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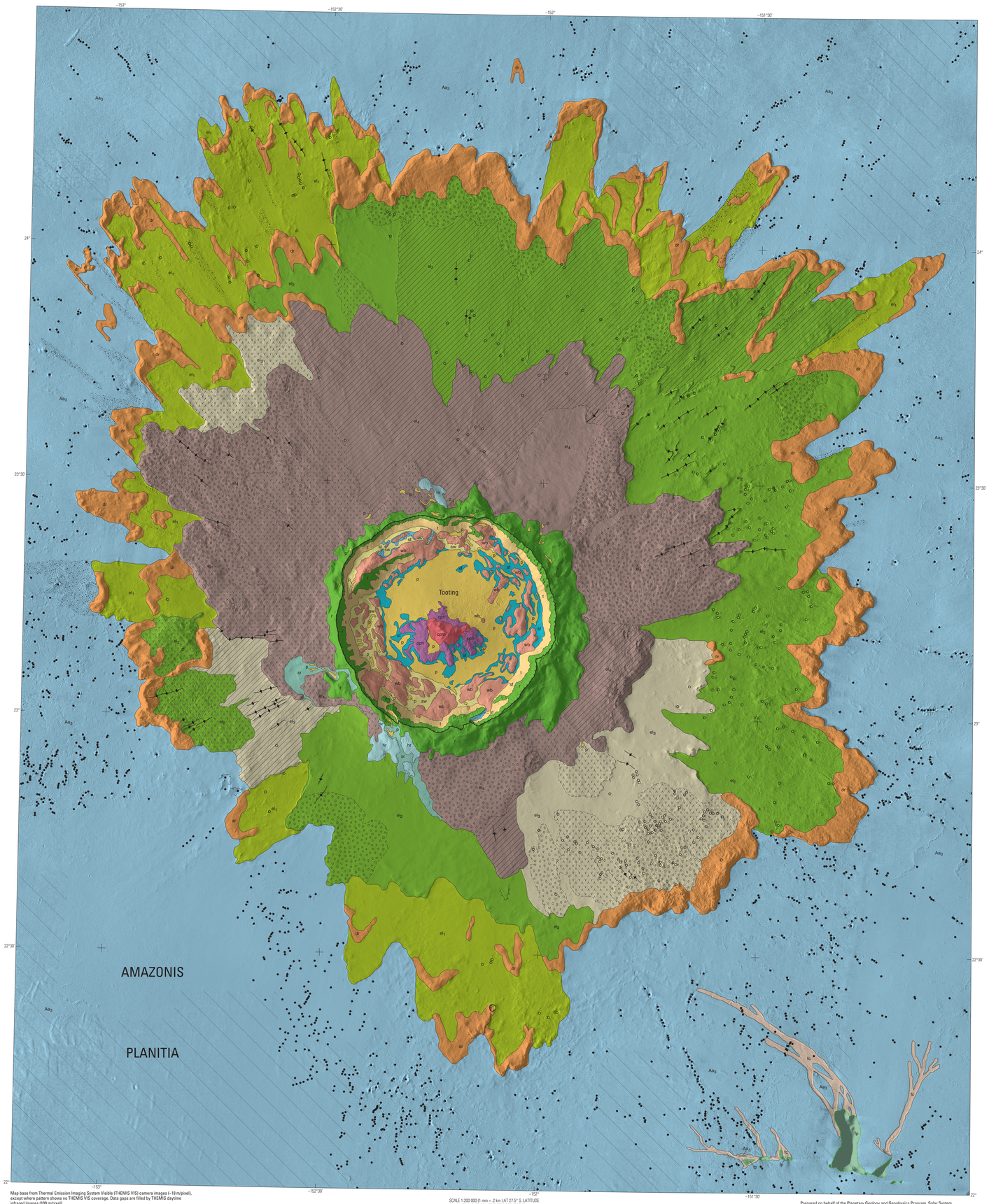
Prepared for the
National Aeronautics and Space Administration

Scientific Investigations Map 3297
Pamphlet accompanies map



Map base from Thermal Emission Imaging System Visible (THEMIS VIS) camera images (~18 m/pixel), except where pattern shows no THEMIS VIS coverage. Data gaps are filled by THEMIS daytime infrared images (100 m/pixel)

Image mosaic created by Mars Space Flight Facility at Arizona State University and controlled to THEMIS daytime infrared by USGS Astrogeology Science Center

Descriptions of nomenclature used on map are listed at http://planetarynames.wr.usgs.gov/

SCALE 1:200,000 (1 mm = 2 km) AT 23.5° S. LATITUDE
TRANSVERSE MERCATOR PROJECTION

0 10 20 30 40 KILOMETERS

PLANETOGRAPHIC LATITUDE AND EAST LONGITUDE COORDINATE SYSTEM

Prepared on behalf of the Planetary Geology and Geophysics Program, Solar System Exploration Division, Office of Space Science, National Aeronautics and Space Administration.
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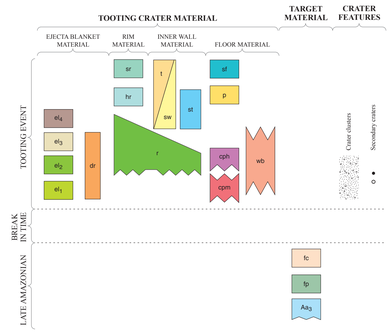
Manuscript approved for publication April 22, 2014

CORRELATION OF MAP UNITS AND CRATER FEATURES



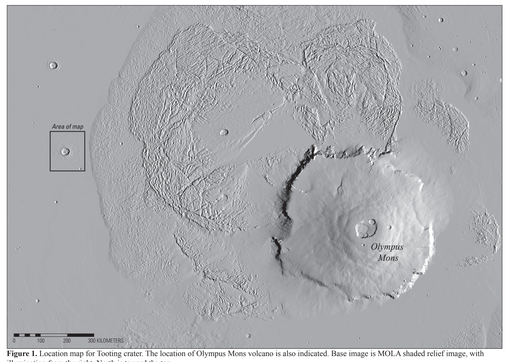


Figure 1. Location map for Tooting crater. The location of Olympus Mons volcano is also indicated. Base image is MOLA shaded relief image, with illumination from the right. North is toward the top.

DESCRIPTION OF MAP UNITS

[Target materials refer to the rock units that existed at the surface before Tooting Crater formed and that were excavated by the impact event]

Unit label	Unit name	Description	Interpretation
		TOOTING CRATER MATERIAL	
		EJECTA BLANKET MATERIAL	
el_4	**Ejecta layer 4 material**	Massive layer surrounding much of Tooting crater, but absent to southwest. Layer perimeter often abrupt and may be scarp >50 m high. Unit displays four principal facies; smooth, hummocky, crenulated, and radial. *Type locality:* lat 23°06′ N., long −151°50′ E.	Innermost continuous layer of ejecta blanket, which may include portions of remobilized rim materials (unit *r*) close to rim crest. This was last ejecta layer to form. Occurrence of different facies within unit indicates a wide variety of flow regimes for ejecta during emplacement.
el_3	**Ejecta layer 3 material**	Continuous layer, observed to northwest, southwest, and southeast of crater rim. Layer lies beneath unit el_4 and lies on top of units el_2 and el_1. Only three facies present, with no evidence for radial facies. *Type locality:* lat 22°46′ N., long −151°47′ E.	Second youngest ejecta layer
el_2	**Ejecta layer 2 material**	North of Tooting crater, large areas of unit display radial facies. Extends to the distal margin of the crater materials to east. Numerous depressions occur within unit. All four facies observed. Parts farthest away from Tooting crater frequently merge into topographic highs (unit *dr*). *Type locality:* lat 23°10′ N., long −151°30′ E.	Second oldest ejecta layer that in places was sufficiently mobile to totally over-ride and bury the outermost unit (el_1). Depressions are partially buried secondary craters
el_1	**Ejecta layer 1 material**	Lowermost ejecta unit occurs at greatest radial distances from Tooting crater, but is absent to southeast. Numerous depressions occur within unit. Parts farthest away from Tooting crater frequently merge into topographic highs (unit *dr*). Only smooth facies observed. *Type locality:* lat 22°30′ N., long −152°24′ E.	First of the ejecta layers to form, as well as the most mobile. Depressions are partially buried secondary craters
dr	**Distal rampart material**	Topographic highs at perimeter of ejecta layer materials el_1, el_2 and el_3. Slope is steepest on the down-range side, and up-range merges smoothly with other ejecta materials. In places may also occur as radial topographic highs. *Type locality:* lat 24°03′ N., long −152°57′ E.	Formed by deceleration and subsequent piling up of ejecta during the final phase of radial flow away from crater. Radial ridges formed by progressive deposition during radial flow of three most spatially extensive ejecta layers
		RIM MATERIAL	
sr	**Smooth rim material**	Smooth surfaces with faint flow textures that point down the inferred local slope. Closely associated with the hummocky rim materials (*hr*). Unit appears concentrated in local topographic lows. *Type locality:* lat 23°05′ N., long −152°34′ E.	Sediment flows that originate from ejecta blanket and are composed of ejecta remobilized by seeping water
hr	**Hummocky rim material**	Overlies rim material (*r*). At CTX resolution, displays hummocky texture and numerous amphitheater-headed canyons. *Type locality:* lat 22°56′ N., long −152°21′ E.	Remobilized ejecta deposits on outer rim. Canyons mark locations where water seeped from ejecta blanket
r	**Rim material**	Undulating topography close to crater rim crest; beyond crater rim shows few signs of erosion. Within crater cavity, shows signs of weathering into vertical columns. Some kilometer-sized blocks within general matrix of unit preserve stratification. *Type locality:* lat 23°03′ N., long −152°00′ E.	Thick layers of ejecta excavated from crater cavity during the cratering event. Stratification indicates that layering is preserved within the rim materials. Erosion within cavity most likely indicates unconsolidated nature of material, which may have been highly fragmented during formation of Tooting crater
		INNER WALL MATERIAL	
t	**Talus material**	Relatively high albedo deposits concentrated within crater cavity at the base of steep slopes below rim material (*t*). *Type locality:* lat 23°13′ N., long −151°54′ E.	Talus derived from weathering of lava flows preserved within inner rim crest
sw	**Smooth wall material**	Smooth surfaces with faint flow textures that point down inferred local slope. Most numerous on southwest sector of crater and absent where large terrace blocks have formed. Closely associated with wall blocks (*wb*). Unit concentrated in local topographic lows. *Type locality:* lat 23°02′ N., long −152°16′ E.	Sediments remobilized by water seeping from inner walls of crater
st	**Smooth terrace material**	Bland material perched on terrace block on northwest side of crater interior. *Type locality:* lat 23°20′ N., long −152°26′ E.	Sediments generated during impact and emplaced onto terrace blocks
		FLOOR MATERIAL	
sf	**Smooth floor material**	Smooth surfaces on crater floor that in places partly infill unit p. Southern outcrops display faint fracture pattern. *Type locality:* lat 23°14′ N., long −152°04′ E.	Crater in-fill material is most likely sediments generated during impact event but subsequently remobilized after pitted material formed. Fractures indicate that material was first cemented and then subjected to local stresses to produce polygonal ground
p	**Pitted material**	Comprises many individual depressions. Depressions are irregular in outline, have common walls, and are concentrated in local topographic depressions. Material is predominately found on crater floor, but also occurs on terrace benches and exterior ejecta deposits to radial distances of ~4 km from rim crest. On southwest crater floor, can be covered by unit *sf*. *Type locality:* lat 23°15′ N., long −152°10′ E.	Origin uncertain, but most likely associated with the degassing of volatile-rich material with multiple possible origins (Mouginis-Mark and Boyce, 2012) that collected in topographic lows after excavation of crater cavity. Isolated patches on terraces and ejecta blanket indicate hot, wet, sediments were ejected during crater excavation
wb	**Wall block material**	Massive blocks on floor and lower parts of wall. Some blocks display layering. Some braiding observed on surface at HiRISE resolution. *Type locality:* lat 23°05′ N., long −152°19′ E.	Segments of crater cavity wall that slid towards crater center during early phase of post-crater modification following impact. No indication that sliding deformed units *sf* or *p*, indicating that this phase of crater cavity collapse was complete before other floor materials formed; exact timing of termination of wall-block sliding, rim emplacement, and formation of inner wall materials cannot be resolved. Layering is series of lava flows, most likely preserved segments of pre-impact surface. Braiding produced by water leaking from wall material to form fluvial channels appears to be similar to source areas of unit southwest of inner walls
cph	**Central peak hummocky material**	Hummocky material on crater floor surrounding the cpm material. Embayed by units *p* and *sf*, and overlies cpm material. *Type locality:* lat 23°10′ N., long −152°17′ E.	Most likely target material that formed original crater floor. Lack of crater fill allows parts of original crater floor to be observed where subsequent sedimentary units (units *p* and *sf*) are sufficiently thin. Possibly affected by uplift of unit cpm, but exact timing of these two events is unclear
cpm	**Central peak mountain material**	Topographically high in center of crater. HiRISE images illustrate layering observed at crest of unit along with smooth material at base of peak. *Type locality:* lat 23°11′ N., long −152°13′ E.	Central peak produced by rebound of target material following impact. Layering is series of lava flows, indicating that target material contained several kilometers of lava flows comparable to those observed in unit Aa_3
		TARGET MATERIAL	
fc	**Fluvial channel material**	Braided depressions cut into unit Aa_3. Topographic highs within depressions have height similar to surrounding terrain, and many of them display streamlined outlines. Numerous small irregular-shaped craters superposed on unit that appear to radiate from Tooting crater. *Type locality:* lat 22°18′ N., long −151°23′ E.	Fluvial channels carved by water flowing from the depression (unit *fp*) eroding surrounding lava flows (unit Aa_3). Irregular craters constitute secondary craters from Tooting crater, which postdate formation of fluvial channel
fp	**Fluvial pit material**	Steep-sided depression with layering seen in topmost units exposed close to the rim. HiRISE images reveal steep boulder-covered slopes with mounds of material on depression floor, some areas of which shows signs of erosion. Shadow-length measurements indicate that height of layered sequence is ~180 m. *Type locality:* lat 22°06′ N., long −151°18′ E.	Fracture cut by rapid release of water onto surface. Layering exposed near rim of pit is sequence of Late Amazonian lava flows that are each ~10–15 m thick. Talus at the base of sequence is rock debris derived from the fluvial erosion of lava flows. Mounds most likely formed from debris (produced during formation of depression) that settled on floor and were subsequently reworked by final phase of fluid discharge
Aa_3	**Amazonian lava flows**	Smooth surface with some wrinkle ridges reminiscent of small lunar mare ridges. Some areas have mottled texture. *Type locality:* lat 23°20′ N., long −151°10′ E.	Young (~240–375 Ma; Mouginis-Mark and Boyce, 2012) lava flows erupted from southwest flank of Olympus Mons volcano. Ridges are deformation features formed by compression of lava surface during late stage of emplacement. Mottled texture interpreted as surface texture of lava flows

EXPLANATION OF MAP SYMBOLS

Ejecta facies
- **Crenulated**
- **Hummocky**
- **Radial**

Crater clusters

No THEMIS VIS coverage

Contact—Internal contact delineates flow boundaries
Facies boundary
Crest of crater rim
Depression margin—Hachures point downslope
Ridge crest—Dashed where approximate
Scarp crest—Hachures point downslope

- **Secondary craters**
- **Buried secondary craters**

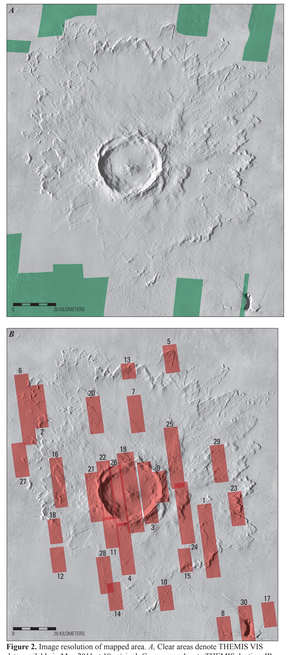


Figure 2. Image resolution of mapped area. *A*. Clear areas denote THEMIS VIS data available in May 2011 at 18 m/pixel. Green areas denote THEMIS daytime IR coverage at 100 m/pixel. *B*. Clear areas denote CTX data at 6 m/pixel. Red areas denote HiRISE coverage available in March 2013 at ~25 cm/pixel. Numbers refer to frame numbers listed in table 1. Base image for both figures derived from THEMIS data. North is toward the top in each image.

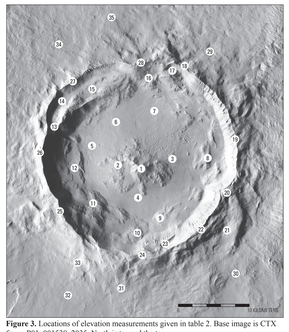
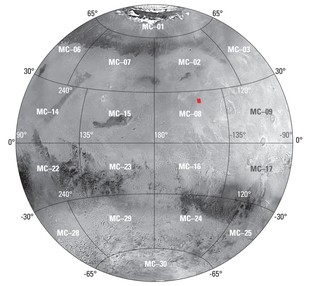


Figure 3. Locations of elevation measurements given in table 2. Base image is CTX frame P01_001538_2035. North is toward the top.



Map Location
Photomosaic showing location of map area (red). An outline of 1:5,000,000-scale quadrangles is provided for reference.

Geologic Map of Tooting Crater, Amazonis Planitia Region of Mars

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