Mapping Epithermal Alteration Mineralogy with High Spatial Resolution Hyperspectral Imaging of Rock Samples

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**Introduction**

Hypogene and supergene alterations (Modified from White & Hedenquist, 1995)

**hypogene:** primary minerals  
i.e.: hydrothermal alterations

**supergene:** secondary minerals  
i.e.: weathering processes

Differentiation between hypogene and supergene

- composition
- crystallinity
- mineral associations and patterns
Objective and Approach

To **quantitatively** study hypogene mineral assemblages to **automatically** classify the alteration zones of an epithermal alteration system.

- Spectral and chemical differences
- Hyperspectral images
- Mineral abundances

SWIR colour composite of sample260
Study area: Rodalquilar Caldera Complex, Almeria, Spain

(A) Location of the Rodalquilar Au deposit, Cabo de Gata volcanic field, south-eastern Spain. (B) Central part of the field (Arribas et al., 1995)

High-sulfidation deposits

Cross-section of the Rodalquilar caldera showing the distribution of the alteration zones modified from White & Hedenquist (1995)
**Image acquisition:** 22 Hyperspectral SWIR images

- Specim Hyperspectral SWIR camera

- 288 spectral bands
  - wavelength range: 1.0µm – 2.5µm
  - pixel size: 0.4mm

![Compilation of the 22 SWIR color composite images from Rodalquilar samples](image-url)
**Visual analysis**: Wavelength maps

Sample 260 Wavelength map between 1200 – 2400nm.
Depth stretching 0 – 1470
**Visual analysis: Alunite spectral and chemical differences**

supergene alunite

hypogene alunite
Visual analysis: Alunite spectral and chemical differences

ASD spectra

Spectra from images

Visual analysis:

Alunite spectral and chemical differences

Spectra from images
Visual analysis: Alunite spectral and chemical differences

ASD spectra

Supergene

Hypogene

Spectra from images

Supergene

Hypogene
Visual analysis: Alunite spectral and chemical differences

Wavelengths maps, range (1460-1495nm)

**Supergene - Hypogene**
**Validation: Geochemical analysis**

Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)

<table>
<thead>
<tr>
<th>Element</th>
<th>Supergene</th>
<th>Hypogene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>13</td>
<td>3402.33</td>
</tr>
<tr>
<td>K</td>
<td>120 x 10³</td>
<td>50 x 10³</td>
</tr>
<tr>
<td>Sr</td>
<td>97.33</td>
<td>533.79</td>
</tr>
<tr>
<td>Y</td>
<td>1.03</td>
<td>3.31</td>
</tr>
<tr>
<td>Zr</td>
<td>&lt;0.26</td>
<td>&lt;0.26</td>
</tr>
<tr>
<td>Na/K</td>
<td>&lt;0.01</td>
<td>0.07</td>
</tr>
</tbody>
</table>

**Thermogravimetric Analysis (TGA)**

![Thermogravimetric Analysis Graph](image)

**Low** | **High**
**Endmember extraction:** Wavelength maps

Offset and hull-removed spectra of alunite and kaolinite endmembers.

Total of 20 endmembers
**Unmixing**: Iterative Spectral Mixture Analysis (ISMA)

Color composites to evaluate spatial distribution of the minerals

- ISMA sample260
  - Alunite long
  - Alunite short-B
  - Silicification

- ISMA sample213
  - Alunite short-A
  - Jarosite overall
  - Montmorillonite

- ISMA sample208
  - Alunite short-B
  - Jarosite 1936
  - Silicification

Steps:
- Image acquisition
- Visual analysis
- Validation
- Endmember extraction
- **Unmixing**
- Quantification
Unmixing: Iterative Spectral Mixture Analysis (ISMA)

i.e.: alunite zonation

ISMA sample 260
- Alunite long
- Alunite short-B
- Silicification

ISMA sample 260
- Alunite long
- Alunite short-A
- Alunite short-B
**Unmixing**: Iterative Spectral Mixture Analysis (ISMA)

i.e.: alunite zonation

ISMA sample260
- Alunite long
- Alunite short-A
- Alunite short-B

![Image acquisition](image)

![Visual analysis](visual)

![Validation](validation)

![Endmember extraction](endmember)

Unmixing

![Unmixing](unmixing)

Quantification

Alunite long
Alunite short-A
Alunite short-B

![Spectra of endmembers](spectra)

Reflectance (Offset for clarity)

Wavelength: 1400 to 2400
Quantification: Iterative Spectral Mixture Analysis (ISMA)

Mineral Abundances per Alteration Zones (Arribas et al 1995)

- Vuggy silica
- Advance argillic Alteration zones
- Interm. argillic
- Supergene
- Non

Mineral concentration:
- Alunite short
- Jarosite
- Gypsum
- Kaolinite PX
- Alunite medium
- Halloysite
- Kaolinite MX
- Montmorillonite
- Illite
- Kaolinite HX
- Nacrite
- Dickite
- Pyrophyllite
- Alunite long
- Stilification
- Minerals

Steps in Quantification:
- Image acquisition
- Visual analysis
- Validation
- Endmember extraction
- Unmixing
- Quantification
Conclusions

- Hyperspectral imaging is an emerging technique for mineral mapping (detection mineral mixtures and spatial patterns)

- Spectra and geochemical analysis offer a good tool to differentiate between supergene and hypogene samples

- Alunite minerals in the Rodalquilar show spectral variations and geochemical analysis prove that they are also different in their chemistry

- For a complete evaluation of alteration mineralogies, LWIR data would be useful

Future work

- Exploring automatic algorithms for the endmember extraction

- Applying the proposed methodology on a larger dataset to precisely develop the automatic classification
Gracias!

Thank you for your attention!

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