The Colorado Plateau Coring Project as a "Source-to-Sink-to-Source" Venue for Integrated Study of Geogenic Contaminants, Remediation, and Resources

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Poster

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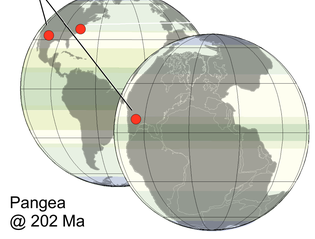
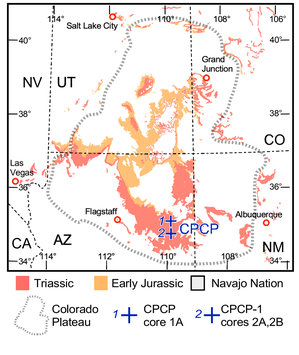
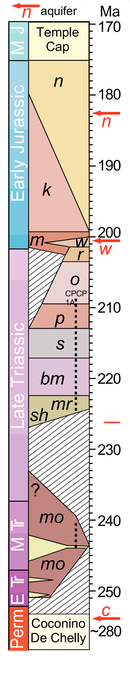
Abstract: The Colorado Plateau Coring Project (CPCP) seeks to recover a 100-million-year record of the early Mesozoic history of the Colorado Plateau and its environs. In addition to exploring the origin of cyclicity in large parts of the section via an exportable, U-Pb-calibrated paleomagnetic timescale and other goals, a major part of the CPCP is an integrated, multidisciplinary Earth system study of the paleoenvironmental origins, sequestration, and release of geogenic contaminants—such as uranium, arsenic, lithium, salts, and hydrocarbons—into the water supply. This includes: (1) the climatic, biological, and tectonic paleoenvironmental contexts that set the stage for the initial concentration of these substances and the development of the physical and chemical properties of the host rocks (i.e., source); (2) the diagenetic concentration of these potential contaminants and their movement, mediated over hundreds of millions of years of deep biosphere modification, in which both in situ and migrated carbon sources play key roles (i.e., sink); (3) the present microbial communities and how they interact with the corehole environment, adapting to and modifying the release of geogenic contaminants into the water column (i.e., source again); and (4) how these contaminants can be efficiently removed at low cost (i.e., remediation). CPCP-1 (2013–2016), which was proof of concept, recovered three cores from two sites spanning nearly the complete Neogene and Triassic stratigraphy at Petrified Forest National Park, AZ, revealing a geogenic contaminant stratigraphy for the Chinle and Moenkopi Formations registered to a detailed U-Pb-calibrated paleomagnetic and environmental stratigraphy. We propose an additional four cores at three sites in Arizona and Utah (totaling ~3 km), spanning nearly the entire Triassic and Early Jurassic stratigraphic column, and implementation of the source-to-sink-to-source Earth system approach, including their use as testbed observatory wells for two Direct Contact Membrane Distillation systems exploring purification efficacy and potential resources for local stakeholders. Our goal is to develop a comprehensive and predictive understanding of the origin and remediation of these contaminant systems. We thank the Heising-Simons Foundation for support and the Navajo Nation for access to outcrops.

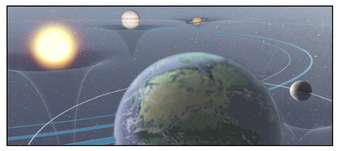






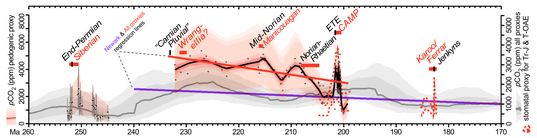
Source

The climatic, biological, and tectonic paleoenvironmental contexts that set the stage for the initial concentration of these substances and the development of the physical and chemical properties of the host rocks.

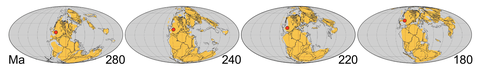


Solar luminosity and celestial mechanical cycles determine insolation, setting most of the baseline for the energy budget of the environment.

Radiative balance

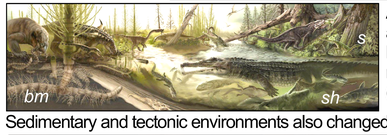


The radiative balance was modulated by a downward trend in the pCO_2 during the early Mesozoic punctuated by volcanic pulses, each of which may have been associated with volcanic winters (1-8).



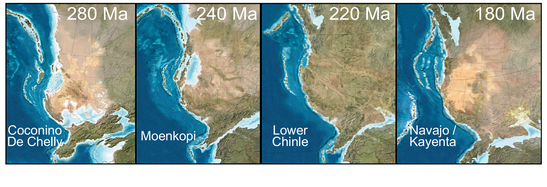
From (9,10)

At any given place, the Earth system translated the result of this modulation into climate — via latitude and a multitude of secondary forcings and feedbacks. Changing climatic context and rare mass extinctions resulted in major biotic changes through time, modulating material fluxes into and out of the "critical zone" and the sedimentary system.



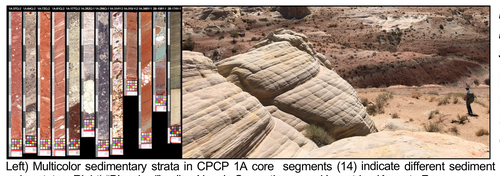
Above, dry Kayenta and Navajo, and left, lower Chinle terrestrial communities (from 11-12).

Sedimentary and tectonic environments also changed though time (from 13).



Sink

The diagenetic concentration of potential contaminants and their movement, mediated over hundreds of millions of years of deep biosphere modification, in which both primary (*in situ*) and migrated carbon sources play key roles.

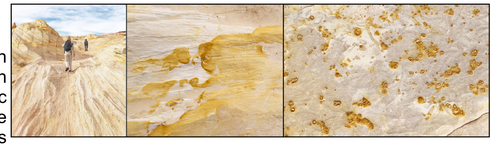


Left) Multicolor sedimentary strata in CPCP 1A core segments (14) indicate different sediment redox states. Right) "Bleached" eolian Navajo Ss, resting on red lacustrine Kayenta Fm.

Deposition and Modification in sediments

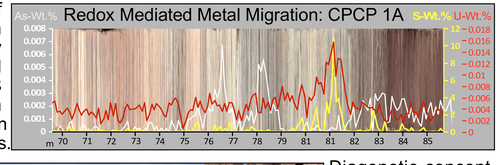
Microbial metabolisms mediate key steps of the sink diagenetic process: microbes generate reductants and ligands (Fe(II), sulfide, organic metabolites), carry out redox transformations of contaminants such as arsenic and uranium, and modify sorption and complexation environments for more conservative ions such as lithium, thereby maintaining geochemical conditions that govern whether these elements remain mobile or become immobilized in the solid phase.

Carbon source migration



"Bleached" eolian Navajo Ss (right) with no indigenous organic matter contain pyrite nodules and fronts from sulfur-reducing bacterial consortia. Migrated hydrocarbons (15) and/or CO_2 (16) were a carbon source with dissolved sulfate providing sulfur, resulting in an arsenic and uranium concentration environment, neither of which were sourced from the depositional environment. These nodules are As and U geogenic contaminant in the Navajo aquifer.

Large-scale mottling in the Navajo Ss and younger units via a similar mechanism involving a migrated carbon source (e.g., 15).



Black Forest Bed of Chinle Fm with diagenetically concentrated As and U (CPCP 1A). S peak is in pyrite from sulfate reduction in fossil plant-rich zones.

Diagenetic concentration can result in U ores, unremediated mines of which can contaminate aquifers. The context for all of these processes is in the depositional (source) environment.

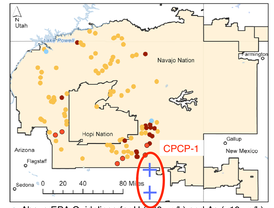
Source

The present microbial communities and how their interactions with the well / corehole environment, adapting to and modifying the release of geogenic contaminants into the water column (i.e., source again); and how these contaminants can be efficiently removed at low cost and useful scale (i.e., remediation).

Introduction of a interconnecting water column

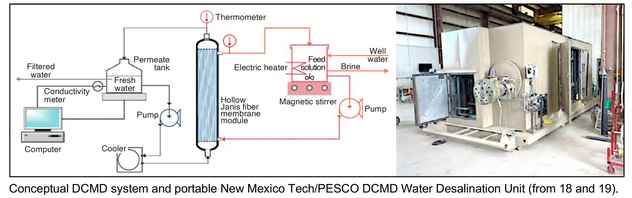
A well bore is a conduit and a new microbial habitat, fundamentally reshaping the adjacent ecosystems and chemical environments by introducing new environmental pressures, opportunities for colonization, changing redox conditions, and radically different material flow properties.

CPCP-1 Coring at Petrified Forest National Park 2013.



As and U in wells on the Navajo Nation with location of CPCP-1 core holes. (Modified from 17)

Like many wells on the Colorado Plateau and environs (left), the proposed CPCP-2 core holes are expected to encounter saline water or water contaminated with arsenic, uranium, or lithium. These core holes will be conduits creating a new, high-energy, microbial habitats that force a cascade of biogeochemical changes in the surrounding environment, worthy of monitoring from its initiation. These sets of novel microbial communities can be expected to mediate the release of geogenic contaminants into the water column and the core holes can be used as observatories for these processes.



Conceptual DCMD system and portable New Mexico Tech/PESCO DCMD Water Desalination Unit (from 18 and 19).

A component of the source to sink to source concept is remediation, one mechanism for which could be experimental use of a direct contact membrane distillation (DCMD) system for saline, contaminated deep aquifer water. Not only can it supply clean water to stakeholders, it can monitor contaminant levels.

Summary: The CPCP investigates ~100 million years of environmental and tectonic evolution on the Colorado Plateau using continuous deep drill cores. One major goal is to determine how geologic and biogeochemical processes controlled the incorporation, redistribution, and mobilization of naturally occurring uranium, arsenic, lithium, salts, and hydrocarbons into modern groundwater systems within a source to sink to source framework. Phase I (2013–2016) coring at Petrified Forest National Park, AZ, established a stratigraphy of contaminant occurrence and host lithologies for part of the section. The next phase proposes to recover four additional cores at three sites in Arizona and Utah, completing boreholes as experimental wells to test groundwater treatment approaches and improve prediction and mitigation of geogenic contamination over a much larger stratigraphic scope.

References