Newcastle University

Microbial control on Anthropocene carbonates in slag drainage waters

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From Newcastle. For the world.

- Weathering of legacy steel slag disposal sites releases alkaline leachates into surrounding soils and drainage systems

- The carbonate deposits in theses hyperalkaline and hypersaline systems can provide a modern analogue to extreme paleo environments such as alkaline lakes in rift volcanic settings

- Site design should focus on maximising carbonate formation as it can be utilised as a remediation and carbonate sequestration technique

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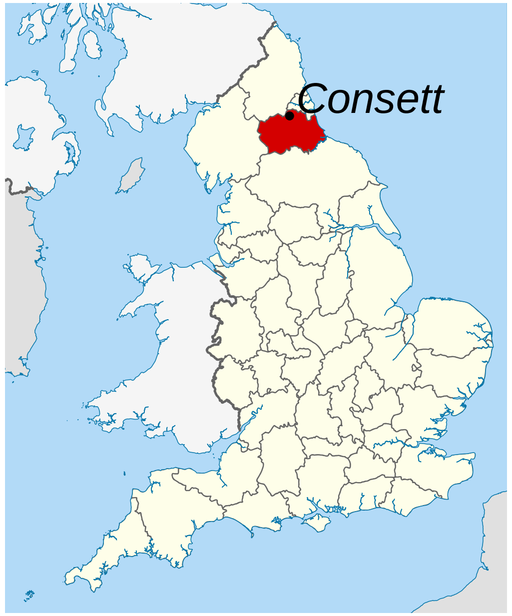
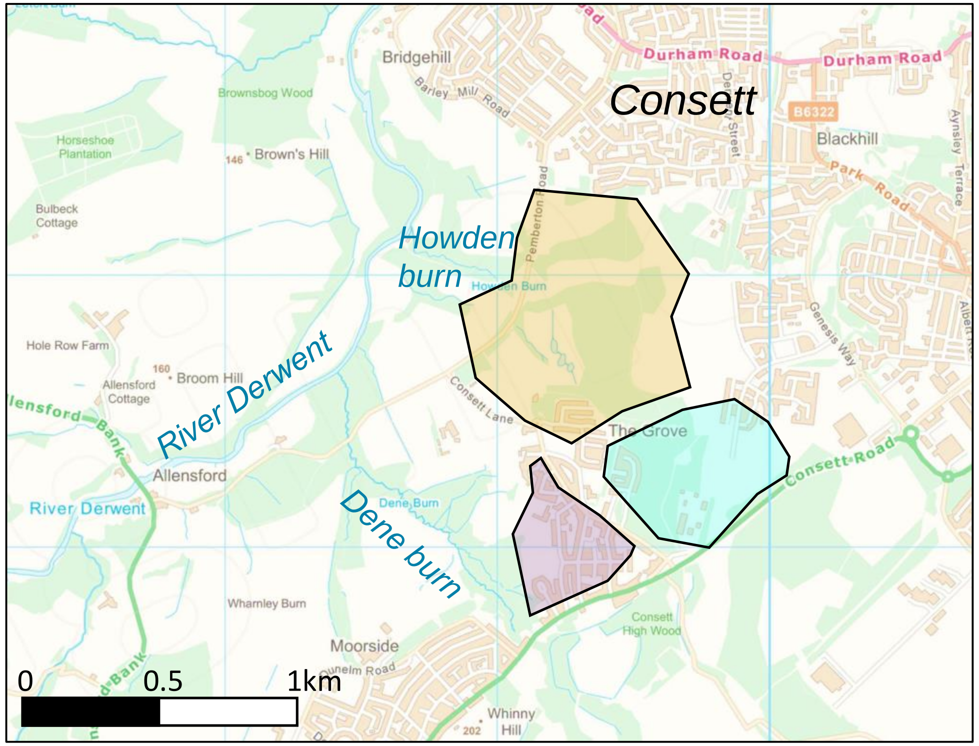


County Durham, England



Former steel plant and slag heaps

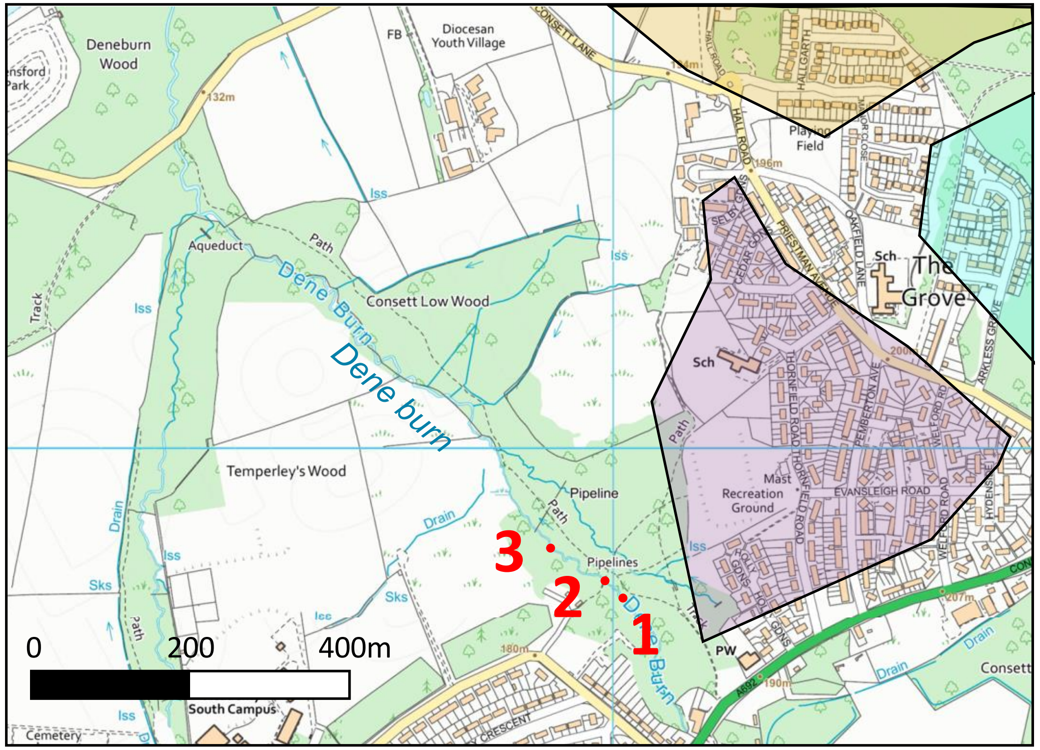
Coke works and plate mill

Grove slag heaps

After Hudson and Sadler, 2017

- Between 1840 and 1980 Consett Iron Company Ltd produced around 120 million tonnes steel and over 20 million tonnes slag
- Slag was deposited in two heaps between two tributaries of the River Derwent
- Active management during operation involved dosing of H_2SO_4 in both streams

Sampling site locations – Dene Burn, Consett



Former steel plant and slag heaps

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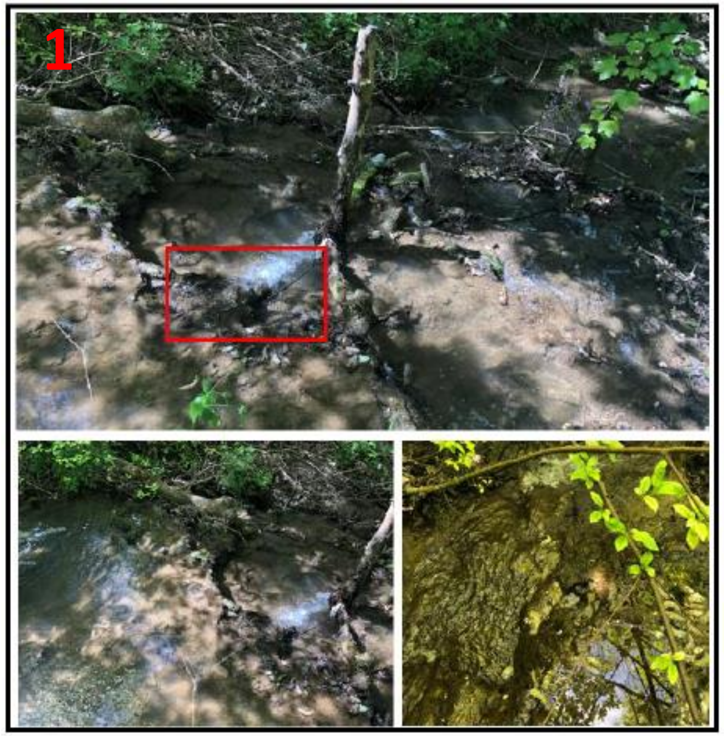
Grove slag heaps

Site 1 to 2 ±45m. Site 2 to 3 ±85m

- Site 1 - Terraced waterfall with flat ridged crust coating bed and sides
- Site 2 - Waterfall coated in thick crust forming a tubular draping structure
- Site 3 – Similar to Site 2 but structure less extensive

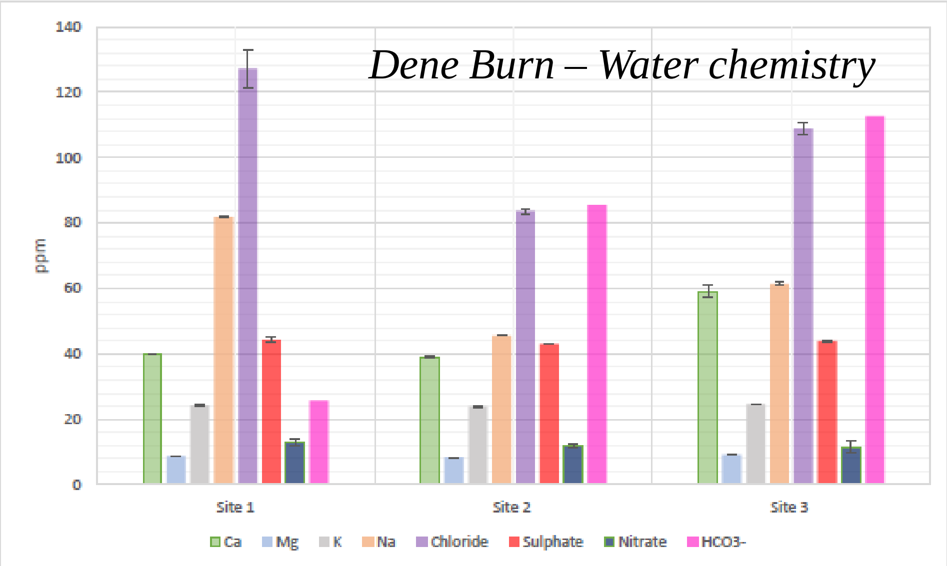
Sampling site locations – Dene Burn, Consett

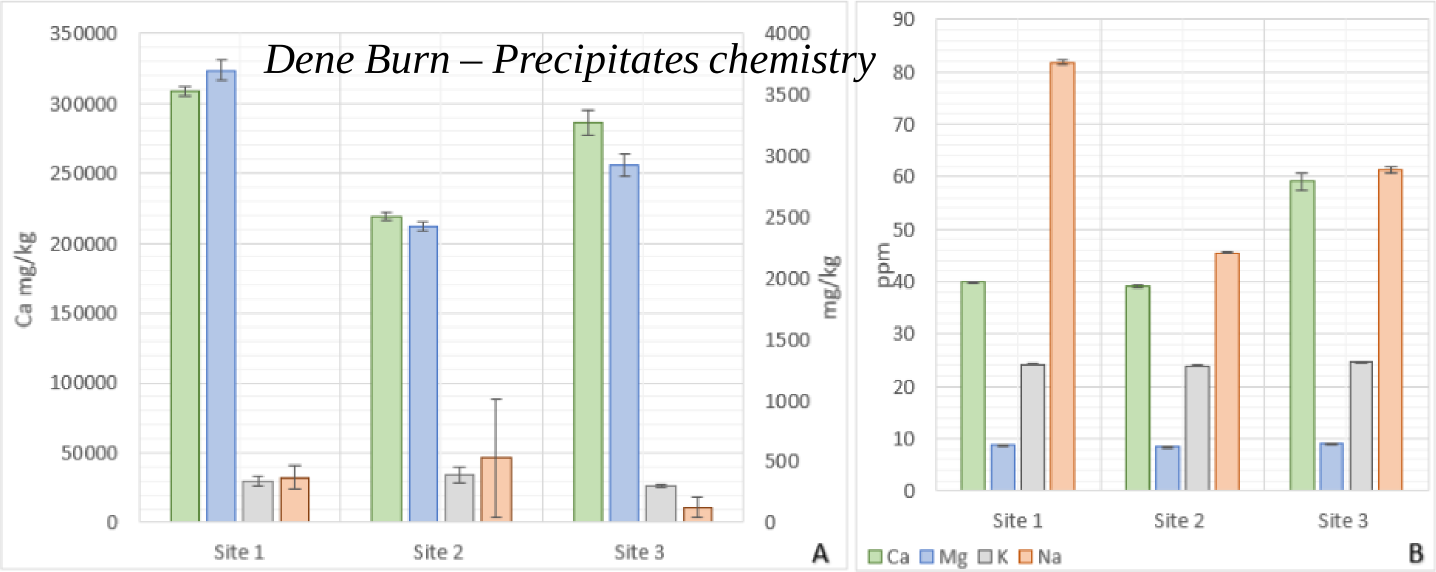


	Site 1	Site 2	Site 3
pH	9.63	9.38	8.46
Temperature (ºC)	11.6	12.9	11.8
Conductivity (µs)	545.4	515.2	605.1
Total alkalinity ($CaCO_3$ mg/ L)	30	87	95

Red box indicate solid sample location

Aqueous and solid geochemistry



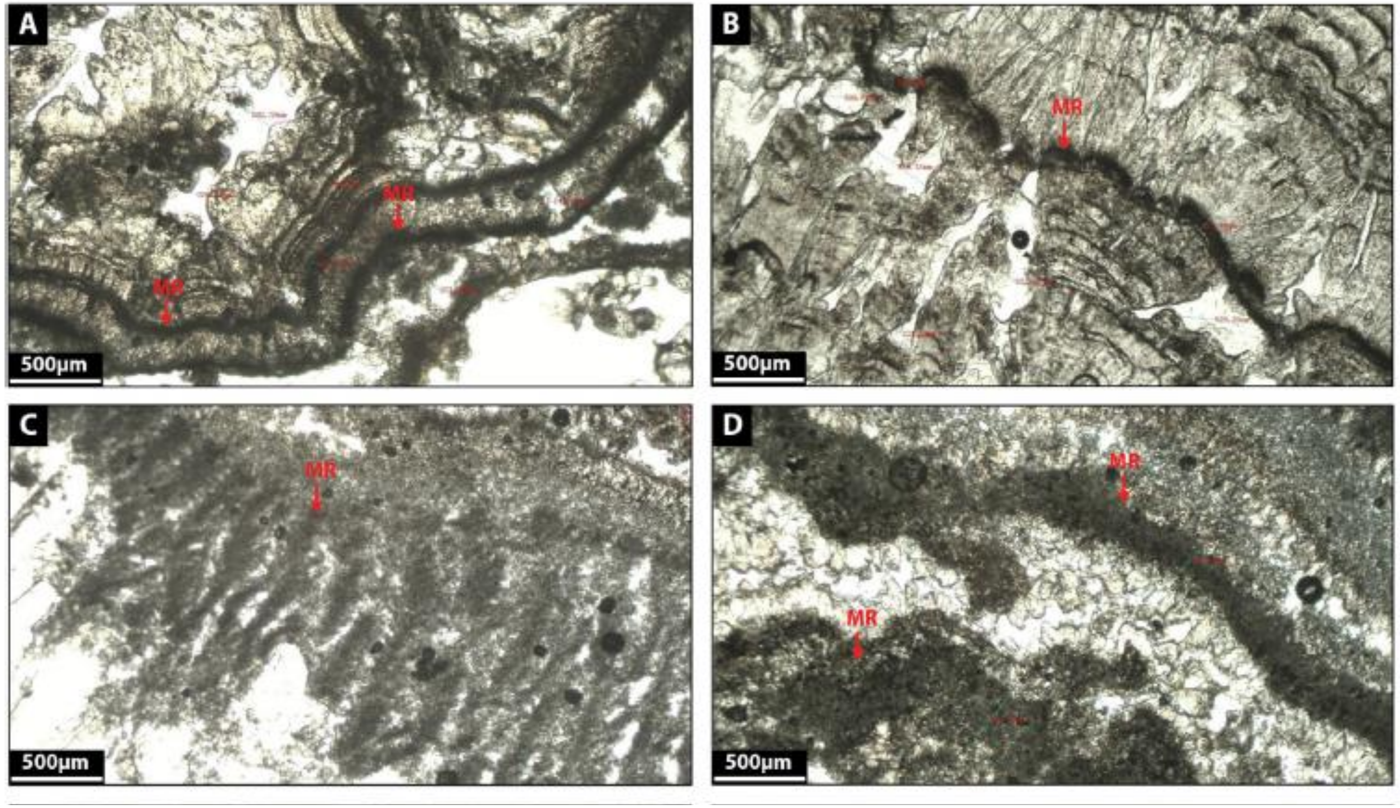


Species	Site 1	Site 2	Site 3
Dolomite ($CaMg(CO_3)_2$)	2.3643	3.0129	1.7002
Calcite ($CaCO_3$)	0.9800	1.3006	0.7249
Aragonite ($CaCO_3$)	0.8135	1.1343	0.5585
Monohydrocalcite ($CaCO_3 \cdot H_2O$)	0.0108	0.3295	*-0.2446*
Magnesite ($MgCO_3$)	*-0.3295*	0.0070	*-0.7373*
Quartz (SiO_2)	-	-	-
Fluorite (CaF_2)	-	-	-
Hematite (FeO_3)	-	-	-
Dickite ($Al_2Si_2O_5(OH)_4$)	-	-	-

- Chemistry and calculated mineral saturation states
- Presence of green shaded mineral are confirmed by XRD

Mineral saturation states

Carbonate microfacies



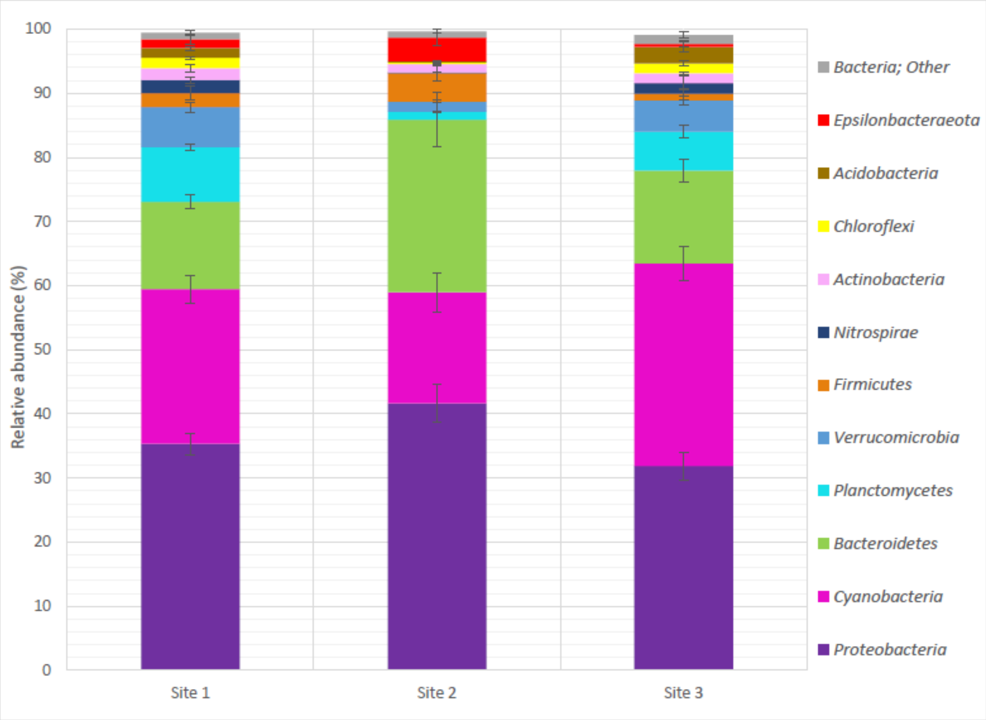
Bastianini et al. 2019 – What Causes Carbonates to Form "Shrubby" Morphologies? An Anthropocene Limestone Case Study

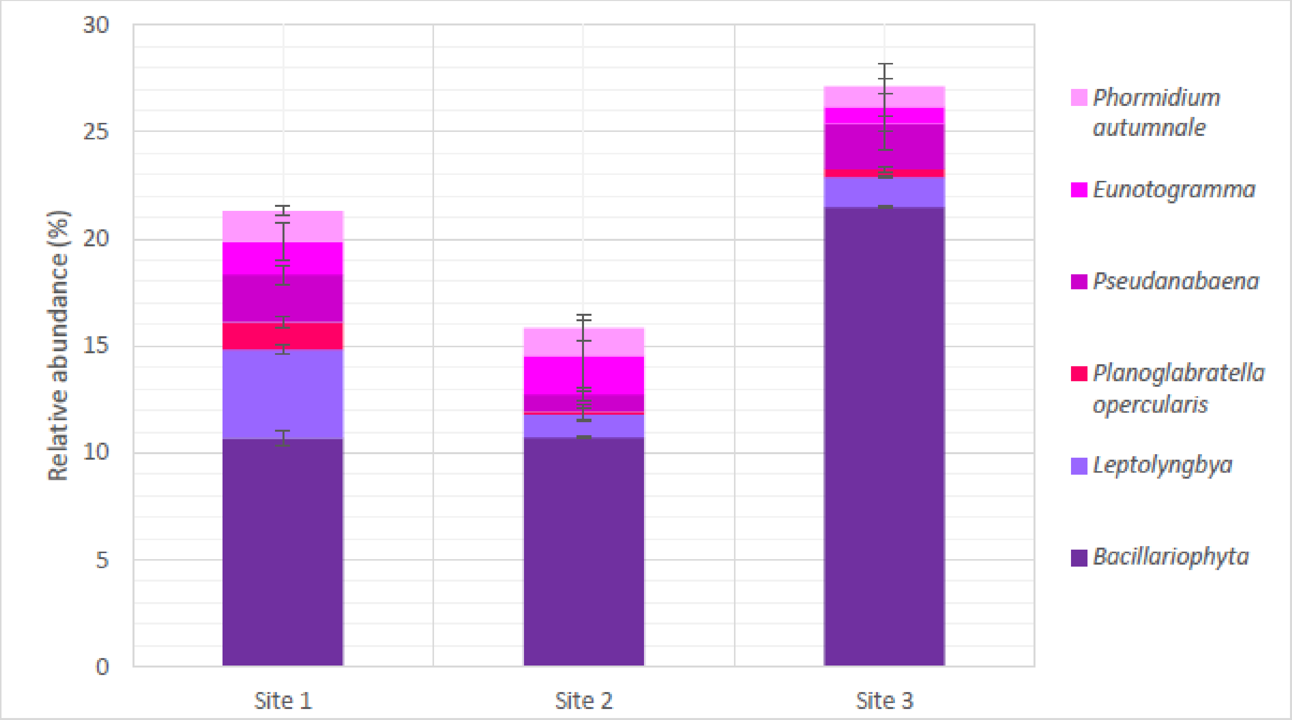
https://www.frontiersin.org/articles/10.3389/feart.2019.00236/full

- Carbonate thinsections of nearby sites in Dene and Howden Burn by Bastianini et al. (2019)
- Identified a "microbial rim" thinsection microfacies

- What is the composition of this microbial community and how are they associated with the carbonate minerals?

Microbial community





- Phylum level microbial communities (left)
- Cyanobacteria taxa across each site (right)

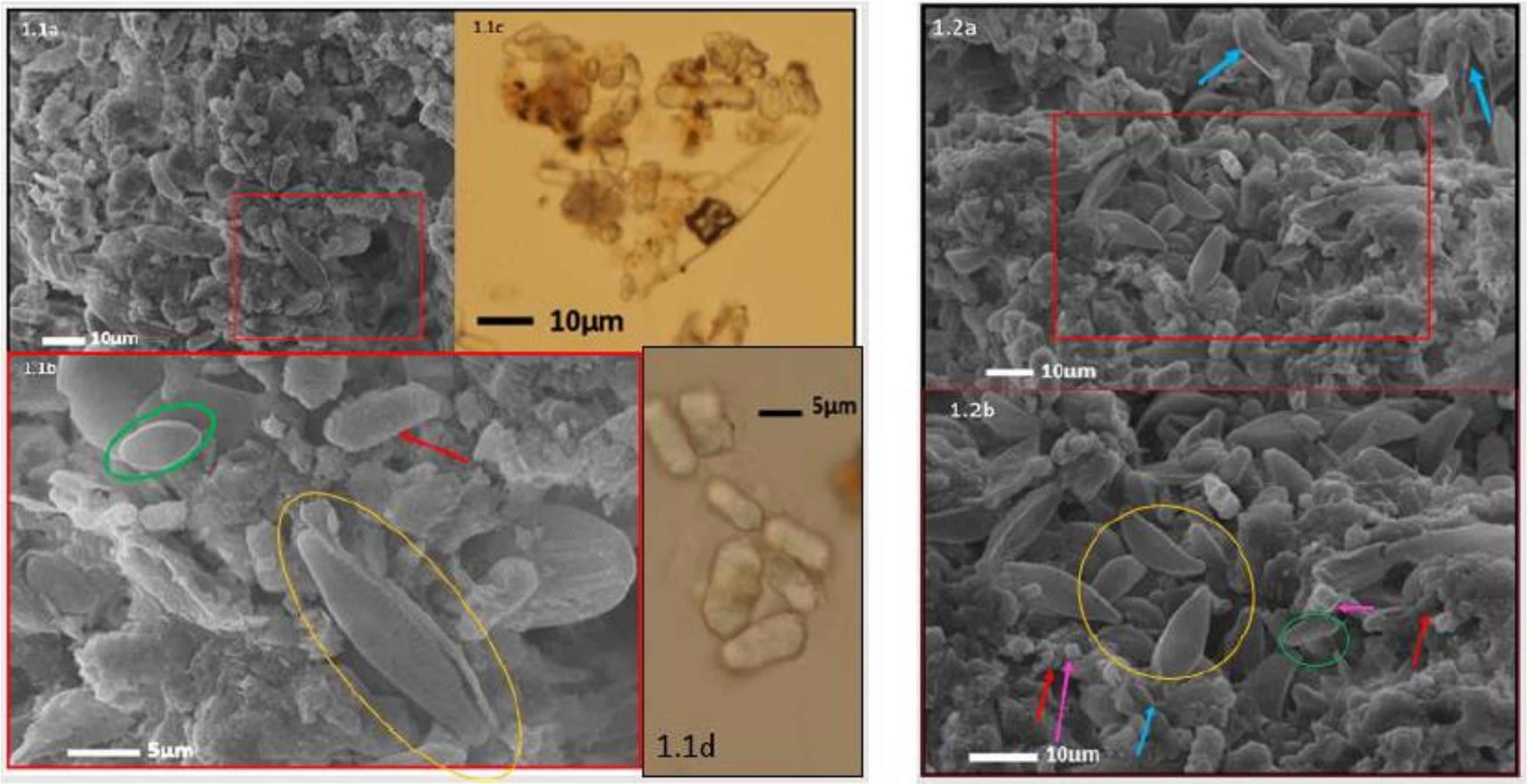


Figure 15. SEM and light microscopy (1.1c and 1.1d) images of site 1. Area dominated by diatoms and rod-shaped bacteria. Light microscopy shows close association of diatoms, rod shaped bacteria with other materials. Red box indicates higher magnification of that area in corresponding image. Yellow circle indicates diatoms (*Bacillariophyta*), green circle shows rod shaped bacteria, red arrow shows rounded and elongated rhomb morphologies, pink arrow shows smooth rhomb morphologies. Blue arrow shows microbes and minerals connected by substance with slimy consistency (EPS)

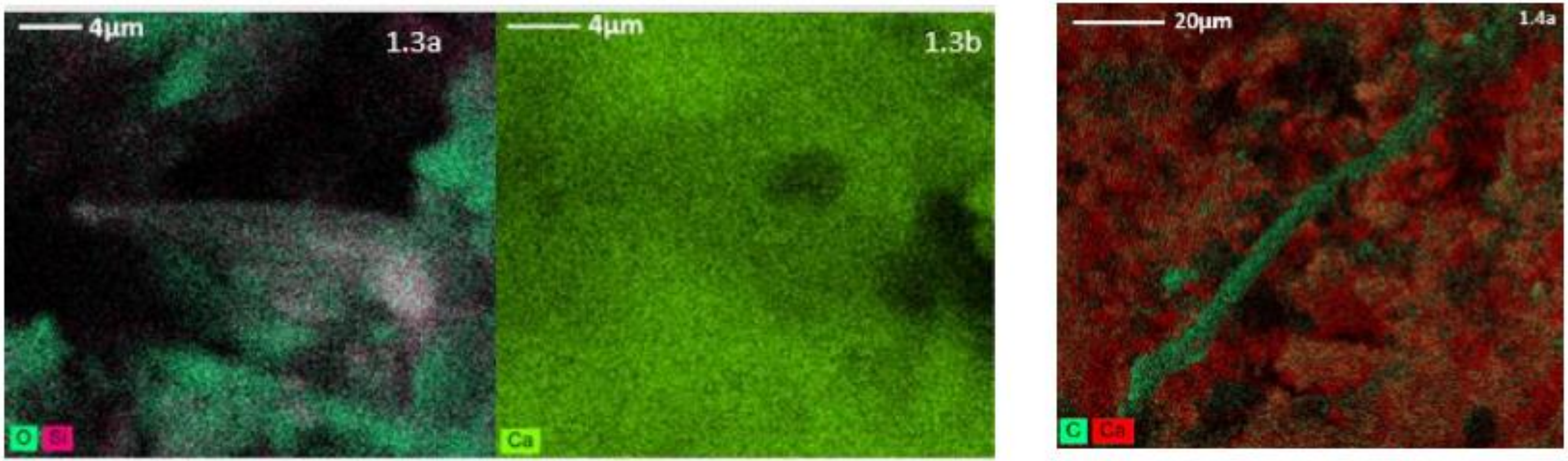


Figure 16. SEM-EDS images from site 1. Elemental map of the same area show diatom in relation to presence of O, Si and Ca (1.3a and 1.3b). Image 1.3 shows diatom to be Ca rich. Filamentous bacteria in relation to C and Ca (1.4a).

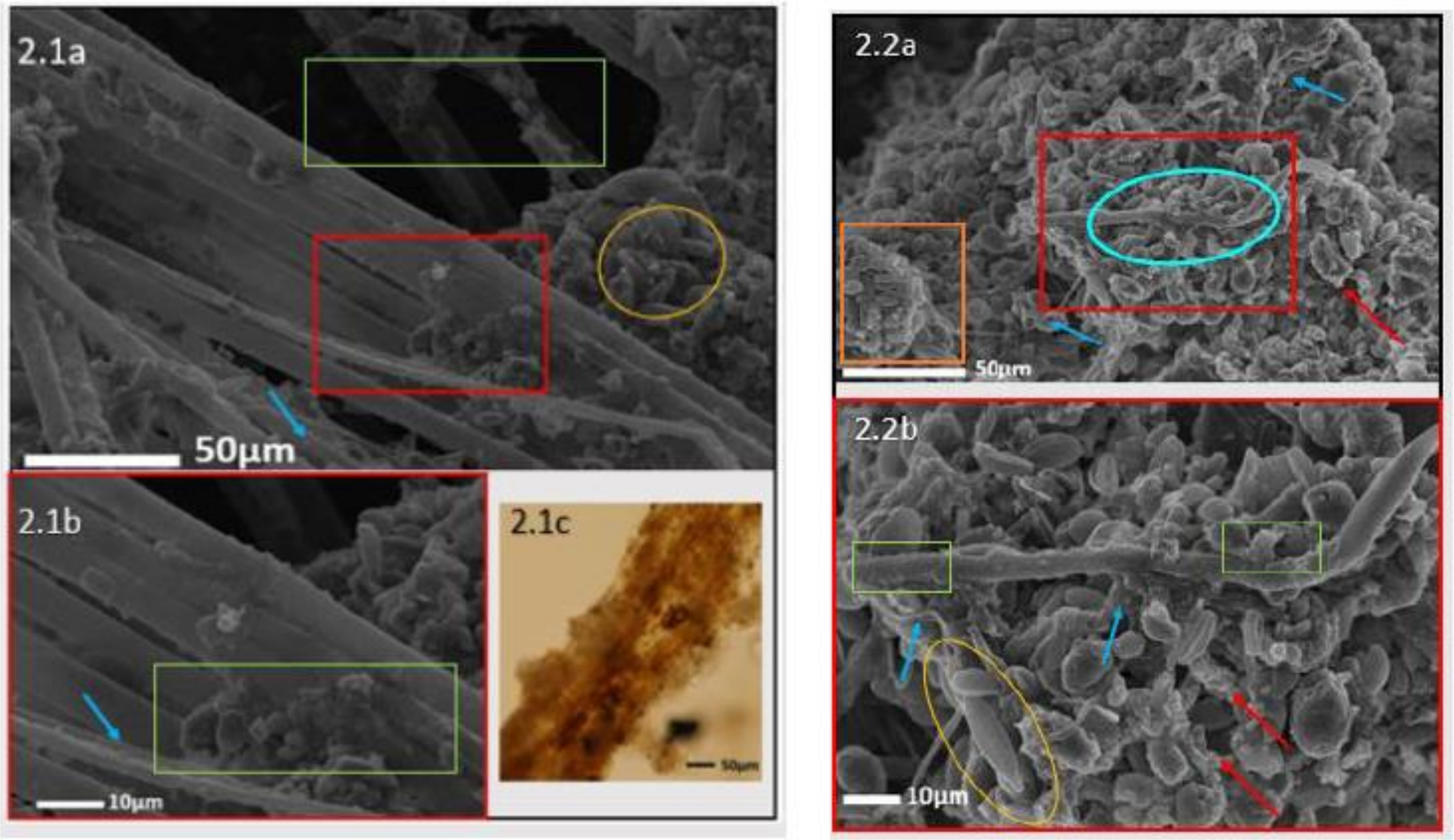


Figure 17. SEM and light microscopy (2.1c) images of site 2. Red box indicates higher magnification of that area in corresponding image. Yellow circles indicate diatoms (*Bacillariophyta),* blue circle shows filamentous bacteria, red arrows show rounded and elongated morphologies, orange box shows spherical cluster of diatoms. Blue arrow shows microbes and minerals connected by EPS, green square shows close association of minerals and filamentous bacteria

Microbe-mineral interaction

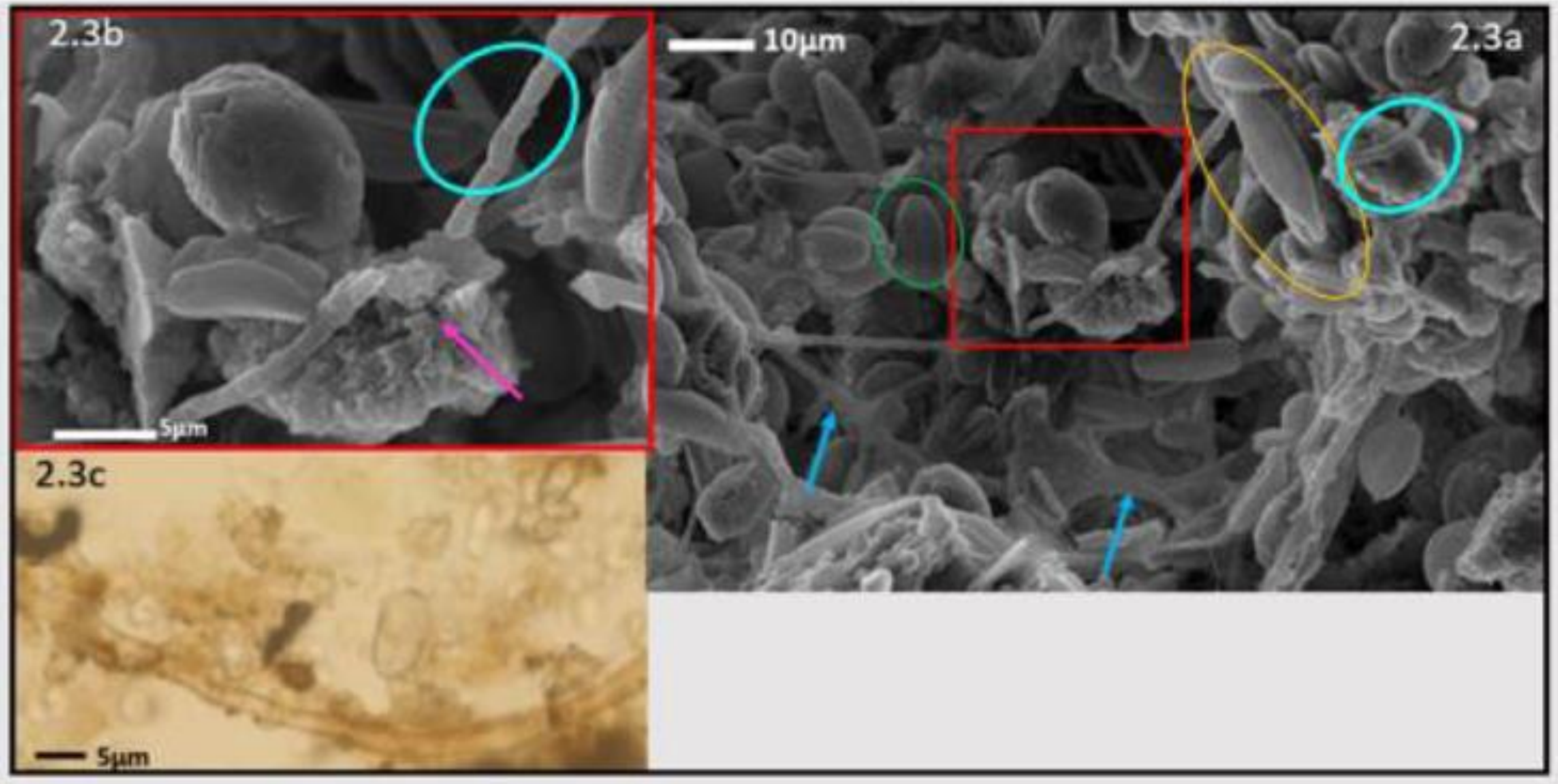


Figure 18. SEM and light microscopy (2.3c) images of site 2. Different microorganisms and minerals in close association with EPS spread throughout. Red box indicates higher magnification of that area in corresponding image. Yellow circle indicates diatoms (*Bacillariophyta)*, blue circle shows filamentous bacteria pink arrow shows smooth rhomb morphologies. Blue arrow shows microbes and minerals connected by EPS

Microbe-mineral interaction

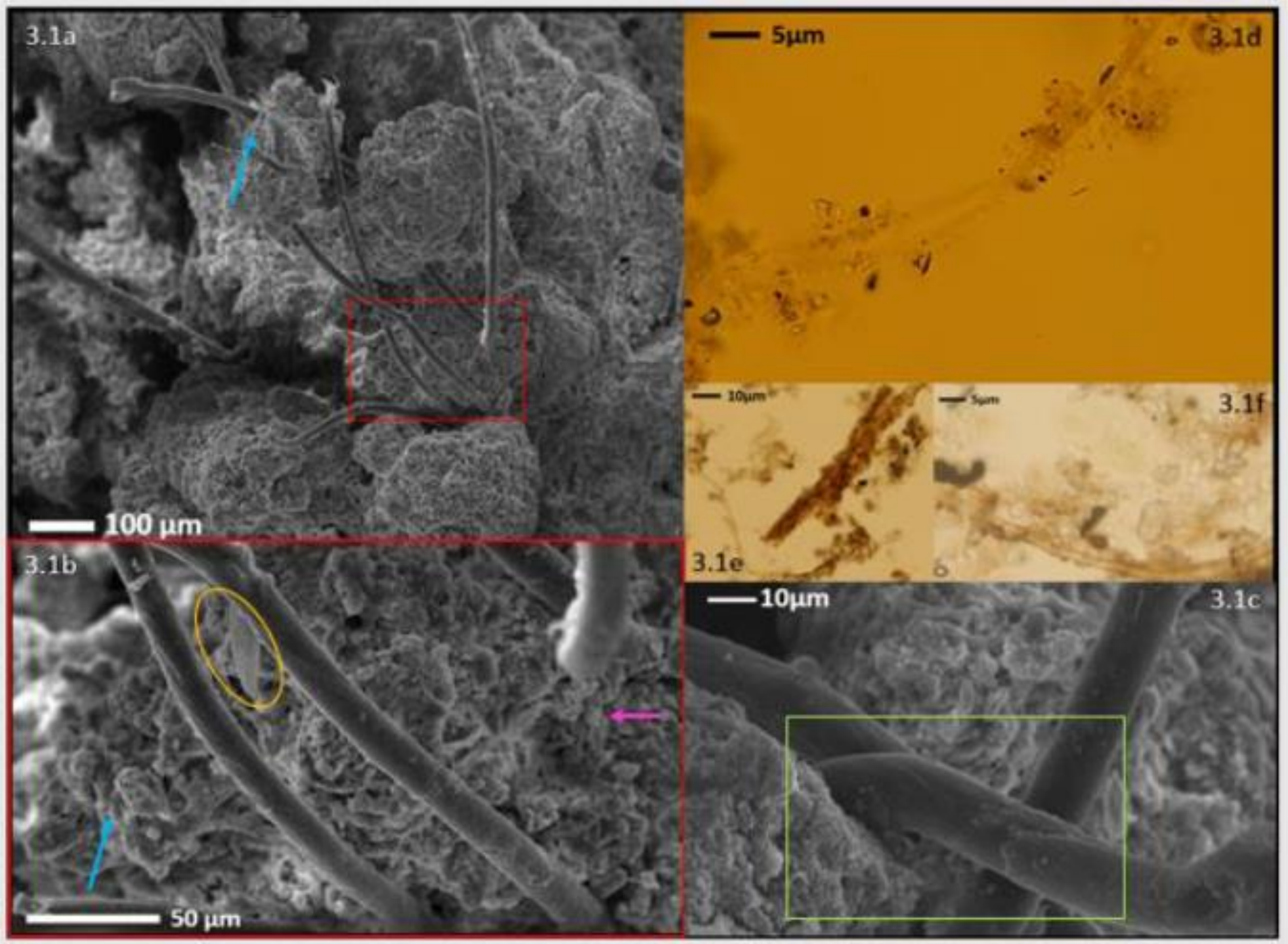


Figure 20. SEM and light microscopy (3.1d, 3.1e and 3.1f) images of site 3. Filamentous organisms intertwined with precipitates and other organisms. Red box indicates higher magnification of that area in corresponding image. Yellow circle indicates diatoms (*Bacillariophyta)*, pink arrow shows smooth rhomb morphologies. Blue arrow shows microbes and minerals connected by EPS, green square shows close association of minerals and filamentous bacteria

Microbe-mineral interaction

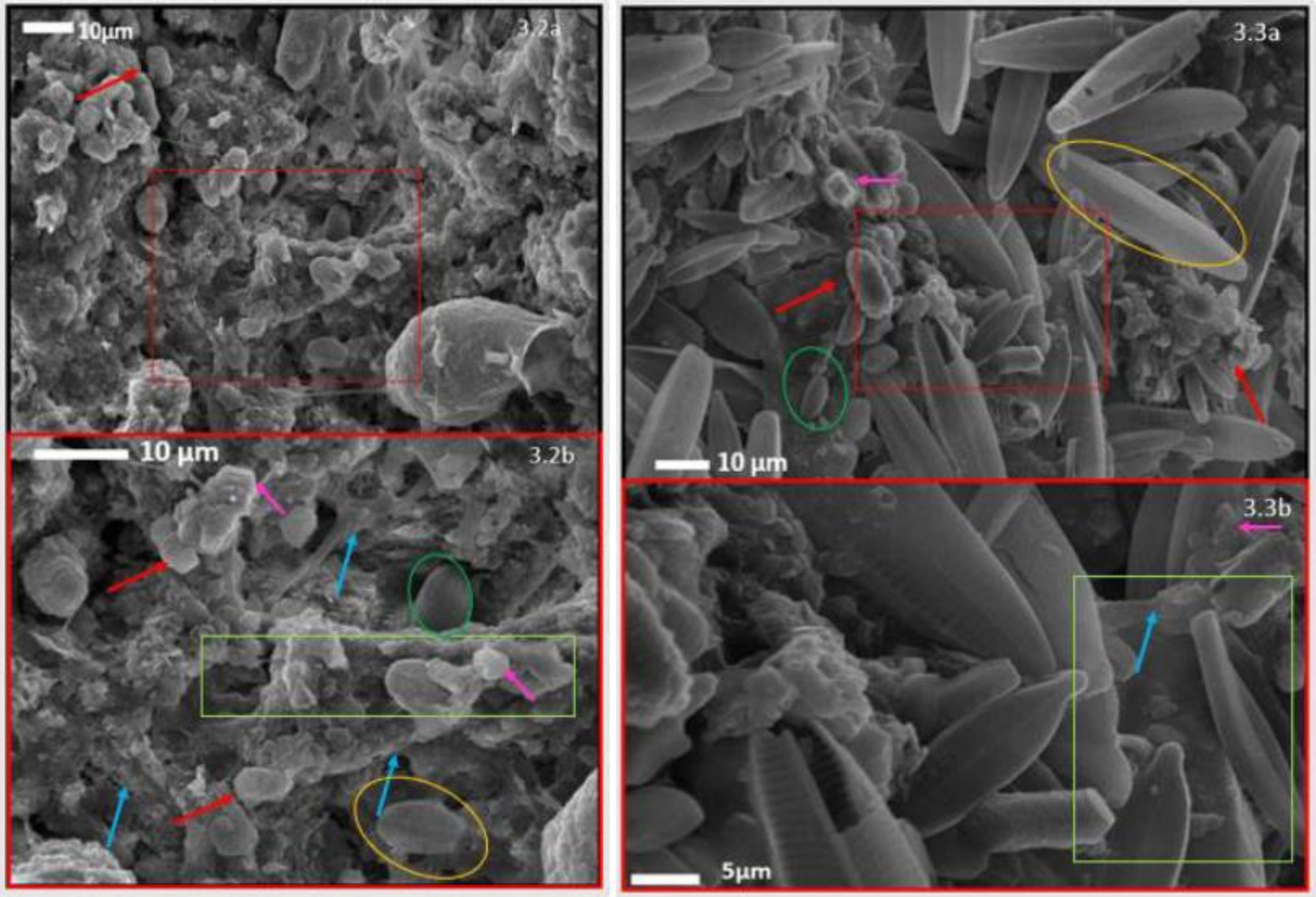


Figure 22. SEM images of site 3. Different organisms and mineral phases connected by EPS. Red box indicates higher magnification of that area in corresponding image. Yellow circle indicates diatoms (*Bacillariophyta),* green circle shows rod shaped bacteria, red arrow showing rounded and elongated morphologies, pink arrow shows smooth rhomb morphologies. Blue arrow shows microbes and minerals connected by EPS, green square shows close association of minerals with microbes in EPS

- Dene Burn – a drainage stream at a former steel production site – show an elevated pH (>9) and is saturated with different secondary phase minerals- particularly calcite
- The microbial community comprises predominantly of *Proteobacteria* (*Alpha*-, *Gamma*-, *Beta*- and *Deltaproteobacteria*), *Cyanobacteria*, *Bacillariophyta* (diatoms) and *Bacteroidetes* (*Flavobacterium)*
- The presence and composition of their biofilms appears to control local carbonate mineralisation rates and carbonate morphologies
- Bioengineering of microbial communities promoting carbonate formation can result in enhanced carbonate formation, promoting site remediation