scientific organisations and to government.*

by B. J. Cooper[1], B.R. Marker[2], D. Pereira[3] and B. Schouenborg[4]

Establishment of the "Heritage Stone Task Group" (HSTG)

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Introduction

During the 34th International Geological Congress, held in Brisbane, Australia in August 2012, the Heritage Stone Task Group (HSTG) was formally established within IUGS with links to Commission C-10 Building Stones and Ornamental Rocks, International Association of Engineering Geology and the Environment (IAEG C-10).

HSTG had its origins at the 33rd International Geological Congress in Oslo, Norway where it was accepted as a project by IAEG C-10. Subsequently a paper was published in *Episodes* (Cooper, 2010). This report led to its acceptance as an IUGS Task Group in 2011. HSTG Terms of Reference were approved at the IUGS Executive Committee Meeting in San Sebastian, Spain in February 2012. In Brisbane, an inaugural HSTG business meeting was held and a Managing Board was approved for the period 2012-2016.

Members of the inaugural HSTG Board of Management are as follows:

President (*ex officio* Chair IAEG C-10): Dr Björn Schouenborg (Sweden)
Secretary General: Dr Barry J. Cooper (Australia)
Vice President Southern Europe: Prof. Dolores Pereira (Spain)
Vice President Central Europe: Dr Sabina Kramar (Slovenia)
Vice President Western Europe: Prof. dr. Jan Elsen (Belgium)
Vice President North America: Dr Joseph T. Hannibal (USA)
Vice President North America: Prof. Brian R. Pratt (Canada)
Vice President North America: Dr Nelson R. Shaffer (USA)
Vice President South America: Prof Fabiano Cabañas Navarro (Brazil)
Vice President East Asia: Dr Hirokazu Kato (Japan)
Vice President South Asia: Dr. Harel Thomas (India)
Vice President Africa: Dr Phil Paige-Greene (South Africa)
Member: Dr Brian R. Marker (UK)

As of 1 March 2013, HSTG has 176 correspondents from 42 countries. Geoscientists wishing to affiliate with the Task Group should register with the Secretary General.

Aims and Vision

The specific goal of HSTG is to facilitate formal designation of those natural stone types that have achieved widespread recognition in human culture, and to create the "Global Heritage Stone Resource" (GHSR) as a term for this designation. Stones that have been used in heritage construction, sculptural masterpieces, as well as in utilitarian (yet culturally important) applications are obvious candidates. In association with this aim there is a need to promote the adoption and use of the GHSR designation by international and national authorities. HSTG will also maintain a register of GHSR approved stones.

HSTG is the first IUGS involvement in the realm of dimension stone (= hard rock used for building, decorative, ornamental or other similar purposes). Its primary aim will create the first ever international geological (as opposed to technical/mechanical) standard associated with dimension stone.

As a consequence of HSTG formation, the largest known international grouping of dimension stone geologists has already been established as "Corresponding Members". This network has significant potential for further expansion.

HSTG work will initially centre on soliciting and approving citations for GHSR status. As a first step an interim or standing list of potential GHSRs is being established. Citations will then need to be developed together with an essential research paper that advocates GHSR recognition in each case. Following this report a GHSR nomination and research paper for "Portland Stone" from the United Kingdom will be published as a model citation for future reference and consideration for possible adoption (Hughes *et al.* in press 2013).

Following satisfactory documentation, HSTG Terms of Reference advise that recognition of GHSR status will be formally approved by the HSTG Board of Management. The Board is encouraged to consult national or regional authorities and Corresponding Members with respect to draft citations and to revise draft citations as appropriate if deemed necessary.

As an alternative to GHSR approval the HSTG Board may also designate a heritage stone as having national or, perhaps, regional significance. Even newly available dimension stone resources may be considered a prospective heritage stone if they meet the necessary criteria in the future. By this method many types of dimension stone might eventually be categorised as a type of heritage stone. A long term HSTG vision may be the preparation of an "International Guide to Heritage Stone Designation".

In general and unlike any other geological standard, the GHSR proposal uniquely addresses the crossover domain between the geological sciences and human culture, given that it will focus both on the place of natural stone extraction as well as on the end utilisation of the extracted resource. It is envisaged that GHSR designation will

HSTG inaugural business meeting in Brisbane, Australia, August 2012: From left - José Kullberg (Portugal), Dolores Pereira (Spain), Björn Schouenborg (Sweden), Brian Marker (UK), Barry Cooper (Australia), Phil Paige Green (South Africa), Atiye Tugrul (Turkey), Rogério Rocha (Portugal), Rolv Dahl (Norway).

complement, and enhance, existing standards and international recognition.

Pre-establishment Phase

During the period 2008-2012, four "Global Heritage Stone Circulars" were issued in May 2009, September 2010, June 2011 and March 2012 and distributed to an ever growing list of Corresponding Members. A website, *www.globalheritagestone.org*, accessible to the public, has also been established where copies of all Circulars remain available together with up-to-date information about the project.

Links have been established with UNESCO World Heritage, International Union for the Conservation of Nature (IUCN), International Council on Monuments and Sites (ICOMOS) and the International Centre for the Study of Restoration and Preservation of Cultural Property (ICCROM) and these organisations have been placed on distribution list for all HSTG information.

At the beginning of the heritage stone project the label "World Heritage Stone Resource" was proposed (Cooper, 2008) however this designation terminology was subsequently abandoned due to its potential confusion with UNESCO World Heritage status. The Global Heritage Stone project has also developed with assistance of regional dimension stone organisations, such as the English Stone Forum. This organisation has, as its principal objective, the encouragement of greater public interest and awareness of the stone built heritage of England and the threats it faces. It also works to encourage the use of English stone for the public benefit and to ensure the availability of the stone required for the maintenance of the built heritage and new buildings. Similarly CONSTRUROCK is working in Spain to establish extensive stone resource databases, initially including all natural stone and quarries in Spain together with new and historical stone buildings that have utilised the quarried material.

In the period 2010-2012 the heritage stone project has also been the subject of presentations (both oral and poster) at the following conferences:

- Global Stone Congress, Alicante, Spain (March 2010)
- 11th Congress of the International Association of Engineering Geology and the Environment (IAEG), Auckland, New Zealand, (September 2010)
- Global Stone Congress, Alentejo (Borba), Portugal (July 2012)
- 34th International Geological Congress, Brisbane, Australia (August 2012)
- International Congress on Science and Technology for the Conservation of Cultural Heritage, Santiago de Compostela, Spain (October 2012)

Future Meetings

In the immediate future HSTG is aiming to establish an annual technical meeting initially as sessions within existing conferences.

In 2013, HSTGwill meet in association with a session of European Geosciences Union (EGU) General Assembly, to be held in Vienna, Austria in April 2013. Details of the session are as follows: Natural stone research and Heritage Stone Designation EGU Conference Session ERE3.4. In May 2013, HSTG will also sponsor a session at the Geological Society of America (North Central America) Kalamazoo, Michigan.

The 2014 conference is envisaged as a session of the 12th IAEG conference to be held in Turin, Italy in September 2014. The same year will also bring another edition of the "Global Stone Congress" in Antalya, Turkey.

Depending on contributions, publication of papers will result.

Checklist for Heritage Stone designation

In order to achieve GHSR designation the HSTG Terms of Reference advise that a stone should have most of several specific characteristics. Most notable of these attributes are wide-ranging geographic application and historic use for a period of at least 50 years.

The nominated dimension stone should also have been utilised in significant public or industrial projects and there should be wide recognition of the stone for its cultural importance, potentially, for example, including association with national identity or a significant individual contribution to architecture.

It is beneficial that stone remains available in active quarrying operations whilst other potential benefits (including cultural, scientific, architectural, environmental, commercial) should be considered.

In order to nominate a GHSR, it is suggested that the following features of the stone need to be documented:

- *Formal GHSR name*
- *Stratigraphic (or geological) name*

- *Other names* (names given to different types or variants of the nominated stone)
- *Commercial designations* (additional commercial names used to market the nominated stone)
- *Area of occurrence* (geographic area where the nominated stone occurs in nature, a map is required)
- *Location of quarry or quarries* (sites of active and abandoned quarries of the stone, specific locations may be specified as a reference locality)
- *Geological age and geological setting* (details of sedimentary basin/ fold belt, tectonic domain, igneous activity etc that place the designated stone in a wider geological perspective)
- *Petrographic name* (technical name of stone as determined by geological assessment)
- *Primary colour(s) and aesthetics of nominated stone*
- *Natural variability*
- *Composition* (distinguishing mineralogical characteristics)
- *Geotechnical properties* eg Water Absorption, Density, Porosity, Compressive Strength, Flexural Strength, Salt Crystallisation, Saturation Coefficient
- *Suitability* (assessment on utilisation, for example, cut building blocks, sculpting stone, roofing, monuments, polished decorative use, technological objects etc.)
- *Vulnerability and maintenance of supply* (availability of future supply including possibility of constraints on supply)
- *Historic use and geographic area of utilisation* (historic and geographic utilisation of the nominee especially in significant heritage or archaeological applications)
- *Heritage utilisation* (an extensive list the significant buildings, monuments, sculptures etc, including dates of construction)
- *Related heritage issues* (information on significant heritage issues that affect the nominated stone for example, alternative heritage listing of buildings or quarry areas associated with the stone, supporting museums, sculpture parks etc.)
- *Other designations (optional)* (proposal of additional designations, for example the epithet 'Classic World granite/marble/etc', 'International Decorative Stone Icon' etc)
- *Related dimension stones* (other dimension stones that are related geographically, geologically or utilised together with nominee, including those in associated Global Heritage Stone Province)
- *Principal literature related to the designated stone* (major scientific papers, books and popular literature dealing with the nominee)
- *Images*(images, historic photos and line illustrations for publication)
- *Any other relevant items*

Benefits of Heritage Stone designation

The designation of heritage stones has numerous long term benefits. For geologists, GHSR designation facilitates formalisation of the characteristics of natural stone materials, for professional purposes and otherwise, in an internationally accepted context. Following from this a mechanism for legally defining a stone type is provided, for example in a similar manner to existing European Union legal provisions that protects food and wine varieties from specific regions.

Undoubtedly heritage stone designation will create increased awareness of natural stone amongst professional workers, not only in geology, but also in engineering, architecture and stone/ building conservation. Such awareness will extend to the general public. In addition heritage stone designation will enhance international co-operation for the research and documentation of natural stone resources.

Finally it is anticipated that heritage stone designation will encourage proper management of natural stone resources and, as part of this, future safeguarding of dimension stone resources can also be addressed.

References

Cooper, B.J., 2008, Recognition of a "World Heritage Stone Resource": A proposal. Abstracts 33rd International Geological Congress, Oslo, Norway, 6-14 August 2008 (compact disc reference only)

Cooper, B.J., 2010, Toward establishing a 'Global Heritage Stone Resource' designation. Episodes, v. 33, pp. 38-41.

Hughes, T., Lott, G.K. Poultney, M.J. & Cooper, B.J., in press 2013. Portland Stone: A nomination for "Global Heritage Stone Resource" from the United Kingdom.

by Elena Druguet[1,#], Cees W. Passchier[2,#], Giorgio Pennacchioni[3,#], Jordi Carreras[1]

Geoethical education: A critical issue for geoconservation

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Some geological outcrops have a special scientific or educational value, represent a geological type locality and/or have a considerable aesthetical/photographic value. Such important outcrops require appropriate management to safeguard them from potentially damaging and destructive activities. Damage done to such rock exposures can include drill sampling by geologist for scientific purposes. In this work, we show how outcrops important to structural geology and petrology can be damaged unnecessarily by drill coring. Unfortunately, regulation and protection mechanisms and codes of conduct can be ineffective. The many resources of geological information available to the geoscientist community, e.g. via Internet, promote access to sites of geological interest, but can also have a negative effect on their conservation. Geoethical education on rock sampling is therefore critical for conservation of the geological heritage. Geoethical principles and educational actions are aimed to be promoted at different levels to improve geological sciences development and to enhance conservation of important geological sites.

Conserving the geological record

Geological Heritage represents a collection of records of Earth's history and processes. Rock exposures are the most important information sources to provide evidence for deciphering the complex evolution of the Earth. Some outcrops are crucial to interpret the geological evolution of a region, others are important for understanding aspects of petrological, tectonic or geomorphologic processes. Occasionally, geologists encounter outcrops which immediately stand out because they are exceptionally clear examples of certain features, text-book examples of certain mechanism or simply structures of a beauty (Fig. 1). Other important outcrops are those where a particular formation or structure has been first described, which become type localities for such features. Such outcrops are of great value for teaching and geotourism, and some have been known for generations and are being visited time and again.

The value and significance of the geological heritage merits appropriate management to safeguard it and, if particularly vulnerable, preservation for education, research and enjoyment of present and future generations. Many geological sites are permanently threatened, even if they are included in protected sites (e.g. Carreras and Druguet, 2000; Reimold et al., 2006). This can be due to the fact that rocks are to many people a fixed, unnoticed and uninteresting background to the biosphere, for which protection measures are irrelevant. Conservation regulation and management plans are often primarily based on biodiversity and ecological criteria, causing a lack of effective tools to take actions to prevent destruction of geological heritage. Over the last two decades, great efforts have been made to promote the recognition of the geological heritage as an important part of natural and cultural heritage. However, when examining current protection plans and nature conservation policies, limitations of their efficacy in geoconservation become evident. For instance, this problem can be detected in the framework given by the International Union for Conservation of Nature (IUCN). The IUCN has established several categories of protected areas which have significance for setting management plans (Dudley, 2008), and these are based on principles that are systematically biased towards biodiversity aspects. It is important to notice that the IUCN is the advisory body for natural heritage nominations to the UNESCO World Heritage List (http://whc.unesco.org/en/guidelines). Specifically targeted for geoheritage is the Global Geoparks Network, a UNESCO supported initiative which aims to stimulate sustainable economic and cultural development of a region based on the presence of significant geological sites (http://www.globalgeopark.org/, Global Geoparks Network, 2010). However, only geosites that are large enough to serve local/regional economic and cultural development can be included in this category. Nevertheless, integrated conservation and management plans seem to represent an adequate strategy to protect the rather common sites where geological heritage is associated with other natural and/or cultural values. In this context, geoconservation, as a sum of strategies related to the assessment and conservation of the geological heritage, must serve to strengthen the implementation of geological criteria in these integrated management plans. However, highly significant and valuable geological sites do not need to be included in protected areas to deserve conservation.

Outcrop damage undertaken in the name of scientific advancement

Outcrops are being threatened in several ways. Outcrops all

Figure 1. Example of an intact outstanding outcrop of refolded folds from the classical Cap de Creus shear zones (Eastern Pyrenees, Spain), and the reaction of a group of enthusiastic geologists during the 2011 GSA Penrose Conference "Deformation Localization in Rocks: New Advances", taking photographs of the outcrop.

gradually weather and erode, and are constantly being destroyed (and created) by road building or construction work. Depending on climate and geological environment, outcrop surfaces remain visible for decades to several thousands of years. This damage by erosion and human construction activity is similar to that experienced by archaeological sites and historical buildings. In some cases, damage, partial loss and destruction cannot be avoided, but generally, less care is taken in protecting geological outcrops than in preserving archaeological sites. For example, in Europe, the 1992 Valetta Treaty forces states to protect their archaeological heritage and to take care that sites are protected or, where this is not possible, properly investigated and recorded (http://conventions.coe.int/Treaty/EN/Reports/Html/143.htm). ICOMOS (International Council on Monuments and Sites) and UNESCO have similar initiatives, such as the "Recommendation on International Principles Applicable to Archaeological Excavations" (UNESCO, 1956). Archaeological sites are commonly discovered during construction work, and in such cases, there is often immediate action to try and protect the site. This is much less common with geological sites, with very few examples of outcrop protection during road building (e.g. Van Hise Rock National Historic Landmark, Wisconsin, USA, http://www.nps.gov/nhl/).

Outcrops are not only threatened by building or similar large-scale destructive activities. On a smaller scale, fossil and mineral rich sites can be damaged by collectors and merchants who collect fossils and minerals for private or commercial purposes (Kiernan, 1997; Sharples, 2002; van Loon, 2008). Outcrops seem to be unique in that they may become the object of damage or destruction motivated by research aims. The extreme clearness and scientific value of some outcrops is tempting geologists, as scientists, to use them for research, and this means sampling. This commonly brings researchers into the moral dilemma that they would like to sample a structure for lab work, but in doing so, the outcrop may be damaged to such an extend that its aesthetic appeal and scientific value are diminished or destroyed. In archaeology and art, preservation of the artefact or artwork is always more important than invasive research that could damage it, and a large number of non-destructive research techniques have been developed. Few people would consider taking a rock sample from the Taj Mahal or the Acropolis of Athens. In geology, we are less used to the idea to protect outstanding outcrops in a similar way as artefacts. The geological community should be more aware of conservation issues and try to conserve exceptional outcrops so that future research work and educational use can continue.

Hammering and drill coring are the two most common techniques used by geologists for rock sampling. With the availability of portable drilling equipments, rock coring has progressively gained popularity over the last decades over traditional methods: coring allows samples to be taken precisely at specific positions of interest from an outcrop pertinent to the geological research being undertaken, especially on smooth surfaces that are hard to sample by hammering. Coring however, although apparently cleaner and less destructive than hammering, can cause much more damage to the outcrops if undertaken irresponsibly. This is because, as explained by MacFadyen (2010), irresponsible coring can deface or even ruin the appearance and photographic value of outcrops. Small-scale geological features may even be completely destroyed by coring. Hammering can also damage outcrops, especially if the interesting structure is completely removed, but otherwise leaves behind a more natural scar which resembles the pattern of fractures and joints that normally constitutes the face of an outcrop: it may blend imperceptibly with the outcrop after a number of years because of weathering. Drill hole scars are much more permanent. Saw sampling is another procedure that can be very adverse to delicate outcrops, but saw cuts can be more easily restored to a natural looking scar by hammering.

In the UK, a country where geoconservation was pioneered and it is now well established, the "Geologist's Association" of the Geological Society of London published in 1989 the "Code of Conduct for Rock Coring" (Robinson, 1989a,b). Despite the existence of this code, irresponsible coring continues to this day in the UK, as reported by Campbell and Wood (2002) and MacFadyen (2006). Increasing concern and awareness of this problem resulted into several publications by MacFadyen (2007, 2010), where particularly destructive cases of coring in the UK are communicated. This resulted in the preparation of the Scottish Core Code by the Scottish Natural Heritage (MacFadyen, 2011) and to the 2011 updating of the former "Code of Conduct for Rock Coring" by the "Geologist's Association" (www.geologistsassociation.org.uk).

Irresponsible sampling is a recognised problem throughout the world. It is common in many countries that scientific and professional geological associations have a code of conduct or ethical behaviour that sets out recommendations and the procedures to be taken into account. However, apart from the above reported documents by the Scottish Natural Heritage and the Geologists' Association in the UK, there is no record of any other national or international document aimed as an ethic protocol or code of conduct specific to rock sampling for the conservation of relevant outcrops. A step in this direction has been taken by the Spanish Association of Geologists (http://www.icog.es/) on its recently updated Deontological Code, through a statement concerning the need for compatibility between geological activities and geoheritage. Besides this, the Geological Society of South Africa recommends the use of the "Code of Conduct for Rock Coring" produced by the UK Geologists' Association.

In order to illustrate the serious damage scientific sampling can do, we give some examples of outcrops important to structural geology and petrology where sampling was undertaken by means of drilling methods, and any protective measures taken (Figs. 2 to 6). They are all relatively small (metre to centimetre scale) outcrops or parts of outcrops that contain delicate structures. After the rock coring actions, the aesthetic and photographic value of these outcrops has decreased considerably.

Laghetti and Ponte Brolla areas, Maggia nappe, Swiss Alps

These are among the most classic and internationally well-known outcrop areas for ductile shear zones. The spectacular shear zones exposed in the Laghetti area (see Fig. 2a, b) were first described by Kerrich et al. (1977), Ramsay and Allison (1979), Ramsay (1980) and Simpson (1981, 1983). Some of the earliest geometric models of shear zones and of quantitative strain estimates were performed using these shear zones as an example. These classic shear zones appear substantially damaged (Fig. 2b) and also a mafic dyke from the same locality has been aggressively drilled (Fig. 2c).

At Ponte Brolla, another delicate outcrop shows melt-filled mesoscale shear bands in migmatitic gneiss of the Insubric mylonite zone (Fig. 3). This is one of the best examples in Europe of high-grade shear zones coeval with anatexis (see Merle et al., 1989; Passchier, 2001; Passchier and Coelho, 2006; and Berger et al., 2008, for further details). The outcrop, which consist of no more that 10-15 well exposed shear bands, is visited by numerous student groups from German and Swiss universities. Defacing of the outcrop took place despite Ponte Brolla-Losone being catalogued since 1977 in the Swiss Federal Inventory of Landscapes and Natural Monuments (http://www.bafu.admin.ch/) which aims to protect landscapes of national importance. In contrast to landscape and bioecological elements, geological heritage is not yet sufficiently integrated into local and national Swiss management plans, so that, according to the Swiss Working Group Geotope of the Swiss Academy of Sciences, the capacity to implement restriction and protection activities on geological heritage sites is still very limited (Stürm, 2005). The Group Geotope started in 2006 an inventory of geosites to promote geoconservation in Switzerland, but currently lacks legal status. The last revision of this inventory (Berger et al., 2011) embraces Ponte Brolla outcrops (geosite #499: Gole di Ponte Brolla), but not yet the Laghetti area.

Mosel valley, Rhenish massif, Germany

This is an exclusive example of cleavage refraction in Devonian slates and sandstones (Fig. 4). Early tectonic quartz veins developed in sandstone layers follow the refractive cleavage and highlight the structure. The outcrop is a classical site visited by many student groups from Germany and Holland. The drill holes shown here were made at the end of the 1980's. In this particular case, we know that the samples were taken for a comparative study of the magnetic properties of sandstone and slate, where any other less spectacular outcrop would have served equally well. In fact, the samples were never used since other, better examples were found later.

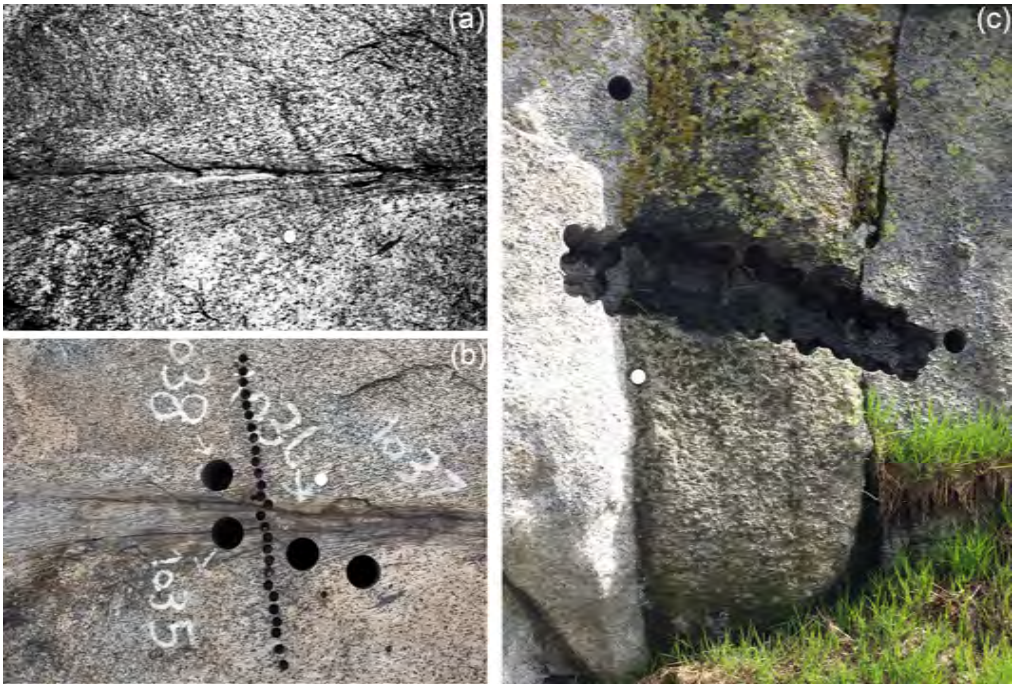

Figure 2. Two examples of destruction by drill coring in the Laghetti area, Swiss Alps. (a) Ductile shear zone in granodiorite, photograph corresponding to Fig. 10a of Ramsay (1980), prior to rock sampling. A sigmoidal schistosity fabric is well developed around the shear zone. Reprinted from Journal of Structural Geology, 2, Ramsay, J.G., Shear zone geometry: a review, 83-99, Copyright (1980), with permission from Elsevier. (b) The same outcrop photographed in 2010. Notice from the graffitied numbers that the four large holes are older than the small ones, which may indicate either two different projects or a repeated sampling campaign. (c) A giant gap made of overlapping core holes to a lamprophyre dyke intruded in granodiorite a few tens of meters from (b), also photographed in 2010.

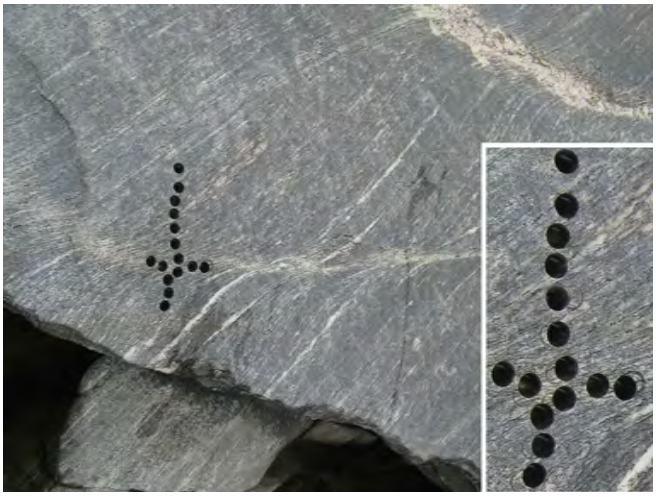

Figure 3. Small outcrop in the Ponte Brolla area (Ticino, Switzerland) showing superb examples of migmatitic gneisses with shear zones filled with melt. The cross-shaped drill coring has destroyed the photogenic interest of the structures and irreversibly removed part of the information that was recorded in these migmatitic rocks.

Aiguablava, Costa Brava, Catalan coastal batholith in NE Spain

The lamphrophyric dyke swarm of Aiguablava configures a site of great scientific and educational value in the fields of igneous petrology and tectonics, located in an outstanding coastal landscape of almost equally magnificent geomorphological value. Dyke emplacement is controlled by the presence of a widespread network of joints developed during cooling of the late Variscan granitic host rocks (Gimeno, 2002; Passchier, 2007; Enrique, 2009; Martínez-Poza et al., 2012). Sa Planassa has become a classic locality to see the dyke cross-cutting relationships and also the intrusive structures associated to different joint sets. Geology professors with students from various Spanish universities and from secondary schools have been regularly visiting this locality for more than forty years, and visits continue nowadays in the presence of defacing coring holes (Fig. 5). In 2009, the most magnificent dyke locality at Sa Planassa (Fig. 5) was marred with numerous drilling holes. It is an unfortunate example of how geological heritage can be destroyed by geologists for scientific interest, while there are nearby other, less conspicuous outcrops where identical samples of these lamphrophyres can be taken. This happened despite Aiguablava being catalogued in the "Inventory of sites of geological interest of Catalunya" (Geozone 354: Aiguablava and Aigua-Xelida dyke swarm, Carreras and Gimeno, 2000) and it being protected by the Catalan legislation for its natural value, as it belongs since 1992 to the "Special plan for protecting the natural environment and landscape" (PEIN "Muntanyes de Begur"). In 2010, after the Aiguablava outcrops had been damaged, the Catalan legislation approved a new plan which regulates the use of the PEIN "Muntanyes de Begur" site for geological site protection.

Bear Creek area, John Muir Wilderness, Sierra Nevada, USA

This spectacular area has hosted numerous detailed studies on post-magmatic deformation of granitoids including the development of ductile shear zone and faults (Segall and Simpson, 1986; Segall and Pollard, 1983; Martel et al., 1988; Pennacchioni and Zucchi, in press). This reflects, in part, the extent of extensive spectacular exposures in glaciated outcrops. The damaged outcrops (Fig. 6) show foliated contractional jogs at the tips of extremely localized sinistral ductile shear zones nucleated on precursor en echelon joints which developed during post-magmatic cooling.

In the U.S. Wilderness areas, urban development is prohibited by law and thus land has to be administered to preserve its wilderness character. The John Muir Wilderness area belongs to the Inyo and Sierra National Forests, established in 1964 by the United States Forest Service. The specific regulation states that a notice of intent and a permit are required for rock sampling, with request to cover the holes before leaving the site. Some of the drill holes in this area have indeed been filled in with concrete by those who carried out the coring under

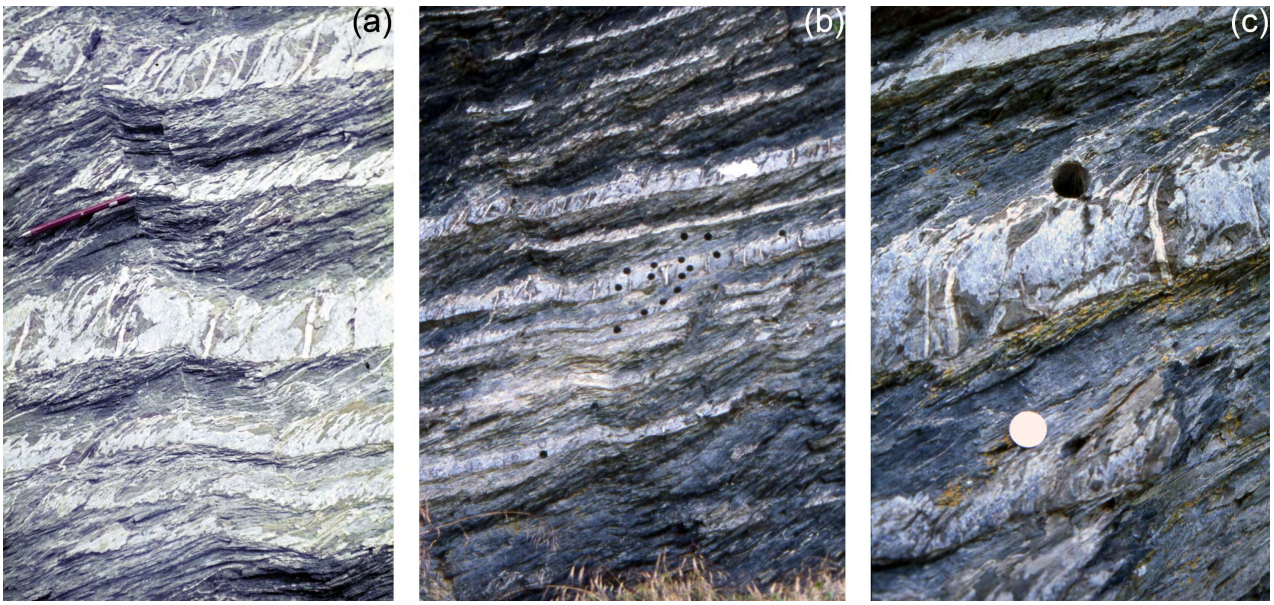

Figure 4. Outcrop from the Mosel valley (Germany) showing excellent examples of cleavage and vein refraction structures. (a) The outcrop in 1971. Pencil for scale. (b) The outcrop in 1999 after devastating drill coring. (c) Detail of (b).

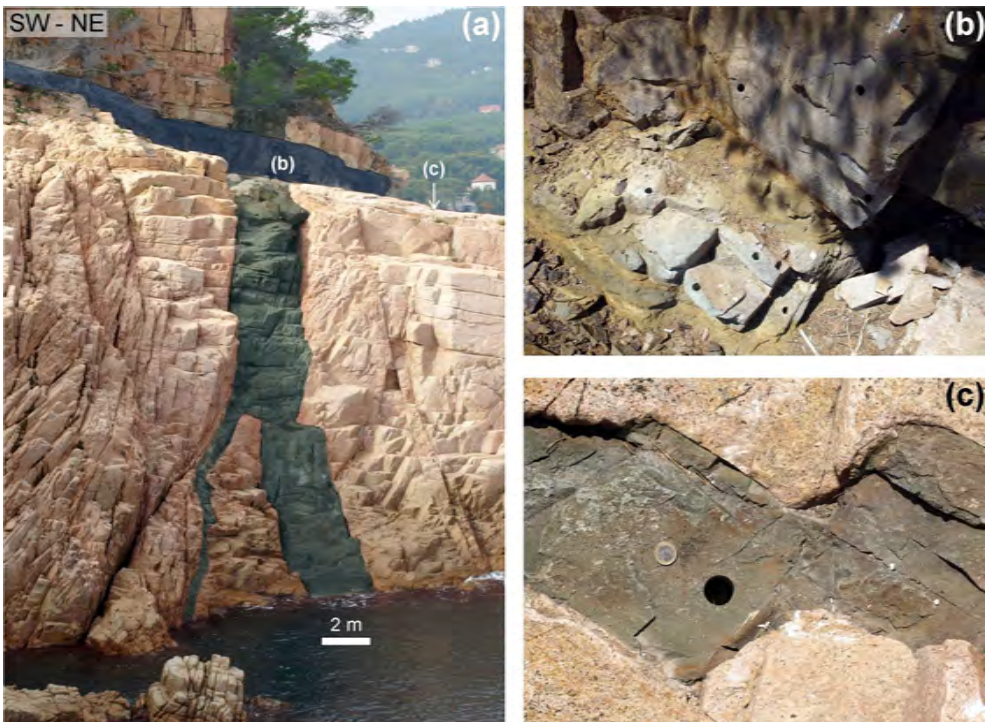

Figure 5. Examples of drill coring in lamprophyre dykes intruded into leucogranites (Aiguablava, Costa Brava, NE Spain). In 2009, the most magnificent dyke localities were drilled. (a) General view of the two cross-cutting dykes at Sa Planassa. See text for further explanation. (b) and (c) Detail photographs of the damage done to dykes.

a permit, although the effect is unsatisfactory as the outcrops have not recovered their original state (compare Figs. 6a and b).

Komati River gorges, Songimvelo Nature Reserve, South Africa

Reimold et al. (2004, 2006) reported damage to many prime exposures along the Komati River gorge in the Songimvelo Nature Reserve, where some of the earliest and most interesting rocks on Earth are found. These were defaced by core sampling for scientific purposes under permission of the Park board (de Wit, 2005). After much discussion among the geological community, the results of this sampling were published in Biggin et al. (2011).

Bartlett Wash, Utah, USA

Recently, another example of damage to an important outcrop was reported by Dr. Bruce Trudgill (Colorado School of Mines) on several internet sites (e.g. http://www.structuralgeology.org/2012/04/geo-vandalism-in-bartlett-wash-utah.html). The defaced exposure, in the Bartlett Wash area near Moab, belongs to an area which is famous for its well-exposed deformation bands in sandstone (e.g. Davatzes et al., 2005; Fossen, 2010, his figure 8.11). Sampling was performed in this case by geoscientists using an electric rock saw.

Networks of information and communication technology: positive and negative side effects

The numerous geological resources now available via Internet are scientifically very useful to the geoscientist community and have actually become one of the most effective media to promote geoconservation and geotourism.

A number of activities have been started in recent years to provide information of relevant geological sites through the indication of the precise outcrop position, easily recorded and located with any modern GPS device. Examples of these initiatives are the DIoGeneS "database of Digital Images of Geologic & nice Structures" (http://www.diogenes.ethz.ch/) and the interactive outcrop database Outcropedia of TecTask (www.outcropedia.org/). It is also increasingly common in scientific papers, guides and divulgation pamphlets to indicate the GPS coordinates of the published figures and spots of interest: this trend should be encouraged and recommended. KML (Keyhole Markup Language), which can be used for expressing geographic annotation and visualization within Internet-based Earth browsers, is now accepted by scientific journals and can become a routine procedure to georeference outcrops. This will allow anybody to access and enjoy the most spectacular geosites. However, it also exposes the same sites to the risk of irresponsible sampling. It is therefore recommended that databases and promotional activities are accompanied by guidance notes of good sampling practice to decrease the risk of damage to outcrops, and to avoid that these new initiatives become frustrated by a dwindling number of scientist who wish to publish the location of spectacular outcrops.

Call for geoethical education strategies

Geoconservation should be a fundamental practice of science and of scientific deontological behaviour. Though sampling, and more specifically coring, is useful and often critical to conduct laboratory analysis and for scientific achievements, it should in most cases be possible to target outcrops where this kind of action has no relevant impact, therefore allowing the best, or unique examples of spectacular geological structures to be protected for future research and educational goals.

It follows that geoethical education is a key issue for geoconservation. Geoethics is an interdisciplinary approach between geosciences and ethics whose main concerns are sustainable development and use of geological resources, appropriate management of natural hazards, geoscience communication and legal aspects, museology and also geoheritage and planetary protection. This concept, first defined by Martínez-Frías (2008) has ben further reviewed and developed by Martínez-Frías (2011), Ferrero et al. (2012) and Peppoloni and Di Capua (2012), among others. The 2011 "International Declaration on Geoethics" states among its recommendations the need to strengthen the links of geoethics with

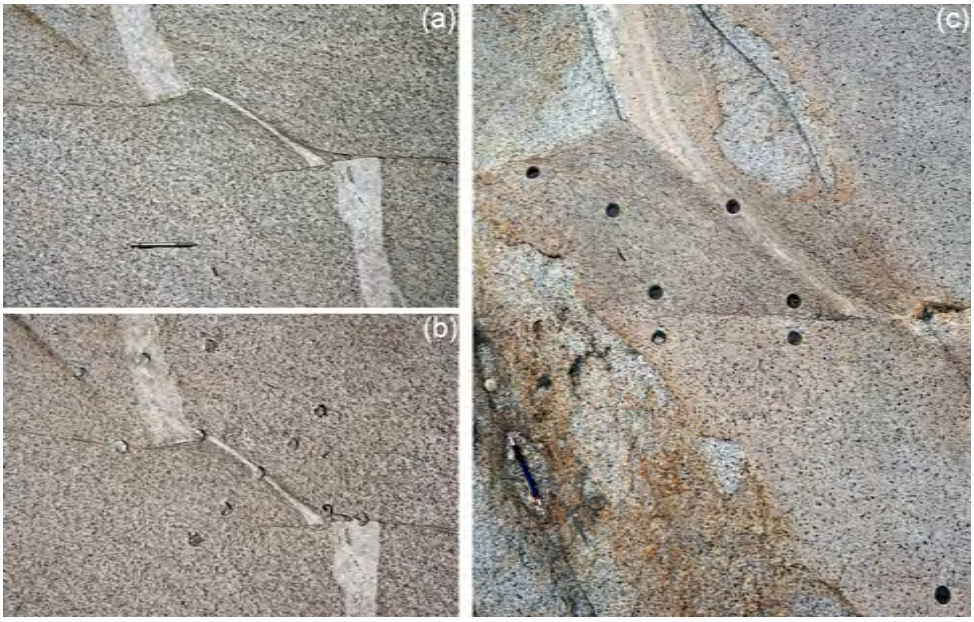

Figure 6. Photographs of spectacular outcrops located in the East Fork of Bear Creek and in the Hilgard Branch within the John Muir Wilderness, Sierra Nevada, USA, where sampling should be particularly careful. (a) Outcrop showing the displacement and thinning of a leucocratic dyke across shear zones and a contractional jog. This figure shows as the outcrop appeared in 2007. (b) The same outcrop as it is now (photograph taken summer 2011). Most of the drill holes in this area have been restored with a concrete filling, in order to somehow repair the visual impact of coring, as is enforced by restrictive sampling permits. However, this is a clear example of how restoration cannot return an outcrop its original beauty and a clear example of an outcrop where drilling or sampling should have been avoided. (c) Another outcrop, from the Hilgard Branch, damaged by drilling.

the new aspects of the geosciences education and to incorporate geoethics into any activity related with abiotic world. This has recently been proclaimed by the "Working Group for Geoethics" of the AGID (Association of Geoscientists for International Development) and the newly established International Association for Geoethics. However, geoconservation concerns are more implicit than explicit in these publications. More clear and explicit is the recently updated Deontological Code of the Spanish Association of Geologists (http://www.icog.es/), which includes a paragraph requesting geologists to be aware of geological heritage while performing their activities on rock exposures.

All these actions should explicitly recognise geological heritage outcrops and call for their conservation. The geosciences community should apply similar principles to geological outcrops as those applied by most historians and archaeologists to the study of ancient monuments or archaeological sites. Such principles are communicated through protocols, codes, best practices, regulations and policies that provide national and international frameworks for heritage protection. In the case of archaeological heritage it is worth to notice the prompt edition of its international protection principles (UNESCO, 1956).

We consider that guides and codes of ethical conduct should incorporate guidelines for rock sampling, and outcrop conservation, such as done by different associations in the UK (referred to in a previous section). Concerning mitigation of damaged outcrops, some guidelines are given and research is being done in Europe by the Scottish Natural Heritage to establish a methodology for outcrop restoration (see MacFadyen, 2011). It would be useful to expand this initiative to investigate what measures can be taken to restore drill-coring damage to outcrops.

We would like to give this tentative outline requesting responsible behaviour, guided and inspired by the UK Geologists's Association "Code of Conduct for Rock Coring":

- Drill sampling is particularly threatening because it has a negative visual impact, whilst many times unnecessary. Before sampling, geologists should think about the question "is drill sampling necessary for the study being carried on?"
- Do not take samples from the centre of a geological type locality or a site of especial scientific, didactic interest or aesthetical/photographic value. If an outcrop is spectacular enough that deserves being photographed, then you should not core or sample the rock face that has been recorded. The same applies to outstanding outcrops stored in websites like the "Outcropedia".
- Sample other parts of the same or a neighbouring outcrop where there is less impact. Core samples must be discrete in location; take cores from the least exposed faces and try to plug the holes using the outer end of the core, if possible.
- Before sampling ask experts and authorities (e.g. Natural Reserve or National Park managers if the area is protected) for advise and permission.

Final remarks

Geoethics, geo-education and geoconservation are intrinsically related principles that are to become integrated for the best practice in geosciences. Geoconservation and geoscientific sampling can be reconciled if we place geoconservation principles before individual research aims. Sampling is not antithetical to geoconservation when done in an appropriate and careful way. Also in geological sciences, it is not just what we do, but how we do it that matters.

Regulations, although necessary, can prove to be difficult to implement and are sometimes ineffective. Therefore, geoethical education on rock sampling seems to be a critical issue for conservation of our geological heritage.

Geoethical principles are aimed to be promoted at different levels:

- Ethical protocols and codes of conduct should include geoconservation issues, being explicit about responsible sampling. This could be included into existing and/or newly designed procedures and standards of different institutions: education and research centres, publishing companies, funding agencies and national or international associations. In this sense, it would also be useful to join and coordinate efforts that are being made by several IUGS commissions and groups on specific aspects that may be directly or indirectly related to geoconservation, such as the TecTask Commission on Tectonics and Structural Geology (to which the authors of this paper belong), the Geoheritage Task

Group (GTG), the Commission on Geoscience Education, Training and Technology Transfer (COGE) and the Initiative on Forensic Geology (IFG).

- Geoscience teachers and supervisors should advise their students of the existing codes and have a general responsibility to teach their students the aesthetic and scientific value of exceptional outcrops, and responsible sampling techniques.
- It is important to promote the principles of geoconservation among landholders, authorities and managers of entities in charge of the protected sites and responsible for the permits. However, we cannot delegate all responsibility to land managers who are often not acquainted with the importance of these outcrops, and can hardly discriminate between common and exceptional rocky outcrops. Geoconservation will only be achieved through effectively coordinated links between responsible field geologists and institutions.
- The promotional activities through information technologies referred to in a previous section, could be complemented with a warning message referred to rock sampling and other geoethical indications.

We trust that these actions will help to improve geological sciences in all their aspects, and will enhance conservation of important geological features (regardless if they are in protected areas or not) for future generations to learn and enjoy.

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References

Berger, A., Burri, T., Alt-Epping, P., and Engi, M., 2008, Tectonically controlled fluid flow and water-assisted melting in the middle crust: An example from the Central Alps: Lithos, v. 102, pp. 598-615.

Berger, J.P., Reynard, E., Constandache, M., Felber, M., Häuselmann, Ph., Jeannin, P-Y., and Martin, S., 2011, Révision de l'inventaire des géotopes suisses: rapport du groupe de travail 2008-2011: Groupe de travail pour les géotopes en Suisse, Fribourg, sc/nat+ Geosciences, Platform of the Swiss Academy of Sciences.

Biggin, A.J., de Wit, M.J., Langereis, C.G., Zegers, T.E., Voute, S., Dekkers, M.J., and Drost, K., 2011, Palaeomagnetism of Archaean rocks of the Onverwacht Group, Barberton Greenstone Belt (southern Africa): Evidence for a stable and potentially reversing geomagnetic field at ca. 3.5 Ga: Earth and Planetary Science Letters, v. 302, pp. 314-328.

Campbell, S., and Wood, M., 2002, Scientific vandalism?: Earth Heritage, v. 17, pp. 3.

Carreras, J., and Druguet, E., 2000, Geological heritage, an essential part of the integral management of World heritage in protected sites, in Barettino D., Wimbledon W.A.P., and Gallego E., eds, Geological Heritage: its conservation and management: Lectures presented in the III International Symposium ProGEO on the Conservation of the Geological Heritage, 1999, Madrid (Spain), pp. 95-110.

Carreras, J., and Gimeno, D., 2000, Geozona 354: Eixam de dics a Aiguablava i Aigua-Xelida: Generalitat de Catalunya, http://www20.gencat.cat/portal/site/mediambient/menuitem.64be942b6641a1214e9cac3bb0c0e1a0/?vgnextchannel=118c1a22693d7210VgnVCM1000008d0c1e0aRCRD&vgnextfmt=default&vgnextoid=118c1a22693d7210VgnVCM1000008d0c1e0aRCRD

Davatzes, N. C., Eichhubl, P., and Aydin, A., 2005, Structural evolution of fault zones in sandstone by multiple deformation mechanisms: Moab fault, southeast Utah: Geological Society of America Bulletin, v. 117, pp. 135-148.

de Wit, M.J., 2005, Geoheritage research: Geobulletin of the Geological Society of South Africa, March issue, pp. 4-11.

Dudley, N., (ed), 2008, Guidelines for Applying Protected Area Management Categories: Gland, Switzerland: IUCN Publications Services, 86 pp. http://data.iucn.org/dbtw-wpd/html/paps-016/cover.html

Enrique, P., 2009, Las espesartitas, camptonitas y bostonitas del complejo intrusivo de Aiguablava (Cadenas Costeras Catalanas): cartografía y composición: Geogaceta, v. 47, pp. 125-128.

Ferrero, E., Giardino, M., Lozar, F., Giordano, E., Belluso, E., and Perotti, L., 2012, Geodiversity action plans for the enhancement of geoheritage in the Piemonte region (north-western Italy): Annals of Geophysics, v. 55, pp. 487-495.

Fossen, H., 2010, Structural Geology: Cambridge University Press, 463 pp.

Gimeno, D., 2002, Estructura y mecanismos intrusivos de los lamprófidos de Sa Planassa - Punta d'Es Mut (Costa Brava, Cordillera Litoral Catalana): su interés didáctico: Treballs del Museu de Geologia de Barcelona, v. 11, pp. 105-133.

Global Geoparks Network, 2010, Guidelines and Criteria for National Geoparks seeking UNESCO's assistance to join the Global Geoparks Network (GGN): UNESCO, 12 pp.

International Declaration on Geoethics, 2011: AGID Working Group for Geoethics, Pribram, Czech Republic, October 2011. http://tierra.rediris.es/Geoethics_Planetary_Protection/AGID_Geoethics_International_Declaration.htm

Kerrich, R., Fyfe, W.S., Gorman, B.E., and Allison, I., 1977, Local modification of rock chemistry by deformation: Contributions to Mineralogy and Petrology, v. 65, pp. 183-190.

Kiernan, K., 1997, Landform classification for geoconservation, in Eberhard, R., eds, Pattern and Process: Towards a Regional Approach to National Estate Assessment of Geodiversity, Technical Series No. 2, Australian Heritage Commission & Environment Forest Taskforce, Environment Australia, Canberra, pp. 21-34.

MacFadyen, C.C.J., 2006, When coring equates to geovandalism: Earth Heritage, v. 27, pp. 12-13.

MacFadyen, C.C.J., 2007, Coreholes: a widespread problem: Earth Heritage, v. 28, pp. 17.

MacFadyen, C.C.J., 2010, The vandalizing effects of irresponsible core sampling: a call for a new code of conduct: Geology Today, v. 26, pp. 146-151.

MacFadyen, C.C.J., 2011, Irresponsible coring: new guidelines and establishing a methodology for outcrop restoration: Earth Heritage, v. 36, pp. 11-12.

Martel, S.J., Pollard, D.D., and Segall, P., 1988, Development of simple strike slip fault zones, Mount Abbot quadrangle, Sierra Nevada, California: Geological Society of America Bulletin, v. 100, pp. 1451-1465.

Martínez-Frías, J., 2008, Geoethics: Proposal of a geosciences-oriented formal definition and future planetary perspectives, TIERRA: Spanish Thematic Network of Earth and Planetary Sciences (http://tierra.rediris.es), RedIris. documentos, 2008, 1.

Martínez-Frías, J., González, J.L., and Rull-Pérez, F., 2011, Geoethics and Deontology: From fundamentals to applications in Planetary Protection: Episodes, v. 34, pp. 257-262.

Martínez-Poza, A.I., Druguet, E., Castaño, L.M., and Carreras, J., 2012, The Aiguablava dyke swarm from a Structural point of view: Geotemas v. 13, pp. 153.

Merle, O., Cobbold, P.R., and Schmid S., 1989, Tertiary kinematics in the Lepontine dome: Geological Society, London, Special Publications, v. 45, pp. 113-134.

Passchier, C.W., 2001, Flanking structures: Journal of Structural Geology, v. 23, pp. 951-962.

Passchier, C.W., 2007, Photograph of the Month: Journal of Structural Geology, v. 29, pp. 1871.

Passchier, C.W., and Coelho, S., 2006, An outline of shear sense analysis in high-grade rocks: Gondwana Research, v. 10, pp. 66-76.

Pennacchioni, G., and Zucchi, E., in press, High temperature fracturing and ductile deformation during cooling of a pluton: The Lake Edison granodiorite (Sierra Nevada batholith, California). Journal of Structural Geology, doi:10.1016/j.jsg.2012.06.001

Peppoloni, S., and Di Capua, G., 2012, Geoethics and geological culture: awareness, responsibility and challenges: Annals of Geophysics, v. 55, pp. 335-341.

Ramsay, J.G., 1980, Shear zone geometry: a review: Journal of Structural Geology, v. 2, pp. 83-99.

Ramsay, J.G., and Allison, I., 1979, Structural analysis of shear zones in an alpinised Hercynian granite (Maggia Lappen, Pennine Zone, Central Alps): Schweizerische Mineralogische und Petrographische Mitteilungen, v. 59, pp. 251-279.

Reimold, W.U., Anhaeusser, C.R., Eriksson, K.A., Hofmann, A., Gibson, R.L., Koeberl, Ch., Simonson, B.M., and Westall, F., 2004, Field Forum Report: Processes on the Early Earth, July 4–9, 2004, Kaapvaal Craton, South Africa: GSA Today, v. 14, pp. 28-29.

Reimold, W.U., Whitfield, G., and Wallmach, T., 2006, Geotourism potential of southern Africa, in Dowling, R.K., and Newsome, D., eds, Geotourism, sustainability, impacts and management, Elsevier, pp. 42-62.

Robinson, J.E., 1989a, A Code of Conduct for Rock Coring: Geologists' Association and Conservation Committee of the Geological Society of London.

Robinson, E., 1989b, For Geologists: A Code of Conduct for Rock-coring: Environmental Conservation, v. 16, pp. 370-371.

Segall, P., and Pollard, D.D., 1983, Nucleation and growth of strike slip faults in granite: Journal of Geophysical Research, v. 88, pp. 555-568.

Segall, P., and Simpson, C., 1986, Nucleation of ductile shear zones on dilatants fractures: Geology, v. 14, pp. 56-59.

Sharples, C., 2002, Concepts and principles of geoconservation: Tasmanian Parks & Wildlife Service, Hobart.

Simpson, C., 1981, Ductile shear zones: a mechanism of rock deformation in the orthogneisses of the Maggia Nappe, Ticino: Unpublished Ph.D. thesis, ETH-Zürich.

Simpson, C., 1983, Strain and shape-fabric variations associated with ductile shear zones: Journal of Structural Geology, v. 5, pp. 61-72.

Stürm, B., 2005, Geoconservation in Switzerland – General situation 2005. – GEOforumCH of the Swiss Academy of Sciences, Working Group Geotope, 7p.

UNESCO, 1956, Recommendation on International Principles Applicable to Archaeological Excavations, New Delhi Recommendation. http://portal.unesco.org/en/ev.php-URL_ID=13062&URL_DO=DO_TOPIC&URL_SECTION=201.html

van Loon, A.J., 2008, Geological education of the future: Earth-Science Reviews, v. 86, pp. 247-254.

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by Chris King

Geoscience education across the globe – results of the IUGS-COGE/IGEO survey

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An international survey of school-level geoscience education acquired data from 32 countries across the globe. Whilst the data is likely to be biased towards those countries which have geoscience educators active enough to respond to the questionnaire survey, the data nevertheless shows that geoscience is taught in a wide variety of contexts across the world, linked to science, geography or both. The majority of children in the countries surveyed had compulsory geoscience education in their curricula, had national standards in geoscience education, and covered a reasonable level of geoscience terminology in their studies. Optional geoscience courses were taught in most countries, but were only generally available to small numbers of 16-18 year olds. Undergraduate geoscience education courses were available in all the countries surveyed, together with graduate education in all but one. There was a wide variety of outreach initiatives recorded, with those in museums reported to be most successful. A general improvement was possibly discernible, but there is ongoing need of support from national and international geoscience organisations, together with need for increased funding and infrastructure and the raising of global awareness of the importance of geoscience education.

Introduction

The survey carried out in 2012 includes data from 32 countries across the globe.

The first international survey was carried out as part of the formation of the International Geoscience Education Organisation (IGEO) in Sydney in 2000. The IUGS Commission on Geoscience Education and Technology Transfer (IUGS-COGE) was formed in 2004 and a collaboration was developed between IGEO and IUGS-COGE to undertake a second survey, as the basis of a bid for International Year of Planet Earth (IYPE) funding. The second survey was carried out over 2005/6 and eventually included data from 27 countries. On the basis of the returns from these countries, a bid was submitted to the IYPE to run pilot workshops in geoscience education in three countries: the Philippines, South Africa and Trinidad and Tobago. The bid was unsuccessful.

During 2011, when a review was undertaken of the progress of IUGS-COGE, the Commission was asked to write an article for *Episodes* using the data collected in the international education survey. Rather than just depending upon the data collected in 2006, this seemed like an opportune time to update and expand the survey. Thus all the contributors to the 2006 survey were invited to update their data, whilst new members of IGEO and IUGS-COGE were contacted and asked to complete a questionnaire response as well.

The Third International Geoscience Education survey that resulted has now been published on the IGEO website (IGEO website) so that all those who contributed the data, and other interested people, can use the data collected, should they wish to.

No similar survey of the international state of geoscience education appears to have been undertaken or published previously.

The data

The survey published on the IGEO website contains data from the 32 countries listed in Table 1 and shown in Figure 1. Twenty countries provided data in 2012; for 12 countries, only the data from 2006 is available. All the contributors who kindly provided the data are acknowledged at the foot of this publication – but should not be blamed for any inaccuracies.

Inaccuracies may occur in the data or in the interpretation because:

- some questions were not clearly understood by some contributors, probably because English is not their first language;
- some of the answers provided were unclear, probably for the same reason;

Table 1. Countries which provided data for the geoscience education survey, with date of latest update

Country	Date of latest data update	Country	Date of latest data update
Argentina	2012	Malawi	2012
Australia	2006	New Zealand	2012
Bangladesh	2012	Norway	2012
Belgium	2006	Philippines	2012
Brazil	2012	Portugal	2006
Czech Republic	2006	Romania	2006
England	2012	Russia	2012
Estonia	2006	Saudi Arabia	2006
France	2006	Scotland	2006
Germany	2012	South Africa	2012
India	2012	Sri Lanka	2012
Indonesia	2012	Spain	2012
Israel	2012	Taiwan	2012
Italy	2012	Trinidad and Tobago	2006
Japan	2006	Uruguay	2006
Korea	2012	United States	2012

Figure 1. The distribution of countries which provided data for the geoscience education survey, with date of latest update schools – with thanks to Googlemaps. Countries providing 2012 data shown in pink, countries with 2006 data in yellow. This map can be found at: https://maps.google.co.uk/maps/myplaces?vpsrc=3&ctz=-60&abauth=50155a03et2mAy988IYCS2vq4qAgZS4UXIw&vps=1&num=10

- in order to summarise the data, simplifications were necessary, which may have led to inaccurate oversimplification;
- where a country has several states (eg. Germany, India, USA), the contributors pointed out that, because of variations across their countries, they have done their best to present a national picture, but this often just reflects the situation in some states.

Please report any inaccuracies to the author so that the data published on the IGEO website can be corrected and so that any further research based on this data is not compromised.

Note that the data may be biased by:

- colleagues from those countries willing to submit questionnaires; where countries have not participated, this may mean that school-level earth science education is less healthy;
- the experience and perceptions of those completing the questionnaires, ranging from Earth science teachers, to Heads of University Geoscience Departments and from teacher educators to government officials.

Data and analysis

Teaching approach

It was possible to identify eight different approaches to the school teaching of Earth science across the globe, as shown in Table 2, with the distribution shown in Figure 2.

The approaches and distributions show that Earth science is taught in a wide variety of different contexts across the world. Some patterns can be discerned, as follows:

- most Latin-American and southern European countries teach Earth science as part of 'Natural Science' where it is taught mainly by biology teachers;
- east Asian countries generally teach Earth science within science, where it is taught mainly by Earth science specialist teachers;
- in many countries, Earth science is taught both within science, by science specialist teachers, and in geography, by geography teachers;
- in some countries (Northern Europe), it is mainly taught only in geography.

Table 2. Approach to the teaching of Earth science in schools

Earth science teaching approach	Countries
Compulsory – part of Natural Sciences – taught mostly by biology teachers	Argentina, Brazil, Czech Republic, France, Italy, Portugal, Spain
Compulsory – part of chemistry and geography – taught mostly by these teachers	England, Sri Lanka
Compulsory – part of general science and geography – taught mostly by these teachers	Bangladesh, India, New Zealand, Norway, Russia
Compulsory – part of general science – taught mostly by these teachers	Israel, Philippines, South Africa
Compulsory – part of science – taught mostly by Earth science teachers	Japan, South Korea, Taiwan
Compulsory – part of geography – taught mostly by geography teachers	Belgium, Germany, Indonesia
Compulsory – part of primary science and geography – taught mostly by primary teachers	Scotland
Not compulsory	Malawi

Figure 2. The distribution of approaches to the teaching of Earth science in schools – with thanks to Googlemaps. This map can be found at: https://maps.google.co.uk/maps/myplaces?vpsrc=3&ctz=-60&abauth=50155a03et2mAy988IYCS2vq4qAgZS4UXIw&vps=1&num=10

These different contexts may affect the teaching style. For example, where Earth science is taught through science, more practical, hands-on approaches might be anticipated, whereas geography teachers may favour more map/ distribution/ hazards-based approaches.

National standards in Earth science

The majority of countries which contributed to the survey do have national standards for Earth science education, as shown in Table 3.

Table 3. National standards in school-level Earth science

Countries with National Standards in Earth Science		Countries with no National Standards in Earth Science
Argentina	Norway	Bangladesh
Brazil	Philippines	France
Czech Republic	Portugal	Germany
England	Romania	India
Estonia	Russia	Scotland
Indonesia	Saudi Arabia	
Israel	South Africa	
Italy	Sri Lanka	
Japan	Spain	
Korea	Taiwan	
Malawi	Trinidad & Tobago	
New Zealand	United States	

Ages of children covered by compulsory Earth science education

The compulsory coverage of Earth science is shown in Table 4.

The data shows that half the 5-7 year olds (52%) in the countries covered by the survey had compulsory Earth science education; four fifths of the 7-11 year olds (80%) were similarly covered, as were more than four fifths (84%) of 11-14 year olds and nearly three quarters (74%) of 14-16 year olds. However, only about a third of 16-18 year olds (35%) had compulsory Earth science coverage.

Table 4. The compulsory coverage of Earth science education (the 'Yes' responses are shaded)

Country	5 – 7 year olds	7 - 11 year olds	11 - 14 year olds	14 - 16 year olds	16 - 18 year olds
Argentina	Yes	Yes	Yes	Yes	Yes
Australia	Yes	Yes	Yes	Yes	No
Bangladesh	No	Yes	Yes	No	
Belgium	No	Yes	Yes	Yes	
Brazil	No	No	No	No	
Czech Republic	Partly yes	Yes	Yes	Yes	Yes
England	Yes	Yes	Yes	Yes	No
Estonia	No	Yes	Yes	Yes	Yes
France	No	No	No	No	No
Germany	No	Yes	Yes	Yes	Depends on the State
India	Yes	Yes	Yes	Yes	No
Indonesia	No	Yes	Yes	Yes	
Israel	Yes	Yes	Yes	Yes	Yes
Italy	Yes	Yes	Yes	Yes	Yes (in some schools)
Japan	Yes	Yes	Yes	Yes	Yes
Korea	Yes	Yes	Yes	Yes	Yes
Malawi	No	No	No	No	No
New Zealand	Yes	Yes	Yes	Yes	As part of Science or Biol
Norway	No	Yes	Yes	Yes	Optional
Philippines	Yes	Yes	Yes	Yes	Depends on school
Portugal	Yes	Yes	Yes	Yes	No
Romania	Yes	Yes	Yes	Yes	Yes
Russia	Yes	Yes	Yes	Yes	
Saudi Arabia	No	No	No	No	Yes
Scotland	Yes	Yes	Yes	No	No
South Africa	Yes	Yes	Yes	Yes	No
Sri Lanka	No	No	Yes	Yes	Yes
Taiwan		Yes	Yes	Yes	
Trinidad & Tobago	No	Yes	No	No	No
Uruguay	Yes	Yes	Yes	Yes	Yes
United States	Yes - in many states it is included in standards			No	No
Totals/31	**16 = 52%**	**25 = 80%**	**26 = 84%**	**23 = 74%**	**11 = 35%**

The data therefore indicates that there is reasonably good coverage in compulsory Earth science education across the globe – particularly for 7-16 year olds.

Textbook availability

The availability of textbooks and other teaching materials supporting Earth science education across the world is shown in Table 5. However, recent studies have suggested that many of these textbooks may contain poor quality material, with errors and oversimplifications (King, 2010).

Of the countries which contributed to the survey, more than half of 5-11 year olds (58% of 5-7 year olds, 52% of 7-11 year olds) had no textbooks and teaching materials, or materials of only poor quality; a third of 11-16 year olds (35% of 11-14 year olds and 42% of 14-16 year olds) had no or poor quality materials, whilst more than a third (39%) of 14-16 year olds were in a similar position.

If textbooks and teaching materials are poor or non-existent in more than a third of the countries surveyed, it might be construed that teaching is also poor in those areas. Even in those countries where better teaching materials are available, there may also be cause for concern if these materials are of poor quality and contain misconceptions.

Benchmarking on the basis of geoscience terms in the curriculum

The benchmarking attempt was made on the basis of the 124 geoscience terms shown in Table 6. Contributors were asked to indicate at which levels, if at all, these terms appeared in the

Table 5. Availability of textbooks and other teaching materials (the positive responses are shaded)

Country	5 – 7 years	7 – 11 years	11 – 14 years	14 – 16 years	16-18 years
Argentina	Poor				
Australia	No	Some	Some	Some	No
Belgium	Some	Some	Some	Some	Some
Brazil			One		
Czech Republic	Some	Some	Some	Some	Some
England	No	Some	Some	Some	Two
Estonia	No	Yes	Yes	Yes	Yes
France			Yes	Yes	Yes
Germany		Book and CD-ROM			CD-ROM (11 Modules)
India	A range of materials, including textbooks, guides and other materials is generally available.				
Indonesia	No	No	Geography textbooks	A geography textbook	
Israel	Yes	Yes - extensive	Yes - extensive	Yes - extensive	
Italy	Textbooks, CD-ROMs, videotapes, DVDs				
Japan	Yes – by Ministry of Education				
Korea	Textbooks by the national agency		Textbooks and other teaching materials by several publishers		
Malawi	Texts are available (geography) at all levels but are out-dated.				
New Zealand		Poor	One	One	
Norway	Several textbooks in geography and general science are available				
Philippines	Yes	Yes	Yes	To be developed	
Portugal	Textbooks	Textbooks	Textbooks/ worksheets	Textbooks/ worksheets	Textbooks
Romania		Yes	Yes	Yes	Yes
Russia	Yes	Text book in nature	Text book in geography	Text book in geography	Text book in geography
Saudi Arabia					Yes, textbook
Scotland	Yes				
South Africa	Yes		Yes - of variable quality		
Sri Lanka	No	No	Basic concepts included	Basic concepts included	Geography textbook
Spain	No		Textbooks, CD-ROMs, videotapes, DVDs in Spanish + other langs.		
Taiwan	One	One	One	One	
Trinidad & Tobago	Textbooks, worksheets	Textbooks, worksheets	Textbooks, worksheets	Textbooks, worksheets	Textbooks, worksheets
Uruguay			Geography	Geography	
United States	FOSS (Full Option Science System)	ESIP (Earth Systems Programme Implementation Project) Project	*Investigating Earth Systems* (IES) curriculum Project CUES	*EarthComm* curriculum http://edmall.gsfc.nasa.gov/aacps/curriculum.html	Advanced Placement Environmental Science
Good quality total/31	**13 = 42%**	**15 = 48%**	**20 = 65%**	**18 = 58%**	**19 = 61%**

Table 6. Terms used to benchmark the Earth science content of the curriculum across the world

General material/ process terms (37)	Plate tectonic and Earth structure terms (12)	Geological time and evolution terms (8)	Natural resource and natural hazard terms (28)	Rock types (19)	Approach – terms used in an Earth science context or in a general context that applies to Earth science (20)
• Mineral • Fossil • Rock • Soil • Atmosphere • Carbon cycle • Water • Water cycle • River/lake • Sea/ocean • Coast/beach/cliff • Mountain/ hill Valley • Wind/eolian • Ice/glacial • Rock cycle • Weathering • Erosion • Deposition • Lithification/ compaction/ cementation • Sediment/ sedimentary • Metamorphic • Igneous • Volcano/volcanic • Eruption • Magma • Lava • Ash • Melting/melt • Partial melting/ melt • Fractional crystallization/ magmatic differentiation • Earthquake • Seismic/P/S waves • Focus/epicentre • Fold/ folding • Fault/faulting • Deformation	• Plate tectonics/ tectonic plate • Lithosphere • Asthenosphere • Subduction • Magnetic stripes • Polar wandering • Mountain building/ orogeny • Continental/ oceanic plate • Crust • Mantle • Core • Outer core/ inner core	• Geological time/ timescale • Dating • Correlation • Stratigraphy • Earth history • Evolution • Natural selection • Fossil record	• Energy source/supply • Renewable/ non renewable • Sustainable/ sustainability • Groundwater • Pollution • Acid rain • Ore • Mine/mining • Quarry/quarrying • Borehole/ well • Fossil fuel • Coal • Oil/ crude oil • Gas/ natural gas • Hydroelectric power • Solar power • Wave power • Wind power • Power from biomass • Landslide/ landslip/ rock fall • Lahar • Nueé ardente • Tsunami • Storm • Flood • Natural hazard • Prediction/ forecast • Disaster planning (or similar)	• Sandstone • Limestone • Shale/ mudstone/ clay • Conglomerate • Coal • Peat • Slate • Schist • Gneiss • Marble • Quartzite/ metaquartzite • Granite • Gabbro • Basalt • Dolerite • Volcanic ash • Andesite • Rhyolite • Peridotite	• Sort/ sorting • Identify/ identification/ recognise • Classify/ classification • Describe/ description • Measure • Explore • Explain/ explanation • Fieldwork/ in the field • Plan • Observe • Experiment with • Interpret • Analyze • Give evidence • Predict • Apply • Evaluate • Enquiry • History of science • Map/ mapwork

curriculum. 25 questionnaire responses were received, and the results are shown in Table 7.

The data shows that, on average, 79% of the 124 terms are found somewhere in the curriculum, broken down to 6% of the terms for 5-7 year olds; 23% of the terms for 7-11 year olds; 45% for 11-14 year olds; 49% for 14-16 year olds; and 58% for 16-18 year olds.

It is not surprising that an increasing number of the terms appear in the curriculum as the ages of children increases. It is also not surprising that all the terms don't necessarily appear at the higher levels, since some may be simpler terms, more appropriate for younger children.

Overall, it could be argued that a reasonable number of geoscience terms is covered by Earth science curricula across the world, even though the situation is rather 'patchy'. This 'patchy' nature can partly be explained by some countries publishing detailed content-filled curricula whilst others have adopted a more 'umbrella' approach, of publishing broad Earth science statements and leaving teachers and examiners to provide the necessary detail.

Availability of optional geoscience education courses

The availability of optional courses in school/college-level geoscience education is shown in Table 8.

The data indicates that, of the countries covered by the survey,

Table 7. Summary of benchmarking data (based on the 124 terms listed in Table 6)

Country	Term is present in curriculum	For 5 – 7 year olds	For 7 – 11 year olds	For 11 – 14 year olds	For 14 – 16 year olds	For 16 – 18 year olds
Bangladesh	11	0	0	11	0	0
Belgium	108	15	44	30	56	105
Brazil	72	0	0	61	15	0
England	60	7	17	40	25	0
Estonia	120	0	47	80	116	120
France	124	1	7	71	111	124
Germany (Lower Saxony)	42	0	2	27	7	12
Indonesia	112	5	10	65	93	112
Israel	112	18	62	92	94	112
Italy	55	15	5	23	14	28
Korea	123	20	79	113	121	123
Malawi	85	8	35	47	53	85
New Zealand	91	7	25	74	43	37
Norway	48	1	10	12	24	43
Portugal	105	20	54	73	87	85
Romania	104	3	18	73	91	104
Russia	128	6	33 - 35	60	26	0
Scotland	31	0	1	14	0	0
South Africa	96	2	3	49	76	107
Saudi Arabia	118	1	9	11	11	86
Sri Lanka	102	5	15	43	91	102
Spain	124	41	85	103	116	124
Taiwan	96	15	40	83	107	97
Trinidad & Tobago	76	19	25	46	36	48
Uruguay	108	0	66	94	103	103
Mean/25	89 = 72%	8 = 6%	28 = 23%	56 = 45%	61 = 49%	72 = 58%

nearly two thirds (61%) have optional geoscience education courses and that these are mostly available to 16-18 year olds in small numbers of schools. Where they are available, they usually can be used to contribute to university entry qualifications. Whilst the global availability of such courses is to be welcomed, it is concerning to note that they are generally only available to small numbers of 16-18 year olds in most countries.

Earth science outreach

Different types of potential Earth science outreach are shown in Tables 9 and 10 with a perception of their effectiveness and how widespread they are.

The data indicates that, where available, the different forms of outreach are widespread to fairly widespread across countries.

Table 9 shows that the most successful forms of Earth science outreach are run by museums in most of the countries surveyed (84%) and that these outreach activities can be very effective; mostly they are effective to fairly effective.

Interactive science centres are available in more than half the countries and are effective to fairly effective. Meanwhile national parks and parks with an Earth science focus are available in around half the countries (national parks – 55%, parks with an Earth science focus – 48%), and are fairly effective.

Networks protecting Earth science sites are available in nearly a third of countries (32%) and are effective to fairly effective.

Table 10 indicates that around a third of the countries have public understanding organisations focussing on Earth science (35%), local "rockhound" groups (39%), groups aimed at children (35%) and Public Understanding of Science events with Earth science content (32%). In general these strategies are effective to fairly effective and widespread to fairly widespread.

These Earth science outreach strategies are to be applauded, particularly where they are effective and widespread, but clearly need more dissemination and support elsewhere. The most successful programmes recorded across the world are listed in Table 11.

Undergraduate and graduate geoscience education

Table 12 lists the numbers of undergraduate and graduate programmes found in the contributing countries.

The figures, although they range from 1 to perhaps 600 intuitions per country offering undergraduate education and 1 to 336 offering postgraduate education, are not very meaningful. At most they probably show that, the more developed and larger a country, the more institutions offer geoscience at Higher Education level.

In only two countries (Taiwan and Germany for geography) do the geoscience higher education institutions have a role in mentoring school teachers of Earth science. Elsewhere, no such links are recorded.

Major problems facing school-level geoscience education

The open-ended responses to this question were wide, varied and difficult to summarise. They do however, need to be set against recent successes in Australia, Norway and the Philippines. In Norway, the

Table 8. The global availability of optional geoscience education courses (the positive responses are shaded)

Country	Are optional earth science or geoscience courses offered in schools/ colleges?	At what age are they available?	Are they available to all/ most/ a few/ hardly any pupils across the system?	Do earth science/ geoscience courses satisfy college or university science entrance requirements?
Argentina	No			
Australia	Yes	16-18 year olds	Small number	Yes
Bangladesh	No			
Brazil	No, but mining courses and environmental sciences training in some technical colleges	17-19 year olds	Few	No courses but some related questions in exams
Czech Republic	Very rarely	17-19 year olds		
England	Yes	16-18 year olds	Hardly any	Yes
Estonia	No			
France	No			
Germany	Yes (depends on the Federal State)	10-16 year olds	No	No
India	No for schools, Yes for colleges	19 year olds	A few	Yes
Indonesia	Technical High Schools offer Mine and Geology courses	15/16-18/19 year olds (schools)	Only for those who take Technical High School	No
Israel	Yes	16-18 year olds	Few	Yes
Italy	No			
Japan	Yes	15-18 year olds	Only students who want to major in earth science-related studies at university take these elective courses	Around 4% of all students chose earth science I as one of their college entrance exam areas in 2008
Korea	Yes	16-18 year olds	Students who want to major earth science-related studies at the university take these elective courses	Around 17% of all students chose earth science as one of their college entrance exam areas in 2004
Malawi	Yes	After the age of 16	Available to all science students	Yes
New Zealand	Yes, but now very reduced to almost none	Years 11-13	Depends on school	Yes
Norway	Yes	17-19 year olds	Depends on the school	Yes
Philippines	Yes	13+ years	No	No
Portugal	In some professional schools			No
Romania	Yes	11-18 year olds		Yes
Russia	Yes	Secondary school level	Students who want to major Earth science-related studies at the university take elective courses	Not enough
Saudi Arabia	No			
Scotland	Yes	14+	Few	Yes
South Africa	No			
Spain	Yes	16-18 year olds	Only to science branch pupils	Yes
Sri Lanka	No			
Taiwan	Yes	Years 11 and 12		Yes
Trinidad & Tobago	No			
United States	Available in some schools.	Varies	Depends on the school.	Variable. Some universities/ colleges do accept geology others do not.
Uruguay	No			
Total/31	**19 = 61%**	**Mostly 16-18 year olds**	**Generally small numbers**	**Mostly 'yes'**

Table 9. The availability of Earth science outreach in museums, interactive science centers, national parks, parks with an Earth science focus and networks protecting Earth science sites (the paler the shade, the less effective/widespread – where limited data are available, this is shown in white) (Key: V = very; F = fairly; Ef = effective; Wi = widespread)

Country	Museums		Interactive science centers		National parks		Parks with an Earth Science focus		Networks protecting Earth science sites	
Argentina										
Australia	Ef	Wi	Ef	Wi	F Ef	F Wi				
Bangladesh	One									
Belgium	V Ef	V Wi	V Ef	Wi						
Brazil	V Ef	Wi	Some		F Ef	F Wi	Four		Yes	
Czech Republic	Ef	Wi			F Ef	Wi	Wi			
England	Ef	F Wi					Several		Ef	Wi
Estonia	Ef	Wi	F Ef	Wi	F Ef	Wi	F Ef	Wi		
France	Ef	F Wi	Ef	F Wi	F Ef	F Wi	F Ef	F Wi	F Ef	F Wi
Germany	F Ef	Wi	F Ef	F Wi			F Ef	F Wi		
India	Some		Ef				Ef			
Indonesia	F Ef	F Wi	Ef	F Wi	F Ef	F Wi	F Ef	F Wi	Ef	Wi
Israel	F Ef	F Wi	F Ef	F Wi	F Ef	F Wi	F Ef	F Wi	F Ef	F Wi
Italy	V Ef	Wi			F Ef	F Wi	F Ef	F Wi	F Ef	F Wi
Japan	Ef	F Wi	Ef	F Wi	F Ef	F Wi				
Korea	V Ef	V Wi	F Ef	F Wi	F Ef	F Wi	F Ef	F Wi	F Ef	F Wi
Malawi										
New Zealand	F Ef	F Wi	One		Minimal		One			
Norway	F Ef	F Wi	F Ef	F Wi			Two			
Portugal			Ef	Wi			Ef	Wi		
Philippines	Ef		Ef		Ef					
Romania	Ef	Wi	F Ef	F Wi	Ef F	Wi	F Ef	F Wi	F Ef	F Wi
Russia	F Ef	F Wi	One				F Ef	F Wi		
Saudi Arabia	F Ef	F Wi	F Ef		Ef	Wi				
Scotland	F Ef	F Wi			F Ef	F Wi	One		F Ef	F Wi
South Africa	F Ef	F Wi					Two		Small scale	
Sri Lanka	V Ef	Wi	Some							
Spain	V Ef	Wi	V Ef	F Wi	Ef	V Wi	Ef	F Wi	Ef F	Wi
Taiwan	F Ef	F Wi	Ef	F Wi	V Ef	Wi	V Ef	Wi	Ef	Wi
Trinidad & Tobago			Ef	Wi						
United States	Ef	Wi	Ef	Wi	Ef	Wi	Ef	Wi		
Uruguay	V Ef	V Wi								
Totals/31	**26 = 84%**		**19 = 61%**		**17 = 55%**		**15 = 48%**		**10 = 32%**	

new optional geoscience courses are proving increasingly popular to 16-18 year olds, whilst recent revamps of the science curriculum in Australia and the Philippines has seen increased content of Earth science at all levels.

Elsewhere, some of the key comments recorded were as follows.

- Lack of support for school-level geoscience education from the science education community (biology, chemistry and physics).
- Lack of support for school-level geoscience education from geoscientists – particularly those in Higher Education.
- The teaching of school geoscience by non-specialist teachers (eg. specialists in geography, chemistry, etc.).
- Earth science being taught in poor, didactic ways with few examples, by non-specialist teachers.
- Lack of Earth science-focussed teacher training.
- Poor Earth science teaching resources.
- Lack of an internationally agreed Earth science curriculum – promoted across the globe.

A summary

The data from the biased sample of the 32 counties included in the survey can be summarised as follows.

- **Curricula** - across the world, Earth science is included in science and geography curricula in a variety of different ways
- **Standards** - most countries have national standards for Earth science
- **Global coverage** – there is fairly good coverage of Earth science in the school curriculum globally – particularly for 7 – 16 year olds

Table 10. The availability of Earth science outreach in Public Understanding organisations focussing on Earth science, local "rockhound" groups, groups aimed at children and Earth science content of local Public Understanding of Science events (the paler the shade, the less effective/widespread – where limited data are available, this is shown in white). (Key: V = very; F = fairly; Ef = effective; Wi = widespread)

Country	Public understanding organizations focusing on Earth science		Local "rockhound" group		Group aimed at children		Earth science content in local Public Understanding of Science Events	
Argentina							One	
Australia			F Ef	F Wi				
Bangladesh	One							
Belgium								
Brazil							Some	
Czech Republic	Magazines				V Wi			
England			Ef	Wi	1 national		F Wi	
Estonia								
France	F Ef	F Wi						
Germany								
India	F Ef				F Ef		F Ef	
Indonesia	Ef	Wi	Ef	Wi	F Ef	F Wi	Ef	Wi
Israel	F Ef	F Wi	F Ef	F Wi	F Ef	F Wi	F Ef	F Wi
Italy							Ef	Wi
Japan								
Korea	V Ef	V Wi	F Ef	F Wi	F Ef	F Wi	F Ef	F Wi
Malawi			F Ef					
New Zealand								
Norway	Geol Day				F Ef	F Wi	F Ef	F Wi
Portugal								
Philippines	Ef		F Ef		F Ef		V Ef	
Romania	F Ef	F Wi	F Ef	F Wi	F Ef	F Wi	F Ef	F Wi
Russia	Magazine				F Ef	F Wi	Some	
Saudi Arabia								
Scotland								
South Africa			F Ef	F Wi	Some		Some	
Sri Lanka								
Spain							V Ef	V Wi
Taiwan	Ef	F Wi	V Ef	F Wi	Ef	Wi		
Trinidad & Tobago	Ef	F Wi						
United States	Ef	Wi	Wi		F Ef	F Wi	Some	
Uruguay	V Ef	V Wi	V Ef	V Wi	Two			
Totals/31	**11 = 35%**		**12 = 39%**		**11 = 35%**		**10 = 32%**	

- **Textbooks** – more than half the textbooks for elementary students and more than a third of textbooks for high school students are of poor quality or are not available
- **Benchmarking** – a reasonably high number of geoscience terms is included in curricula across the world, with the numbers of terms increasing up the age range.
- **Optional geoscience courses** – these are available in schools/ colleges in more than half the countries surveyed – but mainly for small numbers of 16-18 year olds.
- **Outreach** – Earth science outreach across the globe is variable, with a wide variety of different programmes – however, it is difficult to discern a particular pattern of success
- **Higher Education** – the numbers of courses available to undergraduates and postgraduates appears to depend mainly on the level of development and size of the country concerned.
- **Mentoring** – lecturers in Higher Education institutions very rarely mentor school teachers.

Overall, the data indicates that most global developments in Earth science education at school level have been driven by enthusiastic individuals and groups. This being the case, it is not surprising that global development is very patchy. Nevertheless, a general improvement is probably discernible.

Table 11. Records of successful Earth science outreach programmes across the world

Country	Programme
Argentina	Earth Science Week at the University of Buenos Aires
Bangladesh	• Bangladesh National Museum programmes • Mobile educational programmes in some remote areas
Belgium	• Exposition "Dinosaures" - Musée des Sciences Naturelles – Bruxelles • Exposition permanente - Musée africain Tervueren • Expositions minéralogiques temporaires
Brazil	"Caminhos Geologicos: Educacao em Geociencias" ("Geology tracks: Geoscience Education")
France	EDUSISMO LITHOTHEQUE
India	Earth Science Olympiad
Indonesia	• Geoscience course for geography teachers conducted by universities, museums or government agencies. • Talks to local government officers and community by universities or government agencies, especially related to the community service programme of each institution.
Israel	The Weizmann's programme
Italy	• Programs during the International Year of Planet Earth (IYPE) • Earth Learning Idea translations
Japan	Natural History Museums and Science Centres developed many programmes.
Korea	• Science centres operated by the 'Science Education and Science Research Institute (SESRI)' • National science museum/centres located in metropolitan areas
New Zealand	• Language of the Rocks • Univ. of Canterbury • Most University outreach programmes • Royal Society initiatives • Te Papa museum programmes
Norway	5 year 'Geo programme' sponsored by Statoil http://www.naturfagsenteret.no/c1480828/seksjon.html?tid=1488151
Philippines	National Selection for the International Earth Science Olympiad (IESO)
Portugal	Geology in summer
Romania	National Geographic Competition
Russia	• Summer geological school • Geographic Competitions at different levels
South Africa	• Cradle of Humankind • Geological Museum at Museum Africa • National Museum Bloemfontein Palaeontology • Origins Centre - University of the Witwatersrand • Sci-Bono Science Centre • University of Bloemfontein/ EarthWise • University of Kwa-Zulu Natal Science Centre • University of Witwatersrand Geosciences Outreach
Spain	• Bi-annual meetings' on earth science teaching (organized by the AEPECT) • Jornadas sobre Didáctica de Biología y Geología • Summer geological trips • Geolodays
Sri Lanka	• "Earth science for schools" teacher training workshops organized by Geological Society of Sri Lanka • National Olympiad Competition for school students organized by Geological Society of Sri Lanka and the Department of Geology, University of Peradeniya
United States	• Earth Science Week (2nd week of October) sponsored by the American Geological Institute offers many groups suggestions and opportunities to promote the Geosciences. • Many groups and organisations work at local and regional levels to promote geoscience with varying success.

Table 12. Numbers of establishments offering undergraduate and graduate geoscience programmes

Country	How many offer undergraduate degrees in the geosciences or closely related fields?	How many offer geoscience graduate (postgraduate) degrees?
Argentina	14	All of them offer MSc and PhD degrees and orientation courses
Australia	16	16
Bangladesh	3	3
Brazil	34	
England	20	20
Estonia	Yes	Yes
Germany	28	28
India	A few - exact number not known	Several Master courses in different areas of geosciences
Israel	3	3
Italy	29	29
Indonesia	19 (State and Private)	4 (State)
Japan	Many	
Korea	Many	
Malawi	1	1
New Zealand	7	5
Norway	Approximately 9	9
Philippines	5	1
Portugal	Yes	Several Master courses in different areas of geosciences
Russia	36	36
Saudi Arabia	3	2
Scotland	5	5
South Africa	10	10
Spain	10 degrees in geology and 7 mining engineering	All of them offer specific postgraduate programs
Sri Lanka	5	2
Taiwan	30	10
Trinidad & Tobago	1	0
United States	More than 600 institutions "have geology programs, grant geology degrees, or offer geology courses" but not all offer degrees	190 programs that offer Doctorate degrees and 336 programs that offer a Master degree in earth science, geology and environmental science.
27 countries	Range from 1 to perhaps 600; where definite figures are available, mean of 13	Range from 1 to 336; where definite figures are available (excluding US), mean of 10

Despite this, there is no doubt that school-level geoscience education needs more support, in particular:

- the coordinated support of national geoscience communities (for example, by highlighting the contribution of school-level geoscience to undergraduate recruitment – see King, 2011a);
- the support of the international geoscience community;
- the raising of awareness with governments (for example, by highlighting the fact that some of the highest-performing countries in international comparisons in school science have Earth science as a substantial part of the curriculum, for example Japan, Korea and Taiwan (see King, 2011b);
- more resources and infrastructure to fund teacher training in geoscience education, particularly of the science and geography teachers who teach Earth science (eg. see King & Thomas, 2012);
- more resources to fund the development and dissemination of high quality teaching resources;
- better global networking;
- better support for individuals and teams of enthusiasts in different regions and countries seeking to support and enhance the teaching of geoscience in their own communities.

There are success stories in school-level geoscience education across the globe, and these successes need to be celebrated, and the lessons learned from them distilled and disseminated worldwide, through active national and global support networks.

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Table 13. The major problems facing geoscience education (free response)

Country	What do you see as the major problems facing geoscience education in your country?
Bangladesh	• Lack of proper education for students to realize the importance of geoscience education and lack of initiative from concerned people i.e., geoscientific community are the major problems. • Moreover, low literacy rates and economic conditions are also problems facing geoscience education in our country.
Estonia	· Estonia participated in TIMSS 2003. In geography Estonian students were the best in the world!!!
Germany	• The geography curricula emphasize anthropogeography. • The curricula of biology, physics and chemistry barely focus on geoscience topics. • Many geography teachers do not have a sound science education. • The tradition of teaching geoscience topics in geography: very descriptive, quite idiographic, less process-oriented, less connected to biology/ chemistry/ physics.
India	• Geoscience marketing is important because the scientific community doesn't realize the applications of geoscience. • Geoscience careers should be made attractive so that the best talent can be attracted. • Massive Funding is required to promote the subject.
Indonesia	• The curricula have been changed or modified several times; attention to improving the method of teaching and student creativity seems to have been overlooked in each curriculum modification. • Lack of teachers who can manage all subjects and lack of educational funding exacerbate the education problems. We found the following deficiencies especially in geography: • Topics are introduced too early and in too much detail in the elementary school (Year four elementary school). Too much detailed information (but without real examples) make it difficult for pupils to understand. • Some information concerning rock formation and rock classification are not correctly introduced to students. • Lack of real and attractive examples, such as rock samples, slides, CDs, videos, field visits, make this subject un-interesting and rather difficult to understand. • Lack of available funds. • All of the above deficiencies result in poor knowledge, poor understanding and poor appreciation by the public of geoscience. Consequently, when there are any problems concerned with geological hazards, such as landslides, floods, earthquakes, volcanic eruptions, it is hard to warn and protect the public. Some other remarks are: • Geoscience marketing is important because the community doesn't realize what geoscience is. • Geoscience knowledge should be taught earlier in schools, beside the applied technology science. • Educate the lecturers in the Universities and government officials on how to transfer geoscientific knowledge to the entire community. • Funds are needed for improving geoscience education for the community.
Israel	• Although there have been great effort s and successes with students and teachers, the implementation of earth science education in Israel is still limited. • The main reason for that is the science education establishment. This establishment is influenced strongly by committees of scientists, who actually decide what will be taught in practice in schools. Unfortunately, those committees are composed of scientists from physics, chemistry and biology. No earth scientist takes part in these committees firstly because the leaders of these committees don't allowed this to happen and secondly because of the earth scientists don't fight strongly enough to be included. • As a result, whenever we succeed in raising our profile in schools, these committees respond with new decisions that make teachers to stop teaching earth science.
Korea	• There are activities by those active in physics education, chemistry education, and biology education, but not earth science or geo education.
Malawi	• Students are not adequately exposed to earth science at an early stage; Earth science as a subject is offered at undergraduate level. This unawareness has led to the students thinking that geography is just the same as earth science. The shortage of earth scientists in Malawi is obvious.
New Zealand	• Earth science continues to be a major issue in curriculum design. New Zealand is just beginning a review of the national science curriculum in which earth science makes up the fourth strand. • A key issue is teacher training and the role teacher training establishments play in this. There is no independent earth science department dedicated to training the teaching of earth science. Indeed, the lack of teacher expertise in earth science is a major concern, as is a lack of resources and funding. • There is less focus on inquiry and laboratory investigation for geoscience. Fieldwork has been almost non-existent for some time. • External examination for geoscience has now been removed from Year 11 Science. Very few students nationally engage with geoscience after year 11 (and numbers continue to decline at year 11).

Table 13. Contd...

Country	What do you see as the major problems facing geoscience education in your country?
Norway	• Students choose the optional geoscience course because it is interesting and relevant for their understanding of the news, e.g. earthquakes and extreme weather. The number of students choosing the optional subject is steadily increasing every year. • The Norway Center for Science Education has also been contacted by Sweden in order for them to learn about Norwegian geoscience education; we are also in contact with Denmark
Philippines	• Because of the new K+12 curriculum, we need more educational resources to address the requirements of the curriculum • Also because of the new K+12 curriculum, the Teacher Education institutions need restructuring. Specializations must now include Earth Science, among others. But the problem will be the "experts' who will teach the Earth Science subjects.
Russia	• To provide the baseline standards the Government has established standard curricula for the whole school, "Introduction to the geology" within the subject of geography. • However, geology in the standard of geography doesn't have enough teaching time.
South Africa	• Geosciences is unlikely to ever be taught as a main subject as there are simply too many competing well established subjects • Teacher training is required to strengthen the geosciences component of the subjects they are already teaching • Museums out of school informal learning centres need assistance in developing high quality and assessed curriculum related earth science programmes to support teaching in schools • Continued interaction with committees responsible for drafting curriculum statements is required so that the curriculum contains (in whatever subject) the essentials knowledge of Geosciences required by every citizen. • [Internationally it would help if there could be agreement amongst Geoscience educators about what this knowledge is] • At the tertiary level we have difficulty attracting good students into geosciences related fields- good students study medicine, commerce, engineering etc. etc. Weaker students want to do geology because of the prospects of jobs in the mineral industry • At the tertiary level we have a problem of retiring academics with few candidates to replace them. Good postgraduates are attracted into industry or to study overseas. • With regard to teacher training- few geologists with the job prospects of the mineral industry enter into secondary education or into teacher training- teacher trainers will often therefore, only have primary training in one or another of science disciplines (biology or physical sciences)
Sri Lanka	The main problems in promoting geoscience education in Sri Lanka are: • geoscience is not taught as a main subject in school curriculum, • lack of awareness of geosciences among school students, • lack of awareness about geoscience-related job opportunities, • shortage of earth science learning materials in schools, etc.
Trinidad & Tobago	• The high stakes 'end of primary' exam only tests math and language skills so many schools opt to teach little or no social studies and science in the two years preceding this exam.

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	A. Pitawala
Spain	Xavier Juan
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References

King, C. J. H., 2010, An Analysis of Misconceptions in Science Textbooks: Earth science in England and Wales. International Journal of Science Education, v. 32, no. 5, pp. 565–601.

King, C., 2011a, What does it mean to be a trained geology teacher? – and what should we do to keep training geology teachers? Teaching Earth Sciences, v. 36, no. 2, pp. 52-55.

King, C., 2011b, Where should Earth science be situated in the curriculum? Teaching Earth Sciences, v. 36, no. 2, pp. 56-60.

King, C. & Thomas, A., 2012, ESEU: report on the 2-year pilot and 10-year national rollout. ESEU Internal Report, April 2012. (available from the author)

International Geoscience Education Organisation (IGEO) website: http://www.geoscied.org/, 'About the IGEO' section, last accessed December 2012.

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Phanerozoic continental crust evolution of the Inner Caucasian Microplate: The Dzirula massif

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In the Pre-Alpine Dzirula massif of the Inner Caucasian Microplate is coded a wide spectrum of the geodynamic and magmatic events taking place in the region and that's why it represents important and major structure for general geological interpretations. In the given work, on the example of the mentioned crystalline massif evolution are considered processes of the continental crust in Phanerozoic collisional orogens. We consider, that in Variscan consolidation Dzirula massif formations of the Neoproterozoic Pan-African tectonic-thermal events are observed, that are organically involved in the evolution processes of the Caucasian Phanerozoic collisional orogen and their role in these processes are probably caused by the migration of lithospheric residues to the north, that are formed as a result of Gondwana northern edge Late Ordovician destruction and opening of Palaeo-Tethys. Within the Dzirula massif, a Gondwana-derived Neoproterozoic gneiss-migmatite complex is situated obductively on ensialic island arc. In this Variscan collision-accretion structure, the crustal thickening and released water caused partial melting of the ensialic island arc, thus generating the granitoid melt, which intruded the overlying gneiss-migmatite complex. By the end of this process, the Dzirula massif resembled typical Phanerozoic continental crust.

Introduction

The Neoproterozoic marks the onset of modern plate tectonic systems (Stern, 2008), and as such the crust-forming processes preserved from the Pan-African evolution of Gondwana records this critical time period. The early tectonic history is frequently overprinted by younger events, but some of these areas are exposed in basement uplifts within the Alpine orogenic belt. The Dzirula massif in the central part of the Inner Caucasian Microplate in the Republic of Georgia is one of these windows. It exposes pre-Alpine basement, and contains a wide range of granitoids of different pre-Alpine ages. Geochemical and geochronological data provided in this paper helps shed light on crust-forming processes and geodynamics in this critical age range.

Most continental crust was formed from mantle-derived magma before Late Proterozoic, and most intensively in the interval of 3.2-2.5 Ba (Taylor and McLennan, 1985) when the earth's crust was divided into granulite-basic and granulite-gneissic. Crust formation at the end of Proterozoic and the Phanerozoic occurred as a result of lithospheric thickening, and granite-forming processes were localized at subduction zones. Here the continental crust was formed as a result of lateral and vertical accretion of island arc complexes at active continental margins or by mantle-derived magmatic additions. The application of integrated isotopic studies of Nd, Sr, and Ar isotope systematics in the North American Cordillera (Allegre, Ben Othman, 1980; DePaolo, 1981; DePaolo et al., 1991; Samson and Patchett, 1991) in Lachland orogen in the Eastern Australia (Collins, 1998); in Meguma lithotectonic zone in the NE Canada (Clarke et al., 1992); in central Asia (Jahn et al., 2000); in the Shyok-Darbuk corridor of NE Ladakh, in India (Daga et al., 2010) have largely supported this view of crustal formation.

The Pre-Alpine consolidation Dzirula massif is a good example of Phanerozoic lithospheric thickening and continental crustal formation. It is located in the North side of the Caucasus Orogen and represents a complicated and the widest outcropped part of the Pre-Alpine crystalline basement. As a result of the collision and of generation new magmatic centers Neoproterozoic granite-migmatite complex and ophiolites, Cambrian tonalites, Late Paleozoic microcline granites and Triassic orthoclase gabbros (ricothites) were gathered within the borders of the Dzitula massif. In the pre-Cambrian crystalline schist structure and as well as in composition of Phanerozioc magamtites reflects the whole deformation and the new magmatic center generation processes. The significant part of the regional geological events, starting from the Neoproterozoic up to Alpine, it is clear that in the structure and composition of this massif is encoded. It therefore Dzirula massif represents an important object for investigation of Proterozoic to Phanerozoic continental crust evolution. Although well-mapped, there are few isotopic or geological studies of the area (Okrostsvaridze and Clarke, 2003, 2004; Zakariadze et al., 1998). We use these geochemical constraints to further constrain the geodynamic and continental crust-forming processes in this area.

Tectonic setting

The Caucasus represents the Northern segment of the Eastern Mediterranean orogen, which is expended over 1200 km between the Black and Caspian Seas, at the NW-SE direction. Currently it is an expression of continental collision between the Arabian and Eurasian lithospheric plates and its location represents the connecting segment between the Alpine and Himalayan mobile belts. Three major unites are distinguished Structurally in the Caucasian Construction: the

Greater and Lesser Caucasian mobile belts and the Inner Caucasian Microplate.

Paleomagnetic and palaeochemical as well as geological data indicate that within the oceanic area of Tethys, which separated Afro-Arabian and Eurasian continental plates, there were relatively small continental or subcontinental plates (terranes) having various geodynamic and geological histories (Gamkrelidze, 1997; Stampfli et al., 2002). During the Late Precambrian, Paleozoic and Early Mesozoic, these terranes underwent horizontal displacement within the oceanic area of Proto-Paleo- and Meso-Tethys, followed by accretion and ultimately merging with the Eurasian continent. The Arabian and Eurasian lithospheric plates are separated by the Greater Caucasian, Black Sea-Central Transcaucasian, Baibut-Sevanian (Lesser Caucasian) and Iran-Afghan terranes (Gamkrelidze, 1997), which in the geological past represented island arcs or microcontinents (Figure 1). The Black Sea-Central Transcaucasian terrane now is situated between the Greater and Lesser Caucasian mobile belts and we consider it as the Inner Caucasian Microplate.

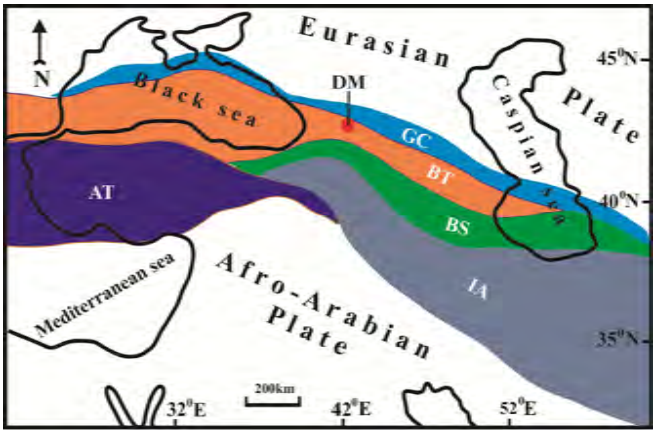

Figure 1. Tectonic zoning of the Caucasus and adjacent area on the basis of the terrane analysis (After Gamkrelidze, 1997). Terranes: GC – Greater Caucasian, BT – Black Sea-Central Transcaucasian, BS – Beiburt-Sevanian, IA – Iran-Afganian, AT – Anatolian. DM – Dzirula massif.

The Inner Caucasian Microplate consists of a pre-Alpine crystalline basement, exposed in the Dzirula and Khrami massifs, that is overlain by an Alpine, non-metamorphosed and moderately folded, nearly 10 km thick through Meso-Cenozoic volcano-sedimentary cover. The Dzirula massif reflects much wider and more interesting spectrum of geological processes, due to that we decided to study it.

Brief geological survey

The Dzirula massif is exposed in the northen part of the Inner Caucasian Microplate and occupies nearly 1200 km^2 at the current of erosion level (Figure 2). It is mainly constructed by Neoproterozoic plagiomigmatites, crystalline schists, and quartz-dioritic gneisses and ophiolites (gneiss-migmatite complex); Cambrian tonalities and granodiorites; Late Paleozoic anatectic microcline granites; and Late Triassic hybrid orthoclase gabbros (rikotites).

Most of the Dzirula massif is composed of the gneiss-migmatite complex. Its protolith was represented by crystalline schists, plagiogneisses and plagiomigmatites, which underwent the

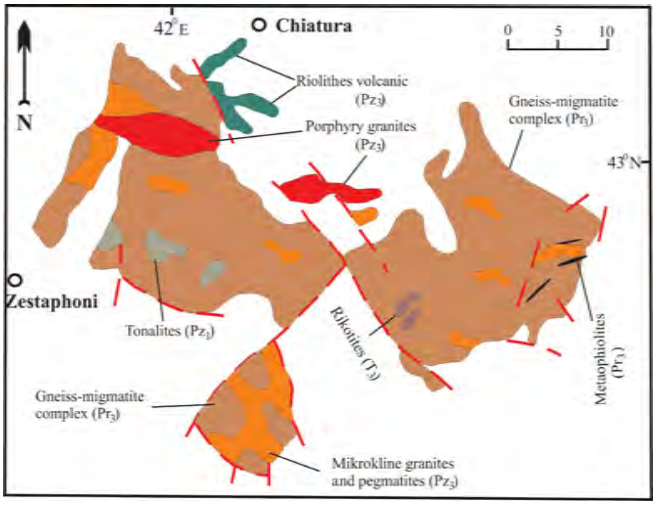

Figure 2. Schematic geological map of the Dzirula massif of the Inner Caucasian Microplate.

Grenvilian regional metamorphism. The wrinkled restites of these rocks, the size of which ranges between one to tens of meters, are found in the Neoproterozoic quartz-dioritic gneisses. Most are represented by metapelites, which underwent regional metamorphism to biotite-muscovite-gneiss, biotite-sillimanite-orthoclase and low-temperature garnet-cordierite-orthoclase facies (Gamkrelidze, Shengelia, 2005).

In the Cambrian, during Pan-African tectonic-thermal events, several tonalite composition bodies were generated in the gneiss-migmatite complex. Later, in the Upper Paleozoic Variscan tectonic-thermal events, numerous intrusions of microcline granites were emplaced, and most of the gneiss-migmatite complex transformed into granite-gneisses, granite-migmatites and porphyroblastic microcline granites.

The northeastern part of the Dzirula massif contains Neoproterozoic ophiolite fragments, and is known as the Chorchana-Utslevi Ophiolitic Zone (Gamkrelidze et al., 1981). The ophiolites are spatially related to the gneiss-migmatite complex, and are cut by the Upper Paleozoic microcline granites. A detailed study of this unit (Zakariadze et al., 1998) identified ultra-basic harzburgites that represent melting restites of tholeitic basalt; their Nd model age corresponds to 810±100 Ma. Later study indicated that not only the Chorchana-Utslevi ophiolitic zone overthrust, but the whole gneiss-migmatite complex overlies it in the Dzirula massif (Okrostsvaridze, Shengelia, 1996; Shengelia, Okrostsvaridze, 1998).

Field relations and granitoid petrography

The majority of the gneiss-migmatite complex of the Dzirula massif is constructed of quartz-dioritic gneisses (~70%). They are dark gray, medium grained rocks, with occasional plagioclase phenocrysts (4-5 mm). Mineral composition includes plagioclase, biotite, quartz, hornblende; secondary minerals include K-feldspar, muscovite, chlorite and epidote; accessory minerals include apatite, zircon, thorite and ore minerals. Quartz-dioritic gneisses are characterized by numerous oval inclusions of gabbro to diorite composition. Inclusions range between tens of centimeters to one meter and in some cases make 30-35% of the entire exposure. We consider that the xenoliths represent the restites of basic injections, which made ensialic protolith assimilation and hybridism.

Cambrian tonalities largest exposures are in the Macharula and Kvirila river gorges where they are exposed over a distance of 800 m. In both sections several tonalitie bodies intruded the gneiss-migmatite complex. The host rock undergoes selective melting and migmatization at the contacts, and biotite gneisses and migmatite inclusions are found in the tonalite intrusive bodies. Late Variscan quartz-muscovite-microcline aplite and pegmatite veins cut each of these features. The mineral assemblage of unchanged tonalites consists of plagioclases (oligoclase) biotite, quartz, and K-feldspar. Accessory minerals include apatite, zircon, thorite and Fe-Ti oxides. As a result of field and petrographic observation we find that tonalities may be the product of anatectic melting of biotite gneisses of the gneiss-migmatite complex.

Upper Paleozoic microcline granites are widely spread in the Dzirula outcrop and represent the product of the Variscan tectonic-thermal events. The gneiss-migmatite complex is saturated with numerous intrusions of these granites. In the northern part of the Dzirula massif, the largest of these granites is exposed; the Rkvia intrusive (~65 km^2) has a lens-like form of NW-SE orientation. The intrusion is composed of porphyritic granites with idiomorphic K-feldspars, the main mass of which is in a medium grained massive structure. The main minerals are plagioclase, k-feldspar, quartz, biotite and muscovite; secondary minerals are: muscovite, sericite, chlorite and epidote; accessory minerals are – zircon, apatite, monazite and ilmenite.

In the eastern part of the Dzirula massif, in the Rikoti river gorge, two small intrusives (thickness- 450 m and 250 m) of orthoclase gabbro are presented, which cross cut quartz-dioritic gneisses. Due to their exotic character the investigators called them the rikotites. Their contact zones are intricate because of Alpine tectonic processes, but partial melting products are detected in the approximately 2-meter wide contact zone. Inclusions of 10cm to 50cm diameters ellipsoid leucocratic quartz-orthoclase are characteristic of rikotites, the number of which decreases from the periphery to the centre. The inclusions are gradually displaced by orthoclase gabbros. Following the field work results, we assume that these acid rocks inclusions are xenoliths – the product of selection melting which were abducted by the intrusive on its way of moving. We relate gabbros magma enrichment by orthoclase and quartz to these processes.

Geochemistry and geochronology

Seventy samples of the Dzirula massif granitoids were collected for complex isotopic research. Major element, trace and rare earth element composition have been analyzed. Based on the petrographic and geochemical work, a subset of twenty four samples were analyzed for Sm-Nd, Rb-Sr and ^{40}Ar-^{39}Ar isotopic systematics. Sm-Nd and Rb-Sr investigations were carried out at the University of California at Berkeley Isotopic Research Centre. ^{40}Ar-^{39}Ar and major, trace and rare earth element composition determination was done at the laboratories of Dalhousie University (Canada).

Neoproterozoic quartz-dioritic gneisses have an average SiO_2 content of 64.08%, with relatively high Al_2O_3 (17.86%) (Table 1). In these rocks Na_2O (4.16%) is higher than K_2O (2.64%) and K_2O/Na_2O=0.64. Quartz-diorite gneisses are metaluminous rocks (Clarke, 1992) and according to A/CNK parameter (1.07) they are I-type (Chappel, White, 1974) or H-type (Castro et al., 1991) granitoids. The D_1-D_2 discrimination diagram (Figure 3) is consistent, indicating an I-type. REE concentration in quartz-diorite gneisses is relatively low. The trend has weak asymmetry and no expressed Eu negative anomaly (Okrostsvaridze, Clarke, 2003), which shows that in quartz-dioritic gneisses magma did not undergo significant fractional crystallization. In quartz-dioritic gneisses I_{Sr} parameter is quite relatively constant at 0.7044; this low value suggests a mantle source for these rocks (Table 2). In these rocks εNd parameter varies from –1.76803 to -2.19501. This shows that they were formed from the protolith which had comparatively low Sm/Nd parameters relative to chondrite. The Sm-Nd model age did not show reliable results (2376±600 Ma) (Table 3), but these results suggest that the protolith may have been middle Proterozoic formations. More reliable results were reached by Rb-Sr system, which corresponds to 686±74 Ma.

Table 1. Chemical composition (%) and some petrochemical parameters of the Dzirula massif granitoids and orthoclase gabbros (rikotites)

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	D_1	D_2	R_1	R_2
Quartz-dioritic gneisses														
Dz 10	64.44	0.84	17.69	6.46	0.07	1.53	4.55	3.96	2.08	0.28	2.3	-19.4	2667	1028
Dz 12	63.92	0.71	17.47	5.18	0.06	1.42	3.92	4.17	2.72	0.22	-1.7	-18.7	2517	997
Dz 13	63.89	0.55	18.42	4.64	0.07	1.47	3.70	4.35	3.14	0.16	-2.7	-16.4	2660	1153
Tonalites														
Dz 31	66.67	0.77	15.83	5.99	0.08	2.44	2.57	2.99	2.92	0.92	4.9	-7.4	2517	520
Dz 32	67.83	0.69	16.29	4.40	0.08	2.00	2.63	2.85	3.72	0.31	8.1	-9.3	2520	490
Dz 44	67.09	0.69	16.18	6.87	0.08	2.60	2.32	2.86	2.71	0.06	7.4	-6.4	2347	533
Dz 45	67.36	0.63	16.37	5.62	0.09	1.36	2.04	2.84	3.71	0.08	5.9	5.7	2410	628
Microcline granites														
Dz 2	72.25	0.27	15.09	2.57	0.04	0.59	1.23	3.55	3.78	0.15	10.4	-5.3	2548	450
Dz 4	71.01	0.56	16.35	2.15	0.07	1.16	1.34	2.16	3.69	0.06	8.3	-2.7	2775	482
Dz 9	74.79	0.07	14.71	1.15	0.06	0.18	0.61	3.65	4.17	0.22	14.6	2.7	2663	507
Dz 15	75.09	0.22	15.21	1.98	0.05	0.51	1.15	3.79	3.75	0.17	5.2	4.7	2733	466
Dz 16	71.88	0.017	15.49	1.74	0.04	0.42	1.15	3.31	5.52	0.15	13.6	-5.3	2365	493
Orthoclase gabbros (rikotites)														
R 20	46.6	0.964	9.87	11.75	0.21	10.84	14.95	1	1.76	0.38	-	-	-	-
R 21	51.02	0.718	7.12	10	0.174	11.99	15.68	1.08	1.11	0.03	-	-	-	-
R 23	50.25	0.7	6.40	9.26	0.195	11.79	17.48	1.25	0.87	0.06	-	-	-	-
R 26	51.57	0.817	16.57	8.36	0.156	4.63	7.99	2.16	2.02	0.43	-	-	-	-

Table 2 . Chemical composition of Rb, Sr, Sm and Nd (ppm) and some isotopic data of the Dzirula Massif granitoids and orthoclase gabbros (rikotites)

Sample	Rb	Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	I_{Sr}	Sm	Nd	$^{147}Sm^{144}Sm$	$^{143}Nd/^{144}Nd$	εNd
Quartz-dioritic gneisses										
Dz10	89.27	387.51	0.4576	0.70872	0.70584	3.24	22.47	0.512362	0.11998	-1.76803
Dz12	97.64	402.23	0.5934	0.71023	0.70441	3.96	20.38	0.512379	0.11780	-1.96703
Dz13	110.22	416.89	0.7476	0.71172	0.70442	4.17	18.87	0.512071	0.12140	-2.19501
Tonalites										
Dz31	116.23	213.75	1.53879	0.72051	0.70920	6.48	38.45	0.512062	0.10410	-6.28938
Dz32	118.87	294.18	1.1432	0.71757	0.70891	3.98	17.08	0.512349	0.14394	-2.87918
Dz44	110.20	248.86	1.2529	0.71826	0.70877	7.10	39.63	0.512044	0.11064	-6.99145
Dz45	89.67	290.02	1.3833	0.71606	0.70882	9.30	48.56	0.512070	0.11823	-6.89080
Microcline granites										
Dz2	114.99	249.60	0.98124	0.71519	0.70722	5.86	33.29	0.51216	0.10863	-4.50135
Dz4	153.83	74.93	1.29801	0.71512	0.71460	8.08	45.59	0.51191	0.10947	-9.36967
Dz9	177.68	36.08	1.82012	0.71783	0.70668	1.20	4.17	0.51223	0.17722	-6.92835
Dz15	130.40	203.49	1.72948	0.71723	0.70671	5.08	23.20	0.51214	0.13525	-6.43603
Dz16	155.39	250.46	1.73452	0.71581	0.70665	3.92	23.31	0.51227	0.10387	-2.19580
Orthoclase gabbros (rikotites)										
R20	442.21	54.82	0.35032	0.70602	0.70497	7.06	33.62	0.51237	0.12968	+0.44803
R21	50.59	215.24	0.66948	0.70715	0.70514	3.60	13.88	0.51258	0.16417	-0.26030
R23	257.81	123.59	0.29257	0.70614	0.70526	6.19	26.67	0.51258	0.14327	+0.28341
R26	836.14	119.42	0.40361	0.70654	0.70533	6.88	37.17	0.51254	0.11421	+0.15332

Proceeding from these data and geological evolution of the region, we can assume that quartz-dioritic gneisses was formed in the Neoproterozoic at the Early Pan-African tectonic-thermal events.

In the Cambrian Tonalites SiO_2 (67.26%) is higher than in the Neoproterozoic quartz dioritic gneisses, but Al_2O_3 is lower (16.16%). In these rocks as compared to quartz-dioritic gneisses Na_2O concentration (2.88%) is relatively low but K_2O is quite high (3.26%). Cambrian tonalites are metaluminous rocks and according to A/CNK parameter (1.22) it is S-type granitoids (Okrostsvaridze, Shengelia, 1996). The D_1-D_2 discrimination diagram (Figure 3) is consistent, indicating an S-type. REE concentration is quite high, but with symmetric trends. They are enriched in lanthanides, comparatively poor in heavy REE and weakly expressed Eu minimum, which shows that crystal fractioning was not an important process in the development of these rocks (Okrostsvaridze, Clarke, 2004).

In tonalites I_{Sr} parameter varies from 0.7081 to 0.7082 which is a consistent with for the upper crust. The εNd parameter ranges from -2.8792 to -6.8906 (Table 2); suggesting a strong influence of upper crustal partial melts.

Rb-Sr isochrones of tonalites showed an age of 538±53 Ma which corresponds to Cambrian age. Biotite samples were also analyzed by ^{40}Ar-^{39}Ar method gave an Upper Paleozoic age of 306±2 (Table 3).

Table 3. Isotopic Ages (Ma) of the Dzirula massif Granitoid and rikotites (orthoclase gabbros)

Rock name	Quartz-dioritic gneisses	Tonalites	Microcline granites	Rikotites
Sm-Nd method	2370±600	-	-	278±48
Rb-Sr method	686±74	538±53	331±21	211±11
^{40}Ar-^{39}Ar method	309±5 (biotite)	306±2 (biotite)	303±4 (biotite)	219±4 (hornblende) 217±3 (biotite)

Proceeding from these data, we assume they tonalities could have been generated at Late Pan-African tectonic-magmatic events by melting of metapelites of the gneiss-migmatite complex.

Late Paleozoic Microcline granites have an average SiO_2 of 73.00%; Al_2O_3 is the lowest among the Dzirula massif granitoids (15.31%). Alkalinity is increased (Na_2O=3.49; K_2O=4.18) and K_2O/Na_2O parameter is equal to 1.20 which is typical upper crust granitoid data (Table 1).

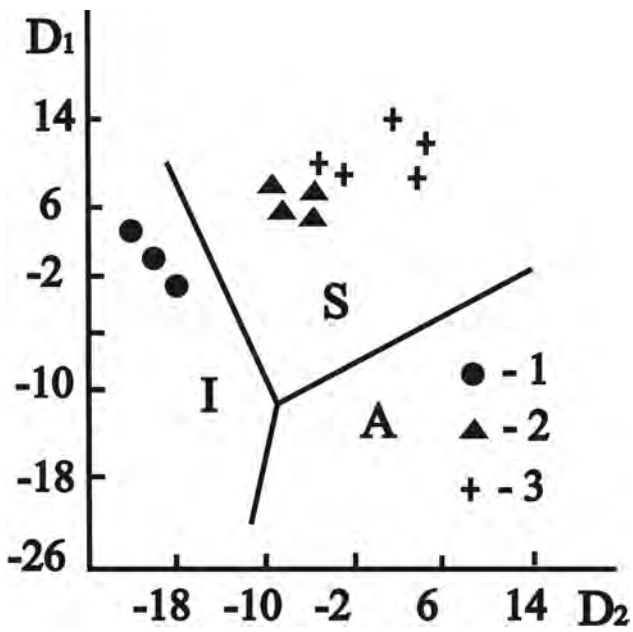

Figure 3. D_1–D_2 Discrimination diagram (Hassan, McAllister, 1992) for the Dzirula massif granitoids. Fields: I – type granites; S – type granites; A – type granites. $D_1 = 0.76Al_2O_3+2.91MnO-1.93Na_2O+1.95K_2O-18.50P_2O_5$; $D_2 = 0.37Al_2O_3+7.25TiO_2-54.08MnO-4.28Na_2O-0.55K_2O+45.81P_2O_5$. Conventional signs: 1 - quartz-dioritic gneisses; 2 - tonalities; 3 - microcline granites.

Upper Paleozoic microcline granites are metaluminous rocks (A/CNK =1.42) and according to it is S-type (Chappel, White, 1974) granitoids. The D_1-D_2 discrimination diagram is consistent, indicating an S-type (Figure 3).

REE distribution in microcline granites are characterized by sharp asymmetry; they show lanthanides high concentration and heavy REE low concentration. They have sharply expressed Eu minimum, which show that intensive crystal fractionation took place in magmatic system (Okrostsvaridze, Clarke, 2004). The I_{Sr} has a very wide range, from 0.70667 to 0.71460. This range suggests extensive incorporation of upper crustal rocks. eNd parameter ranges from -2.19589 to -9.36967; it shows that they were generated by melting of upper crust rocks.

The Rb-Sr isotopic age of microcline granites corresponds to 351±21 Ma (Tab.3). This is Early Carboniferous, correspondingly, the activity appears to be associated with Variscan tectono-thermal events. In microcline granites (sample Dz2, Dz9, Dz16) muscovite isotopic age was determined using ^{40}Ar-^{39}Ar method which is identical nearly in all samples and on average equals to 303±4 Ma, which, like the Tonalite ^{40}Ar-^{39}Ar data, also corresponds to Late Variscan.

Rikotites (orthoclase gabbros) represent protolith rocks which were low in Al_2O_3, Fe_2O_3, K_2O and high in CaO and MgO composition. Rb-Sr data of rikotites show 211±11 Ma. Same date of this intrusive was approximately by hornblende ^{40}Ar-^{39}Ar which corresponds to 219±4 Ma and by biotite dating using the same method in this intrusive - 217±3 Ma (Table 3). The Rb-Sr isotopic system in rocks is closed at 600-700^{0}C; ^{40}Ar-^{39}Ar system in hornblendes at 450-500^{0}C; in biotites 300-350^{0}C. From this we can conclude, that the results are in good correlation with each other and indicate ricotite intrusion took place Upper Triassic during the Cimmerian tectonic-thermal events, approximately in the interval of 210-220 Ma.

Summary of Geochemistry Findings

The geodynamic regime of formation of the Dzirula massif granitoids can be assessed with the R_1-R_2 multipartite diagram (Figure 4), quartz-dioritic gneisses figure points are located within pre-plate Collision granitoids field, while tonalites and microcline granites – within the syn-collision. The petrochemical investigation carried out showed, that the Dzirula massif granitoids are genetically different from each other. Quartz-dioritic gneisses belong to metaluminous I-type granites, which were formed in the volcanic arc geodynamic regime and in which magma crystal fractioning didn't take place. Tonalites and microcline granites represent petrochemically similar formations and belong to S-type paraluminous granites which were formed at syn-collision stage evolution of the orogen evolution.

On the εNd -I_{Sr} isotopic diagram quartz-dioritic gneisses figures points actually do not appear in the field of crust formations and only tonalities and microcline granites figure points follow the upper crust trend (Figure 5). εNd - Intrusive age (Ma) relation diagram shows clearly, that all the granitoid figure points investigated by us are located in the field of Phanerozoic crust (Figure 6), which clearly shows, that the Dzirula massif continental crust is Phanerozoic formation. According to granitoid petrogenetic types, isotopic age and εNd parameters it should be treated as typical Tethyside or collisional orogen (Windley, 1996).

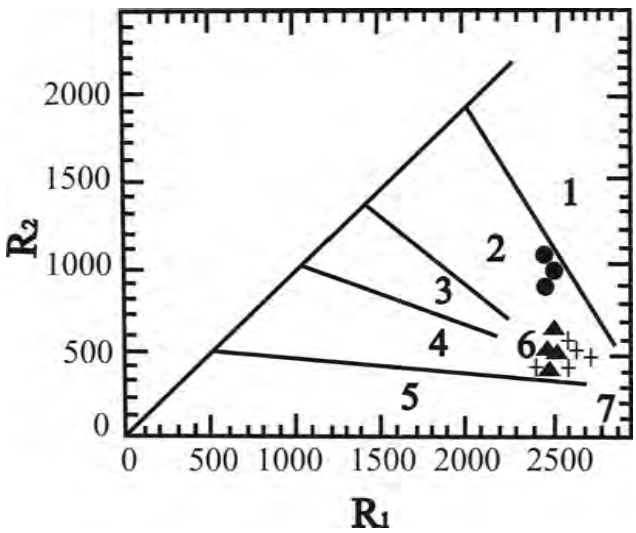

Figure 4. R_1-R_2 discrimination diagram (Bachelor, Bowden, 1985) for the Dzirula massif granitoids R_1 = 4Si-11(Na+K)-2(Fe+Ti); R_2= 6Ca+2Mg+Al. Conventional signs are identical to figure 3.

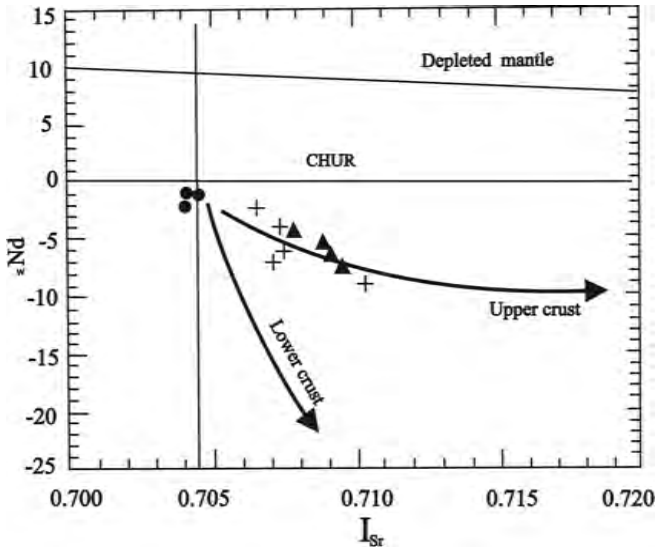

Figure 5. εNd-I_{Sr} isotopic diagram (Jahn et al., 2000) for the Dzirula massif granitoids. Conventional signs are identical of figure 3.

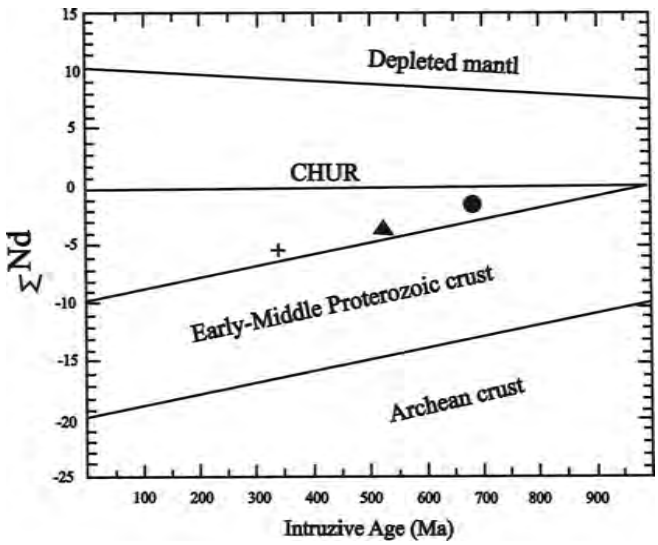

Figure 6. εNd- I_{Sr} intrusive age (Ma) (Jahn et al., 2000) for the Dzirula massif granitoids. Conventional signs are identical of Figure 3.

Geodynamic Evolution of the Region

The geodynamic evolution of the Caucasian orogen, based on geological, paleofacies, paleobiogeographic and paleomagnetic data, centers on the closing of the Tethys oceanic basin at the end of the Alpine cycle as a result of collision of the Afro-Arabian and Eastern European plates (Gamkrelidze, 1991; 1997; Stampfli, Borel, 2002, Raumer et al., 2003). The Inner Caucasian Microplate, of which the Dzirula massif is a part, in these models is treated as microcontinent, island arc or terrane, which was situated in the inner oceanic portion of Tethys. Its genetic relation with any of the continental plates is not well understood. The new tectonic, petrogeochemical and isotopic data obtained from the Dzirula massif gave us an opportunity to constrain the relationship.

Relying on existing information and the data in this paper suggests that the Dzirula massif represents a vertically accretion structure which is constructed of two large formations: Gondwana-derived gneiss-migmatite complex (upper) and ensialic island arc (lower) (Figure 7).

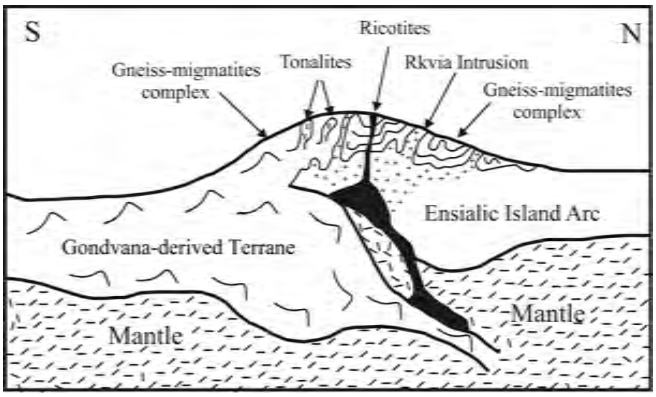

Figure 7.N Hypothetical geological cross section through the Dzitula massif. It is shown on the figure how gneiss-migmatite complex is overlaying ensialic island arc and how base granitoid magma sources are generated. Base magma generation possible model is shown by dark color.

The interrelation of granitoid genetic types and the geodynamic evolution of the region support this structure. In addition, the gneiss-migmatite complex is similar to the Arabian Plate Northern edge in age, composition and construction (Marzouki, Fyfe, 1979; Kroner, Stern, 2008). These authors indicate that the Northern part of Arabian Plate, situated to the south of the Inner Caucasian Microplate, represents a mosaic of microcontinents which were connected by Pan-African tectono-thermal events. Most are characterized by similar composition and tectonic development history to the Dzirula massif gneiss-migmatite complex. The intensive injection of the mantle material, metamorphism, ultrametamorphism and granite-forming processes were of the same character and took place in the intervals of 700-450 Ma. The Pan-African tectonic-thermal events at this time are characterized by a transitional regime, namely, the older inner plate processes are substituted by younger (Phanerozoic) plate edge regimes. Our data indicate that the gneiss-migmatite complex of the Dzirula massif is likely a Gondwana-derived terrane part and separated from the Arabian plate northern edge during the opening of the Palaeo-Tethys.

To make the idea more clear and convincing we will cite a comparison. The Tsakhkuniats massif, which reveals great similarities with Dzirula massif by its tectonic construction, composition and isotopic parameters, is exposed in the South of the Dzirulla massif, within the borders of Iran-Afganian terrane of Gondwanan origin. The above mentioned massif, as well as Dzirula, is constructed of the Neoproterozoic gneissic metabasalts-migmatites (Hancavan complex), which is obducted on gneiss-paraschist (Arzacan complex). The Hancavan Complex as well as Dzirula massif gneiss-migmatite complex also contains lenses of opiolitic serpentinites and is crossed by quartz-dioritic gneisses intrusive; its the Rb-Sr isotopic age is 685±77 Ma and the Isr=0.703361 (Agamalian, 2004). The age of the Dzirula massif quartz-dioritic gneisses determined by the same method, corresponds to 686±74Ma and the Isr=0.70489. So, we can detect many similarities between these two massifs and proceeding from the geodynamic evolution analysis of the region, they are most likely to contains same Precambrian platform relics.

Discussion

This work has identified four distinct granitoid types in the Dzirula massif, including their spatial relationships, intrusion history, and ages. These data, combined with an understanding of the regional geodynamics, provides an understanding of granitoid melt generation and the evolution of the continental crust in the Dzirula Massif.

The Neoproterozoic gneiss-migmatite complex is the most widely distributed, and occupy the upper plate of the structure. This unit is composed of quartz-dioritic gneisses of I or H-type granitoids. The average isotopic parameters of these rocks (I_{Sr}=0.7044±0.0066; εNd = –1.976692) show that they belong to juvenile crust with a high percent of mantle component. The migmatite complex appears to have formed by partial melting of a subcontinental lithosphere by mantle-derived magmas. The age of quartz-diorite gneiss crystallization is 686±74 Ma (Rb-Sr method), which corresponds to the Early Pan-African tectonic-thermal events.

The tonalites have a crystallization age of 538±33 Ma (Rb-Sr age) which corresponds to Late Pan-African tectonic-thermal events. The tonalites are more evolved than the gneiss, being S type granitoids with higher REE concentrations. The tectonic discrimination diagrams indicate the syn-collisional granite field. The isotopic composition of the tonalites indicates a greater upper crustal character compared to the gneiss-migmatite complex (I_{Sr} = 0.7087±0.0011; εNd = –5.762702). The microcline granites have an age of 351±21 Ma (Rb-Sr method), corresponding to the Variscan tectonic-thermal events. The gneiss-migmatite complex is intruded by the microcline granites at this time. These rocks are much more evolved than either the gneiss-migmatite or the tonalites. The microcline granites are biotitic-muscovite peraluminous S type formation and in tectonic discrimination diagrams its plots are in the syn-collision granite fields. The isotopic composition of the microcline granites also indicates a more developed continental crust. The I_{Sr} of these rocks ranges between 0.70667 and 0.71460, and εNd from –2.19589 to –9.96967.

Thus by the late Variscan, the crust of the Dzirula massif has evolved from a primitive composition to one more characteristic of more evolved continental crust. This development occurred during cycles of tectonic-thermal activity that lasted from the upper Proterozoic to the upper Paleozoic. As a result of these cycles, the ensialic protolith S type Upper Paleozoic microcline granites intrude into the mantle-crust hybrid I type Neoproterozoic gneiss-migmatite complex. Based on the geodynamic setting, the gneiss-migmatite

complex was overthrust onto the protolith of the microcline granite, and part of the ensimatic terrane subducted under this protolith (Figure 7). This collision led to release of water from the subducted terrane led to partial melting of the microcline granite protolith and formation of the granitoid melt which intruded into the overlying gneiss. This explanation is further supported by the presence of ophiolite fragments in the northern part of the Dzirula massif.

The fourth magmatic rock in the Dzirula massif is the rikotites (orthoclase gabbros). The age of the Rikotites by Rb-Sr method, the whole rock - 211±11 Ma; ^{40}Ar-^{39}Ar method hornblende - 219±4 Ma; by ^{40}Ar-^{39}Ar method - biotite is 217±3 Ma. The results indicate that the rikotites intruded into the Dzirula massif during the Upper Triassic, corresponding to the Cimmerian tectonic-thermal events. The rikotites, according to all data, belong to island arc formations that collided with the Dzirula massif area. The rikotites contain orthoclase and are potassium rich. The exotic composition of the rikotites provides further clues about the development of the Dzirula massif. The rikotites appear to have a mantle source, and partial melting and incorporation of the potassium-bearing granites or their protolith appear to have led to the potassium enrichment of the rikotites.

Conclusions

Field, petrochemical, isotopic, and geochronological investigation of the granitoids of the Dzirula massif illustrate continental crust forming processes from Upper Proterozoic to Upper Paleozoic. The formation of the continental crust in this area was episodic, occurring during three phases of tectono-magmatic events.

The data in this study also constrain the geodynamic history of the Inner Caucasian Microplate. These processes occurred in the closing process of Palaeo-Tethys and the opening of Meso-Tethys. Within the Dzirula massif, a Gondwana-derived Proterozoic gneiss-migmatite complex is situated obductively on ensialic island arc. In this Variscan collision-accretion structure, the crustal thickening and released water caused partial melting of the ensialic island arc, thus generating the microcline granites, which intruded the overlying gneiss-migmatite complex. By the end of this process, the Dzirula massif resembled typical continental crust. Later, in the Upper Triassic, the structure was further intruded by potassium rich gabbros (rikotites). Later, during the Alpine tectonic-thermal processes the Inner Caucasian Microplate merged with the Euro-Asian continental southern active edge.

Acknowledgements

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References

Agamalian, V., 2004, The Lesser Caucasus Earth Crust formation and evolution in the collision zone of Palaeo-Tethys. Proceedings of the 5th International Symposium on Eastern Mediterranean Geology, pp. 17-20.

Allegre, C.I., Ben Othman, D., 1980, Nd-Sr Relationship in Granitoid Rocks and Continental Crust development: a chemical approach to Orogenesis. Nature, v. 286, pp. 335-343.

Bachelor, R.A. and Bowden, P., 1985, Petrogenetic interpretation of granitoiod rock series using multication parameters. Journal of Chemical Geoogy, v. 48, pp. 43-55.

Castro, A., Moreno-Ventas, J. and De La Rosa, J.D., 1991, H-type (hybrid) granitoids: A proposed revision of the granite-type classification and nomenclature. Earth Science Review, v. 3, no. 4, pp. 237-253.

Chappel, B.W., White, A.Y.R., 1974, Two contrasting Granite types. Journal Pacif. Geology, no. 8, pp. 173-174.

Clarke, D.B., 1992, Granitoid Rocks. London: Blackwell. 283 p.

Clarke, D.B., Chatterjee, A.K. and Giles, P.S., 1993, Petrochemistry, tectonic history, and Sr-Nd systematic of the Liscomb Complex Meguma Lithotectonic Zone, Nova Scotia. Canadian Journal of Earth Science, no. 30, pp. 449-464.

Collins, W.J., 1998, Evolution of Petrogenetic model for Lachlan Fold Belt granitoids: implication for crustal architecture and tectonic models. Australian Journal Earth Science, v. 45, pp. 83-500.

Daga, M.M., Rao, D.R. and Rai, H., 2010, Granite Magmatizm and Crustal Evolution of the Shyok-Darbuk corridor of NE Ladakh, India. Episodes, v. 33, no. 3, pp. 183-199.

DePaolo, D.J., Linn, A.M. and Solubert, G., 1991, The continental crust age distribution: methods of determining mantle separation age from Sm-Nd isotope data and application to the south-western United States. Journal Geophysical Research, no. 96, pp. 2071-2088.

Gamkrelidze, I.P., 1997, Terrane of the Caucasus and adjacent areas. Bulletin Academy of Science Georgia, v. 155, no.3, pp. 75-81.

Gamkrelidze, I.P., Dumbadze, G.D. and Kekelia, M.A., 1981, Ophiolites of the Dzirula massif and problem of Paleotethyse in Caucasus. Geotectonic, no. 5, pp.23-33.

Gamkrelidze I.P. and Shengelia D.M., 2005, Precambrian-Paleozoic regional metamorphism, granitoid magmatism and geodynamics of the Caucasus. M: Scientific World, 458 p.

Hassan, H.H. and McAllister, A.L., 1992, An integrated geological, geochemical investigation of uranium metallogenesis in selected granitic plutons of the Miramichi Anticlinorium, New Brunswick. Canadian Journal of Earth Science, no. 13, pp. 91-115.

Jahn, B., Wu, F. and Chen, B., 2000, Massive granitoid generation in Central Asia: Nd isotope evidence and implication for continental growth in the Phanerozoic. Episodes, v. 23, no. 2, pp. 82-92.

Marzouki, F. and Fyte, W.S., 1979, Pan-African plates: Additional evidence from igneous events in Saudi Arabia. Contribution to Mineralogy and Petrology, v. 60, no.3, pp. 219-224.

Okrostsvaridze, A.V. and Shengelia, D.M., 1996, New Data on the formation of microcline granites of Dzirula salient. Bulletin Academy of Science Georgia., v. 14, no. 1, pp. 93-95.

Okrostsvaridze, A.V. and Clarke D.B., 2003, The First Data on the Investigation of Sm-Nd and Rb-Sr Izotopic Systems of the Dzirula Salient Gneisses-Quartz-Diorites of the Black Sea - Central Transcaucasian Terrane. Bulletin Academy of Science Georgia, v. 168, no. 2, pp. 281-285.

Okrostsvaridze, A.V. and Clarke D.B., 2004, New data of isotopic investigation of magmatic rocks of Dzirula salient of Caucasian Inner Massif. Journal Rep. Russian Academy of Sciences, v. 398, no. 1, pp. 117-121.

Samson S.D. and Patchett P.J., 1991, The Canadian Cordillera as a modern analogue of Proterozoic crustal growth. Australian Journal of Earth Sciences, no. 38, pp. 595-611.

Roumer, I.F., Stampfly, M. and Bussy, F., 2003, Gondwana-derived microcontinents – the constituent of the Variscan Alpine collisional orogens. Journal of Tectonophysics, no. 365, pp. 7-22.

Shengelia, D.M. and Okrostsvaridze, A.V., 1998, New data on the construction of Dzirula salient of Pre-Alpine Georgian block. Journal Rep. Russian Academy of Sciences, v. 559, no. 6, pp. 800-803.

Shengelia, D.M. and Okrostsvaridze, A.V., 1998, New data on the construction of Dzirula salient of Pre-Alpine basement of Georgian block. Journal Rep. Russian Academy of Sciences, v. 559, no. 6, pp. 800-803.

Stampli, G.M., Borel, G.D., Cavazza, W., Mosar, J. and Ziegler, P.A., 2001, Palaeotectonic and paleogeographic evolution of the Western Tethys and Peri-Tethyan domain. Episodes, v. 24, no. 4, pp. 222-228.

Stern, R.J., 2008, Neoproterozoic crustal growth: The solid Earth system during a critical episode of Earth history. Gondwana Research, v. 14, issues 1-2, pp. 33-50.

Taylor, S.R. and McLennan, S.M., 1985, The continental crust: its evolution and composition. London: Blackwell, 312 p.

Windley, B., 1996, The evolving Continent, 3rd edition. Chichester: John Wiley and Sons, 526 p.

Zakariadze, G.S., Karpenko, S.F. and Bazilev, B.A., 1998, Petrology, geochemistry and Sm-Nd izotopic age of Pre-Late-Hercynian paleooceanic complex of Dzirula salient of Transcaucasian massif. Journal of Petrology, v. 6, no. 4, pp. 422-444.

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Long-term stability of large span caverns at the 1400-year Heidong quarry

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Long-term stability of large span caverns is earnest but poorly understood in preservation of cultural relics. The life span of huge caverns is difficult to extrapolate from short period of monitoring or laboratory testing. A huge ancient quarry with 21 caverns whose original status is well kept over 1400 years was found in Tiantai County of South China. One of the caverns has an 81 m span which is far beyond the 50 m expectation on current knowledge. The tension at the core of long stability is the excavation speed versus deliberation. Here we show a unique technique of Digging Holes for Quarrying Vertical Flagstone (DQF) invented by ancestors to ensure the safety, which is much smarter compared to blasting and casting technique that commonly used after the Industrial Revolution. Furthermore, in addition to selecting competent massive rocks via cutting normally to and through faults, they adopted systematically trial adits, dome-shaped cavern, and disposal of waste rocks inside caverns for support. These ancient achievements mark a high level of quarrying in complex natural conditions with manpower. The results are positive to extend our knowledge in category design of cavern scale and stability assessment, and to some extent, they give solutions to the conflict between fast excavation with blasting and induced excavation damaged zone (EDZ) in surrounding rocks.

Introduction

Ancient large scale caverns are attractive in multidisciplinary researches such as engineering geology, rock mechanics and archaeology (Wang et al. 1984). Long-term stability of large span caverns is serious but poorly understood in cultural relics preservation (News and Views, 1930). It is difficult to extrapolate the life span of huge caverns from short period of in-situ monitoring or current laboratory tests (Aubertin et al., 2000).

Some ancient quarrying caverns form integral parts of historic sites visited by tourist worldwide, for example, the bell-shaped caverns of Bet Guvrin excavated 1300 years ago in Israel (Tsesarsky et al., 2000; Hatzor et al., 2002; http://en.wikipedia.org/wiki/Beit_Guvrin_National_Park), the Wieliczka Salt Mine is a world heritage site functioning continuously since the Middle Ages in Poland (Zuber et al., 2000), the Basilica Cistern at Istanbul, Turkey (http://english.istanbul.gov.tr). In recent years, it has been noted that there are some large scale quarry caverns in Zhejiang Province, South China (Yang et al., 2003). For instance, the Longyou Caverns constructed about 2000 years ago at Longyou (Li et al., 2009), Feifengyan Caverns originated 700 years ago at Xianju (Guo, 2006), Shepan Island Caverns at Sanmen (Zhang, 2010), Panlong Caverns at Huangyan (Yang et al. 2007), and Changyu Caverns at Wenling (Yang et al. 2011). Distribution of these ancient large scale caverns are shown in Fig.1a. Some features of these caverns are listed in Table 1. By comparison, the Heidong quarry cavern is the most famous for its largest span of 81 m (for its location, see Fig.1).

From the viewpoint of underground engineering design and construction, as well as cultural relics preservation, it is concerned not only the long-term stability, but also as an inspiration to current society (Butzer and Harris, 2007). What's more, analogical analysis of large scale completed engineering projects (Broch et al., 1996) may also contribute to the current modification of specifications or guidlines of risk engineering design.

As one distinctive case example, the Heidong quarry consists of 21 main and 42 secondary caverns, whose original status is well kept for over 1400 years, distributing in an area of about 24,000 m^2, and was found under Xieshan Hill, in Tiantai County of South China (Fig.2). This region is famous in eastern Asia as the original center of the Tiantai Sect, one of the Exoteric Buddhism of Mahayana Buddhism. Among the caverns, one reaches unsupported spans of up to 81 m, which is far beyond the 50 m expectation on current knowledge (SBMI, 2001; Barton, 2002; Hatzor et al., 2010). As an analogical model, Heidong quarry caverns provide an in-situ test at 1:1 scale, which contains precious data hardly to obtain from short period of in-situ monitoring or laboratory tests (Aubertin et al., 2000). It is known that there are five factors that contribute to its abnormal spatial and life spans. (a) The massive rock is generally integrated with optimal engineering geological conditions. (b) Tools such as short iron chisel and hammer were used for manual quarrying. (c) The ancients excavated the cavern as dome roof. (d) They adopted trial adits or pits for trial and error at the port or passing through faults. (e) They stacked waste stones within abutments or on floors for supporting and farmland-saving.

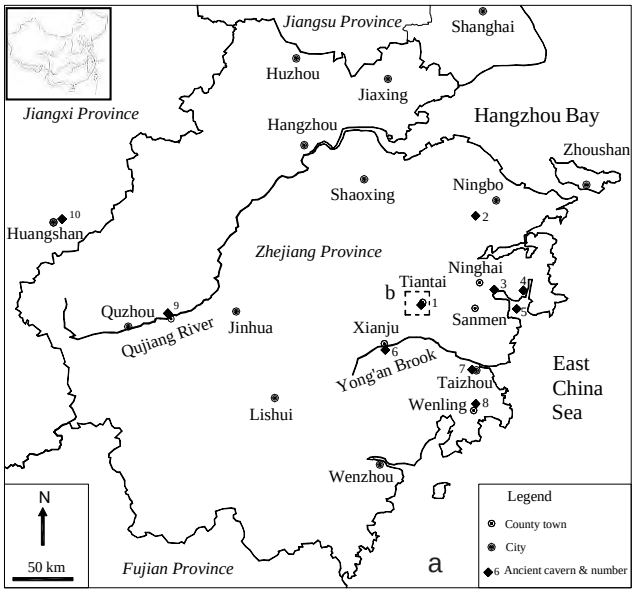

Fig.1 Locations of ancient quarry caverns in SE China. a. Distribution in Zhejiang Province. 1. Heidong qurry, 2. Shanghua Hill quarry, 3. Yishi quarry, 4. Wushan quarry, 6. Feifengyan quarry, 7. Panlongdong quarry, 8. Changyu quarry, 9. Longyou cavern, 10. Huashan cavern. b. Location of the Heidong quarry just in Xieshan Hill as the dark line circle at the southern bank of the Shifeng River, southwest of Tiantai County town.

Materials and methods

Historical records at nearby villages and inscription on stones at temples were used for dating the Heidong quarry. Since the Heidong large scale quarrying is lack of formal literature records in the Tiantai County, we studied textures of written records in memoirs, as well as special geological phenomenon to date its original excavation time.

Field survey and observation method for measurement of engineering geological conditions (including strata, faults, joints and groundwater) were adopted. By means of the TCA2003 type of Leica total station, we measured the magnitude of caverns.

Polar stereographic projection was used for processing attitudes of discontinuities (faults and joints) measured in the field. Discontinuities affect the aligned layout and appearance of common walls of the cavern.

Massive tuffs are host rocks of quarrying flagstones, and are taken as the subject of this research. Intact rocks of tuff were sampled in the quarrying site. Epoxide resin was used for thin section polishing,

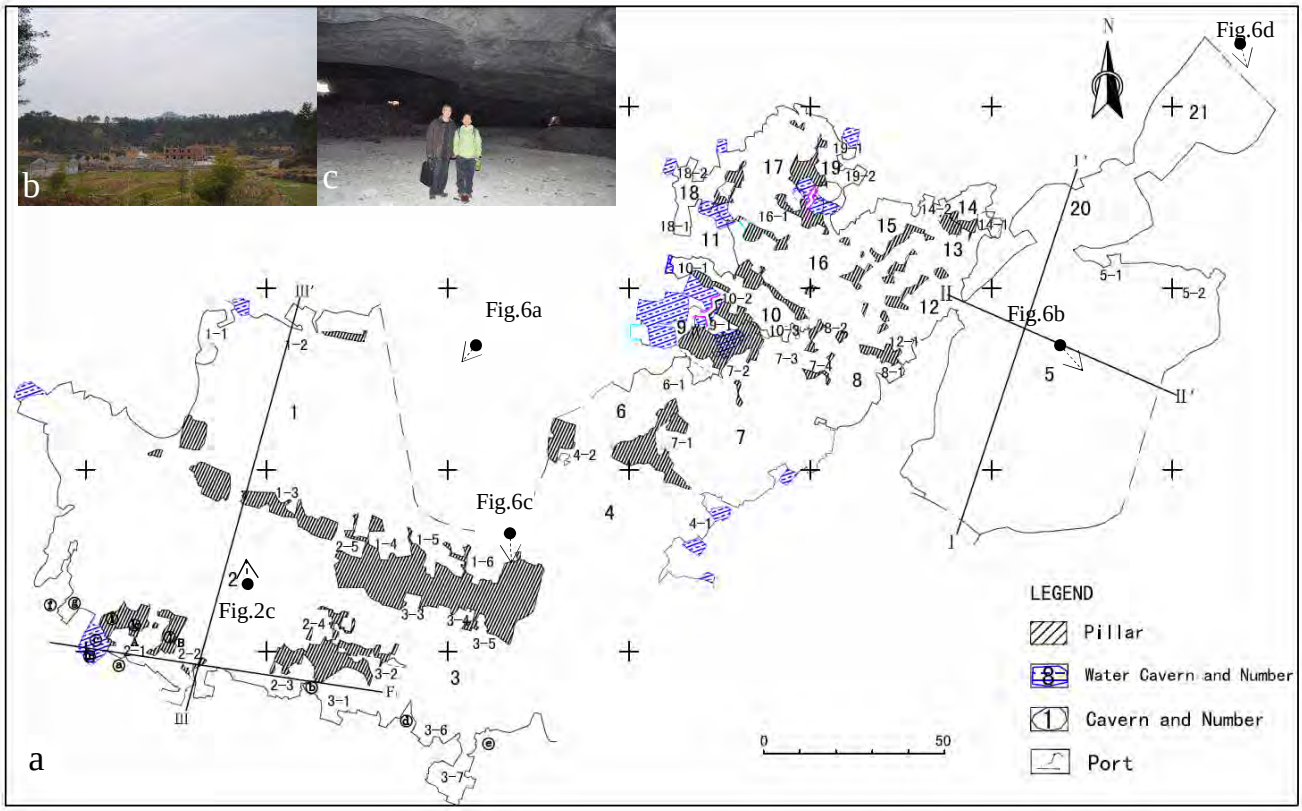

Fig. 2 Layout of the studied 21 caverns at Heidong quarry. a. Plane map of the caverns with pillars in strikes of NW and NE. b. Southward viewing outside of the quarry gate for the subdued Xieshan Hill. c. Northward viewing at No.2 cavern.

Table 1. Some geodata of ancient large scale caverns with respect to geometry

Name	Location	Cave number	Size(cavern span and height)	Original excavation year	Surrounding rock	Reference
Wieliczka Salt Mine	Wieliczka, Poland	2040	extraction 7.5*10^6 m^3, length 200 km	13th century	Salt	Zuber et al., (2000)
Bet Guvrin Caverns	Israel	800	Span 20–40 m, cavern height 15–20 m, cover height 4 m	1300 years ago	Chalk (E_2)	Tsesarsky et al., (2000); Hatzor et al., (2002)
Basilica Cistern	Istanbul, Turkey		Area 9800 m^2 (span 70 m, 9 m high). 336 nos. pillars	532 AD	Marble	http://english.istanbul.gov.tr
Longyou Caverns	Longyou County, China	25	Span 18–34 m, length 16–43m, cover height 0.6–21.3 m*	2000 years ago (Western Han Dyn.)	Brick red pelitic siltstone (K_2q)	Li et al., (2009)
Feifengyan Caverns	Xianju County, China	>46	Area 30000m^2Span 32–43m, cavern & cover height 5–31m & 23–63m	700 years ago (Song Dyn.)	Gray white zeolitization ripple rubble-bearing vitric tuff (K_2t)	Guo (2006)
Shepan Island Caverns	Sanmen County, China	1300	Area 37000 m^2; Span 20–43 m, cover height 7–30 m	800 years ago (Song Dyn.)	Ripple vitric tuff (J_3d)	Zhang (2010)
Panlong Caverns	Huangyan, China	>23	Span 30 m, 64.3 m high	Early than Ming Dynasty	Ripple rubble-bearing tuff (J_3z)	Yang et al., (2007)
Heidong Caverns	Tiantai County, China	21	Area 24000 m^2 Span 50–81 m, cavern and cover heights 5–22 and 5–40 m	1413 years ago (Sui Dyn.)	Gray white ripple vitric tuff (K_2t)	This paper
Changyu Caverns	Wenling, China	1314	Area 68000 m^2 (span 53 m, height 73.4 m)	1600 years ago (The northern and Southern Dyn.)	Light gray brecciform tuff (J_3x)	Yang et al., (2011)

* The most shallow cavern is only 0.6 m underlying. Dyn.-Dynasty.

and polarizing microscope observtion was carried out. The polished thin section is about 0.03 mm thick.

Uniaxial compression test was completed in rock mechanics laboratories.

Finite element numerical method was adopted for simulation of the DQF excavation induced fracture propagation.

Engineering Geological Conditions

The Xieshan Hill, which is striking to azimuth 60 with a height difference of 50m (from 70 m to 120 m above sea level). According to the regional geology, the stratum belongs to Tangshang Group of upper Cretaceous (K_2t). Three nearly horizontal layers are exposed from the top (Layer 8) to the bottom (Layer 6) (Team of Regional Geology Expedition, 1978). The layers 7 and 8 (observed thickness 5–8m) are slightly weathered. Layer 8 is composed of gray purple blocky ripple vitric tuff. The Layer 7 is only 0.3-1.0 m thick with development of horizontal joints. The rock is weak and fractured as moderately weathered. Layer 7 is composed of purplish red blocky tuffaceous conglomerate. The occurrence of Layer 7 measured at No.5 cavern with the largest span is N10–24ºW, NE∠15–28°. Layer 6 is massive or very thick bedding as integrated mass (observed thickness 5–10 m at different caverns) (Table 2). The joints and fissures are less developed with slightly weathered or jointed. Layer 6 is comprised of slight gray massive ripple rubble-bearing vitric tuff, which is partlly distinguished with slight yellow streaks (Fig.3). The caverns were excavated through the transverse isotropic Layer 6 of K_2t.

Table 2. General features of the three layers

Layer	Observed thickness	Rocks	Weathered	Occurrence
6	Very thick bedding 5–10 m	slight gray massive ripple rubble-bearing vitric tuff	fresh	N10–24ºW, NE15–28°
7	0.3-1.0 m	purplish red blocky tuffaceous conglo-merate-bearing bearing sandstone	slightly	
8	Very thick bedding, 5–8 m	gray purple blocky ripple vitric tuff	slightly	

The Quzhou-Tiantai Fault (about 250 km long, extending NEE~EW) located at 12 km south of the Tiantai county town. This fault and few folds were formed at early stage of Yanshan Movement (Team of Regional Geology Expedition, 1978). Their properties are NE Cathaysian structure in a strike of NE dominated by compression discontinuities.

At the No.2 cavern, the fault F_1 (N82°W, SW∠65°) is exposed at its south wall (Fig.2) the gouge is as thick as 0.3–0.4 m (Fig.4a and 4b).

Besides, in site survey we measured 85 joints and their occurrence. The rose diagram of the discontinuities with two principal sets (N7ºE, NW∠89º and N82ºW, SW∠50º) is shown in Fig.5a. Meanwhile, most of the dip angles are over 50º, dominated by 80º–90º (Fig.5b).

Fig.3. Slight yellow streaks found at Heidong quarry. (a) As groups in immediate roof of Layer 6 tuffs obvious found at Nos. 6 and 7 caverns. (b) Single strip at side wall of No.5 cavern. (c) Microscopic texture of the streaks in thin section.

Results

Time of original quarry

Near Heidong quarry, there is Shangqiu village (Fig.1b) which owns a family-preserved ancient book named "A genealogy of surname Qiu at Tiantai Mountain". In this book, there is a sentence "The nearby Xieshan Hill was excavated to be hollow in Shenzhong years of the North Song Dynasty (1068–1077AD)". In other words, the Heidong quarry was already a large scale ancient underground quarry for excavation of flagstones at North Song Dynasty, more than 1000 years ago.

At Tatou Temple 13 km north (Fig.1b), there exists a tablet weighing 1500 kg made of tuffs set up during Tang Dynasty (811AD). The Tatou Temple sits above red layers of Cretaceous series, therefore, the extracted tuffs for the tablet was certainly from other sites. By comparison, it is clear that the close proximity quarry is the Heidong Cavern. Other sites, like the Meiyuan open-pit quarry within the jurisdiction of Ningbo city is located 100 km north, the Changyu Caverns at Wenling is 105 km south (Fig.1a). The flagstone of the Tang tablet is proved to be extracted in Heidong quarry because the rocks are the same as slight gray massive ripple rubble-bearing vitric tuffs. That means, it was quarried from the Layer 6 of K_2t. Moreover, there are 3 slight yellow narrow streaks found in the Tang tablet, which is commonly seen at Nos. 1, 3, 5, 6 and 7 caverns of the Heidong quarry (Fig.3a and 3b). Microscopic observation reveals that the yellow streak is a complex of fine-grained albite, biotite and calcite (Fig.3c). This means that the original excavation of Heidong quarry is earlier than 811 AD, about 1200 years ago.

At Guoqing Temple (Sui Dynasty) 6 km north (Fig.1b), the slight yellow streaks are also found at an ancient Buddha tablet. That tablet was carved in Sui Dynasty (598 AD). It can be inferred that the Heidong quarry was originally excavated no later than 1413 yrs ago, so that, these caverns can be named as millennium quarry caverns.

Trial adits and cavern geometry

At the foot of Xieshan Hill, several trial adits filled with jade-green waters while some trial pits kept with steep cut slopes can be identified by characteristic chisel marks and dark patina (Fig.4c and 4d). They are believed to be extensively exploitated as a trial approach to excessive enlargement of individual caverns extracted in the massive and homogeneous gray tuffs, while avoid or escape from fractured or strongly weathered rocks with signs indicative of distress.

On the basis of field survey, fault F_1 at points A and B within branch caverns 2-1 and 2-2 (Fig.2a) seriously caused the precarious stability of southern lateral wall of No.2 cavern, which was well known by the ancient craftsmen. They applied two entirely warranted approaches to deal with it. Firstly, they excavated normal to the fault with smaller area of working face. Secondly, they left more pillar walls along the southern extremes as for smaller scale branch caverns (Fig.4a and 4b). They tried advancement while working in close proximity to the fault. Till now this kind of observation method is generally preferred in rock engineering design and excavation (Stille and Palmstrom, 2003).

The 3 layers from bottom to top are Layers 6, 7 and 8 (Team of Regional Geology Expedition, 1978), whose engineering geological conditions belonged to most favorable, poor and moderate, respectively. Ancients focused on the integrated and competent Layer 6 as the main quarrying rocks. As immediate roof, the thinnest, fragile and anistropic layer 7 (0.3–1.0 m thick in general) was almost completely excavated or kept at the abutments in case of potential collapse (Fig.6d). And Layer 8 was also well quarried except of the dominant Layer 6 in shallow caverns. The measure of dome roof was adopted in large span caverns such as Nos.2 and 5.

Three cross sections, I-I' and II-II' of No.5, III-III' of Nos.1 and 2 caverns drawn from Fig.2, are shown in Fig.7. According to field

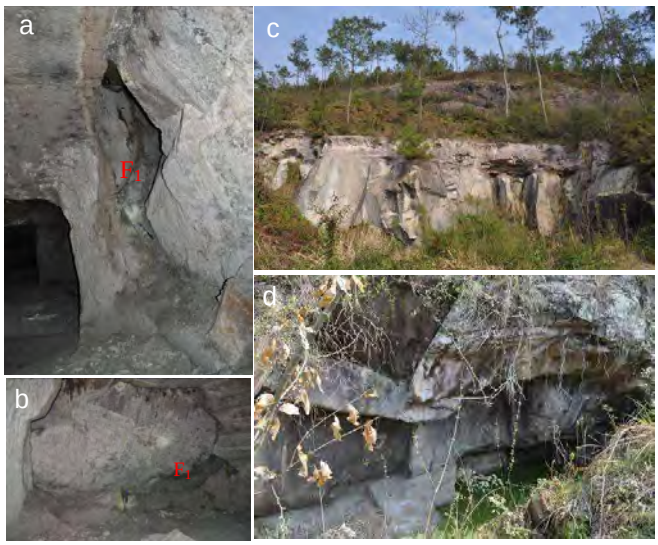

Figure 4. Observation approach in excavation at the Heidong quarrying. The blue geological hammer with a hand length of 35cm is presented for scaling. a, Cut through normally to the fault F_1 with a smaller diameter. b, When F_1 was encountered the excavation was deliberately modified or stopped. c, Trial pits with steep cut cliffs. d, Trial adits filled with water at slope feet.

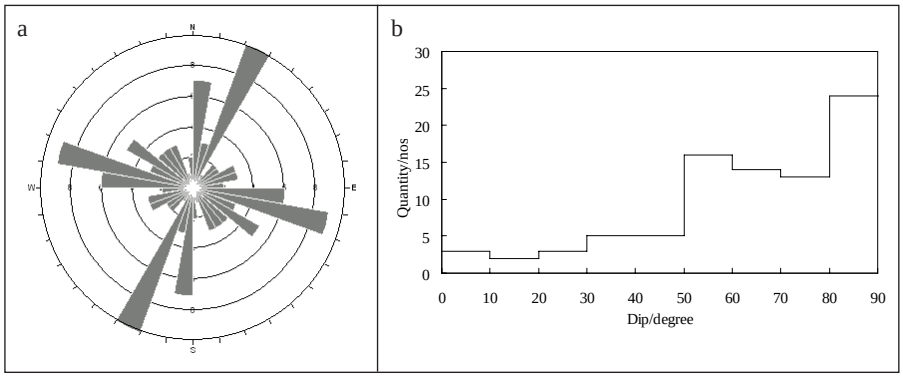

Figure 5 Distribution features of the discontinuities. a. Rose diagram of discontinuity strikes; b. Bar diagram of discontinuity dip vs frequency.

measurement, it is known that the largest span is 81 m. And the common wall is 4–6 m thick, which takes account of 3.4–5.1% of the combined span 117 m of Nos.1 and 2. The two caverns are parallel with each other with spans of 60 m and 53 m, respectively, which are rarely seen up to now (as cross section III-III' in Figs. 2c, 6a and 7c). Generally as dome roof, the span of the No.5 cavern is 62 m in east-west, and 81 m in north-south, respectively (Figs.6b,7a,7b). According to updated referential data, it is the largest span worldwide within unsupported quarrying caverns (Barton et al., 1994; Broch et al., 1996). Additionally, the cover height of No.5 is only 5–20 m, no more than 0.25 times of the span, which makes the miraculous stability over 1000 years.

Mechanical strength and rock mass quality

The mechanical test results of the sampled cylinder restrieved from intact rocks are listed in Table 3. They represent the response of virgin material unaffected by ongoing failure in the process of quarrying. From the uniaxial compressive strength (UCS), it is known the intact rocks at Layers 6 and 8 belong to low to moderate strength, while intact rocks at Layer 7 belongs to very low strength (Stille and Palmstrom, 2003). According to corresponding standards and specifications (Brown, 1981; Ministry of Water Resource, PRC, 1995), the former two belongs to harder rock, while the latter one to softer rock.

Table 3. Mechanical lab test results of intact rocks from Heidong quarry caverns

Layer	γ (g/cm^3)	E (GPa)	μ	UCS (MPa)	C (MPa)	Φ (°)	Rt (MPa)
6	1.932	13.60	0.27	50.00	7.80	55.70	4.8
7	2.361	11.65	0.30	22.44	4.47	38.09	1.1
8	2.279	12.67	0.30	37.49	11.12	29.81	2.9

γ - Bulk dry density, E-elastic modulus, μ - Poisson's ratio,UCS -Uniaxial compressive strength, C - cohesive force, Φ - Frictional angle, Rt - Brazilian tensile strength.

The discontinuities at Heidong quarry are primarily clean joints with little or no infilling materials. A total of 85 discontinuities were mapped in the studied complex. Many joints transect the caverns and exhibit trace lengths of tens of meters.

Rock mass quality classification method, e.g. Q (Barton et al., 1974) and RMR (Bieniawski, 1976) are widely accepted. These two methods have been adopted in the current study, using the site investigation and mechanical test data described above. The results for RMR and Q classifications are listed in Tables 4 and 5, respectively. The RMR values are 77, 36 and 63 for the three layers, belonging to II, IV and II grades, respectively. According to these values, the caverns in Layer 6 up to 10 m span would be expected to sustain a stand up time of 1 year.

If the bulk density and buried depth for the three layers as 30 m for Layer 6 and 20 m for the other two layers then, the maximum tangential stresses are 600 kPa and 450 kPa, respectively. The SRF parameter which incorporates the strength/stress ratio (σ_c/σ_1) can be returned (Barton et al., 1974). The Q value of the single Layer 6 with massive tuff is the most favorite only within this layer. If the Layers 7 and 8 are considered together, the rock mass quality will be decreased with smaller Q values (roughly Q=10–50).

According to Barton et al., (1974), the unsupported span or height/ESR (ESR is Excavation Support Ratio) is about 10. For temporal and permanent mine openings, the ESR = 3–5, and 1.6, respectively. The corresponding span is 30–50 m, and 16 m, respectively. Even the maximum 50 m span of temporal mine openings is far fewer than the actual 81 m span of the No.5 cavern in integrated Layer 6.

From the Chinese current specifications (Ministry of Water Resources, PRC, 1995) it is clear that the most preferred surrounding rocks of Layer 6 belong to class I with weighted mean value of Q = 40–1000. For this kind of rocks, spans without supports are expected to be less than 15 m so as to keep them stable for long time (SBMI, 2001). Here, in Heidong quarry caverns, the Q is less than 51, the unsupported largest span is less than 50 m as temporal mine openings, or 15 m as permanent mine openings (Barton, 2002), but it showed up to be 81 m and kept stable for about 1400 years. This indicates the huge differences between current knowledge and actual stable conditions with respect to unsupported stable time.

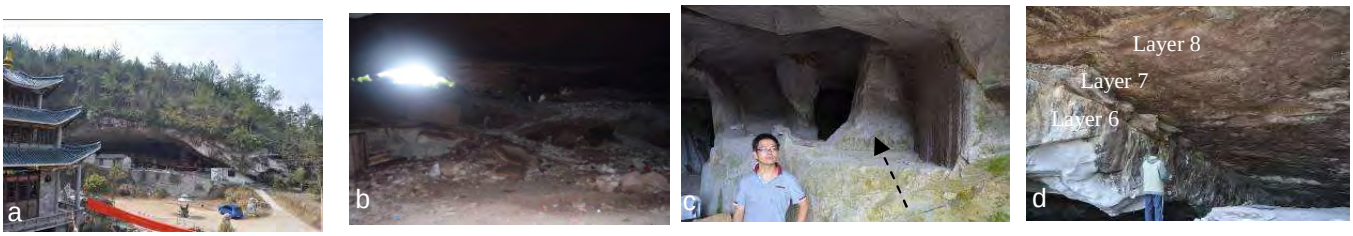

Fig. 6. Plates showing structure of caverns at Heidong quarry (For locations, see Fig 2a). a. SW viewing outside of No.1 cavern. b. SE viewing in No.5 cavern. c. The holes at bottom of one side wall at branch cavern 2-3. d. The three slightly dipping layers (location: port of No.21 cavern).

Table 4. RMR classification scheme for the three layers at Heidong quarrying caverns

	Layer 6		Layer 7		Layer 8	
	Index	Rating	Index	Rating	Index	Rating
UCS/MPa	50	7	22.44	2	37.49	4
RQD/%	90	20	60	8	80	17
Spacing/cm	>200	25	60	10	>200	20
Condition of discontinuities	Slightly rough surface, separation <1mm	20	Slightly rough surface, separation <1mm, with soft fillings	15	Slightly rough surface, separation <1mm	18
Groundwater condition	dry	10	wet	7	dry	10
Orientation of discontinuities	General	-5	General	-6	General	-6
RMR (grade)	77 (II)		36 (IV)		63 (II)	
Stand up time (span m)	1a (10 m)		10h (2.5 m)		1a (10 m)	

Table 5 Q classification for the three layers at Heidong quarrying caverns

	Layer 6		Layer 7		Layer 8	
	Index	Rating	Index	Rating	Index	Rating
RQD	Excellent	95	General	60	Good	80
Number of joint sets (Jn)	2	4	4	12	3	9
Roughness (Jr)	noncontinuous	4	Smooth undulating	3	Smooth undulating	3
Degree of alteration (Ja)	Close contact	0.75	Unaltered	1	Unaltered	0.75
Water inflow (Jw)	Dry excavation	1	Dry excavation	1	Dry excavation	1
SRF(σ_c/σ_1)	50/0.6=83	2.5	22.44/0.45=50	5	37.49/0.45=83	2.5
Q (grade)	51 (Very good)		3 (Poor)		14.2 (Good)	

Quarrying mechanism

In caverns we found lots of holes left in waste rocks and rows of digging holes on the side walls (Fig.6c). It is inferred that the thickness of flagstones is 60-80 mm. Field survey and enquiry with local craftsmen clarify that the ancient craftsmen used short chisel and hammer to quarry flagstones just like splitting rocky sheets in vertical side walls. Firstly, the designed size of the flagstone was circled in a vertical side wall, then three grooves which are 70-90 mm, deeper than flagstone thickness, are made carefully along its three boundaries, top, left and right. After that, a row of small digging holes with both the diameter and intervals of 30 mm are bored in its bottom. All the holes dipped 20–30° upward to make it easy to get the flagstone with uneven margins. Here the technique initially adopted by ancestors is named as Digging Holes for Quarrying Vertical Flagstone (DQF).

Further, theoretical research indicates that the above DQF is concordant with the principle of fracture mechanics (Whittaker et al., 1992). According to geometric conditions revealed in Fig.8a and 8b, a representative digging hole is shown in detail in Fig.8c, the quarrying mechanism can be inferred. Firstly, the short chisel was penetrated into digging holes at its bottom boundary, and using hammer it is struck in sequence. Continuous striking make the holes fractured and tended to be jointed one by one. Then after some circular striking, the jointed cracks developed upward dissecting the left, right and reaching the top boundary grooves. At last, the stone is decoupled from surrounding rocks as a flagstone. In some cases, the mostly vertical dipping joints are used instead of lateral free grooves in quarrying flagstones. And the overall strikes of side walls are parallel with the two sets of joints (Fig.5a). Obviously, using these joints has advantages of saving quarrying time, and lessening rate of stripping with quarrying to increase the efficiency.

Here it should be noted that the quarried flagstone behaves half of a row of digging holes at its bottom boundary, while the other half is kept on walls of the surrounding rocks. So the craftsmen cut down the left half of holes adhered in flagstones, then put them within caverns as waste rocks. Figure 8a just shows a waste rock sample. While Fig.6c shows the other half of holes as a row left in side walls. Obviously, Fig.8 certifies the above inference on excavation mechanism at Heidong quarry.

Besides, the fracturing mechanism is clarified by using 2-D numerical simulation of the finite element method (FEM) (Wang and Li, 2008), which clearly indicated that the crack originated at bottom boundary, developed to grooves at top boundary, thus one flagstone was well obtained.

Volume of waste rocks

The ancestors stacked waste rocks inside and the refuse dump reached 9.4 m thick at No.5 cavern, 6.8 m at Nos.1 and 2 caverns. In fact, all the 21 caverns were used for stacking waste rocks. If the average thickness 3.5 m is taken into account, the bulky volume of waste rocks is about 40,000-84,000 m^3 within the quarry caverns.

The waste rocks inside played a key role of providing confinement and support for limiting the amount of convergence of the rock mass (Tesarik et al., 2009. This measure was also environment-friendly (Butzer, and Harris, 2007). The idea of preserving ecological environment 1400 years ago is surprisingly admirable.

It is understood that there are three advantages to adopt this approach of disposal waste rocks from quarrying extraction within caverns. Firstly, the cost of taking these waste rocks outside of caverns was saved. Secondly, the stacked waste rocks support stability of side walls, even the large scale of caverns because of the decreasing cavern height, as situations of largest span and thinning common walls. Thirdly, the waste rocks kept within caverns prevented a fertile

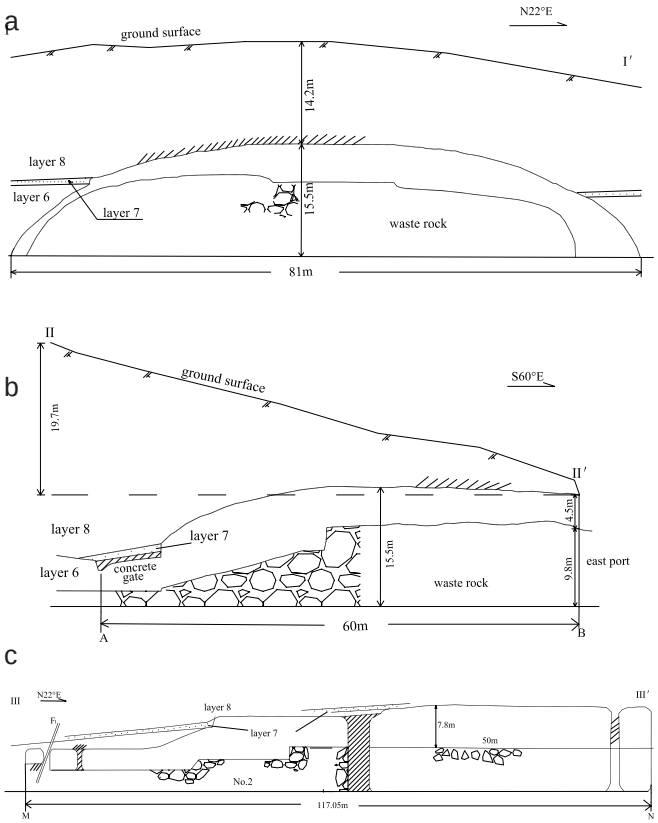

Figure 7 Cross sections of the caverns (For their locations, see Fig.2a). a. Section I-I' along north-south with a span of 81m at No.5. b. Section II-II' along east-west with a length of 62m at No.5. c. Section of the common side wall between Nos. 1 and 2 caverns.

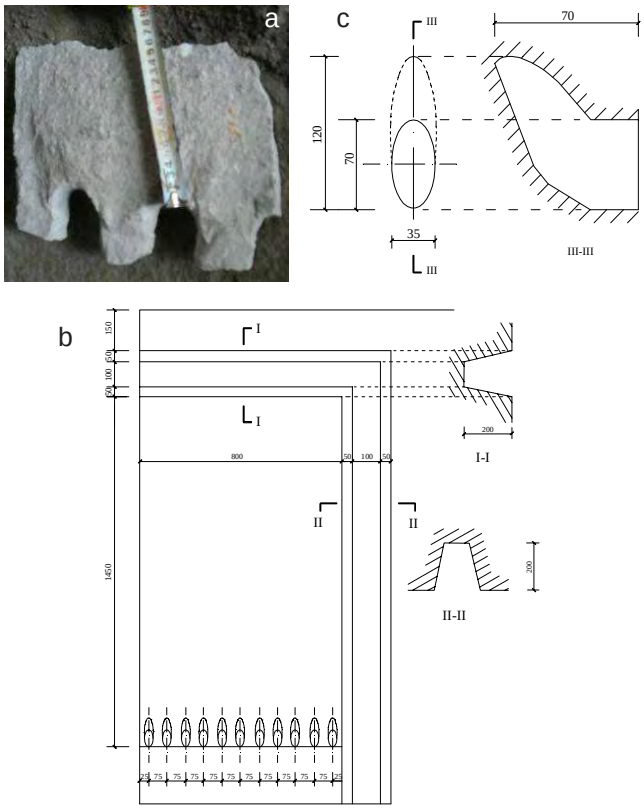

Figure 8 Small digging holes left in Heidong quarrying site. The common side intervals of adjacent holes is 30mm. Unit:mm) a. One waste rock specimen left at caverns with a half of digging holes. b. Plane map showing a row of small digging holes bored at side walls. c. Plane and section showing small digging holes

farmland outside of caverns from burying, thus preserving ecological system.

Discussion

The smart quarrying measure and geometric align led to the surprising long-term stability of Heidong quarry caverns. The caverns were quarried by DQF, rather than blasting and casting technique commonly adopted at present for quick excavation, which results in a noticeable excavation damaged zone (EDZ) (Shen and Barton, 1997) and causes most unstability in surrounding rocks. DQF was special in ancient times, slow but safe. Here, the equipment is a limiting factor, but this kind of construction-oriented approach was successfully adopted (Sagefors and Daerga, 1996). Blasting and casting technique is fast but effective measures must be taken into account in order to eliminate the negative affects on surrounding rocks. Electric saw is widely used today for industrial quarrying which mostly gets only smaller stones and costs lots of energy though a little EDZ (Fig.9). The comparison reminds us how to strike a balance among efficiency, safety and environment-friendly of underground rock engineering. The Heidong caverns keeping long term stability provide a distinct analogical and extrapolative model.

In a word, the Heidong caverns with a largest span cavern was

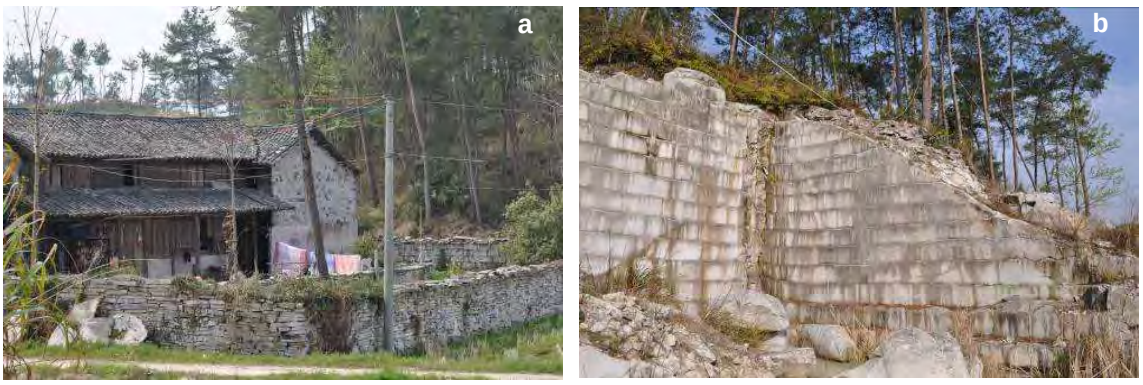

Figure 9 Quarrying stones for building houses in history and adopted techniques at present. a, Historical house building in cut flagstones. b, Quarrying cliff with traces of electric saws.

originally excavated over 1400 years before at background of the Tiantai Sect. Thus, it can be regarded as one important rocky cultural relic (Fig.1), which is comparable to the Wieliczka salt mine as the first batch of world cultural heritage sites (http://en.wikipedia.org/wiki/Beit_Guvrin_National_Park).

Conclusions

The Heidong quarry caverns, comprises of 21 in an area of 24,000 m^2, with a largest unsupported span of 81m. The volume of disposal waste rocks is about 40,000–84,000 m^3 within the quarry caverns. The rock mass quality of massive tuffs in Layer 6 is most favorable with high value of RMR=77, and Q=51. The relatively poor quality of tuffaceous conglomerate-bearing sandstones of Layer 7 makes the quarrying site laid under Xieshan Hill be transverse isotropy and the quality decreases as a whole.

The 1400-year old well-kept 81 m span cavern at Tiantai County in south China is far beyond the 50 m expectation of the current rock engineering specifications, just because of its unique quarrying technique DQF with little excavation disturbance, by adopting systematic measures constituted of geometric dome roof, trial adits for massive tuff, and inside disposal of waste rocks for cavern supporting.

The ancient quarrying achievement marks a high level in complex natural conditions with manpower. These results are positive to extend our knowledge on category design of cavern scale and stability assessment, and light inspiration for resolution of the conflict between quick excavation with blasting and intensive EDZ in surrounding rocks.

Acknowledgements

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References

Aubertin, M., Li, L., and Simon, R., 2000, A multiaxial stress criterion for short- and long-term strength of isotropic rock media. International Journal Rock Mechanics and Mineral Science, v. 37, pp. 1169-1193.

Barton, N., 2002, Some new Q-value correlations to assist in site characterisation and tunnel design. International Journal Rock Mechanics and Minernal Science, v. 39, pp. 185-216.

Barton, N.R., Lien, R., and Lunde, J., 1974, Engineering classification of rock masses for the design of tunnel support. Rock Mechanics, v. 6, pp. 189-236.

Barton, N., et al., 1994, Predicted and measured performance of the 62 m span Norwegian Olympic Ice Hockey Cavern at Gjøvik. International Journal Rock Mechanics and Mineral Science & Geomech. Abstracts, v. 31, pp. 617-641.

Bieniawski, Z.T., 1976, Engineering classification of jointed rock masses. Transactions South African Institute of Mining and Metallurgy, v. 74, pp. 335-344.

Broch, Einar, Myrvang, Arne M. and Stjern, Gisle, 1996, Support of large rock caverns in Norway. Tunnel and. Underground Space Technology, v. 11, pp. 11-19.

Brown, E.T., 1981, Rock characterization, testing method and monitoring. ISRM Suggested Methods. Pergamon Press, Oxford.

Butzer, Karl, W. and Harris, Sarah, E., 2007, Geoarchaeological approaches to the environmental history of Cyprus: explication and critical evaluation. Journal Archaeological Science, v. 34, pp. 1932-1952.

Guo, G.M., 2006, Engineering highlights and protection problems of Longwang Hill large scale quarry at Xianju County. Institute of Geology and Geophysics, Chinese Academy of Sciences (Ph.D. Thesis,).

Hatzor, Y.H., Talesnick, M. and Tsesarsky, M., 2002, Continuous and discontinuous stability analysis of the bell-shaped caverns at Bet Guvrin, Israel. International Journal Rock Mechanics and Mineral Science, v. 39, pp. 867-886.

Hatzor, Y.H., Wainshtein, I. and Mazor, D.B., 2010, Stability of shallow karstic caverns in blocky rock masses. International Journal Rock Mechanics and Mineral Science, v. 47, pp. 1289-1303.

Li, L.H., Yang, Z.F., Yue, Z.Q. and Zhang, L.Q., 2009, Engineering geological characteristics, failure modes and protective measures of Longyou rock caverns of 2000 years old. Tunnel and Underground Space Technology, v. 24, pp. 190-207.

Ministry of Water Resources of the People's Republic of China, 1995, Standard for engineering classification of rock masses (GB50218-94) (China Planning Publishing House, Beijing).

News and Views, 1930, Nature, v. 126, pp. 320-324.

Sagefors, I. and Daerga, P.A., 1996, An excavation method for large vertical cylindrical caverns. Tunnel and Underground Space Technology, v. 11, pp. 279-285.

SBMI (State Bureau of Metallurgical Industry) 2001, Specifications for bolt-shotcrete support (GB50086-2001) (China Planning Publishing House, 2001).

Shen, B. and Barton, N., 1997, The disturbed zone around tunnels in jointed rock masses. International Journal Rock Mechanics and Mineral Science v. 34, pp. 117-125.

Stille, H., and Palmstrom, A., 2003, Rock mass classification as a tool in rock engineering. Tunnel and Underground Space Technology, v. 18, pp.331-345.

Team of Regional Geology Expedition, Bureau of Zhejiang Geology. Expedition report of regional geology (Xianju Sheet, 1:200,000) (Hangzhou, 1978).

Tesarik, D.R., Seymour, J.B. and Yanske, T.R., 2009, Long-term stability of a backfilled room-and-pillar test section at the Buick Mine, Missouri, USA. International Journal Rock Mechanics and Mineral Science, v. 46, pp. 1182-1196.

Tsesarsky, M., Hatzor, Y.H., and Talesnick, M.L., 2000, The stability of ancient bell-shaped caverns at the Bet Guvrin National Park–a comprehensive geomechanical study. Isr. Journal of Earth Science, v. 49, pp. 81-102.

Wang, S.J., Yang, Z.F. and Liu, Z.H., 1984, Stability analysis on underground engineering rock masses. Science Press, Beijing.

Wang, Z.Y., and Li, Y.P., 2008, Rheological theory and numerical simulation of rock mass. Science Press, Beijing.

Whittaker, B.N., Singh, R.N., and Sun, G.X., 1992, Rock fracture mechanics-principles, design and applications. Elsevier Science Publishers B.V., The Netherlands.

Yang, Z.F., Li, L.H., Pan, W., Lu, M. and Zheng, J., 2003, Discussions about large-scale ancient underground engineering. Science Technology and Engineering, v. 3, pp. 464-466.

Yang, Z.F., et al., 2007, Scientific discoveries of Jinxiu-Huangyan Panlong ancient underground cave group and preliminary analyses. Journal of Engineering Geology, v. 15, pp. 322-327.

Yang, Z.F., Guo, G.M., and Zhang, L.Q., 2011, Scientific and technology concerns on large scale ancient Feifeng Quarry at Xianju County and long term preservation. Science Press, Beijing.

Zhang, Z.J., 2010, Engineering geomechanics problem of large-scale ancient underground quarry of Shepan Island in Sanmen County of Zhejiang Province. Institute of Geology and Geophysics, Chinese Academy of Sciences (Ph.D. Thesis).

Zuber, A., Grabczak, J., and Garlicki, A., 2000, Catastrophic and dangerous inflows to salt mine in Poland as related to the origin of water determined by isotope methods. Environmental Geology, v. 39, pp. 229-311.

by N. N. Chombong and C. E. Suh

2883 Ma commencement of BIF deposition at the northern edge of Congo craton, southern Cameroon: New zircon SHRIMP data constraint from metavolcanics

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New SHRIMP data for zircons separated from a metadacite interbedded with banded iron formation (BIF) in the Mbalam region of southern Cameroon provide a 2883± 20Ma age for the commencement of BIF deposition in the Congo craton. Separated zircons from the associated metadacite are brown and euhedral to subheral in form with distinct oscillatory zoning typical of magmatic signatures. These zircons lack internal resorption features and serrated zone boundaries as should be expected of zircons inherited from the surrounding basement rocks or multiple magmatic plumbing events. However, zircons from a surface BIF sample collected ~ 60km west of the sequence from which the metavolcanics were sampled show a different age spectrum (Palaeoproterozoic, 1.0-2.0 Ga) suggesting a latter stage of BIF formation in the region which is not the focus of this work. Geochemical features of the metavolcanic samples analyzed identify the rocks to be rhyolitic, dacitic to andesitic in composition and possibly formed from a single magma by simple fractional crystallization. Trace element plots show negative Nb, Ta, Ti and Ho peaks that are characteristic of arc magmas. The study shows that initial BIF deposition in the Congo Craton was associated with early arc magmatism in the Archean. These ages correlate reasonably with early BIF deposition across the Atlantic in Brazil which was once linked to the Congo craton prior to the breakup of Gondwana.

Introduction

Banded Iron Formations (BIF) are chemical sediments thought to have been formed in an open ocean when the earth's oxygen was still very low (Bekker et al., 2004; Kaufman et al., 2007 and Konhauser et al., 2002, 2007b). Typically, BIF consists of alternating Si- and Fe-rich layers with an evaluated total Fe and Si content of 20 – 40 wt% and 43 – 56 wt%, respectively (Klein, 2005). The deposition of BIF is linked to a contemporaneous process in which clastic sediments from the continent were being deposited in the ocean along with the upwelling of hydrothermal fluids at the Mid-Ocean-Ridge (MOR) (Bau and Möller, 1993; Clout and Simonson, 2005 and Beukes and Gutzmer, 2008). Lavas intercalated with BIF provide a direct tool for constraining the timing of BIF formation in a paleobasin. The determination of BIF depositional age is vital to date key events in the evolution of the biosphere. Precise age constraints on the iron formation across the world both advance our understanding of BIF genesis and enable current stratigraphic and tectonic models to be evaluated. This paper dates for the first time BIF deposition within the Ntem Complex at the Northern edge of the Congo Craton by SHRIMP U-Pb method using zircons separated from associated volcanic material (Fig. 1). In addition, zircons separated from a surface BIF sample in the region are also dated to determine if other BIF depositional events occurred after the Archean phase of BIF formation. These results provide new insights for the correlation of Gondwana fragments in Africa (Congo craton) with those of South America (São Francisco craton) and also allow a better comprehension of the relation between volcanism and BIF deposition in pre-Gondwana break-up setting.

Overview of geology

The Ntem Complex represents the extension of the northern edge of the Congo Craton in Cameroon. Mesoarchean to Neoarchean charnockitic rocks usually of TTG composition (Takam et al., 2009 and Shang et al., 2010) and greenstones associated with metasedimentary formations make up the basement rock suit of the Ntem Complex (Shang, 2001; Pouclet et al., 2007 and Shang et al., 2007). Rocks of the TTG suite are strongly mylonitized and retrogressed along the thrust boundary with the Pan-African Yaounde Group (Takam et al., 2009). Late high-K granites and dolerite dykes generally younger than the TTG and greenstone belts occur as intrusions clearly distinct from the older TTG (Shang et al., 2007, 2010) (See Fig. 2). These have been interpreted as a heat source for remelting TTG and charnockites to generate high-K granites thus suggesting the coeval nature of doleritic magmatism and high-K

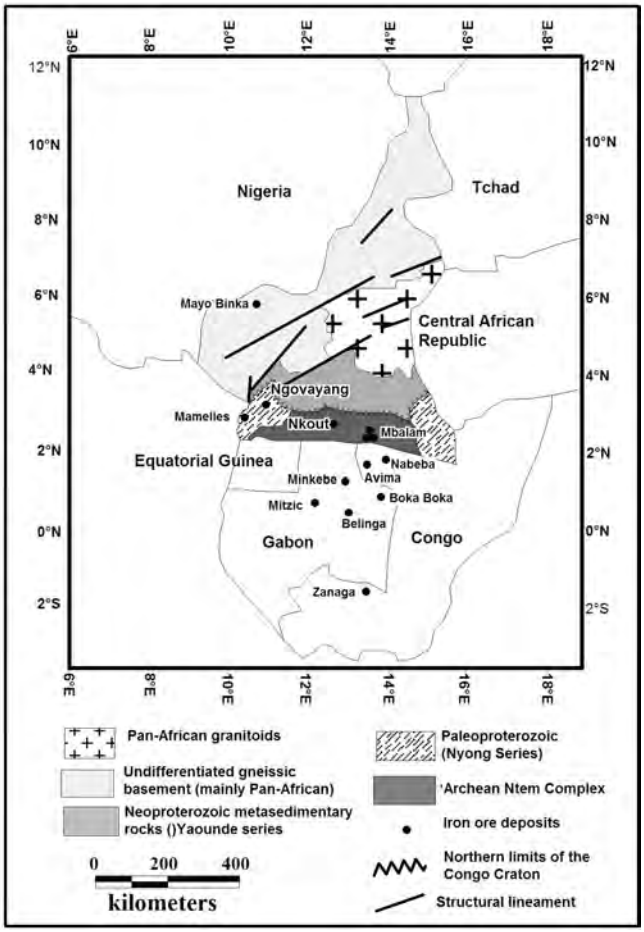

Figure 1. A Regional map showing iron ore deposits within the Congo Craton (Modified after Suh et al., 2008)

granite genesis (Shang et al., 2007, 2010). The high-K granites include monzogranites and syenogranites that occur as leucocratic pods and tongues associated with mafic restite and small scale pegmatitic and aplitic veins and dykes. Biotites and amphiboles dominate the restites while microcline, albitic plagioclase and quartz makeup the primary mineral assemblages with myrmerkitic textures common at the contact between microcline and plagioclase (Shang et al., 2010). Iron ore associated with BIF (Ilouga, in press; Suh et al., 2008; Suh et al., 2009 and Nforba et al., 2010) and the ultramafic rocks with elevated Ni, Cr and Co contents (Milesi et al., 2006) constitute the economic lithologies of the Ntem Complex.

Structural and petrological studies have identified two major Archean deformations at the northwestern edge of the Congo craton (Tchameni et al., 2000). D1 is non-rotational and defines hypersolidus textures and late joints linked to crystallization (Feybesse et al., 1998). D2 deforms the S_1 foliation into low amplitude folds (Feybesse et al., 1998) and is accompanied by the emplacement of plutons, diapirism and recrystallization. The S_2 foliation is vertical and oriented N80E to N120E and N-S. This is evident from relict greenstone belts and the TTG series (Shang, 2001 and Shang et al., 2004a). Sinistral shear planes that trend N-S to N45E - N50E define C_2 surfaces that are associated with partial melting of the TTG rocks (Tchameni et al., 2001 and Shang et al., 2004a). D_3 and D_4 define transcurrent tectonics that are steeply dipping and represented by C_3 mylonitic and shear corridors observed near the contact zone with the Yaoundé nappe front (Shang et al., 2004a and Takam et al., 2009).

BIF of the Congo craton have received very little attention to date. Within the Ntem complex in southern Cameroon, reconnaissance BIF geochemistry, mineralogy and structure have been reported by Suh et al. (2008, 2009) and Nforba et al. (2010). The iron ore concentrates attain grades as high as 96 wt% Fe although the protore has 20 – 45 wt% Fe. The enriched ore consists of hematite and martite with minor goethite. Two BIF facies are encountered in the area, namely the oxide and silicate facies. Banding in both facies is distinct and mesobands rarely exceed 1 cm. The oxide facies BIF is composed of quartz as the main gangue mineral associated with various iron oxides, principally martite, goethite and magnetite. The iron oxide phases could be granular, massive or finely disseminated. The silicate facies (amphibolitic facies) is characterized by abundant brown goethite pseudomorphs after silicate minerals (amphiboles) (Ilouga et al. 2012, *in press*). The bands present similar textures as above, in addition to the alternating white to yellowish silica bands and light green to dark massive iron oxides bands. The common minerals that accompany the silicate in reflected light microscopy are martite, magnetite, goethite, and quartz

Recently, commendable exploration efforts by CamIron (a subsidiary of Sundance Resources, an Australian based company) and Afferro Mining on the Cameroon sector have led to the discovery of prospective major iron ore deposits within the paleobasin at Mbalam

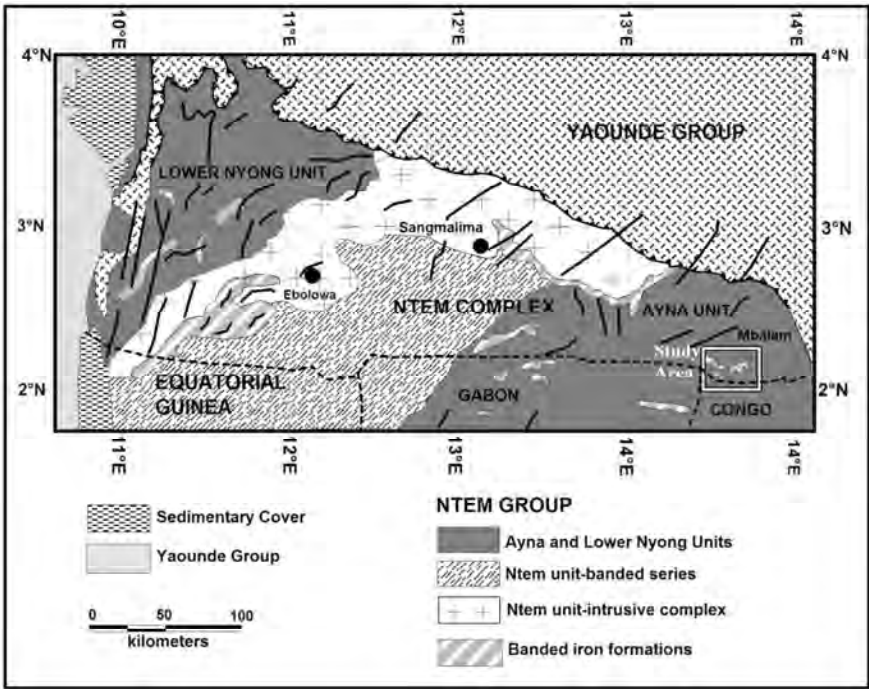

Figure 2. Regional geological map of the northern limit of the Archaean Congo craton (Ntem complex, the Nyong Unit) showing the Mbalam BIF units (study area), late Archean granitic intrusions, and thrust contact with the Pan-African fold belt in Southern Cameroon. (Modified after Maurizot et al., 1986).

and Djoum-Nkout, respectively, (see www.sundanceresources.com.au, www.afferro-mining.com for details).

Samples and analytical methods

A total of five (5) samples of rocks collected from cores were used in this study. Among the 5 samples analyzed were four (4) volcanic rock samples occurring as intercalations within the BIFs and one BIF sample. Polished thin sections of the samples were prepared at the Mineral Resources Institute, Technical University of Clausthal, Germany and studied under reflected and transmitted light at the Department of Geology, University of Buea, Cameroon.

Major and trace elements compositions for whole rock analysis were obtained by ICP-OES and ICP-MS at a commercial laboratory (Acme Analytical Laboratories Ltd., Vancouver, Canada). The major elements and several trace elements were reported on a 0.2g sample analyzed by ICP-OES following a lithium metaborate/tetrabortate fusion and dilute nitric acid digestion. Loss on ignition (LOI) was determined by weight difference after ignition at 1000°C. Rare earth and refractory elements were determined by ICP-MS following a similar lithium metaborate/tetrabortate fusion and nitric acid digestion of a 0.2g sample. In addition a separate 0.5g split was digested in aqua regia and analyzed by ICP-OES to report the precious and base metals. A replicate was done after each analysis for quality control and a standard and a blank run after every 5 samples to calibrate the equipment and ensure optimal precision of the data set obtained.

The volcanic sample, NTV02 and the BIF sample MET510 were dated at the Research School of Earth Sciences (RSES), Australian National University (ANU). Mineral separation was performed in the laboratories of the RSES. The sample was crushed, milled and the fines washed off in a settling beaker. Magnetic minerals were separated using a hand magnet and a Franz isodynamic separator. Heavy minerals were concentrated using both tetrabromoethane and methylene iodide. Concentrated zircons were mounted in epoxy, together with Temora III (416.8 ± 1.3 Ma), FC1 (1099.1 ± 0.5 Ma; and SL13 reference zircons. Temora is the primary U-Pb standard, FC1 was used as a secondary standard and to monitor $^{207}Pb/^{206}Pb$ ratios, and SL13 (Claoué-Long et al., 1995) is a chip of a single crystal with a uniform U content and is used to calibrate U, Th and Pb concentrations. The grains were polished to half the thickness of the average grain in the mount to expose any complex internal structures. All zircons were photographed in transmitted and reflected light and these, together with SEM cathodoluminescence images, were used to decipher the internal structures of the sectioned grains and to target specific areas within the zircons for spot analysis. U-Pb analyses were done using SHRIMP RG at the RSES. The data was reduced in a manner similar to that described by Williams (1998) using the SQUID I Excel Macro of Ludwig (2001). The decay constants recommended by the IUGS Subcommission on Geochronology (as given in Steiger and Jäger, 1977) were used in the age calculations. Uncertainties given for individual U-Pb analyses (ratios and ages) are at the 1ä level; however uncertainties in the calculated weighted mean ages are reported as 95% confidence limits and include the uncertainties in the standard calibrations where appropriate. For the age calculations, corrections for common Pb were made using the measured ^{204}Pb and the relevant common Pb compositions from the model. Concordia plots, regressions and any weighted mean age calculations were carried out using Isoplot/Ex 3.0 (Ludwig, 2003) and, where relevant, include the error in the standard calibration.

Results

Petrography: The volcanic rocks have twinned plagioclase and K-feldspar porphyroblasts that are subhedral to anhedral in shape within quartz-biotite-sericite groundmass defining a poikiloblastic texture. Biotite and sericite flakes are wrapped around feldspars crystals and they represent secondary mineral phases developed by the alteration of the feldspars (Fig. 3a). Biotite and sericite define a strong mineral lineation while relicts of magmatic flow layering, obscured by the metamorphic overprint are still discernable (Fig. 3b).

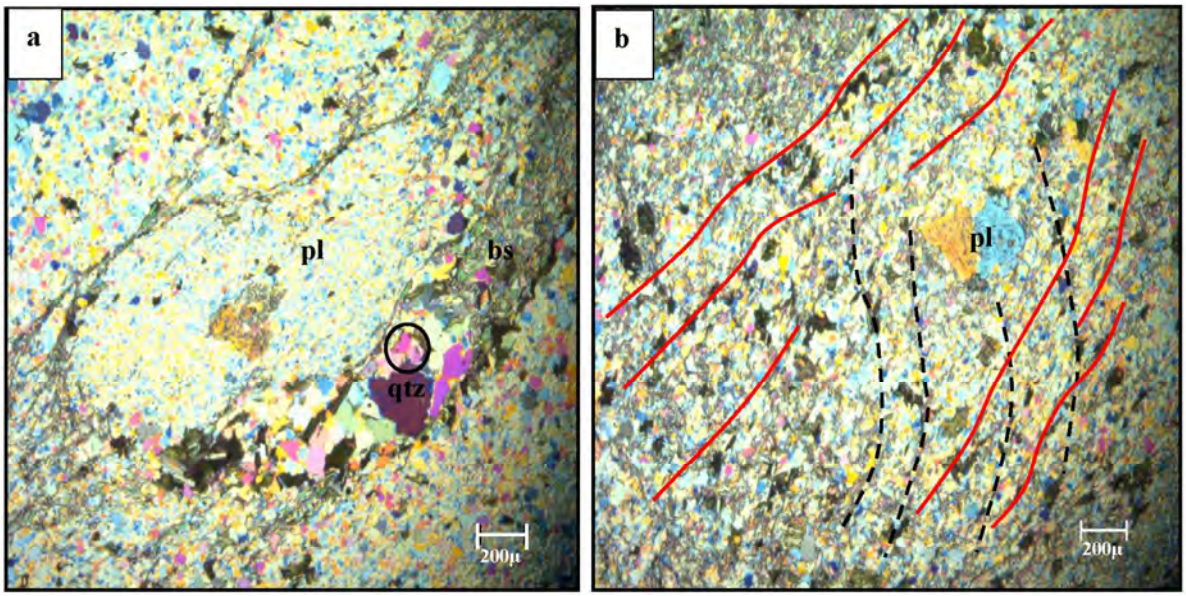

Figure 3. (a) *A plagioclase porphyroblast (**p**) gradually being altered to biotite and sericite (**bs**).Black circle shows subrounded to polygonal quartz (**qtz**) crystals defining 120° grain boundary angle.* ***(b)*** *A Plagioclase porphyroblast (**pl**) with a quartz-biotite-sericite matrix. Red lines follow strong mineral lineation defined by secondary biotite and sericite phases while black broken lines demarcate original magmatic flow layering.*

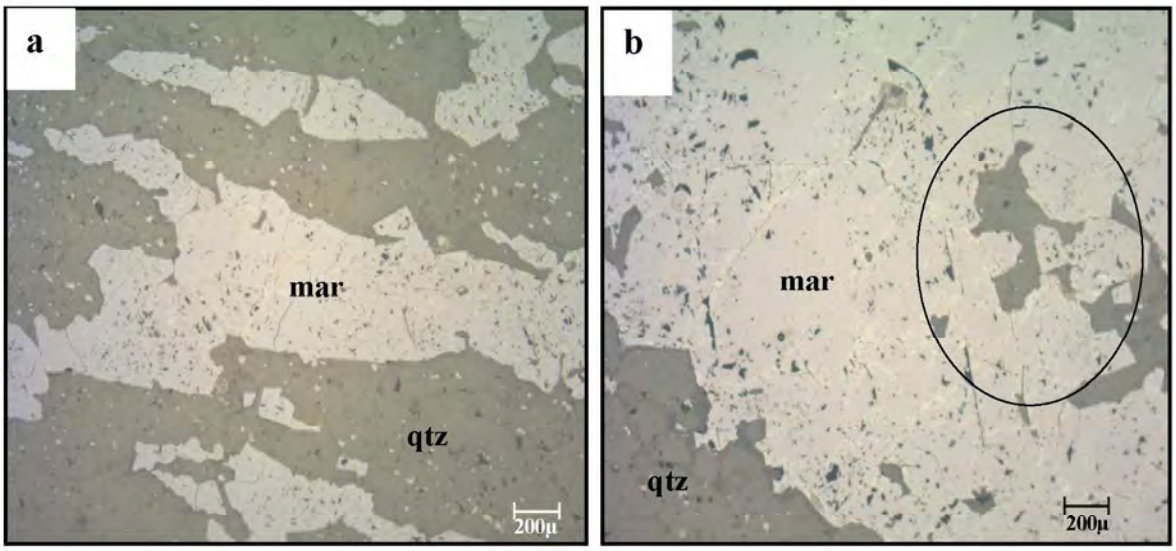

Figure 4. (a) *Alternating bands of magnetite and/or martite (**mar**) with quartz (**qtz**). (b) Magnetite and/or martite (mar) with lobate grain boundaries defining a granoblastic texture (well expressed within the black circled area)*

Quartz crystals are sub-rounded and polygonal with grain boundaries at 120º angle due to recrystallization (See Fig 3a). This buttresses the metamorphic signature of the samples. Extensive carbonate hydrothermal alteration is indicated by the development of calcite megacrysts. Pyrite, chalcopyrite and pyrrhotite are the main opaque phases and they follow the mineral lineation defined by the phyllosilicates.

The MET510 BIF sample shows alternating bands of quartz and magnetite. The magnetite bands show a gradual transformation to hematite (martitization) (Fig. 4a). Hence, magnetite mainly exists as residual phases in martite and as inclusions within corroded quartz margins. The martite crystals have lobate grain boundaries that build a granoblastic fabric (Fig. 4b). The quartz bands show subhedral polygonal quartz crystals with magnetite and martite filling cavities around corroded quartz margins. The polygonal quartz assembly also defines a granoblastic texture.

Geochemistry

Major elements

The volcanic samples have high SiO_2 values ranging from 60.9 to 82.09wt% expressing the felsic nature of the melt composition. Na_2O and K_2O are also of considerable concentrations with values of up to 4.48 and 2.28 wt%, respectively. MgO and CaO occur in low concentration but for sample NTV04 with values of 4.5 wt% and 2.8 wt%, respectively (Table 1). A Total Alkaline Silica plot shows that the samples are rhyolitic (NTV03, NTV02 and NTV05) and dacitic to andesitic (NTV04) in composition (Fig. 5). The MET510 sample has Fe_2O_3 value of 50.12 wt% which is higher than the 20 – 40 wt% attributed to BIF and SiO_2 content of 50.25 wt %. Trace elements concentration such as Rb, Cs, Hf and Th are generally low. This is typical of quartz-itabirite. Unwanted elements in iron ore such as Al_2O_3, P_2O_5 and S are also low (Table 1) buttressing the high grade iron ore potential of the basin.

Trace and REE data

Trace elements data from the 5 samples analyzed were normalized against primitive mantle values obtained from Sun and McDonough, (1989). Spidergrams of the normalized data show pronounced negative anomalies for High Field Strength Elements (HFSE) such as Nb, Ta, Ti and Ho (Fig. 6) while Lithophile Elements (LILE) such as Rb and Sr are present in high concentrations.

Rare earth elements data of the samples were also normalized against Post Archean Australian Shale (PAAS) values obtained from Nance and Taylor, (1976). Spidergrams of the normalized value for the volcanic samples show a relatively flat pattern of the REE data with the HREE just slightly enriched compared to the LREE (Fig. 7). $(La/Yb)_N$ values range from 0.559 to 0.842. The samples have relatively poor REE concentrations with ΣREE ranging from 7.725 to 11.322. All the REE but for Eu show a flat to gentle pattern. Sample NTV03 and NTV05 show a negative Eu anomaly as reflected in their Eu/Eu* value of 0.623 and 0.675, respectively. NTV04 show a weak positive Eu anomaly while NTV02 presents a weak negative to flat Eu pattern.

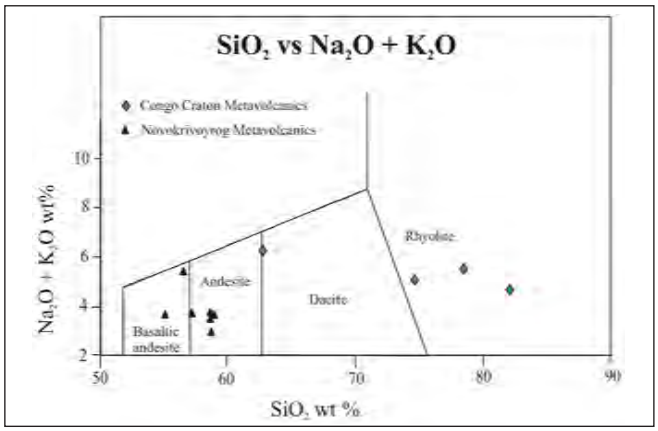

Figure 5. Total Alkali Silica Plot of the metavolcanic samples from the Congo Craton. Note the more basic nature of the Novokrivoyrog metavolcanics compared to the Congo Craton Metavolcanics. A close similarity is however observed between the two cratons as expressed by the dacitic to andesitic sample of the Congo Craton. Novokrivoyrog metavolcanic samples obtained from Mboudou et al. (2012, in press).

Table 1. Chemical composition of metavolcanic samples (NTV02 – 05) and BIF sample (MET510) from the northern edge of the Congo craton examined in this study

Samples	NTV02	NTV03	NTV04	NTV05	MET510
Major elements, wt%					
SiO_2	74.63	78.5	62.9	82.09	50.25
Al_2O_3	12.98	11.81	14.87	9.35	0.25
Fe_2O_3	3.24	1.5	6.3	1.66	50.12
MgO	0.86	0.51	4.5	0.56	<0.01
CaO	1.71	0.86	2.8	0.61	0.02
Na_2O	3	4.48	3.88	3.49	0.01
K_2O	1.99	0.92	2.28	1.11	0.01
TiO_2	0.22	0.09	0.63	0.07	<0.01
P_2O_5	0.04	0.02	0.15	0.02	0.07
MnO	0.06	0.02	0.11	0.03	0.02
Cr_2O_3	<0.002	<0.002	0.014	<0.002	<0.002
Ni	<20	<20	108	<20	<20
Sc	5	3	18	3	2
TOT/C	0.07	< 0.02	0.05	0.12	< 0.02
TOT/S	0.16	0.1	0.04	< 0.02	< 0.02
LOI	1.1	1.2	1.4	1	-0.7
Sum	99.87	99.95	99.82	99.97	99.99
Trace elements, ppm					
Ba	445	224	472	189	12
Be	<1	<1	<1	<1	<1
Co	8.3	3.5	29	4.3	0.7
Cs	3.8	1.3	5.7	1.7	<0.1
Ga	14.6	11.2	16.2	9.9	1.1
Hf	4.1	4.5	4	3.2	<0.1
Nb	7.7	7.6	6.3	5.7	0.3
Rb	93	40.2	86.7	48	0.6
Sn	3	2	2	2	<1
Sr	200.1	97.2	122.8	58.7	4.1
Ta	0.7	0.7	0.5	0.5	<0.1
Th	8.7	8.9	3.8	7.3	0.4
U	2.3	2.5	1	1.8	0.1
V	12	<8	132	<8	8
W	<0.5	<0.5	<0.5	<0.5	<0.5
Zr	138.5	132.9	147.6	99.5	8.5
Y	21.7	25.3	20.2	18.6	16.5
La	23.2	28.1	15.4	18.1	5.9
Ce	47.6	56.4	36.2	37.7	12.8
Pr	5.15	6.05	4.24	3.96	1.79
Nd	19.4	21.5	16.9	14.1	7.3
Sm	3.52	4.29	3.35	2.64	1.56
Eu	0.68	0.57	0.91	0.38	0.62
Gd	3.5	4.24	3.48	2.61	1.75
Tb	0.6	0.71	0.58	0.47	0.31
Dy	3.51	4.12	3.47	2.77	2.04
Ho	0.78	0.9	0.73	0.62	0.49
Er	2.29	2.52	2.18	1.88	1.48
Tm	0.35	0.38	0.31	0.28	0.22
Yb	2.39	2.46	2.03	1.85	1.42
Lu	0.37	0.38	0.32	0.28	0.23
Mo	2.1	0.3	0.4	1.2	0.4
Cu	59.2	63.9	59.7	4	1.9
Pb	4.7	24	2	2.3	1
Zn	144	89	73	29	2
Ni	15.6	7.1	101.6	4.9	1.8
As	<0.5	1.3	1	1	1.4
Cd	0.1	0.4	<0.1	<0.1	<0.1
Sb	<0.1	<0.1	<0.1	0.1	<0.1
Bi	0.3	0.3	0.2	0.1	<0.1
Ag	<0.1	0.3	<0.1	<0.1	<0.1
Au	<0.5	<0.5	<0.5	<0.5	<0.5
Hg	0.01	0.02	0.01	0.01	0.01
Tl	0.4	0.3	0.4	<0.1	<0.1
Se	0.5	<0.5	<0.5	<0.5	<0.5

NTV02 – NTV05 are volcanic materials intercalated with BIFs, MET510- a BIF sample (samples are cores obtained within the Ntem Complex at the northern edge of the Congo Craton)

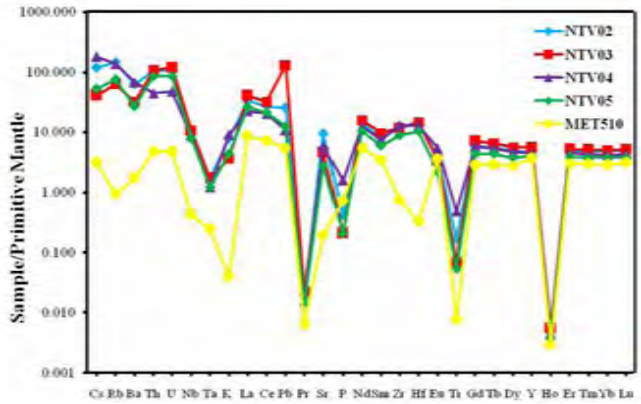

Figure 6. Primitive Mantle normalized trace elements and rare earth element plot. NTV02 – 05 (represents metavolcanic samples), MET510 (BIF sample). Note the negative peaks of Nb, Ta, Ti and Ho expressing the arc magmatic origin of the metavolcanic samples

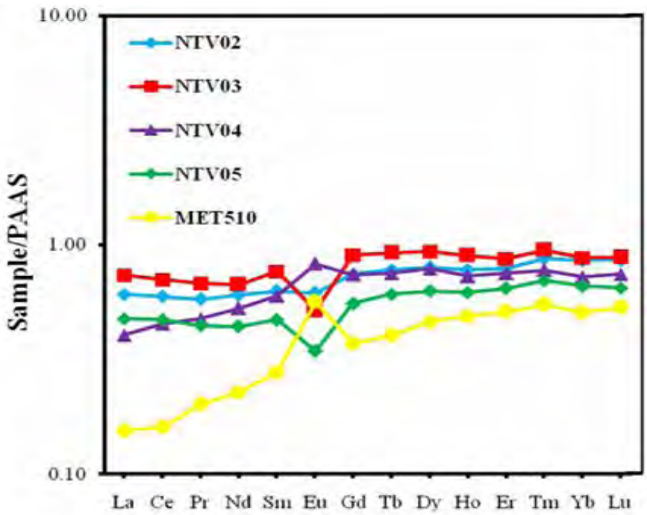

Figure 7. PAAS normalized rare earth elements plot. NTV02 – 05 (represents metavolcanic samples), MET510 (BIF sample). Note the similarity in pattern and positive Eu anomalies of NTV04 and the MET510 sample expressing the pristine nature of sample NTV04.

The MET510 sample shows HREE enrichment over the LREE with positive Eu anomaly. Ce shows a very weak negative anomaly to flat pattern probably influenced by similar poor concentrations of La and Pr. The ΣREE is low with a value of 5.418.

Geochronology

The sample NTV02 that was dated in this study is intercalated with BIF deposits in the Ntem Complex at the northern limit of the Congo craton. The geochronology results are summarized in Table 2 and Fig. 8. Unfortunately, the volcanics have very few zircon grains. Four zircons were found in the heavy mineral separate from the rock. All are brown and euhedral to subhedral in form. Cathodo-luminescence imaging (Fig. 8) shows magmatic oscillatory zoning with varying intensity and scale. These zircons lack internal resorption features and serrated zone boundaries as should be expected of zircons inherited from the surrounding basement rocks. Features of inherited zircons such as patchy wavy extinction and differential deformation

Table 2. Summary of SHRIMP U-Pb zircon data for sample 117 and MET510

Grain Spot	$^{206}Pb_c$ %	U ppm	Th ppm	$^{232}Th/^{238}U$	$^{206}Pb^*$ ppm Age	(1) $^{206}Pb/^{238}U$ Age	(1) $^{207}Pb/^{206}Pb$	Discordant %	(1) $^{207}Pb^*/^{206}Pb^*$	±%	(1) $^{207}Pb^*/^{235}U$	±%	(1) $^{206}Pb^*/^{238}U$	±%	Error corr
Sample 117															
2.1	0.03	144	66	0.47	69	2851±32	2873.4±5.5	1	0.2058	0.34	15.79	1.4	0.5563	1.4	.973
3.1	0.00	177	143	0.83	80.3	2737±26	2889±16	5	0.2079	0.98	15.16	1.5	0.5289	1.2	.762
4.1	0.03	355	236	0.69	168	2828±46	2894.7±3.6	2	0.2086	0.22	15.84	2	0.551	2	.994
2.2	0.06	125	88	0.73	50.7	2494±47	2894.1±9	14	0.2085	0.56	13.58	2.3	0.472	2.3	.972
3.2	0.11	157	120	0.79	66.3	2579±26	2890±30	11	0.208	1.9	14.11	2.2	0.4919	1.2	.548
Sample MET 510															
1.1	0.00	40	14	0.36	7.14	1204±19	1288±30	7	0.0838	1.5	2.372	2.3	0.2053	1.7	.741
1.2	0.43	47	17	0.38	7.64	1117±18	1157±50	3	0.0784	2.5	2.045	3.1	0.1892	1.7	.567
2.1	0.04	185	93	0.52	35	1280±15	1358±14	6	0.08688	0.73	2.63	1.5	0.2196	1.3	.874
2.2	0.24	174	91	0.54	26.3	1045±13	1244±24	16	0.08196	1.2	1.989	1.8	0.176	1.3	.733
3.1	0.10	196	99	0.52	29.3	1034±12	1027±18	-1	0.07346	0.91	1.762	1.6	0.174	1.3	.810
4.1	0.19	164	83	0.53	51.7	2016±22	2056.6±10	2	0.12698	0.57	6.427	1.4	0.3671	1.3	.912

Errors are 1-sigma; Pb_c and Pb* indicate the common and radiogenic portions, respectively. Error in Standard calibration was 0.27% (not included in above errors but required when comparing data from different mounts). (1) Common Pb corrected using measured ^{204}Pb.

lamellae are also absent. These zircons are therefore magmatic in origin. Five analyses were done on 3 grains. The data show variable discordance and some scatter (see Fig. 9) but as a group do give a weighted mean $^{207}Pb/^{206}Pb$ age of 2889 ± 13 Ma (MSWD = 2.7; probability = 0.028). Similarly, an upper intercept age of 2883 ± 20 Ma was calculated, but the high MSWD and low probability of 0.025 reflect the scatter in the data which is attributed to the magma residence time and zircon growth prior to eruption. This has been quantified (Brown and Fletcher, 1999) to be in the order of hundreds of thousands of years. This also explains the large error margin in the data.

A surface BIF sample ~ 60 km west of the area where the metavolcanics were sampled (MET510) was also dated. The zircons in this sample are small (< 150µm in the longest dimension) and show little internal structure, even with the aid of SEM cathodoluminescence imaging, apart from grain #4 (Fig. 10) that has a small dark-CL rim and faint zoning. The oldest zircon in this sample is #4 and the single analysis of this grain is slightly discordant but gives a $^{207}Pb/^{206}Pb$ age of 2057 ± 10 Ma. The remaining analyses show far more complexity and spread along or near the concordia curve with what appears to be variable ages. Three of the 4 analyses are clearly discordant, but analysis 3.1 is concordant within error, giving an apparent age of ~1030 Ma. The $^{207}Pb/^{206}Pb$ "ages" on the other analyses range from 1157 to 1358 Ma (Table 2 and Fig. 10 summarize the geochronological data).

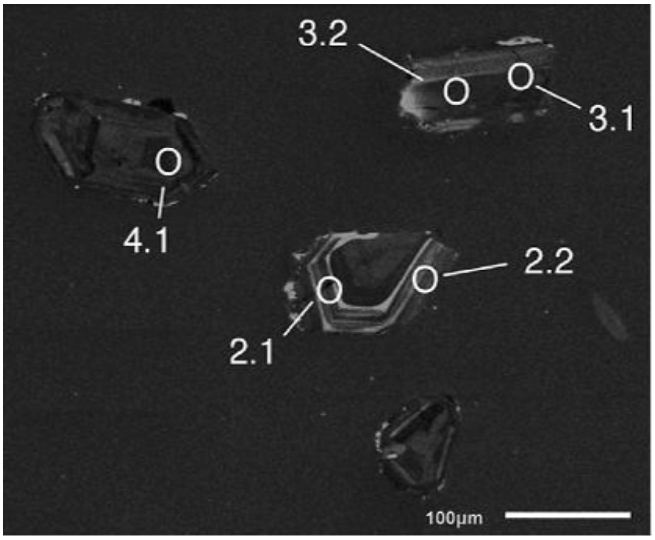

Figure 8. Cathodoluminescence image of a selection of the zircons analyzed from sample 117. The numbered ellipses mark the spots analyzed.

Discussion and conclusions

Major, trace elements and REEs

The negative peaks of Nb, Ta, Ti and Ho shown by the studied metavolcanics on the trace element spidergram (see Fig. 6) suggests that they crystallized from arc magma. Similarly, their high Rb and Sr concentrations are also indicative of a back arc environment (Elburg, 2010). Mantle plumes have been shown to be the major Fe-source of BIF deposits (Konhauser et al., 2007b and Steinhoefel et al., 2010). Economic scale BIF deposition therefore has a direct bearing with volcanic activity. The chemical composition of the mantle plume is a useful tool in determining its source region and depositional milieu of associated BIF deposits. The tectonic evolution of the Ntem Complex has before now identified 3 phases of magmatic

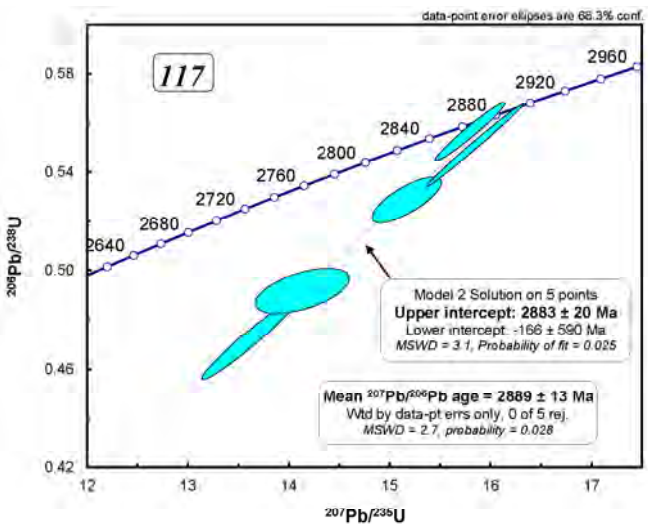

Figure 9. U-Pb concordia plot of all zircon data from sample 117.

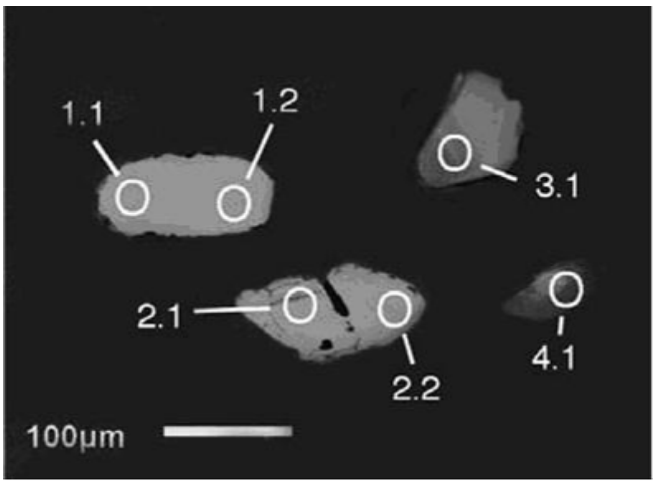

***Figure 10**. Cathodoluminescence image of zircons separated and analyzed from sample MET510. The numbered ellipses mark the spots analyzed.*

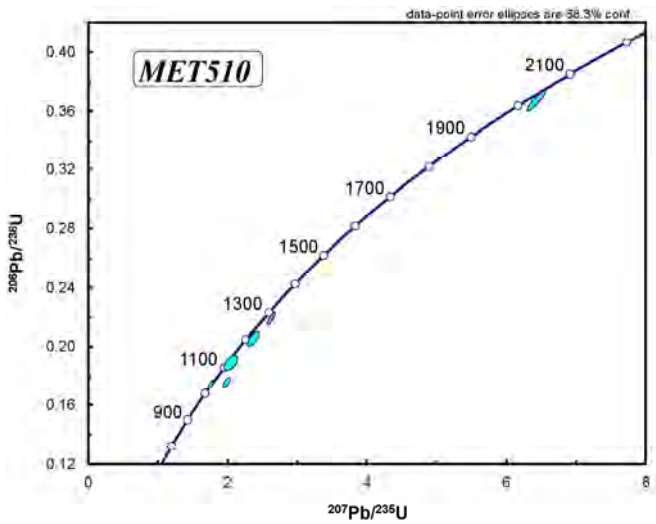

***Figure 11.** U-Pb concordia plot of zircon data from the BIF MET510*

emplacement (Owona, 2008) with the arc magmatic concept invoked for the emplacement of the Ebolowa metasyenites between 3363-3106Ma (Tchameni et al., 2001) and the Makoukou BIFs between 3091 ± 13Ma. A continental arc setting has been favoured over an island arc setting for the emplacement of these units based on the chemistry of the lithologies analyzed. The rhyolitic, dacitic to andesitic nature of the volcanic samples suggest an originally acidic melt composition which is typical of continental arc margins. It is true that crustal contamination and mixing are all possible mechanisms for inducing chemical variations in arc magmas (Elburg, 2010) but the petrography and geochemistry of our samples support a simple fractional crystallization model to be responsible for the development of the various intercalated volcanics within BIFs in the Congo Craton. This is supported by the absence of common features of mixing such as magmatic enclaves and xenomorphic inclusions in the polished sections. Crustal contamination features such as entrained fragments and inversed zoning are equally absent. Rather the samples show similar chemical characteristics with variations in their silica content and their REE pattern which we attribute to crystal fractionation with subtle post emplacement alteration. The weak HREE/LREE expressed by $(La/Yb)_N$ values generally <1 is attributed to an originally basaltic to andesitic magmatic melt in which all the REEs were incompatible in crystallizing mineral phases such as olivine, orthopyroxene and clinopyroxene. However, the ΣREE between 7.725 and 11.322 shows that the original magma source was probably also poor in the REEs. The positive Eu-anomaly of sample NTV04 (a similar pattern to that of MET510) shows the pristine nature of the sample compared to the others with less altered plagioclase minerals. The presence of Na-amphiboles and hornblende could account for the slight enrichment of the HREE/LREE in this sample compare to the MET510.

Fe_2O_3 and SiO_2 content of 20 – 40wt% and 43 – 56 wt %, respectively are typical of BIF deposits (Klein, 2005). The higher Fe content (50.12 wt %) of the MET510 sample is indicative of the gradual replacement of silica with Fe through leaching reflected by the corroded quartz margins and cavities within the quartz bands filled by magnetite and/or martite (Fig. 4). Such features have earlier been described (Suh et al., 2008) in the Ntem Complex for the Metzimevin itabirites and were attributed to hydrothermal activity. However, the lack of hydrothermal particularities such as hematite specularites (Powell et al., 1999 and Cabral et al., 2003) suggests supergene processes. Hence, both processes are feasible in the development of high grade iron ores within the Congo Craton.

Marine signatures in BIF deposits are better expressed by their REE patterns (Derry et al., 1990; Frei and Polat, 2007). MET510, the BIF sample analyzed together with the volcanics in this study show a clear and distinct HREE enrichment over the LREE with a positive Eu anomaly typical of Precambrian marine BIF deposits (Derry et al., 1990; Alibert and McCulloch, 1992). HREE enrichment over the LREE in sea water is controlled by an effect known as lanthanide contraction whereby the HREE have a greater affinity to particle surfaces compared to the LREE, due to their small ionic sizes. Positive Eu-anomaly has been widely attributed to hydrothermal sources (Derry et al., 1990; Frei and Polat, 2007). A negative Ce anomaly is also a key indicator of modern sea water. However, the weakly negative to flat pattern of Ce for the MET510 sample may simply be explained by the poor concentrations of La and Pr. Though La and Pr may account for this, dilution of the sea sediments by river influx may also account for the very weak negative Ce-anomaly (German et al., 1991). Such influx also boosts the positive Eu-anomalies in sea sediments evident for this sample.

Geochronology

Th/U ratio and zircon morphologies are used to distinguish magmatic zircons from xenocrystic and metamorphic zircons. However, the Th/U ratio has been criticized by some authors owed to the fact that the evaluated Th/U ratio of >0.1 for magmatic zircons have been recorded in zircons from other sources (Schaltegger et al., 1999; Rubatto, 2002; Möller et al., 2003 and Harley et al., 2007). The clear oscillatory zoning of the zircons in this study reflects their magmatic origin. The $^{207}Pb/^{206}Pb$ age of 2883 ± 20 Ma obtained for the dacite sample (NTV02) in this study is interpreted as the age of crystallization of the dacite and directly constraints the age of initial BIF deposition in the Ntem Complex at the northern edge of the Congo Craton. With no distinct evidence of metamorphic zoning on the zircons, the minor scatter in the data set is attributed to magma residence time and zircon growth prior to eruption (Brown and Fletcher, 1999). Therefore, the U-Pb concordant ages effectively date the age of eruption of the dacite. The $^{206}Pb/^{238}U$ age window between

2494 ±47Ma and 2851 ±32Ma compare similarly with crystallization ages of 2768 ±16Ma and 2766 ±3Ma obtained for dacites and rhyolites at the lower BIF succession of the Hamersley Province in northwestern Australia. Similarly, Sumner and Bowring (1996) obtained ages of 2521 ±3Ma on volcanic ash beds of the Campbellrand Subgroup, Transvaal Supergroup, South Africa and interpreted these ages to constrain the age of deposition of the Kuruman. Griquatown and Penge iron formations. Also, in the Minas Supergroup, Quadrilatero ferrifero Brazil, recent U-Pb ages of 2.65Ga have been reported on zircon obtained from a metavolcanic layer within the Caué Itabirite Formation (Cabral et al., 2012). This age confirms early SHRIMP U-Pb ages of 2750Ma obtained on zircons (from metarhyolites) by Trendall et al., (1998) on the Carajás formations in the Minas Supergroup. The above ages fall within the 2883 ± 20Ma window obtained in this study for BIF deposition as in the Congo Craton. These age similarities suggest a regional period of magmatic emplacement in the Hamersley Basin, Transvaal, Quadrilatero Ferrifero and the Congo craton associated with BIF deposition as earlier suggested by Trendall et al. (2004) and revisited by Beukes and Gutzmer (2008). Age comparative summaries of these world class iron ore hosted basins to the Congo Craton are summarized in Appendices 1 and 2.

Though the volcanic sample largely gives an Archean age of BIF deposition within the Congo Craton, geochronological data on the BIF sample (MET510) collected on the surface give much younger ages that are typically Eburnean. Earlier reported Eburnean ages similar to that obtained from zircon #4 (between 2400 and 1800Ma) by Rb-Sr on whole rock within the Ntem Complex were attributed to Pb-loss during the reactivation events within the unit. Shang et al. (2004a) reported ages between 2299 and 2064Ma by Rb-Sr on biotite within the Ntem Complex buttressing the Eburnean reactivation of the Congo Craton. More recently, Shang et al. (2010) reported zircon U-Pb ages between 2098 and 2465Ma on the charnockitic suite in the Sangmelima area and largely favored Pb-loss by diffusion and leaching as the main causative factor of the young ages. Though the above authors largely favor Pb-loss in their interpretation of the Eburnean ages, the nature of the zircons observed in MET510 and the wide variation in the data set suggest a more complex mechanism rather than just Pb-loss. Anderson (1978) had shown that diagenetic brines often contain >10ppm Pb thus a small amount of such fluid can alter the Pb-isotopic signature and decrease the U/Pb or increase the Pb/U ratio within rocks. The identification of carbonate minerals on some polished sections of the metavolcanics samples obtained in association with the BIF sample (MET510) are attributed to basinal brines. This suggests the possibility of diagenetic brines within the unit. Therefore the influence of Pb-loss in the sample should have been limited by Pb incorporation in the system from basinal brines hence the variations in the data set should be limited. We therefore attribute these variable zircon ages to a more recent phase of BIF deposition in the Ntem complex which has been unrecognized heretofore.

Although the $^{207}Pb/^{206}Pb$ age of 2883±20Ma represents the age of BIF deposition in the Congo Craton, the exact onset of BIF deposition within this basin is still questionable. Caen-Vachette (1988) have earlier mentioned the deposition of the Makoukou BIFs at 3091 ±13Ma suggesting that the basin must have been opened earlier and remained as an open system for long period. Hence, the 2883±20Ma probably represents the age of maximum BIF deposition within the Congo Craton. This age compares closely to wide spread intrusive emplacement ages within the Congo Craton notably the Sangmelima charnockites and granodiorite with ages of 2899±93Ma and 2882 ±28Ma respectively (Shang et al., 2007). This emplacement has been described (Owona, 2008) as a 3rd Phase (E3) intrusive emplacement within the Congo Craton.

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References

Alibert, C. and McCulloch, M.T., 1992 Rare earth element and neodymium isotopic compositions of the banded iron formations and associated shales from Hamersley, Western Australia. Geochimica et Cosmochimica Acta, v. 57, pp. 187-204.

Anderson, G.A., 1978, Basinal brines and Mississippi Valley-type ore deposits. Episodes, pp. 15-19.

Bau, M. and Möller, P., 1993, Rare earth element systematics of the chemical precipitated component in Early Precambrian iron formations and the evolution of the terrestrial atmosphere-hydrosphere-lithosphere system. Geochimica et Cosmochimica Acta, v. 57, pp. 2239-2249.

Bekker, A., Holland, H., Wang, P.L., Rumble, D., Stein, H., Hannah, J., Coetzee, L. and Beukes, J.J., 2004, Dating the rise of atmospheric oxygen. Nature, v. 427, pp. 117-120.

Beukes, N.J. and Gutzmer, J., 2008, Origin and Paleoenvironmental Significance of Major Iron Formations of the Archean-Paleoproterozoic Boundary. Economic Geology Reviews, v. 15, pp. 5-47.

Blake, T.S., Buick, R., Brown, S.J.A. and Barley, M.E., 2004, Geochronology of Late Archean flood basalt in the Pilbara Craton, Australia: constraints on basin evolution, volcanic and sedimentary accumulations, and continental drift rates. Precambrian Research, v. 133, pp. 143-173.

Brown, S.J.A. and Fletcher, I.R., 1999, SHRIMP U-Pb dating of pre-eruption growth history of zircons from the 340Ka Whakamaru Ignimbrite, New Zealand: evidence for >250Ka magma residence times. Geology, v. 27, pp. 1035-1038.

Cabral, A.R., Rocha Filho, O.G. and Jones, R.D., 2003, Hydrothermal origin of soft hematite ore in the Quadrilátero Ferrifero of Minas Gerais, Brazil: Petrographic evidence from the Gongo Socco iron ore deposit. Applied Earth Science (Transactions of the Institute of Mining and Metallurgy Section B), v. 112, pp. 279-286.

Cabral, A.R., Zeh, A., Koglin, N., Gomes Jr., A.A. S., Viana, D.J. and Lehmann, B., 2012, Dating the Itabira rion formation,Quadrilátero Ferrífero of Minas Gerais, Brazil, at 2.65Ga: Depositional U-Pb age of zircon from a metavolcanic layer. Precambrian Research, v. 204-205, pp. 40-45.

Caen-Vachette, M. , Vialette, Y., Bassot, J.P., and Vidal, P., 1988, Apport de la geochronology à la connaissance de la géologie gabonaise. Chron. Rech. Min. No. 491, pp. 35-54.

Claoué-Long, J.C., Compston, W., Roberts, J. and Fanning, C.M., 1995, Two Carboniferous ages: a comparison of SHRIMP zircon dating with conventional zircon ages and $^{40}Ar/^{39}Ar$ analysis. *In:* Geochronology, Time Scales and Global Stratigraphic Correlation, Berggen, W.A. Kent, D.V. Aubry, M.P. and Hardenbol, J. (eds.), SEPM Special Publication, v. 4, pp.3-21.

Clout, J.M.F. and Simonson, B.M., 2005, Precambrian iron formations and iron formations-hosted iron ore deposits. Economic Geology, v. 100, pp. 643-679.

Derry, L.A. and Jacobsen, S.B., 1990, The chemical evolution of Precambrian

seawater: Evidence from REEs in banded iron formations. Geochimica et Cosmochimica Acta, v. 54, pp. 2965-2977.

Frei, R. and Polat, A., 2007, Source heterogeneity for major components of ~3.7Ga Banded Iron Formations (Isua Greenstone Belt, Western Greenland): Tracing the nature of interacting water masses in BIF formations. Earth and Planetary Science Letters, v. 253, pp. 266-281.

Elburg, M.A., 2010, Source and processes in arc magmatism: the crucial role of water. An inaugural lecture to the society. Geologica Belgica, v. 13/3, pp. 121-136.

Feybesse, J.L., Johan, V., Triboulet, C., Guerrot, C. Mayaga-Mikolo, F., Bouchot, V. and Eko N'dong, J., 1998, The West Central African belt: a model of 2.5-2.0Ga accretion and two-phase orogenic evolution. Precambrian Research, v. 87, pp.161

Fischer, W.W. and Knoll, A.H., 2009, An iron shuttle for deepwater silica in Late Archean and early Paleoproterozoic iron formations. Geological Society of America Bulletin, v. 121, pp. 222-235.

Fryer, B.J., Fyfe, W.S. and Kerrich, R., 1979, Archean volcanogenic oceans. Chemical *Geology,* v. 24, pp. 25–33.

German, C.R., Halliday, B.P. and Elderfield, R., 1991, Redox cycling of rare earth elements in the suboxic zone of the Black Sea. *Geochimica et* Cosmochimica Acta, v. 55, pp. 3535-3558

Hamade, T., Konhauser, K., Raiswell, R., Goldsmith, S. and Morris, R., 2003, Using Ge/Si ratio to decouple iron and silica fluxes in Precambrian banded iron formations. Geology, v. 31, pp. 35-38.

Harley, S.I. Kelly, N.M. and Möller, A., 2007, Zircon behavior and the thermal histories of mountain chains. Elements, v. 3, pp. 25–31.

Hoskin, P.W.O. and Schaltegger, U., 2003, The composition of zircon and igneous and metamorphic petrogenesis. In zircon (Hanchar, J.M. and Hoskin, P.W.O. Eds.). Reviews in Mineralogy and Geochemistry, 53, Mineralogical Society of America. Washington, D.C., pp. 27-62.

Ilouga, D. C. I., Suh, C.E., Tanwi, G.R. (2012, in Press). Textures and Rare Earth Elements Composition of Banded Iron Formations (BIF) at Njweng Prospect, Mbalam Iron Ore District, Southern Cameroon. International Journal of Geosciences

Kaufman, A.J., Johnston, D.T., Farquhar, J., Masterson, A.L., Lyons, T.W., Bates, S., Anbar, A.D., Anold, G.L., Garvin, J. and Buick, R., 2007, Late Archean biospheric oxygenation and atmospheric evolution. Science, v. 317, pp. 1900-1903.

Klein, C. and Beukes, N.J., 1989, Geochemistry and sedimentology of a facies transition from limestone to iron formation deposits in the early Proterozoic Transvaal Supergroup, South Africa. Economic Geology, v. 84, pp. 1733-1774.

Klein, C., 2005, Some Precambrian banded iron-formations (BIFs) from around the world: their age, geologic setting, mineralogy, metamorphism, geochemistry and origin. American Mineralogist, v. 90, pp. 1473-1499.

Konhauser, K. O., Hamade, T., Raiswell, R., Morris, R.C., Feris, F.G., Southam, G., and Canfield, D.E., 2002, Could bacteria have formed the Precambrian banded iron formations? Geology, v. 30, pp. 1079-1082.

Konhauser, K. O., Amskold, L., Lalonde, S.V., Posth, K.A. and Anbar, A., 2007b, Decoupling photochemical Fe (II) oxidation from shallow-water BIF deposition. Earth and Planetary Science Letters, v. 258, pp. 87-100.

Lerouge, C., Cocherie, A., Toteu, S.F., Penaye, J., Milési, J., Tchameni, R., Nsifa, E.N., Fanning, C.M. and Deloule, E., 2006, Shrimp U-Pb zircon age evidence for Paleoproterozoic sedimentation and 2.05Ga syntectonic plutonism in the Nyong Group, South Western Cameroon: consequences for the Eburnean Transamazonian belt of NE Brazil and Central Africa. Journal of African Earth Sciences, v. 44, pp. 413-427.

Ludwig, K.R., 2001, SQUID 1.03, A User's Manual; Berkeley Geochronology Center Special Publication, No. 2, 19 pp.

Ludwig, K.R., 2003, Isoplot 3.00: A Geochronological Toolkit for Microsoft Excel. Berkeley Geochronology Center Special Publication, No. 4, 70 pp.

Maliva, R.G., Knoll, A.H. and Simonson, B.M., 2005, Secular change in the Precambrian silica cycle: insights from chert petrology. Geological Society of America Bulletin, v. 117, pp. 835-845.

Marks, M., Halama, R., Wenzel, H. and Markl, G., 2004, Trace element variations in clinopyroxene and amphibole from alkaline to peralkaline syenites and granites: implications for mineral–melt trace-element partitioning. Chemical Geology, v. 211, pp. 185–215.

Mboudou, G.M.M., Suh, C.E., Mafany, G.T. (2012, in press). Geochemical characterization of Novokrivoyrog metavolcanics: Tetonic implications and Relationship with the early Proterozoic Banded Iron Formation (BIF) of Krivoy Rog in Ukraine. Open Journal of Geology.

Milesi, J.P., Toteu, S.F., Deschamps, Y., Feybesse, J.L., Lerouge, C., Cocherie, A., Penaye, J., Tchameni, R., Moloto-A-Kenguemba, G., Kampunzu, H.A.B., Nicol, N., Duguey, E., Leistel, J.M., Saint-Martin, M., Ralay, F., Heinry, C., Bouchot, V., Doumnang Mbaigane, J.C., Kanda Kula, V., Chene, F.; Monthel, M., Boutin, B. and Cailteux, J., 2006, An overview of the geology and major ore deposits of Central Africa: Explanatory note for the 1:4000, 000 map "Geology and major ore deposits of Central Africa". Journal of African Earth Sciences, v. 44, pp. 571–595.

Möller, A.O., O'Brien, P.J., Kennedy, A., and Kröner, A., 2003, Linking growth episodes of zircons and metamorphic textures to zircon chemistry: an example from the ultrahigh temperature granulites of Rogaland (SW Norway). *In* Geochronology: Linking the isotope record with petrology and textures (Vance, D., Müller, W. and Villa, I.M. Eds.). Geological Society of London, Special Publication, no. 220, pp. 65 – 81.

Morris, R.C., 1993, Genetic modeling for banded iron formations of the Hamersley Group, Pilbara Craton, Western Australia. Precambrian Research, v. 60, pp. 243-286.

Nance, W.B. and Taylor, S.R., 1976, Rare earth element patterns and crustal evolution-I. Australian post Archean sedimentary rocks. GCA 40, 1539.

Nforba, M. T., Suh, C.E. and Kabeyene, K.V.K., 2010, Mbalam iron ore project, northern edge of the Congo craton, southeast Cameroon. In: Goldfarb, R.J., Marsh, E.E. and Monecke, E. (editors): Proceedings of the Society of Economic Geologists "The challenge of finding new mineral resources: global metallogeny, innovative exploration and new discoveries", SEG Extended Abstracts, Colorado G-22.

Owona, S., 2008, Archean, Eburnean and Pan-African features and relationships in their junction zone in the south of Yaounde (Cameroon). PhD Thesis in the Geoscience Department of the University of Douala, Cameroon (Unpublished).

Pouclet, A., Tchameni, R., Mezger, K., Vidal, M., Nsifa, E.N., Shang, C.K. and Penaye, J., 2007, Archean crustal accretion at the northern border of the Congo craton (South Cameroon). The charnockite-TTG link. Bulletin of the Geological Society of France, v. 178, pp. 331-342.

Powell, C.McA., Oliver, N.H.S., Li, Z-X., Martin, D.McB. and Ronaszeki, J., 1999, Synorogenic hydrothermal origin for the giant Hamersley iron oxide ore bodies. Geology, *v.* 27, pp. 175-178.

Rubatto, D., 2002, Zircon trace element geochemistry: partitioning with garnet and the link between U-Pb ages and metamorphism. Chemical Geology, v. 184, pp. 123-138.

Schaltegger, U., Fanning, C.M., Günther, D., Maurin., J.C., Schulmann, K. and Gebauer, D., 1999, Growth annealing and recrystallization of zircon and the preservation of monazite in high grade metamorphism: conventional and in situ U-Pb isotope, cathodluminescence and microchemical evidence. Contributions to Mineralogy and Petrology, v. 134, pp. 186-201.

Shang, C.K., 2001, Geochemistry and geochronology of Archean rocks from the Sangmelima Region, Ntem Complex, NW Congo craton, South Cameroon. Ph.D Thesis, University of Tübingen, Germany, pp.313.

Shang, C.K., Satir, M., Siebel, W., Nsifa, E.N., Taubald, H., Liégeois, J.P. and Tchoua, F.M., 2004a, TTG magmatism in the Congo craton: case study of the Sangmalima region, Ntem Complex, southern Cameroon. Journal of African Earth Sciences, v. 40, pp. 61-79.

Shang, C.K., Satir, M., Nsifa, E.N., Liegeois, J.P., Siebel, W. and Taubald, H., 2007, Archean high K-granitoids produced by remelting of early Tonalite-Trondhjemite-Granodiorite (TTG) in the Sangmelima region of the Ntem Complex of the Congo craton, southern Cameroon. International Journal of Earth Sciences, v. 96, pp. 817–842.

Shang, C.K., Liégeois, J.P., Satir, M., Frisch, W. and Nsifa, E.N., 2010, Late Archaean high-K granite geochronology of the northern metacratonic

margin of the Archaean Congo craton, Southern Cameroon: Evidence for Pb-loss due to non-metamorphic causes. Gondwana Research, v. 18, pp. 337-355.

Sholkovitz, E.R., Landing, W.M. and Lewis, B.L., 1994, Ocean particle chemistry: the fractionation of rare earth elements between suspended particles and seawater. Geochimica et Cosmochimica Acta, v. 58, pp. 1567-1579.

Siever, R., 1992, The silica cycle in the Precambrian. Geochim. Cosmoschim. Acta, v. 56, pp. 3265-3272.

Steiger, R.H. and Jäger, E., 1977, Subcommision on geochronology: convention on the use of decay constants in geo- and cosmochronology. Earth Planetary Science Letters, v. 36, pp. 359-362.

Steinhoefel, G., von Blanckenburg, F., Horn, I., Konhauser, K.O., Beukes, N.J. and Gutzmer, J., 2010, Deciphering formation processes of banded iron formations from the Transvaal and the Hamersley successions by combined Si and Fe isotope analysis using UV femtosecond laser ablation. Geochim. Cosmochim. Acta, v. 74, pp. 2677-2696.

Suh, C.E., Cabral, A.R., Shemang, E.M., Mbinkar, L. and Mboudou, G.G.M., 2008, Two contrasting iron deposits in the Precambrian mineral belt of Cameroon, West Africa. Exploration and Mining Geology, v. 17, pp. 197-207.

Suh, C.E., Cabral, A.R. and Ndime, E., 2009, Geology and ore fabrics of the Nkout high-grade hematite deposit, southern Cameroon. In: P.J. Williams et al. (editors), Smart Science for Exploration and Mining, SGA Publication series pp. 558-560.

Sumner, D.Y. and Bowring, S.A., 1996, U–Pb geochronologic constraints on deposition of the Campbellrand Subgroup, Transvaal Supergroup, South Africa. Precambrian Research, v. 79, pp. 25–35.

Sun, S.S. and McDonough, 1989, Chemical and isotopic systematic of oceanic basalts: implications for mantle composition and processes. Geological Society Special Publication, No. 42, pp. 313–345.

Svenjensky, D.A., 1981, The origin of Mississippi Valley-type deposit in the Viburnum Trend, southeast Missouri. Economic Geology, v. 76, pp. 1848-1872

Takam, T., Arima, M., Kokonyangi, J., Dunkley, D.J., and Nsifa, E.N., 2009, Paleoarchean charnockite in the Ntem Comples, Congo Craton, Cameroon: insights from SHRIMP zircon U-Pb ages. Journal of Mineralogical and Petrological Sciences, v. 104, pp. 1-11.

Tchameni, R., Mezger, K., Nsifa, N.E. and Pouclet, A., 2000, Neoarchean evolution of the Congo craton: evidence from K-rich granitoids of the Ntem Complex, southern Cameroon. Journal of African Earth Sciences, v. 30, pp. 133–147.

Tchameni, R., Mezger, K., Nsifa, N.E. and Pouclet, A., 2001, Crustal origin of early Proterozoic syenites in the Congo craton (Ntem Complex), southern Cameroon. Lithos, v. 57, pp. 23-42.

Toteu, S.F., Van Schmus, W.R. Penaye, J. and Nyobe, J.B., 1994, U-Pb and Sm-Nd evidence of Eburnean and Pan-African high grade metamorphism in cratonic rocks of southern Cameroon. Precambrian Research, v. 67, pp. 321-347.

Trendall, A.F., Basei, M.A.S., de Laeter, J.R. and Nelson, D.R., 1998, SHRIMP zircon U-Pb constraints on the age of the Carajás Formation, Grão ParáGroup Amazon Craton. Journal of South American Earth Sciences, v. 11, pp. 265-277.

Trendall, A.F., Compston, W., Nelson, D.R., De Laeter, J.R. and Bennett, V.C., 2004, SHRIMP zircon ages constraining the depositional chronology of the Hamersley Group, Western Australia. Australian Journal of Earth Sciences, v. 51, pp. 621-644.

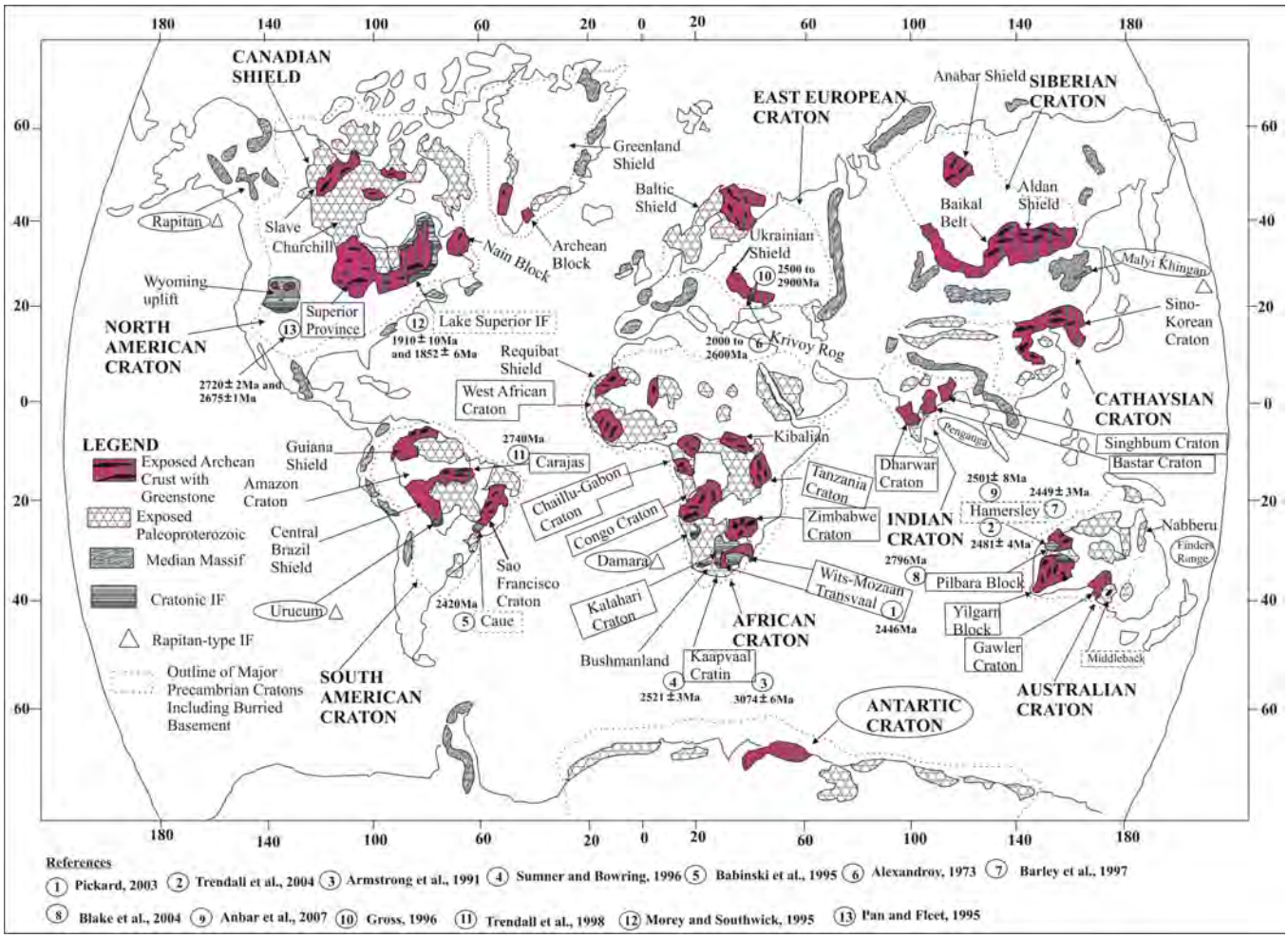
Williams, I.S., 1998, U-Th-Pb geochronology by ion microprobe. *In*: Reviews of microanalytical techniques to understanding mineralising processes, McKibben, M.A., Shanks, III, W.C. and Ridley, W.I. (eds), Reviews in Economic Geology, v. 7, pp. 1-35.

Appendices

Appendix 1: Ages of iron ore-related BIFs in some major cratons around the world

Craton	Location	Method	Age	References
Kaapvaal	Kuruman and Penge Iron Formations	TIMS U-Pb on zircons	2521 ±3Ma	Sumner and Bowring, 1996
Kaapvaal	Kuruman Iron Formation	SHRIMP U-Pb on zircons	2446Ma	Pickard, 2003
Pilbara	Weeli Wolli Iron Formation of the Hamersley Group, Australia	SHRIMP U-Pb on zircons	2449 ±3Ma	Barley et al., 1997
Pilbara	Brockman Iron Formation of the Hamersley Group, Australia	SHRIMP U-Pb on zircons	2495 Ma	Trendall et al., 2004
Pilbara	Brockman Iron Formation of the Hamersley Group, Australia	Re-Os age on pyrites	2501 ± 8Ma	Anbar et al., 2007
São Francisco	BIFs of the Cauê Formation, Itabira Group, Minas Supergroup, Quadrilátero Ferrifero, Brazil	Pb/Pb isochron on carbonate rocks using dual-leach procedure	2520 Ma	Babinski et al., 1995
São Francisco	Iron Formations of the Carajàs Formation, Grão ParáGroup, Minas Supergroup, Quadrilátero Ferrifero, Brazil	SHRIMP U-Pb on zircons obtained from metarhyolites	2750 Ma	Trendall et al., 1998
Superior	Iron Formations of the Manitouwadge Greenstone belt	Single-zircon Pb-evaporation	720 ±2Ma and 22675 ±1Ma	Pan and Fleet, 1995

Appendix 2: Global map showing cratons distribution and age variation of BIFs in some major iron ore districts of the world. Note the gap in the Congo craton (modified after Beukes and Gutzmer, 2008)



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by Clifford M. Nelson

The 28th International Geological Congress, Washington, 1989

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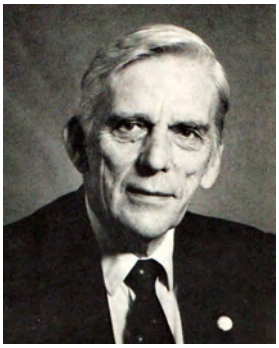
The 28th International Geological Congress (IGC) met from 9 to 19 August 1989 in Washington, District of Columbia, the site of the 5th (1891) and 16th (1933) IGCs. More than 6,000 persons, from the United States of America (USA) and 103 other countries, came to Washington for the 28th IGC, thirteen of them having previously attended the 16th IGC. The U.S. Geological Survey and the U.S. National Academy of Sciences acted as the principal hosts, in cooperation with thirty scientific societies and seven industrial organizations. As sponsors, 115 organizations and five individuals provided financial support. The fourteen themes of the 360 scientific and technical sessions, and ninety poster-paper sessions, included aspects of the dynamic Earth in space and time, mathematical geology, and comparative planetology. Two half-day colloquia of invited presentations provided a planetary perspective on the Apollo *lunar-landing program and the Earth's natural resources. Invited speakers in a late-afternoon series of plenary sessions gave forty-five-minute overviews of the international programs for the decade of natural disaster reduction, geological correlation, geosphere–biosphere, lithosphere, ocean drilling, and sedimentary geology. Two hundred and thirty-three exhibitors, from twenty-six countries, presented displays. Other activities included a Youth Congress, evening lectures and receptions, local tours, institutional exhibits, and an all-member evening picnic on the Mall on 18 July. Innovations included poster-paper sessions, an extensive program of short courses and workshops, the* Gazette *(a daily newspaper), and a field trip to Antarctica (in January 1989). One hundred and three additional field excursions, held before, during, or after the 28th IGC and each with a guidebook, took participants to geologically diverse parts of the USA, Antarctica, the Bahamas, and the Turks and Caicos Islands. The Congress's general-proceedings volume appeared in 1990. Surplus moneys from the Congress provided a foundation for a '28th IGC Fund', managed by the Geological Society of America Foundation, principally to support attendance at future IGCs and the preparation of the next IGC held in the USA.*

Prologue: The Invitation, 1980–1984

The 26th International Geological Congress (IGC) had convened in Paris on 7 July 1980 (Sangnier and Degouy, 1981; Gohau, 2006). Its Council and General Assembly approved an invitation from the Union of Soviet Socialist Republics (USSR, now the Commonwealth of Independent States) to hold the 27th IGC in Moscow in 1984. The Council also endorsed the tentative offer by Vincent E. McKelvey, Chairman of the United States of America (USA) delegation and former Director (1971–1978) of the U.S. Geological Survey (USGS), "to host the 28th Session in the USA in 1988 or 1989" (Hanshaw, 1990, p. 3). In October, H. William Menard, who succeeded McKelvey as USGS Director in 1978, urged Charles L. Drake (Hanshaw, 1998), of Dartmouth College and Chairman of the U.S. National Academy of Sciences–National Research Council's (NAS–NRC) U.S. National Committee on Geology (USNC/G), to accept USA sponsorship of the 28th IGC. Menard promised the same "USGS support" (Hanshaw, 1990, p. 3) that the agency provided in Washington, District of Columbia (D.C.), for the 5th IGC in 1891 (Nelson, 2006) and 16th IGC in 1933 (Nelson, 2009).

By "June 1981, the USNC/G turned down the 1988 date" (Hanshaw, 1990, p. 3) because the Geological Society of America (GSA) planned to celebrate its centennial in 1988 at the annual meeting scheduled for Denver. Instead, the 28th IGC would convene in 1989. Drake and Linn Hoover (USGS), the USNC/G's Secretary, determined during the summer of 1981 that Japan would not be able to host the 28th IGC. In "July 1982, the USNC/G approved July 1989 for the



Charles Lum Drake (1924–1997), President of the 28th IGC

proposed U.S. invitation", Drake "was informally appointed President of the 28th IGC and Chairman of the Preparatory Committee," and he began "negotiations with the Washington Convention Center and nearby hotels" in D.C. (ibid.). In October 1982, NAS President Frank Press asked Yevgeny A. Kozlovsky, Minister of Geology of the USSR and the 27th IGC's President, "to present the USA's formal invitation to host the 28th Session in July 1989" (Ibid.). In November 1982, Kozlovsky agreed to do so. In June and December 1983, Drake and Hoover agreed to serve, respectively, as the 28th IGC's President and Secretary General. Hoover began expanding Drake's preliminary contacts with service organizations.

The 27th IGC met in Moscow from 4 to 14 August 1984, led by Kozlovsky, who also chaired the meeting's Steering Committee, and Nikita A. Bogdanov, Moscow State University and the Institute of the Lithosphere's Director, as Secretary General (Kozlovsky, Bogdanov and Menner, 1987; Milanovsky, 2004). Dallas L. Peck, who succeeded Menard as USGS Director in 1981, led the USA delegation. At the initial meeting of the 27th IGC's Council on 4 August, Peck asked the Council, on behalf of the USNC/G, to request the General Assembly's approval of the USA's invitation for the 28th IGC. The Council unanimously supported Peck's request (Kozlovsky, Bogdanov, and Menner, 1987). On 13 August, the Council discussed invitations from Japan and the People's Republic of China (PRC) to host the 29th IGC, but it reached no decision pending the arrival of preliminary field-excursion programs from both nations (ibid.).

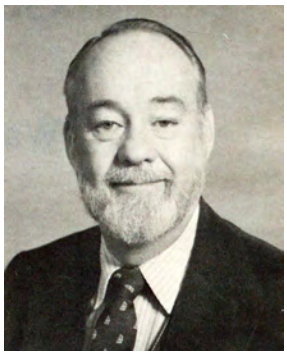
On 14 August, the Council voted to accept the USA's invitation to hold the 28th IGC in Washington, waiving, as was done for the 16th IGC, the rule that required IGCs to convene every three or four years. At the 27th IGC's Closing Ceremony, Kozlovsky and Howard R. Gould (Exxon, now Exxon–Mobil), Drake's successor as Chairman of the USNC/G, formally announced the Council's and the General Assembly's decisions (ibid.).

Organization, 1984–1989

The 27th IGC's Steering Committee, chaired by Kozlovsky, met in Paris on February 5, 1985, to fix the site and time of the 28th IGC, to be co-hosted by the NAS and the USGS. John A. Reinemund (USGS; Gryc and Terman, 2003), Treasurer of the International Union of Geological Sciences (IUGS), participated as one of the Committee's six other members. Gould and Hoover attended as observers and as members of the 28th IGC's Preparatory (later Organizing) Committee. Previous IGCs had emphasized the geology of continents and their fold belts. The Steering Committee now wished to focus future IGCs on active continental margins, volcanic-island arcs, and ocean basins (Kozlovsky, Bogdanov and Menner, 1987; International Geological Congress, 28th, 1987). The Steering Committee accepted the proposal of the Japanese National Committee on Geology to convene the 29th IGC in Japan in 1992. The Committee also recommended holding the 30th IGC in the PRC, if that country's Geological Society reissued its invitation and the 29th IGC's Council accepted it (Kozlovsky, Bogdanov, and Menner, 1987).

But three days later, a heart attack took Hoover's life while he and his USA and Canadian colleagues waited on a plane preparing to leave Orly Airport for an IUGS meeting in Rabat (Brown, 1987). To succeed Hoover, Peck, who would lead the USA delegation to the 28th IGC, asked Drake to appoint the geohydrologist Bruce B. Hanshaw, the USGS's Assistant Director for Research, as the new Secretary General (Hanshaw, 1990; Medlin, Peck, Keith, Robinson and Jones, 2000).

Hanshaw took office and began work on 4 March 1985, aided by Hoover's careful preparations and complete files. The American Association of Petroleum Geologists (AAPG) informally contracted to provide for all logistical services to the Congress, which "became a legal corporation in February 1985" (Hanshaw, 1990, p. 3). Its Bureau met initially on 24 April to fix the Organizing Committee's membership and select chairpersons for the topical committees. In September, the U.S. Internal Revenue Service gave the 28th IGC Corporation tax-exempt status. The 28th ICG and the AAPG signed a formal contract before the end of 1985.



Bruce Busser Hanshaw (1930–1998),
Secretary General, 28th IGC.

The Congress appointed an Honorary President, sixteen Honorary Vice-Presidents, and forty-five Honorary Members. The planning and activities depended on the work of its twelve-member Bureau, twenty-seven topical Committees, a forty-member Committee of Advisors, thirty-seven organizational hosts, 120 organizational and individual sponsors, and a twelve-member IGC Steering Committee. George H. W. Bush, President of the USA, served as the meeting's honorary president. Drake led the Bureau, aided by Hanshaw, Deputy Secretary General Jack H. Medlin (USGS), and Treasurer William C. Prinz (USGS). The Bureau's seven topical vice-presidents included: Robin Brett (USGS), Scientific and Technical Sessions; Maria Louisa Crawford (Bryn Mawr), Workshops and Short Courses; William L. Fisher (Director, Texas Bureau of Economic Geology), Institutional Participation; Howard Gould, Finances; Charles D. Masters (USGS), Operations; John C. Reed Jr (USGS), Field Trips; and Leon T. Silver (California Institute of Technology), Program. Richard S. Fiske (National Museum of Natural History [NMNH], Smithsonian Institution) and E-an Zen (USGS) served as counselors. Michel T. Halbouty (of Halbouty Energy) and Dallas Peck co-chaired the Committee of Advisors. The USGS and the NAS were the principal hosts, aided by twenty-nine scientific societies and seven industrial organizations. IUGS president William W. Hutchison (Canada), IUGS Secretary General Richard Sindig-Larsen (Geological Survey of Norway), Kozlovsky, Bogdanov, Drake, Hanshaw, IUGS Past-President Eugen Seibold (Federal Republic of Germany), and five officers of recent IGCs formed the Steering Committee.

Three new programs provided financial and related aid to enable young scientists, especially those from developing countries, to attend the Congress. After William Hutchison died in 1987, the IUGS established the Hutchison Young Scientist Foundation to enable awardees to participate in the IGCs and other IUGS-sponsored meetings; the Foundation sponsored three persons at the 28th IGC.

Hutchison Young Scientist Awardees, 28th IGC (from left to right): Witold Zuchiewicz (Poland), Maria Aguirre-Urreta (Argentina) and Barth Ekwueme (Nigeria).

Applications for two other support programs were due by 1 August 1988. The USA's Geohost Program, directed by Rosalind T. Helz (USGS) and George R. Helz (University of Maryland) waived the registration fees for the IGC and for one field trip or short course (up to US$600*) and provided twelve nights free lodging at the George Washington University dormitory. A separate Bed and Breakfast Program, using lodgings in private homes, extended GeoHost. The Office of the Division of Earth Sciences (Paris) of the United Nations' Educational, Scientific, and Cultural Organization provided $50,000–$60,000 for air-fares and the remainder for per-diem expenses—for a Travel Grant Program. Travel Grants covered ten to fifty percent of air-travel costs, provided $200 per diem, and benefited from 'no-show' funds. The GeoHost and Travel Grant Programs received "more than 500 applications" and the Selection Committee "ultimately sponsored 79 registrants from 43 countries", or "almost 1.5% of the total registration" (Hanshaw, 1990, p. 25).

In January 1987, the Organizing Committee began sending more than 100,000 copies of the First Circular (International Geological Congress, 28th, 1987) to interested persons, including all of the members of the 27th IGC, scientific societies, government agencies, and industrial organizations worldwide. Receipt of the enclosed questionnaire was requested by 15 May, but later extended to 15 September. Deposits for the 204 proposed field trips and fifty-three proposed short courses and workshops were requested by September 1988 and the remaining sums were due by April 1989. Abstracts of papers for the fourteen categories of proposed scientific and technical sessions and poster-paper sessions were due by 1 October 1988 (later extended to February 1989). To reduce costs, the Organizing Committee decided not to publish the papers presented at the 28th IGC; instead, authors were encouraged to publish them in scientific journals. The Congress would issue a three-volume set of expanded abstracts of "up to 900 words in length and include line drawings, tables of data, and equations if desired" (Hanshaw, 1990, p. 8). Full payment of pre-registrations for participating, accompanying, student, and non-attending members was due not later than June 1989.

In January 1988, the Second Circular (International Geological Congress, 28th, 1989a) went to the more than 5,000 persons who returned the First Circular's questionnaire and indicated that they would be accompanied by nearly 2,500 other adults and about 760 children. Most of the remainder of the Second Circular's 20,000 mailed copies went as reminders to scientific and other organizations. Registration rates of $50 for students, $100 for accompanying members, $125 for nonattending members, $150 for senior participating members, and $200 for participating members were fixed until 1 February. Thereafter, they would rise by $25 during the period 1 February to 1 May and by an equal amount after May 1. The American Geophysical Union (AGU) agreed to publish the Guidebooks and provide fifty free copies for each field trip in return for authority to prepare and sell bound volumes of topically grouped Guidebooks. Penelope M. Hanshaw (USGS and Bruce Hanshaw's wife), appointed Co-Chairman of the Field Trip Committee, edited the Guidebooks for the now 132 field trips—forty-eight pre-meeting, twenty-seven during the meeting, and fifty-seven after the meeting—under the general supervision of John M. Aaron (USGS), Chairman of the Publications Committee. The AGU agreed to publish these Guidebooks, even if some of the trips had to be cancelled, and also agreed to publish the notes for most of the thirty-three short courses. The Second Circular also described seventeen workshops, a nineteen-activity program for accompanying members, and a ten-activity Youth Congress.

Scientific and technical sessions, poster-paper sessions, exhibits, and the scientific theater's screenings would be held in the Washington Convention Center (WCC), bounded by H Street and New York Avenue and 9th and 11th Streets, Northwest (N.W.) in D.C. The adjacent Ramada Renaissance Techworld and the Grand Hyatt

The 28th ICC's venue: The Washington [D.C.] Convention Center (WCC); view looking northwest from 9th Street, N.W., in 1989]. This WCC subsequently was demolished and a new and larger WCC built to the north on the long rectangle of ground between 7th and 9th Streets and K and N Streets, N.W.

Washington served as the 28th IGC's co-headquarters. Accommodations there and at the other eight hotels in Northwest D.C., all within walking distance of the WCC, ranged from $68–$190 for singles, $68–$215 for doubles, or $650–$1,200 for ten-day packages. Dormitory rooms were available at the American, Georgetown, and George Washington Universities. The Washington Metrorail, an underground transit system begun in 1969, was opened in 1976. By 1989, Metrorail's Blue, Orange, Red, and Yellow Lines, some still expanding, facilitated travel within D.C. and also served its National Airport and the nearby portions of Maryland and Virginia. The surface Metrobus system and taxis supplemented Metrorail; other buses and taxis served Dulles International Airport in northern Virginia.

**Hereafter the $ symbol is used to represent U.S. dollars.*

Attendees would encounter D.C.'s usually hot and humid summer, but did benefit from the extensive development of central air-conditioning in public buildings since World War II (International Geological Congress, 28th, 1989a). To save funds, the Congress did not operate a shuttle-bus service.

Copies of the Third Circular (International Geological Congress, 28th, 1989b) went out to all registrants early in April 1989, as announcements and notices continued to appear in *Episodes*, *Geotimes*, and the publications of other professional organizations and societies. The number of registrations received (actually far less than those promised) for field trips by the deadline of 1 February required reducing their number to nineteen before the 28th IGC and twenty-eight after the meeting.

The Program Committee, co-chaired by Robin Brett and Brian H. Mason (NMNH), received about 3,700 abstracts of proposed papers. Eighty-eight percent of these were accepted and fitted into thematic symposiums; those remaining were arranged by subject matter. Each symposium had two conveners—one from the USA and the other from another country. Late abstracts were wait-listed; all but about fifty received places on the program.

Finances

Howard Gould supervised three units: Budget, led by Priestly Toulmin III (USGS) and then William Prinz as Treasurer; Finances, managed by Norman H. Foster and Michael Johnson (both independents at Denver); and Audit, directed by Robert L. Fuchs (GSA). Estimates during October 1985 to February 1989 of the moneys needed for a successful IGC ranged from $4.4 million to $6.9 million and averaged $5.3 million. Expenses incurred by the 28th IGC's Bureau were offset by the arrangements for publication. The final revised budget of February 1989 projected an income of $5 million and expenditures of $4.9 million. The Bureau estimated that it would need to raise $1.8 million, but later lowered that figure to $1.63 million. One hundred and five federal, state, academic, and industrial organizations, and five private individuals pledged and provided $1.55 million by 1 April 1989. The total funds topped $1.63 million by the time the Congress convened. This sum included $230,000 from the USGS, $55,000 in an interest-free loan from the GSA, $10,000 from the Gulf Coast Association of Geological Societies, and $5,500 from the Houston Geological Society. The AAPG deferred payment for its convention services and the AGU printed the field trip guides and most of the short-course notes.

Registration

Members began registering at the WCC on 8 July and received their materials, which included the Program (International Geological Congress, 28th, 1989c) and the three volumes of Abstracts (International Geological Congress, 28th, 1989d). The registration office was open twelve hours each day from 9 to 18 July. Penelope Hanshaw and Joan W. Hoover (Chevy Chase, Maryland, and Linn Hoover's wife) led the Member Services Committee. The Information Booth was open from 8 a.m to 5 p.m. each day, its thirty-person staff being supplemented by volunteers from the International Visitors Information Service (IVIS) of Washington, D.C., who spoke Chinese, French, German, Italian, Japanese, Russian, or Spanish. Attendees who spoke other languages were able to draw on the IVIS language bank, available by telephone 24 hours each day. A total of 5,786 persons registered for the 28th IGC and 5,645 of them attended the meeting. They were accompanied by 399 relatives and friends, and eighty-five children.

Communications

In addition to the regular news releases prepared for members of the press, a twenty-person staff, using scanners and Apple desktop publishing, worked each night to prepare the free daily, four-page Congress newspaper (the *Gazette*). The eight issues (two with special inserts) were available at 7 a.m. each morning of the Congress, to present to news of activities and significant subjects of research and publication.


Gazette

The Planet Earth

This sphere in space is what the 28th International Geological Congress is all about.

The Gazette, *the Congress's daily newspaper.*

Opening Ceremony and First General Assembly

The doors of Hall A opened at 2:30 p.m. on 9 July. The U.S. Marine Corps Band ('The President's Own') played a musical prelude until 3 p.m., when Drake, on behalf of the Organizing Committee, welcomed the participants to the Opening Ceremony. Halbouty read a message of welcome, encouragement, and best wishes for a successful meeting from President George H. W. Bush, and introduced the Under Secretary of the Interior, Frank Bracken, who represented Interior Secretary Manuel Lujan while the Secretary was in New Mexico. Bracken presented greetings and good wishes from Lujan and promised continued strong support by the Department by Interior. Peck emphasized the continuing revolution in the earth sciences that provided new techniques and tools for research and the international cooperation that led to an increased understanding of the Earth and its hazards and resources, made ever more important by the parallel growth in human population. The NAS President, Frank Press, echoed the value of the internationalization of science for reasons both pragmatic and humanitarian.

At 4:45 p.m., Yevgeny Kozlovsky opened the meeting of the 28th IGC's General Assembly and passed to the elections of Drake and Bruce Hanshaw. Drake requested and received ratification of the activities during the Council's meeting that morning, including accepting the Japanese delegates' invitation to hold the 29th IGC in Kyoto in 1992. He noted the invitation from Chen Yuqi D. (PRC) to hold the 30th IGC in Beijing in 1996, which would be submitted for formal acceptance at the 29th IGC. James M. Harrison (Ottawa), the former Director of the Geological Survey of Canada, first President of the IUGS, and former Director of Unesco's Division of Earth

Sciences, recalled the contributions to IUGS by its late President William Hutchison. Umberto G. Cordani (University of Sao Paulo), President of the IUGS, stressed the importance of the geosciences in education, government planning and policy making, and international collaboration. Vladimir Sibrava, Director of Unesco's Division of Earth Sciences, Paris, also promoted international cooperation in science. Bruce Hanshaw noted that the $2 million contributed to the Congress by its more than 110 sponsors had enabled the Organizing Committee to minimize costs; without this aid, registrations might have risen to $750 each. Drake closed the General Assembly's meeting at about 5 p.m. and invited its participants to a Reception that followed immediately in Hall B (Exhibits).

Scientific and Technical Program

From 8:30 a.m. to noon and from 1:30 to 5:00 p.m. each day (except for July 15 and 16) the Congress held the 232 sessions of its fourteen-topic scientific and technical program in Hall A. The attendees delivered about 3,100 oral presentations (in English only) in 360 sessions and displayed 550 poster papers in ninety sessions. Some of the accepted papers by the twenty-five percent of authors who were 'no shows' were replaced by reserve papers, of which two were scheduled for each ten-paper session. The sessions included the following topics:

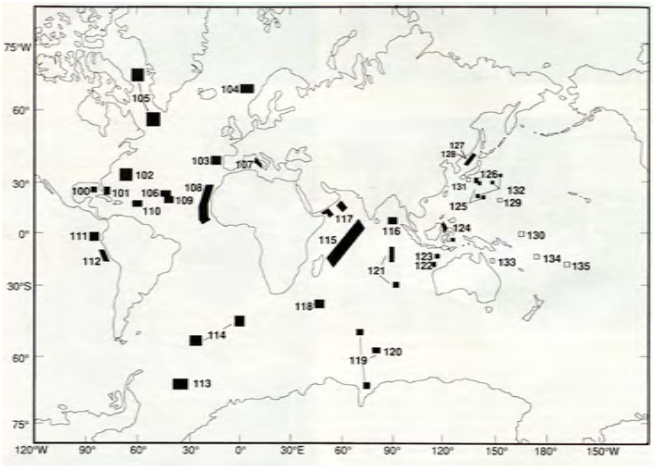
General
Comparative Planetology
Crystalline Crust in Space and Time
Environmental Geology
Extraterrestrial Geology
Geological Education
History of Geology
Mantle and Core in Space and Time
Mathematical Geology
Mineralogy
Paleontology
Resources: Oil, Gas, and Mineral Deposits
Sedimentary Crust in Space and Time
Surface and Near-Surface Processes
Tectonic Processes

Colloquia and Plenary Sessions

Two colloquia were held in Hall A as the only scientific program on two mornings. Invited papers of general interest were presented in the sessions on 'World Natural Resources', chaired on 10 July by Eugen Seibold, William Fisher, and Brian J. Skinner (Yale University), and 'The Twentieth Anniversary of the *Apollo* Moon Landing—A Planetary Perspective' on 19 July, chaired by Valery L. Barsukov (Institute of Geochemistry, Moscow), James W. Head (Brown University) and Dallas Peck.

Invited speakers in a late-afternoon series of six plenary sessions gave forty-five-minute overviews of five principal and ongoing international efforts. Anthony Y. Naldrett (University of Toronto) and Brian Skinner reviewed the Geological Correlation Program in two parts on 10 and 18 July. Karl Fuchs (Geological Institute, Karlsruhe) assessed the International Lithosphere Program on 11 July. Frank Press discussed the International Decade of Natural Disaster Reduction on 12 July. Robert N. Ginsburg (University of Miami) evaluated the Global Sedimentary Geology Program on 13 July. Philip D. Rabinowitz (Ocean Drilling Program [ODP] and Texas A&M University) reviewed on 14 July the achievements by and plans for the ODP as the Deep Sea Drilling Project's successor. The ODP was supported by funds from the NSF, the ten-member Joint Oceanographic Institutions for Deep Earth Sampling, and Australia, Canada, the European Science Foundation, the Federal Republic of Germany, France, Japan, and the United Kingdom. William S. Fyfe (University of Western Ontario) evaluated the progress of the International Geosphere–Biosphere Program on 17 July.

SEDCO/BP 471, was completed for commercial ocean drilling in 1978. The ship, 143.3 meters long, 21.3 meters wide, and with a draft of 7.3 meters and a displacement of 16,906 tonnes, was later converted for use by the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) and renamed Resolution. *This photograph was taken in Baffin Bay during Leg 105 of the Ocean Drilling Program.*



Sites drilled by the JOIDES Resolution during January 1985–November 1989 on Legs 100–135 of the Ocean Drilling Program.

The Spendiarov Prize

The Leonid A. Spendiarov Prize honors "a young and talented Russian geologist of Armenian origin" who attended the opening ceremony of the 7th IGC in St Petersburg in 1897 but died that evening from injuries earlier sustained in an accident while in "the Caucasus region in connection with the preparation of a post-Congress excursion" (Milanovsky, 2004, p. 101). Spendiarov's father convinced Academician Aleksandr P. Karpinsky (Russia, later USSR), the President of the 7th IGC, and its Council, to accept the Prize to be funded by the between-meetings' interest from a bank fund established by the family. Karpinsky was the first recipient of the Spendiarov

Prize at the 8th IGC in Paris in 1900. At the 14th IGC in Madrid in 1926, the Soviet delegation transferred custody of the fund to the IGC. Since 1956, the Prize "traditionally has been presented to an outstanding geoscientist from the host country". It specifically honors "advanced scientific contributions and activities in different fields of geology and international scientific cooperation" (Hanshaw, 1990, p. 31).

Thomas Brennan Nolan (1901–1992, at left) and Susan Werner Kieffer (b. 1942, at right), recipients of the Spendiarov Prize.

On 13 July, at the 28th IGC Council's second meeting, Academician Boris S. Sokolov (USSR) presented the diploma and premium of the eighteenth Spendiarov Prize to Susan W. Kieffer (USGS). (She later transferred the award's honorarium to two elementary-school teachers in Flagstaff and Los Angeles.) The Prize honored Kieffer's contributions to "knowledge of the Earth and the planets" and her research "in fields varying from volcanology and planetology to thermodynamics and river hydraulics" (International Geological Congress, 28th, 1989c, p. 22). Thomas B. Nolan (USGS, retired; Nelson, 2002), who received the Prize's seventh award at the 16th IGC in 1933, was at the 1989 ceremony to add his congratulations to those Kieffer received. Kieffer joined the USGS as a mineral physicist and volcanologist in 1978 but left in 1990 for posts in academia. She was elected to the NAS in 1986.

Educational Outreach

Priscilla C. Grew (Minnesota Geological Survey) and M. Gordon Wolman (Johns Hopkins University), Co-Chairmen of the Public Education Committee, Leon Silver, and their colleagues arranged for a number of varied educational activities. The Smithsonian Institution hosted an evening series of three public lectures at the NMNH's Baird Auditorium. In this series, Eugene M. Shoemaker (USGS) assessed 'Solar System Roulette: Consequences of Large-Body Impacts for Life on Earth' on 11 July, Aleksandr T. Basilevsky (Vernadsky Institute of Geochemistry) reviewed 'Venus: Recent Discoveries' on 13 July, and John F. Dewey (Oxford University) gave an account of recent ideas on the 'India and Eurasia Collision and the Origin of Tibet' on 17 July. The Smithsonian and the USGS co-sponsored at the NMNH an exhibit on 'Active Volcanoes', curated by Richard Fiske. The Smithsonian Libraries' Dibner Library presented an exhibit on 'Stratigraphy's Golden Age—Murchison and his Silurian System'. The Library of Congress's Geography and Maps Division hosted an exhibit and catalogue, by the Division's Assistant Chief (later Chief) Ralph E. Ehrenberg, which illustrated the 'History of Geological Mapping and Maps'. The Science Theater committee, chaired by William H. Mathews III (Lamar University), operating continuously in part of the WCC, showed films and video-tapes of general and specific interest in the earth sciences.

Eighty-five persons between the ages of thirteen and nineteen, from the USA and eighteen other countries, accompanied their parents to the Congress and registered for the Youth Congress and its ten specific activities. Fifty-four of the participants, provided with bus transportation (where needed) and box lunches, participated in organized visits to the NMNH (Y1, Y3) and its Naturalist Center (Y2), the National Air and Space Museum's Center for Earth and Planetary Studies (Y4), the National Aeronautics and Space Administration's Goddard Space Flight Center (Y5), the Potomac River Gorge (Y6), the Calvert Cliffs fossil sites (Y7), Hemlock Overlook County Park (Y8), Prince William County Park (Y9), and the Skyline and Luray Caverns (Y10) during day-long and briefer trips. Local site visits also included the Carnegie Institution of Washington's Geophysical Laboratory, George Washington University's Geology Department, the National Geographic Society's Cartographic Section, the National Institute of Standards and Technology, the NMNH's Mineral Sciences Section, the USGS, and the U.S. Naval Observatory.

Exhibits

Drawing on his experiences with the Circum-Pacific Mapping Project, John Reinemund and his associates arranged for more than 5,000 square meters in 499 spaces for exhibits in the WCC's Hall B. There were 233 exhibitors, from twenty-six countries, occupied 477 spaces each of nine square meters; of these 173 were commercial displays. The three exhibit groups—Educational, General, and USA Government Agencies—generated an income of $415,828, of which $278,820 represented surplus funds (Hanshaw, 1990, p. 21).

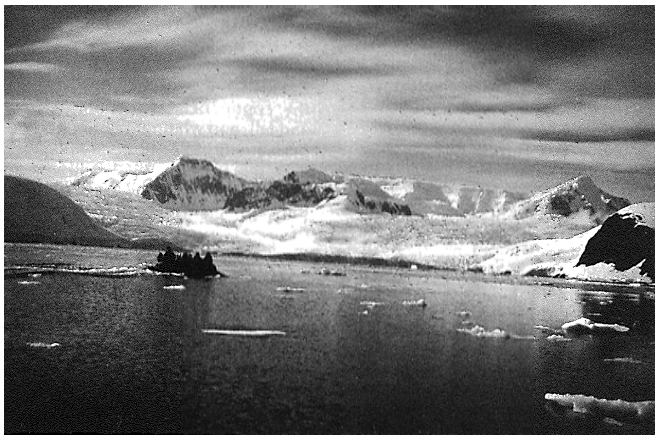
The 28th IGC's exhibits venue: Hall B of the Washington Convention Center.

Entertainment

The accompanying members enjoyed nineteen different cultural, historical, scenic, and social events, spread over ten days and conducted by contract tour guides. These activities included half-day trips (X1–X8) in and around D.C.; weekend day tours (V1–V7) to Annapolis, Baltimore, Charlottesville, Gettysburg, Harper's Ferry-Antietam, Potomac Mills, and Williamsburg; and evening events (Z1–Z3) (two in Washington and a concert at Wolf Trap in Virginia); and the all-member evening picnic on the Mall on 18 July.

Field Trips

Penelope Hanshaw, Robert B. Mixon (USGS), John Reed Jr, Juergen Reinhardt (USGS), and their colleagues arranged 104 field trips of four to ten days duration, most of which were held in the two weeks before or in the two weeks following the Congress. The pre-meeting trips ended in locations offering easy travel to D.C.; the post-meeting trips ended in locations facilitating easy departures for the foreign participants. These trips attracted 1,276 paid attendees; 208 participated in the pre-meeting trips, 670 in those held during the meeting, and 398 in the post-meeting trips.



T180 party in a 'zodiac' (inflatable boat) off the west coast of Graham Land, Antarctic Peninsula, in January 1989 (Dalziel, 1989, top fig., p. 13).

These field trips actually began with a voyage to Antarctica from 1 January to 4 February 1989 led by Ian W. D. Dalziel of the University of Texas (Field Trip T180, 'The Tectonics of the Scotia Arc'). Supported by the U.S. National Science Foundation and the IUGS, it reviewed past work and made suggestions for future studies. Twenty-four earth scientists from eight countries sailed from Punta Arenas in the U.S. Antarctic Research Vessel *Polar Duke* through the waters of the Tierra del Fuego and across the Drake Passage to visit significant sites on the South Shetlands and on the northernmost part of the Antarctic Peninsula.

The other forty-eight pre-meeting field trips included ones in:

Alaska (T101, T102, T104)
Hawaii (T188)
California (T105, T106, T108, T109, T110, T111)
Western U.S. Urban Centers (T181)
Nevada Test Site (T186)
Great Basin (T113, T116, T117, T119, T122, T125, T138)
Grand Canyon (T115)
San Juan Basin (T120, T124)
Colorado Plateau (T130)
Front Range (T129)
Devils Tower/Black Hills (T131)
Rocky Mountain Cretaceous–Tertiary Coals (T113)
Idaho-Wyoming Thrust Belt (T135)
Midcontinent and Eastern United States (T143, T145, T147)
Appalachian Mountains (T150, T152, T156, T157, T161, T162, T166, T167)
Adirondack Mountains (T164)
Boston to Buffalo in the Footsteps of Amos Eaton and Edward Hitchcock (T169)
Atlantic and Gulf Coastal and Coastal Plain (T171, T172, T173, 176, T178)
Florida Aquifer System (T185)
San Salvador Island, Bahamas (T175)
Remote Sensing in Exploration Geology (T182)

The twenty-eight field trips held during the meeting included those in:

Virginia (T201, T202, T203, T207, T213, T221, T236, T244)
Maryland (T204, T206, T211, T214, T217, T226, T231, T233, T241, T243)
Virginia and Maryland (T216, T218, T219, T227)
Washington, D.C. (T208, T209, T234, T235)
Washington, D.C. and Maryland (T232)
Pennsylvania (T242)

The forty-seven post-meeting field trips included:

Alaska (T301)
Hawaii (T304; same as T188)
Northern Cascades Range (T307)
Columbia River (T382)
California (T308, T309, T381)
Grand Canyon (T315, same as T115)
Texas (T317, T376)
New Mexico (T320)
Arizona (T338)
Yellowstone/Grand Tetons/Middle Rocky Mountains (T328)
Wyoming (T332)
Montana (T334, T338, T346)
Vermont (T362)
New York City (T361)
Appalachians (T351, T354, T363, T368)
Exuma Islands, Bahamas (T373)
Turks and Cocos Islands, British West Indies (T374)
Florida (T375)
Physical and Hydrologic-Flow Properties of Fractures (T385)

The AGU published Guidebooks for all the field-trips advertised in the Second Circular and also combined and republished them in twenty-five volumes under thirteen titles:

Coal and Hydrocarbon Resources of North America (2 volumes)
Coastal and Marine Geology of the United States (1 v.)
Environmental, Engineering, and Urban Geology in the United States (2 v.)
Geology of Grand Canyon, Northern Arizona (with Colorado River Guides, 2 v.)
Glacial Geology and Geomorphology (2 v.)
Mesozoic/Cenozoic Vertebrate Paleontology: Classic Localities, Contemporary Approaches (1 v.)
Metamorphism and Tectonics of Eastern and Central North America (3 v.) Mineral Deposits of North America (2 v.)
Sedimentation and Basin Analysis in Siliciclastic Rock Sequences (3 v.)
Sedimentation and Stratigraphy of Carbonate Rock Sequences (2 v.)
Tectonics of the Scotia Arc, Antarctica (1 v.)
Volcanism and Plutonism of Western North America (2 v.).

Short Courses and Workshops

Maria Louisa Crawford, Richard Fiske, E-an Zen, and their colleagues arranged thirty-three Short Courses and seventeen Workshops for the 28th IGC. Limited responses reduced the total held, all on 15 July, to twelve Short Courses and seven Workshops. The instructors for these sessions taught them without receiving honorariums. The AGU published most of the Short Course notes. The Courses were:

- Advances in Geostatistics (S34B)
- Applications of Personal Computers to Geology (S33B)
- Balanced Cross Sections (S28B)
- Brines and Evaporites (S13B)
- Carbonate Sedimentology and Petrology (S14B)
- Coastal Land Loss (S11B)
- Geomorphology from Space (S24B)
- Glacial-Marine Sedimentation (S35B)
- Metamorphic Pressure-Temperature-Time Paths (S29B)
- Metazoan Biomineralization: Patterns, Processes, and Evolutionary Trends (S21B)
- North American Geology, An Overview (S26B)
- Plate Tectonics and Continental Geology (S27B).

The Workshops were:

- Acid Deposition (W6B)
- Extinctions in the Geologic Record (W11B)
- Fossil Crinoids (W12B)
- Geological Problems in Radioactive Waste Isolation—A Worldwide Review (W3B)
- Geology and Mineralogy of Diamonds (W13B)
- Landscape Evolution and Hazards (W4B)
- Metamorphic Fluids (W14B).

Second General Assembly and Closing Session

The second meeting of the General Assembly convened in Hall A at 11:45 a.m. on 19 July. Drake announced the Council's receipt and encouragement of the proposal by Umberto Cordani, speaking for the nine delegates from Argentina, Bolivia, Brazil, Chile, and Peru, to form a consortium of countries and host (as did the Scandinavian countries for the 21st IGC-Norden in 1960) the 31st IGC at a country in South America in 2000. Cordani, Kozlovsky, and Alexander Renwick (Thirsk, England), the 25th IGC's Secretary General, thanked the 28th IGC's Organizing Committee for a successful and rewarding meeting. Sato Tadashi (University of Tsukuba), Chairman of the Organizing Committee for the 29th IGC, invited and encouraged the participants to come to Kyoto in 1992. Drake closed the 28th IGC, comparing the IGCs to the life cycle of the monarch butterflies in his garden. He termed both entities migratory species and noted with pleasure that the IGC's scientific process certainly would repeat itself in Japan in 1992, likely would do so again in Beijing during 1996, and hopefully re-appear in South America in 2000.

Epilogue, 1990

The 28th IGC's general-proceedings volume, detailing (as noted above) the important organizational and operational lessons learned as an aid to the organizers of future IGCs, appeared in 1990 (Hanshaw, 1990, pp. 12–14). The Washington Congress more than balanced its financial books, despite the large discrepancies between the number of persons interested in the field trips and short courses and workshops and those that actually attended them, which led to the 28th IGC's "only substantial financial loss" (Hanshaw, 1990, p. 6). Organizers used the meeting's financial surplus of $278,820 to begin a 28th IGC Fund, managed by the GSA Foundation, principally to support attendance by the 28th IGC's President and Secretary General at future IGCs and the preparation of the next IGC that might be held in the USA.

References

Brown, R. D., 1987, Memorial to Linn Hoover, 1923–1985: Geological Society of America Memorials, v. 17, 4 pp.

Dalziel, I. W. D., 1989, Field trip launches year of the IGC: Geotimes, v. 34, no. 4, pp. 10–13.

Gohau, Gabriel, 2006, The 26th Unternational Geological Congress, Paris, 1980: Episodes, v. 29, pp. 123–127.

Gryc, George and Terman, M. J., 2003, In memoriam—John A. Reinemund (1919–2002): Episodes, v. 26, pp. 47–48.

Hanshaw, B. B., preparer, 1990, General proceedings—28th International Geological Congress, Washington, D.C., U.S.A., July 9–19, 1989: Reston, Va., The [28th International] Congress, 101 + [84] pp.

Hanshaw, B. B., 1998, Memorial to Charles Lum Drake 1924–1997: Geological Society of America Memorials, v. 29, pp. 33–36.

International Geological Congress, 28th, 1987, First Circular: Washington, D.C, The Congress, 60 pp.

International Geological Congress, 28th, 1989a, Second Circular: Washington, D.C, The Congress, 85 pp.

International Geological Congress, 28th, 1989b, Third Circular: Washington, D.C, The Congress.

International Geological Congress, 28th, 1989c, Program: Washington, D.C, The Congress, 200 pp.

International Geological Congress, 28th, 1989d, Abstracts: Washington, D.C, The Congress, 3 v., 264, 767, and 536 pp.

Kozlovsky, E. A., Bogdanov, N. A. and Menner, V. V., eds, 1987, 27th International Geological Congress—General proceedings: Moscow, Vneshtorgizdat, 338 p.

Medlin, J. H., Peck, Dallas, Keith, John, Robinson, Eugene and Jones, Blair, 2000, Memorial to Bruce B. Hanshaw 1930–1998: Geological Society of America Memorials, v. 30, pp. 63–66.

Milanovsky, E. E., 2004, Three sessions of the International Geological Congress held in Russia and the USSR [1897, 1937, 1984]: Episodes, v. 27, pp. 101–106.

Nelson, C. M., 2002, Thomas B. Nolan (21 May 1901–2 Aug. 1992), *in* Betz, Paul, and Carnes, M. C., eds, American National Biography, Supplement 1, pp. 451–453.

Nelson, C. M., 2006, The Fifth International Geological Congress, Washington, 1891: Episodes, v. 29, pp. 279–286.

Nelson, C. M., 2009, The 16th International Geological Congress, Washington, 1933: Episodes, v. 32, pp. 33–40.

Sangnier, Brigitte and Degouy, Michel, eds, 1981, Actes du 26e Congrès Géologique Internationale, Paris—7–17 Juillet 1980: Paris, Gerfau, 330 pp. [in French and English].

Geological Survey of India – The premier Earth science organization of India

Geological Survey of India (GSI) is an attached department to the Ministry of Mines, Government of India and is engaged in collection of basic earth science data through its 33 pan Indian establishments. It employs about 2900 scientific professionals and disseminates the acquired knowledge to the government, industry and general public.

Background

GSI was established in 1851 by the East India Company "to study and explore availability of coals in the eastern parts of India for powering steam transport". Sir Thomas Oldham, the first Director of GSI, broadened the scope of GSI's work to include geological mapping, mineral exploration and basic geoscience research. A major achievement during the pre-independence era was the publication of the first geological map of India and adjoining countries in 1877. The discovery of iron ore deposits in the Chhota Nagpur Plateau in 1906 heralded the industrial revolution in India. For almost hundred years since its inception, GSI was manned mainly by the British geologists and the seminal contributions during this period include (i) publications of Memoirs on geology of Himalaya, Rajasthan, Cuddapah, Singhbhum and Gangpur regions; (ii) discoveries of iron and manganese ores in central India, copper belt in Eastern India, mica fields of Bihar and many other world class mineral deposits; (iii) studies on Siwalik mammals and development of concept of Gondwanaland, (iv) classic studies on Great Cachar (10th January, 1869), Kangra (1905) and Bihar-Nepal (1934) earthquakes and (v) development of the layered theory of the interior of the earth. In the post-independence era, GSI played a pivotal role in fulfilling the aspirations of a developing nation that necessitated establishment of need-based geoscientific organizations and carved institutions like Indian Bureau of Mines, Oil and Natural Gas Commission, Atomic Minerals Division, Central Ground Water Board, Mineral Exploration Corporation and Coal India Limited from its own niche. However, GSI continued its core activities and after liberalisation of India's National Mineral Policy in 1993 and 2008, the robust geological mapping and mineral exploration database generated by the GSI over the years has been found very useful for taking investment decisions by the private entrepreneurs.

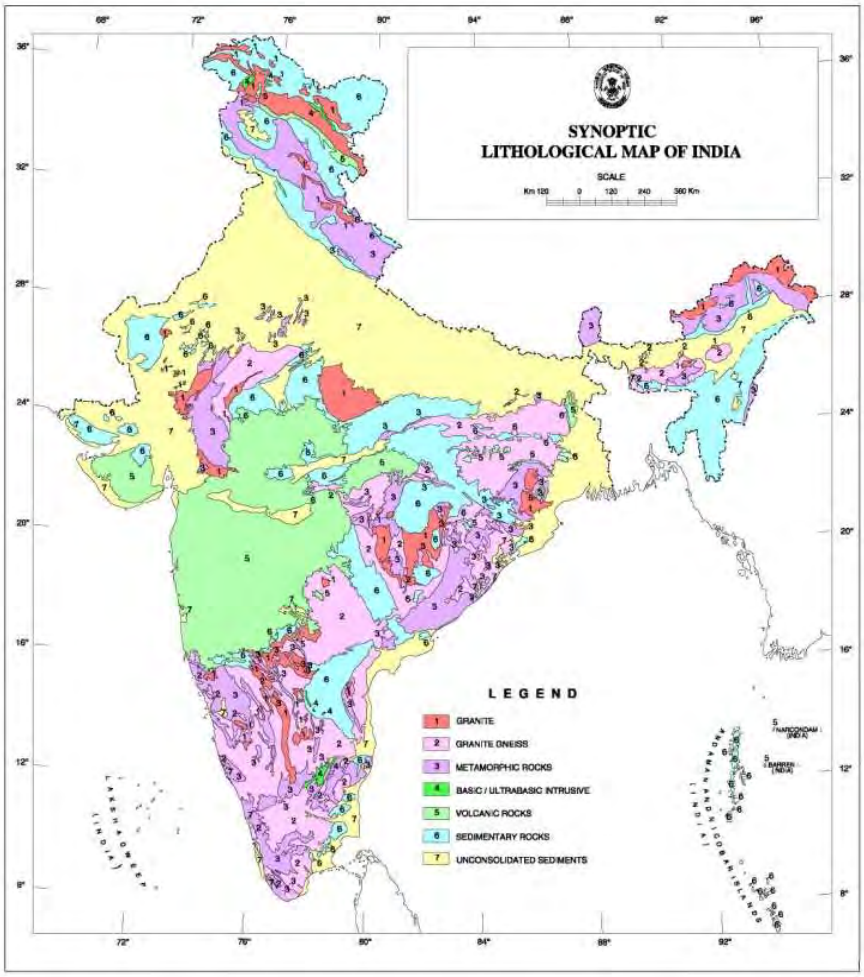
First GSI office complex at Kolkata

Core activities and significant results

Currently, GSI conducts its core activities through five functional missions.

Mission I: Baseline geoscience data generation. Mapping programmes undertaken includes (i) *Systematic Geological Mapping* – 3.09 million sq. km area on 1:50,000/63,360 scale mapped; (ii) *Specialized Thematic Mapping* – mainly to aid fundamental and applied geosciences programmes; (iii) *Marine and Coastal Survey Mapping*–covered 2.015 million sq km of EEZ and Territorial Waters of India (Ocean Going Research Vessel is in final phase of induction); (iv) *Multisensor Airborne Survey* – covered 0.5 million line km over an area of 0.29 million sq. km; (v) *Geomorphological Mapping* – achieved under Natural Resource Census programme, (vi) *Hyperspectral Mapping, and (viii) National Geochemical mapping.*

Mission II: Mineral exploration. This mission monitor programmes pertaining to new mineral search and the projects taken up to augment the existing mineral resources. In



Lithological map of India

GSI's helicopter and ship for aerial and marine surveys.

post-independence period GSI is credited with spectacular discoveries of bauxite, coal, lignite, copper, manganese, chromite, gold, lead, zinc, PGE and coal bed methane. GSI has also identified 340 hot springs from different parts of the country (geothermal resource potential of 10,600 MW has been estimated).

Mission-III. Geoinformatics and geoscience data. It is responsible for acquiring, storing, and analysing geoscience data and information. In response to the increasing public demand for relevant geoscience information, together with its statuary task of supporting government and local authorities in sustainable resource development, environmental protection, and land-use planning and to ensure its compatibility with National Natural Resources Management System, GSI has developed *Spatial Data Warehouse, Metadata catalogue, Map Server and a Net-Portal (*www.portal.gsi.gov.in*). Map production* unit prints thematic maps in GIS platform and the *Publication* unit disseminates the newly acquired data from all the missions. GSI's *Central Library,* established in 1856, houses the richest collection of geoscientific literature in India. Currently it holds in its archive more than 700,000 publications including 600 geological and related journal titles. The archival collection of books in English and other languages dating back to as early as 16th century are some of the rare repository of geoscientific literature.

Mission-IV. Fundamental and applied geosciences programmes handles projects related to the *seismic and geo-environmental hazard assessment and their mitigations* (GSI has published the Seismo-tectonic Atlas of India), *geodynamic studies, seismic tomography studies***,** *landslide studies, geotechnical studies* to the civil engineers, *polar studies***,** (through research stations 'Dakshin Gangotri', 'Maitri' and 'Bharti' in Antarctica and 'Hemadri' at Svalbard in Arctic region), *planetary Studies* (over 600 diverse types of *chondrites, achondrites and iron meteorites,* fell or found, within Indian Territory), glacier studies (a detailed inventory of 9575 Himalayan glaciers has been brought out in published form), *paleoclimatic studies* (through the programmes on coastal regions, glaciology, Himalayan cryosphere, desert geology, and carbon sequestration and Quaternary chronostratigraphy studies (in India as well as ice core studies from Antarctica). The other significant programmes of GSI include studies on *Coastal Wave Dynamics* in east coast, *Thar Desert, elemental contamination* and toxicity in groundwater, *EIA* of urban industrial growth centers, domestic/ hospital/ industrial/ nuclear waste disposal, trace-element *hazard from fly-ash* in coal-based thermal power plants, identification and maintenance of *National Geological Monuments* and *conservation of archaeological monuments* of world heritage sites. Maintenance of *Repository of Index fossil* for Research (includes unique collection of about 250,000 fossils representing the entire spectrum of geological time scale of the Indian subcontinent, accumulated over 160 years).

Mission-V. Training and capacity building. It has several specialized training centers situated in different geological terrains so that the subject-specific field training can be provided with ease. This is the only Institute of its kind in the country where emphasis is given to extensive field demonstrations backed by sound conceptual learning. The training policy of the department envisages (a) induction level training of about one year duration (b) periodic in-service training for the young professionals (c) refresher and advance training programmes for middle/higher level geoscientists and (d) courses on scientific, administrative and management needs. The courses offered include geological, geochemical and geophysical mapping, mineral exploration, airborne and marine surveys, remote sensing, active fault studies, earthquakes and seismic microzonation, geo-informatics for natural hazard studies including risk management, geotechnical investigations, GIS and information technology, management courses and customized courses on client's needs.

Vision for future work

GSI continues to contribute to the nation building by way of providing accurate geoscientific information to policy makers so that it forms part of the government effort that addresses vital issues of food and energy securities to its burgeoning population and also to evolve mitigation mechanisms to shield the life and property from ever-devastating natural hazards. The future visions for the GSI enshrined in its Charter include:

- To simulate the economic development by adhering to long term policies that aim at improving the quality of life in the country
- To create a close-knit national geoscientific community through leadership and collaborative partnership that can take up greater challenges in future.
- To promote and prioritize research in the field of fundamental and applied geosciences.

The unprecedented population growth during last few decades and its likely continuance during next few decades have direct consequence for increase need for natural resources. This has also caused greater stress on geological surveys across the world. There is global concern for urgent need to understand the complex interaction of physical, biological and chemical phenomena that regulate the processes on the planet earth, their symbiosis with humans and problems of increasing water, energy and food scarcity and rapidly depleting natural resources. GSI as the premier earth-science organization of the second most populous country is eager to work with the world geo-community to address these issues.

A. Sundermoorthy, Director General, GSI has a long technical and administrative experience in GSI that includes extensive geological mapping in Precambrian rocks of southern India and Tertiary rocks of northeastern parts of India. He has led multidisciplinary geoscientific projects that helped in identification of significant resources of molybdenum, base metals, lignite and gold in Tamil Nadu and coal in Gondwana basins of eastern India. He prepared a comprehensive XII five year plan document for GSI that outlines thrust areas for mineral exploration, implemented GSI's modernization programmes and adopted proactive role with all the stakeholders in the field of geosciences in forging geoscience partnerships with state geological institutions and central government organizations, academic institutions and geological surveys of other nations for knowledge sharing in specific domains and for collaborative research programmes.

Geoheritage in Europe and its conservation

This note is to bring to your attention a new publication from ProGEO, the European Association for Conservation of the Geological Heritage – an affiliated body of IUGS. This volume, *Geoheritage in Europe*, has just been published. Details can be found on the ProGEO website at *http://www.progeo.se/*.

The volume outlines some of the basic principles in assessing and protecting geosites. It reveals the need to introduce more focussed laws for geoconservation in numerous countries, and to put more Earth scientists into governmental conservation bodies. Even when there is a responsible conservation agency in a country, Earth scientists are seldom employed, and rarely in decision-making jobs. Another issue to be addressed is that geological knowledge (in universities, geological surveys, or societies) is often divorced from the expertise (and power) in conservation.

Geologists and geographers were at the forefront in nurturing a juvenile nature conservation movement, promoting the preservation of the first national parks and natural monuments. However, today in conservation, globally, geology has become a poor relation.

Too often geology is reduced by the media to the obvious, the visual (minus the science) – volcanoes, dinosaurs, big structures – a Great Canyon syndrome. And it is often only used as a backdrop for biotic nature. But the key stages of the evolution of the Earth (organic and inorganic), and the fascinating science, are as much essential heritage as plants and animals. The natural heritage of any country includes its key geological elements – many key geosites, as well as landscapes profoundly shaped and defined by their geology. Fossils, rocks and minerals, and geological processes, are certainly natural heritage, something to be conserved for future generations.

The purpose of *Geoheritage in Europe* is to define the state of the art in geoconservation and to reveal the international differences, problems, challenges, and some successes. However, in some countries in Europe, and many outside, there is no statute or even no official/governmental awareness of the existence of geology, let alone of scientific heritage.

It must be said that everywhere geological heritage is under-valued and threatened, even in countries that have some relevant geoheritage legislation. Practice is so variable between countries: in one a scientifically unique site might be being quarried away or filled with waste, or a coastal cliff site be obliterated by hotel development; in another valid geological research is obstructed by oppressive bureaucratic (conservation) regulations; while in a third at some sites commercial dealers are busy carting off every fossil they can for sale – leaving little behind for scientific pursuits or wider educational use. In recent times, we have seen the famous Pikermian mammalian fossil site in Greece threatened and one of the best J/K boundary sites in Ukraine destroyed.The threats to geological sites are essentially the same in all countries, what differs is the ability or willingness of state agencies to recognise and protect our shared geoscience heritage.

There has been the recent development of Geoparks, in which ProGEO took a founding role. Essential though it is to promote geology to a wider public, it has taken some minds off the ever-present issue – the survival of national/international geoheritage in the form of sites and areas that are often more difficult to popularise. If each country lacks an inventory of its geoscience heritage, it cannot work out its priorities for site protection, or join the fight for resources. And it is necessary to derive such priorities, for all localities cannot be protected in societies where the competition for resources is always acute.

Globally, a minority of countries do see geoconservation as an essential activity. However, in the world as whole, many states make no official recognition that geosites are cultural and scientific goods of national (/ international) importance (and worth protecting). For that reason, Europe has been something of a beacon for other parts of the world, and ProGEO its focus.

Geoconservation is about geosites, large and small, that is, their "protection for use". Other aims are subsidiary to this one defining aim. Knowledge and respect of the Earth's history can only be generated at critical field sites, and our science depends on such areas. No sites, no science - or education or training. As our science is a valued part of our culture, one hopes, their importance cannot be disputed. Once each country is sure that it has adequately protected its top sites, then, and only then, will it be time to think of other things.

This volume, ProGEO, will raise awareness of geoheritage under threat and demonstrate examples of good practice. It aims to bring to the attention of all Earth scientists the need to continually put geoheritage protection on the political and social agenda.

W.A.P. Wimbledon
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Commemoration ceremony, Dr. Wissam Al-Hashimi

On 12 February 2013 a ceremony was held at the Burlington House, London, to commemorate Dr. Wissam Al-Hashimi who was kidnapped, tortured and brutally killed by terrorists in August 2005, in Baghdad, Iraq.

Dr. Wissam Al-Hashimi was President of the Geological Society of Iraq, the Secretary-General of the Arab Geological Association (AGA) since 1993 and Vice-President of the International Union of Geological Sciences (IUGS) from 1996-2002. A well known engineering geologist with significant experience in underground construction, Dr. Al-Hashimi was invited to contribute to the First International Conference on Sustainable Development and Management of the Subsurface, held at Utrecht, The Netherlands in 2003. His article on 'the underground city of Al-Najaf, Iraq' was recently published in a book: *Sustainable Development and Management of the shallow Subsurface*. This book was dedicated to Dr. Wissam Al-Hashimi and to his legacy for the global geoscientific community.

At the ceremony, first copies of the book were presented to his widow Mrs. Muatabar Hasan and to his daughters Farah and Balsam Wissam-Al-Hashimi, who attended the ceremony in person together with other family members and friends. The other dignitaries who attended the ceremony include the President of the Geological Society of London, David Shilston, the President of the International Union of Geological Sciences represented by Dr. Eduardo de Mulder, the authors of the book, the cultural attaché of the Iraqi Embassy in the UK and the Editor of *Geoscientist* magazine, Ted Nield.

David Shilston, President of the Geological Society of London welcomed the delegates and Dr. Robert Hack, co-author of the book, presented some highlights of the book. Dr. Eduardo de Mulder, co-author of the book and former President of the IUGS, whose term partly overlapped with that of Dr. Al-Hashimi as Vice-President of this organisation recalled his personal observations and the significance of Dr. Al-Hashimi for the global geoscience community. The programme came to an end with the vote of thanks presented on behalf of the Al-Hashimi by Mrs. Muatabar Hasan.

From left to right: Eduardo de Mulder (Director Earth Science Matters Foundation, Miss Balsam Wissam Al-Hashimi (Wissam Al-Hashimi's daughter), Mrs Muatabar Hasan (Wissam Al-Hashimi's widow) , David Shilston (President Geological Society of London), and Ms Farah Wissam Al-Hashimi (Wissam Al-Hashimi's daughter).

The ceremony was recorded for broadcast on Iraqi National TV. The event was organised by the Geological Society of London, IUGS, the Earth Matters Foundation and by the authors of the book.

CALL FOR PAPERS

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IGCP in Africa: Workshop on skills development in preparing project applications

26-28 July 2011, UN Complex Gigiri, Nairobi, Kenya

Main challenges of Earth sciences in Africa

The UNESCO's Earth Science Education Initiative in Africa (ESEIA) is probably one of the most important legacies of the International Year of Planet Earth (IYPE). ESEIA was announced by the Director General of UNESCO at the occasion of the Africa Regional Launch of IYPE in Arusha (Tanzania) in 2008. The overall intention of this initiative is to support the development of the next generation of earth scientists in Africa who are equipped with the necessary tools, networks and perspectives to apply sound science to solving and benefiting from the challenges and opportunities of sustainable development[1]. The opportunities in the earth sciences are great, starting with traditional mineral extraction and extending into environmental management such as climate change adaptation, prevention of natural hazards, and ensuring access to drinking water. As a follow-up to the announcement from the Director General of UNESCO, five regional scoping workshops were organized between October 2009 and February 2010 to assess regional capacities and needs in Earth science education, research and industry. These workshops have highlighted some major challenges facing the earth sciences in Africa, among them, the lack of analytical facilities, the isolation facing many researchers and the low level of cooperation between earth science institutions in the region[2].

This preliminary assessment was completed by two other surveys. The first looked into the performance of African earth scientists in the International Geoscience Programme (IGCP)[3]. It revealed the marginal involvement of Africa in IGCP since its launch in 1972, both in terms of number of projects devoted to the continent (only 7%) and in terms of the number of project leaders from the continent (5%). The second survey[4] looked into the performance of African earth scientists in the area of publications, using the case of the Journal of African Earth Sciences (JAES)—an international journal fully devoted to African Geology and covering all the fields of earth sciences. The survey revealed that only 48% of total authors of the articles published in JAES during the period 2000-2010 are affiliated to an African institution. This is less than what would have been expected from a journal fully devoted to African earth science research; also, about 86.5% of Africa's contribution is from only ten countries, among which the four countries contribute more than 62% (Morocco, South Africa, Egypt, and Cameroon). This unequal distribution of outputs emphasizes the need to foster earth science research in the majority of countries. Finally, the survey revealed the low level of co-authoring between reaserchers from African institutions, indicating the need of promoting more cooperative research amongst African researchers and African institutions.

Participants at the workshop, from left to right at the front: Therese Ntonzi Nganje (Nigeria), Caroline Neh Ngwa (Cameroon), Joseph Massaquoi (Director of UNESCO Nairobi office), Yildirim Dilek (USA), Monica Omulo (Kenya), Maideyi Lydia Meck (Zimbabwe), Asrat Asfawossen (Ethiopia); from left to right at the back: Kankeu Boniface (Cameroon), Sadrack Felix Toteu (UNESCO Nairobi), Michael Owor (Uganda), Daud Jamal (Mozambique), Florent Boudzoumou (Republic of Congo), Mousa Isseini (Chad) and Ousmane Wane (Mali).

Looking at its potential as a significant driver of earth science research, UNESCO and the African earth science community have considered IGCP to be a critical focus if earth science research is to be promoted in Africa. During the 23rd Colloquium of African Geology held in Johannesburg in January 2011, the General Assembly of the Geological of Africa adopted a resolution sensitising the African community to the importance of IGCP and on the necessity of revitalising or creating IGCP National Commissions in African countries. Thanks to special funding from the Swedish International Developing Agency (SIDA), UNESCO has embarked on a more vigorous promotion of this internationally recognised programme in Africa, especially through the "Young Scientist IGCP" scheme. During the IGCP Board meeting of February 2011, three projects devoted to Africa were approved for four-year SIDA funding.

IGCP Workshop in Nairobi (Kenya)

The workshop was held in the UNESCO Nairobi office and was funded by both the Swedish International Development Agency (SIDA) and by the regular budget of Earth Sciences of UNESCO Nairobi office. This event was part of UNESCO's efforts

to promote IGCP in Africa and aimed to develop the skills of successful proposal writing, with the overall goal of increasing the number and the quality of IGCP proposals from African earth scientists during the next IGCP scientific board meetings. A call for participation was sent out in March 2011 and the deadline for application was set for 30 May 2011. Each applicant had to submit a project proposal using IGCP format. Out of 16 applications received, 11 were selected and invited to the workshop. Professor Yildirim Dilek of Miami University, Oxford, USA and Member of the IGCP Scientific Board and Dr S. Felix Toteu, Earth Science Specialist at the UNESCO Nairobi office, and leader of the highly successful IGCP project 470, served as facilitators during the workshop. The programme of the workshop was designed to be as informal as possible and to allow intense discussion among participants. The 3-day workshop focused on introductory presentations by the facilitators, presentations on individual projects by participants, break-out discussions, and general synthesis and lessons learnt.

Participants at the plenary session.

Opening ceremony

During the opening address of Prof. Massaquoi, Director of the UNESCO Nairobi office, the importance was stressed of the revitalization of earth science activities in the Nairobi office and on the huge research and collaborative opportunities participants would gain from this workshop.

Introductive presentations

The first introductory presentation was made by Felix Toteu on "The International Geosciences Programme in Africa". He revisited the history of IGCP, its structure including the IGCP National Committees, how IGCP works, and discussed why IGCP has not been successful in Africa. He finally elaborated on how UNESCO is planning to promote IGCP in the continent.

The second introductory paper was made by Yildirim Dilek on "Preparing an IGCP Proposal". It went into detail on the process of elaborating a successful project using the different sections of the IGCP form. This allowed him to stress the evaluation process and what makes a proposal successful. In the African context, he insisted on aspects like project objectives, potential collaboration, and work plan including scientifically relevant field trips.

The third introductory presentation was made by Felix Toteu on "Lessons learnt from IGCP-470". This presentation was used as a show-case of a project prepared and implemented in a context of many challenges faced by most African earth scientists. He discussed 10 ingredients for a successful IGCP in Africa including securing: core participants from Africa and abroad, support from ones' home institution, support from region partner institutions in running field trips, international partnership for laboratory work, efficient use of UNESCO/IUGS seed money, connection with industries. He also highlighted a few cases of career boosting for young scientists involved in IGCP-470. He also stressed on the potential of magnifying the project funding thanks to the UNESCO-IUGS endorsement.

Projects presentation by participants

Each participant was invited to present the project he or she intended to submit for IGCP funding. A total of 11 proposals were presented, each of them followed by discussion. The proposals presented fell into the following IGCP Major Themes:

Deep Earth theme:

- The Panafrican Mayombe (West Congo) fold belt and the adjacent Niari basin in the Central Africa: Geodynamic history, ore deposits context and paleomagnetism study by *Florent Boudzoumou* from the Republic of Congo;
- Neoproterozoic evolution of the continental crust: Geodynamic and metallogenic aspects by *Moussa Isseini* from Chad.
- Magmatic and tectonic evolution of the Mesoproterozoic Fingoe Fold Belt by *Daud Jamal* from Mozambique
- Tectonic, geomorphology and landscape evolution of central Cameroon by *Boniface Kankeu* from Cameroon
- Basaltic magmatic systems in intraplate settings: Insights into Magma Chamber Characteristics and Magma Evolution beneath Mt. Cameroon by *Caroline Neh Ngwa* from Cameroon
- Correlation of stratigraphic and intrusive units of the Massigui regions south Mali) Fada N'Gourma (eastern Burkina Faso) and Diaforou-Drbani (south western Niger) regions : geodynamics of the northern and northeastern borders of Birrimian Man domain of Man by *Ousmane Wane* from Mali.

Global Changes and Evolution of Life:

- Monitoring cave climate, surface and groundwater geochemistry in East Africa: implication for speleothem paleoclimate studies by *Kassaye Asfawossen Asrat* from Ethiopia

Geohazards:

- Temporal Assessment of potentially toxic elements in shale rock, in parts of Southern Benue Trough, Nigeria by *Therese Ntonzi Nganje* from Nigeria

Earth resources:

- Sustainable utilization of minerals for agricultural purposes to enhance future well-being of society by *Maideyi Lydia Meck* from Zimbabwe

Ground Water:

- Sustainable groundwater development for agricultural (irrigation) support in semi-arid regions of Uganda by *Michael Owor* from Uganda

A last proposal initiated by the Association of African Women Geoscientists (AAWG) was related to Geopark development in the Lake Victoria basin (Kenya) and the impact of climate change presented by *Monica Omulo* from *Kenya*

Break-out discussions

After the individual presentation by participants, the debate that followed showed that most projects need to be reviewed to make them really international and to be consistent with IGCP goals. Participants were invited to make sure that their proposal shows clear international potential both in terms of the topic of research and of participation. In this regard the quality of some proposals presented could be enhanced if they were merged into only one proposal based on the following guidelines: (1) have a more attractive title; (2) define four or five clear objectives; (3) make the proposal truly international in terms participants and of institutional partnerships essential for laboratory data production; and (4) identify internationally attractive field trips. The constitution of the break-out groups was defined based on this strategy. Group-1

Participants at the break-out Group-1.

Participants at the break-out group-2.

included the presenters of proposals of the Deep Earth Theme and Group-2 included the presenters of proposals falling in the Geohazard, Earth Resource and Groundwater Themes. All projects standing alone benefited from an intensive review and redrafting of the text during the discussions.

Deliberations in Group-1 led to the merger of all proposals into a very encouraging research theme on "*Proterozoic stabilisation and remobilisation of cratons in Africa: Geodynamics and metallogenesis*", with the objectives to (1) contribute to the understanding of those processes linked to cratonic stabilization and reactivation/ remobilisation during the Proterozoic in Africa, (2) understand deep processes and mantle-crust interactions during successive orogenic cycles that built the Precambrian architecture of the African continent, and (3) clarify geodynamics and metallogenesis links within the frame of the above considered processes. Field trips during the proposed 5-year project are designed to cover the main period of crustal building in Africa—the Archean and Proterozoic cratonic terranne with a show case in West Africa, Burkina Fasso and Mali; the Proterozoic belt in Mozambique; the Neoproterozoic belts in Central Africa, Chad and Cameroon); and the Neoproterozoic crustal growth in NE Africa. Group-2 also came out with similar type of result with a merged proposal entitled "*Earth resources for poverty alleviation, health in Africa*".

Lessons learnt

An important lesson learnt from this workshop is the very high awareness amongst Africans of the need to break their isolation and move from individual and local research projects to regional and international projects. This active outward looking perspective is the only way to be connected to the international earth sciences community and to generate research proposals with the potential of attracting other colleagues and interest from research teams and laboratories abroad. In this regard, participants agreed to maintain the network created during this workshop to exchange information and continue to develop stand alone and merged proposals in view of submission to the IGCP funding.

Acknowledgement

The organization of this workshop has been made possible by a special funding from the Swedish International Development Agency (SIDA) and UNESCO Nairobi office. We extend our special thanks to the UNESCO Nairobi staff who contributed to a successful organization of the workshop.

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Quoted documents

[1]UNESCO Project Brief: Earth Science Education Initiative in Africa: http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/SC/pdf/GEO_Sc-Ed-Initiative-Africa_Project-Brief_05-2011_en.pdf

[2]Earth Sciences Education Initiative in Africa: Scoping workshops synthesis, 10 June 2010. http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/SC/pdf/GEO_eseia_synthesis-10june_en.pdf

[3]IGCP in Africa workshop on skills development. http://www.servirglobal.net/tabid/205/Article/950/call-for-applications-igcp-in-africa-workshop-on-skills-development.aspx,18 May 2011.

[4]UNESCO Nairobi report on "The Performance of African Earth Scientists in the Journal of African Earth Sciences (JAES) during the Period 2000-2010". Prepared by Asrat Asfawossen, consultant, October 2011.

Non-marine Cretaceous biostratigraphy and biochronology

Sha Jin-geng and Spencer G. Lucas (Eds.)

Journal of Stratigraphy,
Volume 36, number 2, 2012, 550 p.
Price: 35 RMB Yuan (= ca. 6 USD)

The Cretaceous saw fundamental changes in the nonmarine ecosystem with the origin and/or rise of major clades, including flowering plants, social insects, derived dinosaurs (hadrosaurids, ceratopsids, tyrannosaurids), birds and therian mammals. The rocks that yield this fossil record are widespread and occur on every continent and often contain significant economic resources, notably coal and gas. There is a long and voluminous literature on the correlation of the non-marine Cretaceous that utilizes many taxonomic groups, from pollen to dinosaurs. However, the diverging continents produced provincialization of non-marine biotas that makes global correlations challenging.

Sha Jin-geng of the Nanjing Institute of Geology and Palaeontology and Spencer Lucas of the New Mexico Museum of Natural History and Science have edited an important new volume that addresses diverse issues in Cretaceous non-marine biostratigraphy and biochronology. This volume is an issue of the Chinese *Journal of Stratigraphy* (*Dicengxue Zazhi*) which is available from the China International Book Trading Company, PO Box 399, Beijing 100044, China.

The volume includes 22 contributed articles and a detailed introductory essay by the editors. The introduction is a very useful contribution that contains a concise but elegant synopsis of the Cretaceous world and its timescale. Sha and Lucas conclude the introduction by identifying six ways to further multidisciplinary approaches to resolve problems of non-marine Cretaceous chronology and correlation: (1) identify marine and non-marine fossils in marine, alternating marine and non-marine Cretaceous strata; (2) utilize the high-resolution of microfossil assemblages/zonations to precisely subdivide, correlate and date non-marine Cretaceous strata; (3) precisely and successively measure radioisotopic ages of interbedded datable volcanic and volcaniclastic rocks to constrain the age of the associated sedimentary rocks/fossils; (4) develop more magnetostratigraphy in direct relationship to non-marine biostratigraphy; (5) concentrate more on the recognition of depositional systems and subsystems and their fluctuation in space and time to facilitate a high-resolution sequence stratigraphic analysis of marginal and continental deposits; and (6) increase use of chemostratigraphy and isotopes for correlation of Cretaceous non-marine deposits. The remaining papers in the volume address nonmarine Cretaceous biostratigraphy, biochronology and correlation using sporo-pollen, megafossil plants, ostracods, conchostracans, non-marine molluscs and vertebrates.

The first six papers are concerned with sporo-pollen. Vajda and Berocovici and Bercovici, Vajda and Sweet provide two papers that review pollen and spore stratigraphy of the Cretaceous-Palaeogene mass-extinction interval in the Southern and the Northern hemispheres, respectively. Each paper is less than a dozen pages long but provides a good overview of the fossil record in the hemisphere and identifies areas that need additional study. The best studied palynological record is in North America, only 2000 to 5400 km from the Chicxulub impact crater, and in general there is a need to better understand the consequences of this event in more distant locations.

Two contributions address the palynostratigraphy of West Siberia. Pestchevitskaya, Smokotina and Baykalova review the early Valanginian palaeoenvironments and vegetation of coastal and continental areas in southeastern West Siberia and note that the palynomorphs exhibit typical features of both the Indo-European and the Siberian-Canadian palaeofloristic provinces. Lebedeva and Pestchevitskaya provide a broader context and establish a reference succession of Cretaceous pollen and spores in western Siberia using palynomorphs from marine sections to calibrate to ammonite zones.

Prámparo evaluates the palynostratigraphy of the important Cretaceous non-marine basins of Argentina and evaluates palynozones. There is obviously a need for additional work, notably in the Late Cretaceous, but this paper provides a good overview of the current state of knowledge.

Dinoflagellates have been recognized in non-marine Cretaceous strata in the past 30 years but principally only in England, China and Australia. Chen and He focus on non-marine dinoflagellate assemblages from China and also review the fossil record in southern England and southwestern Australia. Dinoflagellates clearly have potential importance in biostratigraphy and paleo-environmental reconstruction (notably paleo-salinity).

There is only one contribution on megafossil plants, but it is a very useful review of Cretaceous floras of China by Deng, Lu, Fan, Li, Fang and Liu. The extensive early Cretaceous record and its biostratigraphy are discussed in detail, and the sparse Late Cretaceous floras are also reviewed.

Two very different papers in the volume address ostracods and their potential in biostratigraphy and biochronology. Sames and Horne's stimulating contribution is entitled "Latest Jurassic to Cretaceous non-marine ostracod biostratigraphy: unde venis, quo vadis?" Essentially, ostracods have acknowledged utility in regional correlations but their use in supraregional biostratigraphy has been doubted. Sames and Horne enthusiastically argue that global correlations using non-marine ostracods are feasible given both a more conservative approach to taxonomy and an awareness of paleoenvironmental factors. Essential to this goal is an appreciation of the fact that many non-marine ostracod groups are not restricted to individual water bodies or small geographical regions. Sames and Horne acknowledge that there is much work to be done but they foresee "the dawn of a new late Jurassic to Cretaceous non-marine ostracod biostratigraphy." There is an extensive record of Cretaceous non-marine ostracods in China, and Wang, Sha, Pan, Zhang and Rao provide a good preliminary review of the assemblages and their correlation. This is a very useful review of a voluminous literature.

Chen reviews the Cretaceous conchostracan record in China. The extensive faunas undoubtedly require some taxonomic revision as Chen notes (e.g., the *Eosestheria* and *Euestherites* faunas each have more than 100 species!) but they provide an apparently significant biostratigraphy.

It is gratifying to see that non-marine molluscs receive significant recognition in this volume, with five papers. The diverse European record is almost entirely from the Early Cretaceous and is reviewed by Munt, Delvene and Sha. They describe how a distinctive European freshwater mollusc community had developed by the Barremian. Japan has an extensive record of Early Cretaceous non-marine molluscs that is

reviewed by Kozai, Ishida and Hirsch. Marine intertongues provide accurate age constraints and allow for the recognition of four successive faunas. This paper is notable in the volume for having five photographic plates.

Pan examines Cretaceous non-marine gastropod assemblages from China and distinguishes four principal assemblages. Two of these assemblages may be divisible on the basis of geography or stratigraphy. Sha, Pan, Wang, Zhang and Rao utilize molluscs and radiometric dating to correlate Lower Cretaceous non-marine and marine units in northeastern China, southeastern Korea and southwestern Japan. They date the Longzhaogou, Jixi and Jehol groups and overlying Huashan Group and Sunjiawan Formation of northeastern China, Sindong Group and lower Hayang Group of southeastern Korea, and Tetori and Monobegawa groups of southwestern Japan as Hauterivian–Albian. This conclusion is based on the work of Sha (2007) who correlated the non-marine and marine Cretaceous strata in northeast China and Inner Mongolia. Sha, Pan, Wang, Zhang and Rao conclude that the three areas (northeastern China, southeastern Korea and southwestern Japan) were connected in the Hauterivian-Albian and formed part of the same fluvial system. Cretaceous sedimentary rocks in Thailand, Laos and Vietnam are almost entirely non-marine in origin. Sha, Meesook and Nguyen utilize molluscs (and palynomorphs and dinosaurs) to correlate the Barremian-Maastrichtian of this region.

The volume contains six papers with impressive geographic spread on vertebrate fossils, three on osseous faunas, one on footprints and two on eggs. LeLoueff, Lang, Cavin and Buffetaut provide a useful review of the Early Cretaceous dinosaur-dominated faunas of Africa and identify four successive assemblages: (1) Late Jurassic (Kimmeridgian-Tithonian) to earliest Cretaceous (Valanginian) assemblage with stegosaurids, brachiosaurids and diplodocids; (2) Hauterivian-Barremian? assemblage with baryonychine spinosaurids, the pholidosaurid crocodile *Sarcosuchus*, large iguanodontids and the shark *Priohybodus arambourgi*; (3) Aptian? to early Albian assemblage that still includes iguanodontids but in which spinosaurine spinosaurids replace baryonychines; and (4) an early Cenomanian assemblage characterized by the association of dinosaurs (*Spinosaurus*, *Carcharodontosaurus*), sharks (*Onchopristis numidus*) and crocodyles (libycosuchids, stomatosuchids).

The non-marine vertebrate faunas of Central Asia (Gobi of Mongolia, Inner Mongolia of China) are relatively well known but those of Middle Asia (Uzbekistan, Kazakstan, Kyrgizstan) are much less studied. Averianov and Sues assess the relative stratigraphic positions and ages of the Late Cretaceous assemblages from these areas by means of parsimony analysis of 26 proposed biostratigraphic marker taxa.

The development of the Cretaceous vertebrate biochronology of the Western Interior of North America began in the 1890s. Lucas, Sullivan and Spielmann review and revise the vertebrate biochronology of the Cretaceous of this region by redefining and defining (new Fencelakean) 10 land-vertebrate "ages" to encompass all of Cretaceous time in the Western Interior, which are (from oldest to youngest) – Comobluffian (~Tithonian-Hauterivian), Buffalogapian (~Barremian-early Aptian), Cashenranchian (~early Aptian-late Albian), Mussentuchian (~late Albian-Cenomanian), Fencelakean (~Turonian-late Santonian), Aquilan (~late Santonian-early Campanian), Judithian (~middle Campanian), Kirtlandian (~late Campanian), Edmontonian (~latest Campanian-early Maastrichtian) and Lancian (~late Maastrichtian). This important paper thus represents the culmination of the refinement of a vertebrate-based non-marine biochronology for a region that includes significant dinosaur (and other vertebrate) faunas.

Lockley, Lucas, Matsukawa and Harris examine the global record of Cretaceous tetrapod footprints in detail and their article includes an immense bibliography. They confirm the earlier hypothesis of Lucas (2007) that there are essentially only two global Cretaceous footprint biochrons: (1) Early Cretaceous characterized by sauropod and ornithopod tracks; (2) Late Cretaceous that has fewer sauropod tracks and tracks of hadrosaurs, tyrannosaurids and ceratopsians. However, they also suggest that the Cretaceous footprint record of Asia may allow for the recognition of three or four Cretaceous footprint provincial biochrons.

Dinosaur eggs are notably abundant and widely distributed in China. Wang, Wang, Jiang, Cheng, Zhang, Zhao and Jiang provide a very useful overview of the record of Cretaceous eggs in China. They review the ages of the main egg-producing basins in China and also provide a useful synopsis of dinosaur egg assemblages from other countries. Lucas, Bray, Emry and Hirsch use dinosaur eggs on a more local scale, in combination with plant-based biostratigraphy, to place the Cretaceous-Tertiary boundary in the Zaysan Basin of eastern Kazakstan. They document a stratigraphic succession of Late Cretaceous (Maastrichtian?) dinosaur eggshell overlain by late? Paleocene paleoflora capped by middle Eocene mammals.

Overall Sha and Lucas have produced a very important volume. Even though this is a Chinese publication there is an impressive geographic spread in the articles, covering every continent. The diversity of taxonomic coverage is also laudable, representing the majority of important Cretaceous non-marine taxa, from pollen to dinosaurs. Furthermore, the majority of the articles are high level reviews and thus this volume represents a synopsis of an enormous amount of primary literature. This volume is a landmark contribution to global non-marine Cretaceous chronology and is a must read for all students of the Cretaceous.

References

Lucas S.G., 2007, Tetrapod footprint biostratigraphy and biochronology: Ichnos, v. 14, pp. 5-38.

Sha J.G., 2007, Cretaceous stratigraphy of northeast China: non-marine correlation. Cretaceous Research, v. 28, pp. 146-170.

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The Life and Work of Professor J.W. Gregory FRS (1864–1932)

By Bernard E. Leake

Geological Society of London, Memoir No. 34, 2011

Bernard Leake was for many years professor of geology at Glasgow University. In his fine biography – a large and weighty tome – he details the extraordinary career of one of his most notable predecessors, John W. Gregory. Perhaps writing the book can be thought of as an act of institutional piety, but one from which we can all benefit: Gregory was a man who inspired; and his light will now shine even more brightly.

Gregory came from a modest London family. Though small of stature and retiring disposition he was a person of remarkably robust character, as was his sister: young Gregory (11 ½) and Eleanor (9 ½) walked 55 km through the night when, after an unaccompanied visit to the seaside, their intended return transport was found to be unavailable. And later we learn that his usual walking speed was 8 km per hour.

Gregory studied science subjects at Birkbeck College, London, in evening classes while working for a wool company during the day. Soon he was associating with geologists and writing popular articles. His scientific career was launched when he obtained an appointment as an assistant at the British Museum, Natural History, where he worked chiefly on corals and bryozoans.

Then came two opportunities for expeditions in East Africa. The first (1892–93) was funded by the British Government for 'geopolitical' purposes but was incompetently led by a military officer and was aborted. The second (1893) was under Gregory's leadership and achieved much in the 'wilds' of Kenya, including his recognition of the continent's 'Great Rift Valley' – despite his group having to evade hostile Africans. It was partly financed out of Gregory's own pocket, but used stores abandoned by the preceding expedition. He proceeded despite his suffering from malaria at the time.

The African work was reconnaissance exploration and survey but it was carried through with great success and yielded important results. Thereafter Gregory undertook extensive travels in many parts of the world, including the 'dead heart' of Australia (in the summer!), Spitzbergen, Tibet, the Americas, much of Europe, and of course Britain. Eventually he died at the age of 68 by drowning in a gorge in Peru during an expedition that had crossed the Andes and was trying to get to the east by riverboats.

In 1900, Gregory was appointed to the chair of geology at Melbourne University and he and his family moved to the Antipodes. The University was in financial straits and the facilities were rudimentary. Nevertheless, with his characteristic energy Gregory soon had things moving; and he also assumed leadership of the Victorian Survey and succeeded in resuscitating that also. The Melbourne authorities had mining in mind as the focus of interest of the geology department; so Gregory quickly shifted his focus from palaeontology to mining geology. (He had in fact studied metallurgy, among other subjects, at Birkbeck.) Leake believes that Gregory would have been happy to stay in Australia (and he retained links there for the rest of his life), but his wife preferred to be in Britain and so he obtained the chair at Glasgow, where again he had to resuscitate a department. He did this so successfully that in time Glasgow became the largest department in Britain. But his travels did not cease: he visited the Caribbean, South Georgia, Burma, much of Europe, India, Tibet, Australia again, Angola, the Americas, Scandinavia and other parts of Europe. . . , and of course much of Britain.

Gregory was, as Leake puts it, a workaholic. He authored or co-authored 33 books (including textbooks) and some 313 single-authored papers and reviews, and 32 co-authored items, as well as numerous popular articles. He was on numerous committees, including one that reviewed the state of Indian universities. He was elected FRS and was twice President of the Geological Society (making notable Presidential Addresses). He was renowned as a leader of field excursions and was a highly successful teacher and lecturer, though it seems that he had difficulty in controlling large first-year undergraduate courses (which paradox is not explained by Leake). He willingly 'got up' new fields as needed. But perhaps he spread himself too thinly and he was not a notable theorist, despite being geologically omniscient! He was, like many, a devotee of Suess, but also accepted and upheld W. L. Green's (1875) 'tetrahedral' theory of the Earth's distribution of oceans and continents, according to which large landmasses are 'complemented' by large areas of water at the opposite sides of the globe. The tetrahedral form of the Earth supposedly arose because the tetrahedron is the regular solid with the largest surface area for a given volume; and therefore it might be expected that a cooling and shrinking spherical Earth would produce a form on solidifying that was somewhat tetrahedral.

The corollary of this hypothesis was that the areas of land and ocean would be approximately constant, though with the depth of the oceans varying somewhat over time, so that plant or animal migrations across areas that are presently oceans could occur. So Gregory was a 'fixist' of a kind, and opposed the drift theory espoused, for example by his colleague the younger Edinburgh geology professor Arthur Holmes. Gregory's opposition did not help the mobilist cause. But perhaps having a bet both ways, he wrote in the Van Waterschoot van der Graacht 1926 Symposium volume on the theory of continental drift that had "no *a priori* objection to the drift hypothesis" (p. 94).

Gregory had unorthodox ideas about the formation of eskers and drumlins and also the origin of fiords, which, he thought, originated as a result of some kind of crustal fracture. On the latter point he was ahead of his time. On the former, his ideas have not been accepted. Nevertheless, he did a good deal of geomorphological and Quaternary work

One might have thought that, residing in Glasgow, and leading numerous student excursions into Scotland, Gregory would have become *the* authority on Scottish geology. But Leake describes Gregory's swansong, *Dalradian Geology* (1931), as a "complete disaster". Gregory ignored the then new criteria of graded bedding and cross bedding to determine 'way-upness' that had been proposed by E. B. Bailey (who succeeded him in the Glasgow chair in 1929 and later became Director of the British Survey). The Dalradian rocks of Scotland are an exceedingly complex set of mostly metamorphic rocks of Neoproterozoic age, extending into the Lower Palaeozoic and lying between the Great Glen Fault and the Highland Boundary Fault, all much deformed by the so-called Grampian Orogeny. Gregory imagined a relatively simple structure, with generally north-dipping rocks; and he ignored repetitions of strata due to strike-slip faulting. The mysteries of the Dalradian sequence could only be fathomed

by close mapping of the metamorphic rocks; and Gregory did not do this.

Yet Gregory did not hesitate to offer worldwide correlations for the Scottish successions. This, I suggest, exemplifies the dangers of thinking or working on too grand a scale. Gregory did rather little map-work in his career, and especially not for metamorphic rocks. The Dalradians were almost on his doorstep in Glasgow, and offered more than enough interest and problems to satisfy anyone. But in 1931 Gregory's aging eyes were seemingly set on further reconnaissance survey work, this time in South America, and he did not accomplish what he might have done by painstaking work in the Scottish metamorphics. After Gregory's death, Bailey drew attention to his shortcomings on Dalradian geology.

Having done so much travelling in remote parts of the world, Gregory encountered many non-Europeans, established cordial relations in most cases, and became generally interested in anthropology and human migration. (He also did some archaeological work in Africa.) However, he left Australia as a supporter of the now notorious 'White Australia' policy and might today be regarded as a racist (though he spoke well of the Aboriginal guides he used in Australia). Even so, he was evidently a most agreeable man with a wide circle of friends and acquaintances. Also, as Leake shows, he had a considerable influence on the teaching of geology in Britain, manifesting a kindly respect for his students. On the other hand, he appears to have been tenacious in defending his views—and well able to do so on the basis of his vast first-hand empirical knowledge and his immense knowledge of the literature.

Besides giving a comprehensive account of Gregory's extraordinary career as a geologist Leake also gives interesting and quite detailed accounts of his personal life and the social conventions of a family of a distinguished and influential professor for the period in question. They were rather formal and highly 'respectable', but also endearing.

Gregory's travel books show him to have been extraordinary robust and resilient, and an excellent organiser, apparently getting on well with his various co-expeditionists. One would think from his accounts that he spent all his time simply coping with the rigours of travel, but we also see that he was constantly collecting specimens and making and recording observations. The lists of references to the areas he visited show that he was fully cognisant of previous relevant work. By the time of his explorations, there were some travel advantages such as railroads and regular shipping, but not air travel of course. A lot of his writing must have been done aboard ship or on trains; but it appears that at home a great deal of his writing and thinking was done in the early hours of the morning. He was generally active for twenty hours a day.

Bernard Leake's task must have been a massive one as his subject was so 'large'. But he appears to have examined and digested all likely sources, both in archives and libraries. The book could have become too 'heavy' (and it is indeed a weighty as well as a large tome), but the chapters are relatively short, and each deals with a discrete aspect of Gregory's work. So one does not have to read all at one sitting.

I have, fairly recently, been examining the general issue of geologists' biographies or autobiographies and tabulating a large mass of information (derived especially from William Sarjeant's monumental bibliographical study *Geologists and the History of Geology*, 10 volumes). Certain patterns have begun to emerge. The literature in English, German, and French (in that order) far exceeds that in other languages. Naturally, one is more likely to have a biography if one is a major figure or has made some really major contribution to geoscience. (Yet some major figures like Lapworth, or Bailey for that matter, lack biographies.) If a geologist makes a particularly notable contribution to an institution, then an author from that institution may be more likely to honour him with a biography. People who have special fame in fields other than geology (e.g. Cuvier, Darwin, Teilhard de Chardin, von Humboldt, Linnaeus, Kelvin) receive a great deal of biographical attention. And being a woman helps! But more than anything, being a traveller encourages the writing of both biographies and autobiographies. (And, the evidence reveals, Muslim countries do not produce works of this genre; and India and Africa have had little to offer.) To a large extent, in Gregory's day geology was strongly associated with colonial and imperial activities. Indeed, for the cover illustration of his book Leake uses a global map showing (in red!) the areas that, in Gregory's time, formed parts of the British Empire. And the book reveals that there was formerly a significant link between geology and empire.

So on many counts it is unsurprising that Gregory should receive a biography and that Leake should be the person to have written it. He has done so with enormous diligence and skill, and the result is not only a testimony to Gregory but to the devoted work of his biographer. And for the geologist reader, Gregory should serve as an inspiration. Also the book displays what was known about geological matters in the decades 1890–1930. One can also learn a good deal about geography and social history from it. Thoroughly recommended!

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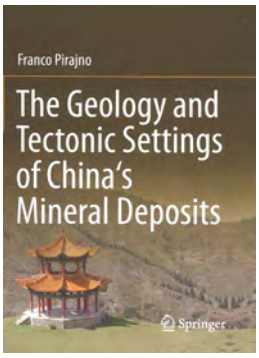
The Geology and Tectonic Settings of China's Mineral Deposits

by Franco Pirajno

Springer Science + Business Media
Dordrecht, 2013. 679 p.
ISBN 978-94-007-4443-1
Price: Euro 120.

China is a voracious consumer and importer of metals: in 2010 it imported 619 Mt of iron ore and around 12 Mt of contained copper (even some antimony!). This and the rapid investment into overseas ventures are responsible for the public perception of China as being poor in mineral resources. This is



far from the truth. In 2011, according to the U.S. Geological Survey Minerals Yearbook data, China has been the #1 world producer of the following metals (percentages of the world's production are in brackets): Rare earths (97%); antimony (88.7%); tungsten (83%); mercury (72.5%); bismuth (70.6%); lead (49%); tin (43.5%); iron ore (42.9%); aluminium (40.8%); molybdenum (37.6%); zinc (31.5%); and gold (12.15%). It has the world's largest endowment of Sb, W, Sn, REE, Be and Mo and world's largest deposits or districts of Sb, Bi, Be, REE, Sn and W.

It is clear that a sound knowledge of the Chinese metal sources (deposits) and their geological setting is essential for international geologists who could greatly extend their inventory of exploration models targeted inside and outside of China, as well as for a variety of mining analysts, commodity specialists, geopoliticians, and others. The Chinese have a great comparative advantage as they can read about the Chinese deposits in original and about the world's deposits in English, a relatively "easy" language compared with Mandarin. The rest of the world's readers have to rely on English translations.

China has a rich history of discovery and utilization of the "classical" metals (Sn, Au, Hg, Cu) going back to the earliest dynasties. Some "modern" metals (W, Sb), mostly for export, were found and developed in the early 1900s. Many "technology" metals (Mo,REE,U,Bi,Be,etc.) have been discovered by the numbered "geological parties" during the People's Republic era, initially under the Soviet tutelage and later by Chinese teams alone, and they contributed to fuelling the phenomenal Chinese industrial growth. The rate of minerals discovery has been significant and whole new districts and metallogenic province have been identified and developed (for example the East Qinling Mo province with 8.5 Mt of Mo endowment now exceeds the United States' Rocky Mountain Mo province of about 6.5 Mt Mo). This trend continues.

The information export, however, lagged behind. While the internal Chinese literature generally kept pace with the progress providing adequate descriptions of mineral deposits and their geology (minus the topics subject to censorship like locations, tonnages, grades), little has come out in English; as late as in the 1980s information on the important Jiangxi tungsten province had to rely on a 1943 paper in Economic Geology and some more recent Russian translations and reviews. This started to change, in parallel with the "China opening" and new economic policies, resulting in accelerating industrial growth. The China-World exchange has greatly increased since the 1980s with Chinese nationals studying at Western universities (and publishing papers in English together with their research supervisors), with numerous symposia held in China, and with a great modernization and internationalization of the Chinese mining and research. A number of papers on Chinese mineral deposits and general geology has been published in the past twenty years in western journals (especially in the Ore Geology Reviews and Mineralium Deposita) so that persistent reader can now achieve a great deal of literacy in these topics. But the references are scattered and often difficult to get. There was a pressing need for a comprehensive treatment of the Chinese ore geology in a book form, not fully addressed by the five volume set of Mineral Deposits of China (1900-1996) and by the "Mineral Facts of China" edited by Zhu (2007, Elsevier Amsterdam). The Pirajno's book fills this gap.

The book has eight chapters of uneven length and an epilogue. The introductory Chapter 1 briefly summarizes the rarely realized mineral strength of China in course of its 8000 years history of mining and ore discovery, and it provides a brief overview of the chapters that follow. Chapter 2 is "China's Tectonic Framework in the Global Context" that treats the bewildering complexity of the Chinese geology in the Euro-Asian context, as an introduction to the subsequent chapters organized by style, timing and regions (cratons, then orogenic belts, then large igneous provinces and finally basins) where more details are provided. Chapters 3 through 8 provide in-depth coverage of the North China and Tarim cratons (#3); Yangtze Craton, Cathaysia and South China Block (#4); orogenic belts in southern, central and north-eastern China (# 5); orogens in the west and northwest (# 6); large igneous provinces (#7); and Chinese volcanic-sedimentary and sedimentary basins. After a brief abstract, each chapter devotes some 20-30% of space to geology that is heavy on geodynamics like timed plate motions, collisions, extensions, sedimentation and magmatism, whereas the rest deals with "mineral systems" and metallogenesis. A mineral system is a regional entity characterized by a prominent association of ore metals (e.g. REE-Nb-Fe), style/type (e.g. porphyry Cu-Mo) in the framework of an association of genetically related rocks and structures, with a shared history of geo-dynamic evolution.

In writing the book Franco Pirajno, a geoscientist "sans frontieres", relied on his considerable insider knowledge gained during prolonged stays at Chinese universities and research institutions as well as at numerous field trips and field-initiated cooperative projects that have resulted in a number of published papers to-date. This book is a meticulous compilation of published works of mostly Chinese researchers, critically selected and reviewed by Pirajno in a style prevalent in the contemporary western writing. Even so it is not an easy reading: crammed with references and unfamiliar names it has had to deal with myriads of conflicting ideas resulting from a science in flux and from blending of some traditional Chinese geoscientific beliefs with modern concepts prevalent here. The Chinese geodynamic history is more complex compared with, for example, the western margin of the Americas shaped by the

monodirectional subduction and accretion at least since the end of the Precambrian. China has been throughout its history at the intersection of the N-S and E-W trends subjected to alternating compression and extension, especially within the old cratonic blocks. This greatly influenced the metallogeny where some popular genetic stereotypes, like porphyry deposits related to subduction, do not work well. China is the home of unique metallogenic anomalies like the enormous overlapping local accumulations of Sn, W, (Bi, Be, Mo) and Sb, (Hg) in south-eastern China; metalliferous "shales"; and the enigmatic REE (and Fe, Nb) super-giant Bayan Obo in Inner Mongolia. Unfortunately, the scope of the book and perhaps restriction of length prevented more detailed description of several key and unique super-giant deposits like Shizhouyuan W-Sn-Be-Bi, Xikuangshan-Sb, Woxi Sb-W>Au, although some others (Bayan Obo, Jiaodong) have received adequate coverage.

The book is well produced and there are a number of colour graphs. I was not specifically on the lookout for errors that would be hard to spot and, in many cases, would be the result of conflicting interpretations. On page 8, however, in reference to Chinese language, Mao Zedong is the pinyin transcription of the Chairman's name that, in Wade-Giles style, is Mao Tse-Tung, not the other way round. This is an excellent and much needed reference book that deserves place on library shelves and/or in electronic information systems.

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Note: Please see IUGS website for more detailed list of meetings.

- Signifies the first announcement of the meeting in Episodes or an amended entry.

2013

March

7 March 2013
Canadian Society of Exploration Geophysicists Symposium. Calgary, Alberta, Canada. Website: http://www.cseg.ca/symposium/

10-15 March 2013
AGU Chapman Conference on Fundamental Properties and Processes of Magnetotails, Reykjavik, Iceland Website: http://www.agu.org/meetings/chapman/2012/gcall/

14-16 March 2013
ICLR13 - International Conference on Landslide Risk. Tabarka-Ain, Drahem, Tunisia Contact: iclr2013@gmail.com

18-20 March 2013
GSA 48th Northeastern Section Meeting. Bretton Woods, New Hampshire, USA. Website: http://www.geosociety.org/Sections/ne/2013mtg/

April

1 - 4 April 2013
- Geosynthetics 2013: geosyntheticss for water and energy challgenges. Long Beach, California, USA. For details: Website: http://geosynthetics 2013.com/

4 - 5 April 2013
- GSA 47th South-Central Section meeting. Austin, Texas, USA. Website: http://www.geosociety.org/Sections/sc/2013mtg/

7 - 12 April 2013
- European Geosciences Union General Assembly. Special Session: Geodiversity and geoheritage in geoscience research (session SSS6.3/GM1.5). Vienna, Austria. Convener: Emmanuel Reynard. Co-Conveners: Han-neke van den Ancker, José Brilha, Erik Cammeraat. Details: http://www.egu2013.eu/

8 - 12 April 2013
- AGU Chapman Conference on the Causes and Consequences of the Extended Solar Minimum between Solar cycles 23 and 24 (4CESM). Key Largo, Florida, USA. Website: http://chapman.agu.org/solarminimum/

22 - 26 April 2013
- 35th International Symposium on Remote Sensing of Environment (ISRSE). Beijing, China. Website: http://www.isrse35.org

23 - 27 April 2013
- 8th International Congress on Climatic Change, Territorial Classification and Socio-Ecnomomic Crisis. Tiruchirappalli, Tamil Nadu, India. Website: http://www.icclimatechange.com

24 - 27 April 2013
- The 14th SCOPE General Assembly, Prague, Czech Republic. Hosted by the Czech Academy of Sciences and the Czech Republic Committee of the Scientific Committee on Problems of the Environment (SCOPE). *Website*: http://www.scopenvironment.org

29 April - 4 May 2013
- Seismic hazards and risk mitigation in Africa. Sponsored by UNESCO-SIDA IGCP 601 Project, and organized by IPRED-UNESCO (International Platform for Reducing Earthquake Disaster), Cairo, Egypt. May 2013 Link between rift, tectonism and intracontinental volcanism, Saxony, Germany. Contact: Joerg.Buechner@senckenberg.de

16-19 April 2013
- AQUACONSOIL 2013 – THE 12TH INTERNATIONAL UFZ-DELTARES CONFERENCE ON GROUNDWATER-SOIL-SYSTEMS AND WATER RESOURCE MANAGEMENT. Barcelona, Spain. Note that the submission of abstracts is now open. Go to http://www.aquaconsoil.org (and click on the Registration and Submission section or use this link: https://conference.ufz.de/frontend/index.php?sub=55). The deadline for abstract submission is June 30th, 2012.

28 April – 2 May 2 2013
THE 2013 NGWA SUMMIT - The National and International Conference on Groundwater. San Antonio, Texas, USA. The USA National Ground Water Association (NGWA) call for session proposals for the Summit is now open - proposals must be submitted online and are due by 31 July 2012. See the website at: http://groundwatersummit.org/

May

2 - 3 May 2013
- GSA 47th North-Central Section Meeting. Kalamazoo, Michigan, USA. Website: http://www.geosociety.org/Sections/nc/2013mtg/

15 - 17 May 2013
- 2nd EnvironmentAsia International Conference. Si Racha, Chonburi, Thailand. *Website*: http://www.tshe.org/EnvironmentAsia2013

15 - 17 May 2013
- GSA 65th Rocky Mountain Section Meeting. Gunnison, Colorado, USA. *Website*: http://www.geosociety.org/Sections/rm/2013mtg/

22 - 24 May 2013
- River Basin Management 2013. New Forest, United Kingdom. Website: http://www.wessex.ac.uk/13-conferences/river-basin-management-2013.html

22 - 24 May 2013
- GAC-MAC 2013 - Geological Association of Canada - Mineralogical Association of Canada Annual Meeting, Winnipeg Convention Centre, Winnipeg, Manitoba, Canada. *Website*: http://gacmacwinnipeg 2013.ca/ *Website*: http://www.wessex.ac.uk/13-conferences/sustainable-development-and-planning-2013.html

June

3-7 June 2013
- CoDaWork 2013. The Fifth International Workshop on Compositional Data Analysis. Vorau, Austria. CoDaWork 2013 offers a forum of discussion for people concerned with the statistical treatment and modelling of compositional data or other constrained data sets, and the interpretation of models or applications involving them. See the website at http://www.codawork2013.com/. For details of other forthcoming courses see http://www.compositionaldata.com//pages/activities/congresses.php

3 - 7 June 2013
- European Geothermal Congress. Pisa (Tuscany), Italy. *Website*: www. geothermal congress2013.eu

8 - 13 June 2013
- AGU Chapman Conference on Communicating Climate Science: A historic look to the future. Snow Mountain Ranch, Grandby, Colorado, USA. Website: http://chapman.agu.org/climatescience/

16-22 June 2013
- SGEM2013 - 13th International Multidisciplinary Scientific GeoConference and Expo. Albena Resort and SPA, Bulgaria. For full details on the SGEM2013 (Surveying Geology and Mining Ecology Management) GeoConference see the website at Website: http:/www.sgem.org

17 - 19 June 2013
- Roof of the World. Joint Geological Society of America and Geological Society of China. Chengdu, Sichuan Province, China *Website*: http://www. geosociety.org/meetings/2013china/

17 - 21 June 2013
- Science and Technology 2013 Conference for the Comprehensive Nuclear-Test-Ban Treaty focuses on three themes: (1) The Earth as a Complex System, (2) Events and their Characterisation, and (3) Advances in Sensors, Networks and Processing. Vienna, Austria. *Website*: http://www.ctbto.org/specials/snt2013/

19 - 20 June 2013
- International Conference "Four Decades of Progress in Monitoring and Modeling of Processes in the Soil-Plant-Atmosphere (SPA) System: Applications and Challenges". Naples, Italy. *Website*: www.spa-conference-naples2013.org

23 - 26 June 2013
- Rapid Excavation and Tunneling Conference

(RETC), Washington, DC, USA *Website*: http:// www.retc.org/

24 - 28 June 2013
- AOGS 2013. 10th Annual Meeting of the Asia Oceania Geosciences Society. Brisbane, Australia. Details: http://www.asiaoceania.org

July

1 - 7 July 2013
- 1st international Congress on Stratigraphy - STRATI2013. Lisbon, Portugal. Details: http://www.strati2013.org

3 - 5 July 2013
- GeoForum 2013: Mineralization and Geosciences in Africa. Johannesburg, South Africa. Website: http://www.gssa.org.za/event/geoforum-2013/

6 - 7 July 2013
- 2nd International Conference on Geological and Environmental Sciences (ICGES 2013). Hong Kong, China. *Website*: http://www.icges.org/

20 - 24 July 2013
- IAVCEI General Assembly - 2013: Forecasting Volcanic Activity: reading and translating the messages of nature for society. Kagoshima, Japan. Website: http://iahs-iapso-iaspei2013. com/index.asp

22 - 26 July 2013
- IAHS-IAPSO-IASPEI Joint Assembly: Knowledge for the Future. Goteborg, Sweden. Website: http://iahs-iapso-iaspei 2013.com/index.asp

22 - 28 July 2013
- INHIGEO Symposium 38. Manchester, England. Website: http://www.meeting.co.uk/conference/ichst2013

7TH INTERNATIONAL EARTH SCIENCE OLYMPIAD – 2013, INDIA. The International Earth Science Olympiad is a competition held annually for secondary school students. Each country can send a team comprising four students (maximum) and two mentors (maximum). Further details from Dr R. Shankar (Email: ineso555@gmail.com)

August

18 - 21 August 2013
- Canadian Quaternary Association Biennial Meeting in collaboration with the Canadian Geomorphology Research Group. University of Alberta, Edmonton, Alberta, Canada. Details: http://www.canqua.com/

16 - 20 September 2013
- Geological heritage and geoconservation at the north western edge of Europe. ProGEO Working group for Northern Europe. 2013 Meeting in New-castle upon Tyne, UK. Contact: Lesley Dunlop, les-ley.dunlop @northumbria.ac.uk

27 - 30 October 2013
- GSA Annual Meeting and Exposition. Denver, Colorado, USA. *Website*: http://www.geosociety.org/meetings/2013/

9 - 13 December 2013
- AGU Annual Fall Meeting. San Francisco, California, USA

27-31 August 2013
- THE 8TH IAG/AIG INTERNATIONAL CONFERENCE ON GEOMORPHOLOGY. Paris. Theme "Geomorphology and Sustainability". The official opening of registration and abstract submission has commenced from 1 June 2012. Details at: http://www.geomorphology-iag-paris2013.com/

November

25 - 27 November 2013
- GEO-SUR 2013: International Symposium on Geology and Geophysics of the Southern Hemisphere. Universidad Andrés Bello, Vina del Mar, Chile. Email: geosur2013@unab.cl; Website: http://www.geosur.org

2014

23 - 28 February 2014
- Ocean Sciences Meeting. Honolulu, Hawaii, USA. Website: http://sites.agu.org/meetings/

19 - 21 March 2014
- Global land project international conference 2014. Berlin, Germany Website: www.globallandproject.org

11 - 16 May 2014
- 5th Edition of the International Congress on Arsenic in the Environment will be held in Buenos Aires, Argentina. Website: http://www.as2014.com.ar

2-6 June 2014
- WORLD LANDSLIDE FORUM III. China National Convention Center, Beijing. Theme: "Landslide Risk Mitigation towards a Safer Geo-Environment". Conference website: http://icl.iplhq.org/HomePage.aspx?TabID=4945&Site=Portal&Lang=en-US

20 - 25 July 2014
- International Symposium on metal-hydrogen systems. Salford, Greater Manchester, United Kingdom. Website: http://www.salford.ac.uk/home-page/events/events/international-symposium-on-metal-hydrogen-systems

1-5 September 2014
- 21st GENERAL MEETING OF THE INTERNATIONAL MINERALOGICAL ASSOCIATION. Sandton Convention Centre, Johannesburg, South Africa. See the website at: http://www.ima2014.co.za/

15 - 18 September 2014
- IAEG XII (International Association of Engineering Geology and the Environment) Congress. Torino, Italy. Website: http://www.iaeg2014.com/