Observations on Wood Effects for the Nave Ceiling of Peterborough Cathedral

First I would like to address the **receded/weathered surface of the planks**.

The majority of oak planks show prominent medullary rays between which the cells (mainly fibre and vessel cells) appear to recede. The rays appear plate-like and smooth ranging from large irregular shapes where the radially-cut surface is through relatively straight-grained wood (Plate 382) to quite small, squarish islands where the grain becomes more irregular, almost as if the wood had been chopped with a blade, though it has not.

There is also a difference in relief between the annual rings, the latewood from the end of the growing season being more prominent than the earlywood cells. Latewood/earlywood relief differences are shown by nested arcs on tangentially-cut faces (Plate 383). In fresher timber, these arcs can be distinguished by colour and texture rather than a relief pattern as here.

Thus we have two types of relief pattern which I would tend to ascribe to a weathering process. Appearance alone suggests the kind of weathering one encounters on ring-porous hardwoods such as oak and in the annual rings of exposed softwoods due to exposure to the relative extremes of external conditions of UV light, erosion from rain, and extreme moisture content changes which tend to fracture differing cell types in adjacent areas due to swelling (moist) and dessication (dry). Old fence timber and telegraph poles show similar effects.

How could this happen on internal surfaces of what is currently a relatively stable interior? There are very few finished oak surfaces of this age in similar circumstances that I know of, though I am not well-informed on the subject. Time and unknown environmental conditions in the past are the main explanation I would propose for this weathering. Perhaps there was a period of decades when the roof was leaky from degradation or when it was partially removed, offering insufficient protection of the timbers below.

Fungal infection (rot) was suggested as a possible cause of these relief patterns. Dinwoodie (see below) offers little discussion specifically in reference to oak so that I would really need to go to a good wood science library (British Library or that of the Building Research Establishment) to research it. European oak heartwood is considered to be durable to fungal attack in ground contact (Table 6.1, p.160) so we can assume that these "sky-born" timbers are durable. But there are few comparable structures whose history are known from which one could get a realistic indication of the deterioration factors.

Wet rots are the only rot I would expect at such a height even though so-called dry rot has been known to spread several meters over other surfaces than wood. Though not a rot expert, I do not believe it to be the cause of the relief pattern. Here is my reasoning. First, the patterns are related directly to the wood structure, while wet rot causes generalised damage not simply confined to the softer cells' walls.

Second, one needs a moisture content of 20% or greater for infection and resulting damage to occur. This is not likely to have occurred for the necessary extended periods in the roof timbers even if they were exposed to rain. Moisture could have been retained in the wood by paint coatings to the extent that rot could occur beneath the paint, but I think that we are searching too far for arguments if we follow this line. The planks would have to have been fully coated on one side at least, probably both larger sides, as oak does not transmit water quickly across the grain (witness oak casks; see below). In addition the planks would still be exposed to strong drying conditions after rain, such as from the (probably) exposed upper side. Or, possibly the roof leaked water everywhere like a sieve but somehow sheltered the exposed sides of boards from drying. Again I think this line of argument is too complicated. We should, as always, expect the obvious even though we may overlook it for that very reason.

Third, I would expect rot to have caused more irregular depths of structural damage in several areas, not as in the homogeneous relief pattern we observe overall. I believe we did note an area toward the middle of the ceiling where rot/insect damage has occurred (insects often inhabit rotting areas) but I would expect just such an obvious damage to be more widespread.

For more on rots, see the excellent book below. You could ask a rot expert to have a look. Mr Ridout was quothed and perhaps he could settle the rot question with a sample, as he suggested. I would also suggest the Building Research Establishment. The problem is that the evidence to explain the relief pattern by rot is probably long gone even though various spores will always be on wood surfaces. Following Mr Ridout's comments further, a differential collapse of wood cells needs it's cause defined. Chemical deterioration from the coke stoves is not my area but judging from your environmental monitoring I doubt that sufficient effluent was deposited on the ceiling surface, other than some smoke. The stoves are relatively recent additions too so their effect might be in evidence in the paint layer analysis.

Another possible argument which I imagined for wood surface degradation is in relation to coatings or paint media. Now, I am not a wall paintings specialist either, but here are my thoughts. Interestingly, Thompson mentions St. Alban's painted ceiling ("Structural Woodwork, p. 41) saying that these wooden surfaces were either unprepared or given a size or general oil coat to equalise absorption of the painted design. (There's your oil content!) What paint media are likely? Oil would not do it. It is possible that a distemper (collagen glue) might have been applied and simply disappeared since. Glue is subject to quite rapid degradation from the acidic nature of oak. However, it would not strip away such a depth of wood with it.

Finally there is lime, which would indeed have been alkaline until it had been completely reacted with atmospheric carbon dioxide. This initial period of alkalinity could degrade the lignin and hemicellulose molecules in the wood cells as they are apparently quite susceptible to alkaline agents. I do not believe that this would remove such a depth of wood either, though I have no examples. Again, the evidence would seem to be non-existent or long gone. However, it may be that an initial loss of wood surface overall by one or more of these postulated mechanisms- wet rot, degrading distemper or alkaline chemical reaction, could contribute to a much greater weathering effect than would occur if the surfaces had remained in a bare or coated but essentially finished state. Rough wooden surfaces weather more quickly.

Superficially viewed, the trefoil designs, because they are in relief, can be confused with the rays, as they tend to meld together in some areas and exposed rays can take on fascinating shapes in themselves. Looking at the surface from my experience in the technology of art and the conservation of paintings, I would attribute the relief of the trefoil designs to a masking effect of a painted surface. That is, the trefoils were painted, thus protecting them from a degrading factor such as weathering, while the surrounding was less protected, though not necessarily unpainted. The trefoils may simply have been painted with a more protective medium such as oil, as your research indicates, while the surrounding may have been a water-based medium, such as a distemper. The latter may have entirely disappeared.

Shallow carving to set out the painted design has been suggested as a possible cause of the relief pattern (Howard, 1998; p. 2). I am essentially in agreement with your report (Phase 2 Survey and Treatment, section 8.2.3, paragraph 2). Though I have done no serious wood carving, I have examined carved surfaces and have some practical experience in wood tooling and painting. I accept that adjacent planks are likely to have been grooved with a plane-like bladed tool or simply a chisel, mallet and straight-edge, to set out the alternating red/black linear design, as grooves would greatly facilitate linear brushwork. However I do not think that the relatively laborious carving away of the surrounding wood surface would have facilitated painting such a cursive design as the trefoils (even given the glory it might have assured the carver(s)). Also, the uniformity of the curvature of the edges do not suggest tooled surfaces to me. They do suggest the flow and swell of a painter's brushwork. Therefore I think we see the remnants of a design simply brushed on the wood surface. I would look for some other signs of setting-out, possibly shallow scribe marks or punctures to locate trefoil positions, though these have probably disappeared if they existed at all.

Next I address the **probable dimensional response in individual boards resulting from environmental fluctuations**, referring to Curteis' Preliminary Report March 1998- January 2000. He discusses diurnal and seasonal (between midsummer and midwinter) conditions in three places: externally; in the roof space above the ceiling; in the space on the underside of the ceiling. The last two affect the ceiling planks directly. The present range of temperature (T) and relative humidity (RH) recorded by the sensors is probably no greater than during any period in the past. The ceiling environment has probably seen greater extremes than these over both the short and long term. It is possible, for example, that greater levels of heating occurred when the coke stoves were in use which would have caused dryer conditions in winter and subsequently greater periodic variations at ceiling level. Or, if the roof had ever been open for reconstruction then the interior would have been exposed to conditions more like the exterior.

The environmental extremes are important in determining the dimensional response of the overall wooden structure and of individual planks. The wood type and plank section are also important factors. If I recall, the oak planks are on the order of 20-25mm thick. I think the planks would still respond overall to environmental changes to about the same degree as when they were first painted. (There is some evidence in the literature that moisture response does not diminish greatly with age.) In my research, though response to RH change at the plank surface is virtually instantaneous, it took about ten days for the moisture content of an oak plank about 3.5mm thick to equilibrate, as indicated by a cessation of wood deformation (ie. warping and expansion/contraction). One could expect that planks 6 or 7 times this thickness would take a correspondingly greater time to equilibrate.

The manner of converting the planks from timber is relevant too. Unlike the ceiling planks, which were riven, the planks used in my research were planed and sanded flat thus leaving a more rapid avenue for moisture transfer through the sectioned vessels. Riven surfaces force moisture to traverse the cell walls, a slower process.

Considering these factors, I would make a broad estimate that equilibration to a change in RH would take from 50-100 days for the ceiling planks. Thus, for each plank as a unit and for the lozenge structures, I would tend to think in terms of a relatively slow response time more on the seasonal order.

**Diurnal** RH varied by up to 20% in the roof space in winter and 25% in summer (p. 7). Below the ceiling, diurnal variations were stable in winter and about 6% in summer (p. 6-7). With the rate of equilibration on the order of 50 to 100 days broadly speaking, as discussed above, diurnal variations would change neither overall plank dimensions nor affect the lozenge structures appreciably. The clinker-built, clinched nail construction would accommodate any minor movement of this sort. If I may diverge to seasonal changes of average RH/T, a lack of obvious splitting in the planks indicates that dangerous restraint of plank movement or of the lozenges in relation to the supporting beams is no longer likely, again thanks to this type of nailed construction.

Diurnal changes will, however, affect wood movement at the plank surface and to a certain depth, depending on moisture gradients. Moisture traverses the plank section as a gradient. A greater change in wood moisture content at the surface, due to an RH change, will provoke a greater difference in MC between the surface and underlying cell layers, thus creating a steeper moisture gradient. In freshly cut wood, cell distortions occur at the plank surface because the swelling or contraction of the surface cells is restrained by the more slowly reacting cells beneath. Steeper gradients cause greater restraint, provoking compression of swelling surface cells during rising RH and fissuring between contracting surface cells during drying conditions. These effects are generally termed "set" and are considered to be permanent cell deformations.

For relatively rapid RH changes these effects are confined to the surface and thicker planks as a whole would not be likely to undergo much deformation as a result. Over several centuries, a maximum degree of set would have been attained, only increasing if planks were subjected to greater extremes than were experienced before. They have been extremely "well seasoned". Over centuries, set and possibly the slow loss of volatile extractives causes a slight permanent decrease in dimensions, as shown by painted oak panels of the 15th and 16th century. This exceedingly slow contraction has long since been accommodated by the original paint and the lozenge structure.

So, as regards direct effects of diurnal changes on wood movement and long-term set, the original paint layers have probably long since adapted through craquelure and losses. If securely consolidated now they should remain well conserved. It seems to me highly unlikely that current conditions expose the planks and the paintings to greater extremes than they have already experienced. There may be some danger from the restraint or differential movement of overpaint or encrusted layers, such as the glue drips have caused. Beneficially, however, I think that the overlying paint of the 18th and 19th centuries also acts to retard moisture transfer to the wood, decreasing wood movement beneath.

**Seasonal** averages at the ceiling underside indicate stable conditions in winter (Preliminary Report 1998-2000, section 4.2, paragraph 2) and summer. On average, there is about a 13%RH difference (59%RH in July minus 46% in winter months). To cause movement corresponding to equilibration at These extremes would have to be maintained for 50-100 days to cause the full range of movement if equilibrium moisture content (EMC) were attained, assuming the above reasoning is correct. Instead, rlative humidity is likely to show a rough shift between these averages so that the planks never really equilibrate to either the winter months or July average value. The plank moisture contents and therefore changes in dimension will instead lag considerably behind, oscillating relatively little over the year. Again, I see little threat to the paint or lozenge structures.

The options for measuring any related movement are numerous, varying greatly in sensitivity, cost, ease of use and general practicality. Making a few estimates based on the above reasoning, European oak moves about 2.5% in the tangential direction, across the grain (the most reactive axis), in equilibrating from 60%RH to 90%RH. For a 10%RH range, which roughly represents the 13% seasonal average range cited above, a maximum of about 1% movement could be expected. So, a plank 200mm wide would expand or contract about 2mm. I think even this is overestimated. Anyway, you would have to detect changes of .1-.2mm to plot curves and statistically this means you need resolution of 0.05mm.

I will suggest only two relatively simple methods to repeat a linear measurement of this type. One utilizes a Vernier style caliper and the other a linear transducer. If you can place a couple of nails about 100mm apart (no greater than 90% of the calipers maximim range) in a plank, or use existing nails, drill a small-diameter hole in each nail head to accept the a caliper tip. The tips must bed at exactly the same points for each measure. Then record measurements relative to the initial span between the holes. Place the points according to the grain direction you wish to measure.

The linear transducer is a sort of plunger that varies an applied voltage ie. a potentiometer. It will give a linear response over a certain range of movement of the plunger and this can be easily converted to a linear measure using a known length. Some types give much greater resolution than you will need. The transducer can be mounted on a plank and the plunger, which can be a sprung type, may be butted against a fixed metal stop. Voltage changes can be periodically recorded using a computer. A colleague of mine has used a similar set-up to measure gap changes in a panel joint, though I believe he used a radial transducer linked to a stiffish cord. I enclose a slightly dated catalogue (TML) of these sorts of things. Some are not potentiometric but are based on resistance, encorporating strain gauges. These can resolve rather too much for your purposes.

Concerning degradation of the hessian/animal-glue covering, I would say that it will continue to degrade, providing little or no support to the planks since the glue's adhesion is virtually spent. The oak tannins are quite acidic and *when exposed to air* a glue on oak will degrade quite rapidly, probably within 50 years at best and definitely within 100 years, according to my experience with canvas strips applied to reinforce oak panels that have been rejoined. (Animal glue in oak joints that were planed well and joined tight will survive much longer because a minimal glue line is exposed to the air and it is more flexible than a thicker glue line. Stresses and glue degradation from acidic tannins at the glue/wood interface often cause even these joints to pop.)

The fabric/glue may slow moisture exchange to a minor degree. It forms a pretty good dust cover too so I would not be inclined to remove or replace it yet.

## References

Dinwoodie, J.M. 1981. *Timber, its nature and behaviour.* Van Nostrand Reinhold Co. Ltd., Berkshire, England.

Bravery, A.F., Berry, R.W., Carey, J.K., and Cooper, D.E. 1992. *Recognising wood rot in buildings* (2nd ed.), Building Research Establishment, Garston, Watford.

Thompson, D.V. 1956. *The materials and techniques of medieval painting*, Dover, New York.

Could you please return the catalogue?

"dissolution of both the lignin and the hemicelluloses occurs under the action of even the mildest alkalies."

"Fungal attack can commence only in the presence of moisture and the threshold value of 20% for timber..." (Sect.6.2, p.150)

To attain this MC Figure 2.1 (p. 38) shows that an RH of 85 to 90% would be necessary.

"Lignin... offers a slight degree of resistance to fungal attack..." (Sect.6.2, p.150)

October 8

Fax to Richard Lithgow, fax 01608.659133
From Al Brewer, fax/tel 01753.830946
Re Peterborough

Dear Richard,

I must apologise for being unavailable for the past month. I have wanted to speak to you to discuss my delay and aspects of my response to some of the points you've raised. However, I have been completely pre-occupied by a pressing, difficult treatment at St. James's Palace. Though I can call you from home after work or on weekends, it is unfortunately not convenient for me to telephone you from work there. Thank you for attempting to return my call last week. Could you try to call me again, either anytime before 10 this evening or between 8pm and 10pm weekdays?

I have written a few pages in response to your various points. With my workdays 6am-8pm, I have only had an hour or two the past few weekends to devote to this work, though I do enjoy it greatly. In conclusion I am trying to interpret Tobit's environmental data with respect to wood deformations and paint condition.

I checked with my wife's brother, Pascal Prunet, an architect closely involved with the conservation of historique buildings in France. He says there are very few existing wooden roof structures of that period in France. I am sending him some of your photograph reproductions (Plates 393, 382, 397, and 383) to show to any of his colleagues who might have encountered such surfaces. I would ask for another set to send to a wall paintings conservator with whom my wife has worked in Switzerland and Paris. If they exist on the continent, he has probably encountered these effects.

Hoping to make verbal contact, I remain

Yours truly,
Al Brewer

Now, it is the more dense cells which give the higher relief, and this is due to more durable cell types. There are four cell types in oak. Density is a factor here and latewood in ring-porous hardwoods like oak is characterised by thick-walled fibre cell types (Sect. 1.2.2, p. 11). The rays are parenchyma cell types, mainly for storage of extractable food material for the tree, and have relatively thin walls. Re-reading Dinwoodie, I temporarily recant my reference to lignin as the "durabilising" factor in the rays. However, though I cannot give you a reasoned quotation and I need to research it a bit more, the ray cells in oak are also more durable cell types.