Comparing Chondrites and Conglomerates

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50th Annual Lunar and Planetary Science Conference
Houston, Texas
March 18-22, 2019

Inspiration

- **Carl Sagan** “Cosmos” [1]

- “Kepler and Newton represent a critical transition in human history, the discovery that fairly simple mathematical laws pervade all of Nature; that the same rules apply on Earth as in the skies; and that there is a resonance between the way we think and the way the world works. They unflinchingly respected the accuracy of observational data, and their predictions of the motion of the planets to high precision provided compelling evidence that, at an unexpectedly deep level, humans can understand the Cosmos.”

Direction

- There is clear direction in the “Cosmos” quotation to researchers to respect observational data from both extra-terrestrial and Earth materials as the basis for theory, in the 21st century as much as those in the 16th and17th centuries did, rather than *vice versa*

- First, observations have to be made using repeatable, understandable methods, and the results systematized

- The making of observations, the gathering of data, forces the observer to look carefully at the observed object(s). It may result in things being seen that have never been noticed before

- Speculation on causes, processes and theories may then proceed

- Theory must fit data--Tycho Brahe’s excellent observational data on the orbit of Mars allowed the formulation of Kepler’s laws of planetary motion

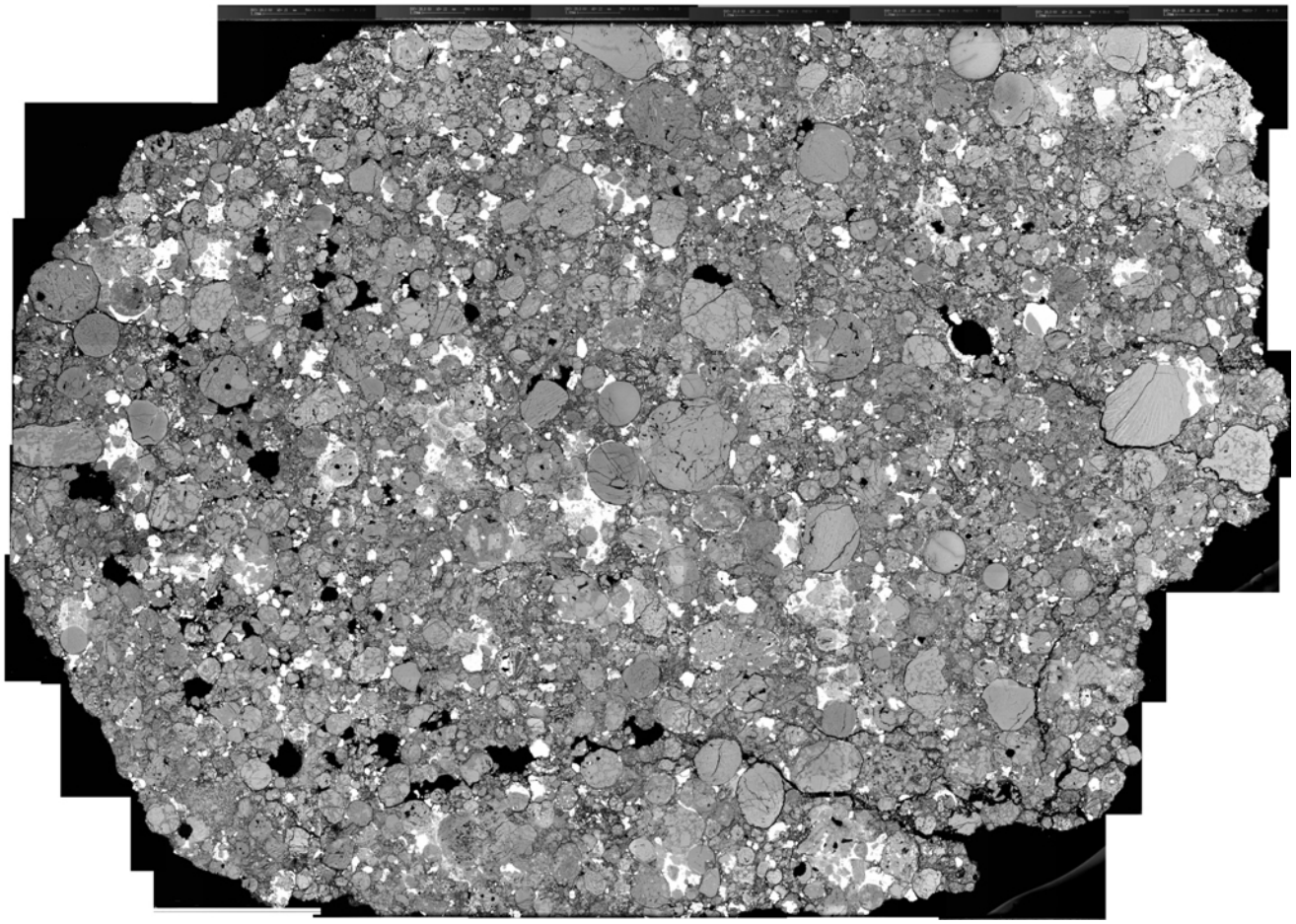
Introduction and Summary

- Textural and structural similarities between terrestrial conglomerates and extraterrestrial chondrites are inescapable

- The fabrics of each are dominated by rounded to fragmental clasts set in finer grained matrices that bind the clasts in the rocks

- Similarities and differences are explored here

BSE Mosaic Saratov L4



Potential Insights

- Chondrites are the largest portion of primitive meteorites, >80 %
- Chondrites are complicated to study and to understand but are not intractable
- Chondrites are aggregates of other rocks, namely chondrules, AOA's, CAI's etc. and other pre-existing chondrite fragments
- Chondrules in chondrites are rocks, made up of primitive minerals, made up of primitive elements
- These primitive meteorites are probably samples from small minor bodies of our Solar System, where primordial "dust and gas" have been sequestered for billions of years after being processed into rocks
- Their study has the potential to provide new insights into what processes are, and have been, at work in galactic, stellar and planetary systems, recognized through textural analysis

Dust and Gas

- Fundamental particles, atoms, elements and compounds are scattered throughout the Universe, or multiple universes if they exist, formed by Big Bang or other, earlier or later, nucleosyntheses

- These constitute the “dust and gas” in space: detritus of cosmic processes, constantly forming and being formed from and by star systems and their planets and satellites, from minor bodies such as asteroids and comets, and from material attracted to black holes e.g. near galaxy cores

- Studies of cosmic dust indicate not all interstellar solids are elements; elements combine to form compounds: some of these are minerals -- solids with specific compositions and crystal structures, i.e. crystalline dust

- Some minerals preserve isotopic and other signatures of their history, e.g. of the types of stars that made them or of later processing

Elements, Minerals and Rocks

- Minerals combined to form aggregates are rocks
- Primitive rocks and their minerals may preserve detailed textural and other evidence of how they were first made and/or later processed
- The above statements apply analogously to space rocks and to Earth rocks, where likewise elements have combined to form minerals, minerals have combined to form rocks and earlier-formed minerals and rocks have been reprocessed multiple times to form new minerals and rocks

Earth Pebbles and Cobbles

Textural Analysis of Chondrules

- Textural analysis to develop nomenclature systems for chondrules and chondrites began with mapping of some polished thin sections of meteorites with BSE imagery
- The first results yielded a means of subdividing the most widely used scheme [2] to group chondrules, into those with similar and different textural components at 4 relative intrachondrule scales [3]
- Further sub-division of [2] is required: using only that scheme leads to treating chondrules simplistically as “igneous textured” or “porphyritic”, implying that all their processing has been “igneous” [4]
- Subdivision of chondrule textures reveals polymodal mineralogy, not necessarily igneous in origin, i.e. not all minerals at all grain sizes in chondrules formed as the result of the same changes in P, T or X (composition)
- Eventually the textural tags of [3] (M =mega, m=macro, µ=micro, and *ms*=mesostasis and modifiers) were expressed in a numbering system that made obvious the textural variations in the occurrence and habits of olivine and pyroxene they represented at the different scales [5]

Textural Analysis of Chondrites

- Study of the BSE images has shown that chondrules in chondrites have variable textures that variably reflect their processing history, in some sort of grouping(s) and sequence(s)

- They formed from primitive material (some of which remains as included relics); were formed into chondrules by some, probably multiple, processes; were then transported and modified during transport; and accumulated into bodies such as proto-planets where they were heated/cooled, equilibrated etc.; and then probably repeatedly experienced all these stages again

- These textural stages were dubbed α, β_1, β_2, and γ, respectively [6,7] with other textural evidence such as shock (σ), hydrothermal alteration/weathering (δ), space weathering (ε) provided for

- The overall textural assemblage of a chondrite is referred to as the ω assemblage

Events/Processes

- Textural stages were seen to be separated by events/processes (ep) [7] suggested by the preserved textures e.g. in grade 3-5 chondrites
- ep0: the formation of the most primitive material, α;
- ep1: the chondrule-forming event in vacuum, gas or plasma, from the most primitive material, resulting in relatively unmodified chondrules, β_1;
- ep2: the chondrule transportation and modification event, resulting in abraded, fragmented and otherwise altered chondrules, β_2;
- ep3: the chondrule incorporation event into some body or their sequestration into reservoirs where they become equilibrated, recrystallized and metamorphosed chondrules, γ .
- With increasing grade their fine-grained textures are increasingly obliterated

WAIFS

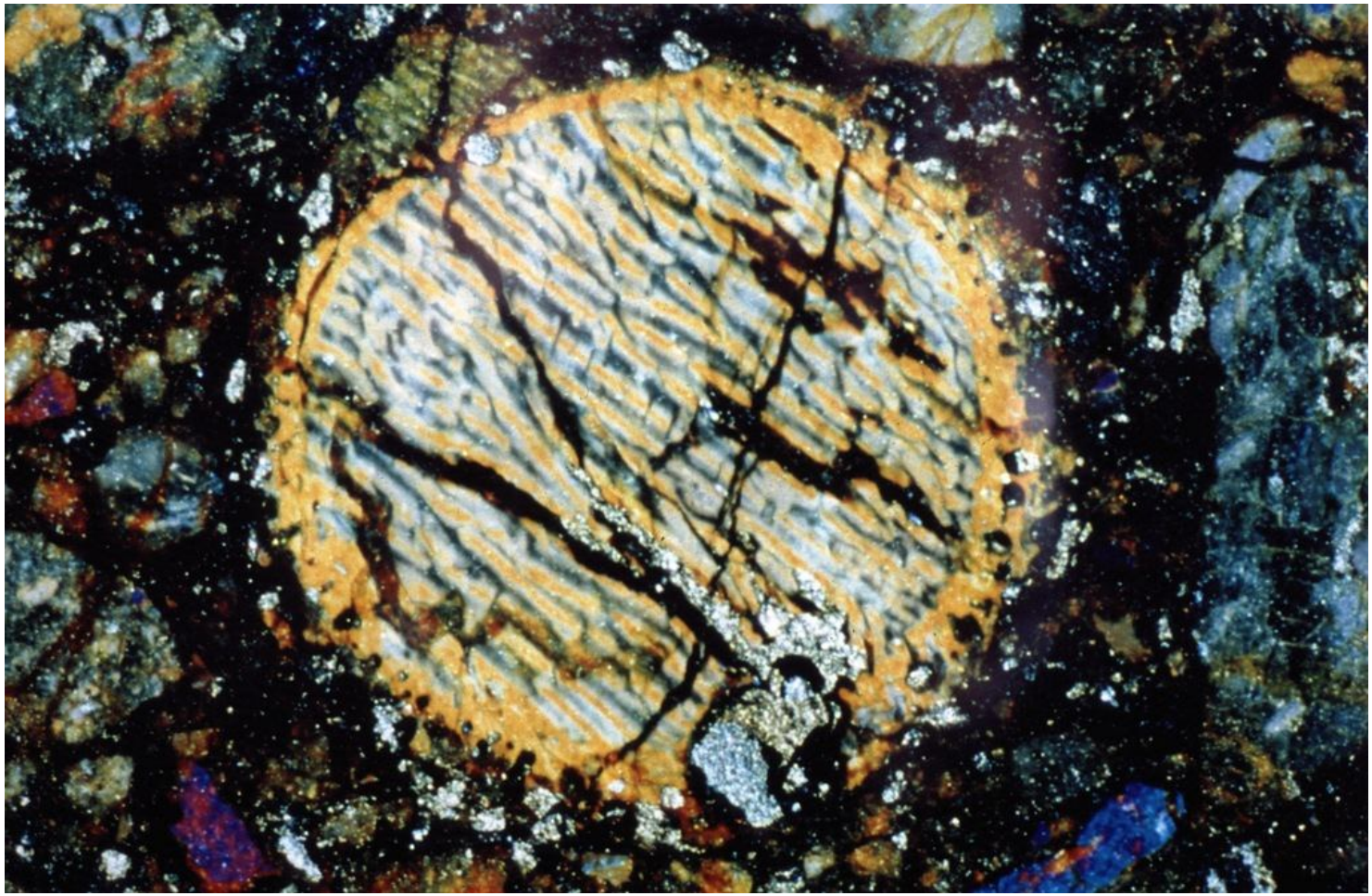
- An additional notation may be used to characterize the preservation and processing of chondrules by observing their margins in chondrule matrices

- w = whole, the chondrule has a distinct margin with no indentations;
- a = abraded, the margin seems to truncate intrachondrule textures;
- i = indented, with re-entrants in the margin;
- f = fragmented, not whole;
- s = sectoral, the fragment seems to derive from a larger chondrule

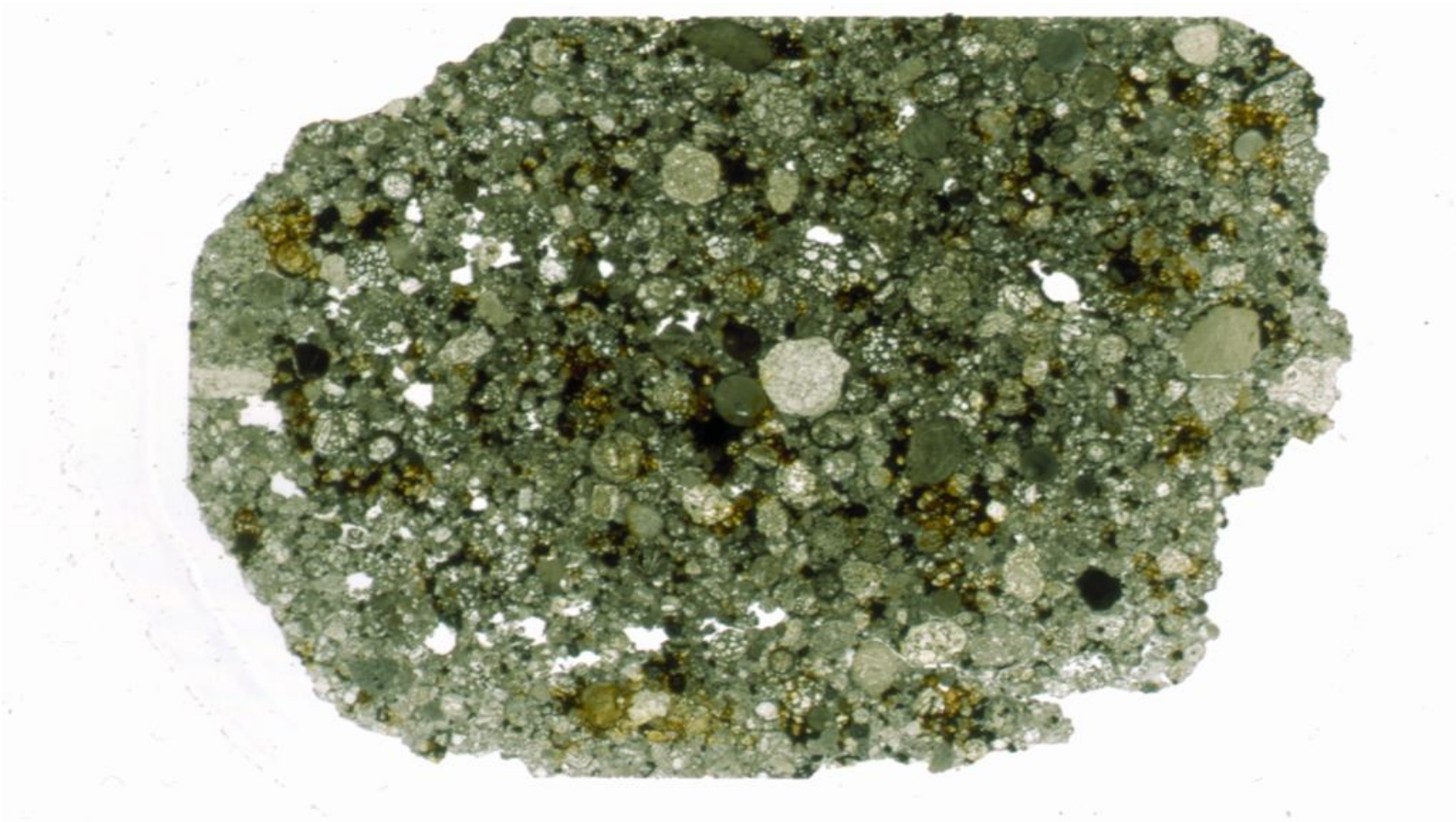
- Not all chondrites, chondrules or chondrule-like objects may be sub-divided in the above ways but many can, and this leads to groupings and separations of these chondrules and meteorites to clarify isotopic and other analyses of their minerals, and of whole rock analyses

- Do these chondrule groupings based on textural analysis coincide with those envisioned as fiefdoms ? [8]

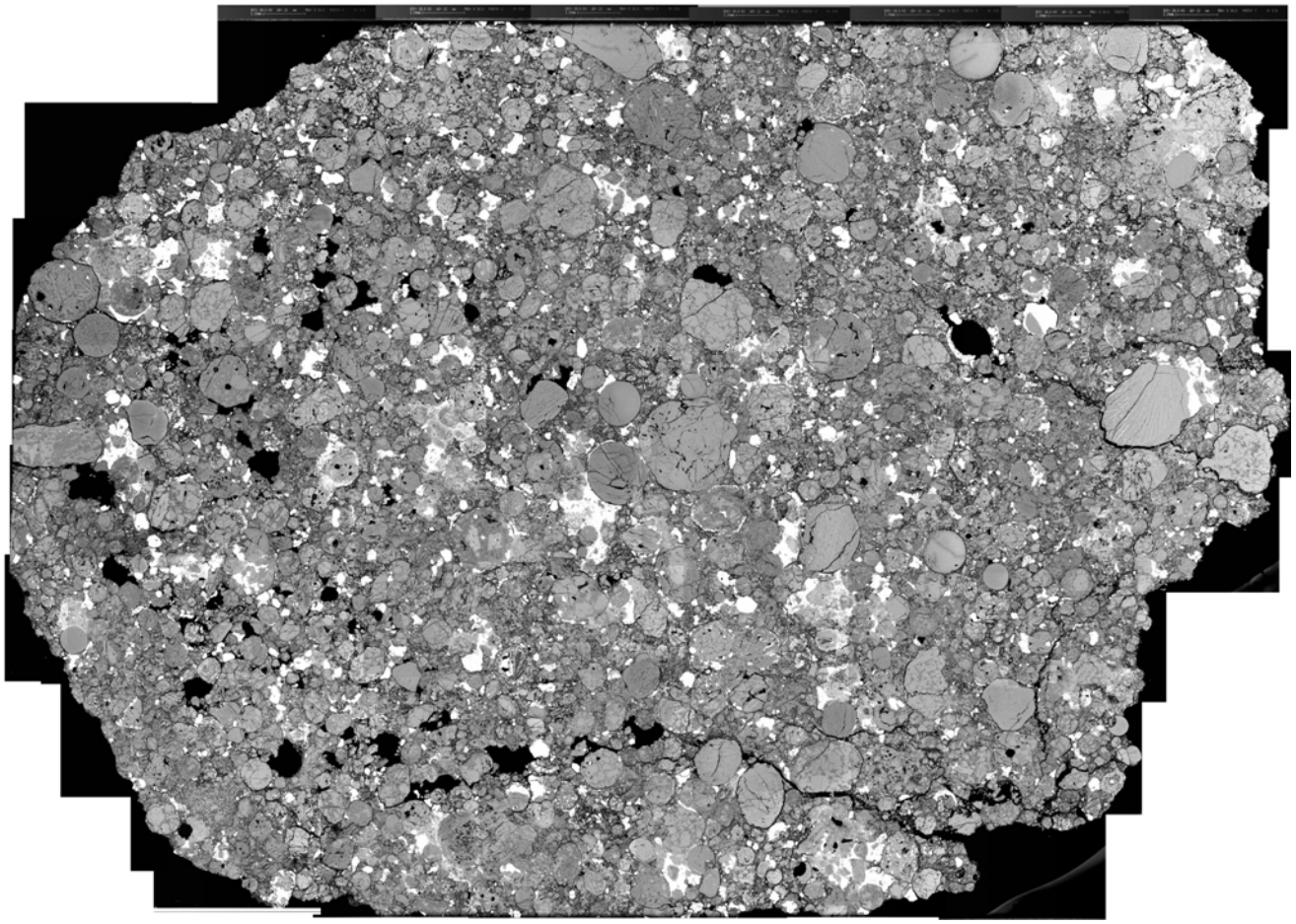
Chondrule



Saratov Section



Saratov BSE Mosaic



Analogues

- Textural analysis as described above includes pattern recognition
- Patterns repeated in Earth rocks and their contained minerals include those associated with heating and cooling, in either liquid or solid states, and those indicating reactions among phases (igneous and metamorphic rocks)
- Erosion, transport and deposition produce fragmental assemblages indicative of comminution (detrital sedimentary rocks)
- Patterns in manufactured substances also may resemble those in rocks: candy, cookies, breads, stews, popcorn; tile, formica, concrete, terrazzo, asphalt etc.

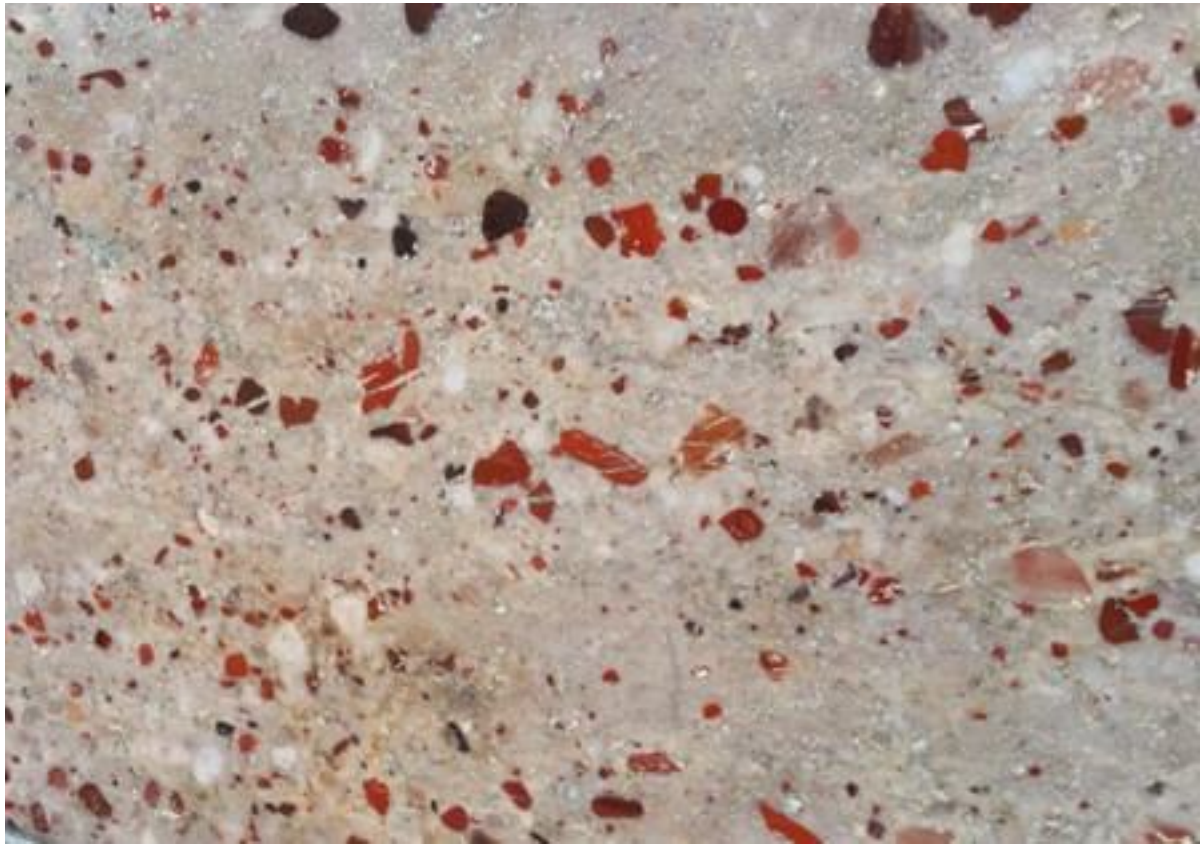
Analogue of Chondrules in a Chondrite? Not Really !

Earth Pebbles and Cobbles

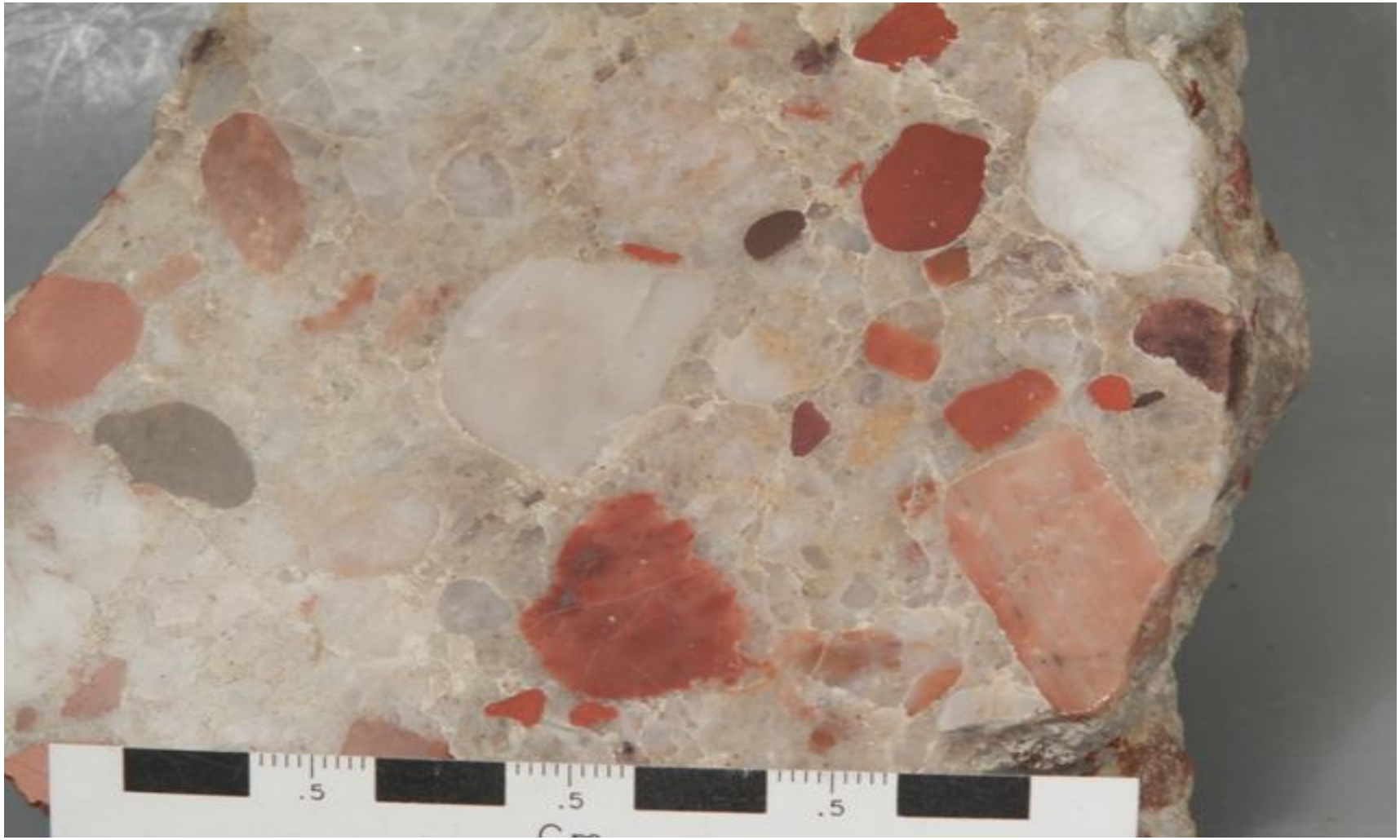
Chondrites = Cosmic Conglomerates

- The BSE mosaic above emphasizes how the L4 chondrite Saratov resembles a conglomerate (field of view about 3.5 cm)
- It looks like a conglomerate. Once the pattern is recognized it becomes obvious and cannot be ignored. It is probably a cosmic conglomerate
- The best natural Earth analogues for chondrites are conglomerates

Analogue of a Chondrite



Detail



Bruce Conglomerate

- This terrestrial 2200 myr old polymictic 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

Sedimentology

- Choosing polymictic conglomerates as chondrite analogues emphasizes a parallelism in aspects of their formation
- Sedimentary structure in the Isheyevo meteorite has been reported [9, 10]
- 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

Conglomerate Analogue 1

- Pre-conglomerate sediment layers containing older minerals and rocks may become relics (α) when the sediment layers are eroded, and represent many early events/processes (ep0)

- Erosion of layers in major detritus-forming events/processes (ep1) produces pebbles and sand analogous to chondrules (β1) and their matrix

Conglomerate Analogue 2

- Pebbles and sand of different provenance are transported and altered (β2) for eons (ep2)

- 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

Implications

- Some characteristics of conglomerates and chondrites are listed in the abstract [11]

- Simply compiling their characteristics together allows questions to be posed about what features of chondrules and chondrites have been ignored or unexamined, features analogous to conglomerates

Questions 1

- (1) From what "terranes" might chondrules have been derived, in other words what differences in chondrule composition and texture define chondrules from different cosmic reservoirs, and are they the same in different chondrites?

- (2) What is the source of the energetic processing of chondrules, the heating and cooling, comminution, sticking together and coming apart, like unto erosion of source rocks and pebbles in conglomerates?

- (3) What fluids or other material surrounded primitive particles and chondrules as they were heated and cooled?

Questions 2

- (4) Where are chondrites and chondrules deposited now, in one set of asteroids or as components of many?
- (5) Was the formation of chondrules and chondrites a marker horizon in the history of our solar system?
- (6) Was such an event/process part of the formation of every planetary system?

Questions 3

- (7) Were some particles in our planetary system derived from other systems?
- (8) What deposits might be found within chondrites?

References

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- [5] Herd R. K. (2017) *80th Annual Meeting of the Meteoritical Society, LPI Contribution No. 1987,* Abstract #6362, p. 64.
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