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The Ascent of Man

Jacob Bronowski

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About the Book

Dr Jacob Bronowksi's *The Ascent of Man* traces the development of human society through o understanding of science.

First published in 1973 to accompany the groundbreaking BBC television series, it is considered o of the first works of 'popular science', illuminating the historical and social context of scientif development for a generation of readers. In his highly accessible style, Dr Bronowski discusses huma invention from the flint tool to geometry, agriculture to genetics, and from alchemy to the theory relativity, showing how they all are expressions of our ability to understand and control nature.

About the Author

Dr Bronowski's magnificent thirteen-part BBC television series *The Ascent of Man* traced our rise both as a species and as moulders of our own environment and future. The book of the programm covers the history of science, but of science in the broadest terms. Invention from the flint tool geometry, from the arch to the theory of relativity, are shown to be expressions of man's specif ability to understand nature, to control it, not to be controlled by it. Dr Bronowski's rare grasp n only of science, but also of its historical and social context, gave him great advantages as an historia of ideas. The book gives us a new perspective not just on science, but on civilisation.

Dr Jacob Bronowski, who was born in Poland in 1908, died in 1974. His family had settled in Brita and he was educated at Cambridge University.

He was distinguished not only as a scientist but also as the author of books and broadcasts on the art Many viewers will remember his science programmes on television: he also wrote radio play including one which won the Italia Prize.

Dr Bronowski, who was an Honorary Fellow of Jesus College, Cambridge, had lived and worked America since 1964, as a Senior Fellow and Director of the Council for Biology in Human Affairs the Salk Institute for Biological Studies, San Diego, California.

Other Books by J. Bronowski

The Poet's Defence 1939 & 1966
William Blake and The Age of Revolution 1944 & 1965
*The Common Sense of Scienc*e 1951
The Face of Violence 1954 & 1967
Science and Human Values 1958
with *The Abacus and The Rose*:
A New Dialogue on Two World Systems 1965
Selections from William Blake 1958
The Western Intellectual Tradition
(with Prof Bruce Mazlish) 1960
Insight 1964
The Identity of Man 1965 & 1972
Nature and Knowledge:
The Philosophy of Contemporary Science 1969

The Ascent of Man

Jacob Bronowski

BBC BOOKS

FOREWORD

by Richard Dawkins

'Last renaissance man' has become a cliché, but we forgive a cliché on the rare occasion when it true. Certainly it is hard to think of a better candidate for the accolade than Jacob Bronowski. You' find other scientists who can parade a deep parallel knowledge of the arts, or – in one actual case combine eminence in science with pre-eminence in Chinese history. But who more than Bronows weaves a deep knowledge of history, art, cultural anthropology, literature and philosophy into or seamless cloth with his science? And does it lightly, effortlessly, never sinking to pretensior Bronowski uses the English language – not his first language, which makes it all the more remarkab – as a painter uses his brush, with mastery all the way from broad canvas to exquisite miniature.

Inspired by the *Mona Lisa*, here is what he has to say about arguably the first and greate renaissance man, whose drawing of the baby in the womb introduced the television version of *T Ascent of Man*:

> Man is unique not because he does science, and he is unique not because he does art, but because science and art equally are expressions of his marvellous plasticity of mind. And the *Mona Lisa* is a very good example, because after all what did Leonardo do for much of his life? He drew anatomical pictures, such as the baby in the womb in the Royal Collection at Windsor. And the brain and the baby is exactly where the plasticity of human behaviour begins.

How deftly Bronowski segues from Leonardo's drawing to the Taung baby: type-specimen of ou ancestral genus *Australopithecus*, victim – as we now know, though Bronowski didn't when h performed his mathematical analysis on the tiny skull – of a giant eagle two million years ago.

There's a quotable aphorism on every page of this book, something to treasure, something to stic on your door for all to see, an epitaph, perhaps, for the gravestone of a great scientist. 'Knowledge is an unending adventure at the edge of uncertainty.' Uplifting? Yes. Inspiring? Without doubt. Bu read it in context and it is shocking. The grave turns out to belong to an entire tradition of Europea scholarship, destroyed by Hitler and his allies almost overnight:

> Europe was no longer hospitable to the imagination – and not just the scientific imagination. A whole conception of culture was in retreat: the conception that human knowledge is personal and responsible, an unending adventure at the edge of uncertainty. Silence fell, as after the trial of Galileo. The great men went out into a threatened world. Max Born. Erwin Schrödinger.

> Albert Einstein. Sigmund Freud. Thomas Mann. Bertolt Brecht. Arturo Toscanini. Bruno Walter. Marc Chagall.

Words so powerful don't need a raised voice or ostentatious tears. Bronowski's words gained impa from his calm, humane, understated tones, with the engagingly rolled Rs as he looked straight into t camera, spectacles flashing like beacons in the dark.

That was a rare dark passage in a book that is mostly filled with light, and genuinely uplifting. Yo can hear Bronowski's distinctive voice through this book, and you can see his expressive han chopping down to cut through complexity and make a point. He stands before a great sculpture, Hen Moore's *The Knife Edge*, to tell us,

> The hand is the cutting edge of the mind. Civilisation is not a collection of finished artefacts, it is the elaboration of processes. In the end, the march of man is the refinement of the hand in action. The most powerful drive in the ascent of man is his pleasure in his own skill. He loves to do what he does well and, having done it well, he loves to do it better. You see it in his science. You see it in the magnificence with which he carves and builds, the loving care, the gaiety, the effrontery. The monuments are supposed to commemorate kings and religions, heroes, dogmas, but in the end the man they commemorate is the builder.

Bronowski was a rationalist and an iconoclast. He was not content to bask in the achievements science but sought to provoke, to pique, to needle.

> That is the essence of science: ask an impertinent question, and you are on the way to a pertinent answer.

That applies not just to science but to all learning, epitomised, for Bronowski by one of the world oldest and greatest universities – in Germany as it happens:

> The University is a Mecca to which students come with something less than perfect faith. It is important that students bring a certain ragamuffin, barefoot irreverence to their studies; they are not here to worship what is known but to question it.

Bronowski treated the magical speculations of primitive man with sympathy and understanding, but the end

> … magic is only a word, not an answer. In itself, magic is a word which explains nothing.

There is magic – the right kind of magic – in science. There is poetry too, and magical poetry on eve page of this book. Science is the poetry of reality. If he didn't say that, it is the kind of thing he mig have said, articulate polymath and gentle sage, whose wisdom and intelligence symbolises all that best in the ascent of man.

INTRODUCTION

The first outline of *The Ascent of Man* was written in July 1969 and the last foot of film was shot December 1972. An undertaking as large as this, though wonderfully exhilarating, is not entere lightly. It demands an unflagging intellectual and physical vigour, a total immersion, which I had t be sure that I could sustain with pleasure; for instance, I had to put off researches that I had alread begun; and I ought to explain what moved me to do so.

There has been a deep change in the temper of science in the last twenty years: the focus attention has shifted from the physical to the life sciences. As a result, science is drawn more an more to the study of individuality. But the interested spectator is hardly aware yet how far-reachin the effect is in changing the image of man that science moulds. As a mathematician trained in physic I too would have been unaware, had not a series of lucky chances taken me into the life sciences middle age. I owe a debt for the good fortune that carried me into two seminal fields of science in on lifetime; and though I do not know to whom the debt is due, I conceived *The Ascent of Man* gratitude to repay it.

The invitation to me from the British Broadcasting Corporation was to present the development science in a series of television programmes to match those of Lord Clark on *Civilisation.* Televisio is an admirable medium for exposition in several ways: powerful and immediate to the eye, able take the spectator bodily into the places and processes that are described, and conversational enoug to make him conscious that what he witnesses are not events but the actions of people. The last these merits is to my mind the most cogent, and it weighed most with me in agreeing to cast personal biography of ideas in the form of television essays. The point is that knowledge in gener and science in particular does not consist of abstract but of manmade ideas, all the way from i beginnings to its modern and idiosyncratic models. Therefore the underlying concepts that unloc nature must be shown to arise early and in the simplest cultures of man from his basic and specif faculties. And the development of science which joins them in more and more complex conjunctio must be seen to be equally human: discoveries are made by men, not merely by minds, so that they a alive and charged with individuality. If television is not used to make these thoughts concrete, it wasted.

The unravelling of ideas is, in any case, an intimate and personal endeavour, and here we come the common ground between television and the printed book. Unlike a lecture or a cinema sho television is not directed to crowds. It is addressed to two or three people in a room, as a conversatio face to face – a one-sided conversation for the most part, as the book is, but homely and Socrat nevertheless. To me, absorbed in the philosophic undercurrents of knowledge, this is the mo attractive gift of television, by which it may yet become as persuasive an intellectual force as th book.

The printed book has one added freedom beyond this: it is not remorselessly bound to the forwa direction of time, as any spoken discourse is. The reader can do what the viewer and the listen cannot, which is to pause and reflect, turn the pages back and the argument over, compare one fa with another and, in general, appreciate the detail of evidence without being distracted by it. I hav taken advantage of this more leisurely march of mind whenever I could, in putting on paper now wh was first said on the television screen. What was said had required a great volume of research, whic turned up many unexpected links and oddities, and it would have been sad not to capture some of th richness in this book. Indeed, I should have liked to do more, and to interleave the text in detail wi the source material and quotations on which it rests. But that would have turned the book into a wo for students instead of the general reader.

In rendering the text used on the screen, I have followed the spoken word closely, for two reason First, I wanted to preserve the spontaneity of thought in speech, which I had done all I could to fost wherever I went. (For the same reason, I had chosen whenever possible to go to places that were fresh to me as to the viewer.) Second and more important, I wanted equally to guard the spontaneity the argument. A spoken argument is informal and heuristic; it singles out the heart of the matter an shows in what way it is crucial and new; and it gives the direction and line of the solution so tha simplified as it is, still the logic is right. For me, this philosophic form of argument is the foundatio of science, and nothing should be allowed to obscure it.

The content of these essays is in fact wider than the field of science, and I should not have calle them *The Ascent of Man* had I not had in mind other steps in our cultural evolution too. My ambitio here has been the same as in my other books, whether in literature or in science: to create a philosoph for the twentieth century which shall be all of one piece. Like them, this series presents a philosoph rather than a history, and a philosophy of nature rather than of science. Its subject is a contempora version of what used to be called Natural Philosophy. In my view, we are in a better frame of mir today to conceive a natural philosophy than at any time in the last three hundred years. This is becau the recent findings in human biology have given a new direction to scientific thought, a shift from th general to the individual, for the first time since the Renaissance opened the door into the natur world.

There cannot be a philosophy, there cannot even be a decent science, without humanity. I hope th sense of affirmation is manifest in this book. For me, the understanding of nature has as its goal th understanding of human nature, and of the human condition within nature.

To present a view of nature on the scale of this series is as much an experiment as an adventur and I am grateful to those who made both possible. My first debt is to the Salk Institute for Biologic Studies which has long supported my work on the subject of human specificity, and which gave me year of sabbatical leave to film the programmes. I am greatly indebted also to the British Broadcastin Corporation and its associates, and very particularly there to Aubrey Singer who invented the massiv theme and urged it on me for two years before I was persuaded.

The list of those who helped to make the programmes is so long that I must put it on a page of i own, and thank them in a body; it was a pleasure to work with them. However, I cannot pass over th names of the producers that stand at the head of the list, and particularly Adrian Malone and Dic Gilling, whose imaginative ideas transubstantiated the word into flesh and blood.

Two people worked with me on this book, Josephine Gladstone and Sylvia Fitzgerald, and d much more; I am happy to be able to thank them here for their long task. Josephine Gladstone ha charge of all the research for the series since 1969, and Sylvia Fitzgerald helped me plan and prepa the script at each successive stage. I could not have had more stimulating colleagues.

J. B.
La Jolla, California
August 1973

CHAPTER ONE

LOWER THAN THE ANGELS

Man is a singular creature. He has a set of gifts which make him unique among the animals: so tha unlike them, he is not a figure in the landscape – he is a shaper of the landscape. In body and in mi he is the explorer of nature, the ubiquitous animal, who did not find but has made his home in eve continent.

It is reported that when the Spaniards arrived overland at the Pacific Ocean in 1769 the Californ Indians used to say that at full moon the fish came and danced on these beaches. And it is true th there is a local variety of fish, the grunion, that comes up out of the water and lays its eggs above t normal high-tide mark. The females bury themselves tail first in the sand and the males gyrate rou them and fertilise the eggs as they are being laid. The full moon is important, because it gives the ti needed for the eggs to incubate undisturbed in the sand, nine or ten days, between these very high tid and the next ones that will wash the hatched fish out to sea again.

Every landscape in the world is full of these exact and beautiful adaptations, by which an anim fits into its environment like one cog-wheel into another. The sleeping hedgehog waits for the spri to burst its metabolism into life. The humming-bird beats the air and dips its needle-fine beak in hanging blossoms. Butterflies mimic leaves and even noxious creatures to deceive their predators. T mole plods through the ground as if he had been designed as a mechanical shuttle.

So millions of years of evolution have shaped the grunion to fit and sit exactly with the tides. B nature – that is, biological evolution – has not fitted man to any specific environment. On the contra by comparison with the grunion he has a rather crude survival kit; and yet – this is the paradox of t human condition – one that fits him to all environments. Among the multitude of animals whi scamper, fly, burrow and swim around us, man is the only one who is not locked into his environme His imagination, his reason, his emotional subtlety and toughness, make it possible for him not accept the environment but to change it. And that series of inventions, by which man from age to a has remade his environment, is a different kind of evolution – not biological, but cultural evolution call that brilliant sequence of cultural peaks *The Ascent of Man*.

I use the word ascent with a precise meaning. Man is distinguished from other animals by h imaginative gifts. He makes plans, inventions, new discoveries, by putting different talents togethe and his discoveries become more subtle and penetrating, as he learns to combine his talents in mo complex and intimate ways. So the great discoveries of different ages and different cultures, technique, in science, in the arts, express in their progression a richer and more intricate conjunctio of human faculties, an ascending trellis of his gifts.

Of course, it is tempting – very tempting to a scientist – to hope that the most origin

achievements of the mind are also the most recent. And we do indeed have cause to be proud of som modern work. Think of the unravelling of the code of heredity in the DNA spiral; or the work goi forward on the special faculties of the human brain. Think of the philosophic insight that saw into t Theory of Relativity or the minute behaviour of matter on the atomic scale.

Yet to admire only our own successes, as if they had no past (and were sure of the future), wou make a caricature of knowledge. For human achievement, and science in particular, is not a museu of finished constructions. It is a progress, in which the first experiments of the alchemists also have formative place, and the sophisticated arithmetic that the Mayan astronomers of Central Ameri invented for themselves independently of the Old World. The stonework of Machu Picchu in t Andes and the geometry of the Alhambra in Moorish Spain seem to us, five centuries later, exquisi works of decorative art. But if we stop our appreciation there, we miss the originality of the tw cultures that made them. Within their time, they are constructions as arresting and important for the peoples as the architecture of DNA for us.

In every age there is a turning-point, a new way of seeing and asserting the coherence of the worl It is frozen in the statues of Easter Island that put a stop to time – and in the medieval clocks Europe that once also seemed to say the last word about the heavens for ever. Each culture tries to f its visionary moment, when it was transformed by a new conception either of nature or of man. But retrospect, what commands our attention as much are the continuities – the thoughts that run or rec from one civilisation to another. There is nothing in modern chemistry more unexpected than puttin together alloys with new properties; that was discovered after the time of the birth of Christ in Sou America, and long before that in Asia. Splitting and fusing the atom both derive, conceptually, from discovery made in prehistory: that stone and all matter has a structure along which it can be split a put together in new arrangements. And man made biological inventions almost as early: agriculture the domestication of wild wheat, for example – and the improbable idea of taming and then riding t horse.

In following the turning-points and the continuities of culture, I shall follow a general but not strict chronological order, because what interests me is the history of man's mind as an unfolding his different talents. I shall be relating his ideas, and particularly his scientific ideas, to their origins the gifts with which nature has endowed man, and which make him unique. What I present, what h fascinated me for many years, is the way in which man's ideas express what is essentially human his nature.

So these programmes or essays are a journey through intellectual history, a personal journey to t high points of man's achievement. Man ascends by discovering the fullness of his own gifts (h talents or faculties) and what he creates on the way are monuments to the stages in his understandi of nature and of self – what the poet W. B. Yeats called 'monuments of unageing intellect'.

Where should one begin? With the Creation – with the creation of man himself. Charles Darw pointed the way with *The Origin of Species* in 1859, and then in his book of 1871, *The Descent of Ma* It is almost certain now that man first evolved in Africa near the equator. Typical of the places whe his evolution may have begun is the savannah country that stretches out across Northern Kenya a South West Ethiopia near Lake Rudolf. The lake lies in a long ribbon north and south along the Gre Rift Valley, hemmed in by over four million years of thick sediments that settled in the basin of wh was formerly a much more extensive lake. Much of its water comes by way of the winding, sluggi Omo. For the origins of man, this is a possible area: the valley of the river Omo in Ethiopia near La Rudolf.

The ancient stories used to put the creation of man into a golden age and a beautiful, legendar landscape. If I were telling the story of Genesis now, I should be standing in the Garden of Eden. B this is manifestly not the Garden of Eden. And yet I am at the navel of the world, at the birthplace man, here in the East African Rift Valley, near the equator. The slumped levels in the Omo basin, th bluffs, the barren delta, record a historic past of man. And if this ever was a Garden of Eden, why, withered millions of years ago.

I have chosen this place because it has a unique structure. In this valley was laid down, over th last four million years, layer upon layer of volcanic ash, interbedded with broad bands of shale ar mudstone. The deep deposit was formed at different times, one stratum after another, visibly separate according to age: four million years ago, three million years ago, over two million years ag somewhat under two million years ago. And then the Rift Valley buckled it and stood it on end, so tha now it makes a map in time, which we see stretching into the distance and the past. The record of tim in the strata, which is usually buried underfoot, has been tip-tilted in the cliffs that flank the Omo, ar spread out like the ribs of a fan.

These cliffs are the strata on edge: in the foreground the bottom level, four million years old, ar beyond that the next lowest, well over three million years old. The remains of a creature like ma appear beyond that, and the remains of the animals that lived at the same time.

The animals are a surprise, because it turns out that they have changed so little. When we find the sludge of two million years ago the fossils of the creature who was to become man, we are struc by the differences between his skeleton and ours – by the development of the skull, for instance. S naturally, we expect the animals of the savannah also to have changed greatly. But the fossil record i Africa shows that this is not so. Look as the hunter does at the Topi antelope now. The ancestor of ma that hunted its ancestor two million years ago would at once recognise the Topi today. But he woul not recognise the hunter today, black or white, as his own descendant.

The animals are a surprise, because it turns out that they have changed so little.
Modern and fossil nyala horns from Omo. The fossil horns are over two million years old.

~~Yet it is not hunting in itself (or any other single pursuit) that has changed man. For we find th~~ among the animals the hunter has changed as little as the hunted. The serval cat is still powerful pursuit, and the oryx is still swift in flight; both perpetuate the same relation between their species they did long ago. Human evolution began when the African climate changed to drought: the lak shrank, the forest thinned out to savannah. And evidently it was fortunate for the forerunner of ma that he was not well adapted to these conditions. For the environment exacts a price for the survival the fittest; it captures them. When animals like Grevy's zebra were adapted to the dry savannah, became a trap in time as well as space; they stayed where they were, and much as they were. The mo gracefully adapted of all these animals is surely Grant's gazelle; yet its lovely leap never took it out the savannah.

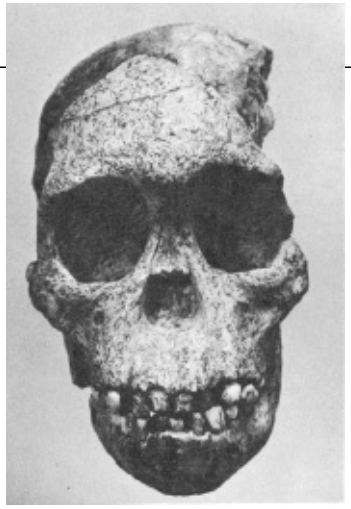
In a parched African landscape like Omo, man first put his foot to the ground. That seems pedestrian way to begin the Ascent of Man, and yet it is crucial. Two million years ago, the fir certain ancestor of man walked with a foot which is almost indistinguishable from the foot of mode man. The fact is that when he put his foot on the ground and walked upright, man made a commitme to a new integration of life and therefore of his limbs.

The one to concentrate on, of course, is the head, because of all human organs it has undergone th most far-reaching and formative changes. Happily, the head leaves a lasting fossil (unlike the so organs), and though it is less informative about the brain than we should like, at least it gives us som measure of its size. A number of fossil skulls have been found in Southern Africa in the last fifty yea which establish the characteristic structure of the head when it began to be man-like. The picture he shows what it looked like over two million years ago. It is a historic skull, found not at Omo, but sou of the equator at a place called Taung, by an anatomist called Raymond Dart. It is a baby, five to si years old, and though the face is nearly complete, part of the skull is sadly missing. In 1924 it was puzzling find, the first of its kind, and was treated with caution even after Dart's pioneering work o it.

Yet Dart instantly recognised two extraordinary features. One is that the *foramen magnum* (that i the hole in the skull that the spinal cord comes up through to the brain) is upright; so that this was child that held its head up. That is one man-like feature; for in the monkeys and apes the head hang forward from the spine, and does not sit upright on top of it. And the other is the teeth. The teeth a always tell-tale. Here they are small, they are square – these are still the child's milk teeth – they a not the great, fighting canines that the apes have. That means that this was a creature that was going forage with its hands and not its mouth. The evidence of the teeth also implies that it was probab eating meat, raw meat; and so the hand-using creature was almost certainly making tools, pebbl tools, stone choppers, to carve it and to hunt.

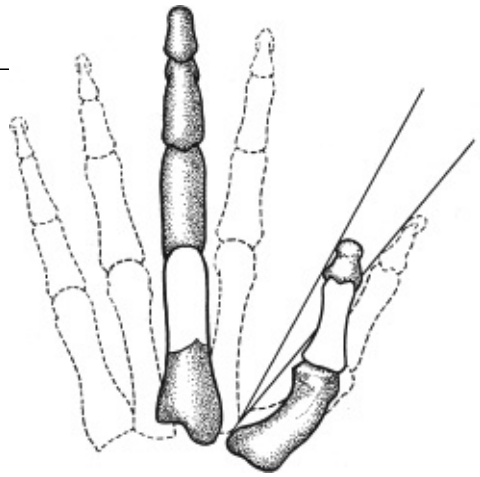
Dart called this creature *Australopithecus*. It is not a name that I like; it just means Southern Ap but it is a confusing name for an African creature that for the first time was not an ape. I suspect th Dart, who was born in Australia, put a pinch of mischief into his choice of the name.

It took ten years before more skulls were found – adult skulls now – and it was not until late in th 1950s that the story of *Australopithecus* was substantially pieced together. It started in South Afric then it moved north to Olduvai Gorge in Tanzania, and most recently the richest finds of fossils an tools have turned up in the basin of Lake Rudolf. This history is one of the scientific delights of th century. It is every bit as exciting as the discoveries in physics before 1940, and those in biology sinc 1950; and it is as rewarding as either of those in the light that it throws on our nature as human being



I do not know how the Taung baby began life, but to me it still remains the primordial infant from which the whole adventure of ma
began.

The Taung child’s skull



The ancestor of man had a short thumb, and therefore could not manipulate very delicately.

Finds of finger and thumb bones of Australopithecus *from the lowest beds of Olduvi Gorge superimposed on the bones of a moder hand*

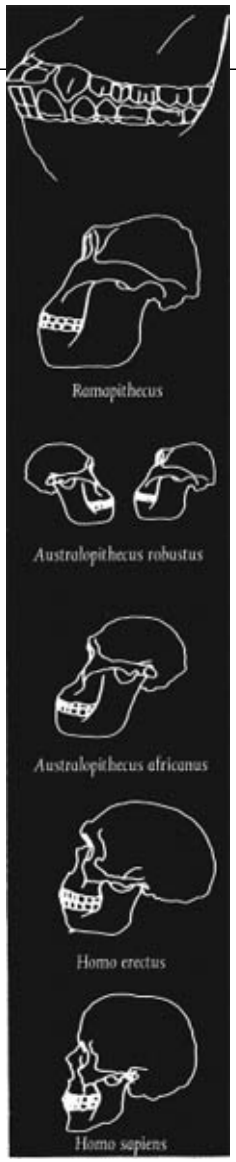
For me, the little *Australopithecus* baby has a personal history. In 1950, when its humanity was b
no means accepted, I was asked to do a piece of mathematics. Could I combine a measure of the si
of the Taung child's teeth with their shape, so as to discriminate them from the teeth of apes? I ha
never held a fossil skull in my hands, and I was by no means an expert on teeth. But it worked pret
well; and it transmitted to me a sense of excitement which I remember at this instant. I, at over fort
having spent a lifetime in doing abstract mathematics about the shapes of things, suddenly saw m
knowledge reach back two million years and shine a searchlight into the history of man. That w
phenomenal.

And from that moment I was totally committed to thinking about what makes man what he is:
the scientific work that I have done since then, the literature that I have written, and in the
programmes. How did the hominids come to be the kind of man that I honour: dexterous, observan
thoughtful, passionate, able to manipulate in the mind the symbols of language and mathematics bot
the visions of art and geometry and poetry and science? How did the ascent of man take him fro
those animal beginnings to that rising enquiry into the workings of nature, that rage for knowledge,
which these essays are one expression? I do not know how the Taung baby began life, but to me it sti
remains the primordial infant from which the whole adventure of man began.

The human baby, the human being, is a mosaic of animal and angel. For example, the reflex th
makes the baby kick is already there in the womb – every mother knows that – and it is there in a
vertebrates. The reflex is self-sufficient, but it sets the stage for more elaborate movements, whic
have to be practised before they become automatic. Here by eleven months it urges the baby to craw
That brings in new movements, and they then lay down and consolidate the pathways in the bra
(specifically the cerebellum, where muscular action and balance are integrated) that will form a who
repertoire of subtle, complex movements and make them second nature to him. Now the cerebellum
in control. All that the conscious mind has to do is to issue a command. And by fourteen months th
command is 'Stand!' The child has entered the human commitment to walk upright.

Every human action goes back in some part to our animal origins; we should be cold and lone
creatures if we were cut off from that blood-stream of life. Nevertheless, it is right to ask for
distinction: What are the physical gifts that man must share with the animals, and what are the gif
that make him different? Consider any example, the more straightforward the better – say, the simp
action of an athlete when running or jumping. When he hears the gun, the starting response of th
runner is the same as the flight response of the gazelle. He seems all animal in action. The heartbe
goes up; when he sprints at top speed the heart is pumping five times as much blood as normal, an
ninety per cent of it is for the muscles. He needs twenty gallons of air a minute now to aerate his bloo
with the oxygen that it must carry to the muscles.

The violent coursing of the blood and intake of air can be made visible, for they show up as he
on infra-red films which are sensitive to such radiation. (The blue or light zones are hottest; the red
dark zones are cooler.) The flush that we see and that the infra-red camera analyses is a by-produ
that signals the limit of muscular action. For the main chemical action is to get energy for the muscl
by burning sugar there; but three-quarters of that is lost as heat. And there is another limit, on th
runner and the gazelle equally, which is more severe. At this speed, the chemical burn-up in th
muscles is too fast to be complete. The waste products of incomplete burning, chiefly lactic acid, no
foul up the blood. This is what causes fatigue, and blocks the muscle action until the blood can b
cleaned with fresh oxygen.



The head is the spring which drives cultural evolution.
Computer-graphic display of stages in evolution of the head

So far, there is nothing to distinguish the athlete from the gazelle – all that, in one way or anothe
is the normal metabolism of an animal in flight. But there is a cardinal difference: the runner was n
in flight. The shot that set him off was the starter's pistol, and what he was experiencing, deliberatel
was not fear but exaltation. The runner is like a child at play; his actions are an adventure in freedor
and the only purpose of his breathless chemistry was to explore the limits of his own strength.

Naturally there are physical differences between man and the other animals, even between ma
and the apes. In the act of vaulting, the athlete grasps his pole, for example, with an exact grip that n
ape can quite match. Yet such differences are secondary by comparison with the overriding differenc
which is that the athlete is an adult whose behaviour is not driven by his immediate environment,
animal actions are. In themselves, his actions make no practical sense at all; they are an exercise th
is not directed to the present. The athlete's mind is fixed ahead of him, building up his skill; and h
vaults in imagination into the future.

Poised for that leap, the pole-vaulter is a capsule of human abilities: the grasp of the hand, the arc
of the foot, the muscles of the shoulder and pelvis – the pole itself, in which energy is stored an
released like a bow firing an arrow. The radical character in that complex is the sense of foresight, th
is, the ability to fix an objective ahead and rigorously hold his attention on it. The athlete
performance unfolds a continued plan, from one extreme to the other, it is the invention of the pol
the concentration of the mind at the moment before leaping, which give it the stamp of humanity.

The head is more than a symbolic image of man; it is the seat of foresight and, in that respect, th
spring which drives cultural evolution. Therefore if I am to take the ascent of man back to i
beginnings in the animal, it is the evolution of the head and the skull that has to be traced. Unhappil
over the fifty million years or so to be talked about, there are only six or seven essentially distin
skulls which we can identify as stages in that evolution. Buried in the fossil record there must be man
other intermediate steps, some of which will be found; but meanwhile we must conjecture wh
happened, approximately, by interpolating between the known skulls. The best way to calculate thes
geometrical transitions from skull to skull is on a computer; so that, in order to trace the continuity,
present them on a computer with a visual display which will lead from one to the next.

Begin fifty million years ago with a small tree-dwelling creature, a lemur; the nam
appropriately, is that of the Roman spirits of the dead. The fossil skull belongs to the lemur famil
Adapis, and was found in chalky deposits outside Paris. When the skull is turned upside down, you ca
see the *foramen magnum* far at the back – this is a creature that hung, not held, its head on the spin
The likelihood is that it ate insects as well as fruits, and it has more than the thirty-two teeth that ma
and most primates now have.

The fossil lemur has some essential marks of the primates, that is, the family of monkey, ape an
man. From remains of the whole skeleton we know that it has finger nails, not claws. It has a thum
that can be opposed at least in part to the hand. And it has in the skull two features that really mark th
way to the beginning of man. The snout is short; the eyes are large and widely spaced. That means th
there has been selection against the sense of smell and in favour of the sense of vision. The ey
sockets are still rather sideways in the skull, on either side of the snout; but compared with the eyes
earlier insect eaters, the lemur's have begun to move to the front and to give some stereoscopic visio
These are small signs of an evolutionary development towards the sophisticated structure of th
human face; and yet, from that, man begins.

That was fifty million years ago, in very round figures. In the next twenty million years, the lin

that leads to the monkeys branches away from the main line to the apes and man. The next creature c
the main line, thirty million years ago, was the fossil skull found in the Fayurn in Egypt, and name
Aegyptopithecus. He has a shorter snout than the lemur, his teeth are ape-like, and he is larger – y
still lives in the trees. But from now on the ancestors of the apes and man spent part of their time o
the ground.

Another ten million years on take us to twenty million years ago, when there were what we shou
now call anthropoid apes in East Africa, Europe and Asia. A classical find made by Louis Leakey goe
by the dignified name of *Proconsul*, and there was at least one other widespread genus, *Dryopithecu*
(The name *Proconsul* is a piece of anthropological wit; it was coined to suggest that he was a
ancestor of a famous chimpanzee at the London Zoo in 1931 whose nickname was Consul.) The bra
is markedly larger, the eyes are now fully forward in stereoscopic vision. These developments tell u
how the main ape-and-man line was moving. But if, as is possible, it had already branched again, the
so far as man is concerned, alas, this creature is on the branch line – the ape line. The teeth show
that he is an ape, because the way in which the jaw is locked by the big canines is not man-like.

It is the change in the teeth that signals the separation of the line that leads to man, when it come
The first harbinger that we have is *Ramapithecus*, found in Kenya and in India. This creature
fourteen million years old, and we only have pieces of the jaw. But it is clear that the teeth are lev
and more human. The great canines of the anthropoid apes are gone, the face is much flatter, and v
are evidently near a branching of the evolutionary tree; some anthropologists would boldly p
Ramapithecus among the hominids.

There is now a blank in the fossil record of five to ten million years. Inevitably, the blank hides th
most intriguing part of the story, when the hominid line to man is firmly separated from the line to th
modern apes. But we have found no unequivocal record of that, yet. Then, perhaps five million yea
ago, we come certainly to the relatives of man.

A cousin of man, not in the direct line to us, is a heavily-built *Australopithecus* who is
vegetarian. *Australopithecus robustus* is manlike and his line does not lead elsewhere; it has simp
become extinct. The evidence that he lived on plants is again in his teeth, and it is quite direct: th
teeth that survive are pitted by the fine grit that he picked up with the roots that he ate.

His cousin on the line to man is lighter – visibly so in the jaw – and is probably a meat-eater. He
the nearest thing we have to what used to be called the ‘missing link’: *Australopithecus africanus*, or
of a number of fossil skulls found at Sterkfontein in the Transvaal and elsewhere in Africa, a full
grown female. The Taung child, with which I began, would have grown up to be like her; fully erec
walking, and with a largish brain weighing between a pound and a pound and a half. That is the size
the brain of a big ape now; but of course this was a small creature standing only four feet high. Indee
recent finds by Richard Leakey suggest that by two million years ago the brain was larger even tha
that.

And with that larger brain the ancestors of man made two major inventions, for one of which w
have visible evidence and for the other inferential evidence. First, the visible invention. Two millio
years ago *Australopithecus* made rudimentary stone tools where a simple blow has put an edge on th
pebble. And for the next million years, man in his further evolution did not change this type of too
He had made the fundamental invention, the purposeful act which prepares and stores a pebble f
later use. By that lunge of skill and foresight, a symbolic act of discovery of the future, he ha
released the brake which the environment imposes on all other creatures. The steady use of the sam
tool for so long shows the strength of the invention. It was held in a simple way, by pressing its thic