# PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2013
Pomona College, Claremont, CA

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ISSN# 1528-7491

The Consortium Colleges    The National Science Foundation    ExxonMobil Corporation

# KECK GEOLOGY CONSORTIUM
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**ISSN# 1528-7491**

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Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1062720
ExxonMobil Corporation

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KECK Geology Consortium
Learning Science Through Research
Published by Keck Geology Consortium
Short Contriubtions
26th Annual Keck Symposium Volume
6 April, 2013
ISBN: 1528-7491

# QUANTIFYING THE PHYSICAL CHARACTERISTICS OF WEATHERING USING THIN SECTION ANALYSIS

**TIMOTHY BOATENG,** Amherst College
**Research Advisor:** Dr. Peter Crowley

## INTRODUCTION

The transition from rock to weathered regolith is pertinent to both geological engineers and geologists. To explore what it means for a rock to be "weathered," the combination of Schmidt hammer measurements and thin section analysis was used to create numerical values for physical characteristics associated with weathering, contextualized by qualitative descriptions. Taking multiple approaches to the quantization of qualitative criteria also provided an opportunity to comparatively evaluate the accuracy of these methods.

## METHODS

Samples were collected in the field along a West-East transect in Northern Central Colorado ranging from the Green Lakes Valley, a roadcut along the Peak-to-Peak highway, Upper and Lower Gordon Gulch, Fourmile Basin, to Betasso Basin, with each respective site being much lower in elevation. At each sample location, the density of planar fractures was measured using the "line-intercept" method. Trend and plunge of the fractures was also recorded.

A Schmidt hammer was used to quantitatively assess each outcrop's uniaxial elastic compressibility in the field. Qualitative descriptions of rock freshness were also made at each outcrop by taking into account color, visible fracturing, friability, and visible mineralogy. The outcrop was then assigned a qualitative label as "fresh" "oxidized," "saprolite," or "soil," based on this information, and samples were collected and impregnated with dyed epoxy for thin section analysis.

## FIELD

In the Green Lakes Valley, the primary lithology investigated was the Long's Peak Granite. In this lithology, planar fractures with a median spacing of 47 cm were observed in the field. Locally, shorter, shallower fractures, spaced evenly (1cm spacing) between the larger fractures measured for the line-intercept test, were observed. Gnammas were also observed in some outcrops. The rocks were peach in color and had an average weathering rating of 1.5, falling between 1 (fresh) and 2 (oxidized). Lichen and spruce krummholz occurred on and around the rocks in this environment. Glacial polish that formed at ~15 ka was present on many outcrops, including the one sampled for the thin section.

In Gordon Gulch, the main lithology seen was a Precambrian biotite gneiss. Fractures in these rocks were spaced on average 61cm apart. This region was heavily forested. Gnammas and granitic dikes were observed in this lithology. Schmidt hammer measurements averaged 12.3 in this region, and the average rock weathering was 2.3 (between oxidized and saprolite), with more than half of the rocks observed being very micaceous.

In Fourmile and Betasso, Boulder Creek Granodiorite was the dominant lithology. Rocks in this region had an average weathering index of 1.8 (between fresh and oxidized), and Schmidt strength averaged 23.7. Hematitic veins were observed in qualitatively fresher-appearing outcrops of this lithology, which tended to appear grey, while more friable rocks tended to be light brown or sandy. Mica was abundant in roughly 25% of these rocks. Fractures in these regions were spaced on average 48cm apart. In Fourmile, one sample, collected adjacent to a river, showed evidence of fluvial polish, while two other samples showed evidence of burning and/or spalling. In Betasso, many rocks were observed to have a relatively wide range of weathering within a geographic area of only a few meters, and the freshest rock sample was collected less than two kilometers away from the most friable saprolite.

## THIN SECTION

In thin section, weathering was largely manifested by the presence of fractures on a variety of scales. Each lithology displayed a distinct pattern of fracturing (Table 1). In all lithologies, three main types of planar fractures were observed, distinguished mainly by their size. Type 1 fractures were most common (Fig. 1). These dark, approximately 0.03mm-wide fractures occurred along grain boundaries and within grains (feldspar grains in particular). These fractures were always present in rocks labeled "saprolitic" in the field, were frequently present in rocks labeled "oxidized," and were rarely present in rocks labeled "fresh." Type 2 fractures were wider (>0.15mm) and easily distinguished because they were wide enough to facilitate the percolation of the blue, dyed epoxy (Fig. 1). Type 3 fractures were the narrowest microfractures (<0.016mm) and occurred within larger feldspar grains, but never between grain boundaries. These smaller microfractures were much rarer, but where they did occur, there could be several dozen of them within a single grain. They were also noted only in samples labeled "fresh" in the field. None of the three types of fractures was the site of extensive chemical weathering. Fine-grained weathering products were not observed along any fractures.

A single relatively unweathered sample of the Long's Peak granite was studied. This sample weathered by the development and linking of Type 1 fractures. Feldspar from Long's Peak Granite also fractured in dark, relatively straight lines of clear breakage and was commonly sericitized. Holes observed in and between feldspar grains were as large as ~0.31mm in diameter. Fractures which crossed grain boundaries either were very wide (up to 0.16mm) linear fractures, or were large holes of this sort.

*Table 1: Results of weathering using different methods. The intensity of weathering determined in the field correlates poorly with the density and interconnectivity of Type 1 fractures seen in thin section.*

| Sample | Qualitative Wx Assessment (Fresh=1, Ox=2, Sap=3, Soil=4) | Avg Schmidt hammer measuremt | Avg fracture spacing (cm) | Avg fracture density (fractures per 1.25mm) | % fractures crossing grain boundaries | Fracture connectivity (% of connected fractures) | % fractures on grain boundaries |
|---|---|---|---|---|---|---|---|
| Long's Peak Granite | Field observations | | | Thin Section Analysis | | | |
| CB 4p | 1 | - | 44 | 11.5 | 87.5 | 90.57 | 60.01 |
| Metasediment | | | | | | | |
| CB 2 | 2 | - | 56 | 11.1 | 15.0 | 91.41 | 54.70 |
| CB 10 | 2 | 18.6 | 75 | 13.7 | 25.0 | 90.47 | 42.50 |
| CB 6B | 2 | 8.4 | 21 | 27.4 | 100.0 | 89.95 | 27.72 |
| *(sample from pit)* CB 9 | 3 | 5 | - | 7.3 | 90.0 | 88.93 | 70.95 |
| B.C. Granodiorite | | | | | | | |
| *(carbon-coated sample)* CB 21B | 1 | - | - | 6.0 | 0.0 | 33.64 | 9.80 |
| CB 18A | 1 | - | 45 | 4.7 | 5.0 | 52.02 | 23.24 |
| CB 17B | 1.5 | - | - | 9.0 | 100.0 | 82.09 | 29.64 |
| CB 17C | 2 | - | - | 7.0 | 55.0 | 75.47 | 31.25 |
| *(spalled sample)* CB 20S | 2 | - | - | 7.5 | 90.0 | 95.44 | 46.93 |
| CB 16 | 4 | 0 | - | 9.8 | 100.0 | 90.99 | 40.09 |

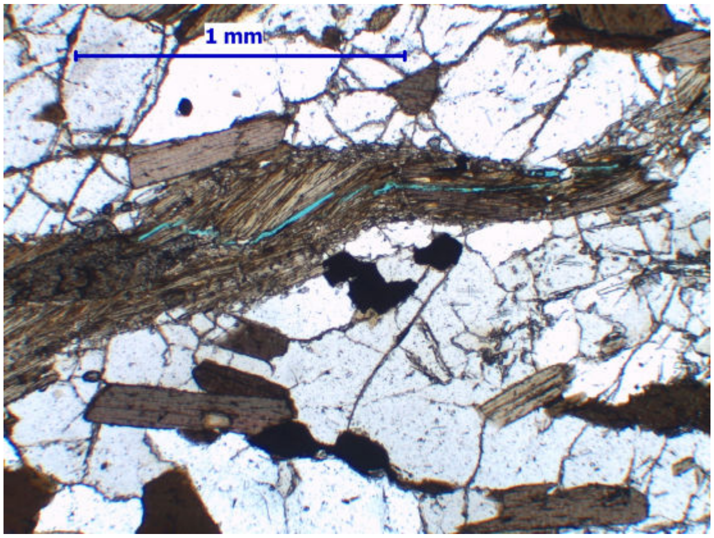


*Figure 1: Biotite seam and blue-dyed epoxy (center of picture) within a Type 2 fracture in Precambrian biotite gneiss from Upper Gordon Gulch. The fracture links short segments that split along biotite grain boundaries. No fine-grained weathering products occur along the fracture. Type 1 fractures are also visible between feldspar grains above and below the biotite-seamed Type 2 fracture.*

The biotite gneiss also weathered dominantly by the development of Type 1 fractures. As weathering increased, the abundance of wider Type 2 fractures also increased dramatically, as did the frequency of holes in feldspars. Notably, these wider Type 2 fractures often followed seams of biotite (Fig.1). Greater consistency in the orientation of linear Type 1 fractures was also observed, and at times, more than one primary fracture orientation would be visible, mirroring the multiple fracture orientations often observed in the field. No sericization was observed in feldspars in biotite gneiss.

Feldspars in the Boulder Creek Granodiorite weathered by the development of Type 1 fractures. However, granodiorite feldspars generally contained far fewer fractures than did those in biotite gneiss. Type 2 fractures were also observed and increased in abundance with weathering. Granodiorite feldspars were observed to be sericizied – Type 3 fractures were present in granodiorite feldspars, but were less common than they were in Long's Peak granite. In the most friable sample, fractures were observed to be up to 0.83mm wide and holes in the rock matrix were up to 0.31mm in diameter.

Two samples of this lithology were sourced from an area of Fourmile which experienced a wildfire in 2010. In the field, rocks from this area were observed to have carbon-coated and/or spalled surfaces. The thin section slide made from a carbon-coated sample of granodiorite rock contained very few (almost no) fractures. In the slide made from the spalled rock, curvature in the orientation of fractures was observed, mirroring a concoidal pattern of breakage observed during the process of cutting the sample for thin section chips. Many fractures were also observed in almost every grain in the slide (Fig. 2).

## DISCUSSION

In the Boulder Creek Granodiorites, Type 1 fractures were abundant and frequently connected to one another, while Type 3 fractures were rare. Both Type 1 and Type 2 fractures increased in abundance

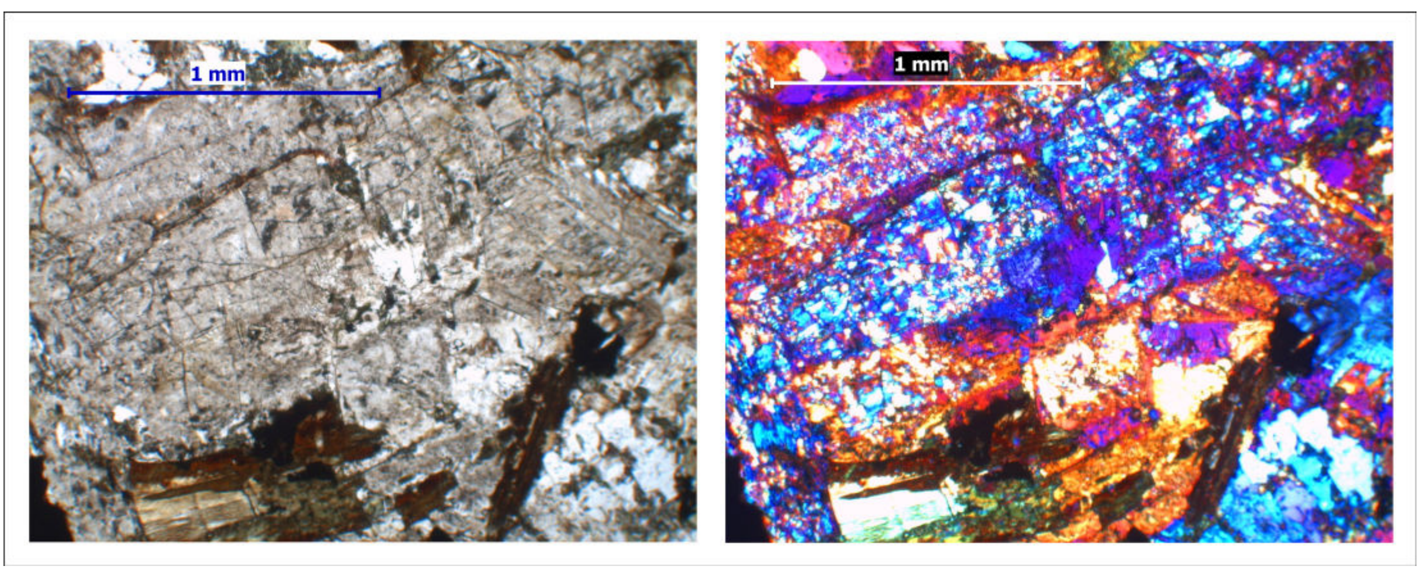


*Figure 2: Numerous fractures within feldspar grain in a spalled granodiorite sample. These fractures do not extend beyond the feldspar.*

with weathering, although the change was far more dramatic in Type 2 fractures. Fracture connectivity (the percentage of fractures which connected to other fractures in each thin-section field of view) increased quite steadily from ~34% to ~91% with weathering.

Fracture connectivity appeared to be the most reliable indicator of the degree of rock weathering – in all lithologies, values for this measurement ranged from 34% in the "freshest" rock to 91% in the most "weathered" rock. The percentage of fractures on grain boundaries also increased with qualitative degree of weathering, but in granodiorites these values ranged only from 23% to 40%. In the metasediment, fracture connectivity was a much less telling indicator of weathering, with values ranging only +/-3%. (Interestingly, the spalled granodiorite rock had the highest recorded interconnectivity, while the carbon-coated granodiorite had the lowest.) The same pattern is visible in the percentage of fractures formed on grain boundaries. This is likely related to the unique patterns of fragmentation observed in the spalled rock (Fig. 2).

The number of fractures which crossed grain boundaries (Table 1) was also informative. These fractures were usually Type 2 fractures which had filled with dyed epoxy. CB 17B and CB 17C, two visually similar rocks collected only a few meters apart from each other, displayed very large differences in this value. The sharp increase in percentage seen between these rocks and in the metasediment samples therefore suggest that this percentage increases rapidly as a rock first begins to weather.

Measurements of the degree of weathering derived from the thin sections agreed poorly with the qualitative assessments of rock weathering made in the field. The density of fracture spacing in thin section (measured here as the average number of fractures which intercepted a line 1.25mm in length) increased in correlation with other measurements such as fracture connectivity and percentage of fractures crossing grain boundaries, but did not increase reliably with Schmidt hammer measurements or qualitative field notes. According to all thin section-derived measurements, CB 17B was more weathered than CB 17C, and CB 6B was more weathered than CB 10, which was in turn more weathered than CB 2. In contrast, the qualitative measurements made in the field would suggest that CB 10 was more weathered than CB 6B and CB 2, and that CB 17C was more weathered than CB 17B. This poor correlation between assessments of weathering derived from thin-section analysis and measurements taken in the field suggest that in the Front Range, very little visible change is seen in a rock until the fractures reach a certain critical density or connectivity, whereupon their friability increases dramatically. This point may be different for each lithology.