Wed. Oct. 11, 2017

- Reading: For Friday
  - Zuber et al. 2013 Grail Lunar Gravity
  - Andrews-Hanna et al. 2013 (GRAIL Procellarium region)

Makeup lecture days -- This Friday at noon

- No Class Oct. 16, 18, 20

Today:

- Deviations from simple lunar differentiation dmodel
- Cratering

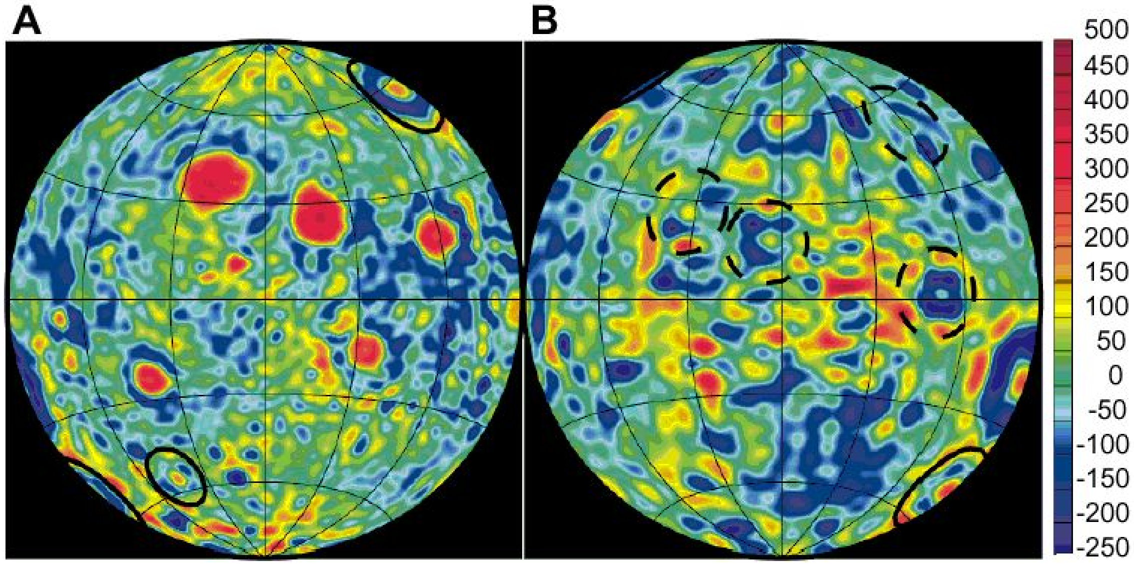
Lunar Mascons:
Excess gravity and mass over near-side basins

- "Excess gravity detected over many impact basins implying "excess" mass
- Two possible causes
  - Higher density mare basalts filled impact basins "from above".
  - Higher density mantle material filled transient crater "from below"

- If lithosphere could adjust then vertical movement would return moon to isostatic equilibrium
  - Gravity would be normal even though denser material present
  - That material would simply "float lower" relative to highlands.

- Presence of mascons indicates failure of isostatic equilibrium
- Spatial variations give time history of equilibrium

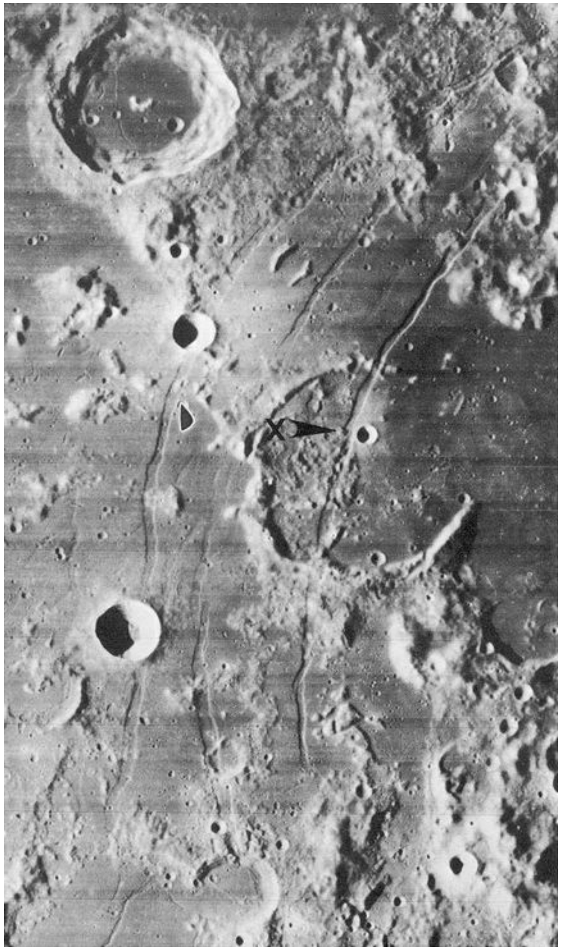
Other constraints on thermal evolution
Changes in isostatic compensation

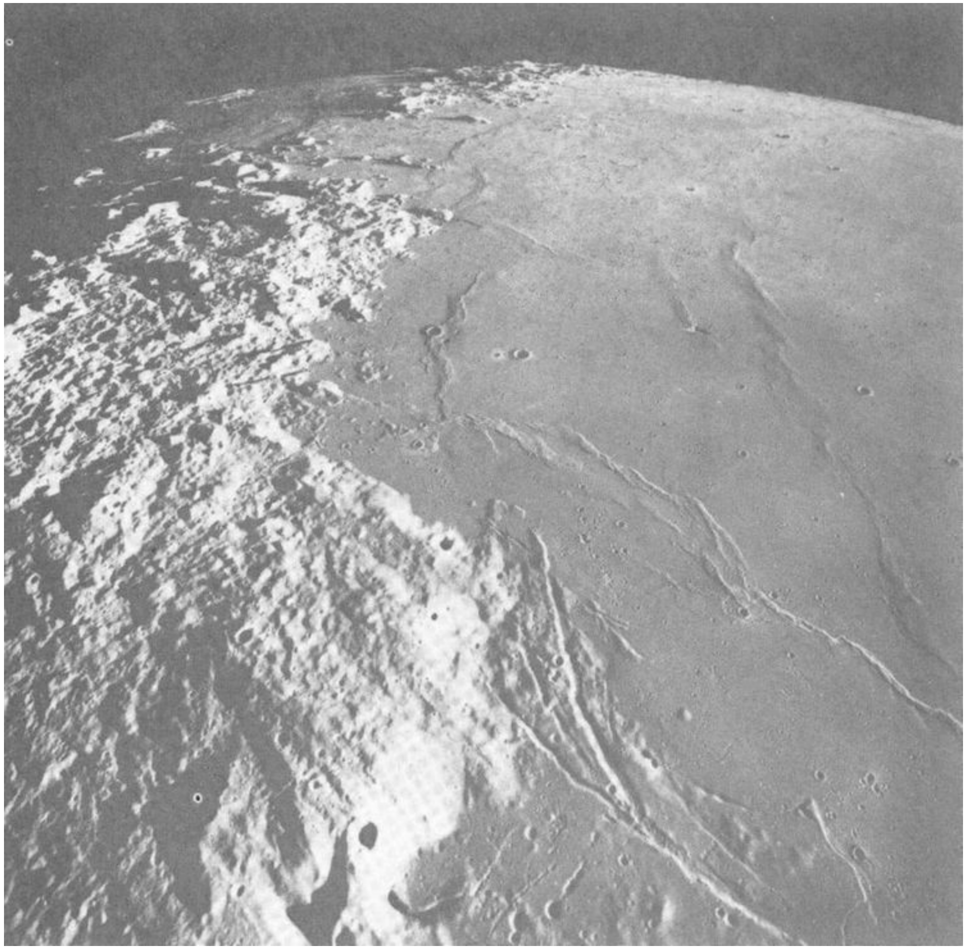


Lunar Prospector
(will update with Grail results later)

1. Old Highlands are isostatically compensated
   – New lithosphere could flex to compensate for early impacts/thickness variations
2. Intermediate age non-mare-filled basins show gravity lows
   – Lithosphere only partially able to adjust at this point
3. Later mare-filled basins show gravity highs (mascons)
   – Lithosphere stress able to support infill from mare basalts
4. Orientale basin shows “bull's-eye” with gravity high over inner mare fill and gravity low over outer unfilled part

Other constraints on thermal evolution
Changing stress in mare margins





- Concentric graben ("rilles") before 3.6 AE
- Concentric thrust faults ("wrinkle ridges") continue after this
- Presumably show shift towards compressive (cooling) stresses

Wrinkle Ridge Structure

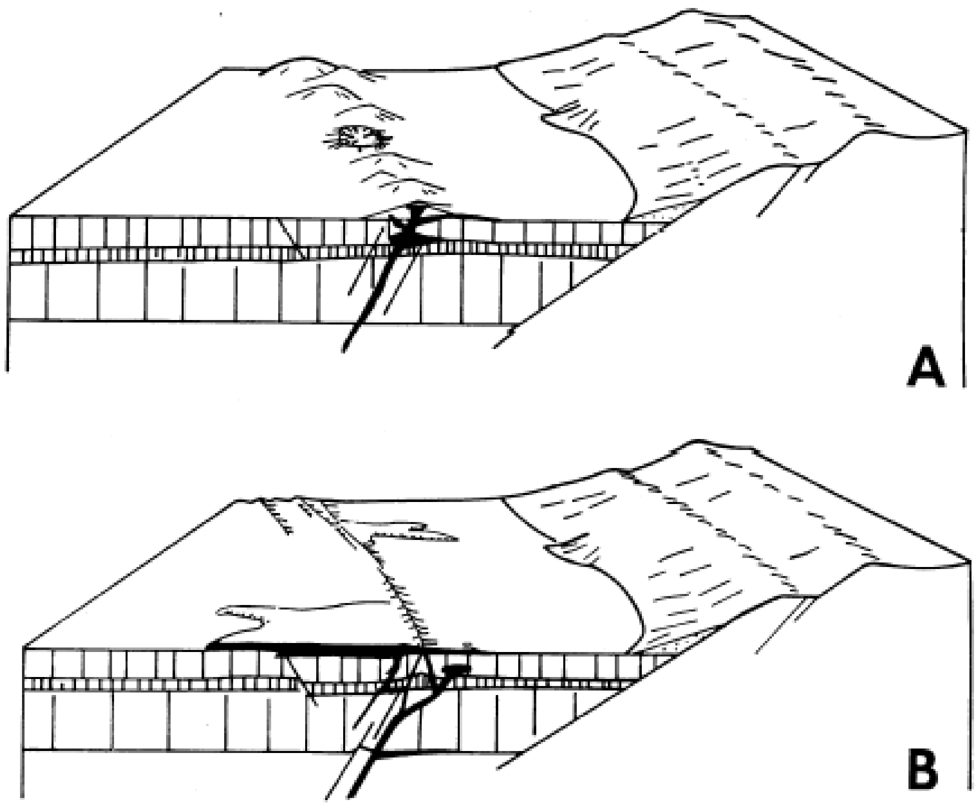
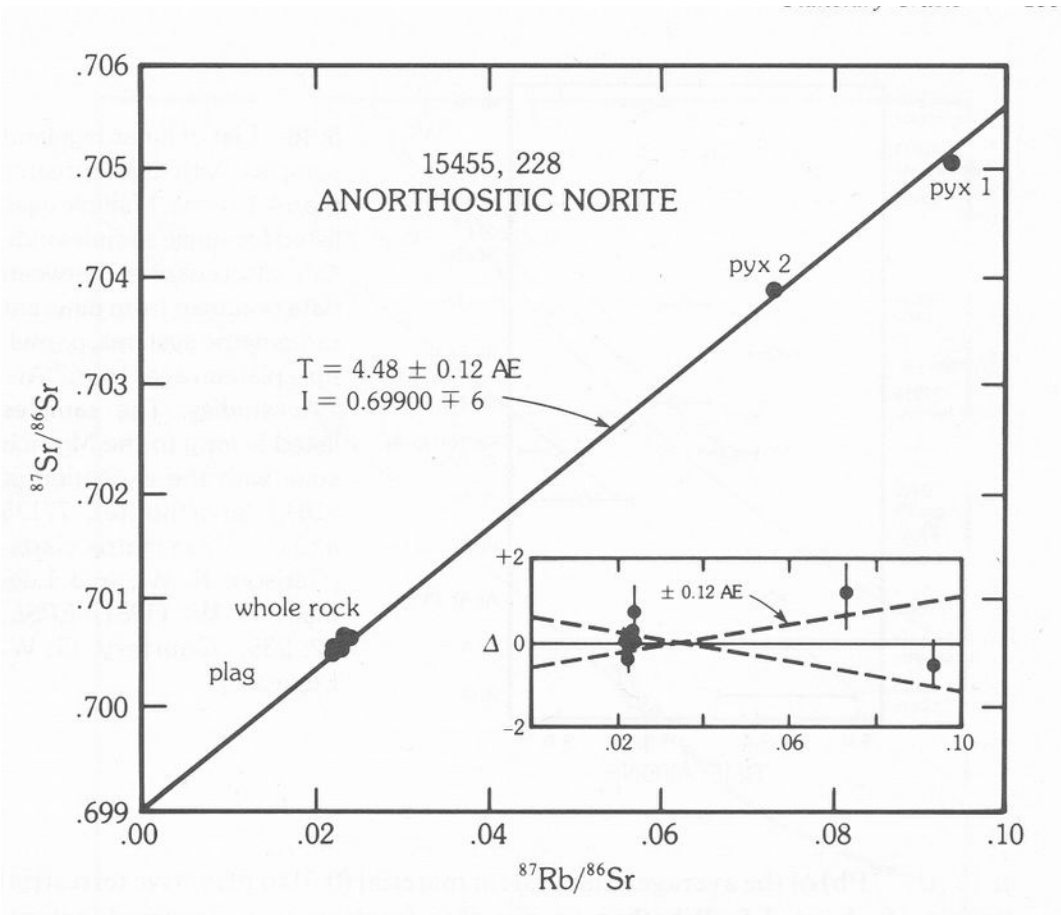


Fig. 41a and b. Cross-sections of lunar basin interiors, showing interpretations of peak-rings and crater-rings (a) and wrinkle ridges (b). Both types of feature are products of volcanic activity along ring fractures corresponding to the Lance-Onat fractures at 0.7 *R*. In case A the magma is more viscous; in case B it is more fluid and produces flows observed to extend from wrinkle ridges.

- Thrust faults – sometimes with volcanic eruptions along them

Radiometric ages for individual highland rocks (1)

- Oldest highland rock is anorthositic norite from Apollo 15
- Rb-Sr isochron gives 4.48 ±0.12 AE
- Note initial $^{87}Sr/^{86}Sr = 0.699$

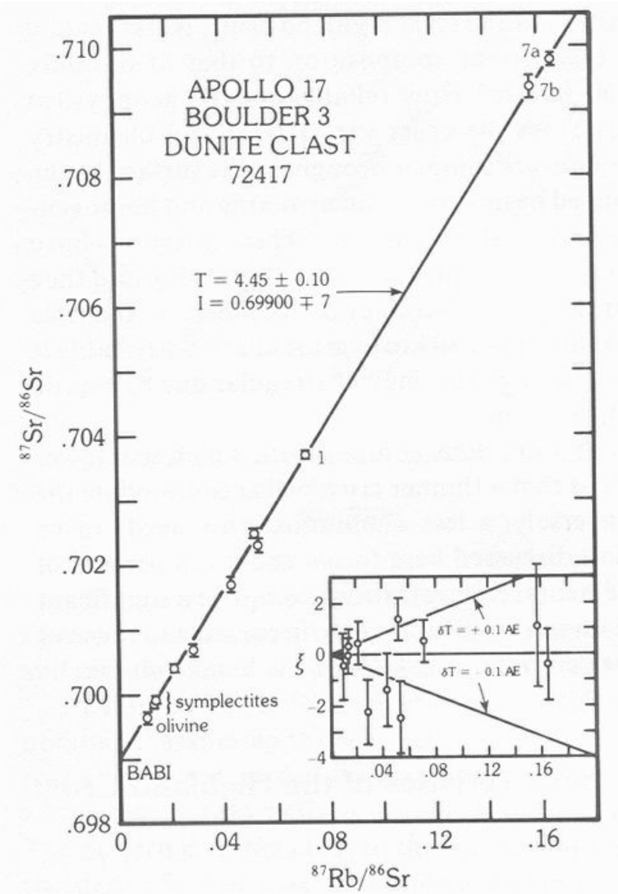


5.29b The oldest lunar rocks. An isochron age of 4.48 aeons for the anorthositic norite 15455, 228. (Courtesy L. E. Nyquist.)

Taylor 1982

Radiometric ages for individual highland rocks (2)

- Apollo 17 Dunite (Olivine) clast at "Boulder 3"
- Rb-Sr isochron gives 4.45 ± 0.10 AE
- Initial $^{87}Sr/^{86}Sr$ also 0.699
  - This is same as "BABI" = "Basalt Achondrite Best Initial" = 0.69877 ± 3
    Best guess at solar system initial $^{87}Sr/^{86}Sr$ from low Rb basalt achondrite meteorites
  - We will use this initial $^{87}Sr/^{86}Sr$ to get age of "reservoirs"

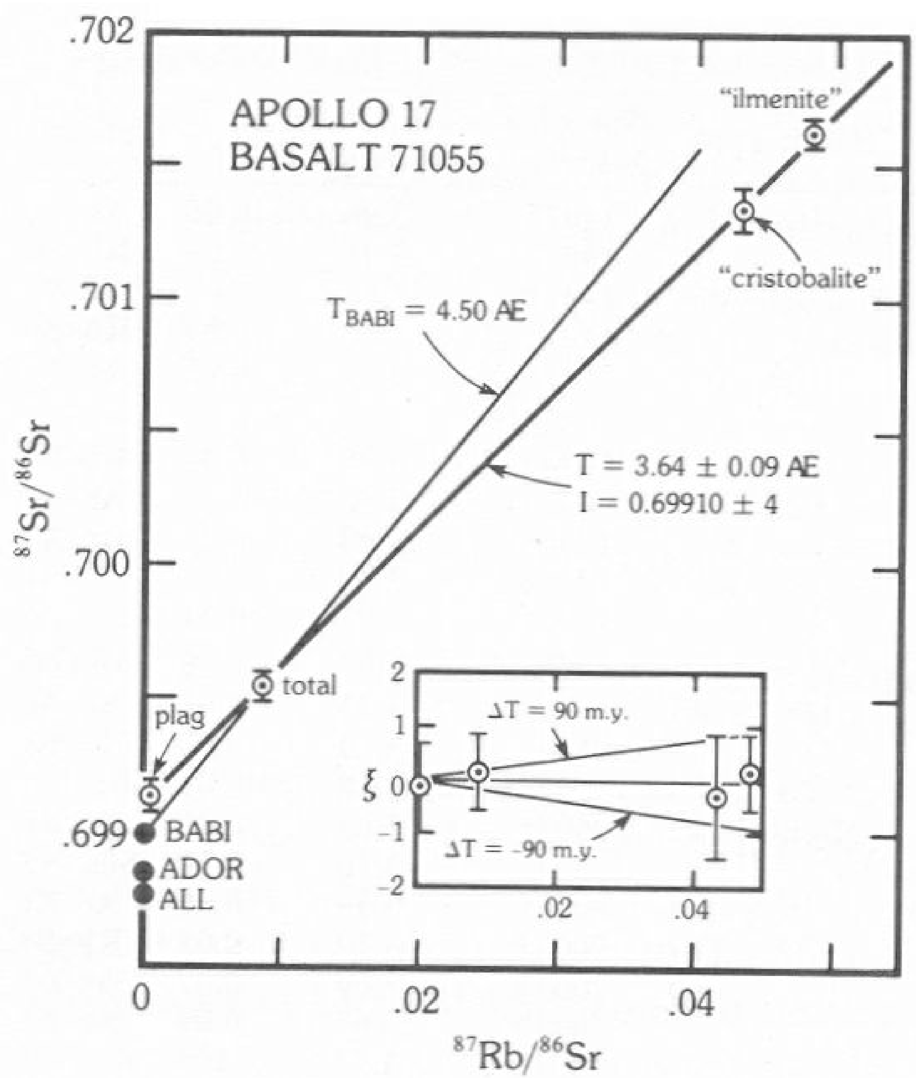


- Old highland crustal rock ages compiled in Taylor 1982 Table 5.6

- 15455 Anorthositic gabbro (Rb-Sr) 4.48 ± 0.10 AE
- 72417 Dunite (Rb-Sr) 4.45 ± 0.10
- 76535 Troctolite (Rb-Sr) 4.61 ± 0.07
- 77215 Norite (Rb-Sr, Sm-Nd) 4.4
- 78236 Norite(Sm-Nd) 4.49
- Various anorthosites ($^{40}Ar/^{39}Ar$) 4.4-4.5

In Taylor 1982, from Papanastassiou & Wasserburg)

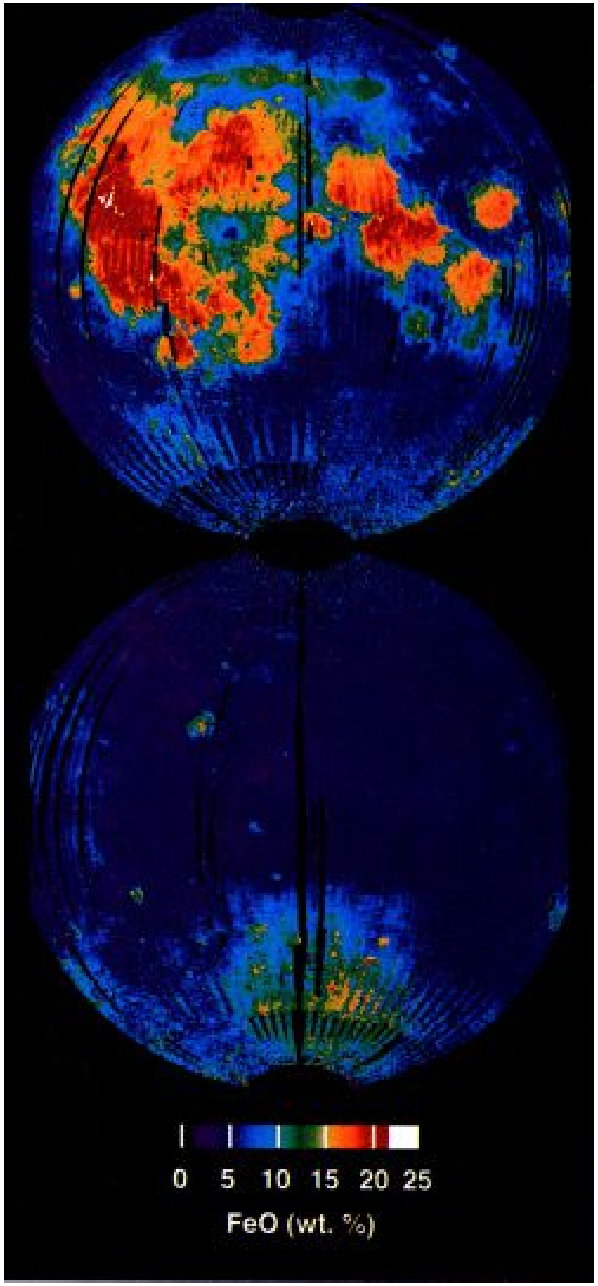
Ages for Basalt Rocks, and Crustal Differentiation (1)



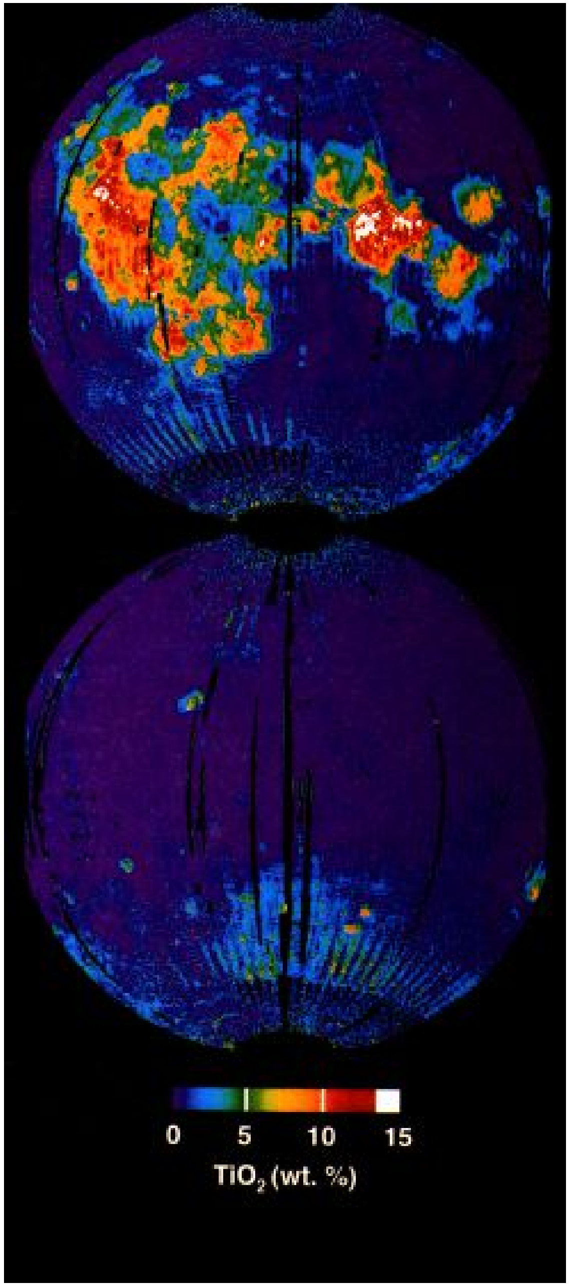
In Taylor 1982, from Wasserburg)

- Apollo 17 Basalt has rock age of 3.64 ± 0.09 AE
- Crustal differentiation:
  - The "Total" symbol gives the ratios for the whole rock. IF there was not two much Rb/Sr fractionation when the source region melted to produce the basalt, then its value represents a "bulk sample" of the source region.
  - A line drawn between this total point and the highland's initial $^{87}Sr/^{86}Sr$ gives an "isochron" for the differentiation event which separated the highland from the mare source region.
  - The resulting model age is 4.50 AE, consistent with the ages of the highland rocks

Why are Mare mostly on the Near Side?



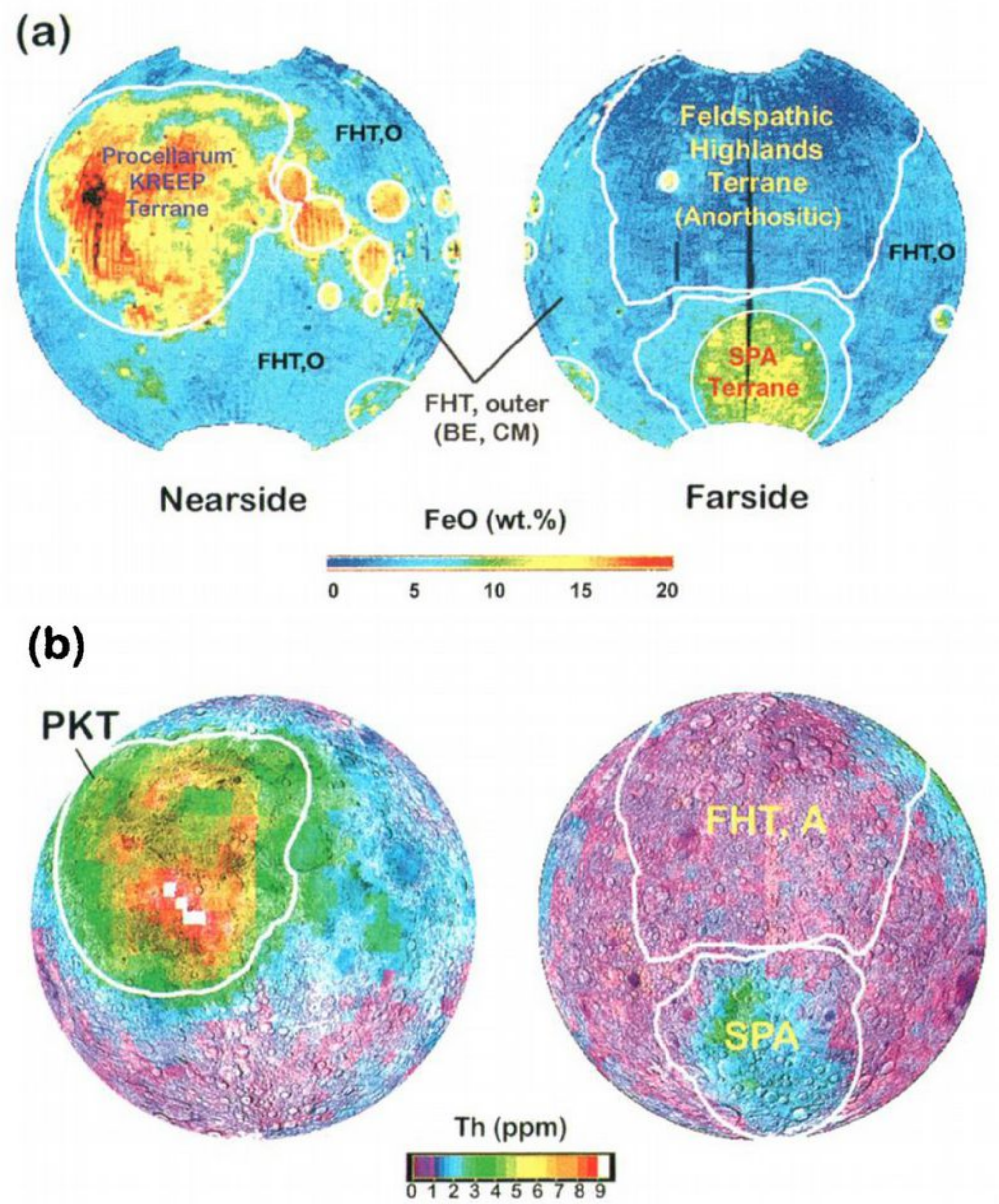
Fe abundance



Ti abundance

- Lucey et al , based on Clementine images
- Note high Ti abundance in Tranquillitatis and the rim of Serenitatis

Global Terranes now typically defined



- FHT: Feldspathic Highlands Terrane
  - A: Anorthositic
  - O: Outer (contaminated with mare material, etc.)
- PKT: Procellarum KREEP Terrain
- SPA: South Pole – Aitken basin

Jolliff et al. 2000

Cratering:

- Slides for Cratering introduction on Wed. are included in the complete cratering slides for Fri. Oct. 13