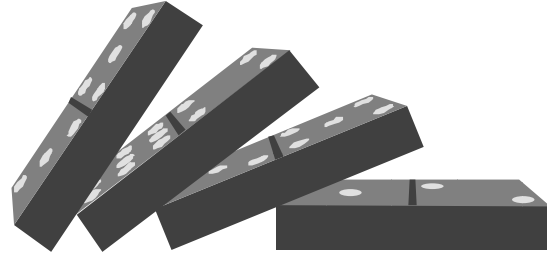


EARLY LUNAR IMPACT EVENTS:
TERRESTRIAL AND SOLAR SYSTEM
IMPLICATION

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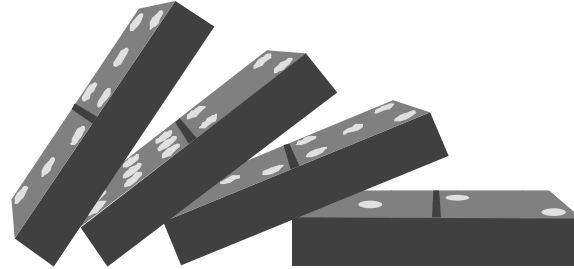
APOLLO MODEL 2000



- **STAGE 1: BEGINNING** 4.57 B.Y.
 - (PRE-NECTARIAN)

- **STAGE 2: MAGMA OCEAN** 4.57-4.2(?)
 - (PRE-NECTARIAN)

APOLLO MODEL 2000

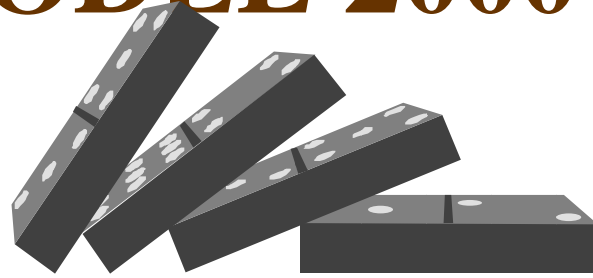


- **STAGE 3: CRATERED HIGHLANDS** 4.4(?) - 4.2(?) B.Y.
 - (PRE-NECTARIAN)

- **STAGE 4: LARGE BASINS** 4.3(?) - 3.8
 - (PRE-NECTARIAN, NECTARIAN - LOWER IMBRIUM)

 - **STAGE 4A: OLD LARGE BASINS** 4.3(?) - 3.92
 - (PRE-NECTARIAN)
 - **STAGE 4B: YOUNG LARGE BASINS** 3.92 - 3.80
 - (NECTARIAN - LOWER IMBRIUM)

APOLLO MODEL 2000



- **STAGE 5: BASALTIC MARIA**

- (UPPER IMBRIUM, PRIMARILY)

4.3(?) - 1.0 (?)

- **STAGE 6: MATURE SURFACE**

- (UPPER IMBRIUM, COPERNICAN AND ERATOSTHENIAN)

3.80 - PRESENT

ORIGIN OF THE MOON

- STAGE 1: BEGINNING



4.57 B.Y.

- GIANT IMPACT ORIGIN SEEMS UNLIKELY

- LARGELY UNDIFFERENTIATED LOWER MANTLE

- PRIMITIVE LEAD IN ORANGE VOLCANIC GLASS

- CHONDRITIC TUNGSTEN IN ORANGE VOLCANIC GLASS

- DISTINCTIVE AU/IR AND ZR/Y IN ORANGE GLASS

- SEISMIC DATA SUGGESTS INCREASED ALUMINIUM BELOW 500KM

- EVIDENCE OF CORE FORMATION AFTER 3.92 B.Y.

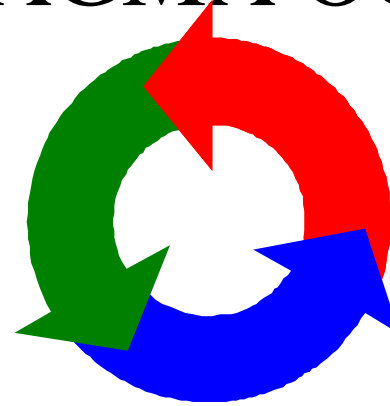
- FEO SUGGESTS SMALL EARTH MANTLE COMPONENT, IF ANY

- STAGE 2: MAGMA OCEAN 4.57-4.2(?)

- HF/W ISOCHRON AND MODEL AGES OF 53-54 M.Y. NARROW WINDOW

- RECENT ACCRETION MODELING ALSO NARROWS WINDOW

“CRATERING” ON MAGMA OCEAN



- **STAGE 2: MAGMA OCEAN 4.57-4.2(?)**
 - **TURBULENT STIRRING AND DEVOLATILIZATION**
 - **TRUE MAGMA CONVECTION, IF ANY, INITIALLY LIMITED**
 - **AGGREGATION OF STABLE ANORTHOSITIC CRUST DELAYED**
 - **REWORKING AND DISRUPTION OF EARLY STABLE CRUST**
 - **MG-SUITE PARENT MAGMAS FORCED INTO LOWER CRUST**
 - **LATE ENOUGH TO ACQUIRE KREEP SIGNATURE**
 - **HF/W MODEL AGE 67 M.Y. VS 45 M.Y. FOR DEEP CUMULATES (?) AND 53 M.Y. FOR CRUSTAL ANORTHOSITE (?) AND KREEP BASALT**

MAJOR CRATERING



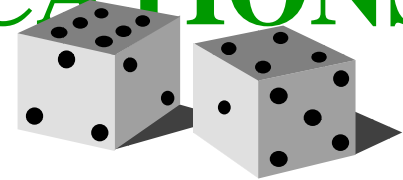
- **STAGE 3: CRATERED HIGHLANDS 4.4(?) - 4.2(?) B.Y.**
 - **SATURATION AT 60-70KM DIAMETER (~25KM DEEP MEGA-REGOLITH)**
 - **PROCELLARUM EVENT (~2100KM DIAMETER) AT ~4.3 B.Y.**
 - **REGIONAL REMOVAL OF EARLY MEGA-REGOLITH**
 - **URKREEP MIGRATION TO BENEATH REGION AND INTO LOWER CRUST**
 - **PRESSURE RELEASE PARTIAL MELTING AND TI-RICH CUMULATE OVERTURN (?) BENEATH REGION**
 - **REGIONAL MARE BASALT ERUPTIONS DELAYED-- TI-BASALTS LATE**
 - **SOUTH POLE-AITKEN EVENT (~2000KM DIAMETER) AT ~4.2 B.Y.**
 - **REGIONAL REMOVAL OF MOST MEGA-REGOLITH**
 - **IMPACT MELTING AND INSITU DIFFERENTIATION OF LOWER CRUST**
 - **ELIMINATION OF MOST REGIONAL MARE BASALT ERUPTIONS**

MAJOR CRATERING



- STAGE 4: LARGE BASINS (~50) 4.3(?) - 3.8
 - STAGE 4A: OLD LARGE BASINS (~36) 4.3(?) - 3.92
 - CRUSTAL STRENGTHENING WITH UPWARD MIGRATION OF URKREEP
 - CRYPTO-MARIA ERUPTIONS (KREEP AND MANTLE DERIVED BASALTS DUE TO PRESSURE RELEASE MELTING)
 - DEGRADED CIRCULAR BASINS -- NO MASS CONCENTRATIONS
 - STAGE 4B: YOUNG LARGE BASINS (14) 3.92 - 3.80
 - SHARPLY CIRCULAR BASINS -- MASS CONCENTRATIONS
 - MANTLE DERIVED BASALTS DUE TO PRESSURE RELEASE MELTING (?)

EARTH/MARS IMPLICATIONS



- STAGE 3: CRATERED HIGHLANDS 4.4(?) - 4.2(?) B.Y.
 - CLAY-WATER-CARBONATE “SOUP” DOMINANT AT SURFACE (DITTO FOR MARS)
 - RETENTION OF CHONDRITIC ORGANIC COMPOUNDS (DITTO FOR MARS)
 - ENERGY, SIMPLE ORGANIC MOLECULES, AND CLAY TEMPLATES (?) (DITTO FOR MARS)
 - PROCELLARUM-LIKE ASYMETRY
- STAGE 4: LARGE BASINS (>>50) 4.3(?) - 3.8
 - EARLIEST EVIDENCE OF LIFE: 3.8 B.Y.
 - END OF LARGE BASIN FORMATION (?)
 - STAGE 4A: OLD LARGE BASINS 4.3(?) - 3.92
 - STAGE 4B: YOUNG LARGE BASINS 3.92 - 3.80

SOURCE OF LARGE IMPACTORS



- **DISCRETE SOURCE**
 - **PERSISTED AFTER RESERVOIR OF CRATERED HIGHLANDS IMPACTORS BECAME DEPLETED**
- **SOURCES TO CONSIDER**
 - **PROTO-KUIPER/EDGEWORTH BELT**
 - **INTERACTION WITH NEPTUNE (WOULD NOT PERSIST FOR 400 M.Y.?)**
 - **ÖORT CLOUD**
 - **INTERACTION WITH STELLAR BODY (WOULD NOT PERSIST FOR 400 M.Y.?)**
 - **PROTO-MOONS OF EARTH**
 - **CAPTURE OF THE PRESENT MOON (WOULD NOT PERSIST FOR 400 M.Y. AND DOES NOT EXPLAIN SIMILAR HISTORY OF MARS AND MERCURY)**
 - **PRECURSOR PLANET OF MAIN BELT ASTEROIDS**
 - **JUPITER-INDUCED BREAKUP (BEST POSSIBILITY FOR NOW)**