LEAG LROC Special Action Team

Final Report

May 12, 2009

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LEAG LROC SAT TEAM

- Chair, Paul G. Lucey, U. Hawaii
- Science Subgroup
  - Jeffrey Gillis-Davis, U. Hawaii
  - B. Ray Hawke, U. Hawaii
- ISRU subgroup
  - Larry Taylor, U. Tenn, Knoxville
  - Mike Duke, At-large lunar scientist
- Operations subgroup
  - Tye Brady, Draper Lab
  - Todd Mosher, Sierra Nevada Corporation
- Observers
  - Mike Wargo, NASA
  - Steve Mackwell, LPI
  - Clive Neal, LEAG

LEAG LROC SAT Tasking

From LEAG LROC Charter:

- Reprioritization between Tiers 1 and 2, if deemed appropriate
- Additional suggested targets and regions of interest that could replace those identified by CxPO
- Adjustment of the target coordinates if deemed appropriate
- Suggested additional regions of interest for a lower priority ranking (i.e., “Tier 3”)

LEAG LROC SAT Report Summary

- CxPO sites individually evaluated using a uniform system of metrics covering science, ISRU and operations characteristics, and compared
- Distribution of sites with respect to geographic and geochemical distribution inspected
- Results
  - SAT concurs that the CxPO sites as a whole provide a qualitatively good sample with respect to science, ISRU and operations
  - Performance metric comparison among sites suggests reordering of Tiers 1 and 2
  - Three specific site locations were moved to improve science merit
  - One site was added in South Pole-Aitken Basin to improve science balance
  - One site was added (Peary crater) that offers “drive-in” access to permanent shadow and is representative of other large flat-floored craters with this characteristic
  - Two sites with low metric scores were deleted to maintain 50 total sites

Task 1: Reprioritization between Tiers 1 and 2, if deemed appropriate

Background:

- CxPO targets have significant community heritage
  - Exploration Systems Architecture Study (ESAS), 2005.
  - A Site Selection Strategy for a Lunar Outpost, Science and Operational Parameters, 1990.
  - Geoscience and a Lunar Base, A Comprehensive Plan for Lunar Exploration, NASA CP 3070, 1990.
- Lunar science, ISRU and operational constraints have evolved since these documents were produced

Proposed methodology to determine if reprioritization is appropriate:

  - Quantitatively evaluate in terms of science, ISRU and operations against metrics
  - Rank and compare Tier 1 and Tier 2 performance against quantitative metrics
- Results
  - As a group Tier 1 does not significantly outperform Tier 2
  - Substantial overlap in performance suggests reassignment

Task 2: Additional suggested targets and regions of interest that could replace those identified by CxPO

Quantitative comparisons reveal gaps in Cx-provided list

- Paucity of mid-latitude, polar sites
- Distribution of targets in geochemical terranes heavily weighted toward region sampled by Apollo

- Recommendation
  - <u>Add SPA and Polar sites</u>
    - Peary Crater
      - Straightforward “drive-in” access to permanent shadow
    - SPA Aitken Rim
      - Mid-latitude SPA site
      - Samples rim of transient cavity
      - Th anomaly

Task 3: Adjustment of the target coordinates if deemed appropriate

Detailed analysis of each site revealed modifications in targeting that improve scientific value of some sites

- Aristarchus region is complex and features best exposure of pure pyroclastics
  - Two CxPO sites at Aristarchus do not occur in purest pyroclastic region. This material may have unique topography that could affect operations. Recommend adjusting "Aristarchus 2" site to better sample pyroclastic deposit
- CxPO sites undersample light plains deposits
  - Mare Frigoris is unusual low iron maria with nearby very young light plains
  - Recommend moving this site to sample light plains deposit
- South-Pole Aitken center CxPO site contaminated by cryptomare
  - Recommend move to purest SPA mafic anomaly and least young basin contamination (Petro and Pieters, 2004)

Task 4: Suggested additional regions of interest for a lower priority ranking (i.e., “Tier 3”)

- CxPO targets have significant community heritage
- LEAG recommendations replace only two sites
- Recommend no addition of “Tier 3”

Detailed Results

Comparison Methodology Overview

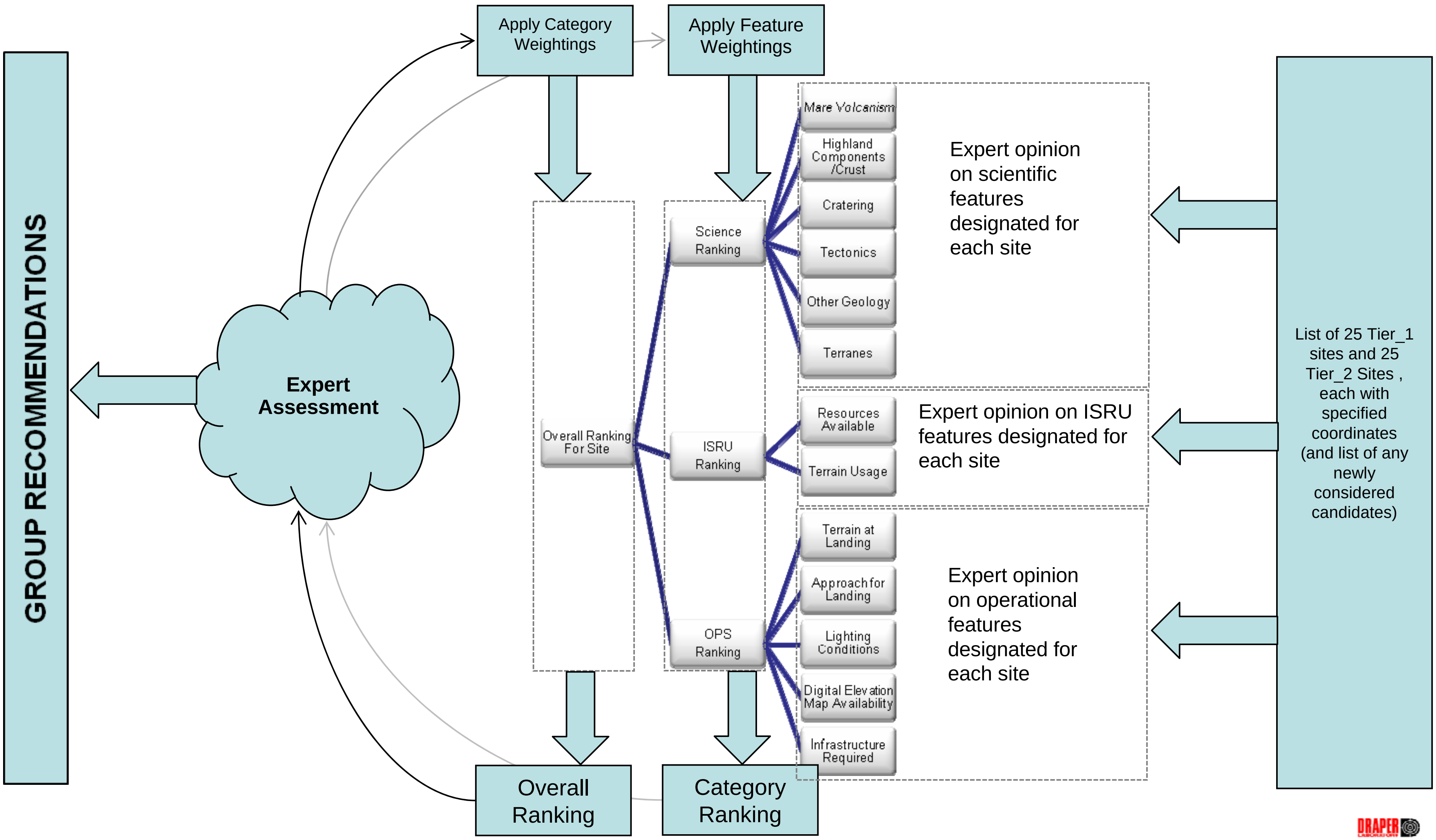
How to go from a list to a list with value

- Simple mechanical method to derive relative value via combination of low level, multiple, distinct, fundamental expert-assessed characteristics associated with each 50 sites
- Weighted, nested, spreadsheet approach *uniformly* compares sites to each other (each site has same weightings applied)
  - Derived composite score is a user configurable weighted function of:
    - Science Score
    - ISRU Score
    - Operations Score
  - Appropriate weighting has been derived by the team, but can be manipulated by stakeholder based on their values
  - Any outliers noted, inspected, and talked about
  - New sites are introduced into the system via the same metrics to see their relative score and compare their relative value
- Science, ISRU, and Ops are further broken down into individual weighted lists based on fundamental characteristics of the scored sites
  - Science: geological characteristics
  - ISRU: potential resources available
  - OPS: evaluation of site as if landing site
- Value is added by having each site characterized by experts at lowest level, with expert-defined weighting yielding a uniform high level product

LANDING TARGETS					TIER		SUMMARY SCORES			WEIGHTED SUMMARY	
Num	Name	Long	Lat	N/F/P	1	2	SCI	ISRU	OPS	WTOT	WGRADE
1	Alphonsus Crater	-2.16	-12.56	N	x		84	94	86	87.7	A
2	Aristarchus 1	-48.95	24.56	N	x		82	93	79	84.4	A
3	Copernicus Crater	-20.01	9.85	N	x		79	90	84	84.2	A
4	Orientale 1	-95.38	-26.20	F	x		87	81	80	82.6	A
5	Tycho Crater	-11.20	-42.99	N	x		79	83	86	82.4	A
6	North Pole	76.19	89.60	P	x		73	83	86	80.7	A
7	Apollo 15	3.66	26.08	N	x		77	91	74	80.7	A
8	Apollo 16	16.47	-9.00	N		x	74	84	84	80.5	A
9	Mare Crisium	58.84	10.68	N		x	79	84	78	80.3	A
10	Malapert Massif	-2.93	-85.99	P	x		73	83	85	80.1	A
11	Bullialdus Crater	-22.50	-20.70	N		x	74	84	82	80.0	B
12	Aristarchus 2	-52.90	25.68	N	x		74	93	73	80.0	B
13	Gruithuisen Domes	-40.14	36.03	N	x		74	91	75	79.9	B
14	Anaxagoras Crater	-9.30	73.48	N		x	75	79	86	79.9	B
15	Rima Bode	-3.80	12.90	N	x		75	87	79	79.9	B
16	South Pole	-130.00	-89.30	P	x		73	83	83	79.6	B
17	Stratton	166.88	-2.08	F		x	74	79	85	79.2	B
18	King Crater	119.91	6.39	F		x	70	79	89	79.1	B
19	Ina ('D-caldera')	5.29	18.65	N	x		75	88	74	79.1	B
20	Murchison Crater	-0.42	4.74	N		x	68	84	86	79.0	B
21	Apollo Basin	-153.72	-37.05	F		x	84	81	73	79.0	B
22	Orientale 2	-87.91	-18.04	N	x		78	81	79	78.9	B
23	Ingenii	164.42	-35.48	F	x		76	88	73	78.9	B
24	Hertzsprung	-125.56	0.09	F		x	75	81	80	78.7	B
25	Aitken Crater	173.48	-16.76	F		x	74	84	78	78.5	B
26	Tsiolkovsky Crater	128.51	-19.35	F	x		73	82	80	78.3	B
27	Flamsteed Crater	-43.22	-2.45	N	x		74	93	67	78.1	B
28	Sulpicius Gallus	10.37	19.87	N		x	72	86	76	78.0	B
29	Dante Crater	177.70	26.14	F	x		68	86	80	78.0	B
30	Balmer Basin	69.82	-18.69	N		x	73	82	79	78.0	B
31	Van De Graaf Crater	172.08	-26.92	F	x		72	81	80	77.5	B
32	Mutus Crater	30.85	-63.77	N		x	69	81	81	77.1	B
33	Riccioli Crater	-74.28	-3.04	N		x	75	84	73	77.0	B
34	Humboldtianum Basin	77.14	54.54	N		x	75	83	74	76.9	B
35	South Pole-Aitken Basin Interior	-159.94	-50.76	F	x		72	82	77	76.9	B
36	Schrödinger	138.77	-75.40	F		x	79	83	69	76.8	B
37	Plato Ejecta	-5.21	53.37	N		x	73	82	76	76.8	B
38	Mare Moscoviense	150.47	26.19	F		x	72	83	74	76.5	B
39	Montes Pyrenaeus	40.81	-15.91	N	x		74	82	73	76.3	B
40	Mare Frigoris	40.74	55.45	N		x	82	83	64	76.1	B
41	Compton/Belkovich Th Anomaly	99.45	61.11	F		x	70	81	77	75.8	B
42	Rimae Prinz	-41.72	27.41	N		x	69	87	71	75.3	B
43	Mare Smythii	85.33	2.15	N	x		72	84	67	74.4	C
44	Lichtenberg Crater	-67.23	31.65	N		x	75	82	66	74.1	C
45	Reiner Gamma	-58.56	7.53	N	x		73	82	67	74.0	C
46	Mare Tranquillitatis	22.06	6.93	N	x		71	84	67	73.9	C
47	Hortensius Domes	-27.67	7.48	N		x	70	84	67	73.6	C
48	Marius Hills	-55.80	13.58	N	x		70	82	67	73.1	C
49	Mendel-Rydberg Cryptomare	-93.07	-51.14	N		x	68	80	70	72.6	C
50	Schickard	-53.96	-44.05	N		x	69	82	66	72.2	C

Comparison Methodology Overview (Illustrated)

Illustrated graphically (right to left is the process)



Preliminary Results: Ranking by Individual Scores

Tier 1

LANDING TARGETS					TIER		SUMMARY SCORES			WEIGHTED SUMMARY	
Num	Name	Long	Lat	N/F/P	1	2	SCI	ISRU	OPS	WTOT	WGRADE
1	Alphonsus Crater	-2.16	-12.56	N	x		86	91	85	87.2	A
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6	North Pole	76.19	89.60	P	x		73	82	88	81.0	A
7	Malapert Massif	-2.93	-85.99	P	x		72	82	87	80.0	A
8	Rima Bode	-3.80	12.90	N	x		75	87	77	79.6	B
9	South Pole-Aitken Basin Interior	-159.94	-60.00	F	x		81	80	77	79.2	B
10	South Pole	-130.00	-89.30	P	x		71	82	84	79.1	B
11	Gruithuisen Domes	-40.14	36.03	N	x		75	87	74	78.5	B
12	Aristarchus 2	-52.40	27.70	N	x		71	90	73	78.0	B
13	Apollo 15	3.66	26.08	N	x		74	87	72	77.8	B
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21	Dante Crater	177.70	26.14	F	x		63	80	78	73.9	C
22	Reiner Gamma	-58.56	7.53	N	x		74	80	65	72.7	C
23	Mare Smythii	85.33	2.15	N	x		67	83	65	71.6	C
24	Marius Hills	-55.80	13.58	N	x		67	80	65	70.8	C
25	Mare Tranquillitatis	22.06	6.93	N	x		63	83	65	70.0	C

Avg Grade: 77.7

Tier 2

LANDING TARGETS					TIER		SUMMARY SCORES			WEIGHTED SUMMARY	
Num	Name	Long	Lat	N/F/P	1	2	SCI	ISRU	OPS	WTOT	WGRADE
26	Peary Crater	30.00	88.50	P			75	88	84	82.3	A
27	Bullialdus Crater	-22.50	-20.70	N		x	74	87	81	80.6	A
28	Apollo 16	15.47	-9.00	N		x	74	84	83	80.4	A
29	Anaxagoras Crater	-9.30	73.48	N		x	71	81	88	80.1	A
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33	Apollo Basin	-153.72	-37.05	F		x	81	84	72	78.7	B
34	Mare Crisium	58.84	10.68	N		x	73	86	77	78.7	B
35	King Crater	119.91	6.39	F		x	67	80	88	78.2	B
36	Hertzsprung	-125.56	0.09	F		x	73	82	78	77.9	B
37	Sulpicius Gallus	10.37	19.87	N		x	70	89	74	77.7	B
38	Balmer Basin	69.82	-18.69	N		x	73	83	77	77.6	B
39	Humboldtianum Basin	77.14	54.54	N		x	73	86	73	77.1	B
40	Plato Ejecta	-5.21	53.37	N		x	70	85	75	76.8	C
41	Mare Frigoris	26.10	59.80	N		x	82	85	63	76.7	C
42	Compton/Belkovich Th Anomaly	99.45	61.11	F		x	67	84	77	76.2	C
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48	Lichtenberg Crater	-67.23	31.65	N		x	73	82	64	73.1	C
49	Mendel-Rydberg Cryptomare	-93.07	-51.14	N		x	67	83	69	73.0	C
50	Hortensius Domes	-27.67	7.48	N		x	67	86	65	72.4	C

Avg Grade: 77.3

Tier 1 insignificantly outperforms Tier 2: Does not support current Tier assignments

*Highlights are LEAG SAT modified sites

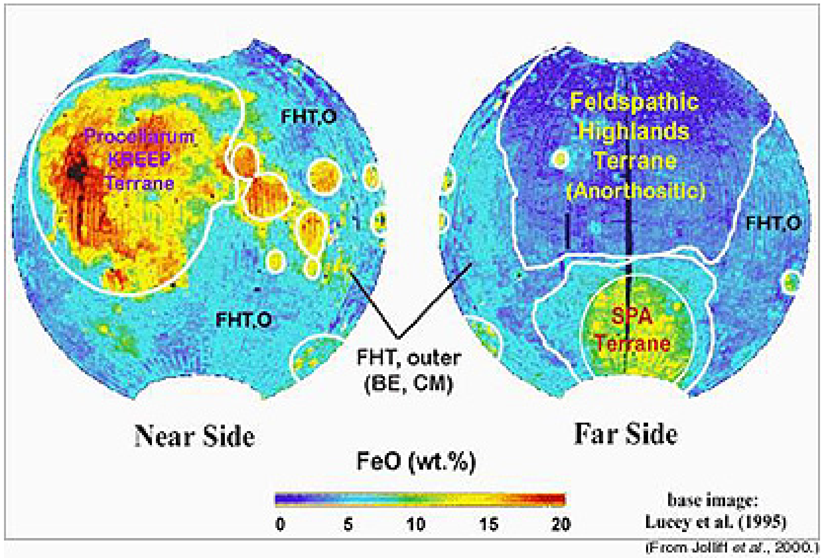
LEAG LROC Site Study: Diversity

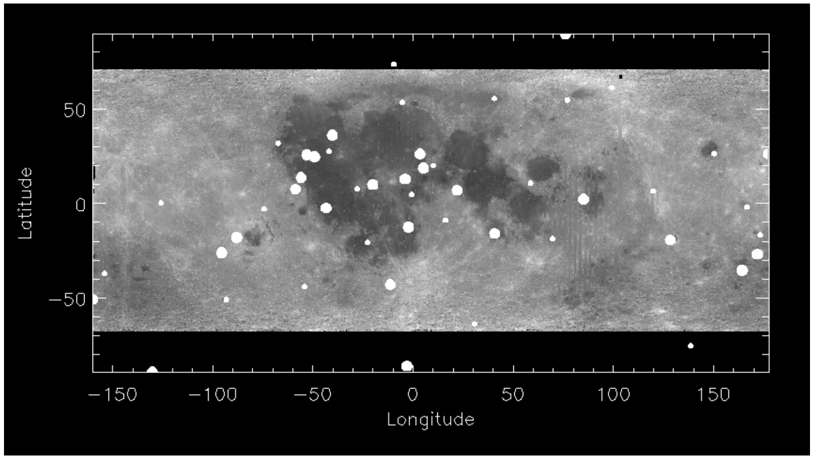
Individual scoring methodology does not take diversity of sites into account. Gaps in important parameters are detected.

- Science
- ISRU
- Operational

Geochemical Terrane

- Moon exhibits three major terranes based on geochemical characteristics
  - Procellarum KREEP Terrane **(PKT)**
  - Feldspathic Highlands Terrane **(FHT)**
  - South Pole-Aitken Terrane **(SPA)**
- Each is believed to have distinct origins and histories
- Apollo, Luna
  - Sampled PKT extensively
  - Sampled outer FHT
- Lunar meteorites
  - May sample inner FHT

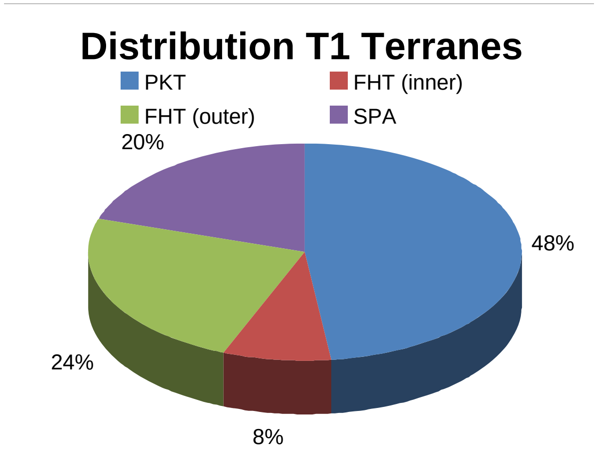


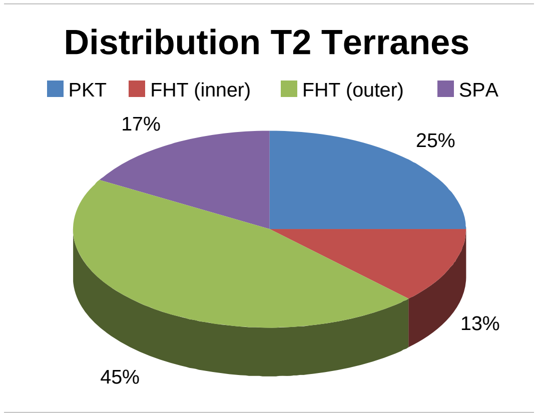


Tier 1, big dot; Tier 2, small dot

Geochemical Terrane

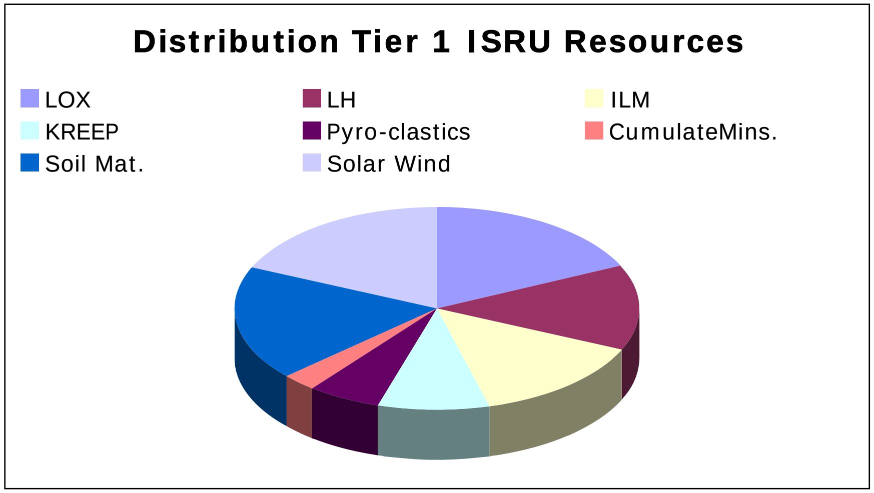
- Taken together, CxPO sites <u>oversample PKT and outer FHT</u>
  - These terranes extensively sampled by Apollo
  - Some of this due to majority of maria in PKT
- Unsampled SPA and inner FHT constitute only 28% (14 of 50) sites
- Partial solution offered:
  - Add polar, SPA sites

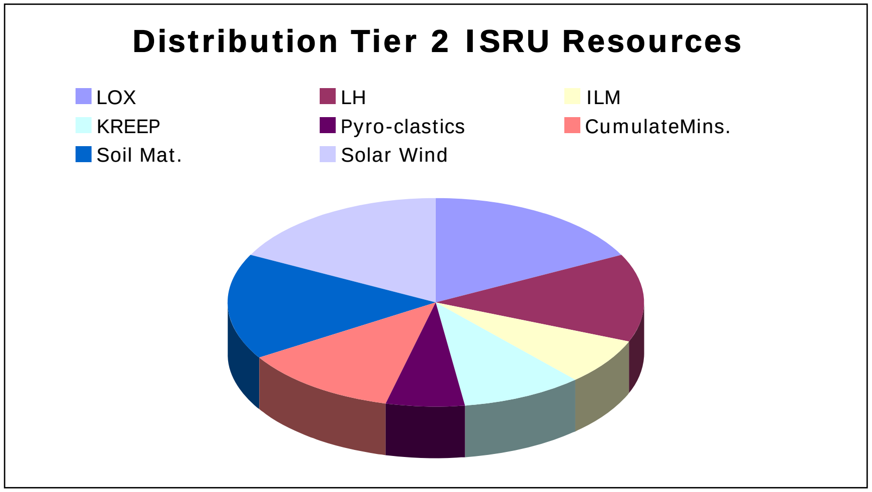




ISRU Resource Distribution

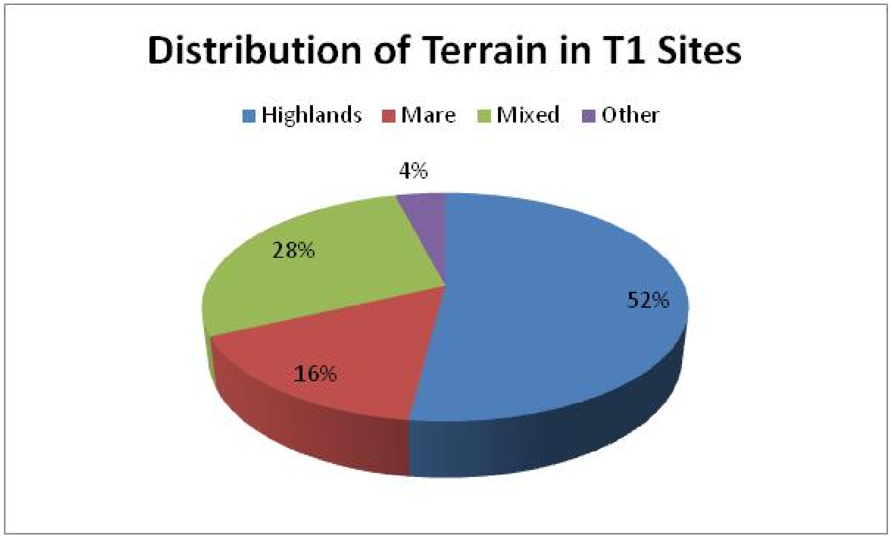
- Overall CxPO sites provide good balance
- Tier 1 somewhat undersamples cumulate minerals and pyroclastics

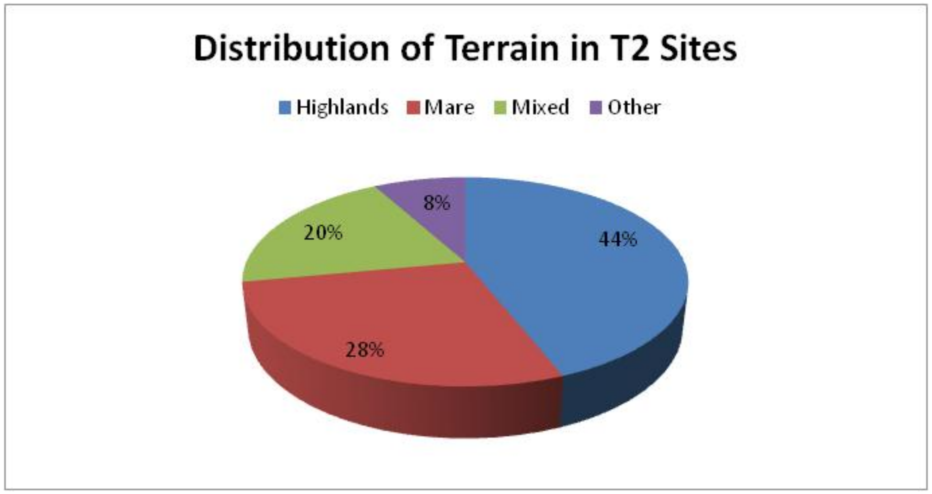




Operational Parameter Distribution: Mare v Highland

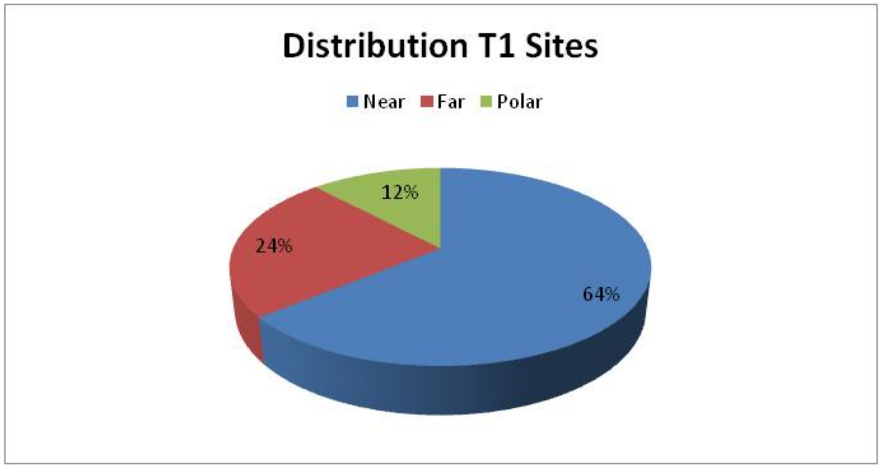
- Majority of sites are highland or mixed mare/highland

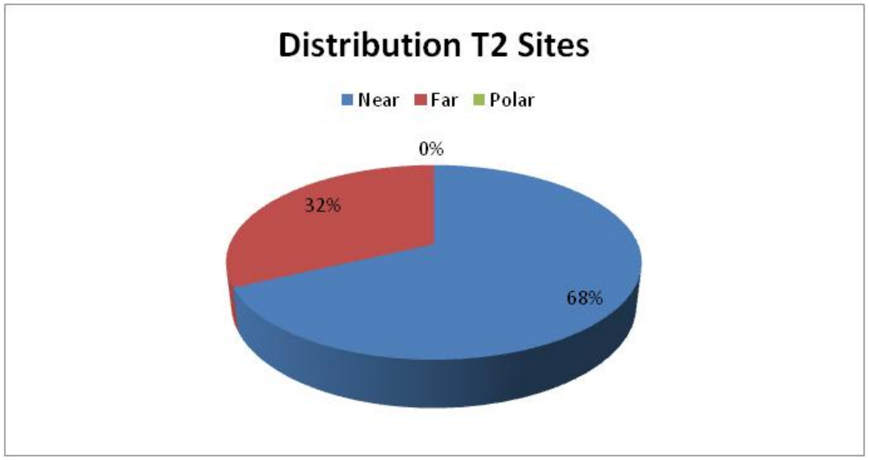




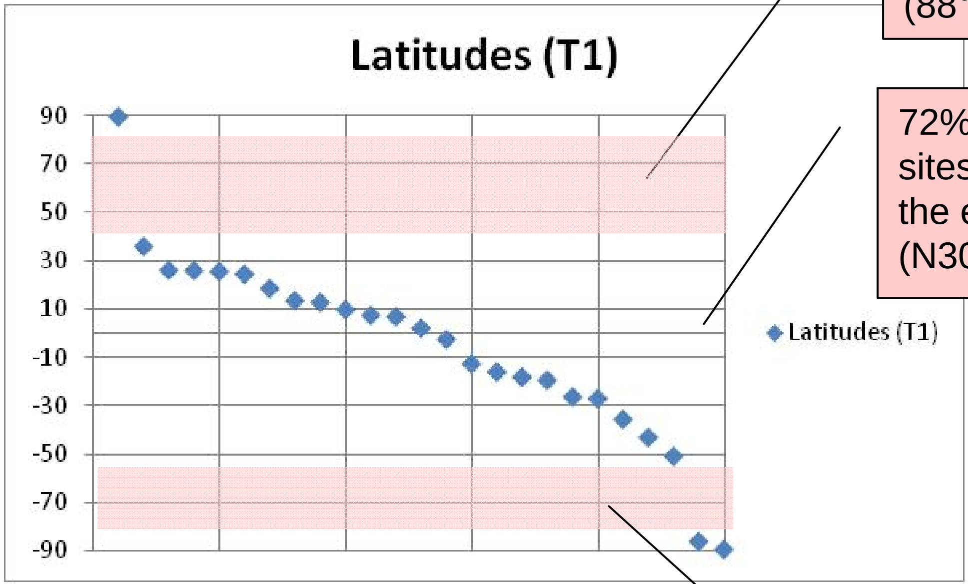
Operational Parameter Distribution: Nearside v Farside v Polar

- Polar sites greatly under-represented in CxPO list
- Farside sites underrepresented





Operational Parameter Distribution: Latitude



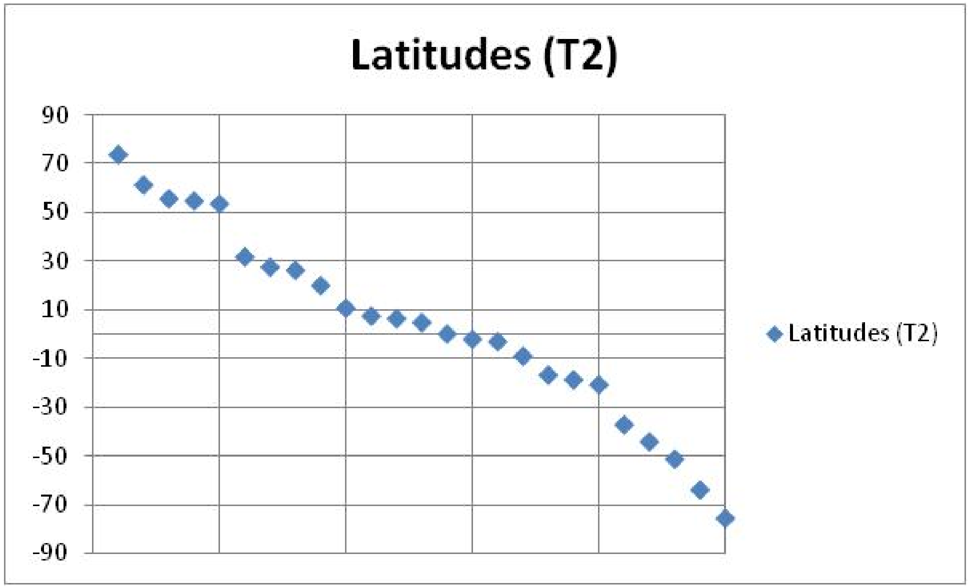
Northern middle and high latitudes absent (88° to 37 °)

72% (18/25) of the T1 sites are located around the equator between (N30° to S30°)

Southern middle and high latitudes absent (-51° to -85°)

* T1 sites are not evenly distributed
* Majority of T1 sites are equatorial
* Mid latitudes are not represented

Operational Parameter Distribution: Latitude



* T2 sites are somewhat evenly distributed in latitude

Alternate Site List

- Criteria are:
  - Farside Polar or Midlatitude location
  - SPA inner or FHT terrane
- Mutus Crater and Schickard cryptomare are deleted based on low scores and redundancy
  - Mutus: 75
  - Schickard: 71

- **NORTH POLE: South Floor of Peary Crater**
  - **Long 30, Lat 88.5; polar farside site**
  - Floor at the south rim of Peary crater is in permanent shadow with low permanent model temperatures. Rest of floor is not in permanent shadow, exhibits low relief, has good southern landing approaches and allows zero slope access to permanent shadow.
  - Within Feldspathic Highland Terrane
- **SOUTH POLE-AITKEN RIM**
  - **Long 170.92, Lat -51.00; farside mid latitude site**
  - **SPA Terrane**
  - Near the rim of the transient crater, deepest portions of the transient cavity formed by the SPA impac expected
  - Highest SPA thorium abundances. There are
  - SPA mare basalts in the vicinity, which should be represented in the regolith.

Re-Order of Tier 1 and Tier 2

- Quantitative rankings of CxPO Tiers show no significant difference
- Both Tiers show wide distribution of weighted scores
- Recommend reassign Tiers by score

Recommended New Tier 1 Assignments

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22	Aristarchus 2	-52.40	27.70	N	x		71	90	73	78.0	B
23	Hertzsprung	-125.56	0.09	F		x	73	82	78	77.9	B
24	Apollo 15	3.66	26.08	N	x		74	87	72	77.8	B
25	Sulpicius Gallus	10.37	19.87	N		x	70	89	74	77.7	B

*Highlights are LEAG SAT modified sites

Recommended New Tier 2 Assignments

LANDING TARGETS					TIER		SUMMARY SCORES			WEIGHTED SUMMARY	
Num	Name	Long	Lat	N/F/P	1	2	SCI	ISRU	OPS	WTOT	WGRADE
26	Balmer Basin	69.82	-18.69	N		x	73	83	77	77.6	B
27	Orientale 2	-87.91	-18.04	N	x		77	78	77	77.3	B
28	Humboldtianum Basin	77.14	54.54	N		x	73	86	73	77.1	B
29	Ingenii	164.42	-35.48	F	x		76	84	72	76.9	C
30	Plato Ejecta	-5.21	53.37	N		x	70	85	75	76.8	C
31	Mare Frigoris	26.10	59.80	N		x	82	85	63	76.7	C
32	Ina ('D-caldera')	5.29	18.65	N	x		74	84	72	76.6	C
33	Tsiolkovsky Crater	128.51	-19.35	F	x		71	80	78	76.5	C
34	Compton/Belkovich Th Anomaly	99.45	61.11	F		x	67	84	77	76.2	C
35	Mare Moscoviense	150.47	26.19	F		x	70	86	72	76.1	C
36	Flamsteed Crater	-43.22	-2.45	N	x		74	89	65	76.1	C
37	Van De Graaf Crater	172.08	-26.92	F	x		71	78	78	76.0	C
38	Riccioli Crater	-74.28	-3.04	N		x	73	84	71	76.0	C
39	South Pole-Aitken Rim	-170.92	-51.00	F			74	82	72	75.9	C
40	Rimae Prinz	-41.72	27.41	N		x	71	88	68	75.8	C
41	Schrödinger	138.77	-75.40	F		x	72	86	69	75.5	C
42	Montes Pyrenaeus	40.81	-15.91	N	x		75	80	71	75.0	C
43	Dante Crater	177.70	26.14	F	x		63	80	78	73.9	C
44	Lichtenberg Crater	-67.23	31.65	N		x	73	82	64	73.1	C
45	Mendel-Rydberg Cryptomare	-93.07	-51.14	N		x	67	83	69	73.0	C
46	Reiner Gamma	-58.56	7.53	N	x		74	80	65	72.7	C
47	Hortensius Domes	-27.67	7.48	N		x	67	86	65	72.4	C
48	Mare Smythii	85.33	2.15	N	x		67	83	65	71.6	C
49	Marius Hills	-55.80	13.58	N	x		67	80	65	70.8	C
50	Mare Tranquillitatis	22.06	6.93	N	x		63	83	65	70.0	C

*Highlights are LEAG SAT modified sites

Summary

- Uniform debiased methodologies applied to tasking
- CxPO site selection endorsed by LEAG SAT
- Detailed assignment to Tiers not supported by analysis
- Gaps in Science and Operational parameters overall
  - Unsampled geochemical terranes underrepresented
  - Polar sites underrepresented
  - Midlatitude sites underrepresented
  - Light plains underrepresented
- Two sites replaced with SPA/polar sites
- Three sites moved to improve science value