Matrix in carbonate impact breccias: Comminution *and* precipitation from supercritical water (SCW)?

Missouri State UNIVERSITY

Kevin R. Evans[1]
Matthew P. McKay[1]
Ridwan Sakidja[2]

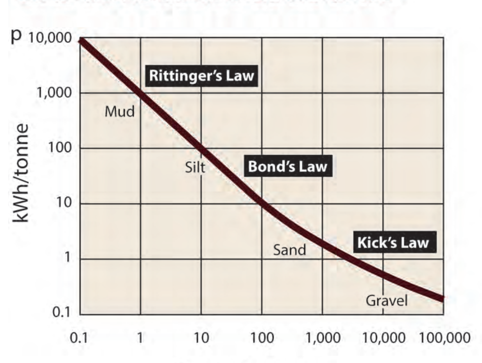
[1]Department of Geography, Geology, and Planning
[2]Department of Physics, Astronomy, and Material Science

Abstract. It is widely held that large meteorite impacts generate breccia matrix through the process of comminution. Fine-grain particles in matrix form from fragmentation of the target rock through blasting, fracturing, crushing, cleaving, grinding, and vibration. The component particles of impact breccia matrix also can include melt that retain geochemical traces related to the impactor. Particles ultimately are cemented together, and diagenesis follows. An additional, potentially significant, yet previously unrecognized, component in generating matrix particles may be mineral precipitates from supercritical water (SCW), especially in carbonate target rock successions and marine impacts.

SCW occurs under high pressure and temperature, beyond a thermodynamic critical point at 22 MPa and 374 °C. SCW has many of the characteristics of a gas but behaves as a relatively low-density fluid with distinctive properties. SCW exists dominantly as monomeric molecules that lack surface tension, viscosity, and the attendant solubility characteristics of subcritical water. With this lack of solubility, salts are precipitated. For example, supercritical water oxidation (SCWO) reactors have seen application in treatment of water contaminated with miscible hydrocarbons, sludge, and other pollutants.

Meteorite impacts generate both extreme pressure and temperature that greatly exceed conditions necessary for the formation of SCW. Large impacts are recognized from features such as high-pressure polymorphs of silicate minerals (> 2 GPa), shatter cones (2 – 30 GPa), and planar deformational features (PDFs) in quartz (5 – 35 GPa). Substantial melts occur in impacts at pressures ≥ 40 GPa. In the contact and compression phase of impact cratering, near ground zero, temperatures are thought to exceed 2000 °C. Even the residual heat of impact would keep temperatures elevated for an extended time; hydrothermal geochemical signatures are common in impact breccias. Given that roughly one-third of large, ancient impact structures (~50) are found in carbonate target successions, and several of these are regarded as marine impacts, the potential for forming SCW-precipitated particles in breccia matrix may be appreciable. Thermobarometry potentially provides a key test for this hypothesis.

Comminution



Comminution is the process of reducing particle size within a material. The process may involve blasting, fracturing, crushing, cleaving, grinding, and vibration.

The energy required for comminution is approximated by a logarithmic increase in work required for generating finer particles. At different grain sizes, different laws govern the relationship between energy required, original particle size or surface area, and the reduced particle size or surface area.

Kick's Law states, "The work required for crushing is constant for a given reduction ratio irrespective of original size."

Bond's Law states, "The work required to particles of size d_p fram a very large particle size is proportional to the square root of the surface to volume ratio (s_p/v_p) of the product."

Rittinger's Law states, "The work required for size reduction is directly proportional to the new surface area created."

Background: Comminution requires an enormous amount of energy in generating the abundant fine particles found in impact breccias. Conditions exist in the transient craters for formation of supercritical water (SCW).

Question: Might carbonate precipitation from SCW add a significant volume to a carbonate impact breccia matrix?

Test: Examine carbonate breccia matrix with SEM/EDS to determine microfabrics.

Prediction: Matrix should consist of recrystallized aragonitic cements (inversion), not exclusively spalled grains in grain-to-grain contact.

Kick's Law

$$\frac{E}{M} = K_K \ln\left(\frac{D_i}{D_p}\right)$$

E = Energy required for crushing mass (*M*) in kg

K_K = Kick's Constant

$\frac{D_i}{D_p}$ = R (reduction ratio) = diameter initial/product particle

Bond's Law

$$\frac{E}{M} = K_B\left(\sqrt{\frac{1}{d_p}} - \sqrt{\frac{1}{d_i}}\right)$$

E = Energy required for crushing mass (*M*) in kg

K_B = Bond's Constant

d_p = diameter of product particle

d_i = diameter of initial particle; where d_f is large this term drops out

Rittingers's Law

$$\frac{E}{M} = K_R\left(s_p - s_i\right)$$

E = Energy required for crushing mass (*M*) in kg

K_R = Rittinger's Constant = 1/Rittinger's Number

s_p = surface area of product particle

s_i = surface area of initial particle

Comminution of small particles requires an enormous amount of energy, yet many impact breccias are matrix supported. Rittinger's Law applies to the finest grain sizes. Rittinger's Number is obtained by drop weight test.

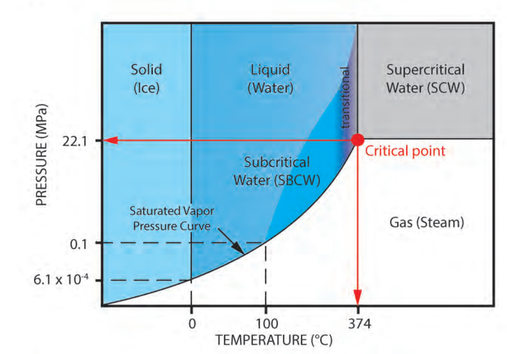
Material	Rittinger's Number (m^2/J)
Galena	0.0957
Sphalerite	0.0573
Pyrite	0.02303
Quartz	0.0179
Calcite	0.07745

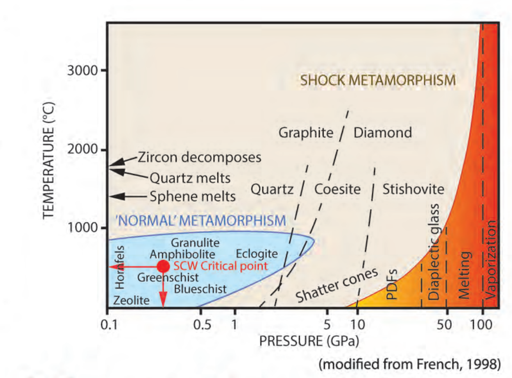
At some point in the comminution process, it becomes more efficient to transport particles rather than to continue the comminution process.

Supercritical Water (SCW)

Super critical water (SCW) is a fourth state that forms at high temperature (647.1 °K) and high pressure (22.06 MPa). Meteorite impacts are capable of generating these conditions. The behavior of SCW is described as having properties of both gasses and liquids. These include low solubility of inorganic solids because of the reduced polarity, and salts are precipitated (Skerget, et. al. 2011).

In contrast, subcritcal water (SBCW), between 373 °K and 575 °K, is capable of dissolving hydrophilic substances. Of course, a reduction in temperature causes particles to prcipitate crystals in the range of 0.5 to 100 µm.





(modified from French, 1998)

Case Study: Weaubleau Breccia

Recovery of shocked quartz, including abundant grains with multiple directions of planar deformational features (PDFs), together with localized intense structural deformation, provides evidence of a meteorite-impact origin for the mid-Mississippian (latest Osagean or early Meramecian series) Weaubleau structure in west-central Missouri. The structure encompasses an area of intensive (proximal) to gentle (distal) structural deformation in a stable platform setting.

Seven distinctive breccia and conglomerate facies, as well as pervasive fractures, faults, and folds are found in the dominantly carbonate target rock. The structure is outlined by two eccentrically orientated annular stream drainage systems that are coincident with areas interpreted as the main impact area, 8 km diameter, and tectonic rim, 19 km diameter. A Bouguer gravity anomaly map indicates uplift located at depth in the central part of the main impact area. Granitic clasts in a crystalline basement conglomeratic facies in drill core from the eastern part of the main impact area shows minimally 500 m of uplift of basement material. From the main impact area outward, a fan-shaped field of deformation indicates down-trajectory structural transport that dies out laterally with decreasing depth. Shallowly focused differential deformation within the tectonic rim primarily is due to variation in material strength of the stratified target succession: incompetent siltstone beds in the Northview Formation served as a décollement, locally separating allochthonous from parautochthonous structural domains. The eccentricity of the structure is consistent with a model for low-angle, northeast-directed (paleogeographic east) impact. Sedimentary structures in the uppermost breccia facies and narrowly constrained biostratigraphic age dates indicate a marine impact.

SEM imagery and EDS analysis was made of the uppermost breccia facies to examine the relationship between clasts and cement. This effort is preliminary but may provide some insight into the role of supercritical water on the precipitation of cements in carbonate impact breccias.

References

French, B., 1998, Traces of catastrophe: *Lunar and Planetary Institute Contribution,* no. 954, 120 p.

Skerget, M., Knez, Z., and Knez-Hrncic, M., 2011, Solubility of solids in sub- and supercritical fluids: a Review: *Journal of Chemical an Engineering Data*, v. 56, pp. 694-719.

Acknowledgments

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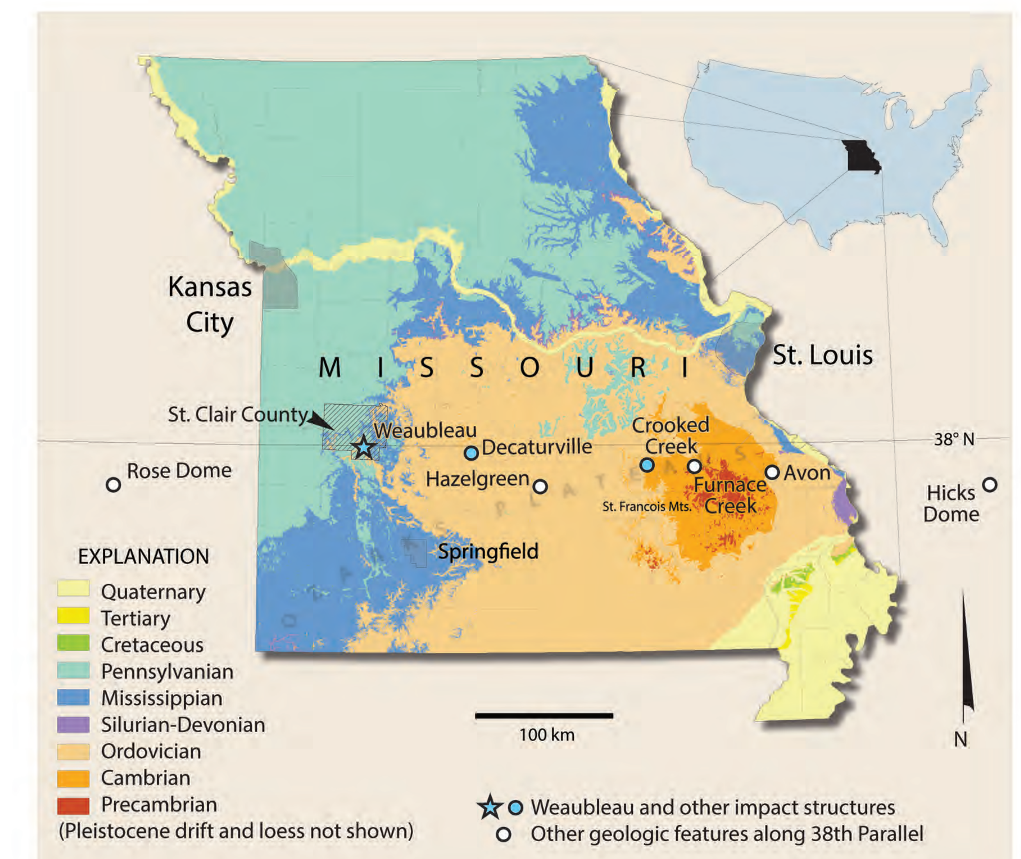
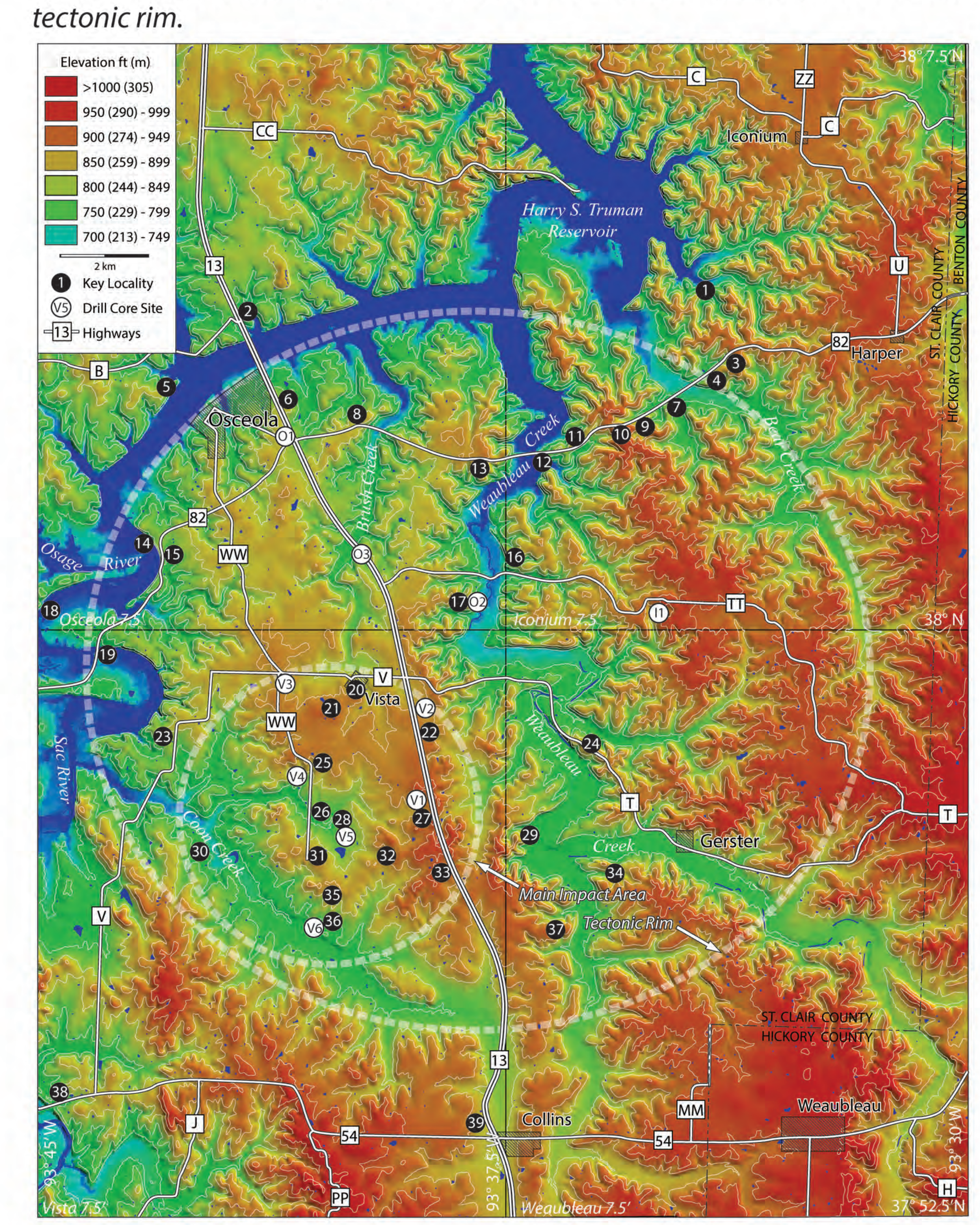
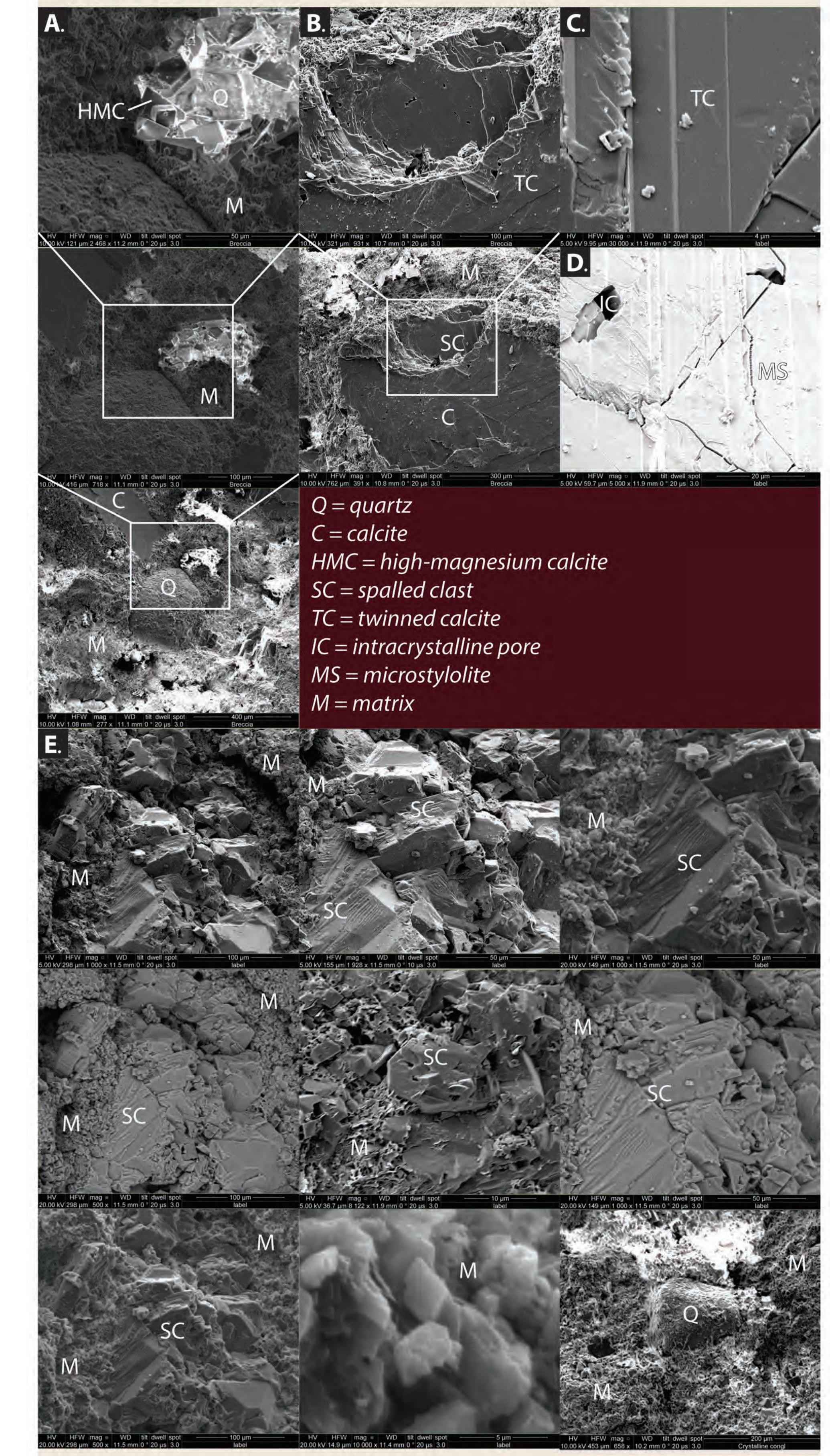


Weaubleau impact structure is located in west-central Missouri. It is aligned with Decaturville and Crooked Creek impact structures. Weaubleau is outlined by two eccentric drainages that are coincident with the main impact area and tectonic rim.



Results



A. Spar-filled vug on border of quartz and calcite grain is an early diagenetic, hydrothermal feature. Borders of calcite and grains are outlined with finely crystalline euhedral calcite. Surface of quartz grains is siliceous despite the rough appearance of euhedral carbonate crystal faces.
B. Spalled calcite grain is overlapped by fine-grain euhedral calcite cement. Note calcite twinning in association with spalled surface. The fracture pattern is consistant with it being an ancient fracture rather than preparation-induced feature.
C. Twinned calcite grain.
D. Twinned calcite grain with microstylolite and cross-cutting intracrystalline pore indicates that this feature likely was induced during impact.
E. Matrix, spalled clasts, and quartz grains. Matrix is dominantly composed of euhedral calcite.

Summary

Testing the idea that precipitation from supercritical water potentially could be a major source of carbonate cementation in carbonate impact breccias is difficult. What cements have recrystallized? What components were precipitated under quasi-normal diagenetic conditions. Even under SEM imagery it is difficult to determine clast origins and the relative sequencing of events that induced spalling. More work is needed. Stay tuned. Or, better yet, work with me in trying to figure out this conundrum. The idea is sound.