Evaluation of the NASA Artemis Regions of Interest for ISRU Water Mine Potential

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The NASA Artemis Campaign has a stated goal to return to the Moon to maintain a sustainable presence; In-Situ Resource Utilization (ISRU) is a key part of sustainability. The regions of interest identified for the Artemis campaign are at Lunar the South Pole where water ice, a valuable resource for ISRU, has been identified. As such, a preliminary evaluation of the ISRU ice mining potential has been performed for of these six regions of interest. A set of ground rules for this evaluation were developed to align with current assumptions for customer needs, hardware capabilities, an initially limited infrastructure, and lunar environments/terrain. Water ISRU is possible at all regions, though the degree to which each criterion is met is variable. The two regions near Shackleton were the most favorable overall, while the de Gerlache region presented the most difficulties meeting the current criteria. The regions were not explicitly ranked due to the nuances associated with the high number of variables but evaluation summaries of each are presented. It should also be noted that all ISRU 'mine' sites in this analysis focused on smaller (few kilometer) size permanently shadowed regions (PSRs). This was necessary to meet proximity requirements between these PSRs and the highly illuminated regions needed for customers and ISRU processing. The areas identified in this study are meant to focus exploration and reconnaissance efforts needed to better evaluate the ISRU potential.

I. Nomenclature

DEM	= Digital Elevation Model
d1	= distance of traverse leg 1
d2	= distance of traverse leg 2
dt	= distance of total traverse (leg 1 + leg 2)
f	= fraction of path distance that exceeds slope criteria
ISR	= Ice Stability Region
ISRU	= In-Situ Resource Utilization
PPP	= Propellant Production Plant
PSR	= Permanently Shadowed Region
Sa	= Average slope over traverse
Sm	= Maximum slope over traverse

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II. Introduction

The NASA Artemis Campaign aims to return to the Moon and maintain a sustainable presence [1]; In-Situ Resource Utilization (ISRU) is a key part of that sustainability. The regions of interest for the Artemis campaign, as outlined in [1] and shown in Fig. 1, are at Lunar the South Pole where water ice has been identified. The potential use of this water (as is, or as oxygen/hydrogen) for NASA and commercial applications, such as refueling vehicles, for power systems, or supplying life support consumables, is one of the considerations the NASA Artemis team is using to evaluate these regions.

As such, a preliminary analysis has been performed to evaluate the ISRU ice mining potential of these regions of interest. A set of ground rules for ISRU sites has been developed to align with current assumptions for customer needs, hardware capabilities, initially limited infrastructure, and lunar environments/terrain. The customer in this evaluation could be any lander, habitat, or other asset that makes use of ISRU product within the Artemis architecture. The initial evaluation of the first four of these regions, along with these associated ground rules, was published in [2]. The expanded evaluation given in this manuscript covers all six regions of interest defined in Fig. 1 and includes a more thorough consideration of various criteria that will drive ISRU potential. Throughout this paper the regions will be referred to primarily by their colloquial names, namely the large crater that they are nearest.

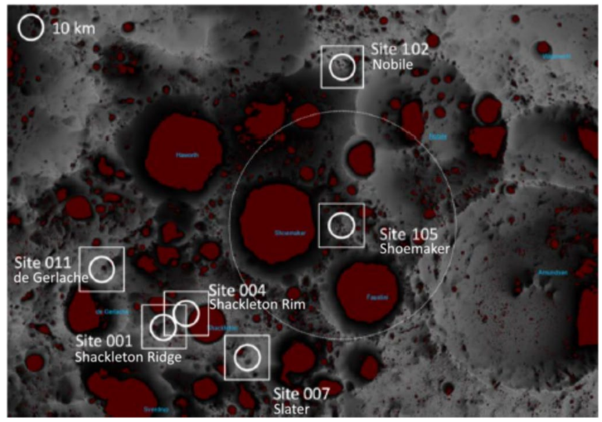

Fig. 1: Artemis regions of interest from [1]. Colloquially the region names are: 001 Shackleton Ridge, 004 Shackleton Rim, 007 Slater, 011 de Gerlache, 102 Nobile, 105 Shoemaker.

It should be noted that a variety of other efforts have performed evaluations of this nature that included some evaluation of ISRU potential of various regions using different assumptions or viewpoints, one the most recent being [3]. However, most evaluations focused on large permanently shadowed regions (PSRs) due to orbital data resolution limitations. The analysis presented here focuses on the needs of early ISRU ice mining operations, which will likely occur in much smaller PSRs to align with anticipated capabilities available during early Artemis. However, it is recognized the confidence of water potential in these smaller PSRs is considerably lower due to present data sets and resolution. One intention of this evaluation is to focus early exploration and reconnaissance efforts to better evaluate the ISRU potential of these areas.

It is important to consider that this analysis is by no means decisional or fully comprehensive. The intention here is to begin to evaluate the ice mining potential of these regions to inform planning for Artemis and the ISRU infusion therein. For example, notional traverse paths were mapped as part of this analysis to broadly understand distances, slopes, etc. for potential ISRU operations in these areas. These traverses were not plotted with least cost analysis methods nor did they consider any particular mobility concept. Pathfinding in real operations will be facilitated by the mobility providers (and instruments therein) as well as detailed planning tools, high resolution maps, etc., once regions are down selected.

III. Evaluation Method

A. Architecture Assumptions

The ISRU architecture assumed for this evaluation was published in [4] and necessitates two ISRU locations: a mine site where icy regolith is mined and where water is extracted, and a propellant production plant (PPP) where water is cleaned and processed into mission consumables, where the initial consumable target is propellant. Fig. 2 depicts a graphic of this two-location ISRU system.

The mine site is assumed to be in a permanently shadowed region where surface ice stability is possible. The ISRU baseline architecture requires water within the top 1 m, so regions where deeper (non-surface) water exist may be options depending on the water extraction technology used. While these areas were identified as Ice Stability Regions (ISRs) in the regional map products, they were not evaluated as mine sites. At this time, only PSR areas with potential surface ice stability were used to increase confidence in the ice potential.

The PPP site is located where there is high illumination so that solar power is an option for high power processes such as electrolysis [4]. This also makes the ISRU product more readily accessible to customers (and their associated mobility assets), who are expected to have similar high illumination requirements. However, the PPP sites are assumed to be independent of the customer site (not co-located). This was done to avoid interference with other customer activities and to provide better proximity to the mine site. This evaluation did not explicitly consider requirements for power architectures to or from the PPP site such as terrain requirements for power beaming, fission power, or cable routing, any of which could alter some of the ground rule criteria.

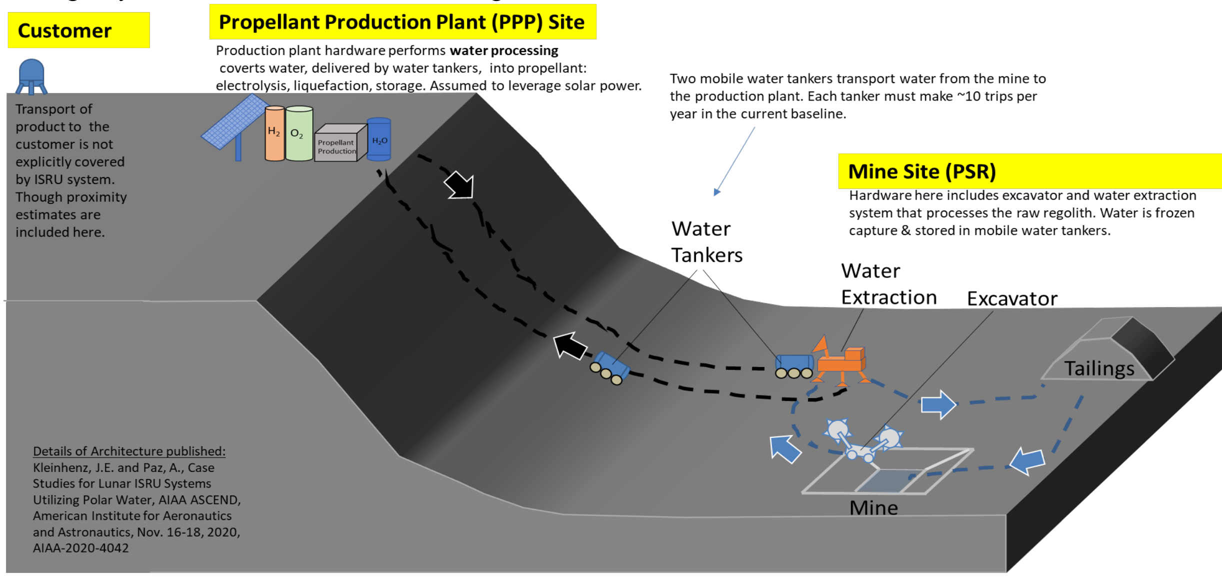

Fig. 2: The ISRU architecture used for this evaluation. Water is extracted at the mine site and transported to a sunlit propellant production plant (PPP) to convert into mission consumables (e.g. H_2 and O_2 propellant).

The customer sites at each region are the highest ranked surface site from [5] for all but region 105, Shoemaker, which did not have a ranked site. In this case the apparent highest illuminated site in the region was selected as the customer site.

Two traverse legs must be considered for this ISRU architecture: delivering water from the mine to the PPP (leg 2) and delivering the product (propellant) from the PPP to the customer (leg 1). Because the customer site was fixed at each region this is considered "leg 1", while the mine traverses had more flexibility so this was "leg 2". Fully mobile assets are assumed to service these legs with no path preparation (e.g. roads) and using the most direct route that could meet slope criteria. Other considerations such as path preparation, switchbacks, or alternate resource/product transfer methods such as pipes, gondolas, etc, will alter the evaluation. The distance and slopes of these traverse legs were the primary considerations in the analysis. Detailed path finding that includes finer scale hazard avoidance (e.g. rock abundance) is not covered here. Likewise, more refined pathfinding using least cost evaluation methods and other data assets is anticipated to occur as various down-selections occur.

Another key factor not currently included in this analysis is Earth visibility. The communications architecture is still being defined. For this study, continuous direct to Earth communication is not assumed to be required.

B. Ground Rules

Table 1 outlines the ground rules used in this analysis and the primary data products used to evaluate them. Traverse distances and slopes are based on current projected mobility capabilities. An expanded distance criteria was evaluated to see how additional capabilities may influence the results. While it is recognized that mobility platforms can exceed the 20 deg slope criterion, this is intended to be an initial planning target.

The PSR size is defined as the area with surface ice stability. This criterion is not strict; smaller PSRs, as small as 700 m, were still considered. Note that these sizes are presented as 'equivalent diameters", where the area of the PSR was measured and converted to a diameter as a more intuitive dimension. In terms of tonnage, the mine site should support multiple years of resource extraction on the order of 10 metric tons a year, minimum. As a rough estimate, assuming ~3% bulk water content, a production cycle of 10 mT of O_2 (from water) per year from pit mines 30 m square and a mine depth of 0.3 m (not including overburden); a 1 km diameter water ice deposit could support 1000 production cycles. While the top-level target was the PSR size (the area of the surface ice stability), the size of the useable area within that region can be less due to crater slopes. In the PSR evaluation (section E), ‘mineable size’ is included with the same target of 1 km.

The PPP site could not be co-located with the customer site (per ground rule) and ideally should be at least 1 km away. Proximity less than 1 km may interfere with the customer operations including risk of ejecta if the customer is an ascent vehicle. The illumination criteria for the PPP sites is a target value. The actual illumination needs have yet to be determined because neither the ISRU technology nor the power architecture have been chosen yet. Areas with values approximately 75% sun visibility or better were considered here as a rough target and a single site was chosen in that area to perform the analysis. In the region evaluation (section F), a rough estimate was made of area within each region that met the illumination criteria, where a greater area would open up more flexibility in PPP site selection.

Table 1: Ground rules for ISRU evaluation of the Artemis regions of interest. Leg 1 is customer to PPP, leg 2 to is PPP to mine.

Parameter	Baseline	Expanded	Data product used
Traverse Leg 1	5 km	10 km	5m/pix High Res LOLA Topography LDEMs from https://pgda.gsfc.nasa.gov/products/78
Traverse Leg 2	5 km	10 km	
Traverse Total	10 km	20 km	
Slopes	≤ 20 deg		5m/pix High Res LOLA Topography Slope from https://pgda.gsfc.nasa.gov/products/78
PSR/Mine Size	≥ 1 km equivalent diameter (multiple pixels in the 240mpp ice stability product)		Diviner: Current Ice Stability layer from LROC Quickmap: based on Siegler 2017: 240mpp https://quickmap.lroc.asu.edu/
PSR Ice Stability (mine)	Surface ice stability corresponding to PSR region		
Sun Visibility (PPP)	> 75% visibility		LOLA 60m/pix Sun Visibility LROC Quickmap https://quickmap.lroc.asu.edu/: Percentage of timestamps when any fraction of solar disc is visible using Mazarico 2011 methodology [5].

C. Traverse Scoring Methods

While it should again be emphasized that this is a preliminary and somewhat coarse analysis of these regions, an attempt was made to score and rank the different traverses to better compare the regions. The traverses were scored based on how well the distance and slope met the ground rule criteria in Table 1. The calculation and weighting factors that went into the total score are shown in Table 2.

For the score criteria 1- distance, the traverse got a full score of 1 if it met baseline criteria of 5 km. Bonus points were awarded for distances less than this; but in the case of Leg 1, a moderate penalty was applied if the distance was less than 1 km. To get the total distance score, each of the legs and the total path distance were weighted and summed. Note that leg 2 is weighted higher because this traverse will have the most traffic.

Slope, score criteria 2, was scored based on three factors. The average slope along the traverse was normalized to 6 deg, which was determined to be a ‘good’ number looking at the average slope distribution and the associated slope maps across all traverses. The slope exceedance number is the percent of the traverse distance in which slopes exceeded 20 deg. Because high resolution pathfinding was not performed in this evaluation, this factor was meant as a ‘forgiveness’ for paths that had small exceedances, where an acceptable path could be found with more refinement. For example, if 20 deg was exceeded over only a few pixels of the Digital Elevation Model (DEM), the score would not be significantly impacted. An exceedance of >1% (or f=0.01) of the path was considered significant, so no points were awarded. The final factor was the maximum slope of the traverse. Again, recognizing that only a pixel at high slope could significantly impact the score, the weighting of this factor was low. Bonus points were awarded for maximum slopes less than 20 deg, with penalties above. Slope scores were calculated separately for the two legs, where the total slope score again has a higher weighting for leg 2. This was done for the same reason as the distance score (more traffic on this leg) and because this leg involves crater traverses which have higher slopes than leg 1, which is usually along ridgelines.

Finally, a small score adjustment (score criteria 3) was included to clearly represent if the traverses fully met all ground rules. The total traverse score was the sum of the total distance, total slope, and ground rule scores with the additional weighting factors shown in Table 4.

Table 2: The scoring methodology for the traverses with the equations used to determine score, and the subsequent weights used for each criteria as they are rolled up into the final score (summed at each step). For example, in the total score the slope average for leg factor would have a weight of 0.154.

<table>
<tr><th></th><th>Score Criteria</th><th>Factor</th><th>Equation</th><th>Weight</th><th colspan="4"></th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Distance</td><td>Leg1</td><td>≤ 1km: d1
≤ 5km: 1+(5-d1)/10
> 5km: 5/d1</td><td>0.3</td><td rowspan="3">Total distance Score</td><td rowspan="3" colspan="3">0.4</td></tr>
<tr><td>Leg2</td><td>≤ 5km: 1+(5-d2)/10
> 5km: 5/d2</td><td>0.5</td></tr>
<tr><td>Total</td><td>10/dt</td><td>0.2</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Slope</td><td>Average</td><td>6/Sa</td><td>0.5</td><td rowspan="2">Slope Leg 1 Score</td><td rowspan="2">0.3</td><td rowspan="3">Total Slope Score</td><td rowspan="3">0.55</td></tr>
<tr><td>Exceedance fraction</td><td>=0: 1
≤ 0.01 1-(f*10)
> 0.01: 0</td><td>0.4</td></tr>
<tr><td>Max</td><td>≤ 20deg: 1+(10-Sm)/10
>20deg: 20/Sm</td><td>0.1</td><td>Slope Leg 2 Score</td><td>0.7</td></tr>
<tr><td>3</td><td>Ground Rule match</td><td>Criteria</td><td>Meet baseline: 2
Meets expanded: 1
Fails criteria: 0</td><td colspan="2">Total Criteria Score</td><td colspan="3">0.05</td></tr>
</table>

IV. Results

Fig. 3 shows the ISRU regions of interest at each of Artemis regions defined in [1]. The location of the customer site selected for this evaluation is indicated by the star. PSR regions are identified by white polygon areas which were drawn using the ice stability overlay identified in Table 1. Likewise yellow polygons indicate the areas that met the PPP criteria based on the sun visibility overlay identified in Table 1. The large circles of 5 km radius are drawn around the customer site and a representative point in each PSR to indicate the baseline criteria range. A PPP site must be in the intersection of the two circles in order for a solution to exist. The dashed lines indicate ice stability regions (no surface ice, but ice in the top 1m). These are noted for reference but not used in the evaluation at this time.

While the regions identified in Fig. 3 give a good indication of which PSRs may be accessible in the criteria, traverse mapping is needed to evaluate the impact of the regional terrain. The notional traverses at each region are shown in Fig. 4 where the base map indicates slope. The traverses include PSRs that have potential to meet either baseline or expanded distance criteria. Each path is numbered with the details in Table 4. The paths that are pink to red, and highlighted in black, are the best traverse at each region.

D. Traverse Evaluation

Table 4 shows the statistics and scores of all the traverses. The coloring of the table is that green shading indicates that baseline criteria are met, yellow meets expanded criteria, and pink fails to meet criteria. Any single criteria that is outside baseline is indicated with a lighter shading in the relevant cell.

The scoring and ranking is driven by the weighting and criteria selected, so certainly more consideration and adjustment will alter the results some. The traverses that ranked highest for each region are clear (and are marked with an asterisk in the path column). Getting rid of the scoring criteria 3 (ground rule match) and allotting its weight to score criteria 1 (distance) in the far right column shows how some of the expanded criteria traverses can outrank some baseline traverses.

The de Gerlache and Nobile regions were some of the most difficult in terms of path finding, as is evident from the slope map in Fig. 4D and E. The Shackleton region has some challenging areas, but generally there are passes available between features to enable path finding. Shoemaker was clearly the least challenging for slope.

E. PSR Evaluation

A summary of the traverse information is also included in the PSR evaluation Table 5. Here the same stoplight color coding as used in Table 5 is used to show if any traverses to each PSR meet the various criteria. Additionally, information about the PSR size is given here. The mine size column is a rough estimate of the area within the PSR that meets the slope criteria, essentially indicating the traversable area within the PSR. As with the PSR size, the area was measured and then converted to an equivalent diameter as a more intuitive size indication. Statistics about the best traverse into each PSR (traverse score and leg 2 average slope) are given in the far-right columns. The average slopes of leg 2 traverse paths are color coded as well, where average slopes 9 deg or greater are called out since these are some of the most difficult areas when cross referenced to Fig. 4.

The PSR that provided the best traverse option for each region is outlined in red and with an asterisk in the "PSR #" column. While these PSRs generally were the best to meet the baseline criteria, they do not account for the PSR size. Mineable area particularly for Nobile and to a lesser extent Shoemaker are not favorable. In general, the PSRs at Nobile were the worst in terms of size. Likewise, while Shoemaker has several PSRs of good size, many have quite limited mineable area. The Slater region has the fewest PSRs in the area, though the traverse paths are favorable. Shackleton Ridge and Shackleton Rim share the same PSRs, and the same PSR (PSR 4) provides the best path for both.

F. Region evaluation

The rollup of the traverse and PSR statistics for each region are shown in Table 3. While not comprehensive, this is a summary of how the regions compare. Green cells are the two best scores for each criterion. The Shackleton regions do the best, providing the most flexibility in terms of accessible PSRs (particularly in the expended range), traverses, and, most especially, locations for the PPP. Certainly, the most sunlit area is available for alternate PPP placement. The PPP areas at Shackleton Ridge are better distributed with respect to the PSRs than those at Shackleton Rim. Shackleton Rim appears to do slightly better (it has more green cells in Table 3) because it has one more PSR accessible within the baseline criteria than Shackleton Ridge. However, one of the extended criteria Shackleton Ridge traverses only exceeds baseline by 200m. That said, neither region had the best traverse score due to slope challenges getting off the rim or ridge (especially to the north). In Table 4, the best Shackleton Ridge traverse is rank 6, and moves to 8 when score criteria 3 is removed. Shoemaker does the best for traverse criteria due to the low slopes in the area, but it is quite poor in terms of available PPP locations. Also, the customer site at Shoemaker was not that favorable for sun visibility in comparison to all the other regions. Nobile has some difficult pathfinding but it does have one path that scored very well (rank 2). This is similar to Slater, which has one good traverse and PSR option, but does not offer much flexibility otherwise. de Gerlache consistently scored last in evaluations (in attempts to assign a numerical score to the regions, Shackleton always ranked first and de Gerlache last). The slopes in the de Gerlache region make pathfinding difficult, such that none of the traverses to any PSR were within baseline criteria. Only one PSR is accessible in expanded criteria.

Table 3: Regional evaluation statistics summary.

	# of traverses mapped	Best Traverse Path Score	Mine size for Best Traverse, km (equivalent diameter)	Best mine size in expanded criteria, km (equivalent diameter)	# PSRs accessible in Baseline criteria	# PSRs accessible in Expanded criteria	Available PPP size, km (equivalent diameter)
001 Shackleton Ridge	6	1.05	1.47	1.47	1	4	2.18
004 Shackleton Rim	6	1.08	1.47	1.47	2	3	2.37
007 Slater	5	1.10	2.62	2.62	1	1	0.52
011 de Gerlache	5	1.02	1.06	1.06	0	1	0.76
102 Nobile	5	1.12	0.65	1.33	1	3	0.85
105 Shoemaker	3	1.23	0.89	1.16	2	3	0.22

V. Conclusions

A preliminary evaluation was performed to assess the ISRU water mining potential at the six Artemis regions of interest identified in [1]. This effort involved defining a set of ground rule criteria for ice mining needs, defining notional traverses within the regions to assess against those criteria, and sorting/ranking the results. This evaluation is intended as initial assessment of the regions, where results will be refined as campaign efforts become more focused, including more refined pathfinding for selected regions, consideration of capabilities of specific hardware, and infrastructure plans.

All regions present some solutions for water ISRU use. While the full baseline ground rules are not fully met at all regions, suggestions for expanded ground criteria are given to indicate what it would take at each region. It should also be noted that the viable PSRs are generally smaller PSRs (a few kilometers). This is typically required to meet the baseline criteria for near term missions, recognizing that with more infrastructure in place more options, such as the larger PSRs in [3], could become available. The confidence of any of these PSRs as a potential ISRU water 'reserve' is not high due to limited data sets. This analysis should be considered as a way to focus exploration and reconnaissance efforts.

001 Shackleton Ridge: There are 4 viable PSRs within expanded criteria, the most of any of the evaluated regions. Some features in the area have high slopes (including the slope off the ridgeline to the north), but generally there are passes available between features to enable path finding. There is one clear best traverse (and PSR) solution which was used in the case study [4]. The high illumination in the region also opens up flexibility in PPP locations, which is part of the reason so many PSRs are accessible.

004 Shackleton Rim: The available PSRs are all common with Shackleton Ridge; no new PSRs are in range due to the dominance of Shackleton crater itself (which is not accessible due to slopes). The best PSR solution is the same as that of Shackleton Ridge. This region offers the most area available for PPP locations; there is plentiful sunlight along the rim. That said, these areas are on a restricted path (the rim itself) with limited off-ramps due to high slope, so traverse paths are limited.

007 Slater: This region has the fewest PSRs available. Only one traverse solution meets all baseline criteria, though it is one of the best options in terms of path score and PSR/mine size. Slopes in regions are favorable, so some traverses even come close to meeting a <15deg path criteria. But this region offers very limited flexibility both in terms of PSRs and PPP areas. Expanding to 10 km per travel leg does not add much value; the criteria would need to go to 15 km reach the other PSR.

011 de Gerlache: There are several PSR options in the region and quite a few ISRs (some very near PPP locations). However, slopes in the region tend to necessitate longer traverses for pathfinding such that no options fully meet the baseline criteria. The one accessible PSR just meets the 1 km size criteria. While the outskirts of de Gerlache itself can be reached with traverses >12 km, these paths all exceed slope criteria (the two traverses attempted to de Gerlache crater are the bottom ranked in Table 4). There are several smaller PPP areas spread out along the crater rim, which would offer options in PPP placement if the PSRs could be accessed.

102 Nobile: This region is broken up by high slope features, with the customer site located in a difficult position among them. While there are several PPP areas available, many are in the opposite direction of the PSRs, so getting to them require some amount of backtracking from the customer site. One PSR meets baseline criteria, and while it is the 2nd best traverse in Table 4, the PSR is small (<1 km) with limited mineable area. The expanded distance criteria does open up two more PSRs, one (PSR2) fully meets size criteria.

105 Shoemaker: Of all the regions, this is the most favorable in terms of slopes, at least for the traverse paths; the PSRs are another story however. There are quite a few in the region of appropriate size, but the high slopes into these PSRs restrict mineable area (such that only one PSR has acceptable mine area) and either limits or eliminates traverses into the PSR. The best traverse in the region is the best among all regions, though the PSR's mineable area is slightly below the target. However, it should be noted that practically the entire region in Fig. 3 is an ISR. The challenge in this area is really the illumination potential, where there are very few options for PPP locations. The confidence of these areas is low, and higher resolution maps and analysis is needed to fully gauge this. This is the only region where the customer site was not ranked in [5].

References

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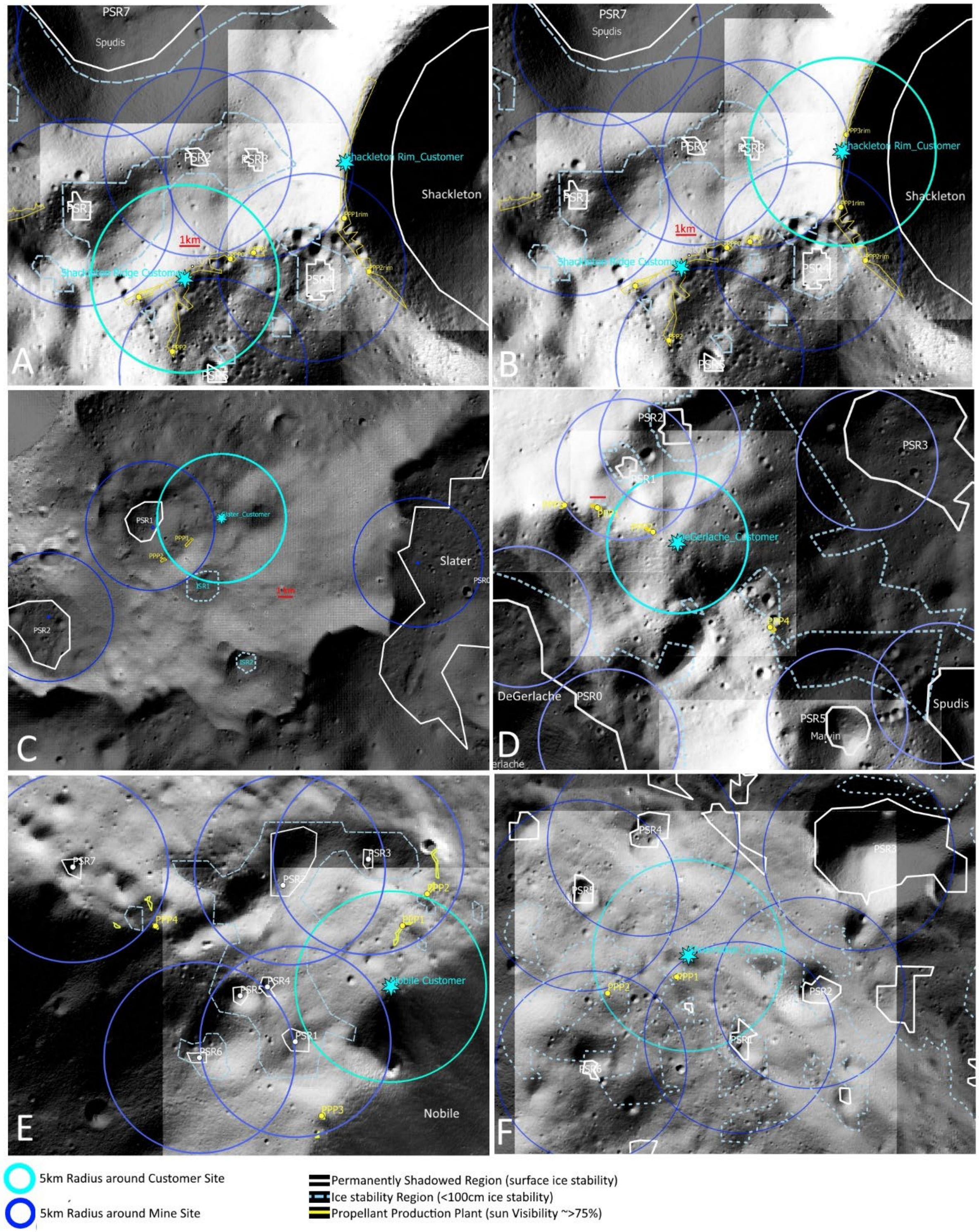

Fig. 3: ISRU Regions of Interest for all evaluated regions. The circles represent the baseline goal of 5 km traverse legs, a PPP site must exist within the intersection of a customer and mine radii. A) 001 Shackleton Ridge, B) 004 Shackleton Rim, C) 007 Slater, D) 011 de Gerlache, E) 102 Nobile, F) 105 Shoemaker (note that the ice stability regions in this area are vast so it is not evident from this image what the lines enclose).

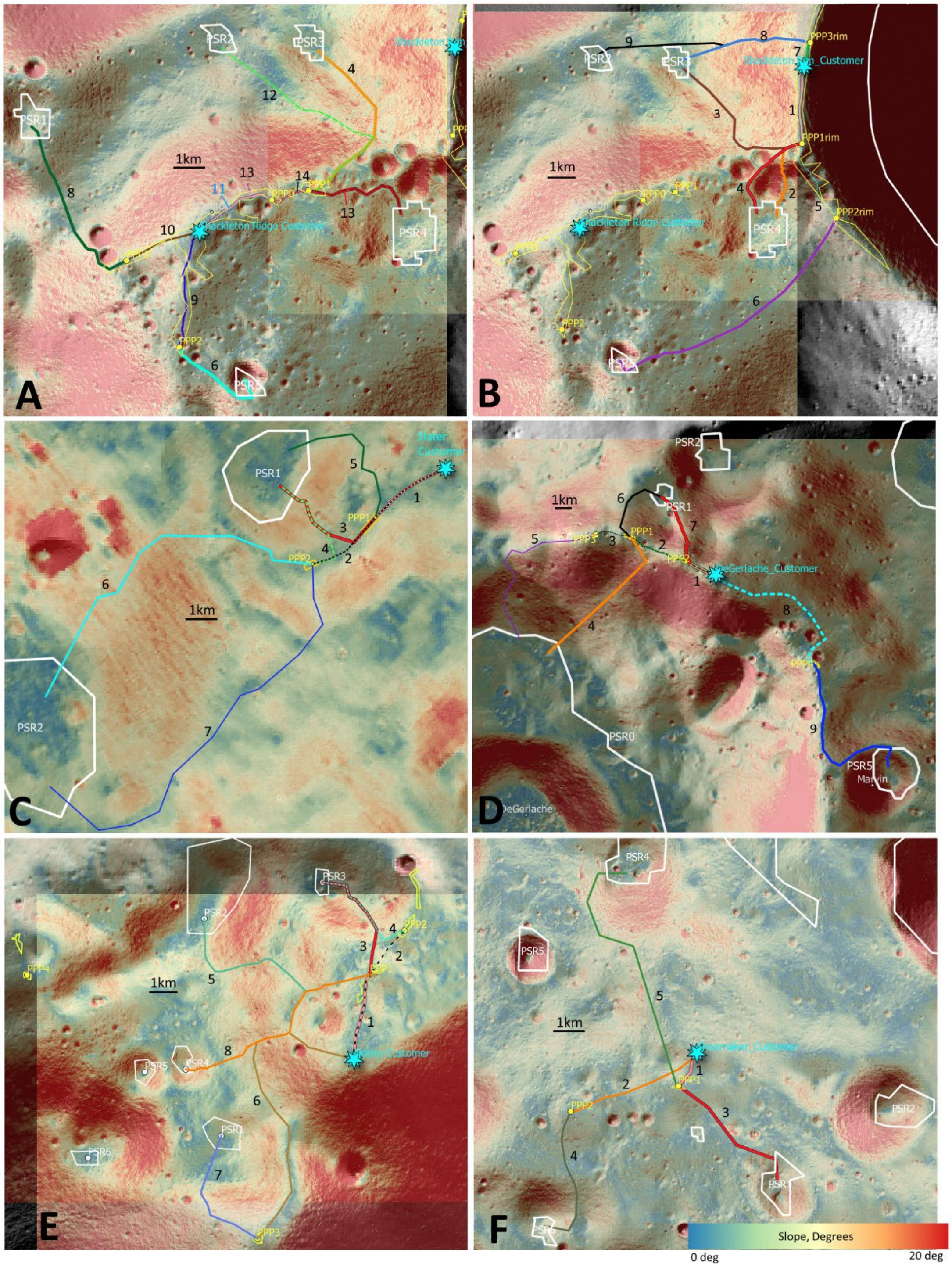

Fig. 4: Notional traverses at each region shown on a slope map. Each is numbered to reference with Table 4. Note that not all traverses are viable with respect to evaluation criteria. The best paths are colored pink/red with a black outline. A) 001 Shackleton Ridge, B) 004 Shackleton Rim, C) 007 Slater, D) 011 de Gerlache, E) 102 Nobile, F) 105 Shoemaker.

Table 4: The statistics and ranking of the notional traverse paths used to evaluate each region. The line numbers can be referenced to those labeled in Fig. 4. The stoplight coloring defines which traverses and factors (lighter shade) meet criteria where green meets baseline criteria, yellow is expanded criteria, and red fails to meet criteria. An asterisk in the path column indicates the best traverse path in that region.

Region	Path	PSR #	PSR designator	Leg 1: Customer (to PPP)							Leg 2: Mine (from PPP)							Slope	Total Score	Rank	Rank without score criteria 3
				Line #	Line name	Distance (d1), km	Max slope (Sm), deg	% path >20deg (f)	Distance >20deg, m	Avg Slope (Sa), deg	Line #	Line name	Distance (d2), km	Max slope (Sm), deg	% path >20deg (f)	Distance >20deg, m	Avg Slope (Sa), deg	Slope Total Score			
105 Shoemaker	A*	1	1051	1	Customer – PPP1	1.3	10.8	0%	0	4.32	3	PPP1 – PSR1	4.9	13.9	0%	0	5.5	1.16	1.23	1	1
102 Nobile	A*	3	1023	1	Customer – PPP1	3.3	9.9	0%	0	4.1	3	PPP1 – PSR3	4.7	14.3	0%	0	8.2	1.05	1.12	2	2
7 Slater	A*	1	71	1	Customer - PPP1	2.91	14.5	0%	0	5.5	3	PPP1 – PSR1	4.4	16.4	0%	0	8.2	0.96	1.10	3	3
4 Shackleton Rim	B*	4	44	1	Customer – PPP1r	2.98	15.8	0%	0	5.56	4	PPP1r – PSR4	3.8	18.9	0%	0	9.36	0.91	1.08	4	4
4 Shackleton Rim	C	4	44	1	Customer – PPP1r	2.98	15.8	0%	0	5.56	2	PPP1r –PSR4e	3.4	19.9	0%	0	11.3	0.86	1.08	5	5
1 Shackleton Ridge	B*	4	14	13	Customer – PPP1	4.2	14.9	0%	0	6.3	2	PPP1 – PSR4	3.9	19	0%	0	8.4	0.92	1.05	6	8
105 Shoemaker	B	6	1056	2	Customer – PPP2	4.7	12.8	0%	0	5.6	4	PPP2 – PSR6	5	19	0%	0	7.5	0.97	1.04	7	11
7 Slater	B	1	71	1	Customer - PPP1	2.91	14.5	0%	0	5.5	5	PPP1 – PSR1N	5.5	15.4	0%	0	6.8	1.02	1.03	8	6
11 DeGerlache	A*	1	111	1	Customer – PPP2	1.96	11.1	0%	0	4.4	7	PPP2 – PSR1	5.2	19.7	0%	0	11.1	0.92	1.02	9	7
1 Shackleton Ridge	A	4	14	11	Customer – PPP0	2.9	12.2	0%	0	5.3	14	PPP0 – PSR4	5.32	19	0%	0	8.4	0.95	1.00	10	9
7 Slater	C	1	71	2	Customer – PPP2	5.62	17.6	0%	0	5	4	PPP2 – PSR1	4.05	16.2	0%	0	7.7	0.99	1.00	11	10
4 Shackleton Rim	D	3	43	7	Customer – PPP3r	0.96	15.1	0%	0	5.8	8	PPP3r – PSR3	5	20.1	0.10%	5	13	0.80	0.99	12	13
102 Nobile	C	3	1023	2	Customer – PPP2	5.4	15.7	0%	0	5	4	PPP2 – PSR3	4.3	17.1	0%	0	8.3	0.97	0.99	13	12
1 Shackleton Ridge	E	1	11	10	Customer – PPP3	2.6	17.2	0%	0	7.6	8	PPP3 – PSR1	6.3	19.8	0%	0	8	0.89	0.94	14	14
105 Shoemaker	C	4	1054	1	Customer – PPP1	1.3	10.8	0%	0	4.32	5	PPP1 – PSR4	9.3	19.9	0%	0	8.9	0.97	0.93	15	15
4 Shackleton Rim	A	3	43	1	Customer – PPP1r	2.98	15.8	0%	0	5.56	3	PPP1r – PSR3	6.3	18.8	0%	0	10.9	0.88	0.92	16	16
102 Nobile	B	2	1022	1	Customer – PPP1	3.3	9.9	0%	0	4.1	5	PPP1 – PSR2	8.6	18.3	0%	0	9.3	0.99	0.92	17	17
102 Nobile	E	4	1024	1	Customer – PPP1	3.3	9.9	0%	0	4.1	8	PPP1 – PSR4	8.6	17.7	0%	0	9.8	0.98	0.91	18	18
11 DeGerlache	B	1	111	2	Customer – PPP1	6.39	12.7	0%	0	5.7	6	PPP1 – PSR1	5.44	19.8	0%	0	8.8	0.92	0.90	19	19
1 Shackleton Ridge	C	3	13	13	Customer – PPP1	4.2	14.9	0%	0	6.3	4	PPP1 – PSR3	6.6	18.7	0%	0	10.2	0.87	0.89	20	20
1 Shackleton Ridge	F	2	12	13	Customer – PPP1	4.2	14.9	0%	0	6.3	12	PPP1 - PSR2	9	18.2	0.00%	0	8.4	0.92	0.86	21	22
4 Shackleton Rim	E	2	42	7	Customer –PPP3r	0.96	15.1	0%	0	5.8	9	PPP3r – PSR2	8.2	20	0.10%	5	9.6	0.86	0.85	22	23
1 Shackleton Ridge	D	5	15	9	Customer – PPP2	4.1	17.9	0%	0	6.8	6	PPP2 – PSR5	3.8	20.8	1.00%	41	6.9	0.66	0.82	23	21
102 Nobile	D	1	1021	6	Customer – PPP3	12.2	21.8	0.20%	22	8.3	7	PPP3 – PSR1	5.2	14.8	0%	0	7.7	0.89	0.78	24	24
7 Slater	E	2	72	2	Customer – PPP2	5.62	17.6	0%	0	5	7	PPP2 – PSR2s	14.9	26.5	0.30%	47	6.5	0.91	0.71	25	25
4 Shackleton Rim	F	5	45	5	Customer – PPP2r	6.43	19.8	0%	0	7.09	6	PPP2r – PSR5	10.9	22.1	0.30%	29	7.69	0.81	0.68	26	26
11 DeGerlache	E	5	115	8	Customer – PPP4	11.5	19.6	0%	0	9.2	9	PPP4 - PSR5	12.6	21.5	0.30%	38	8.3	0.76	0.58	27	27
7 Slater	D	2	72	2	Customer – PPP2	5.62	17.6	0%	0	5	6	PPP2 – PSR2	12.2	34.9	3.30%	401	8.6	0.62	0.58	28	28
11 DeGerlache	D	0	110	2	Customer – PPP1	6.39	12.7	0%	0	5.7	4	PPP1 – PSR0	10.9	30.6	12%	1314	13.7	0.53	0.52	29	29
11 DeGerlache	C	0	110	3	Customer – PPP3	8.85	14.8	0%	0	5.6	5	PPP3 – PSR0	12.8	31.9	2%	238	11.3	0.56	0.49	30	30

Table 5: An evaluation of the PSRs in each region. The PSR numbers correspond to those labeled in Fig. 3 and Fig. 4, and asterisk indicates it's the best PSR option in the region. The stoplight coloring represents how well each factor meets the target criteria (red is poor, yellow is moderate, green is good). The 'equivalent diameter' used to define size was calculated by measuring the area of each feature and converting to circular area to get a diameter.

Region	PSR #	PSR Designator	PSR Size, equivelent diameter, km	Mine size, equivelent diameter, km	Baseline Distance Criteria (5km per leg)	Expanded Distance Criteria (10km per leg)	Slope path evaluation	Best Average Slope for Leg 2	Best Traverse score
001 Shackleton Ridge	1	11	1.20	1.04	Acceptable traverse path exceeds distance (by ~1km)	PPP options in range	Paths available	8	0.94
001 Shackleton Ridge	2	12	0.94	0.88	Acceptable traverse path exceeds distance	PPP options in range	Paths available	8.4	0.86
001 Shackleton Ridge	3	13	1.03	0.94	Acceptable traverse path exceeds distance (by ~1.5km)	PPP options in range	Paths available, but high average slopes	10.2	0.89
001 Shackleton Ridge	4*	14	1.75	1.47	PPP options in range	PPP options in range	Paths available	8.4	1.05
001 Shackleton Ridge	5	15	0.87	0.19	PPP options in range	PPP options in range	Slopes into PSR exceed 20deg in all directions	6.9	0.82
004 Shackleton Rim	2	42	0.94	0.88	Out of range	PPP options in range	Paths available, but high average slopes	9.6	0.85
004 Shackleton Rim	3	43	1.03	0.94	PPP options in range but very close (1km) to customer	PPP options in range but very close (1km) to customer	Paths available, but high average slopes	10.9	0.99
004 Shackleton Rim	4*	44	1.75	1.47	PPP options in range	PPP options in range	Paths available, but high average slopes	9.36	1.08
004 Shackleton Rim	5	45	0.87	0.19	Out of range	PPP options in range	Slopes into PSR exceed 20deg in all directions	7.69	0.68
007 Slater	0	70	17.33	12.65	Out of range	No PPP options in range	Not Evaluated, but one Path available	0	0.00
007 Slater	1*	71	2.87	2.62	PPP options in range	PPP options in range	Paths Available : 1 clear best path	6.8	1.10
007 Slater	2	72	4.77	4.53	Out of range	PPP option in range	Slopes favorable to SE, but requires longer traverses (~15 km)	6.5	0.71
011 De Gerlache	0	110	19.37	9.60	Out of range	PPP options in range	No <20deg paths	11.3	0.52
011 De Gerlache	1*	111	1.29	1.06	Acceptable traverse path exceeds distance (by 0.2km)	PPP options in range	Paths available	8.8	1.02
011 De Gerlache	2	112	2.26	1.62	No PPP options in range	PPP options in range	No <20deg paths	0	0.00
011 De Gerlache	3	113	8.81	8.05	Out of range	No PPP options in range	Options are on Northwest side, would require longer traverses	0	0.00
011 De Gerlache	4	114	8.28	4.01	Out of range	Out of range	No <20deg paths	0	0.00
011 De Gerlache	5	115	3.16	0.75	Out of range	Acceptable traverse path exceeds distances (by <5km)	Paths available on far (east) side of crater, but surrounding slopes high	8.3	0.58
102 Nobile	1	1021	1.27	1.10	No PPP options in range	Acceptable traverse path exceeds distances (by 2km)	Paths available	7.7	0.78
102 Nobile	2	1022	2.95	1.33	No PPP options in range	PPP options in range	Paths available, but high average slopes	9.3	0.92
102 Nobile	3*	1023	0.77	0.65	PPP options in range	PPP options in range	Paths available	8.2	1.12
102 Nobile	4	1024	0.84	0.31	No PPP options in range	PPP options in range	Paths available, but high average slopes	9.8	0.91
102 Nobile	5	1025	0.84	0.37	No PPP options in range	No PPP options in range	Path not evaluated - high crater slope limits mineable area	0	0.00
102 Nobile	6	1026	0.76	0.74	No PPP options in range	No PPP options in range	Not evaluated. One possible path but will have high average slopes	0	0.00
105 Shoemaker	1*	1051	1.35	0.89	PPP options in range	PPP options in range	Paths available	5.5	1.23
105 Shoemaker	2	1052	1.60	0.47	No PPP options in range	Not evaluated due to slope limitation	Slopes into PSR exceed 20deg in all directions	0	0.00
105 Shoemaker	3	1053	6.12	0.85	Out of range	Not evaluated due to slope limitation	Slopes into PSR exceed 20deg in all directions	0	0.00
105 Shoemaker	4	1054	1.90	1.16	No PPP options in range	PPP options in range	Paths available	8.9	0.93
105 Shoemaker	5	1055	1.26	0.16	Not evaluated due to slope limitation	Not evaluated due to slope limitation	Slopes into PSR exceed 20deg in all directions	0	0.00
105 Shoemaker	6	1056	0.78	0.76	PPP options in range	PPP options in range	Paths available	7.5	1.04