

Planetary Science 2025

Was Venus once habitable?

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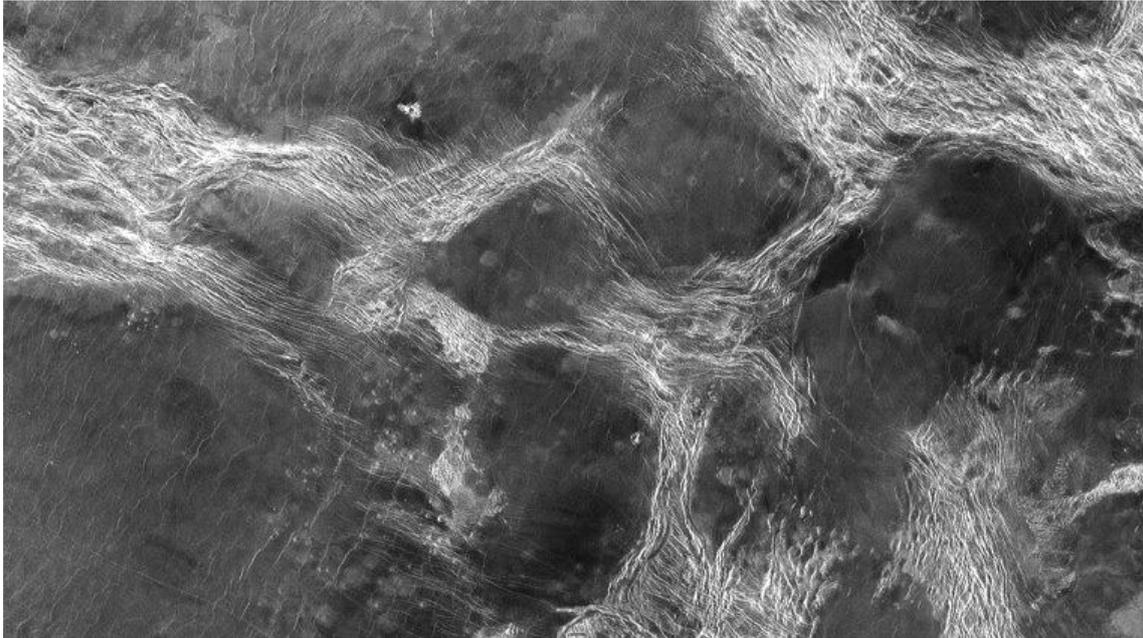


The surface of Venus from the USSR *Venera 14* lander

It is often said that Earth has a twin: Venus, the second planet from the Sun. That isn't true, despite the fact that both have similar size and density. Venus, in fact, is even more inhospitable than either Mars or the Moon, having surface temperatures ($\sim 465^{\circ}\text{C}$) that are high enough to melt lead or, more graphically, those in a pizza oven. The only vehicles successfully to have landed on Venus (the Russian *Venera* series) survived for a mere 2 hours, but some did send back data and images. That near incandescence is masked by the Venusian atmosphere that comprises 96.5% carbon dioxide, 3.5% nitrogen and 0.05% sulfur dioxide, with mere traces of other gases including extremely low amounts of water vapour (0.002%) and virtually no oxygen. The dense atmosphere imposes a pressure at Venus's surface that is 92 times that on Earth: so dense that CO_2 and N_2 are, strictly speaking, not gases but [supercritical fluids](#) at the surface. At present Venus is definitely inimical to any known type of life. It is the victim of an extreme, runaway greenhouse effect.

As it stands, Venus's geology is also very different from that of the Earth. Because its upper atmosphere contains clouds of highly reflective sulfuric acid aerosols only radar is capable of penetrating to the surface and returning to have been monitored by a couple of orbital vehicles: *Magellan* (NASA 1990 to 1994) and *Venus Express* (European Space Agency 2006 to 2014). The latter also carried means of mapping Venus's surface gravitational field. The radar imagery shows that 80% of the Venusian surface comprises somewhat wrinkled plains that suggests a purely volcanic origin. Indeed more than 85,000 volcanoes have been mapped, 167 of which are [over 100 km across](#). Much of the surface appears to have been [broken into polygonal blocks](#) or 'campuses'

(campus is Latin for field) that give the impression of ‘crazy paving’. A peculiar kind of local-scale tectonics has operated there, but nothing like the plate tectonics on Earth in either shape or scale.



Polygonal blocks or ‘campuses’ on the lowland surface of Venus. Note the zones of ridges that roughly parallel ‘campus’ margins. Credit: Paul K. Byrne, North Carolina State University and Sean C. Solomon, Lamont-Doherty Earth Observatory

Many of the rocky bodies of the solar system are pocked by impact craters – the Earth has few, simply because erosion and sedimentary burial on the continents, and subduction of ocean floors have removed them from view. The Venusian surface has so few that it can, in its entirety, be surmised to have formed by magmatic ‘repaving’ since about 500 Ma ago at least. Earlier geological process can only be guessed at, or modelled in some way. A recent paper postulates that *‘there are several lines of evidence that suggest that Venus once did have a mobile lithosphere perhaps not dissimilar to Earth ...’* (Weller, M.B. & Kiefer, W.S. 2025. [The punctuated evolution of the Venusian atmosphere from a transition in mantle convective style and volcanic outgassing](#). *Science Advances*, v. 11, article eadn986; DOI: 10.1126/sciadv.adn986). One large, but subtle feature may have formed by convergence similar to that of collision tectonics. There are also gravitational features that hint at active subduction at depth, although the surface no longer shows connected features such as trenches and island arcs. Local extension has been inferred from other data.

Weller and Kiefer suspect that Venus in the past may have shifted between a form of mobile plate tectonics and [stagnant ‘lid’ tectonics](#), the vast volcanic plains having formed by processes akin to flood volcanism on a planetary scale. Venus’s similar density to that of Earth suggests that it is made of similar rocky material surrounding a metallic core. However, that planet has a far weaker magnetic field suggesting that the core is unable to convect and behave like a dynamo to generate a magnetic field. That may explain why the atmosphere of Venus is almost completely dry. With no magnetic field to deflect it the solar wind of charged particles directly impacts the upper atmosphere, in contrast to the Earth where only a very small proportion descends at the poles. Together with the action of UV solar radiation that splits water vapour into its constituent hydrogen and oxygen ions, the solar wind adds energy to them so that they escape to space. This atmospheric

'erosion' has steadily stripped the atmosphere of Venus – and thus its solid surface – of all but a minute trace of water, leaving behind higher mass molecules, particularly carbon dioxide, emitted by its volcanism. Of course, this process has vastly amplified the greenhouse effect that makes Venus so hot. Early on the planet may have had oceans and even primitive life, which on Earth extract CO₂ by precipitating carbonates and by photosynthesis, respectively. But they no longer exist.

The high surface temperature on Venus has made its internal geothermal gradient very different from Earth's; i.e. increasing from 465°C with depth, instead of from about 15°C on Earth. As a result, everywhere beneath the surface of Venus its mantle has been more able to melt and generate magma. Earlier in its history it may have behaved more like Earth, but eventually flipped to continual magmatic 'repaving'. To investigate how this evolution may have occurred Weller and Kiefer created 3-D spherical models of geological activity, beginning with Earth-like tectonics – a reasonable starting point because of the probable Earth-like geochemistry of Venus. My simplified impression of what they found is that the periodic blurring of magma well-known from Earth history to have created flood-basalt events without disturbing plate tectonics proceeded on Venus with progressively greater violence. Such events here emitted massive amounts of CO₂ into the atmosphere over short (~1 Ma) time scales and resulted in climate change, but Earth's surface processes have always returned to 'normal'. Flood-basalt episodes here have had a rough periodicity of around 35 Ma. Weller and Kiefer's modelling seems to suggest that such events on Venus may have been larger. Repetition of such events, which emitted CO₂ that surface processes could not erase before the next event, would progressively ramp up surface temperatures and the geothermal gradient. Eventually climatic heating would drive water from the surface into the atmosphere, to be lost forever through interaction with the solar wind. Without rainfall made acid by dissolved CO₂, rock weathering that tempers the greenhouse effect on Earth would cease on Venus. The increased geothermal gradient would change any earlier rigid, Earth-like lithosphere to more ductile material, thereby shutting down the formation of plates, the essence of tectonics on Earth. It may have been something along those lines that made Venus inimical to life, and some may fear that anthropogenic global warming here might similarly doom the Earth to become an incandescent and sterile crucible orbiting the Sun. But as Mark Twain observed in 1897 after reading The New York Herald's account that he was ill and possibly dying in London, *'The report of my death was an exaggeration'*. It would suit my narrative better had he said *'... was premature'*!

The Earth has a very large Moon because of a stupendous collision with a Mars-sized planet shortly after it accreted. That fundamentally reset Earth's bulk geochemistry: a sort of Year Zero event. It endowed both bodies with magma oceans from which several tectonic scenarios developed on Earth from Eon to Eon. There is no evidence that Venus had such a catastrophic beginning. By at least [3.7 billion years ago Earth had a strong magnetic field](#). Protected by that thereafter from the solar wind, it has never lost its huge endowment of water; solid, liquid or gaseous. It seems that it did go through [a stagnant lid style of tectonics early on](#), that transitioned to plate tectonics around the end of the Hadean Eon (~4.0 Ga), with a few hiccups during the Archaean Eon. And it did develop life as an integral part of the rock cycle. Venus, fascinating as it is, shows no sign of either, and that's hardly surprising. Those factors and its being much closer to the Sun may have condemned it from the outset.

The earliest known impact structure

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Landsat image mosaic of the Palaeoarchaeon granite-greenstone terrain of the Pilbara Craton, Western Australia. Granite bodies show as pale blobs, the volcanic and sedimentary greenstone belts in shades of grey. The site of Kirkland et al.'s study site is at the tip of the red arrow

Earth has been through a great many catastrophes, but the vast majority of those of which we know were slow-burning in a geological sense. They resulted in unusually high numbers of extinctions at the species- to family levels over a few million years and the true mass extinctions seem to have been dominated by build ups of greenhouse gases emitted by large igneous provinces. Even the most famous at the end of the Cretaceous Period, which did for the dinosaurs and considerably more organisms that the media hasn't puffed, was partly connected to the eruption of the Deccan flood basalts of western India. Yet the event that did the real damage was a catastrophe that appeared in a matter of seconds: the time taken for the asteroid that gouged the [Chicxulub crater](#) to pass through the atmosphere. Its energy was huge and because it was delivered in such a short time its sheer power was unimaginable. Gradually geologists have recognised signs of an increasing number of tangible structures produced by Earth's colliding with extraterrestrial objects, which now stands at [190 that have been confirmed](#).

The frequency of impact craters falls off with age, most having formed in the last ~550 million years (Ma) during the Phanerozoic Eon, only 25 being known from the Precambrian, which spanned around 88 percent of geological time. That is largely a consequence of the dynamic processes of tectonics, erosion and sedimentation that may have obliterated or hidden a larger number. Earth is unique in that respect, the surfaces of other rocky bodies in the Solar System showing vastly more. The Moon is a fine example, especially as it has been Earth's companion since it formed 4.5 billion

years ago (Ga) after the proto-Earth collided with a now vanished planet about the size of Mars. The relative ages of lunar impact structures combined with radiometric ages of the surfaces that they hit has allowed the frequency of collisions to be assessed through time. Applied to the sizes of the craters such data can show how the amount of kinetic energy inflicted on the lunar surface has changed with time. During what geologists refer to as the Hadean Eon (before 4 Ga), the moon underwent continuous bombardment that reached a crescendo between 4.1 and about 3.8 Ga. Thereafter impacts tailed off. Always having been close to the Moon, the Earth cannot have escaped the flux of objects experienced by the lunar surface. Because of Earth's much greater gravitation pull it was probably hit by more objects per unit area. Apart from some geochemical evidence from Archaean rocks (see: [Tungsten and Archaean heavy bombardment](#); July 2002) and several beds of 3.3 Ga old sediment in South Africa that contain what may have been [glassy spherules](#) there are no signs of actual impact structures earlier than a small crater dated at around 2.4 Ga in NE Russia.



Shatter cones in siltstone near Marble Bar in the Pilbara Province: finger for scale. Credit: Kirkland *et al.*; Fig 2a

Now a group of geologists from Curtin University, Perth Western Australia, and the Geological Survey of Western Australia have published their findings of indisputable signs of an impact site in the northern part of Western Australia (Kirkland, C.L. *et al.* 2025. [A Paleoarchaean impact crater in the Pilbara Craton, Western Australia](#). *Nature Communications*, v. **16**, article 2224; DOI: 10.1038/s41467-025-57558-3). In fact there is no discernible crater at the locality, but sedimentary strata show abundant evidence of a powerful impact in the form of impact-melt droplets in the form of spherules together with [shatter cones](#). These structures form as a result of sudden increase in pressure to 2 to 30 GPa: an extreme that can only be generated in underground nuclear explosions, and thus likely to bear witness to large asteroid impacts. The shocked rocks are immediately overlain by pillow lavas dated at 3.47 Ga, making the impact the earliest known. It has been speculated that impacts during the Archaean and Hadean Eons helped create conditions for the complex organic chemistry that eventually led to the first living cells. Considering that entry of hypervelocity asteroids into the early Earth's atmosphere probably caused such compression that [temperatures were raised](#)

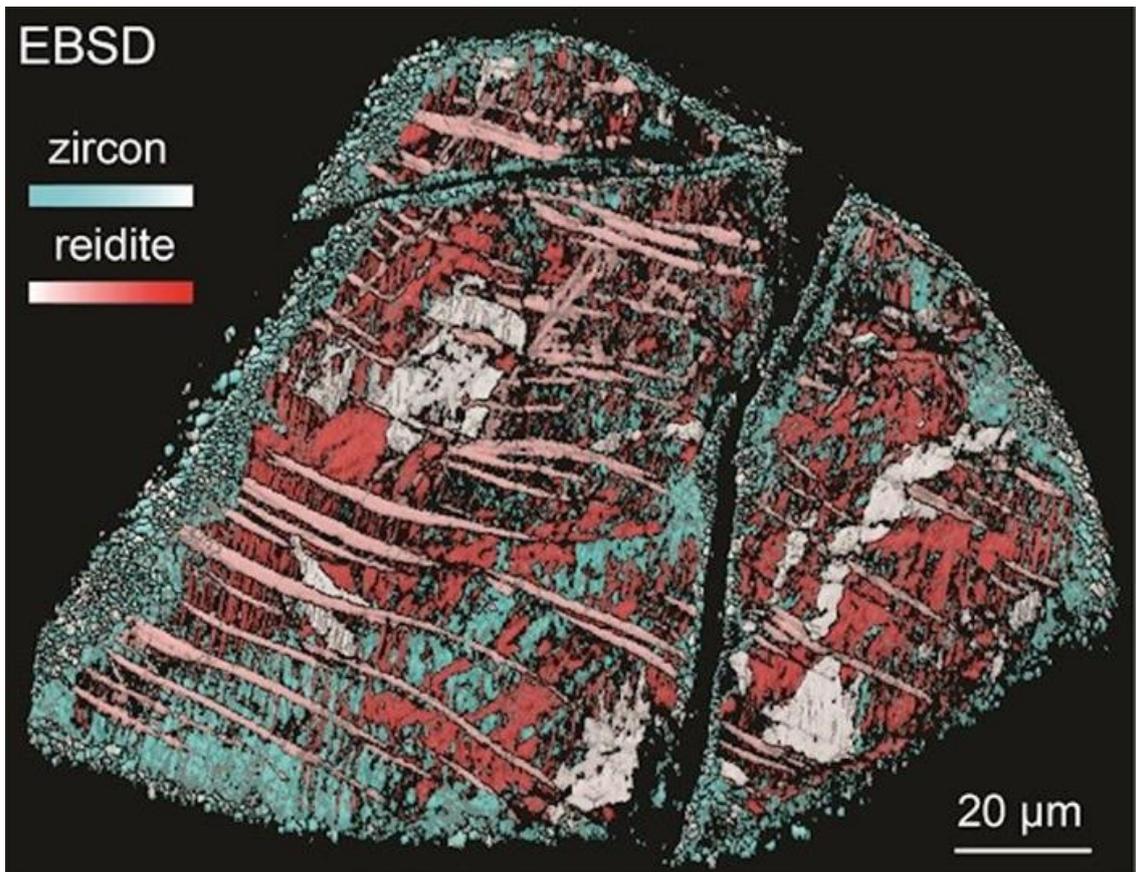
[by adiabatic heating to about ten times that of the Sun's surface](#), their 'entry flashes' would have sterilised the surface below; the opposite of such notions. Impacts may, however, have delivered both water and simple, inorganic hydrocarbons. Together with pulverisation of rock to make 'fertiliser' elements (e.g. K and P) more easily dissolved, they may have had some influence. Their input of thermal energy seems to me to be of little consequence, for decay of unstable isotopes of U, Th and K in the mantle would have heated the planet quite nicely and continuously from Year Zero onwards.

Impact debris in Neoproterozoic sediments of Scotland and biological evolution?

PUBLISHED ON [April 30, 2025](#)

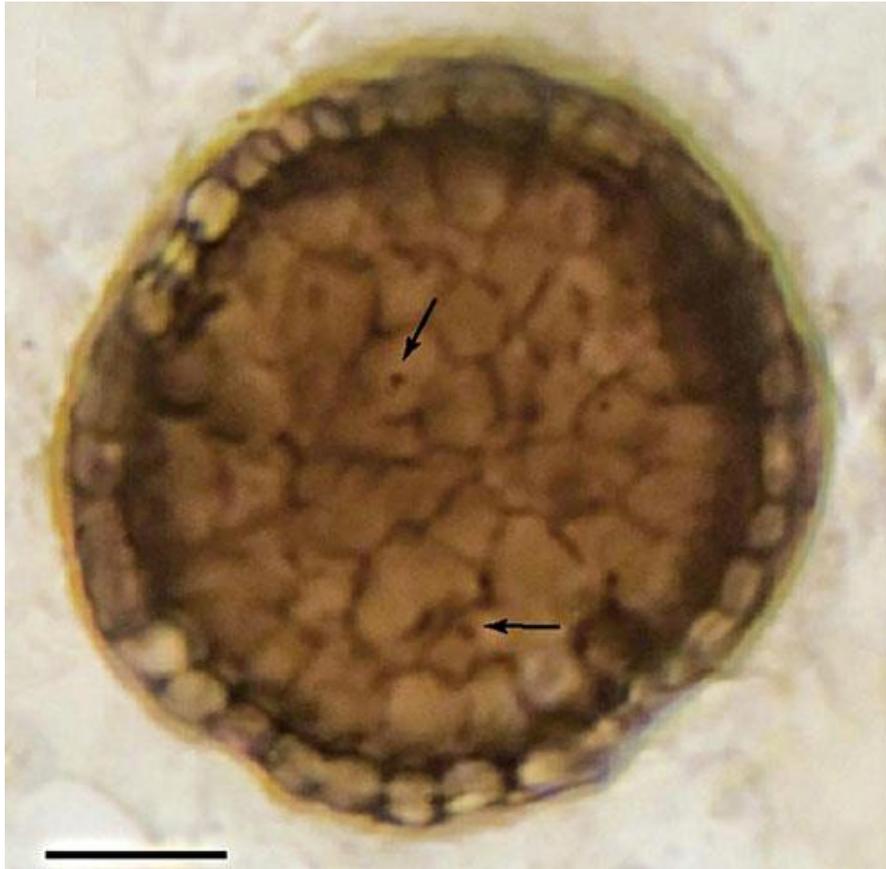
Judging by its content of shards and spherules made of murky green glass, one of the lowest units in the Torridonian continental sediments of NW Scotland had long been regarded as simply red sandstone that contained volcanic debris. This [Stac Fada Member](#) was thus celebrated as the only sign of a volcanic contribution to a vast thickness (up to 2.5 km) of Neoproterozoic lake and fluvial sediments. Current flow indicators suggested that the Torridonian was laid down by large alluvial fans derived by erosion of much older crystalline basement far to what is today the west. That is, the Archaean core of the ancient continent of Laurentia, now the other side of the North Atlantic. In 2002 more sophisticated sedimentological and geochemical analysis of the Stac Fada Member revealed a surprise: it contains anomalously elevated platinum-group elements, quartz grains that show signs of shock and otherworldly chromium isotope concentrations. The 10 m thick bed is made from ejecta, perhaps from a nearby impact crater to the WNW concluded from brittle fractures that may have been produced by the impact. Some idea of its age was suggested by Ar-Ar dating of feldspar crystals (~1200 Ma) believed to have formed authigenically in the hot debris. Being the only decent impactite known in Britain, it continues to attract attention.

A group of geoscientists from Western Australia, NASA and the UK, independent of the original discoverers, have now added new insights (Kirkland, C.L. and 12 others 2025. [A one-billion-year old Scottish meteorite impact](#). *Geology*, v. **53**, early online publication; DOI: 10.1130/G53121.1). They dated shocked zircon grains using U-Pb analyses at 990 ± 22 Ma; some 200 Ma younger than the previously dated, authigenic feldspars. Detrital feldspar grains in the Stac Fada Member yield Rb-Sr radiometric ages of 1735 and 1675, that are compatible with Palaeoproterozoic granites in the underlying Lewisian Gneiss Complex.



False-colour electron microscope image of a shocked grain of zircon recovered from the Stac Fada Member. The red and pink material is a high-pressure polymorph of zircon, arranged in shock lamellae. Zircon is rendered in cyan, some of which is in granulated form. Credit: Kirkland et al. 2025, Fig 2C

In a separate publication (Kirkland, C.L *et al* 2025. [1 billion years ago, a meteorite struck Scotland and influenced life on Earth](#). *The Conversation*, 29 April 2025) three of the authors take things a little further, as their title suggests. In this *Conversation* piece they ponder, perhaps unwarily, on the spatial and temporal association of the indubitable impact with remarkably well-preserved spherical fossils found in Torridonian lake-bed sediments ([Bicellum brasieri](#), [reported in Earth-logs in May 2021](#)), which are the earliest-known holozoan animal ancestors. The Torridonian phosphatic concretions in which these important fossils were found at a different locality are roughly 40 Ma younger than the Stac Fada impactite. The authors of the *Conversation* article appeal to the residual thermal effect of the impact as a possible driver for the appearance of these holozoan organisms. Whether a residual thermal anomaly would last long enough for them to evolve to this biological status would depend on the magnitude of the impact, of which we know nothing.



Photomicrograph of *Bicellum brazeiri*: scale bar = 10 μ m; arrows point to dark spots that may be cell nuclei (credit: Charles Wellman, Sheffield University)

[Eukaryote fossils](#) are known from at least 650 Ma older sedimentary rocks in northern China and perhaps as far back as [2.2 Ga in a soil that formed in the Palaeoproterozoic of South Africa](#). Both the Torridonian organism and impactite were found in a small area of fascinating geology that has been studied continuously in minute detail since Victorian times, and visited by most living British geologists during their undergraduate days. Ideas will change as curiosity draws geologists and palaeobiologists to less-well studied sites of Proterozoic antiquity, quite possibly in northern China.

The world's oldest crust in the Nuvvuagittuq Greenstone Belt, Quebec

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Since 1999, the rocks generally acknowledged to be the oldest on Earth were part of the Acasta gneisses in the Slave Craton in Canada's Northwest Territories; specifically the Idiwhaa tonalitic gneisses. Zircons extracted from that unit yielded an age of 4.02 billion years (Ga) using U-Pb radiometric dating, revealing the time of their crystallisation from granitic magma. But nine years later some metabasaltic rocks from the tiny (20 km²) [Nuvvuagittuq Greenstone Belt](#) on the eastern shore of Hudson Bay were dated using the Sm-Nd method at almost 4.3 Ga (see: [At last, 4.0 Ga barrier broken](#); November 2008). Taken at face value the metabasaltic rocks seemed to be well

within the Hadean Eon (4.6 to 4.0 Ga) and could thus represent primary crust of that antiquity. However, U-Pb dating of zircons from thin sodium-rich granitic rocks (trondhjemites) that intrude them yielded ages no older than about 3.8 Ga. Similar ages emerged from zircons found in metasediments interleaved in the dominant mafic unit. Discrepancies between the two completely different dating methods resulted in the Hadean antiquity of the mafic rocks having been disputed since 2008. It was possible that the Sm-Nd results from the metabasalts may have resulted from the original mafic magmas having inherited a Hadean Sm-Nd isotopic 'signature' from their mantle source. That is, they may have been contaminated and could have formed in the early Archaean.



Glacially smoothed outcrops near Inukjuak, Quebec that reveals rocks of the Nuvvuagittuq Greenstone Belt. Credit: Jonathan O'Neil, University of Ottawa

Jonathan O'Neil, now at Ottawa University in Canada, led the first isotopic investigation of the Nuvvuagittuq Greenstone Belt and has engaged in research there ever since. Further field and laboratory studies revealed that the previously dated mafic rocks had been intruded by large, chemically differentiated gabbro sills. A team of geochemists from the University of Ottawa and Carleton University, including O'Neil, has now published isotopic evidence from the intrusions that suggests a Hadean age for their parent magma (C. Sole *et al.* 2025. [Evidence for Hadean mafic intrusions in the Nuvvuagittuq Greenstone Belt, Canada](#). *Science*, v. **388**, p. 1431-1435. DOI: 10.1126/science.ads8461). The authors used the decay schemes of *two* radioactive samarium isotopes ^{147}Sm and ^{146}Sm ; a significant advance in radiometric dating. The first decays to ^{143}Nd with a half-life of about 10^{11} years, the second to ^{142}Nd with a much shorter half life of about 10^8 years. Due to its more rapid decay, in geological terms, ^{146}Sm is now much rarer than ^{147}Sm . Consequently, using the short-lived ^{146}Sm - ^{142}Nd decay system is technically more difficult than that of the ^{147}Sm - ^{143}Nd system. But the team managed to get good results from both the 'fast' and the 'slow' decay

schemes. They tally nicely, yielding ages of 4157 and 4196 Ma. The gabbros provide a *minimum* age for the metabasalts that they cut through. The original 4.3 Ga Sm-Nd date for the metabasalts is thus plausible. Sole and colleagues consider the dominant metabasaltic rocks to have formed a primary crust in late Hadean times that was invaded by later mantle-derived mafic magma about 100 Ma later. The granitic rocks that constitute about one third of the Nuvvuagittuq terrain seem to have been generated by partial melting more than 300 Ma later still, during the Palaeoarchaeon.

Perhaps similar techniques will now be deployed in granite-greenstone terrains in other cratons. Many of the older ones, generally designated as Palaeoarchaeon in age, also contain abundant metamorphosed mafic and ultramafic igneous rocks. Perhaps their origin was akin to those of Nuvvuagittuq; i.e. more Hadean crust may await unmasking. Meanwhile, there seems to be more to discover from Nuvvuagittuq. For instance, some of the rocks suggested to be metasediments interleaved in the metabasalts show intricate banding that resembles products of bacterial mat accumulation in younger terrains. Signs of Hadean life?

Since the first reliable radiometric dating of Archaean rocks in 1971, there has been an element of competition to date the oldest rocks on Earth: to push history back towards the initial formation of the Earth. It is one of the most disputatious branches of Earth history. Rivalry may play a significant part in driving the science, as well as the development of novel dating techniques and the continuing discovery of clearly old relationships using 'old-fashioned' relative dating, such as signs of intrusion, unconformities *etcetera*. But in some cases there is a darker side: the potential for profit. Recently, samples from Nuvvuagittuq appeared for sale on the Internet, priced at \$10,000. They may have been collected under the guise of supplying museums by a group that shipped-in mechanical excavators in 2016. Unsurprisingly this angered the local Inuit community of Inukjuak. They were also worried about *bona fide* collection for scientific research that had left parts of the small, once pristine area somewhat battered, including cultural features such as an *inukshuk* navigational monument. Their fury at commercial exploitation of their homeland resulted in the community council [closing the area to collecting in 2024](#). I emphasise that this violation of basic geological ethics was by commercial rock collectors and dealers, not academic geologists. The local people are now considering careful issue of research permits so that important research can continue. But further rock collecting may remain banned.

See also: [New Research Verifies Northern Canada Hosts Earth's Oldest Rocks](#). *Scienmag*, 26 June 2025; Gramling, C. 2025. [Earth's oldest rocks may be at least 4.16 billion years old](#). *ScienceNews*.

PS With many thanks to 'Piso Mojado' for alerting me to this paper

A hint of proto-Earth that predates Moon formation by giant impact

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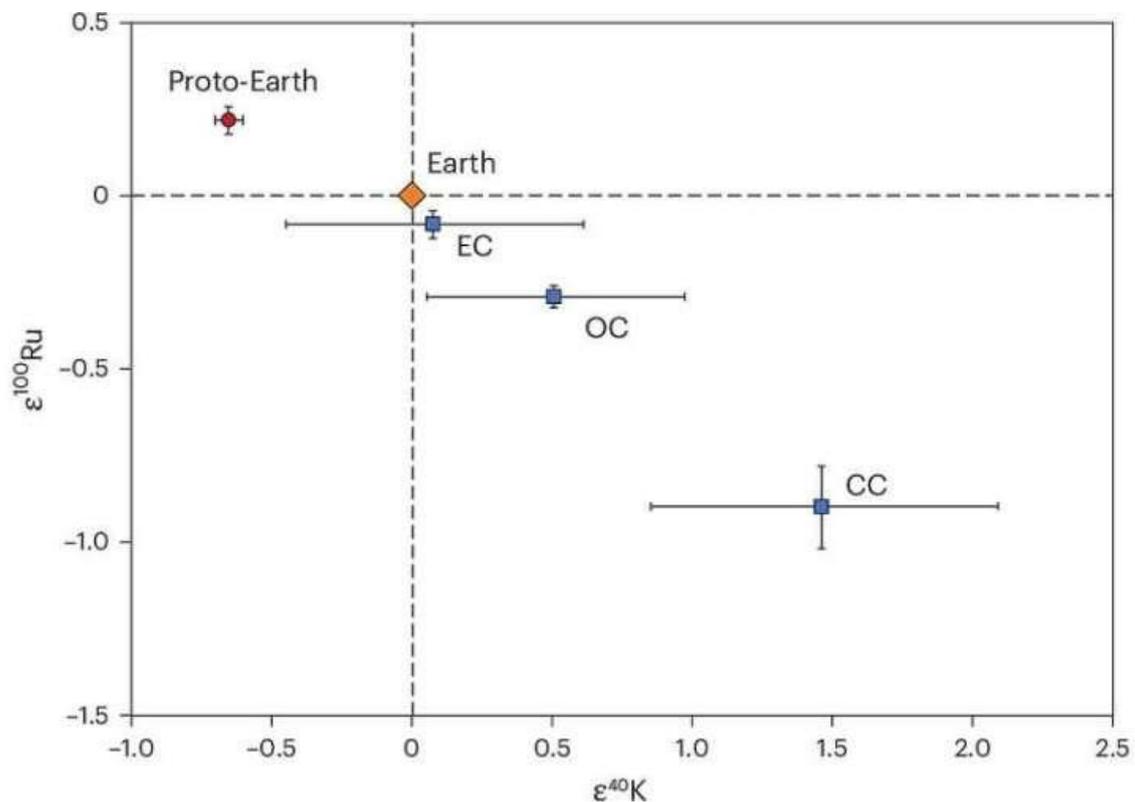


Artist's impression of the impact of a roughly Mars-size planet with the proto-Earth to form an incandescent cloud, from part of which the Moon formed.

Geochemists have gradually built a model of the proportions of the 92 naturally occurring elements that characterise the Solar System. It is based on systematic chemical analysis of meteorites, especially the 'stony' ones. One hypothesis for Earth formation is that the bulk of it chemically resembles a class of meteorites known as C1 carbonaceous chondrites. But there are important deviations between that and reality. For instance the relative proportions of the isotopes of several elements in meteorites have been found to differ. Because nuclei of all the elements and their individual isotopes have been shown to form in supernovae through [nucleosynthesis](#), such instances are known as 'nucleosynthetic anomalies'. An example is that of the isotopes of potassium (K), which was investigated by a team of geochemists from the Carnegie Institution for Science in Washington DC, USA and the Chengdu University of Technology, China led by Nicole Nie (Nie, N.X. *et al.* 2023. Meteorites have inherited nucleosynthetic anomalies of potassium-40 produced in supernovae. *Science*, v.**379**, p, 372-376; DOI: 10.1126/science.abn1783).

A measure for the magnitude of this nucleosynthetic anomaly is the ratio between the abundance in a sample of potassium's rarest (^{40}K) and its most common isotope (^{39}K), divided by the ratio in an accepted standard of terrestrial rock. Since isotopically identical samples would yield a value of 1, the result has 1.0 subtracted from it to emphasise anomalies. Samples that are relatively depleted in ^{40}K give negative values, whereas enriched samples give positive values. This measure is signified by $\epsilon^{40}\text{K}$, ϵ being the Greek letter epsilon. The authors found significant and variable positive anomalies of $\epsilon^{40}\text{K}$ in carbonaceous chondrite (CC) meteorites, compared with non-carbonaceous (NC) meteorites. They also found that $\epsilon^{40}\text{K}$ data in terrestrial rocks are quite different from those of

CC meteorites. Indeed, they suggested that Earth was more likely to have formed from NC meteoritic material. Clearly, there seems to be something seriously amiss with the hypothesis that Earth largely accreted from C1 carbonaceous chondrites.



The correlation between $\epsilon^{40}\text{K}$ and $\epsilon^{100}\text{Ru}$ in meteorites (EC – enstatite chondrites, OC – ordinary chondrites; CC – carbonaceous chondrites), Earth and a geochemically modelled proto-Earth. Credit: Da Wang et al., Fig 2

Three of the authors of Nie *et al.* and other researchers from MIT in Cambridge MA and Scripps Institution of Oceanography in San Diego CA, USA and ETH in Zurich, Switzerland have produced more extensive potassium isotope data to examine Earth's possible discrepancy with the chondritic Earth hypothesis (Da Wang *et al.* 2025. Potassium-40 isotopic evidence for an extant pre-giant-impact component of Earth's mantle. *Nature Geoscience*, v. **18**, online article; DOI: 10.1038/s41561-025-01811-3). To better approximate the bulk Earth's potassium isotopes they analysed a large number of terrestrial rock samples of all kinds and ages to compare with meteorites of different classes. Meteorites also have variable nucleosynthetic anomalies for ruthenium-100 ($\epsilon^{100}\text{Ru}$). So, $\epsilon^{40}\text{K}$ and $\epsilon^{100}\text{Ru}$ may be useful tracers with regards to Earth's history. But, for some reason, the research group did not analyse ruthenium isotopes in the terrestrial samples.

Most samples of igneous rocks from different kinds of Phanerozoic volcanic provinces (continental flood basalts, island arcs, and ocean ridge basalts) showed no evidence of anomalous potassium isotopes. However, some young ocean-island basalts from Réunion and Hawaii showed considerable depletion in ^{40}K . A quarter of early Archaean (>3.5 Ga) metamorphosed basaltic rocks from greenstone belts also showed clear ^{40}K depletion. Yet no samples of granitic crust of similar antiquity showed any anomaly and nor did marine sediments derived from younger continental crust. Even the oldest known minerals – zircon grains from [Jack Hills Western Australia](#) – showed no anomalies. The authors suggest that both the anomalous groups of young and very ancient terrestrial basalts

show signs that their parent magmas may have formed by partial mantle melting of substantial bodies of the relics of proto-Earth. To account for this anomalous mantle Da Wang *et al.* suggest from modelling that proto-Earths ^{40}K deficit may have arisen from early accretion of meteorites with that property. Later addition of material more enriched with that isotope, perhaps as meteorites or through the impact with a smaller planet that triggered Moon-formation. That cataclysm was so huge that it left the Earth depleted in 'volatile' elements and in a semi-molten state. It reset Earth geochemistry as a result of several processes including the mixing induced by very large-scale melting. No radiometric dating has penetrated that far back in Earth history. However, in February 2004, Alex Halliday used evidence from several isotopic systems (Pb, Xe, Sr, W) to show that about two [thirds of Earth's final mass may have accreted in the first 11 to 40 Ma of its history](#).

Curiously, none of the hundreds of meteorites that have been geochemically analysed show the level of ^{40}K depletion in the terrestrial samples. Nicole Nie has comments, "... our study shows that the current meteorite inventory is not complete, and there is much more to learn about where our planet came from."

I'm persuaded to write this by 'Piso Mojado'. And today – 23rd October – is the anniversary of the Creation of Earth, Life and the Universe in 4004 BCE, according to Archbishop James Ussher (1581-1656) by biblical reckoning, which always tickles me!

See also: Chu, J. 2025. [Geologists discover the first evidence of 4.5-billion-year-old "proto Earth"](#). MIT News, 14 October 2025.