
Opening Extract from...

The British

A Genetic Journey

Written by Alistair Moffat

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THE BRITISH
A GENETIC JOURNEY

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BIRLINN

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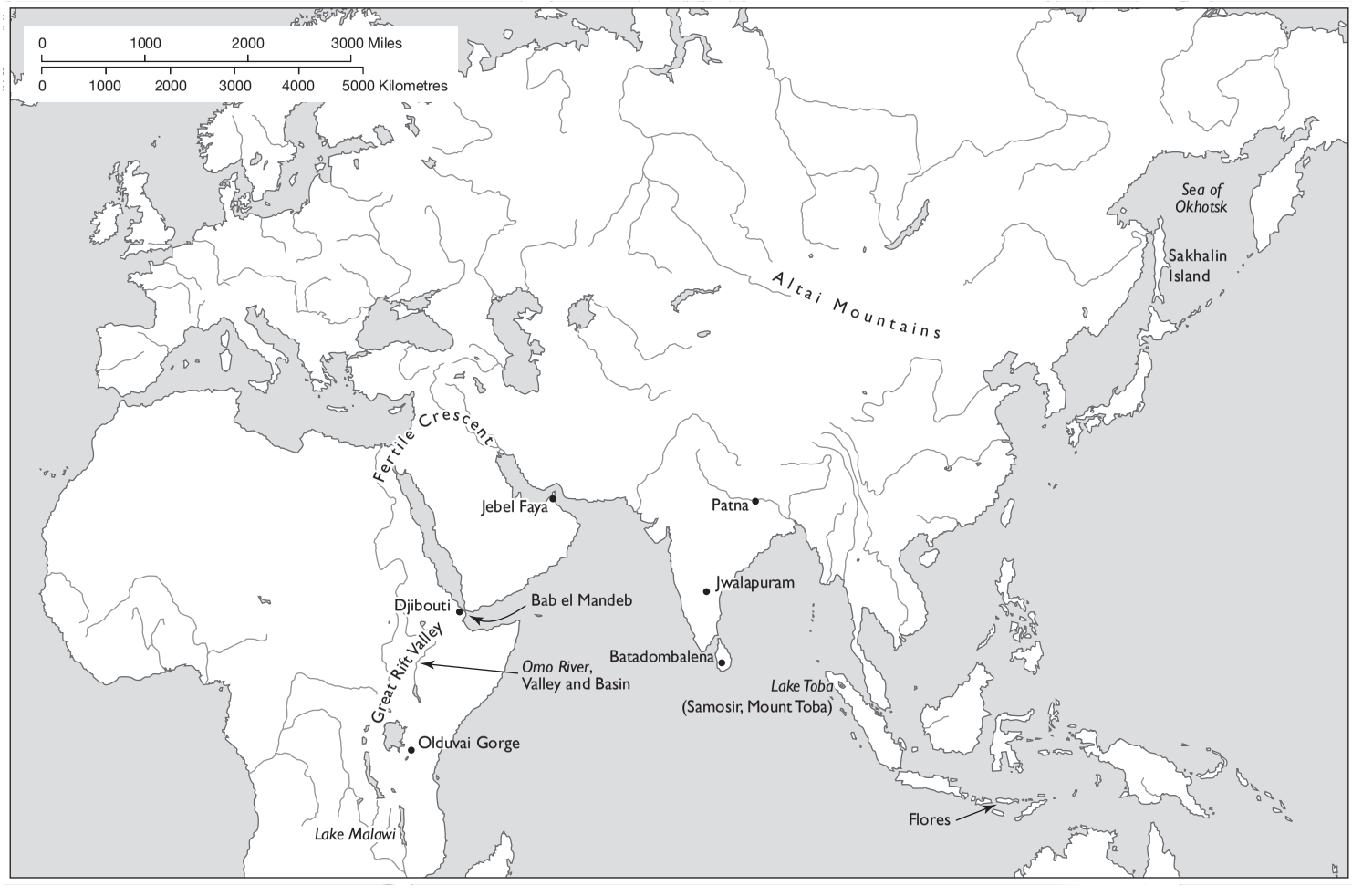
0 50 100 150 Miles
0 50 100 150 200 250 Kilometres
Mousa
Orkney Mainland: Ring of Brodgar,
Stones of Stenness, Maes Howe,
Knap of Howar, Skara Brae, Gurness, Tankerness
South Ronaldsay
(Tomb of the Eagles)
Kilphedir
Rubh' An Dunain/
Loch na h-Airde
North Sea
Argyll
Manau
Echline
East Barns/Barns Ness
Bridgend
Howburn
Fairnington House
Eildon Hill North
Howick
Broighter
Dogger
Bank
(Doggerland)
Ross Island
Starr Carr
Normanton Down
North Ferriby
Great Orme
Pin Hole
Cresswell Crags/
Robin Hood Cave
Peterborough
Feriter's Cove
Ascott under Wychwood
Coygan Cave
Wayland's Smithy
Avebury/Silbury Hill
West Kennet Barrow
Cheddar Gorge
Gough's Cave
Wookey
Amesbury
Danebury
Hembury
Dorset Cursus
Hambledon
Maidens Castle
English Channel
Torquay
(Kent's Cavern)
Carn Brea
Stonehenge, Durrington Walls,
Woodhenge, Boscombe Down
Poldark Tin Mine


Mount Hekla
Stellmoor
Neander Valley
Normandy
Hallstatt
Tisenjoch Pass
Lascaux
Altmira
Ardèche Gorge
Pont d'Arc
Chauvet Cave
Treilles
Rudna Glava
Plocnik
0 100 200 300 Miles
0 100 200 300 400 500 Kilometres


0 1000 2000 3000 Miles
0 1000 2000 3000 4000 5000 Kilometres
Sea of Okhotsk
Sakhalin Island
Altai Mountains
Fertile Crescent
Jebel Faya
Patna
Jwalapuram
Djibouti
Bab el Mandeb
Great Rift Valley
Omo River, Valley and Basin
Batadombalena
Lake Toba (Samosir, Mount Toba)
Olduvai Gorge
Lake Malawi
Flores

Preface

When Herodotus of Halicarnassus wrote history in the fifth century BC, he intended it to be something like an investigation, the collation of statements about events, people and circumstances made by those who had been there and seen them. Like a detective, he was pursuing enquiries. In Greek, 'history' meant something like 'testimony'. Soldiers who fought in battles, travellers who had seen Nile crocodiles, supplicants who had bowed before Persian kings – they were the sorts of people Herodotus wanted to hear from. But as timelines lengthened and perspectives shifted, historians inevitably came to depend on more distant sources, usually the written records of what witnesses or the actors in important episodes said about them. And for many centuries, most of the writing in Britain was done by clerics who were chroniclers often far removed from the action, rarely actual witnesses. Into the modern period archaeology came to supplement the patchy survival of documentary records, and for the long millennia before Herodotus and the statements of witnesses, what could be excavated and reconstructed became virtually the only source of reliable information. Without the patience, skill and imagination of generations of archaeologists, our prehistory would amount to little more than a set of assumptions and guesses.

Recently, population genetics and in particular the study of ancestral DNA have added an entirely new dimension to our understanding of our past. The ability of scientists to identify the origins and dates of DNA markers and to use them to track the movement of people across the Earth has been revealing, sometimes startling.

The dim and very distant prehistoric past can come brilliantly and movingly alive when the passage of a marker is traced from Manchuria and the shores of the Yellow Sea in the North Pacific clear across the Eurasian landmass to be found in Edinburgh in 2013.

For many millennia the last ice age held Britain and much of the northern hemisphere in its sterile, savage grip. In the brilliant white landscape of the ice-domes, frozen mountains a kilometre thick where incessant hurricanes whipped around their flanks, nothing and no one could survive. That brute fact made Britain a clean slate, a place waiting for its people and their DNA to come. When temperatures at last began to rise, the glaciers rumbled, groaned, splintered and cracked, and the land greened once more, people returned. These pioneers, the first of our species to see the rivers, the grasslands, the forest canopy and the hills and mountains that had been sleeping under the ice-sheets, are amongst our earliest ancestors. They may seem like another race, but DNA confirms an unbroken link. And when the last of the ice had gone, more people came north to hunt and gather in the wildwood, to fish and forage on the seashore, and to begin Britain.

Over thousands of years of prehistory, our ancestors walked to the farthest north-west of the Eurasian continent. DNA maps their movement and can approximately date their arrival. For at least four millennia after the ice, Britain was a peninsula and our people could make their journeys dry-shod. The landscape they entered was virgin. The ice had swept all life out of Britain and after *c* 9000 BC the land waited for the hesitant tread of the earliest pioneers. That simple fact makes our islands the sum of many migrations, a destination at the farthest north-west reach of Europe for many genetic journeys. A nation of immigrants on the edge of beyond.

All human beings, indeed all living organisms, have DNA, and that means something unarguable: we are all part of history. When Herodotus' witnesses reported, they tended to remember the doings of the great or the mighty, kings, queens, warriors, battles and politics. But DNA makes us all witnesses, everyone who lives in Britain. Neither spectators nor the crowd barely discernible in the dimly lit background, we are – every one of us – actors in the unfolding drama of our history.

The Irish Sea Glacier

One of the most striking images in studies of the last ice age is what some scientists believe should be called the Irish Sea Glacier. They believe that it rumbled for 700 kilometres from its source in the ice caps of Scotland and Ireland and then squeezed between higher glaciated land either side of the North Channel. It pressed on the northern coasts of Cornwall and the Scilly Isles. It is even conjectured that the glacier continued to flow south even when parts of south Wales, the Bristol Channel and the coasts of south-west England were ice-free. It was a kind of 'valley-glacier' of the sort seen in the Himalayas. Others disagree that such a glacier ever existed, but the value of such speculation is that it forces us to visualise how different familiar landscapes and coastlines were in the deep past.

'The past is a foreign country, they do things differently there', was the opening sentence of L.P. Hartley's *The Go-Between*, and it is apposite in considering the mysteries of our prehistory. Human sacrifice, cannibalism and the decapitation of children are all abhorrent practices now, but they were part of the experience of our direct ancestors, people whose DNA many of us carry. Fragments of their lives, like the unmade pieces of an archaeological jigsaw, lie around us on every side and as we try to make a clearer picture of the ranges and camps of hunter-gatherers, the great timber halls of the early farmers and the rituals that took place inside the stone circles, we must never fall into the trap of thinking of our ancestors as foreign. As Hartley wrote, the past is foreign, but its people were our people and their story is seamless, part of our story.

The balance of this book is heavily skewed to our prehistory for the excellent reason that the nine millennia before written record form the overwhelming proportion of our history. The early immigrations occurred before the brief visit of the Romans in the first century BC, and it is in tracing these that DNA studies can be most illuminating. But there is also a good deal to say about the first millennium AD. DNA can shine a light on what used to be known

as the Dark Ages, the time of the Anglo-Saxons, the Vikings and other Northmen. After 1066, the picture stabilises as significantly fewer new people came and settled.

Since the industrial and agrarian revolutions, and the beginning of affordable sea and rail travel, Britain has seemed to become restless once more as many people moved. Across the Atlantic and further, from countryside to town and city and from upland to lowland, it appears that our people have left their native places in large numbers. But these changes seem more apparent than real. When those who have their ancestral DNA analysed are asked to name and locate their grandparents, it turns out that the demographics of Britain have shifted less than we think. When a Pictish marker was identified in 2013, many of those who carried it still lived in the ancient territories of Pictland in central and north-eastern Scotland.

More recently, Britain has seen an obvious influx of immigrants. After the Second World War, significant numbers of black and brown people have come mainly from the Caribbean and southern Asia to settle. They have not always been welcome and occasional outbursts talk of a threat to the British way of life. Not only is this shameful, it is inaccurate. At the outset of the twelfth millennium after the ice, Britain continues to be the destination of immigrants, just as it has been throughout all that long time. Incomers are not a threat to the British way of life, they *are* the British way of life. Our islands have been constantly enriched and renewed by the arrival of immigrants, they and their DNA have always added to the sum of what we are.

Part 1

1

Origins

On any London Monday morning packed trains rattle into King's Cross, Euston, Cannon Street and Waterloo. The brakes hiss, the doors open and Saracens, Saxons, Berbers, Cave Painters, Vikings, Angles and Picts pour out onto the platforms. On any Saturday afternoon at Ibrox, St James's Park, Old Trafford and Anfield crowds of Caledonians, Deer Hunters, Kurgans, Iberians, Rhinelanders and Anatolians roar on their teams, passionate in support, their sporting allegiances central to their identities. On any weekday morning all over Britain the school run delivers the children of the First Farmers, the Shell Collectors, the Foragers, the Shebans and the Yenesei to the gates of the playground.

These are the British, named by their DNA markers, all of them immigrants, all of them descendants of men and women from somewhere else, from the distant, shadowy millennia of deep time, the survivors of many epic journeys lost in the darkness of the past.

But now they are found, their stories lit by DNA, by the alchemical ability of geneticists to find traces of our history inside us, an immense story printed in the letters of our genome. DNA offers a new narrative, the unfolding – at last – of a people's history of Britain, a story of all of us who live on these islands at the end of Europe.

The story of the discovery of DNA itself is much younger and in some ways no less dramatic. In February 1953 two excited young men burst into the Eagle pub in Cambridge and announced to the

lunchtime clientele that they had discovered the secret of life. If an eyebrow was raised perhaps it was because this was the sort of declaration young men make after spending a few hours in a pub. But in this case it was no less than the truth. Francis Crick and James D. Watson were researchers at the Cavendish Laboratory at the University of Cambridge, and that morning they had completed a model of the molecular structure of DNA, a model they knew was correct, convincing in every detail.

Deoxyribonucleic acid is indeed the secret of life because it is the basis of heredity, a biochemical blueprint for reproduction. The DNA molecule carries the patterns for constructing proteins, the building blocks of our bodies and the machines that run the cells that make up our organs. Every living organism has DNA, from bacteria such as anthrax to a whale, from the tiniest aphid to a giant redwood tree.

When Crick and Watson created a wholly coherent model of the molecule and comprehended how it copied itself, the clouds of conjecture cleared and new scientific horizons opened. Their discovery enabled the creation of entirely new academic disciplines such as the science of molecular biology. How hereditary diseases and disabilities are passed on was at last understood. And by understanding the DNA of diseases, effective means of combatting them could be found. Once they were able to recognise what proteins were deficient or missing, biochemists could manufacture drugs to deal with what had long seemed incurable. The likes of insulin for the treatment of diabetes was made possible by Crick and Watson's breakthrough.

When the two researchers pushed open the doors of the Eagle, they also wanted to celebrate a victory. They had won a race. Three universities had been competing to be the first to make what they all knew would be a momentous, world-changing discovery. At the California Institute of Technology the chemist Linus Pauling had adopted two approaches by developing techniques called X-ray crystallography and by building three-dimensional models. In 1951 he published his model of the protein, alpha helix. With all the resources at his disposal, it was surely only a matter of time before Pauling's techniques led him to a similarly credible model for the structure of DNA, and following the research at CalTech, it was likely to be a helix, a spiral curve.

X-Ray Crystallography

When Wilhelm Röntgen discovered X-rays in 1895, fellow scientists understood them as waves of electromagnetic radiation, another form of light. At the same time, it was recognised that crystals were regular and symmetrical arrangements of atoms and when X-rays were directed at them, the effects were seen to be very revealing about their atomic structure. A helpful analogy is the way in which the waves of the sea strike a lighthouse to produce secondary circular waves. In 1912 a German scientist, Max von Laue, shone a beam of X-rays through a copper sulphate crystal and recorded its diffraction on a photographic plate. This was a very significant advance in working out the atomic structure of matter, and in 1914 von Laue won the Nobel Prize for physics. At Cambridge University, William Lawrence Bragg and his father, William Henry Bragg, developed Bragg's Law, a method of connecting the scattering of X-rays with the structure of the planes within a crystal. It unlocked the atomic structure of molecules and minerals, and the earliest to be understood were those of table salt, copper and diamonds. The Braggs shared the Nobel Prize for physics in 1915, the only father and son ever to do so.

At King's College in the University of London, two brilliant scientists were collaborating, but not happily. Maurice Wilkins was a New Zealander who took a physics degree at Cambridge before the Second World War. Seen as a brilliant young scientist, he found himself working on the improvement of cathode-ray tubes for use in radar during the Battle of Britain. Later in the war Wilkins worked in the United States and was involved in the Manhattan Project. When it became clear that the primary aim was to build an immensely destructive atomic bomb, Wilkins (along with many other nuclear physicists) decided to turn his mind to other projects.

The supervisor of his PhD at Cambridge, John Randall, had also withdrawn from the Manhattan Project and together they began to work on X-ray crystallography, first at the University of St Andrews

and later at King's College, London. Like Linus Pauling in California, Wilkins realised that these new techniques could be central to any understanding of the structure of DNA. There is a palpable sense of talented scientists turning away from the destruction of war to something more creative, optimistic and wholesome – the discovery of how life is made.

At King's Wilkins was joined by a remarkable woman. Rosalind Franklin had also contributed to the scientific effort behind the Allied victory in the more mundane field of investigating the properties of graphite, work that would eventually lead to the manufacture of carbon fibre. After 1945 she gained valuable experience in X-ray crystallography at the Laboratoire Centrale des Services Chimique de l'Etat in Paris before John Randall brought her back to London to work with Maurice Wilkins on DNA.

The collaboration was not a success. Franklin and Wilkins disliked each other so much that the pace of their research slowed and academic plotting and bickering sometimes seemed more important. Rosalind Franklin's response was to do her research alone, and from her notes it appears that she was closest to understanding the structure of DNA. Using diffraction techniques where a beam of X-rays is shone at a DNA crystal and the resulting reflections are captured as a series of dark or grey bands to produce an image, she successfully photographed the DNA molecule early in 1951. Analysis of the image clearly showed that it was a double helix, two spirals and not three as Francis Crick, James Watson and others believed it to be at that time. In her notes, Franklin wrote:

> Conclusion: Big helix in several chains, phosphates on outside, phosphate-phosphate inter-helical bonds disrupted by water. Phosphate links available to proteins.

It was at this point embarrassment and academic pique came into play. Maurice Wilkins remembered James Watson sitting in a lecture given by Rosalind Franklin, 'he stared at her pop-eyed and wrote down nothing'. That turned out to be a crucial lapse. Two weeks later Crick and Watson announced that they had understood at last how DNA was structured, but omitted to mention that their

solution was partly based on Franklin's lecture. The problem was that Watson had been forced to rely on his memory – and it turned out to be faulty. The model was structured around a value given by Franklin in her lecture and Watson had got it wrong. When she travelled up to Cambridge with her colleagues to see the new model, Wilkins recalled that Franklin 'all but laughed out loud'. It was mortifying. Professor Sir Lawrence Bragg, the Director of the Cavendish Laboratory, was not pleased and he instructed Crick and Watson to suspend their research. DNA was clearly something King's College understood far better.

This excruciating episode set a bitter tone. For a year Crick and Watson were frustrated, forced to work on haemoglobin (the protein that carries oxygen in our blood) rather than DNA. But then the instincts of competition came to their rescue. When Lawrence Bragg heard of the progress that Linus Pauling was making at CalTech, he changed his mind and asked Crick and Watson to revive their project. It was at this point human chemistry began to affect theoretical chemistry.

When James Watson went to London to meet Maurice Wilkins at King's College, he found himself arguing heatedly with Rosalind Franklin. Immediately after this altercation, Wilkins took Watson into another room where, without her knowledge, he showed him Franklin's latest and best images of DNA taken by X-ray crystallography. And around the same time more of her findings came into the possession of Crick and Watson. As a matter of routine, researchers at King's College wrote short abstracts on the progress of their work and Franklin's found its way quickly to Cambridge. It was not a private document and there was no suggestion of anything underhand but Franklin was apparently unaware that Crick and Watson had her research findings. 'Rosy, of course, did not directly give us her data. For that matter, no one at King's realised that it was in our hands', wrote Watson some years later. In 1961 Francis Crick admitted that 'the data we actually used' was the work of Rosalind Franklin.

Soon after Wilkins showed Watson the latest images at King's, Watson and Crick built their famous model. It resembled a twisted rope ladder with the uprights made from phosphates and sugars. But it included conclusions not visualised by Franklin. Francis Crick

understood that the two helices, the spirals of DNA, twisted not in parallel but in opposite directions while Watson saw how the linked pairs of base compounds worked as the rungs of the rope ladder. This brilliant aperçu was the key to understanding how the molecule could copy itself, something even more critical than the structure itself. And when papers were published in the spring of 1953 in the leading academic journal *Nature*, only the three male scientists contributed and Rosemary Franklin was not acknowledged. In their famous, and very brief, article Watson's American exuberance about what he had realised about how DNA copied itself was tempered by the English reticence of Francis Crick and it is the subject of one of the greatest understatements in the history of science: 'It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.'

At first this earth-shattering discovery went entirely unreported. When Sir Lawrence Bragg announced at a conference in Belgium in April 1953 that his team had won the race to find the structure of DNA, there was no press coverage whatsoever. It was only when he spoke at Guy's Hospital in London a month later that Ritchie Calder, fortunately a scientist himself as well as a journalist, reported the breakthrough made in Cambridge in *The News Chronicle*.

As Crick and Watson, and to some extent Wilkins, received plaudits, Rosalind Franklin began to realise that she was seriously ill. Suffering from an aggressive form of ovarian cancer, she died in 1958, aged only 37. But surprisingly she appears to have held no grudges and when in a period of remission, she stayed with Francis Crick and his family in Cambridge.

A Nobel Prize can be awarded only to the living, and in 1962 James Watson, Francis Crick and Maurice Wilkins shared the award for medicine. Perhaps if she had lived long enough, Rosalind Franklin might have been similarly honoured for her visionary work.

In the decade following the discovery researchers began to understand much more about DNA. Crick and Watson's model showed how the DNA molecule unfurls, the rungs of the rope ladder separating down the middle into two half ladders, each with one rope and a half of every rung. Along with new phosphates and sugars to make the missing ropes of the ladders (as was mentioned

in Franklin's note of 1951), new bases are then added to each half, and in this way two are created from one – the secret of life.

There are four chemical bases making up the rungs of the ladder; adenine (A), thymine (T), guanine (G), and cytosine (C). Each rung is made up of two sorts of base pairs. Adenine will only link with thymine and guanine only with cytosine. DNA from every living organism has these same ingredients but what makes us different from turnips or spiders is the order or sequence of bases. This is called the genetic code and scientists read it in the letters of the nucleotides, A, T, C and G.

For the decade following the creation of Crick and Watson's model, research concentrated on understanding how the body reads DNA to make proteins and how DNA is copied. The discipline of molecular biology developed quickly. But it was not until the 1960s that human population genetics began to evolve as a distinct academic discipline.

Born in Genoa in 1922 and having qualified as a doctor in 1944, Luca Cavalli-Sforza became interested in the new material on the analysis of blood groups in human populations that was published in the 1960s. It was not until the 1970s that the first sequences of DNA were read, but Cavalli-Sforza could see the value of using the classifications offered by blood groups. His aim was to use them to build evolutionary trees for *Homo sapiens* and to see how these linked and varied between different populations. But what puzzled him was the fact that blood groups were very much more diverse in Africa than they were over the whole of the rest of the world.

When scientists developed methods of reading the genetic code in the 1970s, it was at first a laborious and lengthy process and remained so until the early 1990s, but with the help of computing and other technological advances it accelerated and results began to appear quickly. Blood group classifications or markers were replaced by DNA markers. When all 6 billion letters of human DNA are copied in the act of reproduction, mistakes are occasionally made, and scientists noticed that some letters were out of place in a sequence. Because they are passed on to the next generation, these mistakes, these markers, allowed DNA to be used to trace lineages back into deep time.

Fred Sanger

Born in 1918 and raised as a Quaker, Fred Sanger was a conscientious objector during the Second World War, a time he spent not in prison but at Cambridge University where he began work that would benefit millions. Having completed his PhD in chemistry in 1943, he became fascinated by the problems of sequencing amino acids in bovine insulin. After a long string of spectacular success culminating in the award of a Nobel Prize in 1958, Sanger turned his mind to the sequencing of human DNA. With Alan Coulson and others, he ultimately came up with what is called the dideoxy chain termination method in 1977. A major breakthrough, it allowed long stretches of DNA to be sequenced quickly and precisely. In winning a second Nobel Prize (shared with two others) he joined Marie Curie, Linus Pauling and John Bardeen as the only double laureates in history. Having refused a knighthood because he disliked the idea of being called 'sir', Fred Sanger accepted the Order of Merit and allowed his name to be attached to the Sanger Institute near Cambridge, one of the world's largest genomic research centres. Without his pioneering work, DNA sequencing would still be laborious, time-consuming and disablingly expensive.

Meanwhile an answer to Cavalli-Sforza's conundrum about the diversity of African DNA was eventually supplied. It emerged close to Stanford University, where Cavalli-Sforza worked. At the University of California at Berkeley, a New Zealander of Scots extraction, Allan Wilson, was working on what he called the molecular clock. This was postulated as a means of dating the evolution of *Homo sapiens*, modern human beings, by looking at how DNA changed over time. Wilson and his team noticed that mitochondrial DNA, which is what women pass on to their children, mutated more readily and more regularly than the rest of our DNA. This made it easier to plot changes in mtDNA over relatively short periods of time, and not the millions of years of evolution conventionally envisaged.

This research led to a bombshell, and a solution to Cavalli-Sforza's

puzzle. In the early 1980s Allan Wilson announced the existence of the woman he called Mitochondrial Eve, the mother-ancestor of us all. Using the molecular clock, he believed that it was possible to estimate the time and place where modern humans first evolved. About 150,000 years ago, Wilson asserted, all of us, from Apaches to Aboriginal Australians, from Scots to Zulus, descended from one woman who lived in east-central Africa. The announcement of the findings caused a sensation, and a very attractive Mitochondrial Eve and an Adam found themselves on the cover of *Newsweek* magazine.

PCR, LSD and Non-PC

Kary Mullis is an unconventional scientist. In 1993 he shared the Nobel Prize for chemistry for his improvement of a vitally important technique known as polymerase chain reaction. But in his Prize Lecture, he told his astonished audience that the award didn't make up for the fact that he had just broken up with his girlfriend. A year before he had started up a new business selling jewellery containing the amplified DNA of dead icons such as Elvis Presley and Marilyn Monroe. Mullis also reckoned that he would not have won his Nobel without the experience of taking LSD. Despite, or perhaps even because of these eccentricities, his improvements in PCR were epoch-changing. What Mullis was able to do was use an enzyme to bracket a DNA sequence and stimulate it to replicate almost an infinite number of times. This new technique had all sorts of applications and it allowed scientists to manipulate DNA to attack disease and to undertake complex research at much lower costs and achieve results quickly. It is a method used by all genotyping until very recently.

Wilson's theory ran aggressively counter to the conventional multi-regional view that *Homo sapiens* had evolved in different places from slightly different origins. In Europe it was thought that humans descended from Neanderthals, in China from Peking Man and in Indonesia from Java Man. But the new research insisted that we all have African ancestors, and a great deal of more recent work has supported Wilson's revolutionary view, although it is now

recognised that a small proportion of the DNA of non-Africans descends from these other archaic humans.

Mitochondrial Eve is now thought to have lived approximately 190,000 years ago in east Africa, the area centred on modern Tanzania (although it must be added that evidence exists for a South African location for this prehistoric Garden of Eden, since the lineages of the Kalahari Bushmen and others are very ancient and very diverse). Fossil evidence confirmed the earliest appearance of modern humans, people who looked like us, at this time and as its techniques have developed, readings of DNA samples began to convert a theory into a fact. Researchers now believe that a man who might be called Y-chromosome Adam also lived in Africa, but not at the same time as Eve in a real version of the Garden. The ancestor of all men, traceable back through a Y-chromosome line, is thought to have lived some time around 140,000 BC probably in west Africa It is a misconception to believe that Mitochondrial Eve and Y-chromosomal Adam were the only men and women living at those times. Theirs are the only lineages that survive in the male and female lines, while others have died out. But it is, sadly, clear that Adam and Eve never knew each other.

Even Older

An ancient Y-chromosome lineage from Cameroon has been discovered in an African-American man from South Carolina and it matches that of four men from Cameroon. Labelled as A00, it appears to be very rare, but the startling finding is its date of origin. The oldest lineage was though to be A0 at *c* 140,000 BC, but researchers believe that A00 is much older, at *c* 237,000 BC. Work is ongoing.

As Cavalli-Sforza suspected from his study of blood groups, African DNA is much more diverse than anywhere else in the world, and many more markers are seen there. It seems certain now that the whole of the rest of the world was populated by men and women who walked out of Africa around 60,000 years ago. The probable reason for this ancient exodus is dramatic, emphatic.

In northern Sumatra the world's largest island within an island is green with lush vegetation, and the steeply pitched roofs of its Batak people punctuate the horizon. Samosir lies in the middle of Lake Toba, the biggest lake in south-east Asia at 100 kilometres long and 30 kilometres wide. The sharply pointed gables of the lakeside fishermen's houses mimic the prows of their boats and the brilliant greens of the scenery below are breathtakingly beautiful. But the beauty of the landscape is deceptive, for it is a memorial to a cataclysm.

Lake Toba shimmers quietly in the crater or caldera of a gigantic volcano. Some time around 73,000 BC, it suddenly exploded in a super-colossal eruption, an immensely destructive, climate-changing event, the largest anywhere on Earth in the last 25 million years. When Mount Toba blew itself apart, it may have obliterated life on our planet.

With a roar that must have been heard thousands of kilometres away, the volcano sent out 2,800 cubic kilometres of what geologists call 'ejecta'. Around 800 cubic kilometres of ash rocketed into the atmosphere to create a vast black cloud. High winds whipped up by the eruption quickly blew the ash to the west, out across the Indian Ocean. The year of this nuclear explosion may be only approximately dated but the season is certain. Toba exploded in the late summer, for only the monsoon rains could have deposited such a heavy and rapid fall of ash over the whole of southern Asia. A layer 15 centimetres thick has been calculated but at one site in central India archaeologists have recently found the suffocating grey blanket at 6 metres in depth. The ash covered vegetation of all kinds and the long nuclear winter that followed killed it.

High winds also carried and dropped huge tonnages of ash over the South China Sea, the Indian Ocean and the Arabian Sea. By screening out the sun and poisoning the water, the fallout from Toba killed plankton, sea vegetation, fish and larger creatures. Geologists believe that an even greater volume of volcanic ash may have fallen over the oceans than the land, but the effect was no less cataclysmic.

Around 10,000 million tonnes of sulphuric acid were thrown up into the atmosphere and some of it fell as black acid rain and devastated plants, animals and people. Pumice also shot high in the air and when it fell on the ocean, it instantly solidified into vast white rafts between five and ten kilometres across. These were picked

up by the tsunamis that radiated from Sumatra and smashed into coastlines thousands of kilometres distant.

As thunder boomed and the Earth shuddered, red-hot lava spewed and poisoned rain fell, the eruption continued for two weeks. Sumatra was incinerated and covered by 2,000 square kilometres of boiling lava before the hollowed-out sides of the volcano collapsed in on themselves to form the caldera, what would much later become a beautiful lake. The fires caused by the eruption blazed over a wide swathe and sent vast plumes of smoke into the darkening skies.

As far away as Greenland, geologists have detected in the ice cores an abrupt change in the Earth's climate some time between 69,000 and 77,000 years ago. It can only have been caused by the destruction of Toba, and the cores show that what followed was indeed a long nuclear winter. A deadly sulphuric aerosol mixed with ash and smoke obscured the sun's rays and temperatures plummeted, particularly in the first three months after the eruption. What extended this half-lit, grey winter was the way in which the sun heated the aerosol, ash and smoke so that it rose into the stratosphere where no rain could fall to wash it out. This almost certainly caused a long period of nuclear darkness lasting perhaps ten or fifteen years. People must have thought the gods were angry and that the world was ending. If nothing could grow through the ash-covered ground, then animals and people could not hope to survive. Mount Toba may have almost ended the history of human beings, almost made us as extinct as the dinosaurs.

But the ash did not fall everywhere, and the dark blanketing of the stratosphere cannot have been complete – for human beings did survive. And Luca Cavalli-Sforza and Allan Wilson's research into African DNA suddenly appeared to connect with a recorded historical event. It seemed that the immense, world-wide destruction wreaked by the eruption of Toba was part of the reason why *Homo sapiens* and his (and her) origins are in Africa. It was the refuge where people survived the deadly fallout and the long nuclear winter.

Using computer models based on the number of markers seen in our genomes, geneticists believe that a tiny remnant, perhaps only 5,000 to 10,000 people, survived in the fertile rift valleys of east-central Africa. Other groups hung on in southern Africa and as

far west as Cameroon. They can only have survived the horrors of Toba because the ash clouds and sulphuric aerosols did not obscure the sun completely and vegetation grew sufficiently for animals and people to carry on. Zoologists have noted that the East African chimpanzee, the cheetah and the tiger all saw their populations diminish drastically at this time, before they began slowly to recover.

As the Earth warmed and greened once more, the remnant groups across the continent also slowly recovered. They were hunter-gatherers who depended on a wild harvest of roots, fruits, berries, nuts and what animals they could trap or bring down, and because of their diet and way of life such communities could only grow very gradually. It may have taken many generations for there to be significant expansion, but after a time something surprising happened. A small group broke away from the east African communities and began to walk northwards. Perhaps only 300 to 500 people trekked out of the rift valleys. Geneticists are certain that the breakaway group was small because in their number only one mtDNA lineage that had descended from Mitochondrial Eve was present. All of the women in the world who are not Africans (and some who are Africans) are descended from this lineage, a marker labelled L3. And female descendants of L3, those in the two superclusters of M and N, found across the whole of the rest of the world, are present in Africa now in only very low frequencies, and they appear to be recent arrivals.

A study led by Alon Keinan of Harvard Medical School suggests that more men than women walked northwards out of eastern Africa. By looking closely at variations in our X-chromosome and also at autosomal DNA, researchers have concluded that men were in a majority. No scientific reasons for this have been advanced beyond the sensible observation that in modern hunter-gatherer societies, women generally undertake short distance migration and men usually go on longer expeditions. It may be as simple as that.

After many more generations, the descendants of this small group reached the Horn of Africa, modern Djibouti. There the Red Sea narrows at the straits known as the Bab el Mandeb, the Gate of Tears. Now 15 kilometres wide and washed by treacherous riptides, it will have presented a much less formidable obstacle 60,000 years ago. Sea levels were lower then, the straits narrower and less

deep, and there were small islands easily reached by rafts. A crossing could have been made in stages.

When our ancestors came ashore in the Arabian Peninsula, they stood on the edges of history. From these resourceful, curious, hardy and brave people the whole of the rest of the human race is descended. The DNA of all of us who are non-Africans was hidden in the genes of those who crossed the Gate of Tears and gained the farther shore.