

Founding father

Eric S. Lander and Joseph J. Ellis

Almost two hundred years ago Thomas Jefferson was alleged to have fathered a children by his slave Sally Hemings. The charges have remained controversial. Now, DNA analysis confirms that Jefferson was indeed the father of at least one of Hemings' children.

For two centuries Thomas Jefferson's legacy has been haunted by the first US presidential sex scandal — the charge of an illicit relationship with his mulatto slave Sally Hemings. From the day the story broke in a Richmond newspaper in 1802, 'Tom and Sally' has become the longest running mini-series in American history. Because the evidence was all circumstantial, no authoritative resolution has been possible. Until today, that is. On page 27 of this issue, Foster *et al.*¹ report that DNA testing of Y chromosomes offers strong evidence that Jefferson fathered at least one of Hemings' children.

The saga begins in the mid-1780s in Paris, where Jefferson served as ambassador to France after the death of his wife. Sally Hemings, then 14 years old, was sent to accompany Jefferson's youngest daughter to Paris in 1786. There is no evidence of what transpired there, but Hemings returned to the United States with Jefferson in 1789, and she eventually bore at least five children, starting with Tom in 1790 and ending with Eston in 1808.

At least three pieces of evidence support a relationship between Jefferson and Hemings. First, several of the children bore a

striking physical resemblance to Jefferson. Second, Sally's fourth child, Madison, testified late in life that Sally had identified Jefferson as the father of all her children. Finally, Jefferson was in residence at his mansion in Monticello in Virginia at the time when each of the children was conceived. But many historians have expressed doubts, and Jefferson family tradition has implicated a maternal cousin as the likely father.

To a geneticist, the obvious solution — short of exhuming the principals — is to compare Y chromosomes from modern-day male-line descendants. Most of the Y chromosome is passed intact from father to son, so it can be used to trace paternal lineages. However, such studies require enough polymorphic markers (small regions of DNA that vary among individuals) so that Y chromosomes can be distinguished by the haplotype (set of specific variants) that they carry. Researchers from several laboratories have identified a collection of suitable markers from the Y chromosome over the past two years, and this collection is now fuelling an explosion in male-line genetic studies.

Foster *et al.*¹ examined a haplotype containing 19 polymorphic markers. Jefferson's haplotype (inferred from male-line descen-

Name	Value 1	Value 2	Value 3	Value 4
Red	5 1/2	7		
Tommy	5	7		
Mores 3	4	5		
Sucky 6	3 1/2	4		
Nedj	5 1/2	7		
Peter Hem	5 1/2	7		
Philip	5 1/2	7		1
Rachael	5	7		
Eliza 5	3 1/2	4 1/2		
Ellen 8	2 3/4	3 3/4		
Sally	5	7		1
Hannibal 1	4 1/2	5 1/2		1
Madison 2	3 1/2	4 1/2		1
Eston 8	2 3/4	3 3/4		1
Samuel	5 1/2	7		1

Figure 2 A portion of Jefferson's farm book, in which he recorded the distribution of slave rations by family.

dants of his paternal grandfather) seems to be quite rare, inasmuch as it was not seen among a sample of 670 Europeans or 1,200 people worldwide. The authors found that this rare haplotype perfectly matches that of Eston Hemings' male-line descendant. The probability of such a match arising by chance is low — safely less than 1%. Together with the circumstantial evidence, it seems to seal the case that Jefferson was Eston Hemings' father.

Interestingly, Jefferson's haplotype does not match male descendants of Sally's first son, Tom Woodson. The simplest explanation is that Jefferson was not Tom's father. An alternative explanation would require non-paternities among Tom's offspring. The jury remains out with respect to Sally's other children, but the burden of proof has clearly shifted.

Nothing in Foster and colleagues' study, and nothing in the vast historical literature, sheds any light on the character of the relationship between Jefferson and Sally Hemings. Was it, as his contemporary critics charged, a tale of lust and rape? Was it, as several twentieth-century scholars and novelists have suggested, a love story rooted in mutual affection? Or was it something in-between? These questions are open to endless interpretation but, in a broader sense, the new findings give blacks and whites alike an opportunity to confront a largely secret, shared history.

Politically, the Thomas Jefferson verdict is likely to figure in upcoming impeachment hearings on William Jefferson Clinton's sexual indiscretions, in which DNA testing has also played a role. The parallels are hardly perfect, but some are striking. Both 'improper' relationships involved women about 28 years younger — although there is a world of difference between a slave and master at the close of the eighteenth century, and a White House intern and a married man at the end

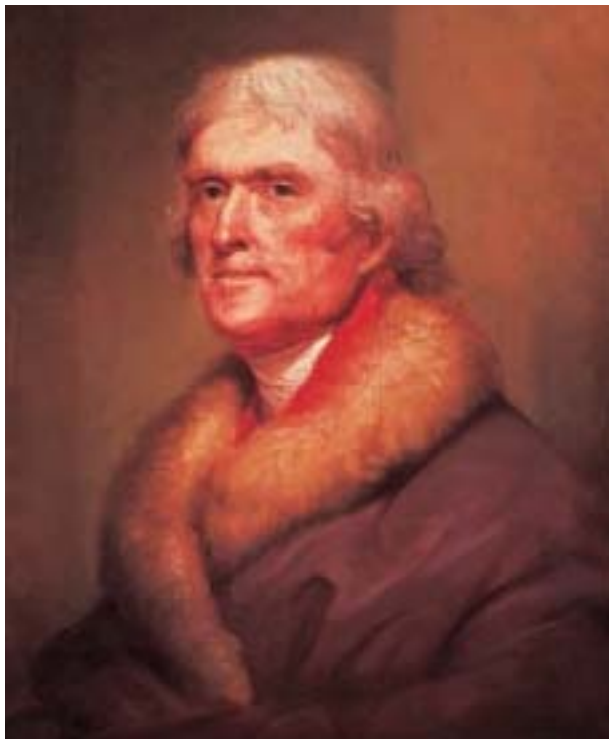


Figure 1 Thomas Jefferson (1743–1826), third president of the United States. DNA analysis by Foster *et al.*¹ shows that he fathered at least one child by his slave, Sally Hemings.

of the twentieth. Both presidents seem to have engaged in politically reckless conduct; in Jefferson's case, fathering Eston six years after allegations appeared in the national press. And both offered evasive denials to the charges. In 1805 the Massachusetts legislature staged a mock impeachment trial of Jefferson, citing several grievances including the accusations about Sally Hemings. Jefferson acknowledged one charge (propositioning a married woman in his youth), but asserted that all the others were false. Otherwise he remained silent, leaving denials to political supporters and family. Nor did the scandal affect Jefferson's popularity. He won the 1804 election by a landslide, and his abiding position was that his private life was nobody else's business, and should have no bearing on his public reputation.

Foster and colleagues' findings renew questions about Jefferson's tortured position on slavery. If Jefferson's relationship with Hemings began in the late 1780s, it would mean that he began to back away from a leadership position in the anti-slavery movement just around the time that his affair with Sally Hemings started. Jefferson's stated reservations about ending slavery included a fear that emancipation would lead to racial mixing and amalgamation. His own interracial affair now personalizes this issue, while adding a dimension of hypocrisy.

Over the past 30 years, research into Jefferson has cast a shadow over his credibility as America's prophet of freedom and equality. Recent work has also emphasized his massive personal contradictions and his dexterity at playing hide-and-seek within himself. The new evidence only deepens the paradoxes.

Jefferson is, with Abraham Lincoln and George Washington, one of America's secular saints. His face looks out from the nickel, the two-dollar bill, the memorial near the Tidal Basin, and Mount Rushmore. His unique capacity to project inspirational words and ideas onto American public life has made him all things to all people. As an icon, Jefferson's legacy has been reinterpreted by every generation. Now, with impeccable timing, Jefferson reappears to remind us of a truth that should be self evident. Our heroes — and especially presidents — are not gods or saints, but flesh-and-blood humans, with all of the frailties and imperfections that this entails. □

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1. Foster, E. A. *et al. Nature* **396**, 27–28 (1998).



Figure 1 Penrose's planar quasiperiodic tiling. It is formed by a set of two rhombuses with edges of equal length, one with angles of 36° and 144° and one with angles of 72° and 108°. Their edges are marked with single or double arrows, and the rules constrain adjacent tiles to have matching arrow types along their shared

edges, which can be interpreted in terms of short-range interactions between atoms in clusters centred on a given vertex. But this mathematical exercise is of little use to the physicist who wants to understand why and how quasicrystals form, as the tiles correspond neither to atoms nor to real atom clusters.

In 1991, Sergei Burkov⁷ realized that planar quasiperiodic tilings can be generated with only a single tile, a decagon, provided that the tiles can overlap. Five years later, Petra Gummelt⁸ gave a mathematical proof that a quasiperiodic Penrose tiling can be generated using a single decagon combined with a novel overlapping rule. This rule is realized by decorating the interior of the decagons (Fig. 2) with a subset of shaded tiles, and two decagons may overlap only if shaded areas overlap. This is equivalent to Penrose's arrow matching rules⁹. In tilings overlapping has to be avoided as a point of principle. Here it becomes a basic construction element; so, using an established mathematical term¹⁰, Gummelt called the pattern a 'coverage'.

Hyeong-Chai Jeong and Steinhardt⁹ then proved that Penrose matching rules can be abandoned altogether and replaced by the condition that the density of a suitably chosen cluster (for instance in the form of Gummelt's decagon) is maximized. And this is where mathematics at last leads to physics. Jeong and Steinhardt concluded that quasicrystals represent a packing of a single type of atom cluster. This cluster can share atoms with its neighbours, and the resulting quasiperiodic pattern is just the one that maximizes cluster density. By postulating that this cluster corresponds to a minimum-energy atom configuration, the authors arrived at a physically plausible picture.

Striking evidence for the coverage model

Quasicrystals

From tilings to coverings

Knut W. Urban

Quasicrystals occur in a great number of alloys, most of which consist of aluminium and transition metals. They were discovered¹ in 1984, being revealed by a rotational symmetry of X-ray or electron diffraction patterns (for instance, five-fold or ten-fold) which is impossible for true periodic crystals. Since then, physicists have wondered why atoms form in these complex patterns rather than in a regularly repeating periodic crystal. On page 55 of this issue² Paul Steinhardt and colleagues present an analysis of new electron microscope data that supports a simple answer to this question.

Although a quasicrystal is non-periodic, its structure still follows a subtle construction plan. Mathematically, this can be described with reference to a higher-dimensional analogue of a cubic lattice: the atom arrangement of an icosahedral quasicrystal (which is quasiperiodic in three dimensions) can be constructed starting from six-dimensional space; the decagonal quasicrystal (whose lattice is quasiperiodic in a plane but periodic along the third dimension) requires reference to five-dimensional space. But why should atoms care about higher-dimension-

al spaces? The mathematical recipe to describe the lattice does not give us any hint as to how the atoms manage to create it.

Ten years before their discovery in nature, quasiperiodic patterns with the same geometric properties as those calculated from five-dimensional hyperspace were described by Roger Penrose³. These are tilings of the plane, in which a set of suitable tiles is arranged without gaps or overlaps according to certain matching rules. An example (Fig. 1) is the set consisting of two rhombuses with edges of equal length, one with angles of 36° and 144° and the other with angles of 72° and 108°. Their edges are marked with single or double arrows, and the rules constrain adjacent tiles to have matching arrow types along their shared edge. Corresponding matching rules have been found for three-dimensionally quasiperiodic patterns based on two types of rhombohedron⁴.

It would appear that Penrose's 'edge' rules can be used to mimic growth of quasicrystals by stepwise addition of tiles to a seed. However, because these rules are strictly local in nature, they are not enough to guarantee a defect-free quasiperiodic pattern⁵. A solution to this growth problem is instead to