IN-SITU TEMPERATURE RISES CAUSED BY CORING VAPOUR-GROWN CO$_2$ ICE. J. R. C. Garry and I. P. Wright, Planetary and Space Sciences Research Institute, The Open University, Milton Keynes, England. (J.R.C.Garry@open.ac.uk).

Introduction: An instrumented drilling system has been built that can grow cryogenic ices from their vapour phase. This apparatus has been used to measure the toughness of water ice and CO$_2$ ice at temperatures as low as 130 K. Small semiconductor thermometers have been used to measure the temperature rise caused in the ice by the drilling action. The thermomechanical properties of ices at low temperatures are compared and the implications of these significant temperature shifts for planetary sampling missions are discussed.

The system: The chamber has an internal volume of around 50 litres within which is a 120 cc cubic sample holder. This sample holder is cooled by a liquid nitrogen loop and a pipeline allows a stream of gas to be directed into the sample holder from an external source. The vacuum chamber of the coring system is shown below.

Some of the frosting around the head and the container is water ice and could not be avoided when the chamber was opened to take this image. The mass at the base of the cubic holder is CO$_2$ ice. More than a dozen of these icy slabs have been grown and studied with this equipment at temperatures of ~140 K. All of these ices were grown from gas over the course of several hours and a typical slab has a measured bulk density of 1550 ± 230 kg m$^{-3}$. This value brackets the value of 1590 kg m$^{-3}$ for fully compacted CO$_2$ ice [1] and the lack of preferred fracture planes or visible grains suggests that this material is largely void-free.

Coring: A typical coring run consists of slowly penetrating the sample material with the rotating coring head. The data from such a process are shown below for an ice at 140 K under 15 Pa of pressure, a depth rate of 0.15 mm s$^{-1}$ and a rotation speed of 1.7 rev s$^{-1}$. The force (F) and torque (T) histories are plotted against the vertical distance traveled by the tool. The initial bump in the force record was an initial ‘smoothing’ of the ice surface with the tool head.

Above the sample holder is an instrumented drilling manipulator that allows a coring head to be driven into the material formed in the holder. The downforce and torque applied to the tool, and the rotation speed and vertical depth rate are all measured and logged by a dedicated computer system.

An example of the stainless steel coring heads used in this work is shown in the following figure which also shows a photograph taken after the head has been driven into a sample of ice. Dimensions in this diagram are in millimetres.
Temperature sensing. To record the temperature rise within the ice a diode-based thermometry amplifier was built. This device sensed and amplified the forward voltage drop across miniature diodes that were engulfed by the slowly growing ice mass. A typical diode is shown below and with this device a precision of around 35 mK could be achieved (corresponding to the logging computer ADC’s least significant bit).

Diods were used in preference to more traditional sensors (thermocouples, Pt100, etc.) because arbitrarily fine wires could be soldered to them. Thermocouple wire is difficult to find in very fine gauges and thermal conduction along the sensor wires was a concern when trying to measure local temperature shifts.

These thermometers were deployed along the path taken by the annular face of the coring head and were destroyed by the coring teeth, the arrow in the previous diagram marks the loss of the diode signal.

Temperature shifts. For the coring run shown earlier the diode’s temperature as a function of the depth of the tool can be drawn up. It can also be appreciated that the reported temperature of the diode may be an underestimate of the true temperature of the material.

The power consumed by the coring head to generate this temperature shift is of interest for practical coring applications. The torque and rotation speed wholly set the power consumed in rotating the tool and the above run dissipated a power of ~1 W through its cutting teeth. Although small, this power is expended through a very small (<1mm$^2$) contact area and lower temperatures, but raised cutting forces, may be generated by broader cutting teeth or slower rotation rates.

Sample warming: Two properties of an ice determine the temperature gradient made by the dissipation of a given heating power in the ice. The temperature shift $\Delta T$ can be shown, from dimensional arguments, to vary as:

$$\Delta T \propto \frac{1}{\sqrt{Kc}}$$

Here $K$ is the thermal conductivity and $c$ is the specific heat capacity of an ice of density $\rho$. For carbon dioxide ice the term $Kc$ at cryogenic (~140 K) temperatures is approximately seven time smaller than the same term for cryogenic water ice [2,3,4,5]. Therefore the expenditure of a given amount of power yields cutting head temperatures in CO$_2$ that are almost three times larger than those which would arise in water ice.

What saves this from being a larger potential problem is the fact that carbon dioxide ice is seen to be much weaker than water ice in these coring experiments and also in more traditional tests [6]. At ~140 K coring a unit volume of vapour-grown CO$_2$ requires half the energy needed to fail the same volume of water ice with the same tool. Or, if the density difference is accounted for, coring a mass of dense CO$_2$ ice requires about 80% of the energy used in cutting the same mass of cold water ice.

In summary, the drilling or coring of a given volume of dense carbon dioxide ice can generate peak temperatures at the tool bit that are 130% ($0.5*\sqrt{7}$) those produced in water ice. Arguably, if cryogenic water ice had been the sample material, the same coring head should have produced a peak bit temperature rise of at least 7 K. These temperatures are, in themselves, unlikely to cause unwanted alteration to planetary ices. However, the power level used in these tests is comparatively low. If the thermal integrity of retrieved samples is important then more energetic samplers have the potential to erode the margins built into the thermal budget in a martian or cometary sample return mission.

Similar cutting mechanisms designed to sample ice-rich bodies are in their last stage of testing for the Rosetta lander. The deployment of similar tools in either martian or europaan settings is likely, and this work has shown that significant temperature rises resulting from relatively small power loads can be measured.

References: