NASA Quality Leadership Forum

Premature Wear of the “Curiosity” Mars Rover Wheels

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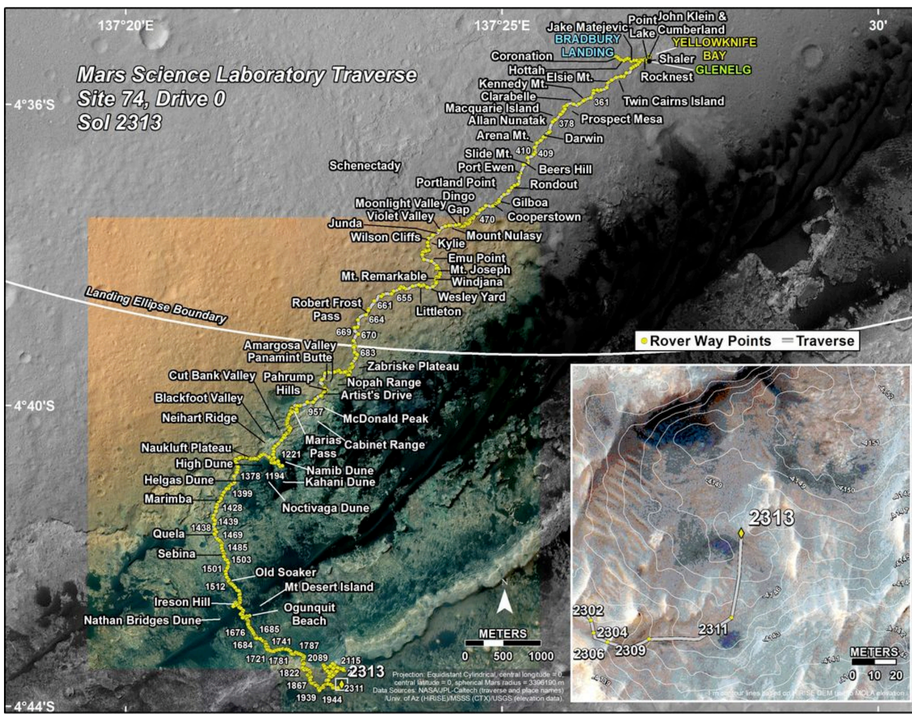
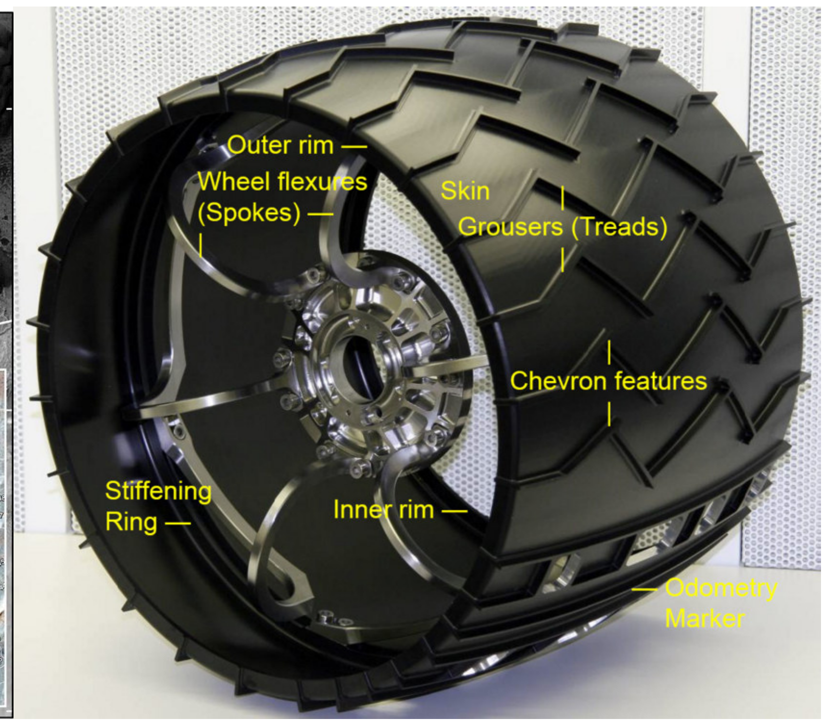
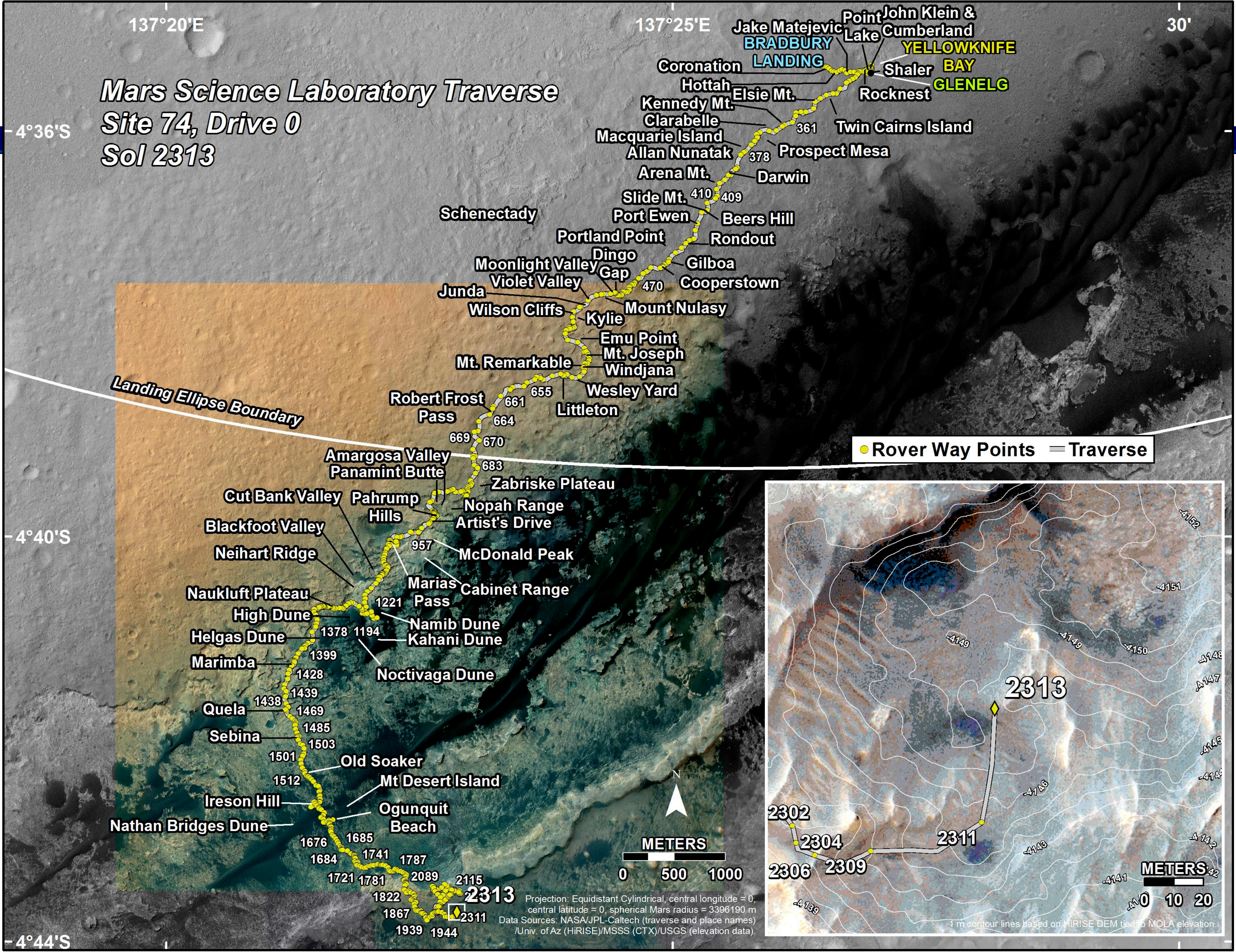
Mars Science Laboratory “Curiosity” Rover

- Landed on Mars in August 2012-- driven 13 miles (20 km)
- Six aluminum wheels were designed for mobility on loose sand, rocks perched on sand, and flat bedrock.






Mars Science Laboratory Traverse
Site 74, Drive 0
Sol 2313
137°20'E
137°25'E
30'
4°36'S
4°40'S
4°44'S
Landing Ellipse Boundary
BRADBURY LANDING
YELLOWKNIFE BAY
GLENELG
Jake Matejevic
Point Lake
John Klein & Cumberland
Shaler
Rocknest
Coronation
Hottah
Elsie Mt.
Kennedy Mt.
Clarabelle
Twin Cairns Island
Macquarie Island
Prospect Mesa
Allan Nunatak
Arena Mt.
Darwin
Slide Mt.
Beers Hill
Port Ewen
Rondout
Schenectady
Portland Point
Dingo Gap
Gilboa
Moonlight Valley
Violet Valley
Cooperstown
Junda
Mount Nulasy
Wilson Cliffs
Kylie
Emu Point
Mt. Joseph
Mt. Remarkable
Windjana
Wesley Yard
Robert Frost Pass
Littleton
Amargosa Valley
Panamint Butte
Zabriske Plateau
Cut Bank Valley
Pahrump Hills
Nopah Range
Artist's Drive
Blackfoot Valley
McDonald Peak
Neihart Ridge
Marias Pass
Cabinet Range
Naukluft Plateau
High Dune
Namib Dune
Helgas Dune
Kahani Dune
Marimba
Noctivaga Dune
Quela
Sebina
Old Soaker
Mt Desert Island
Ireson Hill
Ogunquit Beach
Nathan Bridges Dune
361
378
410
409
470
655
661
664
669
670
683
957
1221
1378
1194
1399
1428
1439
1438
1469
1485
1503
1501
1512
1676
1685
1684
1741
1787
1721
1781
2089
2115
1822
2313
1867
2311
1939
1944
Rover Way Points
Traverse
METERS
0
500
1000
Projection: Equidistant Cylindrical, central longitude = 0, central latitude = 0, spherical Mars radius = 3396190 m
Data Sources: NASA/JPL-Caltech (traverse and place names) /Univ. of Az (HiRISE)/MSSS (CTX)/USGS (elevation data).
2313
2302
2304
2306
2309
2311
-4152
-4151
-4149
-4150
-4148
-4147
-4145
-4144
-4146
-4143
-4142
-4141
-4139
METERS
0
10
20
1 m contour lines based on HiRISE DEM tied to MOLA elevation.

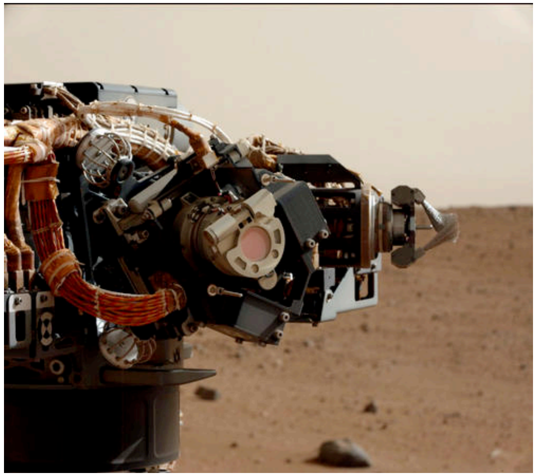
Simulation vs. Operation

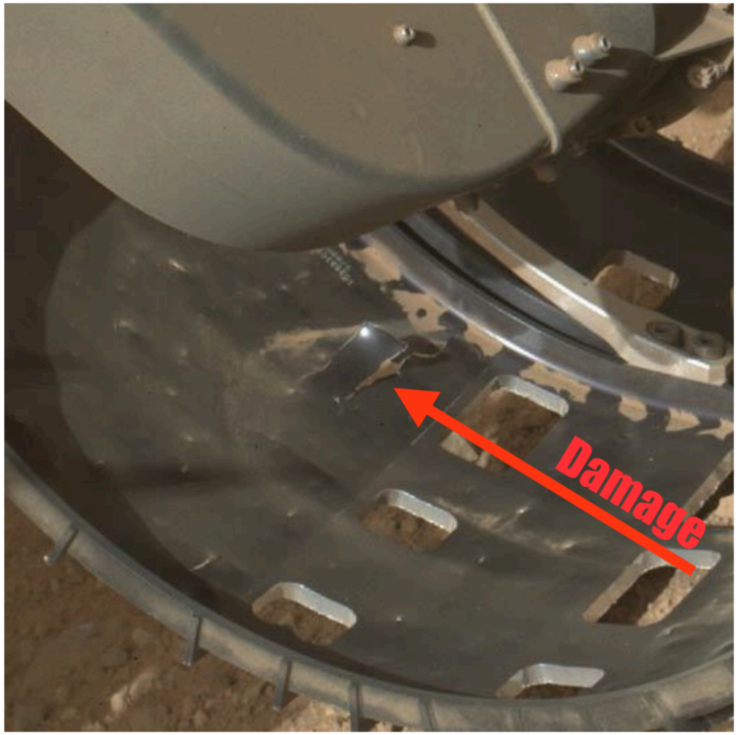
← JPL Mars Yard

Mars Ops →

Anomaly Detection

- MAHLI camera on the rover's robotic arm periodically checks the condition of the wheels →





← Detail view of the inner surface of Curiosity's left front wheel on sol 411. Arrow points to tear

Wheel Wear Progression

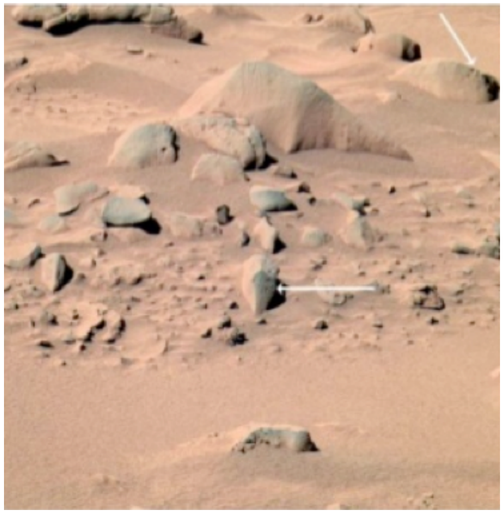
- By sol 463 (11/24/13), a large rip had opened above the Morse-code holes in the left front wheel that was much larger than expected and exceeded any damage seen in testing
- The progressive damage to MSL wheels has continued (image below left)

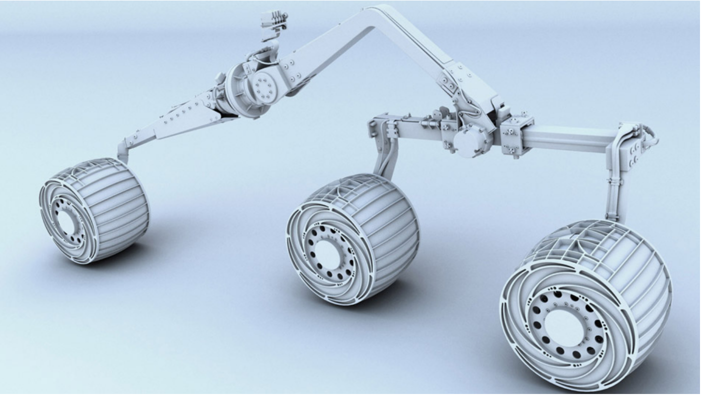
← MAHLI full-wheel imagery of Curiosity's left-middle wheel taken on April 18, 2016 (sol 1,315)

Proximate Cause

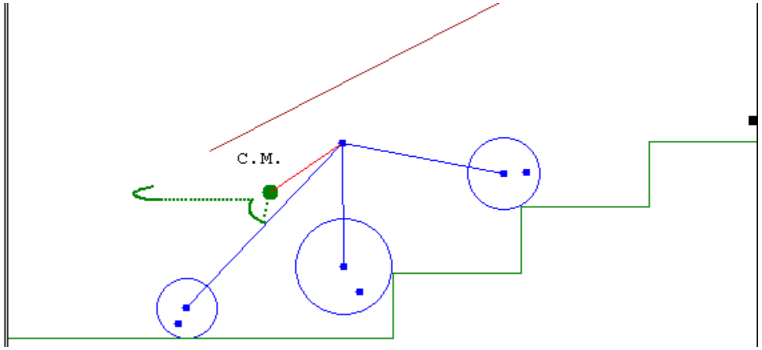
- The impact of ventifacts is exacerbated by a dynamic mechanical load on the wheels

White arrows point to ventifacts found in the Gusev plains →





The rocker-bogie mobility system (the wheels surmounts the face of a vertical obstacle (rock) by having the center and rear wheels force the front wheels against the obstacle

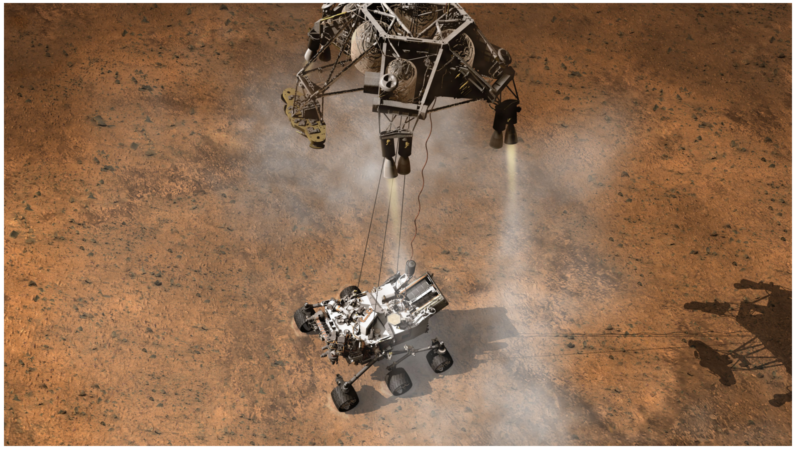


http://i.stack.imgur.com/qcnqs.gif

Mitigations on Mars

- Corrective actions to prevent further wheel damage:
  - Track wear progression and drive so as to minimize wear
    - Avoid hard surfaces and ventifacts
    - Drive backwards on “wheel hostile” terrain
- These measures have proven effective in managing the rate of damage: the rover will be able to complete its extended mission-- and likely further mission extensions
  - Will slow Curiosity’s progress and limit it’s paths

Landing touchdown loads were expected to be the worst case wheel failure mode →



Lessons Learned & Preferred Practices

- **Lesson**: Terrain matters! Wheel life testing under-represented the prevalence of ventifacts to be encountered
- **Practice**: Testing should encompass the anticipated mission environment with ample margin
- **Lesson**: The test program focused more on *static* loads rather than the *dynamic* mechanical loads on the wheels
- **Practice**: Heed the JPL design maxim of *"Test as you fly, fly as you test"*

"When we conduct tests on Earth with the best analogues that we can find, we believe that they will behave in a certain way. But Mars doesn't have to agree with us. So one of the difficulties is that the Mars material is just fundamentally unknown. But to be blunt, if it were all known then we wouldn't need to go there."

- Fuk K. Li, Director, JPL Mars Exploration Directorate