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Title: Automated Image Analysis Corrosion Working Group Update: February 1, 2018

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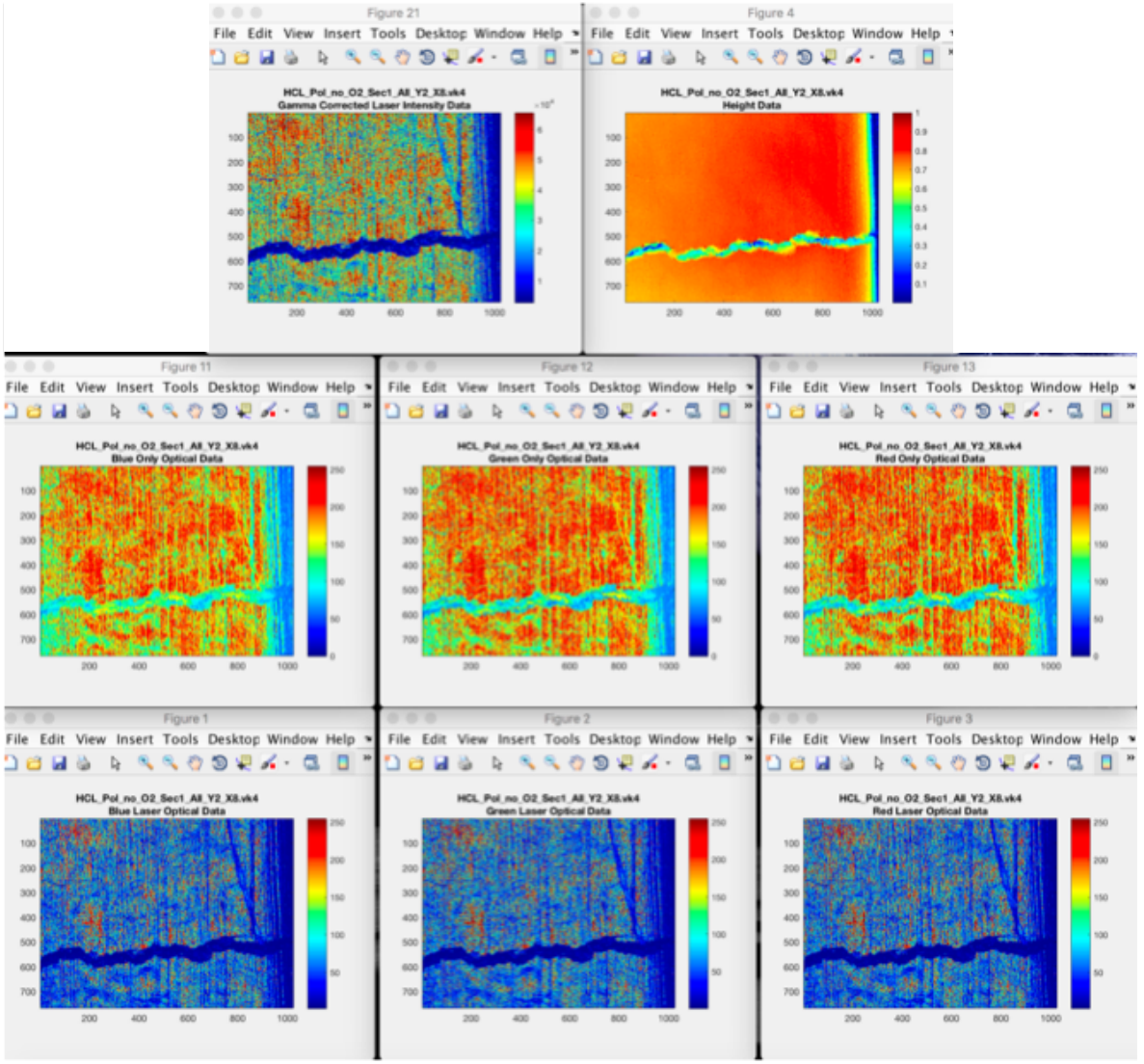
February 1, 2018

National Nuclear Security Administration
Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

Overall Goals

- **Automate the detection and quantification of features in images**
  - Faster
  - More Accurate
- **How to do this?**
  - Obtain Data
  - Analyze Data
- **Focus on Laser Scanning Confocal Microscope (LCM) data**
  - Laser Intensity
  - Laser Height/Depth
  - Optical RGB
  - Optical plus Laser RGB

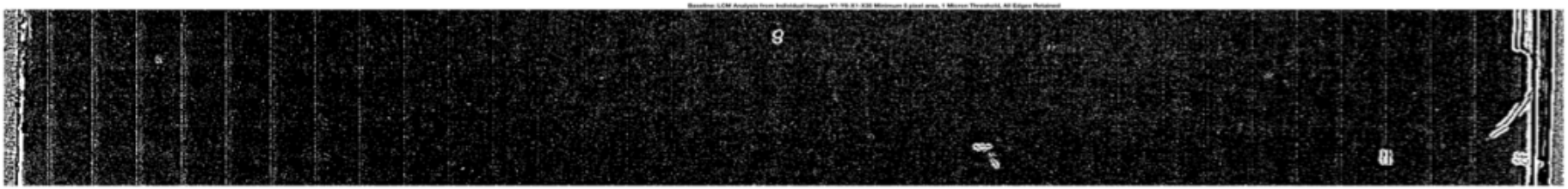


Utilizing the Data

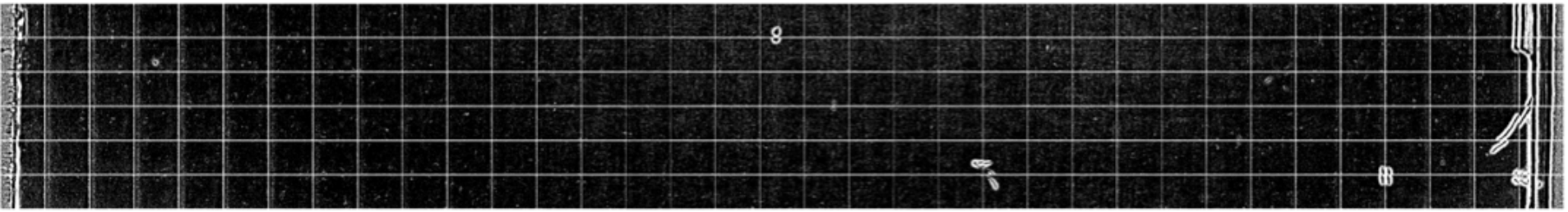
- Focus on Height/Depth data because we want the depth of the features
- Measure voids in the material that are visible at the surface
- The voids or features may be
  - Pits
  - Cracks
  - Corrosion
  - Other imperfections
- What can be expected in a new container?
  - Baseline – size, type, shape, density and number
- What actually occurs on used containers?
  - 300 Images: FY09 DE2
  - 165 of ~600 Images: FY11 HHMC
  - Special select images from Juan
- Are used container images statistically different from baseline images?

Baseline Y1-6 X1-35 Images
Min 5 Pixel Area, Min Depth 1 Micron

- Unframed



- Framed



Practical Issues

- Height/Depth data is influenced by
  - Sample curvature
  - Microscope peculiarities
    - Edge/corner issues
    - Laser is not the shape of a square pixel
  - Edges
  - Welds
- Height/Depth uncertainty (±.5 microns in depth)
- Image is pixelated ~ .7 microns by .7 microns (or .5 square microns) for a 20X, 1024 by 768 image
- Automated image collection overlap

Image Surface Statistics

- Contiguous features of a certain depth or more (rowboat or ship)
  - Shape – groups of neighboring pixels
  - Size – number of pixels or bounding box
  - Depth – variable like the ocean floor
  - Elongation of the feature – major and minor axes (eccentricity)
  - Islands or holes in the voids are material (Euler number)
  - Features of a certain type per unit area
- Type classification – pits, cracks, corrosion, scratches, welds, edges, rubble

"The Euler number is the total number of objects in the image minus the total number of holes in those objects. Objects are connected sets of on pixels." https://www.mathworks.com/help/images/ref/bweuler.html

Baseline Y2X4 Feature Statistics – For All 3,908 Features – Top 10

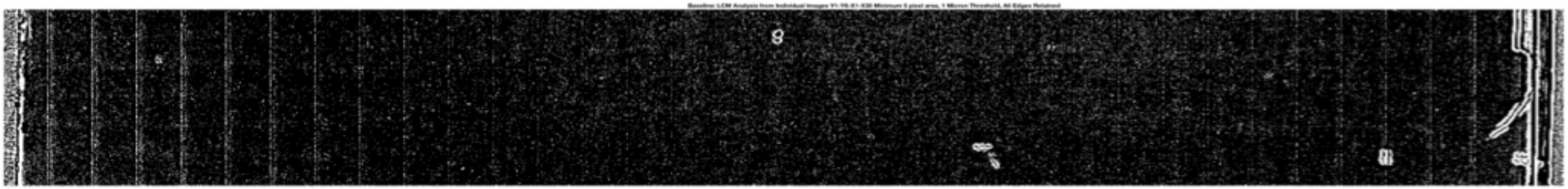
Eccentricity	Orientation	EulerNumber	NumPixels	pixelareamicrons	rows	columns	normalizationfactor	xylength	zlength	cutdepth	cutheight	islandminsize	islandmaxsize	minimum	maximum	pixelarea
0.491194465	-72.58317063	-138	11387	0.475624019	768	1024	1305900	689.655	130590	-0.007657554	0.007657554	5	1000000	-0.125155823	-0.007657756	0.475624019
0.998697543	89.49675114	-106	7097	0.475624019	768	1024	1305900	689.655	130590	-0.007657554	0.007657554	5	1000000	-0.102274083	-0.007658459	0.475624019
0.997824139	89.74103969	-46	3914	0.475624019	768	1024	1305900	689.655	130590	-0.007657554	0.007657554	5	1000000	-0.079644903	-0.007658292	0.475624019
0.959626034	72.10653298	-10	815	0.475624019	768	1024	1305900	689.655	130590	-0.007657554	0.007657554	5	1000000	-0.145811399	-0.007661179	0.475624019
0.956301727	-5.020552916	-2	744	0.475624019	768	1024	1305900	689.655	130590	-0.007657554	0.007657554	5	1000000	-0.047628477	-0.007671504	0.475624019
0.770960845	55.7168565	0	546	0.475624019	768	1024	1305900	689.655	130590	-0.007657554	0.007657554	5	1000000	-0.034476125	-0.007664823	0.475624019
0.774487224	85.41722592	-2	412	0.475624019	768	1024	1305900	689.655	130590	-0.007657554	0.007657554	5	1000000	-0.044309697	-0.007658706	0.475624019
0.912918385	79.14395679	-1	361	0.475624019	768	1024	1305900	689.655	130590	-0.007657554	0.007657554	5	1000000	-0.054422572	-0.007676916	0.475624019
0.869670357	-88.03117918	-5	351	0.475624019	768	1024	1305900	689.655	130590	-0.007657554	0.007657554	5	1000000	-0.047244333	-0.007669768	0.475624019
0.855758165	11.77625494	1	286	0.475624019	768	1024	1305900	689.655	130590	-0.007657554	0.007657554	5	1000000	-0.025744845	-0.007668674	0.475624019

HeightCutoffMicrons	HighAreaMicronsSquared	MaximumHeightMicrons	HighVolumeMicronsCubed	DepthCutoffMicrons	LowAreaMicronsSquared	MaximumDepthMicrons	LowVolumeMicronsCubed
1	0	0	0	-1	5415.930705	-16.34409887	-95.23554551
1	0	0	0	-1	3375.503663	-13.35597248	-51.42137272
1	0	0	0	-1	1861.59241	-10.40082792	-29.05464499
1	0	0	0	-1	387.6335755	-19.04151059	-8.66312361
1	0	0	0	-1	353.8642702	-6.219802753	-5.724823268
1	0	0	0	-1	259.6907144	-4.502237176	-3.148337644
1	0	0	0	-1	195.9570958	-5.786403279	-2.675865498
1	0	0	0	-1	171.7002709	-7.107043652	-2.486592049
1	0	0	0	-1	166.9440307	-6.169637414	-2.32742948
1	0	0	0	-1	136.0284694	-3.362019345	-1.687375183

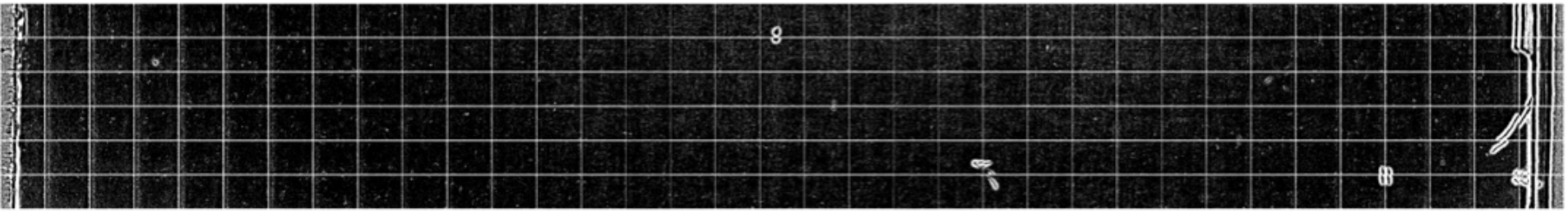
imagename	FeatureNumber	CentroidRow	CentroidColumn	BoundingBoxMinRow	BoundingBoxMinColumn	BoundingBoxMaxRow	BoundingBoxMaxColumn
insideY2X4	1671	481.8596645	563.8386757	400.5	462.5	561.5	666.5
insideY2X4	3783	1014.389319	240.0614344	988.5	0.5	1024.5	489.5
insideY2X4	3883	1015.703373	624.2562596	1000.5	465.5	1024.5	768.5
insideY2X4	2473	652.5803681	385.7730061	634.5	339.5	669.5	432.5
insideY2X4	12	59.54704301	740.6155914	18.5	725.5	93.5	761.5
insideY2X4	104	67.21428571	648.478022	40.5	620.5	91.5	677.5
insideY2X4	241	79.82524272	703.7961165	65.5	683.5	93.5	727.5
insideY2X4	1920	490.9972299	484.2825485	478.5	448.5	503.5	506.5
insideY2X4	1797	453.3532764	167.9230769	443.5	144.5	463.5	184.5
insideY2X4	2893	767.8216783	749.7377622	749.5	739.5	786.5	768.5

Baseline Y1-6 X1-35 Images
Min 5 Pixel Area, Min Depth 1 Micron

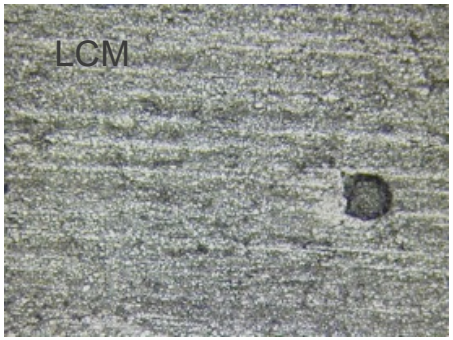
- Unframed

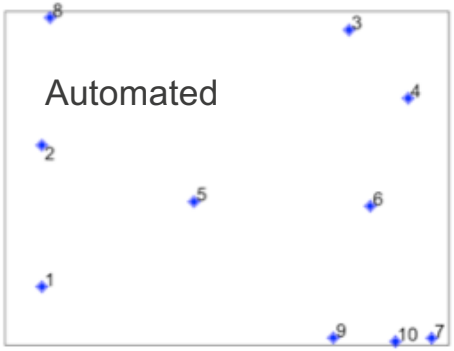


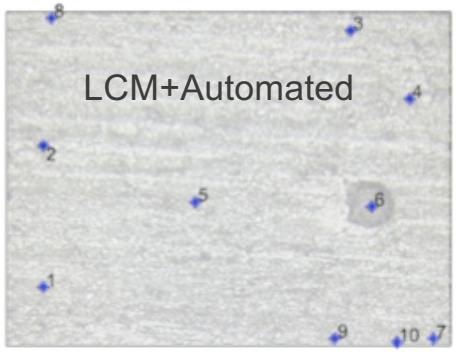
- Framed



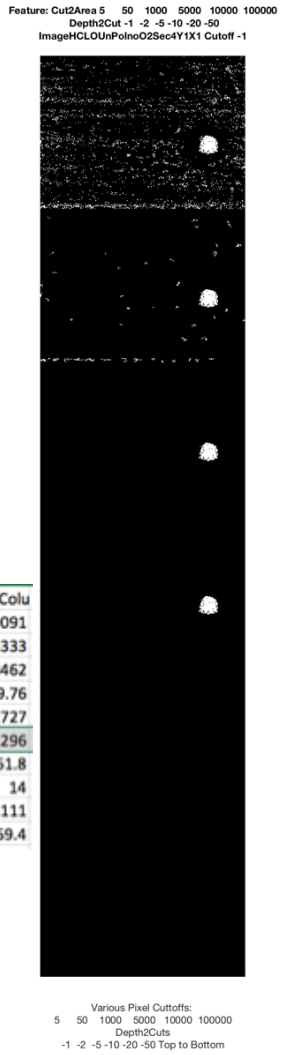
Juan Selected Feature Image: HCL O Un-Polished O2 Sec 4 Y1X1







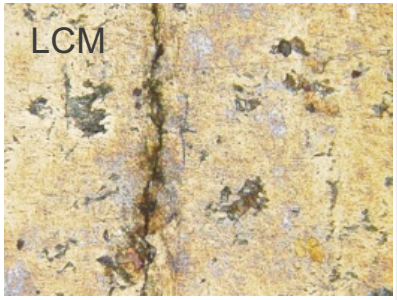
	namefeature	Eccentricity	Orientation	EulerNumber	NumPixels	pixelareamic	minimum	maximum	LowAreaMic	MaximumDe	LowVolumeN	imagename	FeatureNuml	CentroidRow	CentroidColu
2	1	0.8527466	37.103798	1	11	0.475624	-0.2508882	-0.0202338	5.2318642	-12.405166	-0.4235682	ImageHCLOU	490	85	633.09091
3	2	0.9759887	-24.276387	1	45	0.475624	-0.2254221	-0.0205254	21.403081	-11.145994	-1.0527714	ImageHCLOU	436	84.844444	307.73333
4	3	0.7379174	-15.314999	1	13	0.475624	-0.2196738	-0.0238554	6.1831122	-10.861771	-0.3625095	ImageHCLOU	2859	794.07692	42.538462
5	4	0.812773	56.16702	1	25	0.475624	-0.2100518	-0.0237349	11.8906	-10.386013	-0.8033933	ImageHCLOU	3330	930.08	199.76
6	5	0.82896	-58.443467	1	11	0.475624	-0.2087375	-0.0224968	5.2318642	-10.331026	-0.2895235	ImageHCLOU	1714	435.81818	437.72727
7	6	0.2648458	33.331249	-138	6072	0.475624	-0.2087085	-0.0203123	2887.989	-10.31959	-204.83263	ImageHCLOU	2866	842.85293	447.82296
8	7	0.8269705	46.272402	1	15	0.475624	-0.2053381	-0.0231454	7.1343603	-10.15294	-0.7245517	ImageHCLOU	3596	984.33333	751.8
9	8	0.9660469	9.5531765	1	25	0.475624	-0.2013768	-0.0205618	11.8906	-9.9570777	-0.5889571	ImageHCLOU	556	103.8	14
10	9	0.8774884	2.2545324	1	18	0.475624	-0.1936491	-0.0213765	8.5612323	-9.574978	-0.935934	ImageHCLOU	2736	757.5	751.11111
11	10	0.68273	-12.323385	1	15	0.475624	-0.1927109	-0.0219009	7.1343603	-9.5285913	-0.5652071	ImageHCLOU	3235	900.73333	759.4

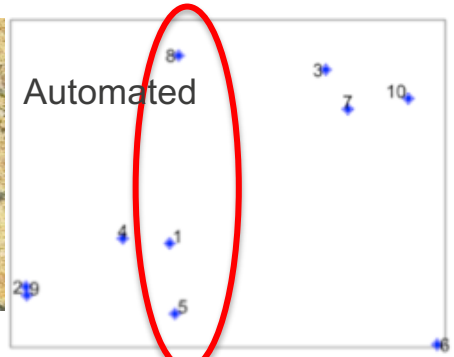


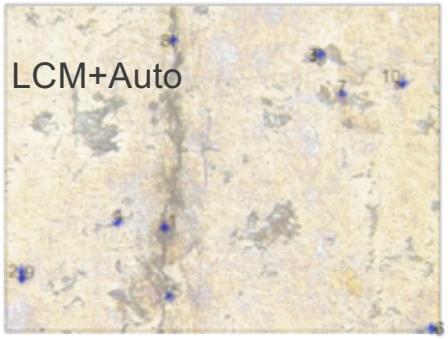
Found the large isolated pit with a low eccentricity value (round).
A lot of information about the image and features within the image.
Still more work need to be done.

Feature ”floor” roughness

Juan Selected Feature Image: MgCl2 Inside Y15X18

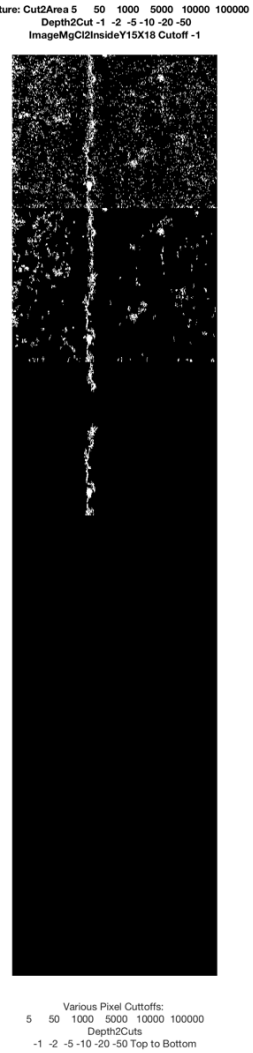




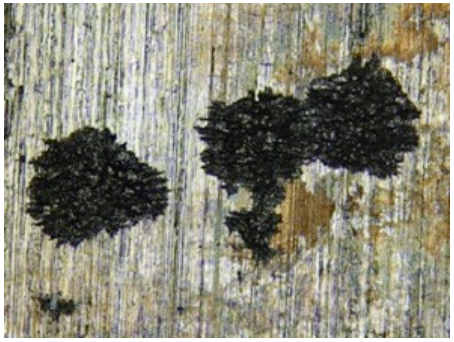


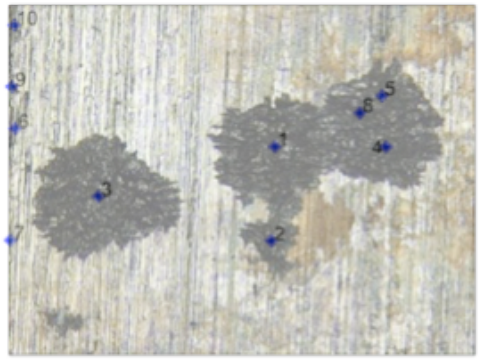
	Namefeature	Eccentricity	Orientation	EulerNumbe	NumPixels	minimum	maximum	LowAreaMic	MaximumDe	LowVolumeM	imagename	FeatureNum	CentroidRow	CentroidColu
2	1	0.9915461	-86.20677	-10	1821	-0.2946765	-0.0183701	866.111339	-16.04366	-38.363161	ImageMgCl2	1718	374.978034	523.125206
3	2	0.62815168	81.3592508	1	27	-0.2369571	-0.0198061	12.8418485	-12.90113	-0.8486833	ImageMgCl2	149	36.2222222	624.777778
4	3	0.60853887	85.5858218	-12	824	-0.1966771	-0.018385	391.914192	-10.708083	-18.040282	ImageMgCl2	3247	742.996359	116.617718
5	4	0.94776335	89.8061451	1	22	-0.1913737	-0.0183853	10.4637284	-10.419343	-0.7717856	ImageMgCl2	1314	264.227273	511.681818
6	5	0.9777823	85.9257306	-23	2633	-0.190033	-0.0183693	1252.31804	-10.34634	-70.818015	ImageMgCl2	1755	387.394607	688.274972
7	6	0.94053828	-67.722469	1	75	-0.1813016	-0.0201035	35.6718014	-9.870965	-1.7863742	ImageMgCl2	4756	1004.94667	761.426667
8	7	0.98974332	90	1	7	-0.1697839	-0.0194568	3.32936813	-9.2438839	-0.2995289	ImageMgCl2	3605	795	209
9	8	0.9734304	-83.247548	-27	1998	-0.1686612	-0.0183686	950.29679	-9.182760	-36.213483	ImageMgCl2	1799	395.952953	83.6106106
10	9	0.840563	-47.381821	1	29	-0.1682455	-0.0185384	13.7930966	-9.1661282	-0.6420672	ImageMgCl2	155	38.4137931	645.034483
11	10	0.90786897	60.5064717	1	45	-0.167794	-0.0185186	21.4030809	-9.1355456	-0.9334971	ImageMgCl2	4393	937.066667	184.022222

Found crack with a high eccentricity value (line)



Juan Selected Feature Image: S1953d Teardrop





	namefeature	Eccentricity	Orientation	EulerNumber	NumPixels	pixelareamicr	minimum	maximum	LowAreaMicr	MaximumDe	LowVolumeM	imagename	FeatureNumb	CentroidRow	CentroidColu
2	1	0.5697757	57.644315	-128	17239	0.4740873	-0.2364627	-0.0153889	8172.7915	-15.370076	-430.04317	ImageS1953c	1086	583.25112	309.76066
3	2	0.6593378	-24.371152	-13	4725	0.4740873	-0.2094698	-0.0154343	2240.0626	-13.615535	-150.95008	ImageS1953c	1169	575.46349	516.0419
4	3	0.6682742	4.372555	-138	22363	0.4740873	-0.198304	-0.0153867	10602.015	-12.889757	-652.63196	ImageS1953c	168	194.5294	419.30381
5	4	0.736682	14.435235	-66	12416	0.4740873	-0.1912681	-0.015387	5886.2683	-12.432427	-342.85588	ImageS1953c	1429	829.19217	309.92349
6	5	0.8612454	-12.861546	-16	3199	0.4740873	-0.131407	-0.0153877	1516.6054	-8.5414567	-83.126519	ImageS1953c	1520	820.17412	198.03782
7	6	0.9765885	-89.076449	-5	1956	0.4740873	-0.1227731	-0.0153926	927.31482	-7.9802533	-56.235594	ImageS1953c	5	11.925869	269.83538
8	7	0.9979053	89.417446	-1	202	0.4740873	-0.1090485	-0.0156292	95.765641	-7.0881502	-3.9016052	ImageS1953c	10	2.3663366	514.93564
9	8	0.9142176	-22.61427	-2	1144	0.4740873	-0.1037458	-0.0154383	542.35591	-6.7434792	-22.906252	ImageS1953c	1445	771.84266	235.88811
10	9	0.9649415	-87.231221	-3	490	0.4740873	-0.1011077	-0.0155358	232.30279	-6.5720019	-11.001666	ImageS1953c	4	5.6367347	177.72857
11	10	0.9669933	88.555063	-7	1419	0.4740873	-0.0999418	-0.0154707	672.72992	-6.4962202	-30.462366	ImageS1953c	1	10.199436	43.250176

Competing factors (cracks at the bottom of pits)
Excellent job by automatic software to identify these features

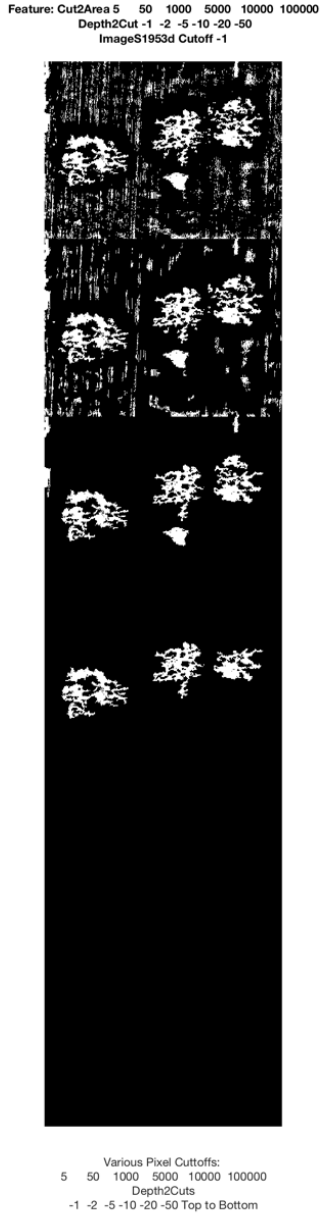
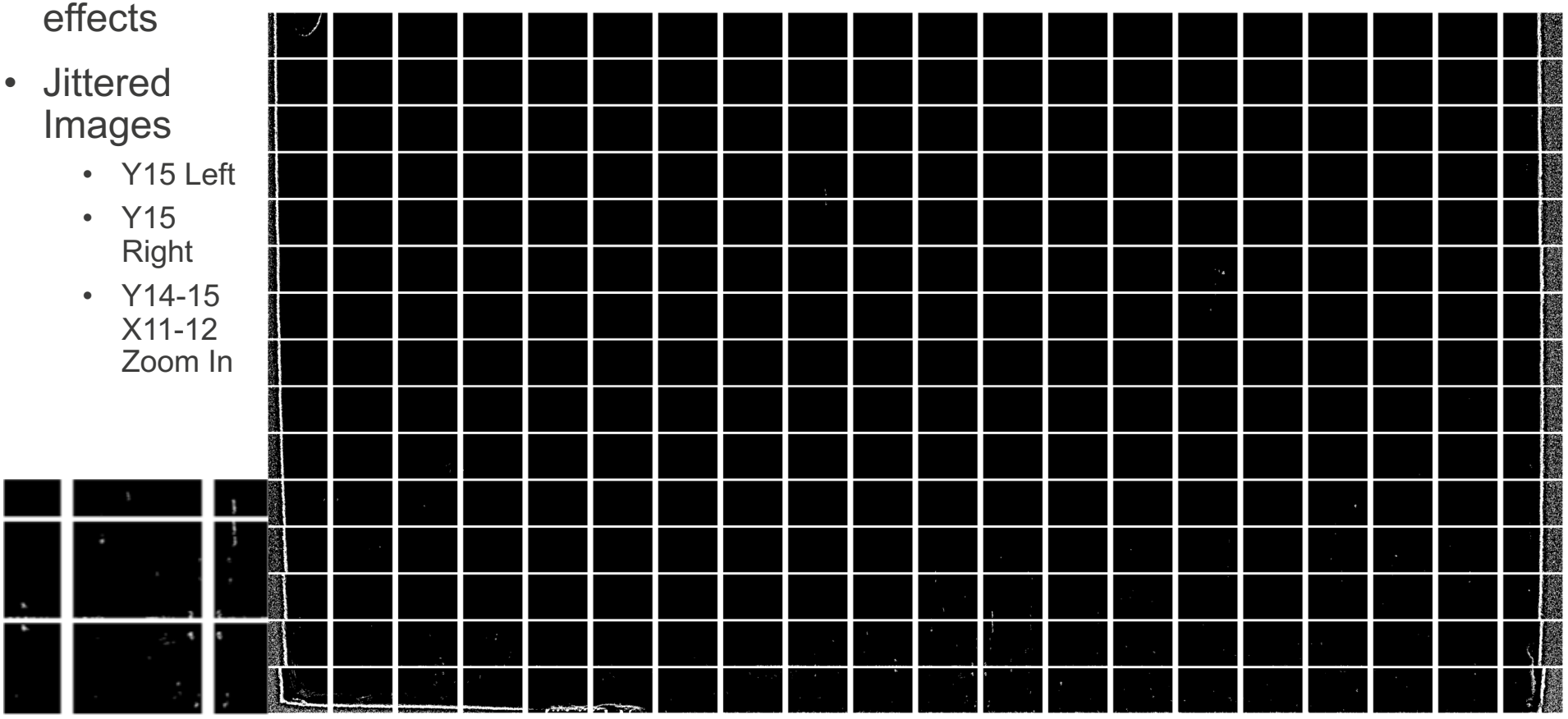


Image Classification

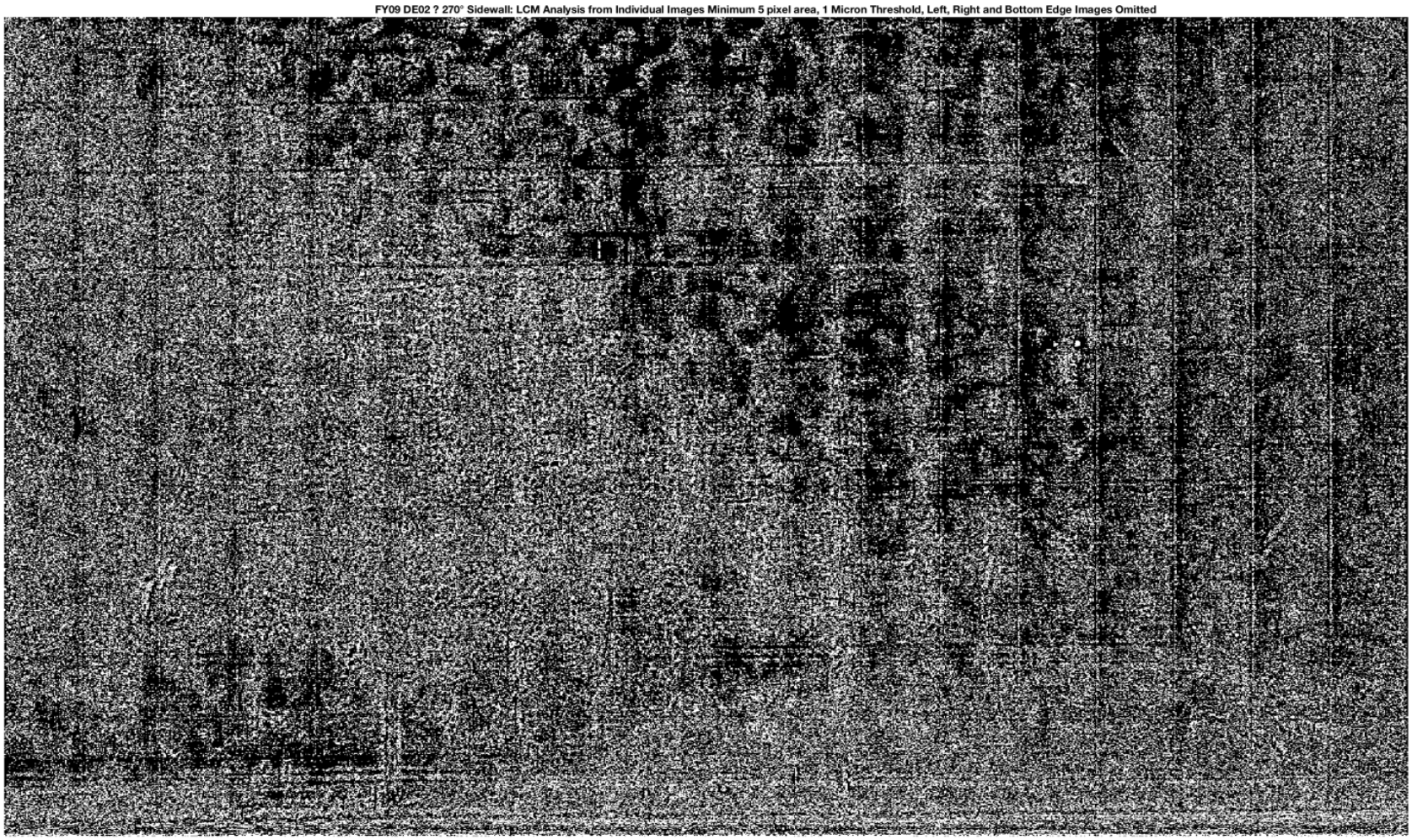
- What features are in the image?
  - Type
  - Number
- How are the images ranked from most to least likely to be scrutinized further?
  - Actual sample images of concern
  - Comparative baseline images
- Scrutinize images with certain types of features
  - Deep non-elongated features (pits)
  - Long or deep elongated features (cracks or parts of cracks)
  - High density of features of a certain size per unit area (corrosion)

FY09 DE02: Montage 300 Images, Framed, With Edges, Minimum 50 Pixel Area, 1 Micron Depth or Deeper

- Edge effects
- Jittered Images
  - Y15 Left
  - Y15 Right
  - Y14-15 X11-12 Zoom In

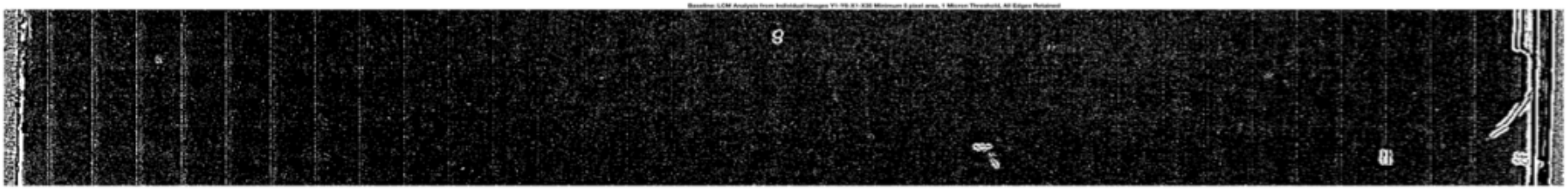


FY09 DE02: Montage 300 Images, Unframed, No edges Minimum 5 Pixel Area, 1 Micron Depth or Deeper

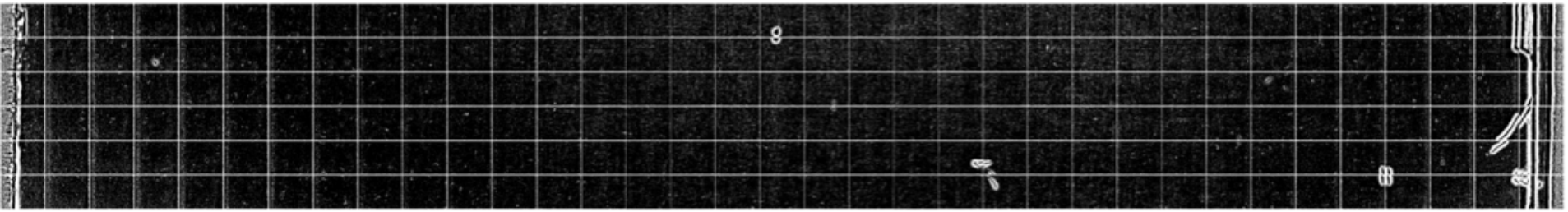


Baseline Y1-6 X1-35 Images
Min 5 Pixel Area, Min Depth 1 Micron

- Unframed



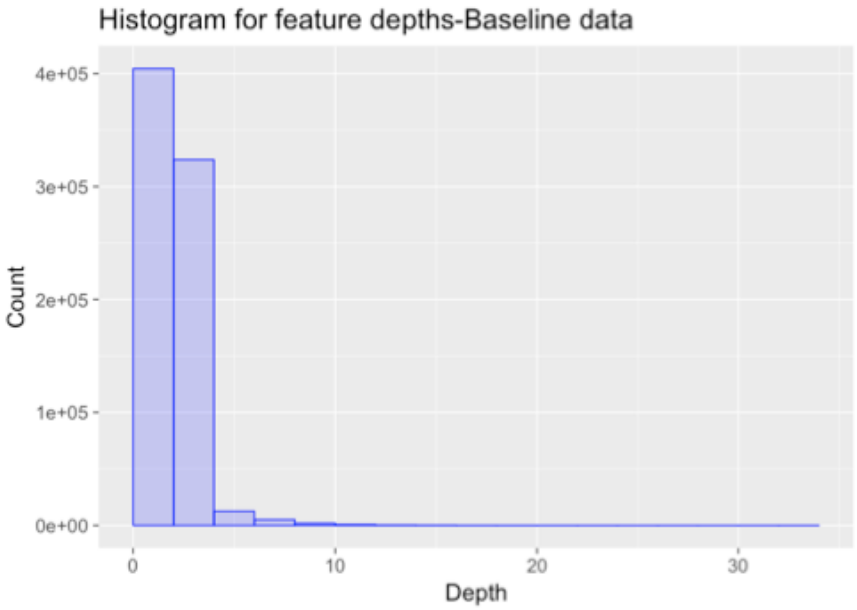
- Framed

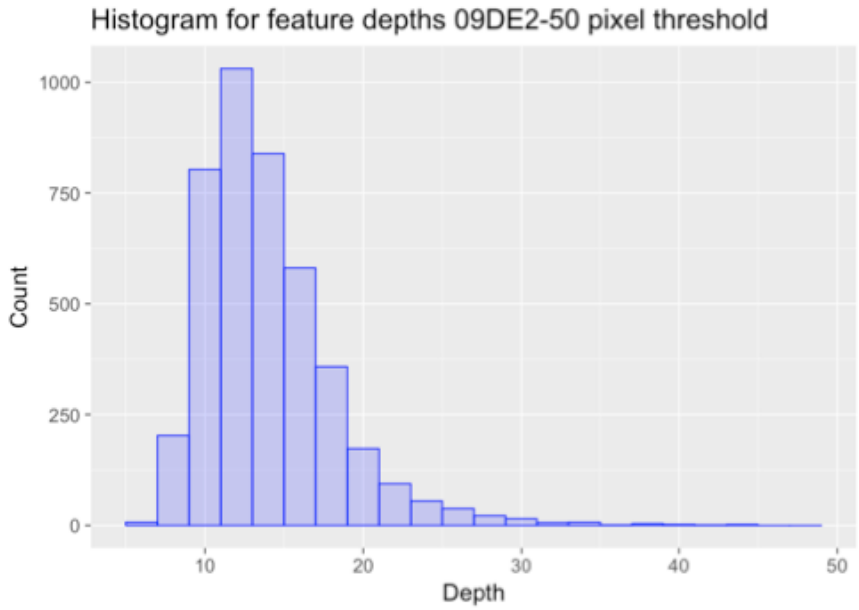


Correlation of Statistics with Subject Matter Expert Analysis Opinion

- Are we finding all the features of interest?
- Are we flagging features that are not of interest?
- Are the images that are ranked near the baseline images of interest or concern?
- Are the images that are ranked as different than the baseline images, practically different than the baseline?

Baseline vs. 09DE2 Feature depth comparison





Obtaining the Data

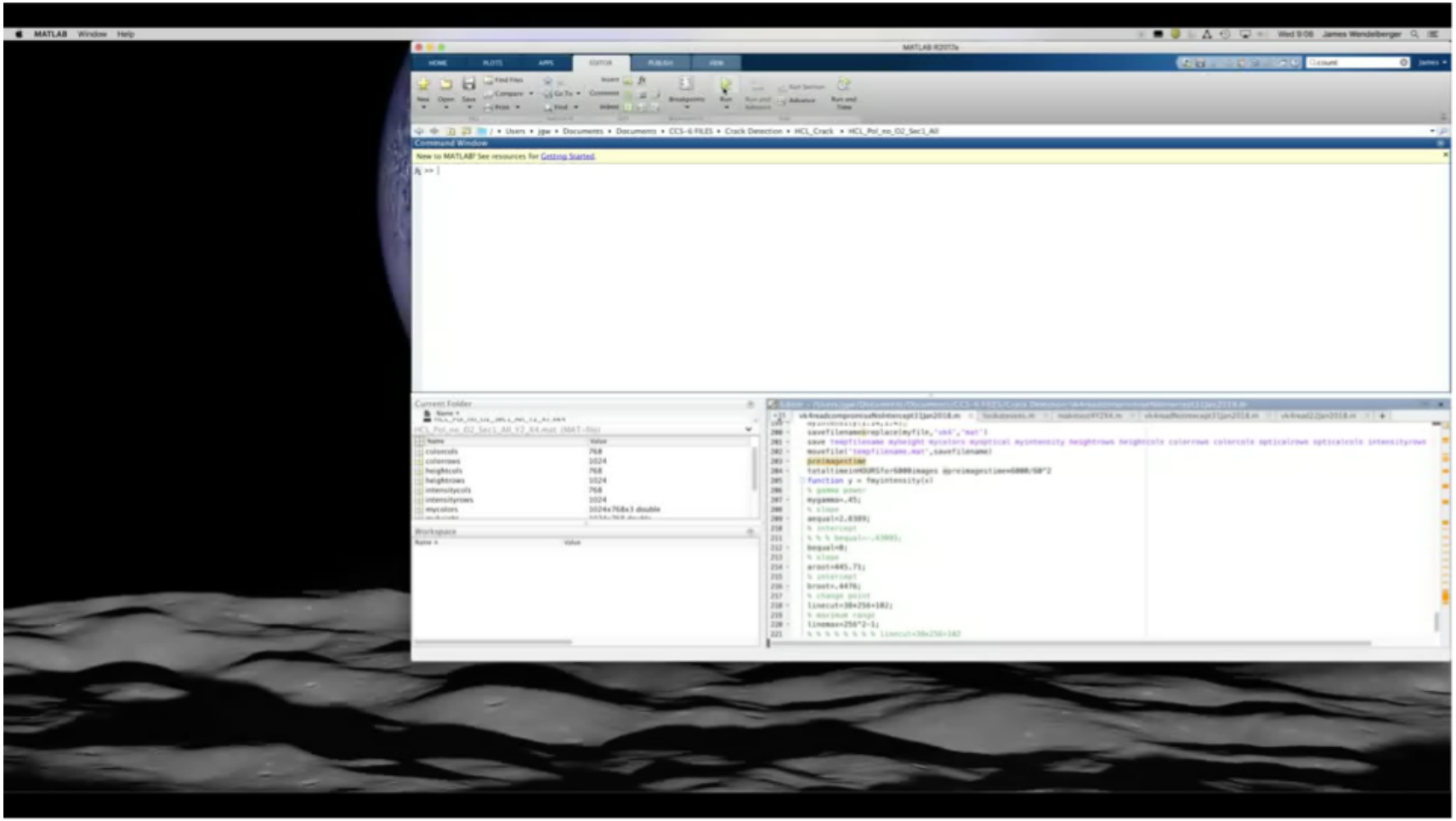
- **Michael sends Juan vk4 data files**
- **Juan sends csv files for analysis**
  - Cumbersome
  - Time consuming
  - Prone to human error
- **Is there another way to obtain the data?**
  - vk4 files
  - Binary data
  - 80838 lines
  - No map

Understanding the vk4 files

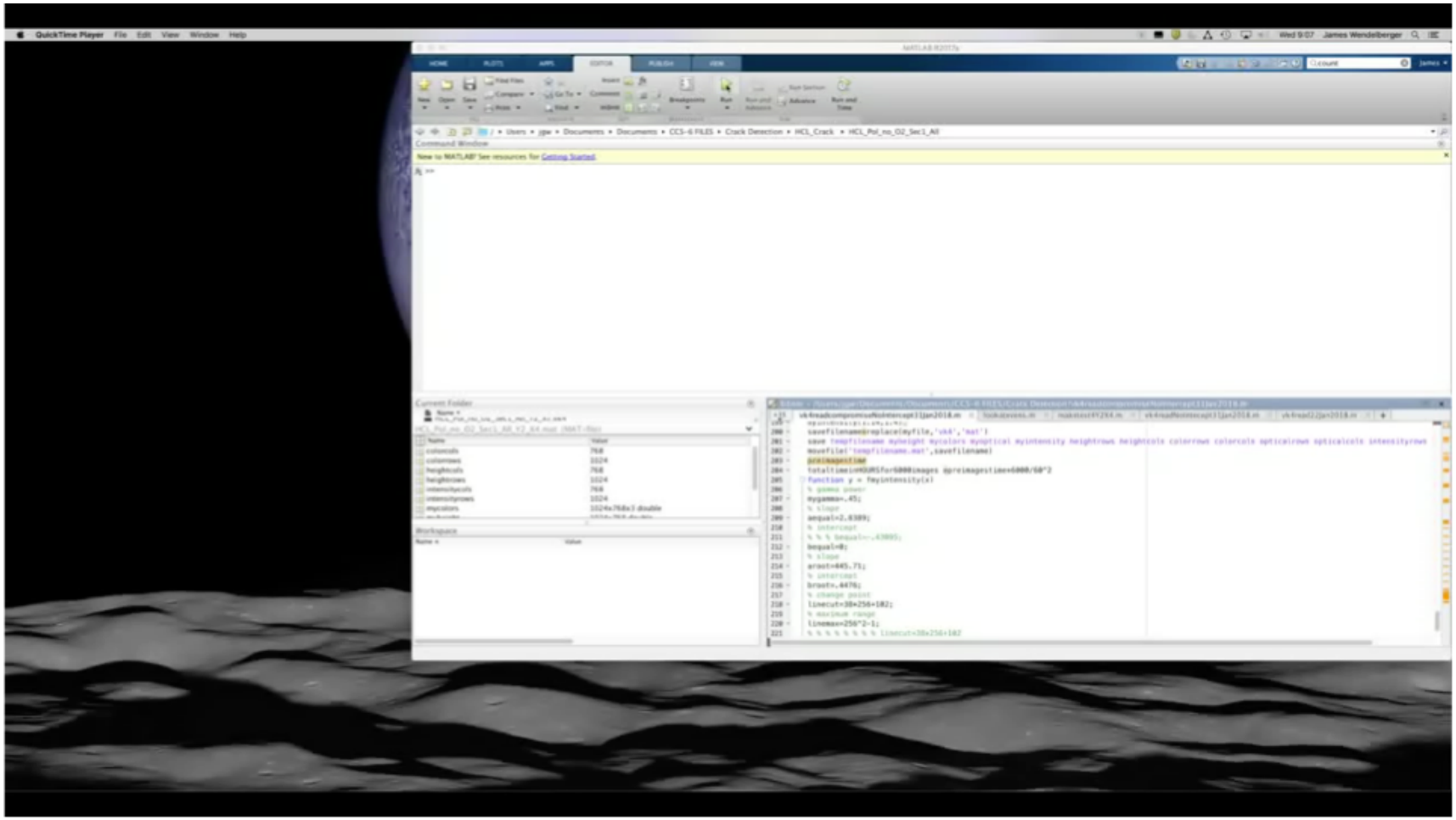
- Keyence (the microscope vendor) would not provide a map or format for the vk4 files – require a new microscope for batch run software
- Image software Gwyddion does read this format
- Keyence (Kevin Dugan) suggested I talk with Gwyddion
- Correspondence with David Nečas (Yeti) <yeti@gwyddion.net>
- All image data except intensity data was read once the location and proper binary conversion was discovered
- The image intensity data requires a binary conversion and location knowledge as well as a “gamma” conversion function (=.45)
- I discovered the gamma conversion function that provides the intensities within ±1 unit out of ~30,000 (difference likely due to Keyence rounding)
- The vk4 files can be read with a Matlab program and produce a Matlab workspace with the eight images from the file
- The ability to read the vk4 file format benefits the project immensely in terms of productivity, accuracy, and efficiency

vk4 File Read – 1.9 Seconds Win Version

TA_Stamp_20X_S1_Y1_X1.vk4



vk4 File Read – 1.9 Seconds Win Version
HCL_Pol_no_O2_Sec1_all_Y2_X4.vk4



Current Capabilities

- Read vk4 file to extract image data
- Analyze image height/depth data to obtain image feature statistics
  - Correct height/depth for curvature
  - Determine number of features
  - Determine statistics of features
    - Maximum depth and/or height, Area, Volume, Eccentricity, Number of holes/islands, Shape in pixels, Bounding box, Centroid, Orientation, Density (specific features per unit area)
  - Classify features
    - Pits by Depth and Area
    - Parts of cracks by Eccentricity
    - Corrosion by Density of features of minimum depth and size
  - Classify Images by contained features
    - Existence of Pits
    - Existence of Parts of Cracks
    - Existence of Corrosion
- Compare Images of Interest to Baseline

Next Steps

- Matlab computer code integration of the vk4 read with the image statistics calculation code
- Improve Matlab code statistics calculation
  - Height and depth at the same time
  - Speed
- May need to construct new statistics
  - Density of smaller features
  - Roughness of pit or crack bottoms
- Work on the 6,000 images
  - Currently tested on 300 at a time - need to handle 6,000
- Utilize feature statistics and various thresholds/cutoffs to classify features of interest based on subject matter expertise
  - Pitting, cracks, corrosion, other
- Identify images of interest – Classify images

Benefits

- **The ability to read the vk4 file format benefits the project immensely in terms of productivity, accuracy, and efficiency**
  - Input for Matlab feature detection, quantification, and analysis
  - Input image data to the big data analysis
- **The feature statistics may be used as input to the big data analysis**

Questions?

Thank you to the following for useful comments in the development of this presentation

- John Berg
- Juan Duque
- Kim Kaufeld
- Elizabeth Kelly
- Laura Worl

Backup Slides

- Elizabeth Kelly – 2 slides
- Gamma correction – 3 slides
- High resolution mac .mov movies

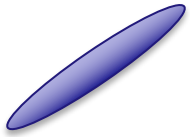
Framework for Initial ICCWR Examinations

- **Automated pitting and surface corrosion analysis**
  - ✓ LCM depth data analyzed using specified parameters for feature identification (2.5 microns area [5 pixels], deeper than one micron) (*do not lose info, can set other parameters for post-processing*)
    - ✓ Identify images that look like baseline and those that are altered by storage environment (e.g., based on distribution of feature depths, …)
    - ✓ Identify images with deepest and largest area features (cutoffs for analysis: ~20 micron area and 10 micron depth)
    - ✓ Identify images with greatest number of features (cutoffs for analysis ~20 micron area and 10 micron depth)

☐ *we can do this now*

Framework for Initial ICCWR Examinations (con't)

- **Automated crack analysis**
  - ✓ LCM depth data analyzed using specified parameters (2.5 sq microns area, greater than one micron depth)
    - ✓ Identify potential cracks –
      - ✓ Features with high linearity
      - ✓ Linear features with high frequency and/or large size
      - ✓ Linear features with connectedness (orientation, location)



☐ *we can do this now*

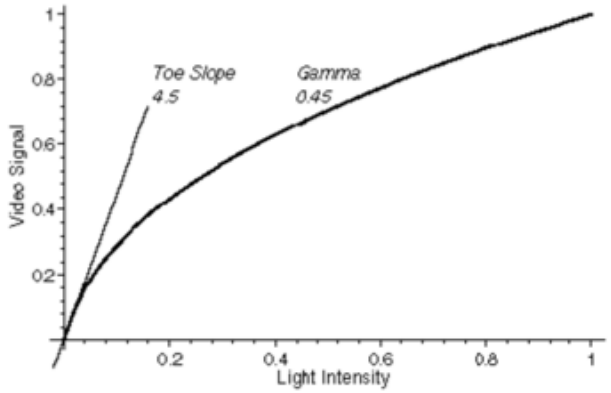
http://archive.is/iuUnG

5. What is *gamma correction*?

In a video system, linear-light intensity is transformed to a nonlinear video signal by *gamma correction*, which is universally done at the camera. The Rec. 709 transfer function [2] takes linear-light intensity (here R) to a nonlinear component (here R'), for example, voltage in a video system:

$$R'_{709} = \begin{cases} 4.5R, & R \le 0.018 \\ 1.099R^{0.45} - 0.099, & 0.018 < R \end{cases}$$

The linear segment near black minimizes the effect of sensor noise in practical cameras and scanners. Here is a graph of the Rec. 709 transfer function, for a signal range from zero to unity:



An idealized monitor inverts the transform:

$$R = \begin{cases} \dfrac{R'_{709}}{4.5}, & R'_{709} \le 0.081 \\ \left(\dfrac{R'_{709} + 0.099}{1.099}\right)^{\frac{1}{0.45}}, & 0.081 < R'_{709} \end{cases}$$

http://archive.is/iuUnG

Real monitors are not as exact as this equation suggests, and have no linear segment, but the precise definition is necessary for accurate intermediate processing in the linear-light domain. In a colour system, an identical transfer function is applied to each of the three *tristimulus* (linear-light) RGB components. See *Frequently Asked Questions about Colour*.

By the way, the nonlinearity of a CRT is a function of the electrostatics of the cathode and the grid of an electron gun; it has nothing to do with the phosphor. Also, the nonlinearity is a power function (which has the form $f(x) = x^{\wedge a}$), not an exponential function (which has the form $f(x) = a^{\wedge x}$). For more detail, read Poynton's article [3].

19. References

[1] Publication CIE No 15.2, *Colorimetry, Second Edition* (1986), Central Bureau of the Commission Internationale de L'Éclairage, Vienna, Austria.

[2] ITU-R Recommendation BT.709, *Basic Parameter Values for the HDTV Standard for the Studio and for International Programme Exchange* (1990), [formerly CCIR Rec. 709], ITU, 1211 Geneva 20, Switzerland.

[3] Charles A. Poynton, "Gamma and Its Disguises" in *Journal of the Society of Motion Picture and Television Engineers*, Vol. **102**, No. 12 (December 1993), 1099-1108, also available on the Internet (PDF format, 138 KB).

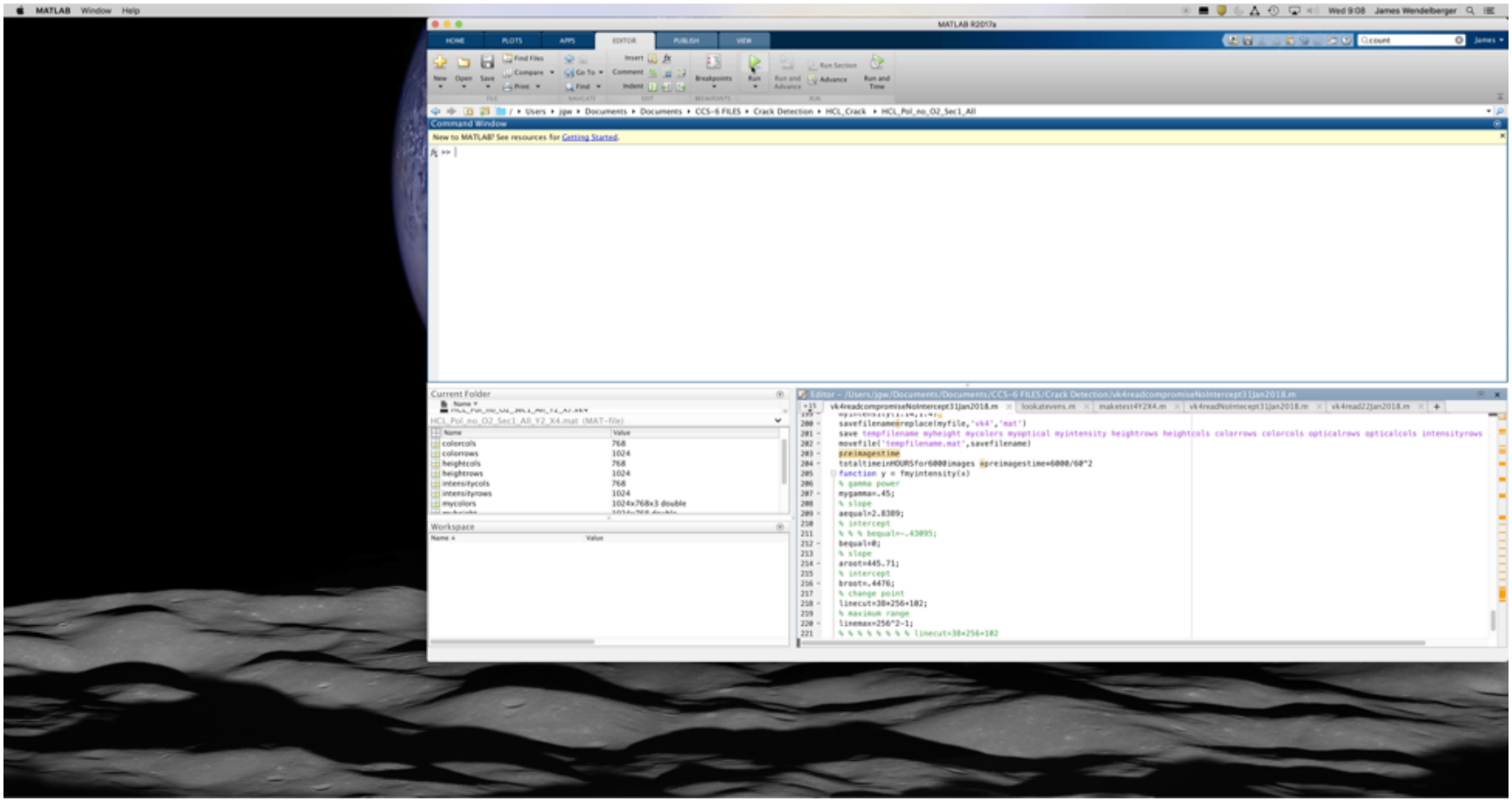
[4] Charles A. Poynton, "Gamma on the Apple Macintosh" (PDF format, 108 KB).

Computing the Gamma Intensity Correction

- Find Gamma Correction Function Coefficients for These vk4 Files
- Gamma = .45 (may be read from the vk4 file)
- Cutoff = 9830 (directly applied to binary data value (BDV))
- First Line $2.8389 \times BDV$, $BDV \leq 9830$
- Second Line $445.71 \times BDV^{0.45} + .4476$, $BDV > 9830$
- Result is the Intensity (±1)

vk4 File Read – 1.9 Seconds MAC Version

TA_Stamp_20X_S1_Y1_X1.vk4



vk4 File Read – 1.9 Seconds MAC Version

HCL_Pol_no_O2_Sec1_all_Y2_X4.vk4