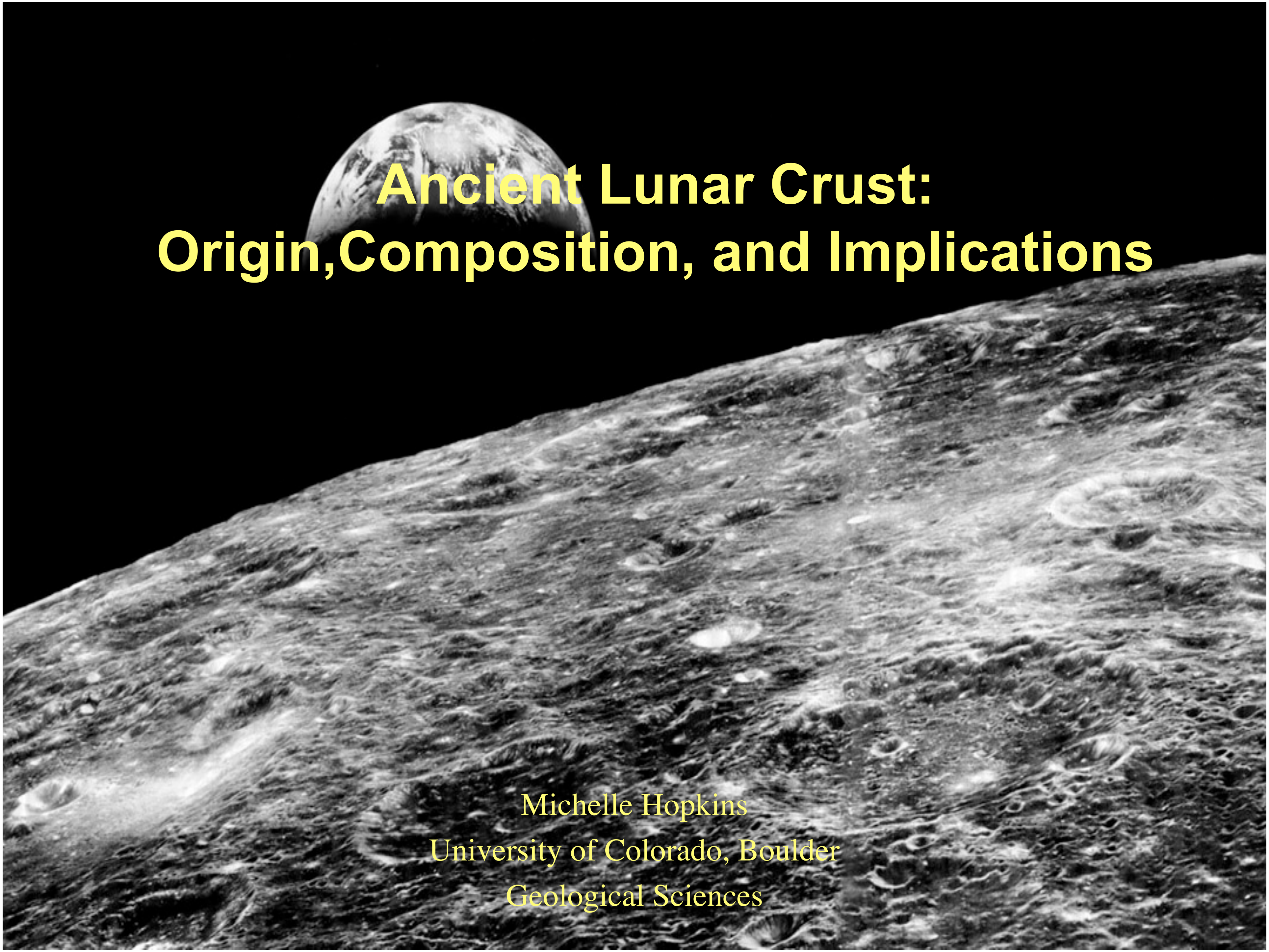
Ancient Lunar Crust:
Origin,Composition, and Implications
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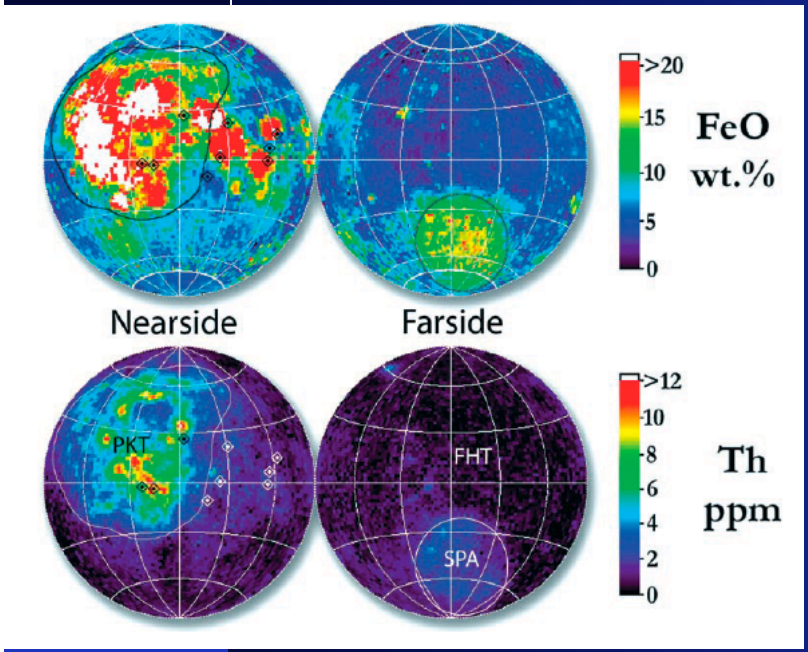
Why we care about moon rocks

- Can tell us about the geochemical evolution of the magma ocean
- Clues to how impacts effect the lunar crust
- Estimating the lunar bulk composition
- Understanding processes for planet accretion and the proto-lunar disk

Farside/Nearside Dichotomy



- Less dark maria and thicker crust on farside
- Remote sensing data reveals chemical differences
- Three distinct provinces

-maria (FeO rich lava)

-PKT (enriched in Th, KREEP)

-Feldspathic Highlands Terrane (Fe-poor,Th-poor, Al-rich)

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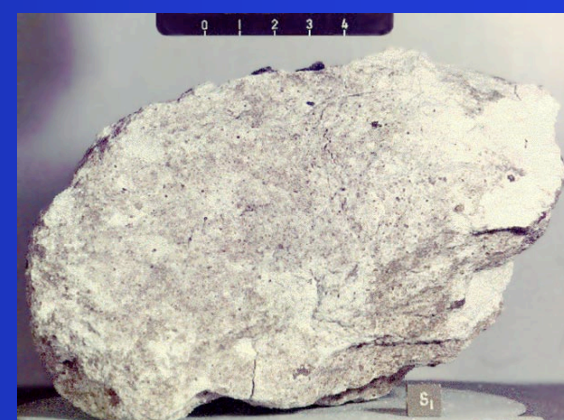
Classifying Lunar Rocks

Heavy bombardment early in the Moon's history altered and broke up the majority of lunar crust

pristine-igneous survivors with coarse-grained textures, uniform mineral comp., and low concentration of siderophile elements

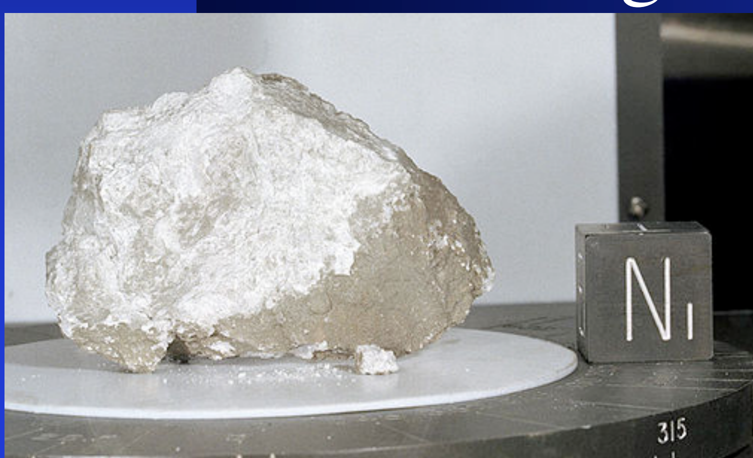
3 Main Non-Mare Igneous Rocks

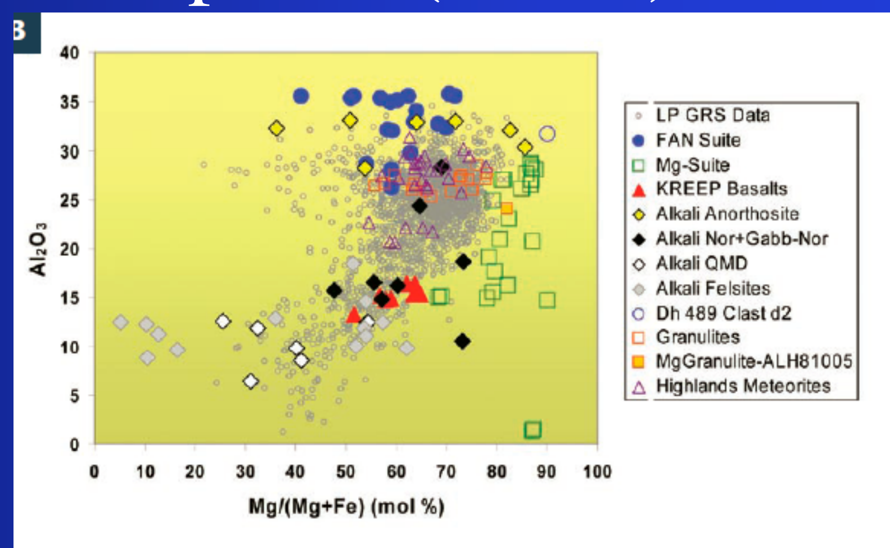
- Ferroan Anorthosite Suite
- Magnesian Suite
- Alkali Suite



Ferroan Anorthosite Suite (FAN)

- Mostly anorthosite (96 vol% plagioclase)
- Accumulated at top of magma ocean
- High Al_2O_3, low Mg# and Na/(Na+Ca)
- ~low incompatible lithophiles (Th,La)
- Four subgroups



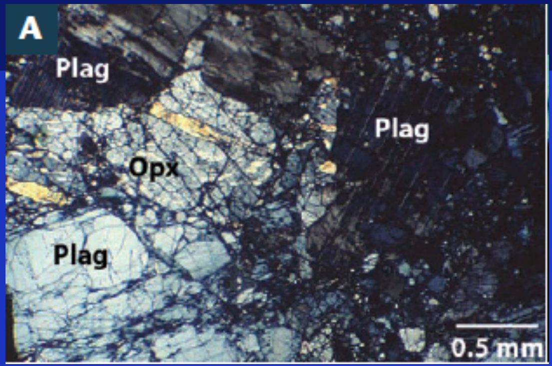


4 Subgroups of FAN

Decreasing Plagioclase

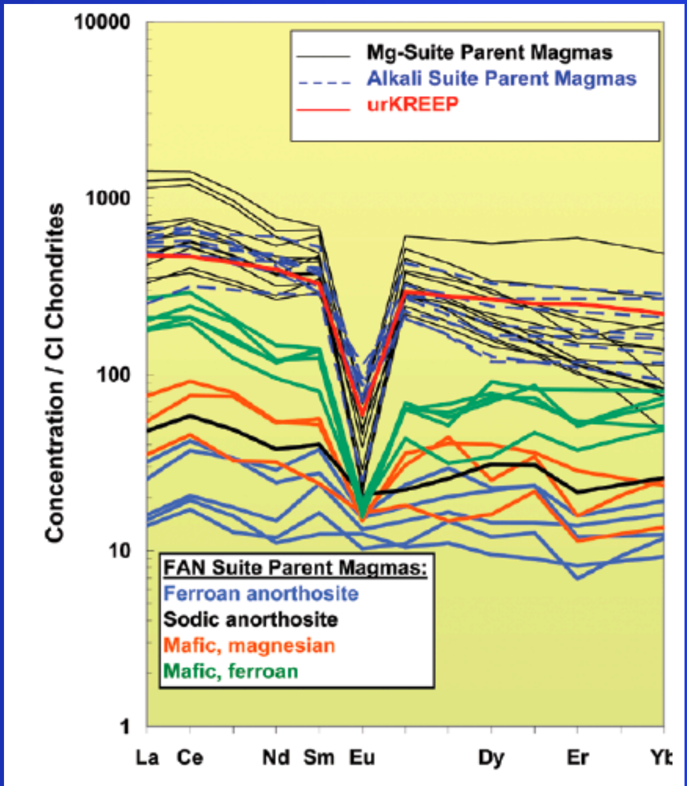
- Ferroan anorthosites (most abundant)
- Sodic anorthosites
- Mafic ferroan rocks
- Mafic magnesian rock

Age ~4.456 Ga

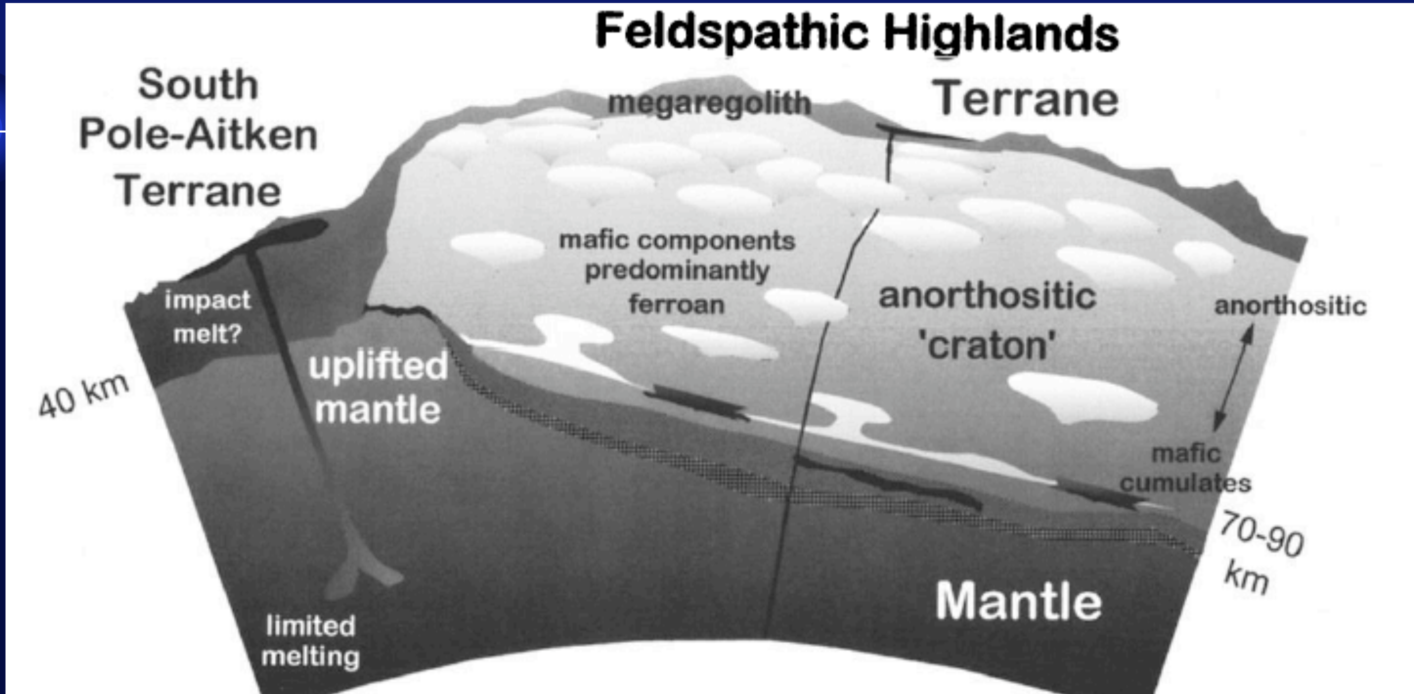


Trace element abundances in individual minerals from the rocks measured by ion microprobe give us trace element concentrations of the parent magma from which the FAN suite crystallized

REE patterns represent either multiple parent magmas or different stages of fractional crystallization



Formation of FAN suite



Jollif et al., 2000

- Pure anorthosite around impacts rings suggests uppercrust modified by intrusions and/or impacts
- Central anorthosite region thickest part of lunar crust
- Basin ejecta suggests upper mantle is more mafic
- SPA may have sampled lower crust or aquired mafic components from impacts

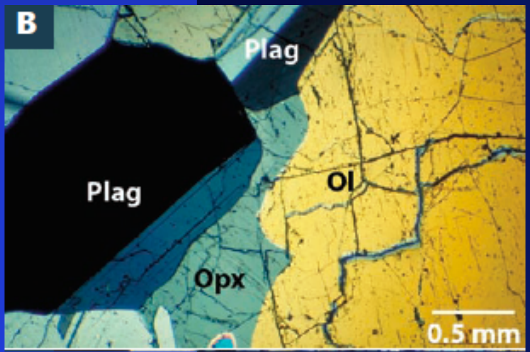
Mg-suite and KREEP

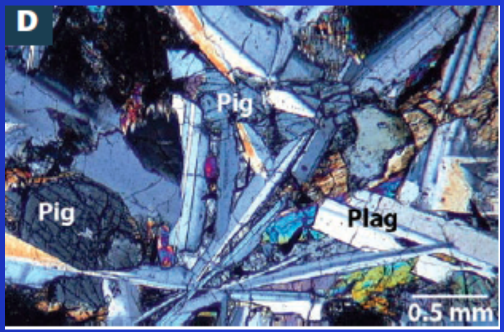
Mg-Suite

• unusual high concentration of Mg # and incompatible trace elements --> suggest incorporation with KREEP

• all located in or near Procellarum KREEP Terrane

• age range from 4.5-4.1 Ga suggests derivation from numerous magmas





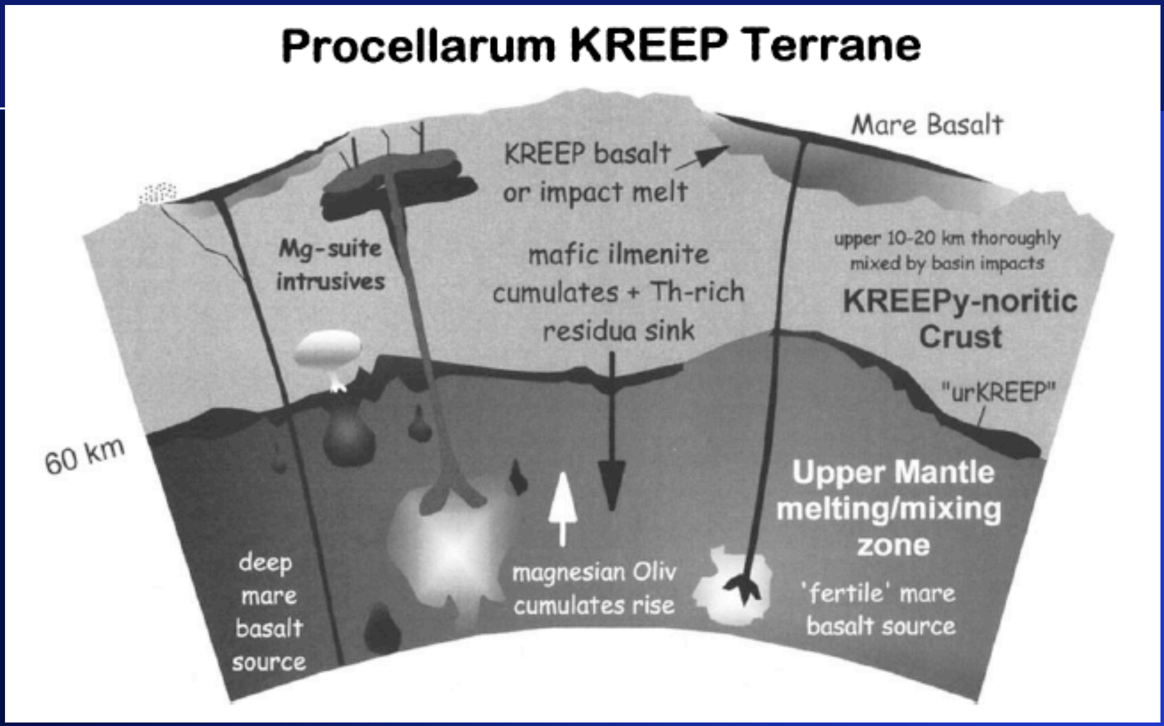
KREEP (aka urKREEP)

•K, REE, and P enriched

•Ties to Mg-suite, Alkali suite, mare basalts

•Residual liquid left after crystallization of magma ocean

Formation of Mg-Suite and KREEP's major role



-Lower crust concentrated in urKREEP, this residua sinks and interacts with rising Mg/Oliv cumulates during overturn of mantle resulting in Mg/Oliv-urKREEP hybrid

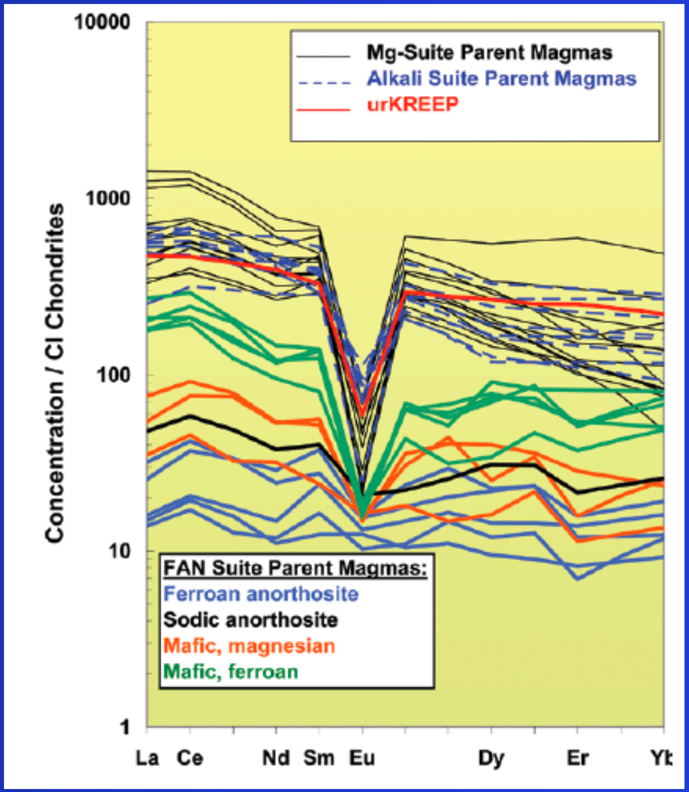
-Also residua sink provides fertile melting zone in upper Mantle for mare basalts

-An alternate model-decompression melting of Mg/Oliv

Alkali Suite and their formation

- Everything else! (KREEP basalts, alkali anorthosite, gabbronorites, felsites, monzodiorites)

- Higher Na/Ca, La, Th and large range in Mg #
- Likely formed from KREEP Basalt magma
- Ages range from 4.3-3.8 Ga
- KREEP basalt are the youngest 4.08-3.93



Cryptic Igneous Rocks

Granulitic breccias and meteorites bulk composition can't be explained by mixture of pristine rocks

- High equilibrium temps don't correlate with the range of Mg #
- Intermediate trace element abundances
- High Al_2O_3 contents suggest feldspar-rich protolith --> possible new primary highland rock (1)?
- Low REE suggest they may be derived from urKREEP-poor Mg magmas (2) --> support for decompression melting
- Likey dominiated on farside, though their origin is still unclear (option 1, 2, or impact-induced)

Implications for Crustal Evolution and Lunar Dichotomy

-Samples consistent with formation of the crust by plagioclase floatation in the magma ocean

-Wasson and Warren (1980) suggest global asymmetry due to heterogeneous solidification of magma ocean by anorthositic material thermally insulating nearside keeping residua molten for a longer time and allowing for extensive differentiation. What do you think???

-Global concentrations of radioactive elements affected the course of magmatism beneath the PKT

-Diversity in nearside magmas suggest a difference in nearside mantle versus farside mantle (which has far less incompatible elements)

Implications for Crustal Evolution and Lunar Dichotomy

- It is expected that mafic intrusion should be relatively abundant of the farside, though not many have been seen.
 Sample Issue? Or if not, why was magmatism so unproductive on the farside?

Can we assess broader questions like processes occurring during planet accretion and the formation of the proto-lunar disk using lunar rocks?

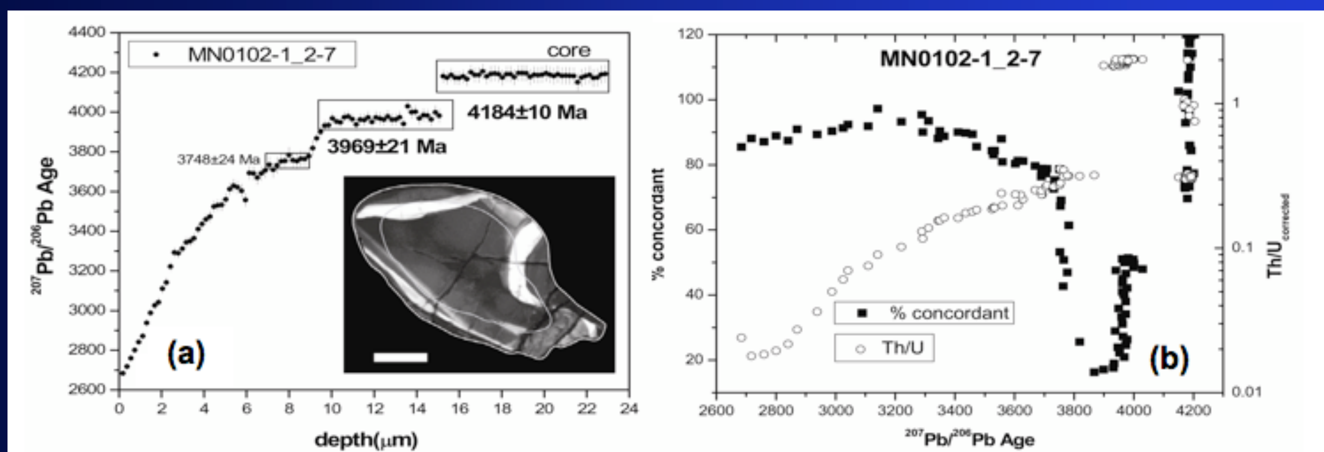
YES! High Al_20_3 content in lunar highlands important for estimating lunar bulk composition (crust plus mantle), which is important for assessing whether the Moon is enriched in refractory elements compared to BSE

What else can we tell from lunar rocks?

NASA LUNAR SCIENCE INSTITUTE

Center for Lunar Origin and Evolution (CLOE)

-constraints on bombardment history of the Moon by analyzing lunar zircons



Younger zircon mantles (external to grain's core),which can be really thin (>5μm) can record timing,intensity, and temperature of later thermal event