Impact melt deposits at Tsiolkovskiy crater: Constraints on crater age

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Introduction

Tsiolkovskiy is a ~180 km diameter mare-filled impact crater on the far side of the Moon (**Fig. 1**). The Diviner instrument on the Lunar Reconnaissance Orbiter (LRO) has observed Tsiolkovskiy to have an unusually high rock abundance for a crater of its reported age, 3.5 ± 0.1 Ga. The location of the enhanced rock abundance to the southeast of the crater is consistent with the location of an impact melt deposit first identified by Hawke and Head (1977) (**Fig. 2**). We suggest that the area of enhanced rock abundance near Tsiolkovskiy crater is related to the large impact melt deposit. The degradation of massive, coherent impact melt deposits is likely a slower process than the degradation of their surrounding ejecta blankets, and so observations of impact melt may provide relative ages for lunar craters older than Copernican (< 1.1 Ga). One interpretation for the high rock abundance is that Tsiolkovskiy is younger than previously thought, perhaps Erastothenian (1.1 – 3.2 Ga) in age.

Observations

We compare the Diviner rock abundance and Mini-RF S-Band (12.6 cm) backscatter data of Tsiolkovskiy crater to two other large craters, Humboldt and Theophilus, which also have exterior melt deposits as identified by Hawke and Head (1977) (**Fig. 2**).

Crater	Diameter	Location	Published age	Melt direction[c]	Diviner RA in melt direction	Mini-RF enhancement?
Humboldt	200 km	27.2°S, 80.9°E	Late Imbrium (3.2 – 3.8 Ga)[a]	ENE, SE	0.2 – 0.4 %	N
Theophilus	100 km	11.4°S, 26.4°E	Erastothenian (1.1 – 3.2 Ga)[a]	NE, N	0.5%	Y
Tsiolkovskiy	180 km	20.4°S, 129.1°E	3.5 ± 0.1 Ga[b]	SE	1%	Y

[a]Wilhelms, 1987, *USGS Professional Paper*, 1348. [b]Tyrie, 1988, *Earth, Moon, and Planets*, 42, 245-264.
[c]Hawke and Head, 1977, In: *Impact and explosion cratering*, Pergamon Press, pp. 815.

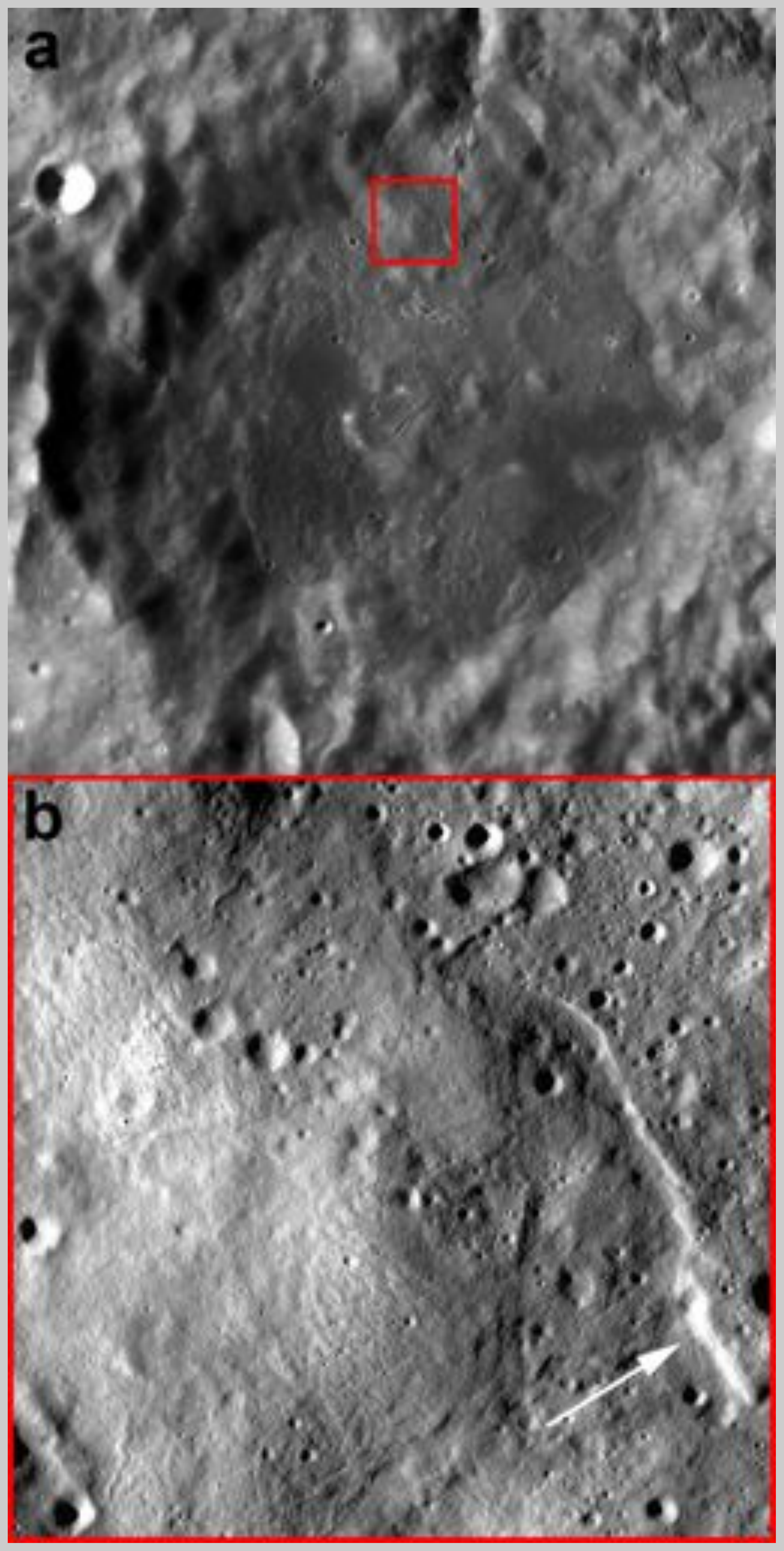

Figure 3: (a) A portion of the Tsiolkovskiy melt deposit as observed by the LROC WAC. (b) A NAC image of the region indicated by the red box shows the lobate shape of the deposit, indicated by a white arrow.

Discussion

We propose that the enhanced rock abundance and radar backscatter near Tsiolkovskiy is correlated with the presence of a large exterior impact melt deposit. Sharp, lobate margins are observed in the Mini-RF data, and evidence of impact melt is also observed in LROC WAC and NAC data (**Fig. 3**).

The preferential enhancement of rock abundance in the melt deposit can be explained by the presence of blocky ejecta, excavated by small impact craters in the massive, coherent melt sheet. Given that impact melt is emplaced as a coherent flow, melt deposits will likely degrade more slowly than their surrounding ejecta blankets, explaining a lack of enhancement elsewhere around Tsiolkovskiy. Observations of Humboldt suggest that melt sheets will eventually degrade to the point where they are no longer distinct in the Mini-RF or Diviner data, but observations of Theophilus suggest that this process may take up to ~3 Gyr.

Buried rocks are detectable with Mini-RF data but not with Diviner rock abundance data, so impact melts may appear to persist for longer in the Mini-RF data, as is observed at Theophilus. The melt sheet at Tsiolkovskiy, however, has a higher rock abundance and radar backscatter than the melt at Theophilus, even though Tsiolkovskiy has been dated as Late Imbrium in age. Possible interpretations include:

(1) A high velocity impact event produced more melt at Tsiolkovskiy than is typical for a crater of its age **AND/OR**
(e.g. Cintala and Grieve, 1998, *Meteoritics and Planetary Science*, 33, 889-912)

(2) Tsiolkovskiy is younger than Theophilus, perhaps < 3.2 Ga
(see Williams et al., LPSC 2013, Abstract #2756)

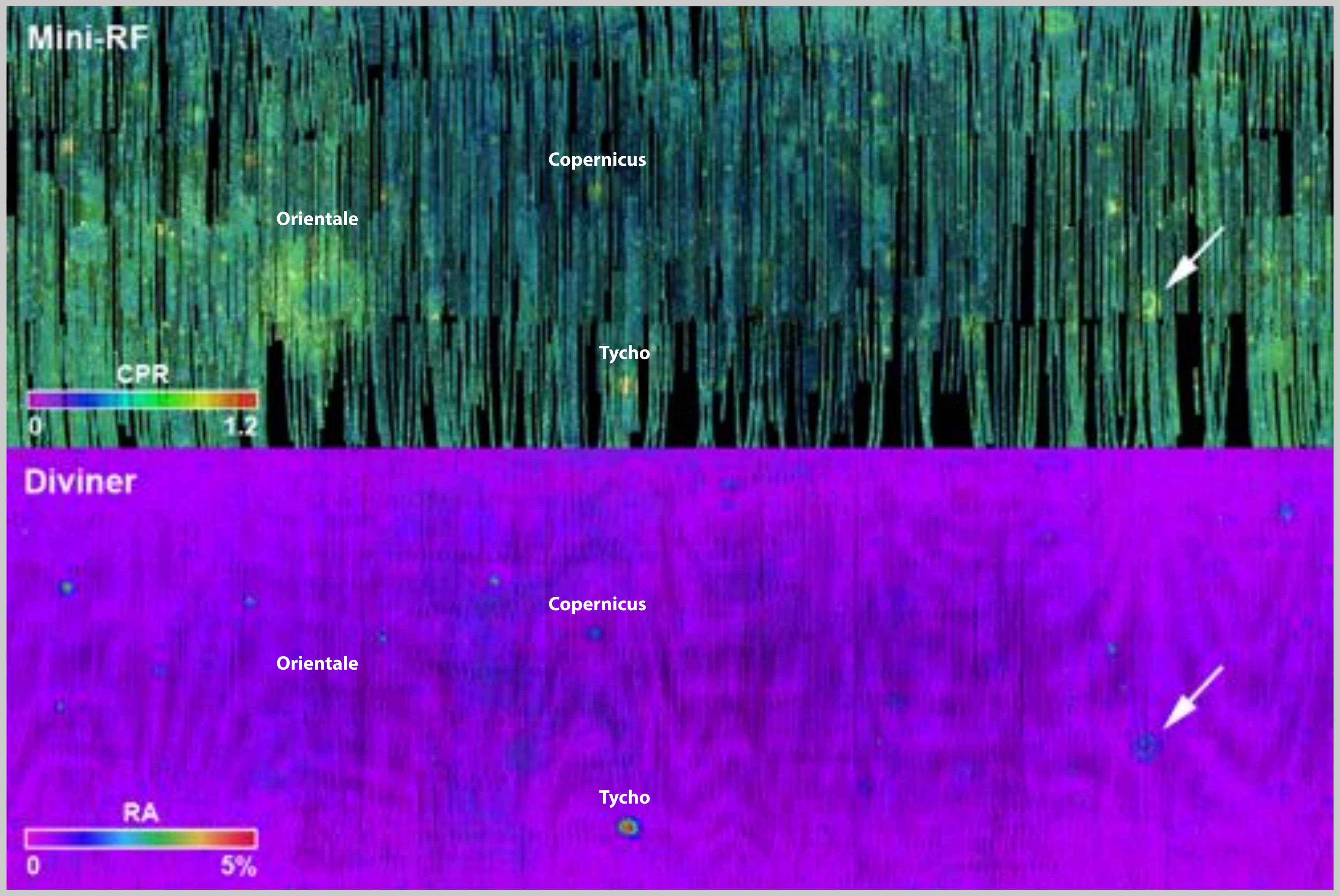

Figure 1: (top) Mini-RF circular polarization ratio data overlaid on same-sense radar backscatter data, mapped in simple cylindrical projection between 60°S and 60°N. (bottom) Diviner rock abundance data mapped over the same region. Tsiolkovskiy crater (indicated by a white arrow) stands out in both data sets.

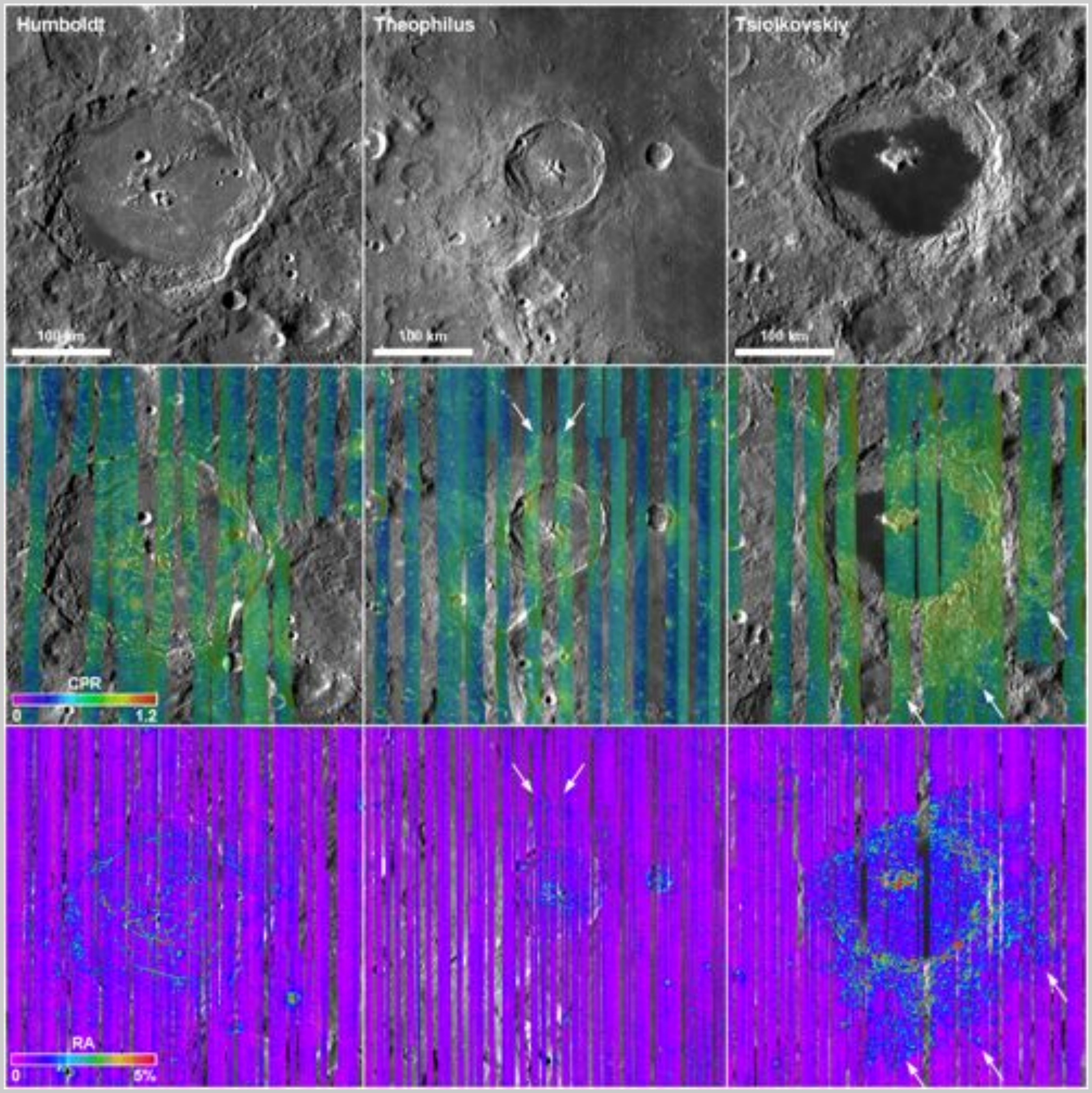

Figure 2: LROC WAC (top), Mini-RF (middle), and Diviner rock abundance data (bottom) of three representative craters: Humboldt, Theophilus, and Tsiolkovskiy. Impact melt deposits are known to have high radar backscatter and circular polarization ratios (CPR), and we have highlighted the edge of likely melt deposits north of Theophilus and southeast of Tsiolkovskiy with white arrows. No obvious melt deposits are observed exterior to Humboldt crater, although Hawke and Head (1977) suggest the presence of melt ponds southeast and east-northeast of the crater rim.