



# OR-CKP-14-1-S, OR-CKP-15-1-S and OR-CKP-16-1-S

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## Summary

This report summarizes the properties of particles collected on contamination knowledge Si wafer mounts: OR-CKP-14-1-S,0 (CK14-1), OR-CKP-15-1-S,0 (CK15-1) and OR-CKP-16-1-S,0 (CK16-1).

CK14-1 was deployed from 4/27 to 6/17 at LM for SARA deployment/flight head test, shipped to KSC, and for s/c spin/balance, battery install, instrument inspections at the KSC PHSF.

CK15-1 was deployed from 6/17 to 7/14 at the KSC PHSF during MLI installation and OLA and OTES cleaning and inspection.

CK16-1 was deployed from 7/14 to 8/26 at the KSC PHSF during solar array install, OVIRS inspection, contamination cleaning and sampling, and encapsulation.

Scanning electron microscopy (SEM) examination of mount CK14-1 identified ~ 90 particles/particle groups ranging in size from ~ 0.5 – 50  $\mu\text{m}$  in the longest dimension. Four particle types were observed and are listed in abundance from greatest to least: Si-rich, C-rich, metallic and ‘others.’ The majority of Si-rich particles near mount edges were fractured grains associated with the collection surface; however, Si-rich particles closer to the mount center contained additional elements including C, O, Mg, Al, Ca, Cl, K, Ti, and, occasionally, more unusual elements including minor amounts of F, Ba, Ge and Zn. In the case of Ge, a group of submicron particles was composed of Si, with minor Ge and C consistent with an alloy ( $\text{Si}_{1-x-y}\text{Ge}_x\text{C}_y$ ) used in the production of semiconductors.

Approximately 20 particles were C-bearing, defined as C present as a major element as detected by energy dispersive X-ray spectroscopy (EDX). Five of these particles were interpreted as likely biogenic since they also contained major/minor N, O, Na, S, Cl, and K, with one containing major P. Here we define the major element range as <10 wt.%, minor elements as 1<10 wt.%, and trace elements as <1 wt.%.

Approximately 20 Al-bearing particles were identified with a few containing minor/trace O. Other metallic particles included those rich in Fe with minor O and/or Cr. Particles in the ‘others’ category numbered ~ 10 and included two rich in F, two with Ba

Fe and S, one with Ba, Fe, S, Zn and Cu, one likely lime (CaO), one halite (NaCl), and one with Cu (60 wt.%) and Zn (40 wt.%), consistent with brass.

The maximum permissible mass limits for key elements were not approached. Calculations for C abundance is estimated to be  $< 100 \text{ ng/cm}^2$ , within the range of the surface limit requirement.

SEM examination of the mount CK15-1 identified  $\sim 90$  particles/particle groups ranging in size from  $\sim 0.5 - 250 \mu\text{m}$  in the longest dimension. Five particle types were observed and are listed in abundance from greatest to least: Si-rich, metallic (Al-bearing), C-rich, metallic (Fe-bearing) and 'others.' Approximately one-third of the particles on the mount were Si-rich; the majority of these were fractured grains associated with the collection surface. This mount was removed post-imaging and reinserted in the FESEM prior to EDX analysis. As a consequence of this sample exchange, additional particles were deposited on the mount and are highlighted by an asterisk (\*) on the montage map and particles removed prior to analysis are designated by a circle-backslash symbol ( $\circ\backslash$ ) (note: particles deposited on the surface as a result of sample exchange were not included in surface limit requirement calculations). Approximately 30 particles/particle groups were Al-bearing with a fraction containing minor O. Approximately 13 particles were C-rich; the largest being  $\sim 200 \mu\text{m}^2$  in size. None of the C-rich particles are interpreted as biogenic. Eleven Fe-bearing particles were observed with compositions including Cr  $\pm$  Ni. Eight particles in the 'other' group include three with major Zn, two with major F, one likely  $\text{CaCO}_3$ , one with K and Cl, and one Si-bearing particle with major Ni, O, Ti, C, Al and Cl.

The maximum permissible mass limits for key elements were not approached on mount CK15-1. Calculations for C abundance are estimated to be  $< 1000 \text{ ng/cm}^2$ , within the range of the surface limit requirement.

SEM examination of the mount CK16-1 identified  $\sim 60$  particles/particle groups ranging in size from  $\sim 2 - 170 \mu\text{m}$  in the longest dimension. Five particle types were observed and are listed in abundance from greatest to least: C-rich, Si-rich, metallic (Al-bearing), 'others' and metallic (Fe-bearing). This mount was removed post-imaging and reinserted in the FESEM prior to EDX analysis. As a consequence of this sample exchange, particles were removed prior to analysis and are designated by a circle-backslash symbol ( $\circ\backslash$ ) on the montage map. Approximately one-third of the particles on the mount were C-rich with nine interpreted as biogenic based on the presence of other elements including N, O, Na, Cl, S and K. Approximately 20 Si-rich particles were identified with only two particles containing other elements. In one case, a siliceous particle contained major Al and K. Approximately 10 Al-rich particles were present with one containing Zn and O. Particles in the 'other' group include two with major Fe, Ba, S and O, one with Ca, O, F, C, Cl and Zn, one with Ti, Fe, and Zn, one with Fe, O, Ti, Cu, Zn, one with Ca and O, one with Zn and O and one likely  $\text{CaCO}_3$ . Two Fe-rich particles were present; one contained Cr and the other O.

The maximum permissible mass limits for key elements were not approached on mount CK16-1. Calculations for C abundance is estimated to be  $< 300 \text{ ng/cm}^2$ , within the range of the surface limit requirement.

## Procedures

The mounts were introduced into a SEM for particle characterization. Image mosaics were obtained for each Si wafer (OR-CKP-14-1-S,0, OR-CKP-15-1-S,0, and OR-CKP-16-1-S,0) taken at 150× with each frame acquired for 30 s. using low-angle backscatter electron (LBE) imaging to emphasize atomic weight variations. All EDX spectra were acquired for 60 s. at 15 keV.

With previous mounts and mount OR-CKP-14-1-S,0, all imaging and EDX analysis were performed in successive fashion without removing the mount from the FESEM. In the case of mounts OR-CKP-15-1-S,0 and OR-CKP-16-1-S,0 however they were removed from the FESEM prior to EDX analysis due to time constraints. In these cases, a few particles were either deposited or removed from the mounts. Particles deposited are highlighted by an asterisk (\*) and particles removed are designated by a circle-backslash symbol (⊘) on the montage maps. Particles deposited on the surface as a result of sample exchange were not included in surface limit requirement calculations. The overall time taken for each mount exchange was < 120 s./mount.

## Observations

Approximately 90 particles/particle groups were observed on mount OR-CKP-14-1-S,0. These were grouped into four particle types, listed from the greatest to least in abundance: Si-rich, C-rich, metallic and ‘others.’ The majority of particles are distributed evenly over the collection surface. The SEM image mosaic, shown in Figure 1, displays particle locations, composition type, and EDX spectra names (designated as ‘Spt 14(1-37)’). Si-rich particles were the most abundant and comprised approximately one-third of the total particle count. Of these, ~ 11 were fractured particles emanating from the collection surface. The remaining Si-rich particles contained other elements including O, F (one), C, Na, Mg, Al, S, Cl, K (one), Ca, Ti, Fe, Zn (one) and Ge (one group). Figure 2 shows an LBE image and a representative EDX spectrum for a group of sub-μm particles containing Ge. Each was composed primarily of Si, with minor/trace Ge and C consistent with an alloy ( $\text{Si}_{1-x-y}\text{Ge}_x\text{C}_y$ ) used in the production of semiconductors. Also shown in Figure 2 is a C-bearing particle with associated KCl crystallites. This particle was interpreted to be siliceous since Si is also detected in the EDX spectrum of a centrally-located KCl crystal (e.g., EDX analysis spot not overlapping with the Si-mount). Figure 3 shows another example of a siliceous particle with major K and a C-rich particle with major K and P, interpreted as possibly biogenic. A total of ~ 20 particles were C-bearing with five interpreted as likely biogenic as they also contained major/minor elements including N, O, Na, P, S, Cl, and K.

Approximately 20 Al-bearing particles were identified with a few containing minor/trace O. Other metallic particles included those rich in Fe with minor O and/or Cr. Particles in the ‘others’ category numbered 10; these included two particles with major F, two with Ba Fe and S, one with Ba, Fe, S, Zn and Cu, one likely CaO (lime), one halite (NaCl), and one with Cu (60 wt. %) and Zn (40 wt. %), consistent with brass. Figure 4 shows LBE images and EDX spectra for a halite crystal and a siliceous particle displaying a tube-shaped external morphology composed of Si and O, likely  $\text{SiO}_2$ . This tube-particle likely originated from a glassy optical fiber.

The particle population on OR-CKP-15-1-S,0 was comprised of ~ 90 particles/particle groups ranging in size from ~0.5 – 250 µm in the longest dimension. Five particle types were observed and are listed in abundance from greatest to least: Si-rich, metallic (Al-bearing), C-rich, metallic (Fe-bearing) and others. The SEM image mosaic, shown in Figure 5, displays particle locations, composition type, and EDX spectra names (designated as ‘Spt 15(1–30)’). Approximately one-third of the particles on the mount were Si-rich; the majority of these were fractured grains associated with the collection surface. This mount was removed post-imaging and reinserted in the FESEM prior to EDX analysis. During this exchange, particles were deposited on or removed from the mount. Particles deposited are highlighted by an asterisk (\*) on the montage map and particles removed are designated by a circle-backslash symbol (⌘) (Figure 5). Approximately 30 particles/particle groups were Al-bearing with a fraction containing minor O (see Figure 6). Approximately 13 particles were C-rich; the largest being ~ 200 µm<sup>2</sup> in size (Figure 7). None of the C-rich particles were interpreted as biogenic based on composition. Eleven Fe-bearing particles were composed of Fe, Cr ± Ni (Figure 7). Eight particles in the ‘other’ group include three with major Zn, two with major F (Figure 8), one likely calcite (CaCO<sub>3</sub>), one with K and Cl, and one Si-bearing particle with major C, Ni, O, Ti, C, Al and Cl (Spt 15(25)), although this particle was added to the mount post-imaging. One fractured Si-particle had an intriguing external morphology (Figure 8), resembling an insignia from a famous science fiction entertainment show.

The particle population on OR-CKP-16-1-S,0 was comprised of ~ 60 particles/particle groups ranging in size from ~ 2 – 170 µm in the longest dimension. Five particle types were observed and are listed in abundance from greatest to least: C-rich, Si-rich, metallic (Al-bearing), others and metallic (Fe-bearing). The SEM image mosaic, shown in Figure 9, displays particle locations, composition type, and EDX spectra names (designated as ‘Spt 16(1–31)’). This mount was removed post-imaging and reinserted in the FESEM prior to EDX analysis. Unfortunately during this exchange, particles were removed from the mount prior to analysis and are designated by a circle-backslash symbol (⌘) (Figure 9).

Approximately one-third of the particles on the mount were C-rich with nine interpreted as biogenic based on the presence of other elements including N, O, Na, Cl, S and K (Figures 10, 11). Approximately 20 Si-rich particles were identified with only two particles containing other elements; the majority of these were comprised only of Si and so were interpreted as fractured grains associated with the collection surface. In one case, a siliceous particle contained major Al and K. Approximately 10 Al-rich particles were present with one containing minor Zn and O. Particles in the ‘other’ group include two with major Fe, Ba, S and O (Figure 12), one with Ti, Fe, and Zn (Figure 13), one with Ca, O, F, C, Cl and Zn (Figure 13), one with Fe, O, Ti, Cu, Zn, one with Ca and O, one with Zn and O and one likely CaCO<sub>3</sub>. Two Fe-rich particles were present; one contained Cr and the other O.

## Discussion

Key diagnostic elements: The Contamination Knowledge effort is monitoring the abundances of the following diagnostic elements in collected particles: C, K, Ni, Sn, Nd, and Pb. Below is a summary for each of these elements:

***OR-CKP-14-1-S,0***

- C: ~ 20 C-bearing particles were present on the mount. Five particles were interpreted to be consistent with a biogenic origin. The maximum permissible mass limits for key elements were not approached. Calculations (see below) for C abundance is within the range of the surface limit requirement.
- K: K was observed as a major element in 3 Si-rich particles. It was also present as a minor element in ~ 5 Si-rich particles and the C-rich biogenic particles interpreted as biogenic.
- Ni: Not observed
- Sn: Not observed
- Nd: Not observed
- Pb: Not observed

***OR-CKP-15-1-S,0***

- C: ~13 particles/groups, from ~1 – 200  $\mu\text{m}$  in the longest dimension, contained major amounts of C. None of these particles were interpreted as biogenic. Calculations (see below) for C abundance is within the range of the surface limit requirement.
- K: K was observed as a major/minor element in 3 particles.
- Ni: 12 particles contained major/minor Ni.
- Sn: Not observed
- Nd: Not observed
- Pb: Not observed

***OR-CKP-16-1-S,0***

- C: ~ 20 particles/particle groups, from ~ 2 – 170  $\mu\text{m}$  in the longest dimension. Nine are interpreted as biogenic based on the presence of other elements including N, O, Na, Cl, S and/or K. Calculations (see below) for C abundance is within the range of the surface limit requirement.

K: K was observed as a major/minor element in ~ 5 of the biogenic particles and in two siliceous particles. Calculations (see below) for K abundance is within the range of the surface limit requirement.

Ni: Not observed

Sn: Not observed

Nd: Not observed

Pb: Not observed

## Calculations

*Estimate of C on OR-CKP-14-1-S,0*

Assumptions: Composed of 100% C

Based on 11 of the largest C-bearing particles

Average size 27  $\mu\text{m}$   $\cdot$  23  $\mu\text{m}$  with an estimated depth of 12  $\mu\text{m}$

*Model using cube:*

C density  $\sim 1.5 \text{ g}\cdot\text{cm}^{-3}$  (ave density of polymer/graphite)

Mount surface area is estimated to be 1 cm  $\cdot$  1.5 cm = 1.5 cm<sup>2</sup>

Volume/particle	= 7452 $\mu\text{m}^3$
Total particles	= 11
Total volume C-rich particles:	= 7452 $\mu\text{m}^3 \cdot 11 = 81972 \mu\text{m}^3$ = $8.197 \cdot 10^{-8} \text{ cm}^3$
Total grams C	= $8.197 \cdot 10^{-8} \text{ cm}^3 \cdot 1.5 \text{ g}\cdot\text{cm}^{-3}$ = $1.23 \cdot 10^{-7} \text{ g}$ or 123 ng
<i>Total C<sub>Particles</sub></i>	= 123 ng / 1.5 cm <sup>2</sup> = 82 ng/cm <sup>2</sup>

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*Estimate of C on OR-CKP-15-1-S,0*

Assumptions: Composed of 100% C

Based on the single, largest C-bearing particle on the mount

Size 200  $\mu\text{m}$   $\cdot$  220  $\mu\text{m}$  with an estimated depth of 20  $\mu\text{m}$

*Model using cube:*

C density  $\sim 1.5 \text{ g}\cdot\text{cm}^{-3}$  (ave density of polymer/graphite)

Mount surface area is estimated to be 1 cm  $\cdot$  1.5 cm = 1.5 cm<sup>2</sup>

Volume/particle	= $8.80 \cdot 10^5 \mu\text{m}^3$
Total particles	= 1
Total volume C-rich particles:	= $8.80 \cdot 10^5 \mu\text{m}^3$ = $8.80 \cdot 10^{-7} \text{ cm}^3$
Total grams C	= $8.80 \cdot 10^{-7} \text{ cm}^3 \cdot 1.5 \text{ g}\cdot\text{cm}^{-3}$ = $1.32 \cdot 10^{-6} \text{ g}$ or 1320 ng
<i>Total C<sub>Particles</sub></i>	= 1320 ng / 1.5 cm <sup>2</sup> = 880 ng/cm <sup>2</sup>

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*Estimate of C on OR-CKP-16-1-S,0*

Assumptions: Composed of 100% C  
Based on the single largest, C-bearing particle on the mount  
Size 170  $\mu\text{m}$  · 80  $\mu\text{m}$  with an estimated depth of 20  $\mu\text{m}$

*Model using cube:*

C density  $\sim 1.5 \text{ g}\cdot\text{cm}^{-3}$  (ave density of polymer/graphite)  
Mount surface area is estimated to be 1 cm · 1.5 cm = 1.5  $\text{cm}^2$

Volume/particle	= $2.72 \cdot 10^5 \mu\text{m}^3$
Total particles	= 1
Total volume C-rich particles:	= $2.72 \cdot 10^5 \mu\text{m}^3$ = $2.72 \cdot 10^{-7} \text{cm}^3$
Total grams C	= $2.72 \cdot 10^{-7} \text{cm}^3 \cdot 1.5 \text{g}\cdot\text{cm}^{-3}$ = $4.08 \cdot 10^{-7} \text{g}$ or 408 ng
<i>Total C<sub>Particles</sub></i>	= 408 ng / 1.5 $\text{cm}^2$ = 272 $\text{ng}/\text{cm}^2$

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*Estimate of K on OR-CKP-16-1-S,0*

Assumptions: Composed of 10% K  
Based on 5 biogenic particles with minor K  
Average size 44  $\mu\text{m}$  · 35  $\mu\text{m}$  with an estimated depth of 20  $\mu\text{m}$

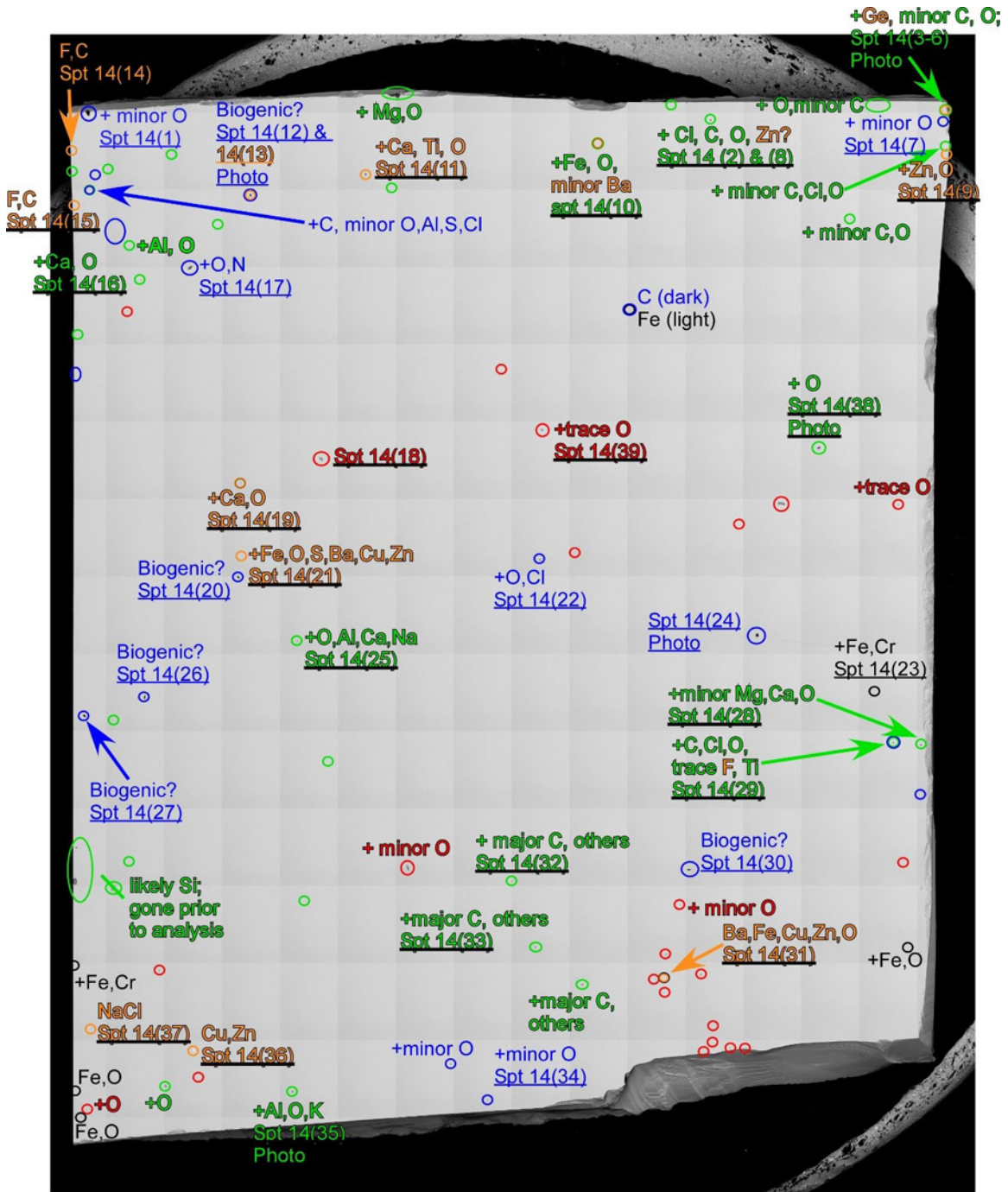
*Model using cube:*

Ave density of C-rich matter (e.g., paraffin wax)  $\sim 1.1 \text{ g}\cdot\text{cm}^{-3}$   
Mount surface area is estimated to be 1 cm · 1.5 cm = 1.5  $\text{cm}^2$

Volume/particle	= $3.08 \cdot 10^4 \mu\text{m}^3$
Total particles	= 5
Total volume particles:	= $1.54 \cdot 10^5 \mu\text{m}^3$ = $1.54 \cdot 10^{-7} \text{cm}^3$
Total particle grams	= $1.54 \cdot 10^{-7} \text{cm}^3 \cdot 1.1 \text{g}\cdot\text{cm}^{-3}$ = $1.70 \cdot 10^{-7} \text{g}$
Total grams K	= $1.70 \cdot 10^{-7} \text{g} \cdot 0.10$ = $1.70 \cdot 10^{-8} \text{g}$ or 17 ng
<i>Total K<sub>Particles</sub></i>	= 17 ng / 1.5 $\text{cm}^2$ = 11 $\text{ng}/\text{cm}^2$

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Figure 1. OR-CKP-14-1-S, SEM montage, particle map. Spectra names are underlined.



- Fe-bearing (oxide and metal)
- C-bearing
- Si-bearing
- Al-bearing
- Other

1 mm

Figure 2. Morphology and composition of particles from Mount OR-CKP-14-1-S ,0. Upper Views: SEM LABE image and representative EDX spectrum (14(3)) of a single particle in the group composed of a Si-Ge-C, likely an alloy used in the production of semiconductors. Lower Views: SEM LABE image of a C-bearing particle (dark) with associated crystallites (light). EDX spectra show the matrix is composed of C, N, O, Na, Si, S, Cl, and K (Spt 14(12)) while the euhedral crystallites are composed of KCl (Spt 14(13)).

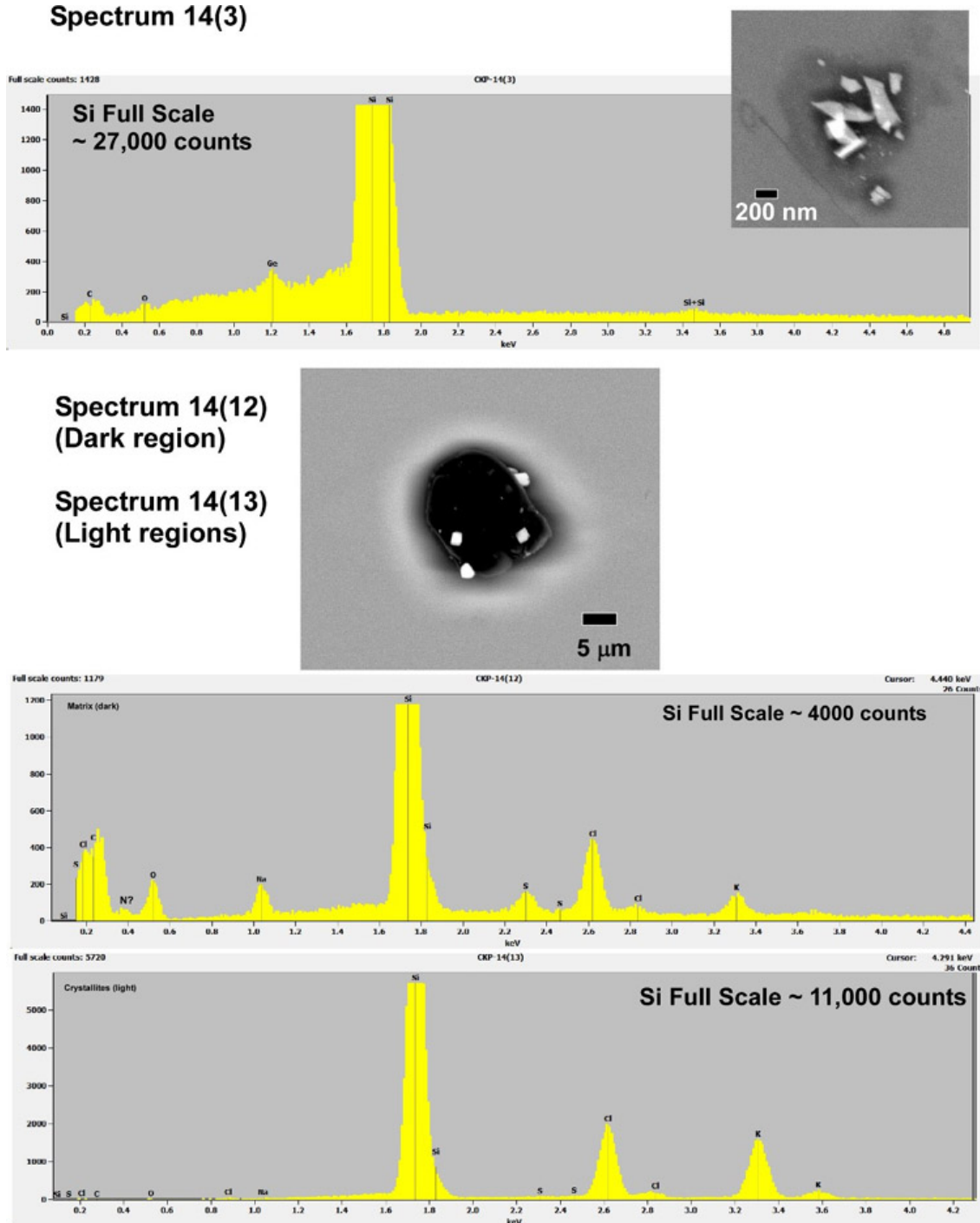
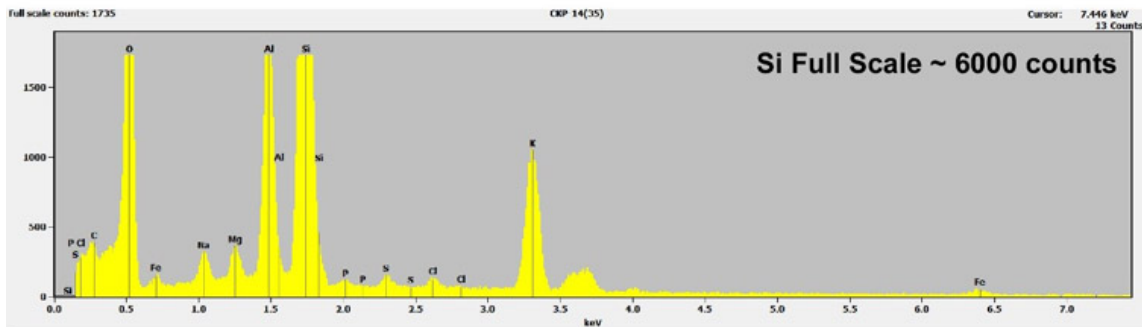
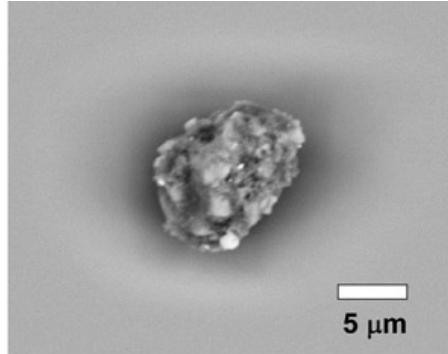


Figure 3. Morphology and composition of particles from Mount OR-CKP-14-1-S ,0. Upper Views: SEM LABE image and corresponding EDX spectrum (14(35)) of a mottled siliceous particle rich in K. Lower Views: SEM LABE image and corresponding EDX spectrum (14(24)) of a C-rich particle which also contains major P & K with minor S & Cl (Si likely from mount). The composition is unusual in that it contains minor/trace O.

### Spectra 14(35)



### Spectra 14(24)

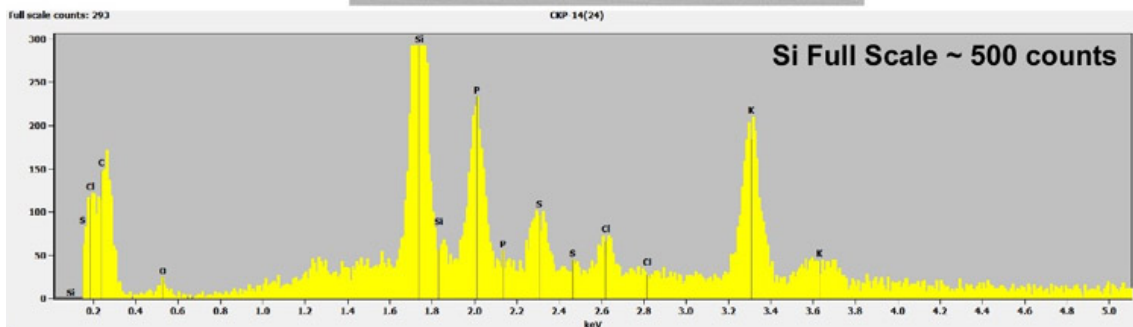
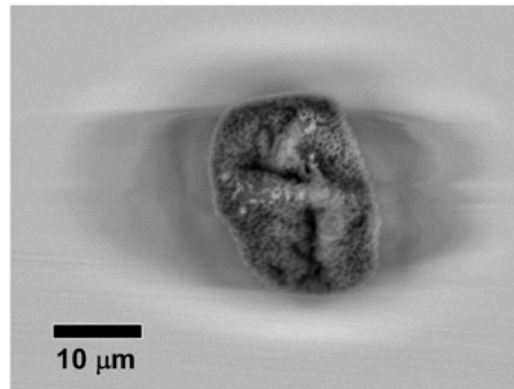
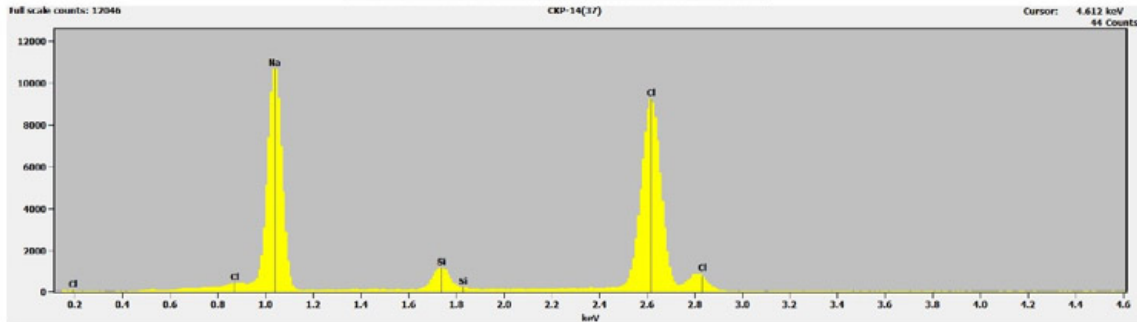
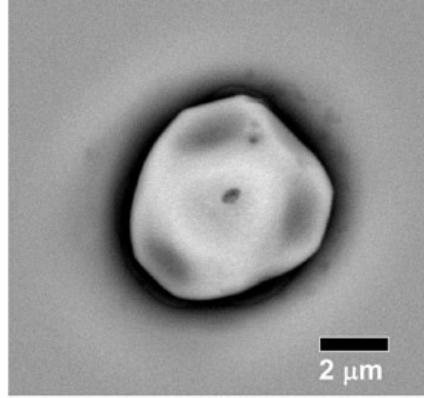


Figure 4. Morphology and composition of particles from Mount OR-CKP-14-1-S ,0. Upper Views: SEM LABE image and corresponding EDX spectrum (14(37)) of a halite (NaCl) particle. Lower Views: SEM LABE image and corresponding EDX spectrum (14(38)) of a tube-shaped particle,  $\sim 28 \mu\text{m} \cdot 18 \mu\text{m}$ , rich in Si and O. This particle likely emanated from an optical silica ( $\text{SiO}_2$ ) glass fiber.

**Spectrum 14(37)**



**Spectrum 14(38)**

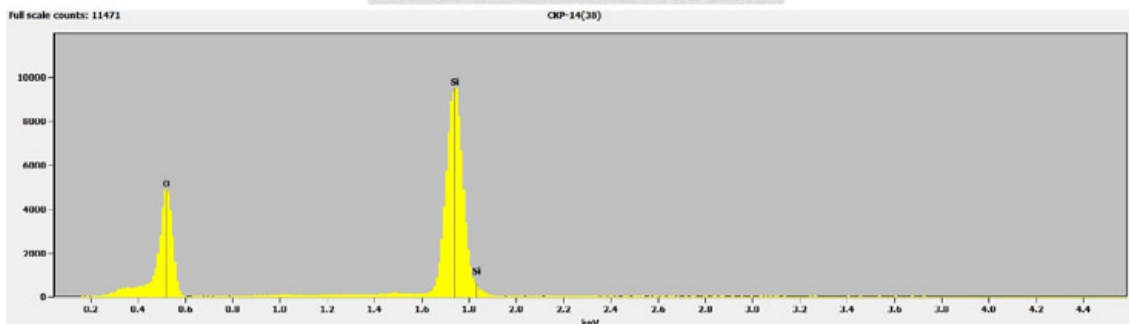
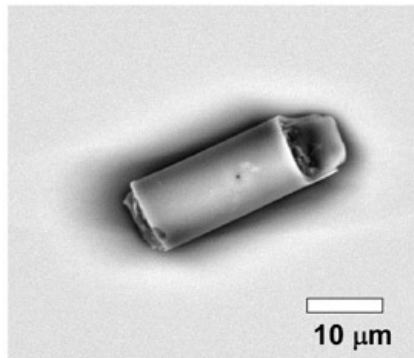
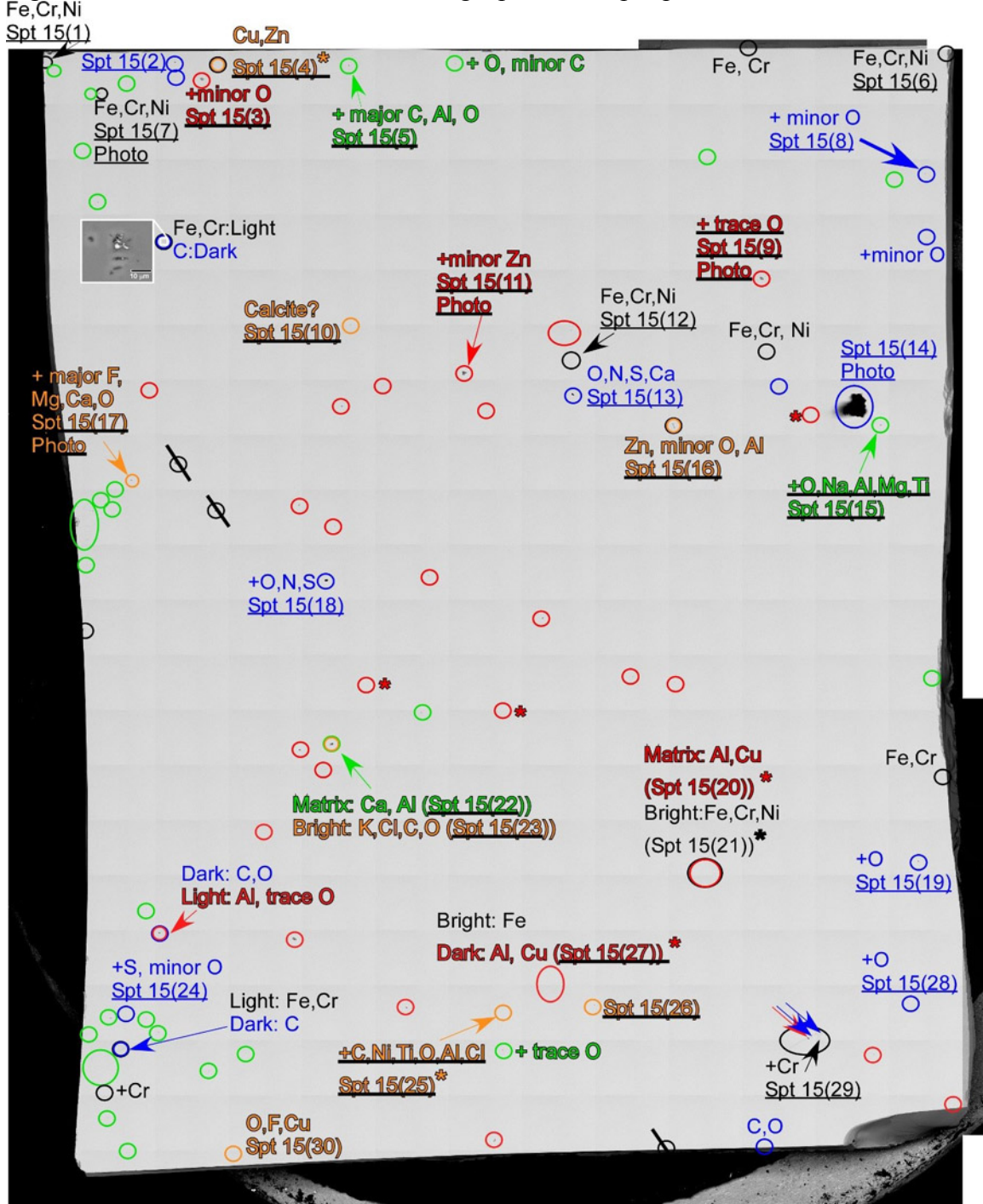


Figure 5. OR-CKP-15-1-S, 0 SEM montage, particle map. Spectra names are underlined.



- Fe-bearing (oxide and metal)
- C-bearing
- Si-bearing
- Al-bearing
- Other

\* Deposited after mapping  
 ⊘ Removed after mapping

Figure 6. Morphology and composition of particles from Mount OR-CKP-15-1-S ,0. Upper Views: SEM LABE image and corresponding EDX spectrum (15(9)) of a metallic Al particle, ~ 30  $\mu\text{m}$  · 35  $\mu\text{m}$ , with trace O; Si from mount. Lower Views: SEM LABE image and corresponding EDX spectrum (15(11)) of a ~40  $\mu\text{m}$  · 20  $\mu\text{m}$  Al-rich particle with Zn & O.

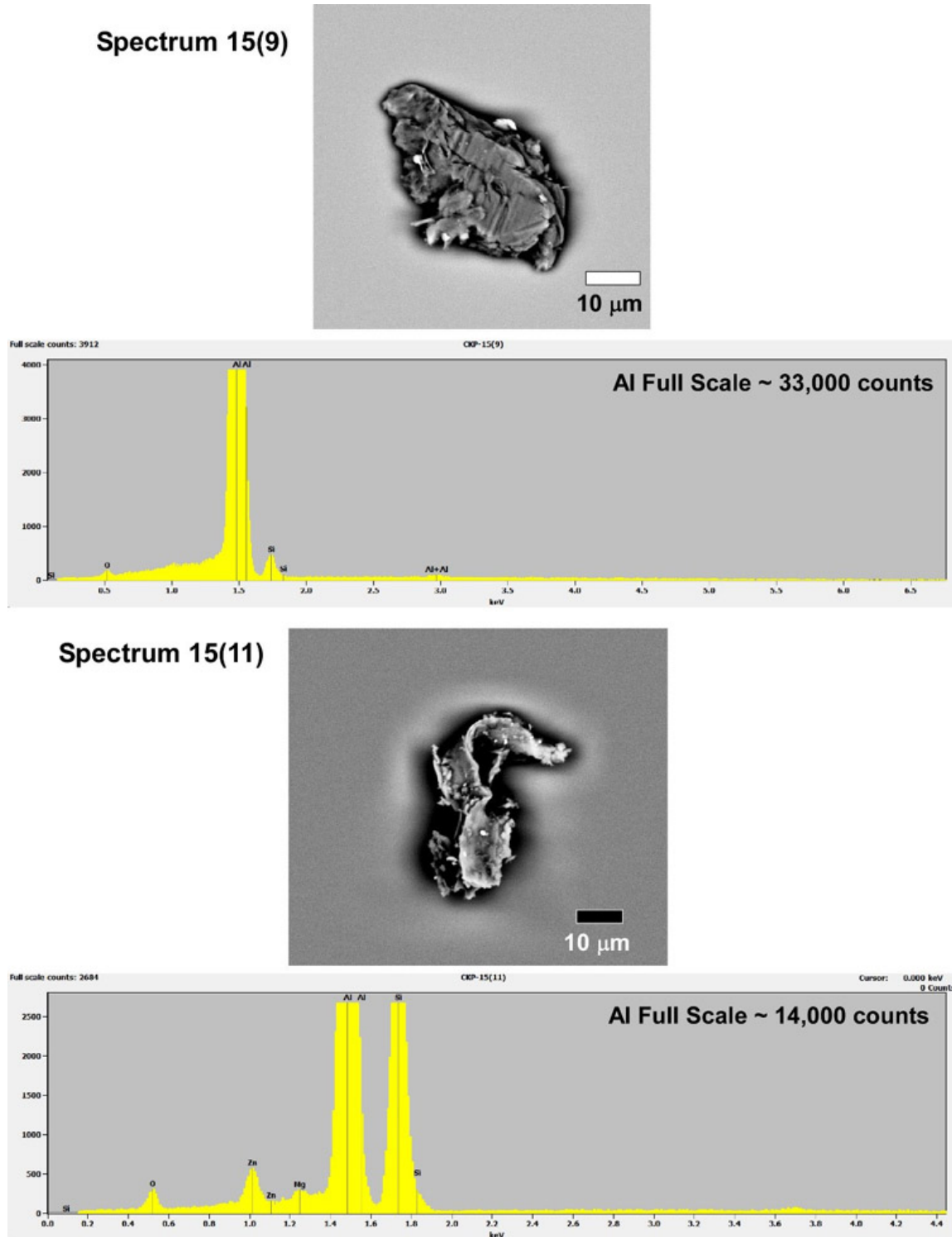
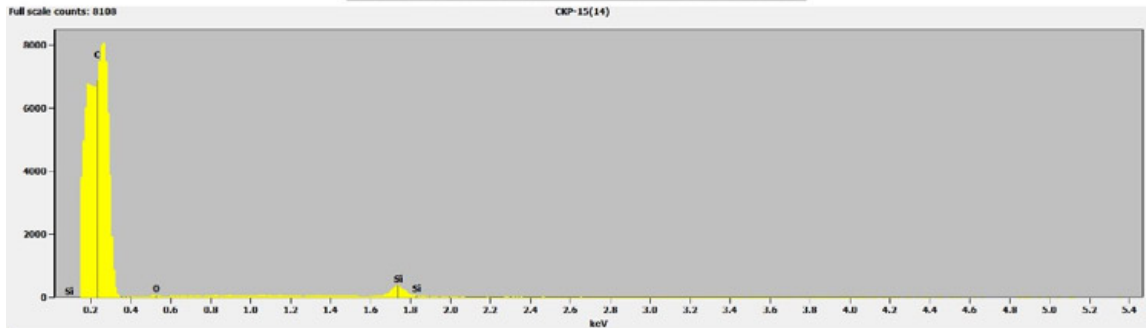
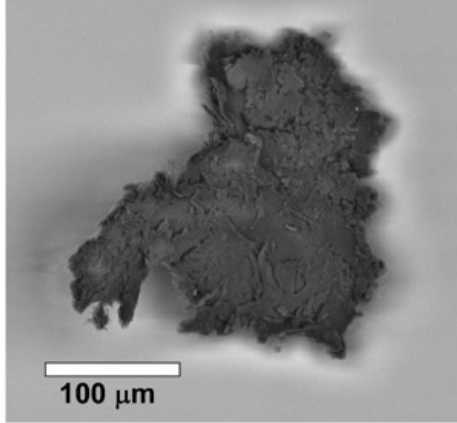


Figure 7. Morphology and composition of particles from Mount OR-CKP-15-1-S ,0. Upper Views: SEM LABE image and corresponding EDX spectrum (15(14)) of the largest C-rich particle on the mount surface. Approximate dimensions for this particle are 220  $\mu\text{m}$  · 200  $\mu\text{m}$  · 20  $\mu\text{m}$ . Calculations for total C are based solely on this particle. Lower Views: SEM LABE image and corresponding EDX spectrum (15(7)) of a Fe-Cr-Ni particle.

**Spectrum 15(14)**



**Spectrum 15(7)**

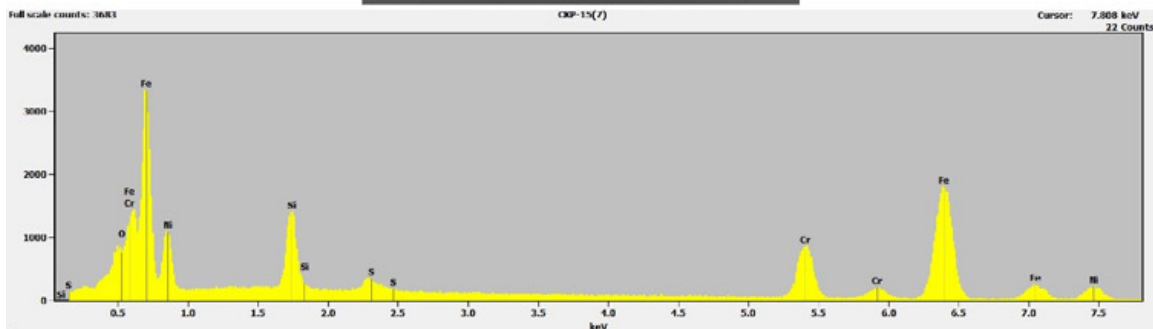
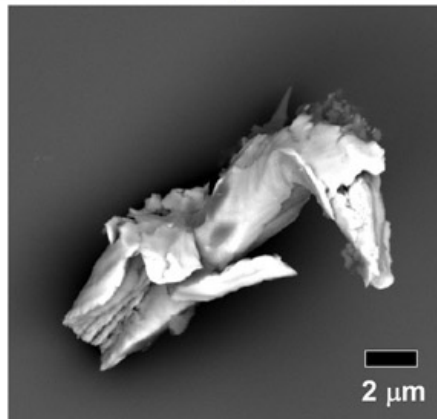


Figure 8. Morphology and composition of particles from Mount OR-CKP-15-1-S ,0. Upper Views: SEM LABE image and corresponding EDX spectrum (15(17)) of an  $\sim 10 \mu\text{m} \cdot 9 \mu\text{m}$  siliceous particle with major F & O. Lower Views: SEM LABE image of a silica particle that bears a resemblance to the Star Trek 'Starfleet Insignia Delta Shield' (star added for emphasis).

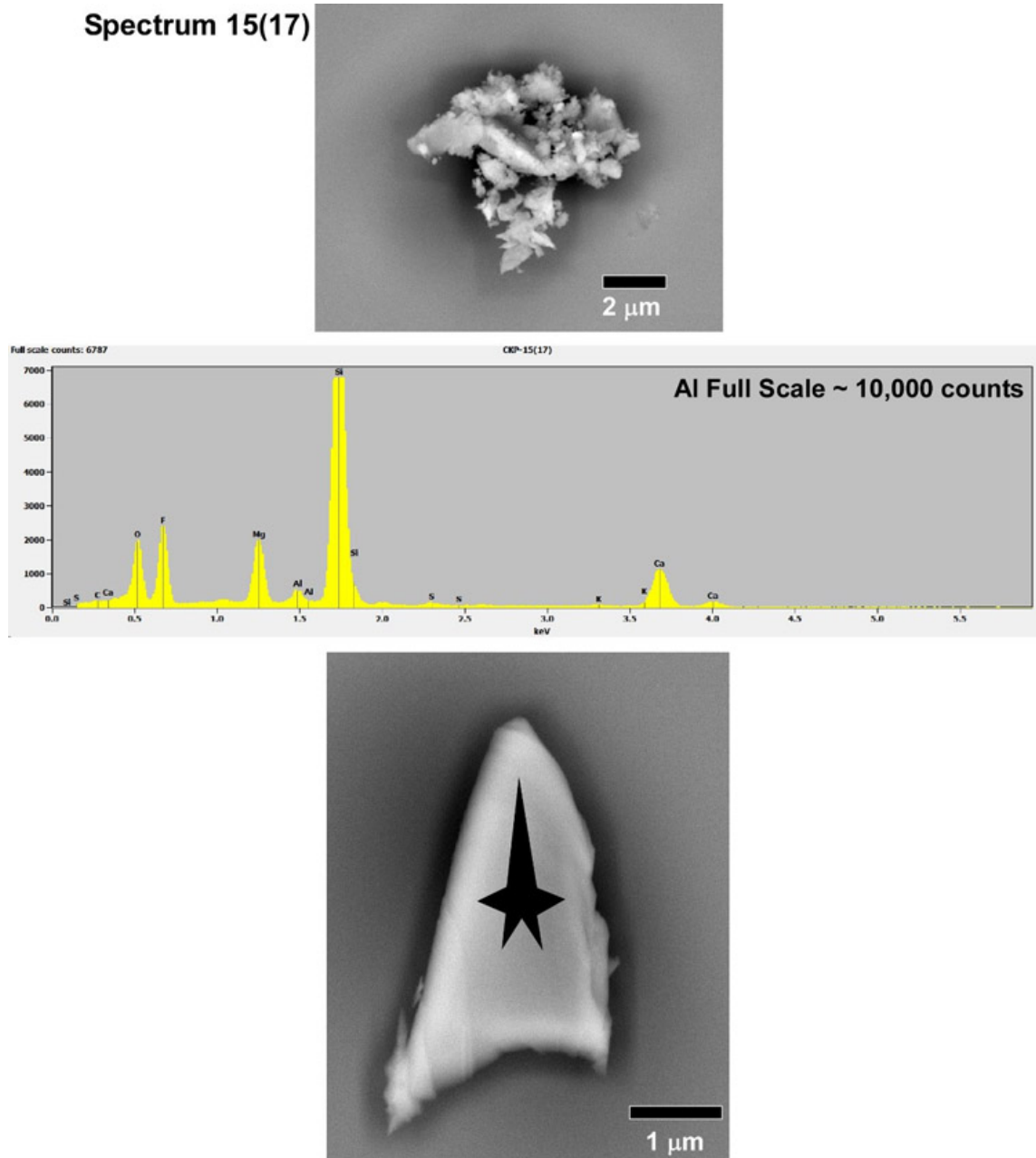
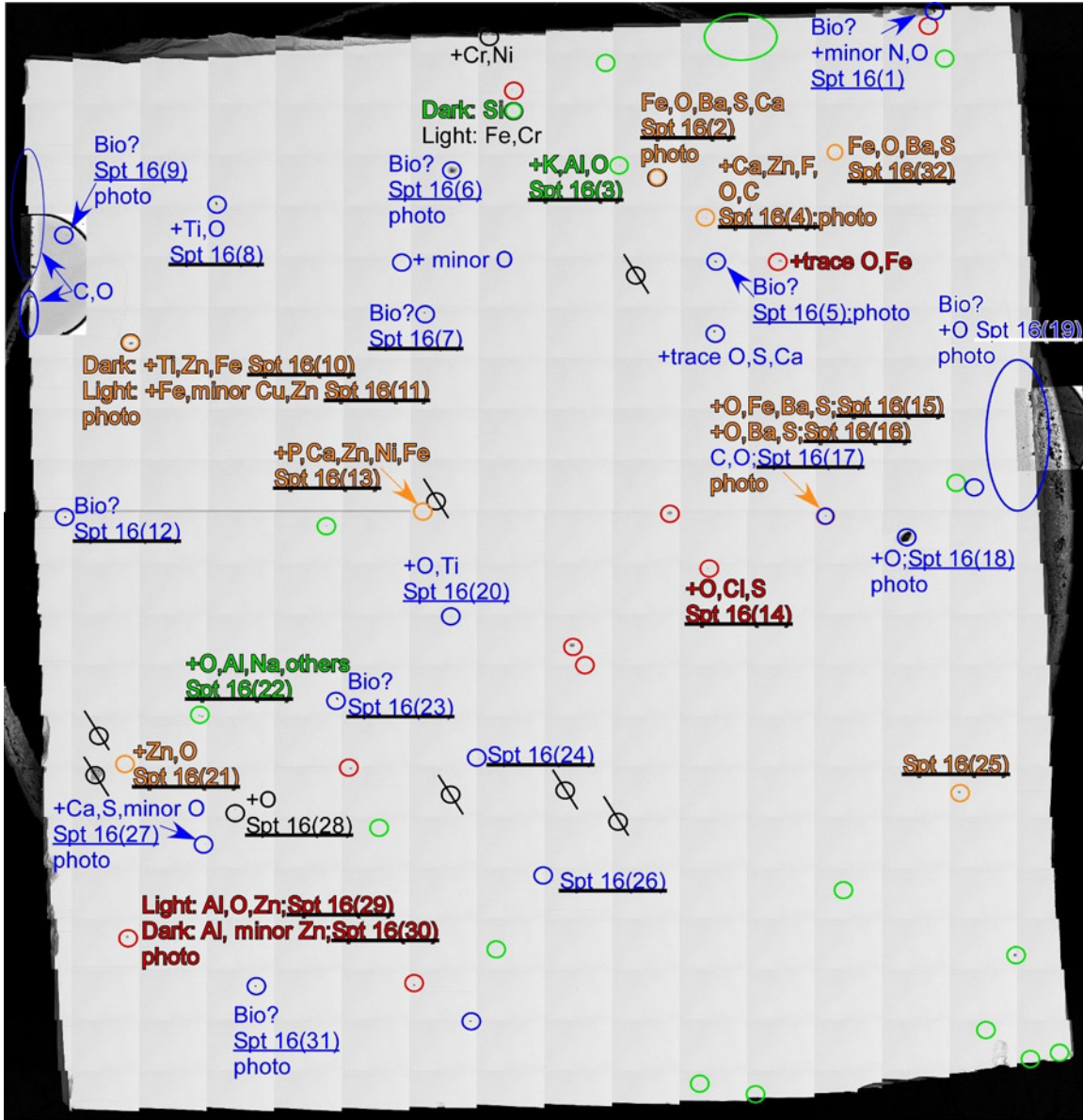


Figure 9. OR-CKP-16-1-S ,0 SEM montage, particle map. Spectra names are underlined.



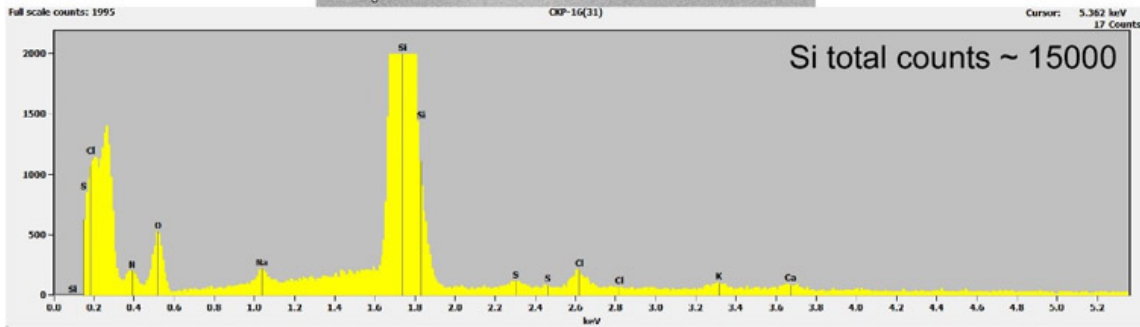
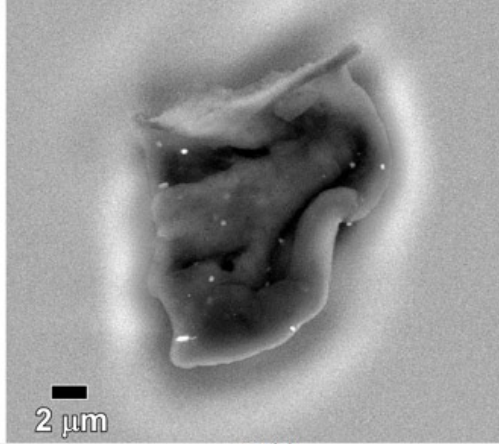
- Fe-bearing (oxide and metal)
- C-bearing
- Si-bearing
- Al-bearing
- Other

1 mm

⊗ Removed after mapping

Figure 10. Morphology and composition of particles from Mount OR-CKP-16-1-S ,0. Upper Views: SEM LABE image and corresponding EDX spectrum (16(31)) of a C-rich particle with N, O, Na, S, Cl, K and Ca. Lower Views: SEM LABE image and corresponding EDX spectrum (16(6)) of a carbonaceous particle, ~ 20 μm · 50 μm with N, O, Na, K, Cl and K. Both particles likely have a biogenic origin.

**Spt 16(31)**



**Spt 16(6)**

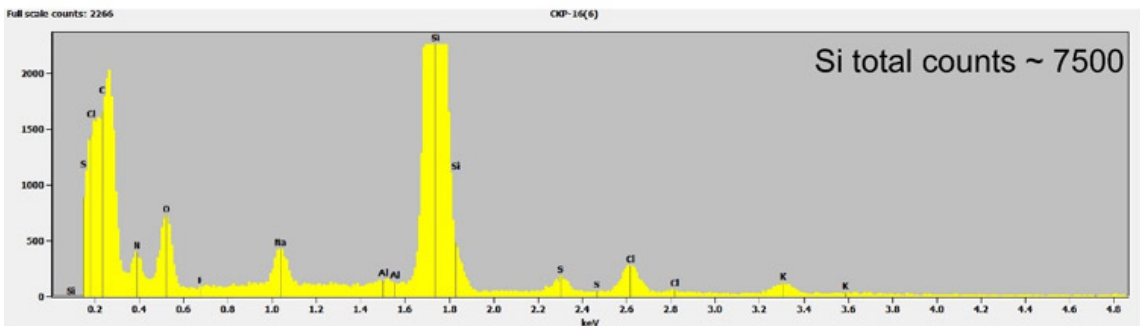
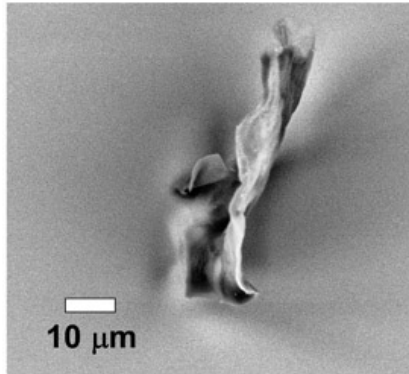


Figure 11. Morphology and composition of particles from Mount OR-CKP-16-1-S ,0. Upper Views: SEM LABE images and corresponding EDX spectrum (16(9)) of a carbonaceous particle with N, O, Na, S, Cl, K and Ca, indicating it is likely biogenic. Lower Views: SEM LABE image and corresponding EDX spectrum (16(18)) of a carbonaceous particle, ~ 170  $\mu\text{m}$  · 80  $\mu\text{m}$  with O and Si, indicating it is inconsistent with a biotic source.

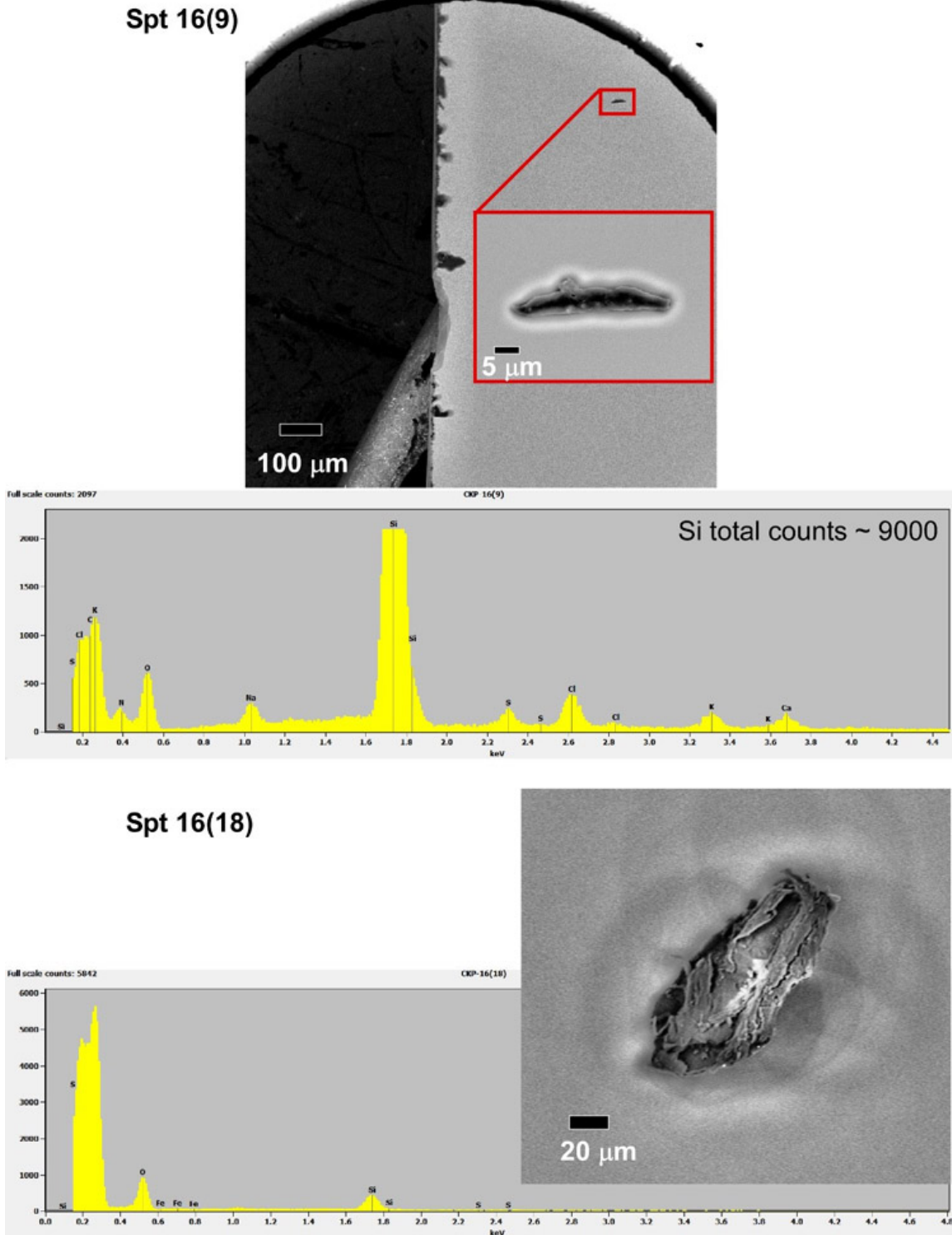


Figure 12. Morphology and composition of particles from Mount OR-CKP-16-1-S ,0. SEM LABE image (top) and corresponding EDX spectra (bottom) of a particle designated as type ‘other.’ This mottled particle is chemically heterogeneous as shown by EDX spot analysis. Spt 16(15) shows the presence of Fe, O, S and Ba; Spt 16(16) shows a decrease in Fe and an increase in both S and Ba compared to Spt 16(15). Spt 16(17) shows a dramatic increase in C with lower Fe and Ba compared with both Spt 16(15) and Spt 16(16).

Spt 16(15)  
 Spt 16(16)  
 Spt 16(17)

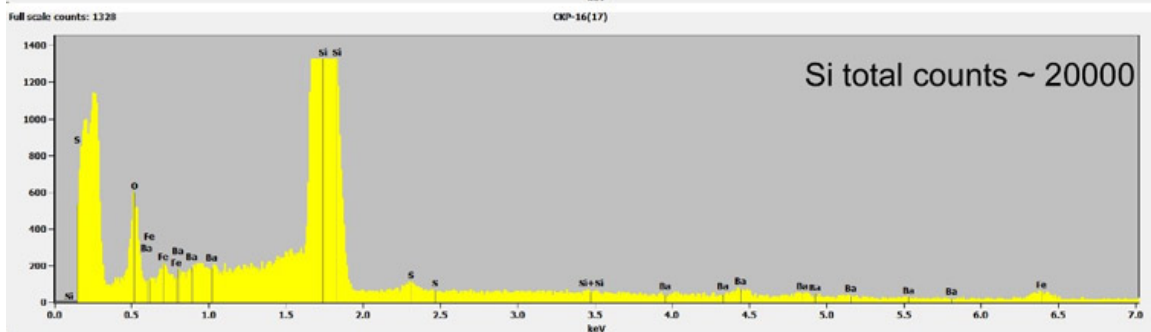
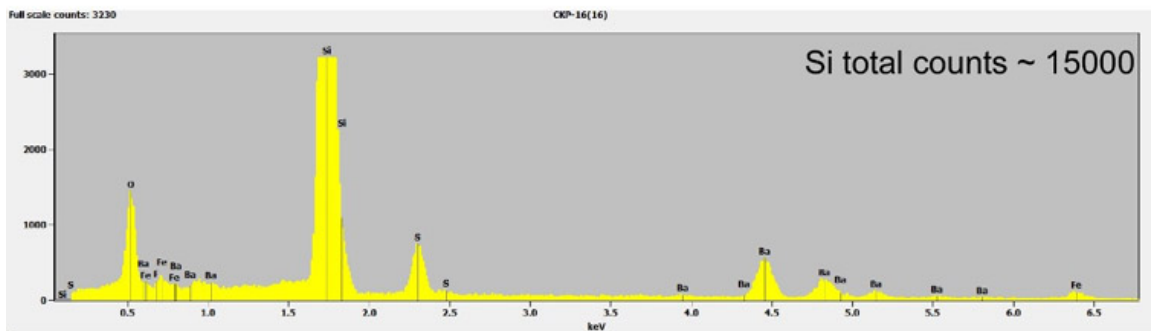
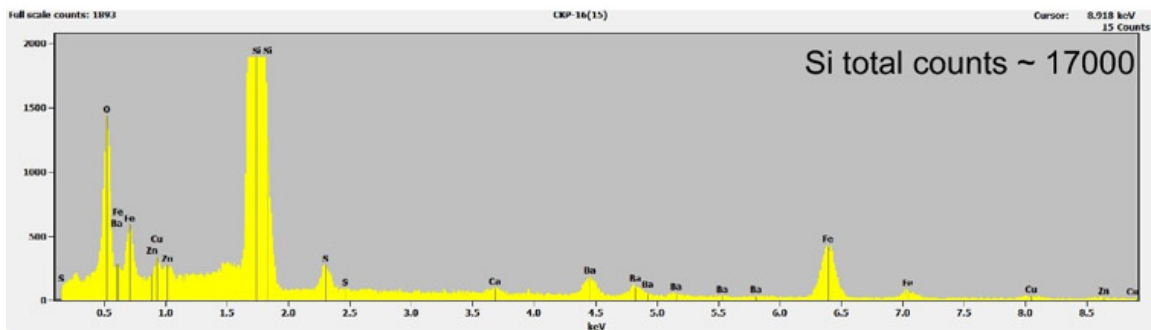
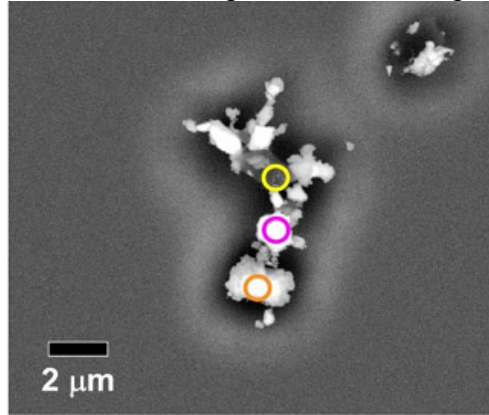
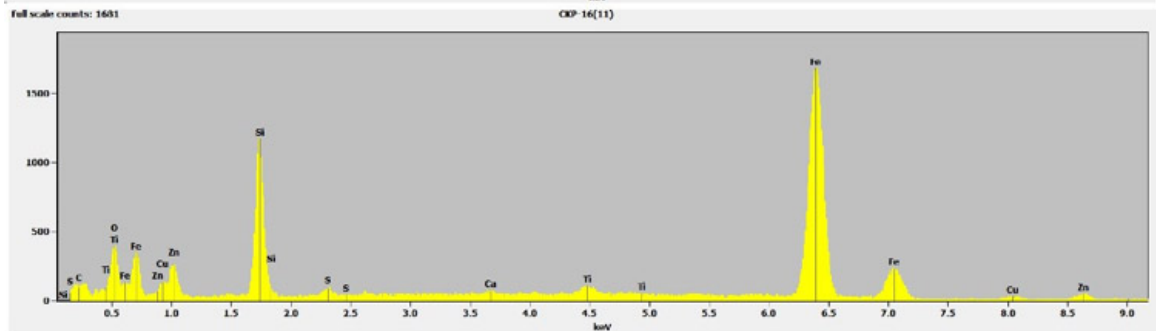
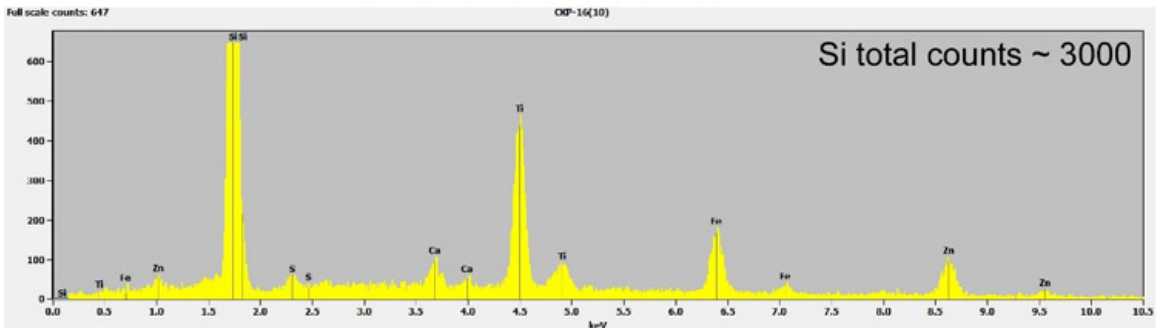
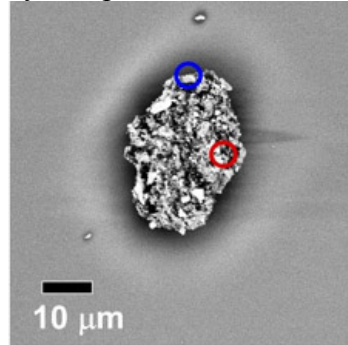


Figure 13. Morphology and composition of particles from Mount OR-CKP-16-1-S ,0. Upper Views: SEM LABE image and corresponding EDX spectra of a particle designated as type 'other.' This particle is chemically heterogeneous as shown by EDX spot analysis. Spt 16(10) shows darker regions are composed of major Ti, Fe and Zn in contrast to lighter regions (i.e., Spt 16(11)) with higher Fe and minor/trace Ti and Zn. Lower Views: A particle in the 'other' category composed of Ca and Zn with O, F and Cl (Spt 16(4)).

**Spt 16(10)**  
**Spt 16(11)**



**Spt 16(4)**

