Landing at Lunar Impact Craters and Basins to Determine the Bombardment of Ancient Earth

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Lunar History

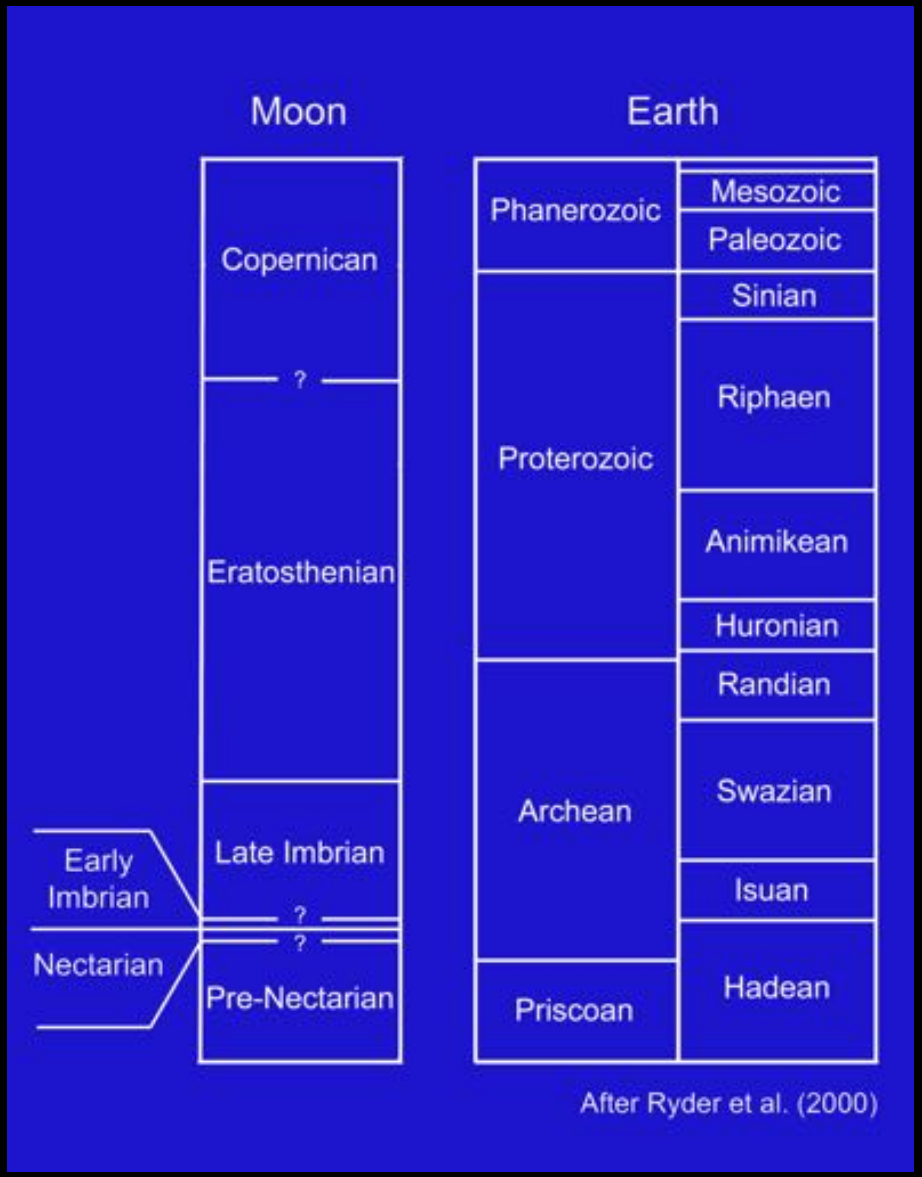
Orbital perspective

(e.g., based on Lunar Orbiter data)

Provides relative ages

Based on:

- Stratigraphy of overlapping impact ejecta blankets and lava flows
- Relative densities of impact craters on surfaces



Jack Schmitt – Apollo 17

Nectarian and Early Imbrian Impact Basins

	Impact Basin	Diameter (km)	Age (Ga)
Early Imbrian Basins	**Orientale**	930	3.82 – 3.85 ?
	Schrödinger	320	
	Imbrium	1,200	3.85 ± 0.01
	Bailly	300	
	Sikorsky-Rittenhouse	310	
Nectarian Basins	Hertzprung	570	
	Serenitatis	740	3.895 ± 0.017
	Crisium	1,060	3.89 ?
	Humorum	820	
	Humboldtianum	700	
	Medeleev	330	
	Korolev	440	
	Moscovienese	445	
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implying ~70 to 90 million year bombardment

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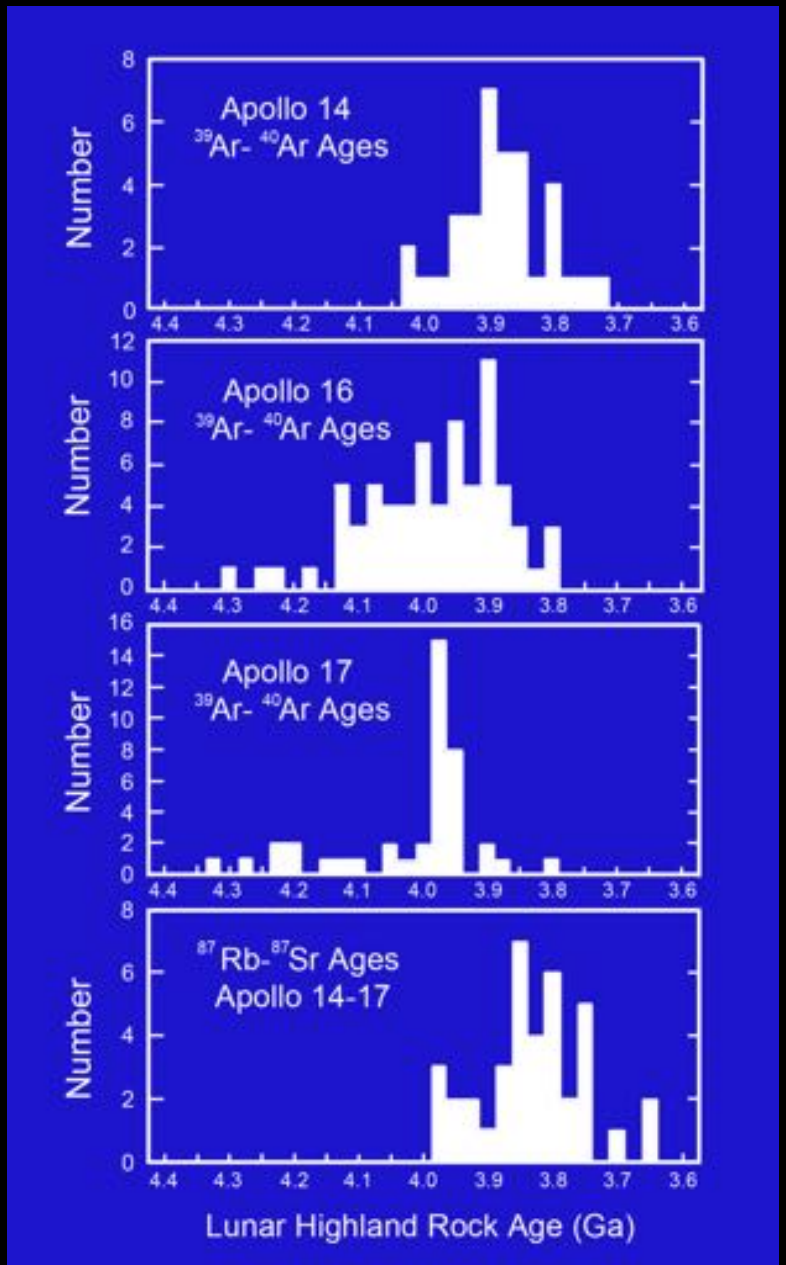
>1700 craters and basins 20 to >1000 km in diameter were produced



The Apollo Legacy –

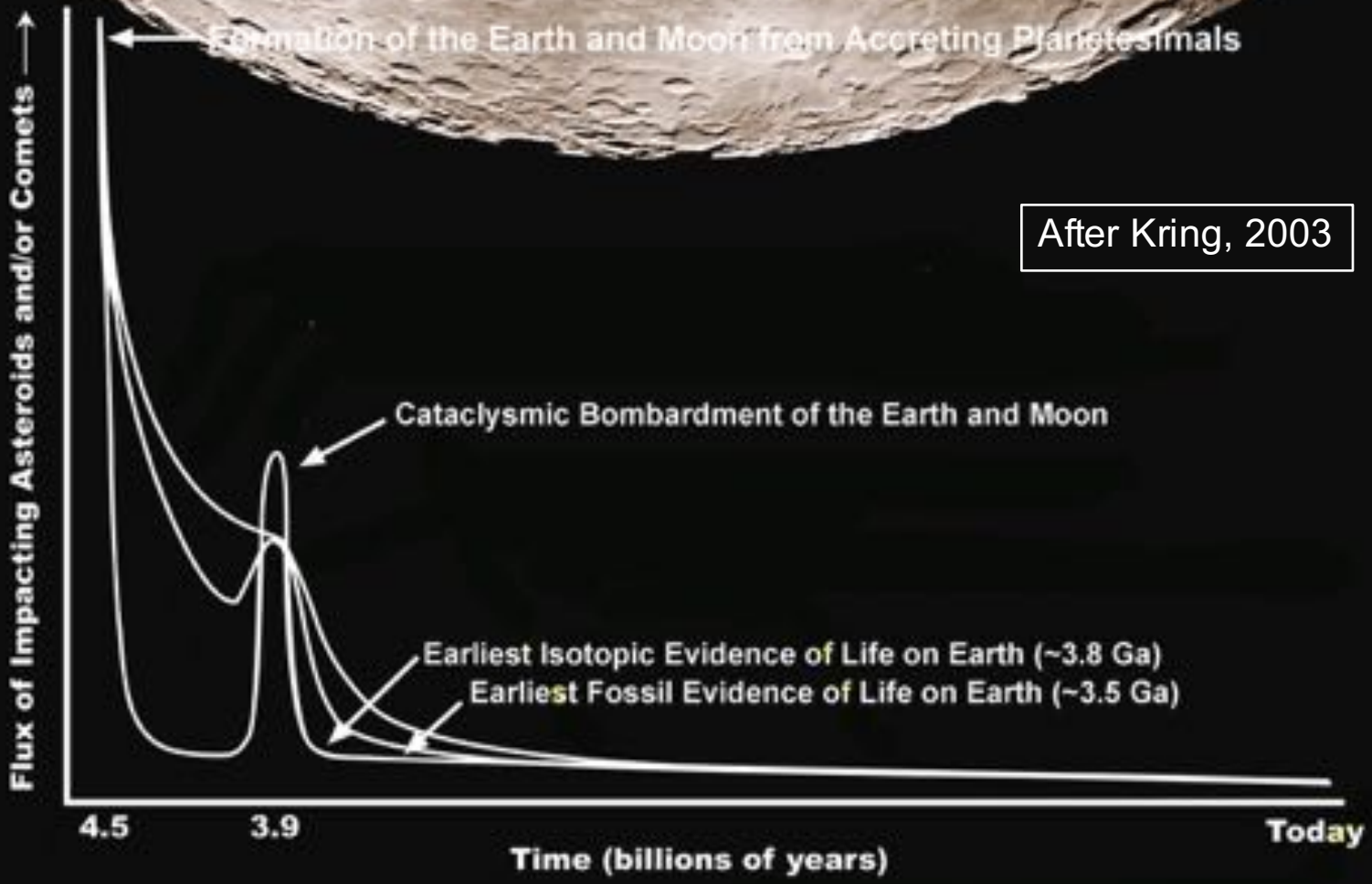
The radiometric ages of rocks from the lunar highlands indicated the lunar crust had been thermally metamorphosed ~3.9 – 4.0 Ga. A large number of impact melts were also generated at the same time.

This effect was seen in the Ar-Ar system (Turner et al., 1973) and the U-Pb system (Tera et al., 1974). It was also preserved in the more easily reset Rb-Sr system. (Data summary, left, from Bogard, 1995.)

A severe period of bombardment was inferred:

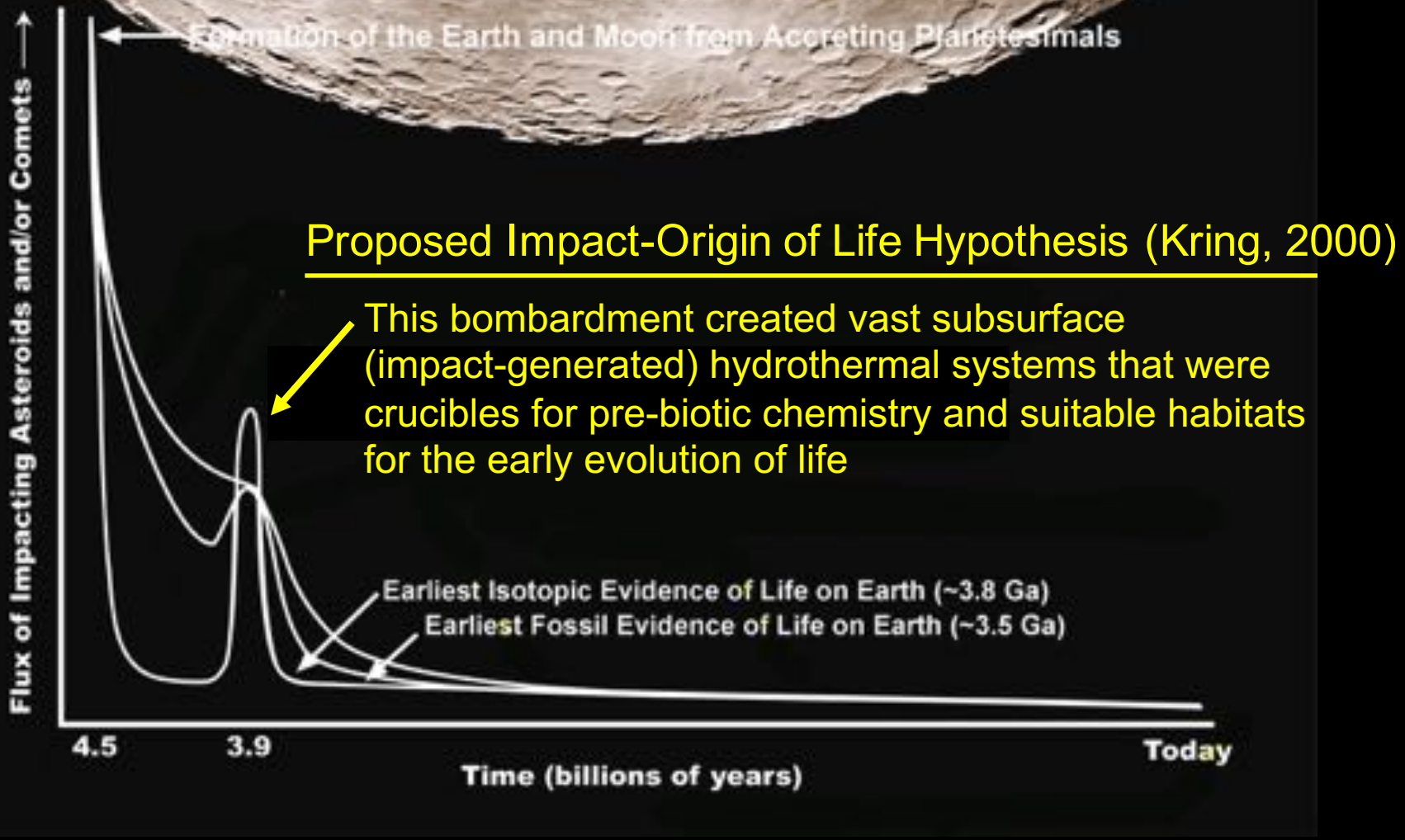
The lunar cataclysm hypothesis.

THE LUNAR CATACLYSM HYPOTHESIS



After Kring, 2003

THE LUNAR CATACLYSM HYPOTHESIS



Proposed Impact-Origin of Life Hypothesis (Kring, 2000)

This bombardment created vast subsurface (impact-generated) hydrothermal systems that were crucibles for pre-biotic chemistry and suitable habitats for the early evolution of life

Bombardment of the Earth during the Hadean and Eoarchean eras

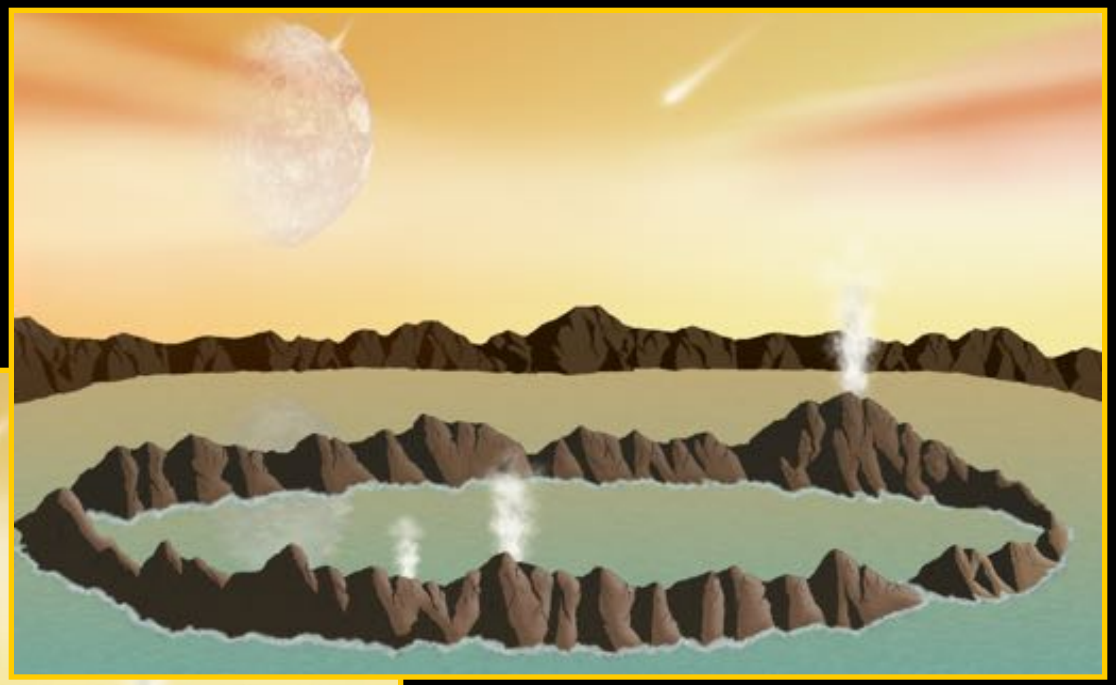
(ca. 3.5 – 4.5 billions of years ago)

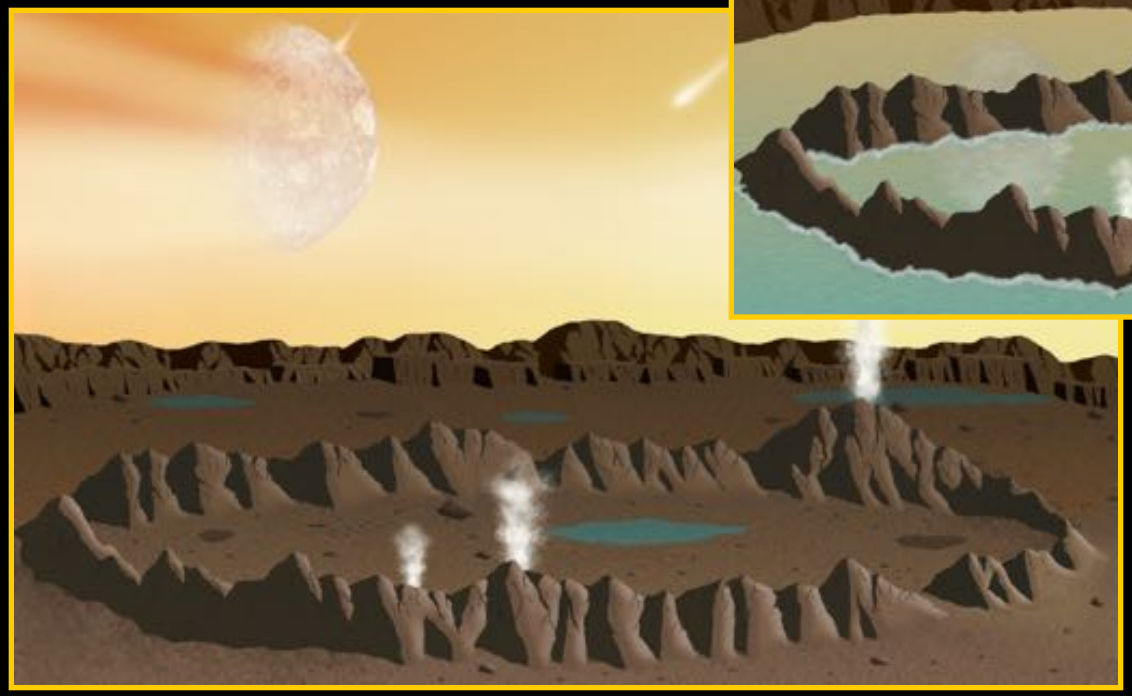
Impact – Origin of Life Hypothesis

Early Earth

Impact-cratered surface w/ or w/o seas

and a much closer Moon





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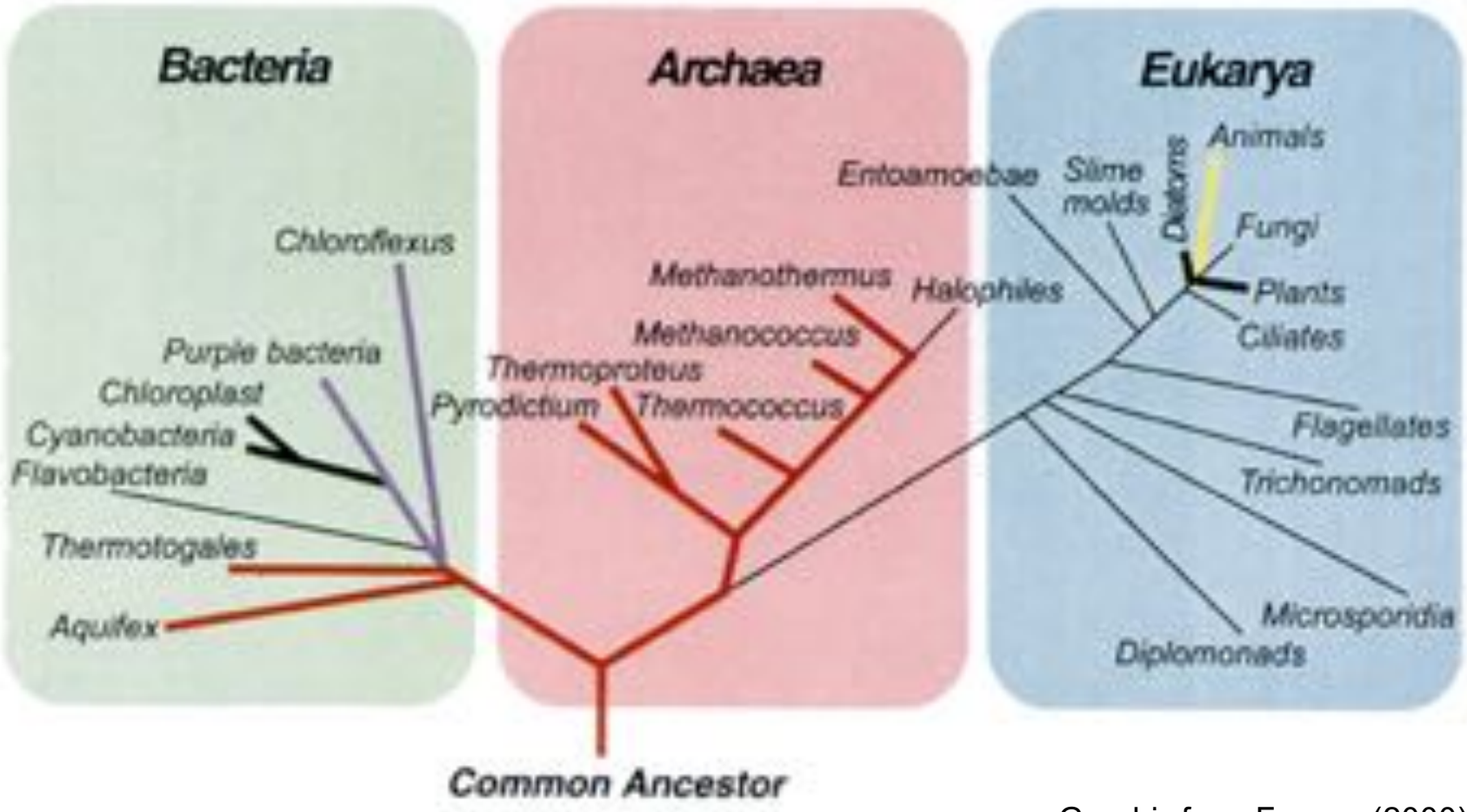

Graphic from Farmer (2000)

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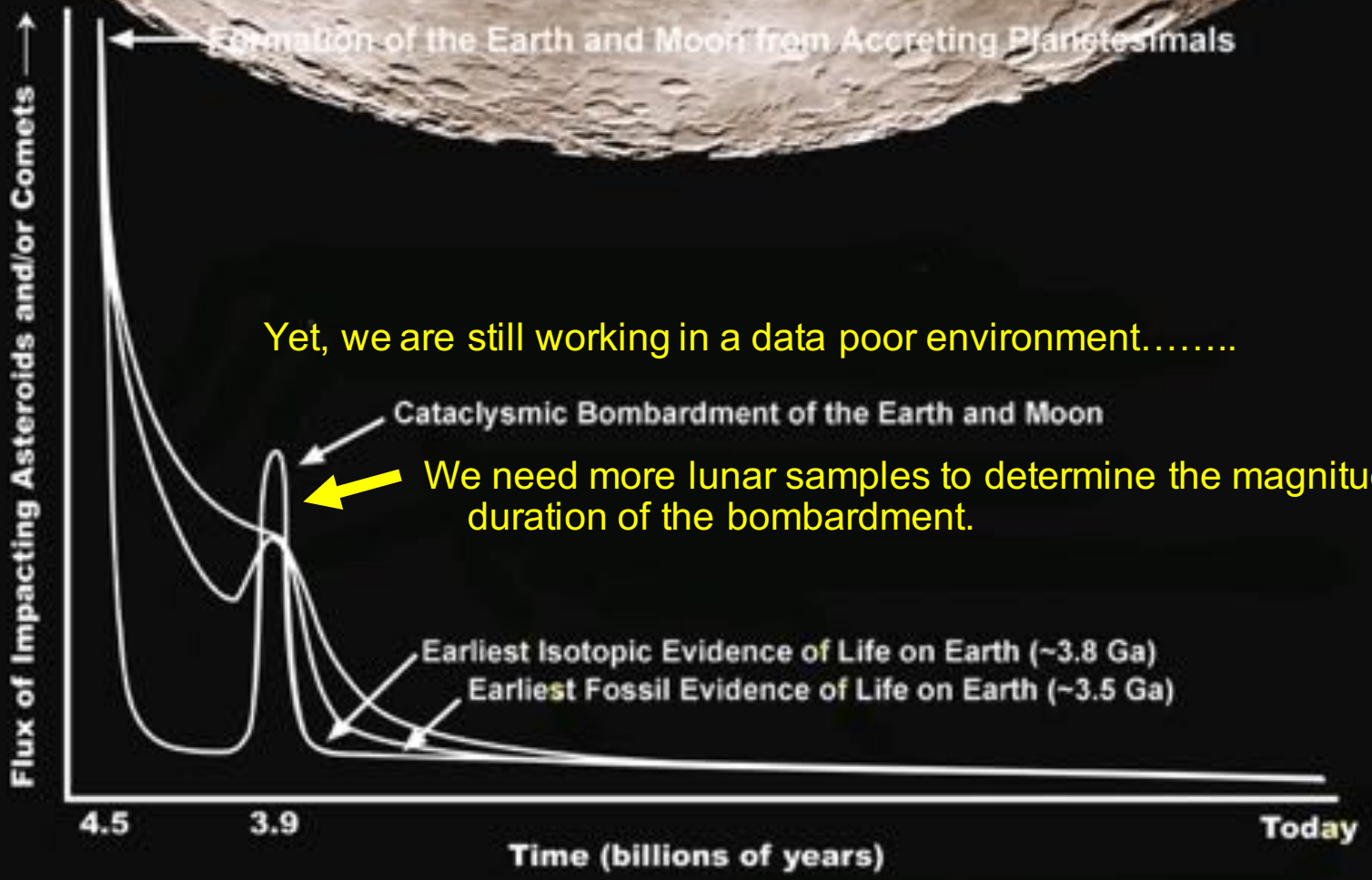
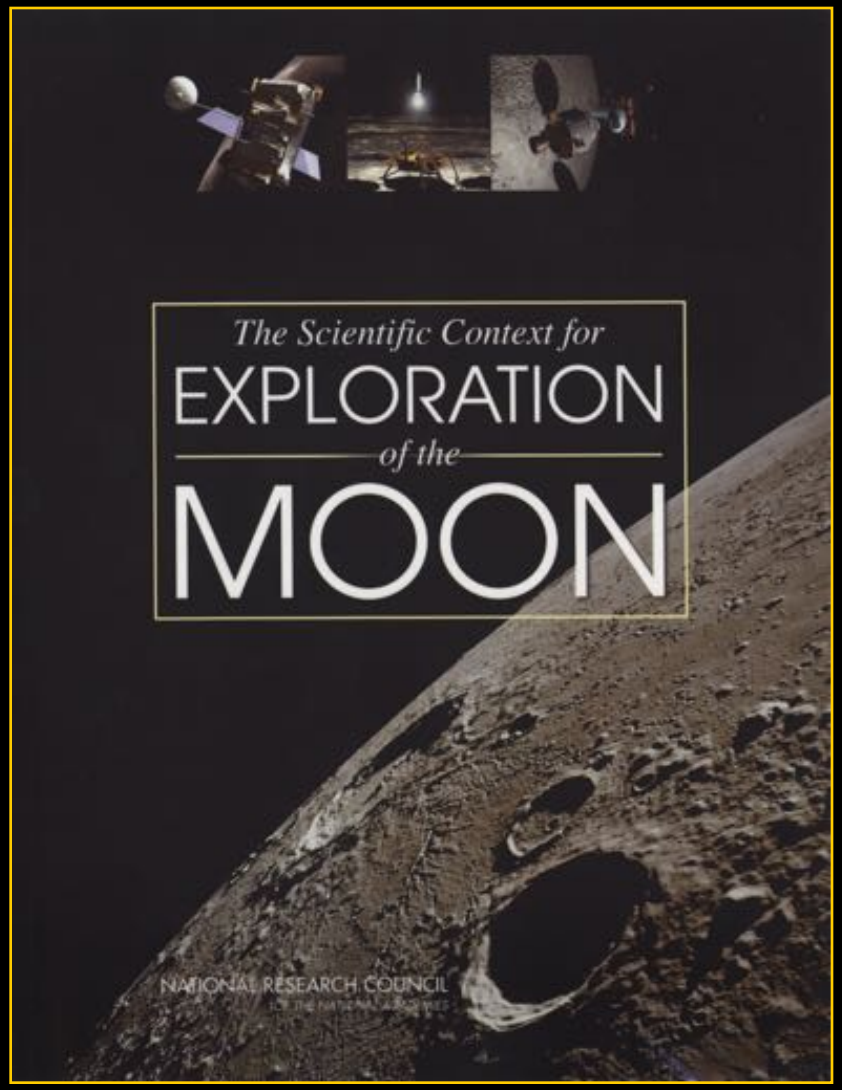


Yet, we are still working in a data poor environment……..

We need more lunar samples to determine the magnitude and duration of the bombardment.

Lunar Science Priorities



Number one science concept
& highest science priorities

1. The bombardment history of the inner solar system is uniquely revealed on the Moon
   a. Test the cataclysm hypothesis by determining the spacing in time of the creation of lunar basins
   b. Anchor the early Earth-Moon impact flux curve by determining the age of the oldest lunar basin (South Pole-Aitken Basin)
   c. Establish a precise absolute chronology *(by measuring ages of representative craters throughout the Moon's history)*
   d. Assess the recent impact flux

There are three paths forward

- Use existing samples and spacecraft data to further test the hypothesis and refine our questions
- Prepare for future robotic and crewed expeditions to the lunar surface, which will provide samples needed to resolve the issue
- Integrate sample analyses with dynamical models

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Target Requirements

To determine the impact flux and any variations in it, we need

- To target impact craters and larger basins that are representative of the flux in both space and time

Target Requirements

To provide a temporally broad chronometer, we also need to

- Target impact craters that provide surfaces (e.g., crater floors) that can be used to calibrate crater counting chronologies and/or

- Target impact craters that provide stratigraphic horizons (e.g., ejecta blankets) that can be used for relative chronologies, even for events that may occur too close in time to be discernable using radiometric techniques

Nectarian and Early Imbrian Impact Basins

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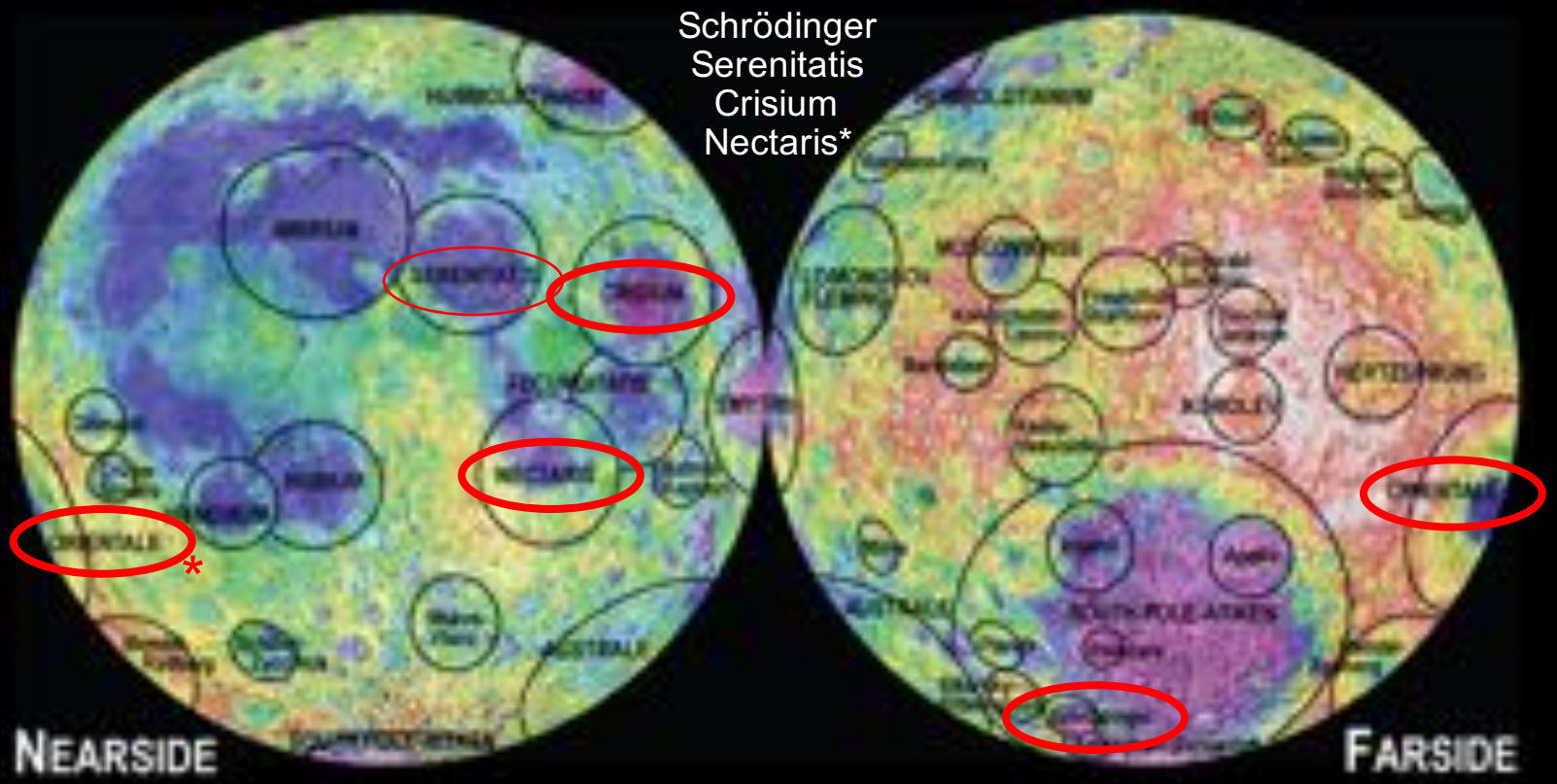
Targeting Nectarian and Early Imbrian Impact Basins

Orientale
Schrödinger
Serenitatis
Crisium
Nectaris*



Broad geographic distribution to assist calibration of relative surface chronology

Also, provides samples of different types of lunar crust

*Schrödinger & Orientale are particularly attractive, because they can also provide details of basin structure.

Pre-Nectarian Basins

Impact Basin	Diameter (km)	Age (Ga)
Apollo	505	
Grimaldi	430	
Freundlick-Sharonov	600	
Birkhoff	330	
Planck	325	
Schiller-Zucchius	325	
Amundsen-Ganswindt	355	
Lorentz	360	
Smythii	840	
Coulomb-Sarton	530	
Keeler-Heaviside	780	
Poincare	340	
Ingenii	560	
Lomonosov-Fleming	620	
Nubium	690	
Mutus-Vlacq	690	
Tranquillitatis	800	
Australe	880	
Fecunditatis	990	
Al-Khwarizmi/King	590	
Pingre-Hausen	300	
Werner-Airy	500	
Balmer-Kapteyn	550	
Flamsteed-Billy	570	
Marginis	580	
Insularum	600	
Grissom-White	600	
Tsiolkovskiy-Stark	700	
South Pole-Aitken	2500	

?

Three estimates of the age of SPA are ~4.35 Ga (Morbidelli et al., 2012; Hiessinger et al. 2012; Kring et al., 2013)

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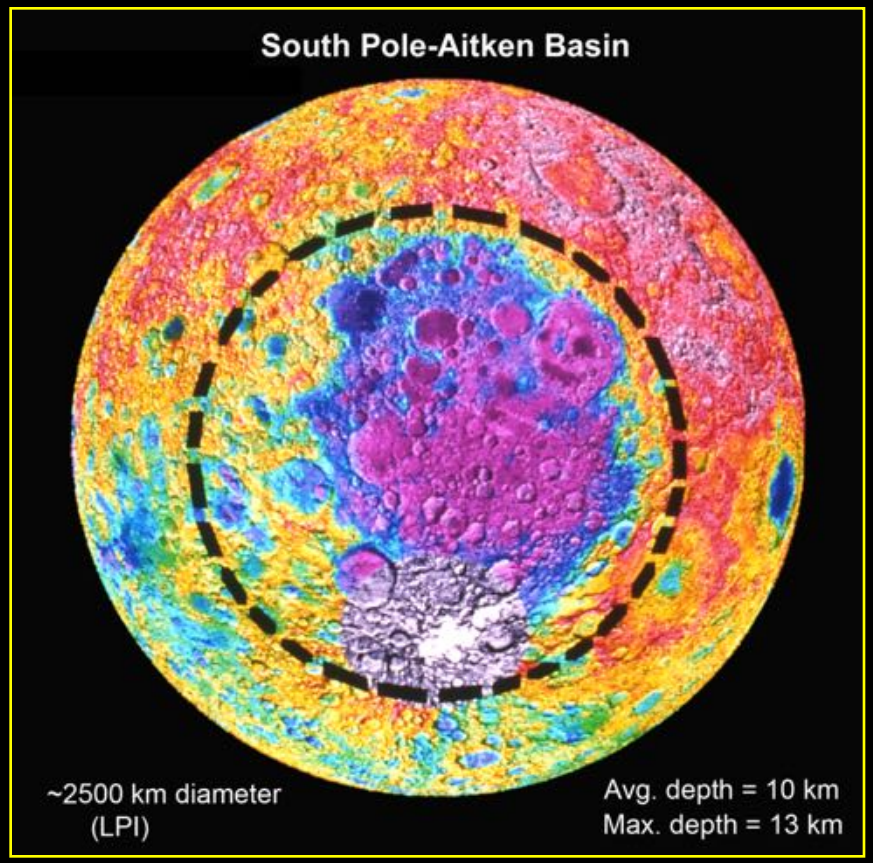
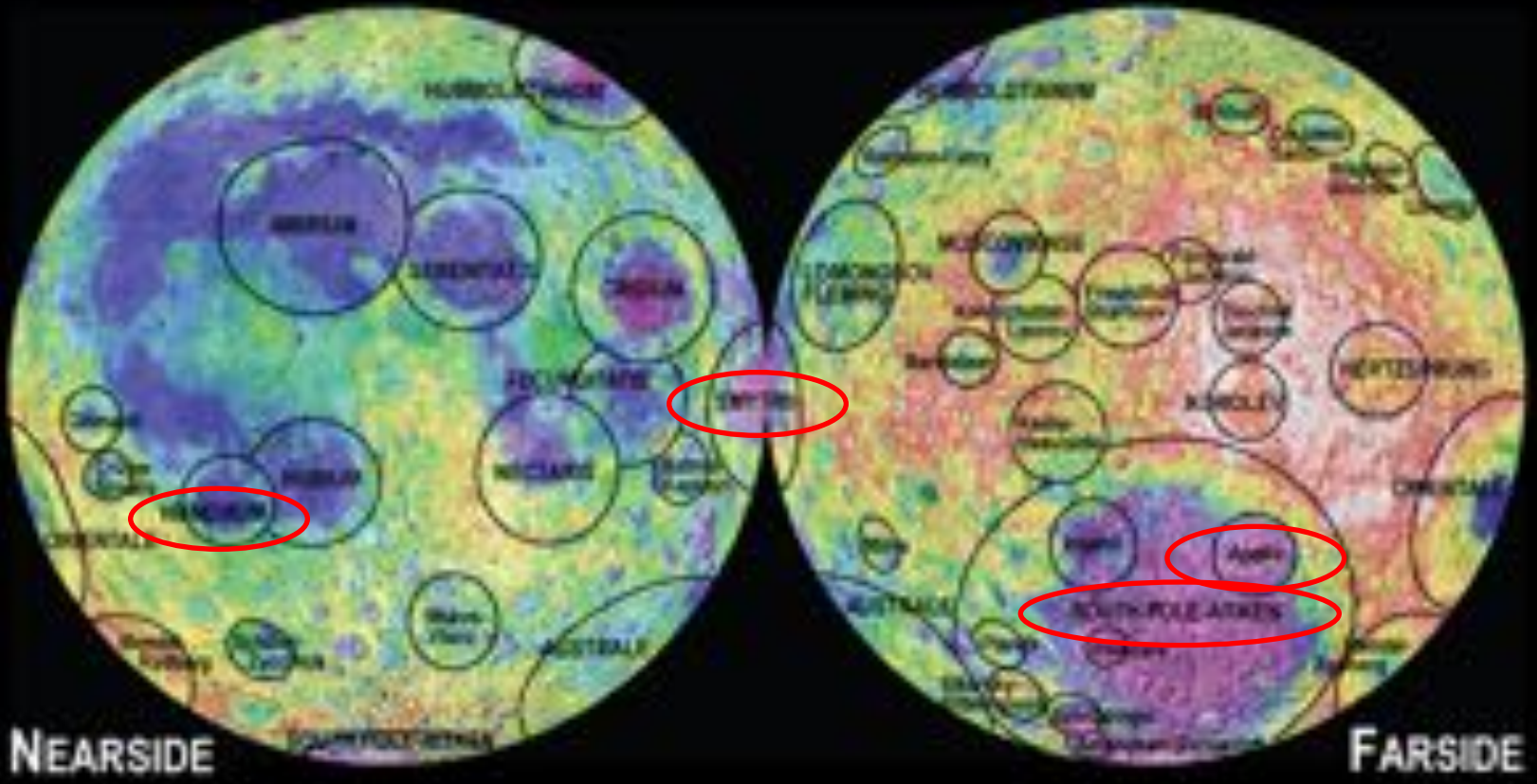


Highest Priority

Pre-Nectarian Basins



with South Pole-Aitken Basin having the highest priority

Pre-Nectarian Basins

Impact Basin	Diameter (km)	Age (Ga)
Apollo	505	4
Grimaldi	430	
Freundlick-Sharonov	600	
Birkhoff	330	
Planck	325	
Schiller-Zucchius	325	
Amundsen-Ganswindt	355	
Lorentz	360	
Smythii	840	3
Coulomb-Sarton	530	
Keeler-Heaviside	780	
Poincare	340	
Ingenii	560	
Lomonosov-Fleming	620	
Nubium	690	2
Mutus-Vlacq	690	
Tranquillitatis	800	
Australe	880	
Fecunditatis	990	
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Pingre-Hausen	300	
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Flamsteed-Billy	570	
Marginis	580	
Insularum	600	
Grissom-White	600	
Tsiolkovskiy-Stark	700	
South Pole-Aitken	2500	1

Representative Eratosthenian Craters

Impact Crater	Diameter (km)	Age (Ga)	
Lambert	30		
Reiner	30		
Archytas	32		
Timocharis	34		
Stearns	37		
Manilius	39		
Herschel	41		
Rothmann	42		
Plinius	43		
Reinhold	43		
Agrippa	44		
Hainzel A	53		
Maunder	55		
Eratosthenes	58		
Bullialdus	61		
Hercules	69		
Werner	70		
Fabricius	78		
Aristoteles	87		
Theophilus	100		(rayed)
Pythagoras	130		
Langrenus	132		(rayed)
Hausen	167		(largest young crater)

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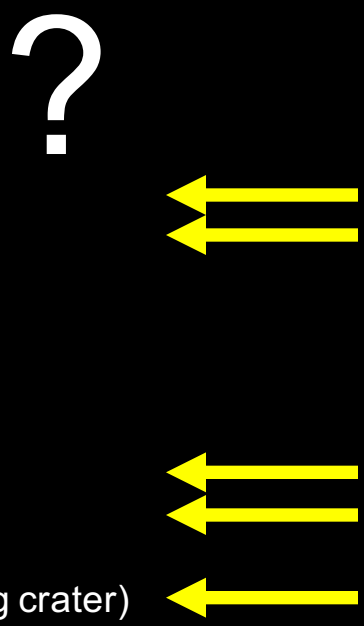

Representative Copernican Craters

Impact Crater	Diameter (km)		Age (Ga)
Kepler	32		
Petavius B	33		
Godin	35		
Autolycus	39	(ray at A15 site?)	1.29
Aristarchus	40		
Olbers A	43		
Crookes	49		
Anaxagoras	51		
Aristillus	55	(ray at A15 site?)	1.29
Taruntius	56		
Eudoxus	67		
King	77		
Copernicus	93	(ray at A12 site)	0.8-0.9
Tycho	85	(landslide at A17 site?)	0.1

The age of only a single large impact event, Tycho, is known during the Phanerozoic of Earth, which is the period of complex life on our planet.
One cannot determine an impact rate with only a single data point.
Were there pulses of activity at, say, 800 and 500 Ma?

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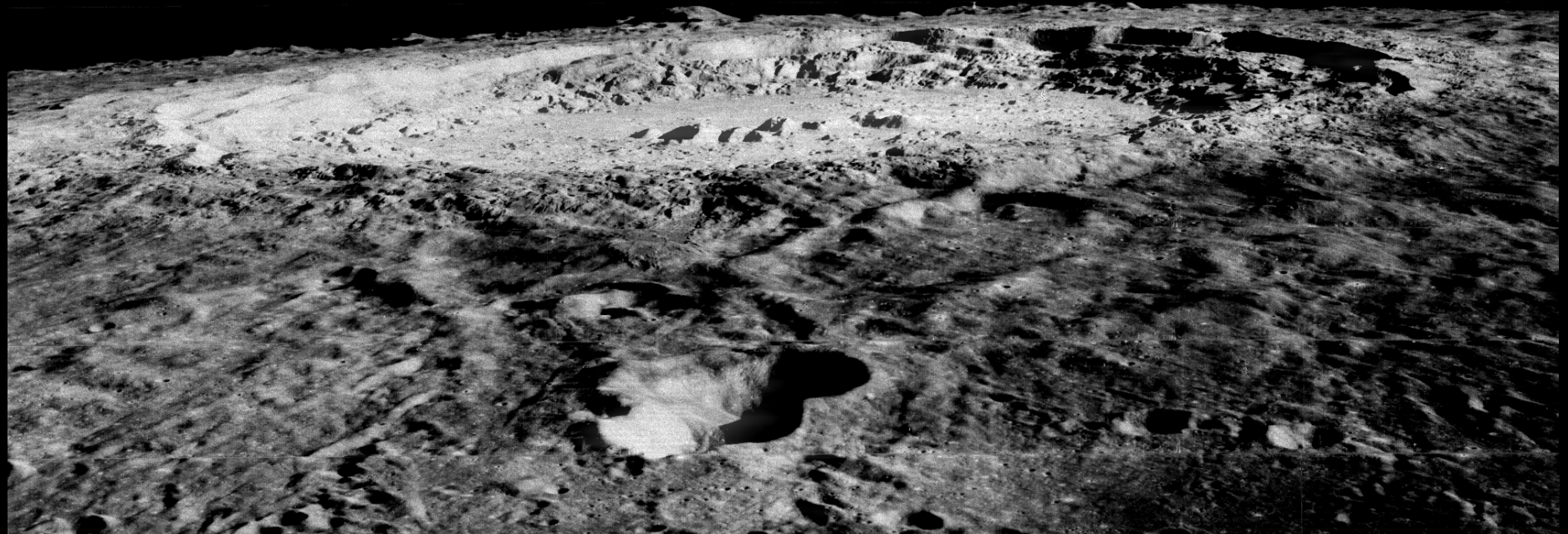
Conclusions

Representative complex craters and multi-ring basins can be sampled to test the lunar cataclysm (inner solar system cataclysm) hypothesis.

These samples will also provide a measure of the impact flux (and its variations) throughout lunar history.

These same impact sites will provide an opportunity to explore the crust of the Moon in the form of exposed cross sections (in crater walls), excavated debris, and impact melt.



Conclusions

They will also provide a window into the events that shaped the geologic *and* biologic evolution of Earth