

Laurea triennale in Scienze Geologiche (L-34)  
Anno accademico 2018-2019



UNIVERSITÀ  
DEGLI STUDI  
DI PADOVA



DIPARTIMENTO  
DI GEOSCIENZE

# The disappearance of pseudotachylytes from the geological record: microstructures and clast size distribution

La scomparsa delle pseudotachiliti dal record geologico: microstrutture e distribuzioni granulometriche.

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23.7.2019

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Correlatore: Michele Fondriest

# Outline of the thesis

1. Motivations

2. Methods

3. Results: artificial pseudotachylytes

3.1 Non-altered pseudotachylytes

3.2 Altered pseudotachylytes

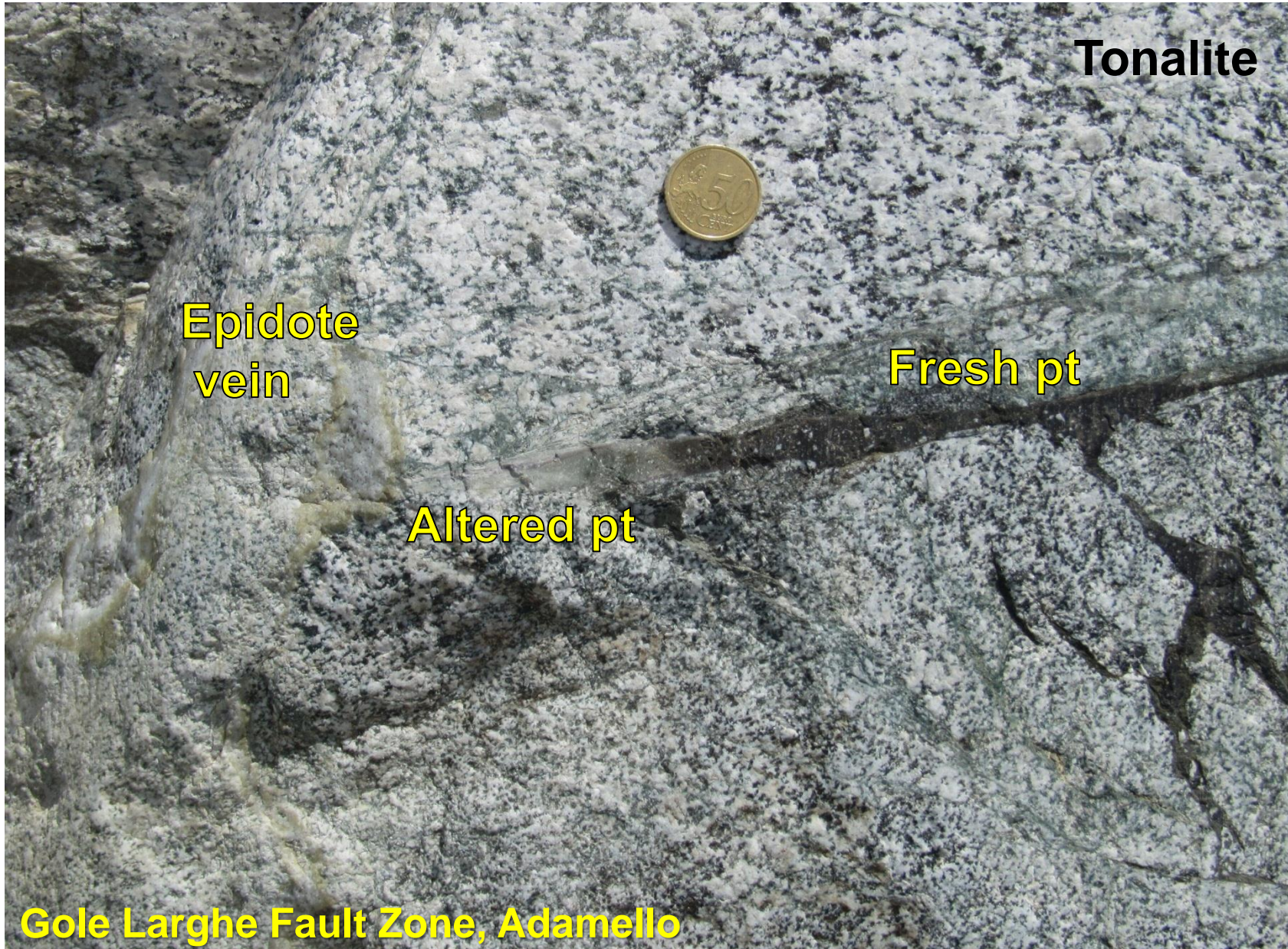
4. Discussion

5. Conclusions

# 1. Motivations

Pseudotachylytes are quite rare in the geological record: but are they rarely generated or are they only rarely preserved?

[Kirkpatrick & Rowe, 2013]



Alteration of these pseudotachylytes occurred at

$T = 250^{\circ}\text{C}$

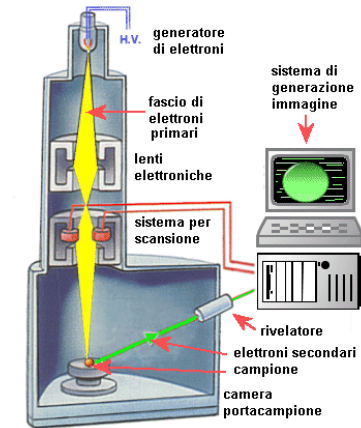
$P_c = 250 \text{ MPa}$

Understand the process of clasts dissolution through clasts size distribution (CSD)

- How the clast abundance varies with alteration ?
- What does alteration produce on clasts morphology ?

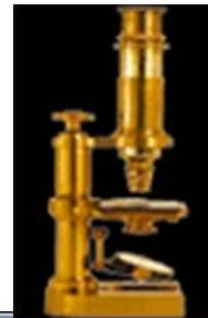
# 2. Methods

- SEM



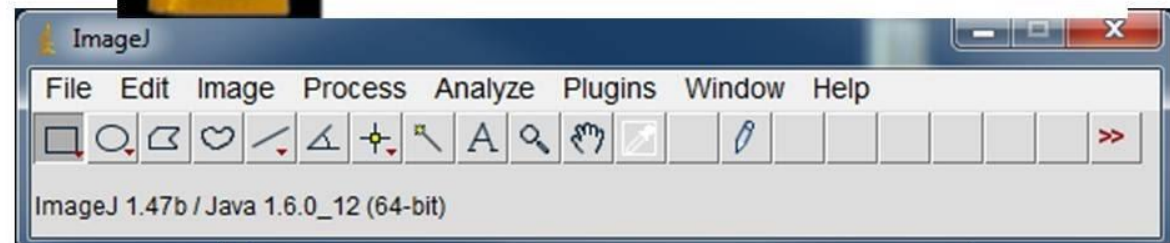
- IMAGEJ

<https://imagej.nih.gov/ij/index.html>



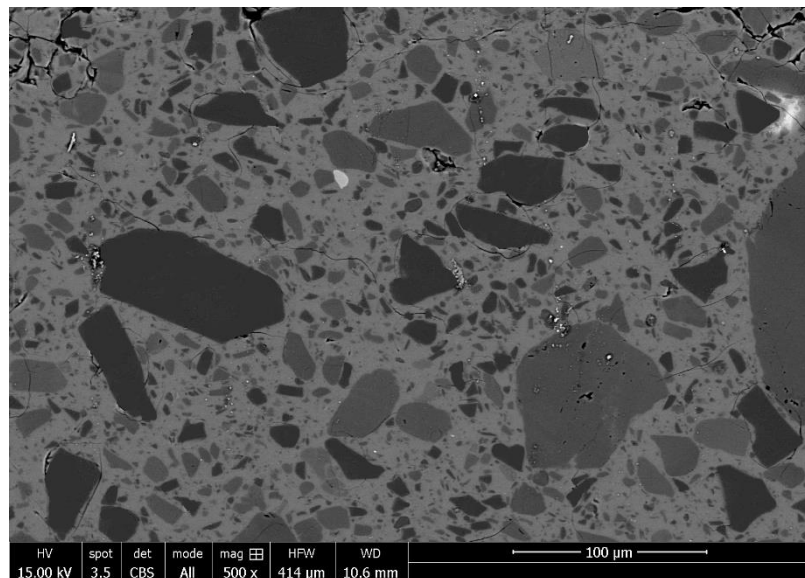
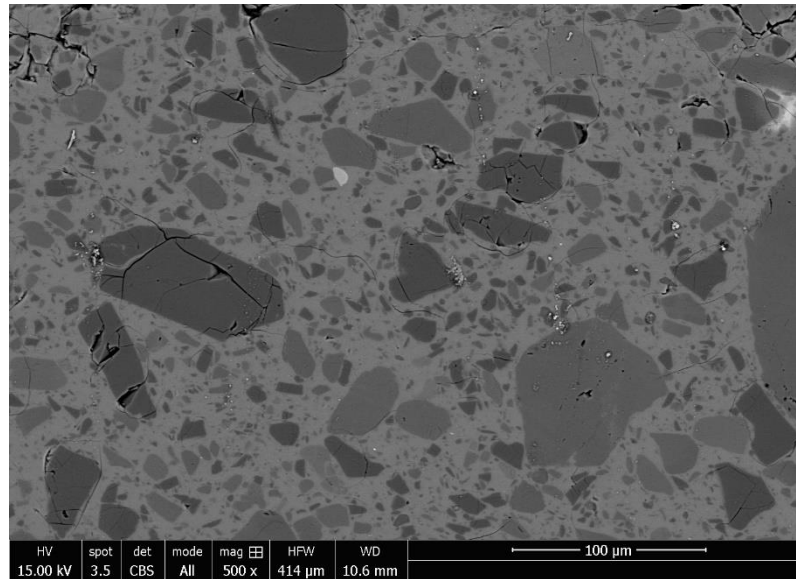
# ImageJ

Image Processing & Analysis in Java

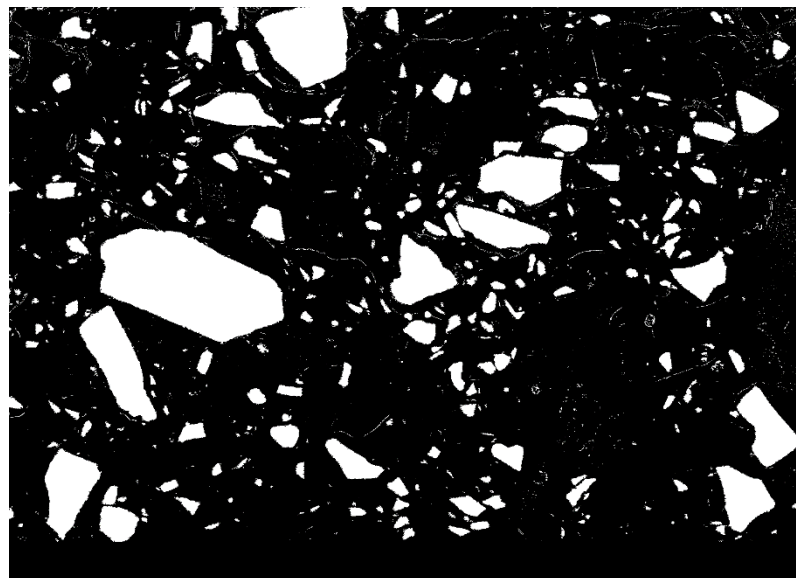


# Steps with Imagej

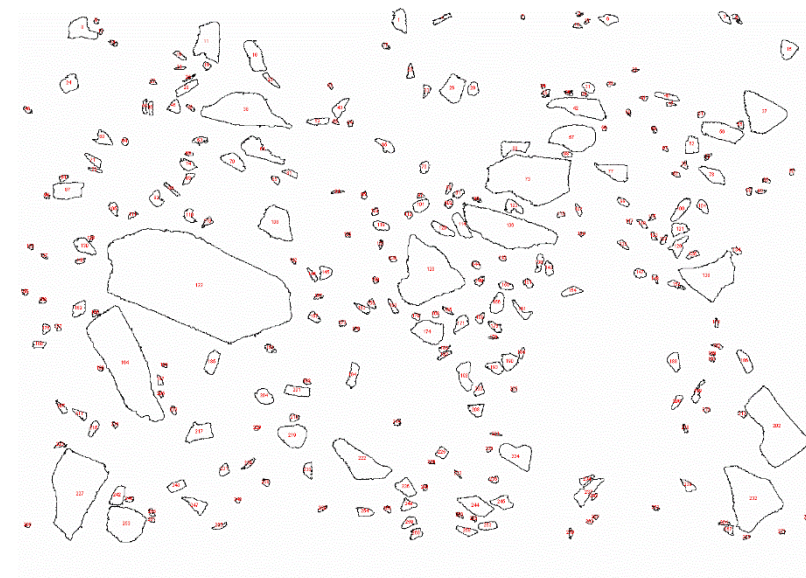
Original image of start  
(non-altered)  
pseudotachylytes



**Step 1 - Image preparation**



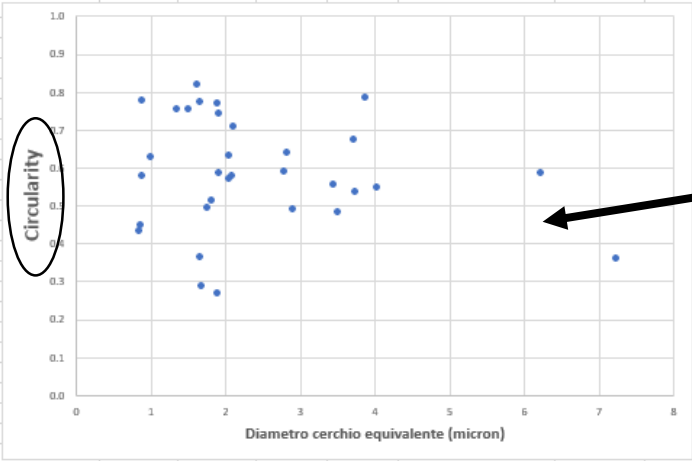
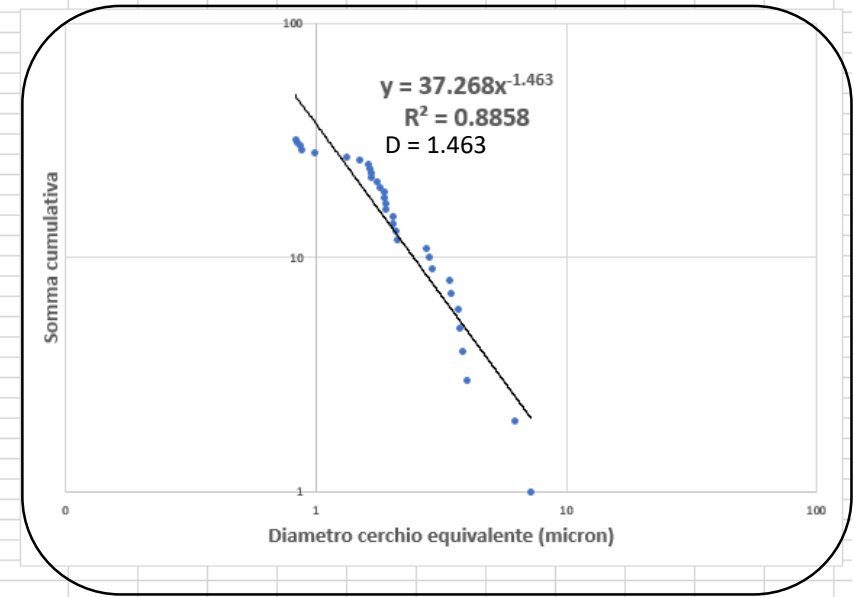
**Step 2 - Clast marker (Threshold)**



**Step 3 - Analyze particles**

# Output file with selected parameters

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z		
	Numero clasto in immagine 018_5000X	Area A (micron <sup>2</sup> )	Perimetro P (micron)	P <sup>2</sup> /A	Circularity	Solidity		Area cerchio equivalente (micron <sup>2</sup> )	Raggio cerchio equivalente (micron)	Diametro cerchio equivalente (micron)		Diametro cerchio equivalente (micron)	Numero clasti di ugual diametro	Somma cumulativa														
1	26	40.9671	37.5347	34.4939	0.3642	0.9200	Valore medio P <sup>2</sup> /A	40.9671	3.6111	7.2223		7.2223	1	1														
2	1	30.2907	25.4727	21.4210	0.5866	0.9531	23.1177	30.2907	3.1051	6.2103		6.2103	1	2														
3	30	12.7188	17.0412	22.8325	0.5504	0.9201		12.7188	2.0121	4.0242		4.0242	1	3														
4	15	11.7692	13.7093	15.9692	0.7869	0.9611	Valore medio Circularity	11.7692	1.9355	3.8710		3.8710	1	4														
5	19	10.9452	15.9579	23.2663	0.5401	0.9245	0.5876	10.9452	1.8665	3.7331		3.7331	1	5														
6	22	10.8108	14.1680	18.5677	0.6768	0.9035		10.8108	1.8550	3.7101		3.7101	1	6														
7	11	9.5427	15.7493	25.9927	0.4835	0.8514	Valore medio Solidity	9.5427	1.7429	3.4857		3.4857	1	7														
8	9	9.2681	14.4520	22.5354	0.5576	0.9273	0.8896	9.2681	1.7176	3.4352		3.4352	1	8														
9	12	6.6063	12.9964	25.5675	0.4915	0.9030		6.6063	1.4501	2.9002		2.9002	1	9														
10	28	6.2381	11.0460	19.5595	0.6425	0.9201		6.2381	1.4091	2.8183		2.8183	1	10														
11	29	6.0657	11.3409	21.2038	0.5327	0.9389		6.0657	1.3895	2.7790		2.7790	1	11														
12	13	3.4711	7.8244	17.6374	0.7125	0.9325		3.4711	1.0511	2.1023		2.1023	1	12														
13	25	3.3835	8.5495	21.6031	0.5817	0.9238		3.3835	1.0378	2.0756		2.0756	1	13														
14	6	3.2812	8.4731	21.8802	0.5743	0.9075		3.2812	1.0220	2.0440		2.0440	1	14														
15	7	3.2403	8.0199	19.8496	0.6331	0.9196		3.2403	1.0156	2.0312		2.0312	1	15														
16	24	2.8313	6.9071	16.8502	0.7458	0.8976		2.8313	0.9433	1.8987		1.8987	1	16														
17	16	2.8137	7.7534	21.3652	0.5882	0.8839		2.8137	0.9464	1.8928		1.8928	1	17														
18	23	2.7816	11.3495	46.3083	0.2714	0.6142		2.7816	0.9410	1.8819		1.8819	1	18														
19	10	2.7611	6.7018	16.2667	0.7725	0.9398		2.7611	0.9375	1.8750		1.8750	1	19														
20	3	2.5537	7.8823	24.3297	0.5165	0.8960		2.5537	0.9016	1.8032		1.8032	1	20														
21	18	2.3988	7.8059	25.4011	0.4947	0.8451		2.3988	0.8738	1.7476		1.7476	1	21														
22	27	2.1914	9.7256	43.1630	0.2911	0.8179		2.1914	0.8352	1.6704		1.6704	1	22														
23	14	2.1476	8.5921	34.3752	0.3656	0.7920		2.1476	0.8268	1.6536		1.6536	1	23														
24	5	2.1359	5.8871	16.2264	0.7744	0.9336		2.1359	0.8245	1.6491		1.6491	1	24														
25	8	2.0511	5.5945	15.2593	0.8235	0.9341		2.0511	0.8080	1.6160		1.6160	1	25														
26	2	1.7356	5.3728	16.6323	0.7555	0.9325		1.7356	0.7433	1.4866		1.4866	1	26														
27	21	1.3937	4.8137	16.6260	0.7558	0.9129		1.3937	0.6661	1.3321		1.3321	1	27														
28	17	0.7626	3.9018	19.9633	0.6295	0.8847		0.7626	0.4927	0.9854		0.9854	1	28														
29	32	0.6048	3.6223	21.6949	0.5793	0.8484		0.6048	0.4388	0.8775		0.8775	1	29														
30	20	0.5844	3.0686	16.1128	0.7798	0.8989		0.5844	0.4313	0.8626		0.8626	1	30														
31	4	0.5639	3.9674	27.9132	0.4502	0.8008		0.5639	0.4237	0.8473		0.8473	1	31														
32	31	0.5376	3.9412	28.8933	0.4349	0.8270		0.5376	0.4137	0.8273		0.8273	1	32														

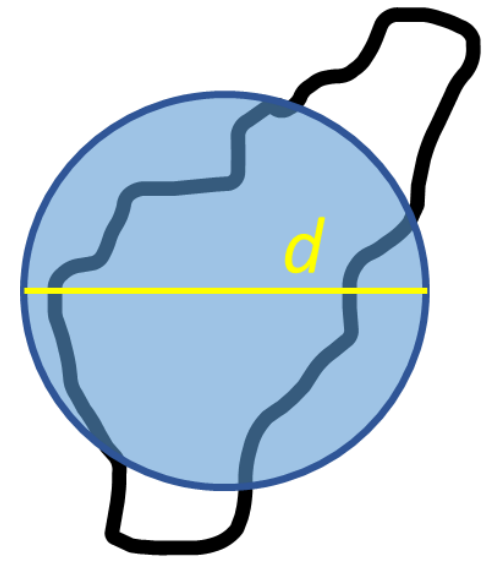


**SHAPE DESCRIPTOR**

**CSD**



# Clast-Size Distribution (CSD)



$$N \sim d^{-D}$$

$$d = 2 (A/\pi)^{0.5}$$

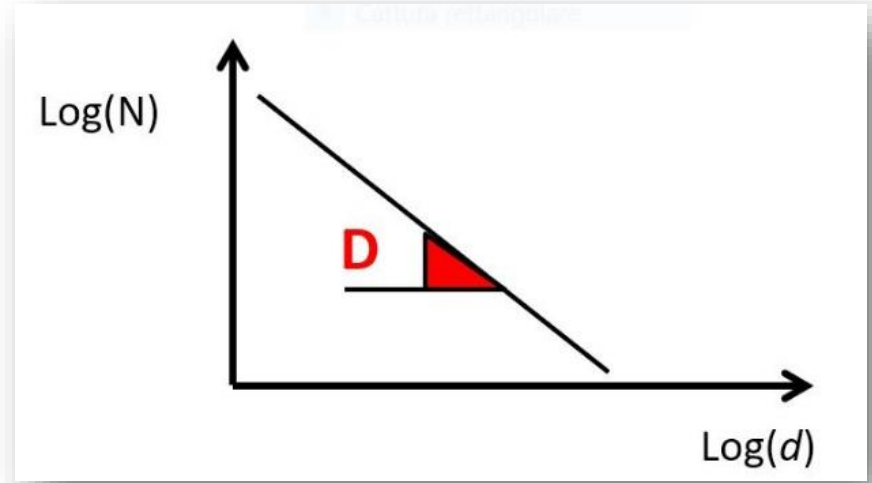
**N** : number of clasts larger than  $d$ .  
 Log frequency, cumulative sum of clast with  $d_{real} \geq d_{eq}$

**d(μm)** = diameter of the area-equivalent circle of a clast of area A

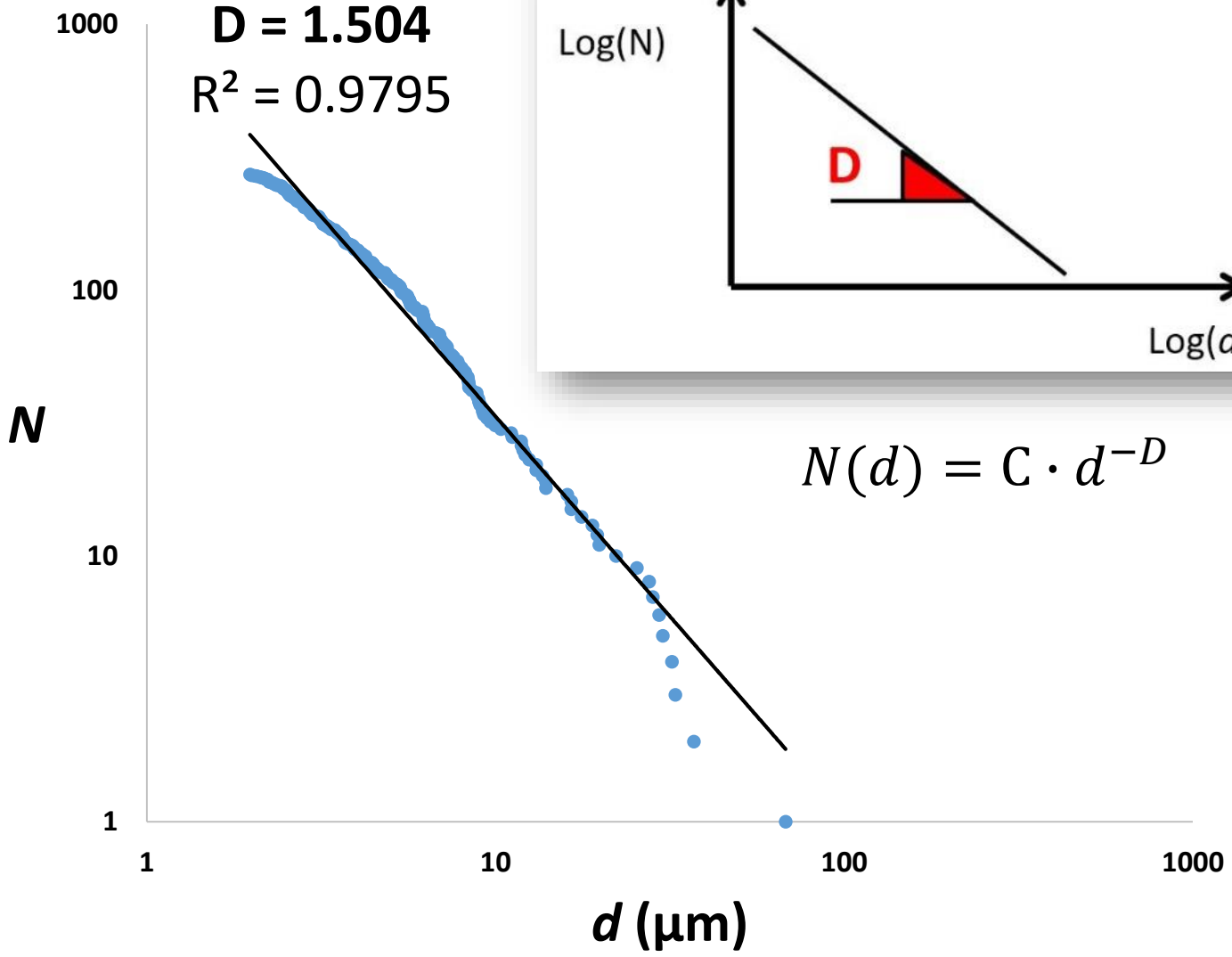
**D** = fractal dimension or slope of the best fit line in the log N - log d plot

**C** = pre-esponential factor

**R<sup>2</sup>** = correlation coefficient

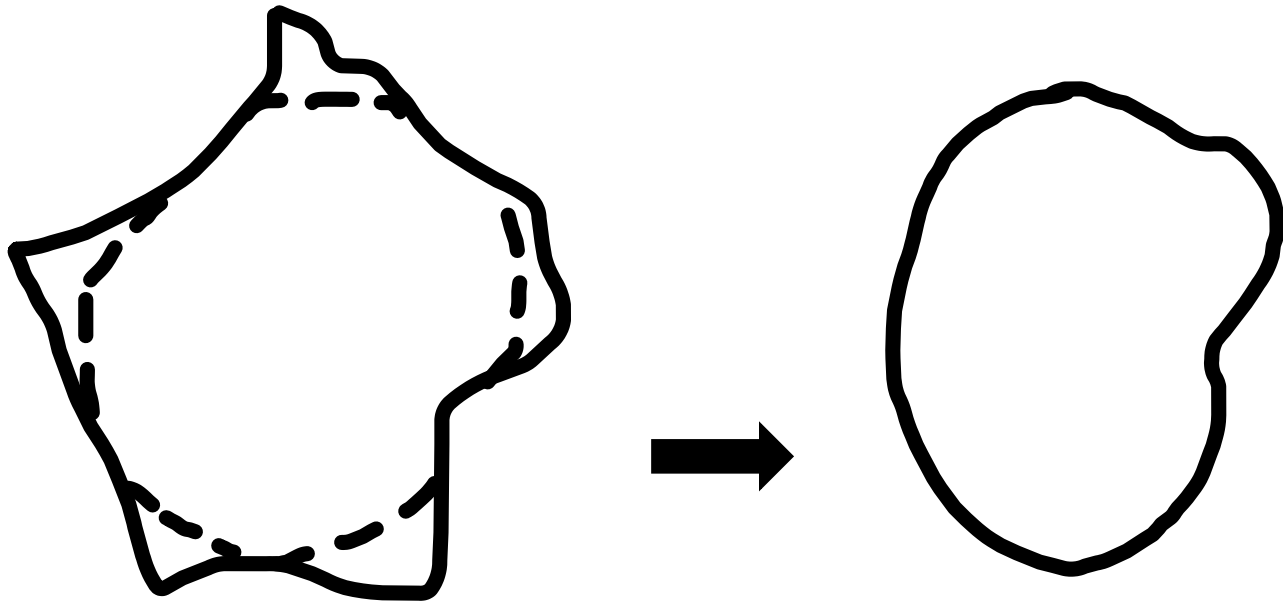


$$N(d) = C \cdot d^{-D}$$



# Circularity

$$= 4\pi \times \frac{[Area]}{[Perimeter]^2}$$



Alteration ?

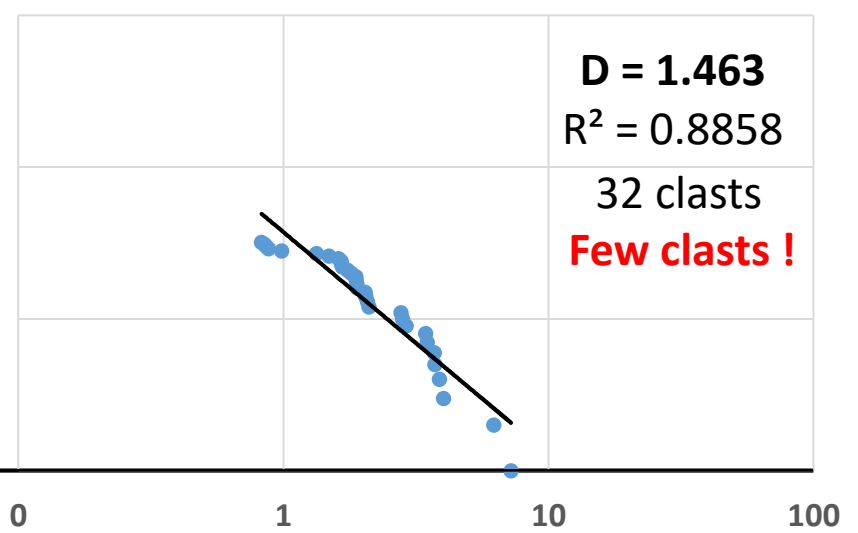
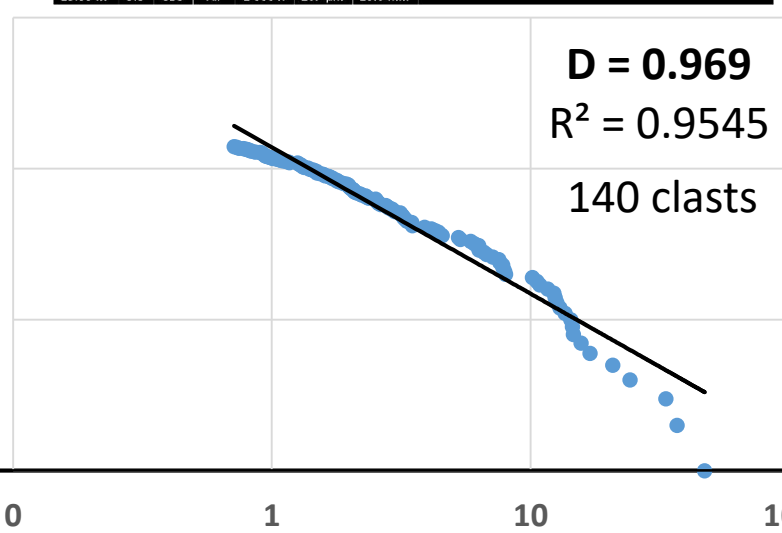
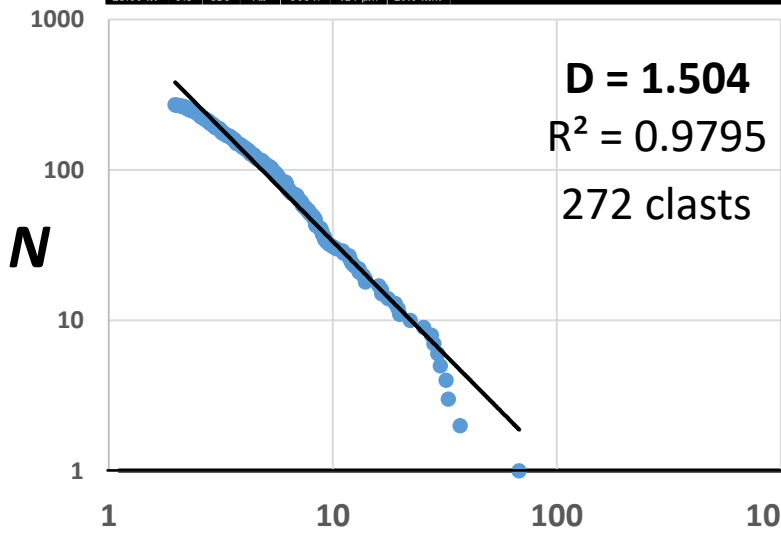
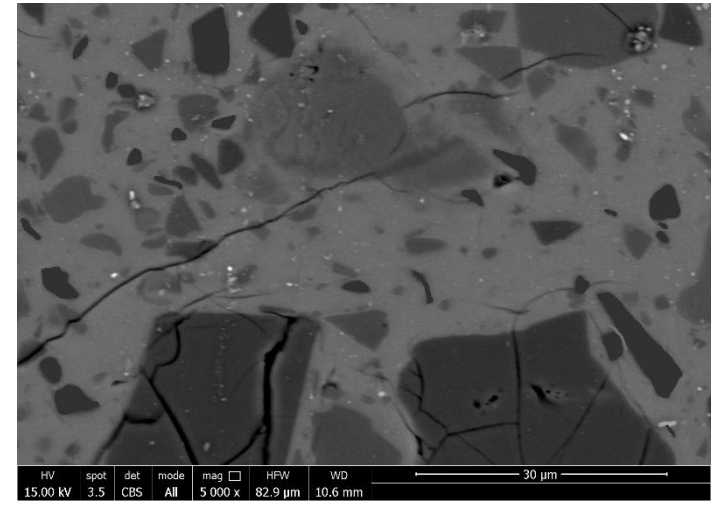
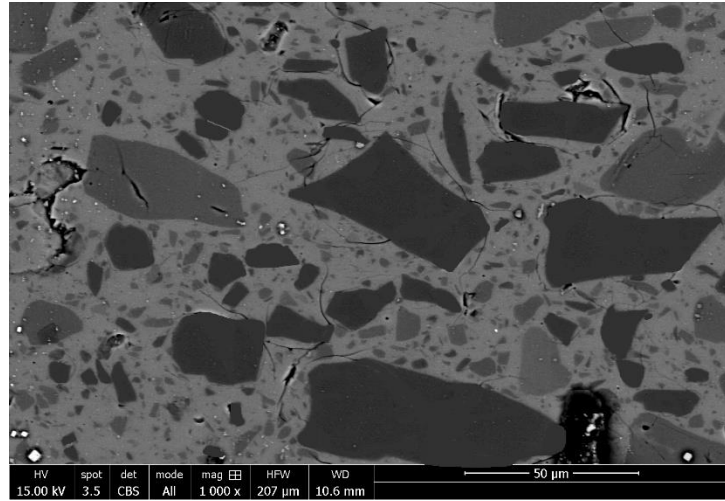
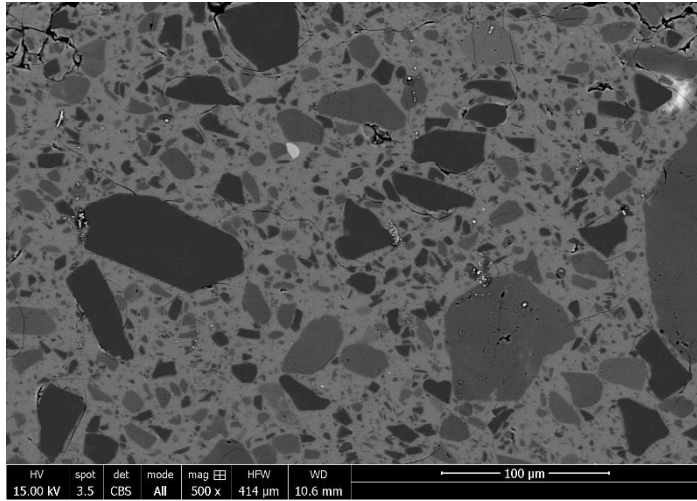
$$0 < \text{circularity} < 1$$

Very angular

Very rounded

# 3. Results

# Qtz CSD: Non-altered pseudotachylyte



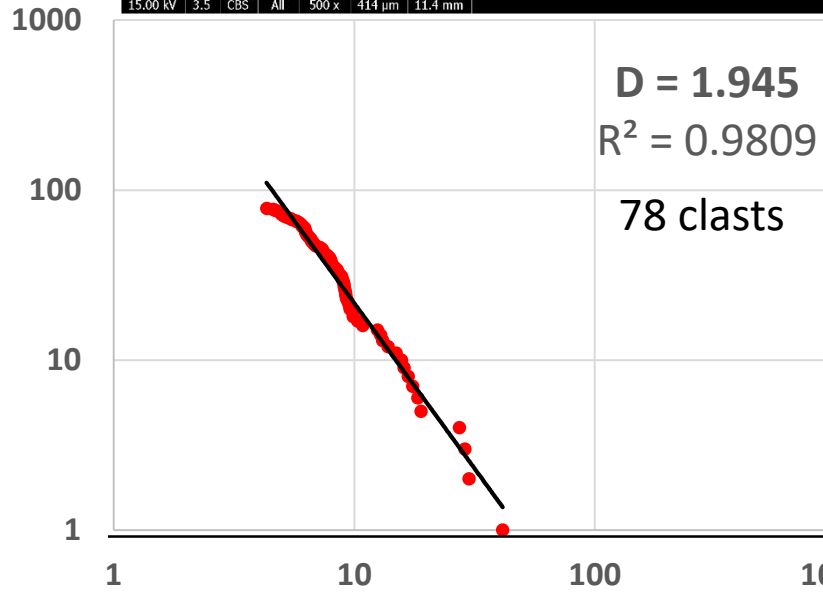
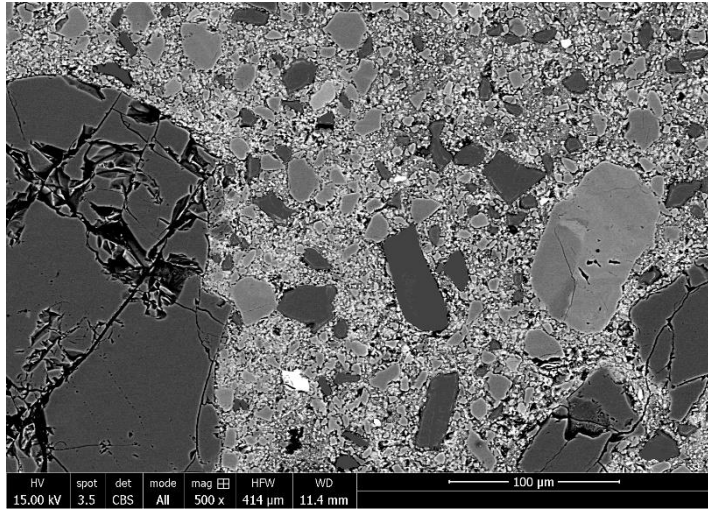
500X

$d$  ( $\mu\text{m}$ )

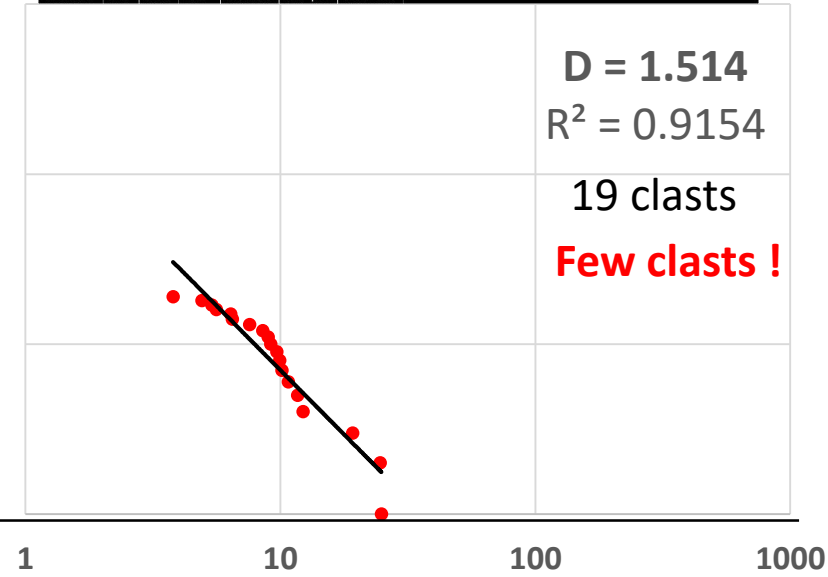
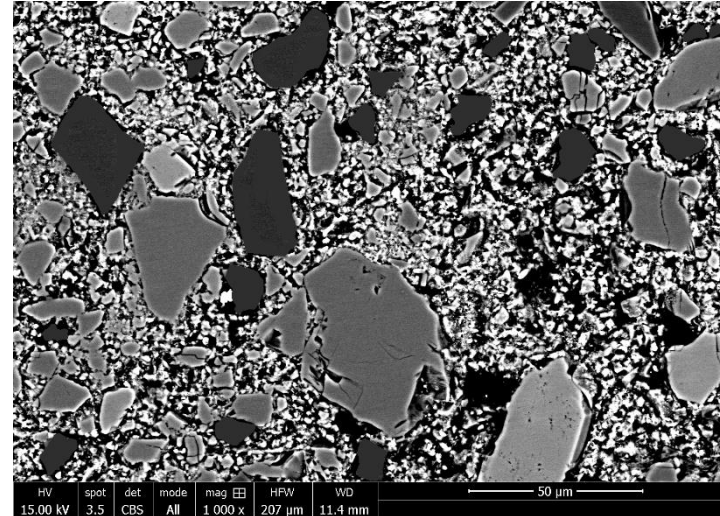
1000X

5000X

# Qtz CSD: Altered pseudotachylyte

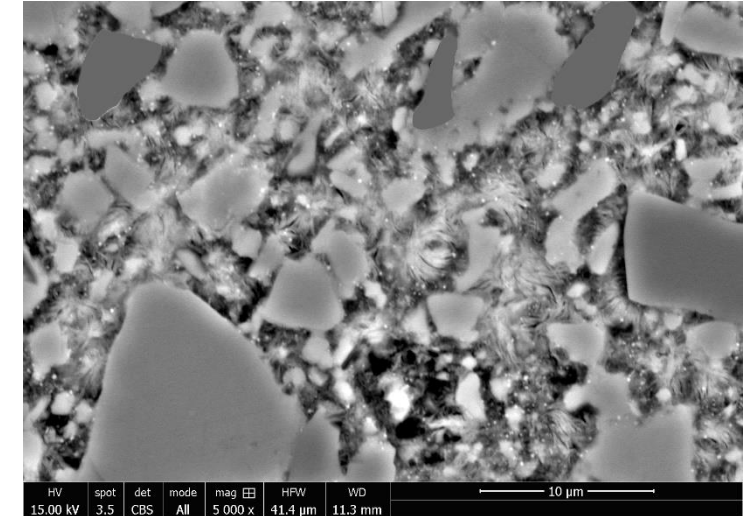


500X



$d$  ( $\mu\text{m}$ )

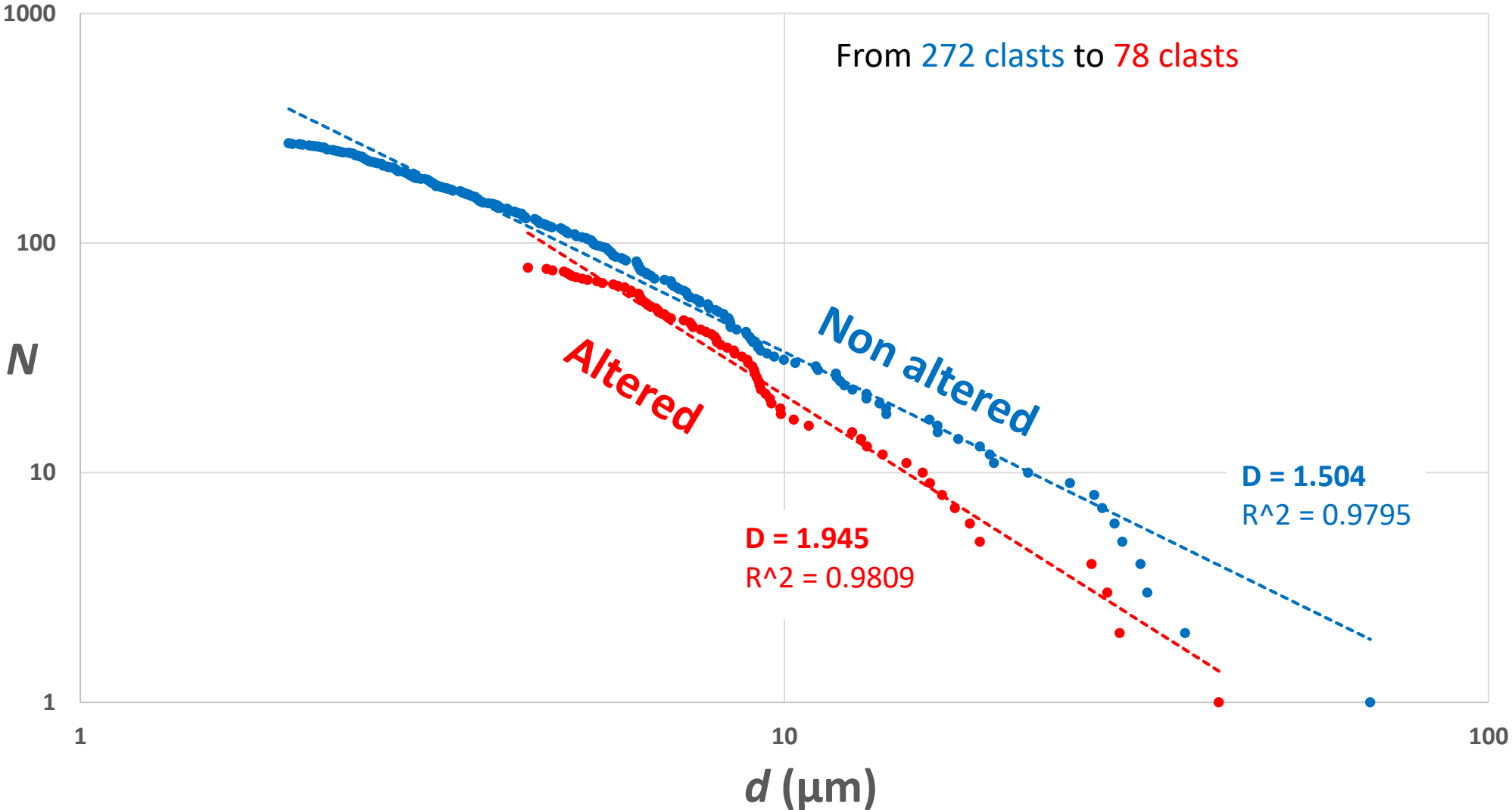
1000X



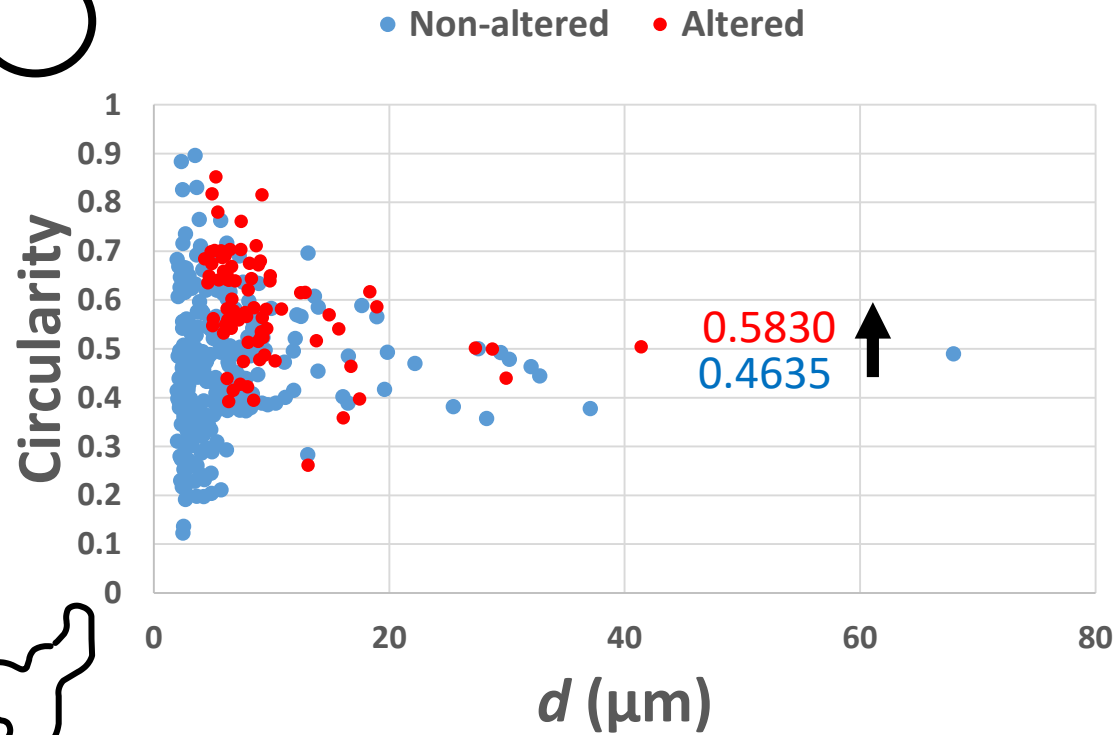
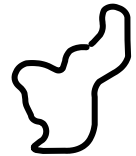
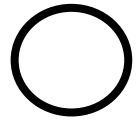
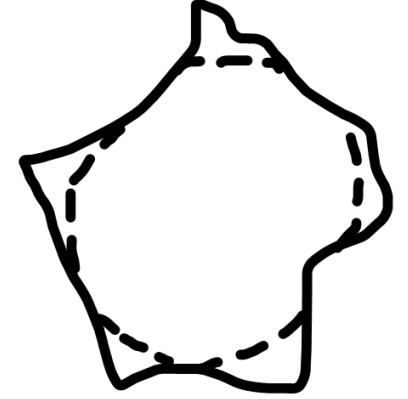
3 clasts  
No results !

5000X

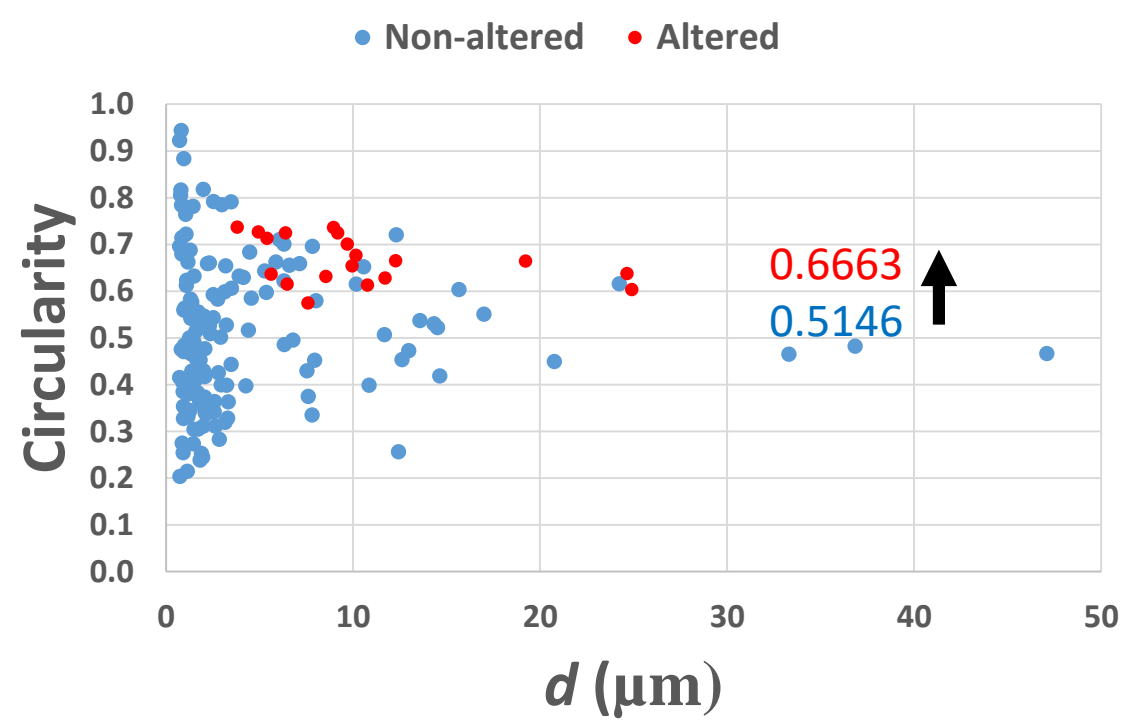
# Qtz CSD (500 x): number of clasts decreases in altered PST (with respect to non-altered PST)



# Qtz: Circularity – roundness of clasts increases with alteration



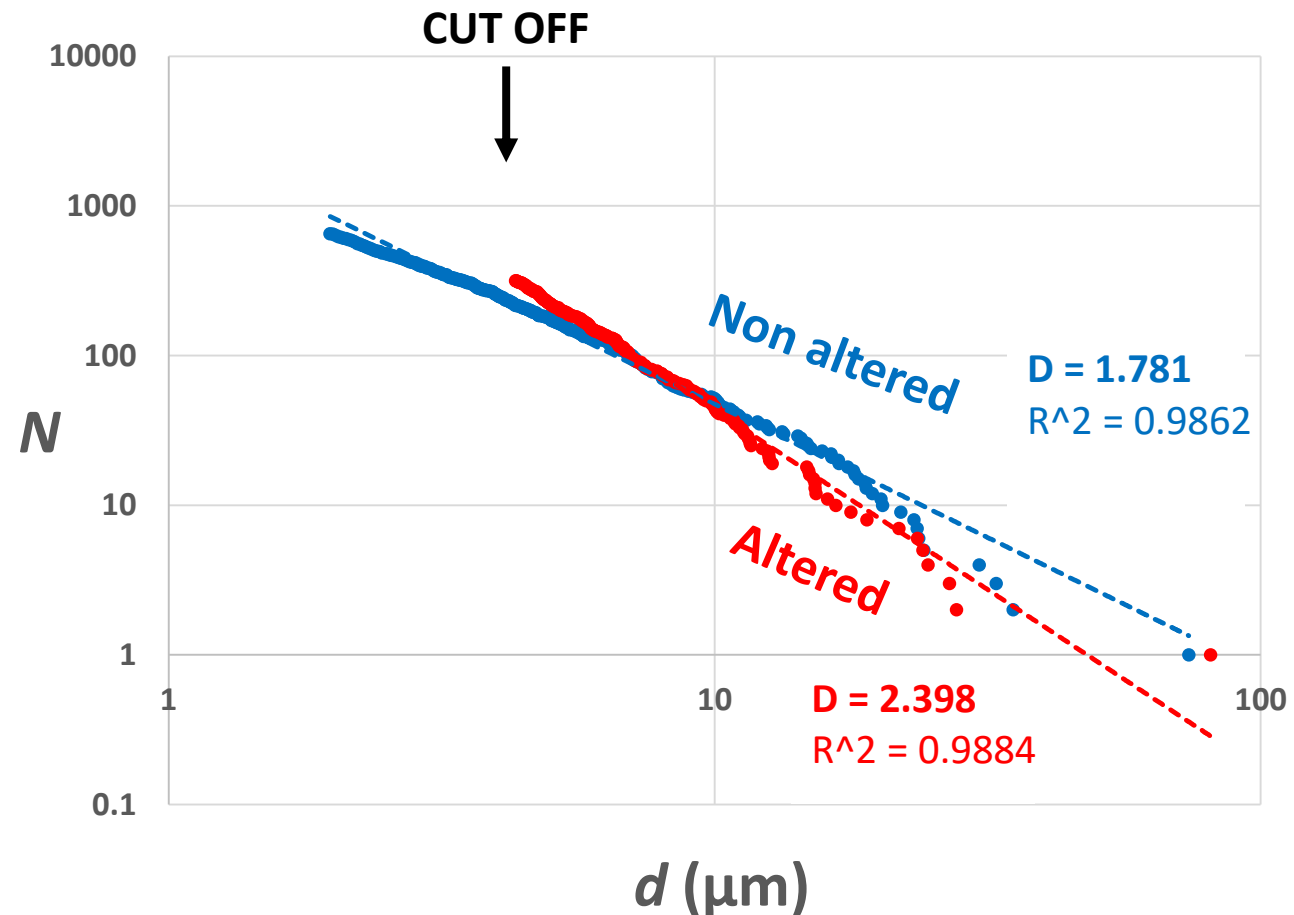
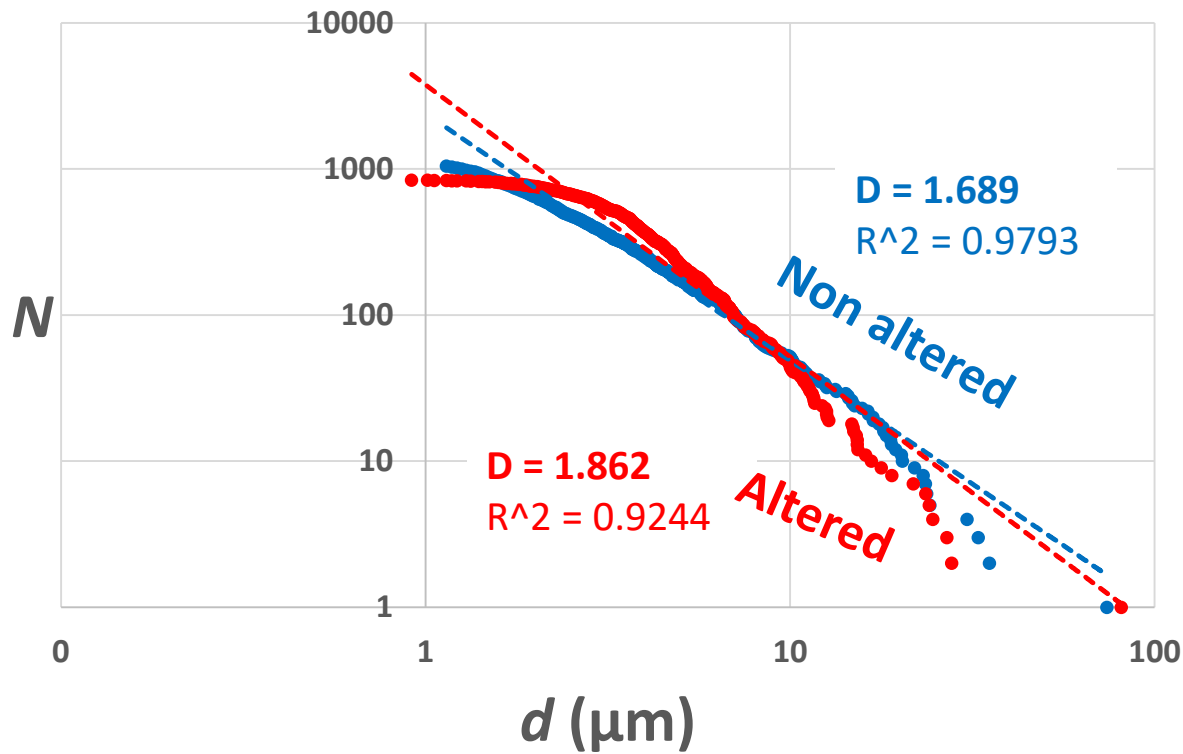
500X



1000X

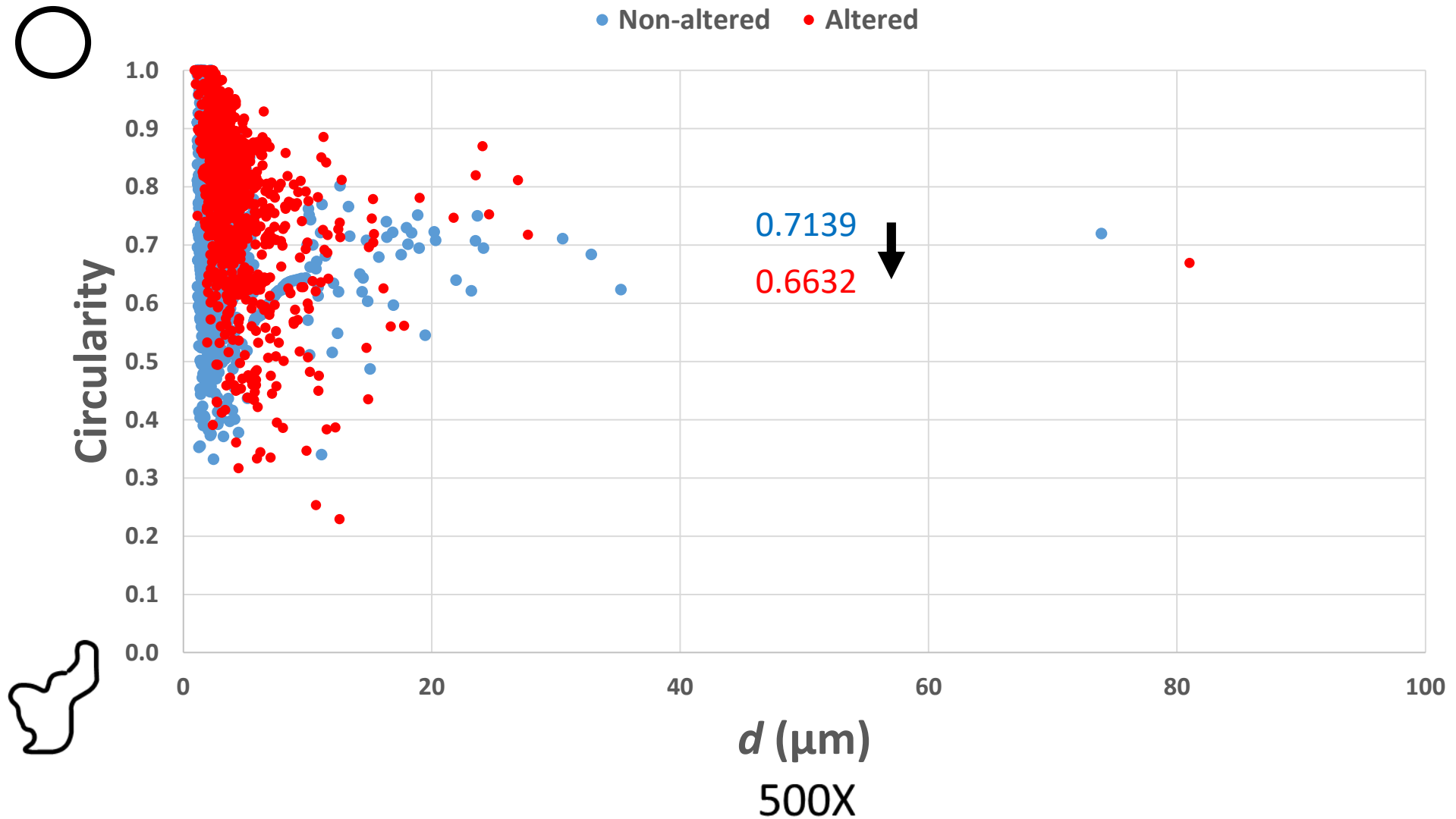
# Feld CSD (500X): number of clasts decreases in altered PST (with respect to non-altered PST)

From 1046 clasts to 839 clasts



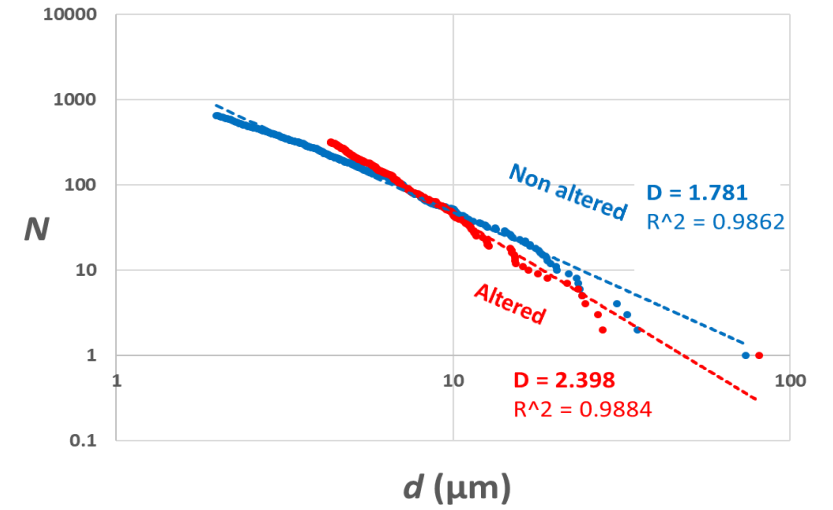
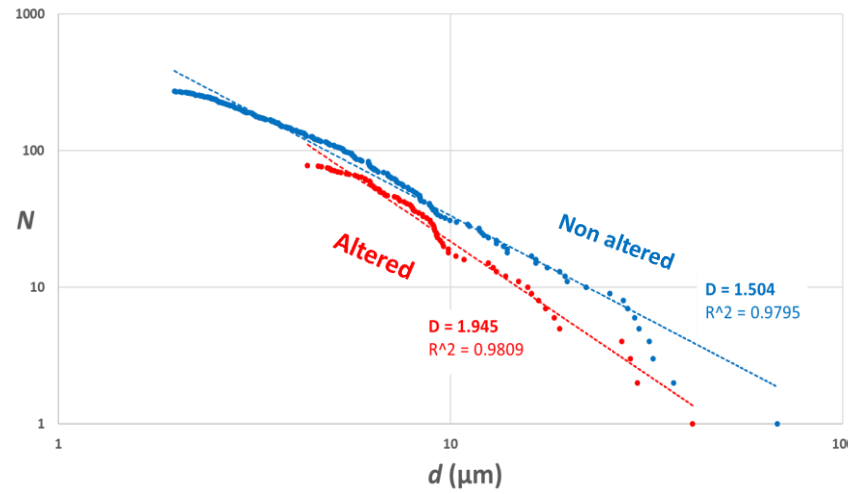


# Feld: Circularity – roundness of clasts decrease with alteration

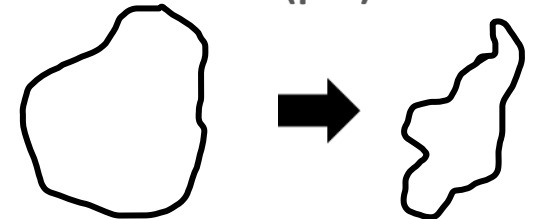
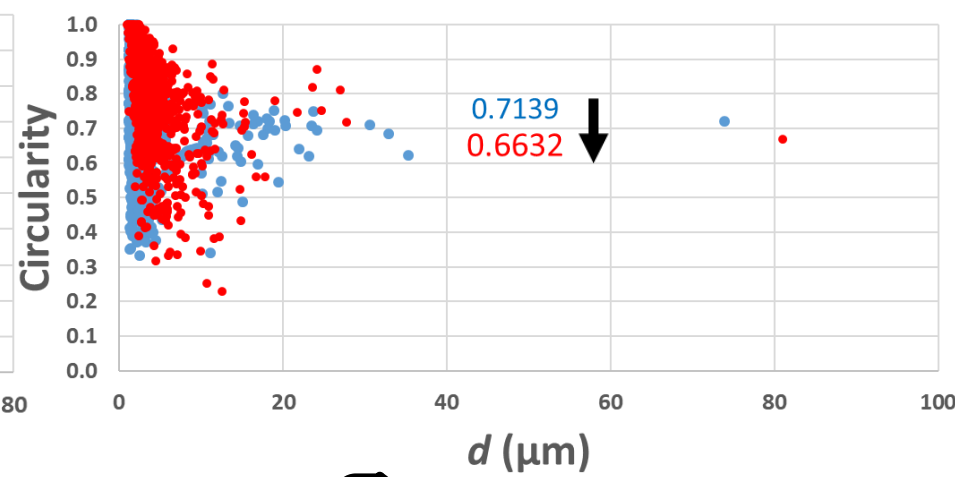
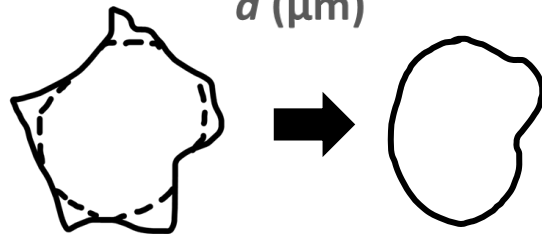
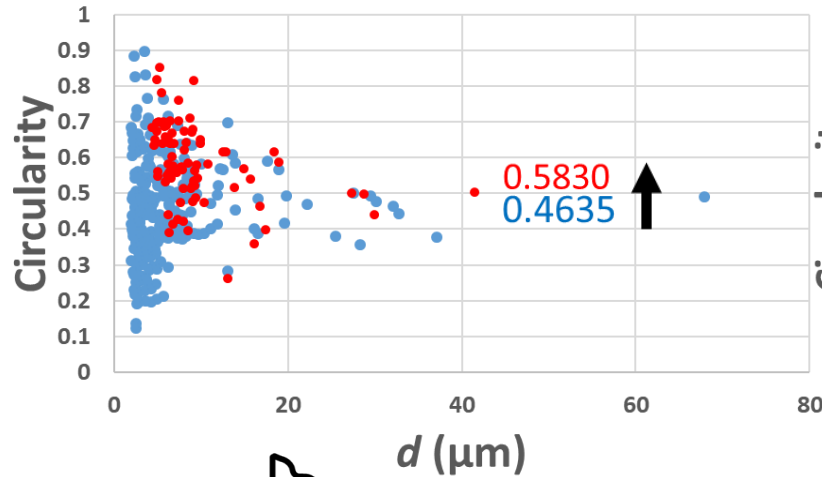


# 4. Discussion

- Number of clasts decreases in altered PST (with respect to non-altered PST)

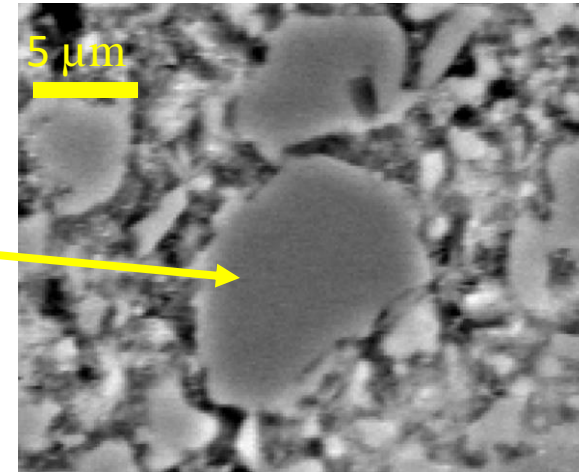
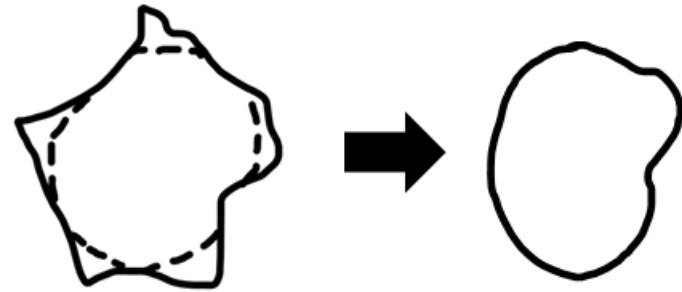


- Trend of circularity varies

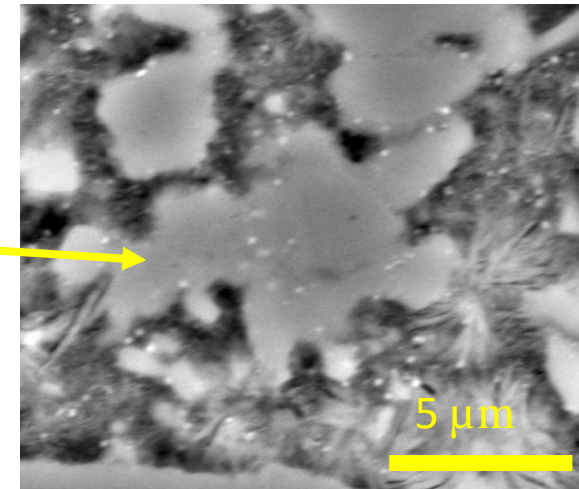
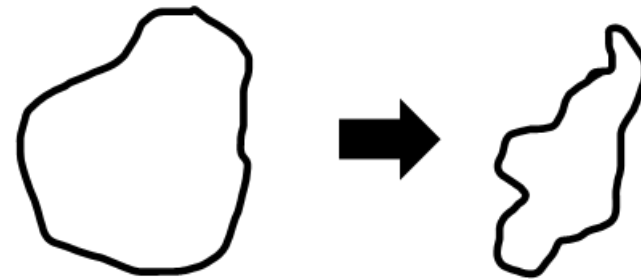


# Circularity evolution with alteration

Quartz

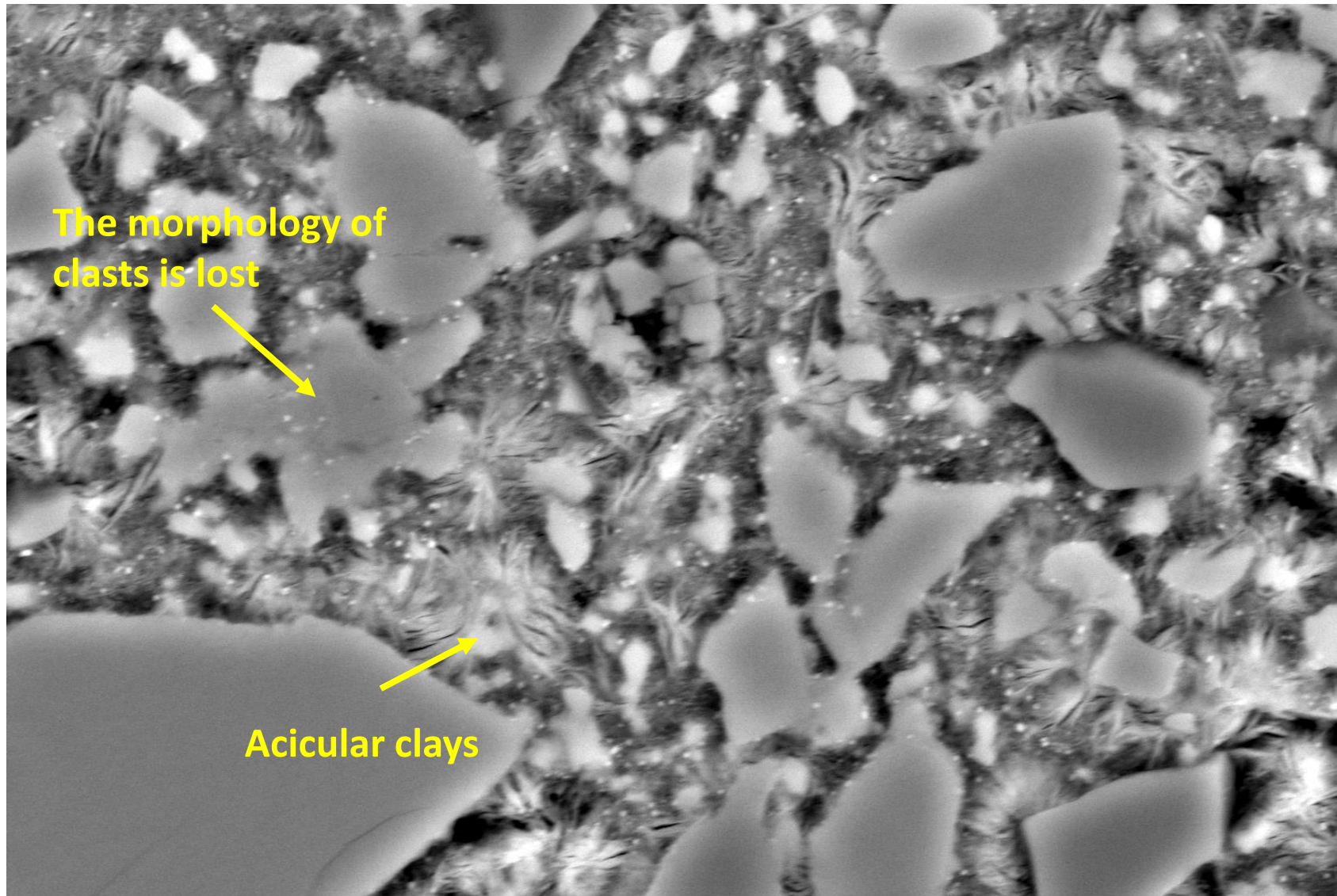


Feldspar



- Quartz: only dissolution?
- Clays: glass devitrification but also alteration of feldspar?

# Rapid and pervasive alteration



HV	spot	det	mode	mag	HFV	WD	10 $\mu$ m
15.00 kV	3.5	CBS	All	5 000 x	41.4 $\mu$ m	11.4 mm	

# Green cataclasites from the Gole Larghe Fault Zone



# Green cataclasites from the Gole Larghe Fault Zone under the scanning electron microscope


Matrix: chlorite +  
epidote + Kfeldspar

qtz

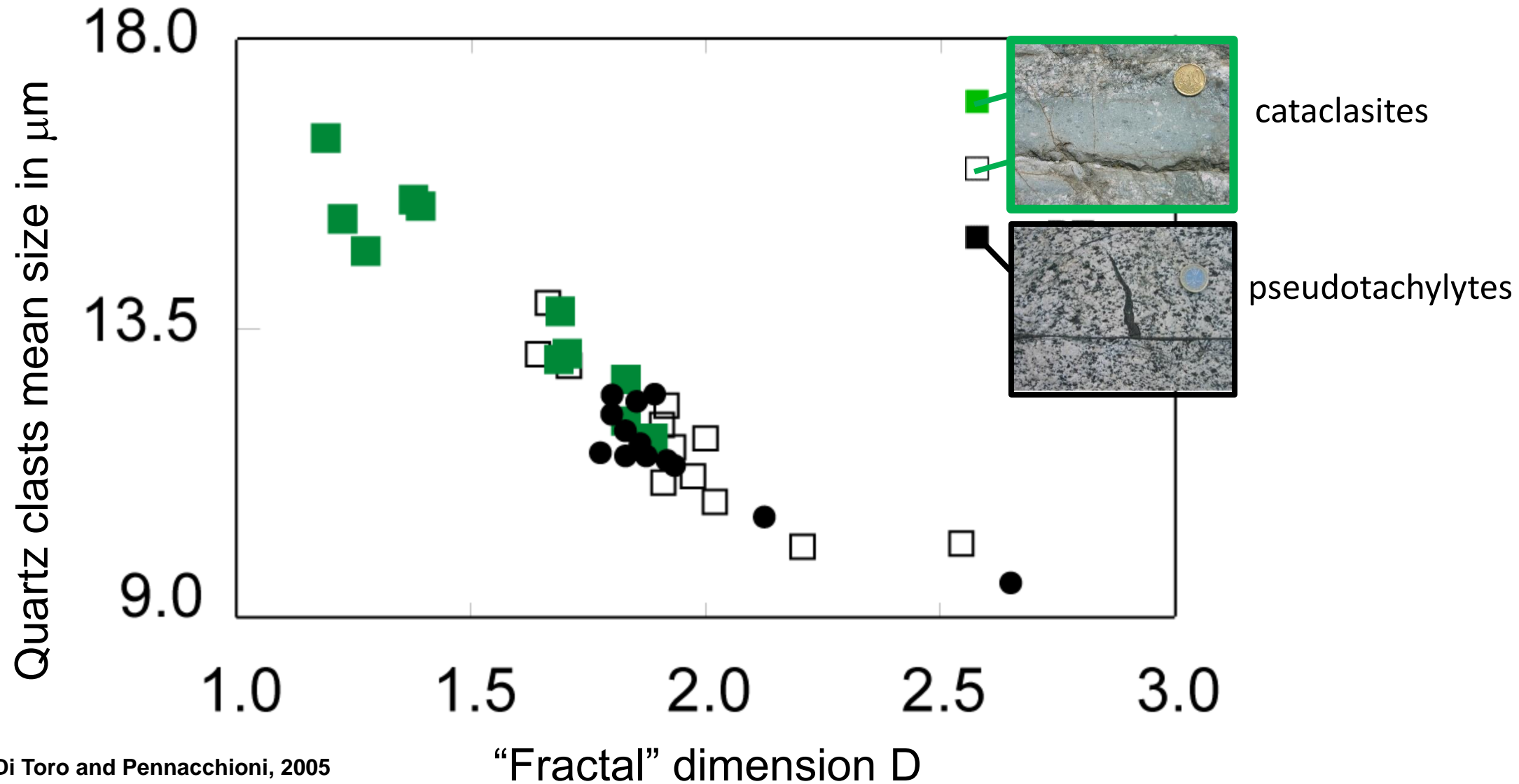
feldspar

30  $\mu\text{m}$

Di Toro and Pennacchioni, 2005  
Tectonophysics

BSC 15.00 kV 3.00 spot 750.0 x 15.79 wd  10  $\mu\text{m}$

Some PST have the same quartz clast distribution of green and whitish cataclasites suggesting that some cataclasites are altered PST.





# 5. Conclusions

Pseudotachylytes are easily lost from the geological record because of fluid-rock interaction and alteration. However, altered pseudotachylytes may retain characteristic pristine microstructural features.

Image analysis allowed us to quantify the CSD and morphology of quartz and feldspar clasts in artificially produced fresh and altered PST.

With respect to non-altered PST, altered PST have:

- 1) a larger number of small grains per big grains (= the slope of the CSD distribution increases with alteration);
- 2) more circular Qtz clasts and more angular feldspar clasts.

This suggest different alteration processes affect quartz and feldspar.

In nature, the similar CSD of some cataclasites and pseudotachylytes suggest that cataclasites are altered PST.

# References

- Di Toro, G. et al. (2010), From field geology to earthquake simulation: a new state-of-the-art tool to investigate rock friction during the seismic cycle (SHIVA), *Rendiconti Lincei.*, 21, 95–114.
- Di Toro, G., Pennacchioni, G., 2005. *Fault plane processes and mesoscopic structure of a strong-type seismogenic fault in tonalites (Adamello batholith, Southern Alps)*. *Tectonophysics*, vol. 402/1-4, pp. 54-79.
- Di Toro, G., Pennacchioni G., Nielsen, S., 2009. *Pseudotachylytes and Earthquake Source Mechanics*. In: “Fault-zone Properties and Earthquake Rupture Dynamics”, Ed. Eiichi Fukuyama, published by the International Geophysics Series, Elsevier, pp. 87-133.
- Fondriest M., Mecklenburgh J., Passelegue F.X., Artioli G., Nestola F., Spagnuolo E., Di Toro G., 2019. *Pseudotachylytes alteration and their loss from the geological record*. Abstract EGU2019 European Geoscience Union General Assembly, Vienna April 2019.
- Kirkpatrick, J.D, and C.D Rowe (2013), Disappearing ink: How pseudotachylytes are lost from the rock record, *J. Struct. Geol.*, 52, 183-198, <https://doi.org/10.1016/j.jsg.2013.03.003>.
- Sibson, R.H. (1975), Generation of Pseudotachylyte by Ancient Seismic Faulting, *Geophys. J. Int.*, 43(3), 775–794, <https://doi.org/10.1111/j.1365-246X.1975.tb06195.x>.
- Sibson, R.H., and V.G. Toy (2006), The Habitat of Fault-Generated Pseudotachylyte: Presence vs. Absence of Friction-Melt, *Geoph. Monograph Series*, 170, 153–166, doi:10.1029/170GM16.

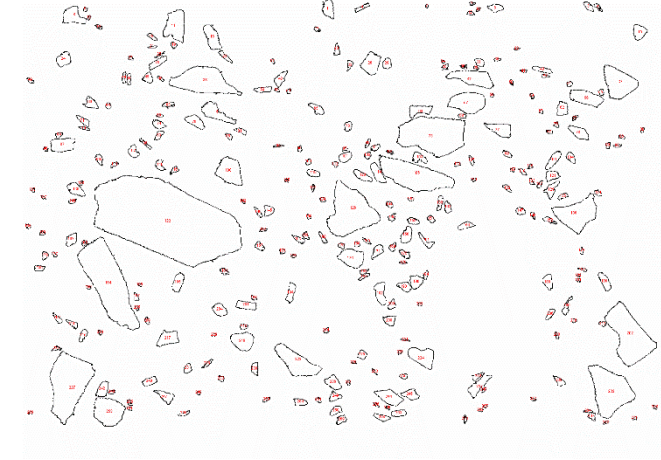
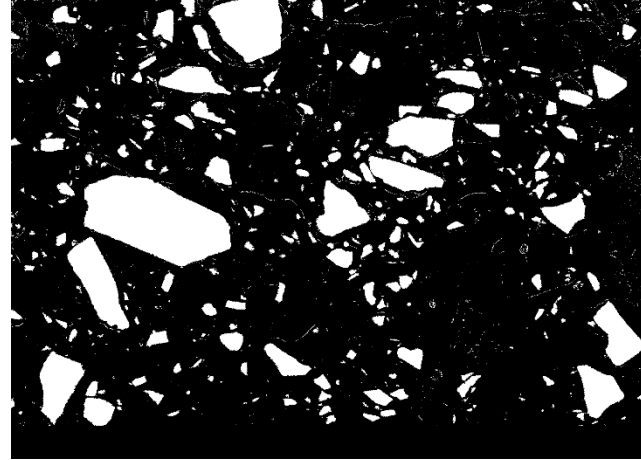
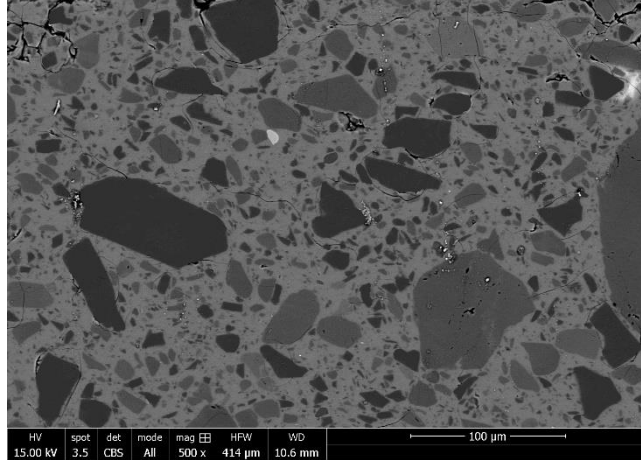
Grazie per l'attenzione

<b>NON-ALTERED</b>	500X-Qtz	1000X-Qtz	5000X-Qtz	500X-Feld
NUMERO CLASTI	272	140	32	1046
AREA MIN ( $\mu\text{m}^2$ )	3.0679	0.4018	0.4137	1.0226
AREA MAX ( $\mu\text{m}^2$ )	3624.9837	1742.1110	3.6111	4291.7481
<b>ALTERED</b>	500X-Qtz	1000X-Qtz	5000X-Qtz	500X-Feld
NUMERO CLASTI	78	19	3	839
AREA MIN ( $\mu\text{m}^2$ )	14.6822	11.3338		0.6574
AREA MAX ( $\mu\text{m}^2$ )	1346.3842	487.0823		5155.0767

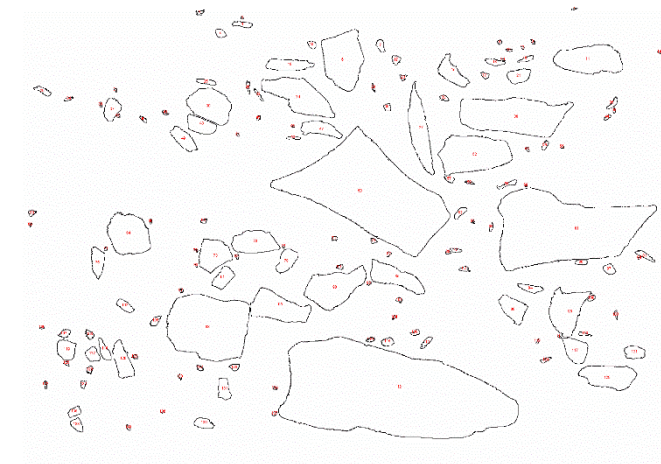
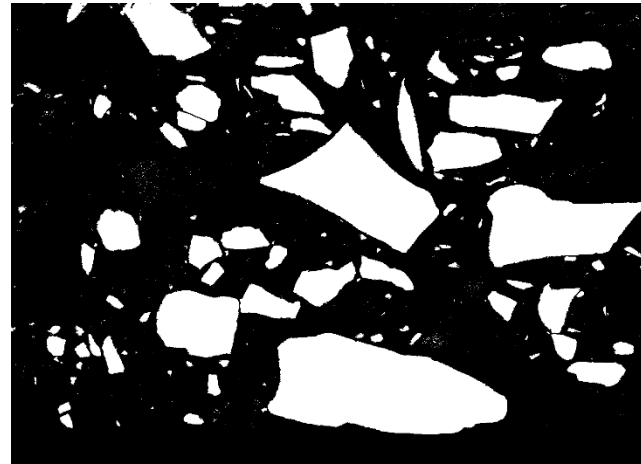
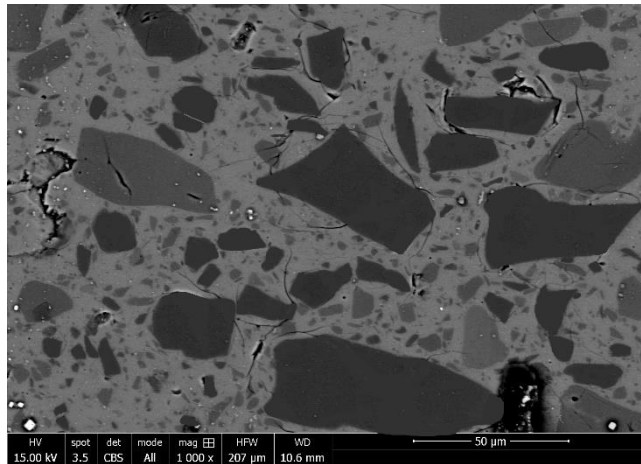
# Non-altered pseudotachylytes

## Qtz clasts distribution

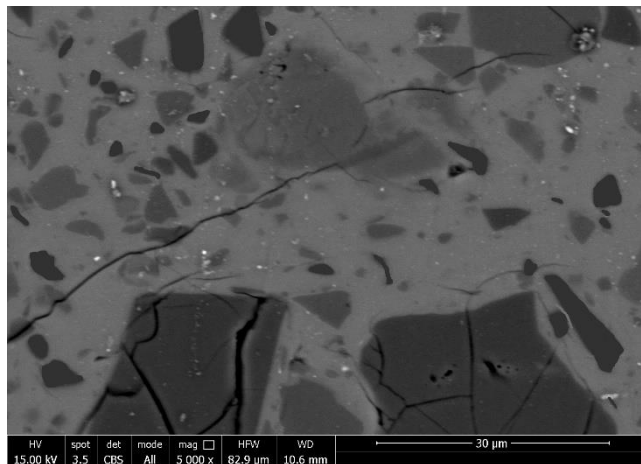
500X



1000X



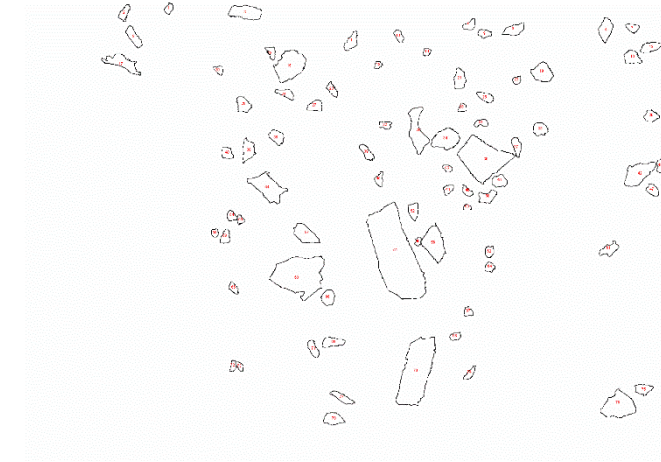
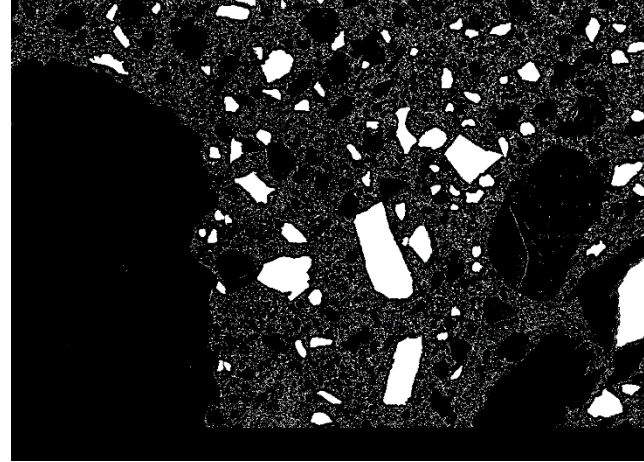
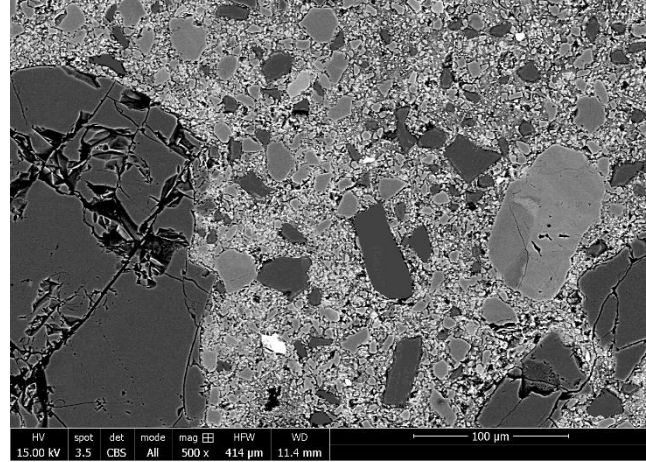
5000X



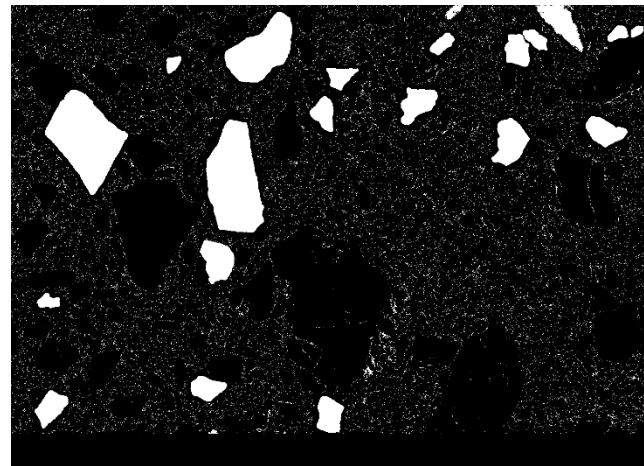
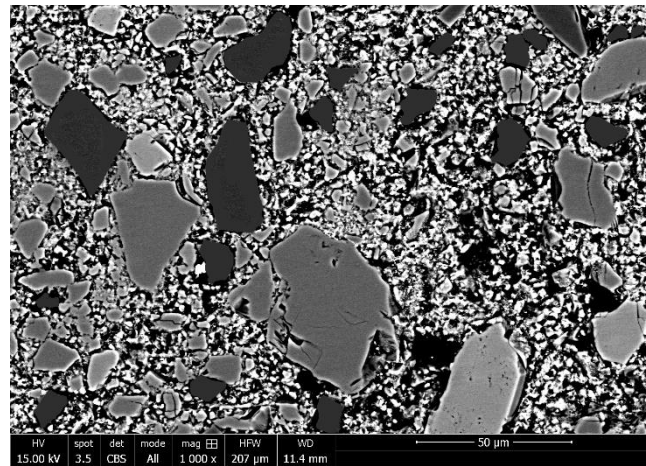
# Altered pseudotachylytes

## Qtz clasts distribution

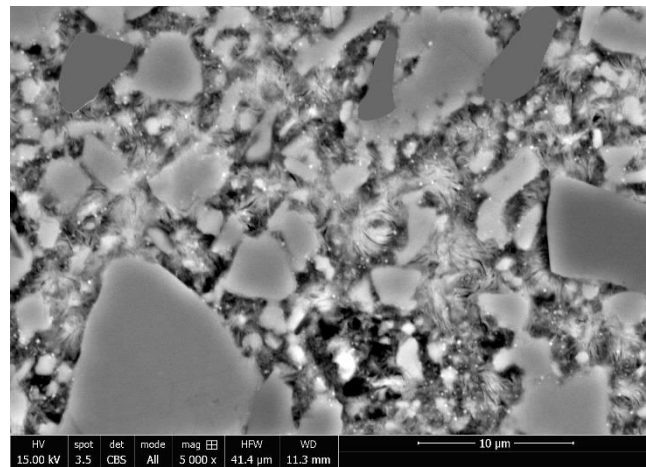
500X



1000X



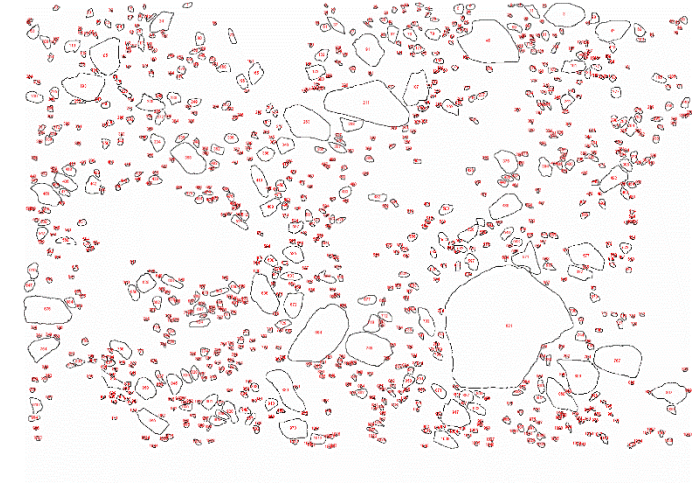
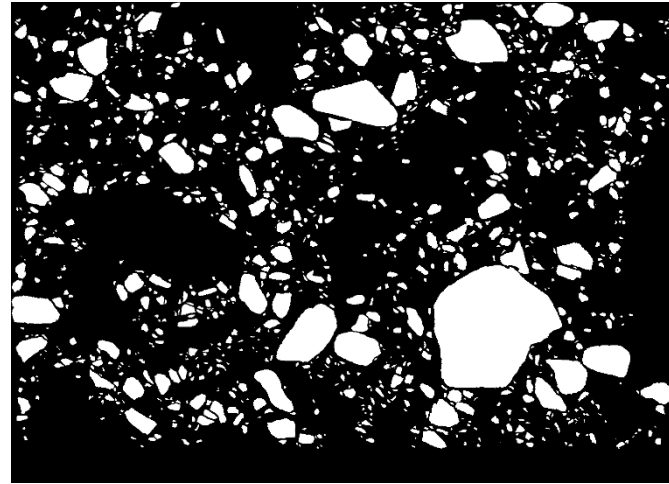
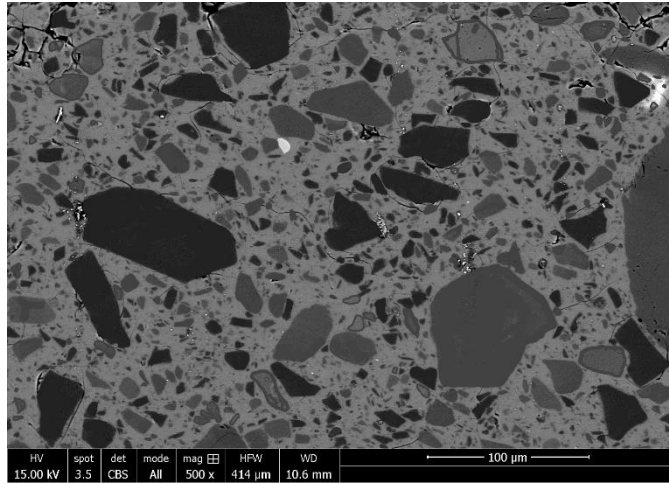
5000X



# Non-altered pseudotachylytes

## Feld clasts distribution

500X



# Altered pseudotachylytes

## Feld clast distribution

500X

