THE MECHANICAL BEHAVIOUR AND FAILURE MODES OF SUEVITE. M. J. Heap[1], P. K. Byrne[2], H. A. Gilg[3] and T. Reuschlé[1], [1]Institut de Physique de Globe de Strasbourg (UMR 7516 CNRS, Université de Strasbourg/EOST) 5 rue René Descartes, 67084, Strasbourg, France (heap@unistra.fr), [2]Planetary Research Group, Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695, USA, [3]Lehrstuhl für Ingenieurgeologie, Technische Universität München, Munich, Germany.

Some of the data presented here can be found in: Heap, M.J., Gilg., H.A., Hess, K.-U., Mertens, L., Pösges, G., and Reuschlé, T. (2019). Conservation and restoration of St. George's church (Nördlingen, Germany), a 15th century Gothic church built using suevite from the Ries impact crater. *MAPS*. In revision [1].

Introduction: The surfaces of planetary bodies are often pockmarked with impact craters [2]. High-energy impacts can produce clouds of shattered and molten rock that radiate from the impact site and deposit to various distances a blanket of poorly-sorted clastic material [3]. The proximal high-temperature deposit can then weld to form rock, called suevite. Due to the abundance of ejecta deposits on planetary bodies, an understanding of their physical properties, mechanical behaviour, and failure modes (i.e. brittle or ductile) may help improve, for example, estimates of physical weathering rates [4] and crustal strength [5], the modelling of fluid flow in the hydrothermal systems associated with impact craters [6], and the determination of fluid pressures in crustal aquifers [7]. However, the preservation of complex impact craters with proximal ejecta deposits is very rare on Earth, largely due to erosion and tectonic activity [8]. However, the Reis impact crater in Germany (Fig. 1), a double-layer rampart crater that shares striking similarities to craters on Mars [9], offers an opportunity to sample impact ejecta rocks to study in the laboratory. Here we present the initial findings of a study designed to explore the physical properties, mechanical behaviour, and failure modes of hydrothermally altered suevites collected from the Reis impact crater.

Experimental Materials: Blocks of suevite were collected from three quarries: Aumühle, Altenbürg, and Seelbronn (Fig. 1). The blocks from Aumühle and Altenbürg (yellow–green in colour) are visibly more hydrothermally altered than the block from Seelbronn (blue–grey in colour; Fig. 2). All of the blocks collected are poorly sorted clastic rocks that contain millimetre- and centimetre-sized clasts of "glass" (aerodynamically shaped bombs and angular fragments), crystalline rocks, and sedimentary rocks within a fine-grained matrix (Fig. 2). Backscattered scanning electron images of the suevite blocks highlight that they are microstructurally complex, containing poorly sorted angular fragments (of quartz, calcite, K-feldspar, plagioclase) within a fine-grained matrix (Fig. 3). The images also show that the suevites are pervasively microcracked (Fig. 3).

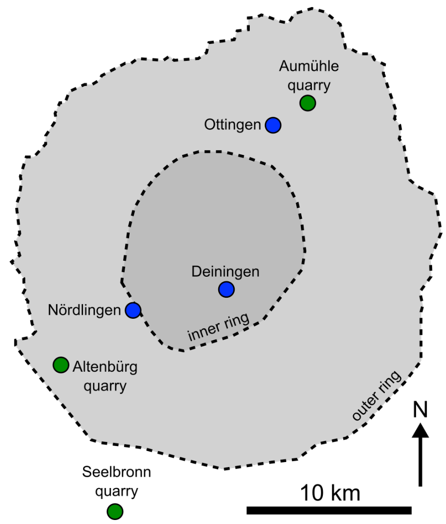

Fig. 1. Map showing the inner and outer ring of the Reis impact crater (Germany). The three rock collection sites (green circles) are highlighted. Modified from Heap et al. [1].

The suevites from Seelbronn and Altenbürg contain amorphous phases, smectite, and plagioclase, with minor quartz, coesite, K–feldspar, calcite, biotite, and hematite, as revealed by X–ray powder diffraction. Microstructural and mineralogical analyses of the blocks from Aumühle will be completed in early 2019.

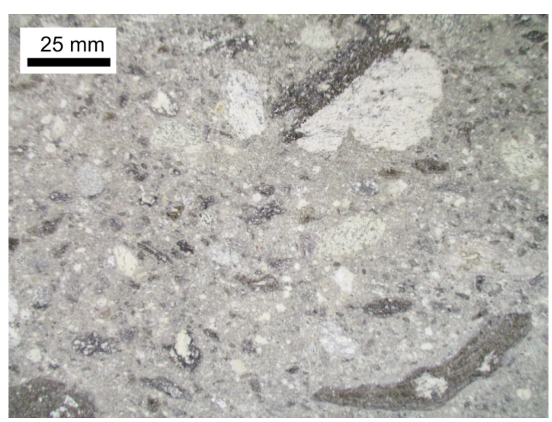

Fig. 2. Photograph of the surface of the block from Seelbronn. Modified from [1].

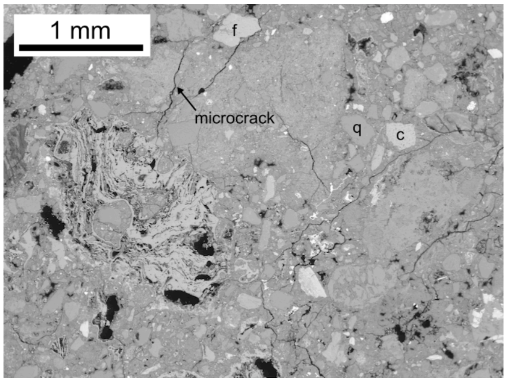

Fig. 3. Backscattered scanning electron microscope image of a sample of Seelbronn suevite. Modified from [1]. f–K–feldspar; c–calcite; q–quartz.

Experimental Methods: Multiple cylindrical core samples were prepared in the same orientation from each of the blocks. The porosities and permeabilities (permeability measured under a confining pressure of 1 MPa) of the samples were measured using a helium pycnometer and a nitrogen-gas benchtop permeameter [10], respectively. Finally, the samples were either deformed uniaxially (σ_2 and σ_3 = 0 MPa) in a uniaxial loadframe or triaxially (σ_2 and σ_3 > 0 MPa) in a triaxial deformation apparatus. All tests were performed on dry samples.

Results, Discussion, and Outlook: Average connected porosities for the suevite blocks from Altenbürg and Seelbronn were 0.238 and 0.245, respectively. Their average permeabilities were essentially identical: ~2×10^{-15} m^2. An example uniaxial stress–strain curve for a suevite sample from the Seelbronn quarry is presented as Fig. 4. The features of the curve are typical for rocks deformed in compression. Uniaxial compressive strength as a function of porosity for both Altenbürg and Seelbronn samples is shown in Fig. 5. These data show that the strength of the suevite tested ranged from ~20 to ~50 MPa. The strength of these deposits (a cohesionless deposit that welded to form rock with a strength up to ~50 MPa) may contrast with pervasively damaged lithologies within or adjacent to the crater, influencing large–scale deformation. The physical properties and strength of the blocks from Aumühle will be tested in early 2019. Pilot triaxial experiments on samples of Seelbronn suevite (confining pressures between 5 and 80 MPa) show that suevite transitions from a brittle deformation mode (the formation of shear fractures) to a ductile deformation mode (cataclastic pore collapse) at a confining pressure between 20 and 30 MPa (a depth of ~2–3 km on Mars and Mercury and ~4–6 km on the Moon). Large ejecta blankets could therefore act (or have acted) as, for example, low-strength crustal layers sandwiched between high-strength basaltic lava that focus large–scale deformation (i.e. décollement surfaces). Future experiments (early 2019) will focus on investigating the influence of hydrothermal alteration on the strength and failure mode (brittle or ductile) of suevite. We anticipate that these data can be used assist in our understanding of impacted planetary bodies.

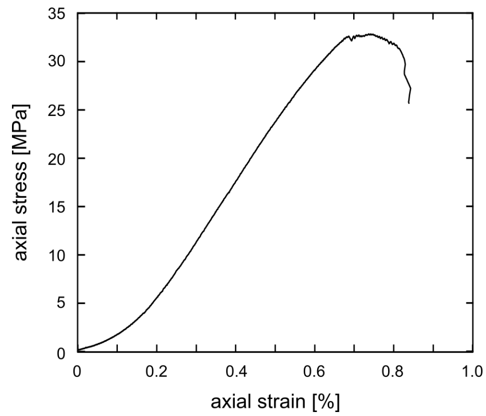

Fig. 4. Stress–strain curve for a sample of Seelbronn suevite deformed under uniaxial conditions.

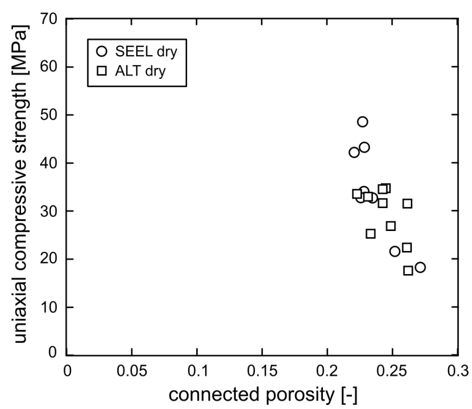

Fig. 5. Uniaxial compressive strength of suevites from Altenbürg and Seelbronn as a function of connected porosity. Modified from [1].

References: [1] Heap M.J. et al. (2019) *MAPS,* in revision. [2] Robbins S. J. and Hynek B. M. (2012) *JGR, 117,* https://doi.org/10.1029/2011JE003966. [3] Siegert S. et al. (2017) *Geology, 45,* 855-858. [4] Eppes M. C. et al. (2015) *Nat. Comm., 6*: 6712. [5] Klimczak C. (2015) *JGR, 120,* 2135-2151. [6] Rathbun J. A. and Squyres S. W. (2002) *Icarus, 157,* 362-372. [7] Hanna J. C. and Phillips R. J. (2005) *JGR, 110,* https://doi.org/10.1029/2004JE002330. [8] Grieve R. A. and Shoemaker E. M. (1994) In: *Hazards due to Comets and Asteroids*, pp. 417-462. [9] Sturm S. et al. (2013) *Geology, 41,* 531-534. [10] Heap M.J. and Kennedy B. M. (2016) *EPSL, 447*, 139-150.