Numerical modeling of the Orientale basin-forming event

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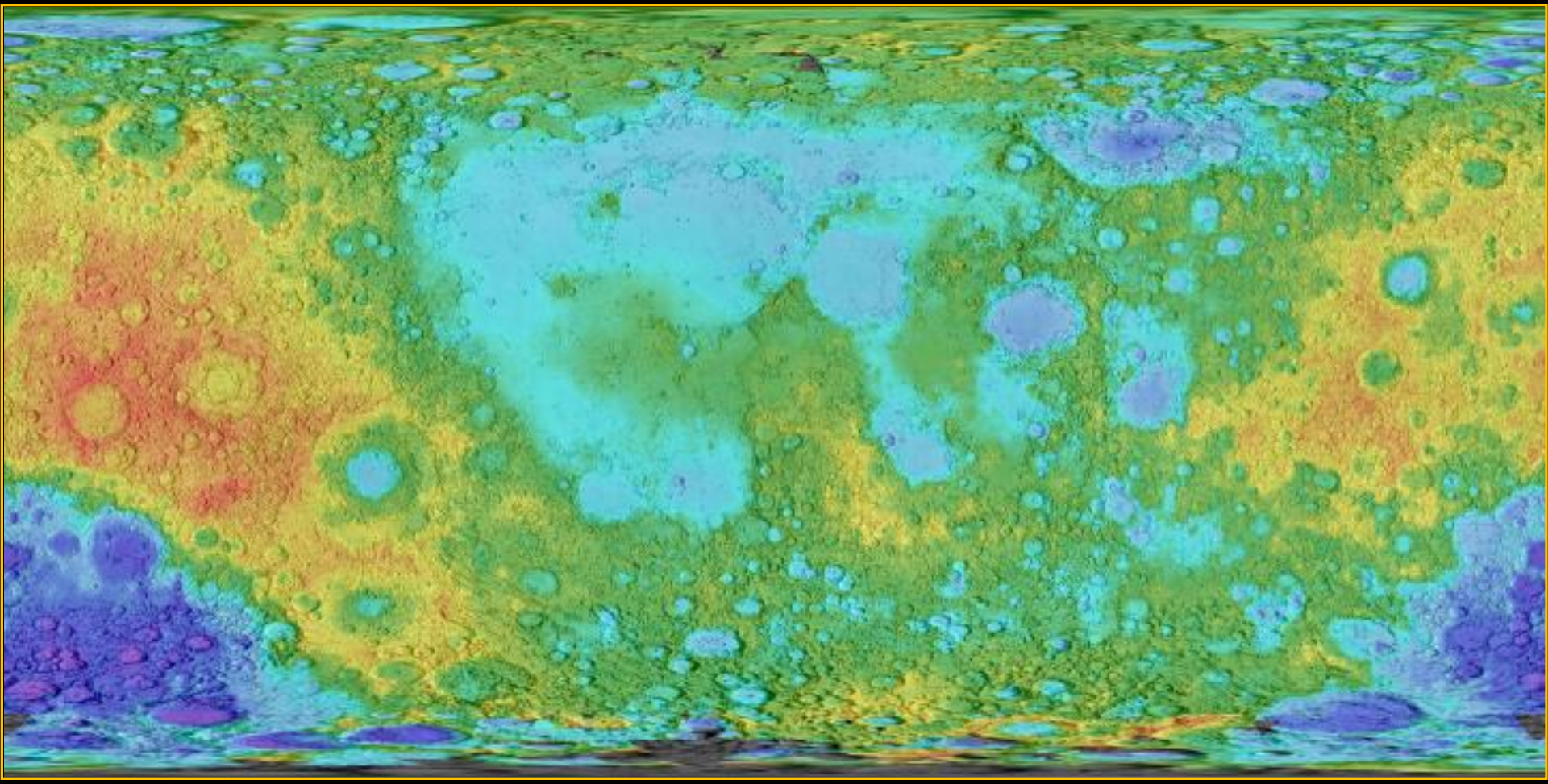
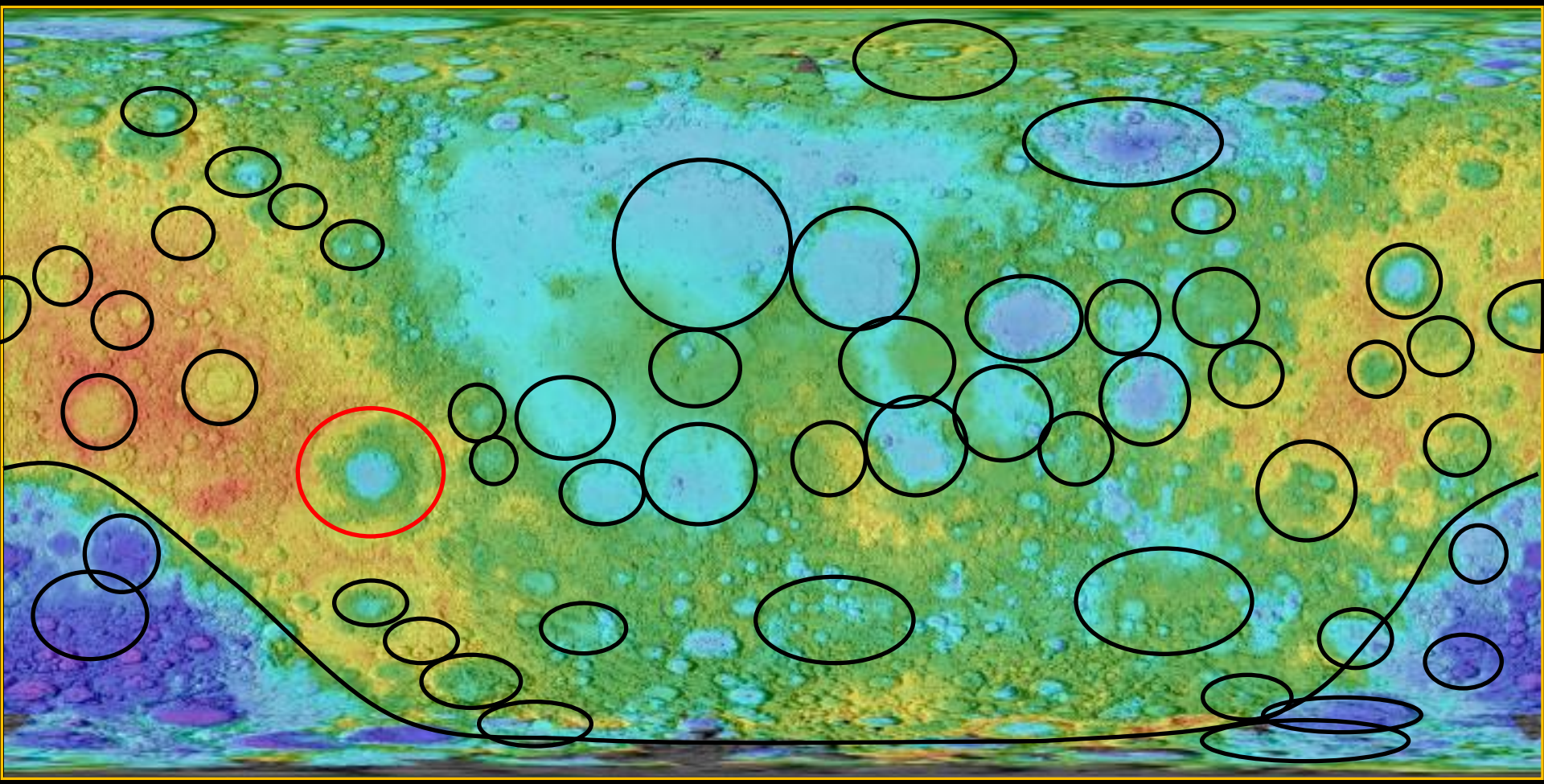
Lunar Basins



ULCN elevation basemap 2005

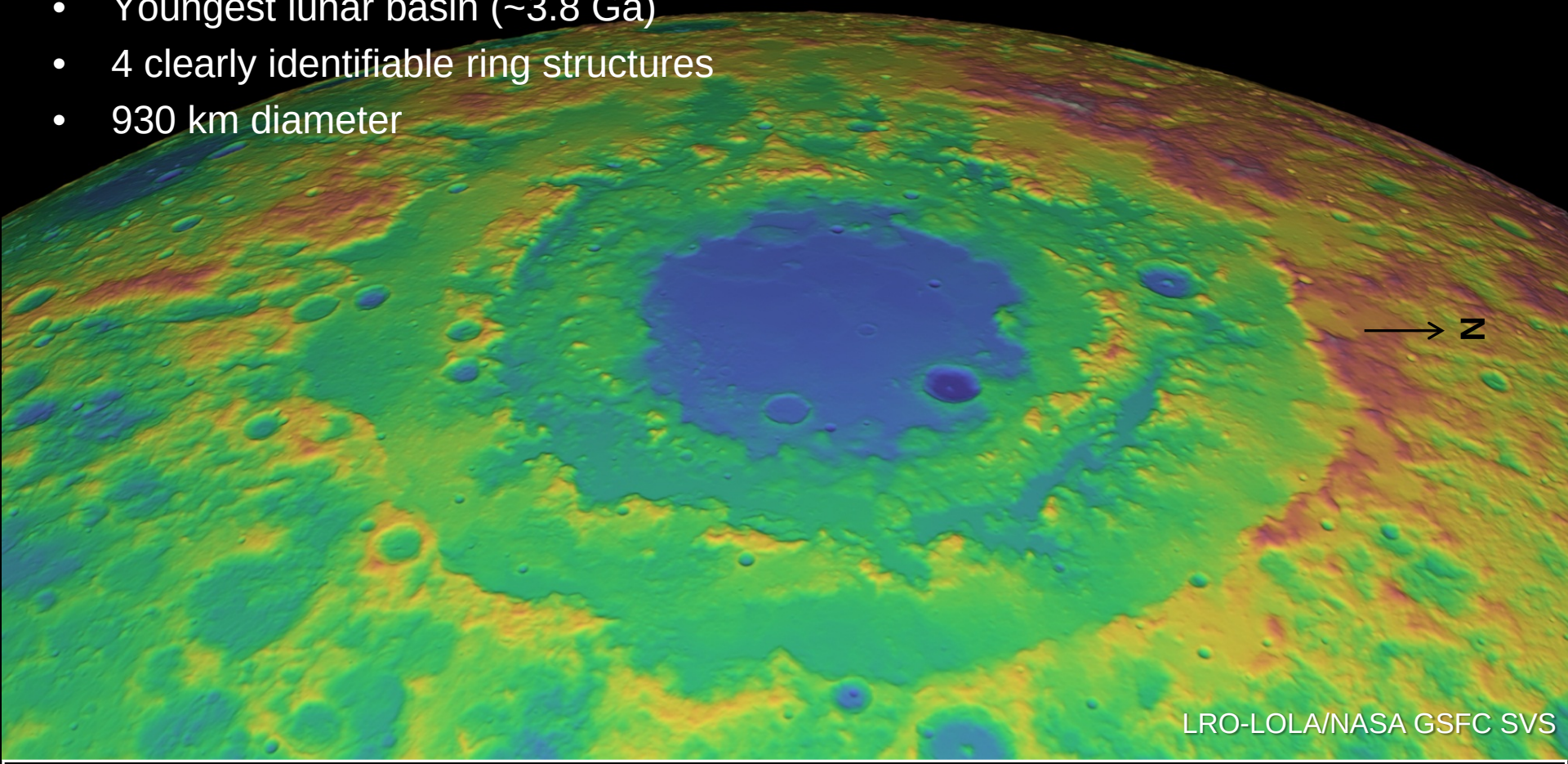
Lunar Basins



ULCN elevation basemap 2005

Orientale

- Youngest lunar basin (~3.8 Ga)
- 4 clearly identifiable ring structures
- 930 km diameter



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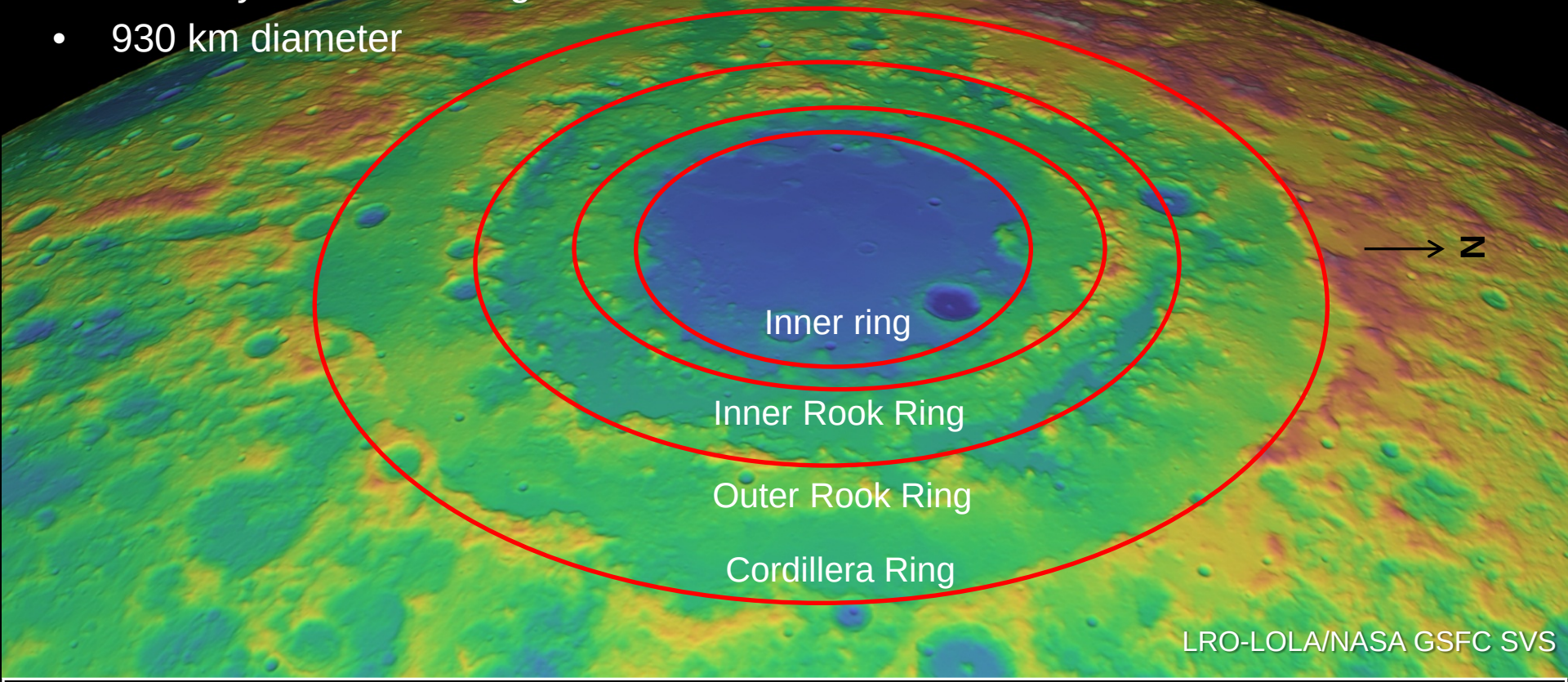

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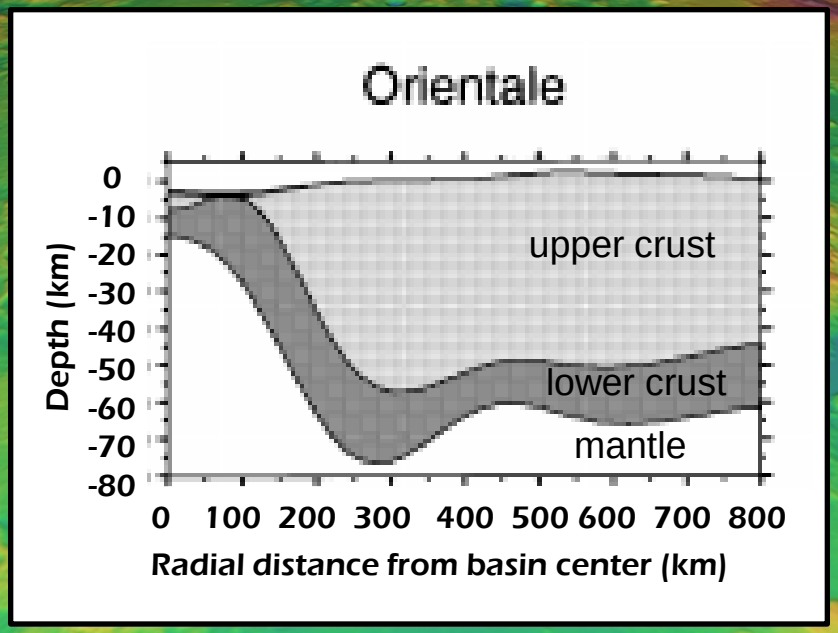

Wieczorek and Phillips (1999)

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Basin Formation

- Lunar basins formed between 4.4-3.8 Ga
- Formation theories:
  - Megaterrace (Head 1974)
  - Ring tectonics (Melosh and McKinnon 1978)
  - Nested melt cavity (Head 2010)
  - Hydrodynamic/tsunami model (Baldwin 1972, 1974)
- Fundamental attributes of basins remain uncertain:
  - Some basins have multiple estimates for their basin rim diameter
  - Orientale transient crater dimensions linked to four different rings

Image Credit: D. Durda

Aim

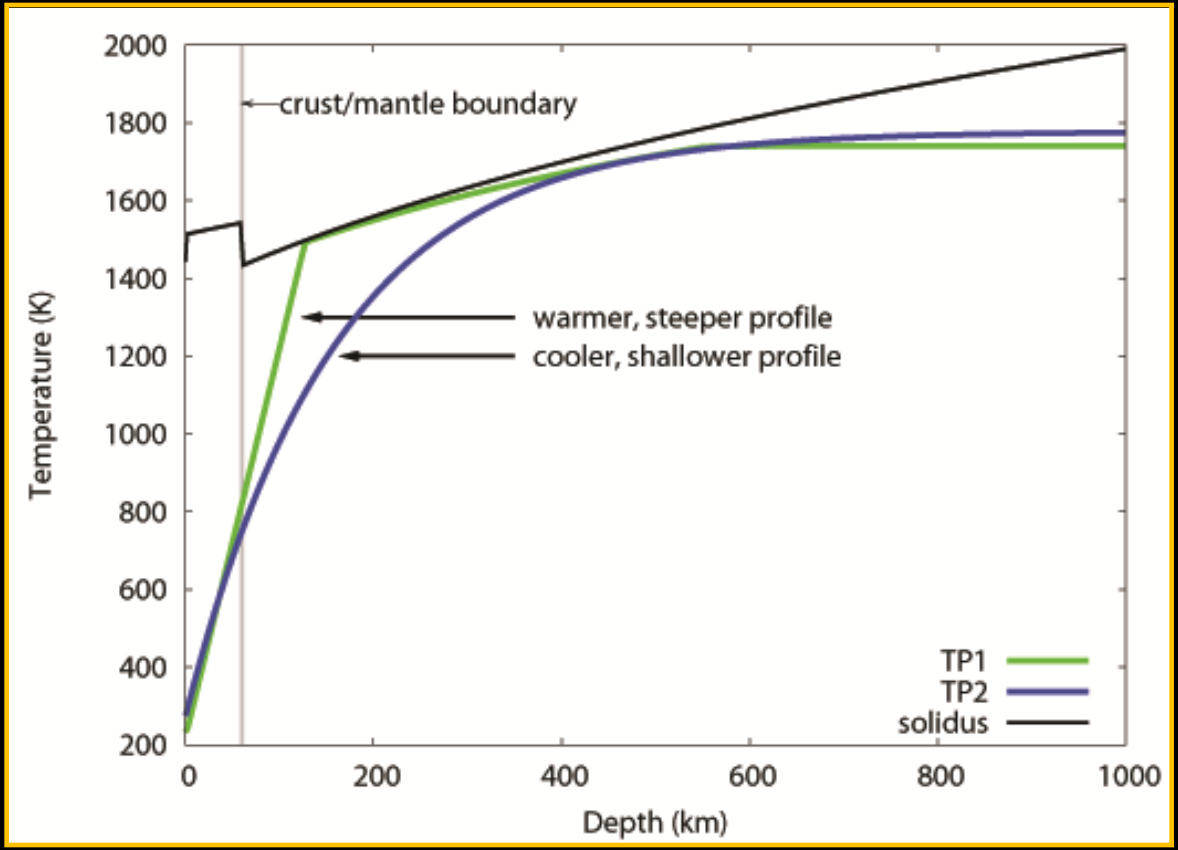
- Resolve some of the uncertainties in basin attributes with numerical models of the Orientale basin-forming process that are consistent with gravity models of Orientale's crustal thickness and provide estimates for impact energy, impactor size, transient crater dimensions, and impact melt volume

Methods

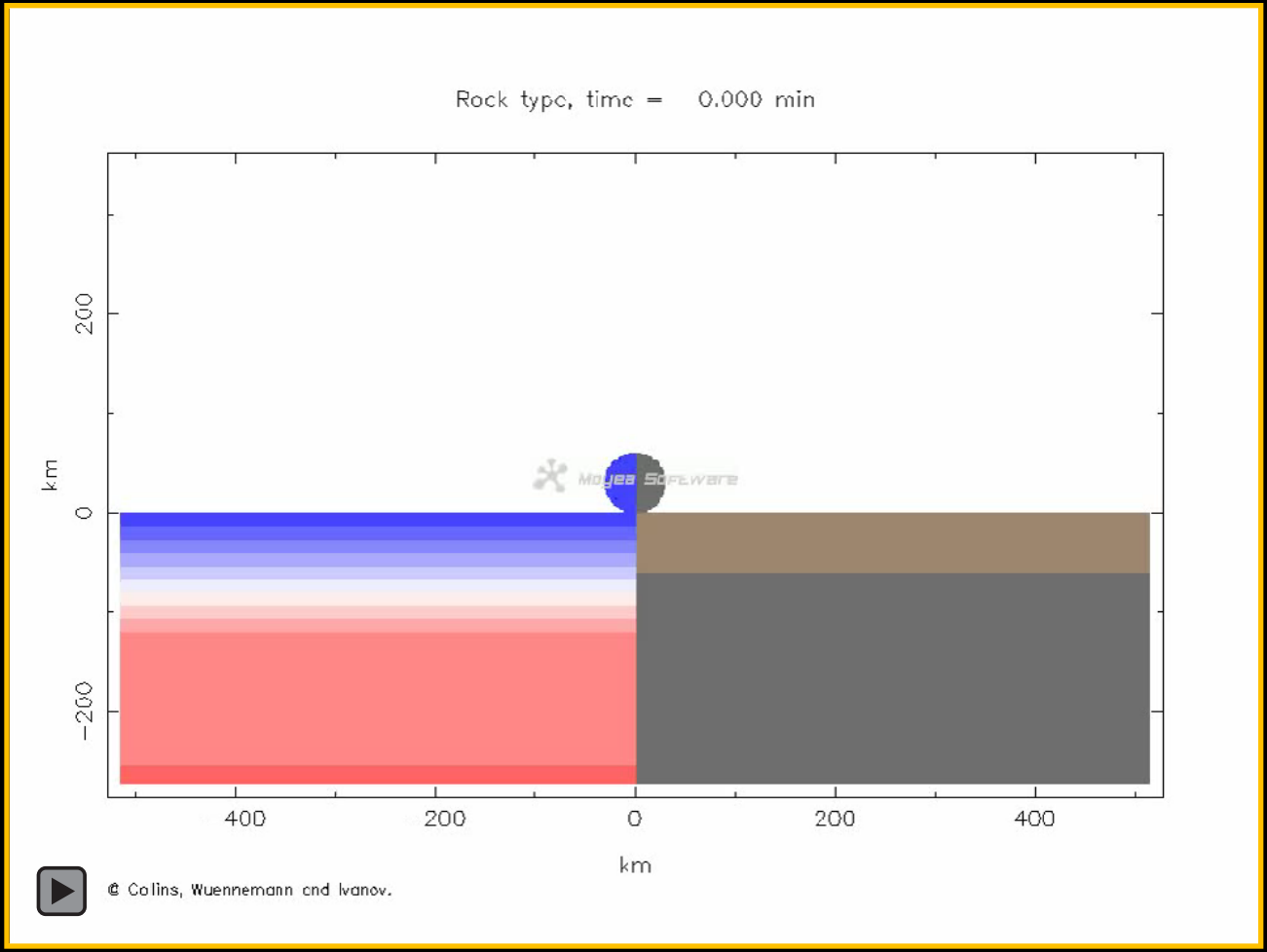
- Used the 2D iSALE hydrocode (Amsden et al. 1980, Collins et al. 2004) to carry out halfspace simulations using a constant gravity field of 1.62 m/s^2
- ANEOS equation of state for dunite (Benz et al. 1989) represent the lunar mantle and impactor. Tillotson equation of state for gabbroic anorthosite (Ahrens and O'Keefe 1982) represents the lunar crust
- Material strength and melting temperatures found by fits (cf. Collins et al. 2004) to experimental data (Azmon 1967; Stesky et al. 1974; Shimada et al. 1983; McKenzie and Bickle 1988; Ismail and Murrell 1990)
- Material weakening mechanisms: thermal softening and acoustic fluidisation
- Additional mechanism: Effective viscosity of 10^{10} Pa s (Potter 2012) applied to partially molten mantle material (temperatures between the solidus and liquidus) to give partially molten material some resistance to shear
- Impactors 40-120 km in diameter (constant 20 cells per projectile radius), velocities 10 and 15 km/s, crustal thickness 60 km

Methods

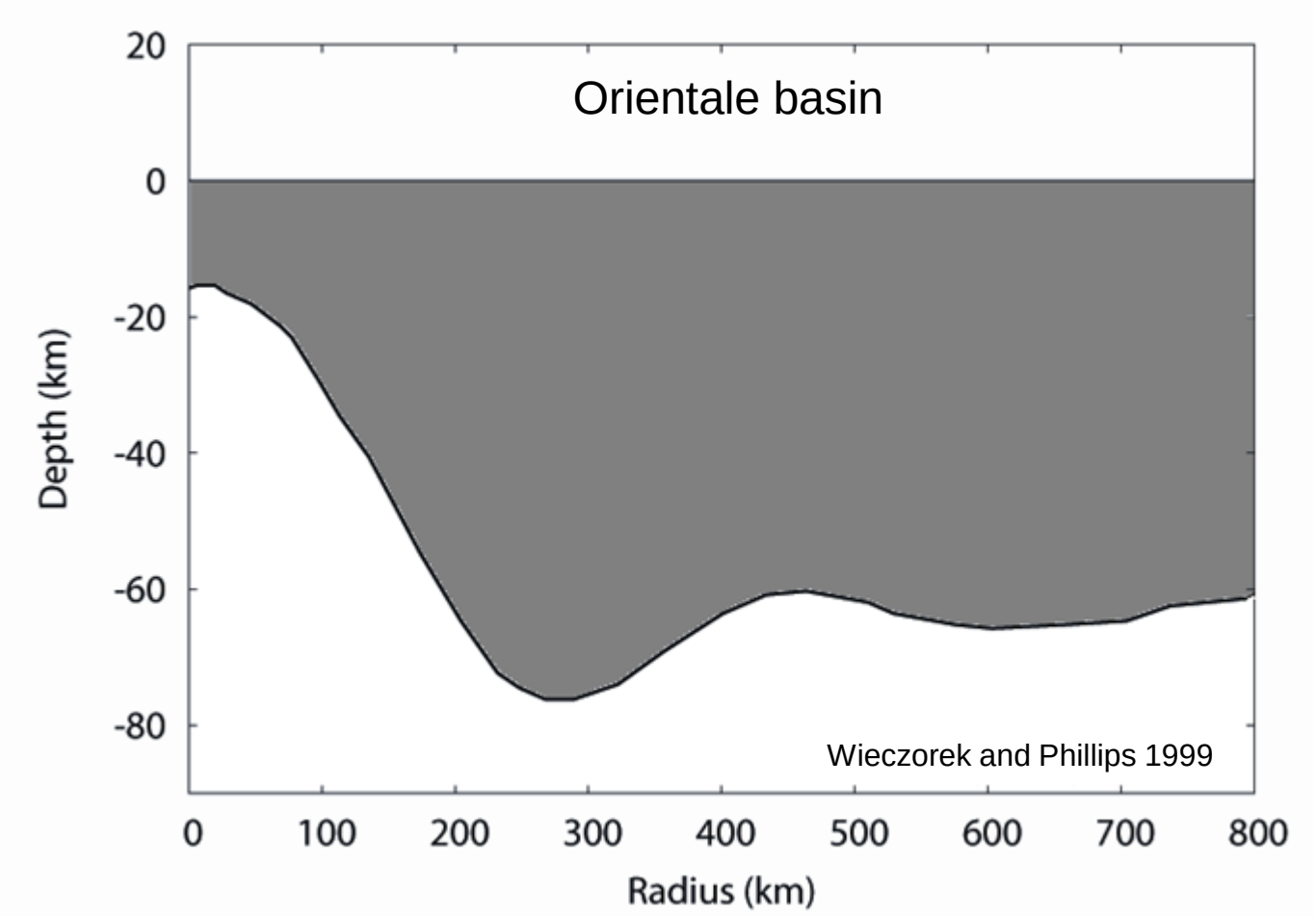
- Two thermal profiles estimating lunar conditions during the latter stages of the basin-forming epoch.
- Based on Potter et al. (2012) and Spohn et al. (2001).



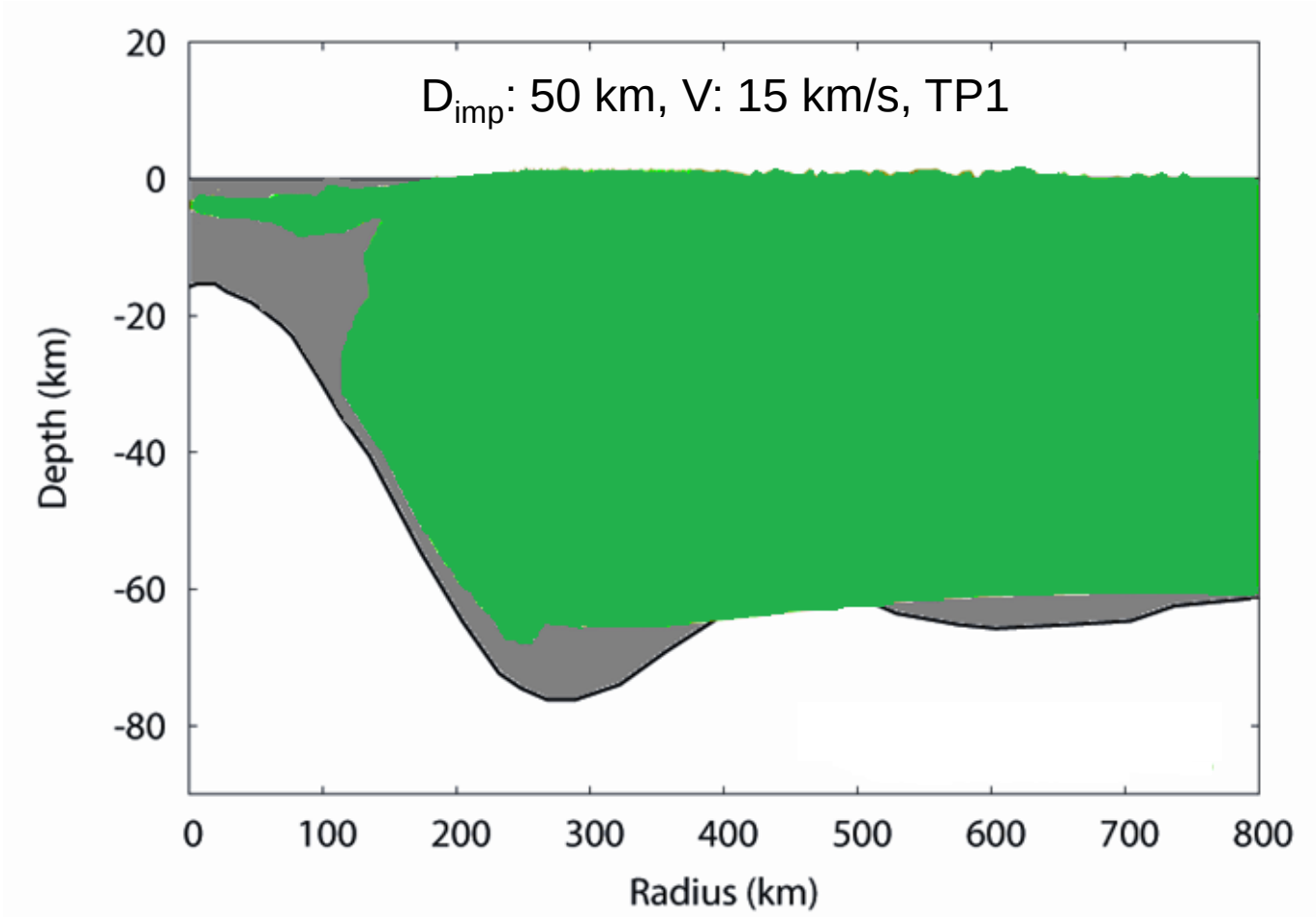
Results


Rock type, time = 0.000 min
200
0
-200
km
400
200
0
200
400
km
© Collins, Wuennemann and Ivanov.

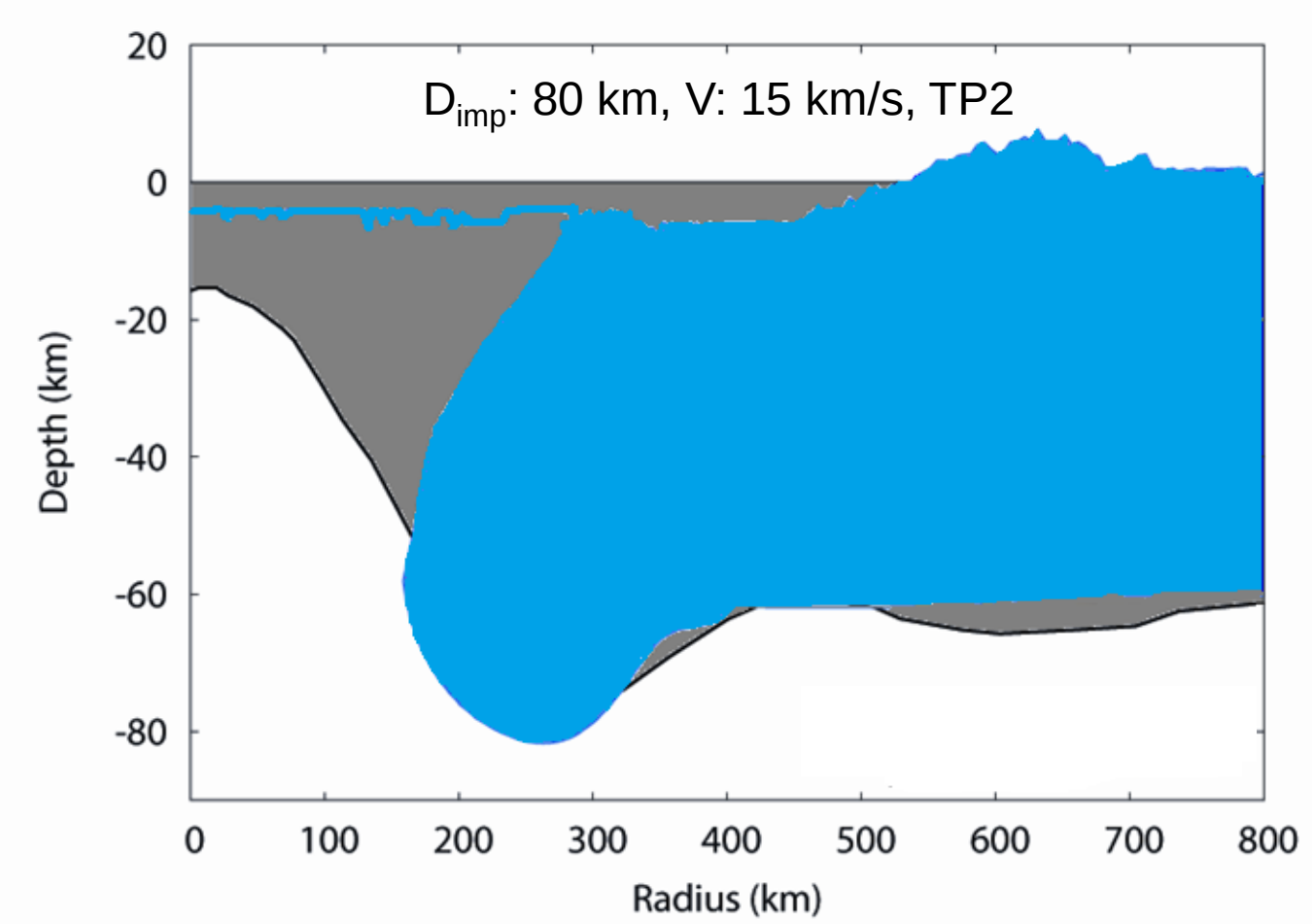
Results


Orientale basin
Depth (km)
20
0
-20
-40
-60
-80
0
100
200
300
400
500
600
700
800
Radius (km)
Wieczorek and Phillips 1999

Results


D_{imp}: 50 km, V: 15 km/s, TP1
20
0
-20
-40
-60
-80
Depth (km)
0
100
200
300
400
500
600
700
800
Radius (km)

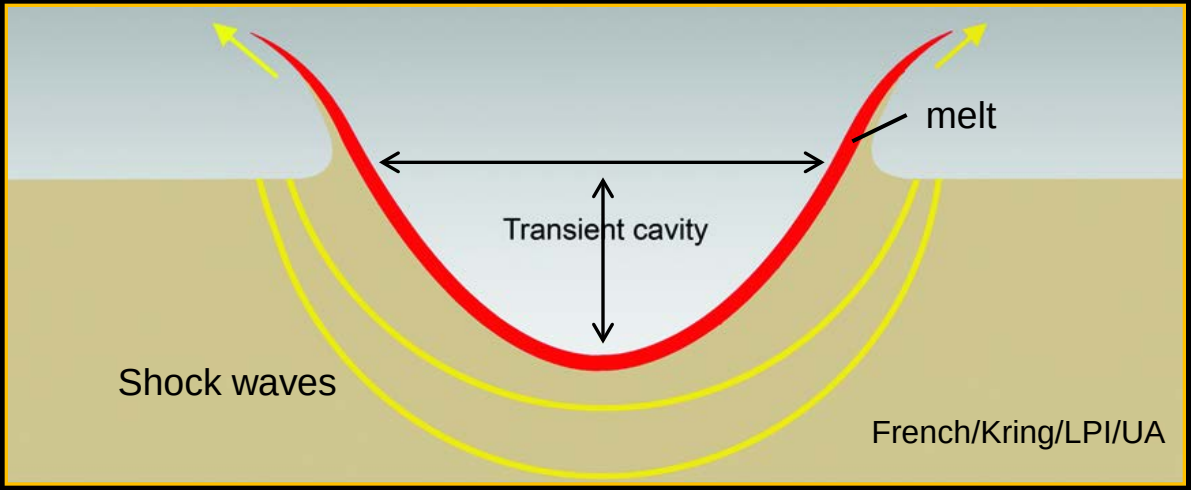
Results


D_{imp}: 80 km, V: 15 km/s, TP2
20
0
-20
-40
-60
-80
Depth (km)
0
100
200
300
400
500
600
700
800
Radius (km)

Results

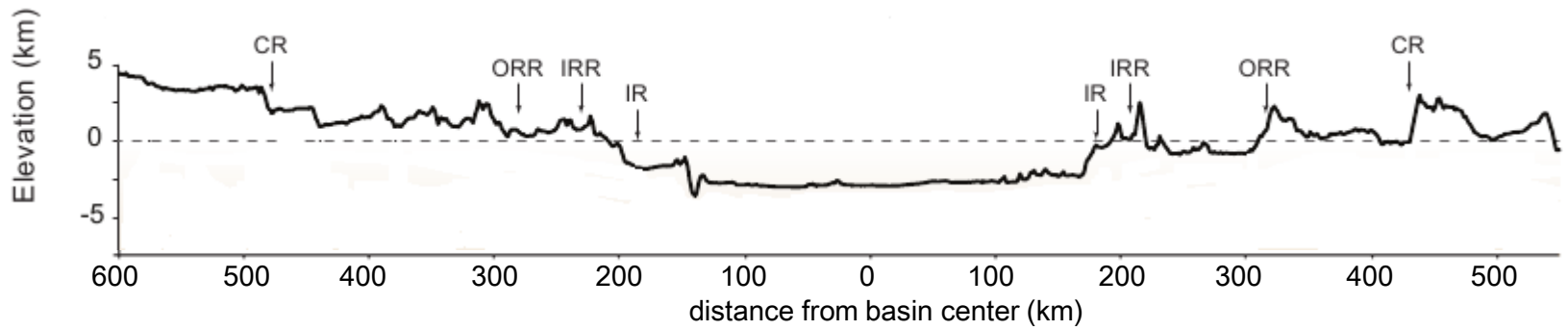
- Best fit to gravity-inferred crustal annular bulge: 2.4×10^{25} (TP1) to 9.9×10^{25} J (TP2)
  - $8\text{-}9 \times 10^{25}$ J Orientale-sized impact (Stewart 2011) using thermal profile similar to TP2
- Basin center filled with molten material agreeing with other basin-scale numerical models (Ivanov et al. 2010, Stewart 2011 Potter et al. 2012)
- Melt volumes comparable to other estimates (Budney et al. 1998, Cintala and Grieve 1998, Vaughan et al. 2012): 10^6 km^3
- Possible differentiation of melt sheet to form crustal layer (Morrison 1998)
- Mantle material not excavated – consistent with spectroscopic data (Yamamoto et al. 2010)

Results – Transient Crater



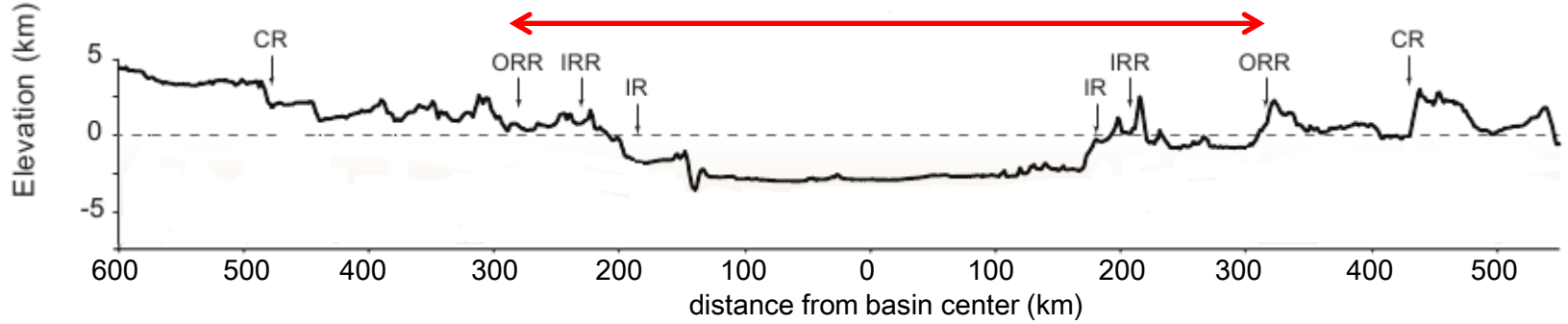
- Can be used to predict with reasonable accuracy impact energy and momentum (Holsapple 1982, Schmidt Housen 1987), volume of impact melt (Cintala and Grieve 1998) and maximum depth and volume of excavated material.

Discussion



Modified from Nahm et al (submitted)

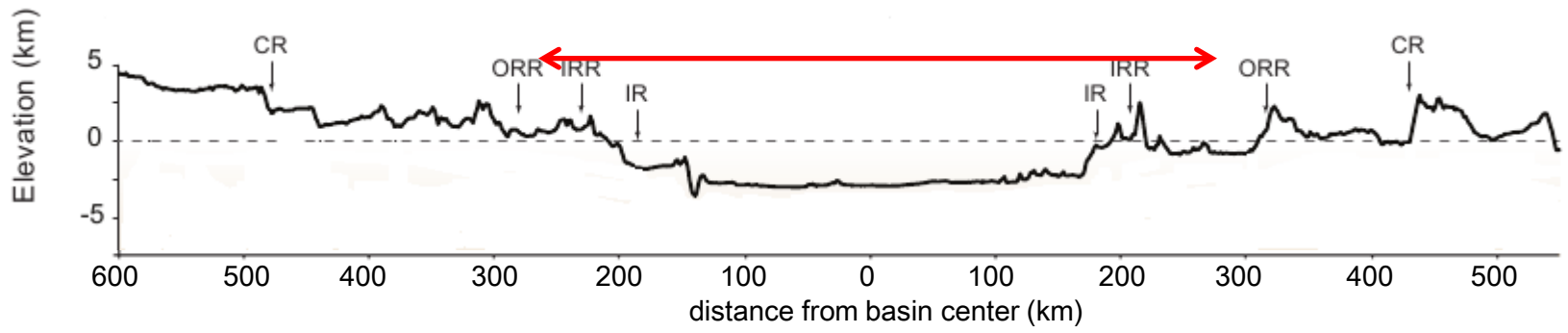
Discussion



Modified from Nahm et al (submitted)

- 620 km diameter: Head 1974; Moore et al. 1974; Scott et al. 1977; Head et al. 1993: Fassett et al. 2011

Discussion



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- 495-518 km diameter: Croft 1985

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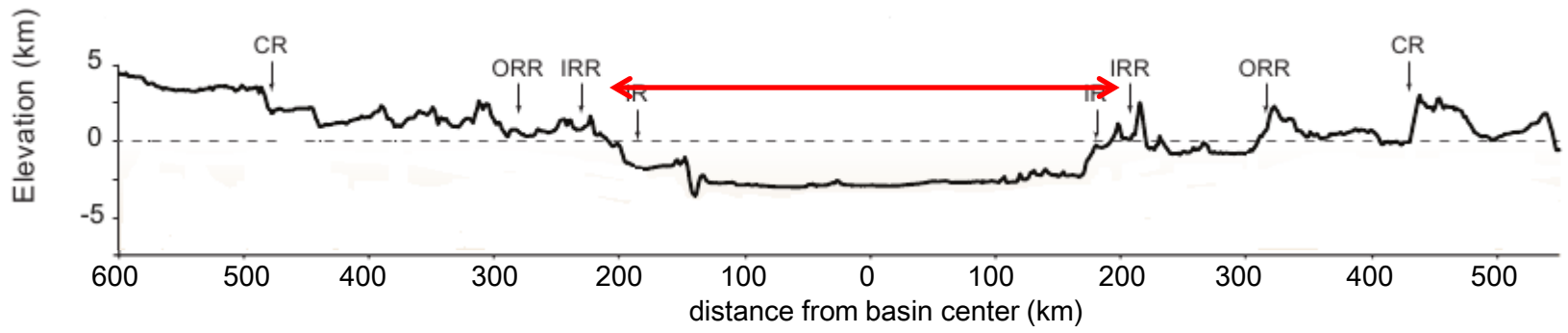

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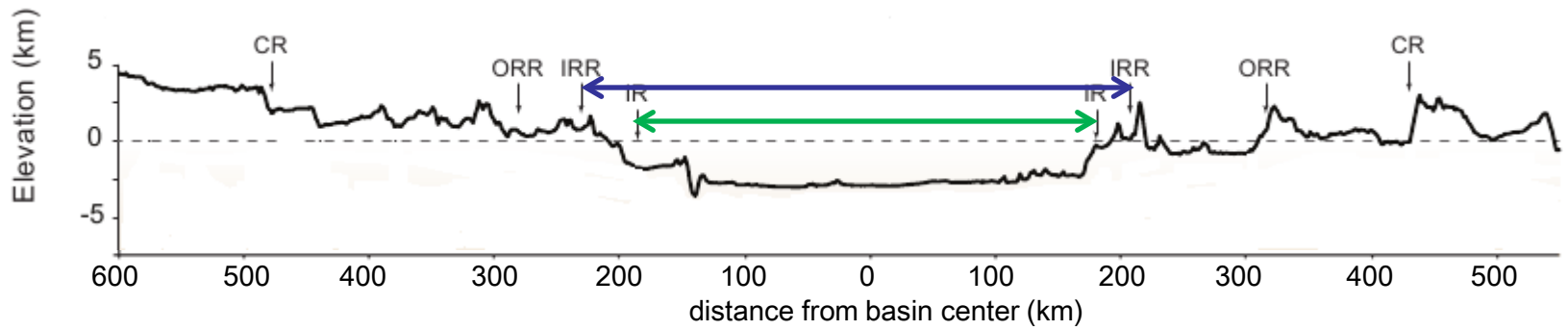

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- ~480 km diameter: this study (TP2)
- ~320 km diameter: this study (TP1)

From our modeling ORR appears an unsuitable approximation for the Orientale transient crater diameter

Conclusions

- An impact using TP1 is consistent with a transient crater diameter approximating the inner ring (320 km). An impact using TP2 is consistent with a transient crater diameter approximating the Inner Rook ring (480 km).
- Impact-generated melt volumes comparable to other estimates; excavation depths agree with spectroscopic data (no excavation of mantle)
- The simulations show initial target thermal conditions have a large effect on basin formation and structure (for a given impact energy)
- Impactor diameters of the best-fit simulations were 50 km (TP1) and 80 km (TP2) for a 15 km/s impact velocity
- Impact velocities during the basin-forming epoch could have been closer to 20 km/s (Marchi et al. 2012, Bottke et al. 2012). Given a 20 km/s impact velocity and an asteroidal impactor composition, the simulations presented here imply impactor diameters of ~40 km (TP1) and ~55 km (TP2) for the Orientale basin-forming event

Thank you

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