ZEOLITE WEATHERING IN LABORATORY AND NATURAL SETTINGS, AND IMPLICATIONS FOR MARS.
R.E. Schofield\(^1\), E.M. Hausrath\(^1\) and S.R. Gainey\(^1\) \(^1\)Department of Geoscience, University of Nevada, Las Vegas, 4505 S. Maryland Pkwy, Las Vegas, NV 89154 schofi35@unlv.nevada.edu.

**Introduction:** Clay minerals have been used as evidence of past aqueous processes on Mars because they form in the presence of water, and can therefore provide insight into past water activity on Mars. Zeolites have been found in the same terrains as clay minerals on Mars [1, 2], and thus zeolites may also provide evidence for aqueous processes affecting these mineral assemblages since their formation. Laboratory and field analyses of zeolite weathering may therefore help interpret the implications and observations of weathered and unweathered zeolites on Mars.

**Zeolite dissolution in laboratory experiments:** Previous laboratory experiments of zeolite weathering indicate the transformation of zeolites to other phases. For example, under alkaline conditions, the low-silica zeolites natrolite and thomsonite have been observed to convert to the zeolite analcime [3] which has been documented on Mars [1, 2]. In contrast, under extremely acidic conditions, zeolites have been observed to alter to amorphous silica-rich phases [4]. In addition, although few dissolution data exist for zeolite minerals, particularly under acidic to near-neutral conditions, and particularly for the Mars-relevant zeolite analcime, those dissolution data that do exist suggest that zeolites should dissolve more rapidly than clay minerals (Figure 1). Zeolites may therefore be more sensitive indicators of weathering conditions occurring on Mars than the clay minerals with which they are found.

**Field analyses of weathered zeolites:** To interpret the effect of initial weathering reactions upon zeolites in a natural environment, we analyzed naturally weathered zeolites from arid Nevada. Samples were collected from the surface of a zeolite deposit that had been mined from 1979-1981 (personal communication D. Eyde). We are therefore able to analyze the initial reactions affecting zeolite weathering over time scales of a few decades in an arid environment, with implications for understanding zeolite weathering in martian environments.

**Methods:**

**Sample collection**
Samples of the zeolite clinoptilolite were collected from Ash Meadows, approximately 67 miles northwest of the University of Nevada, Las Vegas, in Nye County, NV. Samples of clinoptilolite were collected from the top weathered surface of a previously mined outcrop, as well as five cm beneath the surface.

![Figure 1. The limited zeolite mineral dissolution rates present in the literature compared to clay mineral dissolution rate laws from the literature suggest that zeolites dissolve more rapidly than clay minerals under most pH conditions. However, few data exist in the acidic range to observe the effect of zeolite composition on dissolution rates, or the dependence of the dissolution rate on the concentration of hydrogen ions (the slope of the line of the log dissolution rate versus pH under acidic conditions, or n). Specifically, to the best of our knowledge, no data exist in the near-neutral to acidic region for dissolution of analcime, which has been documented on the surface of Mars [1, 2].](image-url)

**Sample analysis**
Samples were crushed and powdered for XRD, SEM, and EDS analyses to determine composition, chemistry, and morphology. Samples were identified by comparing mineral morphology descriptions, chemistry data, and SEM catalogued images from the SEM Petrology Atlas [5] to sample SEM and EDS data.

**Results and Discussion:** Samples were confirmed to be clinoptilolite by powder X-ray diffraction (Figure 2). Characteristic observations from SEM analyses included crystalline clinoptilolite, weathered clinoptilolite, and clay minerals, likely smectite or illite (Figures 3, 4, and 5). Other minerals were also present, including remnants of the parent glass material (Figure 6) as well as minerals believed to be other zeolites.
Figure 2. XRD analyses which confirm that the sample is clinoptilolite.

Figure 3. Characteristic crystalline clinoptilolite found in samples.

Figure 4. Rounded surfaces of clinoptilolite, interpreted to result from weathering.

Figure 5. A clay mineral, likely smectite or illite, found throughout most of the samples.

Figure 6. Apparent glass shards found throughout the most pristine sample.

Conclusions: Previous laboratory experiments suggest that zeolites are likely to dissolve more rapidly than clay minerals at the same pH, although many more experiments are needed, particularly under acidic conditions, and particularly of the Mars-relevant zeolite analcime. Field analyses indicate observations of rounded surfaces of clinoptilolite, potentially indicative of relatively rapid weathering of zeolites in a natural, arid, field environment.

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