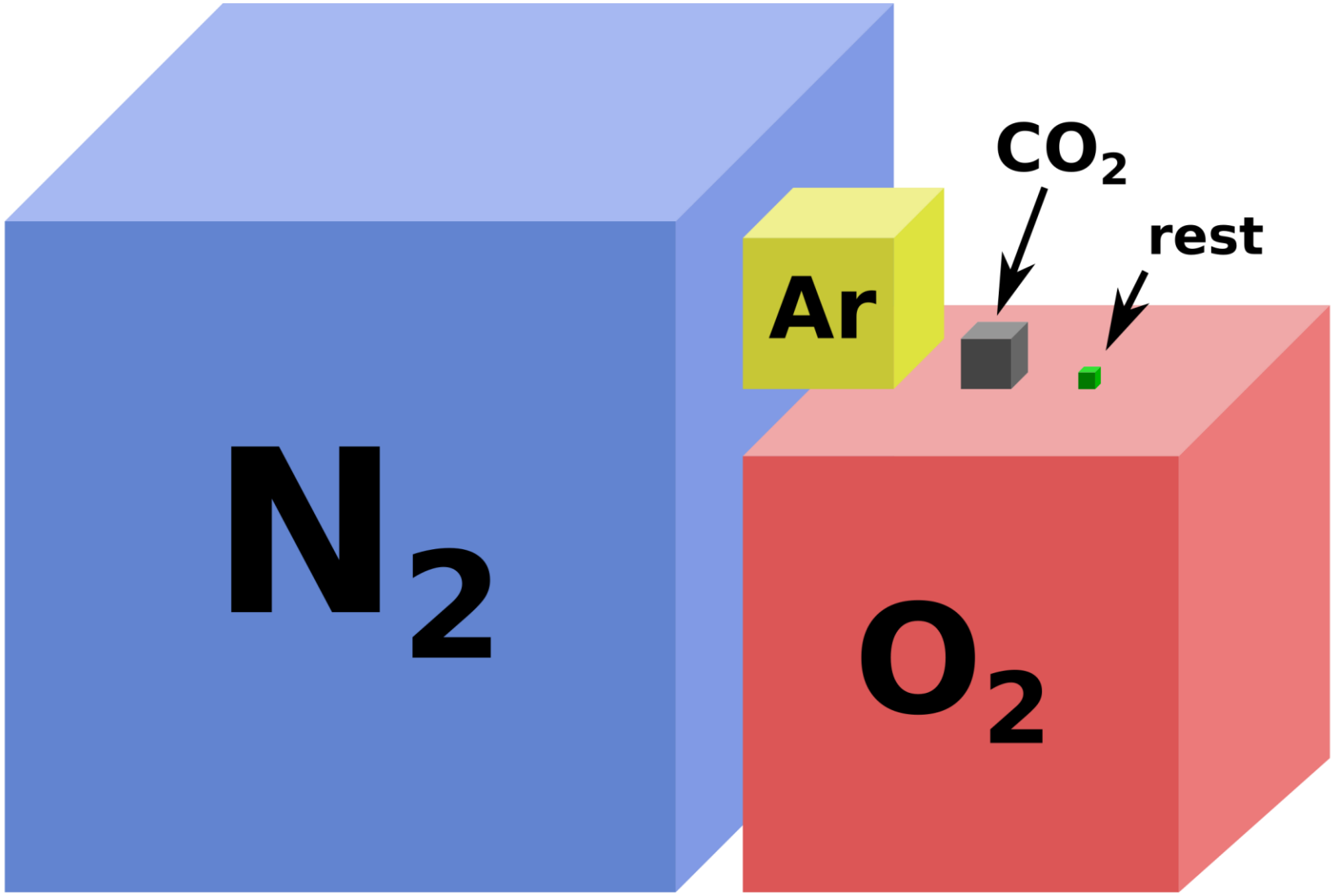
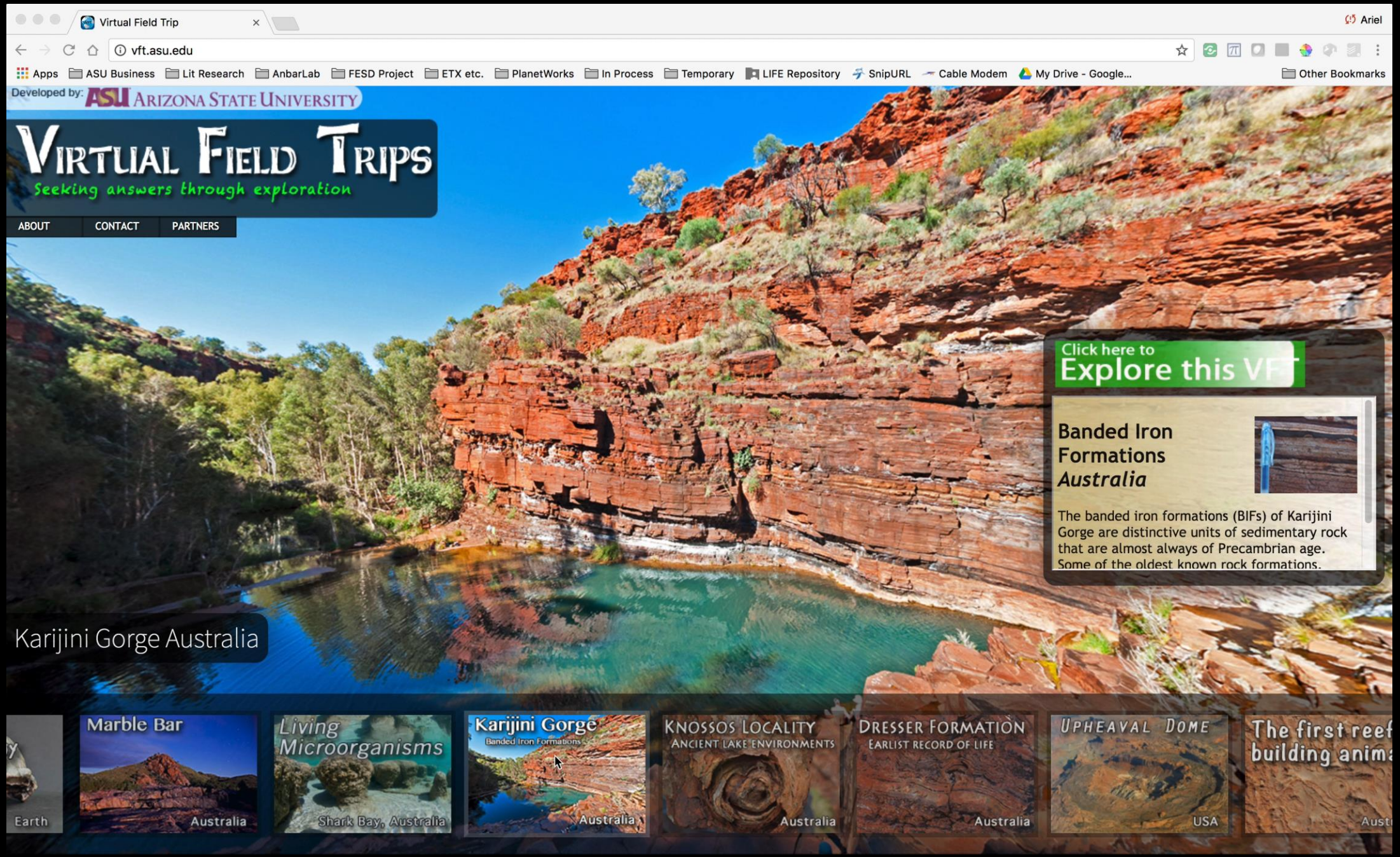
The Great Oxidation Event

Ariel D. Anbar
School of Earth and Space Exploration
School of Molecular Sciences
Arizona State University

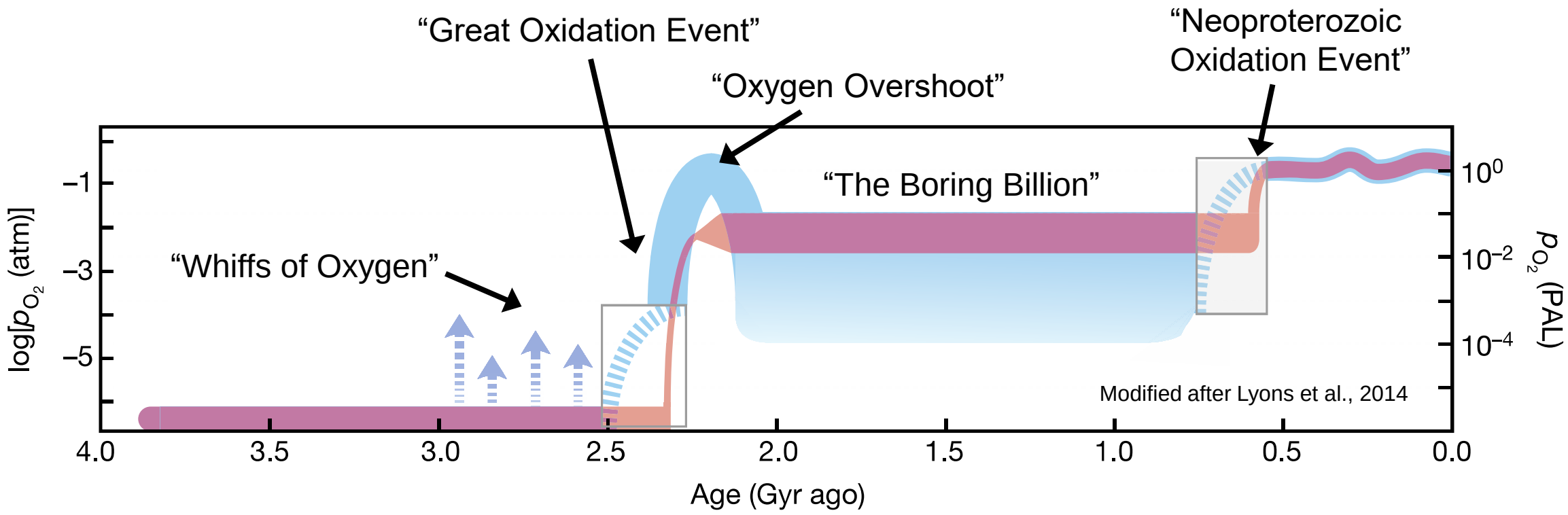
Photo credit: Tanja Bosak

Earth's Atmosphere Composition

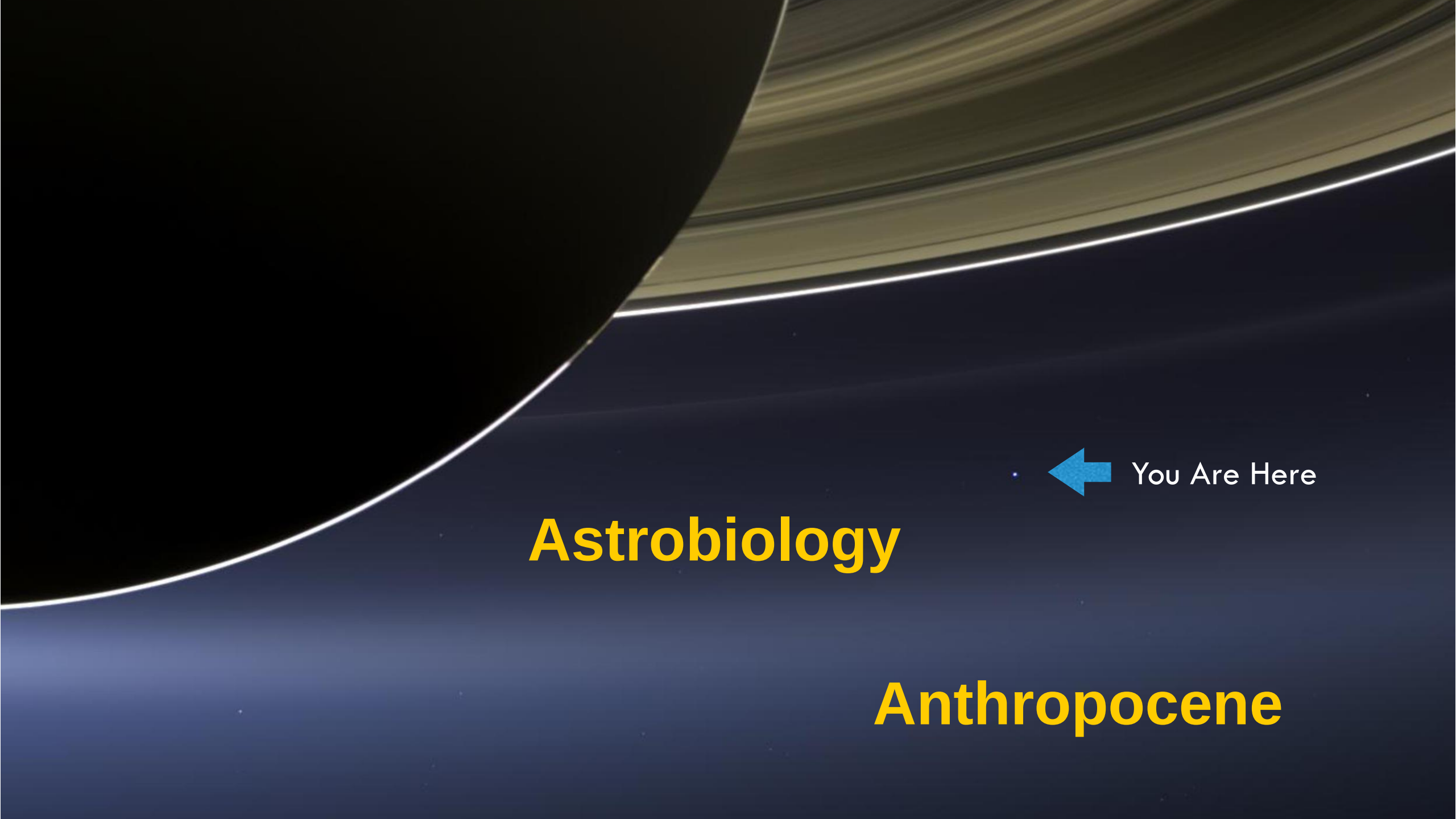



Virtual Field Trip
Ariel
vft.asu.edu
Apps
ASU Business
Lit Research
AnbarLab
FESD Project
ETX etc.
PlanetWorks
In Process
Temporary
LIFE Repository
SnipURL
Cable Modem
My Drive - Google...
Other Bookmarks
Developed by: ASU Arizona State University
Virtual Field Trips
Seeking answers through exploration
ABOUT
CONTACT
PARTNERS
Click here to
Explore this VFT
Banded Iron Formations
Australia
The banded iron formations (BIFs) of Karijini Gorge are distinctive units of sedimentary rock that are almost always of Precambrian age. Some of the oldest known rock formations.
Karijini Gorge Australia
Earth
Marble Bar
Australia
Living Microorganisms
Shark Bay, Australia
Karijini Gorge
Banded Iron Formations
Australia
Knossos Locality
Ancient Lake Environments
Australia
Dresser Formation
Earlist Record of Life
Australia
Upheaval Dome
USA
The first reef
building anim
Aust

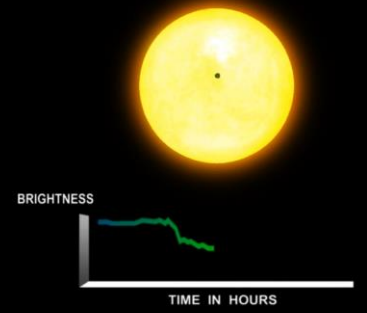
O_2 in Earth's Atmosphere through Time



Why do we care?


You Are Here
Astrobiology
Anthropocene

Exoplanets!



3711 confirmed
4496 candidates
927 terrestrial
... and counting!

https://exoplanets.nasa.gov/

Coming Soon:

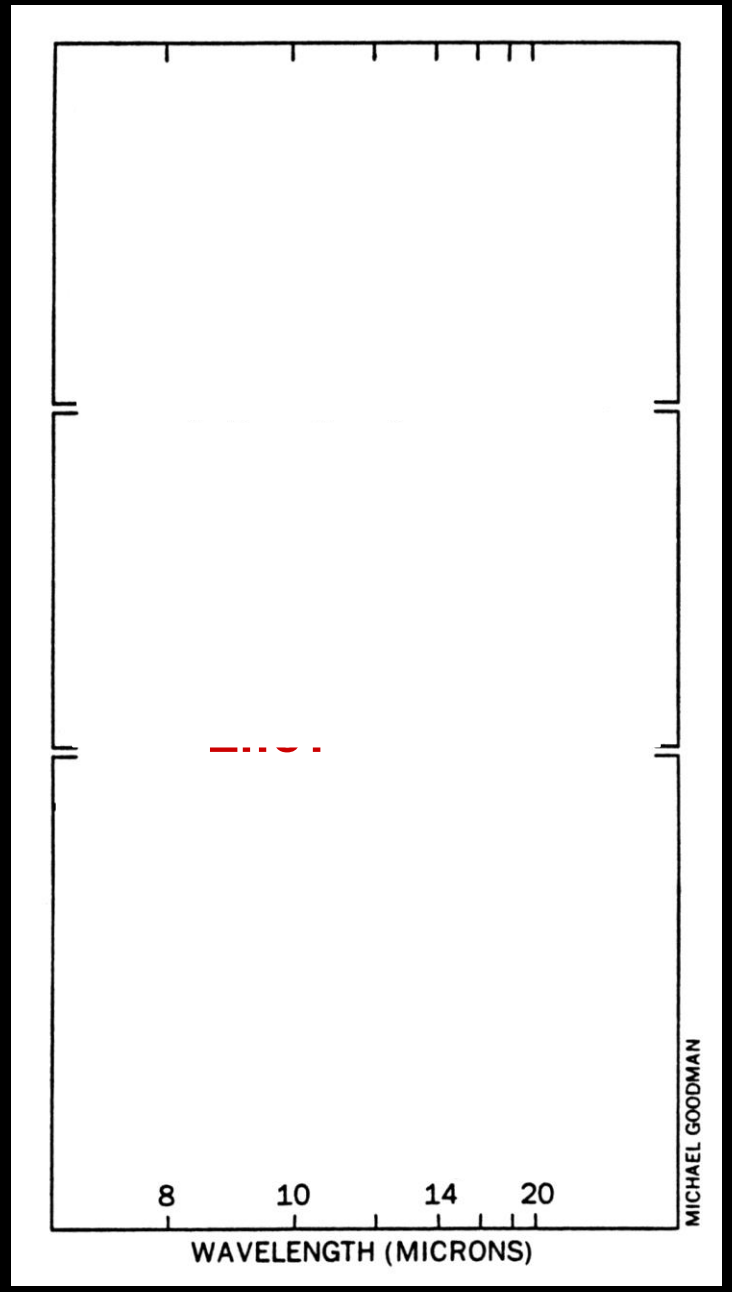
Spectroscopic search for biosignatures

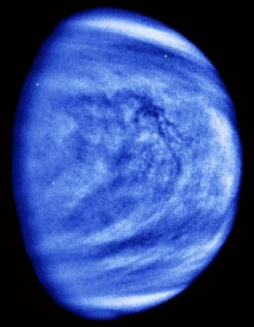
O_2 as a Biosignature

Venus

Earth

Mars

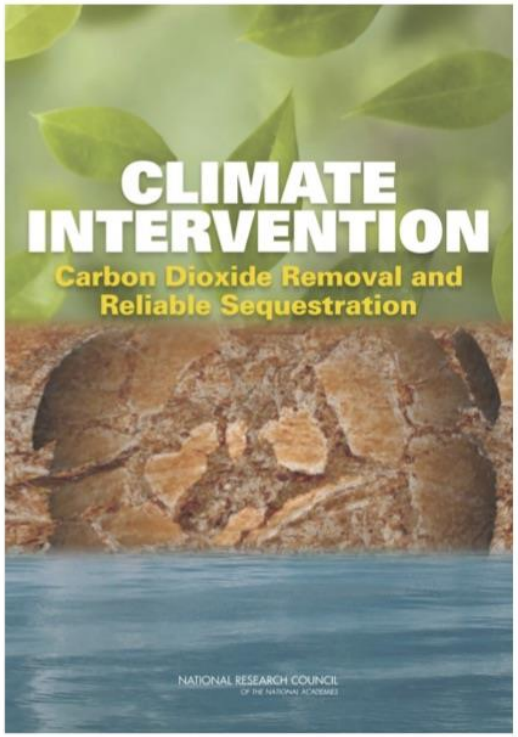


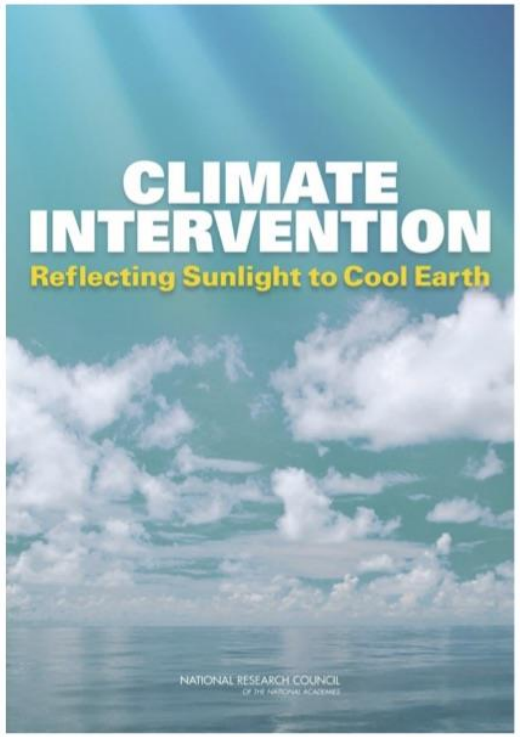


Source:
R. Hanel, Goddard Space Flight Center

Welcome to the Anthropocene!

CLIMATE INTERVENTION





Marcia McNutt (*Chair*), Waleed Abdalati,
Scott Doney, David Titley

BOARD ON ATMOSPHERIC
SCIENCES AND CLIMATE

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE GREEN MARS

Terraforming of Mars

Building up the atmosphere

- Increasing the pressure
- Changing air chemical composition
  - Importing ammonia
  - Importing hydrocarbons
  - Importing hydrogen
  - Using fluorine compounds

Building up water content

- Water sources
  - Melted ice
  - From nearby asteroids
  - Artificial rains (after heating up the planet)

Heating up the planet

- Enhancing greenhouse effect
  - Orbiting space mirrors
  - Nuclear weapons
  - Imported fossil fuels
  - Guided asteroids to hit Mars

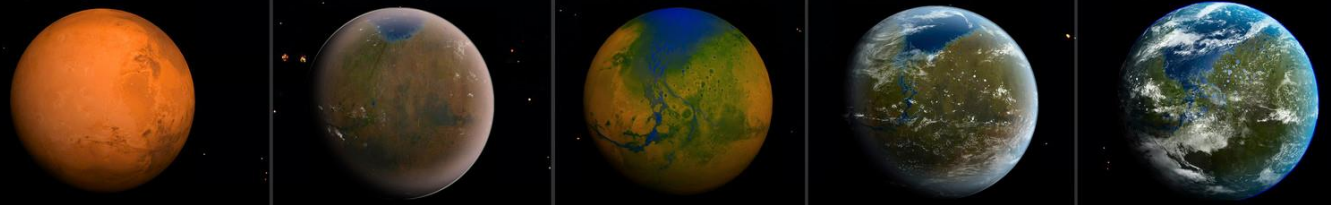
Planting Mars

- By importing
  - Synthetic microbes
  - Genetically engineered seeds

Mars colonization

- Megascale engineering
  - Laser-propelled spaceships
  - Building cities on Mars
  - 3D printed homes

DURATION	90 Years	120 Years	150 Years	50 Years	70 Year
COST	500 Billion USD	700 Billion USD	900 Billion USD	300 Billion USD	1.5 Trillion USD



NASA NATIONAL GEOGRAPHIC Discovery CHANNEL

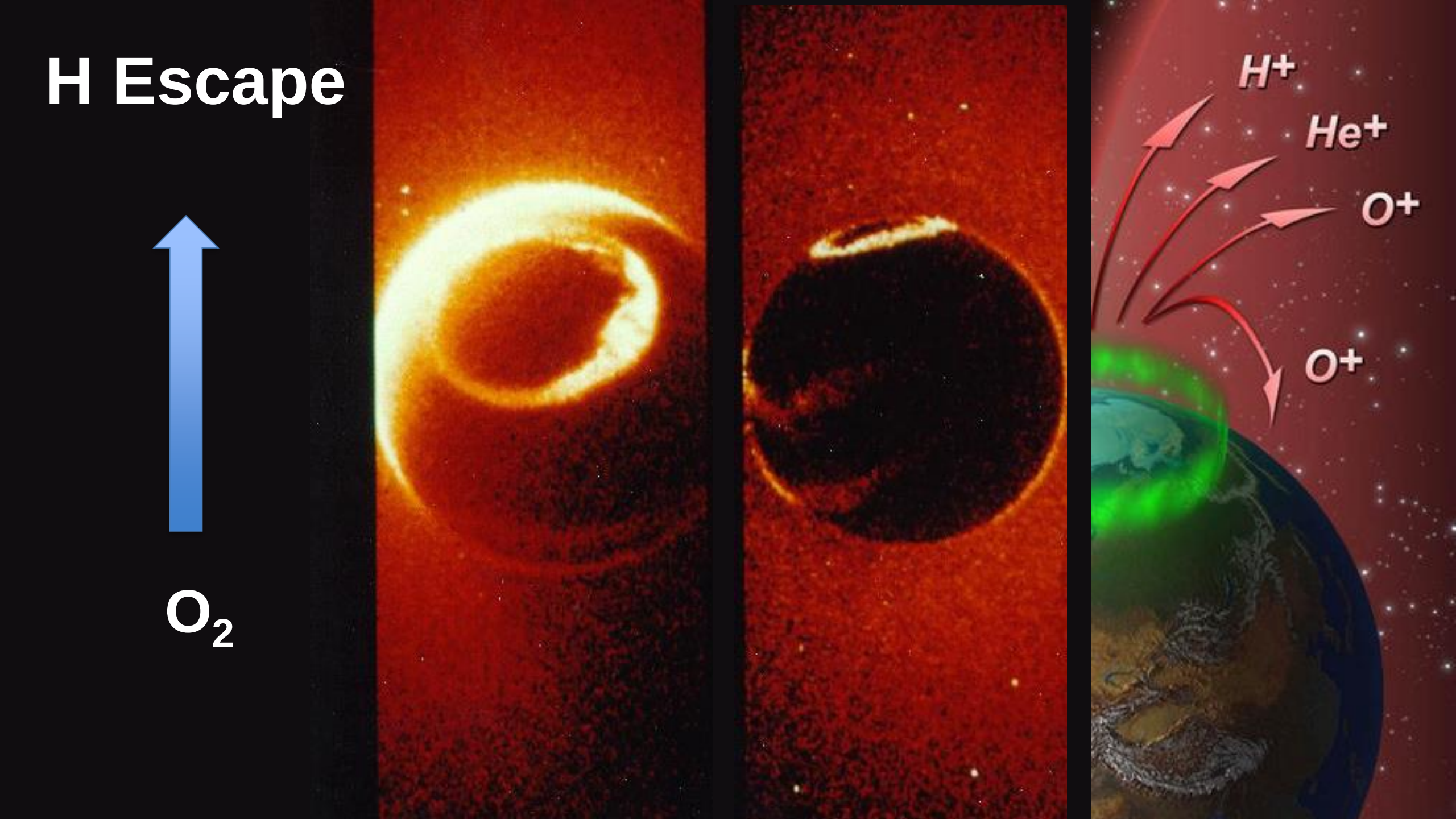
www.facebook.com/hashem.alghaili
h.biotechnology@ymail.com

Elon Musk

"You need to live in a dome initially but over time you could terraform Mars to look like Earth and eventually walk around outside without anything on. ... So it's a fixer-upper of a planet."

What caused the Great Oxidation Event?

H Escape



O_2

Photosynthesis?

$$CO_2 + H_2O \rightarrow O_2 + CH_2O$$

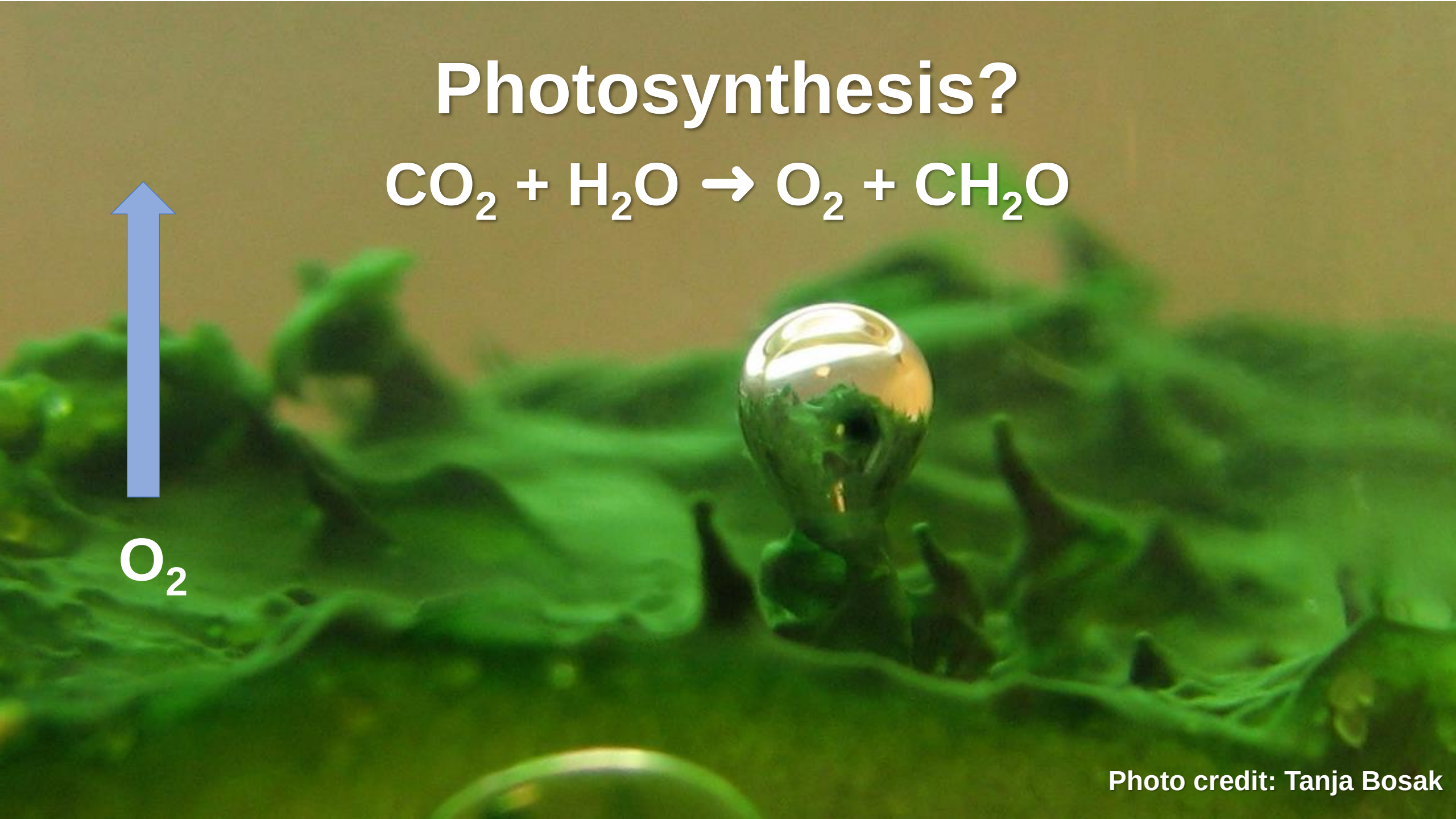
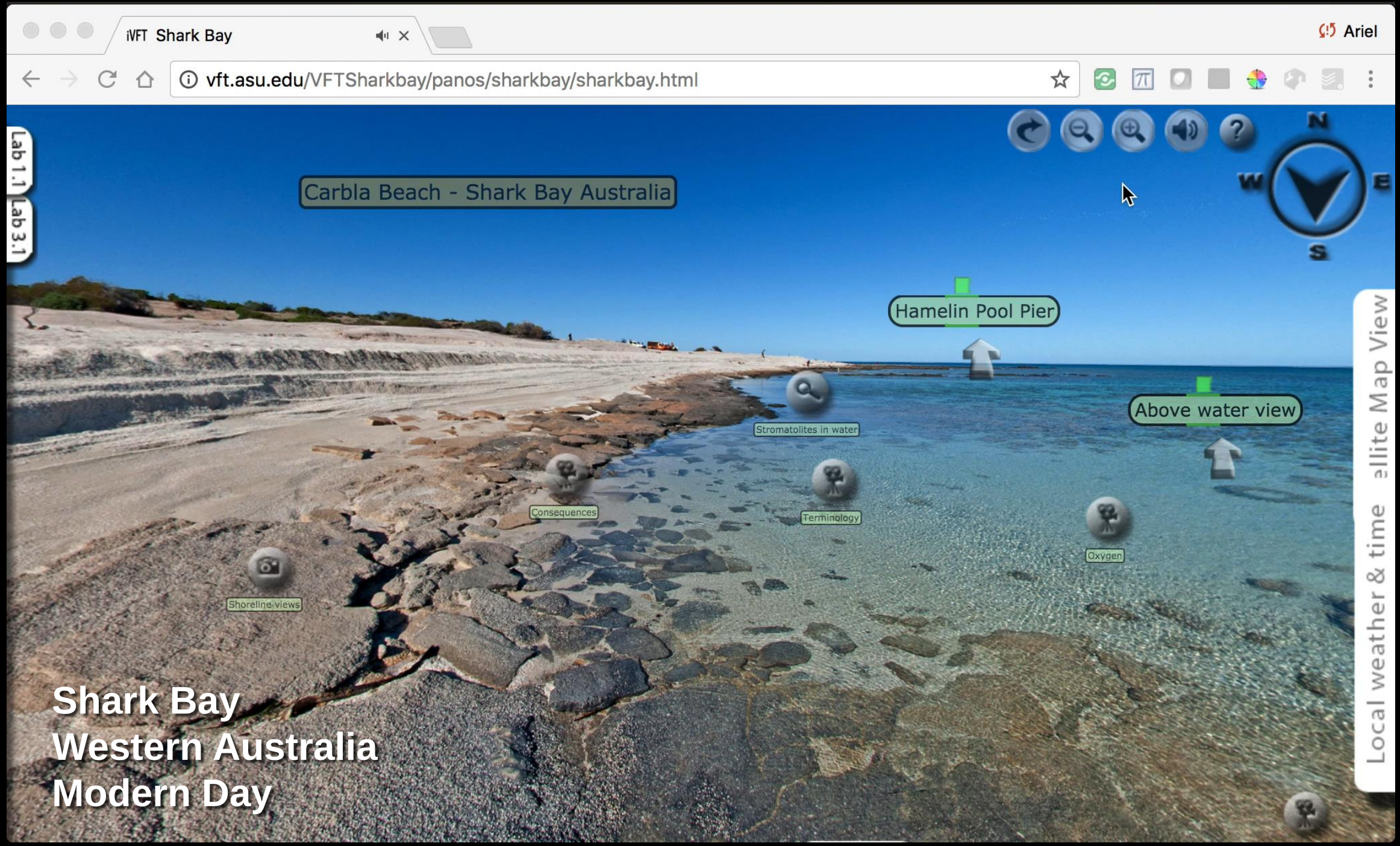
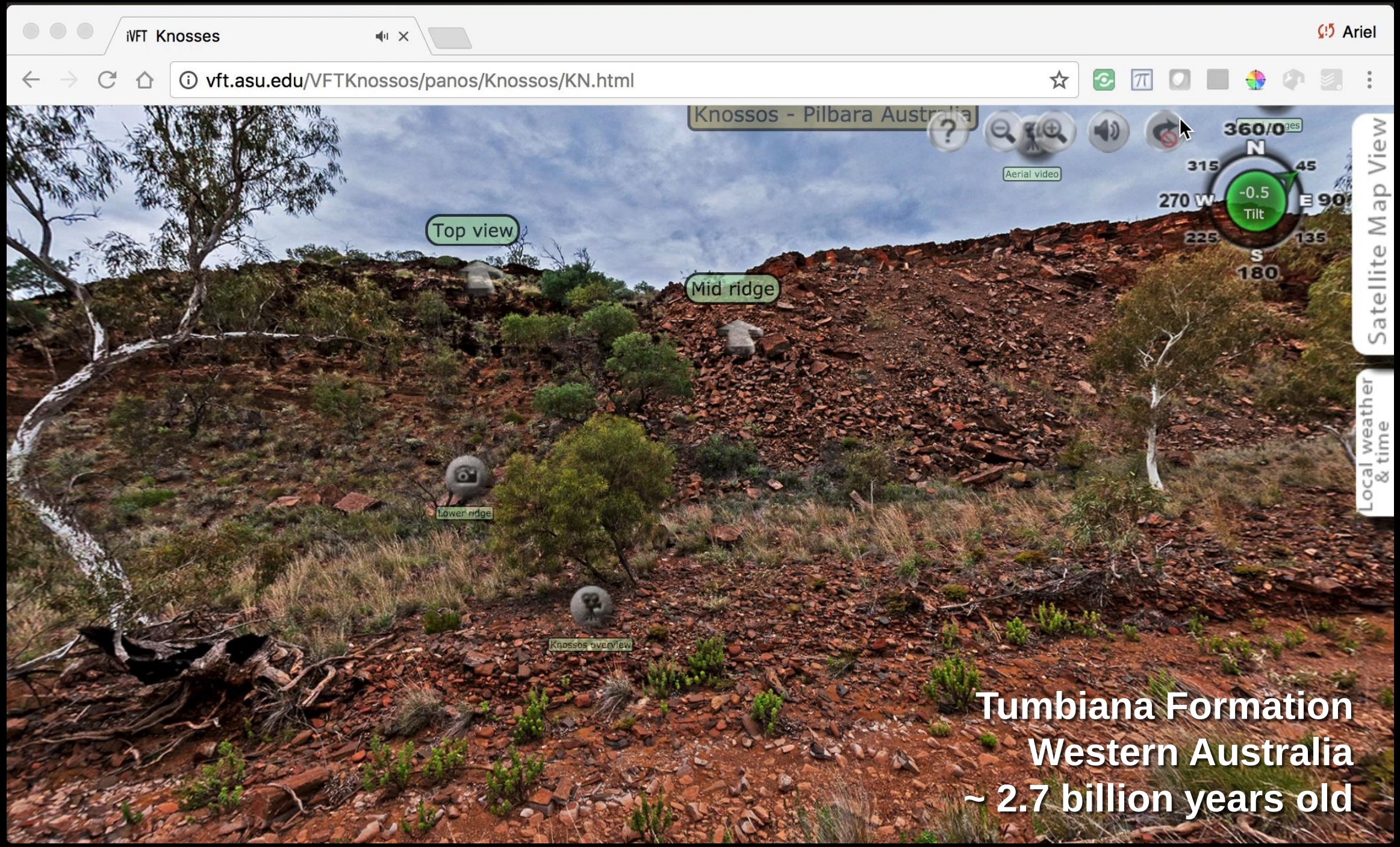
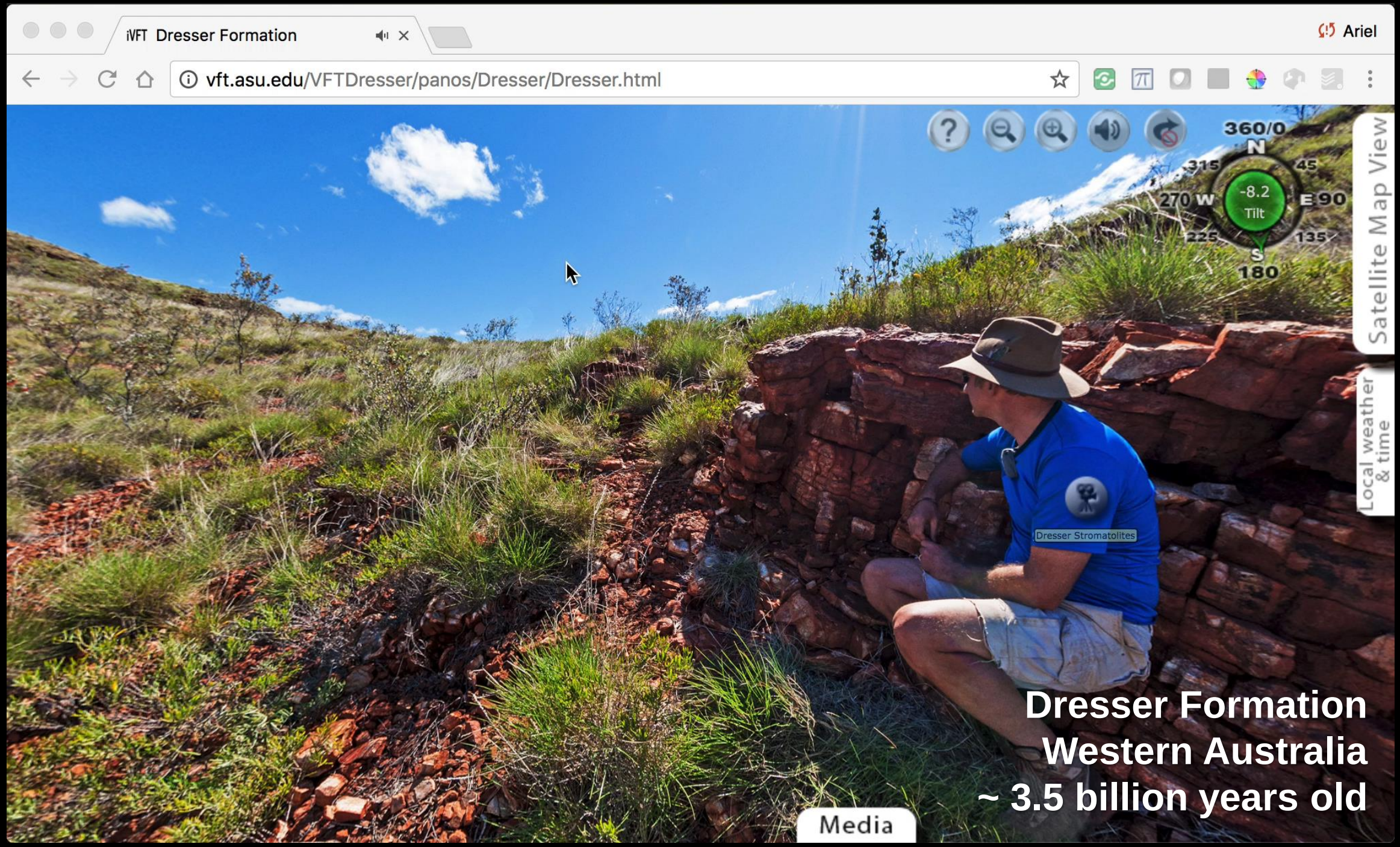
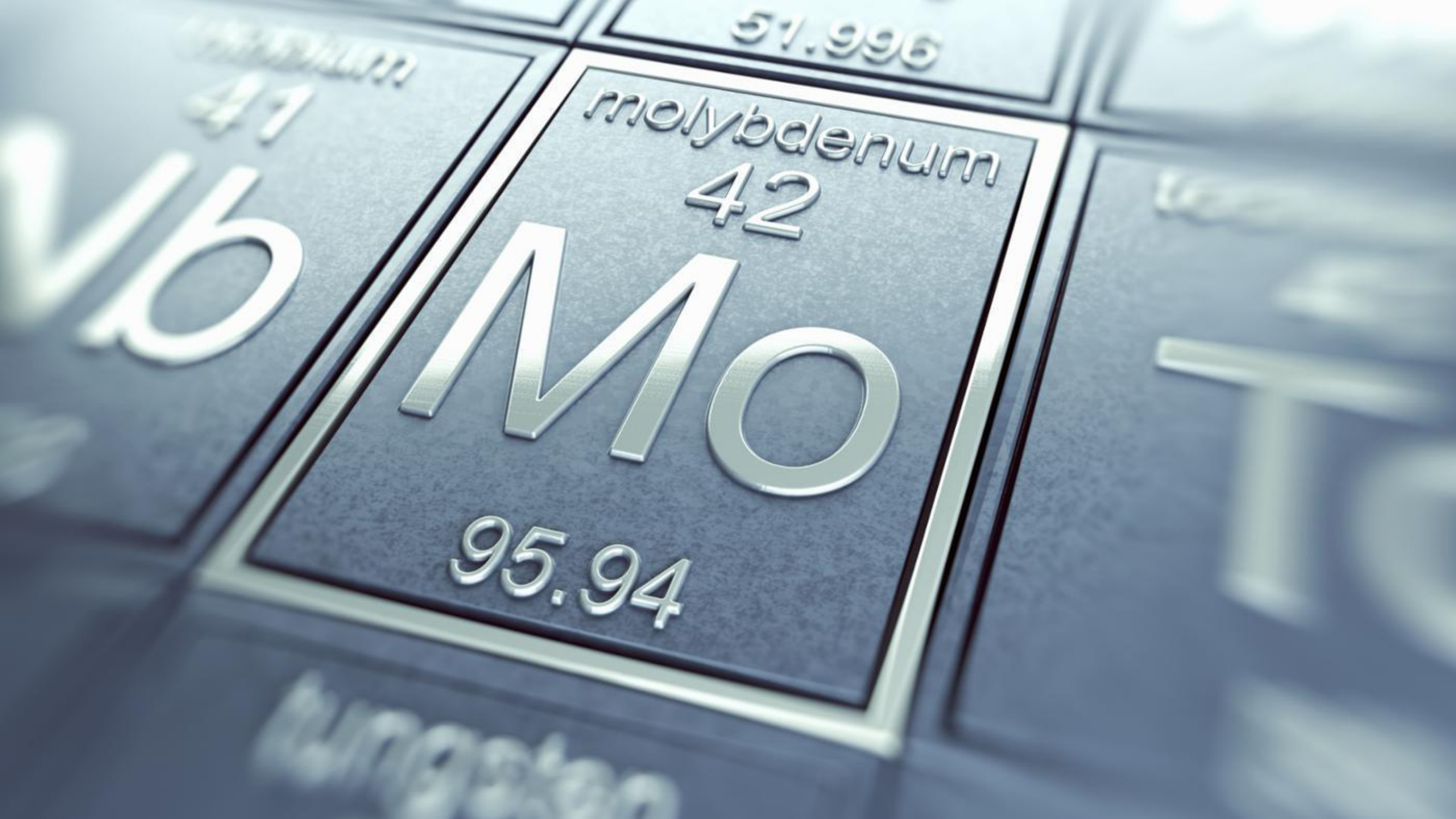


Photo credit: Tanja Bosak


iVFT Shark Bay
Ariel
vft.asu.edu/VFTSharkbay/panos/sharkbay/sharkbay.html
Lab 1.1
Lab 3.1
Carbla Beach - Shark Bay Australia
N
W
E
S
Hamelin Pool Pier
Above water view
Stromatolites in water
Consequences
Terminology
Oxygen
Shoreline views
Local weather & time
ellite Map View
Shark Bay
Western Australia
Modern Day


iVFT Knosses
Ariel
vft.asu.edu/VFTKnossos/panos/Knossos/KN.html
Knossos - Pilbara Australia
Aerial video
360/0
N
315
45
270 W
-0.5
Tilt
E 90
225
135
S
180
Satellite Map View
Local weather & time
Top view
Mid ridge
Lower ridge
Knossos overview
Tumbiana Formation
Western Australia
~ 2.7 billion years old


iVFT Dresser Formation
Ariel
vft.asu.edu/VFTDresser/panos/Dresser/Dresser.html
360/0
N
315
45
270 W
-8.2
Tilt
E 90
225
135
S
180
Satellite Map View
Local weather & time
Dresser Stromatolites
Dresser Formation
Western Australia
~ 3.5 billion years old
Media


51.996
molybdenum
42
Mo
95.94

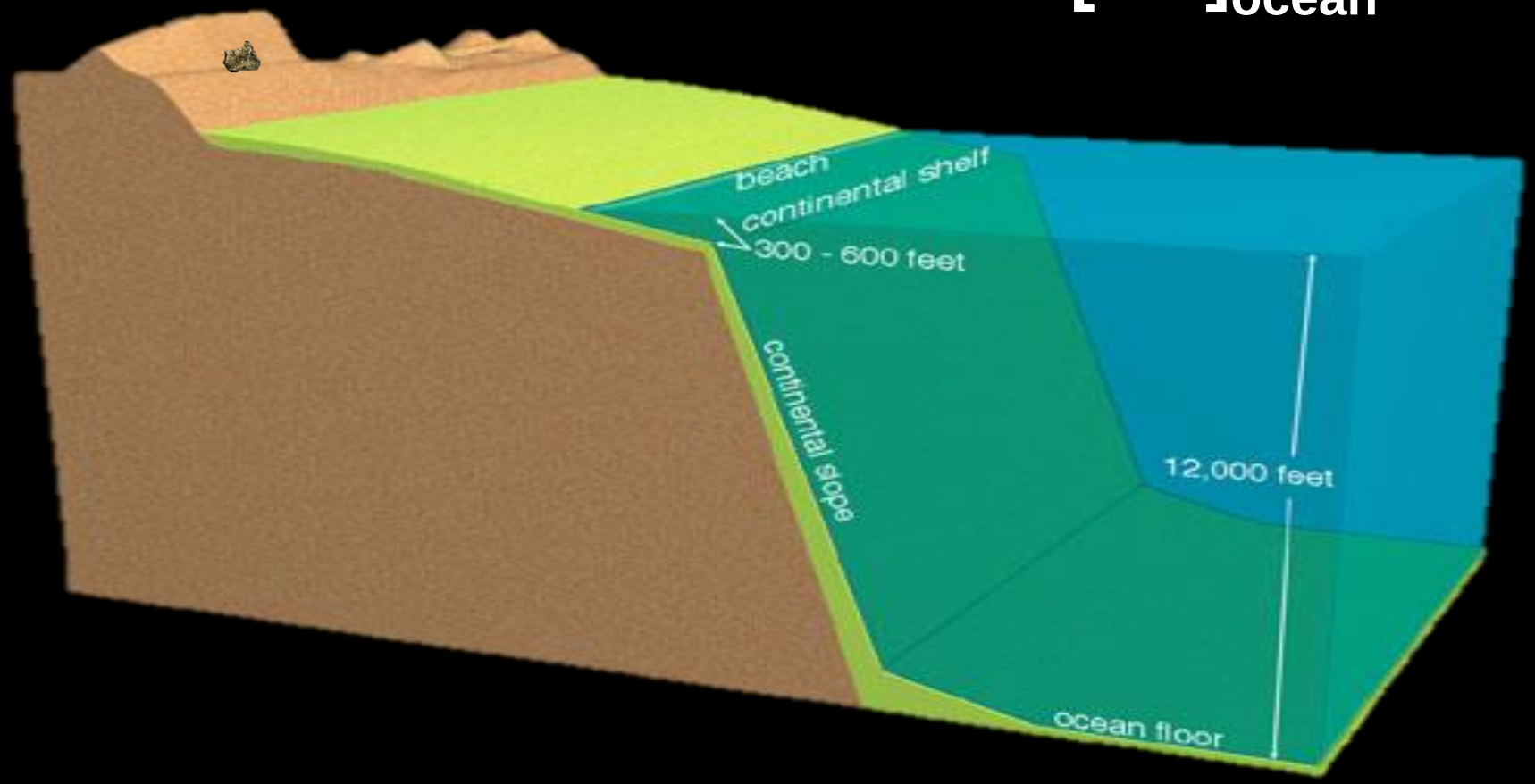
Sulfide Minerals

Major reservoir of Mo

React with O_2

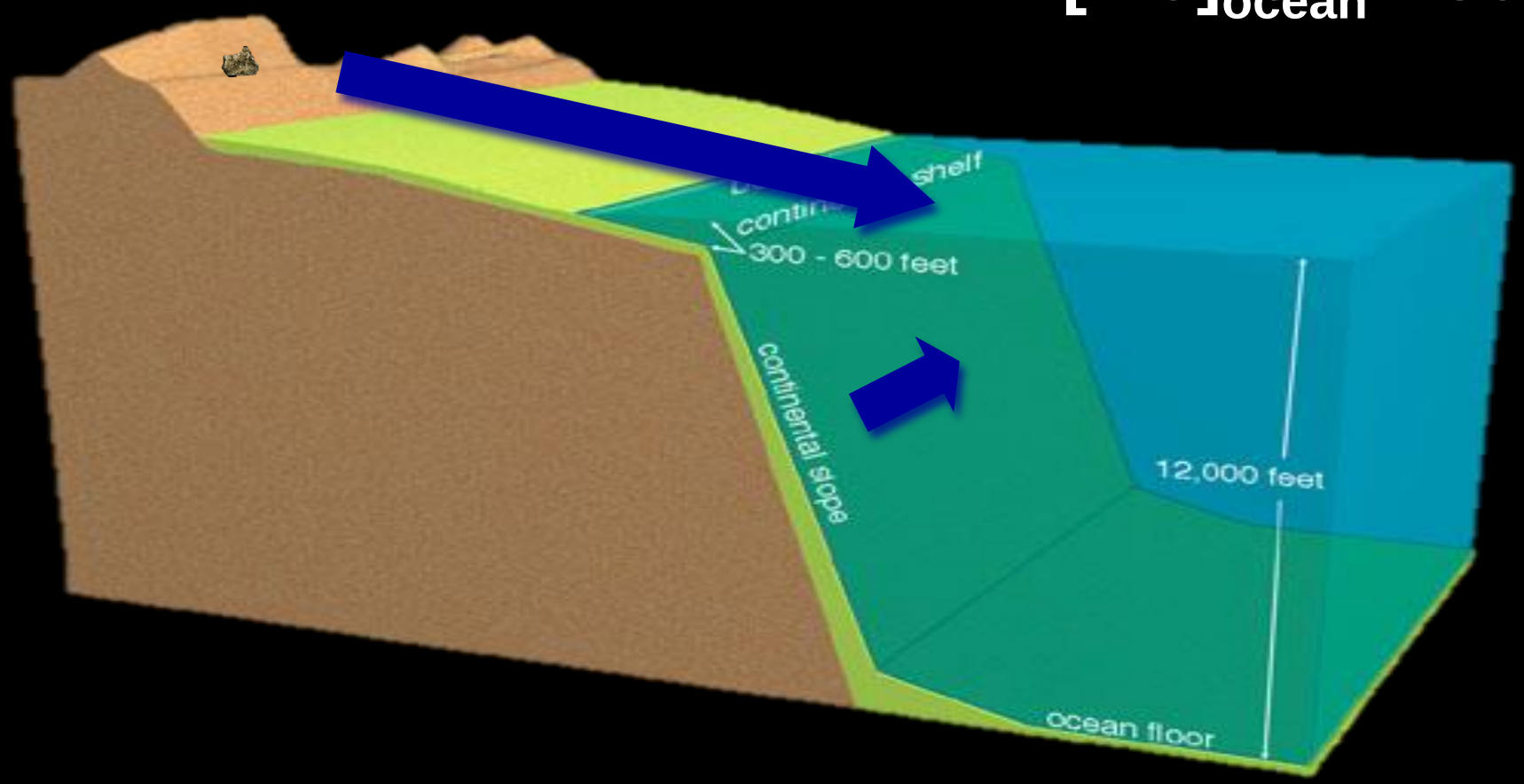
When O_2 is absent:

- Mo locked in sulfides
- $[Mo]_{ocean}$ low

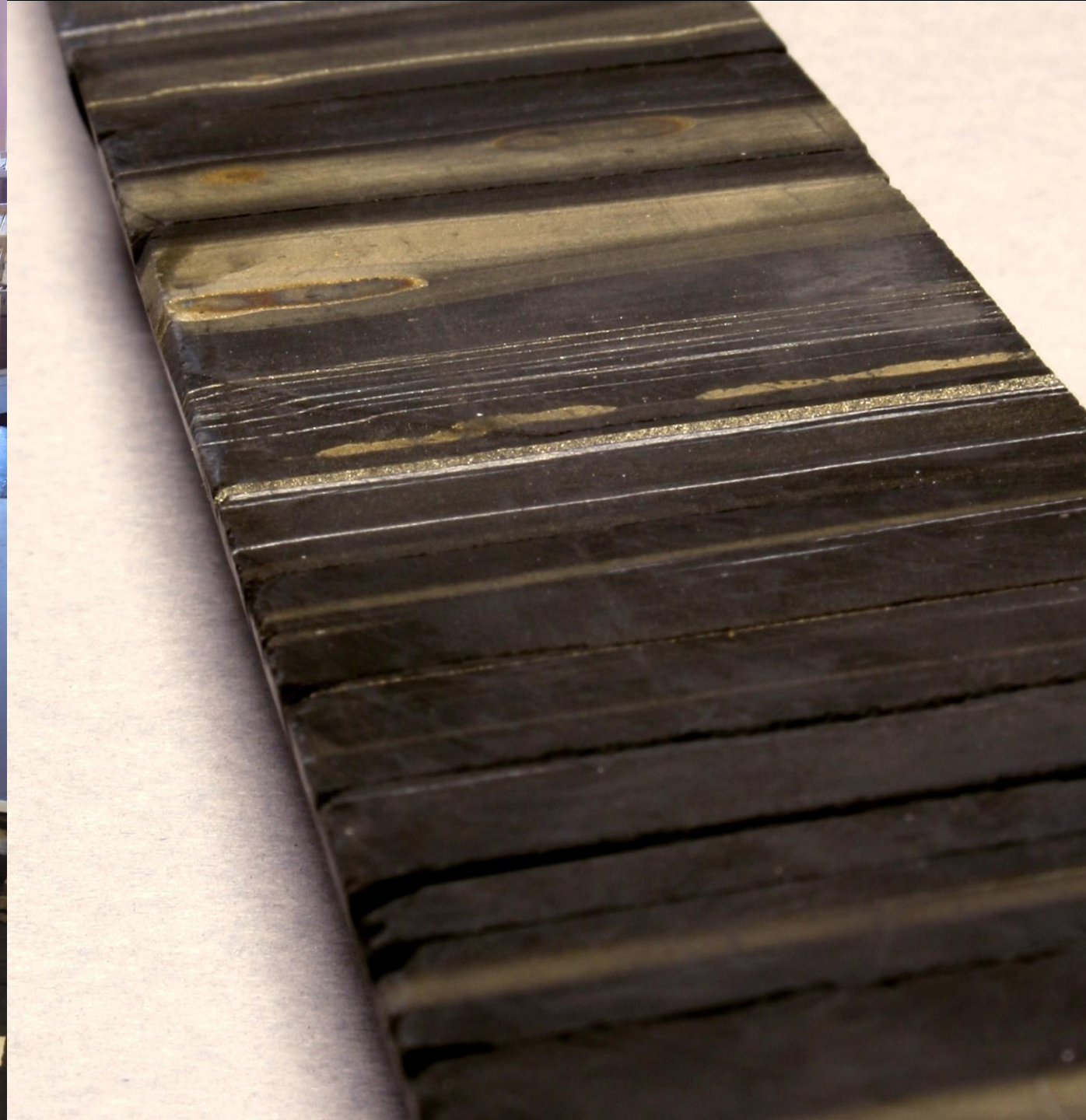


When O_2 increases:

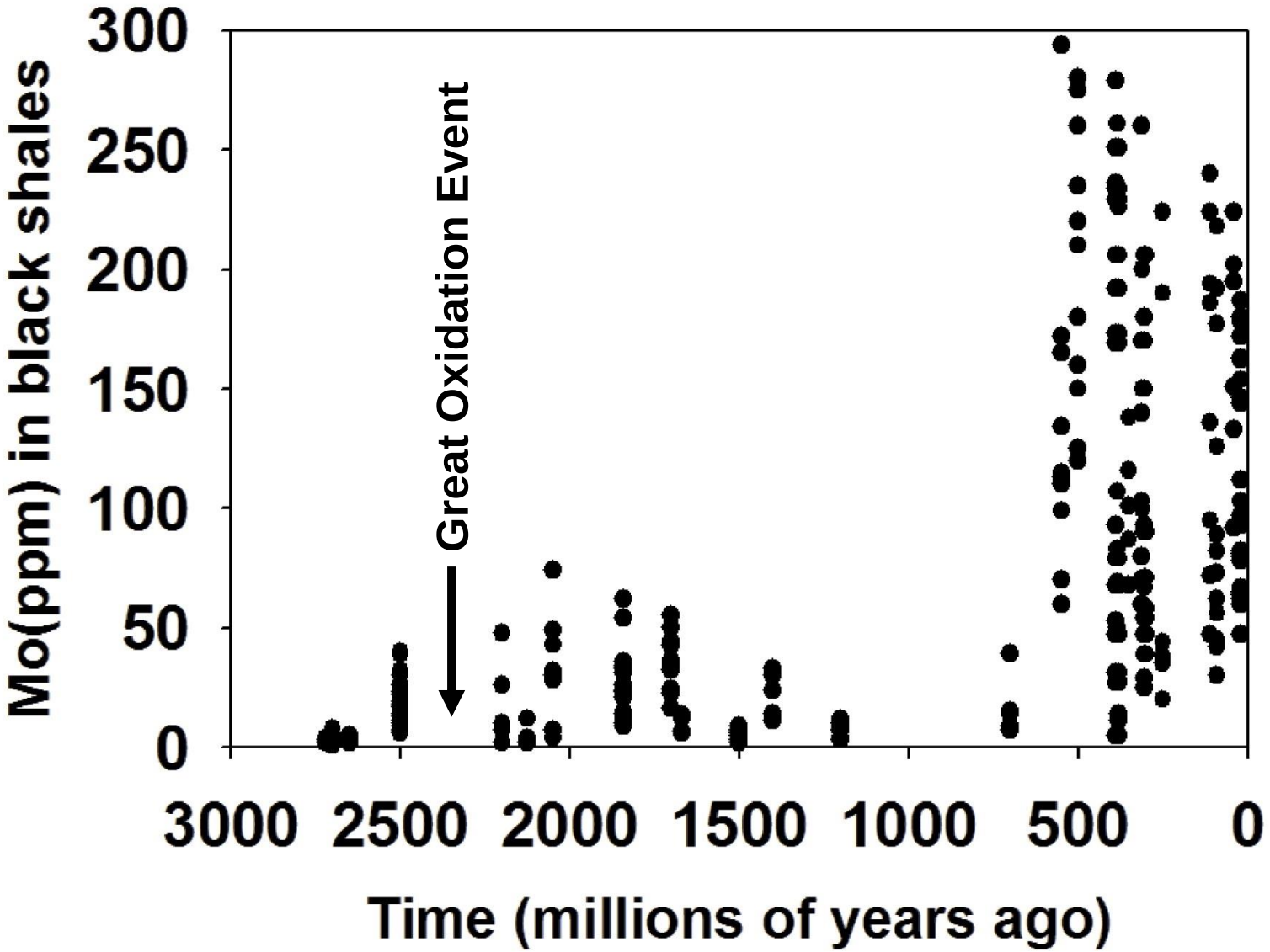
- Sulfides oxidize
- $[Mo]_{ocean}$ rises




AIDP-2
#17
AIDP-2
#18
186.65 ~ 191.00m
AIDP-2
#19
AIDP-2
#23
208.00 ~ 212.30m



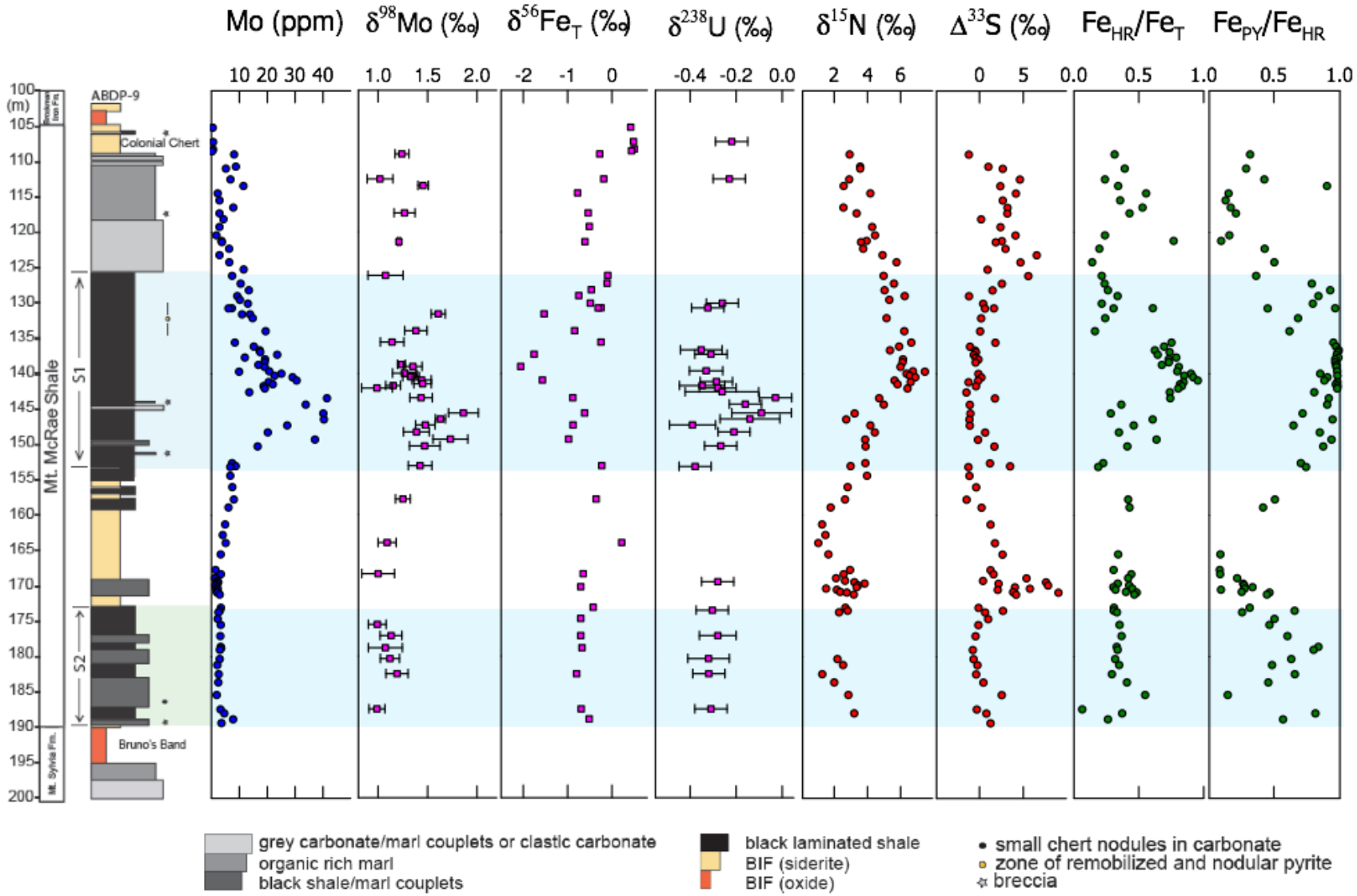
Inferring Changes in Seawater Molybdenum vs. Time



Data from Scott et al., 2008

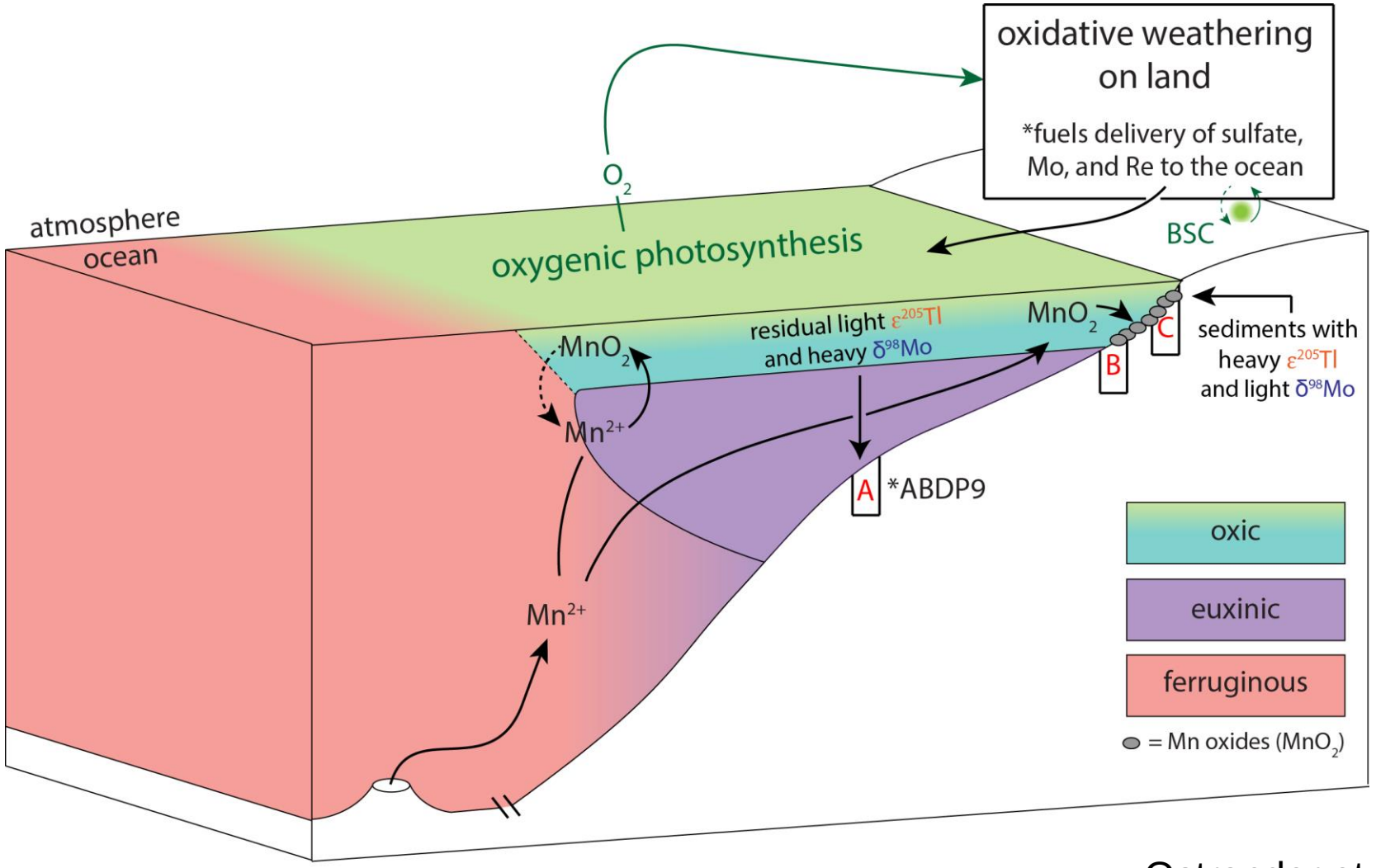
Molybdenum and Other Proxies Indicate a "Whiff" of O_2

2.5 Ga



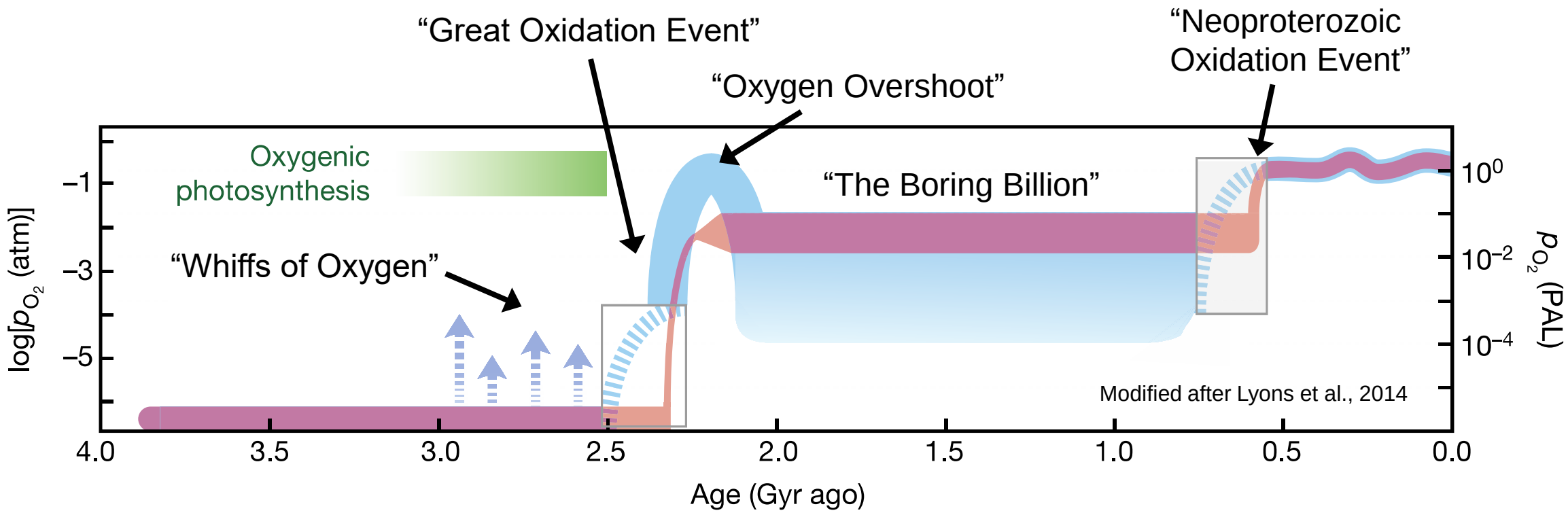
Synthesis after Anbar et al., 2007; Kaufman et al., 2007; Duan et al., 2010; Kendall et al., 2013; Garvin et al., 2009; Reinhard et al., 2009

Before the Great Oxidation Event
A Complex Picture



Ostrander et al., in review

O_2 in Earth's Atmosphere through Time



Summary So Far

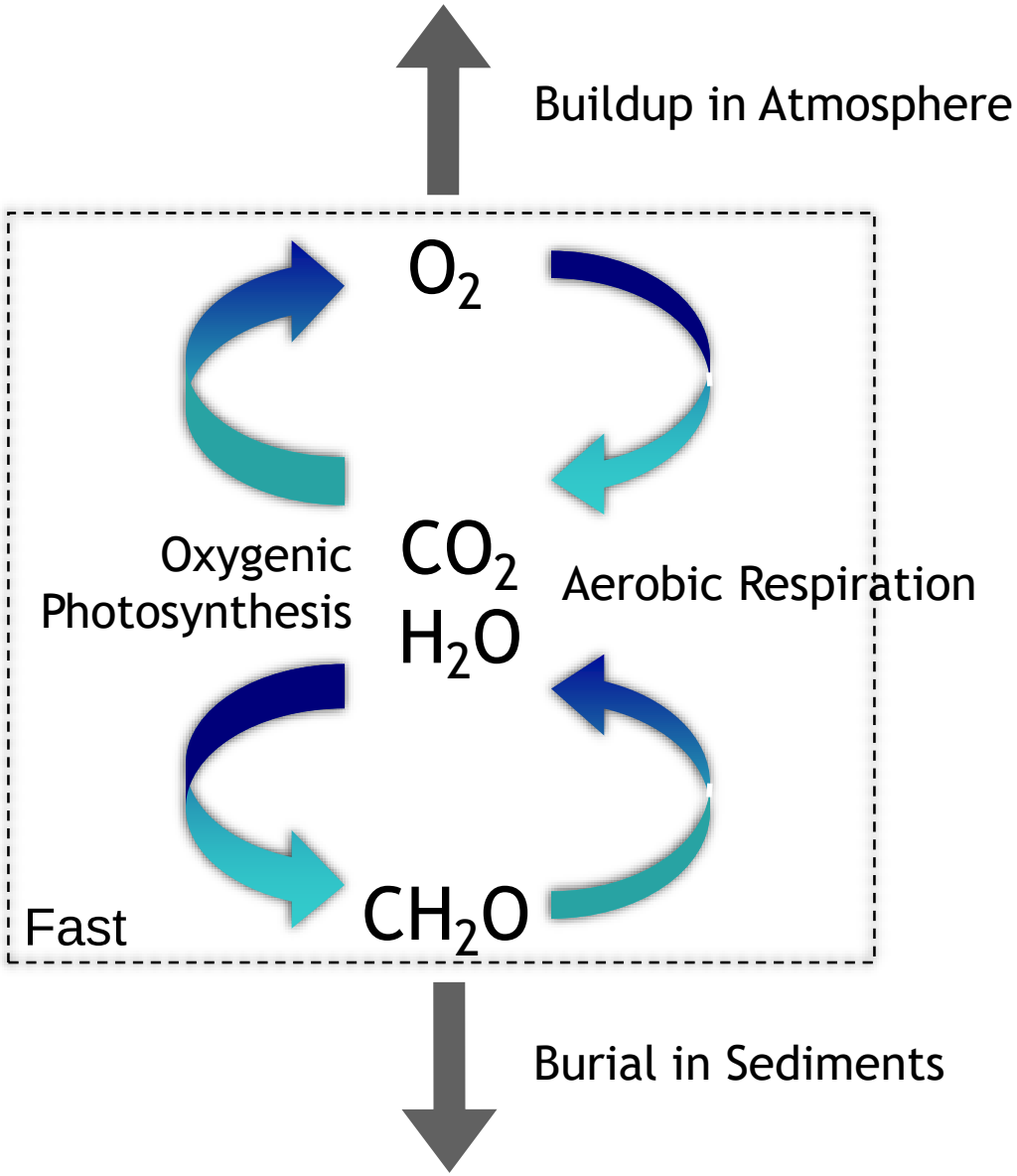
- The Great Oxidation Event occurred around 2.3 billion years ago;
- Evidence of microbial mats ("stromatolites") that might have produced O_2 are found as far back as 3.5 billion years ago;
- Molybdenum and other elements in ancient ocean sediments suggest a slightly oxidizing surface environment – and hence O_2 production – at least by 2.5 billion years ago and maybe a billion years earlier;
- Photosynthesis was necessary for the Great Oxidation Event but it originated much earlier!

What caused the Great Oxidation Event?

What kept O_2 low before the Great Oxidation Event?

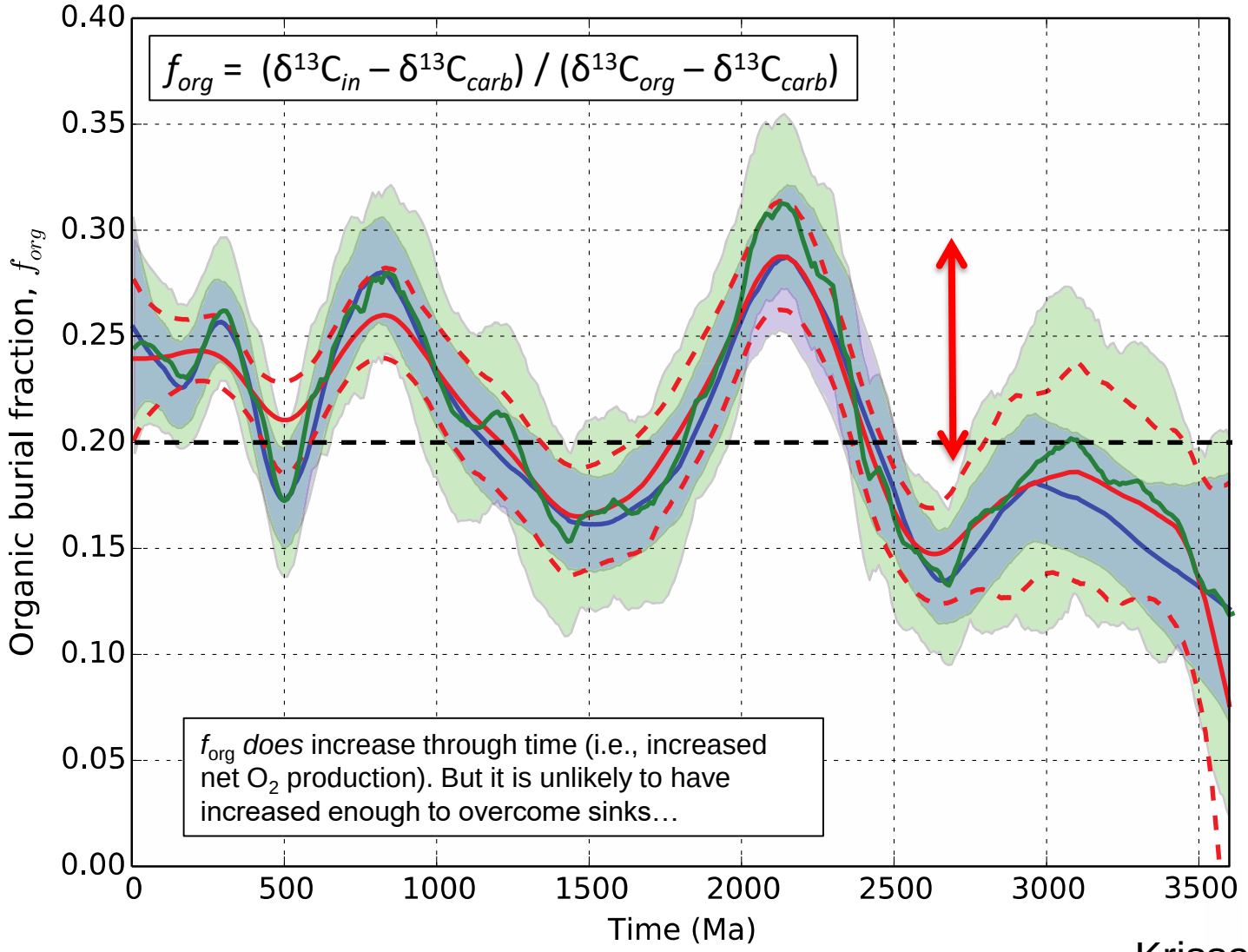
O_2 in the Atmosphere

C_{org} Burial is Important



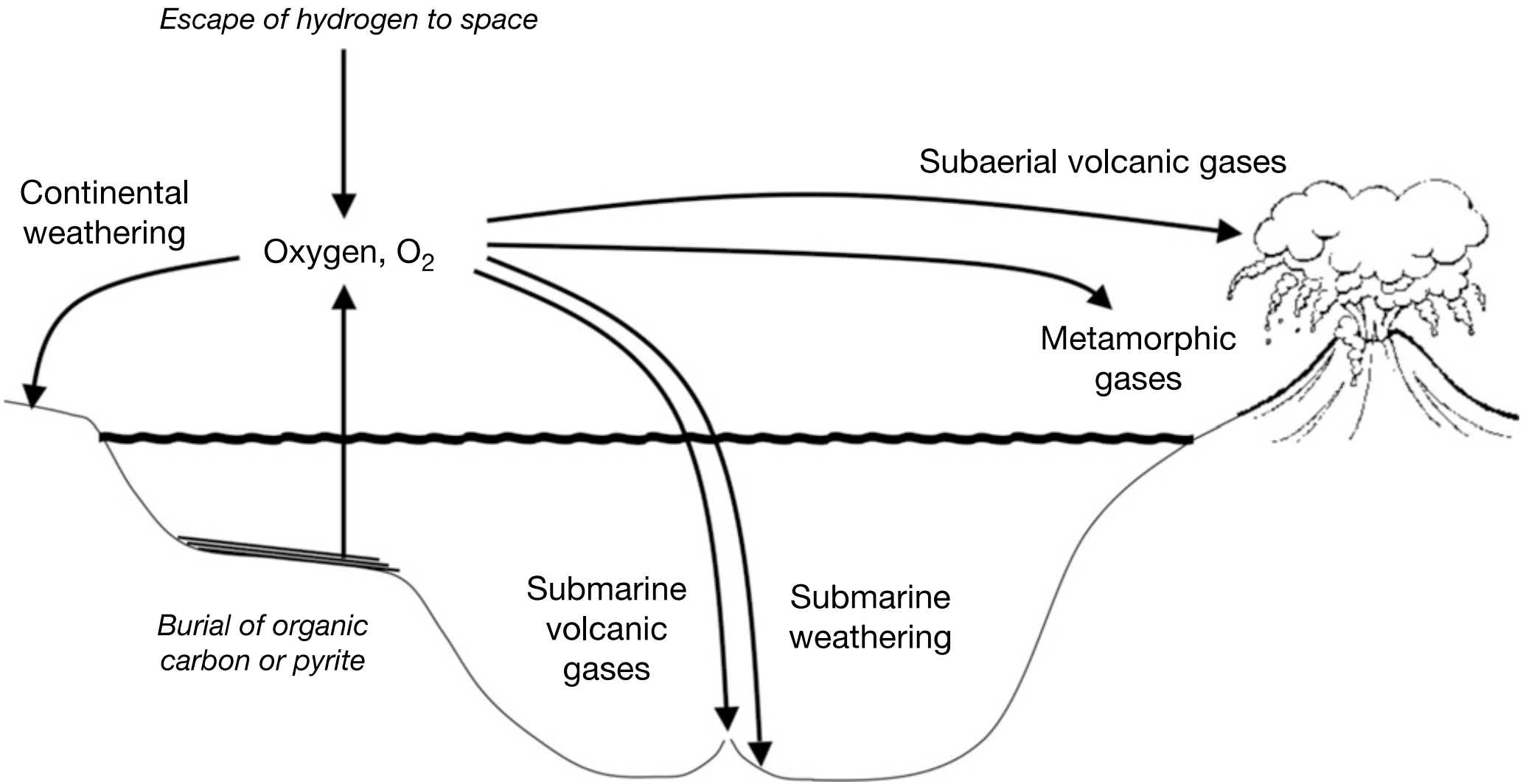
Carbon Isotope Record

Suggests burial of C_{org} has changed but not enough



Krissansen-Totton et al., 2015

What About Geological Sinks?



Catling, 2014

Earth's Interior

An effectively infinite O_2 sink

http://www.merrittcartographic.co.uk/earth_structure.html

Earth's Interior

Possible changes

- Change in mantle f_{O2}
- Change in crustal composition
- Change in composition or flux of volcanic gases

There is some support for each of these ideas!

http://www.merrittcartographic.co.uk/earth_structure.html

nature geoscience

PERSPECTIVE

PUBLISHED ONLINE: 16 MAY 2016 | DOI: 10.1038/NGEO2707

Two-step rise of atmospheric oxygen linked to the growth of continents

Cin-Ty A. Lee[1]*, Laurence Y. Yeung[1], N. Ryan McKenzie[2,3], Yusuke Yokoyama[4], Kazumi Ozaki[4] and Adrian Lenardic[1]

LETTER

doi:10.1038/nature10460

Atmospheric oxygenation caused by a change in volcanic degassing pressure

Fabrice Gaillard[1], Bruno Scaillet[1] & Nicholas T. Arndt[2]

Vol 448|30 August 2007|doi:10.1038/ nature06058

nature

LETTERS

Increased subaerial volcanism and the rise of atmospheric oxygen 2.5 billion years ago

Lee R. Kump[1] & Mark E. Barley[2]

ELSEVIER

Earth and Planetary Science Letters

Volume 460, 15 February 2017, Pages 68–75

Atmospheric oxygenation driven by unsteady growth of the continental sedimentary reservoir

Jon M. Husson, Shanan E. Peters

LETTER

doi:10.1038/nature11024

Statistical geochemistry reveals disruption in secular lithospheric evolution about 2.5 Gyr ago

C. Brenhin Keller[1] & Blair Schoene[1]

THE GEOLOGICAL SOCIETY OF AMERICA®

Evidence for a reducing Archean ambient mantle and its effects on the carbon cycle

Sonja Aulbach[1] and Vincenzo Stagno[2]
[1]Institut für Geowissenschaften, Goethe-Universität, 60323 Frankfurt am Main, Germany
[2]Earth Sciences Department, Sapienza University of Rome, 00185 Rome, Italy

nature geoscience

ARTICLES

PUBLISHED ONLINE: 1 AUGUST 2016 | DOI: 10.1038/NGEO2772

Redox-induced lower mantle density contrast and effect on mantle structure and primitive oxygen

Tingting Gu[1]*, Mingming Li[2†], Catherine McCammon[3] and Kanani K. M. Lee[1]

nature geoscience

ARTICLES

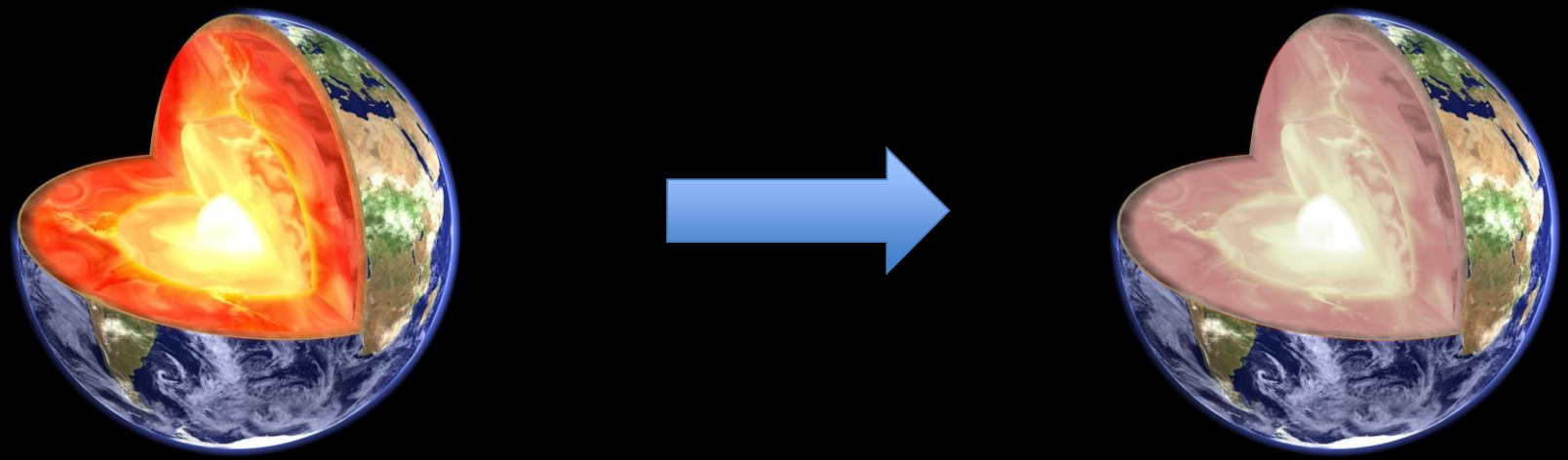
PUBLISHED ONLINE: 18 SEPTEMBER 2017 | DOI: 10.1038/NGEO3030

Earth's early O_2 cycle suppressed by primitive continents

Matthijs A. Smit[1]* and Klaus Mezger[2]

Consequences of Cooling

A Geo-Gedanken Experiment



Hot Earth

Rapid surface-deep exchange

O_2 can never rise

Cold Earth

Slow surface-deep exchange

O_2 rises easily

To understand the Great Oxidation Event we must develop a theory of Earth system evolution, integrating surface and deep Earth geoscience.