Workshop on:
Continuity of DCO databases, instrumentation, research consortia, and resources beyond 2020
19-20 April 2017.
Department of Earth Sciences, University of Florence, Florence, Italy.

1. Introduction

The workshop was focused on planning for the continuity of DCO legacies, including datasets and databases, sample repositories, software, instrumentation. Specific tasks were to:

(1) assess the current state of the legacies,
(2) clarify the crucial science drivers justifying the continuation of these legacies,
(3) identify mechanisms and funding sources for continuing the legacies,
(4) begin scoping proposal activities to support these continuation efforts beyond 2020.

Four sessions were held around different themes. Each session started by a series of talks by invited speakers and was followed by thematic group discussions/brainstorming. Final plenary sessions were devoted to sharing outcomes and to identifying crossover sources of support. 33 scientists from 7 different countries were in attendance.

2. Databases and Sample Repositories

Presentations
Peter Fox (RPI, USA). Data Science, Data Bases, Data Journals and Data Mining.
Carlo Cardellini (Univ. Perugia, Italy). Volcano databases.
Mitch Sogin (MBL, USA). VAMPS database (Visualization and Analysis of Microbial Population Structures).
Liz Cottrell (Smithsonian Inst., USA). Sample repositories and sample curation.

Key Findings

- Data and sample curation requirements vary enormously from country to country.
- DCO is positioned to have its data discoverable, managed and curated after 2019 if DCO scientists prepare.
- Curation cultures vary enormously. A DCO requirement to curate data and samples was hotly debated.
- Sample curation is hugely beneficial and often essential to many different types of research. Resources for sample registration and curation are available.
- DCO data that is curated in a database with web services will automatically be discoverable though commercial search engines, such as Google.
- If we prepare now, DCO's data legacy, in terms of discoverability, visualization, and analysis, will be secure without a long-term funding plan specific to DCO (obviously each database needs a long-term plan for sustainability).

- Existing databases with long-term stability must develop web services within the next year to ensure data discoverability and analysis during DCO's synthesis phase and beyond.
- Existing databases without long-term stability, but which host critical DCO data, must be identified. Orphaned databases must either (a) find a long-term home (b) have some or all of their data subsumed into existing databases (c) develop long-term stability.
- The VAMPS database is an example of a database that hosts DCO data with web services and a sustainability plan.
- Integrated visualization of multiple databases is achievable (e.g. GEOMAPAPP) and would be hugely beneficial.

3. Instrumentation and Software

Presentations

Ed Young (UCLA, USA). Frontiers in high precision instruments.

Daniele Antonangeli (Univ. Pierre et Marie Curie, France). Overview of high P-T instrumentation and software.

Karyn Rogers (RPI, USA). Experimental devices for the biological community.

Tobias Fisher (Univ. New Mexico, USA). Portable volcano mass spectrometers.

Mark Ghiorso (OFM Research, USA). Thermochemistry and thermodynamics of high-temperature aqueous solutions and silicate melts: MELTS-DEW software and ENKI project.

Key Findings

- DCO instrumentation may be maintained beyond 2019 using traditional funding sources for national facilities but needs some central coordination for their use at international level. With minimal funding sources, periodic workshops for instrumentation and software would be very useful for keeping alive their use among the international community. Previous experience is available.
- Instrumentation in field networks like DECADE or NOVAC need maintenance and repairing. Regional hubs and a coordination office for the extension of the networks would be very useful. The direct involvement of volcanological observatories is crucial. Those can be attracted by the capacities of new instruments to detect and monitor eruption precursors and to improve eruption prediction.
- Development of new instrumentations can attract industrial partners. A way to involve them more could be undertaking analyses for industry and training people from industries. Another way could be designing new advanced devices. A session for new ideas at the upcoming Deep Carbon Gordon conference would be useful.

4. Scientific Consortia and Networks

Presentations

Alessandro Aiuppa (Univ. Palermo, Italy). *DECADE,* an international research network for volcanic carbon outgassing.

Bo Galle (Chalmers Univ., Gothenburg, Sweden). *NOVAC,* an array for measuring volcanic gas emissions and aerosols.

Orlando Vaselli (Univ. Florence, Italy). *VOLAK* collaboration on volcanic degassing and volcanic lakes: a recent research network focussed on volcanic crater lakes that host huge amount of gases at depth (CO2) and may generate lethal limnic eruptions).

Steve Shirey (Carnegie Inst., USA). *DMGC,* the Diamonds and Mantle Geodynamics of Carbon Consortium.

Key Findings

- Long-term systematic observations are needed instead of sporadic measurements.
- Field measurement networks like DECADE and NOVAC cannot survive without support from observatories. The existing World Organization of Volcano Observatories (WOVO) is not appropriate because it is essentially a data management system. Each observatory is local and has its own rules, which hampers participation in an international network with universal guidelines.
- Field networks need operational support and scientific leadership. Both DECADE and NOVAC should continue and expand.
- An effort to integrate Deep Life community with volcano networks would be extremely useful, for example for studying microbiological communities living in the volcanic lakes studied by VOLAK and/or geothermal environments in the MAGA database.
- The DMGC consortium is a good example of how to do interdisciplinary and international research in the future. More coordination is needed for access and exchange diamond samples.

5. Funding and management of scientific organizations

Presentations

Kiyoshi Suyehiro (JAMSTEC, Japan). IODP, multisource international funding.
Ulrich Harms (GFZ, Germany). ICDP, multisource international funding.
Massimo Cocco (INGV, Italy). European Union EPOS, single source multinational funding.
Beth Orcutt (Bigelow, USA). C-DEBI, national single source funding.

6. General conclusions

- A “DCO 2.0” with present structures and goals focused on carbon is neither desirable, achievable, nor fundable. Great reams of DCO data are still uncatalogued and not visible.
- Many databases are lacking the MetaData that would make them useful to scientists from a wide range of disciplines. Filling this gap is an enormous challenge.
- Several research initiatives begun during DCO have enough coherence to continue on their own beyond DCO (although they could also be a part of a new program). Examples are the Diamond and Mantle Geodynamics of Carbon (DMGC) consortium, the Census of Deep Life (within the broader VAMPS program at MBL).

- Funding for integrating databases could come from commercial internet-service companies (e.g. Google, which is already supporting similar initiatives).
- Many aspects of the Deep Life research community are included in the pending phase 3 program of the Center for Dark Energy Biosphere Investigations (C-DEBI), although this program is focused on the marine subsurface (and not the continental subsurface).
- A Deep Volatiles Observatory (DVO) might be better suited to studies of volcanic degassing than a carbon-focussed program.

7. Recommended Actions

- DCO must inventory DCO data (review where DCO data are presently stored vs proposed/planned submission to databases).
- DCO must inventory the status of DCO samples (review sample collection plans and where DCO samples are now, and which repositories may eventually archive the samples).
- DCO should use its influence now to:
  - encourage existing sample repositories and museums to take in DCO collections with willing donors.
  - encourage PI's to deposit their samples in repositories or museum collections.
- DCO must lead by example and promote a change in science culture. DCO must now fund or enforce, before 2019, plans for data and sample curation (e.g. creation of web services for existing databases). Leadership should come down from the Secretariat and up from the PIs.
- The DCO must strive to ensure continuity of data and sample legacies beyond 2019 by contacting relevant data and sample managers to assess current obstacles to maintaining these legacies.
- DCO must promote publication in Data Journals such as Nature Scientific Data.
- The research and community momentum generated through DCO should form the basis of both (1) one or a small number of new large programs focused on different unifying science topics, and (2) offshoot smaller programs that maintain research foci initiated within DCO.
- Possible topics for a new large science program could be some combination of volatiles and planetary evolution, with an eye towards understanding origins of life. Based on prior experiences, such a large program will coalesce from a few investigator-lead initiatives that can be greater than the sum of their parts. DCO can foster this unification by identifying promising investigator-lead initiatives and encouraging cross-synergy.
- A DCO white paper describing future science goals should be the product of the TF2020 following the workshops and survey.

Note: This workshop report has been seen, amended, and vetted by Task Force 2020 Committee Members, but is also out for review by all workshop attendees. The final report, including any further changes, will be included in TF2020's global analysis.

APPENDIX

CONTINUITY WORKSHOP LIST OF PARTICIPANTS

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Workshop on
Global geodynamical models:
linking the large-scale dynamics of our planet to environmental
and biological evolution.
24-26 May 2017.
Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow, Russia.

1. Introduction

The purpose of this workshop was to:

(1) evaluate the needs for upscaling models in the different DCO communities. "Upscaling models" stands for efforts on aspects of the Earth's engine at increasingly larger scales (i.e. working one's way up from an individual arc volcano to a whole arc and then to a whole subduction zone for example).
(2) identify unexplored or poorly explored connections (for example relationships between major biological changes and geological activity).
(3) evaluate requirements for global models of the carbon cycle: what data should be fed into the models, in what form, at which scales in space and time.
(4) promote the use of carbon-related constraints in global geodynamic models (carbon as a marker / tracer of geodynamic processes).
(5) explore ways and structures to promote large-scale modelling efforts in relation to carbon.

The workshop was split in two parts, a first part devoted to recent Russian scientific achievements followed by a programmatic session. It began with a full day of scientific talks and posters by Russian scientists from a wide range of institutes, companies and provinces. The next two days were focussed on current understanding of the Earth's global dynamics, stumbling blocks that impede progress and how to link the large-scale workings of our planet to environmental and biological evolution. These two days were built around four main topics and each topic was associated with a few specific issues. Each speaker was assigned a specific issue and was asked to avoid limiting his/her presentation to a narrow topic or his/her current research interest. Each session was followed by an open discussion and brainstorming session.

Participants were chosen in order to achieve a mix of early-career and senior scientists and a representation of many different countries and scientific disciplines (Appendix). 31 scientists from 9 different countries were in attendance.

The expected outcomes of the workshop were two-fold:
(1) to develop contacts between scientists with overlapping interests and to enhance Russian participation in the international Deep Carbon Science effort.
(2) to promote new international cooperative projects with special attention to:
- sustaining modelling efforts on all aspects of the global carbon cycle,
- enhancing awareness and use of carbon-related constraints in global geodynamical models.

2. Tracing the carbon cycle Tracking the carbon cycle through isotopes and other elements.

Presentations

Nicolas Coltice (Université de Lyon, France). Introduction.

Bernard Marty (Ecole Nationale Supérieure de Géologie, Nancy, France). Tracing mantle carbon heterogeneities with noble gases.

Andrew Steen (University of Tennessee, USA). Controls on the preservation of organic carbon in deep, cold sediments.

Key points

- Carbon isotopes do not provide any long-term radioactive chronometer and must be used in conjunction with unstable isotopic systems.
- Rare gases allow strong constraints on the carbon cycle because they coexist with carbon phases during degassing.
- Rare gas signatures of CO_2 water springs, diamond inclusions or carbon related rocks provide a time-integrated history of mantle/sedimentary physical processes.
- Organic carbon is sensitive to oxygen exposure and mineral surface area. The activity of cells is very slow beneath a shallow superficial layer.
- Exploring how organic carbon degradation has worked through deep time provides constraints on environmental conditions.

3. Time-scales of global models The slow (secular) carbon cycle with a focus on long-term evolution.

Presentations

Raj Dasgupta (Rice University, USA). The Origin and Early Evolution of Carbon on Earth.

Katie Cooper (Washington State University, USA). The deep structure of continental lithosphere.

Erik Galimov (Vernadsky Institute, Russia). Role of the faint luminosity of the Sun in the history of the biosphere.

Yuichiro Ueno (Earth-Life Science Institute, Tokyo, Japan). Reducing early atmosphere and the carbon cycle.

Key points

- The origin of Earth's carbon is a key issue.
- Large amounts of carbon may have been stored in the Earth's core during its formation.
- Carbon flux into the mantle may have been larger in the past, leading to progressive carbon enrichment of the Earth's deep interior.
- The rise of atmospheric oxygen in the late Archean – early Proterozoic may have been due to burial of organic carbon following the onset of efficient subduction.
- Large amounts of carbon may be stored in thick continental lithosphere.
- Formation of thick lithosphere in the Archean predates the appearance of diamond eclogitic inclusions and the onset of kimberlite magmatic activity.
- Internal structure of the lithospheric mantle provides clues of formation mechanisms.

- The geochemistry of organic carbon may have changed in early stages of Earth history, in connection with the activity of the Sun. This may have lead to a transition from abiotic CH_4 to biogenic CH_4 in the Hadean/Archean, followed by a transition from CH_4 to CO_2 at the beginning of the Proterozoic.
- CO could have been the major carbon molecule in the early atmosphere, leading to strong fractionation of carbon isotopes.
- A CO-rich atmosphere may have been responsible for CO bacterial metabolism.

4. Modelling across the scales Carbon transport from small scales to the scale of the Earth.

Presentations

Nicolas Coltice (Université de Lyon, France). Introduction.

Clint Conrad (Centre for Earth Evolution and Dynamics, Oslo, Norway). The deep carbon cycle and mantle-lithosphere dynamics: looking backward from today.

Mark Jellinek (University of British Columbia, Canada). A reverse energy cascade for crustal magma transport and outgassing.

Key points

- Fluctuations of atmospheric CO_2 levels are correlated with sea-level changes.
- Changes of surface temperature and CO_2 in the Phanerozoic are associated with shifts in mantle convection and can be tied to cycles of continental aggregation and dispersal.
- The sedimentary record provides strong constraints on plate reconstructions and mantle dynamics.
- Changes in the composition of the oceans can be linked to global geodynamics and deserve more attention. Their impact on biological evolution could form the basis of new inter-disciplinary studies and experiments.
- There are important feedbacks between tectonics, magmatic activity and the climate.
- The importance of intrusive activity is underestimated in models of volcanic processes.
- The magnitude of fluctuations is an intrinsic property of complex dynamical systems that deserves as much attention as long term progressive changes.

5. Global data and global models global datasets for large-scale models of the carbon cycle.

Presentations

Carolina Lithgow-Bertelloni (University College, London, United Kingdom). Global models and global challenges.

Emil Ruff (University of Calgary, Canada). The Census of Deep Life: Diversity and biogeography of microorganisms in the deep subsurface.

Sabin Zahirovic (EarthByte, University of Sydney, Australia). Linking models and databases in a deep time and deep Earth community framework.

Key points

- Changes in the amount of oceanic sediments and in the carbonate compensation depth through time provide powerful constraints on plate reconstructions in the Earth's past.
- Changes of mineral physical properties as a function of temperature may have led to the temporary isolation of deep mantle reservoirs.
- Different problems require models at different scales, implying that one global model for everything is not an appropriate goal.
- It is crucial, but very difficult, to integrate models that operate over very different timescales.
- Integrated frameworks of numerical dynamical models, digital databases and data exploration tools allow studies of the global Earth through time.
- Plate tectonic reconstructions allow estimates of subducted carbon fluxes in the mantle as well as the evolution of carbonate platforms through time.
- Exploring forms of life in a given environment is possible as long as chemical models of the environment are available.
- A marked divide separates subsurface and surface organisms.
- There is a bacterial population for every environment at temperatures below ≈ 80°C.
- Growth of microbial populations can be regarded as instantaneous on geological time-scales.

6. General conclusions

- Timelines illustrating the relationships between different variables and phenomena are a very efficient way to stimulate models (experiments in biology, physical concepts etc.).
- The relative stability of carbonate $\delta^{13}C$ values over almost the whole age of the Earth is a puzzling and unexplained feature of Earth's evolution. In a constantly changing planet, where life develops and profoundly modifies the surface environment, where plate tectonics was probably not active at all times, such a stable isotopic composition must be telling us a lot about the chemical and physical processes at play.
- The start of subduction is an absolutely key issue. The present-day subduction regime is the most fundamental part of the carbon cycle (carbon coming from arcs through erosion and transport, degassing of the slab and mantle wedge, etc…).
- "Synchronous" changes of the composition of mantle related rocks and environmental conditions at different times suggest a relationship between life and the dynamics of the lithosphere and convecting mantle.
- Using any database entails many caveats. Thus, tutorials and proper metadata are essential to guarantee reliable results and a maximum return on investment.

7. Recommended Actions

- A diamond database with associated metadata must be made available.
- A comprehensive database of mineral properties in extreme (P,T) conditions over a large temperature and compositional range is required for models of Earth's evolving mantle and carbon budget through time.

- Diamond samples are available in a very large age range and document changes of mantle composition and thermodynamic conditions through time. Investigating these constraints on mantle dynamics should be a priority.
- The relationship between carbon, nitrogen and other isotopic ratios could be crucial to unraveling the evolution of carbon in the mantle and lithosphere. This should be investigated and documented systematically.
- Georeferencing and timereferencing data, is crucial to progress.
- Coupling global models operating at different temporal and spatial scales should be attempted (e.g. EarthByte, University of Sydney).
- A thermodynamics database for bio-chemical reactions is needed to investigate the co-evolution of life and geological conditions.
- Changes in the composition of oceans due to geodynamical processes and their impact on biological evolution could form the basis of a new inter-disciplinary research program.
- Metadata for natural bacterial populations (temperature, composition of co-existing fluids and minerals) must be collected systematically and made available. Gaps in current databases hamper progress in studies of the co-evolution of life and geological conditions. Standardization of formats and contents should be sought.
- Proper attention to the relationship between intrusive and volcanic activity and to the plutonic record is required in models of the subduction process.
- Studies of the sedimentary record provide key information on seawater composition, plate tectonics and climatic conditions in the past and should be encouraged.

Note: This workshop report has been seen, amended, and vetted by Task Force 2020 Committee Members, but is also out for review by all workshop attendees. The final report, including any further changes, will be included in TF2020's global analysis.

APPENDIX

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