

CALORIMETRIC "WEATHEROMETER" FOR STONY METEORITES

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INTRODUCTION. Terrestrial weathering can render troublesome effects in the mineralogical, chemical and isotopic analyses of meteorites that might confound their cosmochemical interpretations [1]. Nonetheless, the scientific community's supply of new meteorite specimens continues to grow principally through weathered "finds" recovered from Antarctica and other remote locations where natural conditions have favored meteorite concentrations. Therefore, it is important to establish reliable methods for rapidly and quantitatively measuring the degree of weathering of a given meteorite specimen. For Antarctic meteorites, an A-B-C scale serves as a visual assessment of the relative rustiness of whole specimens [2]. "A" represents very little rust while "C" indicates abundant rust; a subscript "e" is added if evaporite (salt mineral) deposits are seen. Even if it could be extended to non-Antarctic finds, the A-B-C-e system remains subjective and inadequate for quantitative studies.

In the present work, we evaluate differential scanning calorimetry (DSC) as a weatherometer method using L-chondrites as a test case. DSC is quantitative, rapid (1-2 hr per analysis), uses small samples (10-20 mg), and is sensitive to weathering products in stony meteorites, including oxyhydroxides, salts and clays.

SAMPLES AND METHODS. Samples were selected from the U. S. Antarctic meteorite collection [2] for L3 and L6 chondrites which had been chemically analyzed by Jarosewich [3]. Non-Antarctic comparison samples, also previously analyzed by Jarosewich [3], included the Khohar (L3) and Saratov (L4) falls, the Ioka (L3) find, and the Holbrook, Arizona (L6) chondrite, which has been analyzed as both a fall (1912) and find (1931, 1968) [4-6]. Point counts of meteorite thin sections were used to determine volumetric abundances of Ni-Fe metal, sulfides, silicates, and "rust." For the Antarctic specimens, additional point counts for fractures were made with rectilinear grids overlain on photographs of the original rock specimens.

DSC analyses were performed on splits of homogenized powders analyzed by Jarosewich [3] and Holbrook powders from Gooding [6]. For each analysis, 10-12 mg of powder in an aluminum oxide crucible was heated from 300-1000 K at 10 K/min under 20 cm³ Ar/min in a Perkin-Elmer DSC-7. The sample was cooled to room temperature, weighed, and then re-heated. Empirical corrections for bulk heat-capacity effects were made by subtracting second-heat data from first-heat data; the residual consisted of peaks from nonreversible phase transitions and chemical reactions. A zinc standard (NIST SRM-2221) was run regularly for instrument calibration. Reference analyses were performed on ferric oxides and oxyhydroxides as well as on minerals representative of Antarctic evaporites (nesquehonite, gypsum, and epsomite).

RESULTS. Fig. 1 shows a positive trend of modal rust (from our point counts) with bulk $Fe_{total}/(Fe^{\circ} + FeS)$ computed from chemical analyses by Jarosewich [3] for Antarctic samples, or by Mason and Wiik [4] and Gibson and Bogard [5] for Holbrook samples. Fig. 1 confirms that rust accumulates

as metallic iron and troilite (FeS) corrode but also underscores the limitations of existing A-B-C categories as broad and indefinite indices of the corrosion trend.

The DSC contrast between fresh and weathered specimens is illustrated in Fig. 2 for Holbrook but essentially the same features characterize Antarctic L-chondrites. "Weathering product" peaks are attributable primarily to ferric oxyhydroxides; the "rust" peak (Fig. 2) corresponds to unresolved dehydration peaks from FeO(OH) polymorphs, including goethite, lepidocrocite, and akaganeite. Broad peaks at 350-400 K reveal more poorly crystallized ferric oxyhydroxides akin to ferrihydrite, $5Fe_2O_3 \cdot 9H_2O$. Fundamental peaks for maghemite ($\gamma-Fe_2O_3$) or magnetite (Fe_3O_4) appear weak or absent; peaks for hematite ($\alpha-Fe_2O_3$) are fundamentally weak and not easily detected at low abundance. Fig. 3 shows that the DSC "rust" peak covaries with the bulk iron ratio more coherently than does the modal rust volume. Therefore, the DSC "rust" peak is a

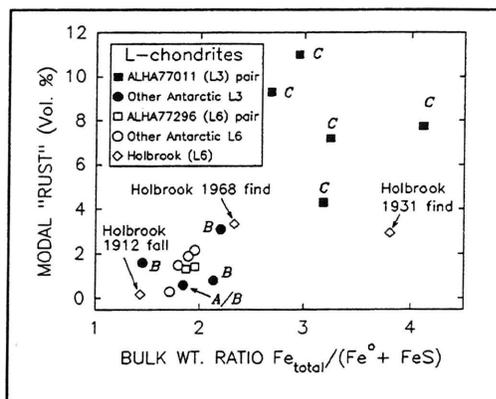


Figure 1. Covariation of rust abundance (thin sections) with bulk iron ratio (chemical analyses). The A-B-C weathering classifications for Antarctic samples [2] are diffuse when compared with the quantitative scales.

METEORITE WEATHEROMETER: Spargur C. S. and Gooding J. L.

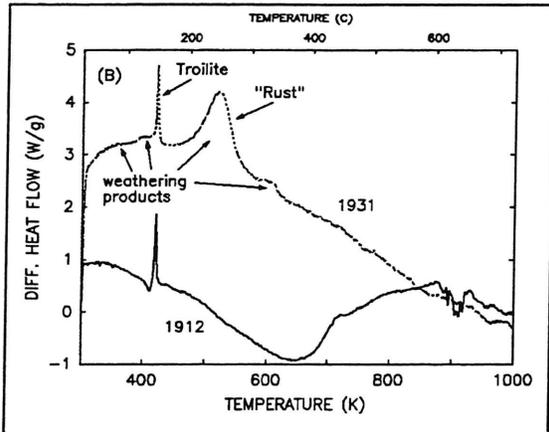


Figure 2. Residual DSC heat-flow data for fresh (1912 fall) and weathered (1931 find) samples of the Holbrook (L6) chondrite. Each curve represents a smooth spline drawn through about 1200 data points. The troilite peak corresponds to the α/β solid-state inversion of primary FeS. The "rust" peak represents dehydration of FeO(OH) polymorphs.

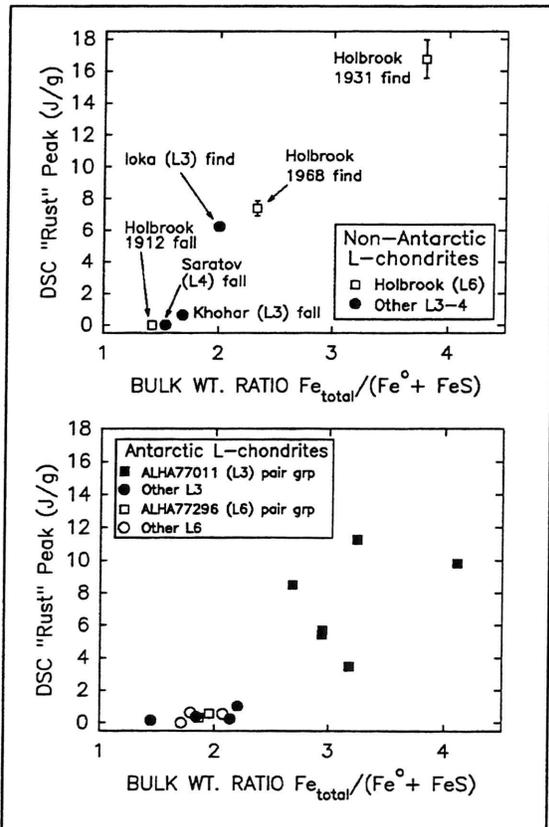


Figure 3. Covariation of DSC integrated "rust" peak with bulk iron ratio. Error bars on the Holbrook points represent standard deviations of triplicate analyses. Antarctic finds are measurably more oxidized than documented falls.

useful proxy for the abundance of ferric iron, and hence the degree of oxidative weathering, in each sample. For the Antarctic sample suite, there is no obvious increase in DSC rust index with declining ^{26}Al activity [2] (a proxy for terrestrial residence age) except in a false sense when the ALHA77011 (L3) group is indiscriminately included.

The ALHA77011 (L3) pairing group [7] scatters widely regardless of which weathering index (modal rust, iron ratio, or DSC rust) is selected. Possible explanations are that (a) the various stones were exposed at the glacial surface for different lengths of time, (b) the size (i.e., surface-to-volume ratio) of each stone moderated diffusion-driven reactions, or (c) fractures controlled penetration of water and atmospheric gases. In our data, DSC rust index does not correlate with mass but rust appears to positively covary with fracture abundance (Fig. 4), supporting hypothesis (c).

CONCLUSIONS. DSC offers a rapid method for measuring the degree of oxidative weathering of ordinary chondrites. With further development, the method could probably be extended to other types of chondrites and achondrites. For a given terrestrial residence age, weathering of Antarctic chondrites may be strongly influenced by fracture abundance.

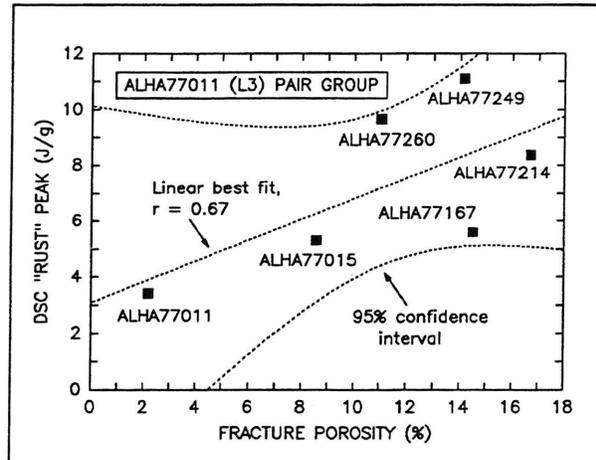


Figure 4. Covariation of rust with fracture abundance for constant terrestrial age. The correlation is suggestive but below the critical value of r (0.811) for rejection of the null hypothesis with 95% confidence.

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