Alteration in Hawaiian Drill Core Using a Portable Field Spectrometer

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The UNR group has surveyed both drill core and chips to explore hydrothermal alteration in geothermal systems at varying temperatures.

Past studies have helped establish sampling protocols and methods.

Data acquisition is rapid, but detailed analysis somewhat more time consuming.
Past Surveys

- Established reliable methods for core/chip surveys.
- Can rapidly measure samples with high depth resolution.
- Temperature dependent mineral assemblages are found, as narrow zones and gradation with depth.
- Si-Opal geo-thermometers are clearly resolved and seen only in highest T wells.
- Can readily identify argillic and propylitic alteration suites.
- Provide initial survey and point to sections of interest for detailed additional analysis.

<table>
<thead>
<tr>
<th>Site</th>
<th>Type</th>
<th>Max T. (°C)</th>
<th>Lithology</th>
<th>Depth (m)</th>
<th>Common spectral types Identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desert Peak DP23-1</td>
<td>Cuttings</td>
<td>204</td>
<td>Tuffs, sediments, phyllite, granodiorite</td>
<td>2938</td>
<td>Epoxy glue, chlorite, illite, muscovite, unaltered phyllite, hematite</td>
</tr>
<tr>
<td>SAFOD Pilot and MHST1</td>
<td>Cuttings</td>
<td>n/a</td>
<td>Sediments, granite, granodiorite</td>
<td>2170; 4000</td>
<td>weakly altered, smectite clays (montm.), walnut chips.</td>
</tr>
<tr>
<td>Blue Mountain DB2</td>
<td>Core</td>
<td>167</td>
<td>Phyllite, dacite</td>
<td>1128</td>
<td>unaltered phyllite, mont./illite, <strong>hydr. qrtz/opals</strong>, chlorite+montm, serp+prehnite, carbonate, jarosite</td>
</tr>
<tr>
<td>Humboldt House HHP3-1</td>
<td>Core</td>
<td>110</td>
<td>Conglomerate – silicified or mud/sand supported</td>
<td>198-306</td>
<td>weakly altered mafics, illite/chlorite, <strong>hydr. qrtz/opals</strong>, kaolinite, jarosite.</td>
</tr>
<tr>
<td>Hawthorne HWAAD-2</td>
<td>Cuttings</td>
<td>49</td>
<td>Alluvium, sandstone, and granite</td>
<td>~surface-1437</td>
<td>montm., mont+illite+chlor, chlor+epidote, walnut chips</td>
</tr>
<tr>
<td>Hawthorne HWAAD-3</td>
<td>Cuttings</td>
<td>43</td>
<td>Alluvium, sandstone, and granite</td>
<td>~surface to 1175</td>
<td>montm., mont+illite+chlor, chlor+epidote, carbonate</td>
</tr>
<tr>
<td>Akutan HSB2</td>
<td>Core</td>
<td>162</td>
<td>Basalt, andesite ash tuff, lithic basalt</td>
<td>254</td>
<td>Zeolites, epidote &amp; prehnite, calcite, muscovite, kaolinite</td>
</tr>
<tr>
<td>Akutan HSB4</td>
<td>Core</td>
<td>160</td>
<td>Basalt, andesite ash tuff, lithic basalt</td>
<td>457</td>
<td>Zeolites, calcite, muscovite, kaolinite</td>
</tr>
</tbody>
</table>

Summary paper is in prep
Humu‘ula Groundwater Research Project (HGRP) drilled a 5786 foot (1760m) deep hole off the saddle road of the big island, on the grounds of the Pohakuloa Training Area (PTA).

The primary goal was to characterize the groundwater resources of the region.

Surprisingly, bottom hole temperatures reached 100°C.

Logging of core noted alteration did not really begin until about 3000'.

In May, 2014 we collected 780 spectra for the depth interval from 3190 to 5785 feet in 3 days.
Dominant lithology is basalt with varying levels of plagioclase and olivine phenocrysts.

Various sub aerial flow textures noted (pahoehoe to aa).

Limited sedimentary units, some possible explosive units of scoria, ash and glass.

Various lavas representing flows from ~ 4ka to > 250ka representing the shield building phase of the island.

Blog archive and core photos: hgrp.blogspot.com
Data Collection

- We use the ASD contact probe, so each spectrum integrates an area about the size of a Canada dollar.

- Periodic recalibration over the course of the day.

- Field operator makes real-time decisions on locations to sample or whether to systematically sample at fixed interval.

- The HGRP survey focused on alteration minerals and skipped many visually unaltered locations.

- Detailed note taking on depth/spectrum # is imperative.
Several commercial software packages are used for preliminary display and analysis.

Automated identification routines provide a starting point for more detailed interpretation.
Methods - Mapping

- Point spectra are “expanded” to provide visual sense of width and stacked into a “image cubes” representing depth.
- ASD are smoothed and subsampled to 5nm and 430 channels (no loss of mineral detail).
- We use statistical and experience-based methods to identify scene spectral types and map them in the drill stack.
- Select “unique” pixels as scene spectral endmembers or types.
- Spectral similarity and matching to map similar spectra at different depths.
Some layer silicates with very similar features may not be well separated: dickite-halloysite-kaolinite or illite-paragonite-muscovite.

Overlapping bands may also make it difficult to resolve minerals that commonly occur together in alteration assemblages.
Representative HGRP spectra (r,g,b) with basalts from the JPL spectral library (m,c).

Olivine bearing spectra (r,g,b,c) with augite (b, top) and olivine (sg) from the USGS library.
Map of Unaltered Spectra

SAM map of basalt (red) in core stack. ROI average of 68 spots.

Olivine bearing (green) did not map well and represents an average of 7 spots (rows).

Map of locations overlain on albedo at 750nm
Representative spectra (r,g,b) with USGS library clinochlores.

Note that unlike remote sensing, 1.4 and 1.9 regions are very diagnostic.
Phlogopite/Vermiculite

Representative spectra (b,b,r,g) with USGS library phlogopites and vermiculite.

Starting spectra (solid) and SAM average of 25 spots.
Sepiolite

Representative spectra (b,g) with USGS library sepiolite.

Core spectra show marked absorption by Fe from 0.5 to 1.8 µm, more “chlorite like”.

Starting spectra (solid) and SAM average of 9 spots.
Zeolites: Stilbite/Clinoptilolite

Many zeolites are quite similar.

VSWIR is not good at distinguishing heulandite, stilbite, laumontite, clinoptilolite.

Analcime distinct feature at 1.8 \( \mu \)m.

Natrolite group abundant fine structure
Zeolites: Analcime

Average of 5 spots (dashed) already starts to lose the diagnositic feature of analcime.
Zeolites: Natrolite family

Natrolite and scolecite are a better match than hydrated sulfates (mirabilite or kainite).

Likely a combination that averages narrow features.
Alteration Trends

Green and blue show varying strength of pyx, 1.4 and 1.9 features and development of 0.55 peak.

Cyan and magenta 1 µm has shifted to look more like Fe-clays, and 2.3 µm feature is well developed.

2.3 only (pholg/vermic/sep) vs 2.25 and 2.3 (clinchlIr)
Alteration Patterns with Depth

Preliminary depth log shows locations of type end members in the core and transition from less altered to more altered.

Pyroxene: red (68)
Olivine: green (7)
Clinochlore: sea green (31)
Phlogopite: maroon (25)
Sepiolite: blue (9)
Zeolite: natrolite: cyan (19)
Zeolite: stilb/clinopt: purple (61)
Zeolite: analcime: purple (5)

An example of where we can take this (Littlefield and Calvin, 2012) is detailed comparison with lithology, thin section and XRD on the Akutan core.

Spectra ID – circles thin section squares.

Spectroscopy is rapid preview for more detailed analyses.
Next Steps for HGRP

- Based on the spectral analysis common spectral types were sampled and thin sectioned for more detailed analysis using petrographic techniques and XRD.
  - Preliminary thin section did not discriminate clay minerals. Stilbite, clinoptilolite and other zeolites are common, calcite identified in one section.
  - Detailed comparison is pending (see N. Lautze poster at AGU)

- Determine mixtures using endmember spectral types identified here.

- Sections will be measured using FTIR to refine mineral identifications using a wider wavelength range (0.4 to 25 \(\mu\)m).

- Hope to do high resolution FTIR (100 \(\mu\)m) on the thin sections as well.