PROSPECT ProSEED Sensor Utilization Requirements

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1 INTRODUCTION

1.1 Purpose of the document

The PROSPECT project aims at developing a package for drilling in lunar polar areas and analysis of acquired surface and subsurface samples. [AD1]. The purpose of this document is to define the requirements for the utilization of the PROSPECT ProSEED sensors, specifically the ProSEED camera [RD1, RD2] and the drill-integrated permittivity sensor [RD3]. For the camera, this includes its use for engineering, science, and PR purposes, and covers and implies aspects of design, configuration, and operations. For the permittivity sensor, the provided requirements cover operational aspects.

2 ACRONYMS AND ABBREVIATIONS

AI	Artificial Illumination
AIU	Artificial Illumination Unit
CU	Camera Unit
ESA	European Space Agency
FOV	Field of View*
ICD	Interface Control Document
IRD	Interface Requirements Document
LED	Light Emitting Diode
MIR	Multispectral Imaging Region
P-sensor	Permittivity Sensor
PR	Public Relations
ProSEED	Drill element of PROSPECT
PROSPECT	The ESA project
PUG	Prospect User Group
ROI	Region of Interest
SIS	(ProSPA) Solids Inlet System
SOC	Science Operations Center
TBC	To be confirmed
TBD	To be determined
TC	Telecommand
TM	Telemetry

* The Field of View (FOV) of the camera shall be defined as the part of the environment that is visible on images that are acquired with the camera having a particular position and orientation in space. Objects outside the FOV when the picture is taken are not recorded in the photograph.

3 DOCUMENTS

3.1 Applicable Documents

Applicable documents (AD) are fully applicable in their entirety to this document and are listed below as dated or undated references. These normative references may be cited at appropriate places in the text.

[AD1] PROSPECT System Requirements Document, ESA-LEX-PRO-SRD-0001, latest version.

3.2 Reference Documents

Reference documents (RD) are listed below for information and as an aid for understanding. Citations in the document text may point to specific document sections.

[RD1] Camera Unit for PROSPECT Project Design Report, PRO-ED-DDD-3DP-0005, latest version.

[RD2] ProSEED Imaging System Requirement Specification, Rev. B, PRO-ED-PRS-LDO-0013, latest version.

[RD3] PROSPECT Permittivity Sensor Interface Control Document, HRE-ESA-PROSPECT-IF0001, latest version.

4 PROSEED CAMERA UTILIZATION

The following table summarizes the utilization areas that have been identified for the ProSEED camera system.

Engineering Support	*Science Data Acquisition*	*Public Relations Imaging*	*Notes*
Map drill working area	Images can be interrogated for regolith geotechnical information and interpretation of depth of regolith removed during landing i.e. stratigraphy of drill site relative to local vicinity	PR images to build anticipation for future drilling operations.	Enables selection of drilling spots and 3D reconstruction of work area surface (TBC; can improve depth accuracy)
	Multispectral imaging of drill working area		Imaging of surface in several spectral bands before drilling
Observe SIS and drill integrity and -function after landing		PR images of equipment post-landing	PR and general observation images can use higher compression ratio / lower bandwidth than science related images
Provide drill-SIS positioning accuracy data via images for fine-tuning sample delivery position			Verify positioning accuracy in relation to SIS sample inlet funnel; can be done during commissioning (without actual sample delivery) as a post-landing calibration. Maybe the only way to detect and compensate for landing induced deformation / unexpected position deviations
Observe drilling process and progress		PR images / video of lunar drilling operations	High data compression ratio may be used for PR
	Multispectral imaging of drill cuttings pile		Imaging of excavated sub-surface material in several spectral bands
Image borehole wall for assessment of stability for repeated drilling in the same hole			Important for repeated drilling in the same hole (select drilling speed / operations efficiency)
Witness drill positioning for Russian sample delivery			Verify positioning accuracy in relation to related hardware and funnel
Witness Russian sample delivery	Provide cross contamination info for Russian samples		Image any material remaining stuck to the sample chamber / auger / funnel, to determine cross contamination between Russian samples
	Observe delivered Russian sample size / volume estimation via 3D imaging		Allows estimation of delivered sample size via images from multiple angles to enable 3D reconstruction (TBC)

Engineering Support	***Science Data Acquisition***	***Public Relations Imaging***	***Notes***
Observe robotic arm activity		PR images / video of robotic arm operations	High compression to be used for PR
Provide info on robotic arm positioning accuracy at sample delivery point			Verify positioning accuracy in relation to related hardware and funnel
Witness positioning of drill vs ProSPA Solids Inlet System (SIS)			Observe positioning accuracy in relation to SIS sample inlet during sample delivery
Witness ProSPA sample delivery		PR images / video of sample delivery / SIS hardware	Allows assessment of delivery geometry / correct sample delivery
	Observe dust deposition on surfaces		Provide information on dust migration in Lunar environment
Enable effectiveness assessment of robotic activities (drilling, excavation, sample delivery, ..)			Images / video taken during the drilling activity allow assessment of operations effectiveness / confirmation on tool-soil interaction assumptions
	Enable observation of lunar soil properties (angle of repose, particle size distribution, multispectral properties, stickiness, ..)		Also of interest from an engineering point of view (comparison with lab studies, Apollo samples and data, other)
Support debugging mechanical systems			In case of problems during drilling, sample delivery, robotic operations etc. images are highly useful for debugging
	Support assessment of permittivity sensor electrode to soil contact / electrode coverage		The permittivity measurement accuracy depends on the knowledge of soil-electrode contact. Images can provide this information / provide constraints
Detailed imaging of trenches dug by robotic arm scoop in working area			Expected to be of interest for robotic arm operations

Table 1: ProSEED camera activity types

The following chapters provide specific requirements for the individual activity categories (engineering, science, public relations).

These requirements are intended as a complement and / or refinement of requirements provided in AD1 and RD1.

Note: For “shall” requirements compliance is considered mandatory; for “should” requirements the compliance is the design goal. For better distinction and improved readability, any “should” is underlined in requirements texts.

4.1 General Imaging Requirements

PC-GEN-0010 The exposure time setting for images shall ensure that the image sensor dynamic range is fully utilized for the acquired image/sub-frame.

Comment: *This means that images shall not be underexposed, and selected exposure times should aim for fully utilizing the sensor dynamic range. In case overexposure of image parts is to be avoided, a suitable margin of 0.5 bit TBC shall be kept. In case the main interest lies in the dark image parts, overexposure of bright image parts may be intended and justified. Exposure times shall be selected based on modelling or prior experience / experiments.*

PC-GEN-0020 For imaging with artificial illumination, only those light sources that are needed for the specific imaging purpose shall be activated.

Comment: *This may be achieved by controlling the illumination LEDs individually or in groups that correspond to the different imaging activities and the acquired image sub-frame.*

4.2 Engineering Support Imaging Requirements

4.2.1 General Engineering Support Imaging Requirements

PC-ENG-0010 For general engineering support imaging with artificial monochrome illumination, illumination intensity variations within the camera FOV, measured at the distance of optimum focus, shall be < 50% of maximum intensity.

Comment: *This relates to intensity of emitted light measured at the specified distance, not intensity of reflected light. The distance of optimum focus can be found in [RD1].*

PC-ENG-0020 For imaging with artificial monochrome illumination, unless not required for specific reasons, pairs of images with identical temperature, exposure time, FOV and imaging position shall be acquired in close temporal proximity (1 image with AI, 1 image without AI, within 10 seconds TBC).

Comment: *This is required for being able to subtract solar illumination contributions that are present in the FOV. Solar illumination contributions may distort important details (optical markers, etc.) in the images. Sensor temperature and light conditions in the imaged scene should vary as little as possible to enable an accurate subtraction result.*

PC-ENG-0030 For general engineering support imaging with artificial monochrome illumination, the artificial illumination intensity within the FOV shall be at least 10% of the maximum intensity of solar illumination present in the FOV.

Comment: *This is required for achievement of a minimum S/N for images taken in the presence of solar illumination. If exposure time is set to utilize 11 bits of dynamic range (out of 12), then the AI component will allow the generation of images that have approx. 8 bit dynamic range after subtraction of solar illumination contributions.*

4.2.2 Engineering Support Image Data Quality Requirements

PC-ENG-0100 For the compression of engineering support images, a typical lossy data compression factor of 10 … 20 (TBC) should be used.

Comment: *Lossy compression is the baseline due to bandwidth limitations. If needed, the number of bits per image pixel specified to the algorithm can be set such that compression is effectively lossless.*

4.2.3 Mapping the Drill Working Area

PC-ENG-0200 For mapping the drill working area with artificial monochrome illumination, the nadir image slice (also see Annex A) shall be defined as a part of the FOV that is limited as follows:

- full FOV width
- lower ~15 degrees (TBC) of the FOV that includes the nadir direction

PC-ENG-0210 For mapping the drill working area with artificial monochrome illumination, the camera system shall provide homogenous illumination of the nadir image slice (also see Annex A) with illumination intensity variations < 20% in a plane normal to the drill axis at the vertical camera distance of optimum focus

PC-ENG-0220 For mapping the drill working area with artificial monochrome illumination, ProSEED shall place the camera system to a position "CAM_MAP_VIEW" at a nominal vertical surface distance of optimum focus and move the camera along an arc via actuation of the rotation joint in TBD steps.

Comment: *At TBD positions along the arc, image slices are expected to be acquired which can be merged into a panorama of the drill working area that allows selection of drilling locations. This is expected to be first done during post-landing commissioning, and may be repeated at later stages of the mission. Depending on the local surface topography of the landing site, actual surface distance is expected to deviate from the distance of optimum focus. The distance of optimum focus can be found in [RD1].*

4.2.4 Observation of SIS and Drill Tip Integrity & Function

PC-ENG-0300 For the observation of the SIS, ProSEED shall move the camera to a position "CAM_SIS_VIEW" that keeps the relevant SIS parts (sample inlet, optional optical markers) within the camera's optimal focus range.

Comment: *In addition to witnessing the sample delivery process, this position also allows to acquire information on the drill-SIS positioning accuracy after landing. Information acquired during commissioning allows to adjust positioning operations for sample delivery.*

PC-ENG-0310 For the observation of the drill tip, ProSEED shall move the drill tip to a position "DRILL_TIP_VIEW" within the camera's optimal focus range that allows to visually inspect the drill tip and, if deployed, the push tube / sampling mechanisms.

Comment: *This position also allows to inspect sample material residue in the Russian sample volume, and supports acquisition of images and video during Russian sample delivery.*

Imaging of drill tip, ProSPA sample inlet system, drill-integrated sample mechanisms and drill rod movement also supports debugging of these systems (when needed), and assessment of mechanical wear.

4.2.5 Provide Drill-SIS Positioning Accuracy Information

PC-ENG-0400 The camera system shall support the acquisition of data on the relative positioning of drill rod, drill tip, and SIS sample inlet via acquisition of images.

Comment: *Such images, presumably taken during post-landing commissioning, will allow to assess the positioning accuracy for sample transfer, and provide information on any unexpected misalignment of drill and SIS as a result of landing shocks, related deformation, or unaccounted thermal conditions.*

Comment: *The camera system contractor may propose requirements for optical markers (position, color, size) to be placed on drill and SIS in case such markers are required for acquisition of position information.*

4.2.6 Observations during the Drilling Process

PC-ENG-0500 For the observation of the P-sensor electrode, ProSEED shall move the drill rod (which accommodates the P-sensor electrode) to a position

"DRILL_PS_VIEW" within the camera's optimal focus range that allows to image the electrode.

Comment: *The knowledge of the drill rod azimuth at a specific time is required for re-constructing the azimuth of the drill-integrated permittivity sensor. As there is no prior exact knowledge of the drill rod azimuth, one or more sub-frame images of electrode and / or optical markers are expected to be necessary.*
The camera system contractor may propose requirements for optical markers (position, color, shape, size) to be placed on drill rod to allow the determination of the drill rod azimuth from a single drill rod image in the "DRILL_PS_VIEW" drill rod position.

PC-ENG-0510 For the observation of the drill cuttings cone, ProSEED shall position the drill box at a height above the surface that allows to maintain the drill cuttings cone surface within the camera focus range.

PC-ENG-0520 For the observation of the borehole / borehole wall with retracted drill, ProSEED shall move the drill box to a position where the borehole / cuttings pile tip is within the camera's optimal focus range.

4.2.7 Observations during Sample Delivery

PC-ENG-0600 For the observation of the delivery of the Russian sample, ProSEED shall move the drill box to position "CAM_RSD_VIEW" that places the Russian sample delivery point within the camera's optimal focus range.

Comment: *In this position, the Russian sample reception mechanisms (robotic arm scoop / end effector / funnel) shall be visible; images acquired here also support the assessment of sample cross-contamination.*

PC-ENG-0610 For the observation of the delivery of the ProSPA sample, ProSEED shall move the drill box to position "CAM_SIS_VIEW" that allows to witness the ProSPA sample discharge operation.

PC-ENG-0620 For the observation of the Russian robotic arm scoop / end effector, ProSEED shall move the drill box to position "CAM_ARM_VIEW" that allows Russian operators to place the scoop / end effector within the camera's optimal focus range.

Comment: *Images of the arm / end effector in this specific position, taken both before and after landing, allow to assess arm positioning errors and positioning repeatability errors, and can aid in debugging activities.*

4.3 Science Data Acquisition Requirements

PC-SCI-0010 ProSEED imaging science products shall include monochromatic surface images, multispectral surface and drill cuttings investigations, monochromatic images in support of soil mechanical property investigations, and related imaging for calibration purposes.

4.3.1 Monochromatic Science Imaging Requirements

PC-SCI-0100 For the acquisition of monochromatic science images, the angle between acquired scene part - camera optics and acquired scene part – light source shall be between 10 degrees (TBC) and 60 degrees (TBC).

Comment: *This ensures that on the one hand a minimum of contrast is present in images of surface material that shows surface structure but uniform color, and on the other hand ensures that the illumination remains efficient. NOTE: Acquired scene parts may be surface patches, drill cuttings cone parts, drill rod parts, and others. This implies constraints for the placement of white light LEDs.*

4.3.2 Multispectral Science Imaging Requirements

PC-SCI-0200 For multispectral observations of the drill cuttings cone, the most relevant region for imaging shall be near the cone tip where freshly excavated material is exposed.

PC-SCI-0210 For multispectral observations of the drill cuttings cone, the variation of the image focus and the illumination conditions as a result of the cuttings pile growth should be minimized by adjustment of the drill box position.

PC-SCI-0220 For multispectral observations the following image series shall be acquired:

- 1st Image without artificial illumination
- Image 1..N with color illumination channel 1..N active, and exposure time setting as in 1st image

Comment: *The acquired images may be restricted to sub-frames showing the multispectral imaging region (MIR) which is expected to be a small part of the overall camera FOV.*

PC-SCI-0230 For multispectral observations, the angle between MIR - camera optics and MIR – light source shall not exceed 45 degrees (TBC).

Comment: *This is required to guarantee an acceptable luminous flux back to the camera optics. NOTE: This implies constraints for the placement of color LEDs.*

PC-SCI-0240 For multispectral observations, the angle between MIR - camera optics and MIR – light source for individual color light sources shall not differ by more than 10 degrees (TBC).

Comment: *This is required to ensure similar luminous flux from the MIR to the camera optics for different colors. NOTE: this implies constraints for the placement of color LEDs.*

PC-SCI-0250 For multispectral observations of the working area surface before drilling, the image focus and the illumination conditions <u>should</u> be optimized by adjustment of the drill box height.

Comment: *It is expected that scientists will be interested in observing the drill working area in multiple spectral bands in order to place the landing site into context with remote sensing observations.*

4.3.3 Science Image Data Quality Requirements

PC-SCI-0300 ProSEED imaging science products shall be acquired in camera modes that exploit the 12 bit image mode and associated dynamic range, taking into account the optional combination of natural and artificial illumination.

PC-SCI-0310 For ProSEED monochromatic surface science images that are obtained after subtraction of solar illumination contributions, the dynamic range shall not be less than 9 bit.

Comment: *Due to the limited electrical power available for the camera system (ca. 25W max total, ca. 20W for illumination, all TBC), images of scenes that include solar and artificial illumination will have limited S/N for the artificial illumination part. Note that surface science images are expected to be limited to a part of the FOV only (nadir image slice, or specific target sub-frame).*

PC-SCI-0320 For ProSEED multispectral science images that are obtained after subtraction of solar illumination contributions, the dynamic range shall not be less than 7 bit.

Comment: *Due to the limited electrical power available (ca. 25W max total, ca. 20W for artificial illumination, all TBC) images of scenes that include solar and artificial illumination will have limited S/N for the artificial illumination part. In particular the color LEDs must be expected to have limited power output, if their color is achieved via filtering of light from a high power white LED. Achieving an acceptable S/N in the MIR is then expected to require a narrow illumination angle concentrating the artificial light on the ROI. A higher S/N for image parts without solar illumination may be achieved by accepting a partial overexposure of the image.*

PC-SCI-0330 For the compression of science images, a typical lossy data compression factor of 3 ... 10 (TBC) should be used.

Comment: Lossy compression is the baseline due to bandwidth limitations. If needed, the number of bits per image pixel specified to the algorithm can be set such that compression is effectively lossless.

4.3.4 Color Calibration

PC-SCI-0400 For the observation of the SIS-mounted calibration target, ProSEED shall move the drill box / camera to a position “COLOR_CAL” where the color LEDs are pointing at the calibration target which at the same time is in the camera FOV and within the optimal focus range.

4.4 Public Relations Imaging

4.4.1 PR Image Targets

PC-PRI-0010 For the acquisition of PR images, one of the scenes expected to be imaged frequently shall include relevant PROSPECT logos.

4.4.2 PR Image Data Quality Requirements

PC-PRI-0100 For the compression of PR images, a typical lossy data compression factor of 10 ... 20 (TBC) should be used.

PC-PRI-0110 For the compression of PR images that form part of a video, a typical lossy data compression factor of 15 ... 30 (TBC) should be used.

Comment: Lossy compression is the baseline due to bandwidth limitations. If needed, the number of bits per image pixel specified to the algorithm can be set such that compression is effectively lossless.

5 PERMITTIVITY SENSOR UTILIZATION

The permittivity sensor [RD3] is integrated in the ProSEED drill rod and allows to determine the electrical permittivity of materials in contact with the sensor electrode. The sensitive volume corresponds approximately to the electrode dimensions. The following chapters provide requirements for the sensor utilization.

5.1 General Utilization Requirements

PPS-CAL-0010 During all measurements performed using the P-sensor, the drill shall be stationary.

Comment: *The electrical permittivity is a local property of subsurface materials and a measurement must therefore be taken on a sample of material that is constant during the measurement.*

PPS-CAL-0020 During all measurements performed using the P-sensor, mechanisms should not be actuated.

Comment: *Active actuators would increase the noise level on supply and signal lines. In case mechanisms must be actuated, this can be compensated by taking a higher number of P-sensor measurements and averaging the measurement results.*

5.2 In-flight Calibration Requirements

PPS-CAL-0010 All measurements performed using the P-sensor shall be preceded by a calibration measurement in air/vacuum.

Comment: *This measurement may be performed within the drill box as long as no box parts affect the measurement due to their proximity to the electrode.*

PPS-CAL-0020 All measurement series performed using the P-sensor <u>should</u> be followed by a calibration measurement in air or vacuum.

Comment: *The electrical permittivity is derived by comparing the subsurface measurement result with the vacuum/air measurement result. Taking one additional calibration measurement after drilling provides additional information on temperature trends and sensor signal stability.*

PPS-CAL-0030 P-sensor calibration measurements shall consist of one or more data time series acquisitions, where the electrode is at least 50mm away from any adjacent solid or liquid material.

Comment:	*All materials other than vacuum or gases exhibit an electrical permittivity >1 or an electrical conductivity that would disturb the measurement. Therefore a minimum distance of several electrode dimensions must be kept between electrode and such materials.*
PPS-CAL-0040	P-sensor calibration measurements should be performed with an at least coarsely cleaned electrode.
Comment:	*For calibration measurements performed after drilling, the measurement may be performed after retraction of the electrode patch into the drill box which ensures a cleaning of the electrode by the brush system mounted at the drill box bottom.*
PPS-CAL-0050	For P-sensor calibration measurements taken before the start of a drilling process, a sub-frame image of the P-sensor electrode should be acquired and compressed using a medium to high compression factor.
Comment:	*Images allow to assess the sensor cleanliness. For this, only moderate quality images of the sub-frame that shows the electrode are sufficient. This is typically a lower priority operation.*

5.3 Subsurface Measurement Requirements

PPS-SSM-0010	P-sensor subsurface measurements shall consist of one or more data time series acquisitions taken at a specific drill depth and constant azimuth.
Comment:	*Multiple acquisitions may be chosen to increase S/N.*
PPS-SSM-0020	P-sensor horizontal subsurface scans shall consist of N measurements, N being 8,16 or 24 TBC, taken at a specific drill depth with different drill rod azimuth.
Comment:	*With N=8 measurements target independent subsurface material volumes, while N=16 or N=24 provide measurements on partially overlapping material volumes for higher accuracy.*
PPS-SSM-0030	For P-sensor horizontal subsurface scans, the drill rod azimuth steps should be 360/N degrees, with a relative azimuth position error not larger than 360/N/2 degrees.
PPS-SSM-0040	P-sensor vertical scans shall consist of M measurements taken at different drill depths.

Comment: *For electrical images (see PPS-SSM-060) the chosen depth step should ideally be similar to the horizontal scan azimuth step, and should not be larger than 10mm.*

PPS-SSM-0050 For P-sensor vertical scans, the steps in drill depth should be equidistant.

PPS-SSM-0060 P-sensor subsurface electrical images shall consist of a series of horizontal and vertical subsurface scans, providing N * M measurements.

PPS-SSM-0070 P-sensor subsurface volatile scans shall consist of measurements that involve acquisition of a potentially high number (60 TBC) of data time series acquisitions taken at a specific drill depth and constant azimuth.

Comment: *The signature of volatiles (specifically: water ice) at low concentration and at very low temperature is expected to be very faint and requires a high signal to noise ratio which can be achieved by averaging a large number of individual measurements. It is expected that subsurface volatile scans are executed only occasionally, and only at the maximum drill depth for each drilling operation. The requirement suggests that commands that trigger a P-sensor measurement should include a parameter that describes the number of measurements (to avoid large numbers of individual commands). The actual number of measurements will be set by the operations team.*

PPS-SSM-0080 For P-sensor subsurface measurements, the drill forward speed (penetration speed) should be selected such that at the time of the measurement the electrode is covered with subsurface material.

Comment: *The degree of coverage of the electrode by cuttings material transported upwards by the drill auger has a strong effect on the measurement accuracy. Only partial electrode coverage means that part of the measurement volume consists of vacuum (permittivity = 1) while subsurface material typically exhibits a permittivity of 2 to 8. Partial electrode coverage therefore leads to a permittivity measurement result that is lower than the actual material permittivity, and should be avoided where sub-surface soil mechanical properties allow "fast enough" drilling. Note that electrode coverage mainly affects 'normal' permittivity measurements but has little impact on volatile detection, which relies on the measurement of permittivity over frequency. The following figure shows an example where an electrode that is accommodated between the auger windings would be sufficiently covered (coverage ~80-90%).*

Figure 1: ProSEED drill – electrode coverage example

6 ANNEX A: SCENES OF INTEREST FOR IMAGING

The following images show examples for relevant fields of view (FOV) and for possible locations of the multispectral imaging region of interest (MIR).

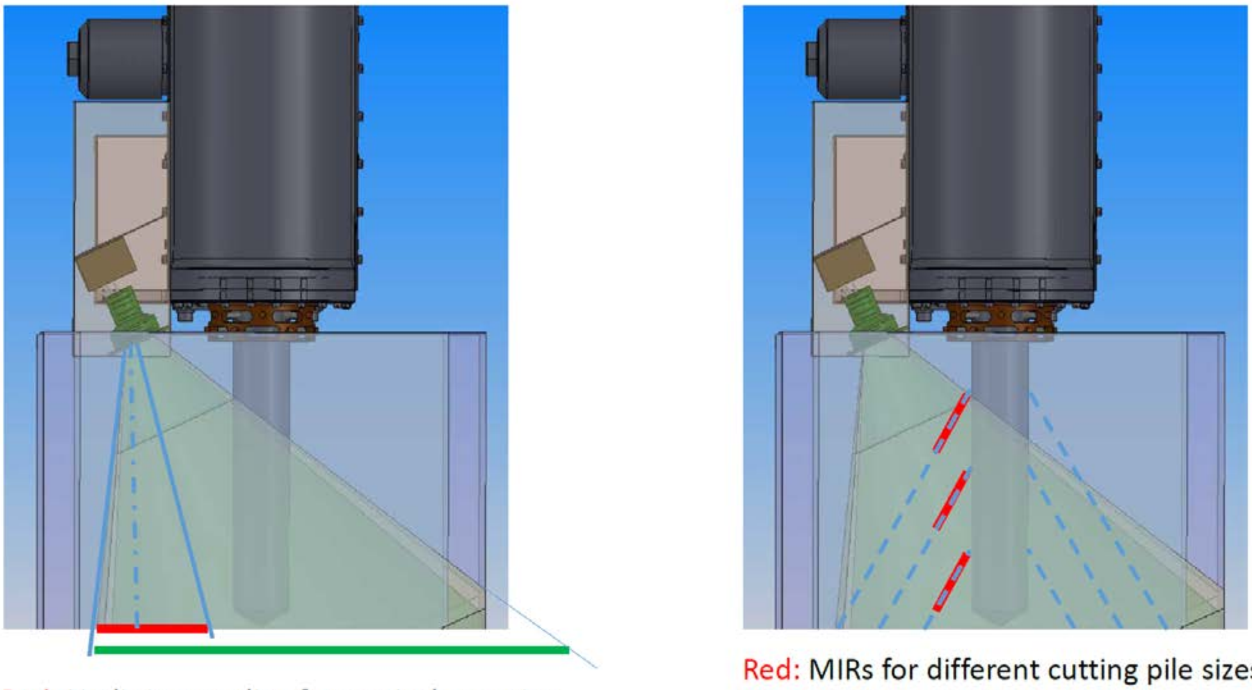

Figure 1: ProSEED camera scenes of interest before and during drilling