The “suevite” conundrum, Part 1:
The Ries suevite and Sudbury Onaping Formation compared

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Background:

The term “suevite” has been applied to various impact melt-bearing breccias found in different stratigraphic settings within terrestrial impact craters. Suevite was coined initially for impact glass-bearing breccias from the Ries impact structure, Germany, which is the type locality. “Suevite” is currently defined as a polymict breccia with a particulate matrix, containing lithic and mineral clasts in all stages of shock metamorphism, including impact melt particles (Stöffler and Grieve 2007). The use of *particulate* to describe the matrix replaced the earlier use of *clastic* (Stöffler 1977). This was in response to the discovery that some Ries suevite samples have melt material in the matrix (Osinski et al. 2004). This change exemplifies the inherent dynamic nature of the definition of specific lithologies in that they are arbitrary and evolve, with changing technology and understanding of their genesis. Since the original discovery of suevite at the Ries and the conclusion that it was produced by impact processes, the occurrence of so-called “suevite” has been described at a large number of impact structures (e.g., Masaitis 1999; Dressler and Reimold 2001) and from a variety of geological and spatial contexts within impact structures.

Various working hypotheses have been proposed to account for the formation of the Ries suevite deposits over the past several decades (Stöffler et al. 1977; Engelhardt and Graup 1984; Newsom et al. 1990; Bringemeier 1994; Osinski et al. 2004; Meyer et al. 2011), with the most recent being molten-fuel-coolant interaction (MFCI) between an impact melt pool and water (Artemieva et al. 2013; Stöffler et al. 2013). This mechanism is also the working hypothesis for the origin of the bulk of the Onaping Formation at the Sudbury impact structure, Canada (Grieve et al. 2010).

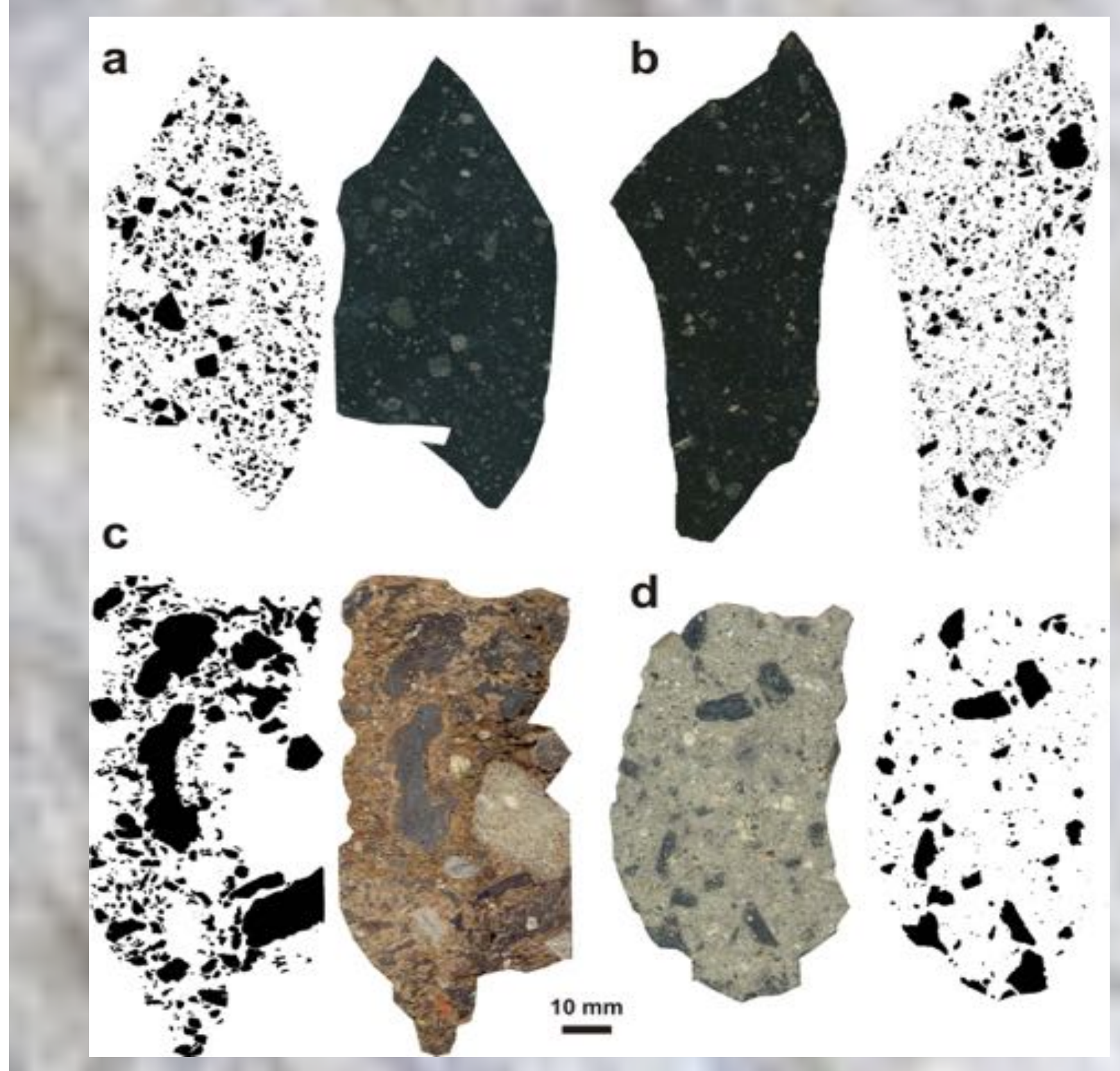

Fig. 1. Scanned polished slabs and processed images of the Sandcherry Member of the Onaping Formation (a, b) and outer suevite (c, d). (a) Onaping Formation sample ONP-3b from Onaping Falls. (b) Onaping Formation sample OS-5 from the East Range. (c) Ries suevite sample W-50.2 from the Wörnitzostheim drillhole (depth 50.2 m) (d) Ries suevite sample RI-05-007 from the Aumühle quarry. The black areas in processed images correspond to vitric phases. Note differences in size and shape variants in vitric clasts between Onaping Formation and Ries suevite.

This Study (Accepted in *MAPS*):

In this study, the key characteristics of the Ries suevite, the Onaping Formation, and MFCI deposits from phreatomagmatic volcanic eruptions are compared. In virtually every instance, there are clear and significant lithological, stratigraphic, and petrographic differences between the Onaping Formation and the Ries suevite (Table 1). It follows from the fundamental principles of geology that these two rocks types cannot, therefore, share the same history and formation mechanism(s). Unlike the Ries suevite, the Onaping Formation shares many similarities with MFCI deposits (Table 1) (Büttner et al. 2002; Wohletz et al. 2013), most important of which are that both these deposits are layered, well sorted, relatively fine-grained, dominated by vitric particles with similar shapes, and deposited at relatively low temperatures. These differences argue against the viability of MFCI as a working hypothesis for genesis of the Ries suevite and for a required alternative mechanism for its formation. We propose the ejecta emplacement model of Osinski et al. (2011) is valid for the Ries.

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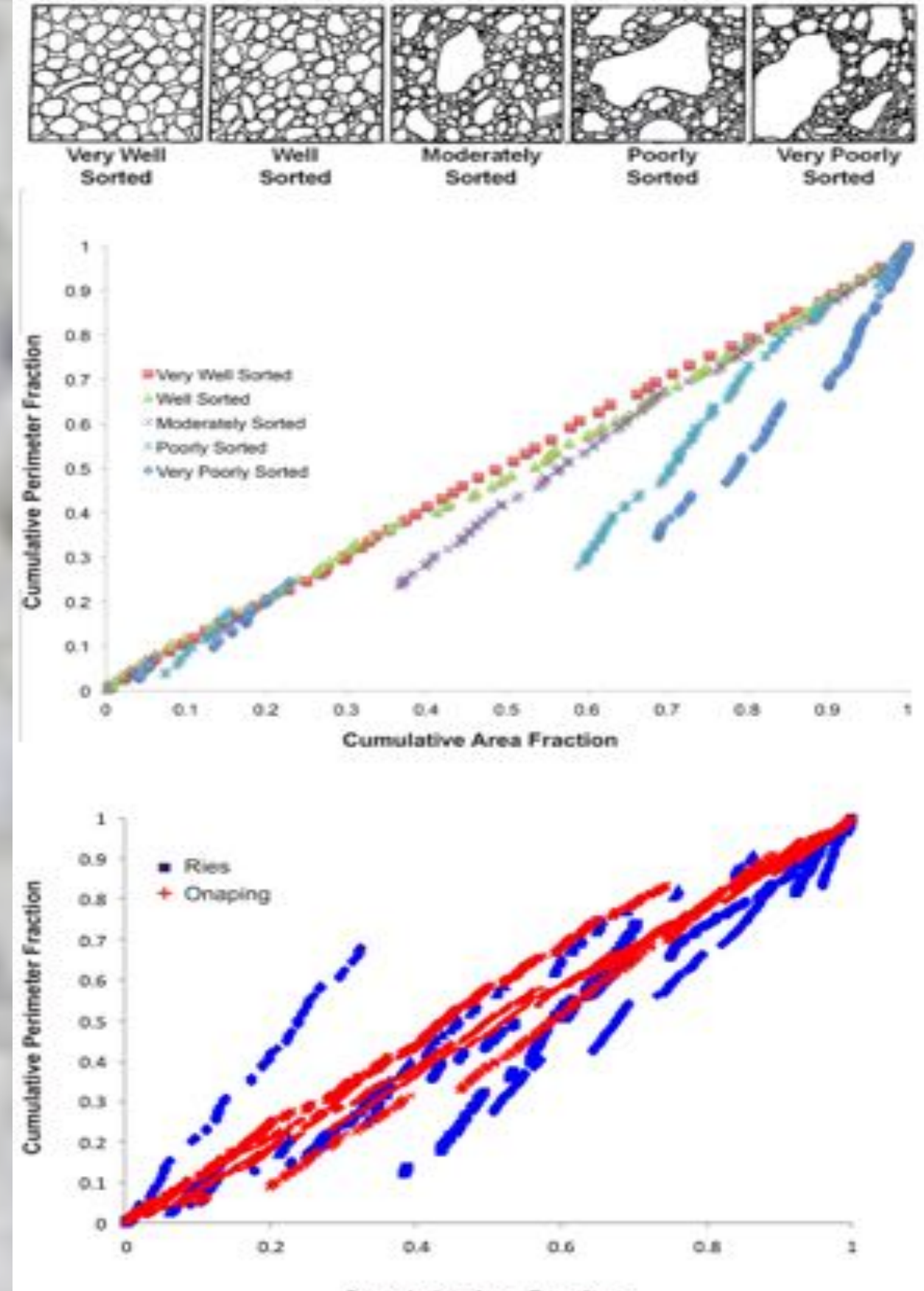

Fig. 3. Cumulative area and perimeter fractions to demonstrate sorting in impactites, using the methods of Chanou et al. (2014). (Top) Results for a typical sorting scale clearly differentiate each sorting level. Very well-sorted samples will have a slope of ~ 1 and will show a continuous linear distribution. Steeper and more discontinuous distributions occur with less sorted samples, with very poorly sorted samples possessing slopes > 3. (Bottom)) Results for the Ries suevite and Onaping Formation clearly demonstrate the poor sorting of the former and the high degree of sorting of the latter. More data are available than are shown; however, the results are reproducibly consistent. The Ries data are outer suevites, 2 samples from the Wörnitzostheim drillhole, and 1 each from the Aumühle, Otting, and Seelbronn quarries.

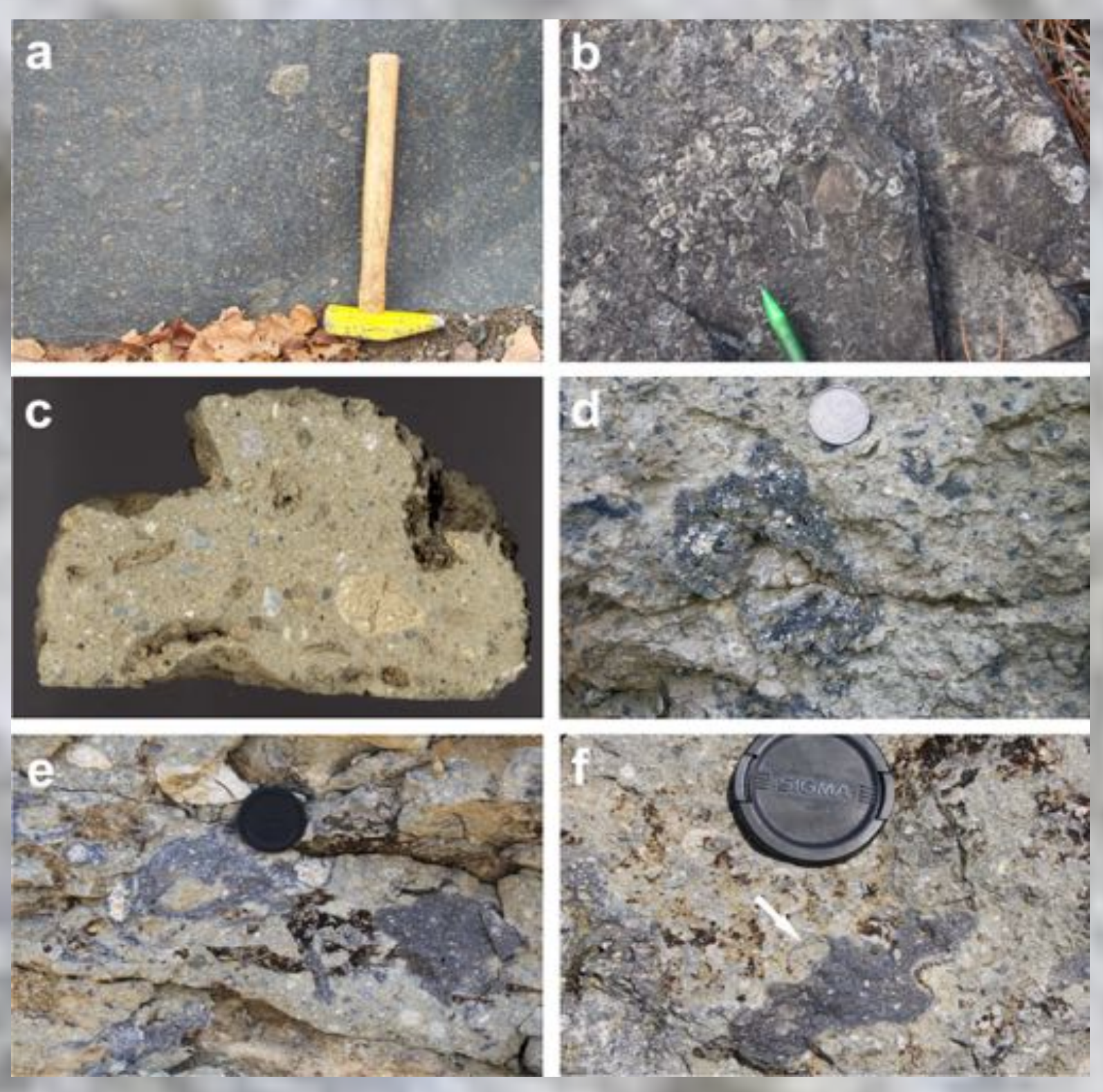

Fig. 2. Field images of the Onaping Formation (a and b) and Ries suevite (c–f). a) Image of typical Sandcherry Member of the Onaping Formation. Note the well-sorted nature. Rock hammer is 30 cm long. b) Image of unusually large vitric fragments in the Sandcherry Member of the Onaping Formation. This unit is still well sorted. 3 cm segment of a 14 cm pencil for scale. c) Crater suevite from a depth of 331 m in the Nördlingen 1973 drill core. The dark irregular “holes” are altered glass clasts. Image is 12 cm across. d and e) Typical outer suevite from the Otting (d) and Seelbronn (e) quarries. 2 cm coin and 6 cm lens cap for scale, respectively. f) Outer suevite from the Seelbronn quarry displaying intricate fine fingers of glass in the groundmass (e.g., white arrow). 6 cm lens cap for scale. Note differences in size and shape variants in vitric clasts between Onaping Formation and Ries suevite.

Table 1. Basic characteristics of the Ries “suevite”, Onaping Formation, and MFCI deposits.

Stratigraphy	**Ries (outer suevite)**	**Ries (crater suevite)**	**Onaping Formation[a]**	**MFCI deposits[b]**
Relationship to topography	No internal stratigraphy; thin fine-grained “basal” variant in places	Melt-poor and melt-rich variants	Internal lithologies; layered	Internal lithologies; layered
Vitric clasts:	Deposits infill topography	N/A	Deposits drape topography	Deposits drape topography
Vol. %	16 %[c] (although finer fraction of the groundmass also has glass particles)	Unclear due to alteration	> 60 % up to 80 % in Sandcherry; 25–40 % in Dowling	Typically > 80–90 vol%
Size	Typically 1–10 cm, but up to 1 m[d]	Unclear due to alteration but cm to dm	Typically 100s µm to 1–5 mm; rarely > 1 cm	Typically 10s to 100s µm
Shape	Irregular[d]	Irregular[e]	Regular	Regular
Alignment?	Yes	Unknown	No	No
Mineral/lithic fragments in clasts?	Abundant[d]	Common[e]	None	None
Vesicles?	Abundant[d]	Common[e]	Absent to rare	Absent to rare (< 5%)
Schlieren?	Abundant[d]	Unknown	Rare	None/rare
Quench crystallites?	Abundant[d]	Unknown	None	None
Sorting 0.5 mm	Poorly to very poorly sorted[f]	Only in reworked deposits[e]	Well to very well sorted	Well to very well sorted
Groundmass:				
% of rock	Variable but average is 60 vol% [h]	Unclear due to alteration	25–30 % for Sandcherry; up to 60% for Dowling	So well sorted that no distinction between clasts and groundmass
Constituents	Primary crystallites and glasses, secondary clays and zeolites, vesicles	Secondary clays and zeolites	Various secondary alteration phases	N/A
Properties	Clastic and impact melt phases	Unknown	Clastic	Clastic
Deposition temperature	High (~ 900 °C)	Unclear due to alteration	Low	Low
Shock level of lithic clasts	8 % unshocked/shocked < 10 GPa[g]	41 % unshocked/shocked < 10 GPa[g]	90 % unshocked	N/A

[a] (Muir and Peredery 1984; Ames et al. 2002; 2008). [b] (Büttner and Zimanowski 1998; Buttner et al. 1999; Büttner et al. 2002; Wohletz et al. 2013). [c] (Engelhardt and Graup 1984). [d] (Stähle 1972; Engelhardt 1990). [e] (Stöffler et al. 1977). [f] (Hörz 1982). [g] (Engelhardt 1997). [h] (Osinski et al. 2004).

MFCI Deposits:

There are clear differences between the products of explosive volcanic eruptions, which produce pyroclastic rocks, and phreatomagmatic or hydroclastic eruptions, that involve the interaction of magma with water resulting in MFCI. An excellent region to study the products of both these styles of eruption is in the Lake Taupo region, New Zealand. GRO carried out fieldwork in this region in December 2015.

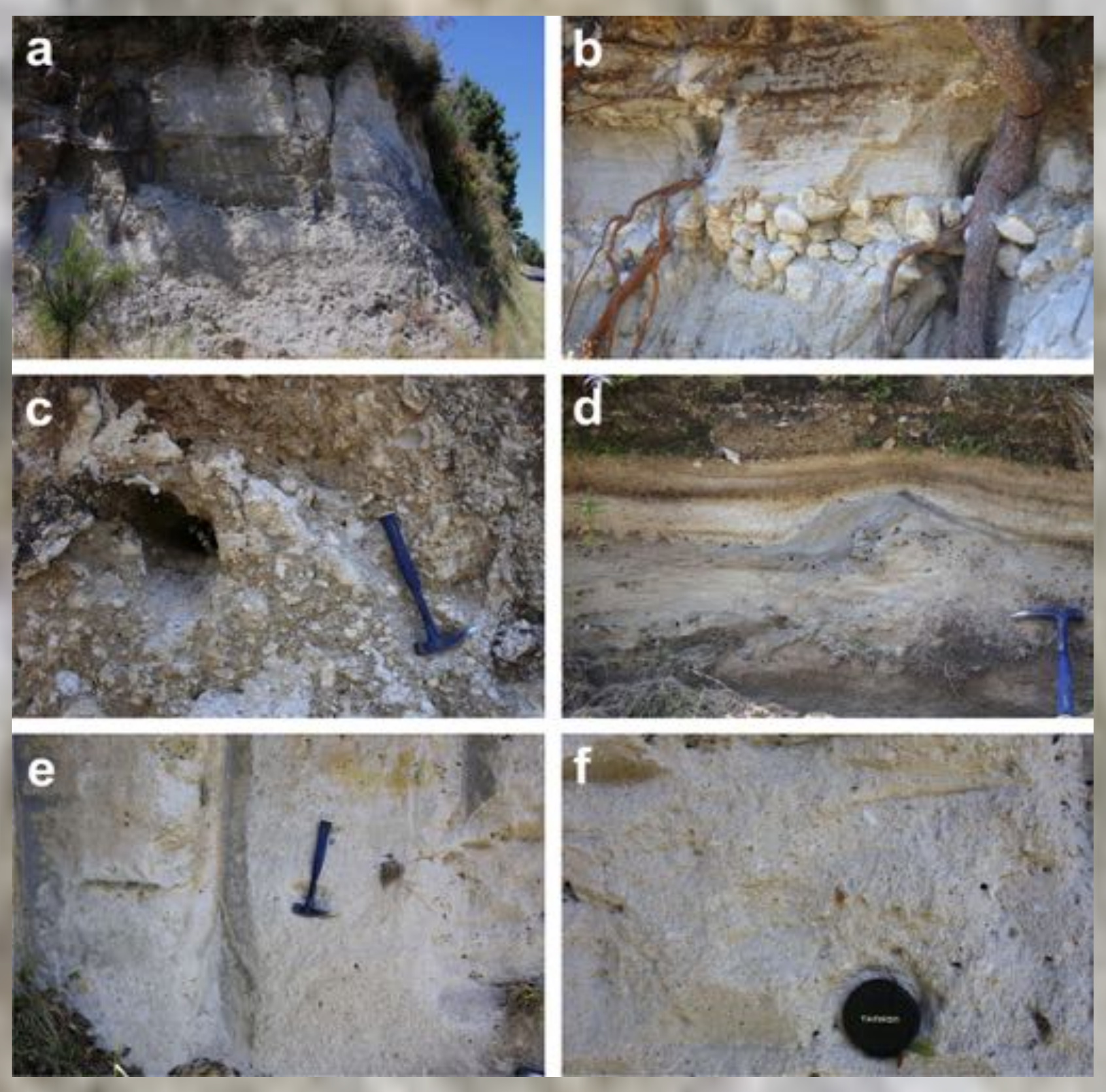

Fig. 4. Field images of the pyroclastic Taupo Pumice Formation (a–c) and the hydroclastic Oruanui Formation (d–f) formed via MFCI. 35 cm long rock hammer and 8 cm diameter camera lens cap for scale. All images are from outcrops along Whangumata Road west of Taupo, New Zealand. a) Well-bedded outcrop of the Taupo Pumice Formation. b) Close-up of a) showing large, white pumice fragments. c) Poorly sorted and massive outcrop of the Taupo Pumice Formation. Large white pumice fragments up to ~ 30 cm across are common. d) Well-bedded outcrop of the Oruanui Formation. Note the fine-grained nature compared to the Taupo Pumice Formation. e) and f) Well-sorted, fine-grained thick bed of the Oruanui Formation.

Funding:

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