Use of MicroCT to Visualise the 3D Structure of Pith Paper

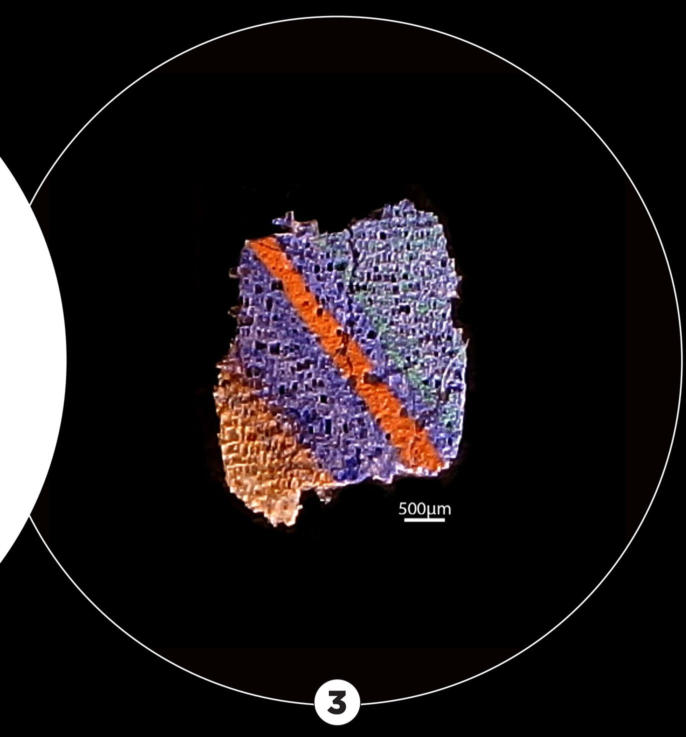

Fig. 1 *Tetrapanax papyrifer* located in bed 95 at the Royal Botanic Gardens Sydney. Planted in 1994 from seed that arrived from the Arboretum Nový Dvur (Czech Republic). The seed was collected in Taiwan, Taitung County, Southern Cross – Island Highway on 16 Dec 1991.

Fig.2 Watercolour from album of twelve paintings on pith mounted on Chinese paper bound with silk covers. All paintings have some mechanical damage. Sample fragment from gutter. *Chinese paintings,* albums owned by David Scott Mitchell, undated, PXC 289, State Library of NSW

Fig. 3 Pigment sample fragment at 500µm

'TO ATTAIN KNOWLEDGE OF THE PLANT WHICH PRODUCES THIS CURIOUS SUBSTANCE HAS FOR MANY YEARS BEEN A DESIDERATUM TO BOTANISTS IN EUROPE.'

JC BOWRING, MEMBER OF CHINA BRANCH OF THE ROYAL ASIATIC SOCIETY, 1852

INTRODUCTION

This study has been undertaken to better understand the anatomy of pith paper and the preservation needs of the unique cultural objects made using pith paper.

In 18th century China a new fusion of Chinese and Western painting techniques emerged in response to the diplomatic activities of Emperor Qianlong (1711–1799).[1] These local innovations in painting held great appeal to the foreign merchant traders in China and, more importantly, for their customers in Europe.

By the early decades of the 19th century the artists at work in the port city of Canton (Guangzhou), as a consequence of the mercurial state of trade, adapted a local diaphanous material — pith paper (also known as rice paper)[2] — to the new craft of export watercolour painting. (Fig. 2)

European botanists were active in China in the 18th century, some of whom were commissioned by Sir Joseph Banks. When they examined rice paper they determined it was composed of pith cells not rice fibre. However, it took many decades to discover the origin of this plant and assign a scientific name.

1851	plant found and manufacturing process described
1852	first living plant arrived in Royal Botanic Gardens, Kew, London
1852	placed in family Araliaceae and tentatively ascribed to genera *Aralia*
1857	first planted in Royal Botanic Gardens, Sydney
1859	alternate suggested genera name *Tetrapanax*

The genera debate raged well into the 20th century when new technology provided evidence to support the use of the currently accepted name *Tetrapanax papyrifer* (Hook.) K. Koch.[3,4] (Fig. 1)

Recent DNA sequencing data indicates the genus *Tetrapanax*[5]:

- is endemic to Taiwan and has a restricted natural distribution
- is monotypic (is a single species genera)
- split approximately 70 million years ago from the main Asian group of the family Araliaceae.

Ancient history provided us with an explanation for the epithet, *papyrifer,* which is derived from the earliest writing support, the papyrus plant.

Pith paper is a product that is cut directly from the dried inner stem (pith) of *Tetrapanax papyrifer* through a simple process that keeps the cell wall structure intact. As it is the only paper-like material to be produced directly from the pith of a plant stem, it is therefore closer in structure to a herbarium specimen than a fabricated sheet of paper.

MicroCT

- Pith paper samples were imaged using an Xradia MicroXCT-400 MicroCT. Projected X-ray images (1801 images) were captured with the sample rotated 0.2° between each image (with a total capture time of 17 hours).
- This is a non-destructive, non-staining imaging technique.
- All data sets ≈1000 images were captured with a resolution of 2.23µm.

TERMINOLOGY

In this poster, botanical terminology will be used to describe the orientation of MicroCT images. This approach is designed to map the botanical orientation of the cylindrical pith stem onto the rectangular sheet of pith paper.

A sheet of pith paper can be viewed in three orientations. (Fig. 4)

1. Periclinal tangential longitudinal

This is the verso/recto orientation (the surface that can be painted). The cells in this orientation are aligned in rows along the direction of stem growth.

- **Periclinal** orientation runs parallel to the meristem (the cells where growth takes place just under the bark). Pith paper is cut in a spiral path parallel to the bark.
- **Tangential** orientation does not pass through the stem centre.
- **Longitudinal** orientation is parallel to the stem.

2. Transverse orientation is at right angles to the stem direction.

3. Anticlinal radial longitudinal

- **Anticlinal** is at right angles to the meristem (and bark).
- **Radial** orientation is in the direction of the centre of the stem.
- **Longitudinal** orientation is parallel to the stem.

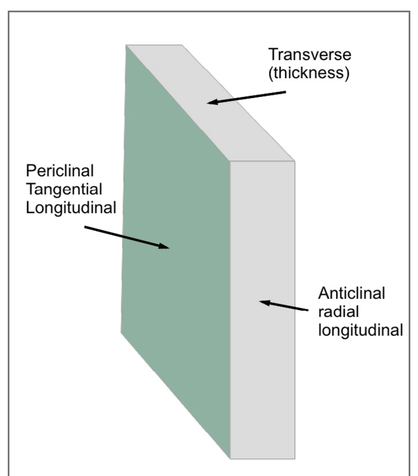

Fig. 4 Pith paper sheet, the three orientations labelled. The diagram is aligned in the direction of the *Tetrapanax* stem (top to bottom).

PITH PAPER STRUCTURE

Four physical parameters were measured on both old and new pith paper: cell size, thickness, porosity (all measured from MicroCT data) and colour (measured using an X-Rite RM200QC Colorimeter). (Table 1)

Cell Size

There is a significant difference in cell sizes between old and new pith paper (using t tests 0.05 significance level). This likely represents normal biological variation within and between plants. (Fig. 5)

Thickness

There is a significant difference in thickness between old and new pith paper (using t tests 0.05 significance level). This represents the expected variation in a handcrafted product.

Porosity

- Porosity is defined as the fraction of air space in the sample.
- Pith paper has a high porosity ≈ 75%, which is one of the contributing factors in its translucency.
- In comparison, Whatman No. 1 filter paper had a measured porosity ≈ 51%.

Colour

- The old paper (mid 1800s) was slightly more yellow and darker than new pith paper (ΔE =7.86).
- This represents a moderate yellowing (pith cells have little lignin)[6] compared with printed books of similar age (ΔE = 20 – 30).[7]

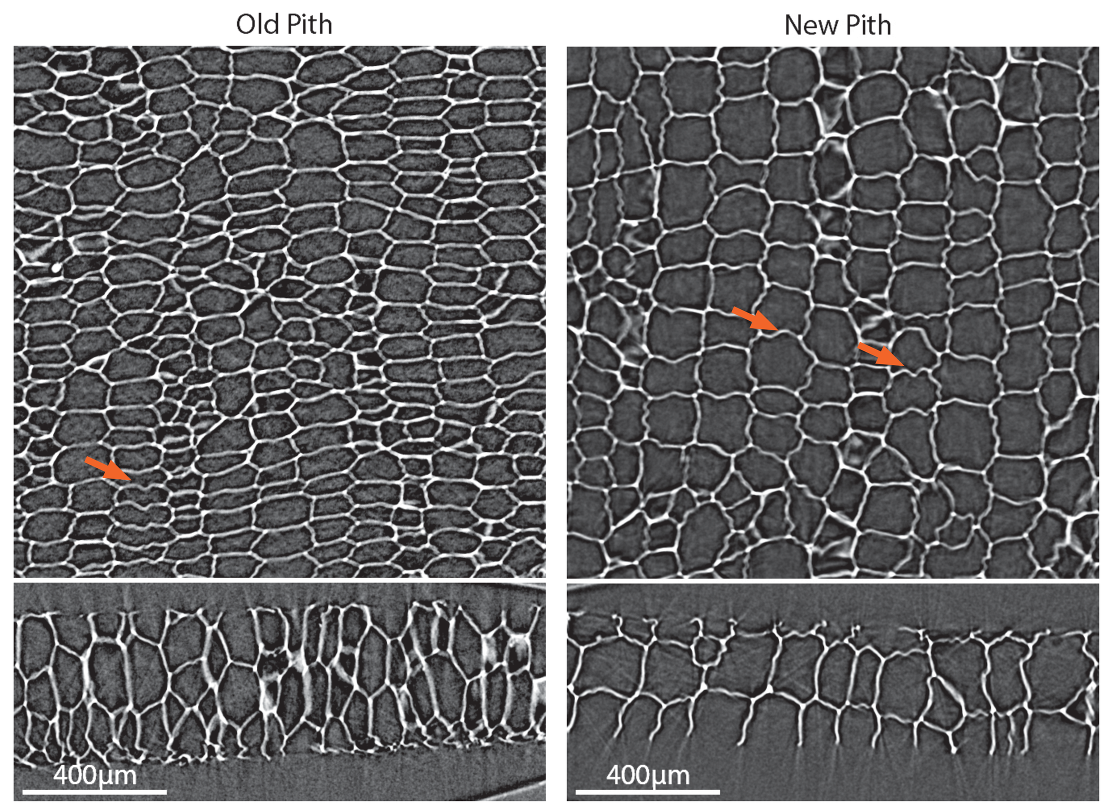

Fig. 5 The upper images are periclinal tangential longitudinal slices and the lower images transverse slices (thickness). Note the presence of cell wall undulations (arrows) — these most likely occur as the pith paper dries.

OBSERVATIONS ON CELL WALLS

- No signs of deterioration were observed in the cell walls of old pith paper.
- Pith cell walls have two states: straight walls and undulating walls — which most likely occur as the pith paper dries.[6] It has been observed that pith paper expands when wet — some of this expansion could be due to the straightening of the undulated cell walls.

	Pith Cell Dimensions (µm ± SE)			Pith Paper Thickness (µm ± SE)	Porosity ± SE		Colour Change			
	Periclinal Tangential Longitudinal		Transverse	Transverse						
	X	Y *	*	*				L	a	b
Old	164.35 ± 5.30	69.99 ± 5.30	188.62 ± 5.91	423.96 ± 2.24		0.75 ± 0.01		92.75	0.62	11.75
New	154.74 ± 3.50	123.54 ± 8.81	213.55 ± 4.37	351.07 ± 1.91		0.78 ± 0.01		97.5	0.05	5.52
					Whatman # 1	0.51 ± 0.01	CIE76 ΔE	7.86		

Table 1 Physical parameters measured on old and new pith paper.
* Indicates a significant difference between old and new pith paper at the 0.05 level of significance.

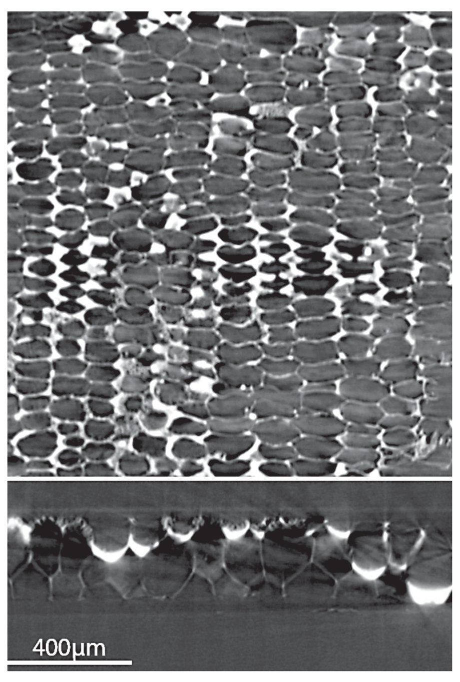

Fig. 6 The upper image is a periclinal tangential longitudinal slice and the lower a transverse slice from pigmented pith paper.

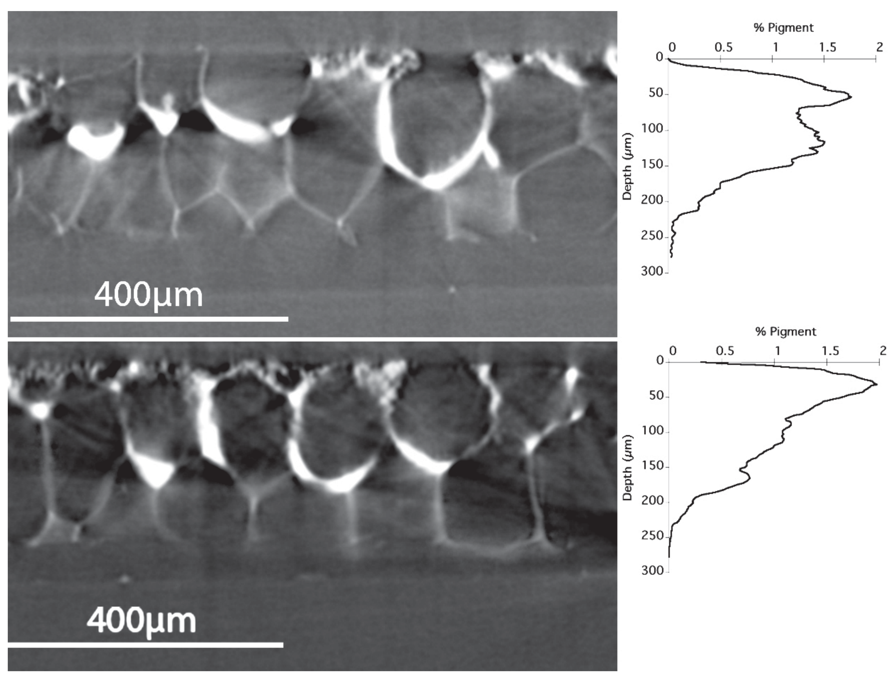

Fig. 7 Two transverse slices through pigmented pith with their corresponding pigment depth profiles. Both have the painted surface at the top.

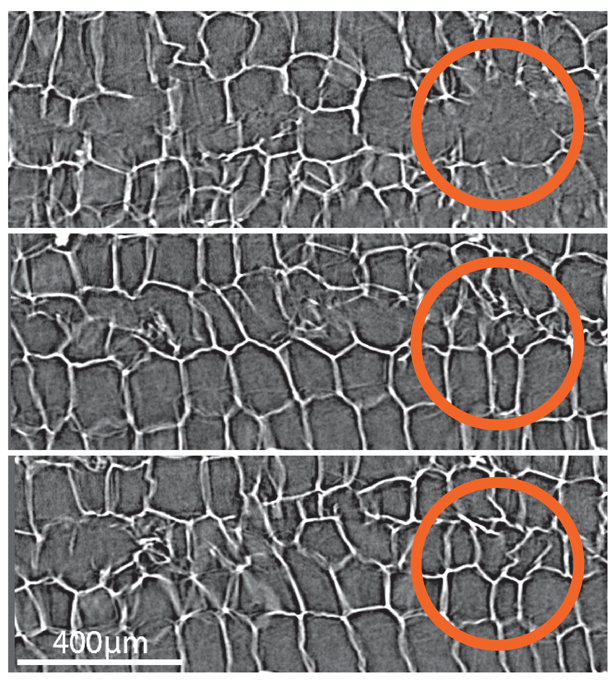

Fig. 8 Three slices through new pith paper showing experimental join — at depths of: 4µm, 113µm and 160µm from the upper to lower surface. Circle indicates same area through the three depths. All images are periclinal tangential longitudinal.

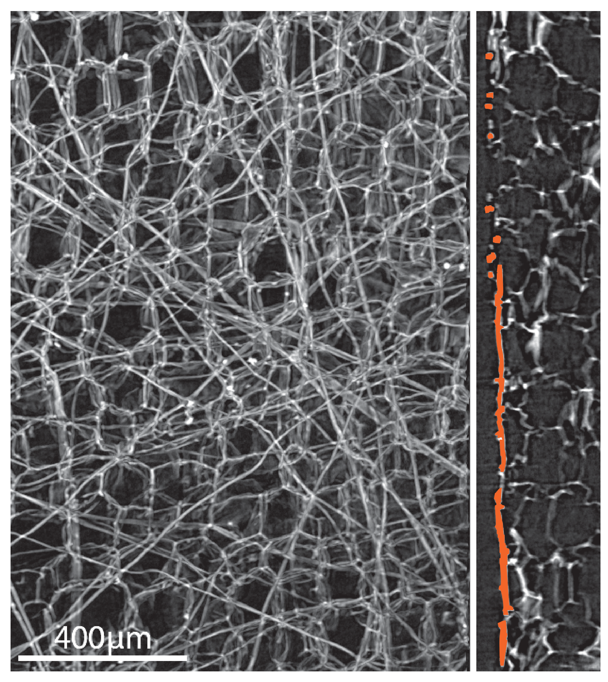

Fig. 9 Left image: pith paper lined with Berlin Tissue, periclinal tangential longitudinal view.
Right image: transverse view through the thickness of pith paper and Berlin Tissue. The Berlin Tissue is highlighted.

PIGMENT

The samples (<2 mm) were randomly selected from a set of small fragments that had drifted to the album gutter. (Fig. 4)

Observations

- The pigments were readily visualised in the pith paper compared to the pith cell walls due to their greater X-ray density. (Fig. 6, 7)
- Pigment was observed to coat the surface of uncut pith cells and to pool at the bottom and sides of cut pith cells. This observation was most clearly seen in the transverse slices. (Fig. 7)

Measurement

- Pigment profiles were produced by a custom macro written in the image analysis software ImageJ. The pigment depth profile shows the pigment distribution averaged throughout the thickness of the pith paper. Some indicative depth profiles are shown in Fig. 7.
- These examples indicated that the pigment is dispersed through the thickness of the pith paper.
- Depth profiles will vary greatly across the image area due to variations in pigment application by the workshop artists combined with the local pith structure.
- This degree of pigment penetration, combined with the translucency of pith paper, is likely to produce the unique optical characteristics of pith paintings.

TEST SAMPLES

Sample preparation for join

- New pith paper was folded and torn along weakened edges.
- A 2%w/v methylcellulose was adhered to one edge and a butt join was formed.
- Light pressure was applied until dry.
- The join was imaged in the MicroCT.

Observations

- MicroCT produces 157 slices through the thickness of the join. Three slices were selected at different depths to show different combinations of adhesion points. (Fig. 8)
- Overall adhesion along the join is achieved through an accumulation of many small points of contact that occur within the depth of the pith paper.
- Other adhesives, including diluted wheat starch paste and 2%w/v Klucel G, had similar results.

Sample preparation for lining

- Remoistenable tissue was prepared from Berlin Tissue (Gangolf Ulbricht) (2g/m² Koso and Mitsumata fibres) 2%w/v Klucel G in ethanol.
- Remoistenable tissue was activated with ethanol, new pith paper was positioned over the lining and light pressure was applied until dry. (Fig. 9)

Measurements

- Pith paper colour measurements before and after lining gave ΔE = 1.55 (ΔE < 2.0 is commonly regarded as a minimal colour difference).
- Berlin Tissue porosity was measured as 87% air space.

SUMMARY

- Pith is not paper, it is more like a herbarium specimen and needs to be handled accordingly.[8]
- Pith is a biological sample, therefore natural variability is expected throughout a single sheet and between sheets.
- General observation of dry pith cells suggests they will expand when wet and contract when dry without incurring damage, unless movement is impeded.[6]
- The pigment in pith paper is distributed throughout the thickness of the sheet — but can only do so when the cell wall has been cut during the manufacturing process.
- The combination of two properties: pigment depth distribution (due to the cut cells) and the diffusion of light (due to high porosity and translucent pith cell walls) could help explain the unique optical characteristics of the pith painting.
- Serial 3D images through a join illustrate the multiple points of contact between cell walls at different depths. This provides evidence for the mechanism by which overall adhesion is achieved.
- The porosity of Berlin paper (87%) was greater than pith paper (75%), explaining the minimal colour change (ΔE = 1.55) between lined and unlined pith.

Authors

Dana Kahabka: Conservator, State Library of NSW

Dennis Dwarte: Honorary Associate, Medicine & Sydney Microscopy & Microanalysis, University of Sydney

Corresponding author:
dana.kahabka@sl.nsw.gov.au

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