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Mars Blueberries, origin?
 Hypotheses:
 - Volcanic chemical origin?
 - Sedimentary origin?

- Impact ejecta (e.g. Vredefort crater)
 - Weathering of impact ejecta
- Volcanic (e.g. Hawaii)
 - Ejecta alteration of basaltic igneous
- Sedimentary (e.g. Utah, Czech)
 - Eolian precipitation
 - High NH4+ and iron(II) analog studies integrated with hydrothermal (alkaline) environments for diagenetic aqueous solution formation

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Impact origin of hematite in sediments on Mars (e.g. Knauth et al., 2005)

- Deposition and subsequent weathering during a ground turbulent flow of impact surge deposits:
 - Irregularly weathered forms persist from original iron impact surge deposits
 - No shallow bodies of water necessary
 - Cross-bedding is common in surge deposits

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Hematite spherules in basaltic sands on Hawaii (e.g. Wolf et al., 2003)

- Hematite spherules (10 - 100 μm) in basaltic sands with spherulitic nodules formed by aqueous, acid-sulfate alteration of basaltic igneous
- Spherulitic nodules formed from iron-bearing concretions, cylindrical forms with concentric spherulitic radial patterns
- Spherules contain magnetite and the hydroxide mineral goethite (major mineral) and hematite
- Spherules formed diagenetically in basaltic sands or by alteration of basaltic sands and subsequent hydrothermal alteration
- This process formation path is similar to hematite spherules in basaltic sands of the Hawaiian Islands (Hawaii formation)
- Hydrothermal conditions would be required for hematite formation on Mars (they are not formed by hydrothermal conditions at low temperatures)

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Hematite/Goethite nodules strikingly resemble Mars "blueberries" (e.g. Chan et al., 2004)

- Mars blueberries are concentrated by weathering out from the parent sedimentary rock. The same process occurs in Utah in Navajo sandstone formation
- Concretions are thought to be formed by oxidizing fluid that causes the iron held in ion saturated solution to precipitate out and form these nodules.

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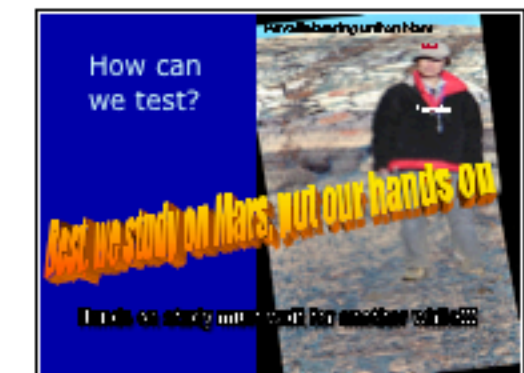


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Hematite bearing unit on Mars (e.g. Christensen and Wolf, 2003)

- Deposition of hematite in weathered basaltic
 - Uniform deposits of hematite (10-100 μm) over large areas
 - Shows vertical weathering hematite - iron oxides
 - Goethite as precursor of hematite
 - Hematite soil formation
 - Lack of hydrothermal minerals
 - Coarse grained basaltic sandstone formation

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Magnetic Analyses of concretions - how can they help?

- Terrestrial Utah and Czech Concretions are similar and carry significant magnetic signal
- Magnetic signal can be used for mapping the history of Mars' Earth magnetic field
- Magnetic analyses can be implemented on Mars

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Terrestrial Hematite concretions

- Show striking similarities to the hematite spherules in basaltic sands on Mars (Hawaii)

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Sedimentary and hydrothermal

- Concretions are thought to be formed by oxidizing fluid that causes the iron held in ion saturated solution to precipitate out and form these nodules.

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Mars spherules

- Hematite and Goethite nodules identified by Mössbauer spectroscopy

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Terrestrial Concretions

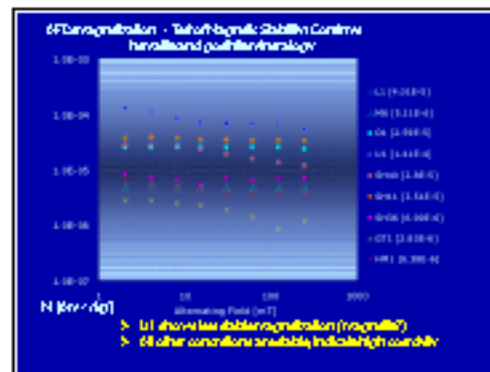
- Hematite and Goethite nodules identified by Mössbauer spectroscopy

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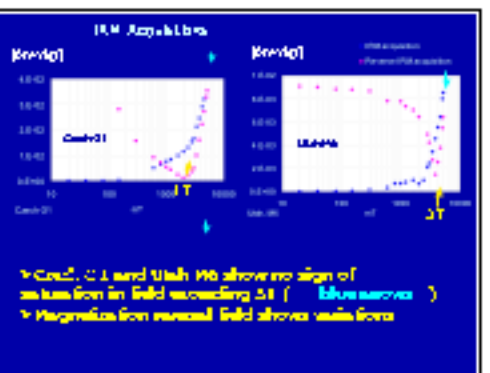
Magnetic Characterization

- Composites: Hematite and Goethite
- Method of magnetic characterization:
 - Common techniques of rock magnetism:
 - Natural Remanent Magnetization (NRM)
 - Alternating Field Demagnetization (AF Demag)
 - Isothermal Remanent Magnetization (IRM)
 - Saturation Magnetization (M_{sat})
 - IRM-Hemalite curves
- Peak: Paleofield

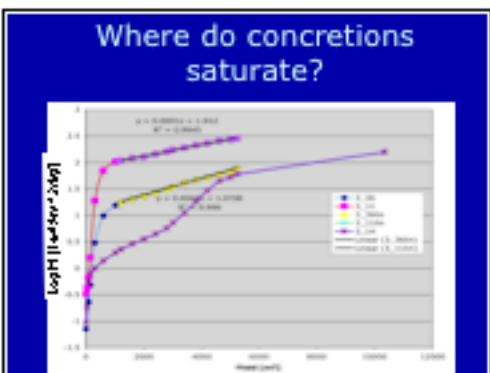
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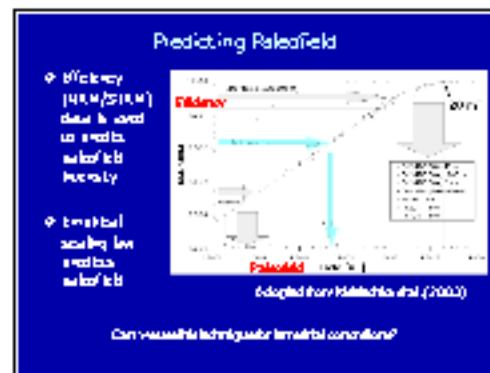
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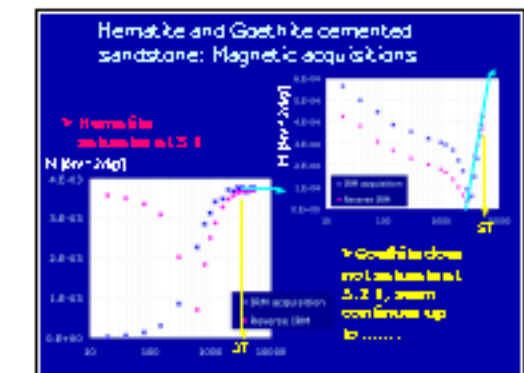


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What are the concretions made out of?

- Microscopic observations reveal many of concretions (mostly quartz in Utah and quartz with hematite in Czech concretions, respectively)
- These concretions are associated with hematite and goethite
- While hematite concretions are associated with goethite (yellow) or hematite (red) concretions (white) (bleached concretions)
- Such concretions are formed for magnetic minerals to undergo oxidation to hematite or goethite within the concretions

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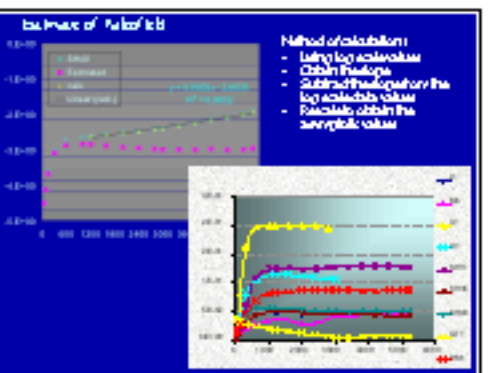


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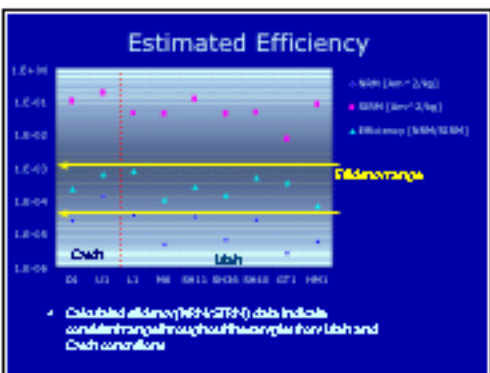
How to get paleointensity from concretions?

- Method of calculation:
 - Using log-log plot
 - Obtain the slope
 - Subtract the slope from the log-log plot
 - Result: obtain the paleointensity

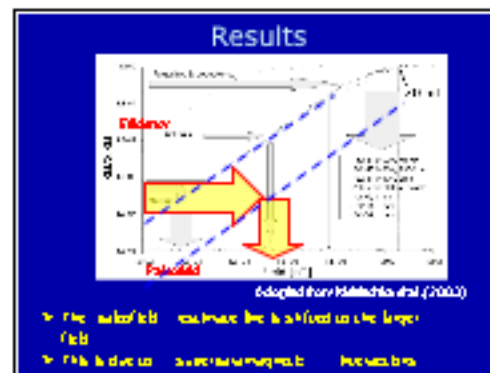
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Conclusions

- Eolian concretions, spherules formed by rapid erosion of basaltic sands and hematite nodules (Hawaii) contain hematite and goethite (Czech) concretions also contain hematite and goethite
- Hematite component reaches magnetic saturation by 10 T
- Goethite component does not show signs of magnetic saturation up to 10 T
- Superparamagnetic behavior is observed for both hematite and goethite
- For Utah and Czech concretions, paleointensity estimation is not possible to hematite and goethite
- Demagnetization curves were used to estimate paleofield (H₀) for the hematite and goethite

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