Some Stages in the Petrogenesis of Ordinary Chondrites: Constraints from Textural Observations
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Some Inspiration

• **Bruce Cockburn**
  “I’m always living and I always die on the event horizon of your eyes.”

• **Albert Einstein**
  “The mind that opens to a new idea never returns to its original size.”
Introduction and Summary 1

• Meteorites contain over 430 different minerals
• Meteoritic minerals formed by more than a dozen basic processes that are not all mutually distinct [1]
• Over 80 % of meteorites are chondrites, predominantly ordinary chondrites
• These possess textures that are similar to some Earth rocks but not necessarily formed in the same way
Introduction and Summary 2

• The challenge is to describe and to sort, chondrule and chondrite textures without favouring particular origins or interpretations [1]
• Stages in their genesis may defined by compiling these observations
• An empirical framework results, within which studies of chondrites may be set
• The textural context of any phases may be stated when reporting analytical results
Chondrule
Methodology and Perspective

• Textures of chondrites can be parsed based on BSE photos of intra-chondrule and inter-chondrule assemblages, in addition to determinations of grade and metamorphism made on the aggregate

• Three approaches are effective:
BSE Mosaic
Questions

• Based on the preserved mineralogy and textures, questions may be posed of each image of a chondrule in its matrix
  • (a) What thing(s) happened first in the genesis of this area of the rock?
  • (b) What thing(s) happened next?
  • (c) What thing(s) happened last?
• This establishes a sequence of textures
Events/Processes

- Another way of analyzing the images is to recognize dominant textures that must therefore have been produced by major events and processes [cf. (b) above]
- To consider what happened before that [cf. (a) above]
- To consider what happened after [cf. (c) above]
- Recognition of events/processes may link the textures to external influences that explain the evolution of the textures in time and space
- An event/process that changes the texture of the phases may be linked to change in P, T and X (pressure; temperature; composition of solid phases or fluids containing them) in open or closed cosmic systems
- E.G. the influence of star-forming regions; dust clouds drawn into but escaping black holes; shock waves from supernovae etc.
Analogues

• A third way of sub-dividing chondrule / chondrite textures is to consider analogues and analogue processes that produce similar-looking products, and to consider if any such processes are relevant to the meteorite textures and mineralogy
Analogue of Chondrules in a Chondrite?
Better: Popcorn!

- Consider a sample of popping corn, made of several different colours of corn, of different grain size, perhaps contaminated by impurities and partially or previous popped corn and fragments thereof…
- The majority of the corn is popped when hot air is introduced in a popping machine (an event/process)
- Depending on physical properties the different kinds/colours of corn “pop” at different temperatures/ times
- The popped corn circulates in the machine until it is perhaps coated in something and removed to be served (2 other events/processes)
- Relics in the machine and in removed samples include the original relics prior to the (most recent) popping incident, plus relics from the latter
- A bag of coated popped corn will cool, soften and clump (another event/process)
Natural Terrestrial Analogues

• The best analogues are Earth rocks, formed in the Earth’s interior or on its surface under variable Pressure (P), Temperature (T), and compositional (X) conditions

• Igneous, Metamorphic and Sedimentary Earth rocks are related by the Rock Cycle
Analogue of a Chondrite?
The terrestrial 2200 myr old Bruce Conglomerate from northern Ontario is an excellent analogue for an extraterrestrial chondrite. It contains different varieties of quartz pebbles, of different sources and provenance, some in excess of 2700 myr old, in a sandstone/quartzite matrix.
Saratov Section
Sedimentology

• Choosing polymictic conglomerates as chondrite analogues emphasizes a parallelism in aspects of their formation
• Sedimentary structure in the Isheyevo meteorite has been reported [4,5]
• Sediments are produced from primary source rocks and minerals that form, outcrop, and are eroded to various kinds of detritus in systems open to PTX changes
• This detritus is transported away from source areas by fluids, and may be altered before being redeposited
• Deposition, erosion, transport, alteration, re-deposition and diagenesis may be repeated multiple times: the Bruce Conglomerate represents 500 myr of sedimentary petrogenesis
Descriptive Scheme

• Relict phases are witnesses of what preceded chondrule formation ((a) above)
• The defining and dominant event/process in any chondrite is chondrule formation. This answers (b) above)
• Later events are chondrule alteration (ongoing (b) above) and incorporation or agglomeration ((c) above)
Alpha to Omega Updated

- These stages can also be related to the $\alpha$ (alpha) to $\omega$ (omega) scheme proposed previously:
  - $\alpha$: relics developed by events/processes prior to chondrule formation (actually $\alpha_{1 - n}$)
  - $\beta$: events/processes and products of chondrule formation and alteration prior to incorporation (actually $\beta_{1 - n}$);
  - $\gamma$: alteration in an agglomerated body ($\gamma_{1 - n}$);
  - $\delta$: hydrous alteration, weathering;
  - $\epsilon$: space weathering; $\sigma$: shock; etc. [2].

- Each stage may be the product of multiple sub-stages/events/processes, and be repeated to result in complex textures
- The $\omega$ (omega) assemblage is the final assemblage of minerals and textures very analogous to the Bruce conglomerate
Observations: Relics

• α: Relict phases are present by definition in each chondrite, because they are the mix of minerals and other particles that gave rise to the ferromagnesian phases, feldspars, glass, spinellids, oxides, carbides, phosphates etc. now present. Textural relics are rarely observed in chondrules and matrix.

• Relics may have multiple provenance and be the products of many prior events/processes.
Observations: Chondrules β1

- β (β1): chondrules ideally form spheroidal bodies but there is a range of shapes included in what are considered chondrule-like bodies. After formation, without interacting with one another, they may be cooled or heated to change their mineralogy and textures. Their formation from previous materials is a definitive event/process.

- Numeric codes to document their textures and to associate those possibly formed in similar ways have been developed [3].
Observations: Chondrules $\beta 2$

- They may also ($\beta 2$):
  - group [6]; un-group;
  - develop overgrowths and rims [7];
  - be abraded physically, chemically or thermally;
  - develop coatings [7];
  - fracture;
  - be weathered;
  - include objects mined from agglomerations and previously annealed.
- Modification after formation is another event/process.
Incorporation: γ1-3

- γ1 +: Once chondrule-like objects are incorporated they are subject to recrystallization of glass, equilibration and loss of zoning (in olivine by grade 4). PTX: heating in a solid body
- γ2: recrystallization of glass to feldspar and pyroxenes, and of both olivine and pyroxene microcrysts (µ) as grade increases (grades 4-6). PTX: Heating at depth in a solid body
- γ3: Eventually textures within and outside of chondrules become recrystallized and merge by grade 6. Evidence of shock along with PTX changes
- Collectively these may be the last events/ processes the meteorite records
- Note that even the most altered texturally and mineralogically may still contain relics of earlier stages of their origin:
  - BO and RP chondrules especially resist complete recrystallization
  - Modification by incorporation is another event/process
Conclusions

• Chondrules and their matrix in ordinary chondrites may be used to define the following sequential textural contexts and events/processes:
• Formation of pre-chondrule relics (α);
• chondrule formation (β1);
• chondrule alteration prior to incorporation (β2);
• chondrule alteration after incorporation (γ)
Conglomerate Analogue 1

- Formation of pre-conglomerate sediment layers containing older minerals and rocks
- These may become relics ($\alpha$) when the sediment layers are eroded, and represent many early events/processes
- Erosion of layers in major detritus-forming events/processes ($\beta1$). The population of pebbles and sand is analogous to chondrules and their matrix
Conglomerate Analogue 2

- Pebbles and sand of different provenance are transported and altered for eons (β2)
- Information on their compositions from recognizable source areas allows comparison with their final compositions
- Pebbles and sand are lithified, made into quartzite while preserving sedimentary history (γ) even though affected by PTX
PTX Changes

• Rocks record processes that made them, through preservation of their minerals and textures through change with time: they evolve

• Chondritic meteorites show evolution, from primitive dust and partially or previously crystallized phases to chondrules, by being heated and cooled

• Chondrules are further processed under thermal conditions, eroded etc. before being aggregated

• Dynamothermal processing, recrystallization and annealing ultimately destroy almost all textures that record their petrogenesis

• These can be recovered by careful observations
References