Sulfur Composition of MacEwan Meteorites

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Why Study Sulfur

• Roles in biology:
  – It forms part of two essential amino acids: cysteine and methionine
  – It plays a key role in the central metabolism of cells
  – It can act as a bioenzyme
  – Some bacteria rely on it as an energy source
• Life as we know it would not be possible without sulfur’s presence in the primordial soup
  – Carbonaceous chondrites may have made a contribution to the reservoir of prebiotic molecules available on the Earth at the time of life’s origin
• Proof that the cosmos have delivered exogenous organic material (including S-bearing molecules) to the Earth is provided by the content of carbonaceous chondrites
Goals for Study

• An understanding of the thermal history of the parent body
  – Chemical evolution of the sulfur-bearing species in the meteorite (i.e. have any aqueous oxidation reactions taken place)
  – How prebiotic molecules were synthesized within the parent body

• The fractionation and distribution of sulfur among the primitive bodies in the early solar system
  – How the nature, isotopic signatures, abundances, and distributions of the organic species in meteorites impose bounds on the solar system’s formation and evolution (i.e. positive isotope ratios indicate a nebular origin)

• If there are reasonable differences in the S isotope ratio numbers for different classes of carbonaceous chondrites
Carbonaceous Chondrites

• Minimal amounts of heating, melting, and planetary formation $\Rightarrow$ primitive meteorites

• High bulk S content
  – $S^0$, organic sulfur, sulfates, and sulfides

NWA 1180

Murchison
Sulfur Species

- $\text{SO}_4^{2-}$
- $S^0$
- $S^{2-}$

Most oxidized

• Organic sulfur compounds: dibenzothiophene, thiophene, methionine, and cysteine

Dibenzothiophene

$S_8$
### Simulant

<table>
<thead>
<tr>
<th>Species</th>
<th>SO$_4^{2-}$</th>
<th>$S_8$</th>
<th>Dibenzothiophene</th>
<th>Thiophene</th>
<th>$S^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration (ppm)</td>
<td>718</td>
<td>1402</td>
<td>300</td>
<td>3705</td>
<td>87</td>
</tr>
</tbody>
</table>

- Water-soluble: SO$_4^{2-}$
- DCM-soluble: $S_8$, dibenzothiophene, thiophene
- FeS is not soluble in water or DCM
DCM Extract

- DCM refluxing 5 hours
- Centrifugation
  - Precipitate
  - Solution
  - Residue A
  - DCM soluble matter
- Rotary evaporation
- GC-MS analysis

Simulant refluxing in DCM
DIBENZOTHIOPHENE STANDARD CURVE

Standard Curve

\[ y = 5 \times 10^{-7}x - 59.567 \]

\[ R^2 = 0.9294 \]

CONCENTRATION (PPM)

CORRECTED AREA
Standard Curves

$S_8$ STANDARD CURVE

$y = 3E-06x + 11.686$

$R^2 = 0.9902$
DCM Extract: GC-MS

Dibenzothiophene

$S_8$
DCM Extract: Results

Sample Calculation: Dibenzothiophene

Extract:

Average corrected area = 434925014.5
Concentration (ppm) = 157.9 ppm (from standard curve)

\[
1 \text{ ppm} = \frac{1 \mu g}{1 \text{ mL}} \quad 157.9 \text{ ppm} = \frac{x \mu g}{2.5 \text{ mL}} \quad x = 394.74 \mu g
\]

Theoretical:

\[
1 \text{ ppm} = \frac{1 \mu g}{1 \text{ g}} \quad 300 \text{ ppm} = \frac{x \mu g}{2.86 \text{ g}} \quad x = 858 \mu g
\]

Percent Yield:

\[
\frac{394.75\mu g}{858 \mu g} \cdot 100\% = 46.00\%
\]

\( S_8 \) percent yield: 45.12%
DCM Extract: NWA 1180

- S oxidized to sulfate in desert
Water Extract

H₂O refluxing 12 hours

centrifugation

precipitate
solution

Residue B

Water-soluble matter

BaCl₂ addition

centrifugation

precipitate
solution

BaSO₄(s)

Water-soluble matter

Simulant refluxing in H₂O

Ba²⁺(aq) + SO₄²⁻(aq) → BaSO₄(s)
Water Extract: Results

Sample Calculation: Extraction 1

Theoretical:

\[
1 \text{ ppm} = \frac{1 \mu g}{1 \text{ g}} \quad 718 \text{ ppm} = \frac{x \mu g}{4.51 \text{ g}} \quad x = 0.00324 \text{ g}
\]

Percent Yield:

\[
\frac{0.00288 \text{ g}}{0.00324 \text{ g}} \times 100\% = 86.42\%
\]

Extraction 2 percent yield: 2829.35%
Water Extract: NWA 1180

- Mass of sulfate recovered: 0.02519 g
- Calculated sulfate concentration in NWA 1180: 4646 ppm
Sulfide Extraction

\[ S^{2-} \text{(aq)} + 2 H^+(\text{aq}) \rightarrow H_2S(\text{g}) \]

\[ H_2S(\text{g}) + 2 Ag^+(\text{aq}) \rightarrow Ag_2S(\text{s}) + 2 H^+(\text{aq}) \]
Sulfide Extraction: Results

Accumulation of $\text{Ag}_2\text{S}(s)$ in $\text{AgNO}_3(\text{aq})$ solution
Future

• Extract sulfur from the remaining meteorites in the MacEwan Collection
  – Isotope ratio determination (Dr. James Farquhar from the University of Maryland)

• Apply techniques to extract sulfur from the Tagish Lake meteorite at the University of Alberta
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