



# Riding the Climate Rollercoaster 4 T4 2025

## 4. Climate Change Drivers II: Cosmic Rays, Earth's Orbit and Bolide Impacts

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Slides by Rob Kirk & Malte Ebach

Teacher  
Earth  
Science  
Education  
Programme Ltd



We wish to acknowledge the Traditional Owners of the land on which we meet today.

We also wish to pay our respects to Elders past, present and future.

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Earth  
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## PARTNERS

### PLATINUM

- Sydney Mineral Exploration Discussion Group (SMEDG)



AUSTRALIAN  
INSTITUTE OF  
GEOSCIENTISTS  
Supporting Geoscientists

### GOLD

- Australian Institute of Geoscientists



### SILVER PLUS

- South 32
- Minerals Council of Australia (Vic. Div.)
- Evolution Mining Limited



### SILVER

- Yancoal
- AIC Mines
- Australian Society of Exploration Geophysicists

### In-kind support

- AusGeol.org – Virtual Library of Australia's Geology
- Australian Geoscience Council
- Australian Museum
- Australian National University – RSES
- Australian Rare Earths Ltd
- Bureau of Meteorology
- Federation University Australia
- Geological Society of Australia
- Geological Survey of New South Wales
- Macquarie University
- Monash University
- OzMinerals
- Pyrenees Quarries
- Quantum Victoria College
- Rob Kirk Consultants
- Scienceworks
- Victorian Space Science Education Centre

### BRONZE

- Aeris Resources
- ATCO Australia
- Atmos Renewables: Cherry Tree Windfarm
- Australian Rare Earths Ltd
- Energy Australia
- iTech minerals
- Geological Society of South Australia
- VHM Limited (Melbourne)
- Geological Survey of Australia (VIC)
- VHM Limited



## SPONSORS OF ROCK KITS TO SCHOOLS & SCHOOL VISITS

### SILVER PLUS

- BHP Olympic Dam
- South 32

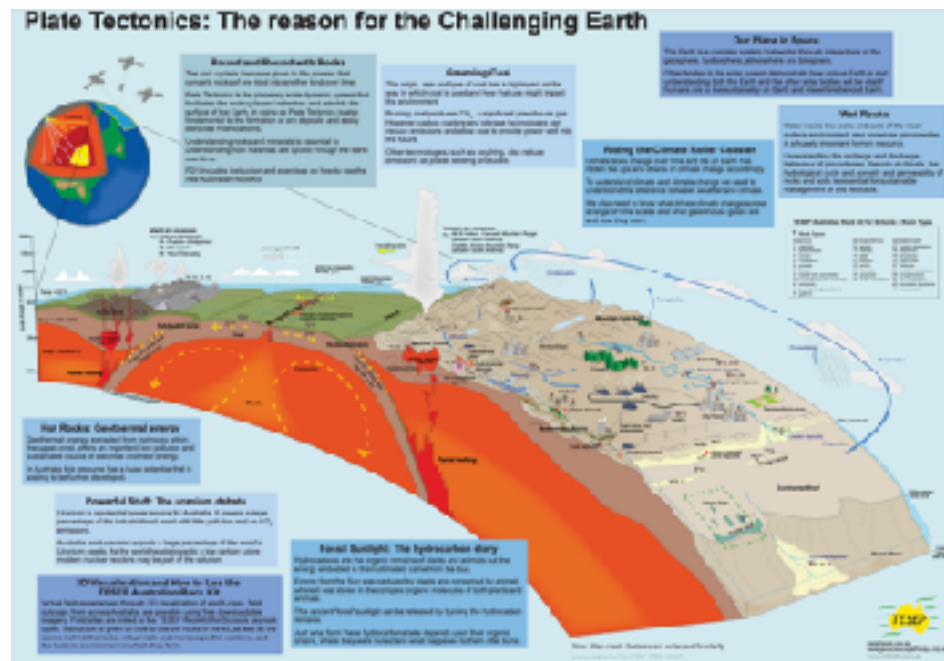
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### BRONZE

- Aeris Resources Ltd
- Alkane Resources Ltd
- Astron Corporation (Donald Mineral Sands)
- Atmos Renewables (Cherry Tree Windfarm)
- Aurelia Metals Ltd (Peak Gold Mines)
- Australian Rare Earths Ltd
- Ballarat Gold
- Bengalla Mining Co (New Hope Group)
- Dart Mining
- Energy Australia
- Glencore Coal
- Gnostic Exploration Services
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- Kingston Resources Ltd (Mineral Hill)
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- OZ Minerals
- Providence Gold Minerals Pty Ltd
- Squadron Energy
- Stawell Gold Mine
- Sydney Mineral Exploration Discussion Group (SMEDG)
- Whitehaven Coal
- WIM Resource
- Yancoal



# TESEP Rock Kit and Plate Tectonics Poster



A great to teach where rocks form and the industries that extract and use them.

Get them from [haines.com.au](http://haines.com.au) or host a [PD at your school!](#)

You can also get them as a [bundle](#)

# TESEP Rock and Mineral Check



With each School visit we offer a free rock and mineral check:

- To identify specimens no longer useful for teaching (e.g., pebbles, small specimens etc.)
- To identify any misplaced specimens or valuable specimens (for display only)
- To identify any hazardous material (e.g., asbestos, pitchblende etc.)

# TESEP Australian Critical Minerals Kit



2 boxes with 26 minerals:

- Critical minerals
- Metallic minerals
- Rock forming minerals
- Moh's scale of hardness
- Online resources include:
  - Mineral Stories
  - Questions for students
  - 3D renders



## All TESEP webinars are recorded

After each webinar episode you will be sent a link with:

- access to the slide set for that episode (including any embedded videos and links)
- access to a recording of that episode (YouTube)

After each episode you will also be sent:

- A TESEP Certificate of Attendance (NESA recognised)

Please [subscribe](#) for news about forthcoming and new webinar series!



## Australian Curriculum v.9 (F-10)

We will be following the Australian Curriculum v.9 (2022):

- Curriculum content for Years 7-10 only
- Focus on the Earth and Space science sub-strand
- Will follow as many other sub-strands as possible

# Australian Curriculum v. 9 (2022): Examples.

Year 10 (Earth and Space Sciences)

“They appreciate how energy drives the Earth system and how climate models simulate the flow of energy and matter within and between Earth’s spheres”.

- Use models of energy flow between the geosphere, biosphere, hydrosphere and atmosphere to explain patterns of global climate change (AC9S10U04).
- Explain how scientific knowledge is validated and refined, including the role of publication and peer review (AC9S10H01).
- Investigate how advances in technologies enable advances in science, and how science has contributed to developments in technologies and engineering (AC9S10H02).

# Australian Curriculum v. 9 (2022): Examples.

Year 10 (Geography)

“develop a range of questions for a geographical inquiry related to a phenomenon or challenge”.

- planning an investigation of a phenomenon or challenge being studied at a range of scales, using digital tools; for example, investigating the causes of human-induced climate change at the global scale and its impacts on Australia, Bangladesh and/or a Pacific Island country at the national scale (AC9HG10S01)



# The new TESEP Mineral Kit



A great to teach where minerals form and the industries that extract and use them.

Get them from [haines.com.au](http://haines.com.au)!



## Climate Change Drivers II: Cosmic Rays, Earth's Orbit and Bolide Impacts



# Climate Change Drivers

Explore some BIG picture ideas with which to challenge students:

Cosmic Rays

Bolide Impacts

Milankovitch Cycles

Young Sun Paradox



# Individual Class Exercise

Which of these ideas could be the ultimate driver for climate change?

Cosmic Rays

Bolide Impacts

Milankovitch Cycles

Young Sun Paradox



# Group Exercise

Which of these ideas could be the ultimate driver for climate change?

Cosmic Rays, Bolide Impacts, Milankovitch Cycles, Young Sun Paradox  
(You can choose more than one!)

Argue your point and give some examples from the geological record

(You can use fossils, rocks and minerals, proxy data or models)

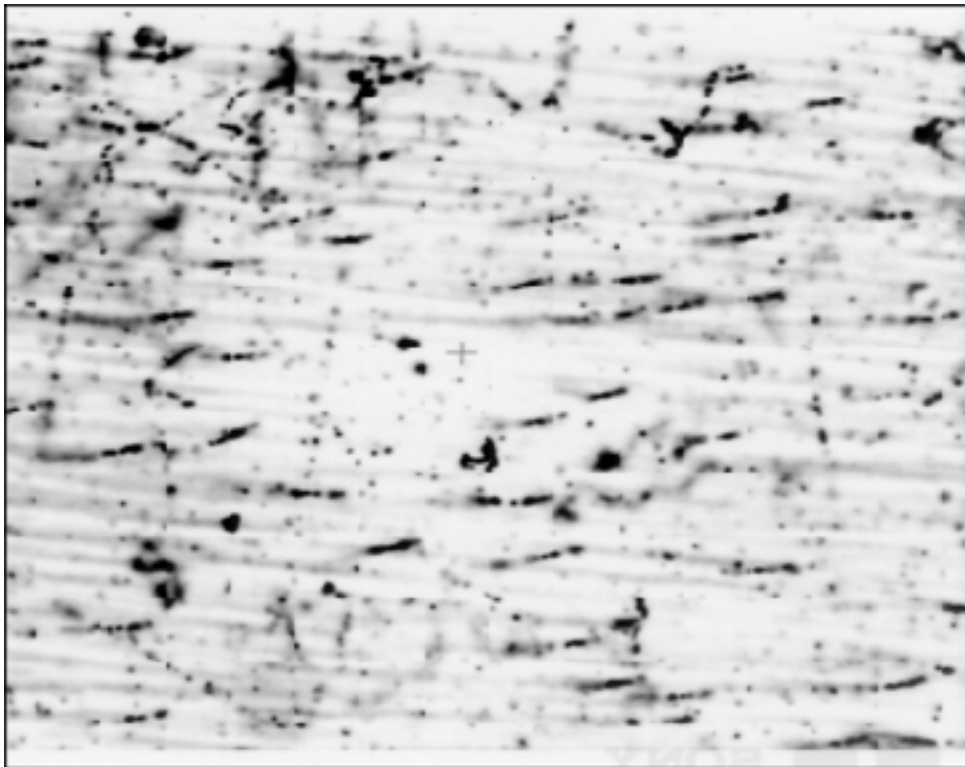
# Cosmic Rays



Could cosmic rays have affected climate in the long and/or short term?

Cosmic rays are high-energy protons (89% H nuclei, 10% He nuclei, 1% heavier elements)

Originate from our galaxy (e.g., exploding stars) and constantly bombard the atmosphere



A photomicrograph shows where high-energy electrons blazed through a film emulsion located in a spectrometer outside the target chamber for the petawatt laser tests. The tracks are slightly curved from the emulsion being slightly curved in its holder (Image: NASA/ Marshall Space Flight Center and the University of Alabama in Huntsville).

# Cosmic Rays: Svensmark Effect



Svensmark Effect:

Cosmic rays collide with particles in the atmosphere and create aerosols

Aerosols grow to form seeds for cloud droplets (Cloud Condensation Nuclei)

Aside ... how do clouds seed?

# Cosmic Rays: Cloud Formation



It's complex ...

Size of particles that seed clouds:

Smaller particles = whiter clouds

Larger particles = darker clouds

Whiter clouds scatter more light

>>>> Mount Pinatubo Effect

High albedo (leads to cooling)

Less precipitation (leads to drying)



Source: <https://www.usgs.gov/observatories/hvo/news/volcano-watch-pinatubo-effect-can-geoengineering-mimic-volcanic-processes>

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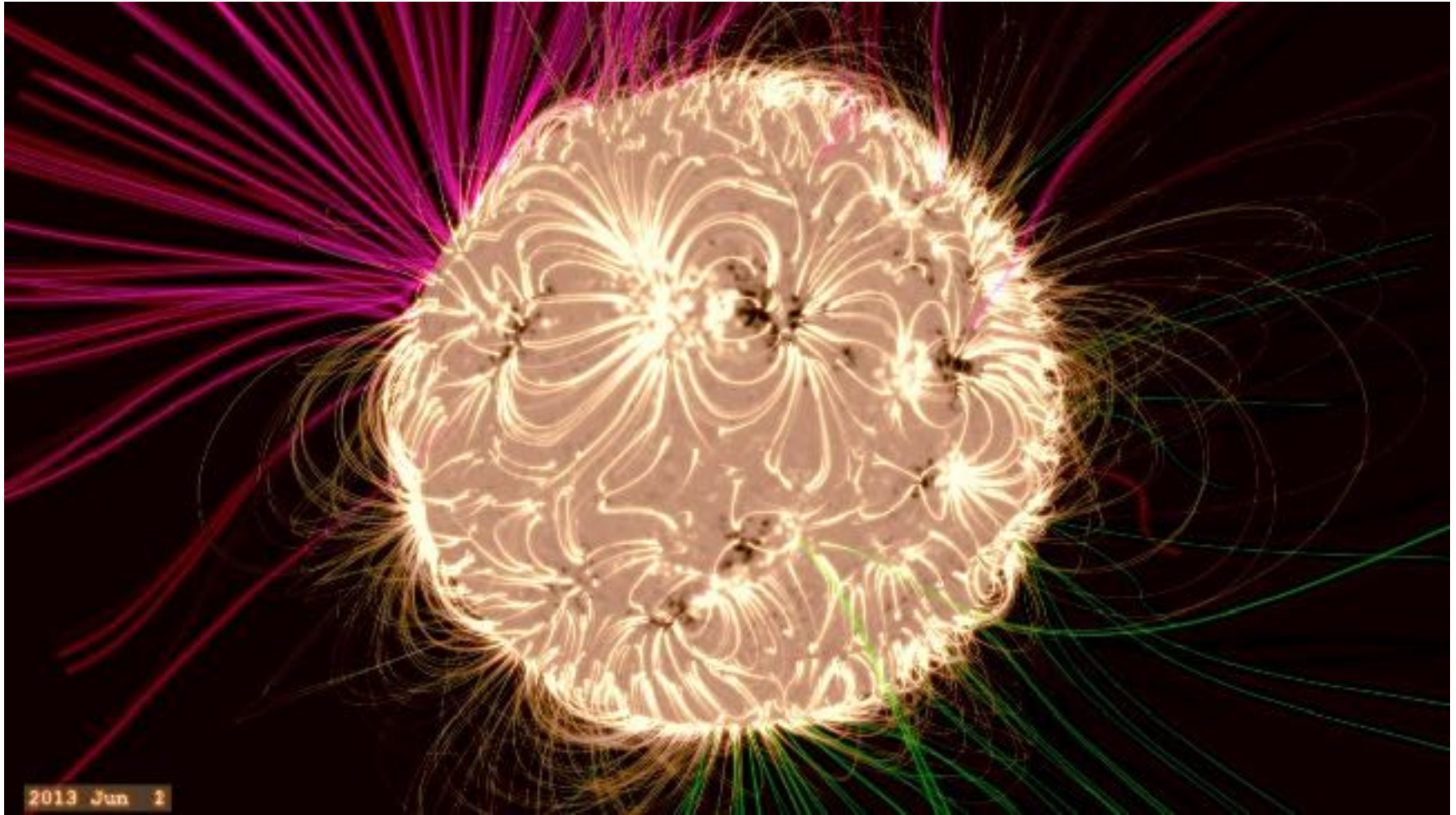
Sun has a 11 year solar cycle (we are now in the active “summer phase”)

High solar activity (more sun spots) shields us from cosmic rays

The sun has a magnetic field that protects us ...

Source: <https://www.nature.com/articles/s41467-017-02082-2>

# Cosmic Rays: Sun's Magnetic Field



Source: <https://www.youtube.com/watch?v=2g1epPpplOM&t=78s>

# Cosmic Rays: Svensmark Effect



Svensmark Effect:

The sun has a magnetic field that protects us from cosmic rays

An active sun (“summer phase”) = wider/stronger magnetic field

Fewer cosmic rays, less cloud formation

>>>> (Think: Reverse Mt Pinatubo)

Warmer climate

# Cosmic Rays



Could cosmic rays have affected climate in the long and/or short term?

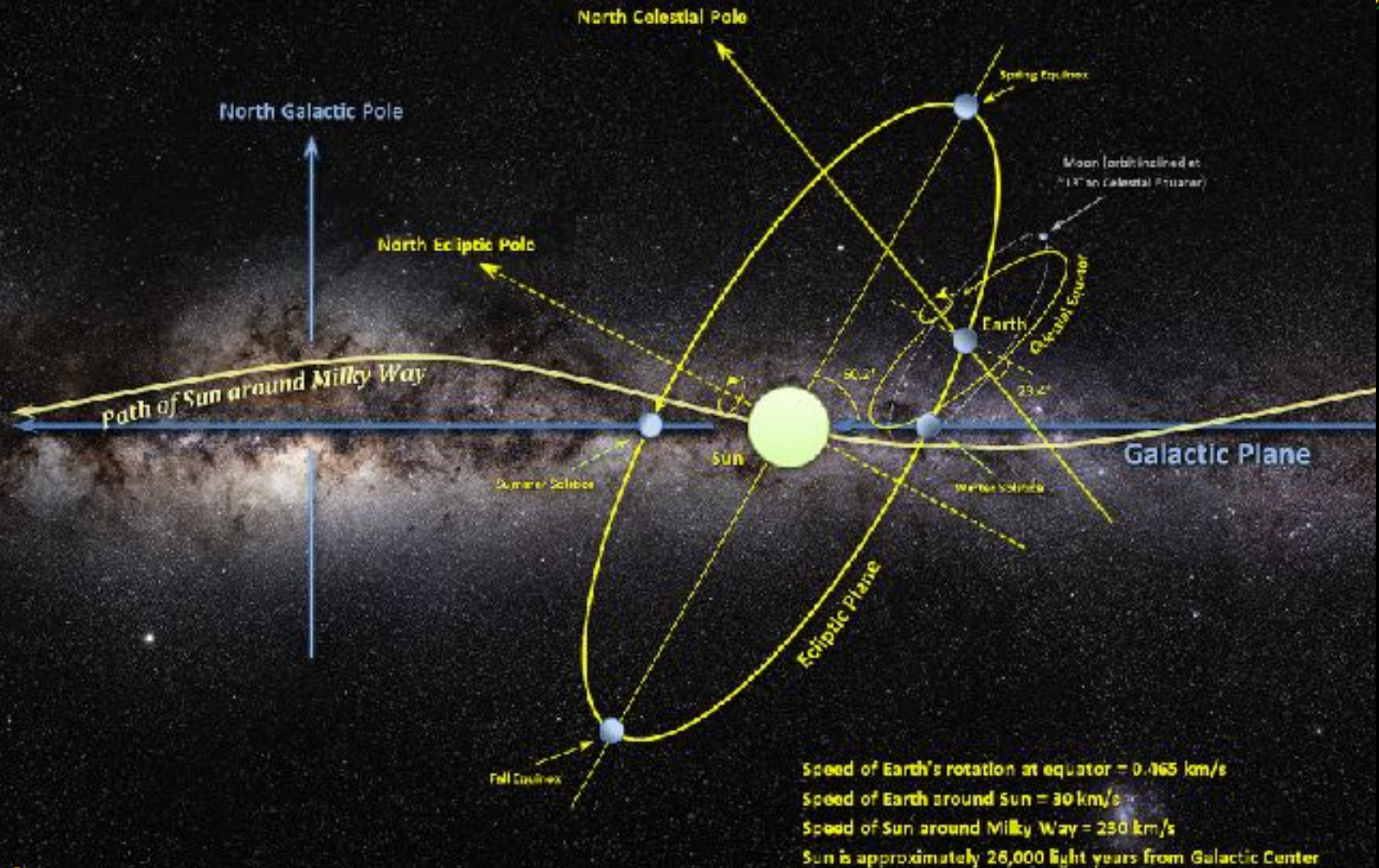
Short term (0 - 100,000 years):

No. Human activity has more impact (e.g., sulphur free fuels)

Long term (100,000 - millions of years):

Perhaps. Increase in solar/supernova activity could have an effect ...

# MOTION OF EARTH AND SUN AROUND THE MILKY WAY



Source

Diagram not to scale

Background Image Credit: ESO/S. Brunier



MORN1415

**QUICK  
SPLANATION**



Source

# Bolide Impacts: Cosmic Dust



Every year ~40,000 tonnes of cosmic dust fall to the Earth

What is it?

Interstellar dust (i.e., blocks light from stars)

Interplanetary dust (i.e., scatters sunlight; material that made our planets)

Terrestrial dust changes in composition during different climates (- polar ice cores)

Cosmic dust remains the same during glacial and inter-glacial periods

Source: <https://www.earth.columbia.edu/articles/view/920>

# Bolide Impacts: Meteorites



Impact needs to be irregular and big enough to disrupt the biogeochemical cycle

How big (according to NASA)?

<25m burn up and turn into cosmic dust

<1km significant damage to local area (i.e., change in weather)

>1km could have global effect (i.e., short-term climate change)

But ... it is a little more complex.

Size does matter, but so does the substrate that the meteorite lands on!

Source: <https://www.nasa.gov/solar-system/asteroids/asteroid-fast-facts/>

# Bolide Impacts: Meteorites



Target rocks need to release CO<sub>2</sub> and CH<sub>4</sub>:

Devolatilisation of CO<sub>2</sub> from carbonates  
Disrupt clathrates to release CH<sub>4</sub>

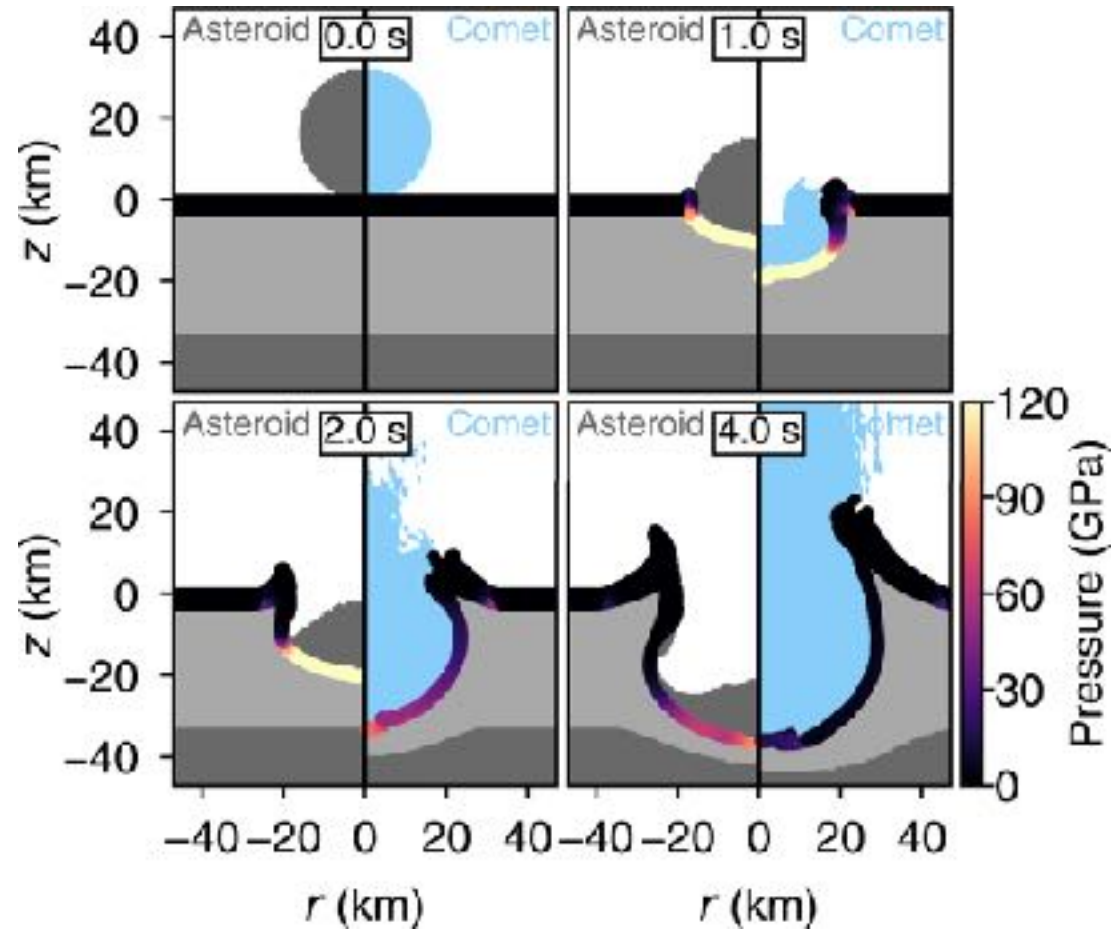
You need energy and heat!

<10km too small to generate required heat

>10km ideal (Dino-killer was ~12km)

>10km bolides are rare (2 - 4 per Ga)

<10 bolides did not cause climate change



32km bolide model: Grey = dunite; light grey = crust; blue = ice; black = calcite

Source: <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2022GL099313>

# Bolide Impacts: Chicxulub Impact 66Ma



Evidence: Earth covered in Ir @ 66Ma

>>>> Climate Disruption

Impact winter

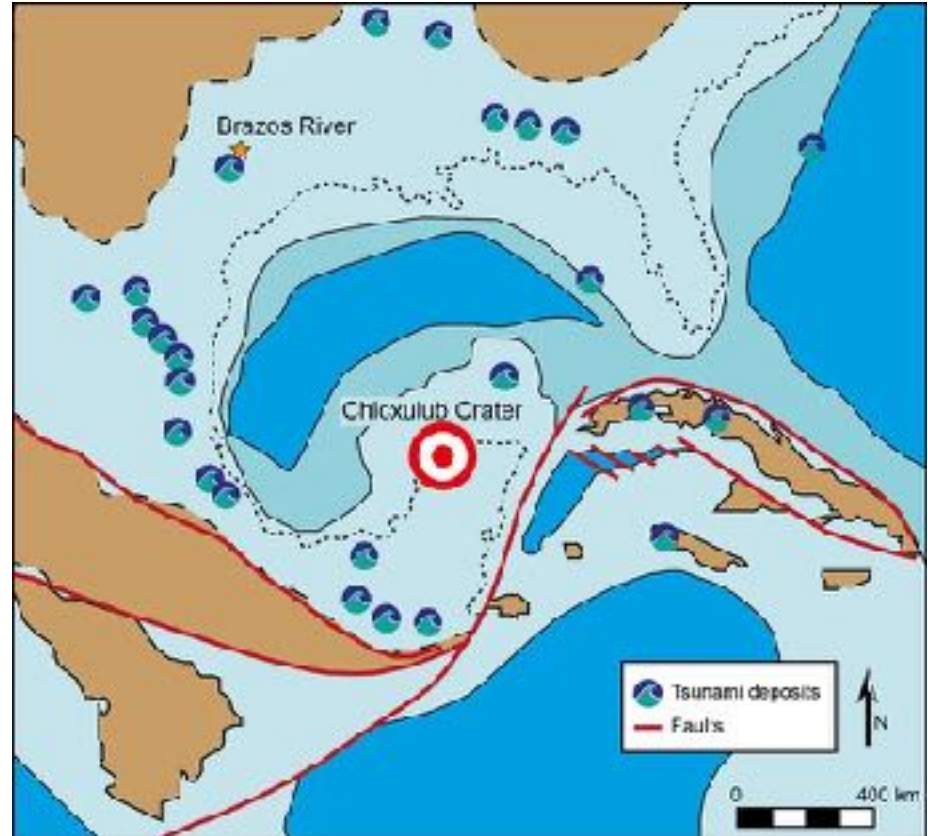
Volatilisation of carbonate rocks

Massive CO<sub>2</sub> release

All sulphate rocks vaporised

Massive SO<sub>2</sub> release

Impact during end-K climate change



Source: <https://eos.org/science-updates/a-post-impact-deep-freeze-for-dinosaurs>

# Bolide Impacts: Tanis Event 66Ma



Evidence: Impact caused earthquakes

>>>> Fast burial of Tanis biota

Tanis in North Dakota

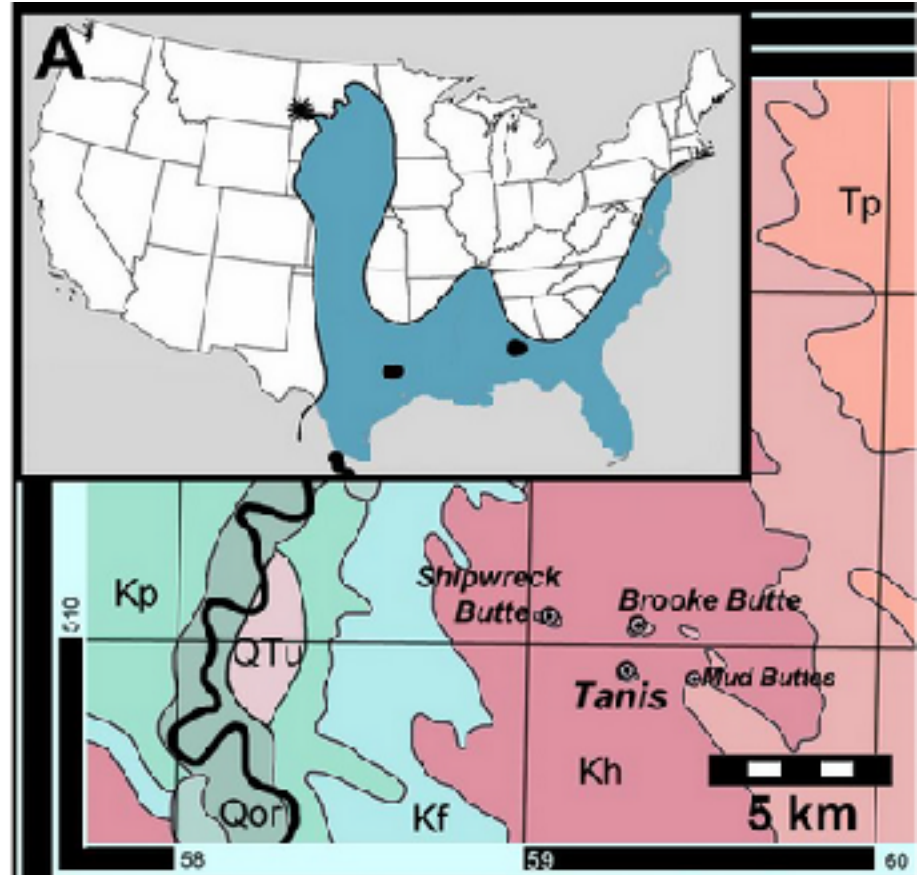
Deposition within <1 hour of impact

Mixed marine/terrestrial biota

Lots of debris

Ejecta in sediment and gills of fish

*The Day the Dinosaurs Died*



Source: <https://www.newyorker.com/magazine/2019/04/08/the-day-the-dinosaurs-died>

# Earth's Orbit: Milankovitch Cycles



Driver of long-term climate change

Milankovitch Cycles include:

1. Shape of Earth's orbit: Eccentricity
2. Angle of Earth's axis: Obliquity
3. Direction of Earth's axis: Precession

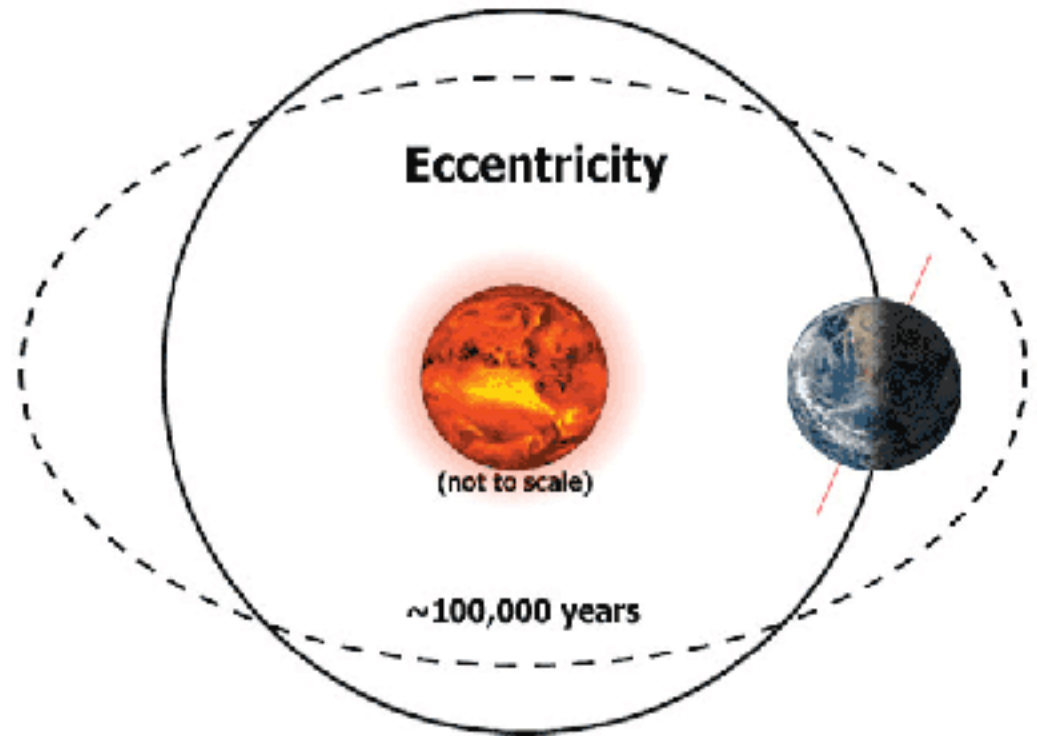
>>>> Eccentricity

Pull of gas giants change Earth's orbit

Circular orbit becomes more elliptical

We are moving to the least elliptical

100,000 year cycle



[Source: NASA](https://www.nasa.gov)

# Earth's Orbit: Milankovitch Cycles



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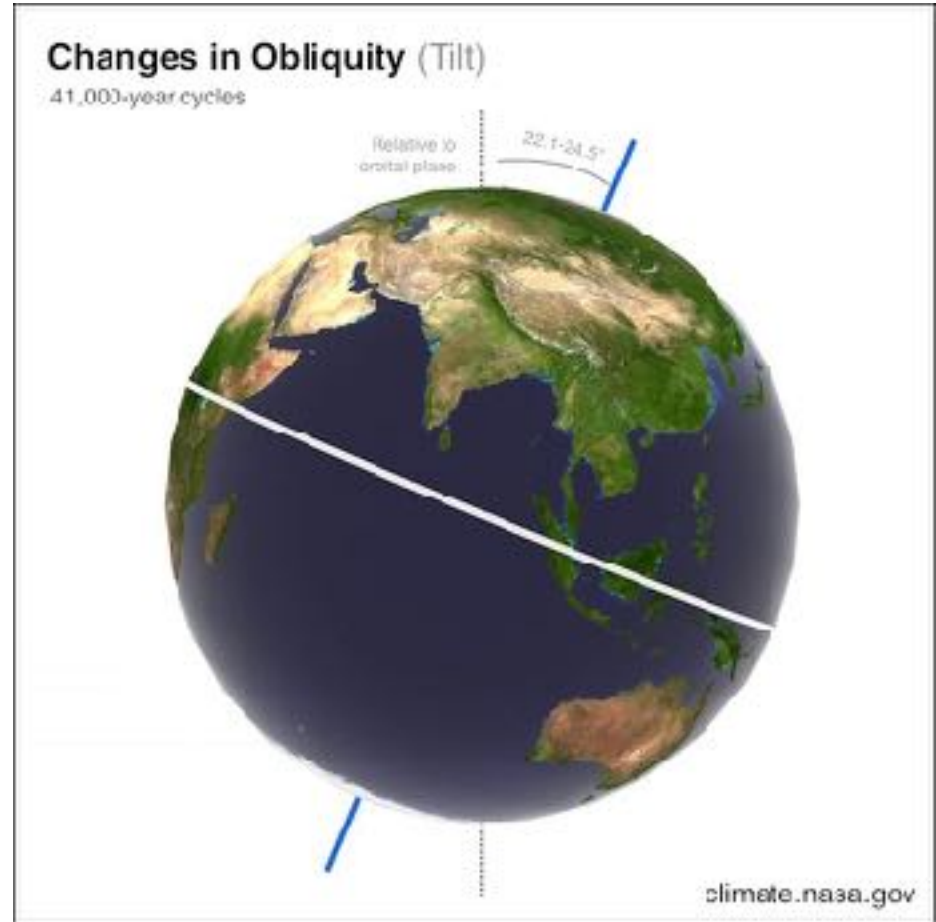
>>>> Obliquity

Axis angle changes (22.1 - 24.5 degrees)

Greater tilt more extreme the seasons

We are half way (23.4 degrees)

41,000 year cycle



[Source: NASA](https://www.nasa.gov)

# Earth's Orbit: Milankovitch Cycles



Driver of long-term climate change

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1. Shape of Earth's orbit: Eccentricity
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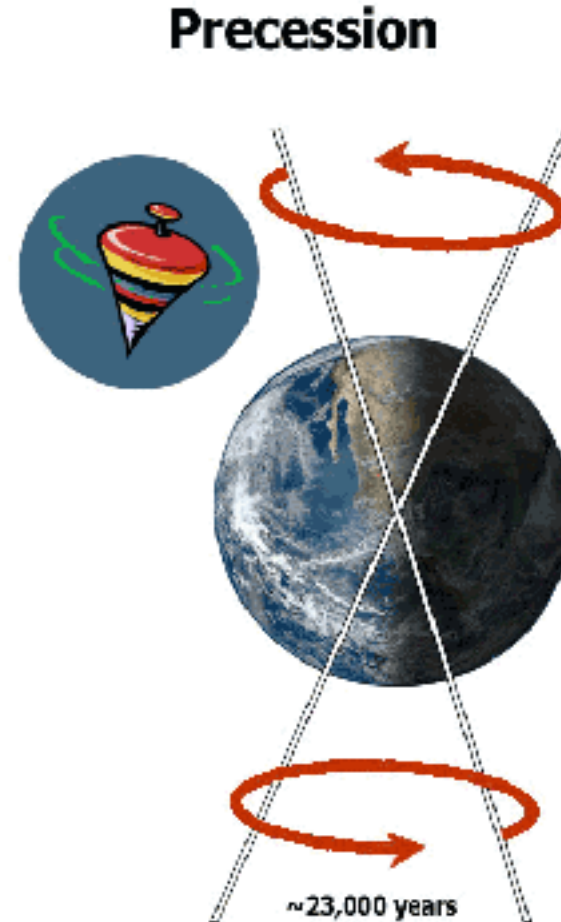
>>>> Precession

Earth wobbles on its rotational axis

Due to gravitation of Sun and Moon

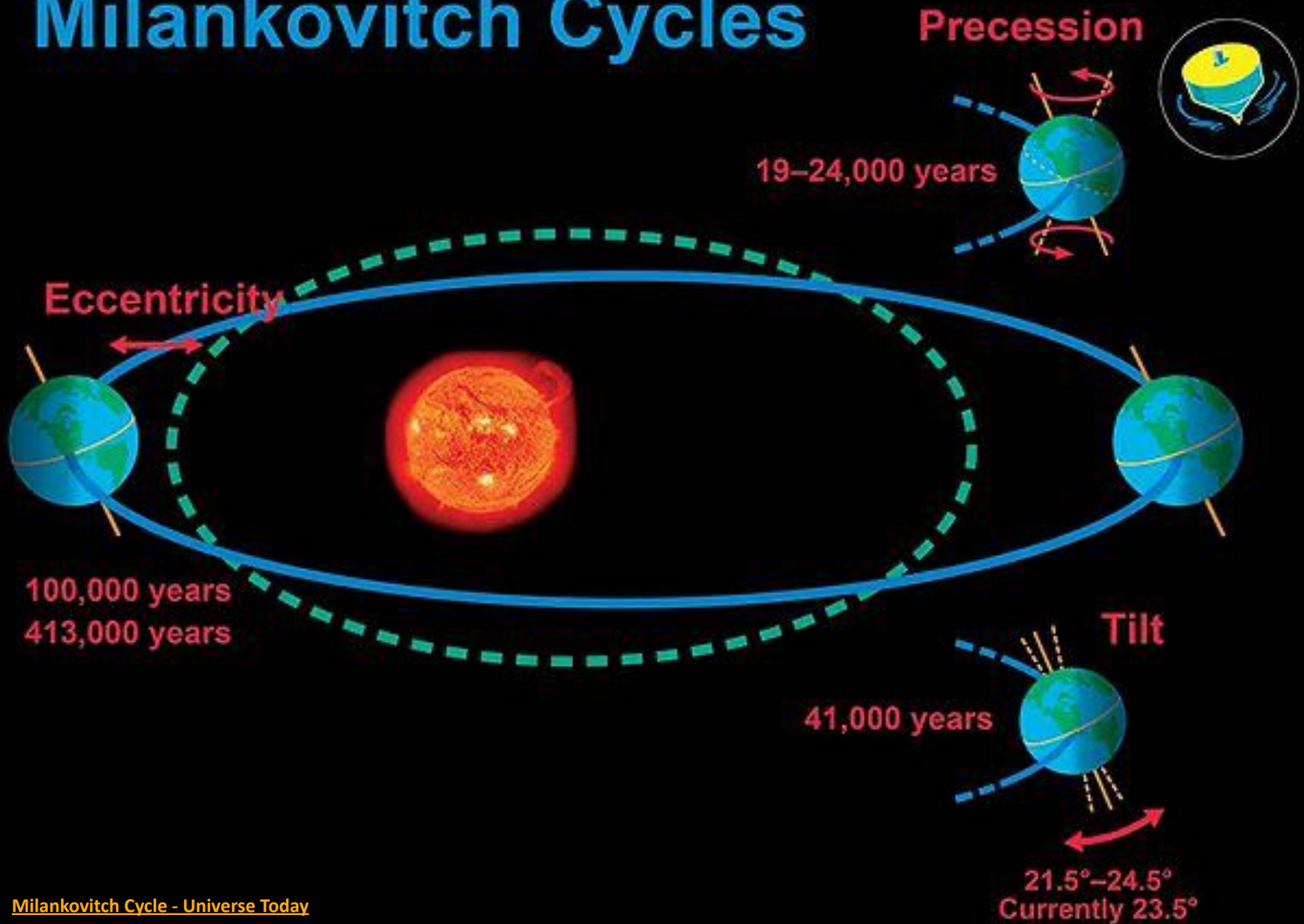
Think of a spinning top (extreme seasons)

26,000 year cycle

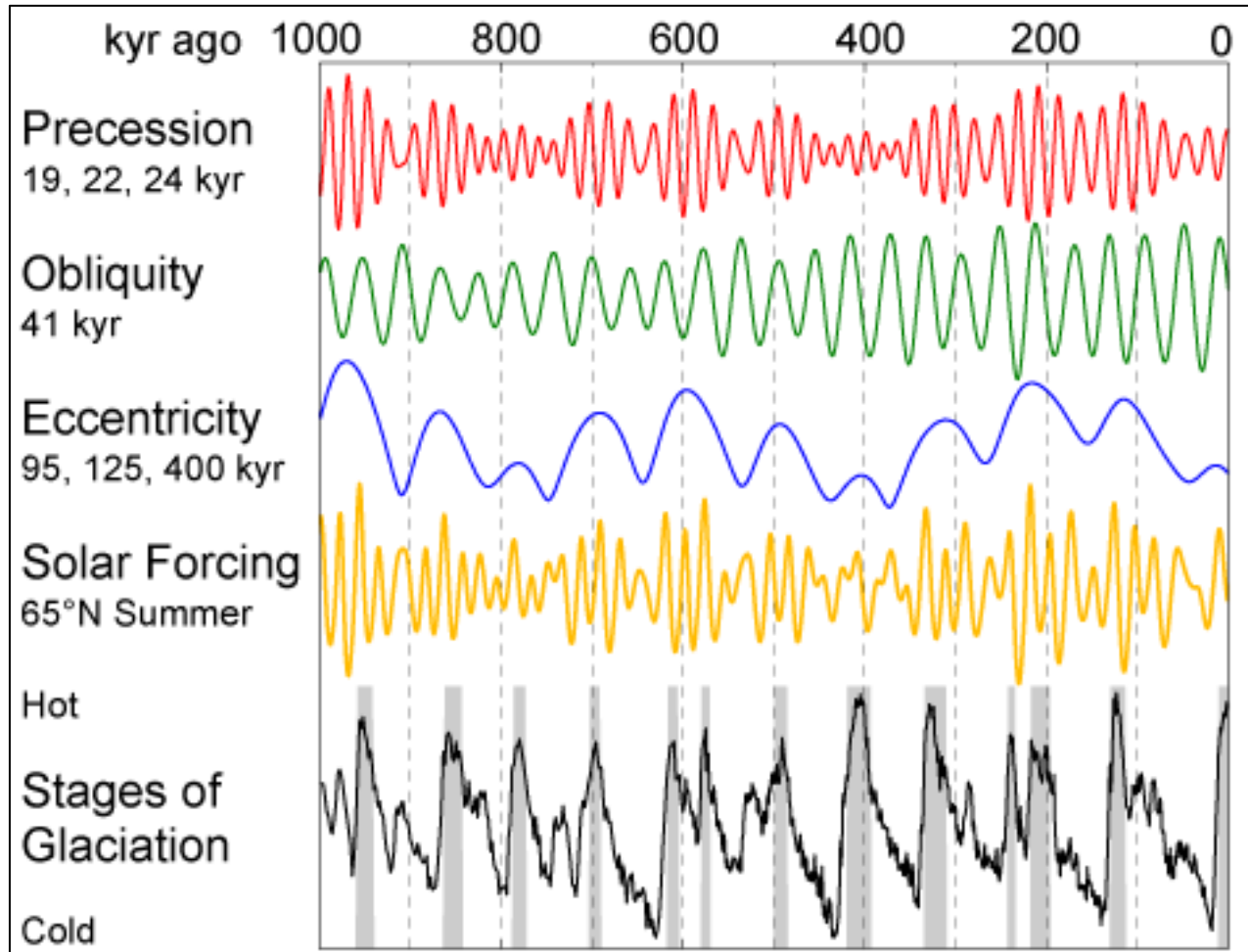


[Source: NASA](https://www.nasa.gov)

# Milankovitch Cycles

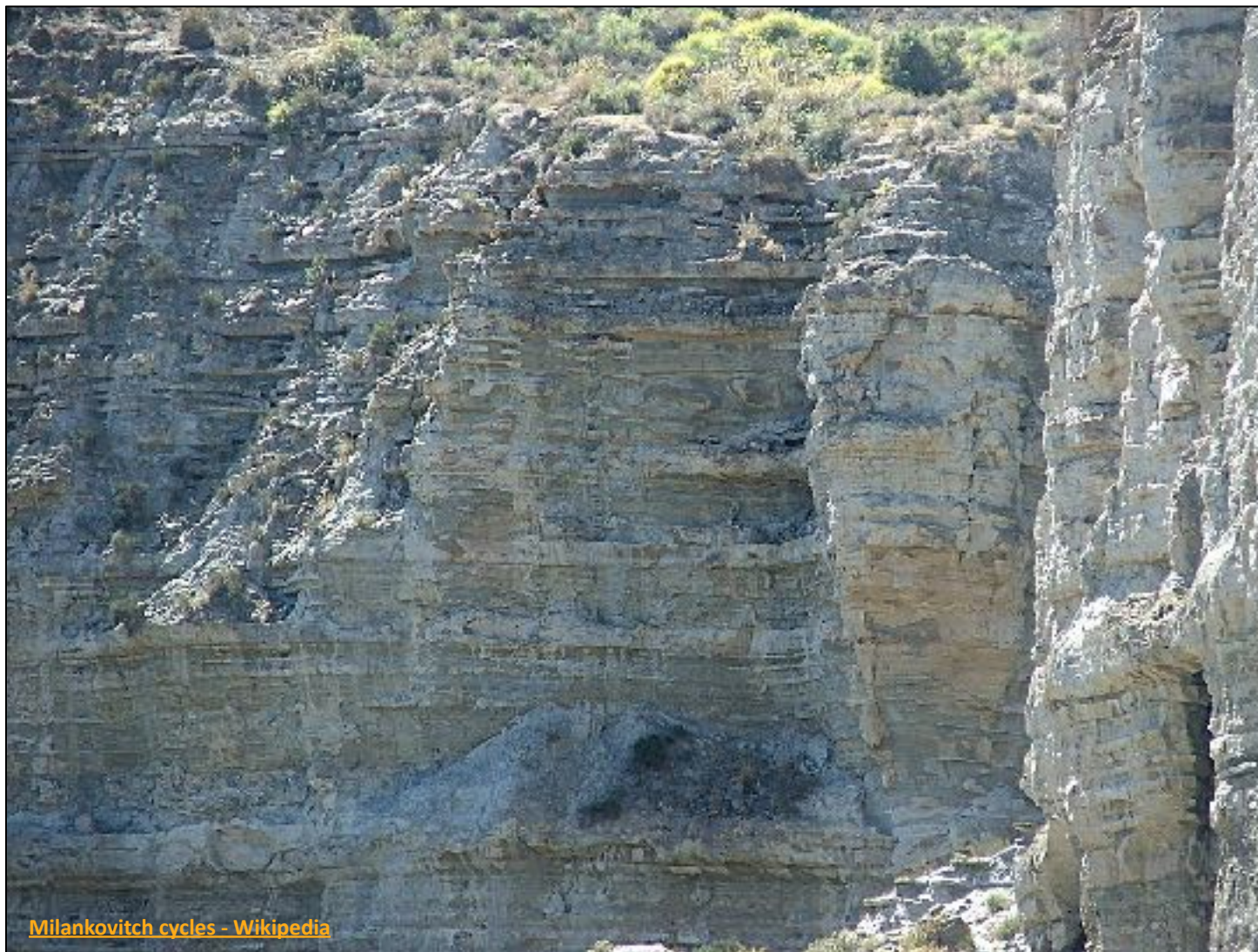


[Milankovitch Cycle - Universe Today](http://www.universe-today.com)



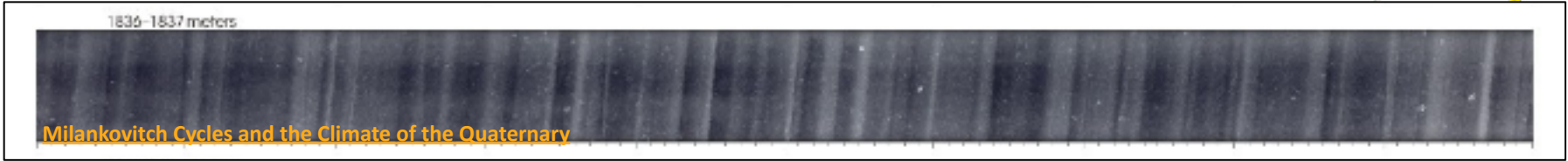
Taken together, the Milankovitch cycles *may* generate the Ice Ages over roughly 100,000 years.

[Milankovitch Cycles \(utexas.edu\)](http://utexas.edu)

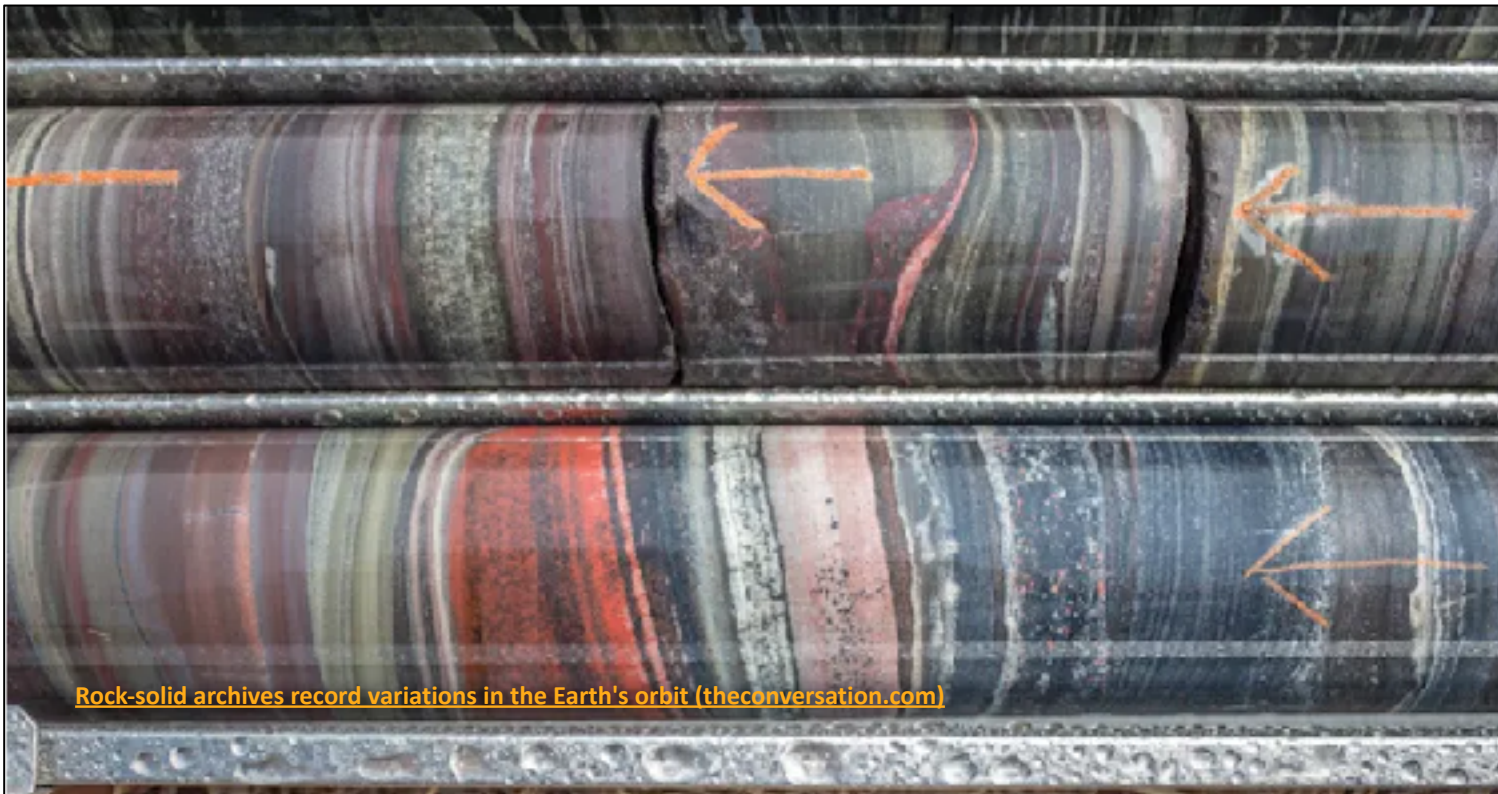


[Milankovitch cycles - Wikipedia](#)

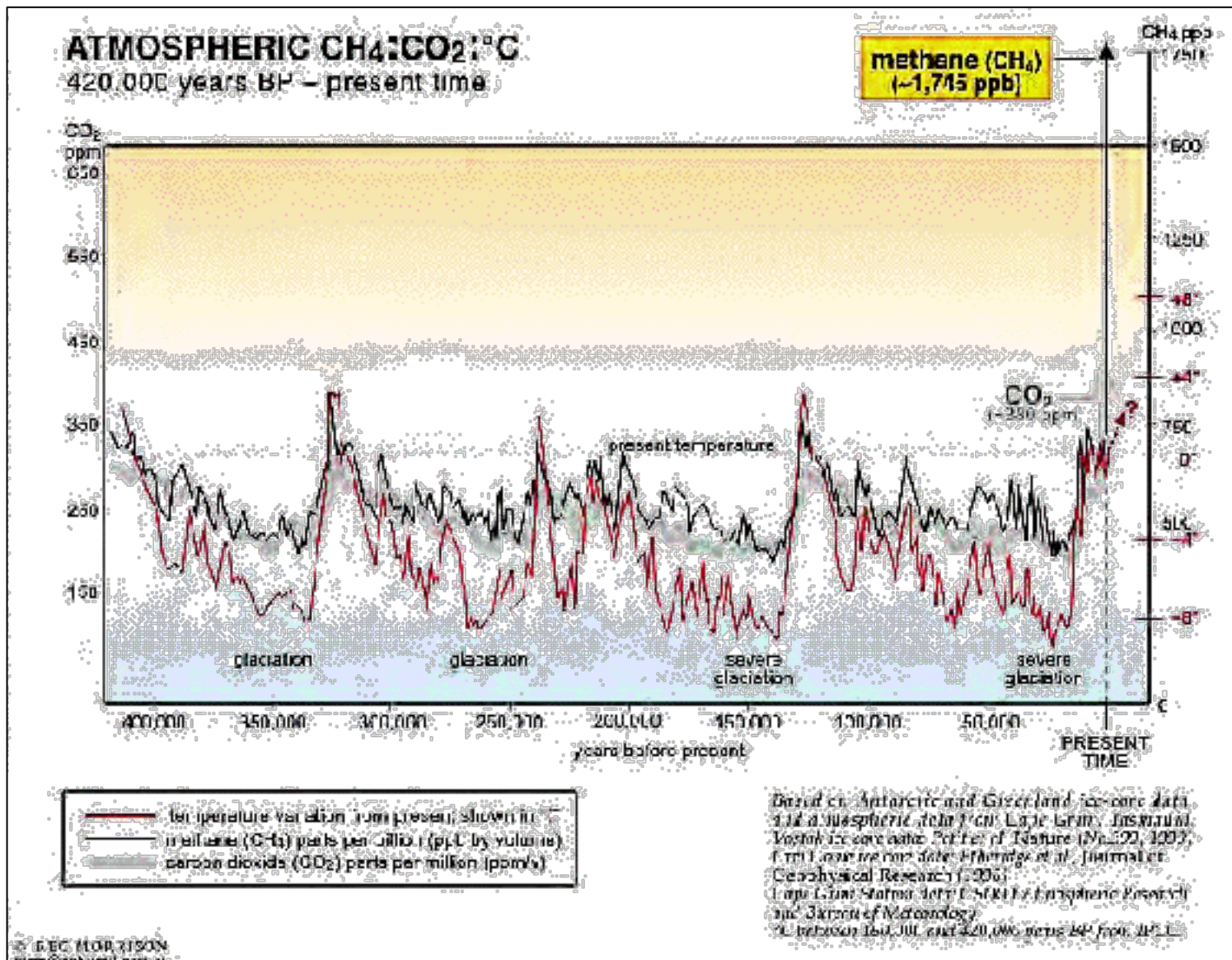
Outcrop in Tabernas, Spain, showing Milankovitch cycles in the thin bedding.



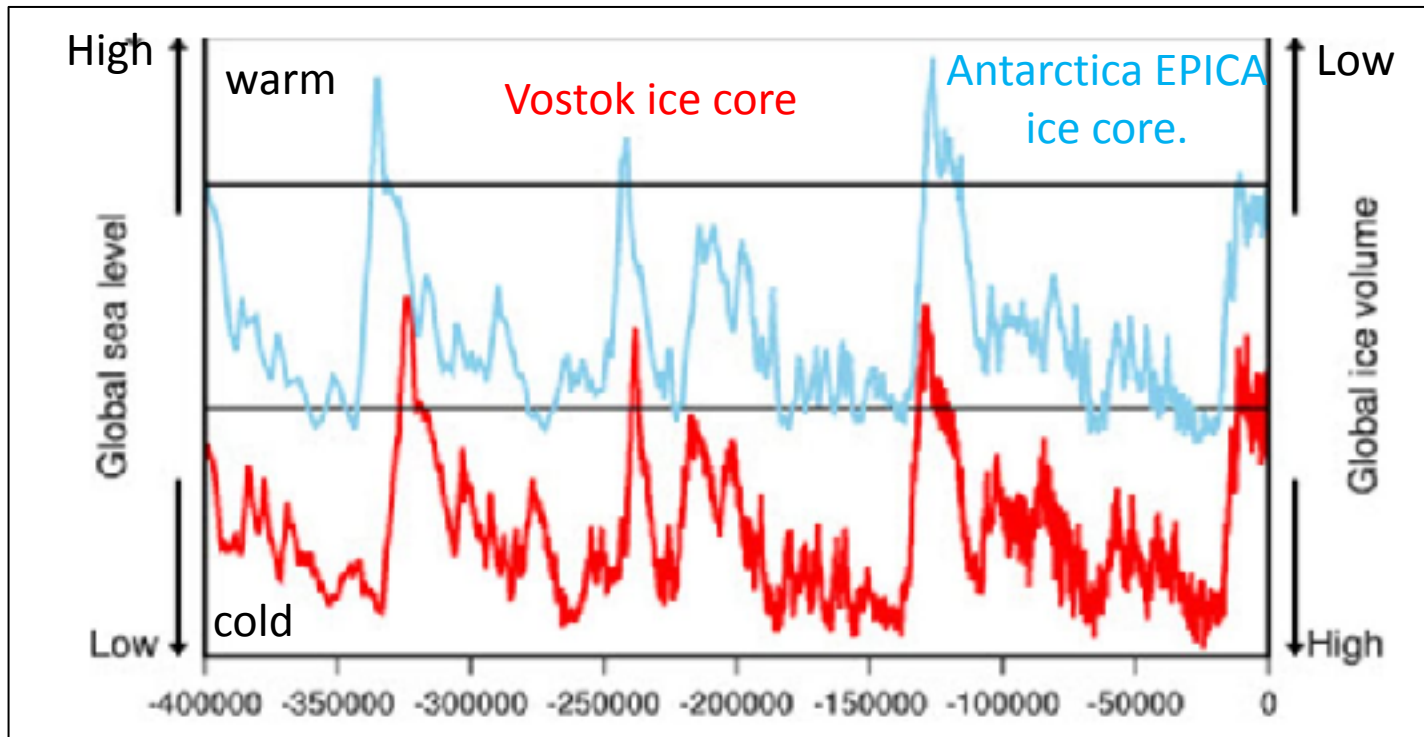
Ice core shows Milankovitch cycles.



2.5 billion year old banded iron formation shows Milankovitch cycles.



[Milankovitch Cycles \(utexas.edu\)](http://Milankovitch Cycles (utexas.edu))



[Milankovitch and Paleo Sea-Level Changes](#)

The Milankovitch cycles *may* drive global warming and cooling and hence sea level changes

# Biggest Climate Change ever



Has anyone heard of the Faint Young Sun Paradox?

[Source](http://www.tesep.org.au)

# The Faint Young Sun Paradox



Early Sun's (4Ga) output 25% lower (77% of current value)

A cooler sun would have led to a cooler Earth

We know Earth and Mars were much warmer at 4Ga

Both had liquid water on surface

What heated up the early Earth and Mars?

>>>> Greenhouse Gases!

Cosmic Rays (weaker magnetic field & solar rays)

Greater short-wave radiation (i.e., UV and X-ray)

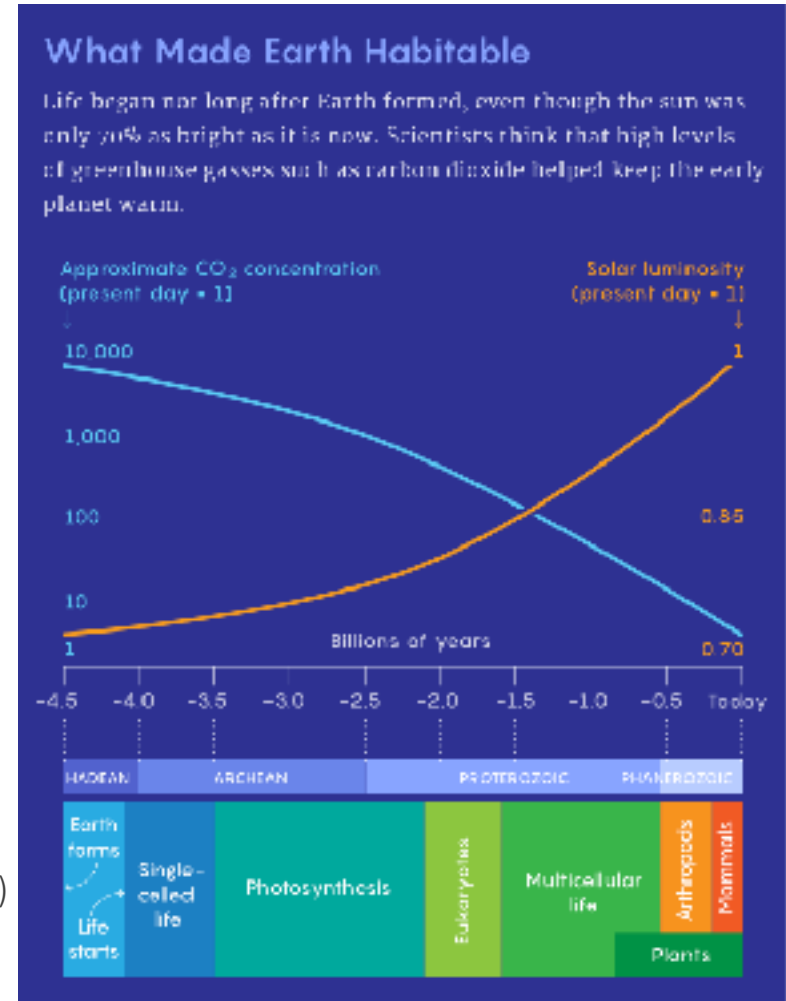
Cosmic dust and bolides (there were more of them)

Milankovitch cycles (spin and orbit were faster)

Planets may have been closer together

Slightly different greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, but also HCN, H<sub>2</sub>, NH<sub>3</sub>)

[Source](#)



# Resources

What causes the Earth's climate to change? (British Geological Survey)

<https://www.bgs.ac.uk/discovering-geology/climate-change/what-causes-the-earths-climate-to-change/>

Cosmic Rays and Climate (CERN)

<https://home.cern/science/physics/cosmic-rays-particles-outer-space>

The Day the Dinosaurs Died (New Yorker)

<https://www.newyorker.com/magazine/2019/04/08/the-day-the-dinosaurs-died>

Milankovitch Cycles (NASA)

<https://climate.nasa.gov/news/2948/milankovitch-orbital-cycles-and-their-role-in-earths-climate/>

Faint Young Sun Paradox (Geological Society of America)

<https://rock.geosociety.org/net/gsatoday/science/G403A/article.htm>