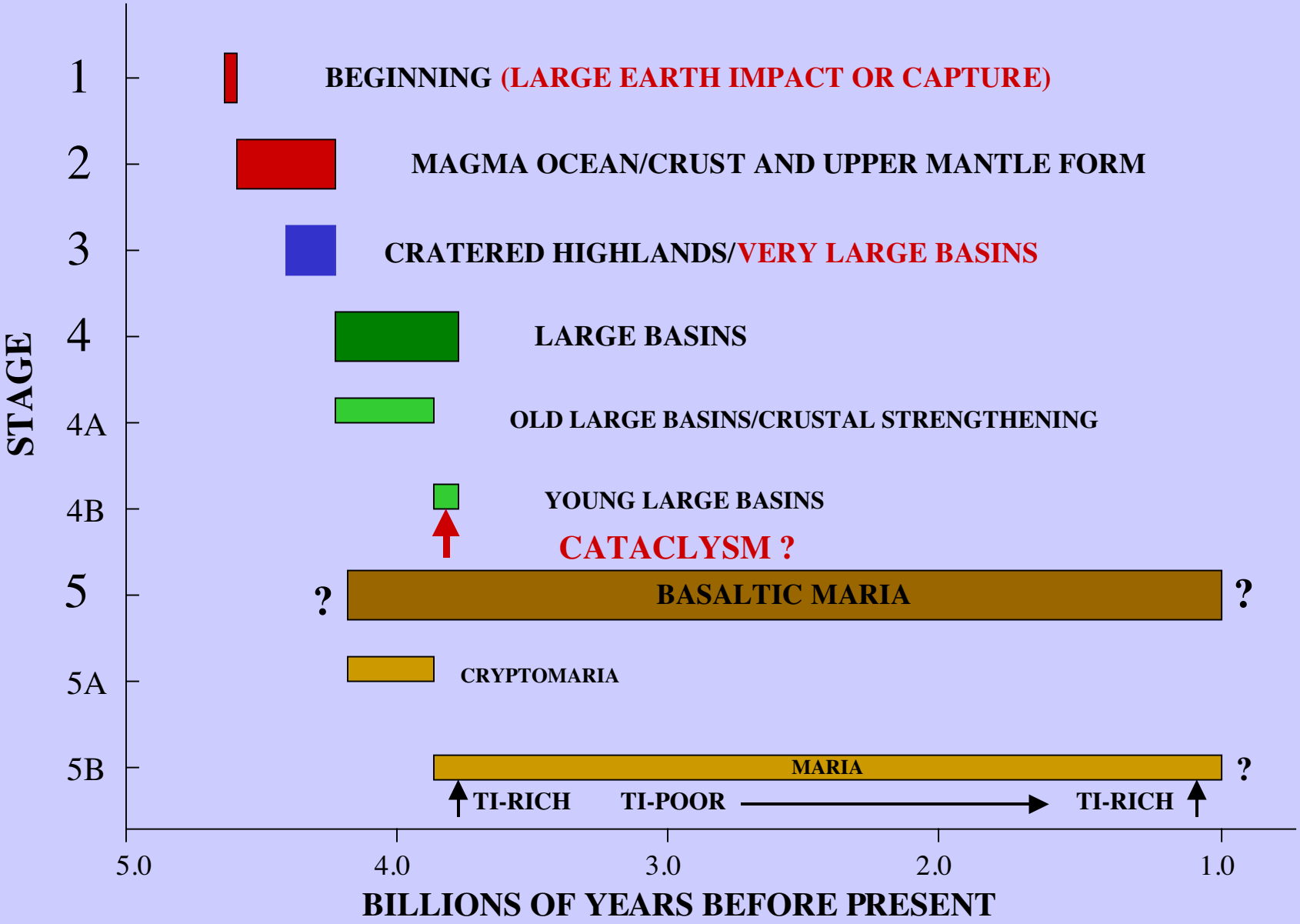
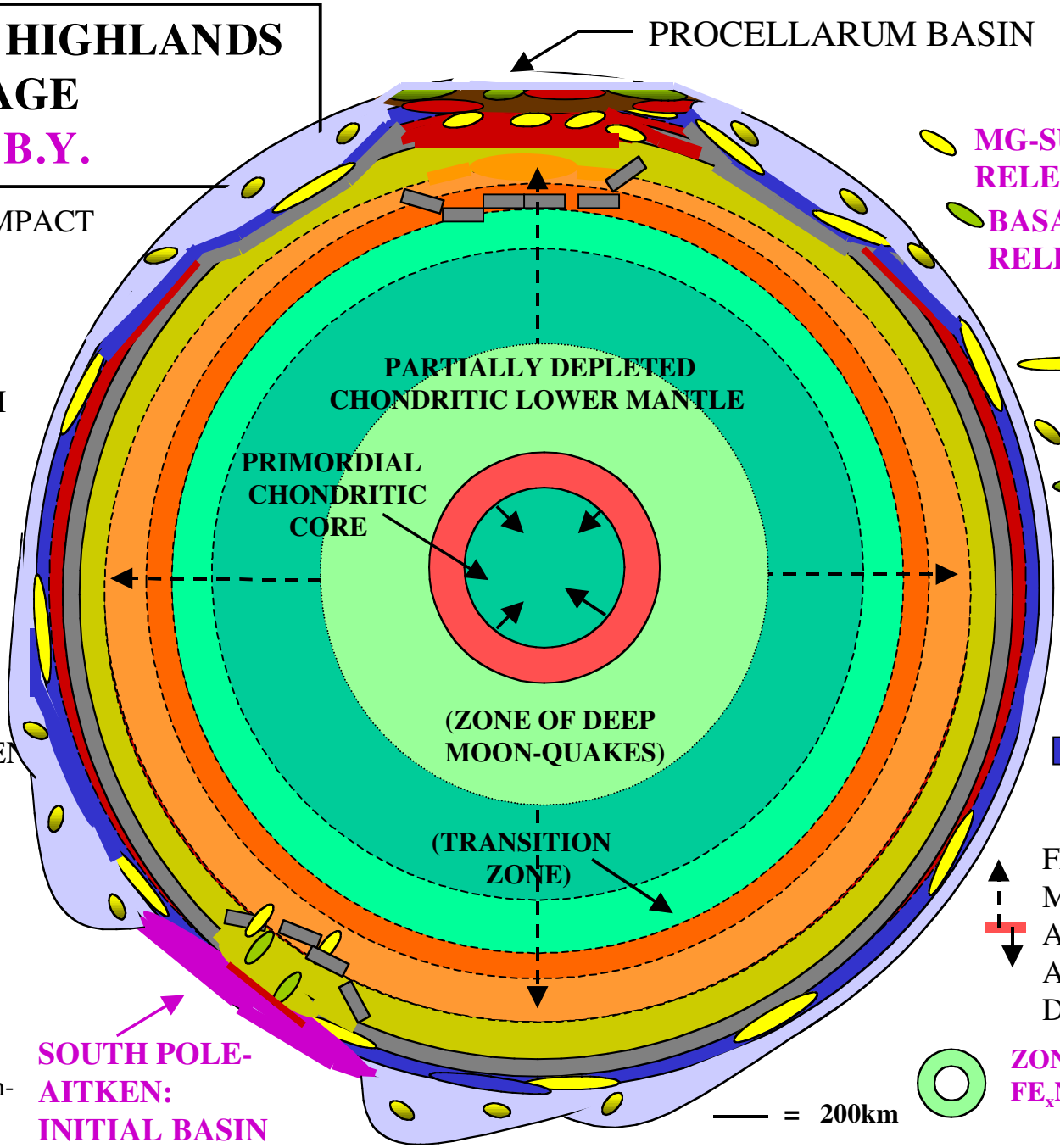
MAJOR STAGES OF LUNAR EVOLUTION



RED = MAJOR UNCERTAINTY

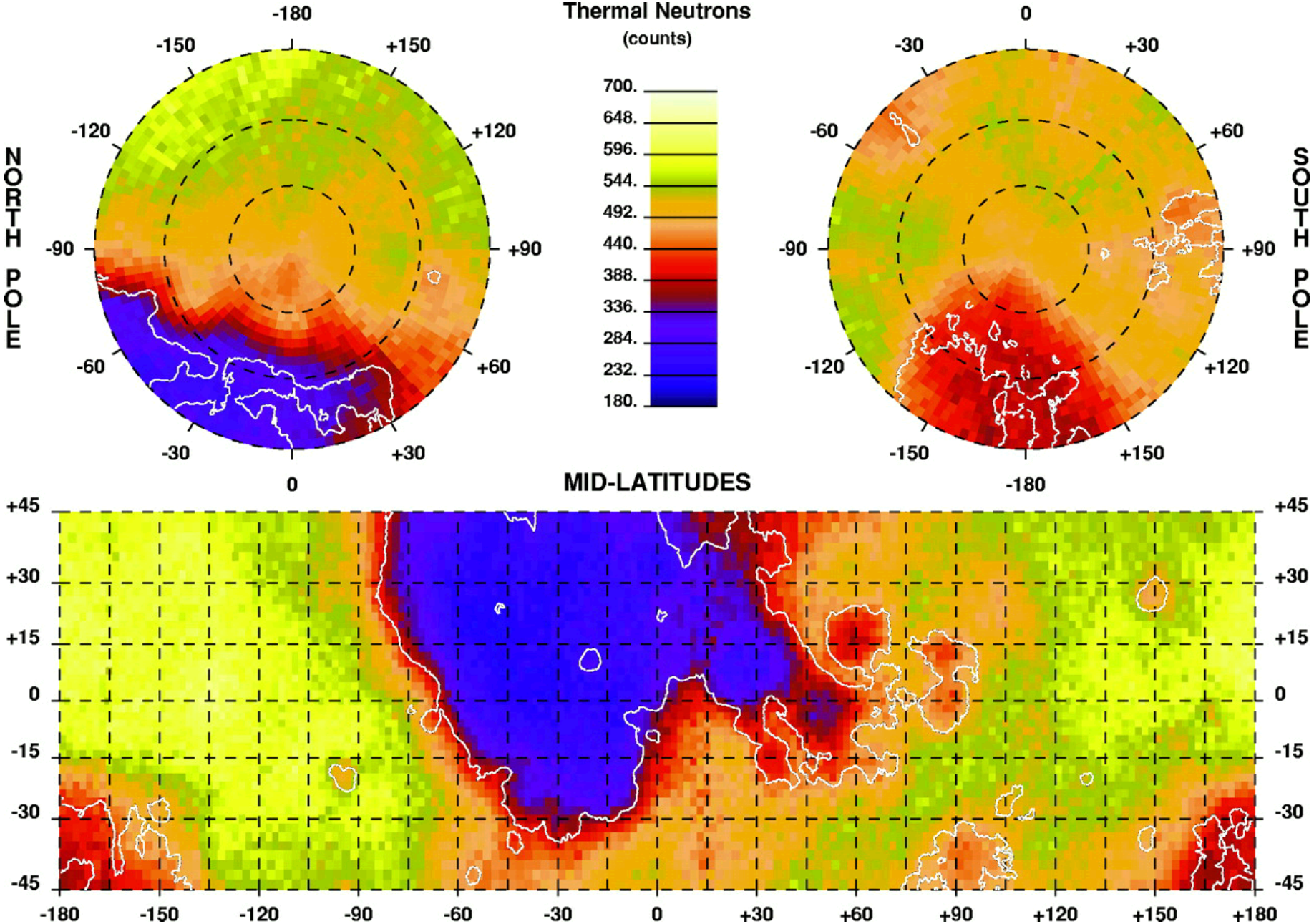
APOLLO MODEL OF LUNAR EVOLUTION

CRATERED HIGHLANDS STAGE
~4.2 B.Y.



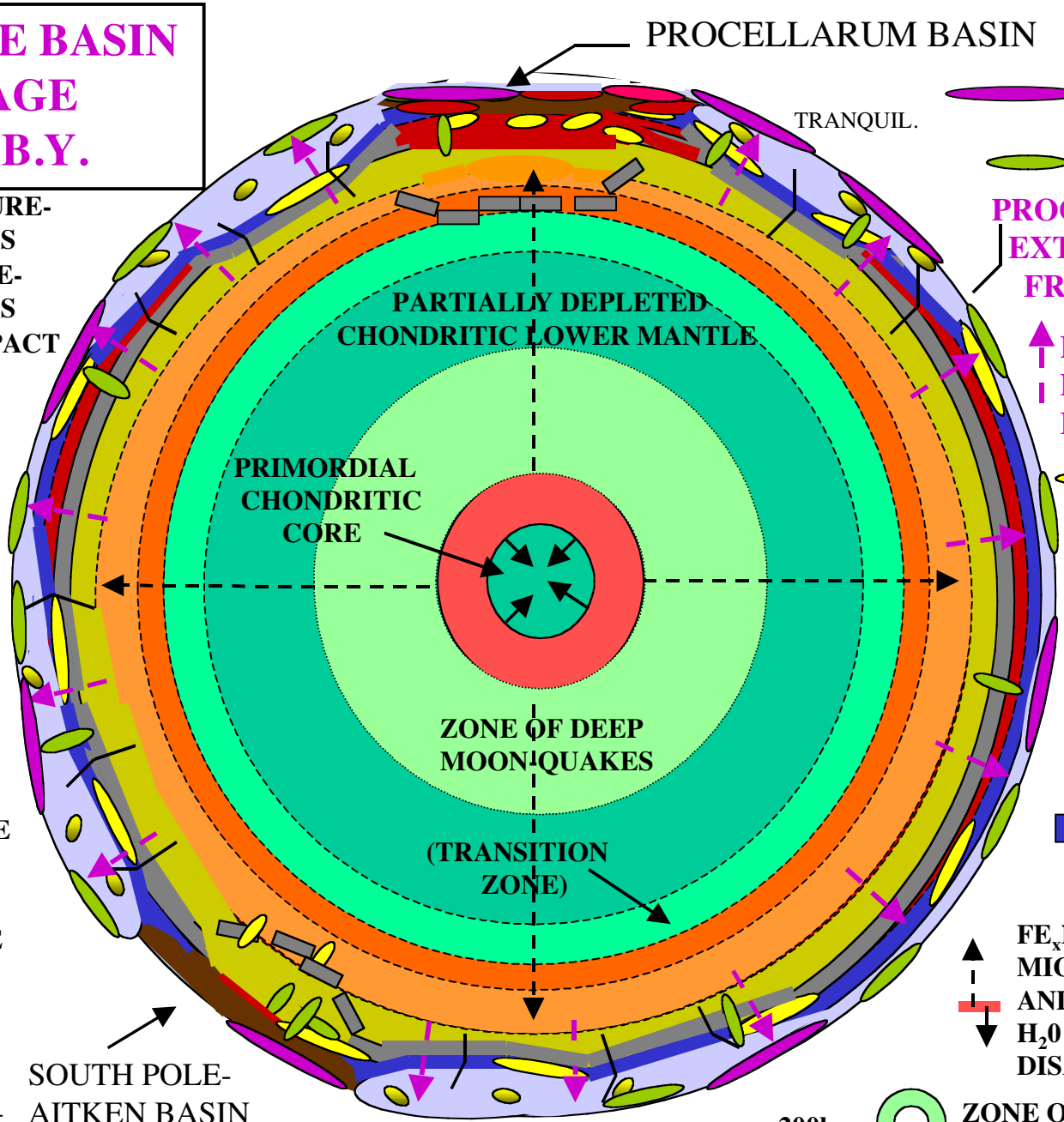
- SOLIDIFIED IMPACT MELT SHEET
- ILMENITE CUMULATE MASSES
- OLIVINE, HIGH CA-PYROXENE, AND ILMENITE CUMULATE
- RESIDUAL URKREEP LIQUID+KREEP BASALTS
- OLIVINE AND HIGH CA-PYROXENE CUMULATE
- OLIVINE AND LOW CA-PYROXENE CUMULATE
- OLIVINE CUMULATE

- MG-SUITE PRESSURE-RELEASE MAGMAS
- BASALT PRESSURE-RELEASE MAGMAS
- MG-SUITE INTRUSIVES
- MG-SUITE DEBRIS
- EARLY KREEPY BASALT EXTRUSIVES
- INSULATING CRATERED HIGHLANDS AND EJECTA
- CONSOLIDATED PLAGIOCLASE CUMULATE
- $FE_xNI_yS_z$ LIQUID MIGRATION AND H MIGRATION AFTER H_20 DISASSOCIATION
- ZONE OF ISOLATED $FE_xNI_yS_z$ LIQUID MASSES


Thermal Neutrons
(counts)
700.
648.
596.
544.
492.
440.
388.
336.
284.
232.
180.
NORTH POLE
SOUTH POLE
-180
-150
+150
-120
+120
-90
+90
-60
+60
-30
+30
0
MID-LATITUDES
+45
+30
+15
0
-15
-30
-45
-180
-150
-120
-90
-60
-30
0
+30
+60
+90
+120
+150
+180

APOLLO MODEL OF LUNAR EVOLUTION

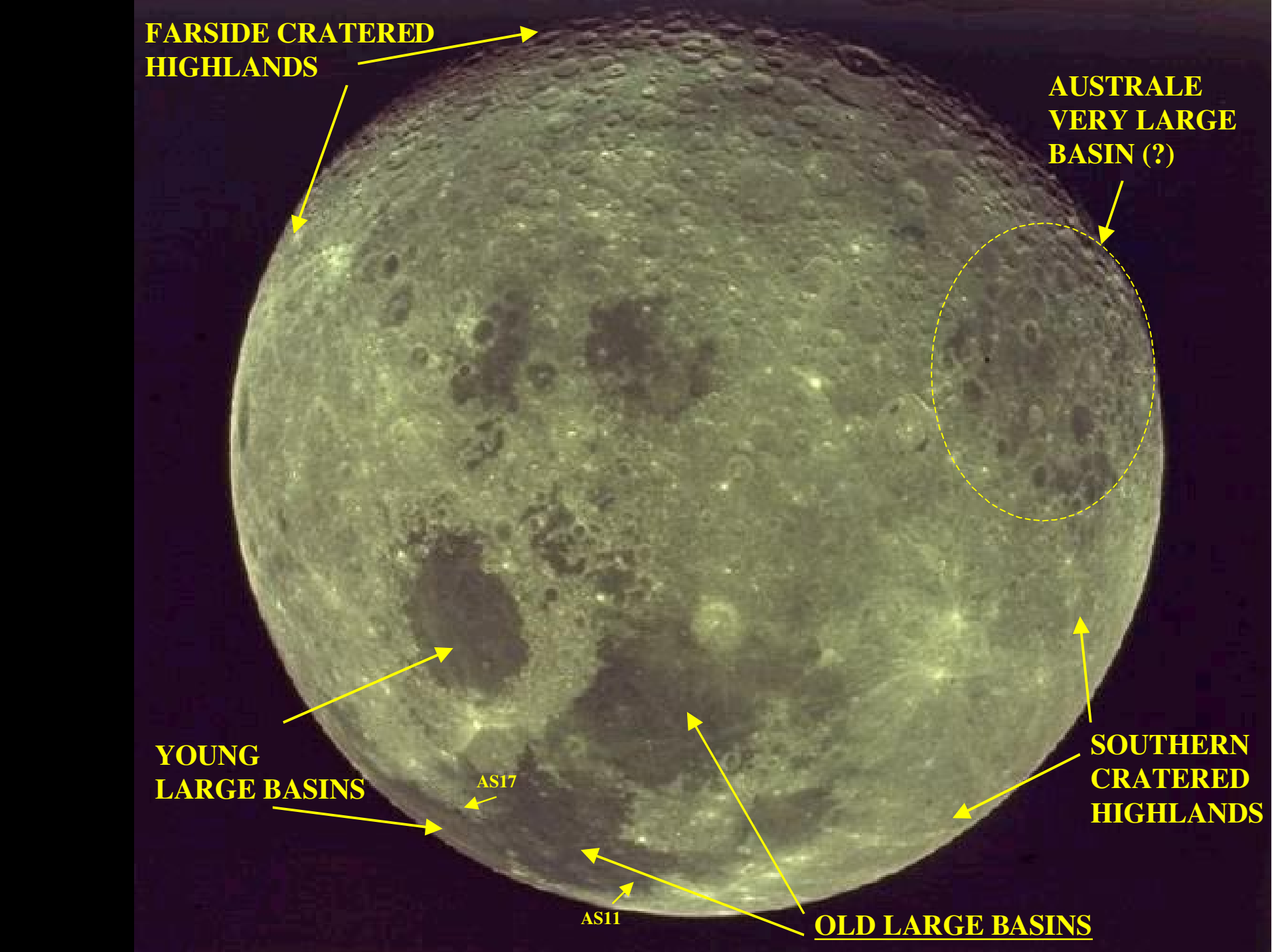
OLD LARGE BASIN SUBSTAGE ~4.2-3.9 B.Y.



- MG-SUITE PRESSURE-RELEASE MAGMAS
- BASALT PRESSURE-RELEASE MAGMAS
- SOLIDIFIED IMPACT MELT SHEET
- ILMENITE CUMULATE MASSES
- OLIVINE, HIGH CA-PYROXENE, AND ILMENITE CUMULATE
- RESIDUAL URKREEP LIQUID+KREEP BASALTS
- OLIVINE AND HIGH CA-PYROXENE CUMULATE
- OLIVINE AND LOW CA-PYROXENE CUMULATE
- OLIVINE CUMULATE

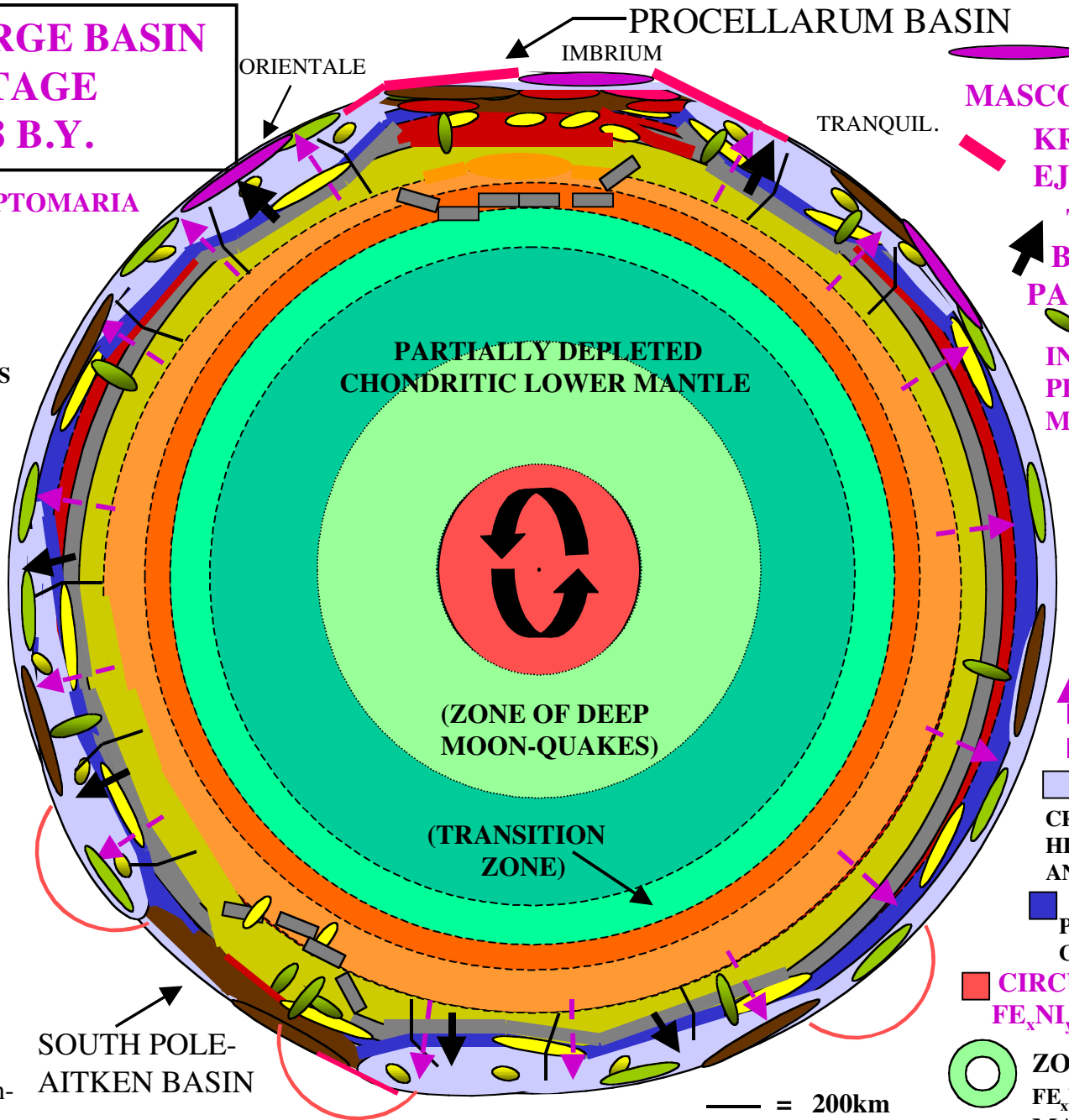
- OLD LARGE BASINS
- CRYPTOMARIA
- PROGRADE THERMAL EXTENSION FRACTURES
- H_2 DRIVEN LIGHT PLAINS DEBRIS ERUPTIONS
- MG-SUITE INTRUSIVES
- MG-SUITE DEBRIS
- LATE KREEP BASALT EXTRUSIVES
- INSULATING CRATERED HIGHLANDS AND EJECTA
- CONSOLIDATED PLAGIOCLASE CUMULATE
- $FE_xNI_yS_z$ LIQUID MIGRATION AND H MIGRATION AFTE H_20 DISASSOCIATION
- = 200km
- ZONE OF ISOLATED $FE_xNI_yS_z$ LIQUID MASSES


OLD LARGE BASINS
IRRECULAR
NO MASCONS
FECUNDITATIS
TRANQUILLITATIS
NORTH
SOUTH


FARSIDE CRATERED HIGHLANDS
AUSTRALE VERY LARGE BASIN (?)
YOUNG LARGE BASINS
AS17
AS11
SOUTHERN CRATERED HIGHLANDS
OLD LARGE BASINS

APOLLO MODEL OF LUNAR EVOLUTION

YOUNG LARGE BASIN SUBSTAGE 3.9-3.8 B.Y.

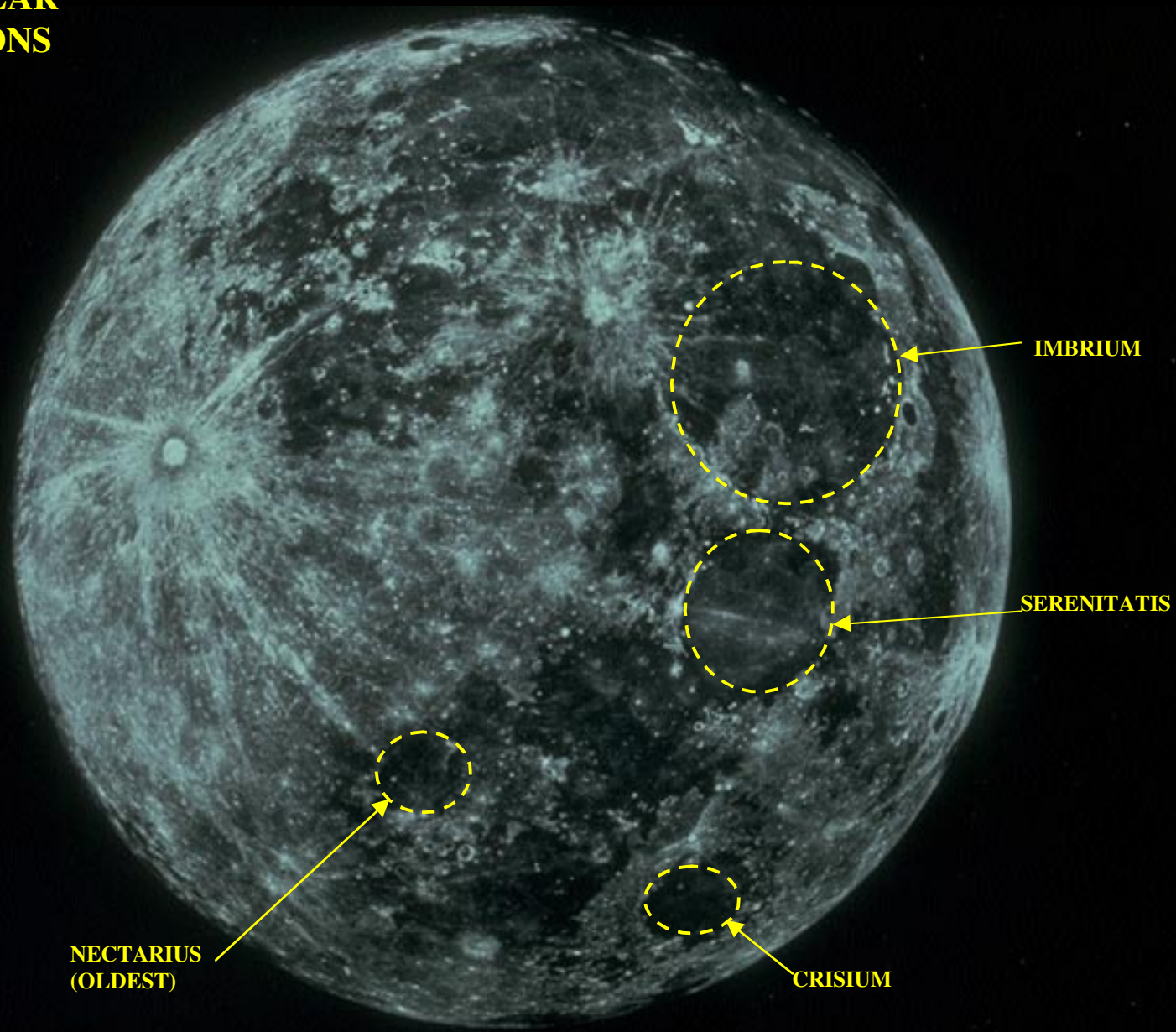


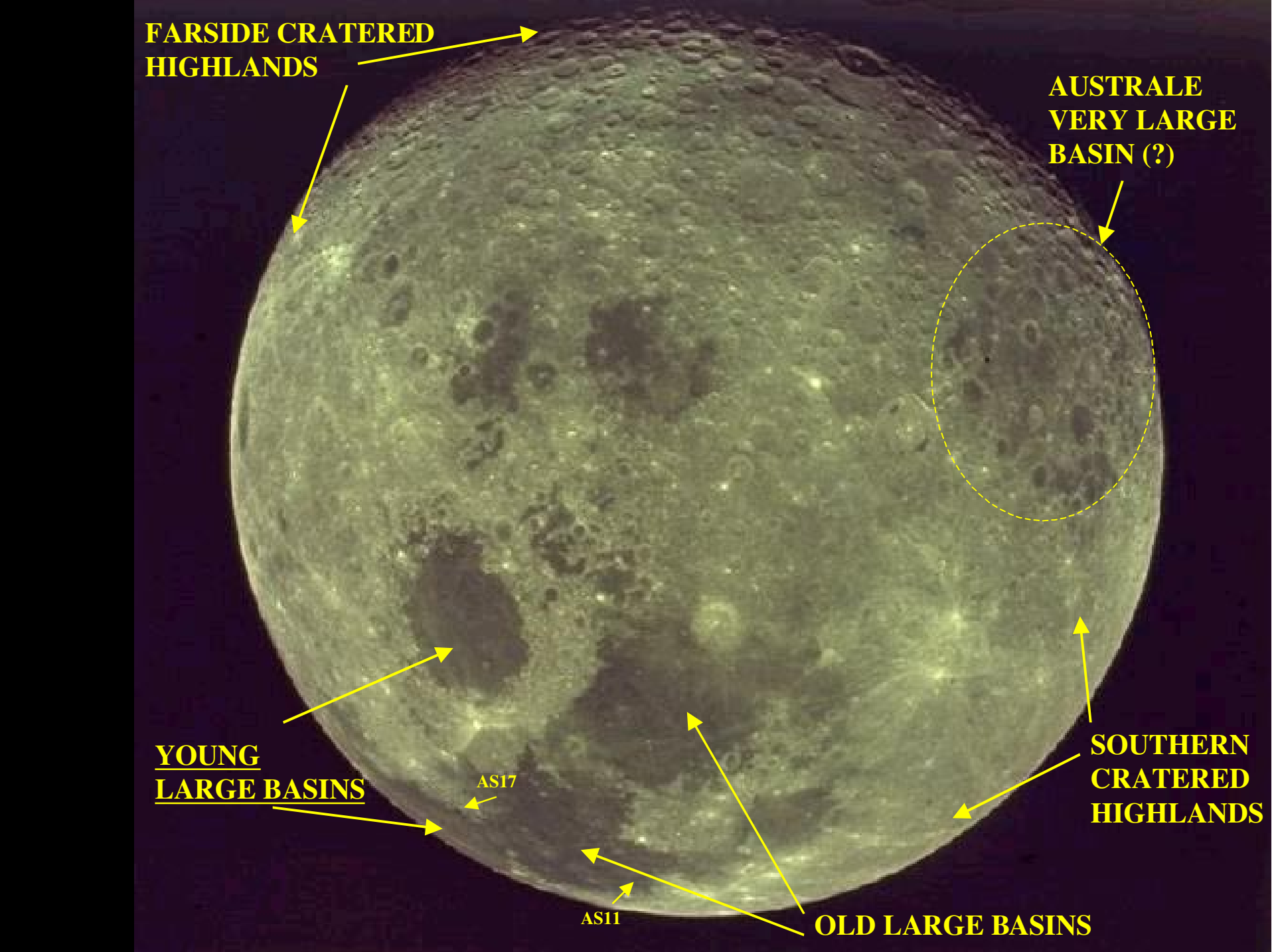
- BURIED CRYPTOMARIA
- KREEPY BASALT EXTRUSIVES
- MG-SUITE INTRUSIVES
- MG-SUITE DEBRIS
- SOLIDIFIED IMPACT MELT SHEET
- ILMENITE CUMULATE MASSES
- OLIVINE, HIGH CA-PYROXENE, AND ILMENITE CUMULATE
- KREEP BASALTS
- OLIVINE AND HIGH CA-PYROXENE CUMULATE
- OLIVINE AND LOW CA-PYROXENE CUMULATE
- OLIVINE CUMULATE

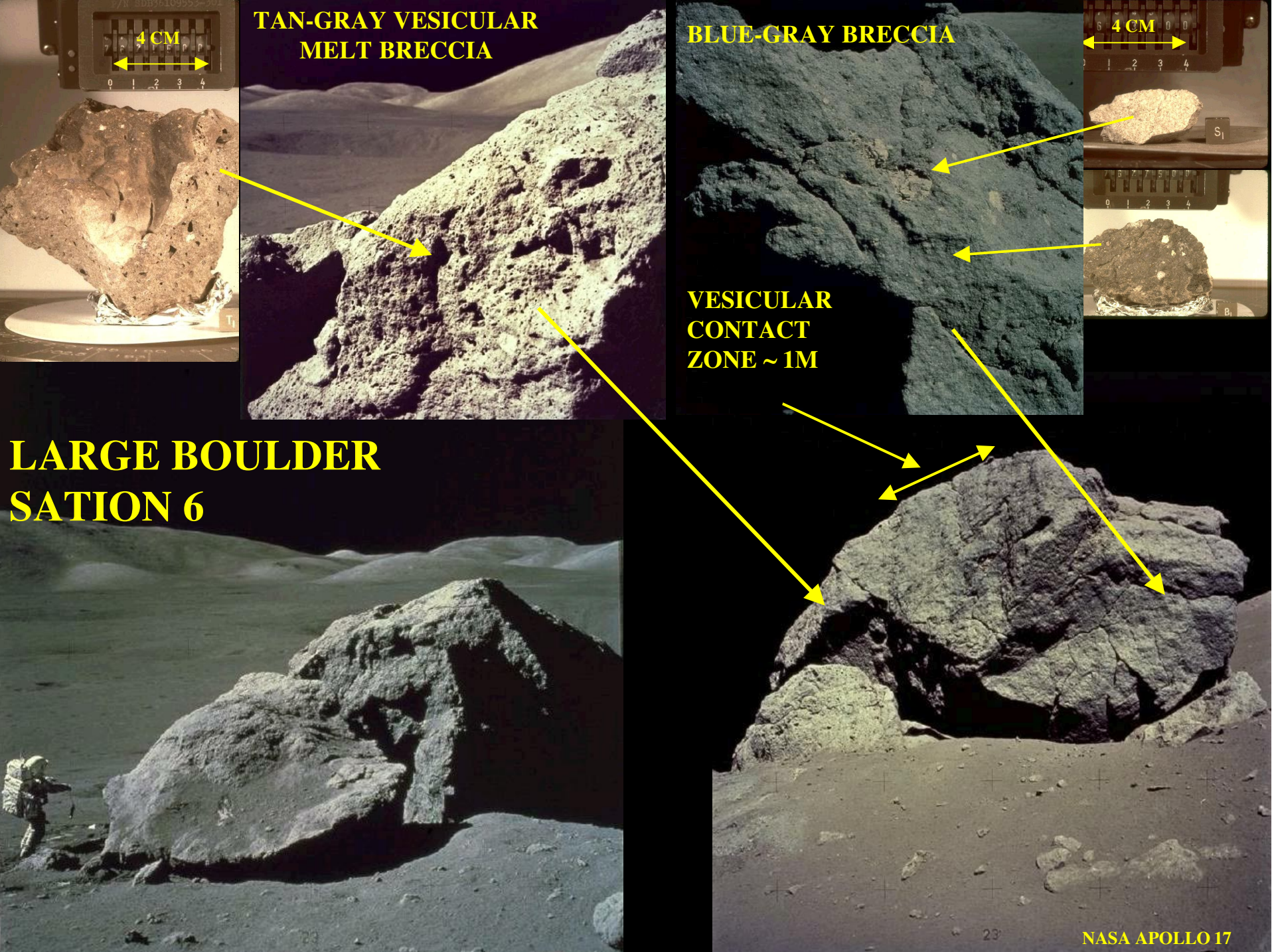
- YOUNG LARGE MASCON BASINS
- KREEPY IMBRIUM EJECTA
- TI-RICH BASALT PARTIAL MELTS
- BASALT INTRUSIONS OF PRESSURE-RELEASE MAGMAS
- PROGRADE THERMAL EXTENSION FRACTURE
- REMANENT MAGNETIC ANOMALY
- H_2 DRIVEN LIGHT PLAINS DEBRIS ERUPTIONS
- INSULATING CRATERED HIGHLANDS AND EJECTA
- CONSOLIDATED PLAGIOCLASE CUMULATE
- CIRCULATING $FE_xNI_yS_z$ LIQUID CORE
- ZONE OF ISOLATED $FE_xNI_yS_z$ LIQUID MASSES

= 200km

YOUNG LARGE BASINS CIRCULAR MASCONS



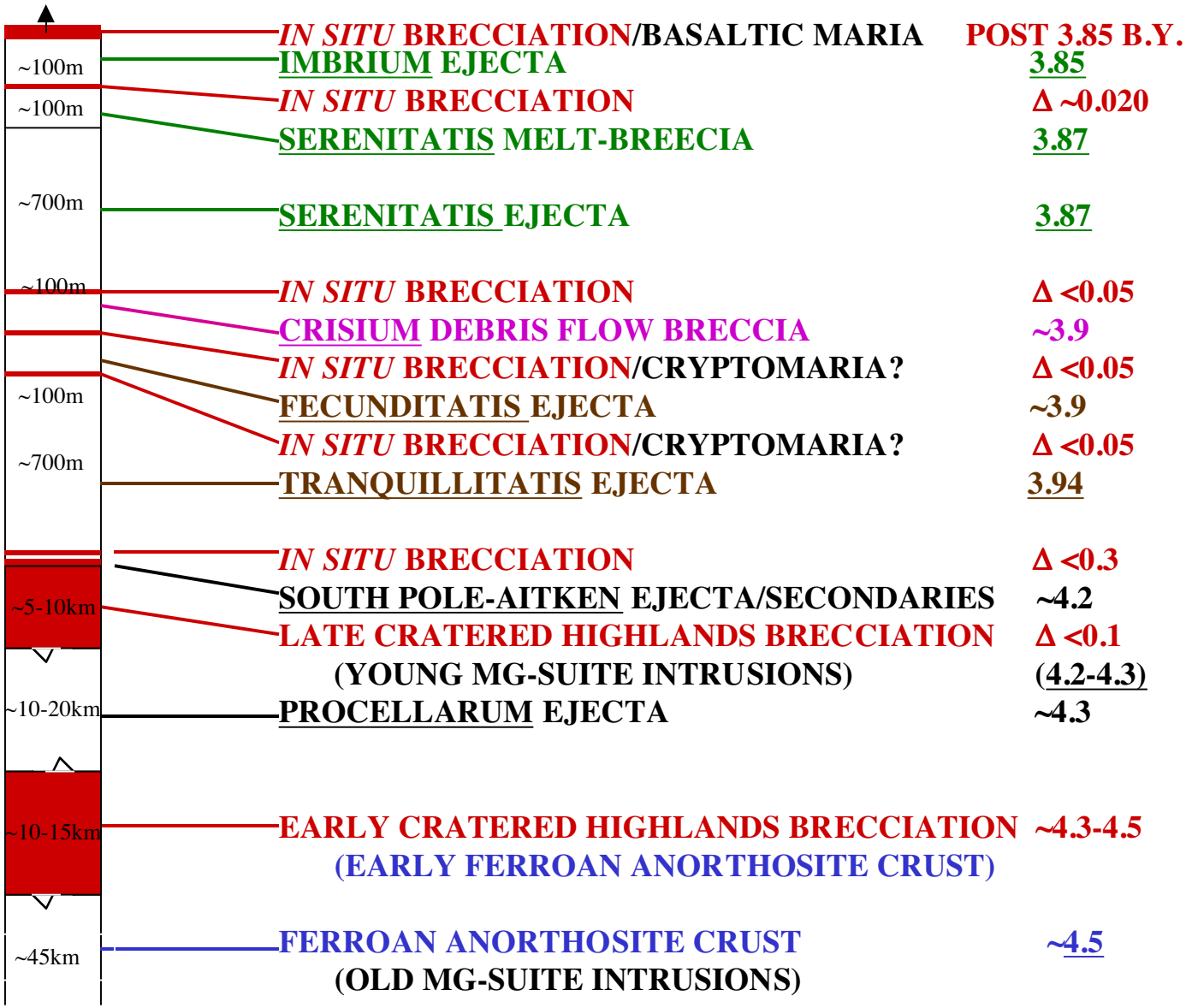

FARSIDE CRATERED HIGHLANDS
AUSTRALE VERY LARGE BASIN (?)
YOUNG LARGE BASINS
AS17
AS11
OLD LARGE BASINS
SOUTHERN CRATERED HIGHLANDS


4 CM
TAN-GRAY VESICULAR
MELT BRECCIA
BLUE-GRAY BRECCIA
4 CM
VESICULAR
CONTACT
ZONE ~ 1M
LARGE BOULDER
SATION 6
NASA APOLLO 17

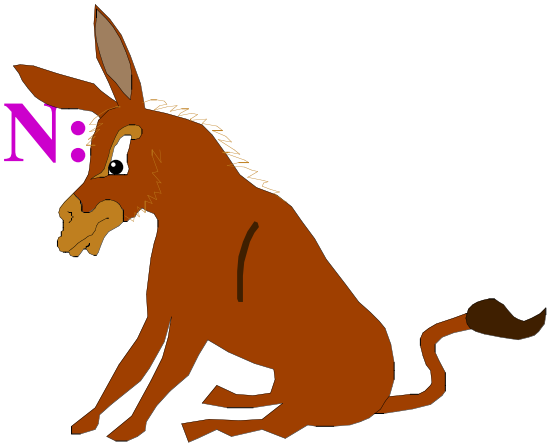
NASA APOLLO 17

PRE-MARE TIME-STRATIGRAPHIC SEQUENCE

VALLEY OF TAURUS-LITTROW



LUNAR ORIGIN AND EVOLUTION: STANDARD HYPOTHESIS - 2



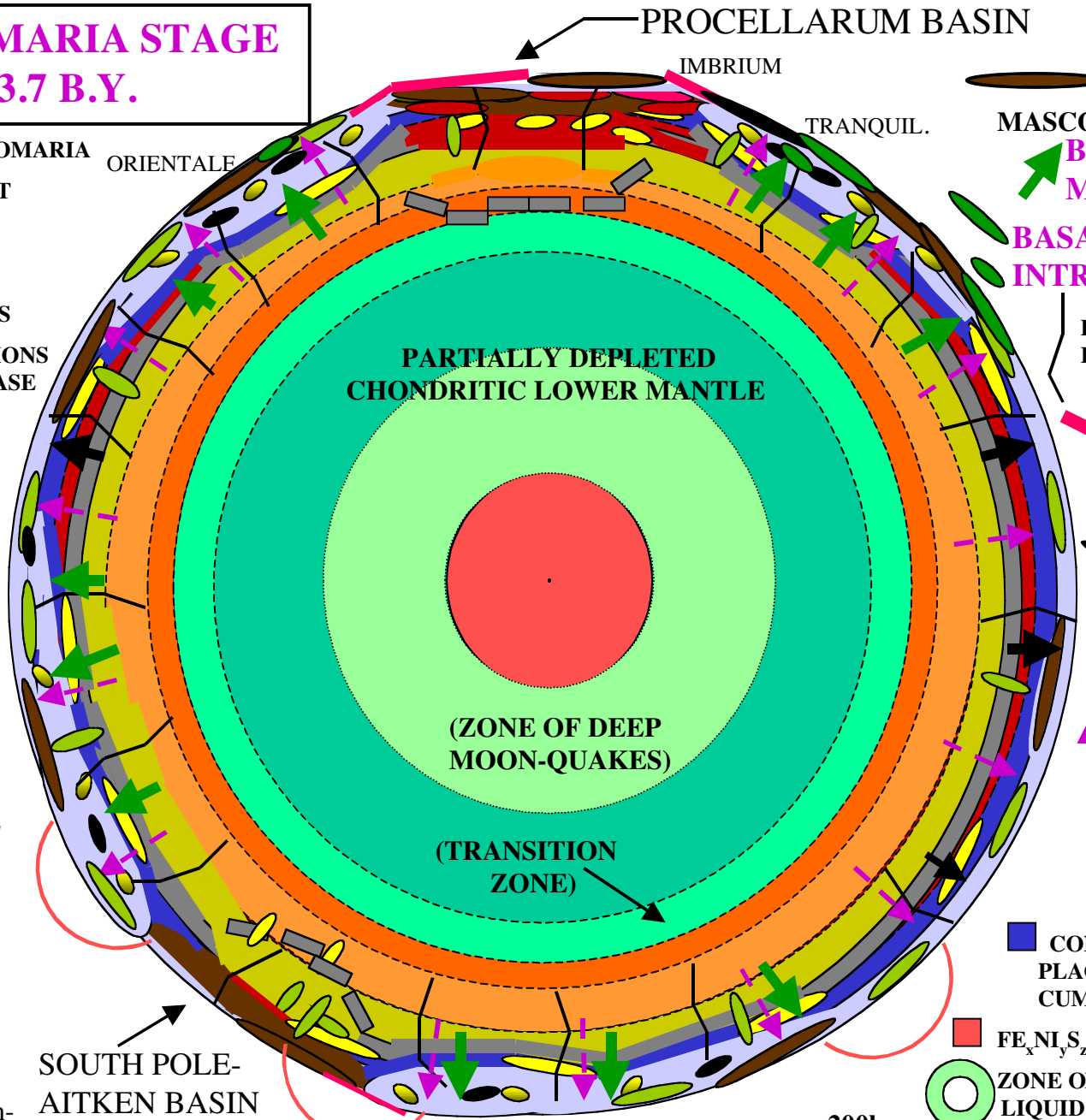
- **BASALTIC MAGMATIC ACTIVITY**
  - **MG-SUITE OF PLUTONIC ROCKS (4.5-4.2 B.Y.)**
  - **KREEP-RICH BASALTIC LAVAS (4.3-? B.Y.)**
  - **CRYPTOMARIA (PRE 3.9 B.Y.)**
- **LUNAR CATACLYSM (~3.9 B.Y.)**
  - **~50 LARGE BASINS IN ~100 M.Y.**
  - **ONE EXTREMELY LARGE BASIN (SOUTH POLE-AITKEN)**
    - **PROCELLARUM BASIN IS ARTIFACT OF SEVERAL BASINS**
  - **AGES OF IMPACT GLASSES RESET TO ~3.9 B.Y.**
- **GLOBAL MAGNETIC FIELD**
  - **AT LEAST BETWEEN 3.9 AND 3.8 B.Y.**

SOURCE OF LARGE IMPACTORS

- **DISCRETE SOURCE**
  - APPEARED AFTER ACCRETIONARY RESERVOIR OF CRATERED HIGHLANDS IMPACTORS BECAME DEPLETED
- **SOURCES TO CONSIDER**
  - PROTO-KUIPER BELT (450+ OBJECTS)
    - INTERACTION OF MISSING LARGE BODIES WITH GAS GIANTS
  - ÖORT CLOUD
    - INTERACTION WITH STELLAR BODY
  - MAIN BELT ASTEROIDS
    - JUPITER-INDUCED EXPULSION

APOLLO MODEL OF LUNAR EVOLUTION

BASALTIC MARIA STAGE 3.8-3.7 B.Y.



BURIED CRYPTOMARIA

KREEPY BASALT EXTRUSIVES

MG-SUITE INTRUSIVES

MG-SUITE DEBRIS

BASALT INTRUSIONS OF PRESSURE-RELEASE MAGMAS

SOLIDIFIED IMPACT MELT SHEET

ILMENITE CUMULATE MASSES

OLIVINE, HIGH CA-PYROXENE, AND ILMENITE CUMULATE

KREEP BASALTS

OLIVINE AND HIGH CA-PYROXENE CUMULATE

OLIVINE AND LOW CA-PYROXENE CUMULATE

OLIVINE CUMULATE

YOUNG LARGE MASCON BASINS

BASALT PARTIAL MELTS

BASALT EXTRUSION/ INTRUSION

PROGRADE THERMAL EXTENSION FRACTURE

KREEPY IMBRIUM EJECTA

TI-RICH BASALT PARTIAL MELTS

TI-BASALT EXTRUSION/ INTRUSION

REMANENT MAGNETIC ANOMALY

H_2 MIGRATION

INSULATING CRATERED HIGHLANDS AND EJECTA

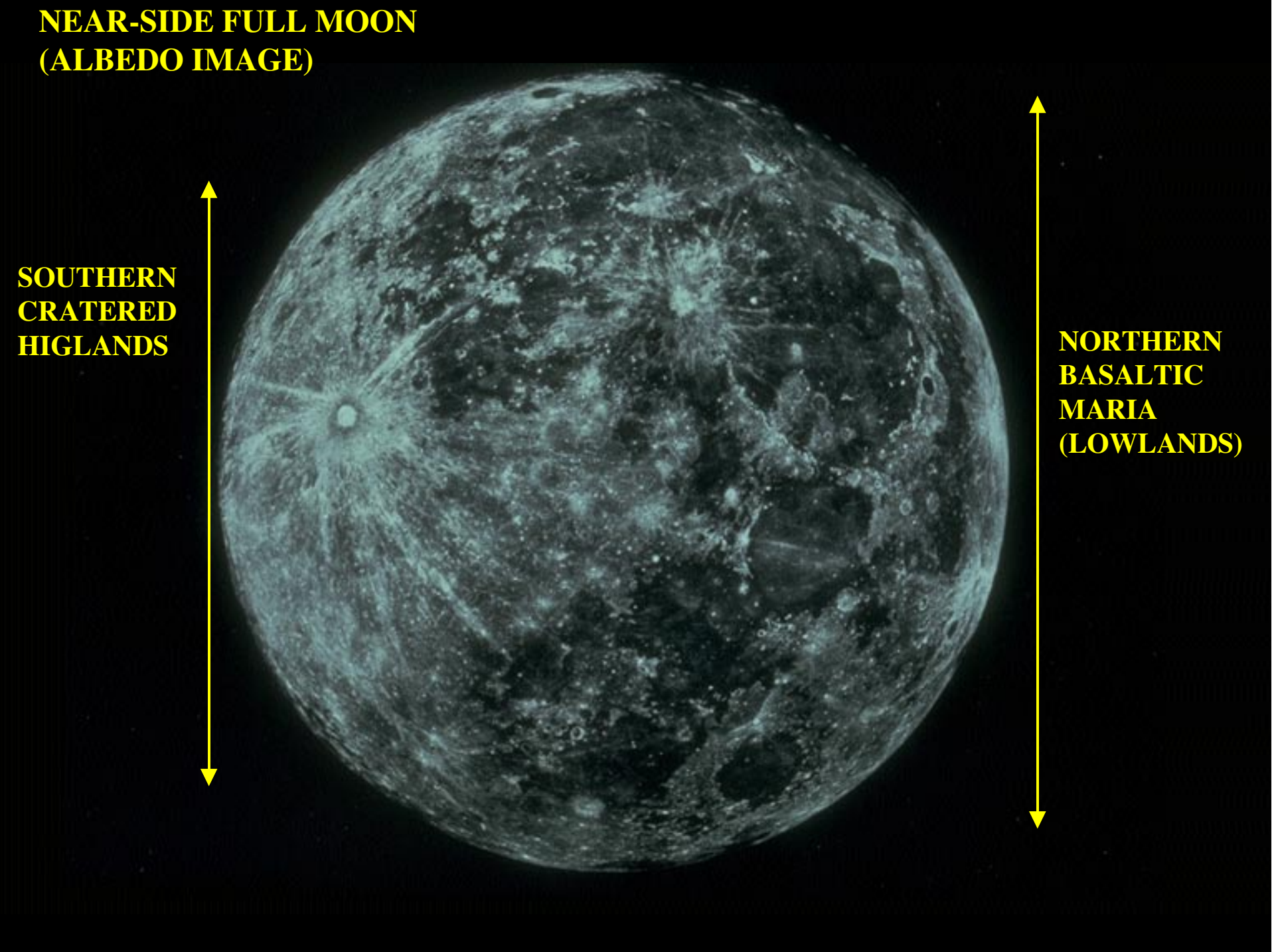
CONSOLIDATED PLAGIOCLASE CUMULATE

$FE_xNI_yS_z$ LIQUID CORE

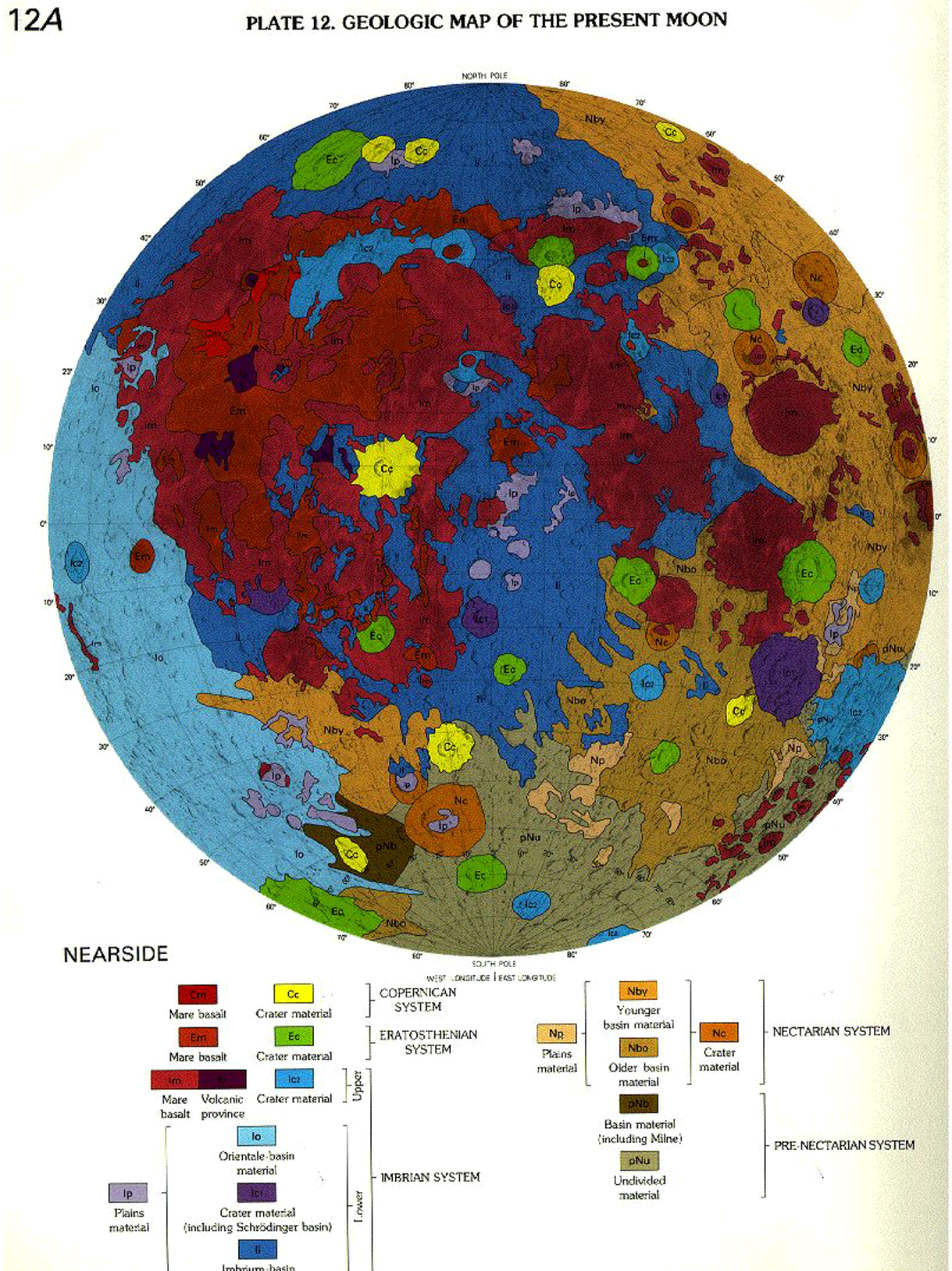
ZONE OF ISOLATED $FE_xNI_yS_z$ LIQUID MASSES

= 200km

NEAR-SIDE FULL MOON
(ALBEDO IMAGE)



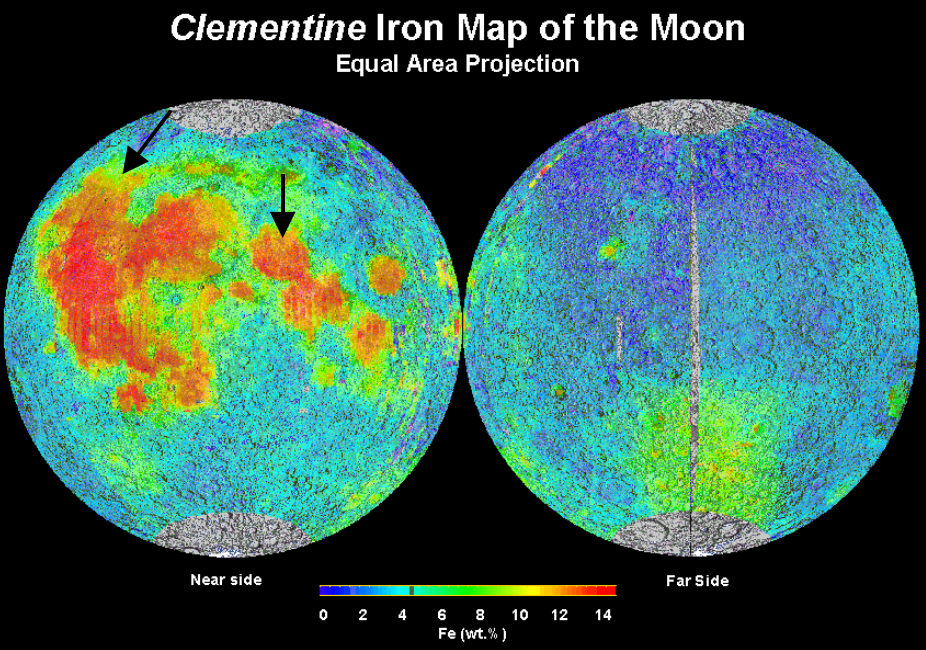
MAJOR BASALTIC MARIA UNITS MAPPED BY THE USGS.

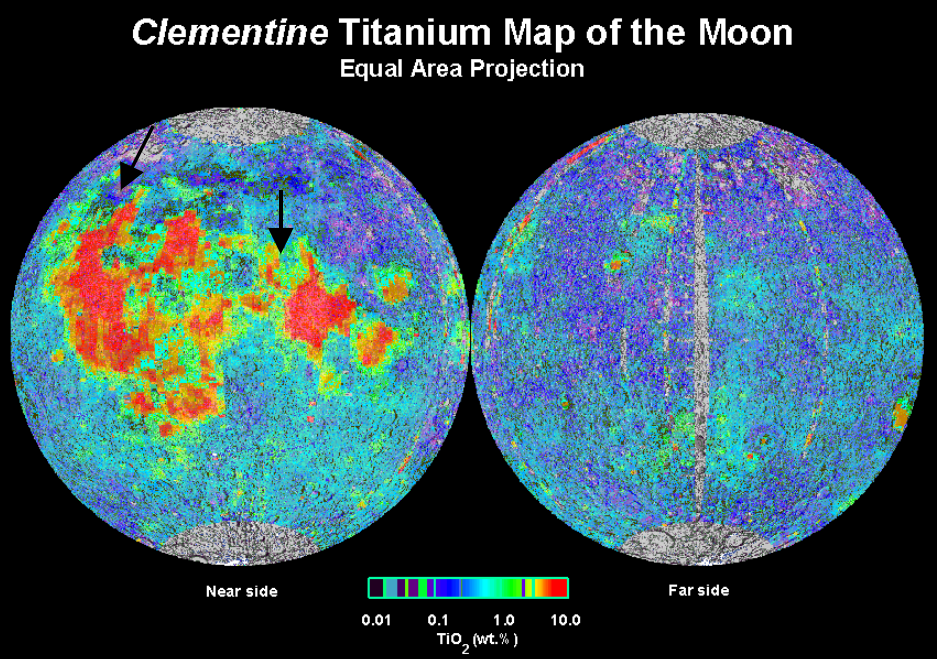


WILHELMS, 1984

DISTRIBUTION OF BASALTIC MARIA

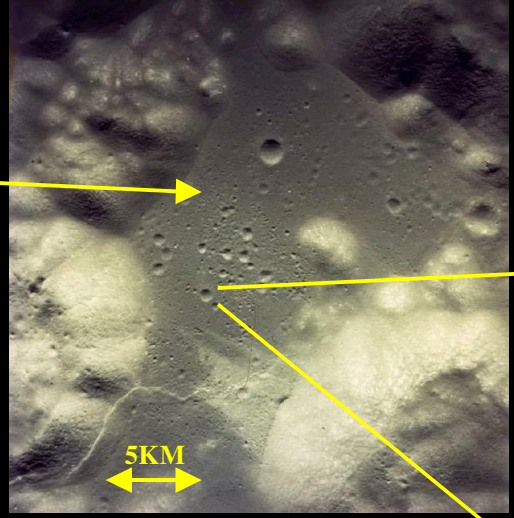
SHOWN BY IRON DISTRIBUTION (LEFT)
CONTRAST WITH VARIABILITY OF TITANIUM DISTRIBUTION
(ARROWS INDICATE DIFFERENCE IN SERENITATIS MARIA AND NORTERN OCEANUS PROCELLARUM)



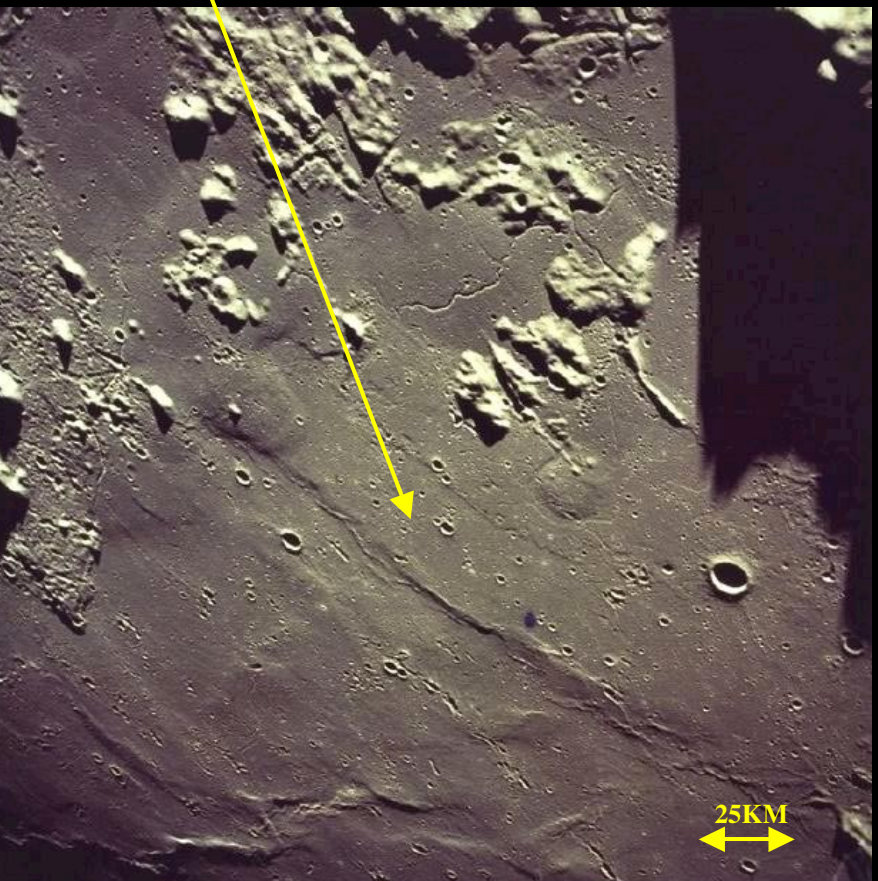


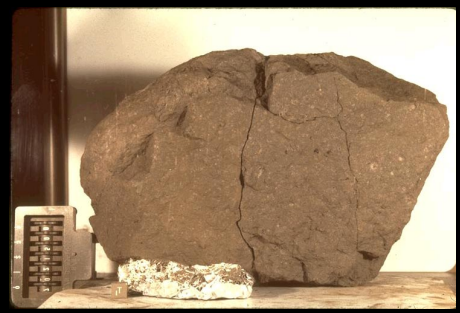
BASALTIC MARIA

TAURUS LITTROW MARE



EASTERN IMBRIAN MARE

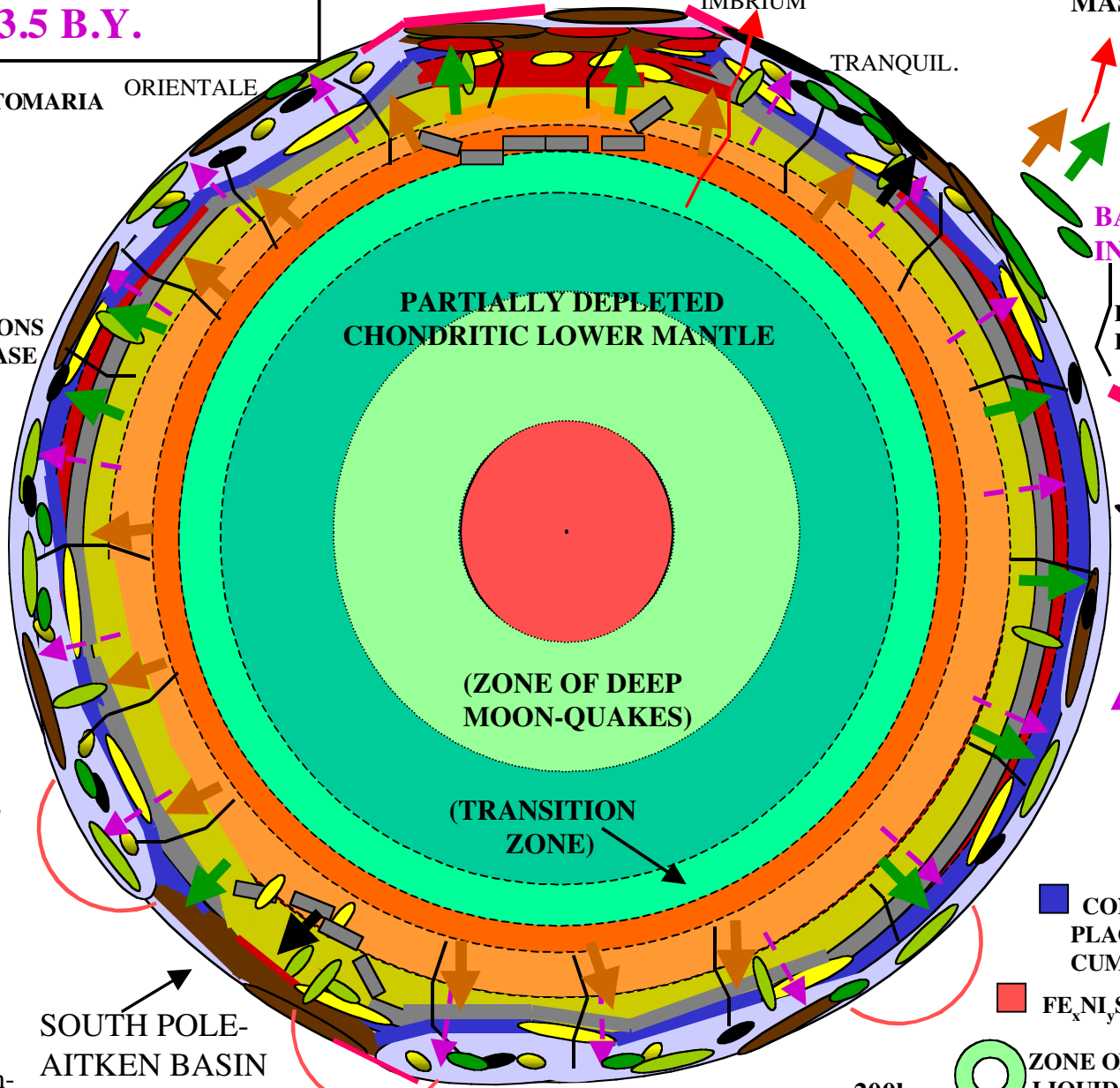




MARE BASALT TEXTURES

APOLLO MODEL OF LUNAR EVOLUTION

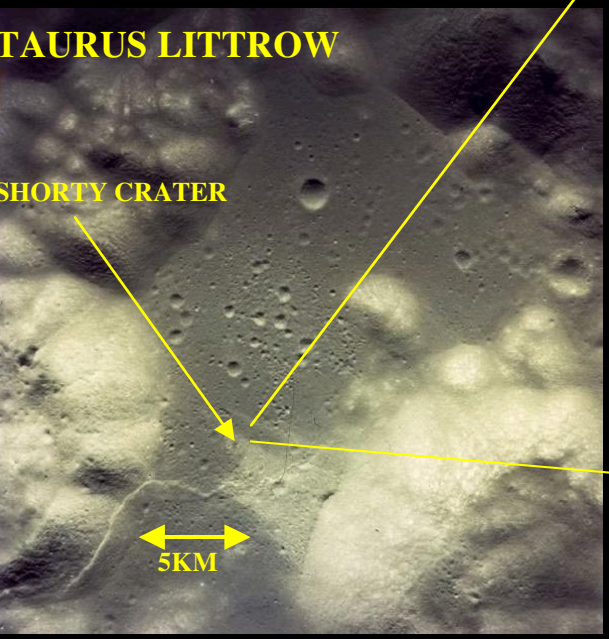
BASALTIC MARIA STAGE
3.7-3.5 B.Y.

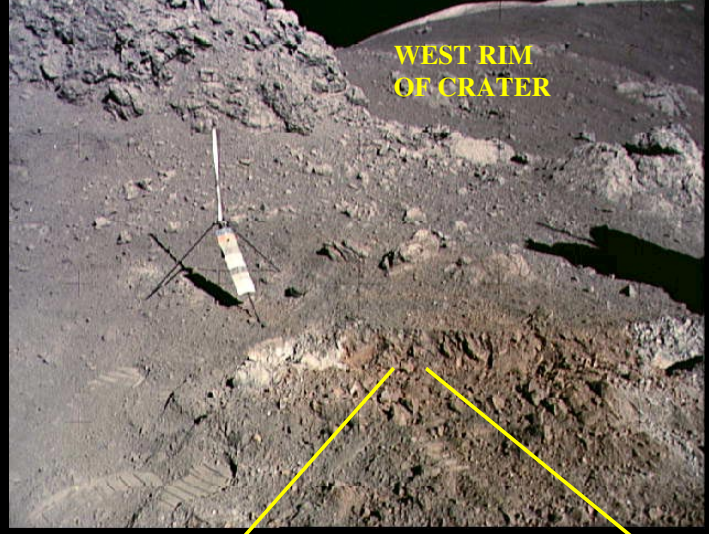


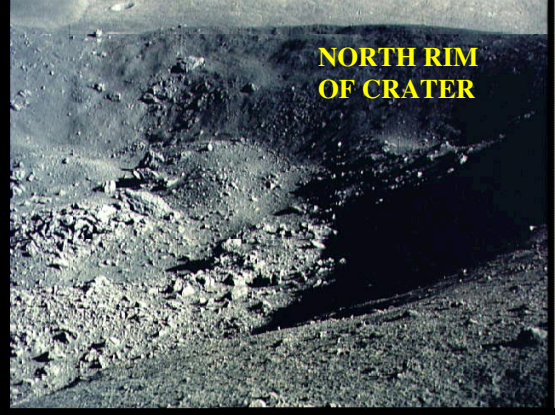
- BURIED CRYPTOMARIA
- KREEPY BASALT EXTRUSIVES
- MG-SUITE INTRUSIVES
- MG-SUITE DEBRIS
- BASALT INTRUSIONS OF PRESSURE-RELEASE MAGMAS
- SOLIDIFIED IMPACT MELT SHEET
- ILMENITE CUMULATE MASSES
- OLIVINE, HIGH CA-PYROXENE, AND ILMENITE CUMULATE
- KREEP BASALTS
- OLIVINE AND HIGH CA-PYROXENE CUMULATE
- OLIVINE AND LOW CA-PYROXENE CUMULATE
- OLIVINE CUMULATE

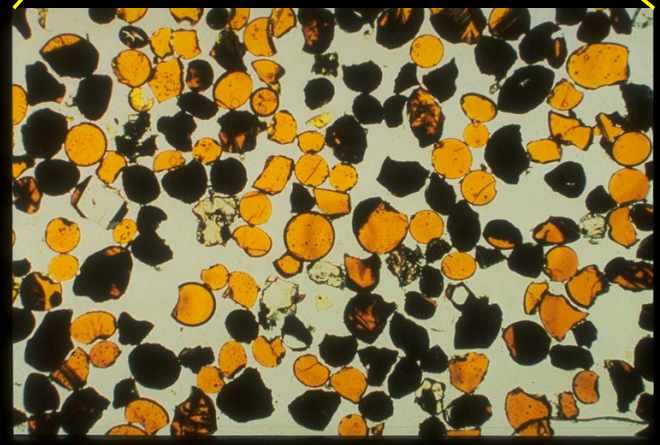
- YOUNG LARG MASCON BASINS
- PYROCLASTIC ERUPTIONS
- BASALT PARTIAL MELTS
- BASALT EXTRUSION/ INTRUSION
- PROGRADE THERMAL EXTENSION FRACTURE
- KREEPY IMBRIUM EJECTA
- TI-RICH BASALT PARTIAL MELTS
- TI-BASALT EXTRUSION/ INTRUSION
- REMANENT MAGNETIC ANOMALY
- H_2 MIGRATION
- INSULATING CRATERED HIGHLANDS AND EJECTA
- CONSOLIDATED PLAGIOCLASE CUMULATE
- $FE_xNI_yS_z$ LIQUID CORE
- ZONE OF ISOLATED $FE_xNI_yS_z$ LIQUID MASSES

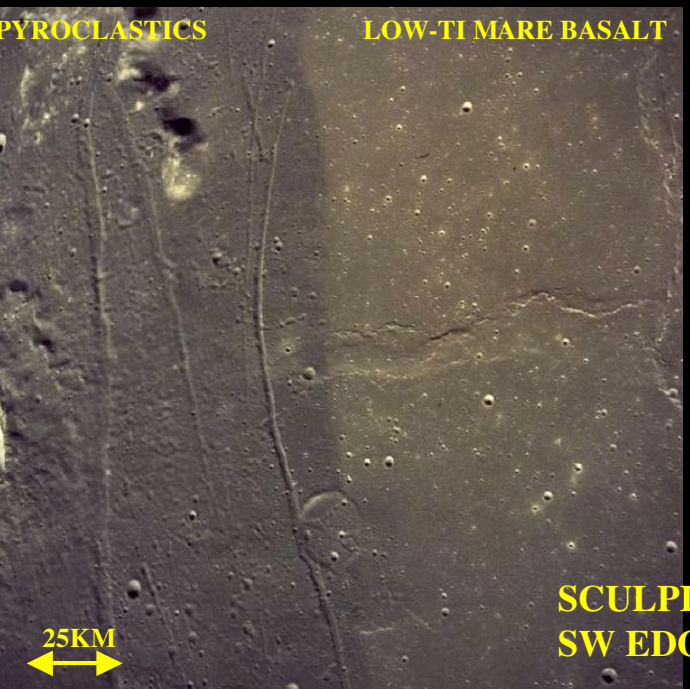
—— = 200km









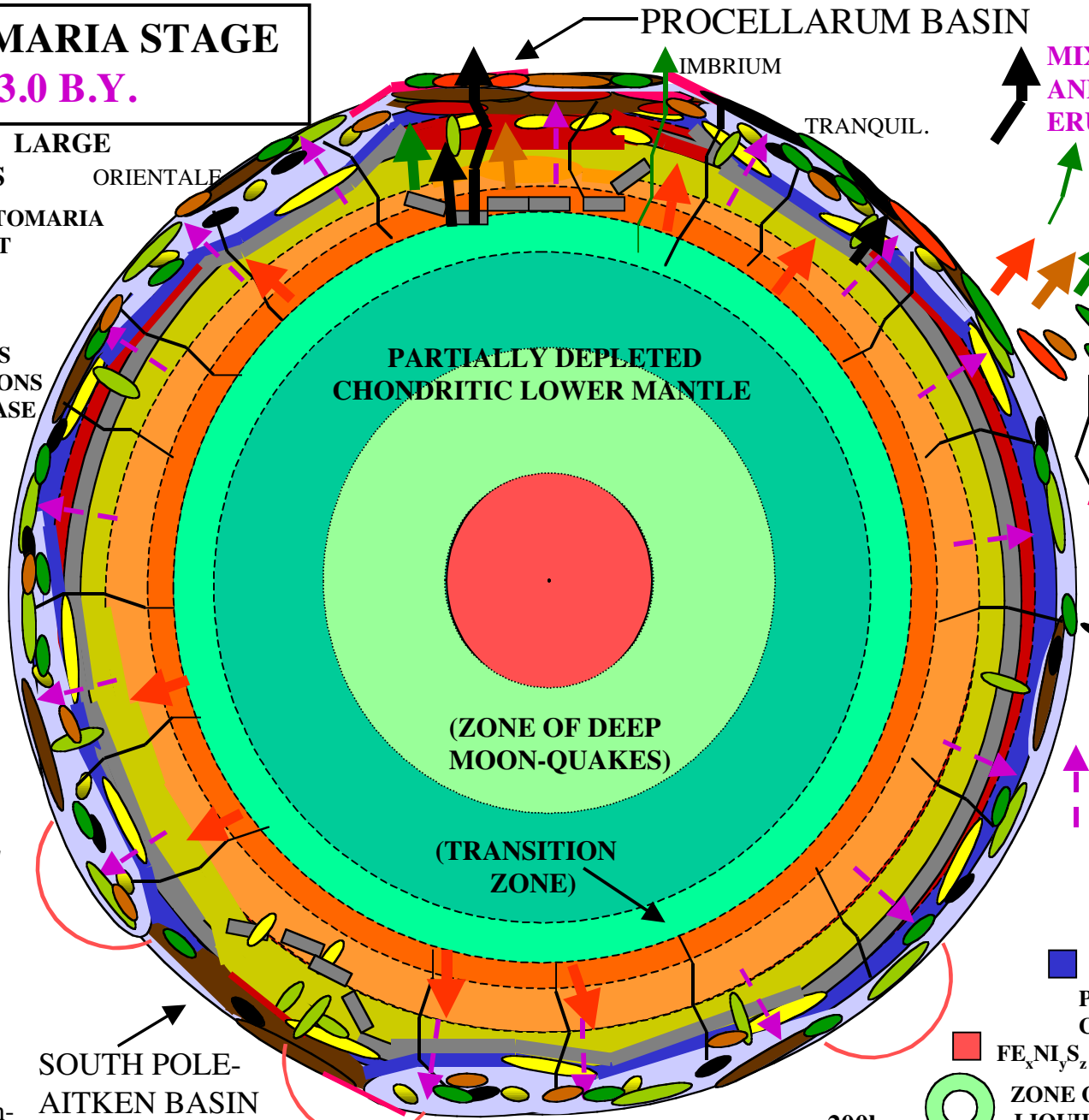


SCULPICCIUS GALLES REGION
SW EDGE SERENITATIS BASIN

PYROCLASTIC GLASS DEPOSITS

APOLLO MODEL OF LUNAR EVOLUTION

BASALTIC MARIA STAGE
3.5-3.0 B.Y.



YOUNG LARGE MASCON BASINS

BURIED CRYPTOMARIA

KREEPY BASALT EXTRUSIVES

MG-SUITE INTRUSIVES

MG-SUITE DEBRIS

BASALT INTRUSIONS OF PRESSURE-RELEASE MAGMAS

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ILMENITE CUMULATE MASSES

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OLIVINE AND HIGH CA-PYROXENE CUMULATE

OLIVINE AND LOW CA-PYROXENE CUMULATE

OLIVINE CUMULATE

MIXED PYROCLASTIC AND LAVA ERUPTIONS

PYROCLASTIC ERUPTIONS

BASALT PARTIAL MELTS

BASALT EXTRUSION/ INTRUSION

PROGRADE THERMAL EXTENSION FRACTURE

KREEPY IMBRIUM EJECTA

TI-RICH BASALT PARTIAL MELTS

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REMANENT MAGNETIC ANOMALY

H_2 MIGRATION

INSULATING CRATERED HIGHLANDS AND EJECTA

CONSOLIDATED PLAGIOCLASE CUMULATE

$FE_xNI_yS_z$ LIQUID CORE

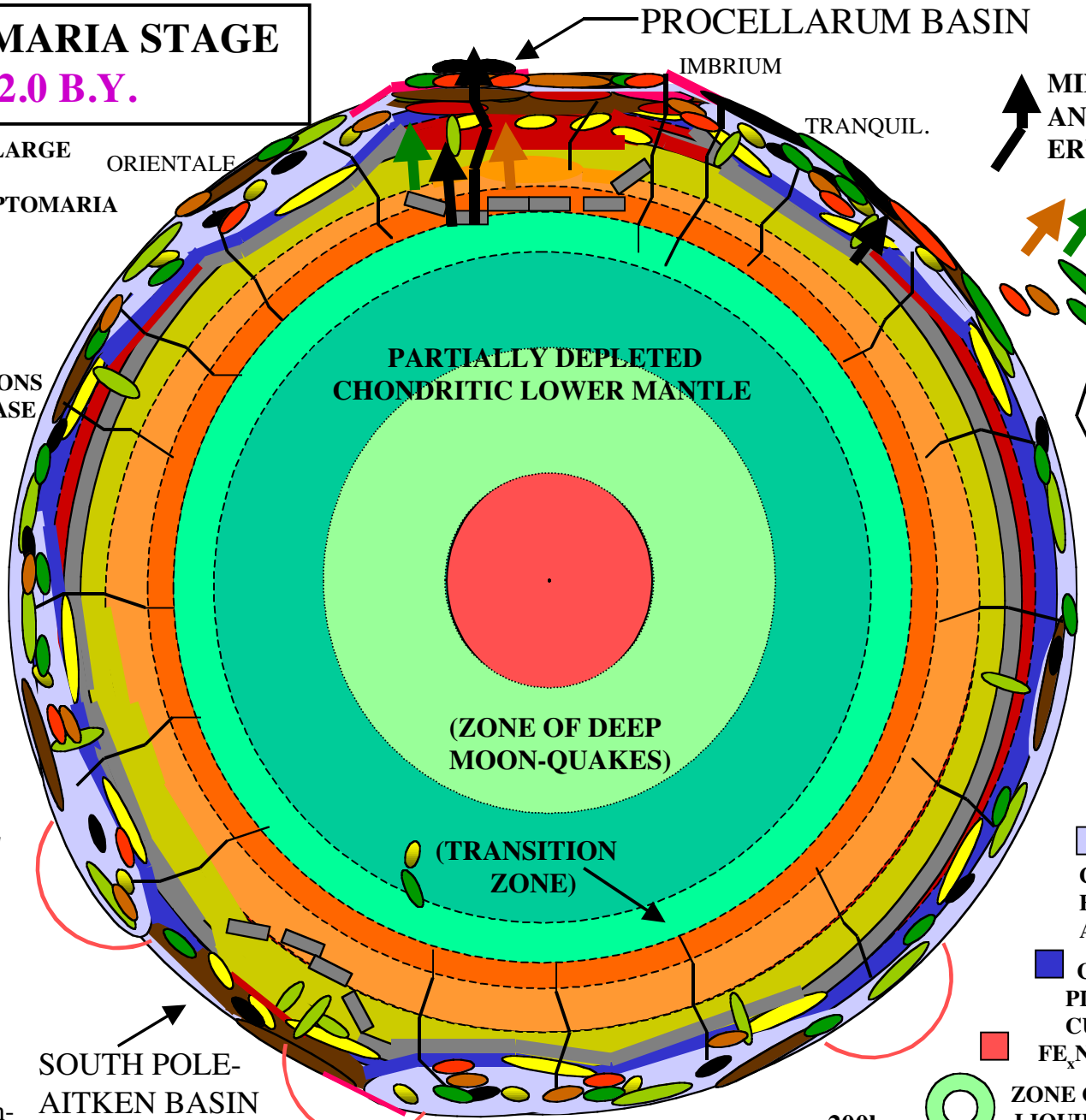
ZONE OF ISOLATED $FE_xNI_yS_z$ LIQUID MASSES

—— = 200km

University of Wisconsin-Madison

APOLLO MODEL OF LUNAR EVOLUTION

BASALTIC MARIA STAGE
3.0-2.0 B.Y.



- YOUNG LARGE MASCON BASINS
- BURIED CRYPTOMARIA
- KREEPY BASALT EXTRUSIVES
- MG-SUITE INTRUSIVES
- MG-SUITE DEBRIS
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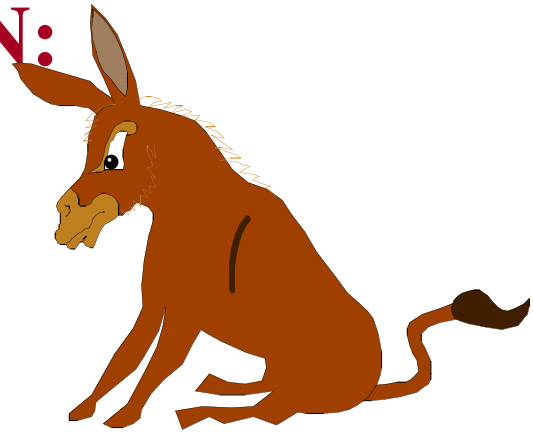
- OLIVINE AND LOW CA-PYROXENE CUMULATE
- OLIVINE CUMULATE

- MIXED PYROCLASTIC AND LAVA ERUPTIONS
- BASALT PARTIAL MELTS
- BASALT EXTRUSION/ INTRUSION
- CLOSED EXTENSION FRACTURE
- KREEPY IMBRIUM EJECTA
- TI-RICH BASALT PARTIAL MELTS
- TI-BASALT EXTRUSION/ INTRUSION
- REMANENT MAGNETIC ANOMALY
- INSULATING CRATERED HIGHLANDS AND EJECTA
- CONSOLIDATED PLAGIOCLASE CUMULATE
- $FE_xNI_yS_z$ LIQUID CORE
- ZONE OF ISOLATED $FE_xNI_yS_z$ LIQUID MASSES

— = 200km

LUNAR ORIGIN AND EVOLUTION: STANDARD HYPOTHESIS - 3



- **MARE BASALT/PYROCLASTIC ERUPTIONS**
  - **3.9-1.0 B.Y.**
  - **LARGELY ON THE NEAR SIDE**
- **MAJOR FEATURES LITTLE MODIFIED AFTER 3.9 B.Y.**
  - **~100KM CRATERS AND SMALLER**
  - **SEVERAL METERS OF REGOLITH**