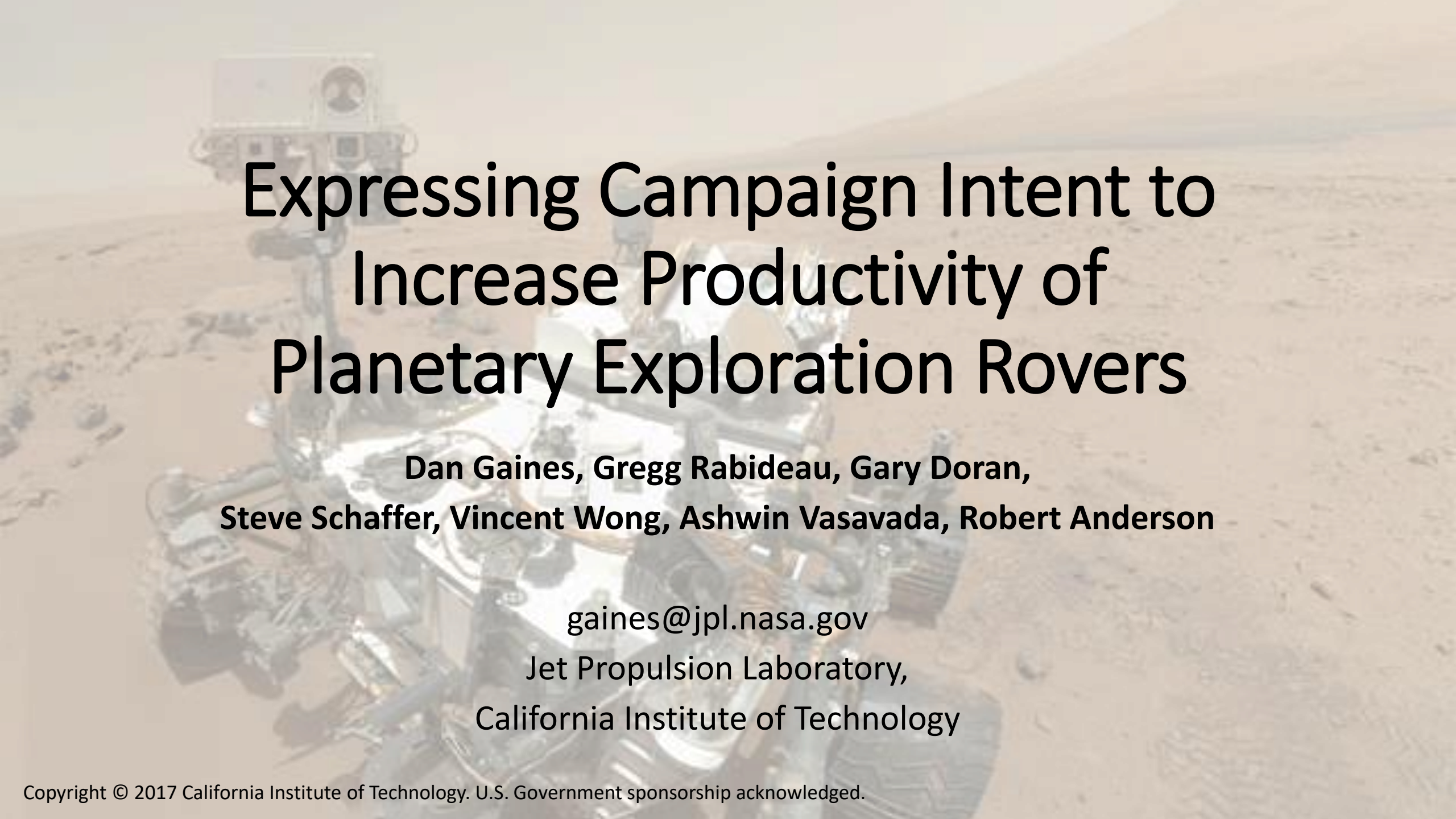

# Expressing Campaign Intent to Increase Productivity of Planetary Exploration Rovers

**Dan Gaines, Gregg Rabideau, Gary Doran,**
**Steve Schaffer, Vincent Wong, Ashwin Vasavada, Robert Anderson**

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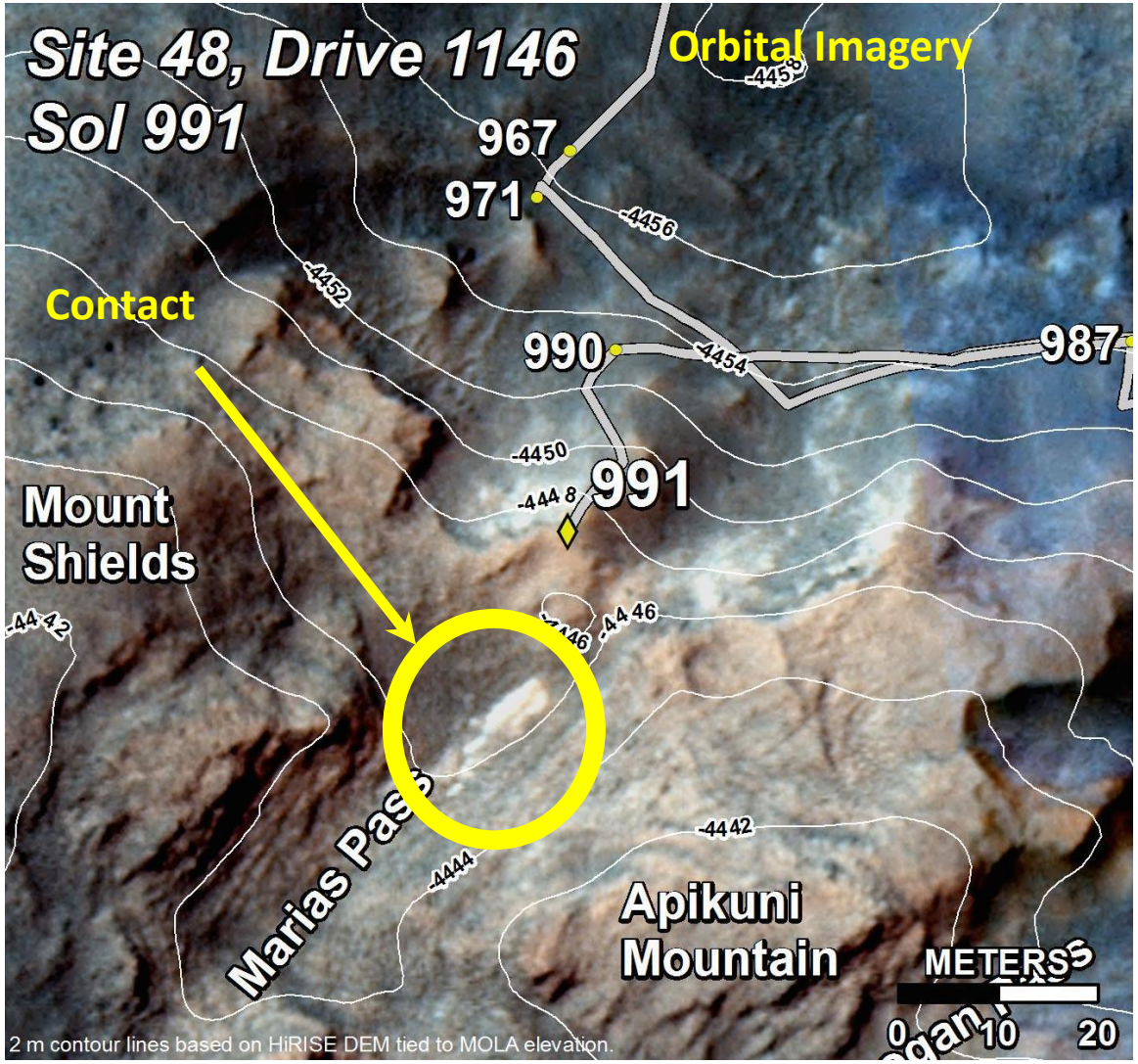
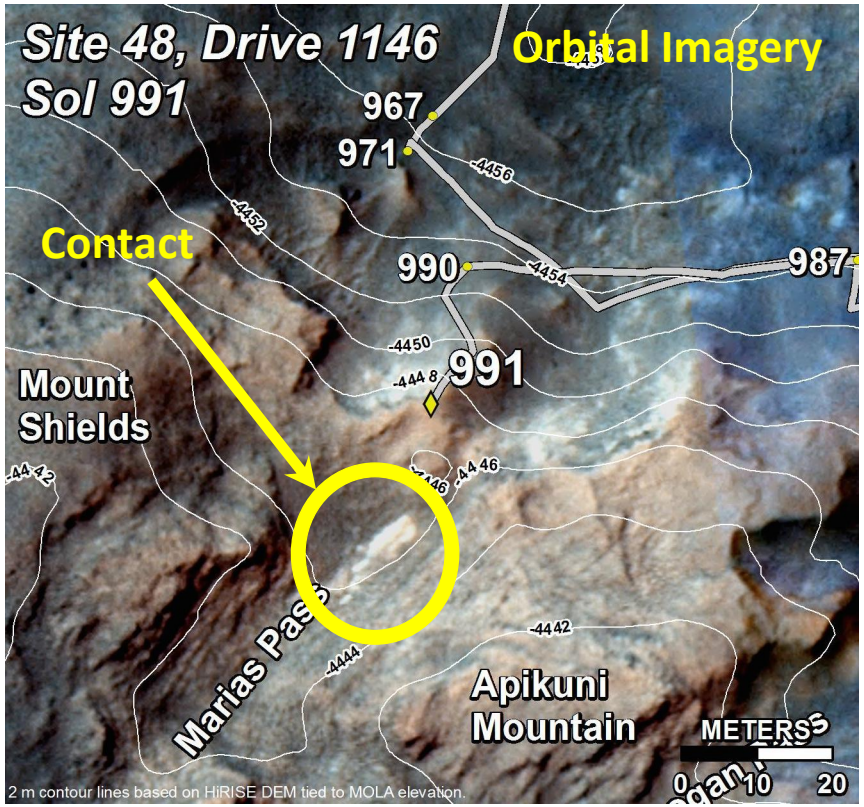
California Institute of Technology

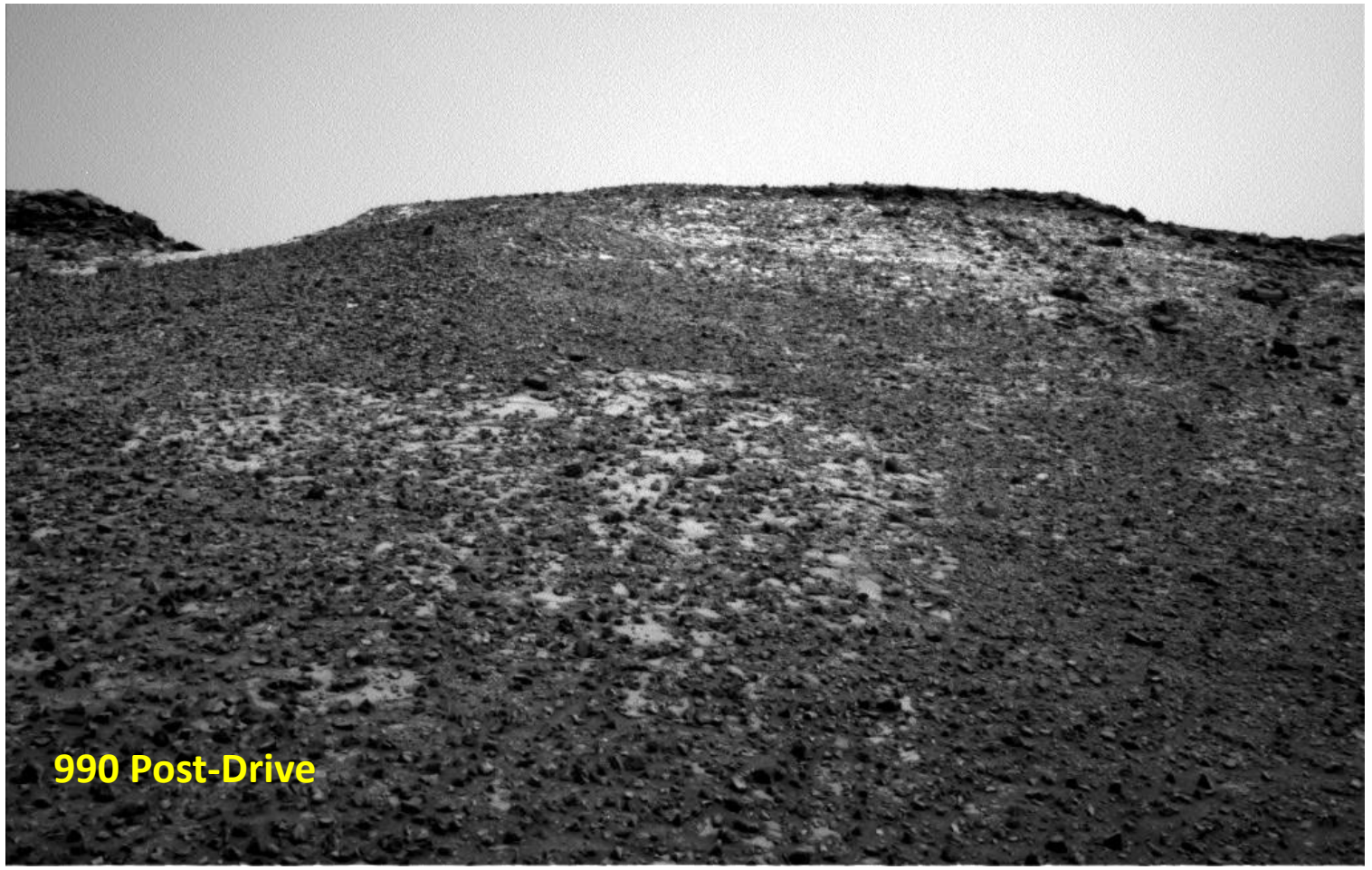
# Illustrative Campaign: MSL Marias Pass Campaign




Objective: explore contact between the Murray and Stimson formations

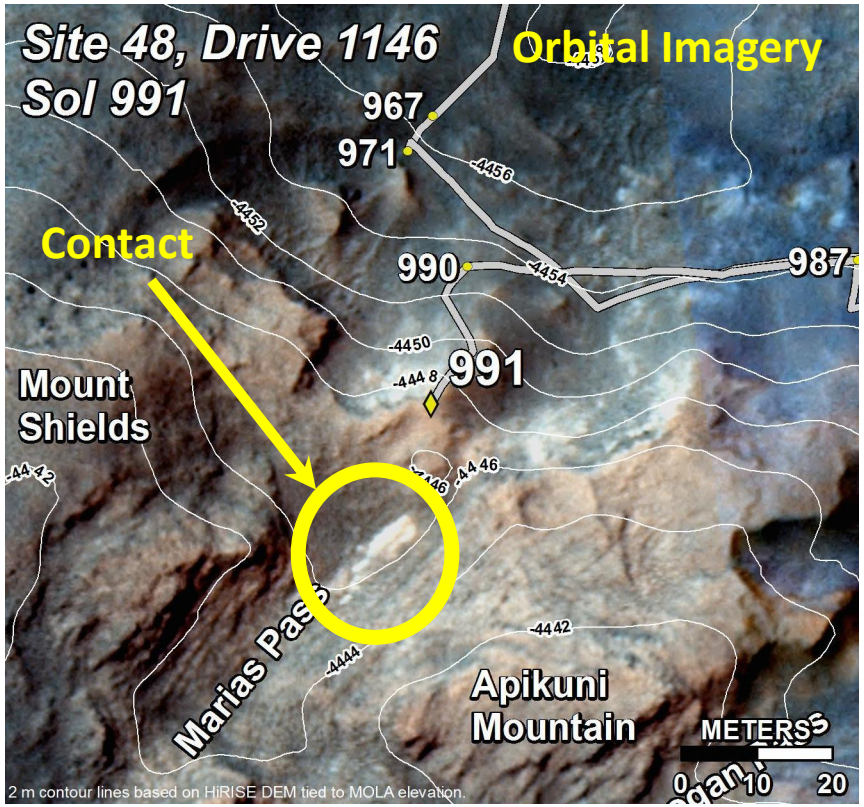
# MSL Marias Pass Campaign

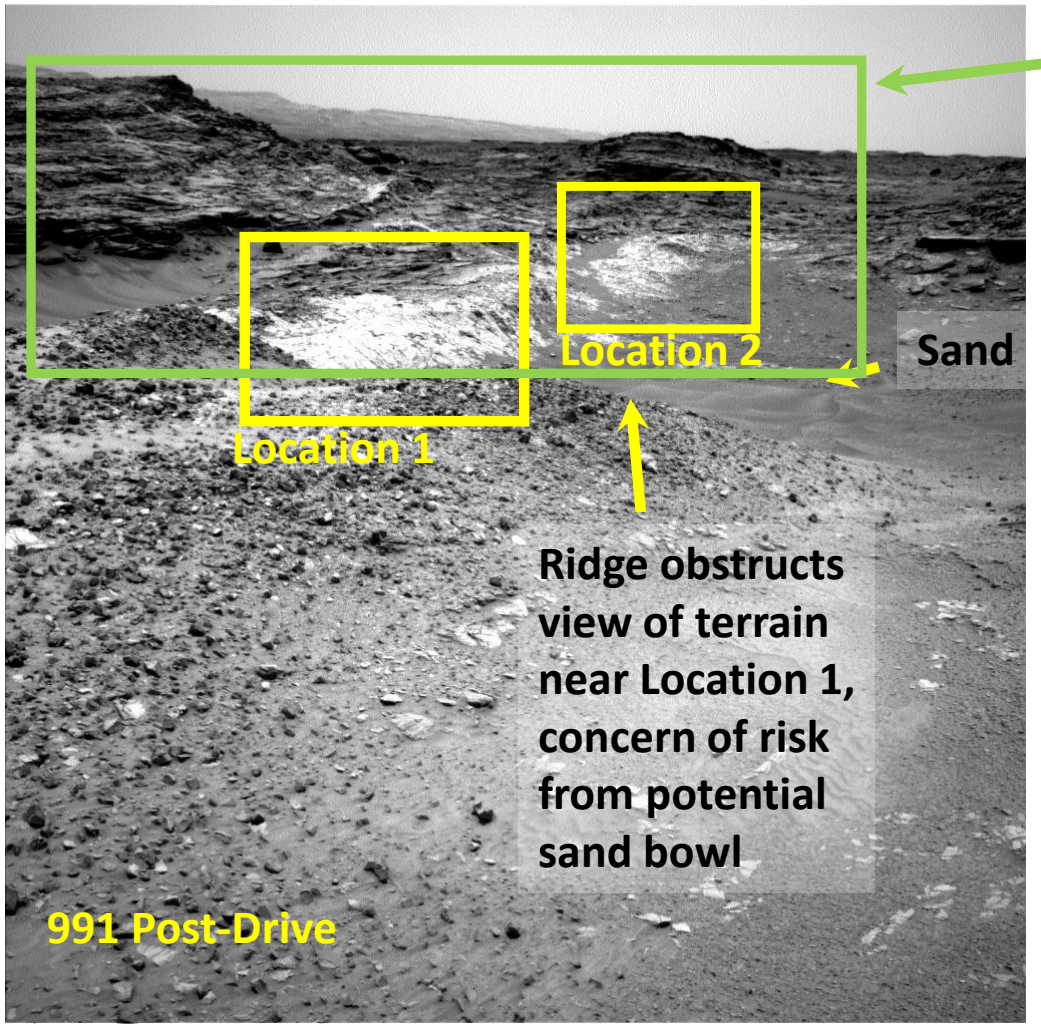



Sol 991: Rover's view prior to arriving at the contact, view of contact blocked by hill

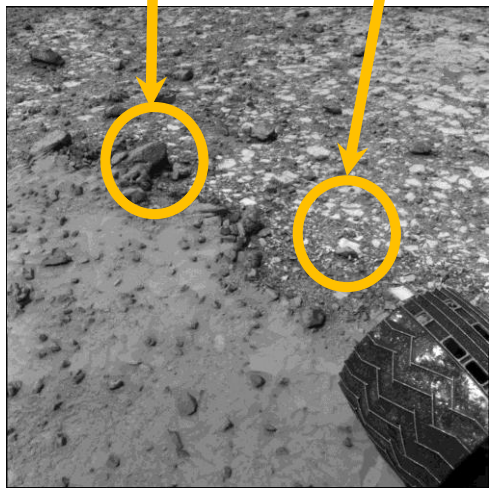
# MSL Marias Pass Campaign




Example observations planned:

- Mastcams of formations and contact
- ChemCam of light-toned rock, and dark rock, samples of area leaving and area entering

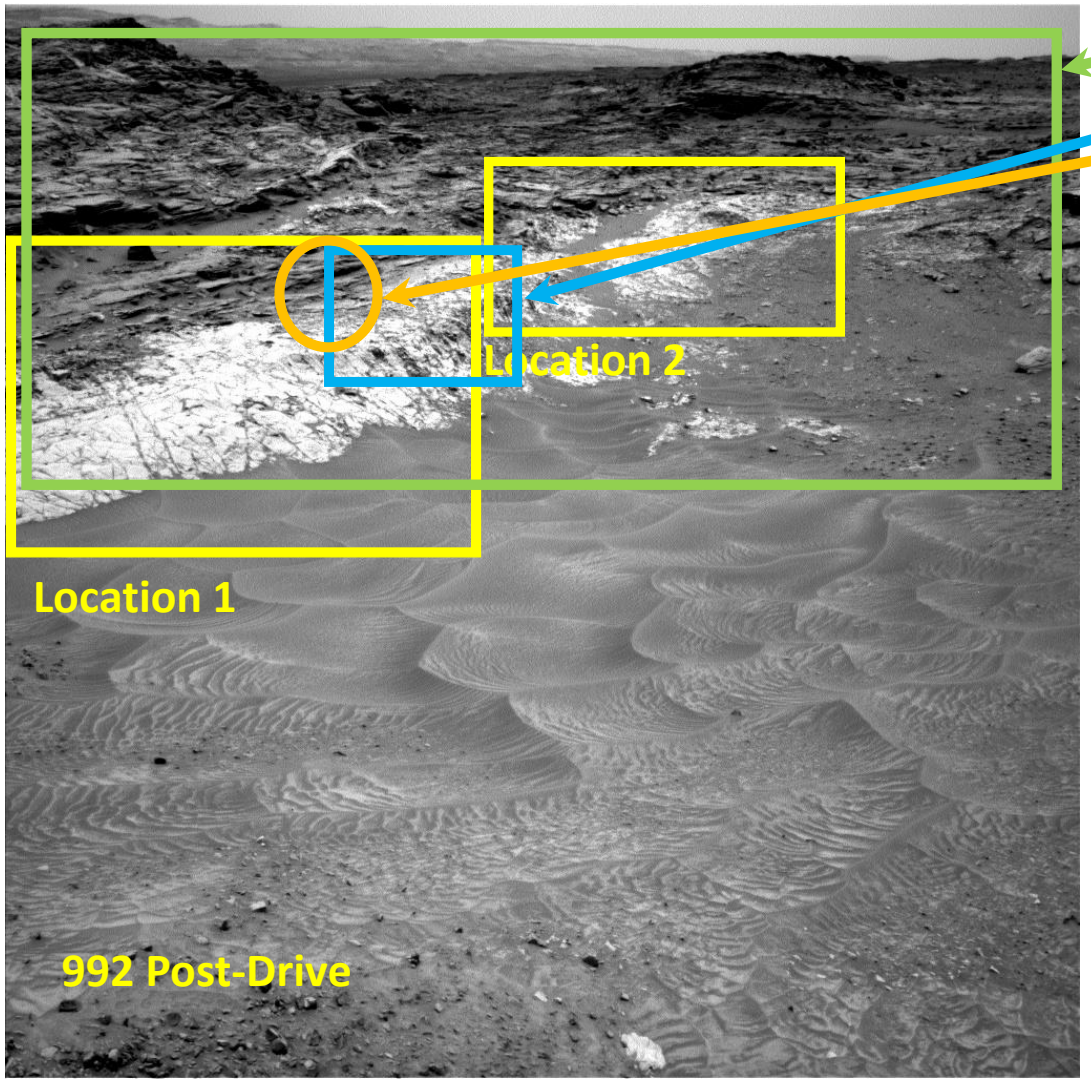


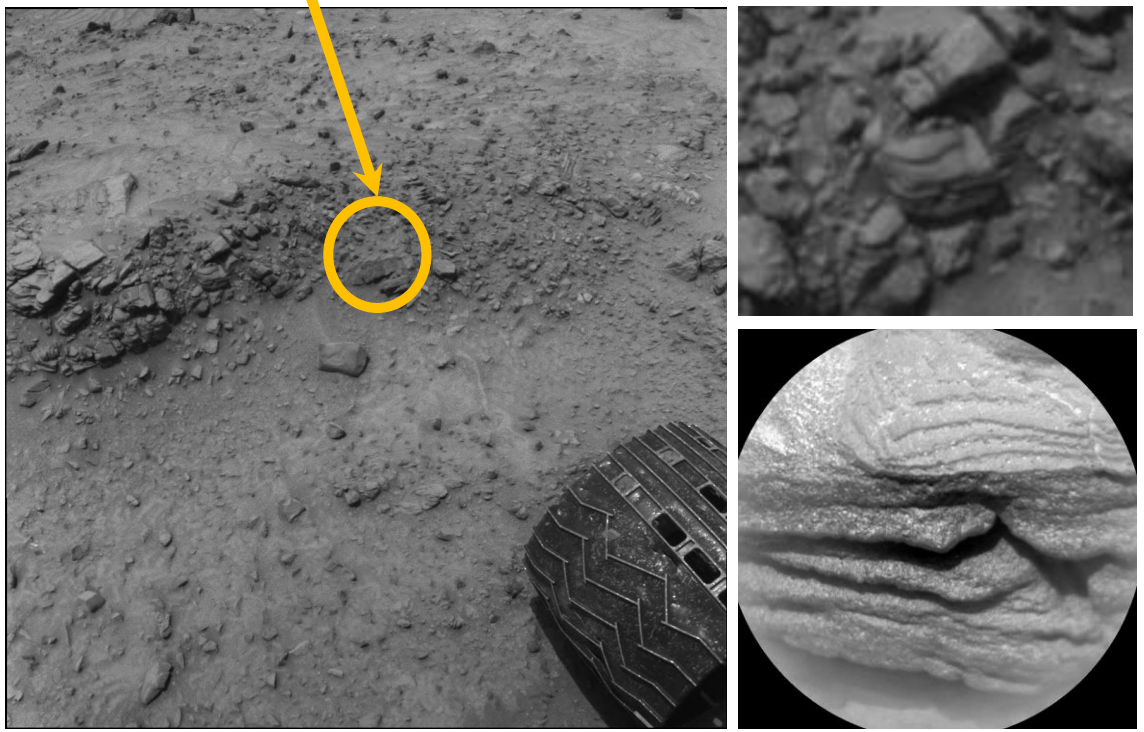
Sol 992: First view of contact, scientists identify areas of interest, but unable to plan drive to desired location due to incomplete terrain knowledge

# MSL Marias Pass Campaign

Example observations planned:

- Mastcams of formations and contact
- Mastcam multispectral of contact
- ChemCam of contact
- ChemCam of layered rock
- Periodic atmospheric opacity
- Mastcams of Deimos eclipse
- Instrument calibrations



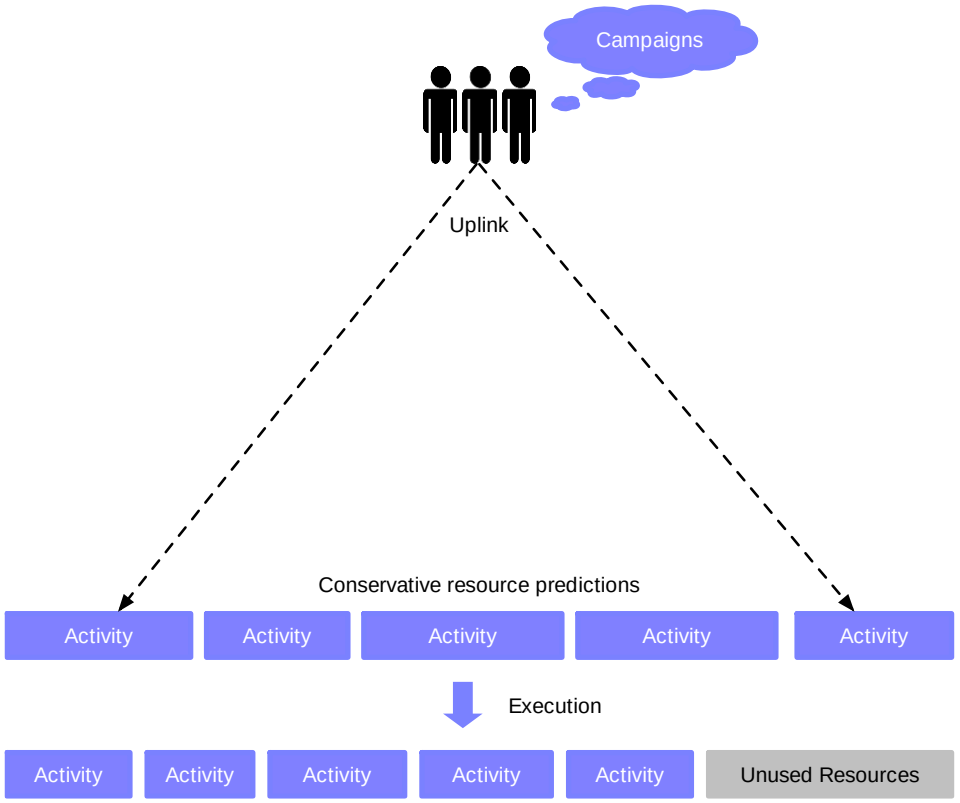



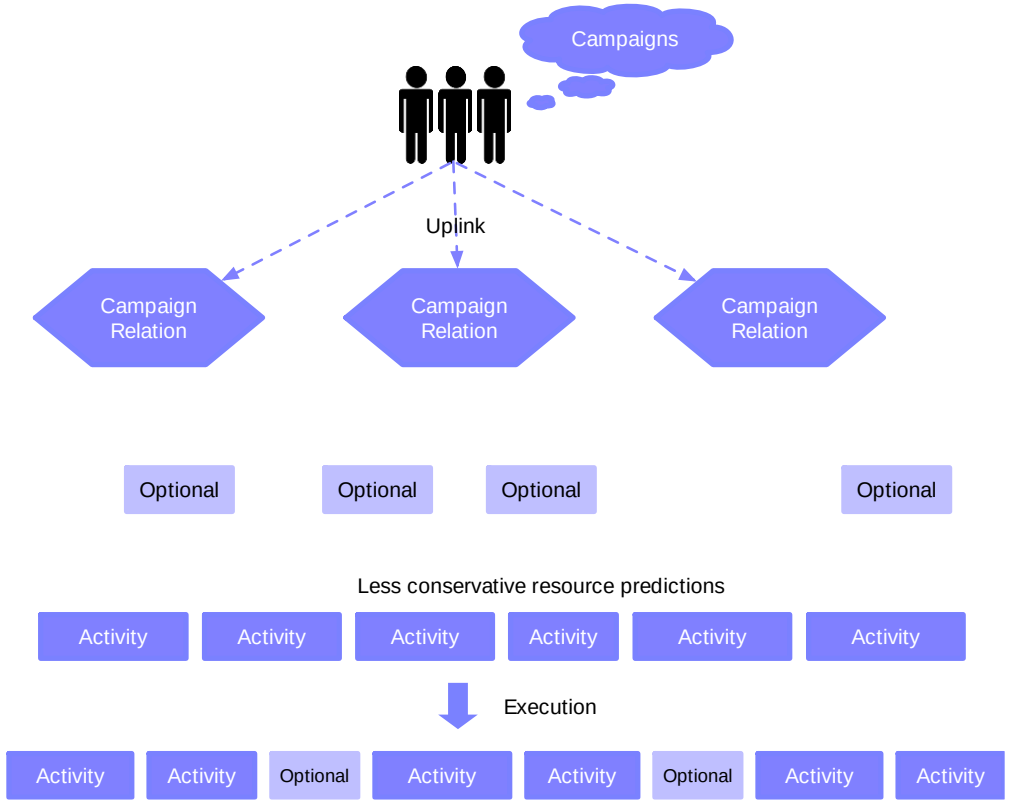
Sol 993-996: Extended plan for Memorial Day weekend, full view of contact, sand blocks approach to Location 1, planned drive around sand to Location 2

# Observations from Marias Pass Campaign

- High reliance on ground-in-the-loop decision making
  - Drive planning to avoid sand hazards
  - Targeting of science observations
  - Selection of specific activity to fit within predicted vehicle resources
- Multiple objectives competing for vehicle resources
  - Stimson formation, Murray formation, contact between formations
  - Interesting features: light toned rocks, layered rocks, veins, fractures
  - Atmospheric observations
  - Engineering maintenance activities: instrument calibrations, various rover maintenance activities and monitoring
- Value of activities depend on one another
  - Multiple samples of each formation and across contact
  - Repeated atmospheric observations across diurnal cycle and over sols / seasons
  - Cadence of various engineering maintenance activities
- Productivity challenges
  - Difficult to accurately predicting resource requirements of activities (e.g. duration, energy)
  - Reduced ground-in-the-loop cycles results in significant reduction in productivity

# Comparison with Current Operations




## Current operations

- Detailed planning on the ground
- Conservative resource allocations to avoid over-subscription
- No onboard knowledge of relationships among activities
- Results in unused vehicle resources

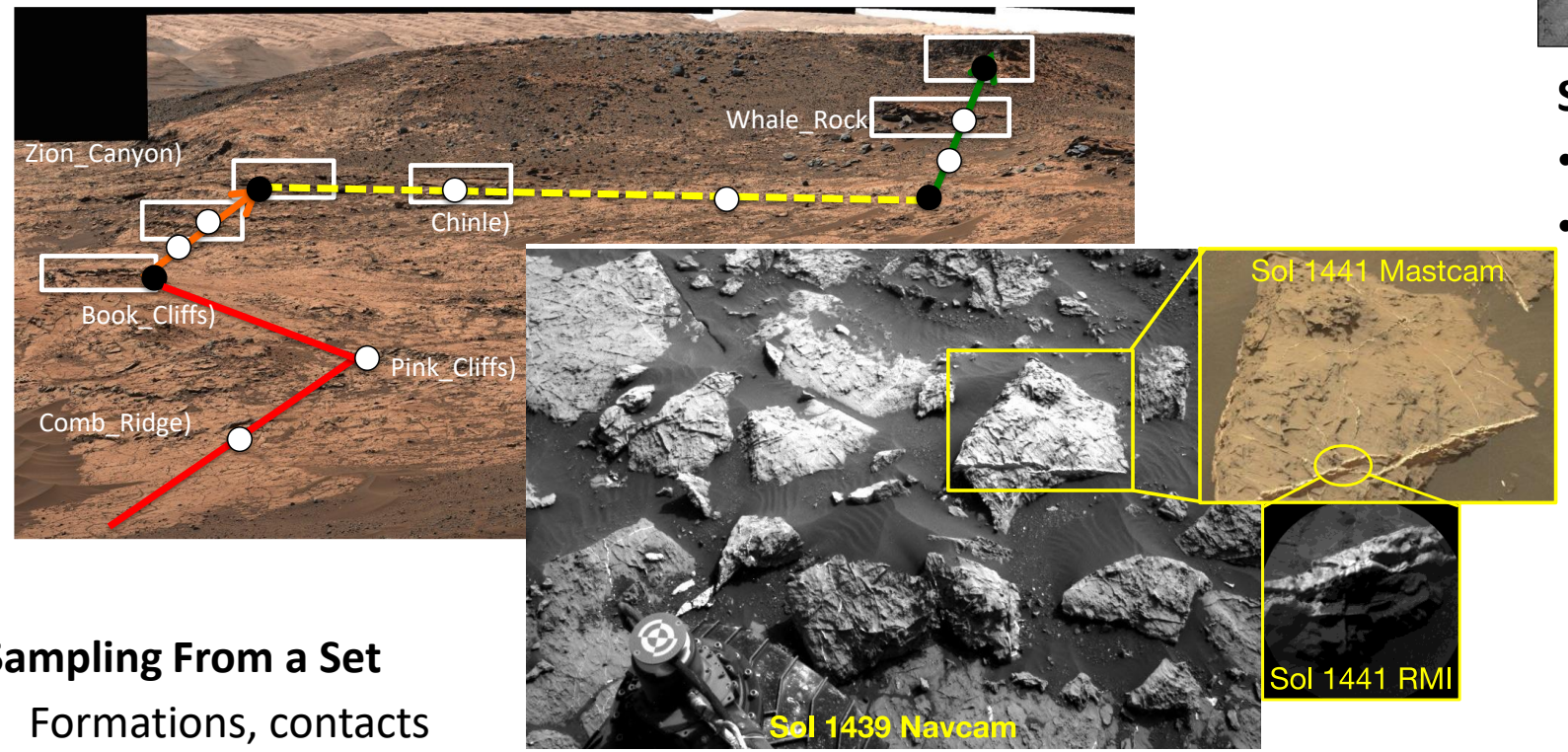
## Our approach

- Onboard planning, resource management
- Less conservative modeling, over-subscribe vehicle
- Campaign intent expresses relations among activities
- Results in increased resource use

# Identifying Campaign Intent

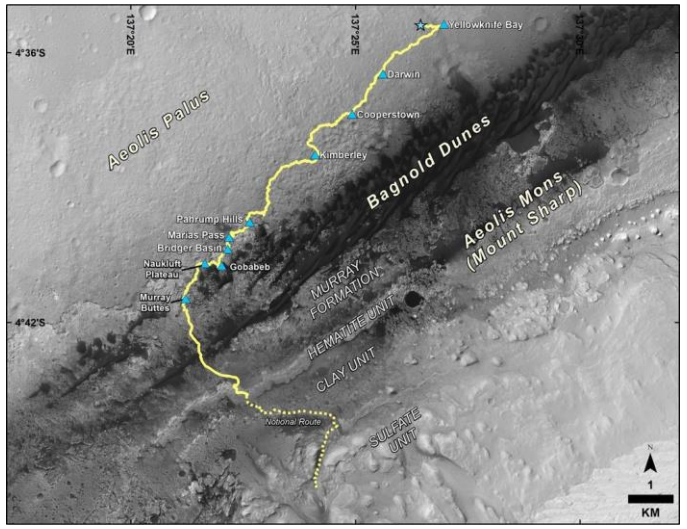
**Campaign Intent**

- Specifies relationships among activities
- Informs selection of activities to meet mission objectives



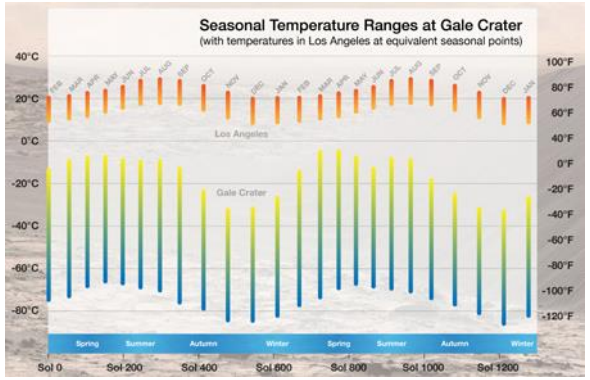

**Sampling From a Set**

- Formations, contacts
- Veins, light/dark toned rocks
- Textures, layers




**State-Based Sampling**

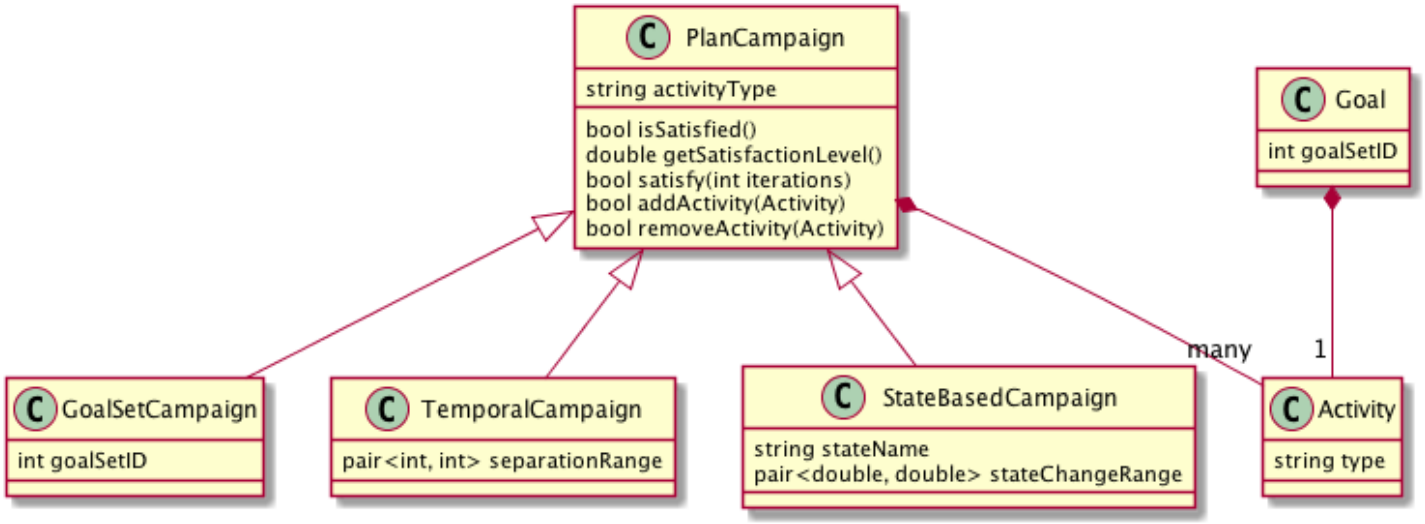
- Drilling at varying elevations
- Surveys over rover traverse




**Temporally-Periodic Sampling**

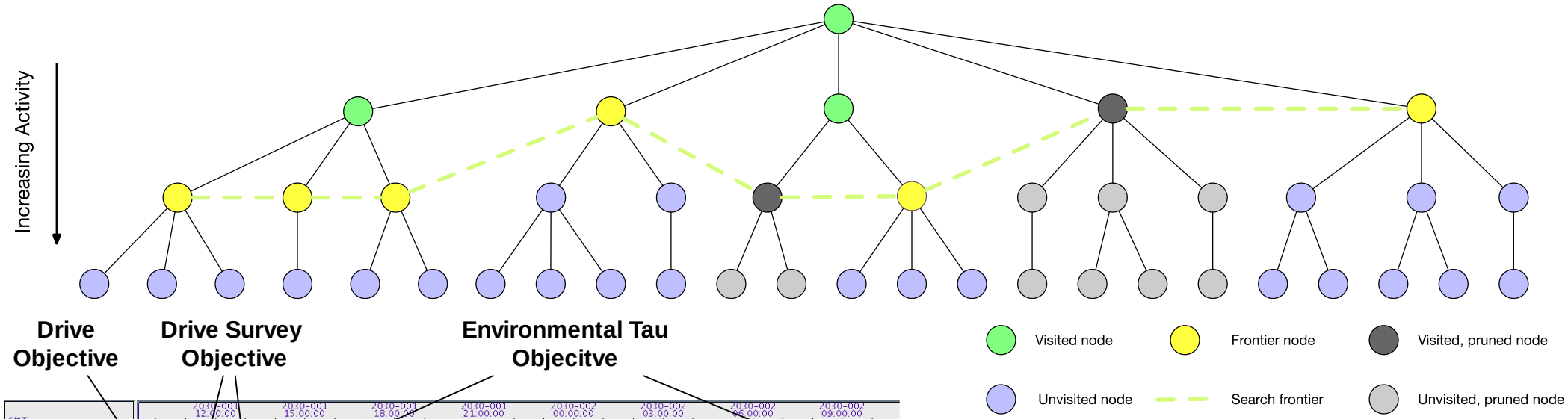
- Across diurnal cycle
- Over seasons
- Periodic vehicle maintenance

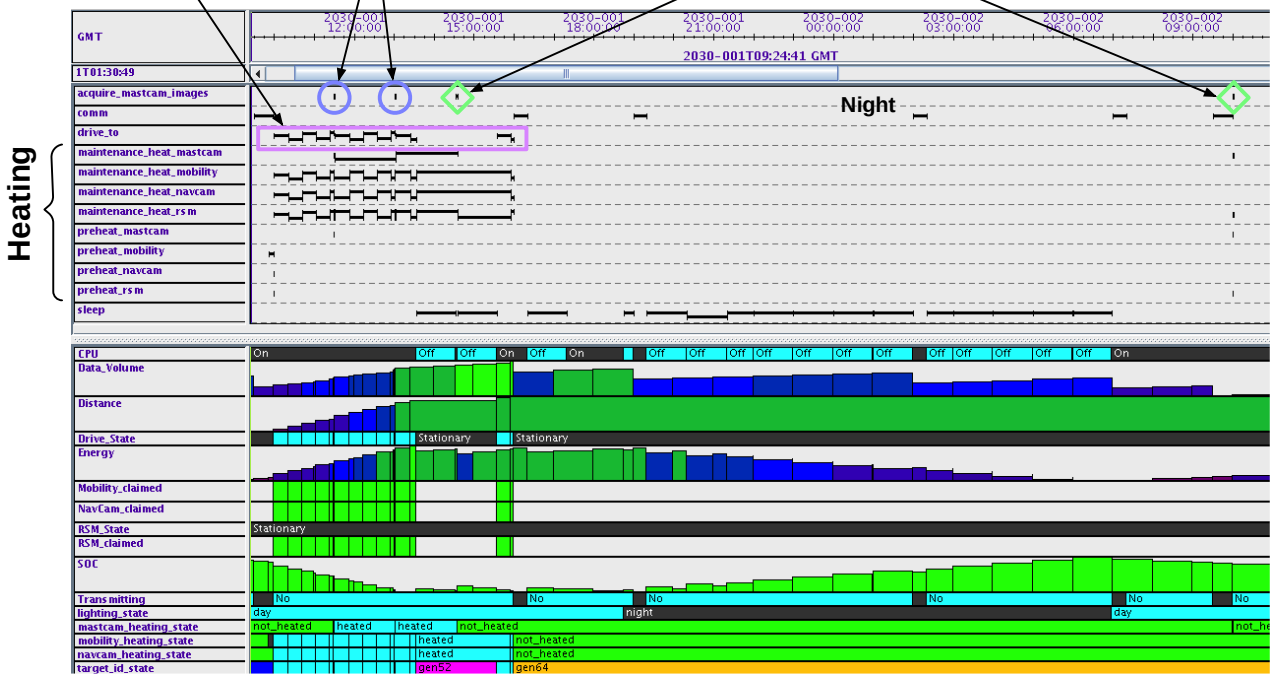
# Expressing Campaign Intent




- **Goal Set Campaign**
  - Activities scheduled from a defined group
  - Value is a function of number achieved within group
- **Temporal Campaign**
  - Activities scheduled based on temporal separation preferences
  - Value is a function on compliance with requested cadence
- **State-Based Campaign**
  - Activities scheduled based on state-change separation preferences
  - Value is a function on compliance with requested separation

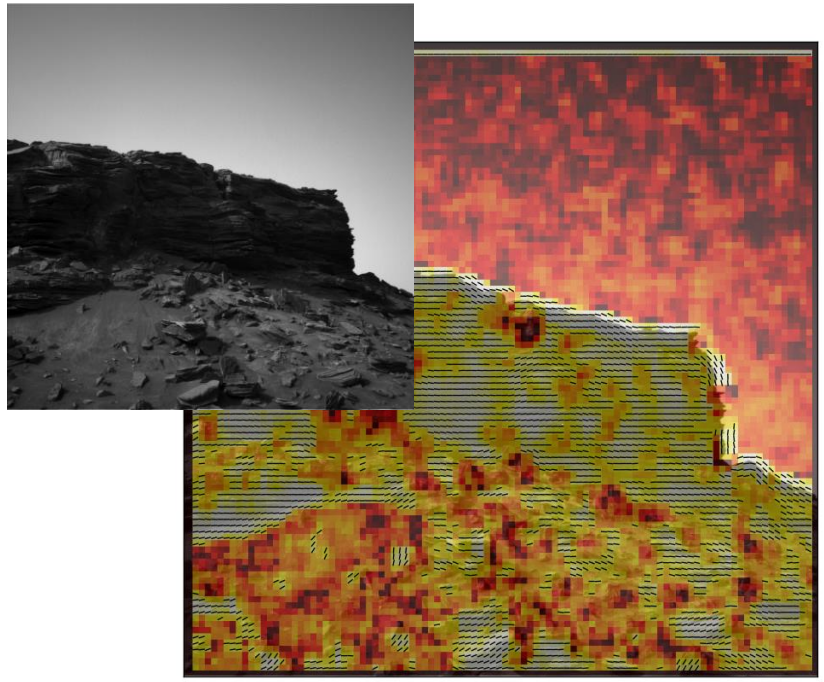
# Using Campaign Intent – Planning



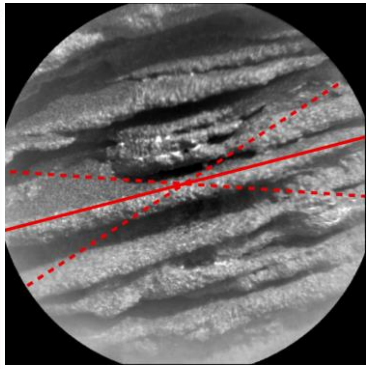




- Best-first branch-and-bound search
  - Node utility based on priorities of goals in plan and satisfaction of campaign intent preferences
- Example plan illustrating managing competing objectives and resources
  - Science objectives
    - Strategic drive
    - Drive survey every 50m
    - Tau every 5.5hr
  - Resource management
    - Thermal, battery SOC, data volume

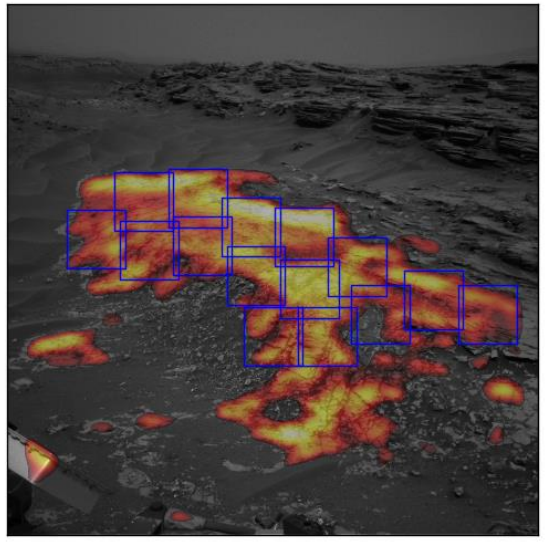
# Using Campaign Intent – Autonomous Science



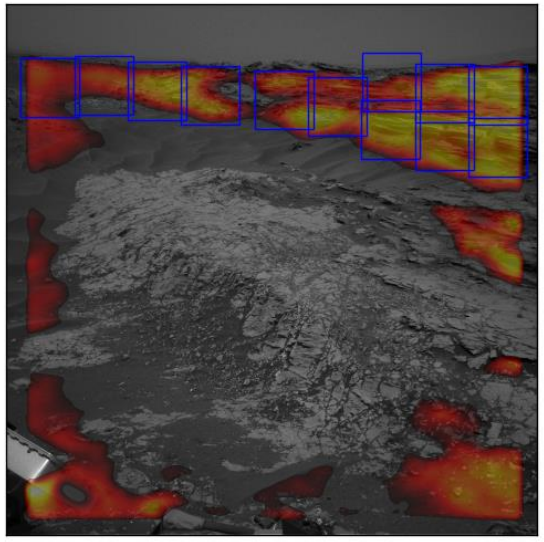
Murray Buttes layers



RMI layers

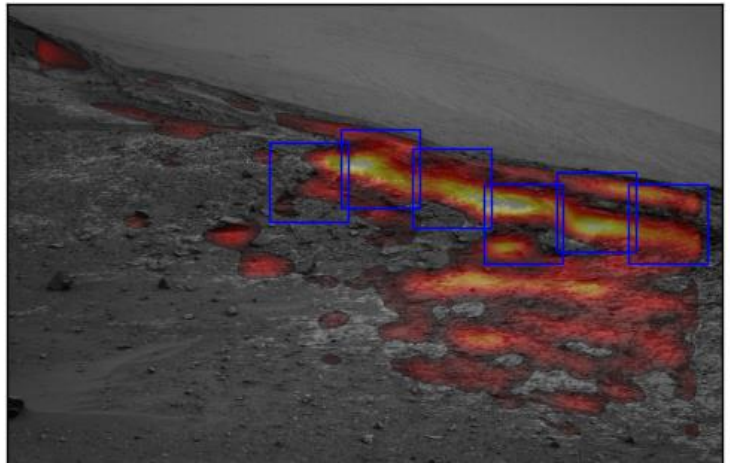


**Murray formation**:
Light-toned mudstone



**Stimson formation**:
Darker-toned sandstone

- Campaign guides use of autonomous science techniques
  - Layer detection
    - FOLD (gradient analysis)
  - Formation, contact detection
    - TextureCam (decision trees)
  - Target selection
    - AEGIS (edge detection, feature extraction)



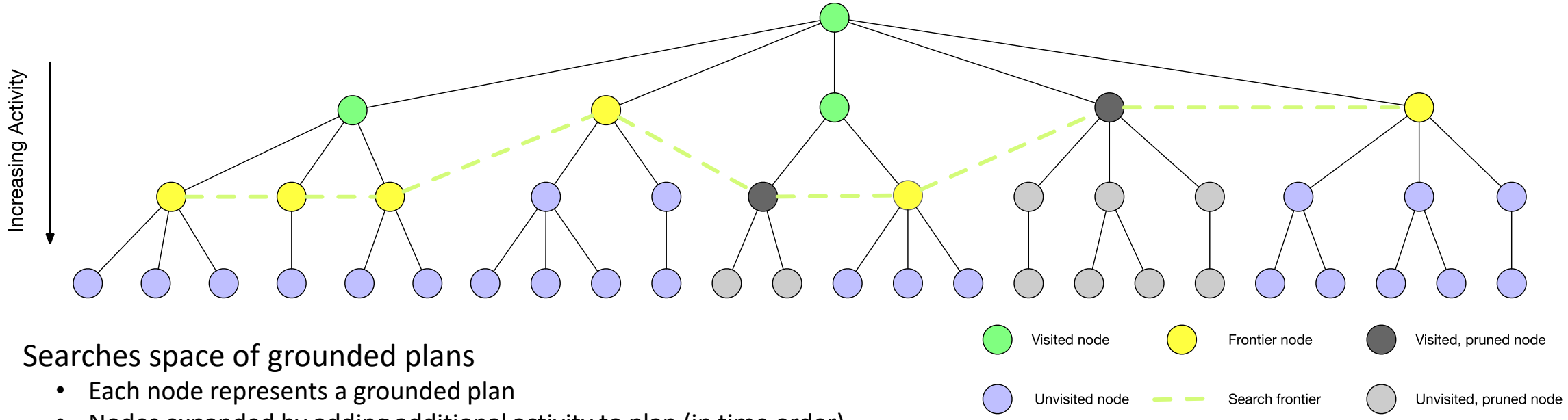
**Murray-Stimson Contact**

# Conclusions

- Identified campaign intent to express mission objectives
  - Relationships among activities
  - Derived from MSL mission plans
- Using campaign intent to guide onboard decision making
  - Increased quality of generated plans
  - Use of autonomous science to meet science objectives
- Future work
  - Incorporating campaign intent into integrated autonomous rover architecture
    - Planning, execution, autonomous science, navigation, health management
  - Will be conducting evaluations in realistic, multi-sol scenarios

# Backup

# Pathogen Search




- Searches space of grounded plans
  - Each node represents a grounded plan
  - Nodes expanded by adding additional activity to plan (in time order)
- Each visited node evaluated to assign utility
  - Based on priorities of goals in plan and satisfaction of campaign intent preferences
  - Keeps track of node with current highest utility
- Frontier nodes expanded in best-first utility order
  - Frontier nodes sorted intermittently, thus technically this is stochastic hybrid of best-first and depth-first search
- Node (and children) pruned if best possible utility is less than current highest utility
  - Best possible utility: sum of current utility achieved plus potential future utility of all still-feasible goals not yet in plan
  - Feasibility based on admissible heuristic check on whether adding goal would cause a conflict