EVOLUTION OF THE EARLY SOLIDS
IN THE SOLAR NEBULA:
METEORITIC EVIDENCE

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## Classification of meteorites

### Meteorite classification

<table>
<thead>
<tr>
<th>Class</th>
<th>Carbonaceous</th>
<th>Ordinary</th>
<th>Enstatite</th>
<th>Nonchondrites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>CI CM CO CR</td>
<td>H L LL</td>
<td>EH EL</td>
<td>Primitive</td>
</tr>
<tr>
<td>Petr. type</td>
<td>1 1-2 3-4</td>
<td>3 3-4 3-6</td>
<td>3-6 3-6 3</td>
<td>Differentiated</td>
</tr>
<tr>
<td>Subgroup</td>
<td>CB&lt;sub&gt;a&lt;/sub&gt;</td>
<td>CV&lt;sub&gt;A&lt;/sub&gt;</td>
<td>EH EL</td>
<td>Single asteroid?</td>
</tr>
<tr>
<td></td>
<td>CB&lt;sub&gt;b&lt;/sub&gt;</td>
<td>CV&lt;sub&gt;B&lt;/sub&gt;</td>
<td>3-6 3-6 3</td>
<td>Acapulcoites</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CV&lt;sub&gt;red&lt;/sub&gt;</td>
<td></td>
<td>Lodranites</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Winonaites</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IAB silicate inclusions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IIICD silicate inclusions</td>
</tr>
</tbody>
</table>

**Achondrites**
- Angrites
- Aubrites
- Brachinites
- Ureilites
  - HED

**Stony irons**
- Mesosiderites pallasites

**Irons**
- IAB*
- IC
- IIAB
- IIC
- IID
- IIE*
- IIIB
- IIICD*
- IIIE
- IIIF
- IVA*
- IVB

*irons with silicate-rich irons
Principal constituents of chondrites:

- refractory Ca,Al-rich inclusions (CAIs & AOAs)
- less refractory Mg,Si-rich chondrules (CHON)
- Fe,Ni metal grains (± troilite, FeS)
- fine-grained, volatile-rich matrix containing fragments of the above components, organics and pre-solar grains

Secondary (asteroidal) processes have altered primordial characteristics of many chondrites
Condensation sequence: A phase diagram of the solar nebula
Characteristics & Interpretation

- **Shape, texture, and structure**
  Nature of the last major modification event (melted or not)

- **Mineralogical composition**
  Mode of crystallization; Physicochemical conditions of the environment

- **Chemical composition**
  Chemical history of the precursors & the object itself

- **Isotopic composition**
  Evaporation/condensation history; Relative and absolute ages; Extent of mixing of different nucleosynthetic materials
Chronology of meteorites & their components

From Kita et al. (2005) ASP Conference series 341, 558-601
SJ101 FoB CAI: Texture & mineralogy

Mg : Ca : Al

3 mm
SJ101: REE pattern & isotopes
SJ101: Chemistry of lithologies

P = 9 × 10^-5 bar
Ti = 0.9
ξ (Hib) = 0.01
ξ (Per) = 0.05
ξ (Sp) = 12
ξ (Mel) = 0.05
T = 1380.4 K
T = 1373.3 K
T = 1372.8 K
T = 1371.1 K

15% Inert + 85% Reactive

Ine: Sp82.5 Mel14.1 Hib2.5 Per0.9
Rea: Cpx87-96 Sp3-4 Fo0-9

Reactive:
Cpx65.7 Fo28.3 Sp2.6 FeNi3.4
### SJ101: Suggested formation scenario

<table>
<thead>
<tr>
<th>Stage</th>
<th>Event</th>
<th>Processes</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Evaporation of dust</td>
<td>Slow cooling, condensation</td>
<td>Gas(1), RS(2), IS(2), IS(3)</td>
</tr>
<tr>
<td>II</td>
<td>Rapid cooling, condensation</td>
<td>Flash heating</td>
<td>Gas(2)</td>
</tr>
<tr>
<td>III</td>
<td>Flash heating</td>
<td>Slow cooling, condensation</td>
<td>Gas(3), Gas(4)</td>
</tr>
<tr>
<td>IVa</td>
<td>Slow cooling, condensation</td>
<td>Mg, Si and Fe condensation</td>
<td>Gas(4), Gas(5)</td>
</tr>
<tr>
<td>IVb</td>
<td>Flash heating (lower intensity)</td>
<td>Accretion of SJ101</td>
<td>Gas(6)</td>
</tr>
<tr>
<td>V</td>
<td>Flash heating</td>
<td>Reaction of SJ101 with gas</td>
<td>Gas(7)</td>
</tr>
</tbody>
</table>

**Components:**
- **Gas**: Gas phase components
- **RS**: Reactive solids
- **IS**: Isolated (inert) solids
- **SRR**: Super refractory evaporation residue
- **Corroded external rim**: Corroded external rim

**Processes:**
- **Evaporation of dust**
- **Rapid cooling, condensation**
- **Slow cooling, condensation**
- **Flash heating**
- **Mg, Si and Fe condensation**
- **Accretion of SJ101**
- **Reaction of SJ101 with gas**

**Products:**
- **Melted rim**
- **Melted CAI**
- **Fo-Cpx**
- **Sp-Cpx**
- **Mel+An+Sp+Cpx cores**

**Notes:**
- SJ101:
  - Suggested formation scenario
  - SRR – super refractory evaporation residue
  - IS – isolated (inert) solids
  - RS – reactive solids
SJ101: Absolute age

$4567.18 \pm 0.21 \text{ Ma}$

$\sim 1.4 \text{ Ma before the Allende chondrules}$

Amelin et al. (2010) EPSL, submitted revised