THE ORIGINS OF PAPER

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Various advances have been proposed as distinguishing humans from other animals, such as walking upright and using tools. But neurophysicists tell us that without language, thought cannot move past a very rudimentary stage, so in terms of culture and knowledge, indisputably the single greatest development of humans was when they moved past animal body language and developed verbal language.

A limitation of verbal language for early humans was its restriction in time and place - it lasted only for the duration of the speech, and you had to be close enough to hear it, or rely on re-telling by others. Abstract concepts in particular are subject to distortion when transmitted this way, and without conserving the advances in thought through generations, culture could not advance very rapidly or spread very widely.

The problem of *time* was overcome with the development of visual language. Whether the cave painters of Altamira were attempting to communicate something particular to other humans, or to non-human powers they hoped to influence, we don't really know. But it *is* clear that they were attempting to give permanence to some knowledge or ideas that until then would have disappeared with the death of the possessors of that knowledge.

However, pictures of animals or humans are limited in what they can transmit. They do not permit economic reckoning, for example, or genealogies, or specific instructions from leaders to their subjects. It is not, therefore, surprising that as civilizations developed, humans came up with the notion that abstract visual signs could function like words, standing for ideas rather than just being representations of the real world. And like words, both the inherent concept and the way in which the signs are strung together in chains can alter their meaning almost endlessly.

Of itself, that didn't overcome the second problem, that of place. Painted cave walls or petroglyphs on rocks weren't too easy to move about, so what was needed was a portable medium to carry these signs. Various things were used to scratch and draw on, such as wood, animal bones and skins (ultimately as parchment), woven fabrics, and even clay tablets that could be impressed with tools and then fired for permanence. All of these served their purpose, and rolls of fabric and sheets of parchment were used for many centuries, are even today used for specific purposes. But all were rather cumbersome.

The Egyptians hit on an ingenious solution when they found a way of splitting and flattening the firm stems of a plentiful riverbank sedge plant, and gluing them criss-cross into two layers. The resulting sheets could be written on easily, stored flat and bound into books - a great advance on hoards of clay tablets. The Greeks and Romans adopted this material, and it has been persuasively argued that their empires could never have been administered without it. It is from the Greek name for this material, *papuros*, and the Latin *papyrus,* that the English word *paper* comes.

Mesopotamian impressed and fired clay tablet

Cylinder seal and impression

Detail of part of sheet of papyrus

But the paper we know did not evolve out of papyrus at all. Though as a writing medium it was a wonderful advance on animal products or clay tablets, even woven cloth, it was a technological dead end, and though it is still made as a curiosity in Egypt, no technical evolution has been possible.

The story of true paper started in China. Like the Egyptians, the Chinese had, nearly 5,000 years ago, developed a pictographic form of writing, and they too had been using various objects to write on, notably strips of bamboo and woven silk, and possibly the barkcloth they were making for other purposes by beating out and felting the white inner bark of a particular member of the fig family, the Paper Mulberry, *Broussonetia papyrifera*. Legend tells us that in 105AD an official called Tsai Lung "invented paper", though it is clear from archaeological finds that in fact it was in existence in China for at least two centuries before him (for a much fuller account of all of this, see my online article 'Barkcloth and the Origins of Paper'.) An official history written some centuries later records:

Postage stamp with stylised portrait of Tsai Lung

In ancient times writing was generally on bamboo or on pieces of silk, which were then called ji. But silk being expensive and bamboo heavy, these two materials were not convenient. Then Tsai Lun thought of using tree bark, hemp, rags, and fish nets. In 105 he made a report to the emperor on the process of paper making, and received high praise for his ability. From this time paper has been in use everywhere and is called the "paper of Marquis Tsai."

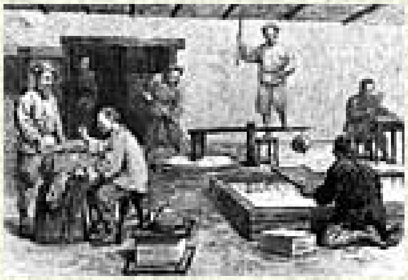
Perhaps he had a very good press secretary! But what is important is that they discovered that they could pound certain plant-derived substances into a pulp, remove impurities, float the pulp in water, sieve it out onto fabric sheets, and allow it to dry. When it dried, it congealed into a firm, tough sheet that was very light, and as long as it did not get wet, proved remarkably durable.

This simplest of papermaking technologies is still practised in exactly the same way in Tibet and Nepal, the first countries to learn the craft from China. A simple frame has a cotton cloth stretched over one side, and very watery pulp is poured into the other side (which has the "walls" made by the frame) and spread around until it is even. Then it is suspended somewhere to allow the water to drain out of it and the pulp to dry into a paper sheet which can be peeled off. At some stage a clever developer figured that making a frame with ribs, and placing a fine removable bamboo mat over this, would allow the process to be speeded up enormously. Instead of tying up one mould for each sheet of paper, severely limiting the number of sheets that could be made at one time, a stack could be built up layer upon layer of sieved pulp, with only a piece of cotton thread between them to facilitate later separation. The stack is then pressed lightly, and each sheet, or layer of pulp, transferred to a board to dry. This is the way in which Chinese and Japanese handmade papers are still made. Technological improvements, such as using caustic solutions to weaken the plant material before pounding, and adding a suspension agent to prevent the pulp from clumping, have not changed the fundamental principle.

Many of you will be aware that in the first century AD, a trade-route developed between China and Europe, known as the Silk Road, running through Samarkand in modern-day Uzbekistan and ending in Damascus, whence Asian wares spread into Europe. (I remember as a schoolboy being stirred by James Elroy Flecker's poem "The Golden Road to Samarkand", which refers to the western end of this route). One of the goods these traders possessed was particularly fascinating to their clients - paper.

However, the Chinese closely guarded the secret of paper manufacture, until in 751AD when the T'Ang army was defeated by the Ottoman Turks at the Battle of Talas River (in present-day Kazakhstan). Among the prisoners were two papermakers, who were forced to reveal their craft. Very soon, a papermill was established in Samarkand and another in Baghdad, and the Arabs were able to develop great libraries. But it was not until the Egyptians learned papermaking from the Arabs in the 10th Century that the way was open for the knowledge to pass, as a result of the Crusades, into Spain in 1150AD. It spread over the next few centuries into Italy, France, the low countries and Germany, and finally Britain. In 1453 Gutenburg developed movable type and a printing press, and as they say, the rest is history.

There were some very important innovations in Europe, without which the mass-production of paper could not have developed. The first was to replace the tree-bark of Eastern papers completely with cotton or hemp rags. This in turn required a new approach to pounding the vegetable material into pulp. The cotton and linen rags were fermented but still took a great deal of pounding to break down. The Eastern traditions of hand-beating and hand- or foot-worked stampers were quickly replaced in Europe with stamping machines driven by wind and water mills. The noise these large machines make when operating is something fierce.



Chinese papermakers using foot-operated stamper

Then during their cultural and scientific heyday in the late 17th Century, the Dutch developed a cylinder-beater (which came to be called a Hollander)**,** again driven by windmills or watermills. This ingenious machine circulates the pulp as it cuts, squeezes and brushes it, allowing finer control over all of the processes of pulp preparation. It is the principal machine still used by hand-papermakers today.

The third was a modification of the Asian mould. Europe did not have available the bamboo of the Chinese, but were master metalsmiths, and developed a wire-gauze rigid variant of the mould. Instead of taking the flexible bamboo mat off the mould, here the "fence" that traps the pulp is removable. It is called a *deckle*, and when it is removed it allows the pulp to spread slightly, giving the attractive "deckled edge" to handmade paper. The layer of pulp can then be "kissed off" the mould onto successive sheets of felt (a process called *couching*), and then pressing the stack of felts with their load of couched sheets of pulp. Once pressed, the sheets are taken off the felts and hung on lines or rails to dry. This metal mesh mould also permitted watermarking by sewing wire designs onto the mesh, or even by burnishing the wire mesh itself to achieve tonal watermarks. In each case, what is affected is the thickness of the pulp, and thus the amount of light it lets through.

The machines used in the great industrial papermills today, which allow paper to be produced at incredible speed and volume in continuous rolls, are all descendants of a machine made by Messrs Fourdrinier, in Hertfordshire, two centuries ago. The wire mesh of moulds and layers of felt are replaced by endless belts of each, and the "stream" of paper then passes through press rolls and drying rolls before finally being wound onto reels. Cotton cloth and other plant fibres have been progressively replaced by wood fibre since 1853, when two Englishmen, Watt and Burgess, patented a chemical process , and a decade later a German called Voelter patented a mechanical process, for breaking down the wood. Today a combination of both processes is used. Initially only softwoods were used, and it was not until well into the 20th century that Australian scientists perfected the use of hardwoods.

You will have noticed that all I have spoken about is water and plant fibre, no glue of any sort to make those fibres stick together. Though trial, error and ingenuity had shown the world *that* it works, just *how* a slurry of plant fibres can be turned into a sheet of paper was not figured out until well into the 20th Century, by a

Canadian scientist called Boyd Campbell.

The plant fibres involved are cellulose, the building material of plants. I won't attempt to go into too much detail about the chemistry involved, but explain just a little to show what an extraordinary substance paper really is. First, for those of you without any background in chemistry, it is necessary to understand that atoms have what you can think of as little grappling-hooks that allow them to attach to other atoms. The number of these that each element has determine what is called its *valence*. Hydrogen has only one of these, oxygen has two, carbon has four, and so on. So you can get compounds like methane gas, which is CH_4, using up all of the carbon 'hooks' to grab each single hook of four hydrogens. The strength or weakness with which they attach is what makes the compound stable or volatile.

Well, cellulose fibres are made up of many long carbon chains, in fact cellulose is a type of glucose, or polysaccharide chain. These chains have, attached to their carbon atoms, many hydroxyl ions - that is, oxygen and hydrogen in combination, just as they are in water.

Water, in fact, is the other part of the story. It is *itself* an extraordinary, anomalous substance. Though theoretically H_2O should be a gas, oxygen tends to be rather promiscuous when it comes to hydrogen atoms. While it forms molecular bonds with two hydrogens or with a hydrogen and another element such as carbon, as described above, it likes to "have a bit on the side" with any nearby hydrogens as well as its own, "partner-swapping" to the extent that it is difficult to be sure which hydrogen really belongs to which oxygen. This means that neighbouring H_2O molecules actually stick to one another, causing it to be a liquid.

Now, when cellulose is beaten, two things happen. First, the surface of the fibres is damaged, causing many cellulose strands to fray out, and greatly increase the number of hydroxyls exposed. This is called *fibrillation*. Second, the oxygen in the water in which this takes place plays its usual games, and attaches itself happily to the hydrogens belonging to the exposed hydroxyls. This is called *hydration*. The result is a thoroughly soggy fibrous mass of pulp. When the water is squeezed out of this pulp, and even more when it dries, these water to cellulose bonds are broken, but the oxygens on the surface of the cellulose latch on to the liberated hydrogens of neighbouring cellulose fibres. This is called *hydrogen bonding.* As well, the micro-fibrils *physically* tangle with one another. The result is a very strong, patent, sheet of paper. But if it gets wet, the process is reversed, the oxygen in water woos the hydrogens away again, and the cellulose fibres tend to float apart.

This much of the story is now clearly understood, and paper chemists are able to control the process so well that they can make everything from greaseproof paper to toilet paper and everything in between, by controlling the manner in which the cellulose is beaten and chemically treated, and how it is settled and dried.

In the few minutes left, I would just like to tell you where I come into this story. For the past twenty years, I have been working as an anthropologist as well as an artist, in fact my doctorate is in sociology and anthropology, not art. I have been studying, in particular, the barkcloth made by the people of the Pacific, particularly my home country of Fiji. This barkcloth is what is commonly called *tapa* by Westerners, though it is interesting that virtually none of the people that make and use it call it that. About fifteen years ago, my knowledge as a papermaker made me realise that the water, beating, and felting that was going on in bark-cloth making in the Pacific was precisely the same thing that was occurring in papermaking. I knew of the vagueness surrounding Tsai Lung's "discovery". I had also learned that prior to that discovery, China also had a long history of making bark-cloth. They used the strong, supple sheets for everything from paper money to religious offerings. They even used it for armour for horse-soldiers, pleated around the body so that it could trap arrows and absorb sword-cuts, while remaining flexible and lightweight. So important was this material to them that it was regarded as sacred, worn for weddings, burned ritually at funerals and so on. These attributes were later transferred to paper — in fact one of the Japanese words for paper, *kami*, also means god, or spirit. In the Pacific and elsewhere, bark-cloth retains this spiritual quality, while on the other side of the pacific from Asia, the Otomi Indians of Central America still make a coarse brown barkcloth called *amatl*, that they cut into little figures and use for magico-religious rites.

I coupled those things with the fact that the peoples of the Pacific and the Americas originated in the Asian continent, that the plant used throughout the Pacific for making barkcloth is the Asian paper mulberry, brought with them on their voyages of settlement, and that their barkcloth, though a functional item of clothing and general-purpose fabric, invariably has sacred connotations. And finally, that it was apparent that there was an intriguing evolution from the fairly basic coarse bark-cloth of the north-west Pacific to an incredibly fine, paper-like product in Eastern Polynesia. It started to dawn on me that what we were seeing in the Pacific was a recapitulation of what may well have occurred in China with the evolution of paper, a process that occurred separately both at home after the first Pacific settlers left, and in the emigrants' new home.

Progressively, Pacific islanders had introduced the stages that occurred in the evolution of paper. First partial breaking down of the inner bark of the mulberry, achieved with heavy beating with water, causing fibrillation. Then felting, achieved with beating together wet sheets of cellulose-material, with attendant hydrogen bonding. By the time they reached Tahiti they had started partially rotting the bark to facilitate the beating, just as in Asia they used caustic solutions and in Europe they rotted ("retted") the cloth partially. Then in Hawaii they actually carried this process to the point of pulping the bark completely with heavy clubs, and using their beaters to both spread it out very evenly and, by carving patterns on the beaters, to watermark the cloth. The one step that was not developed in the Pacific was floating the fibres in a slurry and sieving them out. But since they did not have writing, although they both painted and printed their cloth, they needed very large sheets for their uses, so there would have been no point in their doing so. I have dealt with my theories on this subject in considerably more detail elsewhere.

Given this evidence, I contend that it is possible to see exactly how the Chinese developed paper, the sieving no doubt emerging from other technologies they possessed. Their reverence for their barkcloth and its paper offspring has been amply justified by the knowledge revolution it has facilitated.