Workflow Algorithm

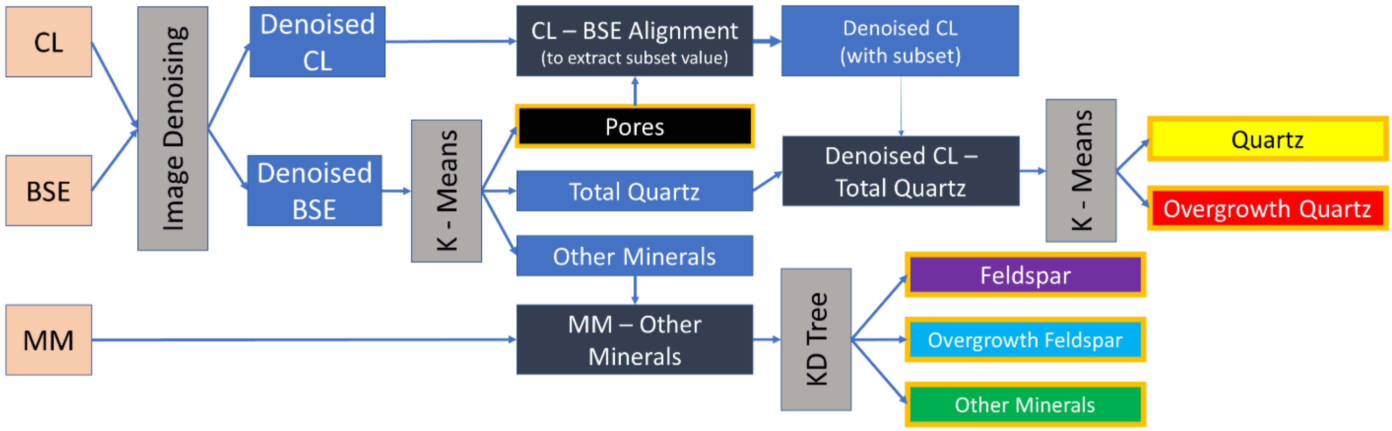

Figure 1. Algorithm Workflow

Detail Algorithm

We understand that there are two main elements for processing the microscope image based on Machine Learning – Deep Learning: Shape & Color. When we talk about the data related to shape, we will mostly discuss how we define edges during the processing or data input (for Deep Learning). But here, as we prefer to bring a "Lite" and "Fast" version of BSE – CL microscope image processing, we prefer to play with Value colors.

Before we talk about the algorithm, we must know that the image started with the representation of three channels (RGB) which is very fragile for heavy computation. Therefore, all processing in this algorithm use HSV representation, focusing only on V (Value). Thus, In the task, the image color scales are converted to HSV from BGR. HSV is an alternative cylindrical representation of RGB color models. Hue separates the colors (the dominant color as perceived by an observer), Separation (the amount of white light mixed), and Value (the chromatic notion of intensity). This is done as the HSV color representation is easier to handle and manipulate with NumPy. Then, jump into the main topic, the algorithm works in three main steps: Image Conditioning – Image Processing – Image Calculation.

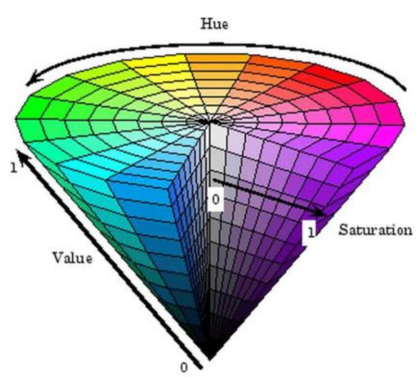

Figure 1. HSV Cone Representation (Erdoğan and Yilmazm 2014)

a. Image Conditioning

The crucial part starts with image conditioning, where the denoising for CL & BSE images is conducted. In general, CL images are very noisy, and BSE has some brightened colors that need to be adjusted. Brightness is the absolute and overall lightness or darkness of the image as a whole. Contrast is the brightness difference between different regions of the picture. In a photo, a contrast ratio is used. The contrast ratio is between the maximum (brightest white) and minimum (darkest black) brightness. For the CL image, we applied BM3D denoising – Unsharpen Image Kernel.

In the code, the BM3D (block-matching and 3D filtering) algorithm is used for denoising. It is a popular method to attenuate image noise. Although it is created for grey images, it is later extended to color images. The image is read by using Scikit images. The image is imported as grey, as the thin sections do not have any colors). The algorithm is based on block matching. A reference region (blocks) is extracted, and other similar blocks are searched. The searched blocks have similar noise distribution and grey scale values. The blocks are matched if the block fragments fall below a specified threshold. After the blocks are matched, they are then stacked to form a 3D cylinder-like shape resulting in the formation of groups. Linear transform and wiener filtering are then done on the block group, and the transform is inverted to obtain the filtered blocks. The image is then de-stacked into a 2D image. The hyperparameter used are sigma_psd (Sigma noise standard deviation) and stage_org (filtering to be used on the image; HARD_THRESHOLDING and ALL_STAGES). ADD MICROSCOPE IMAGES TO SHOW THE FILTERING. The denoised image is not sharp, so unsharp masking techniques from the scikit library are used to sharpen the image. The sharp details are identified as a difference between the original and the blurred image. The details are then scaled to the original image's original features and applied to the original image. BM3D does the blurring step. (ADD IMAGES)

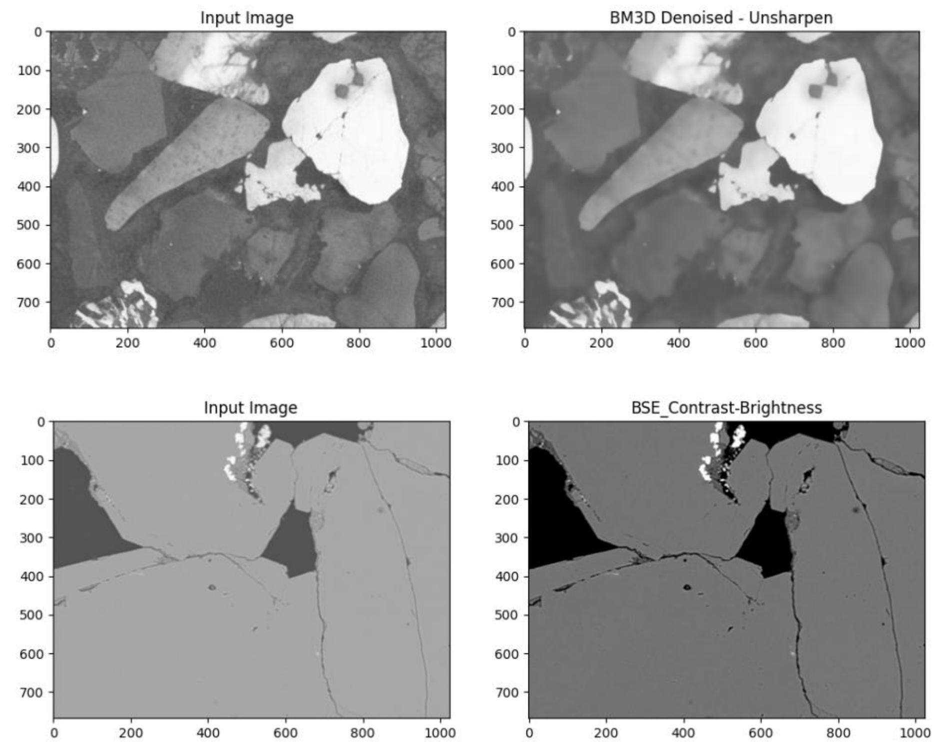

Figure 2: Result of Image Conditioning

b. Image Processing

Then, in Image Processing, we start with the BSE K – Means to separate Total Quartz, Minerals, and Pores. There is no doubt that the BSE image has the most stable color value with a very clear image compared with the CL image. Therefore, we try to make the most of it to create separation between these three components. This separation is crucial as later, for the Other Minerals separation, we don't have to consider Quartz and Pores part anymore as K – Means separation will make the best separation among the three. KMeans is a clustering method for unsupervised learning. KMeans is available in python as Sklearn.cluster.KMeans. The algorithm searches for a user-defined number of clusters within an unlabelled dataset of multiple dimensions. The two properties of a cluster are the centroid and inertia.

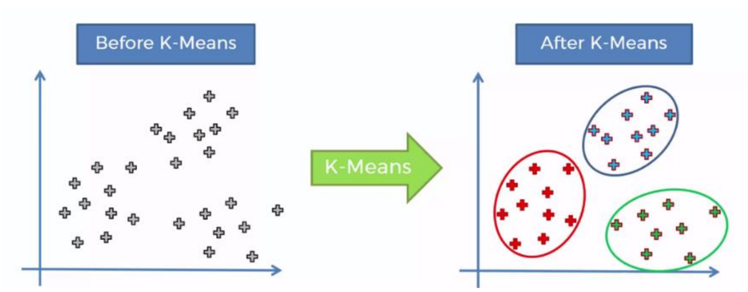

Figure 3: Scattering of data points before and after KMeans. The number of clusters is user-defined.

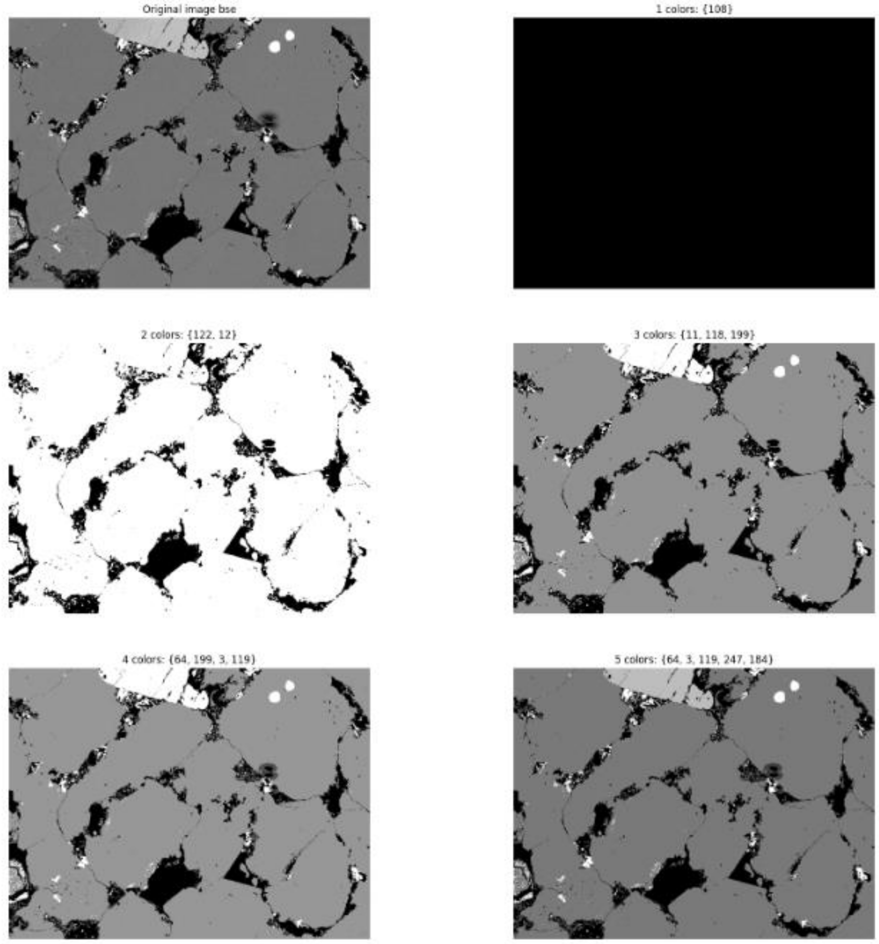

Figure 4: The results of K-Means in BSE image

Before we jump to the further separation for Total Quartz and Minerals, there is one crucial step that needs to be done: image alignment between BSE and CL. Image alignment is a technique of overlaying or warping images so that the key features lie on top of each other. Images can be translated, rotated, shifted, scaled, and sheared. All the above operations can be done on 2D and 3D images. Here, our idea is used after we did the K – Means separation in which the alignment is only based on the pores. Why? Because pores are the only part that should have the most distinguished for BSE and CL. If we talk about Quartz and Overgrowth Quartz, of course, BSE couldn't be able to separate it. Therefore, we need one component that can be clear for each image: the pore component. Then, the image alignment is conducted with the module of Transform EEC. The image EEC technique is a similarity measure between two images based on Enhanced correlation coefficient maximization. The traditional image alignment works on pixel intensities, but EEC is immune to distortions in contrast and brightness. The image alignment follows a linear function, so it is computationally inexpensive to align the image. It estimates the geometrical transformation between input and output images. The main output from this image alignment is the image subset value. The subset value is the value to see where is the best overlay area for BSE and CL.

Then, the journey of image processing comes to one of the prominent cases separating Quartz and Overgrowth Quartz from only Total Quartz. Here, the K – Means separation technique is used, with the help of another image pre–condition called CLAHE. CLAHE (Contrast Limited Adaptive Histogram Equalization) is an advanced variant of AHE. While AHE improves contrast in images by redistributing the image's lightness, CLAHE limits the amplification of the contrast in regions where the histogram is highly concentrated. With this CLAHE, the K – Means separation works much better to separate Quartz and Over Growth Quartz. Then, after case 1 has cleared, we jump to case 2 to separate all minerals into Feldspar, Over Growth Feldspar, and Other Minerals. The idea is simple: multiplying the separated Minerals component (from K – Mean BSE) with the MM data. But, because the resolution sampling in MM is so big, the multiplication somehow not representative as some color that is not part of the minerals is also extracted after the multiplication, mentioning yellow, which is Quartz that has nothing to do again with the separated Minerals component. Therefore, we applied KDTree to change the color that does not represent the minerals with other colors that represent either Feldspar, Over Growth Feldspar and other minerals. Hence, we got the very best representation of case 2. KDTree is the abbreviation for K- Dimensional tree. It is a binary search tree that searches for the nearest neighbor. Each data in a node represents a kth dimensional point in space. It helps organize data by several criteria all at once. Each node holds k values (K is the number of properties each node has; it is the number of planes used to represent a tree). KDTree is available in python as scipy.spatial.KDTree.

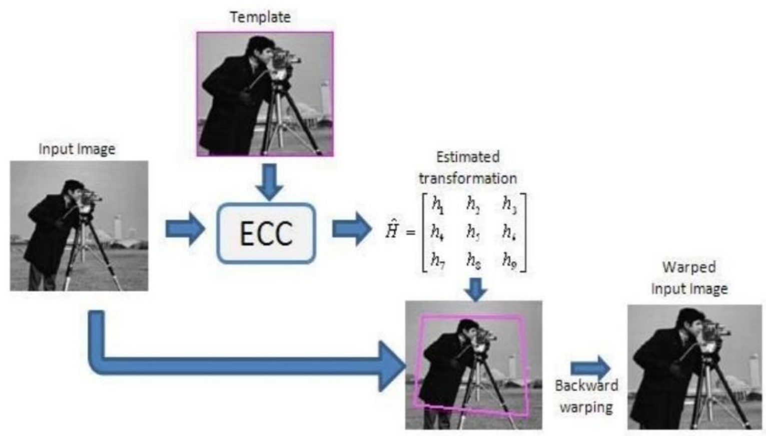

Figure 5: In the image alignment Enhanced correlation coefficient maximization workflow, the input image and the reference image undergo a geometrical transformation using a vector which is warped on the input images after taking reference points from the template. This results in the final aligned image.

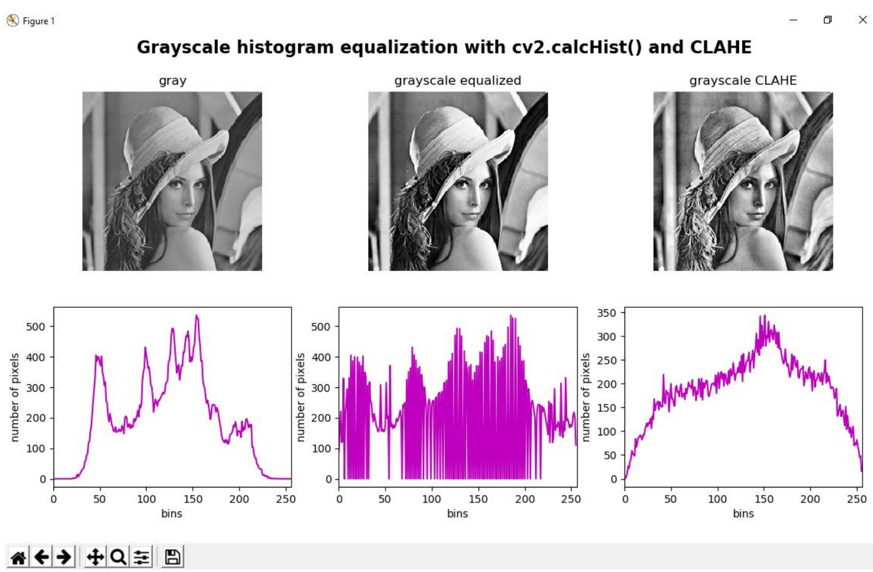

Figure 6: Images processed with HE and CLAHE, with the corresponding histograms below.

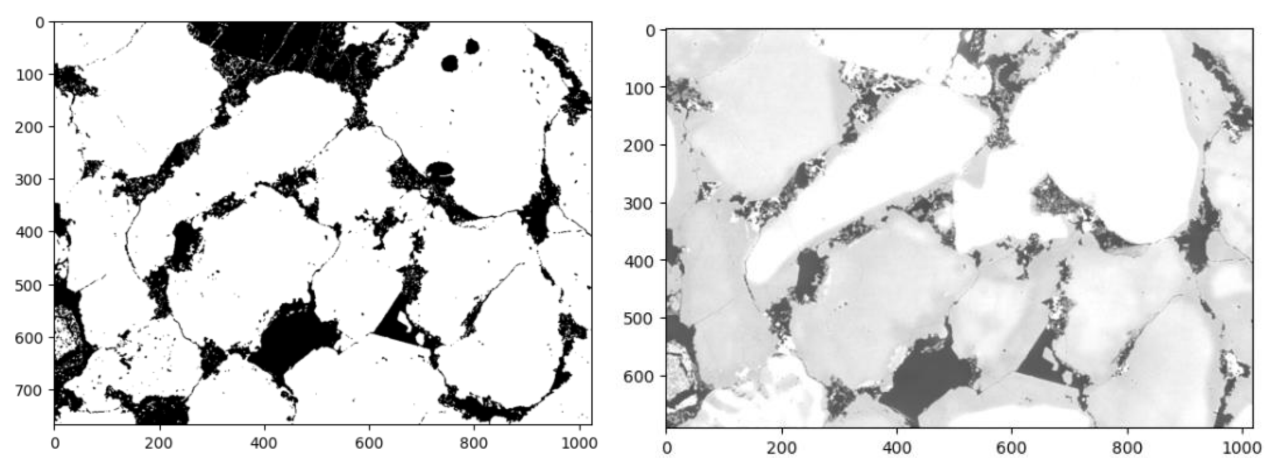

Figure 7: The results of BSE segmented Quartz – Overgrowth Quartz after K-Means (Left) and BSE-CL overlaying image after Transform EEC (Right)

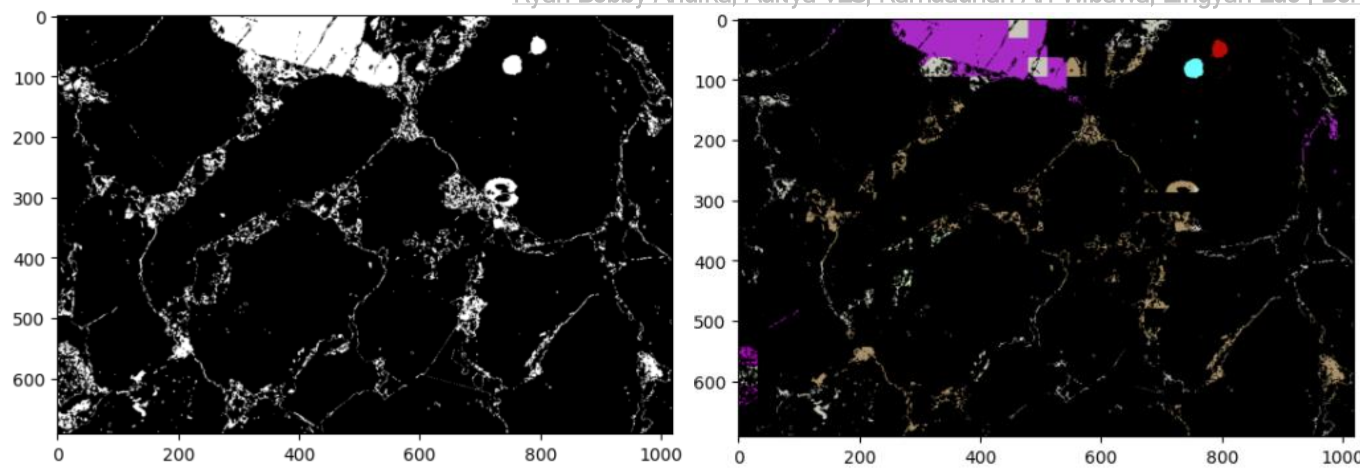

Figure 8: The results of BSE Minerals segmented after K-Means (Left) and Segmented Minerals after KDTree (Right)

c. Calculation

Finally, for the Calculation, it's super easy as, since the beginning, the components have been portioned at pixel level since the BSE image. Therefore, the relative area can be calculated by referring to the total pixel for each image after the subset is applied.

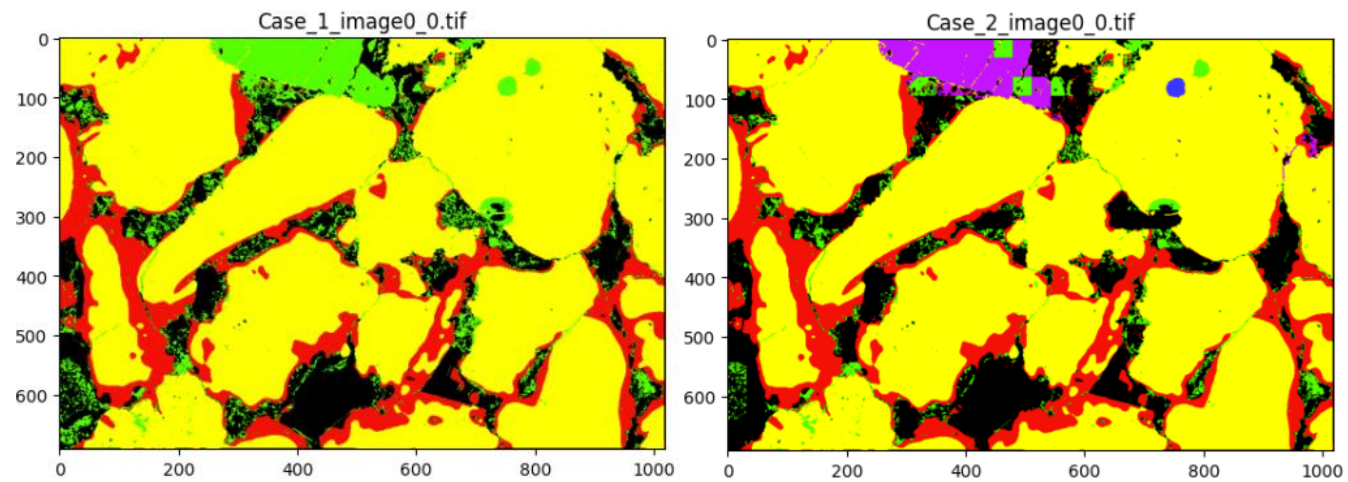

Figure 9: The result of all Segmentations for Case 1 [Red: Ovg-Quartz, Yellow: Quartz, Green: Other Minerals, Black: Pore] & Case 2 [Red: Ovg-Quartz, Yellow: Quartz, Green: Other Minerals, Purple: Feldspar, Blue: Ovg-Feldspar, Black: Pore]

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For Case 1:
```

'quartz_rel_area': [0.6453666464345074]	'overgrowth_rel_area': [0.13882475735590258]
'otherminerals_rel_area': [0.08585006268187671]	'pores_rel_area': [0.12995853352771333]

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For Case 2:
```

'quartz_rel_area': [0.6453666464345074]	'quartz_overgrowth_rel_area': [0.13882475735590258]
'otherminerals_rel_area': [0.03652282925002978]	'pores_rel_area': [0.15025781821688497]
'feldspar_rel_area': [0.02780692847458973]	'feldspar_overgrowth_rel_area': [0.0012210202680855 65]

The final remark is about how crucial Quartz overgrowth is. Quartz overgrowth is the development of quartz cement around the detrital grains. The Quartz is usually precipitated by the migrating fluids resulting in the quartz cement growing in optocal continuity with the enclosed grains. Overgrowth tends to decrease the reservoir quality because of a decrease in porosity and permeability. The overgrowth material extends into the pore spaces, reducing pores and isolating the existing ones. This causes difficulty in producing fluids from the subsurface. The overgrowth areas need stimulation to reactivate the pore spaces.

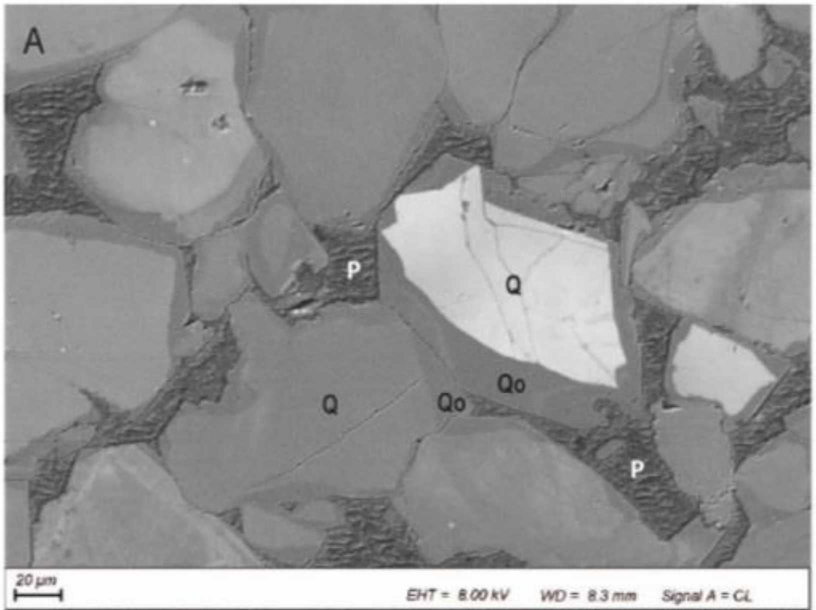

Figure 10: A thin section containing overgrowths. Q- Primary Quartz, Q0 – Overgrowth quartz, P- Plagioclase. Intuitively, we can deduce that the overgrowth of Quartz reduces the pore spaces and permeability.

References:

Erdoğan, Kemal & Yılmaz, Nihat. (2014). Shifting Colors to Overcome not Realizing Objects Problem due to Color Vision Deficiency. 10.15224/978-1-63248-034-7-27.

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(https://sites.google.com/site/georgeevangelidis/ecc?pli=1)

https://stackoverflow.com/questions/4418450/how-does-the-kd-tree-nearest-neighbor-search-work