Hall's Notes and Queries

NQ10

Micrographia, Ketton limestone and porosity

In [1] I included the remarkable image of an oolitic limestone from Hooke's *Micrographia*. My purpose was just to introduce the idea

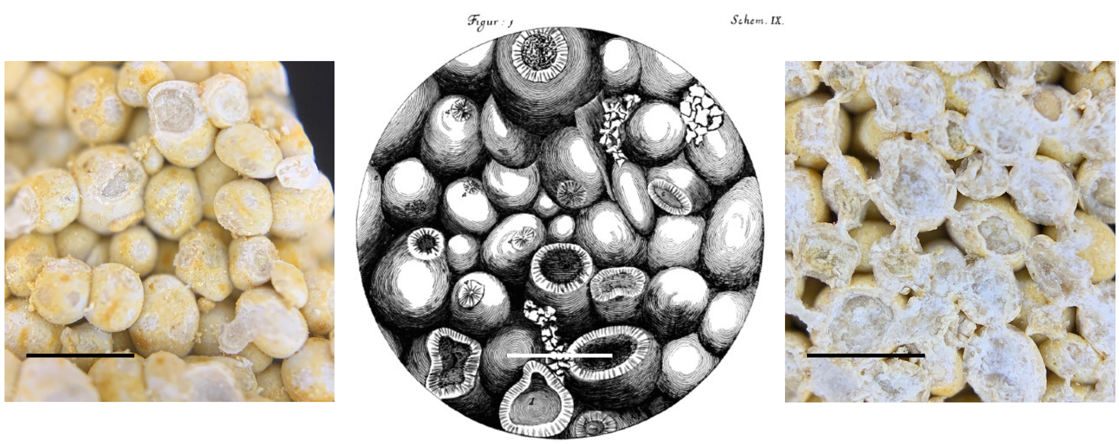

Figure 1: Centre: Hooke's microscopic view of Kettering stone from *Micrographia* (1665), Observ. XV, Schem. IX (1 mm scale bar added, estimated from Hull [2]); left: fracture surface of Ketton stone; right: sawn surface of Ketton stone; 1 mm scale bars both; images taken with an Apexel 200× micro-lens and iPhone XR camera; Ketton stone specimens from Fairhaven Stone, Bottisham, UK.

"that we can understand materials by looking at their internal structure in finer and finer detail ... the explanatory framework at the core of materials science".

Several years later, when by chance I started to study the capillary properties of Ketton stone, it was immediately obvious that Hooke's Kettering stone was in fact the Ketton stone that I had in my hand.[1] I soon discovered that Derek Hull had realised the same thing many years earlier and had documented it in detail in 1997 [2]. I can add nothing to Hull's account except in one respect. Hull's words are sharp and clear, but his images less so. I have therefore added two new close-up views of Ketton stone in Fig 1 using the simplest equipment. These show, as Hooke noted, that the outer shells of the individual ooids "… are of a white colour, a little dash'd with a brownish Yellow". We see "the innumerable company of small bodies", a few of which are broken open to reveal the internal structure, all exactly as seen by Hooke.

Hull is a distinguished expert on the mechanics of materials, and was interested in the nature of the surface that Hooke depicts. He concludes that it was a freshly-formed fracture. My observations tend to confirm this. Hooke had snapped a small piece of Ketton stone to look inside. What Hull does not discuss is the matter that concerns me in this NQ, and which forms a large part of Hooke's essay in Observ. XV: namely the porosity of the stone and the interstices between the ooids. Hooke notes that the interstices are connected so that the stone is "equally pervious every way, not only forward, but backwards and side-ways …", as he proves to himself by blowing spittle through "a pretty large piece of this stone". The isotropic permeability and full connectivity contrasts with what

[1] Kettering, Northamptonshire, lies to the west of the Lincolnshire limestone formation and has never had quarries for building stone; on the other hand Ketton, some 20 miles to the north-east of Kettering, in Rutland, has had working quarries for many centuries, and supplied stone for many important buildings in Hooke's day [3, 4].

Hooke observes in some natural materials like cork. These materials are also porous but often the cells are closed and not connected, so that for example cork floats on water.[2] In other materials such as bones and "Wood, and other vegetables ..." the pores are in the form of channels running in a single direction "for the conveyance of appropriated juyces to particular parts ...".

Next, Hooke explains the optical effects of filling the interstitial porosity with liquids. He more or less correctly suggests that the liquid – water or oil of turpentine – alters the way that light propagates through the material.[3] Opaque material becomes "pellucid". He notes that some stones such as marble must have some connected porosity, even if it is not visible in his microscope, because they become translucent when soaked in water.

And so to a remarkable passage in Observ. XV, in which Hooke quotes at length from a report to the Royal Society "by the Eminently Learned Physician, Doctor Goddard,[4] of an Experiment ... on a seemingly close stone call'd *Oculus Mundi*". Oculus mundi we now recognise as the hydrophane opal, composed mostly of amorphous silica, and which has value as a gemstone. Such opals are opaque when dry but become translucent when immersed in water. Hooke concludes that they must therefore be porous. Goddard has weighed two small specimens of oculus mundi before and after soaking "for a night", and then again after drying them. He records the weights (which are about 5 and 19 grains dry) to a precision of 1/256 part of a grain in the first case and 1/128 in the other (one grain being today set equal

[2]Hooke writes more on this in Micrographia, Observ. XVIII.

[3]For a summary of the modern explanation see [5].

[4]Jonathan Goddard was active in the Royal Society from its foundation until his death in 1675. I claim a remote connection: from 1651 until 1660 Goddard was Warden of Merton College, Oxford; 309 years later my Oxford research supervisor Rex Richards likewise became Warden of Merton.

to 64.79891 mg). So Goddard's weights are good to 0.25 mg. Goddard's report,[5] transcribed by Hooke in *Micrographia*, is the earliest example that I know of a gravimetric measurement of what we now call capillary imbibition, and from which the volume-fraction porosity f can be calculated. The solid density $\rho_{\rm s}$ of many hydrophane opals has been measured by Pearson [6], from whom we can confidently take a value of 2185±5 kg/m^3. Then with $w_{\rm d}$, $w_{\rm w}$ Goddard's dry and wet weights, and using the relation

$$f = \frac{\rho_{\rm s}}{w_{\rm d}\rho_{\rm w}/(w_{\rm w} - w_{\rm d}) + \rho_{\rm s}} \tag{1}$$

where $\rho_{\rm w}$ is the density of water, let us say at 20 °C, we calculate the porosity f of Goddard's first oculus mundi as 0.078, and of his second as 0.145. These values are perhaps a little low, but well within Pearson's range.

Goddard does not say how he weighed these little stones. Presumably he used a beam balance of the kind that was well established for the assaying of minerals and the proving of coinage.[6] But the precision claimed by Goddard is remarkable. Isaac Newton [8] wrote in 1697 of the assaymaster of the Royal Mint that "[his] scales turn wth ye 128th part of a grain", the turn being the amplitude of the small oscillations detected by the excursions of the balance pointer.[7] However, I can find no description of a "philosophical" balance in

[5] A manuscript of the report is in the Royal Society archives, document RBO/1/28.

[6] Such an assayer's beam balance (in a glass case) is illustrated in Ercker's treatise on mining and metallurgy published in Bohemia in 1574 and translated into English by Pettus as *Fleta minor* in 1688. The Goldsmiths' Company also had particular interest in precision weighing in the late sixteenth century [7].

[7] A high-precision long-beam balance constructed by the London instrument maker Jesse Ramsden in 1788 "… turns on 1/100th of a grain." [9]. For more on the significance of turns as a measure of sensitivity (or, properly, discrimination [10]), see [11]. It remains an open question how exactly Goddard was able to determine weights to 1 part in 2^7 or 2^8 of a grain, and why these particular sub-fractions were used.

the archives of the early Royal Society.

References

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[9] Anita McConnell. *Jesse Ramsden (1735–1800): London's leading scientific instrument maker*. Ashgate, 2016.

[10] Erich Robens, Shanath Amarasiri A Jayaweera and Susanne Kiefer. *Balances: Instruments, Manufacturers, History*. Springer, 2014.

[11] HW Chisholm. 'On the science of weighing and measuring, and the standards of weight and measure'. In: *Nature* 9 (1873), pp. 47–49.

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