Water and Other Volatiles on Mars: Resource Base and Implications for Terraforming*

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Abstract

Water ice and other volatiles are vital in sustaining human settlement in space. Hydrogen and oxygen extracted from water by hydrogen-oxide reactions can be used as propellants on short-range interplanetary missions in the inner Solar System prior to developing more advanced propulsion systems for subsequent long-range interplanetary missions. The resource base for Martian water-ice and other volatiles far exceeds the resource base on the Moon and Mercury. Water ice occurs in abundance on Mars in polar ice caps, shallow permafrost, and in layered terrain adjacent to the poles. Martian permafrost, which holds more water ice than the poles, occurs as tropical mountain glaciers and in polygonal terrain with morphologies similar to those of terrestrial periglacial features. Subsurface ice on Mars has an aerial distribution exceeding 20 million square kilometers, whereas the polar caps, although 2.7 and 3.1 km thick at the North and South poles respectively, each encompass an area <1 million square kilometers.

Mars possesses sufficient water and volatile resources amenable to terraforming, although other volatiles from ammonia-rich comets can also be introduced artificially from human-induced impacts to accumulate greenhouse gases in the tenuous Martian atmosphere. At least four comets, each with a mass of 10 Gt (10 billion metric tons), would be required to trigger a Martian greenhouse effect. Moreover, in situ methods of constructing an artificial Martial atmosphere could involve greenhouse gas factories expelling halocarbon gases (CFC's), with 39 Mt (million metric tons) necessary to sublimate the southern carbon-dioxide ice cap. Other methods can involve deploying orbital reflection arrays with a collective mass of up to 200,000 tons to produce sufficient insolation for volatilizing the Martian polar caps. However, the lack of a robust magnetosphere is a major obstacle to successful terraforming of Mars, as solar flares could periodically strip away up to 30% of the newly created, sparse

atmosphere. Best-case terraforming scenarios may require centuries, and the technology to construct a protective Martian electromagnetic field protection could involve a similar timescale.

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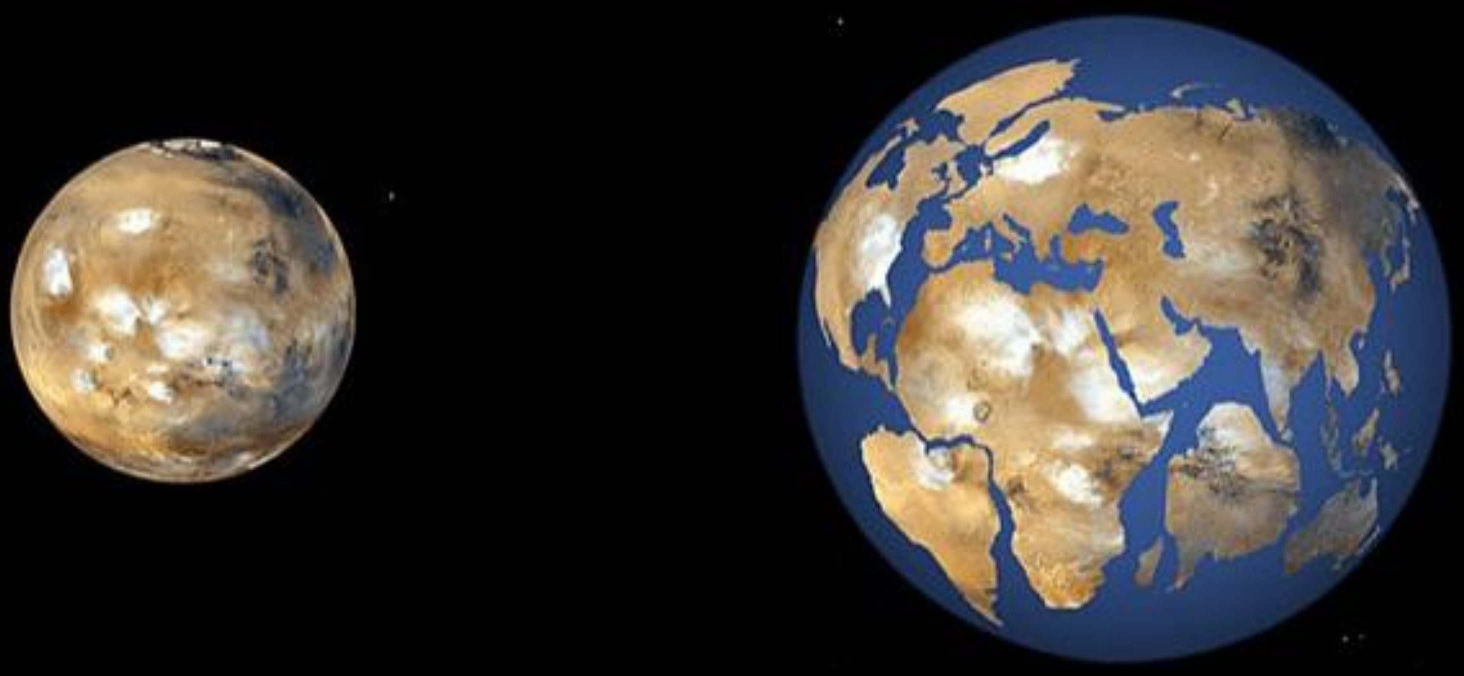
BUREAU OF ECONOMIC GEOLOGY

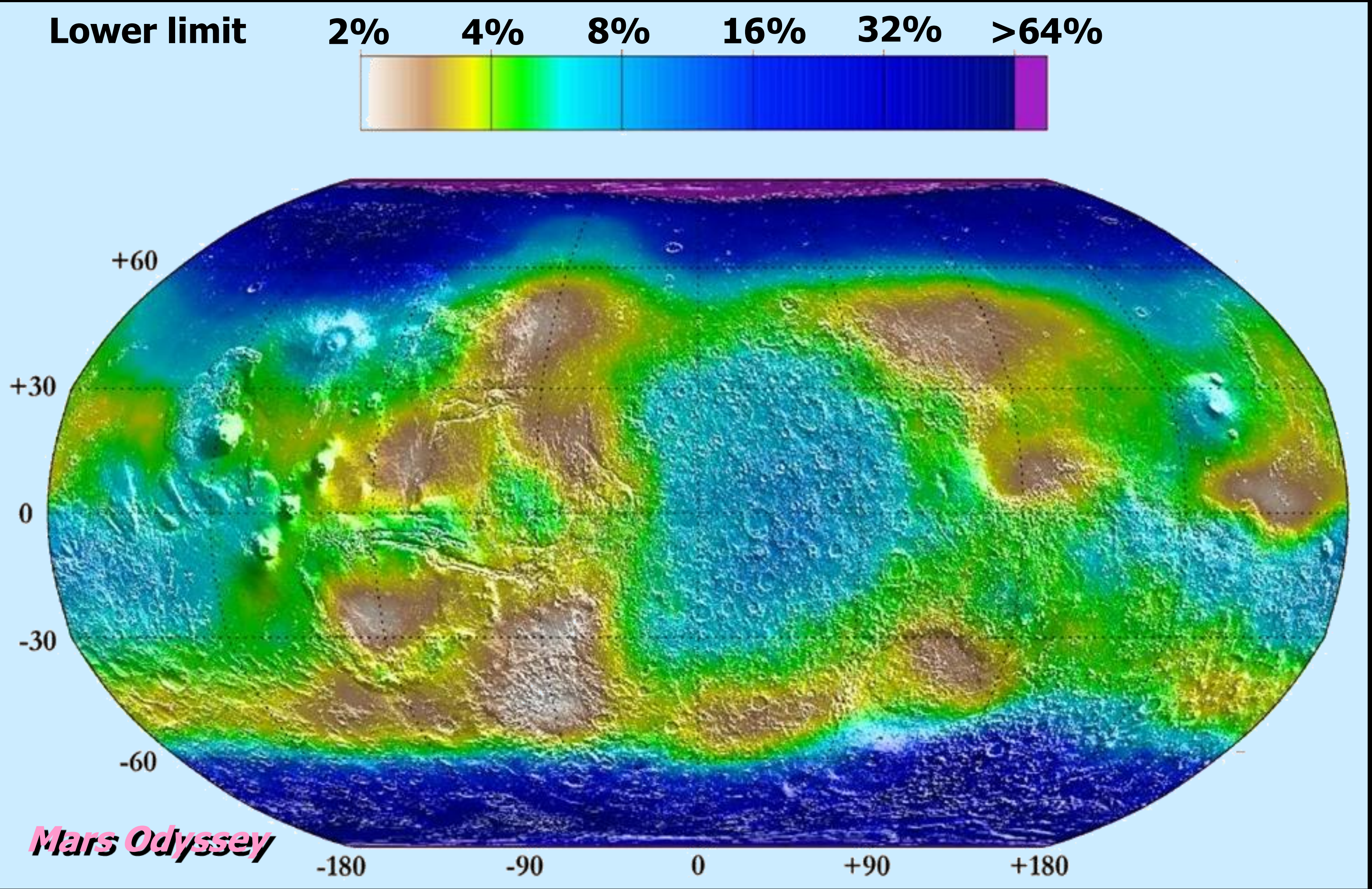
Mars Versus Earth

Most Earth-Like Planet

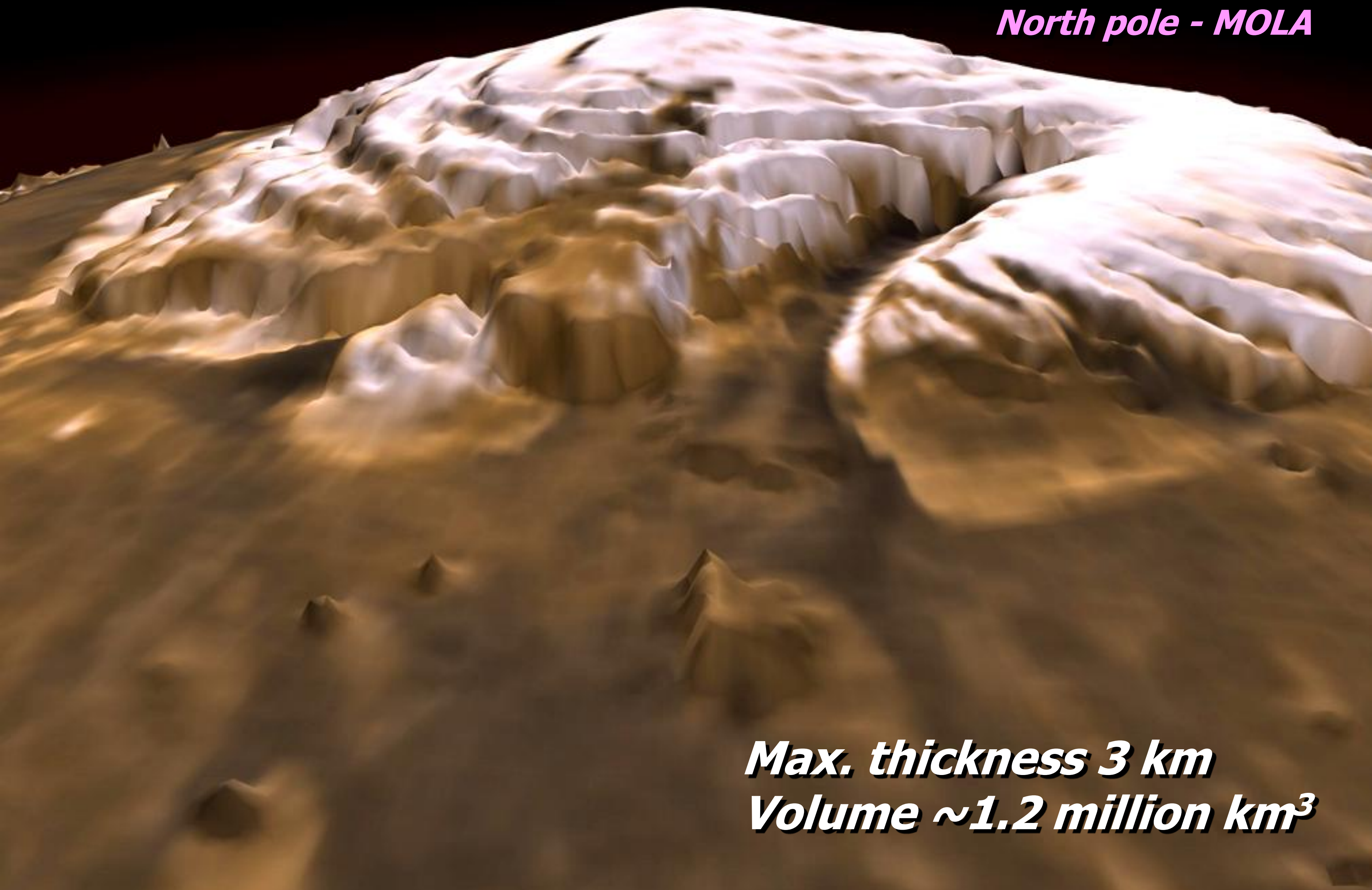
-Second-closest planet (>200-d trip with conventional rocket)
-Earthlike seasons; Day = 24 hours, 37 minutes
-As much land surface as the Earth



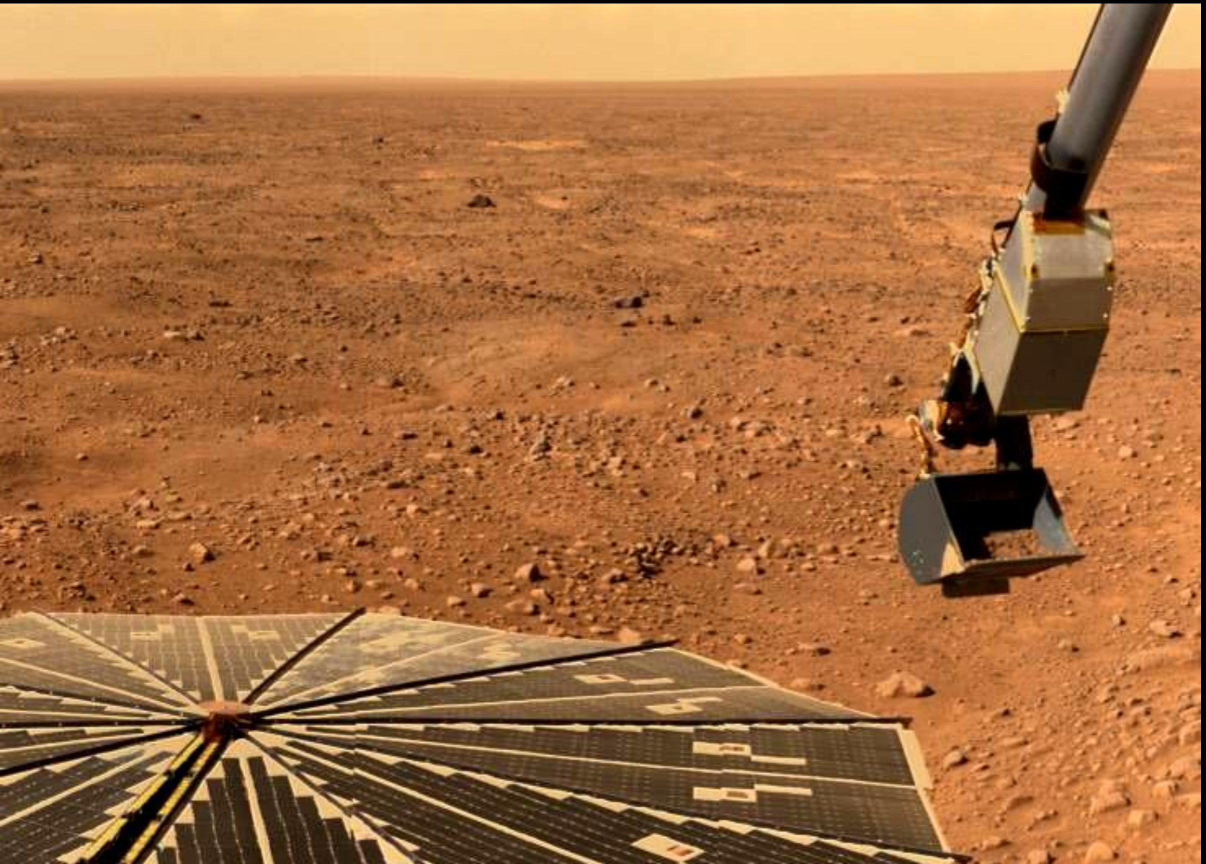
Mars: Global Water Distribution



Ice Caps

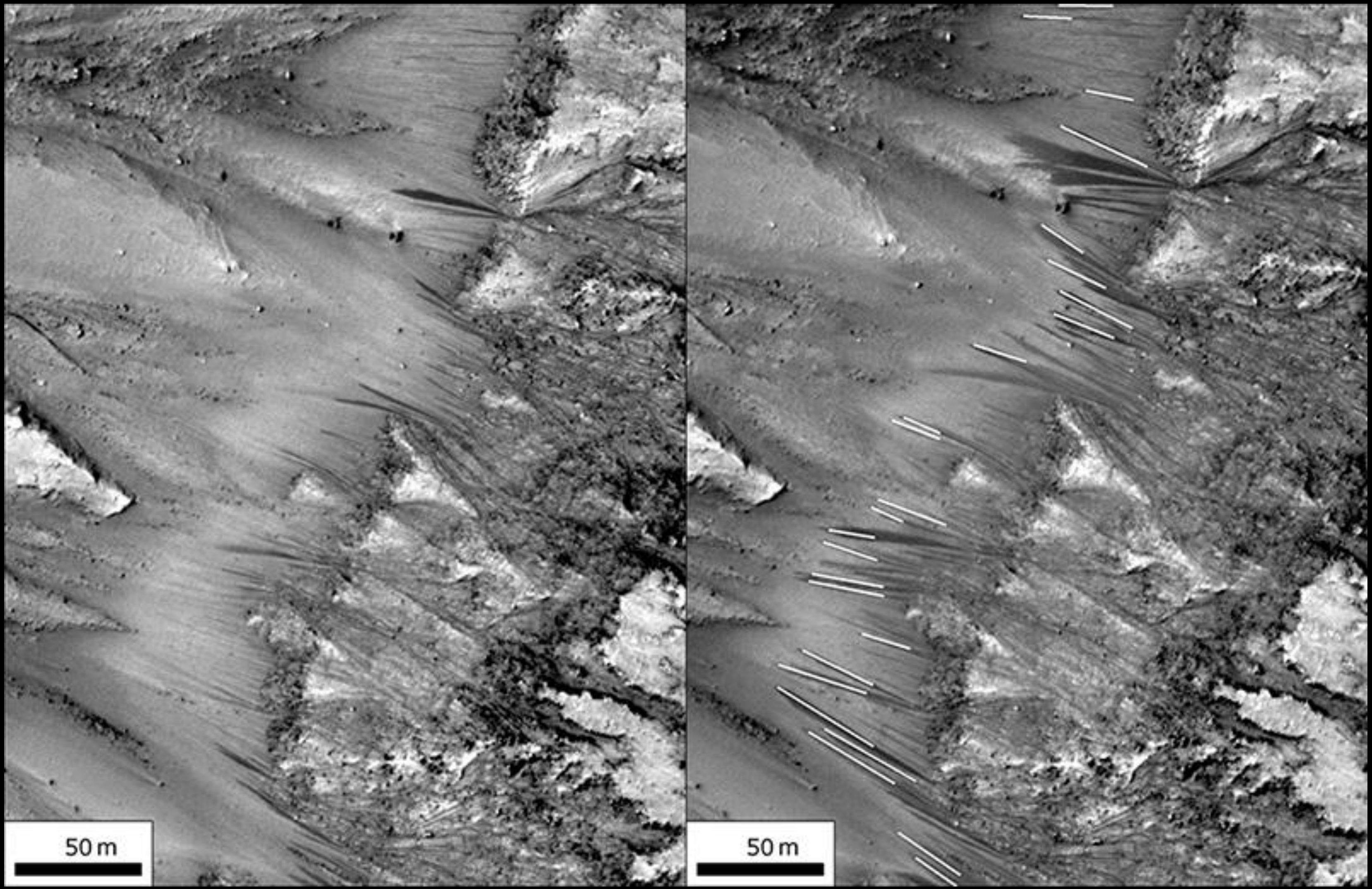


Martian Permafrost
Phoenix Mission



Mars Water Tracks

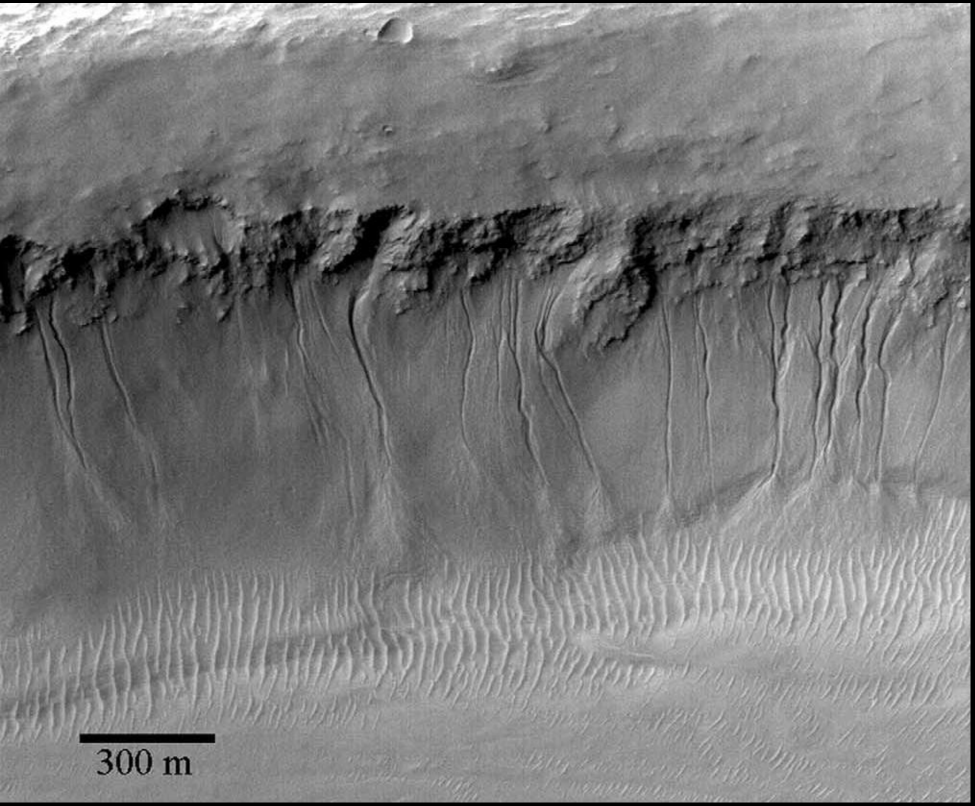
Recurring slope linae at Palikir Crater



Levy (2014)

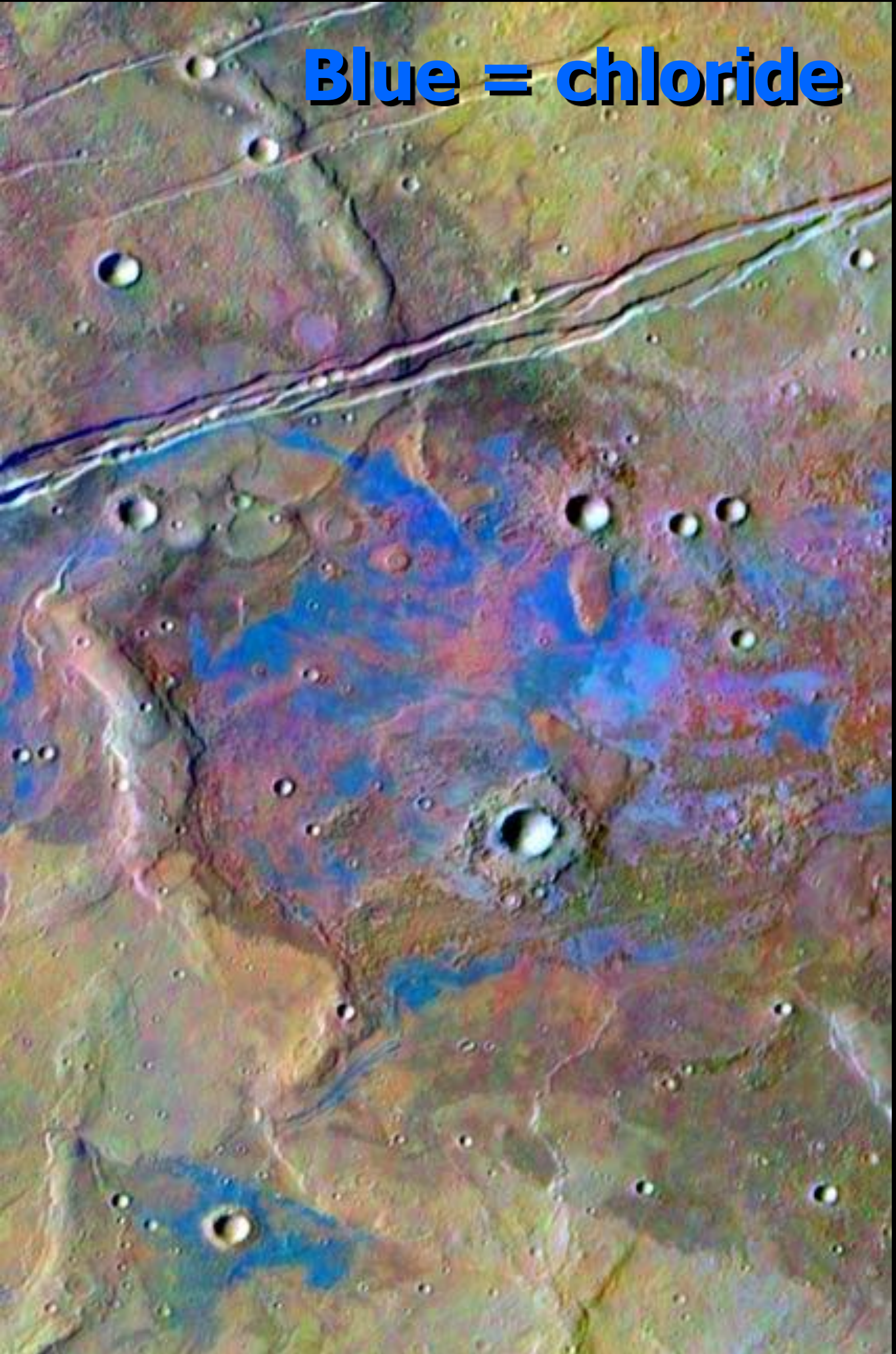
Hillside Water Bursts

Mars



Iceland

Hartmann et al. (2003)



Martian Salt Deposits

Dried-up brine pools

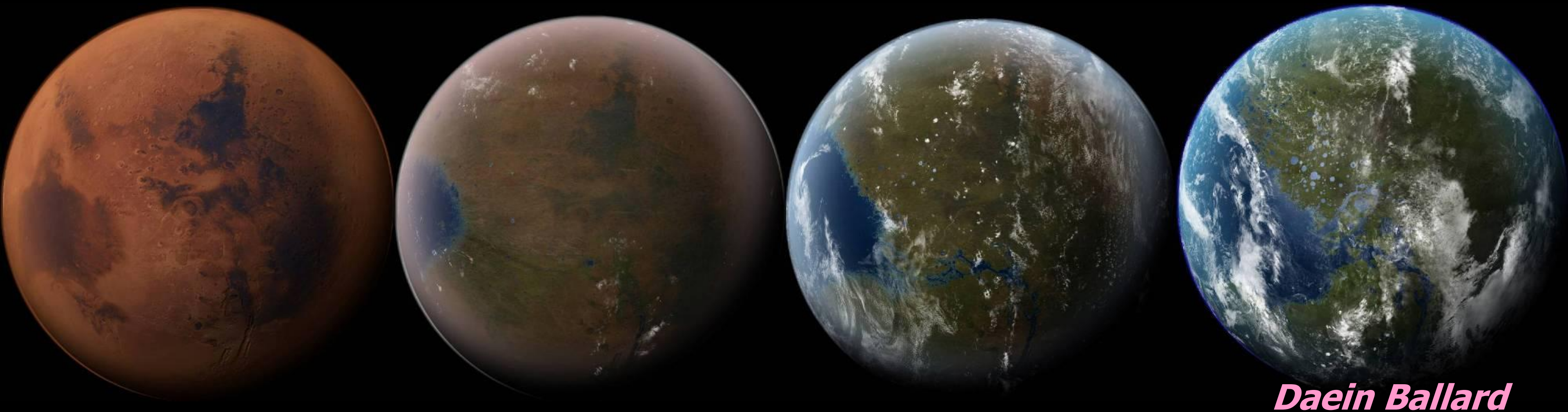
Clays/hydrated minerals

Other salts rich in:

Magnesium
Sulfur
Calcium
Potassium
Phosphorus

Christensen (2009)

Terraforming Mars

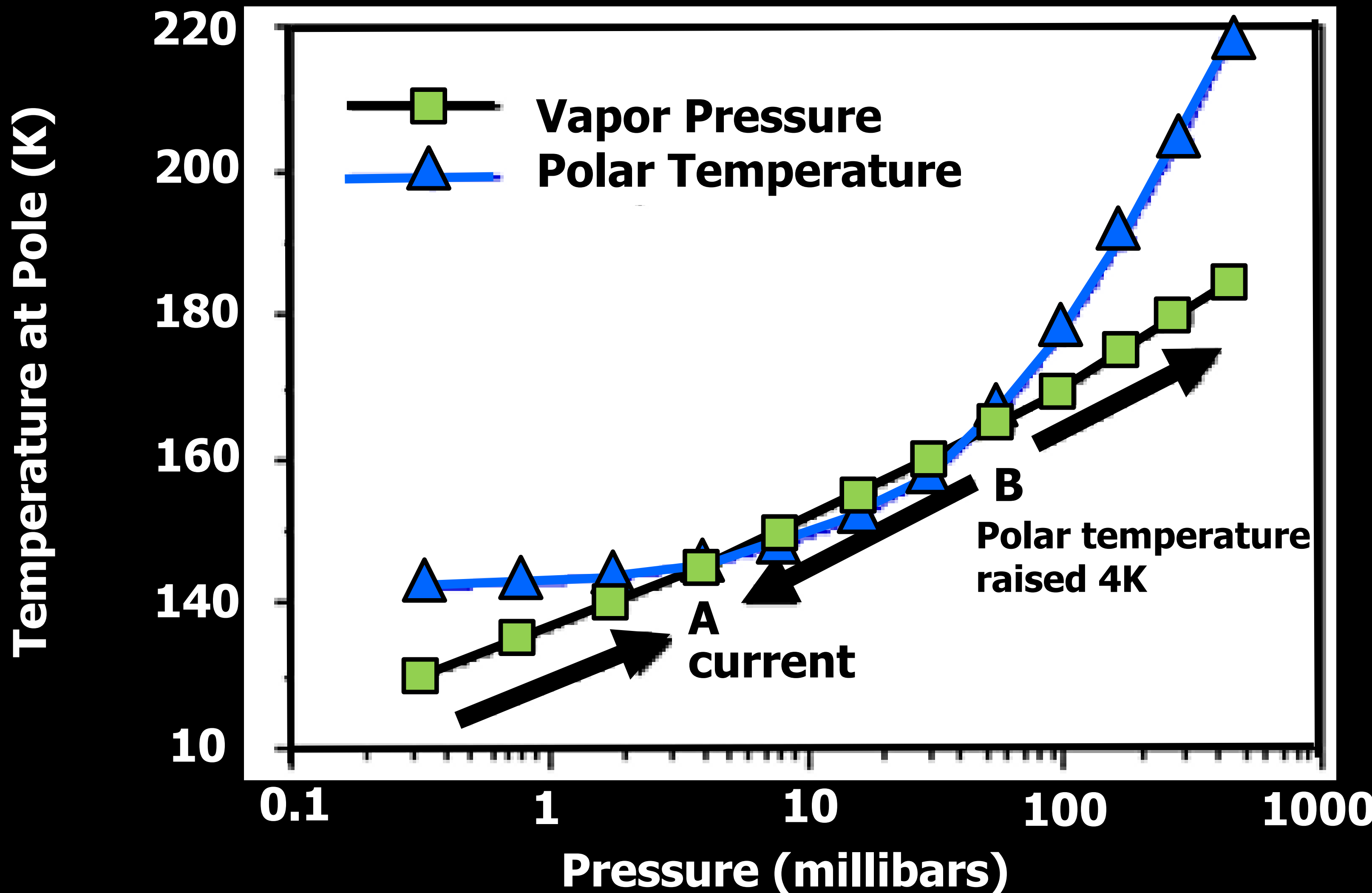


Requirements

Raise surface temperature
Increase atmospheric pressure
Change chemical composition of atmosphere
Surface water
Reduce UV flux at surface

Greenhouse Effect of Polar CO_2

Human habitation: minimum partial pressure of O_2 130mbar.



Modified from Zubrin and McKay (1997)

Terraforming Mars

Reflection Arrays

Rigel Woida

Greenhouse Gas Factories

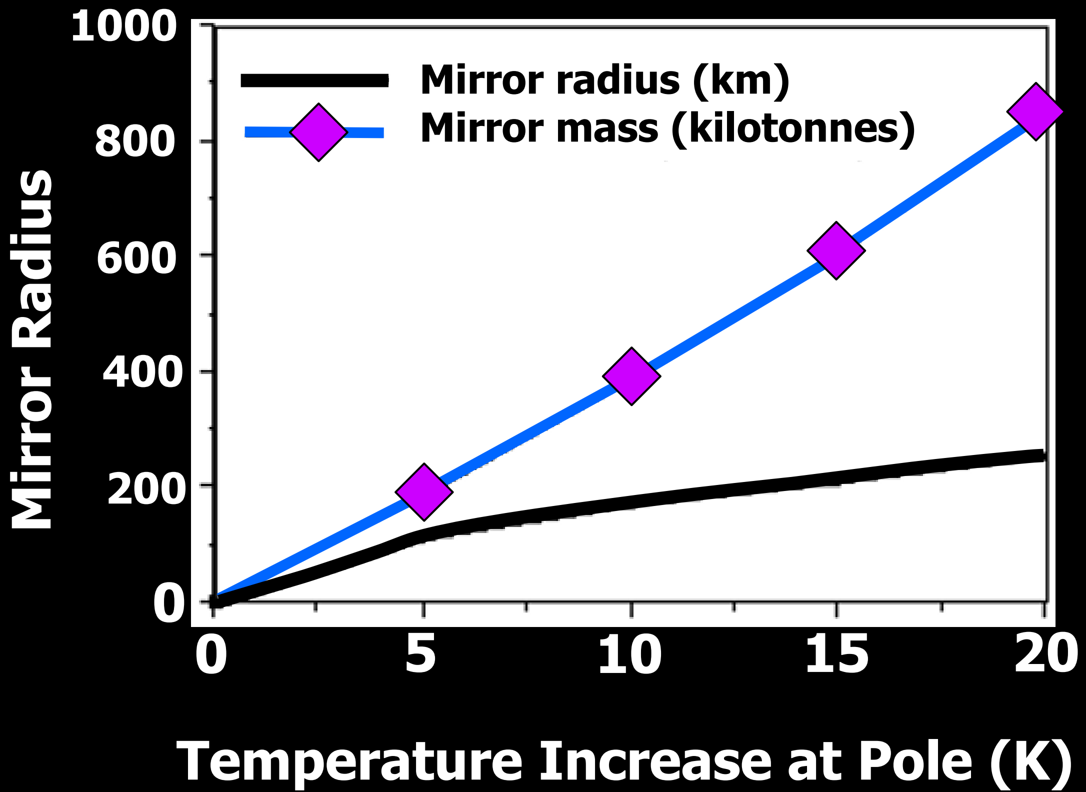
Plant Cultivation

Ice Comet Impacts-NH_3, H_2O

Reflection Arrays

Rigel Woida

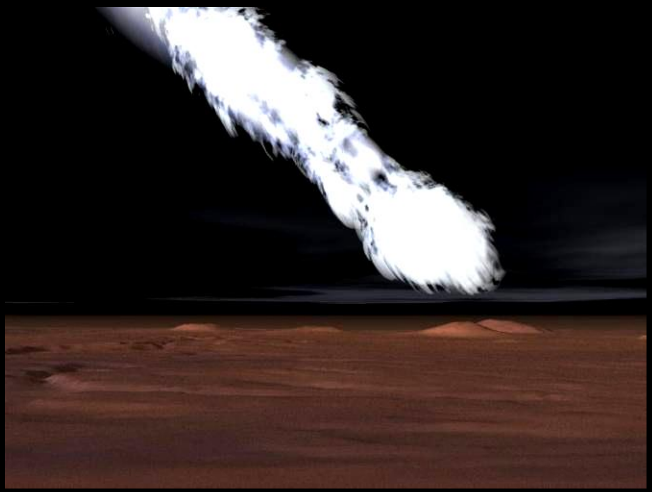
Mass: ~180,000 tonnes
Altitude: 214,000 km



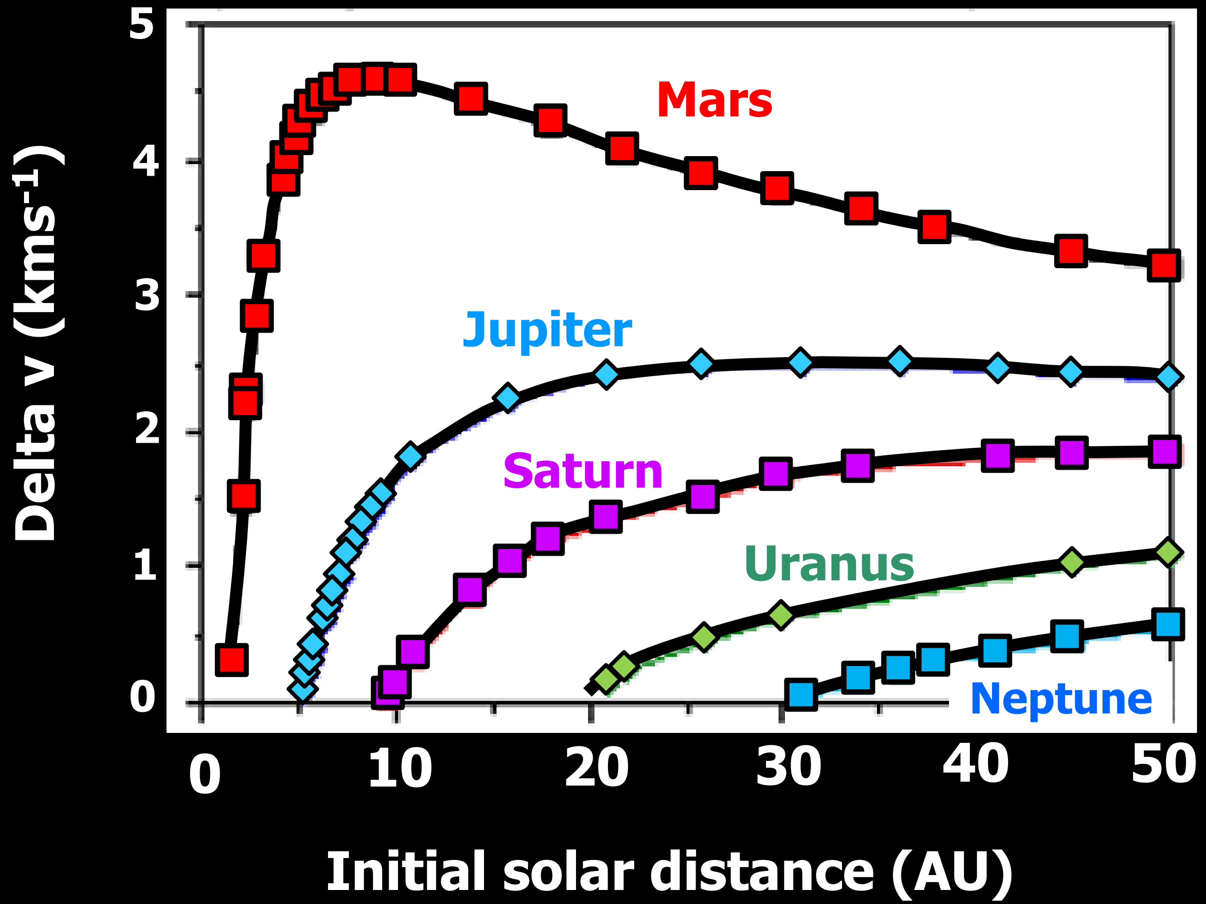
Modified from Zubrin and McKay (1997)

Ice Comet/Asteroid Impacts

Four 10-GT objects



Orionsarm.com



Modified from Zubrin and McKay (1997)

Greenhouse Gas Factories

3 trillion tons of CFCs yr-1 to keep up with atmospheric decomposition

Induced Heating (K)	CFC Pressure (mbar)	CFC Production (ton/hr)	Required Power (MWe)
5	0.012	263	1315
10	0.040	878	4490
20	0.110	2414	12070
30	0.220	4829	24145
40	0.390	8587	42933

Modified from Zubrin and McKay (1997)

Plant Cultivation

Requirements

Increase atmospheric O_2 N_2
Increase surf. Temp. 60K
Liquid water
Reduce surface UV,
Reduce cosmic ray flux

Ecopoiesis

Anaerobic Extremophiles
Photosynthetic cyanobacteria

Extremophiles

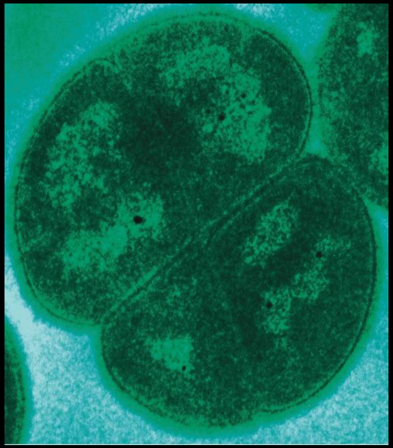
https://microbewiki.kenyon.edu/index.php/Terraforming

Chroococcidiopsis

Cyanobacterium

Desiccant-resistant.

Antarctic rocks, thermal springs, and hypersaline habitats.



Daly (Uniformed Services University)

Deinococcus radiodurans

Bacterium

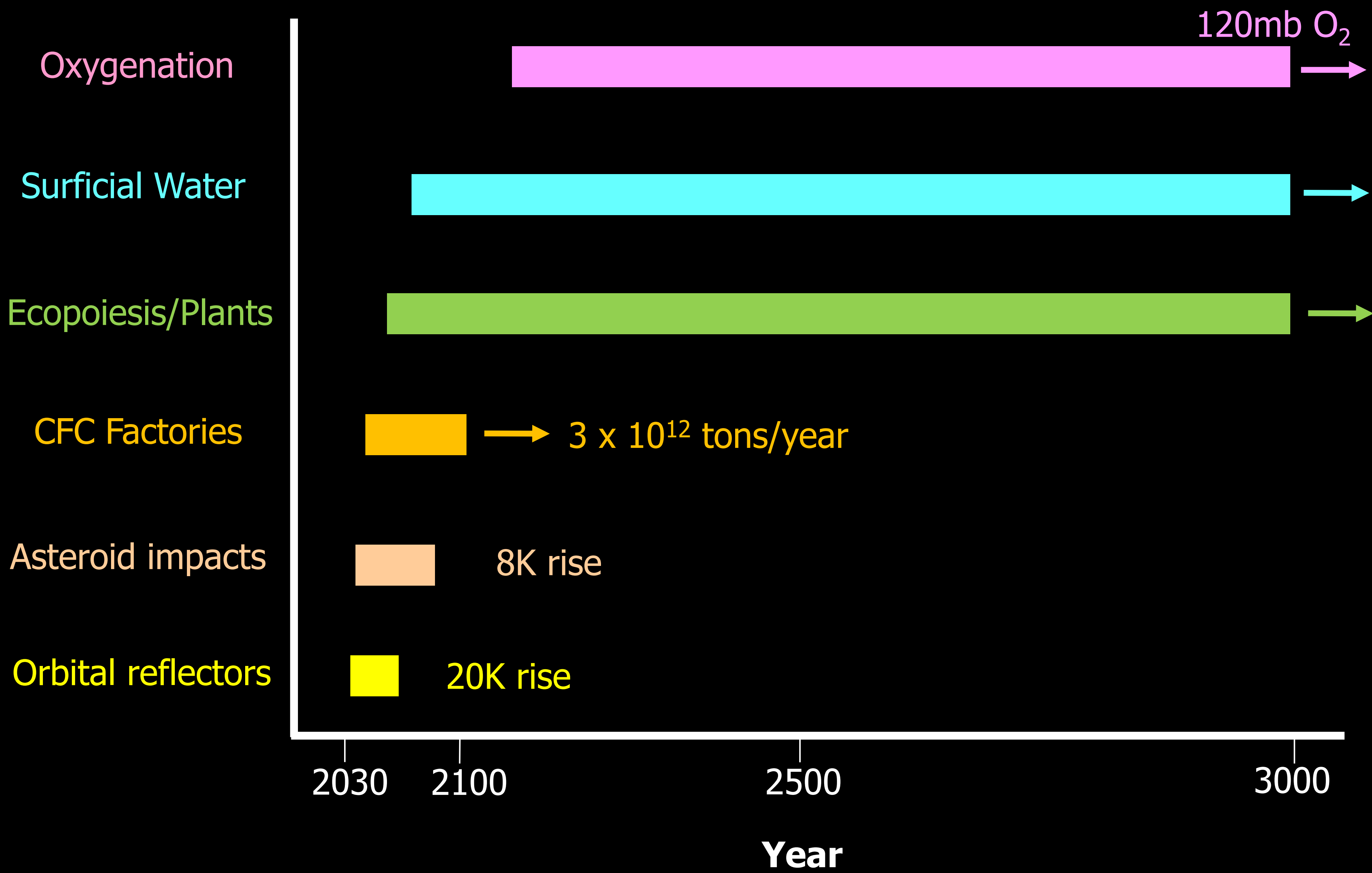
Radiation-resistant

Peroxide-resistant

Technical Challenges

- **No Magnetosphere: Atmospheric Stability**
  - Creation of substitute for planetary magnetosphere beyond current or reasonably expected technology.
- **Hostile Radiation Environment**
  - Personal protection, local (crop- & city-scale appears practical).
- **Low-temperature Environment**
  - Current technology: ample power availability
- **Weak Greenhouse Effect**
  - Methane, CFCs, and artificially enhanced GHGs are practical.
- **Soil Nitrates**
  - Genetic engineering provides foreseeable solutions.

Terraforming Mars: Timeline



Sunset on Mars