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Program roots

In 1995, grants from the Alfred P. Sloan Foundation supported Cornell University physicist Thomas Gold in writing a book based on his path-breaking 1992 PNAS paper, [The Deep Hot Biosphere](#). Gold's 1999 book, [The Deep Hot Biosphere](#), addressed controversial questions, including the possibility that life originated deep in Earth rather than in a warm little pond on its surface or extra-terrestrially, arriving from space on a comet or meteorite. It also argued that a large fraction of Earth's hydrocarbons (natural gas, oil, and coal) had primordial, abiotic origins and accumulated in the crust from upward outgassing rather than forming as "fossil fuels" from the shallow burial of biomass during the Jurassic and other epochs. While the Foundation took no position on Gold's propositions, Sloan President Ralph Gomory (1990-2007), mathematician and former chief of research for IBM, believed that big questions of the kind Gold raised were useful scientific stimulations. Sloan also supported "[Renegade Genius](#)," a documentary on Gold which appeared in 2009, five years after Gold passed away.

In 2007, geologist Robert Hazen (Carnegie Institution of Washington) published the book [Genesis](#), aimed at public understanding of questions associated with the origins of life. The book came to the attention of Sloan program manager Jesse Ausubel, who had handled Sloan's grants with Prof. Gold. Hazen's book calmly weighed evidence for and against several of Gold's propositions, as well as pointing to other major unanswered questions in geosciences, including the ecology and evolution of minerals.

Program initiation

Sloan invited and provided funds to Hazen to organize a May 2008 conference to explore the limits of knowledge (the known, unknown, and unknowable) of deep carbon science, which Hazen did together with his colleague, geophysicist Russell Hemley, then director of Carnegie's Geophysical Laboratory. In the interim, MIT microeconomist Paul Joskow had assumed the presidency of Sloan. Joskow had a keen interest in energy resources and a long-standing relationship with Richard Meserve, President of Carnegie Institution of Washington and former head of the Nuclear Regulatory Commission.

The May 2008 meeting proved very lively. Joskow asked Ausubel to consult experts and stakeholders, and to prepare an internal Strategy Paper for a 10-year international initiative about deep carbon science to be anchored by Sloan, and to convene an expert group to vet the strategy. Among those consulted and immediately enthused were former Sloan Trustee and National Academy of Sciences President Frank Press and also Walter Munk (Scripps Institution of Oceanography), who helped start the international program for drilling in the sea floor during the 1960s.

The process proceeded well and resulted in an invitation in early 2009 from Sloan to Carnegie for a 3-year \$4 million grant to initiate a major program in deep carbon science, spanning biology as well as solid-earth sciences. Hemley suggested the framework of a "Deep Carbon Observatory." The Sloan Trustees approved the grant in June 2009, and the DCO officially came into existence 1 July 2009, with Hazen as lead scientist and Hemley chairing a distinguished international steering committee. Founding members included John Baross (USA), Tara Bryndzia (Australia/US), Claude Jaupart (France), Adrian Jones (UK), Barbara Sherwood Lollar (Canada), Eiji Ohtani (Japan), and Sergei Stishov (Russia). An

administrative secretariat was established at Carnegie. Assuming the DCO proceeded very well, the Sloan Trustees committed to provide about \$5m/yr for ten years, a total of about \$50m.

Early years

Over the next two years, a series of workshops led to emergence of four communities to carry out the work of the Observatory: Deep Life, Deep Energy, Reservoirs and Fluxes, and Extreme Physics and Chemistry. Each community prepared a set of “decadal goals” to achieve by the end of 2019 and agreed to organize the work along the four themes of origins, quantities, movements, and forms. Cross-cutting teams concerned with Data Science and with Engagement (communications and community building) were formed in 2011–2012. Early grant-making focused on instrument development, using both open, competitive calls for proposals and invited proposals. Subsequently the majority of Sloan DCO funding was used to support a global network of graduate students and post-docs.

Much effort went into community building, for example, cultivation of DCO support in Germany, France, Italy, UK, Russia, China, and Japan as well as the USA; development of a website for both internal and external purposes; and “branding” to give DCO a recognizable identity and a family feeling. The program used the major international meetings in geosciences (especially the annual meeting of the American Geophysical Union and the annual Goldschmidt conference in geochemistry) to bring together the growing network of participants in DCO.

Middle years

At the outset of the program, Sloan requested the DCO prepare a report describing the baseline of knowledge about deep carbon which could be used to help measure progress achieved by 2019. The DCO leadership chose to try to create not only a benchmark but a landmark and in 2013 published the 20-chapter, 698-page open access volume [Carbon in Earth](#). Released at an “all-program” meeting of close to 200 people at the US National Academy of Sciences in Washington DC (March 2013), along with a [press release](#) summarizing DCO goals, the volume also served to attract many more scientists to the DCO network, which grew to about 500 by the end of 2013. A [December 2013 press release](#) highlighted early discoveries. The December 2014 [Mid-term Scientific Report](#) by Hemley summarized the first 5 years of the program. Subsequent all-program meetings took place in Munich (April 2015) and Scotland (March 2017)

A question early in the DCO was whether to foster an effort to drill through the crust into the mantle, as strongly advocated by Japanese members. After the spring 2011 Tohoku earthquake, Japan deferred interest in the Mohole. Another early question was involvement of the private sector, especially oil, gas, and mining companies with capacity for deep exploration and samples. Several early attempts to engage the private sector met with only small successes and were not continued after the first 3–4 years.

During 2014 Sloan organized a far-reaching mid-term review by an external group of experts who had no stake in the DCO. While very positive about early DCO scientific output, the mid-term review led to major additions and changes in the program: preparation of an annual progress report, more aggressive tracking of DCO publications and inclusion in the Bibliography on the DCO website, and formation of a new group to take responsibility for synthesis and integration (Synthesis Group 2019), and another to consider life after Sloan (Task Force 2020). The mid-term review also pushed the program to do better

in regard to gender diversity and the under-representations of minorities, and to expand its efforts to empower early career scientists.

The mid-term review also stimulated a reorganization of the Executive Committee, and a shift of the Chair of the EC away from the Secretariat at Carnegie to UCLA. Craig Manning (chair, UCLA), Marie Edmonds (Cambridge, leader of Synthesis), and Louise Kellogg (leader of modeling) emerged as leading figures. The Executive Committee of the DCO itself met twice each year in person, with good participation by the senior scientists, and by telephone about every 6 weeks, with participation mainly by administrative personnel. Dr. Connie Bertka served as the founding full-time administrative director of the DCO at Carnegie and was succeeded in 2013 by Dr. Craig Schiffries, supported by a staff of 3 FTEs.

Later years

The 2014 structure remained stable with the addition of one more cross-cutting team, concerned with modeling and simulation of the totality of deep carbon flows from the mantle through the crust and including deep life. The Synthesis Group and much of the strategic management of the DCO was handled by the Engagement team at the U. of Rhode Island (Sara Hickox and later Darlene Crist). The Rhode Island team skillfully organized an October 2015 workshop that formulated most of the synthesis activities of the DCO. The active membership of the DCO network reached a total of about 1200 scientists from about 50 nations in 2019. In the later years the substantial flow of DCO peer-reviewed publications included numerous papers in *Science*, *Nature*, and other prestigious outlets. Health issues caused some leadership shifts, but the program otherwise proceeded in 2018 and 2019 as planned and foreseen. A 50-page decadal report, press release, three books, special issues of journals and hundreds of other articles as well as videos and blogs summarize the work of the program.

Sloan processes and expenditure

Environmental scientist Jesse Ausubel operated the program for Sloan, as a program director through 2011 and afterwards as a science advisor to Sloan. Sloan program director and chemist Paula Olsiewski joined Ausubel in managing the program in 2014. Sloan operated review processes for all proposals over \$125,000, typically engaging 7–8 reviews to which PIs responded in an iterative process that led to many influential decisions about program direction. Approximately half the reviews were conducted by members of a small Advisory Committee for the DCO for Sloan and about half were *ad hoc* by individuals with relevant expertise.

Each year the Sloan program managers prepared a prospective “Strategic Update” for the Sloan president and trustees, as well as retrospective Program Report. For each request above \$125,000 the program managers prepared a 1-page summary of the activities proposed. Sloan provided a grand total of about \$57 million in about 80 grants; about 50 were “Trustee” grants averaging about \$1 million vetted with extensive peer review and about 30 were “Officer” grants averaging about \$100,000 vetted mainly with internal (staff) review. Although the Secretariat was asked to track matching and leveraged funds, the actual amounts are difficult to ascertain because of different forms of funding in different nations, inflated statements aimed to impress Sloan, and other reasons, a cautious estimate is that \$200-\$250 m in funds from sources other than Sloan were spent in the DCO program between 2009 and the culminating events in October 2019.