Constraints on Early Mars atmospheric pressure from small ancient craters

Edwin Kite (Caltech), Jean-Pierre Williams (UCLA), Antoine Lucas (Caltech), Oded Aharonson (Caltech/Weizmann)

Rationale: Dense atmospheres brake, ablate and disrupt small impactors, so impact crater size is a probe of atmospheric pressure.

e.g. Vasavada et al. 1993, Hartmann et al. 1994

Today, use small ancient craters to find atmospheric filtering and thus atmospheric density ~3.7 Ga on Mars

Kite et al., arxiv:1207.6726
Paleopressure: key variable in Early Mars climate

- May enable **stable** warm-wet greenhouse at high $P$ ($P \sim P_{CO2}$)

- Boosts **transient** warming triggered by impacts, volcanism, infrequent orbital conditions.

e.g., Forget et al., Icarus 2012; Segura et al., JGR 2008; Haberle, JGR 1998; Pollack et al., Icarus 1987; Kite et al., arXiv:1205.6226 (Icarus, accepted)
Impactor-atmosphere interactions

Atmospheres filter out small hypervelocity surface impacts.
Variables: entry angle $\phi$, entry velocity, impactor size/density/strength, impactor ablation coefficient, target strength, **atmospheric density**
Monte Carlo model of crater size-frequency distribution ($10^6$ impactors per run)

Williams et al., LPSC, 2012. Previous work includes (e.g.) Paige et al. 2007, Chappelow & Golombek 2010, Kreslavsky 2011, Popova et al. 2003, Ceplecha et al. 1998
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River deposits such as Aeolis Dorsa are good places to hunt embedded craters.

1) Easier identification
2) Results constrain climate that allowed large rivers

Large embedded craters indicate accumulation rate \( \leq 20-300 \, \mu\text{m/yr} \) (Kite et al., arxiv:1207.6726)
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Small embedded craters
2 HiRISE DTMs, 60 km apart, both straddling same contact.

PSP_007474_1745/ESP_024497_1745
ESP_017548_1740/ ESP_019104_1740
1) Stable multibar atmosphere ruled out at 2σ (Nevada desert alluvium), unstable multibar atmosphere is possible
2) If target had basalt-like rock-mass strength, constraint is relaxed
3) Small embedded craters harder to identify - result is upper limit
Well-controlled geologic context
- places result in the Early Mars ‘big picture’

• **Stratigraphic control:** Large-river deposits and channels are embedded within rock unit now being eroded by aeolian processes. Rivers were not incised into modern topography.

Embedded craters are stratigraphically dispersed - not a disconformity

Sediments between channels most simply interpreted as floodplain deposits

Our DTMs sample near the center of a >300m-thick interval of river deposits (>1 Myr duration from embedded-crater density), and do not represent the final gasp of large-river activity.

• **Age control:** “Early Mars,” could overlap Gale

Almost certainly pre-Amazonian, probably Early Hesperian or older.

\[ N(1) = 2049\pm158, \ N(2) = 634\pm88, \ (A = 8 \times 10^4 \text{ km}^2) \]

Probable and definite postfluvial craters. Age in agreement with Zimbelman & Scheidt (2012), Kerber & Head (2010).
If Mars did not have a stable multibar atmosphere, long-term average temperatures were probably below freezing.

1) No currently known solution self-consistently allows long-term average $T > 273K$ in a manner consistent with data
2) Transient warming (impacts, short-lived volcanogenic gases) possible
3) Higher background $P$ primes the climate system for transient warming

Constraints shown:
- Ancient craters
- Other geologic/directly-observed
- Mineralogical, compositional or isotopic

Cassata et al., 2012
Van Berk et al., 2012
Manga et al., 2012
Ehlmann et al., 2009
Not all constraints shown (e.g. Paige, Kreslavsky, others)
Conclusions

• Small size of craters interbedded with ancient river deposits disfavors a stable multibar atmosphere: < 2 bar at 2σ (preliminary)
  – Early Mars atmospheric filtering not much greater than modern Earth

• Applying ancient-crater technique to deposits of different ages could test the 40-year-old prediction of a connection between atmospheric decay and the drying of Mars’ climate.

Draft at gps.caltech.edu/~kite/Paleopressure, comments appreciated
Backup
Other sites on Mars

- Quick inspection of Mawrth, Juventae plateau, E Meridiani
- Good candidate ancient craters exist at all sites
- Mawrth most promising for paleopressure fit
- Difficulty: as intrinsic (volume) density of ancient/syndepositional craters drops, misidentified younger/synerosional craters start to dominate statistics