

PICAT User Guide

Petrographic Image Capture and Archiving Tool (PICAT):User Guide

Author:	W. Crawford, C. Bennight
Reviewer(s):	J. Beck
Management Approval (Name, Title, Date):	D.J. Houpt
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Introduction

This system was designed to digitally photograph Petrographic Thin Section samples, capturing the entire slide in an efficient manner in both cross-polarized and single (plane)-polarized states. Microscopes are commonly used for imaging thin sections, but they do not have a field of view wide enough to image the entire specimen. A whole specimen view is needed to provide a map (or guide) showing the relationship of the entire sample to specifically captured higher-detailed regions. The most common method of obtaining a full specimen image has been with the use of a modified flat bed or film scanner. Whereas these methods have been successful in some instances, they are cumbersome, slow, and tedious when the entire workflow process is considered.

The PICAT (Petrographic Image Capture and Archival Tool) provides an easy and versatile imaging process that captures a publication-quality image (8 x 10 inches at 300 DPI) within seconds rather than minutes. When coupled with a workflow-optimized software package, the time, effort, and training needed to capture thin section image data is significantly reduced. The live image displayed on a computer monitor instantly shows errors in exposure, focus, color balance, and cropping. The operator is confident the image is correct before rendering the sample to digital state.

Apparatus and Materials

Hardware

The PICAT thin section imager consists of the following hardware:

- Kaiser Camera Stand and Photo Table
- System-V RGB Light with OSRAM HLX 12V 100W Bulb
- Canon EOS 5D Mark II Camera
- Lenses
- Canon MP-E 65 mm 1x–5x Macro Lens
- Cannon EP 100 mm IS Macro Lens
- B&W 95 mm Diameter Linear Polarizing Glass Filter Element (2)
- Custom Filter Module with Friction Wheel
- Specimen Holders
- HP LP3065 Wide Gamut 30 inch LCD Monitor
- HP xw4400 PC Workstation

Camera

The camera for this system is a Canon 5D Mark II with video capability. The sensor is a CMOS full-frame sensor with a resolution of 21 megapixels. The camera produces "Live View" images that can be displayed on a tethered computer system. The system is also capable of 1920 x 1080 video. The camera system is considered a prosumer type model and therefore has simple settings such as the "green box," choices of program modes, or manual operation. Refer to the camera manual for more detailed information.

The camera is powered by an AC adaptor. Menu items and presets on the camera are as needed. Raw files plus a small JPEG file is the production setting for the camera at this time.

The camera colorspace is SRGB. As the Raw file the color space is assignable postprocessing and will be archived; the larger colorspace of Adobe 1998 will be added later. The camera provides the smaller JPEG file. This smaller file is used by the scientist for onboard use and the Web. SRGB colorspace is used for Web, JPEGs, and printing.

Lenses

This system uses two lenses.

- A 100 mm macro lens for images of the full thin section or smear slide. This pro-quality lens with auto-focus is recommended for production-type tasks such as recording an entire slide. This lens, coupled with the slide carrier, simplifies the task of image capture.
- The 65 mm macro lens used in this system is one of a kind in the industry. It is capable of 1x–5x magnification. This magnification refers to projection of the size of the image to the sensor plane. For example, an image of a dime is projected to the sensor at full size when the lens is set to 1x and focused at that point. At 5x the coin is projected at 5 times full size at the sensor plane. A total of 21 million pixels projected via a 30 inch monitor results in a magnification of 2500% at a setting of 1x when viewing the image at 100%. If the camera is set to capture at 5x, the effective magnification is 12,500%. This is variable to the output device and resolution of that device.

Imaging with such a sensor size and lens combination approaches the range and exceeds some low-end microscope/camera combinations. In addition to the field of view and ease of operation, this system has advantages over other current imaging systems.

Details about the camera operation and the software are available in the Canon 5D operations manual and disk provided with the system.

Filter Module and Friction Wheel

The filter module is the unique part of this system and is the only component that was custom designed and manufactured for this system. The entire module when assembled weighs about 10 lb.

Overview

Microscopes commonly spin or rotate the sample, allowing the viewer to explore the birefringence. In this system, spinning of the sample was not an option because the sample orientation and the camera sensor must remain fixed. Instead, a unique magnetic coupling linkage was designed to allow the filters to turn in unison, negating the need for a spinning image sensor. Having the filters turn synchronously while in a cross-polarized state allows control of orientation and precise cropping of the image.

This approach to viewing the birefringence and the ability to precisely choose the degrees of rotation to achieve specific visual states in select crystal structures within the sample is not possible with flatbed scanners or modified film scanners.

Another distinct advantage of this filter configuration is the ease of cleaning and minimizing the effect of dust and lint in the light path. Converse to film or flatbed scanners, the light path can be monitored for unwanted foreign matter. Because the filters lay far out of the field of focus, overlooked dust or lint is never recorded, resulting in a clean usable image that requires no clean-up postprocessing.

Description

The module consists of a top plate holding the analyzer filter (top filter), a stage with appropriate attachments to hold the thin section sample, and an additional plate to hold the polarizing filter. The specimen stage is bolted to a center mounting block, while the filter plates are attached in a manner that allows them to rotate in and out of the light path. Each of the filter plates houses a 95 mm polarizing filter within a rotating ring to allow rotational adjustment. In addition, a friction wheel-shaft-coupling allows both of the filters to turn in a synchronized manner. The top filter platform houses the filter ring, and its analyzer filter is recessed within that ring to achieve the lens barrel clearance required when certain lenses are used at maximum magnification.

The bottom filter ring platform and filter ring is configured differently to allow the rotation of the polarizing filter to the housing ring to achieve the cross-polarized state.

Specimen Holders

Currently there are two styles of holders: standard specimen carrier and X/Y style specimen holder. These holders are similar to what might be found in a Photography Darkroom Enlarger being used as a negative or slide holder.

Standard Specimen Carrier

The standard specimen holder has 2 rails on either side of the specimen stage that serve as sliders to center the slide under the center of the sensor on the camera. This assures ease of cropping and faster operations when multiple specimens are imaged in a short period of time. The standard specimen holder also ensures consistency in cropping and alignment of the image in the camera, eliminating the need to crop the image in postproduction. The standard specimen carriers hold 1 x 2 inch or 2 x 3 inch specimens.

X/Y Style

The X/Y specimen holder is used in the following circumstances:

- Specimens are not of the standard size.
- Higher magnifications are necessary.
- The image must be taken off dead center

The X/Y style specimen holder allows movement of the specimen through different areas of the field of view when using the higher magnification settings and lenses.

Software

The thin section imager system makes use of the following software:

- Cannon EOS Control Utility
- IODP In-house "Image Capture" software
- Adobe Bridge
- Adobe Photoshop and Camera Raw (in some alternate workflows)

Cannon EOS Control Utility

Available on request from the photographers, this is a Cannon-supplied utility that provides drivers and a software interface for tethering a camera to a computer. Note that this must be installed from original Cannon CDs, as the updates available on the Internet require that the software already be installed. This utility allows full control and settings of the camera, though typically only the photographers will be involved in the more advanced and esoteric settings. This software is what defines the capture location of images (what directory they will be written to) and in our current configuration creates the date-based subdirectories as well.

Adobe Bridge

This is installed by default when Adobe PhotoShop is installed. This software is not required for the standard workflow and essentially serves as a branching point for those who wish to edit software directly in Photoshop or some other software before upload.

Adobe PhotoShop and Camera Raw

These packages are installed when the PhotoShop suite is installed. They are not needed in the standard workflow but may be used by the photographer and others for alternate or specialized workflows.

IODP ImageCapture software

This is an in-house software package that facilitates the transfer of images and metadata to the LIMS database, as well as manages naming and location of local files on the computer. The source code for this software is located at <https://shiptest.ship.iodp.tamu.edu/svn/jr/NET/CloseupCapture>. It requires the .NET 4.0 runtime (Client Profile) to be installed on the computer before it can operate. It can be installed (via click once) from <http://web.ship.iodp.tamu.edu/tasapps/closeup>.

The software makes use of the following Web services:

- Resteasy-lims-webservices
- Creates tests (TSIMAGE) and logs data and files to those tests
- Enumerates lists of samples based on expedition/site/hole/sampletype(s)
- Validates scanned in text_id's
- Image-tiling-services
- Triggers the automatic generation of a close-up image tileset when an image is uploaded to asman (image tileset as web/imagetiles/EXP???.thinsections/)

The software is the only application that logs data to the TSIIMAGE analysis. TSIIMAGE analysis is defined as follows:

Name	Order	Alias	Reportable	Optional	Description
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camera	1	Camera	T	T	Camera used to take the image
iso	2	ISO Speed	T	T	ISO Speed (sensitivity) of camera
aperture	3	Aperture	T	T	Aperture of camera (f-stop)
shutter_speed	4	Shutter Speed	T	T	Shutter Speed
focal_length	5	Focal Length	T	T	Focal length of lens
date_taken	6	Date Taken	T	T	Date the photo was taken (from EXIF)
macro	7	Macro Setting	T	T	Reduction in field of view due to macro lens setting
polarization	8	Polarization	T	T	Polarization setting (none, cross, single)
polarizationangle	9	Polarization Angle (cross-pol)	T	T	Polarization Angle (for cross-pol only)
jpeg_filename	10	Jpeg Filename	F	T	Filename of closeup image
jpeg_asman_id	11	Thin Section Image	T	T	Asman id of thin section image
raw_asman_id	12	Raw Image	T	T	Camera RAW image file
raw_filename	13	Raw Image Filename	F	T	Raw image original filename
comments	14	Comments	T	T	Comments

When deploying, the only setting that needs to be changed is the publish location and default server.

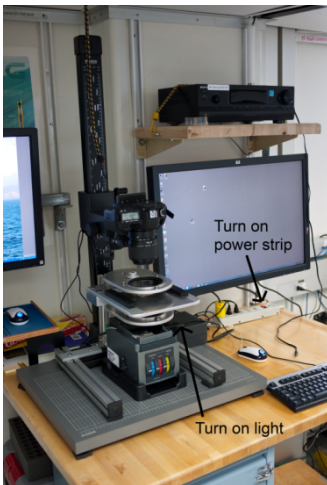
Standard Operation

The following sections describe the standard procedure for imaging and cataloging a thin section aboard the *JOIDES Resolution*. Notations are made where alternate workflows may be substituted, but such workflows are not described in this document. Standard operation includes

1. Starting up the system
2. Acquiring an image
3. Processing and uploading an image
4. Shutting down the instrument

Starting up the system

1. Start the computer and navigate to the Windows desktop.
2. Ensure that the power strip under the monitor and the light power source are turned on.



3. Remove the lens cap from the camera.

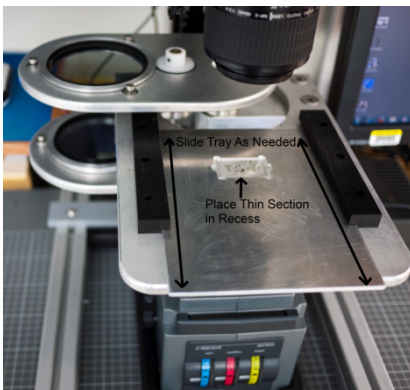


Acquiring an Image

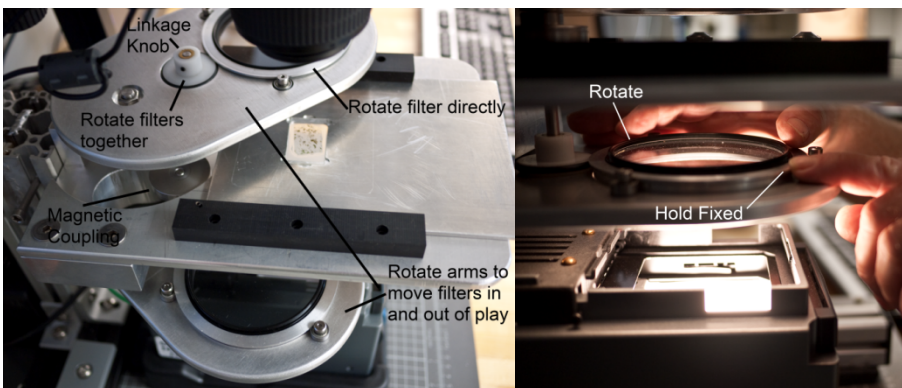
1. Select the type of specimen holder (for instructions on changing to the X/Y stage holder see Hardware > Specimen Holders > /Y Style Holder).

Installing the X

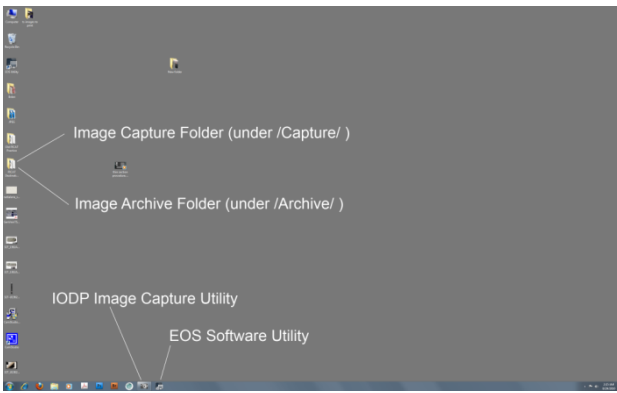
2. Load the thin section slide into the recessed portion of the tray. Slide the tray in and out as needed.



3. Two polarization filter holders, one above the tray and one under it, are coupled by a magnetic linkage. The entire assembly can be rotated out of the way as needed. The filters can be rotated independently or together (the former by turning the polarizing [bottom] filter while preventing the filter holder from rotating, the latter by turning the white linkage knob).



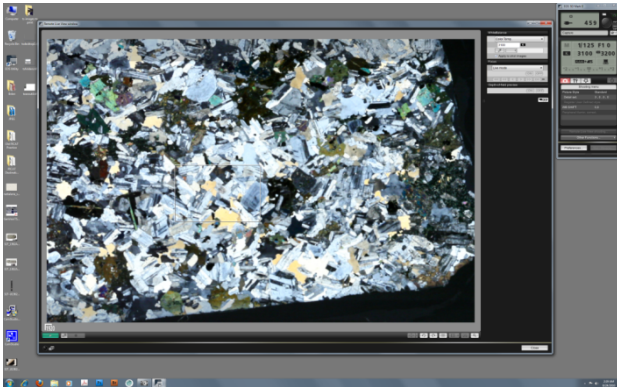
4. Start the EOS capture software.



5. After startup click on the **Live Image Preview** button



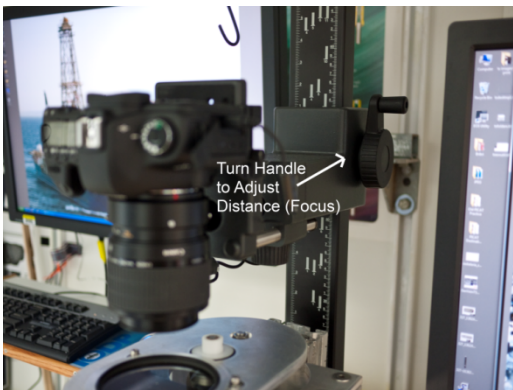
6. A window shows exactly what the thin section image will look like.



7. If you are using the 65 mm macro lens, adjust the **Macro** (a zoom effect) setting on the side of the camera as desired.



The lens in this camera has a fixed focal point; to bring the image into focus, adjust the distance of the camera from the sample using the hand crank attached to the camera arm.



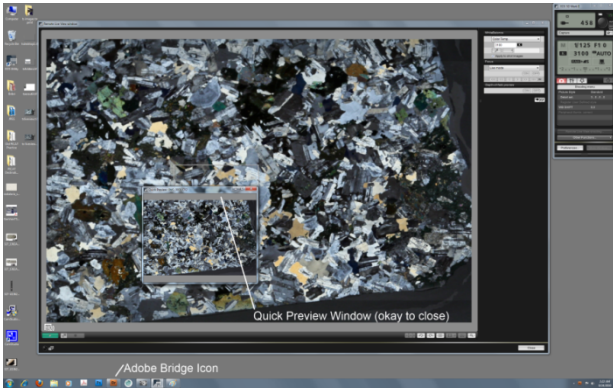
8. Adjust the filters at this point as follows:

- Single-polarization mode: move the entire top filter assembly arm to the left (out of the optical view path).
- Cross-polarization mode:
 - a. Ensure that both filter arms are engaged (in the optical path).
 - b. Turn the bottom polarizer while viewing the display on the monitor until a dark-field is achieved.
 - c. Turn the friction wheel at the top filter plate to rotate both of the filters to view the effects and adjust the image as preferred.
- As a matter of good practice check the dark-field and thus the cross-polarized state before the image is captured.
- Refocus the image when switching polarization states, as the diffraction of light of the Analyzer filter and its subsequent removal affects the light path and focus.
- If the camera is in auto-mode and is calculating the exposure properly, no further adjustment is needed.
- If the camera is in manual mode, adjust the combination of aperture, shutter speed, and or ISO settings for the desired effect.

9. When the image on screen is deemed acceptable press the capture image button in the cannon EOS software (the large circle).

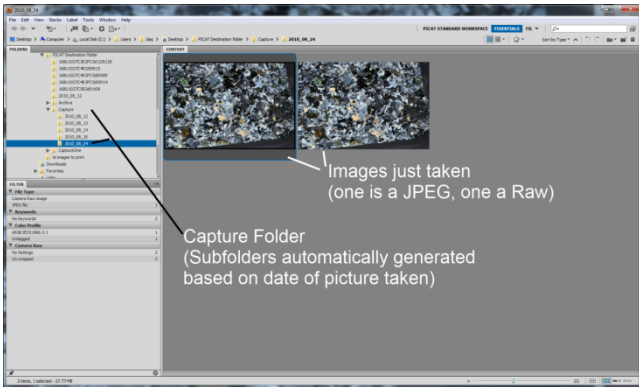


10. A preview window displays the captured image.



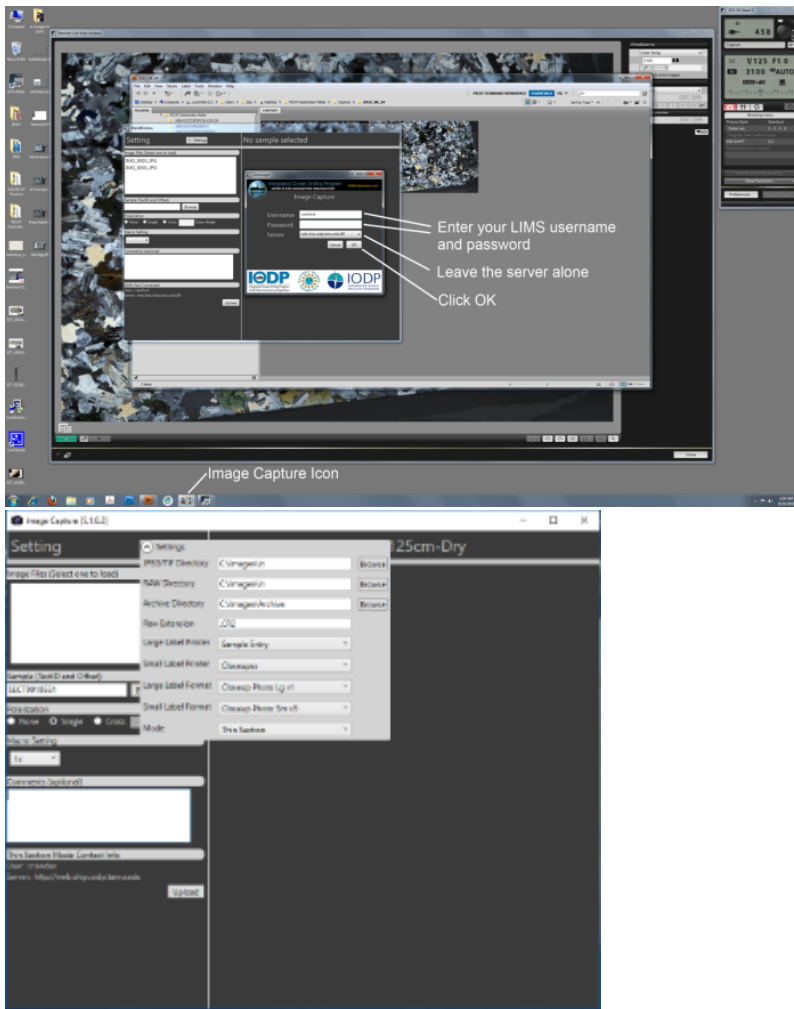
11. The preview window can be ignored/closed without affecting anything. If Adobe Bridge is already loaded, its icon will flash in the taskbar (burnt-orange square with the letters "Br"). If Bridge is not already loaded, it will open automatically after a few moments.

12. No action needs to be taken in Bridge at this point. Close/minimize Bridge at any time. The camera automatically creates and saves the JPEG and RAW files.

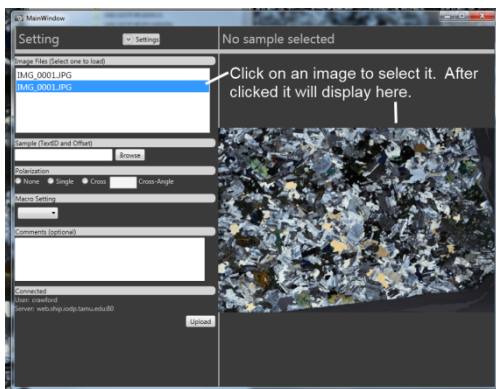


Processing and Uploading the Image

1. Start the IODP Image Capture software and login using LIMS username and password. Under the Settings menu, select the Thin Section Mode. Here you can also select the folders Image Capture will look for the images taken.

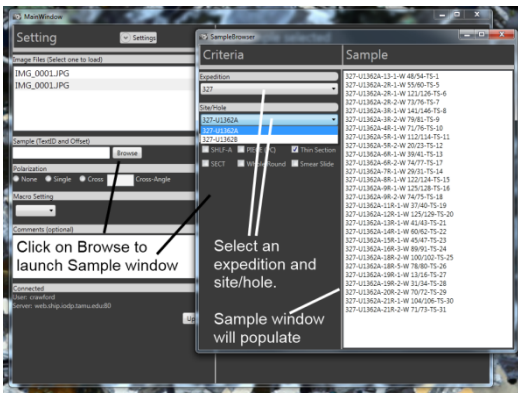


2. After software log-in, the list displayed the upper left corner shows the images that were just taken (the JPG files specifically). Click on one of the images to select it for processing.

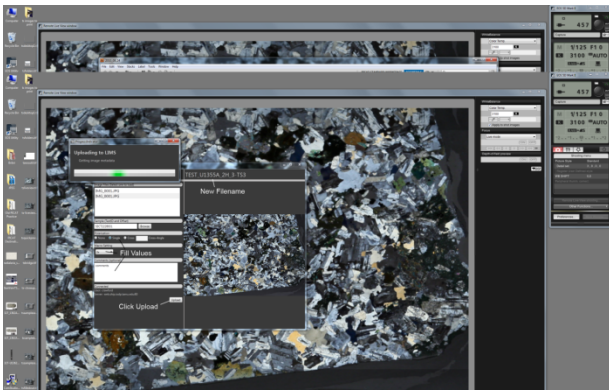


3. Next, associate this image with a sample:

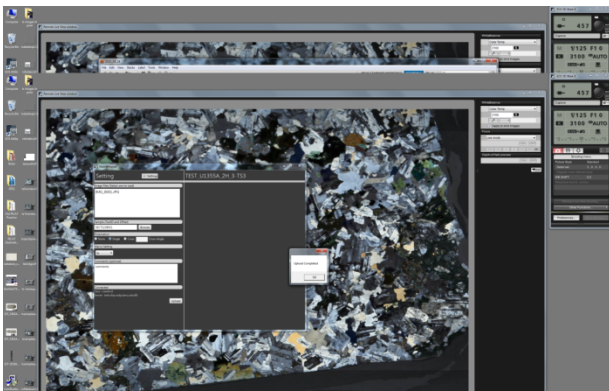
- Click on the **Browse** button.
- Select a site and hole to select a sample (default type = Thin Section [TS]).
- Select a sample from the list and go back to the main window (close/minimize/ignore sample browser window; it will open back to same location).



4. Once a sample has been selected, the sample text_id field populates and a new label is generated in the top right that indicates the new filename, based on the sample selected. If multiple pictures were taken of the same sample, the filename is appended with _2, _3, _4, etc., based on the number of previous images taken **and processed**. Fill out the rest of the values based on the conditions when the image was taken.



5. Click **Upload** to open a window indicating the upload status. When the upload process is finished another dialog box will appear indicating that the process is complete



6. Once uploaded, the selected image is removed from the pending uploads list and loaded into LIMS. Continue processing additional images.

7. After upload, the images are moved to the archive folder (at the same level as the capture folder). Under the archive folder are 3 subfolders:

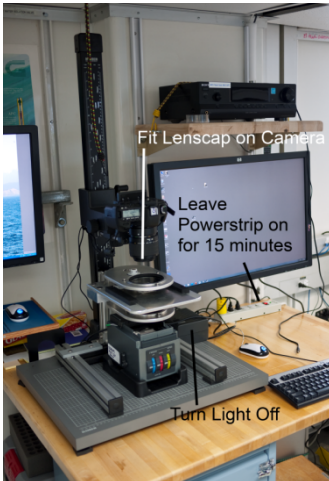
- JPEG
- TIFF (tiffs are not generally created in the standard workflow)
- RAW

These folders contain a hierarchy in the form of `\\Expedition\\SiteHole\\filename.ext` of all the files (essentially, images are organized by type, expedition, and site-hole when stored in the archive folder). These images do not need to be backed up (as they are already in LIMS/ASMAN) but can be selected by the photographers, etc., for alternate archiving if desired.

Note: These images may be deleted at any time, without notice, by the technicians or other scientists. They will continue to be available via LIMS. A local copy can be saved as well.

Shutting Down the Instrument

1. Shut down the Cannon EOS utility if it is still running.
2. Place the lens-cap back on the camera.
3. Turn off the light, but not the power strip. This is important to ensure the fan cools the light while it is still hot. The power strip can be shut down 15 min after light has been turned off.



Safety

- There are no outstanding safety issues associated with operation of this instrument
- When maintaining this instrument the technician should be aware of pinch hazards associated with the extremely strong magnets used in the magnetic filter coupling assembly.

Hardware Maintenance and Troubleshooting

This section contains detailed information about hardware theory, maintenance, and disassembly of

- Specimen Holders
- Filter Module/Friction Wheel

Specimen Holders

There are two styles of interchangeable specimen holders, the standard specimen holder and the X/Y style stage holder.

Standard Specimen Holder

The standard specimen holder is suited for standard workflow. When using the standard specimen holder, make sure both of the stage rails are installed. However, it is not necessary to have the specimen stage glass installed, as the holder itself supports the specimen entirely. It is therefore advantageous to remove and store the glass in a safe place, taking care to be aware of the sharp edges of the glass. Working without the glass also clears the light path of unneeded obstructions and removes two surfaces that might attract dirt, dust, and fingerprints. Removal of the specimen stage glass is NOT an option when using the X/Y specimen holder.

On the standard specimen stage there are two positions and centering pinholes. The nearest to the light path is used for slides that measure 1 × 2 inches or similar. The aft pinhole setting is for use with specimen slides that are 2 × 3 inches in size. Using these pinhole settings centers the slide within the movement limitations of the slide holder.

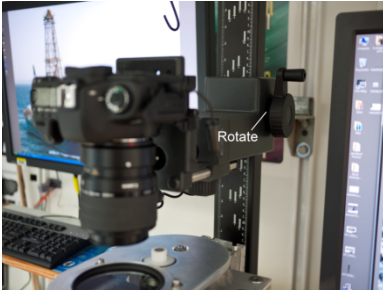
X/Y Style Specimen Holder

The X/Y style holder allows movement of the specimen through different areas of the field of view when using higher magnification settings and lenses. The mechanism in this system was surplus from Zeiss standard microscopes no longer in use. Before any using the X/Y stage, the specimen stage glass must be installed (clean before inserting).

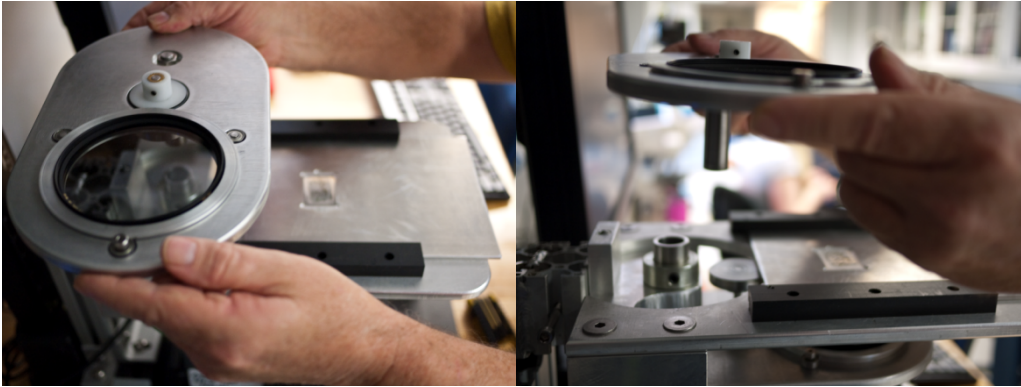
Installing the X/Y Specimen Holder

To install the X/Y specimen holder, the rail on the right side of the specimen stage (when facing the filter module) is modified by removing the three Allen screws that attach the rails to the specimen stage. Once the screws are removed, the rail can be swung back to the right and stored aft. Although it is not necessary to remove the rail entirely, you may do so if you wish. Detailed instructions follow.

1. Rotate the camera height adjustment wheel to give at least 12 inches of clearance between the camera lens and the top filter assembly.



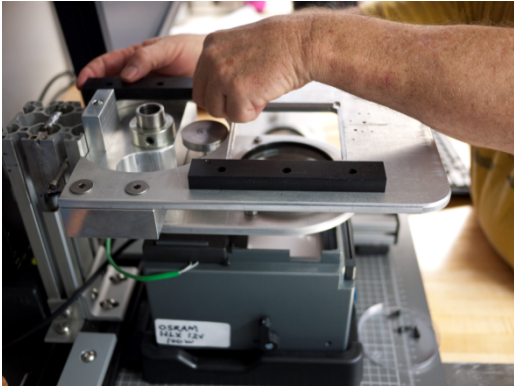
2. Lift the top filter assembly upward until it disengages from the stage plate under it. Keep the unit oriented in the normal position so filter parts do not fall out.



3. Slide the specimen holder out and begin loosening the bolts holding in the slide rails on the right side. Remove the bottom two bolts and loosen the tip bolt.



4. Rotate the right rail out of the way



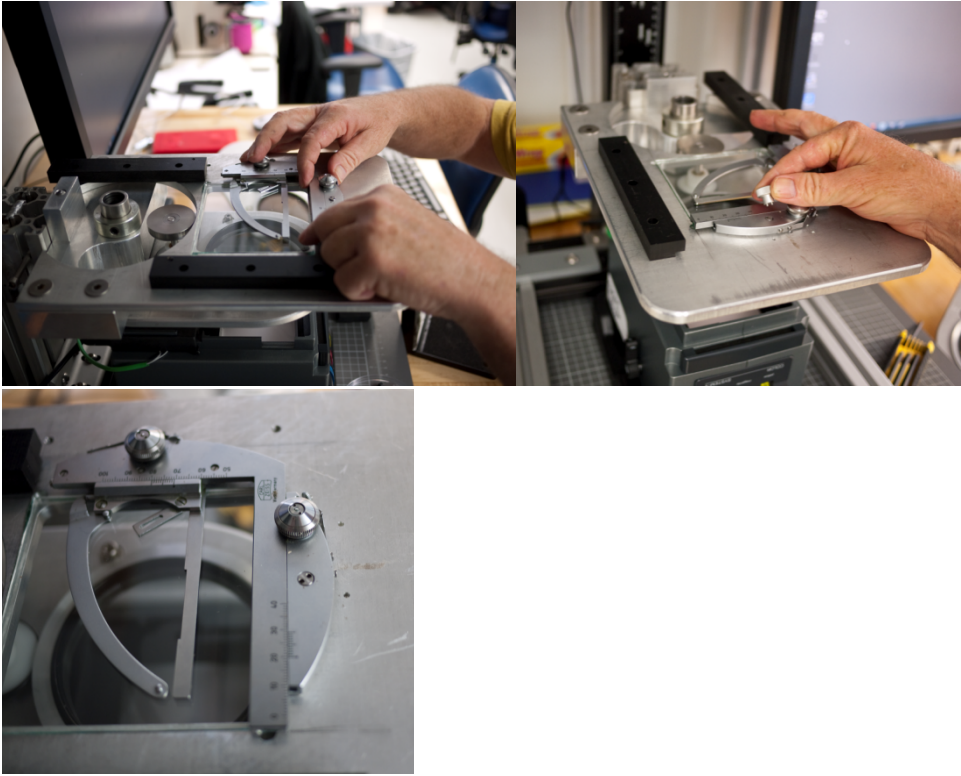
5. Remove the X/Y stage from the box and prepare to install it.



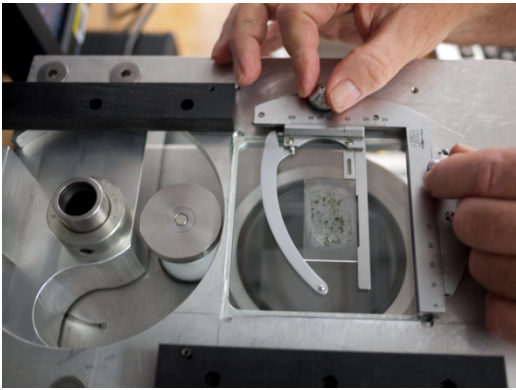
6. Note the holes in the stage plate. These are what the X/Y stage will attach to.



7. Place the X/Y stage in position and attach it with screws threaded into the holes.



8. Once the stage is located, place a slide in it and use the X and Y adjustment knobs to set the final position.



Filter Module and Friction Wheel

The filter module is simple and robustly built. Other than routine cleaning and maintenance, having to disassemble and reassemble should occur on only rare occasions.

The top filter plate is milled to countersink the friction wheel and bearings into the plate itself. The filter ring is machined so that the polarizing filter nestles within the filter holder ring. This configuration reduces the overall thickness of the assembly to allow maximum lens clearance. When using the Canon 5x magnification, the focus distance between the specimen and the lens barrel is 41 mm. The clearance between the surface of the Analyzing Filter (top polarizer) and the lens barrel is 5 mm! Care must always be taken when rotating the Analyzer Platform out of the light path. **THE IMPACT OF THE PLATE AND THE LENS BARREL IS REAL POSSIBILITY; PLEASE BE AWARE.** Because of countersink configuration of the top polarizer plate, the bottom and the top filter plates are not exchangeable.

The polarizing filter on the bottom filter plate and filter holder ring is installed so the polarizing filter ring can be reached by fingers and turned in relationship to the bottom filter holder ring. This is how the operator achieves the cross-polarized state. The top polarizing filter is recessed in the filter ring, and the bottom polarizing filter is placed (backwards or upside down) so that the body of the filter extends above the filter holder ring. This allows for manual adjustment of the polarization state. Note also that the bearings, friction wheel, and filter holder ring are surface-mounted because clearances for rotation were not factors in the design of the lower filter plate. Because of the countersunk nature of the components of the top filter ring, dust can accumulate over time. Periodic cleaning with canned air or a directed flow of clean compressed air will help to ensure free rotation and a friction-reduced operation.

Because both the lower and the upper filter plates rotate in and out of the light path, motion stops were designed into the mechanism. Detent balls are installed in the mounting block, and each filter plate has a semicircular track and indentions to hold the plates over the light source and 90° of left or clockwise rotation. The lower plate is held in position by a shaft collar around the tube that protrudes through the mounting block. This collar keeps the lower filter plate assembly from falling out of the mounting block.

A swing pathway was milled for the lower filter plate and assembly and a mounting shaft was installed in the very back. This is machined for the elevator block to receive the filter module. There is a detent ball on the elevator block and a receiver depression on the module. When these are aligned and tightened the filter module will be square fore and aft to the alignment of the column itself.

When reassembling this unit and adjusting the collar in place, squeeze the lower plate to the block, which in turn compresses the detent ball. Then snug the collar to the block and tighten. Attempt to rotate the lower filter out of the light path and note the amount of effort required to do so. Use your judgment in determining whether the rotation is too loose or too tight and adjust the pressure/collar as necessary.

All that is required is that the lower filter plate depression stops pull up to the detent ball. Conversely, the top filter plate shaft is placed inside the lower filter plate tube. Gravity holds this in place; therefore, the plate to detent ball adjustment is automatic and no adjustment is necessary. The machine fit between the top filter plate shaft and the bottom filter plate tube is 1/2000 inch.

Maintenance

No major maintenance is necessary on the detent balls or plates other than slight lubrication with petroleum jelly along the track path to lessen the etching effect, which the chrome detent ball will have on the softer aluminum material of the filter plates.

Wipe the shaft with a silicone lubricant occasionally. Do not lubricate with a product that might gum the assembly, or the shaft and tube might have to be disassembled and cleaned.

The mounting block is milled from solid aluminum and is maintenance-free except for dusting and cleaning. Although mounting of the camera can be done improperly, leading to alignment problems, the filter module is simply installed and tightened and its alignment is assured.

Clean the polarizing filters with the same care as cleaning a lens. Begin with the least aggressive technique, such as a camelhair brush, followed perhaps by lens cleaner and fluid. Never apply friction to the glass before brushing with a camelhair brush to remove grit or particles. Be aware of substances that may be abrasive to the filter surface.

Disassembly of the Filter Module

Note the following when working with or disassembling the filter module:

- The polarizing filters are not fixed to the rotating filter rings. If the unit is turned upside down, the filters will fall out and break.
- The rotating filter rings are not attached to the filter platforms. If the assembly is turned upside down the rings may fall out and cause damage. Note: the filter rings are custom machined so there is a significant lead time involved in obtaining replacement parts.
- Strong magnets are used to couple the top and bottom filter platforms. These magnets can cause pinching, contusions, and lacerations. Be careful.
- Do not attempt to disassemble the magnetic coupling units unless there is at least ½ inch of nonmagnetic material is placed in between the two magnets.

Prior to disassembling the filter unit, ensure that the camera is raised to a height that is well clear of the upper filter module (at least 6 inches of clearance). Rotation of the top filter plate to the left will clear the lens and allow the entire filter plate to be lifted and removed. It is held in place by the force of the magnet and the machine fit of its shaft held within the cylinder of the bottom plate. Rotating the top filter plate when the lower filter plate is in its home or natural position breaks the force of the magnet. Removal of this plate is convenient when exchanging specimen holders or cleaning. Note that the contact between the filter ring and the friction roller is a compression fit. The O-ring on the friction wheel is compressed against the filter ring to provide the necessary friction for the ring to rotate.

To reassemble, press the face of the ring firmly up against the O-ring of the friction wheel. Upon doing so the filters ring will slip into place as held by the bearings on the edge of the light path opening.

Disassembly of the Friction Wheel

The friction wheel provides traction and transmission for rotation and coordination of the two filters, due to the compression of the O-ring of the friction wheel to the surface of the filter-holding ring. The friction wheel also secures the shaft, which passes through the top filter stage, to which half of the magnet coupler is attached.

CAUTION: LOOSENING THE SET SCREWS WILL RELEASE THE MAGNET, WHICH CAN CAUSE SEVERE PINCHING DAMAGE TO HANDS AND/OR POSSIBLE DAMAGE TO THE COUPLING ITSELF. THESE ARE VERY POWERFUL MAGNETS. PLEASE EXAMINE AND UNDERSTAND BEFORE ATTEMPTING DISSASSEMBLY.

The filter-holding ring and the filter is held in place by press fit, and the filter is easily removed from the holding ring by gentle pressure with the fingers. It is best to wear cotton gloves when handling the filters; otherwise removal of fingerprints from the glass filter will be required later on. The filter-holding ring is easily removed from the three bearings that secure it to the top filter plate.

Note that reinstalling the filter-holding ring into the top filter plate requires compression of the friction wheel O-ring with the surface of the filter-holding ring. Push gently with the filter-holding ring held level and then push the ring vertically into location. Take care not to pinch the O-ring and subject it to damage during reassembly.

The magnetic coupling when installed has a sizable gap between the magnets (5/8 inch or 16 mm). The gap between the magnetic couplings is set by the total length of the assembly of the friction wheel-shaft-coupling assembly attached to the lower filter plate. This assembly and subsequent total length is set by a collar attached to the bottom of the shaft on the underside of the lower filter plate.

IMPORTANT: THE LOWER MAGNETIC COUPLING MUST NOT EXTEND ABOVE THE SURFACE OF THE SPECIMEN STAGE PLATE. IF THIS OCCURS, THE FIXED SPECIMEN SLIDE CARRIER WILL BE OBSTRUCTED, PREVENTING CENTERING OF THE IMAGE UNDER THE CAMERA. THE LOWER MAGNETIC COUPLING SURFACE IS APPROXIMATELY ¼ INCH BELOW THE TOP SURFACE OF THE SPECIMEN STAGE PLATE.

As stated earlier, the magnetic couplings are very powerful and exert a force in rotation equal to 5-inch-pounds. The 16 mm gap weakens that force in order to ease the movement of the top and bottom filter stage plates in and out of the light path. This also serves to lessen the downward pull (top filter plate) and upward pull (bottom filter plate) that introduce a frictional force that is harmful to the free synchronous rotation of the filter holder rings.

The "take home message" here is: assembly of the magnetic couplings with too small a gap is bad. Assembly of the lower magnetic coupling above the surface of the specimen plate is bad.