# The Geological Newsletter

News of the Geological Society of the Oregon Country

**2020 Archive of Club Activity**

Volume 86, Number 1


# CLUB ACTIVITIES

## GSOC BOARD OF DIRECTORS 2020-2021

Board of Directors serves from March 1, 2020 to March 1, 2021. Slate of nominees for Board of Directors was voted and approved at the Annual Business meeting on February 14, 2020.

President ...................................................... Sheila Alfsen
Past President ...................................... Paul Edison-Lahm
Secretary .................................................. Bonnie Prange
Treasurer .................................................. Barbara Stroud
Programming Director ....................... Dennis Chamberlin
Membership Director.............................. Barbara Stroud
Field Trip Director ................................ Carol Hasenberg
Communications Director.................... Paul Edison-Lahm
Outreach Director ....................................... Sheila Alfsen
Member at Large ................................Clark Niewendorp
Member at Large .........................................Carole Miles

## GSOC ACTIVITIES 2020

January/February 2020: Several important changes were instituted in the society's structure, organization, and communications at the beginning of this year. Major changes in the GSOC Bylaws were ratified at the business meeting in February 2020. These included changes in articles relating to memberships, board of directors' structure, and The Geological Newsletter. The board of directors is now composed of the four officers – President, Past President, Secretary and Treasurer – five management directors – Programming, Membership, Field Trip, Communications and Outreach – and two Members at Large. The society also rolled out a new internet-based platform (Wild Apricot) which has the capability of managing memberships, automatically announcing due dates for membership dues, collecting dues payments and recording payment status, managing events and collecting payments for events, and several other functions. The newsletter is now not to be published bimonthly, but is to be collected into an annual report of the society's activities, personnel, and web articles. It will be published and sent to subscribers and archived online. This document is the first edition of the annual report.

## GSOC FRIDAY NIGHT MEETINGS, BANQUETS, PICNICS

Jan 10, 2020 - Friday Night Lecture: "What the Frac is Going On?" Dr. Laird Thompson, managing partner, UF3 LLS, speaker.

Jan 18, 2020 - Volunteer Recognition/Planning Event, Lucky Labrador Brew Pub, a celebration of our volunteers and planning for 2019.

Feb 14, 2020 - Annual GSOC Business meeting and Friday Night Lecture: "Geotouring the Northwest – and Hitting Complexities!" Dr. Marli Miller, University of Oregon Department of Earth Sciences, speaker.

**The COVID-19 coronavirus pandemic begins. Most of the videos of the following Zoom platform lectures are available on the website:**

April 18, 2020 – GSOC Meetup Online Lecture: "Assembling Oregon," Sheila Alfsen.

May 8, 2020 –Friday Night Online Lecture: "Fake Fossils," Dr. William Orr, Professor Emeritus Oregon State University.

May 16, 2020 - GSOC Meetup Online Lecture: "Geology of Death Valley National Park," Andrew Dunning.

June 12, 2020 - Friday Night Online Lecture: "Geology of Iceland, Land of Fire and Ice," Dr. Scott Burns, Professor Emeritus Portland State University.

July 10, 2020 - Friday Night Online Lecture: "Behind the Scenes of Geologic Mapping," Chanel Dvorak, Portland State University Department of Geology graduate student, speaker, discussing her work mapping Jump-off Joe Mountain, Big Canyon, and the Strawberry Volcanics.

August 14, 2020 - Garret Romaine, Executive Director of the Rice Museum, and Sheila Alfsen, GSOC President, hosted an online tour of the Rice Museum collections for the "GSOC Virtual Picnic."

September 11, 2020 – Friday Night Online Lecture, "Outrageous Geological Hypothesis: Bretz and the Spokane Flood Controversy," Dr. Victor R. Baker, Departments of Hydrology and Atmospheric Sciences, Geosciences, and Planetary Sciences, The University of Arizona.

October 9, 2020 - Friday Night Online Lecture: "Paleoseismic Evidence for Holocene Surface Rupturing Earthquakes on Gales Creek Fault, Northwest Oregon," Dr. Ashley Streig, Portland State University Department of Geology.

October 24, 2020 - GSOC Meetup Online Lecture: "Sunstones," Dr. Emily Cahoon.

November 13, 2020 – Friday Night Online Lecture: "Monitoring Oregon's Vanishing Glaciers," Dr. Anders Carlson, Oregon Glaciers Institute.

December 11, 2020 – Friday Night Online Lecture: "Stories in Stone: Travels Through Urban Geology," David B. Williams, author, naturalist, tour guide and curatorial assistant at the Burke Museum.

## Live Lectures cancelled due to COVID-19 outbreak:

March 8, 2020: The GSOC 85th Annual Banquet, "The Rocks Don't Lie," Dr. David Montgomery, University of Washington Department of Earth and Space Sciences, scheduled speaker. Banquet was cancelled right at the outbreak of COVID-19 coronavirus. Several ticket holders donated their ticket fees to the club to allay the costs of the cancellation.

April 10, 2020 – Planned Friday Night Lecture: “Gold Mining in Oregon,” Clark Niewendorp, retired from Oregon Department of Geology and Mineral Industries, GSOC Board Member.

May 8, 2020 –Friday Night Lecture: “Dinosaur Field Notes from a Paleontologist,” Dr. David Taylor, Portland State University Department of Geology and University of Oregon Department of Earth Sciences, speaker. Dr. Taylor is rescheduled to speak in January 2021 on “Finding Late Cretaceous Dinosaurs in Wyoming and Oregon.”

June 12, 2020 - Friday Night Lecture: “J Harlen Bretz and the Ice Age Floods,” Dr. Victor R. Baker, Regents Professor, Professor of Planetary Sciences and Geosciences, Department of Hydrology and Water Resources, University of Arizona, speaker. Dr. Baker gave an online lecture in September 2020 and it is available to view on the GSOC website.

## GSOC FIELD TRIPS IN 2020

The following field trips were planned for 2020 by GSOC. Unfortunately, we were in the midst of the COVID-19 pandemic and had to cancel or postpone all of the trips until 2021. Here’s the lineup of the trips and the status:

May 26-29, “Rafting on the John Day River with Ouzel Outfitters,” Dr. Gordon Grant, former Research Hydrologist, USDA Forest Service, and courtesy professor, Oregon State University Geology and Geophysics discipline in the College of Earth, Ocean, and Atmospheric Sciences, guest leader. POSTPONED UNTIL 2021

June 1-4, “Rafting on the John Day River with Ouzel Outfitters.” POSTPONED UNTIL 2021

June 6, “Downtown PDX Building Stone (South Tour)” POSTPONED UNTIL 2021

June 27, “Eastside Bike Geology Ride” POSTPONED UNTIL 2021

July 11-12, “Mt. Hood Faults,” Ian Madin, field trip leader. POSTPONED

July 24 and July 25, “Tourmaline Hunting in the North Santiam Mining District,” Clark Niewendorp, field trip leader. POSTPONED INDEFINITELY DUE TO COVID AND THE BEACHIE CREEK FIRE IN 2020.

August 7-11, “Coaledo Formation,” John Armentrout, Laird Thompson and Frank Hladky guest leaders. POSTPONED UNTIL 2021

Downtown PDX Building Stone (North Tour) October 3 POSTPONED UNTIL 2021

Well, in retrospect it was not a good year for GSOC field trips. However, several small field trip reconnaissance missions were conducted. Also, John and Carol Hasenberg documented a DIY geology field trip in eastern and central Washington state. The documentation for this trip, which first appeared as an article on the website, will be archived in the field trip guides of the GSOC website. The board of directors have plans for many field trips in 2021.

## NEW MEMBERS FOR 2020

At the latest count, GSOC has 244 memberships and 271 members. That's more memberships than the club has had in its history, according to the records that we have.

Vincent and Lindsey Aarts
Dorothy and Tom Atwood
Ann and John Bakkensen
Margaret and Sara Berroth
Judy Bradley and Dave Mitchell
Lucretia and James Brown
Darlene and Kendall Conrad
Melinda Cordasco and Jason Raby
Tommy and Faye Gregg
Gordon and Eleanore Hale
Laura and Mike Joki
Kim and Mike King
Nicole and Tim Ledbetter
Bernadette LeLevier and Brian Scott
Nolan and Chrysta Milojevich
Susan and Lee Rosenbaum
Tom Tinkler and family
Robert Baker
Kes Barcas
Sandra Bowman
Wayne Buck
Michael Bunsen
Bonnie Campbell
Anders Carlson
Susan Cassidy
Susan Dolan
Chanel Dvorak
Earl Anthony Farasy
Christopher Gibson
Samuel Giese
Liz Gilliam
Arthur Glasfeld
Andrew Gold
Peter Griffen
Monte Jarvis
Todd Jarvis
Thure Johnson
Sara Kauffman
Marcia Knadle
Lena Lane
John Lasher
Chris Lazarus
James Lee
Dr. Deb Luchsinger
Richard McMullen
Michael Neunzert
Steven Newkirk
Bob Oblack
Eriks Puris
Rachel Secrest
Nancy Siegel
Vicki Sironen
Ashley Streig
Laird Thompson
Barry Walker
David Williams
Kimberly Burroughs
Danielle Corona
alexandra kowalczyk
Amanda Meaders
Natalie Petersen
Isaac Pope
Micah Read

## DONORS

The society would like to thank all the members who made donations to GSOC for Friday Night Meetings, banquet cancellation costs and other purposes:

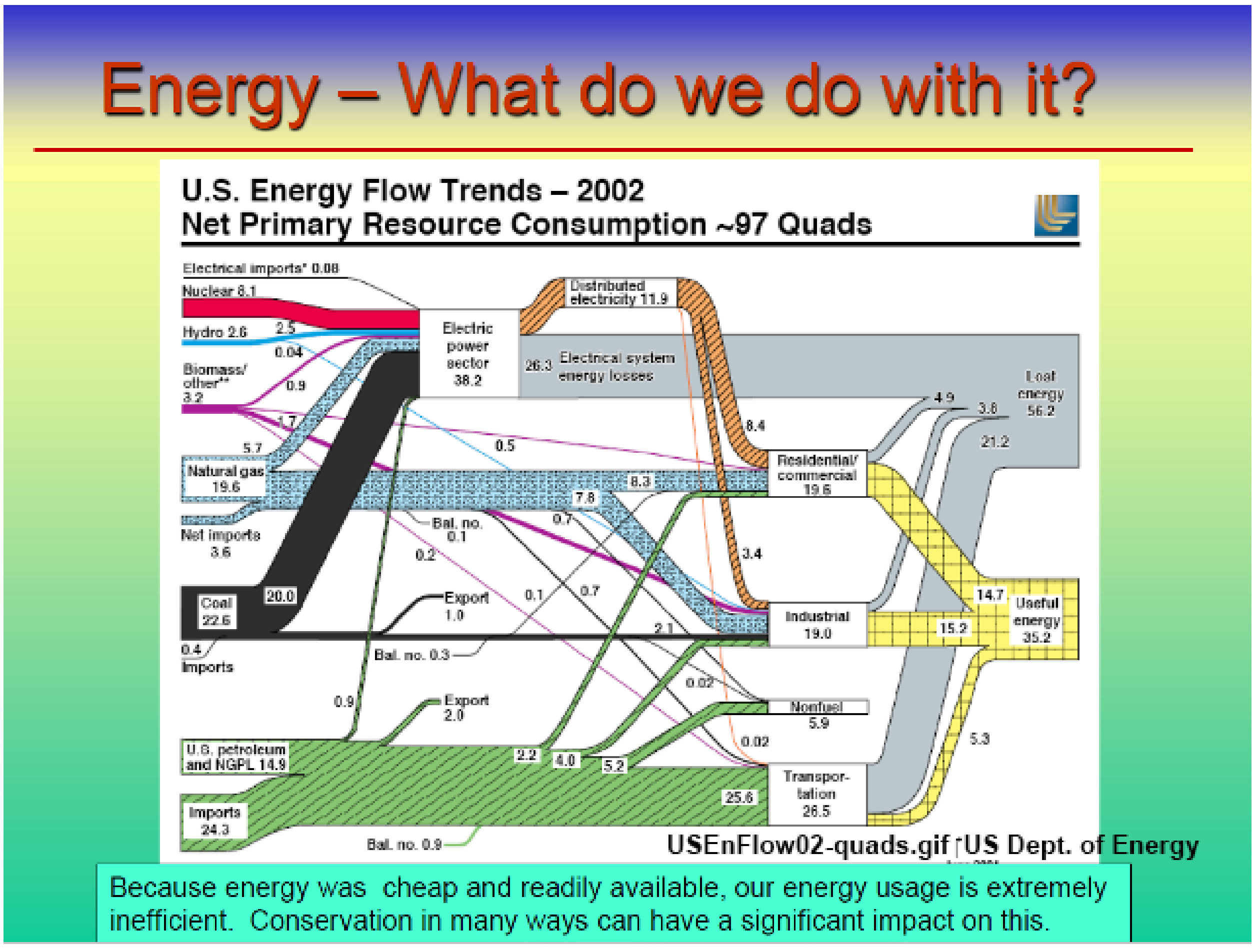
Kes Barcas
Michael Christenson
Glenn Kirkindall
Nancy Siegel
Ann McKinney
Blaine Moody and Ann Comely
Christina Peterson
Ray Wells
Kimberly Burroughs
Susan Hayden and John Beaston
Joyce Mills
Bonnie Brunkow and Neal Olson
Cynthia Kenyon
Tom and Dorothy Atwood
Alice Brocoum
Lucretia and James Brown
Thomas D. and Sally A. Fouch
Bonnie Prange
Julia Lanning and Mark Anderson
John and Ellen Ullrick
Michael Neunzert
Alfred and Nina Fleckenstein
Arthur Glasfeld
Wes Mahan
Mary Lou and Louis Oberson, charter member's daughter!
Wayne Schweinfest
Lawrence Jordan

Carol and John Hasenberg
Cris Morgante
Peter and Robin Samson
Laurie Elliott
William N. Orr
Fenella Robinson
Anne F. O'Neill
Carrie Gordon
Carole and Mike Miles
Fred and Judy Shipley
Sheila Alfsen
Jill Cohen
Harold E. Hinds
James and Marilyn Bull
Michael Dunn and Cynthia Smith
David Wilson and Lynne Williams
Melanie and Matt Klym
William Boettner
Paul and Peregrine Edison-Lahm
Jan Kem
Jim Jarzabek and Teresa Meyer
Herb Dirksen
Barbara and Jon Stroud
Clay and Barbara Kelleher
Doug and Janet Rasmussen

## A FRACKING OVERVIEW

*Based on the January 10, 2020 GSOC Friday night lecture by Dr. Laird Thompson, Managing Partner of UF3 LLS. Slides courtesy Dr. Thompson*

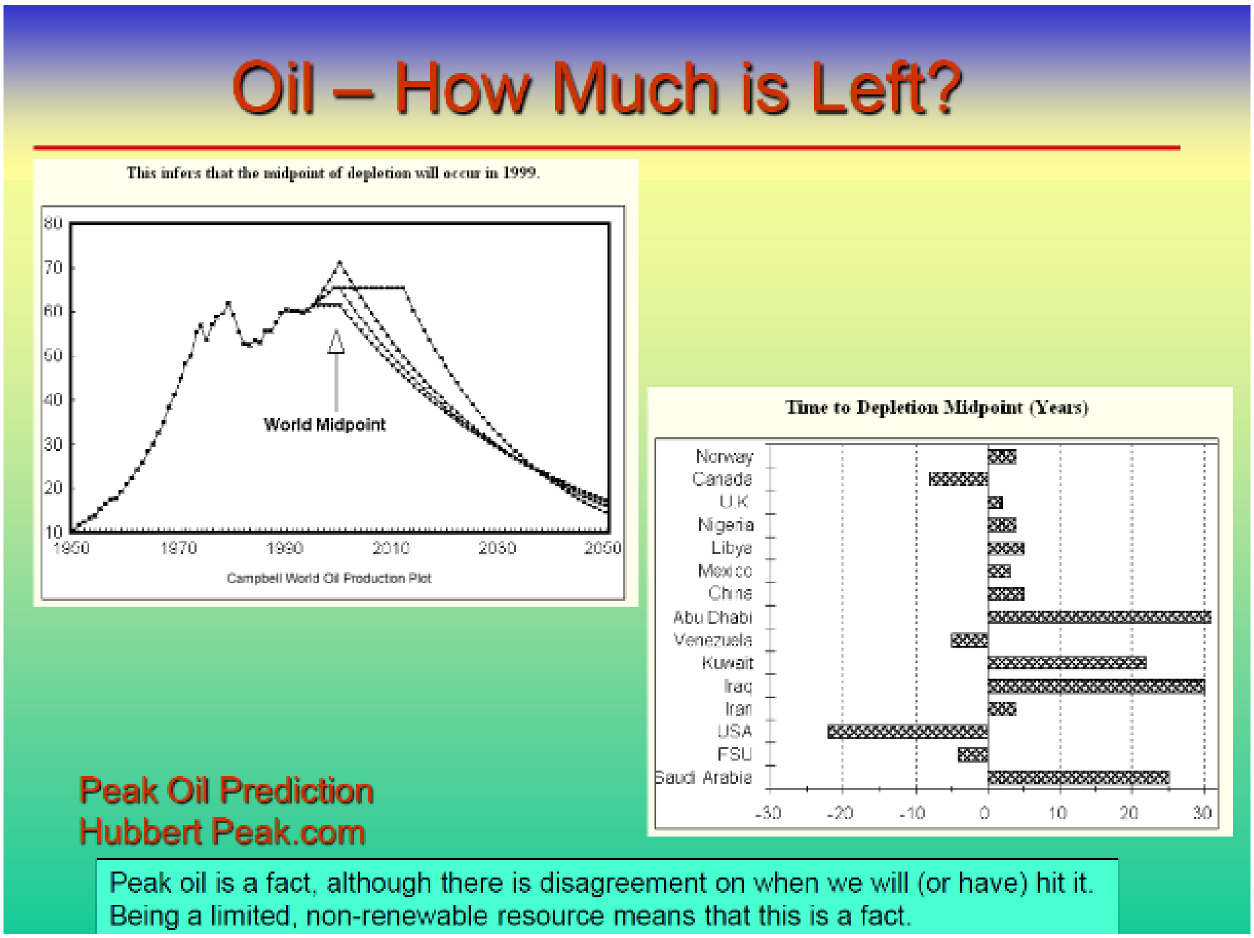
*By Carol Hasenberg*




Dr. Laird Thompson is an expert on rock fracturing and after working on imaging technology for boreholes in the 1980's, he was appointed head of Mobil Oil's fracture technology. He owns his own consulting firm now and is currently partnering on some work which has brought him into Oregon -- where GSOC is fortunate to have him as a speaker. He is the author or coauthor of several reference books which are the standards for the fracking* industry.

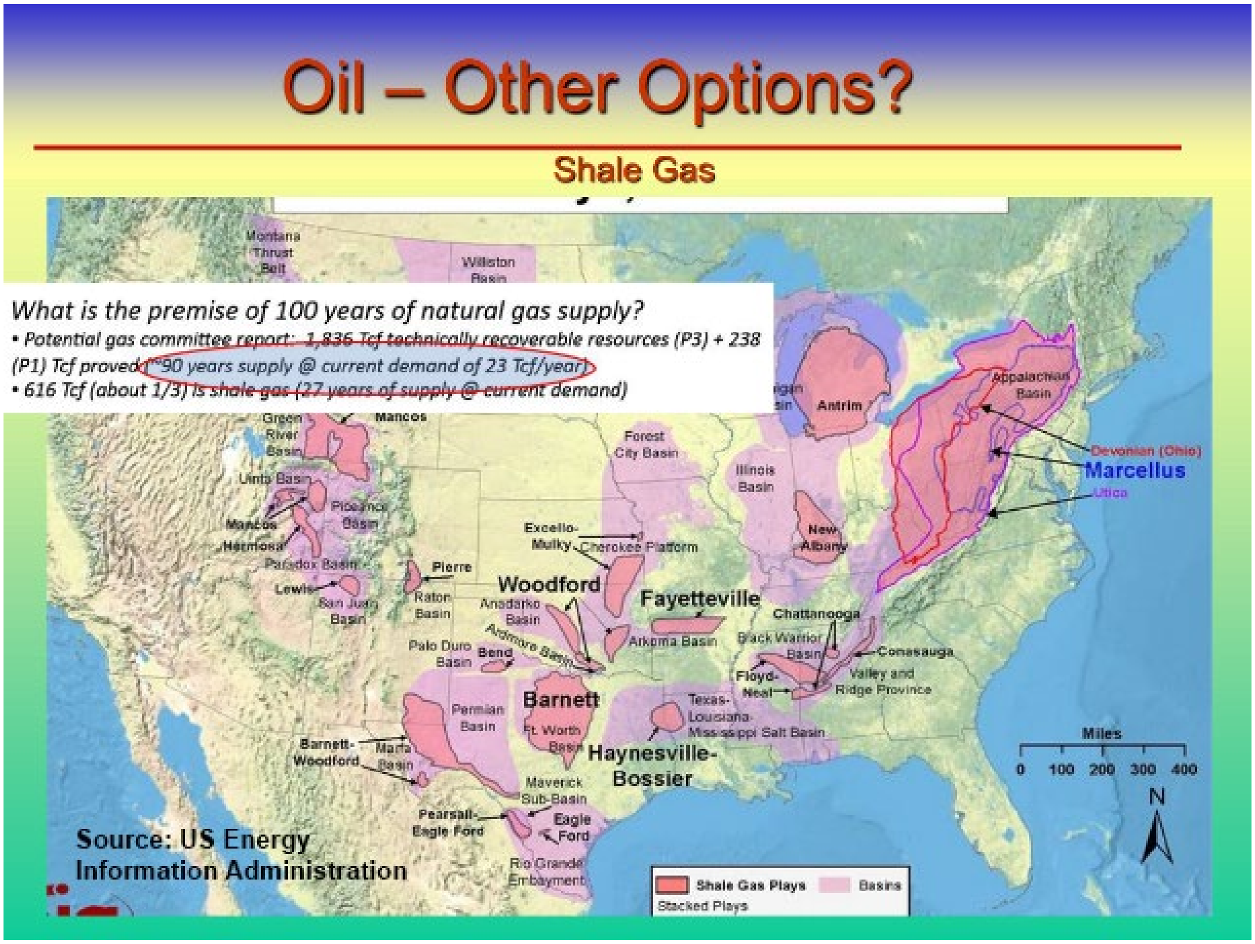
In explaining the rise and importance of fracking, Thompson reviewed the natural, financial and geopolitical history of the oil industry. Oil** is a commodity whose value is shaped by the laws of supply and demand. It is a commodity that is limited in supply. For the most part, it was created from biomass, which on earth is concentrated in the ocean in the form of diatoms, plankton, etc. These little oceanic critters have died by the trillions, and the little drops of oil they used as ballast have turned into oil reserves over millions of years.

Prior to the recognition of large petroleum reserves in the earth, people harvested whales for oil. One might somewhat cynically credit the oil industry for having ‘saved the whales’. The price of whale oil in the 1800’s had steadily risen with the growing scarcity of whales, until the oil industry came along and pulled out the proverbial rug from its base. Thus the distribution of whale oil followed a classic bell-shaped (normal) curve from the birth to the death of the industry. Inevitably, the same thing is going to happen to petroleum. Petroleum had been really cheap between 1880 and 1970, when the Arab oil embargo caused prices to skyrocket. Then prices stabilized between 1985 and 2005. Prices are now on the rise. According to many estimates, we are now approaching a point of peak production of conventional liquid oil and it will become increasingly scarce as time goes on, especially with population increasing as well.




These are facts of which most people are aware, and the big question is, how to move on from here? Our civilization is heavily invested in a commodity that is going to run out. Thompson offered 3 strategies which are not necessarily mutually exclusive. First off, our oil usage is extremely inefficient. He presented a chart of US energy usage which showed that only about 35% of the energy sources we use are used to make electricity or run machinery. Transportation and heating uses are one-time uses where that energy is lost. So, the number one thing to do is conserve the use of petroleum.

Secondly, alternative sources of energy need to be brought on line which will reduce the use of petroleum in the short term and replace it in the long term. For example, Thompson mentioned that an extremely efficient way to heat buildings is with geothermal energy. Various open and closed loop systems have been engineered that can heat and cool buildings efficiently even at the residential scale and proximity to a geothermal heat source (i.e., a volcano) is not required. Of course, geothermal power plants using a geothermal source are also being used.




And lastly, there are more oil reserves in the ground than just conventional liquid petroleum. The source rock of liquid petroleum is much more voluminous than the liquid being extracted. And here Thompson returned to the fracking industry. There’s a lot of hydrocarbon products (oil and gas) locked up in the shale gas basins of the world. The problem is that the permeability of shale gas rock is very low. If, however, a fracture can be opened up in a shale gas rock basin, the permeability is increased exponentially. To crack the rock, one must exceed the lithostatic pressure on the rock (basically, the pressure caused by the weight of rock above it).

In a fracking operation, one must pump in fluid to break the rock, add something to the fluid to keep the cracks propped open, then extract the hydrocarbon products. The operation generally involves drilling vertically down to the shale gas rock, then horizontally through the shale gas rock for some distance. Starting at the far end of the well, the fluid is pumped at high pressure through holes that fracture the rock surrounding the drill hole, and then the hydrocarbon products are extracted from the hole. After the fracture has extracted its payload, then the unfractured rock adjacent to the first is fractured, and so forth until the hole is depleted. There are ways of monitoring the extent of fracturing using microseismic imagery during the procedure. After the first hole is completed, the driller will then drill another hole parallel to the first and the procedure is repeated.

Fracking operations involve lots of trucks, tanks, and spoils ponds. With many small operators drilling through drinking water aquifers and along seismic faults, what could possibly go wrong? The first problem is getting rid of the used fracking fluid, which is generally water which may contain benzene and other proprietary additives, as well as the hydrocarbon infusions from the well. Other problems include propagation of the fractured zone to higher strata and gas bleeding out through poorly sealed wells, which can cause ground disruption and pollution of drinking water aquifers.


There are problems that create problems. Wastewater disposal wells are often used to get rid of the pesky used fracking fluid. Improperly sited, they can cause lubrication of natural faults which in turn can cause earthquakes; this has been documented. Thompson confirmed that lots of mom and pop operations are doing the fracking and it is hard to control the level of professionalism in the field. Some fracking is now being done using nitrogen as the fracking fluid; this is much cleaner because there isn't the fluid disposal problem.

In spite of its problems, fracking is attractive to Americans because it continues to stoke an already established industry and reduces dependency on foreign oil. In terms of the future of continuing to depend on the oil industry, Thompson advised the audience to 'conserve energy and vote smart'.

## Footnotes

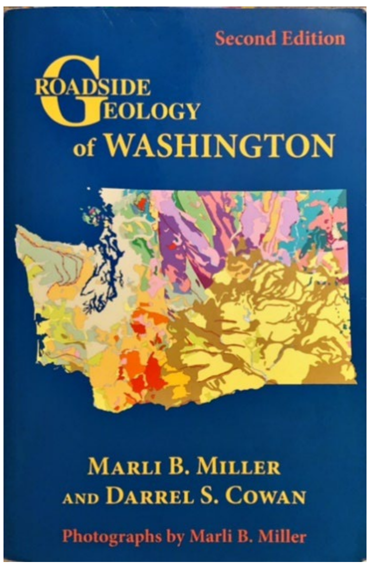
*Fracking or fracing? Author's note: when it comes to spelling the word, there seems to be two camps: most of the industry spells it fracing or fraccing, because etymologically it is a shortening of the term hydraulic <u>frac</u>turing. However, the journalism trade considers that the word should be spelled phonetically – thus, fracking (rhymes with cracking). There's been a bunch of rather humorous writing done on this (mostly by journalists) but the bottom line is that Merriam-Webster, Microsoft and Google have come down on the side of fracking. Sorry, oil industry! -- Here's some references fuelfix.com/blog, HighCountryNews blog, Columbus Business First.

**Author's note: I mostly refer to petroleum, or crude oil, in this article as 'oil' using the parlance of our time. I refer to it as petroleum in the paragraph about whale oil to avoid confusion.

## WASHINGTON STATE – LAND OF GEOLOGIC COMPLEXITY

*Based on the February 14, 2020 lecture by Dr. Marli Miller, Department of Earth Sciences, University of Oregon and her book co-authored with Dr. Darrel Cowan.*

*By Carol Hasenberg*

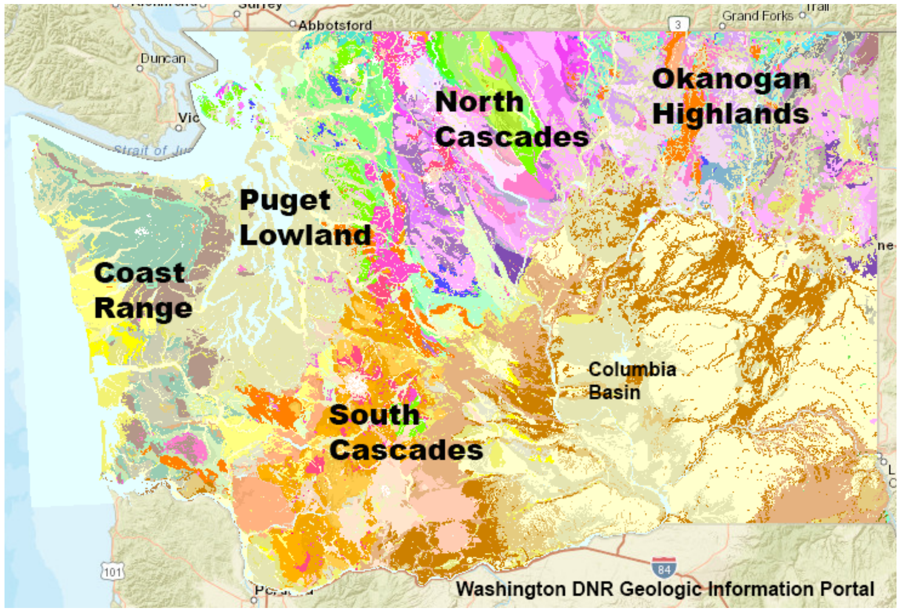



GSOC members were delighted to welcome back Dr. Marli Miller to speak to the society about her latest book, Roadside Geology of Washington Second Edition (Mountain Press, 2017). Miller co-wrote the book with her former PhD. Thesis advisor, Dr. Darrel Cowan of the University of Washington, whose experience and perspective in understanding the geological framework of the state was invaluable. In her opening remarks, she said that her favorite thing to say about writing these (roadside geology) books is that she learns so much.

In her lecture Miller broke down the geological history of Washington into a series of events, which define the physiographic provinces of the state, because it is the bedrock of a region that influences the outward appearance. The original western boundary, the Laurentian margin, is now on the eastern margin of Washington, and these ancient rocks are highly deformed and metamorphosed to varying degrees. A series of accreted terranes, starting with the Quesnellia terrane accreted in the Jurassic, and the latest Siletzia, which stretches from southern Oregon to southwestern British Columbia, and which accreted 50 million years ago, comprise the basement for the remaining part of the state. Atop and within these lie volcanic and sedimentary bodies that covered or erupted through the basement rocks. Stitching plutons were igneous masses that erupted as a result of terranes accreting to each other or to the continent.

The Columbia Basin Province, bordered on the north and west by the Columbia River, was inundated during the Miocene by vast floods of basalt, and later in the Pleistocene by the waters of the enormous Ice Age Floods. Glaciation from the Cordilleran Ice Sheet in the north and Puget Sound area and mountain glaciers in the North Cascades and Olympic Mountains heavily marked the state's geography, and also deposited unsorted glacial till in vast areas, wind-blown loess and glacial outwash features.

All these events created a number of physiographic provinces within the state: The **Okanogan Highlands** province in the northeastern corner, home to the oldest rocks in the state, preserves the longest geologic history. To the south of this lies the vast **Columbia Basin**, land of flood basalts and channeled scablands. The western **Coast Range** Province contains the Willapa Hills to the south and the Olympic Peninsula to the north, the latter one of the finest examples of an accretionary wedge complex that one can find anywhere. Directly to the east of the Coast Range lies the **Puget Lowland**, consisting of Puget Sound and the flat country adjacent to its east and south shores, a forearc basin heavily scoured by the Puget Lobe of the Pleistocene Cordilleran Ice Sheet. To the east of this is the volcanic arc of the Cascadian Subduction Zone, and it is divided into two provinces, the **Southern Cascades**, purely the expression of the volcanic arc with Mt. Rainier, Mt. Adams, and Mt. St. Helens as its prominent peaks; and the **Northern Cascades**, an area under so much compressive stress that the basement rocks have been uplifted to dominate the scenery, and with a couple of arc volcanoes, Mt. Baker and Glacier Peak, thrown in for good measure.




After describing the basic physiographic provinces of Washington, Miller described the geology of Washington as characterized by complexities. She therefore treated the audience to a series of vignettes which illustrate the complex nature of Washington geology.

One of Miller's favorite topics throughout the lecture was the Siletz Terrane, or Siletzia, a large body which forms the basement rock from southern Oregon to the south of Vancouver Island. This terrane thus forms the basement in the Coast Range Province of Washington, and the rocks from this volcanic island arc are known as the Crescent Formation here, from the Crescent Lake type location in the Olympic Peninsula. And excellent examples of pillow basalts from the Crescent Formation can be viewed as one drives along Hurricane Ridge Road in the Olympics, the first vignette described by Miller.

Not a part of the Siletz Terrane, but an oceanic accretionary wedge, the core of the Olympic Mountains is composed of slightly metamorphosed sedimentary rocks. The sediments were thrust under the Siletz Terrane and are highly folded and deformed, then uplifted starting around 16 million years ago and exposed by erosion. Amongst the most interesting are the mélanges of the Hoh assemblage on the western coast of the Olympics, where the layers are mixed into a jumble. The sea stacks of Ruby Beach are erosional remnants of this mixture.

Miller then proceeded across the northern section of Washington on state highway 20, and her first stop was Anacortes on Fidalgo Island, which is almost entirely composed of the Fidalgo Ophiolite, a slice of late Jurassic oceanic crust and early Cretaceous sediments that were accreted approximately 100 million years ago. The origins of the San Juan-Cascade Nappes sequence of terranes which contains the ophiolite are somewhat mysterious, and they may have been transported a distance by tectonic forces.

Heading to the east on highway 20 all the way to the Okanogan Highlands, Miller introduced another vignette. One current theory about the belts of metamorphosed rock in the drive between Tonasket to

Colville is that the Mississipian to Jurassic metavolcanic and metasedimentary rocks of the Quesnellia island arc were thrust over the highly metamorphosed Proterozoic to late Paleozoic rocks that represent the western margin of the continent Laurentia at the breakup of Pangea. The actual boundary between the accreted terranes and the old continent is somewhat confused by all the faulting and folding. On the highway traveling from west to east, one passes the Okanogan core complexes containing mylonites, or fine-grained gneisses which form in fault zones. One also passes through the Toroda Creek and Republic grabens which formed by crustal extension during the Eocene, when Siletzia was accreting and the subduction zone was temporarily shut down. There are also outcrops of glacial till, a much more recent remnant of the Cordilleran Ice Sheet.

Miller then proceeded south into the Columbia Basin, where Columbia River Basalt can be found everywhere. An estimated 52,000 cubic miles poured out of the faults in eastern Oregon and Washington, mostly between 17 and 14 million years ago. The basalt flowed down the ancient Columbia River to the sea and we see this basalt at several prominent areas on the Oregon coast, including Cape Lookout, Neakanie Mountain, Saddle Mountain and Hug Point.

Miller then touched briefly on the rotation of the Pacific Northwest and the faulting and folding in the Columbia River Basalt which has resulted. The Yakima Fold Belt is an example of this. The Columbia River Gorge runs just north of the trough of a syncline in this fold belt. Thus, the rock layers dip gently to the south along a cross section through the gorge. This produces an asymmetry to the profile and can be clearly seen from vantage points such as Crown Point or Cape Horn. In addition, below the Columbia River Basalt (which makes the steep cliffs on the Oregon side of the river) lies the Miocene Eagle Creek Formation and the Oligocene Ohanapecosh Formation, deposits of volcanic material from the ancestral arc volcanoes. The weathered clay top of the Ohanapecosh makes a perfect plane for sliding. The Washington side of the gorge is therefore highly susceptible to landslides. At 600 years, the Bonneville Landslide complex is the youngest and is believed to be responsible for the Bridge of the Gods legend.

Although the Columbia River is very ancient and has existed for at least 15 million years, its current dramatic look was enhanced about 18,000 to 15,000 years ago by a series of between 40 and 100 Ice Age Floods that tore down its length and reached depths of hundreds of feet. Most of these floods had their origin in Glacial Lake Missoula, which formed as a result of an ice dam created by a lobe of the Cordilleran Ice Sheet. As they tore across the Columbia Basin, they also created the channeled scablands and other erosional and depositional features.

These quick vignettes presented by Miller merely hint at a state with the most complex and interesting geologic history and variety. For more explorations you may want to read their excellent book on Washington Geology. It features Miller's own superb photography, color cross sections and geological maps which were produced with the assistance of Washington's Department of Natural Resources geological mapping division.

### Additional Reading

Marli B. Miller and Darrel S. Cowan, Roadside Geology of Washington, Second Edition, Mountain Press Publishing Company, Missoula, Montana, 2017.

E.H. Brown, B.A. Housen, E.R. Schermer, "Tectonic evolution of the San Juan Islands thrust system," The Geological Society of America Field Guide 9, 2007, Washington Department of Geology, Western Washington University, Bellingham, Washington 98225, USA.

## THE CORONAVIRUS AND ONLINE GSOC LECTURES

*By Carol Hasenberg*

In February and March we all thought that this coronavirus wave would burst over us and be done in a couple of months, and then we'd all go back to normal. Meanwhile GSOC President Sheila Alfsen had been conferring with the March 8 GSOC Annual Banquet speaker David Montgomery, who told her that he had been in and out of the SEATAC airport several times the week preceding the banquet and might have been exposed to the virus. They reluctantly concluded that the banquet needed to be postponed. The decision was accepted by the GSOC Board of Directors and proved to be prophetic. Within hours of the decision the University of Washington closed, and within a week it became clear that to combat this highly contagious virus homes and businesses in the Pacific Northwest were going to have to go into a quasi-quarantine state for awhile. But we still entertained hopes of returning to normal sooner than later. With great reluctance the GSOC board also decided to try meeting via this new meeting platform called Zoom. A couple of the board members had tried it and thought it might be easy enough to try for board meetings, but the consensus was that our membership would not be willing to see an online lecture, and it would be technically difficult. So, we cancelled the lecture for April and crossed our fingers.

Well, it's the end of May now and here we all are and the coronavirus has been slowed but has not gone away. With vaccines still a long way from being available, it looks like this year is going to be a bit surreal. Things are starting to open up a bit, and strategies are being tried to get as much of the economy going as possible while minimizing widespread disease and death, but as far as public geology lectures and field trips go this year is looking like a big fizzle. But wait, what about those Zoom board meetings?

Well, the GSOC board started slowly with a practice session using Zoom in late March and then met for real in April on our usual date. The meeting was successful, and the more distant board members liked the fact that they were not having to drive for hours to attend the meeting. By then key people were getting a handle on videoconferencing and public online meetings. Our president Sheila Alfsen got up to speed using Zoom rather quickly and agreed to give an online talk on April 9 to the Tualatin Valley Gem Club entitled "Mt. St. Helens – Then and Now," The lecture, with Zoom meeting technical improvements, was reprised for the local chapter of AWG (Association for Women Geoscientists) and is now available for viewing through a link from the GSOC website. This lecture turned out to be a success and was well attended. The next video project was an online GSOC Meetup lecture on April 18 called "Assembling Oregon's Geology," which Sheila presented and with our Communications Director Paul Edison-Lahm hosting the meeting for GSOC. Once again the lecture went well and was well attended.

So then it was time to try a formal GSOC Friday night lecture, and paleontologist Dr. William Orr, who has given many lectures for GSOC over the last several years and is one of our favorite speakers, agreed to speak. His topic, "Faking Fossils for Fun and Profit (The Lying Stones of Marrakech)," was presented on May 8. We hope that those of you who attended enjoyed the lecture and the Q & A session following. We hope to bring a number of these online talks to the membership this year and hope that you will attend, learn from, and enjoy them. Our June lecturer will be Dr. Scott Burns, who is also a society favorite and quite a popular lecturer in Portland and elsewhere. Dr. Orr is also planning a few more online lectures for this summer and we will announce them as the information is finalized.

Not only is GSOC working to get online, but a number of sister organizations are doing so as well. AWG, COGS (Central Oregon Geoscience Society) and IAFI (Ice Age Floods Institute) are presenting online lectures. And Nick Zentner of Central Washington University has been doing his "Nick at Home" broadcasts live on his YouTube channel since March 17.

If you've never attended a Zoom meeting, you can do so using a smartphone or desktop or laptop. A video camera and mic are helpful but not essential (your smartphone has all of these features embedded). You will need to load the software onto your device. Questions can be asked from your mic or the chat feature of the Zoom software, and GSOC meetings include a chat moderator who facilitates this feature for our attendees. We recommend that you practice having a meeting with someone before the lecture, so you are familiar with how to use the software.

We're waiting to see how things work out this summer, and perhaps get a day-long field trip together if it seems safe in late summer or early fall. So…until we meet again, stay tuned!

## FAKES, FAKES AND MORE FOSSIL FAKES

*An article based upon the online lecture "Fake Fossils" of May 12, 2020, by Dr. William Orr for GSOC*

*By Carol Hasenberg*

There are many reasons why people might produce a fake fossil, but here are the leading contenders:

- Fossils can be very valuable items, and if one wants to make some easy money, one can mass produce fossil products for profit, and
- Wouldn't it be fun to fool the gullible public into believing in this fake I've made!

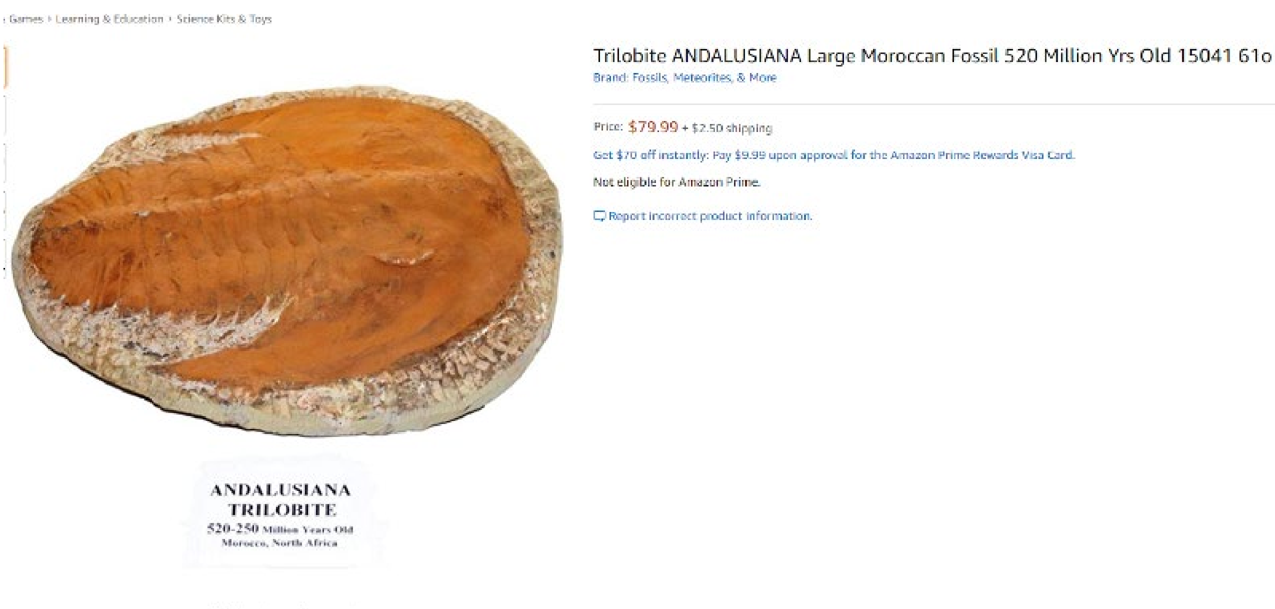
Dr. Orr had lots of examples of these enterprises that have been done since man first started studying fossils. A spectacularly popular fake of the early Twentieth Century was Piltdown Man, a fake "missing link" fossil made by Charles Dawson in Britain. He combined a human skull with the mandible from an orangutan and this was passed off as real for 40 years, until the advent of Carbon-14 dating exposed it as a fraud. Charles Dawson produced other fake fossils and must have been a strange character himself.

A similar and even less believable fraud was the Cardiff Giant, "discovered" in New York just after the Civil War. This was a 10-foot-tall body of a man carved from a block of gypsum. A funny twist to this fake was that P.T. Barnum, who was thwarted from buying the carnivalesque statue, made one of his own and claimed that he had the "real" Cardiff Giant!

An example that the author found most amusing was the story of Johann Beringer, a German professor who began finding "fossils" carved from mudstone in a nearby quarry. Orr showed the audience pictures of a lot of these, and they are so unbelievably fake that most children of today would not be fooled by them. Yet this was the 18th Century, and Beringer collected these and even wrote books about them. Then one day, he began to find slabs carved with his own name in Hebrew script, and he finally tumbled to the prank, which was perpetrated by two of his colleagues at the University of Würzburg. Ach indeed! He set about trying to buy up all the books to clear his name, but after his death his survivors dealt him the unkindest blow of all by collecting the remaining books, republishing and selling them for a tidy profit. History has dubbed these fakes "The Lying Stones of Beringer."

Undoubtedly the most mass-produced fakes of recent times have been those being made in Morocco, a country which is known for some real Paleozoic fossil beds famously containing trilobites, ammonites, and Orthoceras. For those of you who frequent the Tucson Gem and Fossil Show in early February, you know that all sorts of Moroccan fossils abound, and Dr. Orr warned the unwary that these include lots and lots of fakes, some selling for extravagant amounts of money. He presented a list of things to watch out for and gave examples therein for trilobites:

- Fossils which are exact replicas of each other
- Painted fossils
- Fossils from different ages on the same slab
- Fossils slapped together from different parts of real fossils
- Fossils that look too "perfect"
- Bigger trilobites of the same species that have the same number of segments as smaller ones. Trilobites molted and each time added a new segment to their bodies; therefore, the bigger ones would have more segments as the smaller ones of the same species.
- Huge fossil trilobites. The bigger the fossil, the more money can be made, so the uncommon Cambrian trilobite genus Andalusiana are frequently faked and even sold on the internet through vendors who should perhaps be a bit more discriminating. But at $80 a pop, they are quite a bargain and can be delivered free to your doorstep!




*An example ad for an Andalusiana trilobite.*

Conversely, traits which lend verisimilitude to a trilobite fossil include:

- A grouping of overlapping specimens – too difficult to carve
- Tiny, detailed fossils – not profitable to make

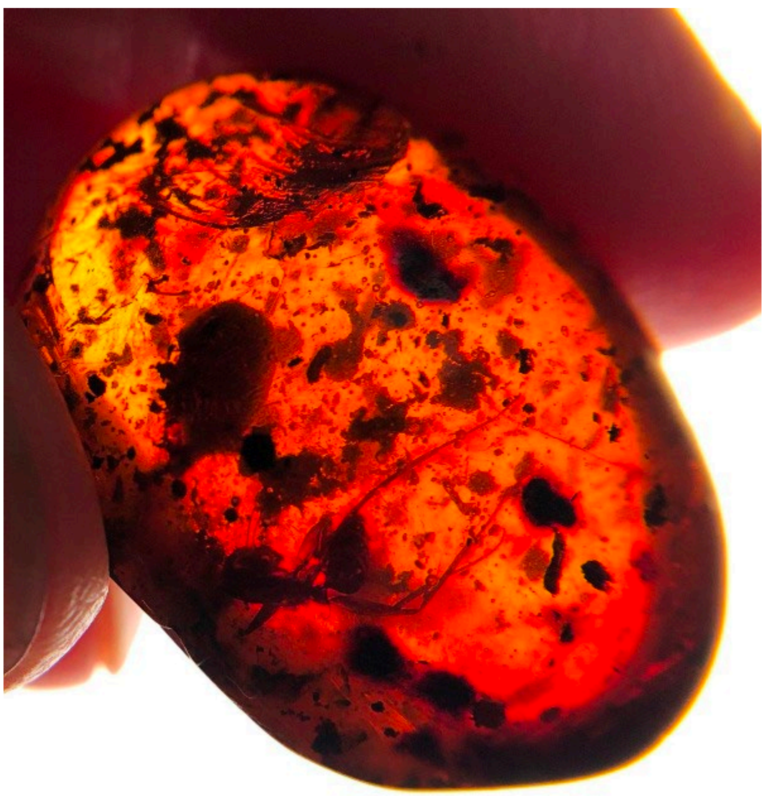
Trilobites are well-known indicator species and therefore few paleontologists would be fooled by fake trilobites. They are well-studied and new taxa would draw lots of attention – and expose them if they are fakes. Yet there are lots of dilettantes and tourists who will purchase unknowingly.

Another commonly faked fossil is the fish fossils found in the Eocene Green River Formation of Wyoming. These 50-million-year-old fish were well preserved at the bottom of a fresh water lake and can be found as intact specimens (bones and impressions of actual surface shape). Fake specimens may be painted right on the shale slabs or a real fossil may be enhanced by paint. This puzzles Orr, as the real fossils can be purchased for 3 or 4 dollars each. Other similar fakes he has spotted are impressions of animals such as a seahorse all with soft body parts and looking perfect.


*An example of another ad skating on the edge of being truthful. Fossil insects are implied to the unwary. Home Decorations?*

Fake amber is an industry all to itself, and has been for centuries. The material itself is often faked and so are animal and plant "inclusions" found in it. Not only can plastic resin be substituted for amber, but ground amber can be reconstituted as pressed amber, and so forth. Plastic resin fakes are easier to spot than pressed amber, which has properties similar to that of natural amber. Also, real amber may be heat treated to clarify it and produce "sun spangles" or small circular included planes that catch the light and glitter. Insects can be cast in resin within hollowed out real amber pieces. The buyer should be wary of small amphibians, reptiles or large insects that look too perfect (and offered at such a bargain price!). Real animal inclusions often are contorted or disarticulated from their struggles in trying to free themselves from the sticky resin. Real fossils also do not retain their original colorful skins or shells.

*The author acquired this piece of Baltic amber with 3 insect inclusions for about $30 at the Tucson Gem and Fossil show about 15 or 20 years ago. She's always been a bit suspicious about this piece, because the insects look a bit too perfect and there are those cracks in the piece right by two of the insects. But then there are the legs on the large insect sticking down into the next layer…*



*This is a piece of Dominican amber with a wasp inclusion. Buggy amber from the Dominican Republic tends to be very "dirty" and darker in color than Baltic amber. So the insects are harder to see. The wasp (in the lower left quadrant of the piece) has a more typical death pose than those in the Baltic piece.*

Quantities of fossils are being faked in China. Fossil reptiles and dinosaurs are favorite targets. These specimens often look too perfect, and the “fossil” part has been painted to distinguish it from the matrix. Other types of Chinese fake fossils are constructed all or partly out of real fossils, but faked to look like something they’re not – a giant fossil spider is faked from a real fossil crayfish, etc. Some interesting hybrid dinosaur hybrid fakes are done as well - causing fossils coming out of this country to be treated with suspicion.

So let the buyer beware! The best way to avoid fake fossils is to (1) collect them yourself, or (2) know the preparator.

# THE MAJOR GEOLOGIC EVENTS OF DEATH VALLEY

*A companion article to Andrew Dunning's online Meetup talk about Death Valley geology to GSOC on May 16, 2020.*

*By Carol Hasenberg*

*Zabriskie Point and badlands of light-colored Cenozoic playa sediments of the Furnace Creek Formation. Author photo.*

## A BEGINNER'S GUIDE

Death Valley National Park, the largest in area in the lower 48, boasts the lowest point in North America and the world record hottest temperature. It is also the driest desert in North America, contains relief of over 11,000 feet and exposes a remarkably full geologic history spanning 2.5 billion years (2.5 Ga.). The faults that created it are part of a system that in time may become the plate boundary between the Pacific and North American tectonic plates. Significant fossil finds from many different time periods have been made in the park. The combination of all these features make it one of the most geologically valuable sites in North America.

## GEOLOGY OF DEATH VALLEY ONLINE

*Andrew Dunning presented from "Death Valley", or the next best thing (DV background on Zoom).*

GSOC was privileged to have an excellent speaker in the form of Andrew Dunning, a recent graduate of geology at Portland State University, a former counselor at Camp Hancock who helped leading tours of this area in the September 2018 GSOC field trip there, and the creator of the Better Geology YouTube channel which we have referenced in previous articles, speaking to GSOC online at the May 2020 Meetup get together. Dunning also had the advantage growing up in Orange County, California, and visiting Death Valley numerous times throughout his young life to be able to take the audience on a thoroughly satisfying geotour of the area.

There are different ways to approach explaining the geology of Death Valley, whose rock history stretches way back possibly into the Paleoproterozoic, and also contains a nearly complete sequence of strata stretching from 1.3 Ga to the Permian period, 252 Ma. One might begin by describing Death Valley as a pull-apart basin whose modern topography began to take shape about 16 Ma. with the crustal extension and faulting that resulted when the Farallon tectonic plate was completely subducted by the North American plate in the vicinity of California, and the formation of the San Andreas fault. One can also describe the various regions of the Death Valley National Park in discrete physiographic units or units accessible from a particular route and proceed from there. The problem with these approaches is that one tends to de-emphasize the importance of the evolution of the area through the depths of time. So, the approach Dunning took by laying out the geology of Death Valley from deep time forward has great validity in understanding its importance in revealing tectonic processes in earth's history.

## RODINIA ASSEMBLY AND BREAKUP

*Layers in the Pahrump group found in Johnson Canyon of the Panamint Mountains. Photo by Andrew Dunning.*

Death Valley contains surface exposures of metamorphosed Proterozoic basement rock. The post-metamorphic dates given for this highly deformed material is 1.7 Ga., although there are trace dates of about 2.5 Ga., leading some investigators to believe that this area was a cratonic microplate (Mojavia), one of the building blocks of Laurentia (North American continent), or at least assembled atop subsurface fragments of older material. By approximately 1.7 Ga., Mojavia was accreted to the North American continent.

A gap in the sedimentary record occurred between 1.7 and 1.3 Ga., and the only material from that time are some dikes and plutons that intruded into the basement rock at about 1.4 Ga. Then additional, less deformed sediments began to accumulate in a shallow oceanic basin. A continuous record of these sediments to 1.08 Ga. exists in the Crystal Springs Formation of the Pahrump Group. The sediments consist of conglomerate, then sandstone grading to mudstone in the lower strata. Layers above these contain thinly bedded limestone with remains of microbial mats (stromatolites) and microfossils. These rocks were then intruded by diabase sills at about 1.0 Ga. and the heat cooked the surrounding carbonate rock into talc, which has been extensively mined in the area. The basin that accumulated these sediments may have been an extensional feature called an aulacogen, or failed crustal rift; although a more recent interpretation is that of an oceanic basin between converging continents in the assembly of the Rodinia supercontinent.

Another gap in the sedimentary record occurred between 1.08 Ga. and 787 Ma. Then the remainder of the Pahrump group (ending at 635 Ma.) records the beginning of the breakup of Rodinia and several other important geologic and evolutionary events. In the sequence of supercontinent breakup, the western coast of North America began to rift away from neighboring continents to eventually form a passive continental margin. In the Horsethief Springs (formerly the upper Crystal Springs) Formation, the Beck Dolomite, and the Kingston Peak formation the sedimentary and fossil record makes these outcrops "an iconic record of Neoproterozoic environmental change." The rise of multicellular organisms appeared during this time.

## SNOWBALL EARTH

*Noonday Dolomite polished in Mosaic Canyon contains clues about the end of global glaciation in the Vendian Period. Author photo.*

Around 750 Ma., the accumulation of diamictites and dropstones in the Kingston Peak Formation strengthens the evidence for the "Snowball Earth" or "Slushball Earth" scenarios, when Sturtian glaciation nearly or completely covered the earth. Scientists studying these periods have been in the process of carefully dating and recording the fossil content of the stratigraphy during this time to develop a picture of the changes to the biota before, during, and after the event, and understand causal relationships between life forms and the earth's climatic changes. A second major period of glaciation, the Marinoan glaciation, is postulated to have occurred around 635 Ma. and this event is recorded in the uppermost strata of the Kingston Peak Formation (and the Pahrump Group). Much more research is being conducted on these theories and the role of Death Valley strata in them, and we look forward to hearing about progress in the years to come.

The Death Valley strata that span the remainder of the Neoproterozoic and the Paleozoic Eras record accumulation of sediments from a passive tectonic plate margin as Laurentia travelled from its role in the supercontinent Rodinia to the assembly of the supercontinent Pangea in the Permian Period. The Noonday Dolomite is the first formation of the sequence, and its age is that of the Vendian (Ediacaran), the age of the earliest multicellular life. The Noonday Formation is believed to contain in its lowest member the "cap carbonate" layer formed when earth recovered from the global glaciation periods. The reader is referred to the Wikipedia article "Snowball Earth" for discussions about this and other mechanisms involved in the process of initiating global glaciation and recovering from the same. Towards the southwest the outcrops of upper Noonday Dolomite become the Ibex Formation, a deeper water counterpart.

*Mosaic Canyon parking lot in 2003. A fault runs up the cleft in the hills, with the Stirling Quartzite and Johnnie formations on the left and the Noonday Dolomite on the right (info from Geology Underfoot). At the edge of the parking lot cemented terraces from debris flows out of the canyon lithify quickly from cementation of the carbonate content of the material. Author photo.*

The contact between the Noonday and the underlying layers is also interesting, as it is an angular unconformity. In the southern end of Death Valley, the Noonday overlies the Kingston Peak Formation conformably but as one goes north it overlies progressively older layers, until it rests directly on the basement rocks. This would indicate that an upland had been formed in the north in the ancient Pahrump time and its highlands had eroded down to the Proterozoic basement complex. In Mosaic Canyon it is the Noonday Dolomite that is polished in the narrows area.

## PALEOZOIC ERA AND THE FOSSIL RECORD

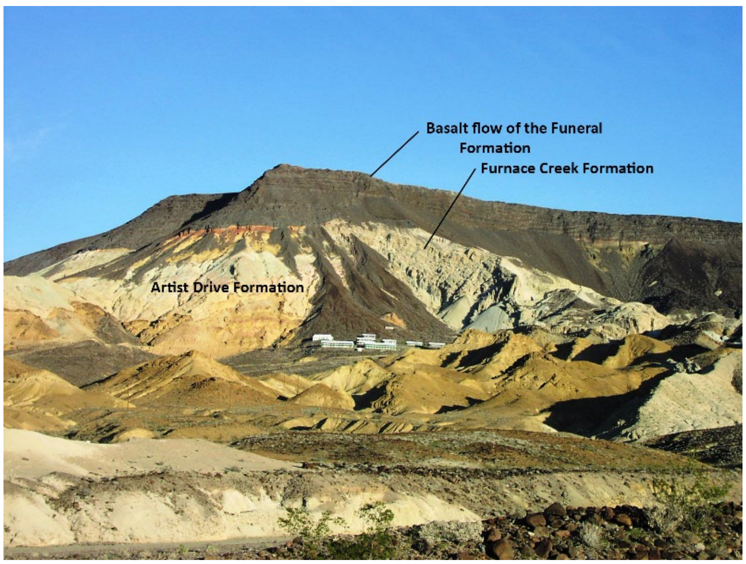

*Structures and fossils of the Paleozoic in Death Valley area. Photos by Andrew Dunning.*

Sedimentary formations which complete the sequence from the Neoproterozoic through the Permian period are the Johnnie and Stirling Quartzite, also of the Vendian (Period); the Wood Canyon, Zabriskie Quartzite, Carrara, Bonanza King and Nopah Formations of the Cambrian; the Eureka Quartzite and Ely Springs Dolomite of the Ordovician; the Hidden Valley Dolomite of the Devonian and Silurian; the Lost Burro and Tin Mountain Limestone of the Mississippian; and the Resting Spring Shale of the Pennsylvanian and Permian. This sequence of formations make a nearly continuous sedimentary record of a continental passive margin during the entire Paleozoic Era. From the Noonday Formation, the paleontological record has proceeded from the stromatolites and microfossils found therein to limited amounts of Ediacaran fauna in the Stirling Quartzite and finally, in the Wood Canyon Formation and above, the more familiar trilobites and other fauna of the Cambrian explosion, starting about 540 Ma. The record of marine fossils continues in nearly every one of the these formations, making this area an invaluable one to paleontologists. The sedimentary record reveals sea level fluctuations as well as periodic episodes of emergence from the ocean as demonstrated by fluvial braiding and other terrestrial processes.

*The older strata in Death Valley all show evidence of folding and thrust faulting that took place in the Mesozoic. Author photo.*

## THE BIG CRUNCH OF THE MESOZOIC

Then, beginning in the Permian Period at about 250 Ma., tectonic forces transformed this slowly changing undersea world forever. The supercontinent Pangea had assembled, and the west coast of North America was about to become an active plate margin. The landscape underwent violent transformations, but shaped itself into something we can more closely recognize today when we visit Death Valley NP. Although there is no sedimentary record for the Mesozoic Era in Death Valley, the effect of the tectonic processes on the previous stratigraphic record is clear to see in the folding and faulting that occurred during this time. The forces induced onto the North American continent by the subducting Farallon Plate was the cause of the massive compression. Also, the Sierra Nevada Mountain Range was forming in a similar manner to that of the Cascade Range today, and plutonic bodies intruded into the older strata as far east as the western mountain ranges of Death Valley NP. Uplift also occurred, and Death Valley was transformed from a continental shelf environment to a terrestrial landmass and has remained so to this day.




*The author's photo of Ryan Mesa and mining camp east of Zabriskie Point taken in 2003. Marli Miller had a similar photo showing the Cenozoic sediments and this photo is labeled in a like manner.*

So, Death Valley would not be a good place to look for dinosaur fossils, although Dunning pointed out that there have been dinosaur tracks found in sandstone south of the park. However, the igneous intrusions of the Jurassic and Cretaceous did cause a lot of metals to be deposited around their margins. There was a lot of mining done in Death Valley in the days of the Wild West, and interesting features along with the geology are the ghost towns from those days. Tourists of today also enjoy driving through Titus Canyon, which has a remarkable recumbent fold in the strata in which the older layers sit almost horizontally atop the younger layers.

In the north part of Death Valley NP, one can find sediments as old as the Late Eocene, the Titus Canyon Formation (38-35 Ma.). This formation consists of conglomerates, breccias, sandstones and finer strata. It was in this formation that the titanothere *Protitanops curryi*, a large rhino-like mammal, was discovered in 1935. Many other fossils, such as *Mesohippus*, an early horse, have also been discovered in this formation. During this time, the terrain that comprises Death Valley today was relatively flat and uniform; the valley that we know today had not developed yet.

## DEATH VALLEY FORMS IN THE MODERN TECTONIC ENVIRONMENT

During the Miocene at about 16-18 Ma., Death Valley began to transform itself into the valley we visit today. This process was also driven by tectonics. By about 20 Ma., the Farallon Plate had been consumed, and the Pacific Plate and the North American Plate were forming a strike-slip plate boundary, which we know as the San Andreas Fault. What had once been a compressional stress field now became a shear zone, with a right lateral movement direction. This shear zone has enlarged to affect the motion of most of California, and today up to 25% of the shear stress has been accommodated by motion on the strike-slip faults of the Eastern California Shear Zone and the Walker Lane Complex, of which Death Valley is a part. Some speculate that eventually the Pacific and North American plate boundary may be located east of the Sierra Nevada.


*Various Cenozoic sediments in Death Valley area. Fossil footprints found in the Panamint Mountains and the Black Mountains are extraordinary. Photos by Andrew Dunning.*

It was also during the Miocene that the Basin and Range physiographic province developed in the western interior of the continent, which is characterized by east-west crustal extension. Certainly, the elimination of subduction compressive stress was a factor in its creation, and other tectonic processes may have been involved, since the subducted Farallon plate was freed from its western edge constraints over a large area. So the creation of the valley was a product of the shearing of the western margin of the continent plus the extension happening in the interior. Today strike-slip fault zones combine with normal faults to produce a trapezoidal "pull-apart basin" that is Death Valley proper, and several other valleys in the vicinity were formed in this manner.

Getting back to the stratigraphy, the valley formation enabled sediments to collect and form rock. Conglomerates from alluvial fans ("fanglomerates") and playa and lake sediments are present in Miocene deposits. Also regional and local volcanic centers spewed ashfall tuffs and basalts into the valley sediments. Artist Drive and Furnace Creek Formations contain playa sediments and igneous tuffs from the early to mid-Miocene. Other Miocene to Pliocene formations include the Nova Formation, the Funeral Formation, and the Copper Canyon Formation. The Copper Canyon Formation contains one of the world's most valuable animal track sites from about 5 Ma.

## PLEISTOCENE LAKES IN DEATH VALLEY AREA

Death Valley was filled by a large Pleistocene lake, Lake Manly, which waxed and waned in the valley for at least 200 ka. At is largest extent, it was up to 600 feet deep. Many lakes existed in the other valleys of the area, and they were much interconnected by streams and channels. Lake Owens, Lake Searles, Lake Panamint, Lake Tecopa and Devil's Hole in Nevada were part of that system. We know they were connected because of the desert pupfish. These hardy descendants of a formerly larger population inhabited the vast system of lakes and streams. They hang on in isolated colonies in Owens Valley, Salt Creek, Saratoga Springs, and Devil's Hole.

## DEATH VALLEY TODAY

Bajada on the west side of Death Valley. Author photo.

Lake Manly dried up about 15 ka., although a much smaller remnant lingered on until about 2000 years ago. People of the Clovis Culture inhabited the valley starting about 9000 years ago. But today the forbidding topography and parched climate discourages permanent habitation. The once abundant waters of the lake have dried into a thick and forbidding salt pan with place names like Badwater and The Devil's Golf Course. The valley floors are nearly flat playas, filled by thousands of feet of sediment. The valley sides are bounded by strike-slip and normal faults. Features of normal faulting include faceted spurs, wineglass canyons, alluvial fans and fault scarps which cut across the fans. The eastern face of the Panamint Mountains (which form the western side of Death Valley) is bounded by a massive bajada constructed of old alluvial fans which have merged into a continuous slope. Several dune fields exist in the valley floors with sand dunes up to 700 feet in height.

Vulcanism is also a common feature of today's Death Valley, and there are volcanic features that are as young as several thousand years. Ubehebe Crater, on the north side of the park, was blasted out of Miocene basin sediments by a phreatic explosion several thousand years ago. Several cinder cones dot the same area. Badlands were carved from Miocene ashfalls and lake sediments. The geology of Death Valley continues to evolve and change with time.

*Author standing on the Devil's Golf Course in 2003. These salt deposits from Lake Manly, which have buckled from growth of the salt crystals are unexpectedly craggy. Telescope peak and the Panamint Range rise 11,000' in the background. Author photo.*

## AUTHOR'S COMMENTS ON THE GEOLOGY OF DEATH VALLEY

The author visited Death Valley in 2003, and the things that she noticed were how many features of this desert valley were created by water and volcanoes. How little did she know about the vast history that is encapsulated by this amazing landscape! The oldest rocks in the park, the Proterozoic basement complex, are exposed along the western slopes of the Panamint and Black Mountain Ranges, and these ranges also expose large cross sections of the park's geologic history. A return trip is definitely in order.

## References and Additional Reading

But wait! There's lots more reading to do on the geology of Death Valley…Here's a list of the material that the author referenced in the writing of this introductory article:

Marli B. Miller and Lauren A. Wright, Geology of Death Valley National Park, Third Edition, 2015, Kendall Hunt Publishing Company. An invaluable reference on the subject, lavishly illustrated with color photos, maps, and road trip guides.

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Ian Norton, "Two-stage formation of Death Valley", Geological Society of America *Geosphere*; February 2011; v. 7; no. 1; p. 171–182.

Wikipedia articles "Geology of the Death Valley Area", "Snowball Earth" and "Ubehebe Crater".

Andrew Dunning's recommended reading list:

- A Trip through Death Valley's Geologic Past: The Magnificent Rocks of Death Valley (Kenneth E. Enger)
- Death Valley: Geology, Ecology, Archaeology (Charles B. Hunt)
- Geology Underfoot in Death Valley and Owens Valley ( Robert P. Sharp and Allen F. Glazner)
- Hiking Death Valley by Michael DiGonnett

## OXYGEN ISOTOPE ANALYSIS IN PALEOCLIMATOLOGY

*By Carol Hasenberg*

*The intent of this article is to provide a simplified explanation for the uses of oxygen isotope analysis in determining past climatic conditions. We've had several speakers over the last few years who have used or made reference to this type of analysis and so you might find this information helpful in understanding a future GSOC talk.*

Most of us are familiar with the "solar system" type atomic model of oxygen from our K-12 education, having 8 electrons, 8 protons and 8 neutrons. In actuality, there are quite a few types of oxygen atoms out there, some containing as few as 3 neutrons and as many as 18 neutrons! Fortunately for scientists, only 3 of these oxygen isotopes are stable: the familiar $^{16}O$ isotope; the 9-neutron type $^{17}O$; and the 10-neutron variety $^{18}O$. The others are radioactive and unstable. I'm going to be notationally lazy and call these O16, or "light" oxygen, O17, and O18, or "heavy" oxygen.

99.762% of the oxygen found in earth's atmosphere is O16 and 0.204% is O18. O17 comes in a distant third in abundance at 0.037%, and is generally not studied in these analyses. Since they are stable, at any time the earth contains a finite number of these isotopes and we'll be looking at how they are distributed in atmospheric water, surface water, and the oceans. This analysis is a type of shell game for any given climatic condition and global climate is the primary factor in variations of O18 abundance in any one location, although other factors come to play in analyzing samples and determining past climate temperatures.

The core observation driving the model used in paleoclimate analysis of oxygen isotopes is that heavy oxygen is less likely to evaporate than light oxygen. That is, it takes relatively more energy for a water molecule containing a heavy oxygen isotope to evaporate, and this effect is more pronounced the lower the temperature of the atmosphere. The scientific term for this effect is **fractionation**, a process of concentrating certain types of matter (in this case isotopes) in response to a phase change.

The abundance of heavy oxygen in comparison to light oxygen is measured in a unit called $\delta^{18}O$ (delta OH-eighteen), calculated from the following formula:

$$\delta^{18}O = \left( \frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1 \right) * 1000\ {}^{o}\!/_{oo}$$

The standard ratio is based on a value called Vienna Standard Mean Ocean Water (VSMOW) where O18 to O16 is 0.020052 -- this is an arbitrary value selected by an international standard agreement. The unit symbol ‰ refers to parts per 1000 and is called a "per mille" symbol. Using this formula, we characterize an overabundance of O18 with a positive value and a dearth of O18 with a negative value.

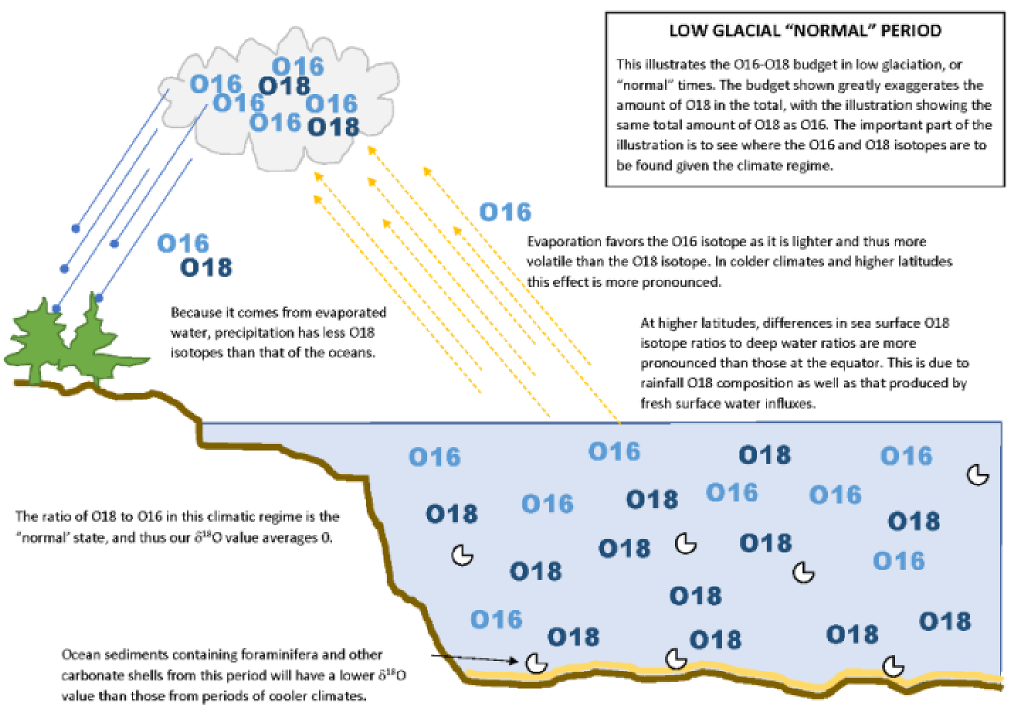



Figure 1. Oxygen isotope balance during a low glacial "normal" period.

Looking at Figures 1 and 2, we see that the fractionation of O18 is more pronounced in colder conditions than in warmer "normal" conditions. This means that in colder conditions evaporated water has more O16 than in warmer conditions. The opposite is true for oceans during colder conditions – there we find a higher concentration of O18 in colder than in warmer conditions. So when we are looking for evidence of past paleoclimates, it matters where and what we are sampling as to how the data is analyzed.

A common proxy used in the analysis of past climates is by measuring $\delta^{18}O$ in the carbonate shells of foraminifera and other carbonate shelled animals that collect in ocean floor sediments. When these creatures die the shells fall to the sea floor. Because the sediments come from animals living in the ocean, higher $\delta^{18}O$ values indicate a colder past climate and lower $\delta^{18}O$ values indicate a warmer past climate. Analysis may also be species, and even size-specific for data consistency.

Conversely, if the samples are ice taken from ice in glacier cores, lower $\delta^{18}O$ values indicate a colder past climate and higher $\delta^{18}O$ values indicate a warmer past climate. This is because the glacier ice lies on the other end of the evaporation cycle described in Figures 1 and 2.

Ok, now that we've gotten the basic principles down, what do these oxygen isotope analyses show for past climates? Here are examples of paleoclimatology for the Pliocene/Pleistocene to modern times, and the Cenozoic era.

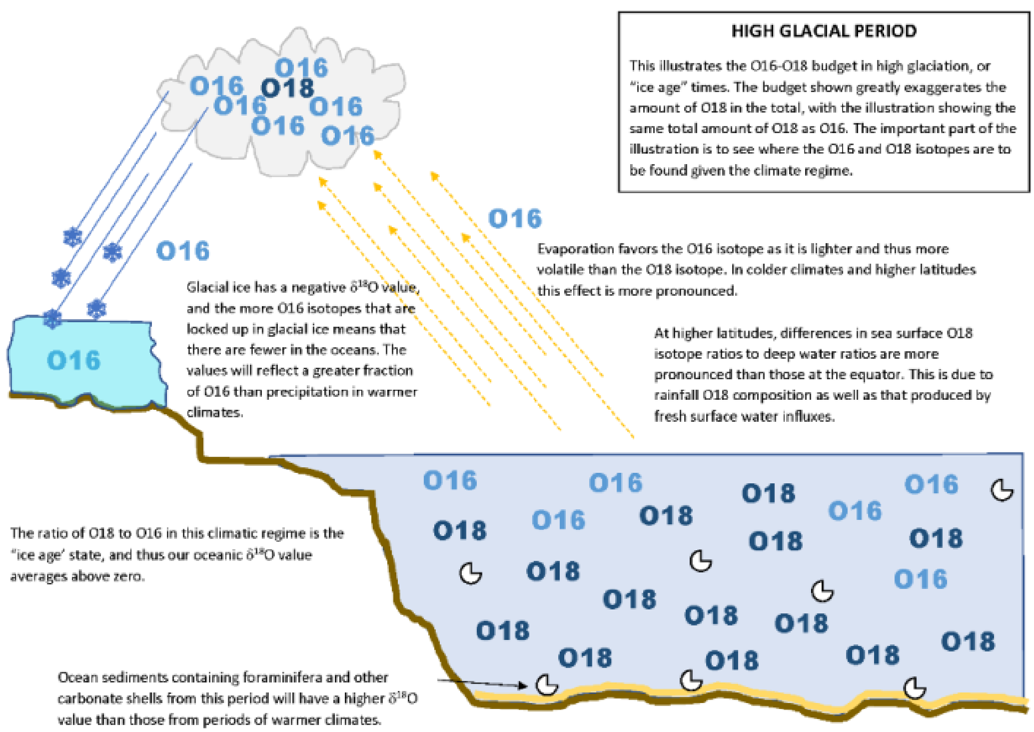
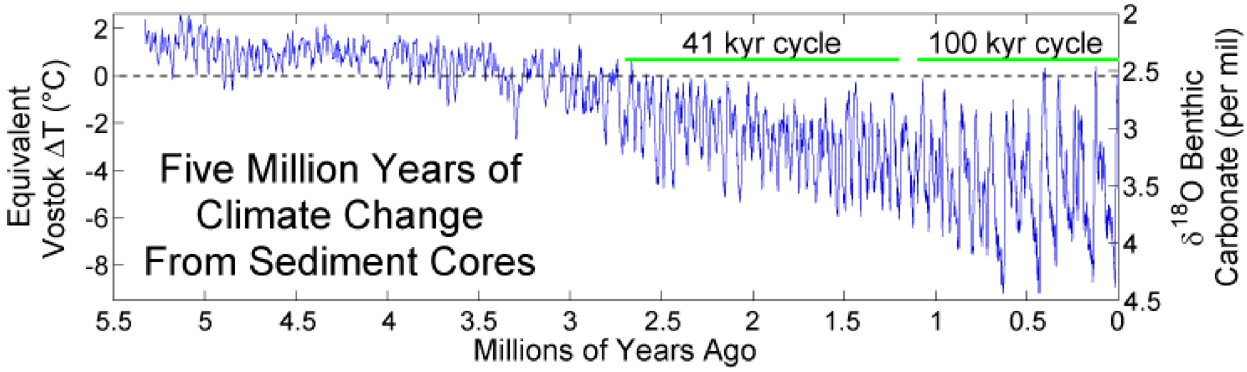
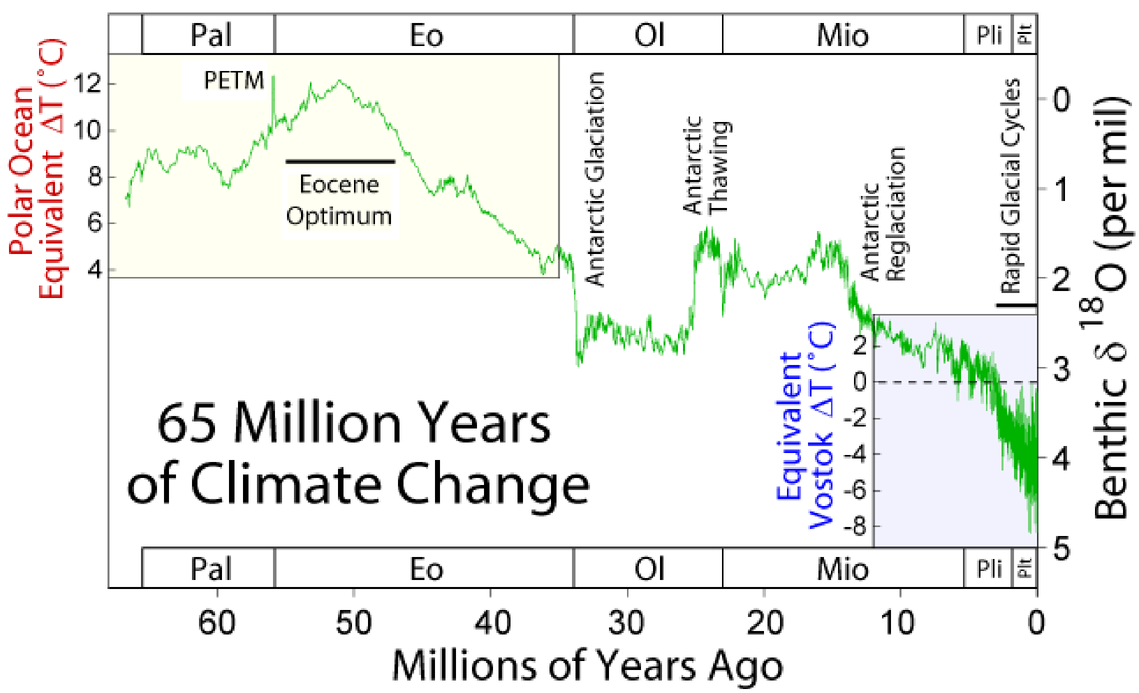


Figure 2. Oxygen isotope balance during a high glacial period.




The first example comes from data obtained in a 2005 (Lisiecki and Raymo) study and is the product of stacking 57 foraminifera records from seafloor sediment cores around the world together, which averages the values and decreases the influence of ocean currents and other local anomalies. The record serves to confirm the timeline for the beginning of the Pleistocene ice age. It also has a pattern of cycles which do correspond to astronomical data for the earth's orbit and wobble (Milankovitch cycles). The right-side scale refers to the $\delta^{18}$O values taken in the 2005 stacked records. The scale on the left is the corresponding temperatures derived from the $\delta^{18}$O values in ice cores for 420 ka taken in Vostok Station, Antarctica, in the 1970's.

The second example comes from a study done with a larger scope of time as its target. This study was based on data from the Deep Sea Drilling Project (1968-1983). Here we see a very amazing account of the past temperatures during the Cenozoic record. Earth's oceanic temperatures have varied quite a lot. During the Eocene epoch, for example, Antarctica was not frozen as it is today, and temperatures everywhere were quite a bit warmer. All this data gives climate scientists a way to look at the past and also a lens from which to view the future.



### Citations for illustrations used in this article:

Pages used to collect illustrations with references to data origins: https://commons.wikimedia.org/wiki/File:Five_Myr_Climate_Change.png, https://commons.wikimedia.org/wiki/File:65_Myr_Climate_Change.png and https://en.wikipedia.org/wiki/Vostok_Station#Ice_core_drilling.

65 Ma data illustration: CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=466265

5.5 Ma data illustration: By Dragons flight (Robert A. Rohde) - original image by User:Dragons flight, based on data (figure 4?) from Lisiecki and Raymo (2005), CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=449975

### References and Additional Reading

R. Dorsey, "A Brief Explanation of Oxygen Isotopes in Paleoclimate studies,"

Lisiecki, L. E., and M. E. Raymo (2005), "A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records," *Paleoceanography*, 20, PA1003, doi:10.1029/2004PA001071.

Zachos, James, Mark Pagani, Lisa Sloan, Ellen Thomas, and Katharina Billups (2001). "Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present". Science 292 (5517): 686–693. doi:10.1126/science.1059412.

Zachos, James C; Stott, Lowell D; Lohmann, Kyger C (1994): "Stable isotope ratios of foraminifera from various DSDP/ODP sites." PANGAEA, supplement to: Zachos, JC et al. (1994): "Evolution of early Cenozoic marine temperatures." Paleoceanography, 9(2), 353-387,

Wikipedia articles "Isotopes of oxygen" and "δ18O."

Synopsis of the Deep Sea Drilling Project: 50 Years of Ocean Discovery: National Science Foundation 1950-2000, Ocean Studies Board, National Research Council, ISBN: 0-309-51744-3, 276 pages, 8.5 x 11, (2000), pp. 59-61,124-125.

NASA Earth Observatory Website has a good explanation of paleoclimatology and its relationship to Earth's orbit (Milankovitch cycles)

Harvard University's page on Equable Climate evidence https://www.seas.harvard.edu/climate/eli/research/equable/evidence.html

Ana Christina Ravelo! and Claude Hillaire-Marcel, "The Use of Oxygen and Carbon Isotopes of Foraminifera in Paleoceanography," Chapter 18, *Developments in Marine Geology*, Volume 1 r 2007 Elsevier B.V., ISSN 1572-5480, DOI 10.1016/S1572-5480(07)01023-8.

### Videos

Minute Earth, "How These Sea Shells Know the Weather in Greenland," A really fun You Tube video!

Callan Bentley, "An introduction to isotope fractionation," You Tube video containing simple explanations for isotope fractionation

A longer but very worthwhile lecture from The Geological Society London Lecture Series of 2015 features University of Cambridge professor Colin Summerhayes' lecture "Earth's Climate Evolution." The lecture reviews the history of climate research in tandem with development of plate tectonics and other key geological developments to future climatic predictions. It is well-produced and easy to hear and has some great slides.

Are you planning your career and interested in this dance between life and climate and geology? Check out this video about the emerging multidisciplinary field of biogeodynamics.

## MORE ON STABLE OXYGEN ISOTOPES

The geochemistry of rocks is a study that brings many great tools to the geologist's tool chest. In the last article from October 2020, "Oxygen Isotope Analysis in Paleoclimatology," I addressed an aspect of the geochemistry of the ocean and **meteoric** water on earth (meteoric water being rainwater, snow, water vapor in clouds, etc.) in the form of oxygen isotope distribution. This is a sort of shell game using stable isotopes of oxygen and how they are preferentially distributed in the waters of the earth. I will in this article explore the distribution of oxygen isotopes in rocks of the earth. These types of analyses are commonly used in many aspects of geological research and the reader will undoubtedly run across them in academic papers.

This article is not intended as a mathematical derivation of the equations used in isotope **fractionation** studies. (Recall that in the October 2020 article the term fractionation was described as a process of concentrating certain types of matter, in this case isotopes, in response to a phase change.) Instead, I will discuss in qualitative terms the principals that dictate how stable isotopes of oxygen distribute themselves in the rocks of the earth, and the resulting ranges of the isotopic ratios one expects to find in the rocks of the world.

The stable oxygen isotopes are introduced in the October 2020 article and the two studied most often are heavy oxygen, $^{18}O$, and light oxygen, $^{16}O$. The one equation I've used is one that defines a comparative ratio of the amount of heavy oxygen, $^{18}O$, in the study substance to the amount of $^{18}O$ found in seawater during "normal" climatic conditions:

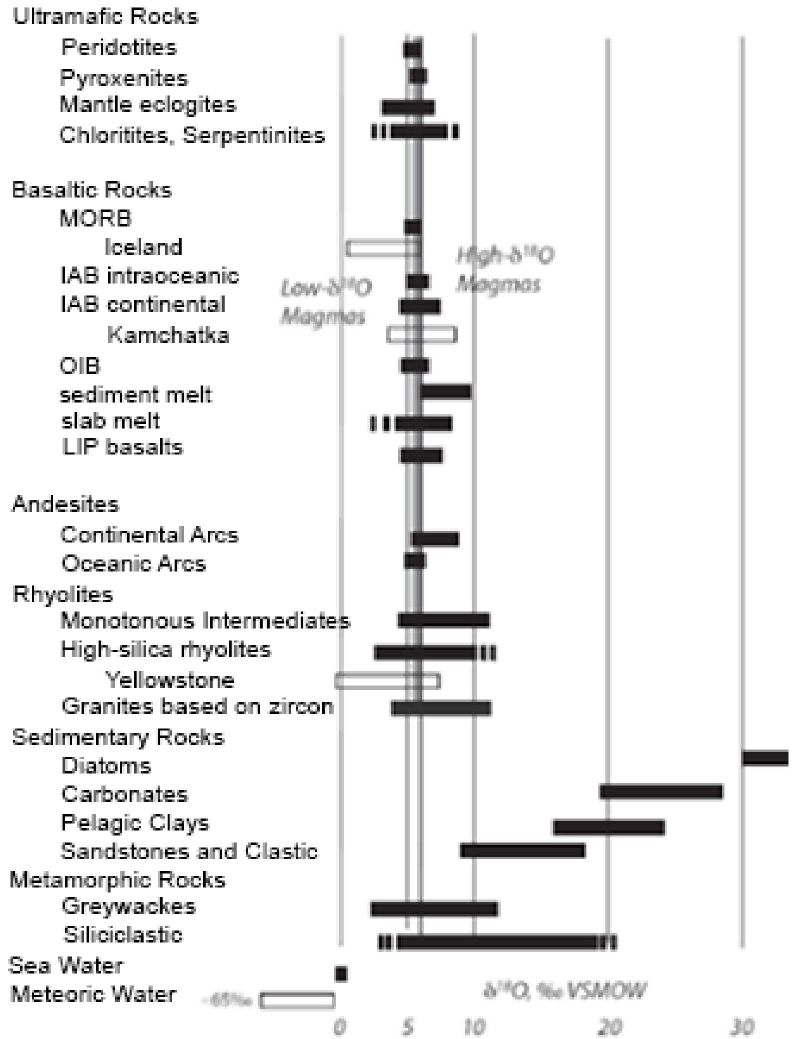
$$\delta^{18}O = \left( \frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1 \right) * 1000\ ^o/_{oo}$$

And, in paleoclimatic studies as discussed in the October 2020 article, it has been determined that $\delta^{18}O$ values are 0 for "normal" seawater, and vary at a ball park range between -5 and +5‰ for meteoric water vs. glacially depleted ocean water. Also, the driving force behind the fractionation of oxygen isotopes in water is that the $^{18}O$ isotope forms tighter bonds in water molecules than their $^{16}O$ counterparts and so are more difficult to vaporize into the atmosphere.

The same principle is true in rocks with oxygen bonds. Quartz is the perfect example and the bonds between silicon (Si) and oxygen in this pure silicate compound ($SiO_2$ lattice) are strong covalent bonds. In fact, quartz is the mineral with the highest preference for heavy oxygen (8.2‰) because the heavy oxygen forms such strong bonds in this substance. Metals tend to form less strong bonds with oxygen than silicon, so minerals with metal-oxygen bonds are less rich in heavy oxygen. Some other values of $\delta^{18}O$ for common rock minerals are 7.5‰ for albite and potassium feldspar, 6.6 ‰ for anorthite (Ca, Na feldspar), 6.4 ‰ for zircon, 6.3 ‰ for pyroxene graduating down in amphibole, biotite, garnet, and olivine to 6.1 ‰, 4.9 ‰ for ilmenite and 3.5 ‰ for magnetite. So we see that felsic minerals (i.e., quartz and feldspars) found in granites and rhyolites are higher in heavy oxygen than mafic minerals (ones containing iron and magnesium) which are abundant in the earth's mantle.

The bar graph in Figure 1, reproduced from the Bindeman 2008 article, shows the measured ranges in various categories of rocks. At the top of the figure we see $\delta^{18}O$ ratios for mantle rocks lies between the gray lines of 5.5 to 5.9 ‰. The first two rock types typify some mantle minerals and exhibit this range of values. The next category, basalt, has some variations but the MORB (mid-ocean ridge basalt) and the oceanic IAB (island arc basalt) fall very close to the mantle range, their source of material.

In both mantle and arc derived rocks, the ranges of $\delta^{18}O$ becomes more variant when the magma source is mixed with felsic continental rocks or hydrated rocks. Due to their own amounts of $^{18}O$, these substances can either increase the $\delta^{18}O$ value (adding seawater, continental crust) or decrease it (with rocks hydrothermally altered by meteoric water). As we move to continental magmas in the andesite and rhyolite categories, we see that most of these exhibit $\delta^{18}O$ values above those of mantle-derived rocks, since they contain abundant quartz and feldspar minerals with a higher $\delta^{18}O$ ratio than the mantle constituents. However, meteoric water in the mix can act to reduce the $\delta^{18}O$ values. The Yellowstone rhyolites have a very low (but still positive) $\delta^{18}O$ value due to the mixing of the magma with meteoric hydrothermal water.




Sedimentary rocks have even more complex sources of $\delta^{18}O$. Since many sedimentary rocks found on continents were formed in the oceans, we need to look to the source of much of this sediment. Diatoms construct silica shells with very high $\delta^{18}O$ values of 30+ ‰ in their cold oceanic habitats. These tiny creatures are abundant in the ocean and when they die, their shells rain down on the ocean floor creating deep sea sediments of chert. Carbonates formed from

*"Figure 1. Oxygen isotopic variations in magmas and rocks on Earth. Gray band between 5.5 and 5.9 represents "normal- $\delta^{18}O$ magmas" for ultramafic and basaltic rocks that constitute predominant mantle and products of is melting; closed system differentiation of such magma into andesite and rhyolite that show normal $\delta^{18}O$ values of 5.8 to 6.5 ‰ ... High- $\delta^{18}O$ rocks and magmas result from low-temperature precipitation or interaction with sea water... Low- $\delta^{18}O$ rocks and magmas result from high-temperature interaction with, or subsequent remelting of, materials that interacted with meteoric waters at high-temperatures.... Data are from both original sources and compilations by Muehlenbachs (1998); Eiler (2001), Valley et al. (2005); Hoefs (2005); Sharp (2006). Selected areas emphasized in this review are shown as open boxes." Ilya Bindeman, 2008.*

coral reefs are likewise high in $\delta^{18}O$. This greatly increases the $\delta^{18}O$ values of the sediments that contain them. This explains the high $\delta^{18}O$ values in the sedimentary and metamorphic rock sections.

Stable isotope geochemistry has been used extensively in the studies of magma and ultimately, continental crust and mantle evolution. These studies have developed over the last 50 years, and until the new millennium, were performed on larger, whole rock sample sizes. Nowadays the sampling process can pinpoint tiny areas on single crystals using laser technology, providing a revolution in accuracy of the measurements. For example, phenocrysts in a magma melt may be quite different in age and creation environment than the liquid melt, and so would yield different results and skew the results found in whole rock analysis. Durable crystals such as zircon can have growth rings and different crystallization environments on a single crystal, necessitating the use of pinpoint accuracy for correct analysis.

I hope that this article helps you to feel a bit more comfortable with stable isotope geochemistry. I have concentrated on the element oxygen because it is the most abundant element in the earth's crust and atmosphere, and is most extensively used in geochemistry studies. Other traditionally studied elements with multiple stable isotopes include carbon (C), nitrogen (N), hydrogen (H), sulfur (S), lithium (Li), and boron (B), and added to that are newer iron (Fe), molybdenum (Mo), and copper (Cu) stable isotope systems.

This is the second article in the geochemistry series. I've got one more in the works for zircon geochronology, or the age dating of zircon crystals. These articles are intended to give our readers a bit of background in the technology that is driving modern geological research.

### References

Ilya Bindeman, "Oxygen Isotopes in Mantle and Crustal Magmas as Revealed by Single Crystal Analysis," Reviews in Mineralogy & Geochemistry, Vol. 69 pp. 445-478, Mineralogical Society of America, 2008. I used the introductory parts of this article to get most of the technical info found in this article. The author goes on to discuss stable and unstable equilibrium in magma melts in the meat of the article which gets fairly technical. There is also more info on laboratory techniques.

J. W. Valley, J. S. Lackey, A. J. Cavosie, C. C. Clechenko, M. J. Spicuzza, M. A. S. Basei, I. N. Bindeman, V. P. Ferreira, A. N. Sial, E. M. King, W. H. Peck, A. K. Sinha, C. S. Wei, "4.4 billion years of crustal maturation: oxygen isotope ratios of magmatic zircon," Contributions in Mineral Petrology, (2005), DOI 10.1007/s00410-005-0025-8. I haven't completed reading this article, but a key component of its analysis is oxygen isotope research. It discusses earth's mantle development and continental growth of the early earth. John Valley is a leading expert in the field of geochemistry and is a professor at the University of Wisconsin.

Quartz lattice reference By Andel - Own work, Details see below, CC0, https://commons.wikimedia.org/w/index.php?curid=79753303

### Recommended Videos

There aren't any cartoonish, lite-technical explanatory videos that I could find specifically for this topic. The reader may want to refer to the videos about stable isotope fractionation referenced in the October 2008 article for some intro concepts.

Ann Bauer, University of Wisconsin, "Chemical Crustal Evolution & Oldest Crust, PCE3 Prebiotic Chemistry," October 10, 2020. This is a great educational lecture about the crustal evolution of the earth which addresses the role of the evolution of granitic rocks as a proxy to the existence of surface water, the significance of the oxygen isotope composition of the Jack Hills zircons, the evolution of the chemical composition of mantle and crustal melts, models for crustal growth over earth's history, crustal composition over time, the inception of plate tectonics, and plate tectonic models of the early earth. Some knowledge of chemistry and isotope analysis is needed, but her explanations are excellent and help the reader get more comfortable with some of the momentous topics she is covering. This type of research is at the heart of modern geology. 48 minutes.

W.M. White, "Introduction to the stable isotope Lecture," Feb 1, 2016, 38 minutes. and "Stable Isotopes fractionation and use in geosciences," GeoOceanology YouTube channel, Oct 14, 2016, 61 minutes. These lectures explore the technical details of isotope fractionation geochemistry. Not for the casual reader, but possibly helpful if you're planning to delve into some of the literature on geochemistry. This author, a professor of geology at Cornell University, has a leading textbook on the subject as well.

John Eiler, Geological and Planetary Sciences, Caltech professor of geology and geochemistry, "Sagan lecture: Isotope Geochemistry and the Study of Habitability and Life on Other Planets," 2010 AGU Fall Meeting, Dec 22, 2010. John Eiler is clearly a brilliant geochemist and a great speaker. In this lecture he describes the geochemical intricacies of determining if there is life on Mars. Armed with our small smattering of stable isotope geochemistry and a high school chemistry course you can probably make it through this lecture without having your head explode. 74 minutes.

Robert Hazen, Geophysical Laboratory, Carnegie Institution, and Executive Director and PI, Deep Carbon Observatory, "Mineral Evolution and Ecology and the Co-evolution of Life and Rocks," March 11, 2015, Simons Foundation YouTube channel. This video on mineral evolution is a bit off topic but I found it to be very very fascinating. Also probably the least technically difficult of the recommended videos. 45 minutes.

### Further Reading

These articles give the readers a taste of the range of studies being done using stable isotope geochemistry:

T. C. Feeley, M. A. Clynne, G. S. Winer, and W. C. Grice, "Oxygen Isotope Geochemistry of the Lassen Volcanic Center, California: Resolving Crustal and Mantle Contributions to Continental Arc Magmatism," Journal Of Petrology, Volume 49, Number 5, pages 971-997, May 2008. doi:10.1093/petrology/egn013.

Richard C. Greenwood, Jean-Alix Barrat, Martin F. Miller, Mahesh Anand, Nicolas Dauphas, Ian A. Franchi, Patrick Sillard, and Natalie A. Starkey, "Oxygen isotopic evidence for accretion of Earth's water before a high-energy Moon-forming giant impact," AAAS, Sci Adv. 2018 Mar; 4(3): eaao5928. Published online 2018 Mar 28. doi: 10.1126/sciadv.aao5928.

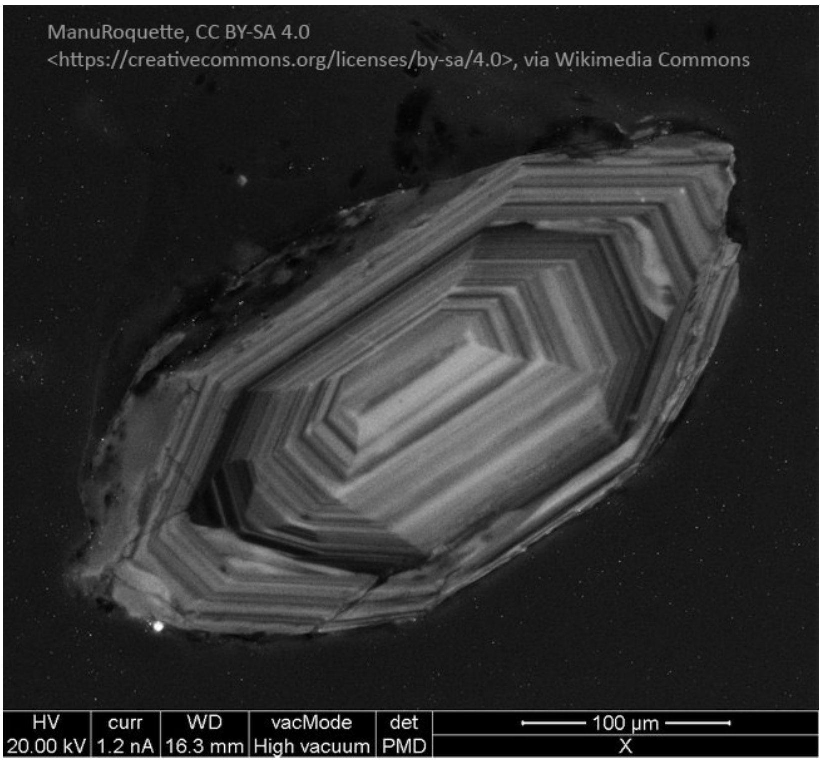
O'Neil, J. R. & Adami, L. H., "Oxygen isotope analyses of selected Apollo 11 materials," Geochimica et Cosmochimica Acta Supplement, Volume 1, Proceedings of the Apollo 11 Lunar Science Conference held 5-8 January, 1970 in Houston, TX. Volume 2: Chemical and Isotope Analyses. Edited by A. A. Levinson. New York: Pergamon Press, 1970., p.1425.

D. Rumble, S. Bowring, T. Iizuka, T. Komiya, A. Lepland, M. T. Rosing, Y. Ueno, "The oxygen isotope composition of earth's oldest rocks and evidence of a terrestrial magma ocean," AGU publication Geochemistry, Geophysics, Geosystems Volume 14 Number 6, June 2013

# A BRIEF INTRODUCTION TO ZIRCON GEOCHRONOLOGY

Zircon crystals—**zirconium silicate** to be precise—have become a very important age dating medium for geologists. Let's take a look at why, how geochronology analysis is done, and what types of applications are being made of this technology.

This article, the third in a series of three articles focused on geochemistry for fall and winter of 2020, have been written to **familiarize our readers with some key tools used in modern geological research.** Written in plain language, they describe the techniques used in analyzing these crystals. References to papers and videos are provided to further the reader's understanding of and provide insights on how these analyses are being used in geological research today.




*Zircon crystal SEM-CL image showing growth patterns similar to tree rings.*

*ManuRoquette, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons*

Zircon crystal age dating is conducted using the principals of radiometric dating. Basically, all **radiometric dating techniques** rely on measuring the ratio of two isotopes in a substance: the parent isotope which is radioactive and therefore unstable, and the stable daughter isotope which is the end product of the radioactive decay of the parent. (In our case the parent is uranium and the daughter is lead.) The radioactive decay of a substance follows an exponential curve, halving the parent amount in a time period equal to the "half-life" of the particular parent isotope. So the parent material never totally disappears, but shrinks to minute quantities over a handful of half-lives.

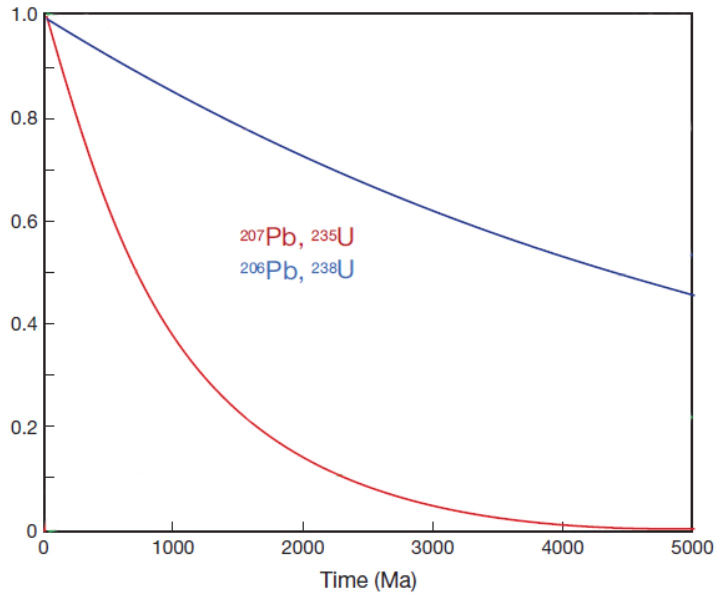



*Figure 1. The decay of uranium isotopes into lead isotopes follow exponential curves. The functions can be written in the form A(t)=0.5^kt where k is the reciprocal of the half-life and A is the remaining fraction, shown on the vertical scale. So, the amount of uranium converted to lead in the sample depends on the half-life of a particular isotope's decay process over the course of the sample's existence. The half-life of U235 is 704 Ma and that of U238 is 4468 Ma. Modified from Shoene 2014.*

Zircon crystals are ideal for age dating because:

- They are commonly formed in **felsic igneous rocks**, such as granitic batholiths. They can also be formed in **metamorphic** rocks. However, because the melting point of zircon is very high (800C), these processes may add on new layers to the crystal rather than completely reworking it.
- They are found in beach sand, river sediments, eolian sediments, alluvial sediments, turbidites, etc. The only rock that does not contain many zircons is basalt.
- They have a very high melting temperature and hardness, which means that they are very **durable**. They are nearly chemically non-reactive as well.
- They are heavy but also **non-magnetic**, which means that they can be easily separated from iron-based minerals.
- Their **heaviness** allows them to be easily separated from lighter minerals using a shake table. A dense fluid is also employed to separate the zircons, amongst the heaviest of minerals, from moderately dense materials.
- They contain a small but measurable amount of uranium which substitutes for the zirconium in the crystal lattice when the crystal grows. These are the isotopes $^{238}U$ and $^{235}U$, which are radioactive and decay into $^{206}Pb$ and $^{207}Pb$, respectively. Lead, which is the end product of the decay process, is nonetheless excluded in the crystal growth process of the zircon crystal. Because of this, the only lead isotopes that one finds in a zircon crystal are those produced by the radioactive decay of the uranium. The decay half-life of these processes (4.5 Ga and 700 Ma, respectively) are such that very **precise measurements can be made of very old rocks**.
- The two different decay systems in zircon crystals (from $^{238}U$ and $^{235}U$) can be cross-correlated by the use of **Concordia diagrams**. Should the crystals have leaked some lead isotopes during their lifetimes, this technique can (1) test for this problem and (2) resolve an actual date from the remaining isotopes.

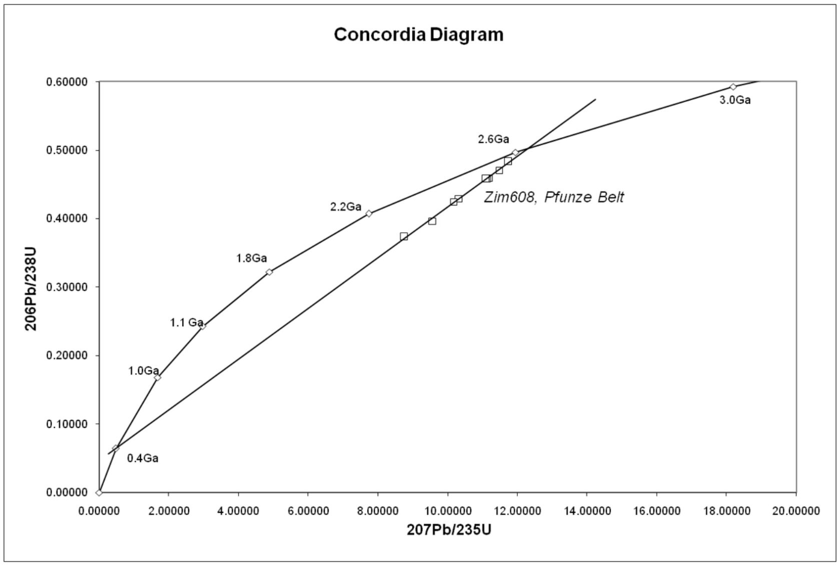



*Figure 2. "A concordia diagram as used in uranium–lead dating, with data from the Pfunze Belt, Zimbabwe. All the samples show loss of lead isotopes, but the intercept of the errorchron (straight line through the sample points) and the concordia (curve) shows the correct age of the rock." Illustration by Babakathy - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=5027761*

Techniques of zircon **geochronology** (radiometric age dating) have been refined to the point that very small laser incised samples can be taken to test. This has two advantages. Crystals with multiple stages of growth can be selectively sampled as they will yield multiple dates. Also, valuable specimens can be preserved for future analysis, such as the **Jack Hills specimens from Australia**, the oldest detrital zircons found. A variety of techniques for measuring ages of zircon crystals are employed, and their accuracy is such that an age date within about a million years can be achieved with rocks 3-4 billion years in age.

Oxygen can be extracted from zircon crystals using strong (hydrofluoric) acid and laser methods, and thus oxygen isotope analysis can be performed. This technique has given researchers additional information about the environment where the crystal has grown. Specifically, on the Jack Hills specimens, over 4 billion years in age, the researchers discovered that the $\delta^{18}O$ values indicate that liquid oceans may have existed a mere 200 million years after the assembly of the planet! These valuable techniques (geochronology and stable isotope geochemistry) are driving some intense research on the evolution of the planet.

**Detrital** zircons are those that have weathered out of the parent igneous or metamorphic rock and these can be found in sediments just about everywhere. These zircons are often analyzed by quantitative analysis. For example, a bucket of sand is extracted from a river or ancient lake bed and the results of all the ages of the zircons therein are plotted on the same graph. The peaks showing the most numerously computed ages are compared with possible igneous or metamorphic sources for the sediment. Since zircon geochronology is so precise, sources can often be pinpointed to a particular body of magma. This is particularly helpful in determining the courses of ancient drainage systems.

Detrital zircon analysis is limited only by the imagination of the researchers. Current research includes determining continental growth over time for the entire earth, and providing clues as to the rate of tectonic activity.

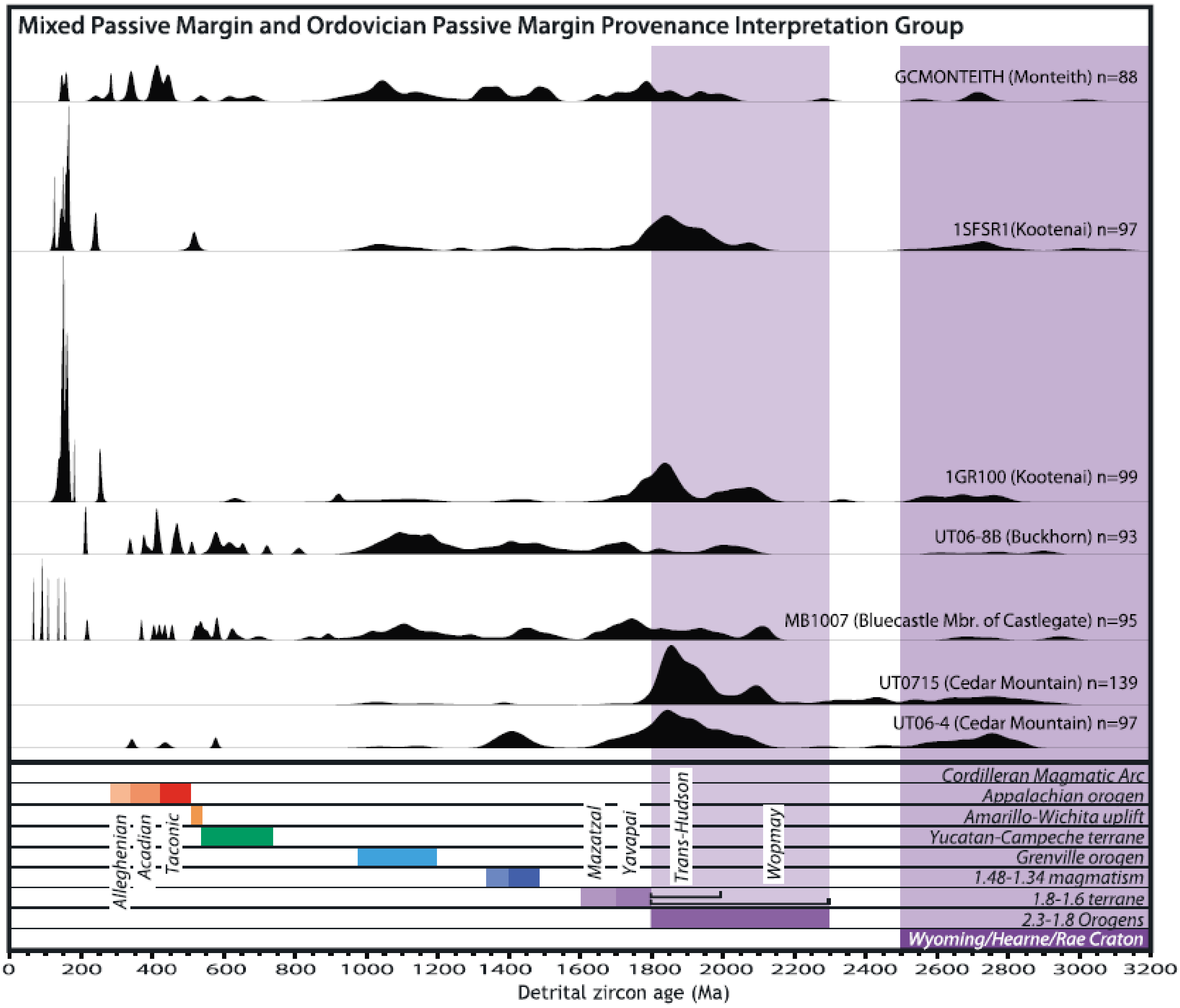



*Figure 3. An example plot from a quantitative detrital zircon study. Each line represents ages of samples taken from a particular location. Source ages can be shown to be regional when all the samples contain material of the same age or local when only one or two of the samples exhibit material from a particular time period. Time periods for potential source materials are shown in the lower lines of the diagram. From Laskowski et al, 2013*

## References


"Detrital zircon geochronology" from Wikipedia. There's a lot of information packed in this Wikipedia article about zircon age dating.

American Museum of Natural History, "Zircon Chronology: Dating the Oldest Material on Earth."

Blair Schoene, Princeton University, "U–Th–Pb Geochronology," Elsevier, 2014. Pg. 346 has a good description of Concordia plots in cross-correlating dates between multiple decay results. .

Concordia Diagram reference: Babakathy - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=5027761.

### Let's explore Zircon Geochronology with easy to understand videos:

Minute earth, "How to Date a Planet," is a fun way to learn the basics about U-Pb dating of zircon crystals. 3 min.

American Museum of Natural History, "Science Bulletins: Zircons—Time Capsules from the Early Earth." Zircons are tiny crystals with a big story to tell. Some of these minerals are the oldest Earth materials ever discovered, and therefore yield clues about what the planet was like after it formed 4.5 billion years ago. In this new Science Bulletins video, travel to a remote island off Greenland's coast and a zircon-making lab in New York State to learn how geologists are using these time capsules to build new hypotheses about the early Earth. 9 mins.

### More technical videos on Zircon Geochronology:

This video from Benjamin Shepler, whose You Tube channel has a remarkable set of chemistry- and physics-related educational clips, goes through the math calc for computing zircon age dates in "Uranium-lead dating." You do need to know the workings of a basic algebra equation and what a natural log is to feel comfortable here, but even if you're a bit rusty the math is pretty easy. 8 mins.

Want to get down to the nitty gritty and review and compare lab techniques for computing zircon age dates? Here's a great video by Prof. Greg Dunning in the Dept. of Earth Sciences, Memorial University of Newfoundland, Canada. 16 mins.

### World's Oldest Zircons:

Here's a news-flash style video from SciShow entitled "How the Oldest Rocks on Earth Changed History" that lays out the basics of what we know about the oldest zircon found from earth and more. 5 mins.

This presentation, "Zircons Are Forever: 4.4 Billion Year Record of Oxygen Isotopes in Zircons," by Liz King of the Geologists of Jackson Hole puts together oxygen isotope analysis with zircon age dating in discussing zircons from the Jack Hills. Who could ask for more? 70 mins.

Here's another video about work on the magnetic properties of the Jack Hills zircons by Caltech student Alec Brenner titled "Detrital Zircons of the Jack Hills, Western Australia: Rock Magnetic and Mineralogical Assessments." 18 mins.

### Source-to-Sink Provenance for Detrital Zircons:

USGS researcher Lydia Staisch has a nice explanation of her work on Pacific NW rivers on her website. Written document https://lydiastaisch.wixsite.com/lydiastaisch/ancestral-rivers and poster https://lydiastaisch.wixsite.com/lydiastaisch/publications and https://e7a5bd36-ac2d-4c73-8e88-aab523cef47a.filesusr.com/ugd/6e0220_aac394b2f19646baa956756b3ebe8285.pdf

Check out this video featuring Andrew Laskowski of Montana State University speaking to students from Montana Tech at in a talk entitled "Detrital Zircon Records of Cordilleran Mountain Building." This video discusses Phanerozoic (540 Ma. to present) detrital zircon sources for the North American continent, especially the transport of sediment from the Grenville and Appalachian orogenies to the western margins of the continent. His language does get a little technical at times but I think the basic idea and the scale of the project can be grasped. 64 mins.

Andrew Laskowski, Peter DeCelles, and George Gehrels, "Detrital zircon geochronology of Cordilleran retroarc foreland basin strata, western North America," Tectonics, Vol. 32, 1–22, doi:10.1002/tect.20065, 2013. . This article looks at detrital zircons and their sources in the western US.

### *Monitoring Tectonic Processes such as Continental Growth:*

"Reconciling the detrital zircon record and crustal growth within juvenile accretionary orogens," a short presentation by NMW Roberts and CJ Spencer of the NERC Isotope Geosciences Laboratory, Keyworth, UK and PA Cawood of the University of St Andrews, St Andrews, UK at the 2014 AGU Fall Meeting. This presentation discusses continental growth as measured by the earth's detrital zircon record. 14 mins.