PROTEAN GEOSCIENCE

Are critical zone observatories materially advancing regolith science?

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Australian Regolith Geoscientists Association Conference
Wallaroo 9 – 11 April 2018

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We need to talk about Kevin

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What is the 'critical zone'?

- The Critical Zone (CZ) is a term coined in 2001 by the National Research Council (NRC) in a report commissioned by the National Science Foundation (NSF) on 'Basic Research Opportunities in the Earth Sciences' (NRC 2001)

The NRC definition

- The Critical Zone is "the heterogeneous, near-surface environment in which complex interactions involving rock, soil, water, air, and living organisms regulate the natural habitat and determine the availability of life-sustaining resources"

NRC 2001

Sound familiar?

What is the ‘critical zone’?

- “Regolith is the surface blanket of material including weathered rock, sediments, soils and biota that forms by the natural processes of weathering , erosion, transportation, and deposition. It has a complex architecture, and may vary in thickness from a few centimetres to hundreds of metres. It hosts or hides valuable mineral deposits, we live on it, we grow our food in it, it is the foundation of many major engineering works, and much of our water supplies are stored in it. It underpins our economic, social and infrastructure systems.”

Eggleton 2001

NRC objective

- The Critical Zone was proposed by the NRC as an umbrella concept that would focus attention on "a wide spectrum of interconnected problems that bear directly on societal interests"

- Five CZ research priority areas identified

NRC CZ research priorities

1. Better understanding of the terrestrial carbon cycle *and its relationship to global climate change, including the temporal and spatial variability of carbon sources and sinks and the influence of weathering reactions*

NRC CZ research priorities

1. The terrestrial carbon cycle
2. Quantification of microbial interactions in mineral weathering, *soil formation, the accumulation of natural resources, and the mobilization of nutrients and toxins*

NRC CZ research priorities

1. The terrestrial carbon cycle
2. Quantification of microbial interactions in mineral weathering
3. Better understanding of the dynamics of the land-ocean interface, *which governs how coastal ocean processes such as tides, waves, and currents interact with river drainage, groundwater flow, and sediment flux*

NRC CZ research priorities

1. The terrestrial carbon cycle
2. Microbial interactions in mineral weathering
3. The dynamics of the land-ocean interface
4. Better understanding of the coupling of the tectonic and atmospheric processes *through volcanism, precipitation, fluvial processes, glacier development, and erosion, which regulate surface topography and influence climate on geological time scales*

NRC CZ research priorities

1. The terrestrial carbon cycle
2. Microbial interactions in mineral weathering
3. The dynamics of the land-ocean interface
4. Coupling of the tectonic and atmospheric processes
5. Understanding the formation of a geological record that encodes a four-billion-year history of Critical Zone processes, *including environmental variations caused by major volcanic episodes, meteorite impacts, and other extreme events*

NRC CZ research priorities

1. The terrestrial carbon cycle
2. Microbial interactions in mineral weathering
3. The dynamics of the land-ocean interface
4. Coupling of the tectonic and atmospheric processes
5. The formation of a geological record that encodes a four-billion-year history of Critical Zone processes.

NRC concerns

- The NRC recognised that if study of the CZ was to progress then collaboration would need to be encouraged between scientists practising in a number of related disciplines (e.g. hydrology, geomorphology, biology, ecology, soil science, sedimentology, materials research, and geochemistry).

NRC solution

- The NRC suggested that the NSF could encourage problem-focused, multidisciplinary field work into the Critical Zone by funding the establishment of "natural laboratories" in which detailed, long-term observations could be made using a variety of disciplinary tools.

NSF funding

- 2007 - $US14.6M (~ $AUS19M) for three Critical Zone Observatories (Shale Hills, Boulder, Southern Sierra)
- 2009 - $US13 M (~$AUS17.1M) for a further three CZOs (Luquillo, Christina River, Catalina - Jemez)
- 2013 - $US4.7M (~$AUS 6.2M) for another 4 CZOs (IML, Calhoun, Eel, Reynolds)
- 2014 - $US .4M (~ $AUS .5M) for a CZO National Office
- 2014 – $US .7M (~$AUS .9M) for a CZO Science Across Virtual Institutes (SAVI)

Source: www.grantome.com

NSF funding

- Total of $US 62M (~$AUS 81M) allocated to CZ research by the NSF between 2007 and 2017
- 84 separate grants
- 25 institutions
- ~130 personnel

Source: www.grantome.com

Compare CRC LEME (2)

- Total of ~$AUS 20M allocated by the CRC Secretariat between 2001 and 2008
- 1 grant
- 8 institutions
- 135 staff members

Source: CRCLEME Annual Report 2008

NSF funding: outputs to 2016

- 9 CZOs
- 133 published papers
- 120 graduate students

Compare CRC LEME (2)

- 206 published papers
- 175 graduate students

What are CZ Observatories?

- CZOs are "time telescopes that allow focus, not only on the processes and fluxes operating today, but to compare these to the record of the processes in the rock and soil and sediment record – then to use quantitative models parameterized from these observations across scales of space and time to project the future using various scenarios of human behavior."

NRC 2001

CZOs in the USA in 2017

Are CZOs catching on?

- 2009 - 4 Terrestrial Environmental Observatories (TERENO) established in Germany *(http://teodoor.icg.kfa-juelich.de/overview-en)*
- 2009 - 4 Soil Transformation in European Catchments (SoilTrEC) sites established by EU in Switzerland, Austria, Greece, and Czech Republic *(http://www.soiltrec.eu/index.html)*
- 2015 - 7 CZOs established in China, 5 co-funded by a Sino-UK joint program (Guo and Lin, 2016)
- 2016 - total 69 CZO-like sites registered worldwide (Guo and Lin, 2016)

Are CZOs catching on?

Registered CZOs in red, purple and orange and CZO-like sites in blue.

Source: Guo and Lin, 2016

Are CZOs catching on?

What about Australia?

- 2013 - Pingelly CZO established by UWA (Matthias Leopold and Diedre Gleeson) in the Avon River catchment. Part funded by NSF to host an international workshop on CZOs in the southern hemisphere in Perth in 2014
- 2013 – Main Range CZO established by UQ (Talitha Santini, Joshua Larsen, David Doley, Steven Howell)
- Victorian Dry Eucalypt Terrestrial Ecosystem Research Network (TERN) site registered as an international affiliate in the Critical Zone Exploration Network (CZEN)
- All TERN sites shown as unregistered CZOs by CZEN

Australian sites registered with CZEN

All Australian sites shown on CZEN

Are CZOs catching on?

- 2011 - Delaware workshop “Sustaining Earth’s Critical Zone”: only one Australian present (David Rowlings, QUT), no-one else from the southern hemisphere or from Canada
- 2014 - Beijing workshop “Frontiers in International Critical Zone Science”: representatives of science funding agencies from China, France, Germany, UK and USA. No-one from Australia or Canada

CZ research key findings reported in 2018

1. Deep Surface Variability - For the first time, we have obtained observations that reveal how the deep surface of the Critical Zone varies across landscapes.

2. Deep Surface Predictability - New mechanistic models now provide quantitative predictions of the spatial structure of the deep surface relative to the ground surface topography.

3. Earth Surface Energy Propagation - For the first time we have obtained observations that reveal that differences in energy inputs at Earth's surface translate into differences in water, minerals, and biotic activity at depth, and we are starting to detect how these deep properties also impact the biota and climate

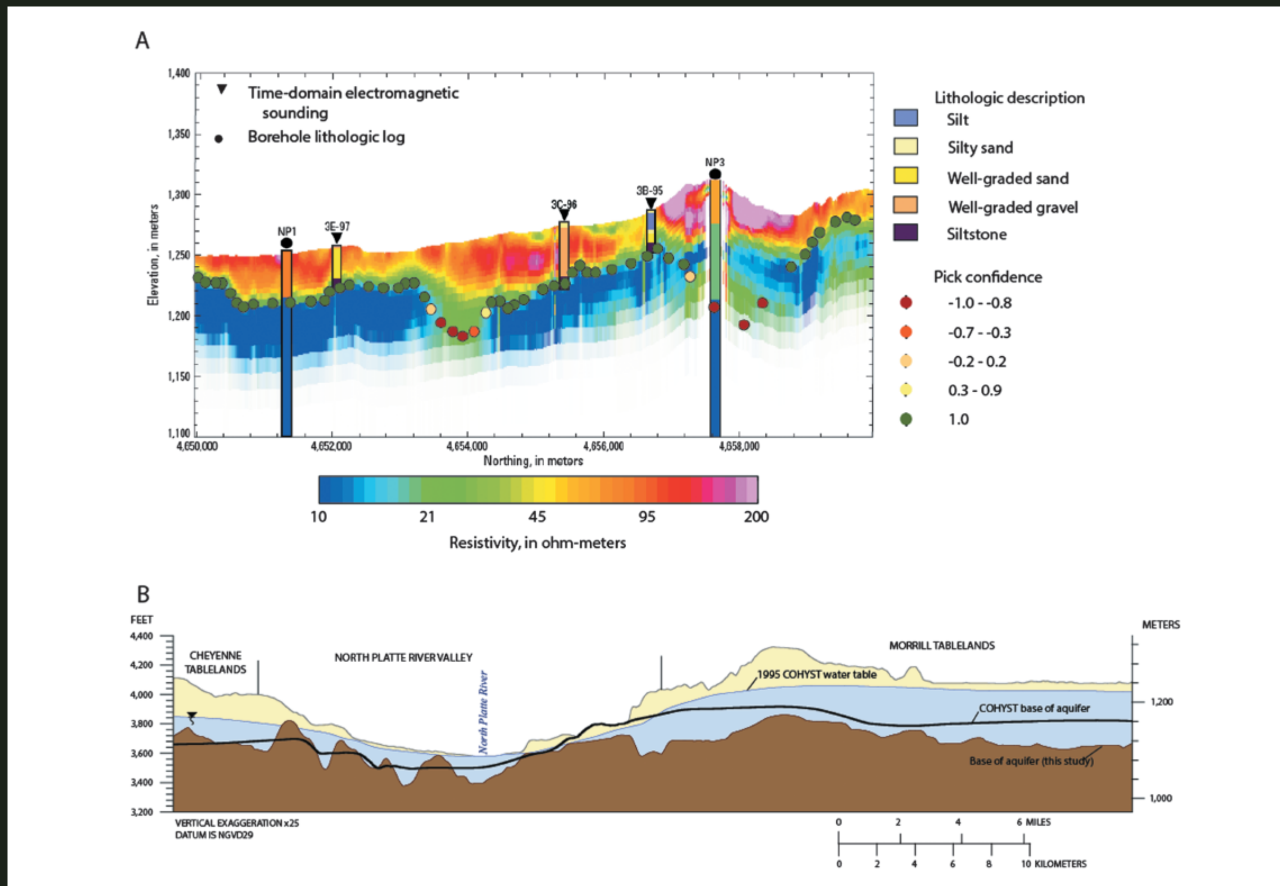
http://criticalzone.org/national/research/key-findings/
Accessed 30/03/18

CZ research key findings

1. Deep Surface Variability - For the first time, we have obtained observations that reveal how the deep surface of the Critical Zone varies across landscapes.

Parsekian, A. D., K. Singha, B. J. Minsley, W. S. Holbrook, and L. Slater (2015), Multiscale geophysical imaging of the critical zone, *Rev Geophys*, **53**, 1–26.

CZ research key findings



A. Resistivity section from a HEM survey showing lithologic data from nearby wells

B. Interpreted cross section comparing data used by the hydrologic model (black line) and current data (brown shaded zone). Improvement demonstrated by the increased level of detail. Source: Parsekian et al., 2015

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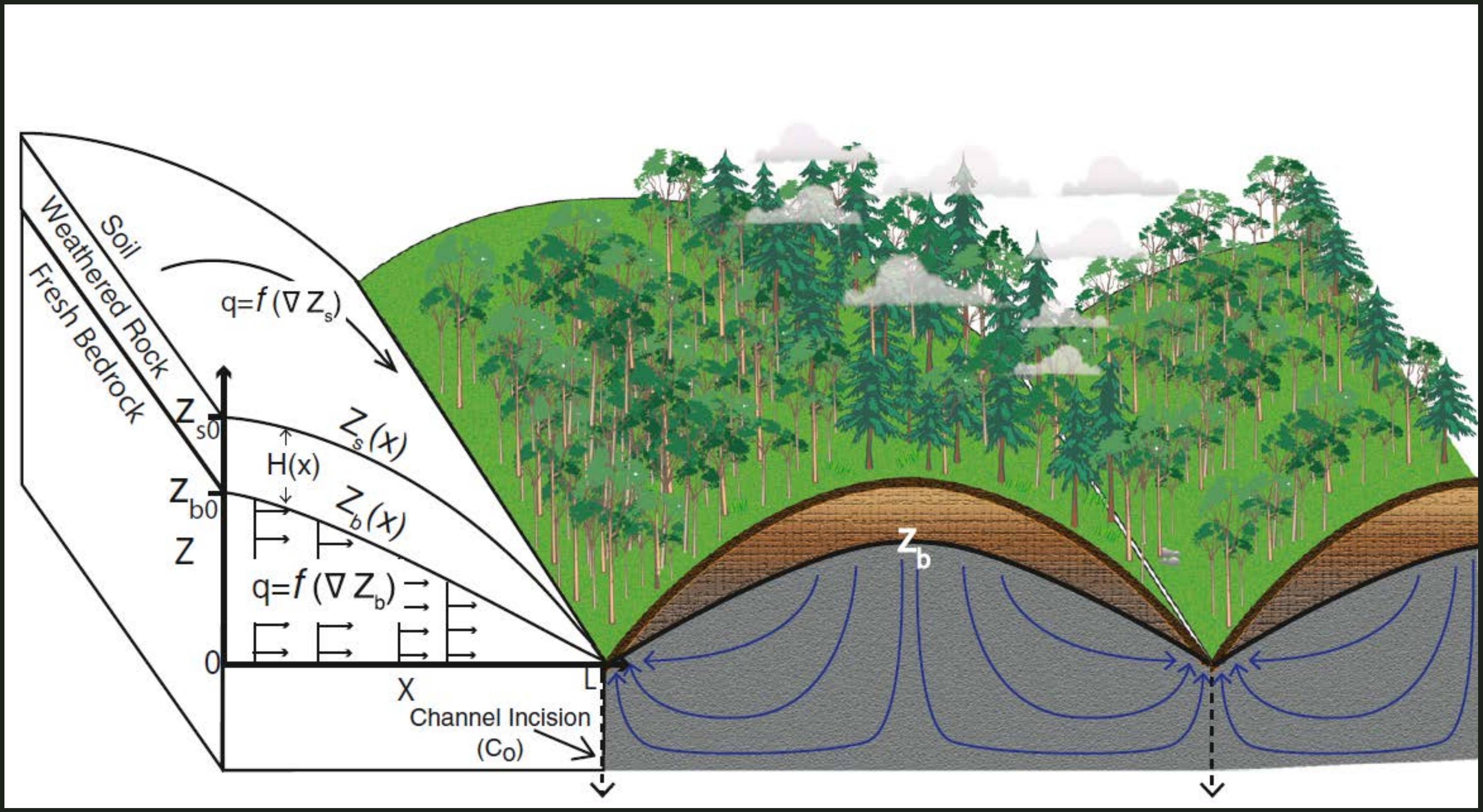
CZ research key findings

2. Deep Surface Predictability - New mechanistic models now provide quantitative predictions of the spatial structure of the deep surface relative to the ground surface topography.

Rempe, D. and Dietrich, W.E. (2014): A bottom-up control on fresh-bedrock topography under landscapes. *PNAS* **111**(18): 6576-6581

CZ research key findings



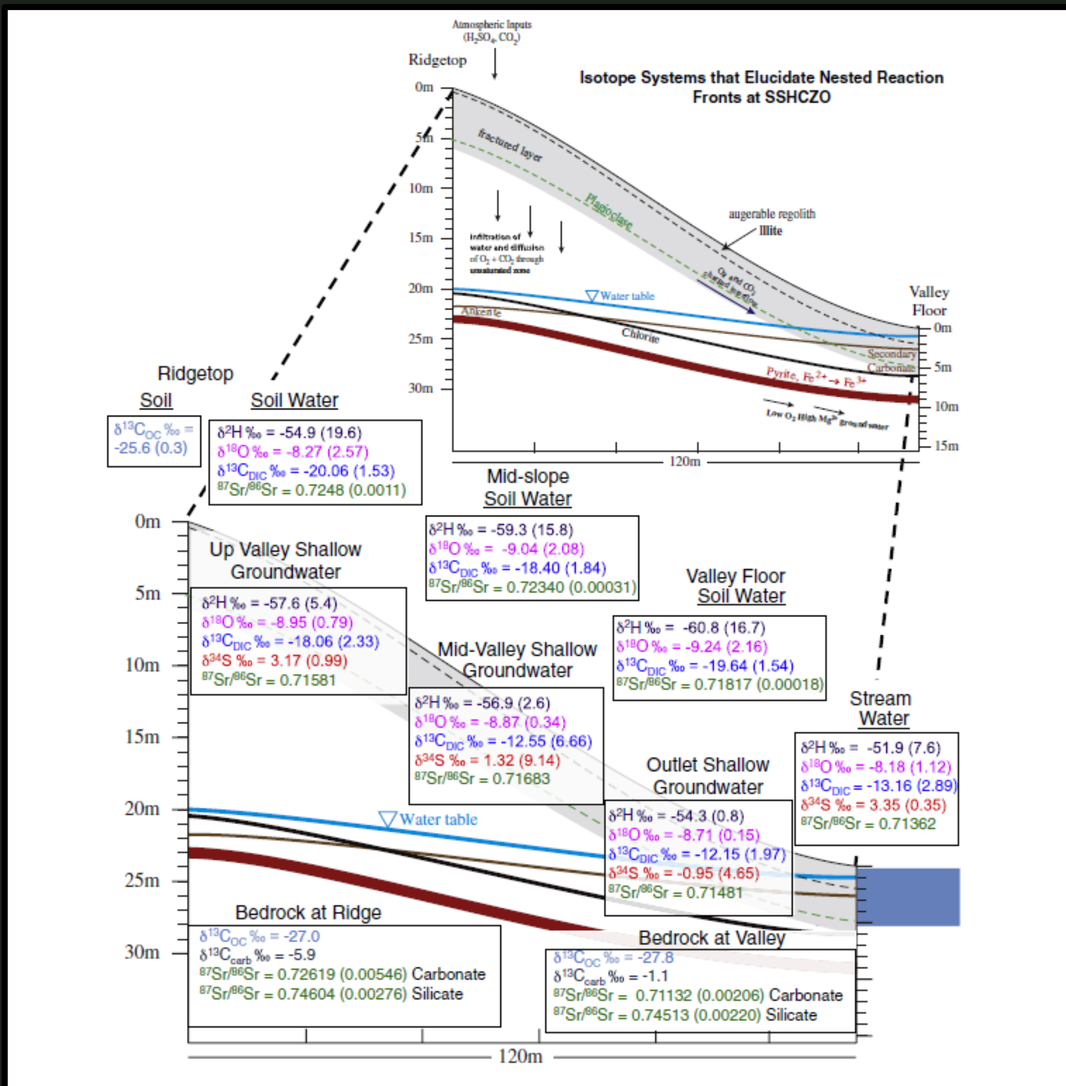
Conceptual model showing the elevation of fresh bedrock, Zb, under ridge and valley topography with a thin soil mantle overlying a weathered bedrock zone that extends to Zb. Channel incision, at the rate Co, drives hillslope erosion and drainage of fresh bedrock (flow paths illustrated with blue arrows). Source: Rempe and Dietrich, 2014

CZ research key findings

3. Earth Surface Energy Propagation - For the first time we have obtained observations that reveal that differences in energy inputs at Earth's surface translate into differences in water, minerals, and biotic activity at depth, and we are starting to detect how these deep properties also impact the biota and climate

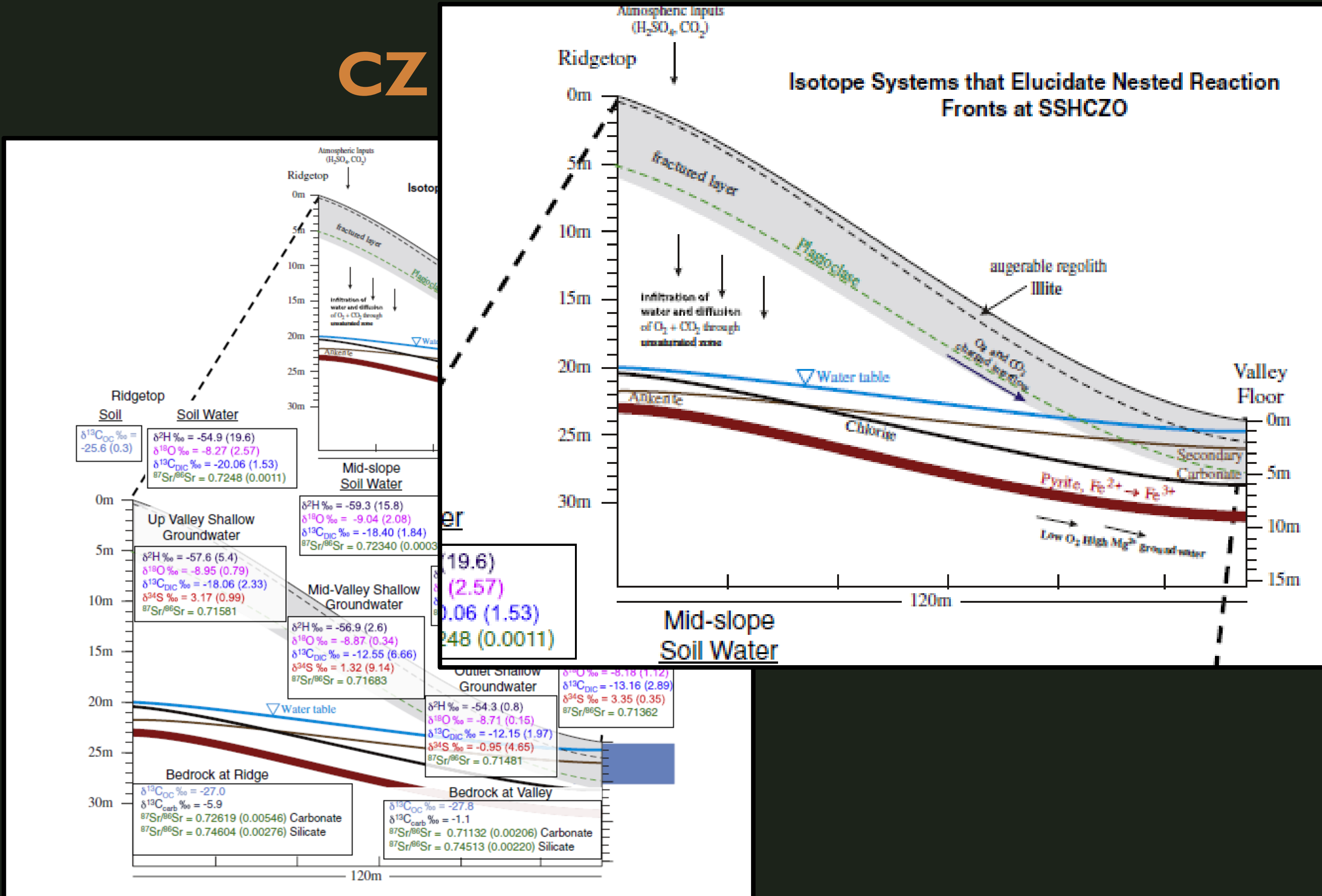
Sullivan PL, Ma L, West N, Jin L, Karwan DL, Noireaux J, Steinhoefel G, Gaines KP, Eissenstat DM, Gaillardet J, Derry LA, Meek K, Hynek S, and Brantley SL (2016). CZ-tope at Susquehanna Shale Hills CZO: Synthesizing multiple isotope proxies to elucidate Critical Zone processes across timescales in a temperate forested landscape. *Chemical Geology*, **445**, 103-119.

CZ research key findings



Source: Sullivan et al., 2016

CZ



Source: Sullivan et al., 2016

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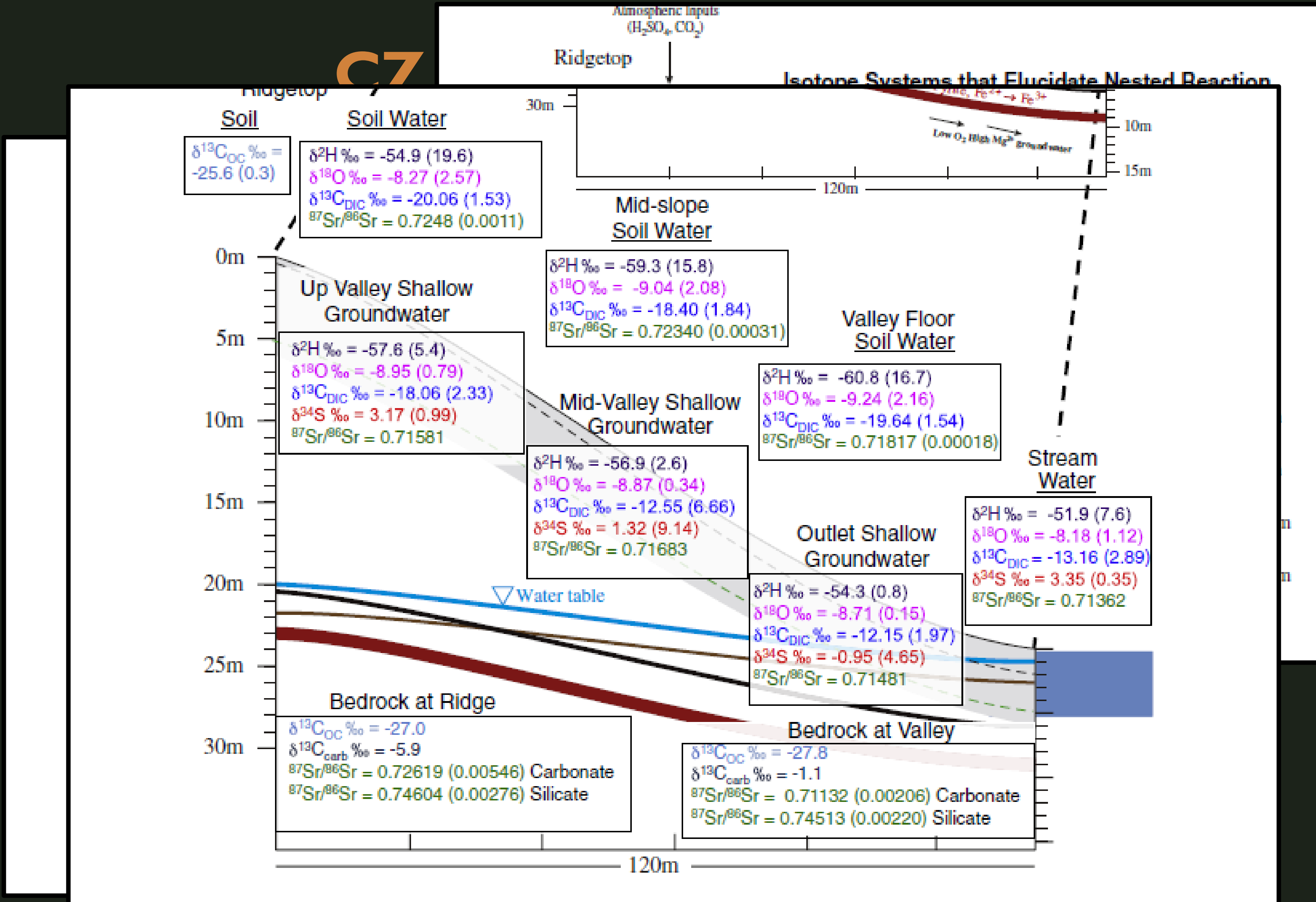
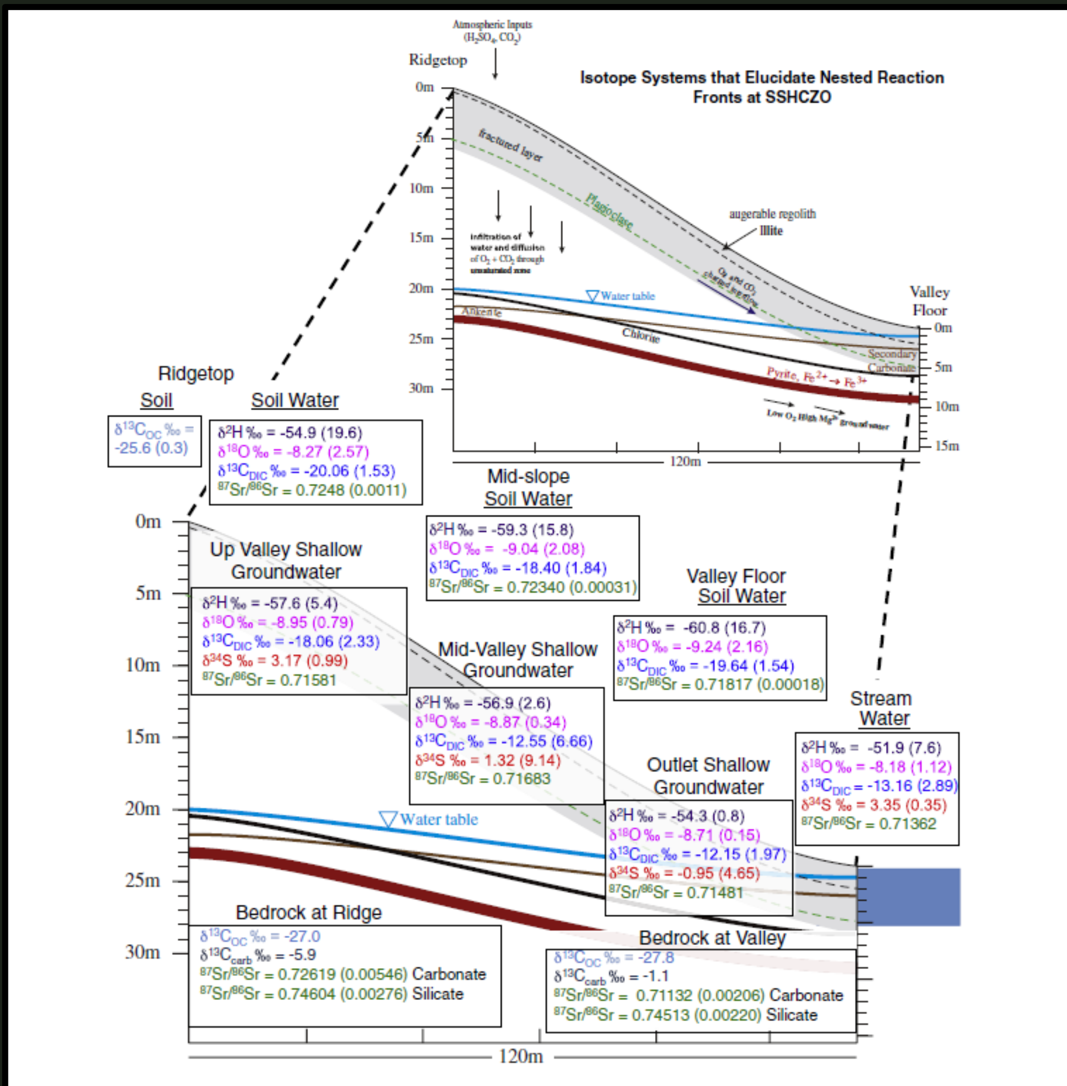


Source: Sullivan et al., 2016

CZ research key findings



- Subsurface flow paths govern the advancement of nested reaction fronts in the CZ over millennia.
- Rate estimates show recent relatively rapid movement of carbonate reaction front attributed to acid rain
- Significant mass loss as particle transport in the subsurface

Source: Sullivan et al., 2016

Conclusions

Are Critical Zone Observatories materially advancing regolith science?

Initial challenges

- Fostering multi-disciplinary collaboration
- Agreeing on what to measure, how to measure it and how to describe it
- Data sharing

Initial response

- Use of non-discipline specific language
- Attention focused on a limited number of sites

Conclusions

Are Critical Zone Observatories materially advancing regolith science?

- My very personal assessment is that researchers in this "new" field have been playing catch up over the last 10 years but that their work has now reached a tipping point where they are poised to make a real contribution to the understanding of regolith processes, leading to advances not only in environmental management but also in mineral exploration.
- In my mind the question now is how we, as regolith scientists, engage with these researchers. There is no doubt we have something to offer (as well as a lot to gain).

Conclusions

ARGA (as an independent multidisciplinary association of regolith scientists) could play an important role in facilitating engagement by:

- Sponsoring senior (ex LEME) scientists to report on regolith research in Australia to major international conferences e.g. Goldschmidt
- Connect with CZ science via an affiliated site at the next ARGA conference
- Seek SAVI (Science Across Virtual Institutes) funding to bring CZ scientists to Australia/the next ARGA conference

Theme 11: Weathering, Erosion, and Geochemical Cycles

11g: Coupled Critical Zone Dynamics Across Aquatic Gradients Groundwater-Surface Interactions in Continental and Coastal Areas: Developing and Strengthening Geochemical Investigations Submarine Groundwater Exchange

Theme 12: Soils and the Critical Zone

12a: Using Big Data to Understand the Critical Zone
12b: Controls on the Recalcitrance of Organic Matter Across Diverse Environmental Conditions and Perturbations
12c: Biogeochemical Cycling of Metals, Radionuclides, and Associated Colloids within Earth's Critical Zone
12d: Interactions between Soil and Biota as Controls on Ecosystem Function from Canopy to Rhizosphere
12e: Redox Transformations and Biogeochemical Cycling in the Critical Zone
12f: Identifying and Modeling Mechanistic Drivers of Elemental Cycles Across the Critical Zone
12g: Co-evolution of the Critical Zone