

September 30, 2024

[J. Robert Oppenheimer on freedom and scientific inquiry](#)

News and notes

Before going on to discuss the natural nuclear reactors, such as [Oklo in Gabon](#), here are some news items I thought were interesting.

Free Geology Books

Free geology books can be downloaded from these sites, I'll add more as I find them:

- [OreZone Readers and Experts Telegram Channel](#); the Ore Zone channel also shows employment opportunities for geologists.
- [The Groundwater Project](#).
- [Lithium in Nevada-origins, extent, role in the energy transition, and implications for economic development and national security](#).

Geopolitics

- [Mali junta arrests four employees of Barrick Gold](#); accused of financial crimes.
- More financial shenanigans: [Glencore Congo copper mine hit with €800 million royalty row](#).
- Italian Prime Minister, Giorgia Meloni, [tears a strip off of France](#) and President Emanuel Macron for France's neocolonial policies in Africa.
- Related to last week's post on Gabon, video: [Gabon: How a Tiny African Nation Runs Russia's Shadow Fleet](#).
- Countdown to WWII:
 - [Hezbollah leader Hassan Nasrallah killed in Israeli strike](#);
 - [Prof. John Mearsheimer commentary on the Ukraine War](#);
 - [Putin reveals new rules on nuclear weapons in Russia's latest warning to the West](#);
 - [China Releases Photo of Rare ICBM Test in Pacific](#);
 - [Israel's army chief tells his forces to prepare for ground invasion of Lebanon: Wider Middle East war seems inevitable as region spirals towards disaster](#).

Research and News

- Geochemistry and the Eoarchean: [Seawater-oceanic crust interaction constrained by triple oxygen and hydrogen isotopes in rocks from the Saglek-Hebron complex, NE Canada: Implications for moderately low- \$\delta^{18}\text{O}\$ Eoarchean Ocean](#).
- Scientists behaving badly: [Fraud, So Much Fraud](#).

- If you are interested in the connection between Bourbon Whiskey and geology, check out [Episode 34 of the The Big Blue Rock Pod](#) from the [Kentucky Geological Survey](#).
- [Garnet chemical zoning: a clue for the tectono-metamorphic history of the Proterozoic Mayombe chain \(West Congo Belt\), Congo-Brazzaville.](#)
- Planetary geology: [Perseverance rover spots unusual striped rock on Mars.](#)
- Sand dunes: [Spatial variability in aeolian abrasion: Ibez Dune Field, Death Valley National Park.](#)
- [Toward defining the Anthropocene onset using a rapid increase in anthropogenic fingerprints in global geological archives.](#)
- [Earth Shattering Kabooms: Simulation of asteroid deflection with a megajoule-class X-ray pulse;](#) Live Science summary [here](#).

Coastal Geology

- [How do you save a sinking city?](#)
- [Third North Carolina house to collapse from erosion in a single week.](#)

Plate Tectonics

- [Mesozoic intraoceanic subduction shaped the lower mantle beneath the East Pacific Rise;](#) Phys.org summary [here](#).
- [Integrated analysis of the Neogene–Quaternary Valdera-Volterra Basin \(Northern Apennines\). Evidence for composite development of hinterland basins.](#)
- [Zircon geochemistry from early evolved terranes records coeval stagnant- and mobile-lid tectonic regimes;](#) Phys.org summary [here](#).

Paleontology

- [OSL dating of marine isotope stage 5e marine terrace deposits on southeastern Kii Peninsula, southwestern Japan.](#)
- [A New Tyrant Dinosaur from the Late Campanian of Mexico Reveals a Tribe of Southern Tyrannosaurs.](#)
- [Brazilian fossils reveal homoplasy in the oldest mammalian jaw joint;](#) Sci News summary [here](#).
- [Late Miocene transformation of Mediterranean Sea biodiversity;](#) Science summary [here](#).
- [Paleontologists unearth giant skull of *Pachyrhinosaurus* in northern Alberta.](#)
- My friend Graham Young is a co-writer on this paper: [An unusual strophomenide brachiopod association in the Late Ordovician William Lake Lagerstätte, Williams Member of the Stony Mountain Formation \(latest Katian\), Manitoba.](#)
- Video: [Arthropod Origins Revealed by Crazy Detailed Fossil Deep Evolution News.](#)

- [A Late Devonian coelacanth reconfigures actinistian phylogeny, disparity, and evolutionary dynamics](#); Phys.org summary [here](#).
- [Early Pennsylvanian Lagerstätte reveals a diverse ecosystem on a subhumid, alluvial fan](#); Phys.org summary [here](#).

Mining and Energy

- [Junior miners pocket provincial grants for mineral exploration](#).
- [Saudi Arabia Scraps \\$100 Oil Price Target to Boost Market Share](#).
- [The Pipeline Changing America's Access to Cheap Canadian Oil](#).
- Ooh, shiny: [Karelian closer to finding green diamond source in Finland](#).
- [Quantum CEO Claims the Shale Revolution Is Over](#).
- Deep sea mining research: [Insights Into a Correlation Between Magnetotactic Bacteria and Polymetallic Nodule Distribution in the Eastern Central Pacific Ocean](#); Phys.org summary [here](#).
- 23/09/24 [Trouble Deepens for North Sea Oil and Gas](#).
- [Foran advances McIlvenna copper-gold build in Saskatchewan](#).
- Coal fired electrical power plant: [The UK helped usher in the coal era – now it's closing its last remaining plant](#).
- [US backs Australian lithium, rare earths projects for up to \\$786 million](#).

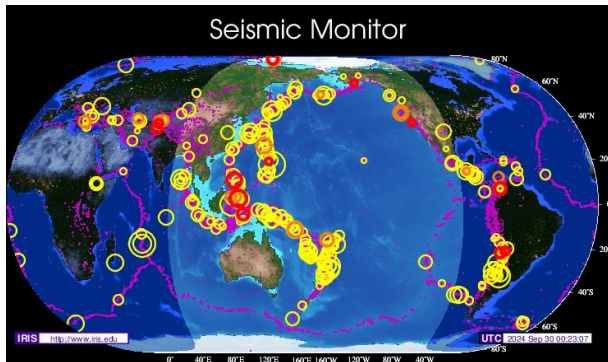
Environmental Geology and Hydrogeology

- [Hydrogeological structure of a seafloor hydrothermal system deduced from a pair of positive and negative self-potential anomalies observed at the Oomuro-dashi hydrothermal field in the Izu-Ogasawara Arc, south of Japan](#).
- [Cracks and sinkholes appear across Iran amid groundwater crisis](#).
- [Breaking: Fluoride in Water Poses 'Unreasonable Risk' to Children, Federal Judge Rules](#).
- [EPA Scientists Said They Were Pressured to Downplay Harms From Chemicals. A Watchdog Found They Were Retaliated Against](#).
- [\(De\)hydration Front Propagation Into Zero-Permeability Rock](#); Phys.org summary [here](#).

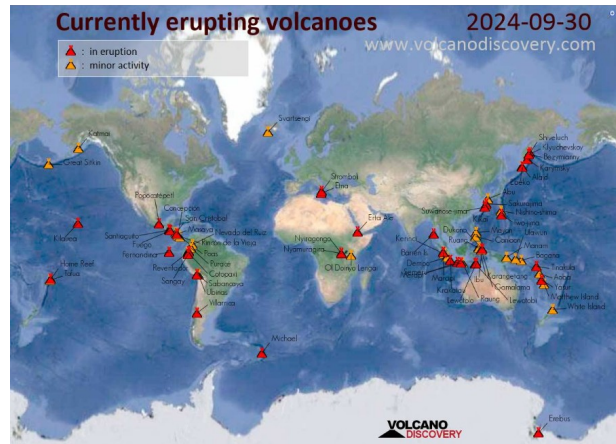
Glaciers and Climate Change

- Opinion poll from the US Environmental Protection Agency: "True or False: Humans are the dominant cause of climate change"; [guess the result](#).
- Opinion: [The Real 'Climate Change Deniers' Are Those Who Deny the Climate Changed Before We Started Burning Fossil Fuels, Says Geologist](#).

Volcanoes, Earthquakes and Geohazards



[Seismic Monitor](#)



[Active Volcano Map](#)

Volcanoes

- United States Geological Survey (USGS) Volcano Watch: [Understanding magma storage and migration in Kilauea's active East Rift Zone.](#)
- USGS Yellowstone Volcano Observatory: [Safety first when building roads and bridges in Yellowstone National Park.](#)
- [Smithsonian / USGS Weekly Volcanic Activity Report.](#)

Earthquakes

- [Euro-Mediterranean Seismological Centre](#)
- [Earthquakes Monitoring Live Worldwide.](#)
- From Kyle Bradley and Judith A Hubbard: [Does this machine learning model predict large earthquakes? Maybe not.](#)
- [Why Do Great Continental Transform Earthquakes Nucleate on Branch Faults?](#) Sorry, behind a paywall, Phys.org summary [here](#).

Upcoming Events

- [GeoFutures: Planetary Geoscience Conference](#), 14-15 November 2024, hybrid meeting.
- [The Saskatchewan Geological Open House, December 2 to 4, Delta Bessborough Hotel, Saskatoon](#); the Bessborough Hotel is the most beautiful building in Saskatoon.
- [Groundwater Week 2024](#), December 10-12 in Las Vegas, Nevada.
- [Copper to the World Conference, Tuesday 26 – Wednesday 27 August 2025](#), in Adelaide, Australia; report on 2024 conference [here](#).
- 2024-2025 [Society of Petroleum Engineers Distinguished Lecturer Schedule.](#)
- [List of geoscience events in 2025 from the International Union of Geological Sciences.](#)

September 30, 2024

Natural Nuclear Reactors – A Short Discussion



Figure 1 – Samples of Uranium Ore from Oklo
Credit: Ludovic Ferrière, Vienna Natural History Museum

It's great to get feedback on a blog post and with that in mind, this week we're going to take a break from geopolitics and look at the phenomena of [natural nuclear reactors](#). After last week's posting on Gabon, one of my readers, Marcus S., suggested a blog post just on the Oklo deposit in Gabon, a natural nuclear reactor. Another reader, Martin H., pointed out that there were actually three such deposits: [Oklo](#) and the closely associated [Okelobondo](#) and [Bangombe](#) deposits. Looking at the three, they can all be considered part of a single complex and we'll treat them as such. Many thanks to both Marcus and Martin.

Nuclear Reactions

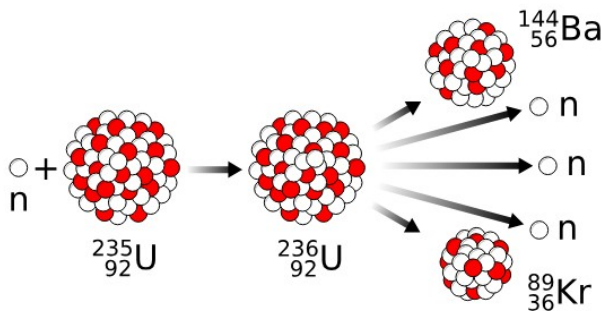
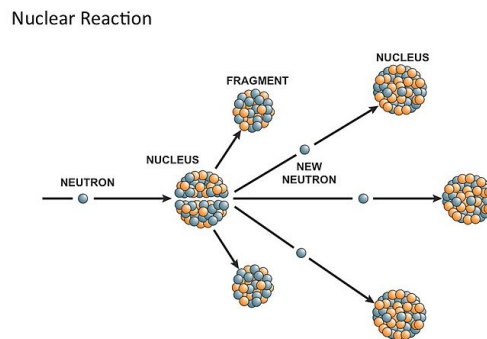


Figure 2 – Fission Reaction, Uranium 235
Credit: MikeRun, Creative Commons Attribution-Share Alike 4.0 International license



U.S.N.R.C.
United States Nuclear Regulatory Commission
Protecting People and the Environment
As of July 2018

Figure 3 – Nuclear Reaction
Credit: Nuclear Regulatory Commission, Creative Commons Attribution 2.0 Generic license

There are two kinds of [nuclear reactions](#) in nature: [fission reactions](#), where an atom splits, releasing [energy](#) and [neutrons](#); and [fusion reactions](#), where atoms fuse, also releasing energy and neutrons. The reactions that occurred in the Oklo complex were fission reactions, so let's take a look at those.

[Radioactive elements](#), like uranium, have unstable [nuclei](#) which spontaneously breakdown in fission reactions. Atomic fission can also be induced by the interaction of a neutron with the nucleus, as in Figure 2, a process sometimes called "[splitting the atom](#)". The neutrons released by a fission reaction can then go onto initiate a [chain reaction](#) that leads to further fission reactions, as in Figure 3. A controlled or limited series of continuous fission reactions will lead to a nuclear reactor; an uncontrolled or runaway series of fission reactions will lead to an atomic bomb.

While simple in concept, creating a controlled nuclear reaction proved to be a difficult task. One complexity had to do with the nature of neutrons, namely if the neutrons could be slowed down, or moderated, there was a much greater chance that they would interact with the nuclei of a [fissionable element](#). Materials that made good [moderators](#) are [graphite](#), [deuterium oxide \(heavy water\)](#), and ordinary or [light water](#). Another complication is that while both common [isotopes of uranium](#), U-235 and U-238, are fissionable, it is much easier to induce a chain reaction in U-235 and it is this isotope that is most involved in the nuclear reaction.

The [first artificial nuclear reactor](#) was built at the University of Chicago on Dec. 2, 1942, in a squash court under the stands of Stagg Field at the University of Chicago (nuclear safety was in its infancy). On August 6, 1945 an atomic bomb based on the U-235 reaction was [detonated over Hiroshima, Japan](#).

The Oklo Deposit

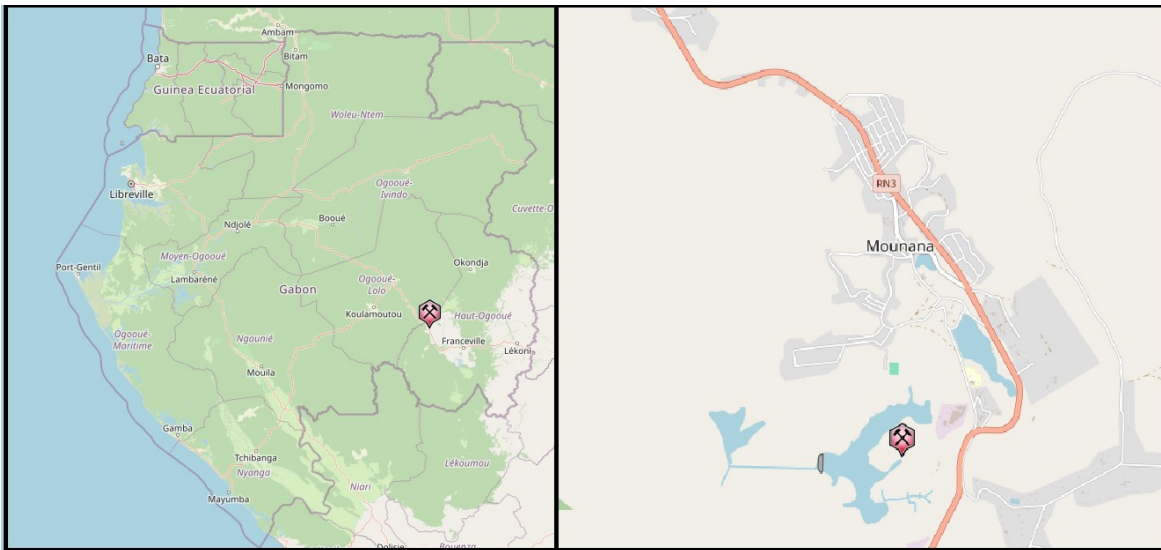


Figure 4 – Oklo Mine, Léboumbi-Leyou Department, Haut-Ogooué Province, Gabon

Credit: ©Mindat.org

In 1956, prior to the discovery of the Oklo deposit in Gabon, [Dr. Paul K. Kuroda](#) (1917-2001) of the University of Arkansas [predicted](#) that a natural nuclear reactor would be found. Interestingly, the same year, geologists working for the [Commissariat à l'énergie atomique et aux énergies alternatives](#) (CEA) found uranium near the village of Mounana in the then French colony of Gabon. The CEA mined

uranium at Oklo for 40 years before the mine was shut down when there was no more economically accessible ore.

The discovery that there was something strange about the Oklo deposits came in 1972 when [a physicist at CEA, Dr. Francis Perrin](#), noticed that the concentration of U-235 in the uranium was only 0.717% compared to the normal concentration of 0.720% (the vast majority of uranium in any deposit is U-238). There was some fear that someone had stolen some of the U-235, for sale as weapons-grade uranium. Further investigation showed that the anomalous results for U-235 concentrations were the result of natural processes, i.e. a [natural nuclear reactor](#).

In 1976, the story of [Oklo was published in Scientific American](#). Since then there have been many papers written on the phenomena, I'll list some at the end of this posting. [A 2011 paper](#) indicated that there were some 15 reactor zones found in the Oklo complex.

The uranium at Oklo was [deposited around 2.1 billion years ago](#) (Gya), during the [Paleoproterozoic Era](#), roughly coincident with the [Great Oxidation Event](#). The geological units noted in Figure 5 (below) are part of the 1-4 km-thick [Francevillian Series](#) that was deposited on a metagranitic late [Archean](#) basement about ~2.1 Gya. The basal Formation A (FA) Formation consists of deltaic and fluvial sandstones and conglomerates, which host uranium ore deposits and natural fission reactors. Overlying the FA Formation is Formation B (FB) which are thick marine black shales.

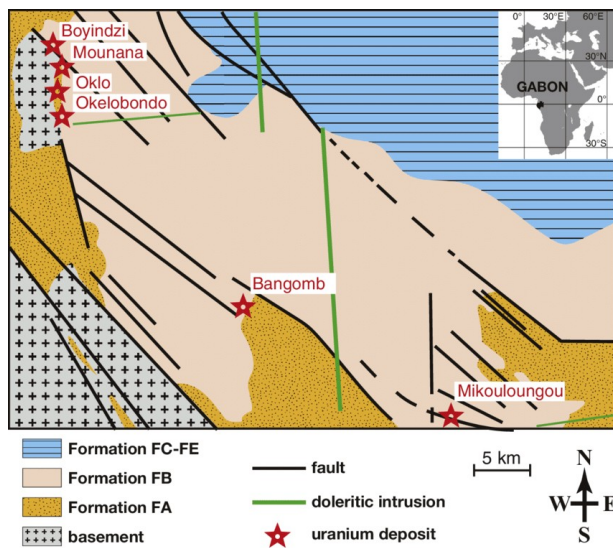


Figure 5 – Geological Map of the Oklo Area, Gabon
Credit: Figure 4 in [Ebisuzaki & Maruyama, 2016](#),
[CC BY-NC-ND 4.0](#)

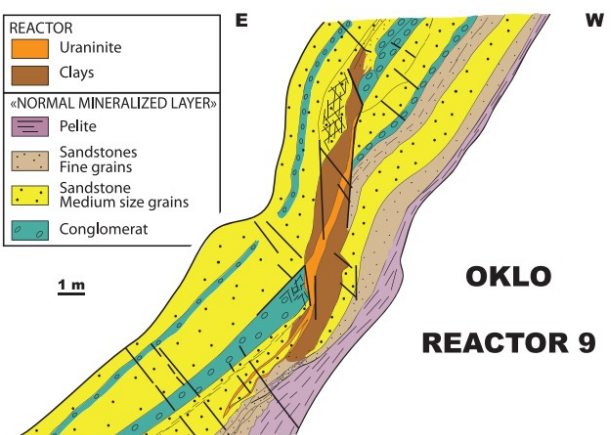


Figure 6 – Profile of Natural Nuclear Reactor No. 9 at Oklo
Credit: [Bentridi et al, 2011](#), [Creative Commons Attribution-Share Alike 3.0 Netherlands license](#)

The pore spaces and fractures within the sandstones of the FA formation includes solidified petroleum (pyrobitumen). The uranium ore deposits formed along the normal faults, hydraulic fractures and hydraulic breccias where uranium was precipitated out of groundwater. The [uranium was precipitated when uranium bearing brines](#) interacted with oil in sandstone reservoirs. The [presence of free oxygen was also significant](#) in that it created strong redox gradients for the precipitation of the uranium out of

solution. Also, in his book [Ages of Gaia](#), James Lovelock suggested that [bacterial mats were also critical in the precipitation of the uranium](#) and fossils of possible bacterial mats have been found in the [Francevillian Series](#).

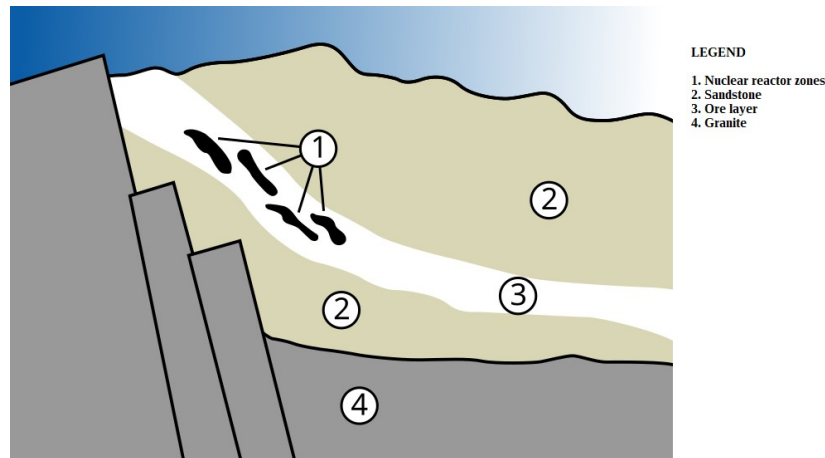


Figure 7 – Schematic of Reactor Zones at Oklo

Credit: MesserWoland, Creative Commons Attribution-Share Alike 3.0 Unported license

So how did the nuclear reaction occur? First, it appears that the [concentration of U-235](#) in the Oklo deposit during the Proterozoic was around 4% of the total uranium. Modern uranium deposits are generally around 0.720% U-235 and the Oklo deposit has 0.717%. The 4% U-235 in the Oklo deposit during the Proterozoic was sufficient to initiate a nuclear reaction, with groundwater acting as a moderator, similar to modern [light water reactors](#) using [enriched uranium](#). The nuclear reaction also seems to have worked in pulse manner where the reaction heated up the groundwater, which then was driven out in a steam driven geyser. The reaction would cease until groundwater came back into the formation and the cycle would begin again. The reactions ceased when the concentration of U-235 dropped below that was needed for the reaction.

Fun times in the Proterozoic!

Winding it Up



So that is the basic story about the Oklo deposits. There is much, much more if you want to go down the rabbit hole on this subject. For example, the Oklo deposits have helped people understand the long term implications for [storage of nuclear waste](#). In their [2016 paper](#), Toshikazu Ebisuzaki and Shigenori Maruyama suggest that the “nuclear geyser” was a driving force to promote the synthesis of building blocks of life. Here’s a partial list of references below, in chronological order. chase the rabbit all you wish.

Figure 8 – Alice Going Down the Rabbit Hole, Looking for More Scientific Papers

Credit: Valerie Hinojosa, Creative Commons Attribution-Share Alike 2.0 Generic license

References

- Cowan, George (1976). *A Natural Fission Reactor*. Scientific American. Vol. 235, no. 1. pp. 36–47. Bibcode:1976SciAm.235a..36C. [doi:10.1038/scientificamerican0776-36](https://doi.org/10.1038/scientificamerican0776-36). JSTOR 24950391. Federation of American Scientists. Los Alamos Scientific Laboratory.
- Nagy, B; Gauthier-Lafaye, F.; Holliger, P.; Mossman, D. J.; Leventhal, J. S.; Rigali M. J. (July 1993). *Role of organic matter in the Proterozoic Oklo natural fission reactors, Gabon, Africa*. Geology, Volume 21, Number 7, [doi.org/10.1130/0091-7613\(1993\)021%3C0655:ROOMIT%3E2.3.CO;2](https://doi.org/10.1130/0091-7613(1993)021%3C0655:ROOMIT%3E2.3.CO;2).
- Lovelock, J. (March 1995). *The Ages of Gaia: A Biography of Our Living Earth*. W. W. Norton & Company.
- Gauthier-Lafaye, F.; Holliger, P.; Blanc, P.-L. (December 1996). *Natural fission reactors in the Franceville basin, Gabon: A review of the conditions and results of a 'critical event' in a geologic system*. Geochimica et Cosmochimica Acta. 60 (23): 4831–4852. [doi:10.1016/s0016-7037\(96\)00245-1](https://doi.org/10.1016/s0016-7037(96)00245-1). ISSN 0016-7037.
- Meshik, Alex P. (2005). *The Workings of an Ancient Nuclear Reactor*. Scientific American. Vol. 293, no. 5. pp. 82–91. [doi:10.1038/scientificamerican1105-82](https://doi.org/10.1038/scientificamerican1105-82).
- Gauthier-Lafaye, F. (January 2006). *Time constraint for the occurrence of uranium deposits and natural nuclear fission reactors in the Paleoproterozoic Franceville Basin (Gabon)* [https://doi.org/10.1130/2006.1198\(09\)](https://doi.org/10.1130/2006.1198(09)). Chapter 9 in *Evolution of Early Earth's Atmosphere, Hydrosphere, and Biosphere – Constraints from Ore Deposits*. Geological Society of America. <https://doi.org/10.1130/MEM198>. ISBN print: 9780813711980.
- Coogan, L.; Cullen, J. (October 2009) *Did natural reactors form as a consequence of the emergence of oxygenic photosynthesis during the Archean?* GSA Today, Volume 19 Issue 10, pp. 4-10. [doi:10.1130/GSATG41A.1](https://doi.org/10.1130/GSATG41A.1).
- Bentridi, S.; Benoît Gall, B.; Gauthier-Lafaye, F.; Seghour, A.; Medjadi, D.; (December 2011). *Inception and evolution of Oklo natural nuclear reactors*. Comptes Rendus Geoscience, Volume 343, Issues 11–12, Pages 738-748, ISSN 1631-0713, <https://doi.org/10.1016/j.crte.2011.09.008>.
- Ebisuzaki, T. & Maruyama, S. (October 2016). Nuclear geyser model of the origin of life: Driving force to promote the synthesis of building blocks of life. Geoscience Frontiers. 8.(2) [doi:10.1016/j.gsf.2016.09.005](https://doi.org/10.1016/j.gsf.2016.09.005)
- Ragheb, M., G. Wetherhill, Mark G. Inghram and Paul K. Kuroda (2017). *Natural Nuclear Reactors, The Oklo Phenomenon*. Engineering, Environmental Science, Physics. <https://api.semanticscholar.org/CorpusID:16565230>.
- Gil, L.; (August 2018). *Meet Oklo, the Earth's Two-billion-year-old only Known Natural Nuclear Reactor*. IAEA Office of Public Information and Communication, <https://www.iaea.org/newscenter/news/meet-oklo-the-earths-two-billion-year-old-only-known-natural-nuclear-reactor>.

Lecomte, A; Michels, R; Cathelineau M.; Morlot, C.; Brouand, M.; Flotté, N. (August 2020). *Uranium deposits of Franceville basin (Gabon): Role of organic matter and oil cracking on uranium mineralization*. Ore Geology Reviews, Volume 123, 103579, ISSN 0169-1368, <https://doi.org/10.1016/j.oregeorev.2020.103579>.

Pawuła, A. (February 2021). *The Phenomenon of a Natural Thermonuclear Reactor*. Journal of Geoscience and Environment Protection, 9, 92-109. [doi: 10.4236/gep.2021.92006](https://doi.org/10.4236/gep.2021.92006).

Nimal, J.C. (November 2023). *Oklo: historic and lessons learned*. Radiation Protection Dosimetry, Volume 199, Issue 18,, Pages 2262–2268, <https://doi.org/10.1093/rpd/ncad043>

Standard Caveat

The purpose of my weblog postings is to spark people's curiosity in geology. Don't entirely believe me until you've done your own research and checked the evidence. If I have sparked your curiosity in the subject of this posting, follow up with some of the links provided here. If you want to, go out into the field and examine some rocks on your own with the help of a good field guide. Follow the evidence and make up your own mind.

In science, the only authority is the evidence.