Supporting information: A. sampling sites and bulk chemical and mineralogical composition of the soil samples Figs. S1-S6, Table S1; B. SEM-BSE images of MSC and MOM (Figs. S7-S10); C. TEM, SAED and STEM-EDS images of all identified phases (S11-S28); D. Table S29, Point of zero charges for selected phases identified in this study.
Supplementary data A

Sampling sites Figure S1 and S2

Bulk mineralogical composition Figures S3-S6

Bulk composition Table S1
Figure S1, Sampling site North, May 2016
Figure S2, Sampling site South East, May 2016
North side, sample 2, Figure S4
South-East side, sample 3, Figure S5
South-East side, sample 4, Figure S6

Counts per seconds

Degree Two-Theta
### Table S1. Bulk chemical analysis

<table>
<thead>
<tr>
<th>Sample Description</th>
<th>Analyte: Al (ppm)</th>
<th>As (ppm)</th>
<th>B (ppm)</th>
<th>Ba (ppm)</th>
<th>Bi (ppm)</th>
<th>Ca (ppm)</th>
<th>Cd (ppm)</th>
<th>Ce (ppm)</th>
<th>Co (ppm)</th>
<th>Cs (ppm)</th>
<th>Cu (ppm)</th>
<th>Fe (%)</th>
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</thead>
<tbody>
<tr>
<td>North site 1</td>
<td>5.78</td>
<td>843</td>
<td>28</td>
<td>1050</td>
<td>35</td>
<td>1.27</td>
<td>28.5</td>
<td>61</td>
<td>19.4</td>
<td>2.7</td>
<td>566</td>
<td>3.66</td>
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<tr>
<td>North site 2</td>
<td>6.11</td>
<td>820</td>
<td>24</td>
<td>1130</td>
<td>32.7</td>
<td>1.36</td>
<td>35.5</td>
<td>53</td>
<td>10.3</td>
<td>3.2</td>
<td>610</td>
<td>3.75</td>
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<tr>
<td>South East site 3</td>
<td>6.6</td>
<td>440</td>
<td>21</td>
<td>950</td>
<td>17.5</td>
<td>1.51</td>
<td>24.2</td>
<td>61</td>
<td>10.2</td>
<td>3.2</td>
<td>450</td>
<td>3.6</td>
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<td>South East site 4</td>
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<td>470</td>
<td>23</td>
<td>1060</td>
<td>20.2</td>
<td>1.42</td>
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<td>76</td>
<td>23.3</td>
<td>3</td>
<td>465</td>
<td>3.47</td>
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<table>
<thead>
<tr>
<th>Sample Description</th>
<th>Analyte: K (%)</th>
<th>Mg (%)</th>
<th>Mn (ppm)</th>
<th>P (%)</th>
<th>Pb (ppm)</th>
<th>S (%)</th>
<th>Sb (ppm)</th>
<th>Si (%)</th>
<th>Sn (ppm)</th>
<th>Sr (%)</th>
<th>Ti (%)</th>
<th>Zn ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>North site 1</td>
<td>1.4</td>
<td>0.61</td>
<td>590</td>
<td>0.34</td>
<td>16600</td>
<td>0.32</td>
<td>766</td>
<td>22.6</td>
<td>146</td>
<td>0.33</td>
<td>3520</td>
<td>5</td>
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<tr>
<td>North site 2</td>
<td>1.62</td>
<td>0.71</td>
<td>695</td>
<td>0.37</td>
<td>14000</td>
<td>0.26</td>
<td>720</td>
<td>21.5</td>
<td>125</td>
<td>0.38</td>
<td>3850</td>
<td>5</td>
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<tr>
<td>South East site 3</td>
<td>1.61</td>
<td>0.72</td>
<td>745</td>
<td>0.44</td>
<td>8800</td>
<td>0.21</td>
<td>440</td>
<td>23.2</td>
<td>112</td>
<td>0.35</td>
<td>2440</td>
<td>5</td>
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<tr>
<td>South East site 4</td>
<td>1.55</td>
<td>0.67</td>
<td>638</td>
<td>0.48</td>
<td>10100</td>
<td>0.24</td>
<td>360</td>
<td>21.9</td>
<td>80</td>
<td>0.38</td>
<td>2590</td>
<td>5</td>
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</tbody>
</table>
Supplementary data B1

SEM-BSE images of Mineral surface coatings

Figures
S7 North site
S8 South East site

Elements are listed if their concentrations are above 1 at%
Supplementary data B2
SEM-BSE images of (partly) mineralized organic features in the soils at both sampling sites

Figures
S9 North site
S10 North site / South-East site
All MOM are mainly composed of C, O and most likely H. Other elements are only listed if their concentrations are above 1 at%
Supplementary data C1

Nano-phases TEM images and diffraction pattern for the mineral surface coating
Silica matrix

Broad peak between \( d = 4.1 \) and \( 4.4 \) Å characteristic for Opal A/C/CT

Diffraction spots for anglesite nanoparticles
Fluorapatite, (Ca+Pb) : P : F = 5 : 3 : 1
Ca: Pb = 10 : 1
Illite + Nanoparticles of anglesite

K: Al: Si = 1: 3: 7

Parallel growth of anglesite on the surface of illite
Pb: red
P: green
Zn: blue

Detrital rounded grains of Franklinite, ZnFe2O4

Blue crystals: Zn : Fe = 1:2

D=4.9
D=3.0
D=2.5

S14
Pb: red
Fe: green
As: blue

Fe : (As+S) = 1: 1

Tsumcorite Group

Formula: \( AM(XO_4)^2(OH,H_2O)^2 \)
A group of complex phosphates, arsenates, vanadates and sulphates with a complicated crystal chemistry (symmetry either triclinic or monoclinic, depending on various ordering schemes).

In the general formula given above, A is typically Pb or Ca, rarely Bi, M is typically \( Fe^{3+} \), Mn, Cu, Zn, Co or Ni and X is typically P, As or V
andalusite crystals (blue) in spherical quartz grains (green)

Pb: red
Si: green
Al: blue

Blue crystals:
Al : Si = 2 : 1

Tetragonal symmetry
Elongated tetragonal prisms

D=5.5
D=2.75
D=2.22
Zn-bearing spinels: Franklineite and Zn-magnetite
Fe: Zn ratios vary between 2 : 1 and 3 : 1
Mixture of various spinels
Fe : Zn : Sb = 4 : 7 : 2
Possible Sb-spinel:
Zn-Sb(V) spinel Zn₇Sb₂O₁₂

Pb: red
Zn: green
Sb: blue

Indicated magnification: 15kx

D=5.0
D=2.5
D=1.7

Indicated magnification: 1000x
carbonaceous material material (red) with Sb-bearing nanoparticles inclusions (green)

Unidentified Sb-bearing Nanoparticles
Supplementary data C1

TEM, SAED and EDS-STEM images of nano-size phases in the mineralized organic matter

All listed elemental ratios are given as atomic ratios
Kintoreite, mineralized organic matter

P : As = 3 : 1 – 4 : 1
Fe : Al = 3 : 1 – 4 : 1
(P + As) : Pb = 3 : 1

P in red
Pb in blue
Franklinite with anglesite nanoparticles in the mineralized organic matter

Zn in red \( \text{Zn} : (\text{Al} + \text{Fe}) = 1 : 2 \)
Fe in green
Pb in blue

S21
Franklinite

Anglesite spots
D = 5.4
D = 3.8
D = 1.4

Nano-diffraction of anglesite nanoparticles on the surface of franklinite with spots belong to franklinite

Blue: nanoparticles of anglesite
Pb : S = 1 ; 1
Intergrowth of crystals of gahnite (Zn : Al = 1:2; yellow/green) and a Zn-Al-Ti-(hydr)oxide phase (Zn : Al = 4:1; violet) SAED pattern display most commonly diffraction spots of both phases.
The Zn-Al –Ti oxides in this sections are composed of hydroxides with mainly Zn. The latter layers are decorated with tetrahdra or OH groups and have characteristics d-spacings of $d = 7.65$ and $d = 4.0$. 

S24
Pb-Fe-Al-P-As
Nanoparticles in silica matrix and close to kintoreite
Pb : (Al+Fe) : (P+As) ~ 10 : 14 : 8
Intergrowth of linarite PbCu(OH)2(SO4) (Yellow, Cu : S ~ 1:1) with kintoreite (blue)
yellow Pb : Ti ~ 1:1
macedonite, PbTiO₃

As : P ~ 2 : 1
rodolicoite, Fe(PO₄)

Blue: phosphosiderite, Fe(PO₄)(H₂O)₂
Fe : (As+P) ~ 1 : 1
## Supplementary data D, Table S29

### Selected minerals identified in the MSC and MOM and their point of zero charge

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Point of zero charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>anglesite</td>
<td>4 (^3)</td>
</tr>
<tr>
<td>Synthetic hydroxyapatite</td>
<td>7.7-8.1 (^1)</td>
</tr>
<tr>
<td>Kintoreite</td>
<td>(\sim 3-6)</td>
</tr>
<tr>
<td>(\text{Fe}_3(\text{PO}_4)_3)</td>
<td>3.3 (^5)</td>
</tr>
<tr>
<td>(\text{Fe}_3(\text{PO}_4)_2(\text{H}_2\text{O})_8)</td>
<td>4.0-5.6 (^1)</td>
</tr>
<tr>
<td>(\text{FePO}_4(\text{am}))</td>
<td>3 (^4)</td>
</tr>
<tr>
<td>Al-rich spinel</td>
<td>9 (^1)</td>
</tr>
<tr>
<td>(amorphous MgAl(_2)O(_4))</td>
<td></td>
</tr>
<tr>
<td>Fe-rich spinel</td>
<td>6.2-8.5 (^1)</td>
</tr>
<tr>
<td>(magnetite)</td>
<td></td>
</tr>
<tr>
<td>hydrous silica</td>
<td>4.1 (^1)</td>
</tr>
<tr>
<td>(listed as precipitated silica)</td>
<td></td>
</tr>
<tr>
<td>illite</td>
<td>2.5 (^1)</td>
</tr>
<tr>
<td>Quartz</td>
<td>2-3 (^2)</td>
</tr>
</tbody>
</table>