CONTRIBUTIONS to SCIENCE, **5** (2): 183–191 (2009)
Institut d'Estudis Catalans, Barcelona
DOI: 10.2436/20.7010.01.74 ISSN: 1575-6343
www.cat-science.cat

Charles Darwin: The scientist as hero

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Resum. Hi ha poques figures que han assolit la importància cultural de Charles Darwin. Aquí tenim un científic a qui nosaltres (els altres científics) ens agradaria posar com a model: era una bona persona, creatiu i que estava a favor d'un avenç científic que pogués ser entès per tothom. La seva idea de l'origen comú era senzilla i realment va canviar la manera que veiem el món; de la mateixa manera que el coneixement dels gens i el codi genètic ha transformat biologia i medicina. Aquest article explora a la figura de Darwin, i la història de vida més específicament. Som conscients que el món evoluciona, i vida amb ell. La història del canvi des d'un món dominat per procariotes (sense nuclis organitzats) fa 3500 milions d'anys a l'aparició d'eucariotes amb nuclis i d'organismes sexualment diferenciats fa aproximadament 1300 milions d'anys, i després a organismes complexos de gran mida 700 milions d'anys més tard, és tant un homenatge a la intuïció Darwiniana com una història amb desemvolupaments nous que exploraré.

Paraules clau: Charles Darwin · història de la vida · registre fòssil · explosió càmbrica · fauna dels esquists de Burgess (*Burgess Shale*) · les 'millores' de Darwin

Summary. There are few figures that have attained quite the cultural significance of Charles Darwin. Here is the scientist as we (our fellow scientists) would like the creature to be portrayed: he was a good human being as well as a creative one and he stood for a scientific advance that could be grasped by everyone. His idea of common descent is a simple one and it really did change the way we see the world; just as knowledge of genes and the genetic code really has transformed biology and medicine. This article takes a look at Darwin and the history of life more specifically. It has become clear that the world evolved, and life with it. The story of the change from a world dominated by prokaryotes (lacking organised nuclei) at 3.5 billion years ago to the appearance of eukaryotes with nuclei and of sexually differentiated organisms at about 1300 million years ago, and thence to complex organisms that achieved large size 700 million years later is both a tribute to Darwinian intuition and a story with new developments which I will explore.

Keywords: Charles Darwin · history of life · fossil record · Cambrian evolutionary explosion · Burgess Shale fauna · Darwin's "improvements"

Introduction

As just about the only science writer who apparently has NOT got a book out about Darwin in the last six months, I feel especially qualified to speak to you today!

Over the last few months it has been instructive to observe the way Charles Darwin's bicentenary and the sesquicentenary of the *Origin of Species* have been celebrated in public. I wonder sometimes whether the description of Darwin and his achievements tells us almost as much about contemporary attitudes to science and scientists as it does about the achievements of the great man himself. There are few figures that have attained quite the cultural significance of Charles Darwin, and the common characteristic of such icons is that they are remade and recruited as a kind of imprimatur of respectability and influence. Darwin is at the moment at this kind of apogee.

I believe a number of reasons can be invoked for his special status. The first emanates most particularly from scientists themselves. Scientists do have a problem with public perception; or perhaps I should say rather that scientists are neurotically worried about how they might be perceived by the public, which is not quite the same thing. Scientists want to be understood, to have the public appreciate what they actually do, and how the scientific method works. Scientists themselves worry that their image is not generally an encouraging one. First, there is a kind of hangover from the days of the boffin in the back room–the classic nerd, to use the modern term–out of touch with anything except his computer and unable to explain to anyone other than his fellow scientists exactly what it is he (and usually he) does. Then, by complete contrast, we have an

Based on the lecture given by the author at the International Symposium, "Darwin: 150 years of the theory of evolution", organized by the Institute for Catalan Studies and the Government and the University of the Balearic Islands, at the Royal Academy of Medicine, Mallorca, on 12 June 2009. Richard Fortey is a Fellow of the Royal Society and a Fellow of the Royal Society of Literature.

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increasing number of public portraits of famous scientists who are revealed as monsters of egotism–the match of every self-regarding novelist or poet. Think of the recent biographies of Newton and the mathematician Paul Erdos (the latter in *The Man Who Loved Only Numbers*), or the portrayal of John Nash in *A Beautiful Mind*. Who can forget Nash's withering dismissal of many of his contemporaries as "one theorem minds", with the infinity of arrogance thus implied. That madness followed in Nash's case could have seemed retribution as much as tragedy. Well, scientists want to be thought of as human and I believe that the notion of science as "the disinterested pursuit of truth" remains an ideal whose practice remains elusive.

This is where Darwin comes to the rescue. Here is the scientist as we (our fellow scientists) would like the creature to be portrayed: possessed of patience and generosity towards others (recall the kindly ways in which he assured all his many correspondents of his gratitude and attention at all times); the long life well conducted and creative to the end; the warm attachment to his family (and who can doubt the grief of the man at the early death of his daughter Annie?). The popularity of the portraits of Darwin as an old man–the white beard, the deep-set eyes brimming with wisdom and touched with sadness–demonstrates the preference for what I might term "Saint Darwin". It is a paradox, of course, but the image of the aged Darwin is really not so different from Caravaggio's portrait of St Jerome. The scientists' "saint" comes with relics, particularly the notebooks, and with such sacred texts as that famous sketch postulating the notion of common descent, with the wonderfully ambiguous statement "I think" at the top of the page. How much more appealing that short phrase than "I know" or "I understand"; it is a characteristically modest approach to originality, a tentative prod towards a change in *Weltanschauung*. So this is the scientist as ideal, the one that all scientists might, theoretically, aspire to–and ultimately fail to match up to. One is pushed hard to think of any other scientist who might press all the same buttons; the only name in the same league I can think of is possibly Dorothy Hodgkin, but there is no icon allowing her comparison with the late Darwin (Fig. 1). However inappropriately, Darwin rests in Westminster Abbey. You cannot help but feel that he might have preferred to be interred beneath his worm stone at Down House.

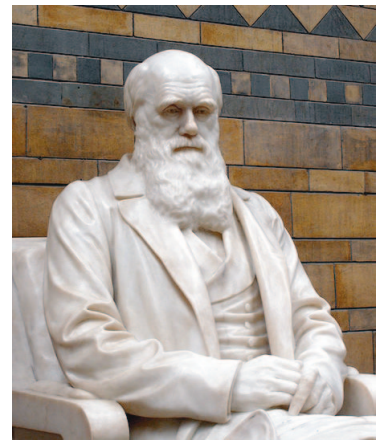

Fig. 1. Statue of Charles Darwin by Sir Joseph Boehm in the main hall of the Natural History Museum, London, where the author works. This image is published under a Creative Commons Attribution-Share Alike 3.0 Unported License.

The man

Darwin has a second great claim on his special place in the scientists' pantheon. His ideas are considered comprehensible to the thinking layman–and since nobody likes to be considered incapable of thought, this includes just about everyone. There is none of the kind of general nervousness in contemplating Darwin that Einstein or Max Planck inspires. Mathematics is genuinely beyond the comprehension of many articulate people, and mathematicians tend to inspire a kind of discombobulated awe. Having just returned from a large US campus I have seen how Einstein has been "domesticated" on T-shirts that combine one of the slightly bonkers photographs of him with a selection of his more transparent bon mots and aphorisms; but I think most people realise that this is missing his real substance, the difficult part. However, most people "get" Darwin, or think they do, and therefore also think they have a right to an opinion on Darwinism. Thus we arrive at opinion polls with their dispiriting conclusions: Miller and colleagues, in a 2006 report in the journal *Science*, found that 62% of US respondents agreed with the statement "Human beings were created by God as whole persons and did not evolve from earlier forms of life". Even polls in the UK have revealed that some 30% of respondents do not "believe" in Darwinism. One simply cannot imagine a poll happening in which people would confidently assert that they do not "believe" in the Special Theory of Relativity. Indeed, belief or otherwise in the Higgs boson or relativity is simply not an issue for democratic assessment. While the implications of both Darwin and Einstein percolate into the everyday of medicine or electronics, for example, it seems only the former has the property of being capable of being rejected in opinion polls. Such polls never ask whether those questioned believe that all medical treatments predicated on the assumption that evolution actually happened should henceforth be discontinued, which raises interesting issues about the way polls are conceived for the convenience of those asking the questions. But, however one looks at it, what remains is the apparent ease of understanding of what Darwin is supposed to have said as compared with other advances in mathematics, chemistry and physics. And this may indeed be true–for all those that perversely grasp the wrong end of the stick. The idea of common descent is a simple one and it really did change the way we see the world; just as knowledge of genes and the genetic code really has transformed biology and medicine. But somehow, many people are able to accept the onward-rolling implications of Darwin while still feeling able to reject his "-ism" so to speak. For scientists, it is the comprehensibility of so much of Darwin's research that provides another reason for his iconic status. Would that we could all transform the world by an idea so capable of forthright expression.

At this point it is instructive to compare Darwin with that other dominating figure of the last century, Sigmund Freud. I am old enough to recall a time when Freud was regarded as semi-

nal in an analogous way to Charles Darwin. If *On the Origin of Species* was one of the sacred texts, then so was the *Ego and the Id*. The story of the dethronement of Freud as scientist is familiar enough–crucially perhaps that his mechanics of mind was capable of infinite elaboration and immune to falsification (not really science at all) as Karl Popper and his associates pointed out. Nonetheless the language of Freud endures, from id to subconscious, and his influence in literature and art (especially surrealism) is genuine enough, although perhaps having something of an historic ring to it. Does anyone now really believe that Salvador Dali's extraordinary landscapes were produced by pure psychic automatism direct from the unconscious? Equally, the idea of conducting an opinion poll asking the populace whether they believe in Freudianism, or even in the existence of the Unconscious Mind, seems rather ridiculous now. Still, it is not inappropriate to compare Freud in his heyday with Darwin, if only because both produced ideas that were graspable by the many. Moreover, both acquired "bulldogs" to promulgate their ideas–albeit in the case of Freud hounds of variable loyalty–and those ideas entered common parlance. However, with the sidelining of Freud in the understanding of the mind, it seems to me that the importance of Darwin to scientists increased commensurately. While Freud's disciples, notably Carl Gustav Jung, became more mystical than mechanical, the fruits of Darwin's ideas emerged from the trees of science and of life itself. The language of natural selection slowly began to oust the elaborate jargon that had guaranteed the esoteric hegemony of the psychoanalysts, and helped to perpetuate their fat fees. The compass of Darwin has extended to occupy what had once been Viennese territory; laboratory and statistical surveys have replaced the psychiatrists' plush couches. Analysis has continued largely as the prerogative of the leisured and wealthy neurotic.

Nonetheless, as an aside, the compelling attraction of the case-history narrative pioneered by Freud has retained its place. I think of the casebooks of Oliver Sacks–his brilliantly summarised brief lives continuing the tradition of John Aubrey. They are attractive just because they acknowledge the singularity of human lives, and they show that a reliance on interpretative jargon is not necessary to obtain psychological insight. The brain as an evolutionarily engineered organ still makes stories.

Thus, scientists need Darwin because he is the ideal scientific hero: he was a good human being as well as a creative one, he stands for a scientific advance that can be grasped by everyone (even though this carries with it a particular blight of opinion polls). Indeed, he has outlasted Freud and taken on some of his territory. Paradoxical though it might seem to the atheist vanguard, Darwin has become a kind of secular saint, complete with elements of his own special iconography, and with Down House as his shrine. Even today, researchers seek his blessing by finding appropriate quotes from the great man buried in the *Origin* or in his autobiography. Whether or not he would have asked for them he still has his sturdy defenders more than a century after T.H. Huxley retired as his "bulldog"; with Richard Dawkins as Darwin's Rottweiler, perhaps, and Steve Jones as Darwin's Jack Russell terrier.

The idea

So now we can look at Darwin and the history of life more specifically. We have to recall at this point that enough was known at the time Darwin published the *Origin* to reassure him that the fossil record was consistent in a broad way with the notion of evolutionary "progression". Darwin himself worked thoroughly upon the fossils of barnacles, publishing a Palaeontographical Society monograph about them in 1851–1855–so he had studied the imperfections of the fossil record at close hand. Even the earliest systems of the Palaeozoic had been defined (although the Ordovician had to wait for a few years) and the dominance of invertebrates in these early strata was well-known. The great advances made by Cuvier on the continent, and the likes of Sedgwick and Murchison closer to home, had sufficiently established the succession of strata so as to allow the history of life to be conceived as a sequence of "ages", in popular assessment, with each one, of course, carrying with it an inevitable hint of advancement. Crucial scientific titles meanwhile filled in the time period between the return of the *Beagle* and the publication of the *Origin*. I think of Hugh Miller's book *The Old Red Sandstone* of 1841 (5 years after the Beagle returned), which documented "the age of fishes"; or Waterhouse Hawkins' *Book of the Great Sea Dragons*, published the year before, and its significance for suggesting "an age of reptiles" or even the age of "sea monsters" of popular imagination. And the dinosaurs had already become known before Darwin departed on his epic voyage, thanks to Gideon Mantell's description of Iguanodon from the Weald in 1825. Well, several more species were known much more completely by the time the *Origin* was in proof. Baron Cuvier had made great strides with the subsequent "age of mammals" in the Paris Basin and Darwin himself added several more from his visit to South America. To this list we should doubtless add Richard Owen's history of the British fossil mammals and birds (1844–1846), Davidson on brachiopods, Hawle & Corda and the great Joachim Barrande on Bohemian trilobites–the list goes on, and it is no exaggeration to say that these books represent the world of palaeontological discovery during Darwin's famous inter-regnum, while he delayed over the publication of *On the Origin of Species*. Darwin was very aware of this factual progress. Indeed, the sheer abundance of new material may have contributed to his caution.

It is speculation–but I think rather plausible –that what Darwin was hoping for was some kind of spectacular demonstration of the truth of evolution; not just the general "improvements" I have mentioned but a real fossil link between major groups of organisms. When he finally did decide to publish, he outlined in Chapter 6 what he termed "difficulties on theory". Prominent in this section was what he referred to as "the rarity or absence of intermediate forms", which was followed by a disquisition on the lacunae and fickleness of the fossil record. I think that the non-arrival of the perfect demonstration probably hurt him more than one might think, and he realised (prescient as always) where his critics might come from. He was acutely aware of the "holes" in his theory, which the fossil record might be expected to fill. For example, he knew about and acknowl-

edged in print the surprising suddenness with which fossils of complex organisms appeared in the Cambrian strata.

I do not think it would be too much of an exaggeration to say that a large amount of palaeontological effort over the last 150 years has been devoted to identifying precisely those "intermediate forms". Equally, I think it is a story of outstanding success–for all that single and simple "missing links" are the exception and not the rule and complex sets of intermediate forms are common. Only recently I learned of the discovery of the latest intermediate form to turn up: a half-way-house turtle, now named *Odontochelys semitestacea*, which proves that the turtle shell was sealed first from below, before completing the most perfect armour in the animal kingdom by sealing up above as well. You *can* have half a turtle. Nearly all the seminal breakthroughs in the history of life, including the colonisation of new habitats like land, for example, now have a matching series of fossils bridging the gap between before and after. Of course, Darwin would only have to have waited two more years for the primitive bird *Archaeopteryx* to have turned up–with its teeth and other reptilian features it is exactly the kind of link Darwin might have profoundly wished had been available when he published the *Origin of Species*. Doubtless it would have figured prominently in his arguments. But then of course we would have been celebrating in 2011.

Evolution and paleontology

During the course of my working life I have seen the ancestry of the birds from among the dinosaurs progress from a rather radical hypothesis to a generally accepted–well, I had better not say "fact" because there are still those who will not buy into the idea. What I will say is that the discovery of whole ranks of "dinobirds" from China has re-enforced the hypothesis that feathers had a use before flight, and that what Stephen Jay Gould called exaptation, the recruitment of a character to new purpose, is common in history: feathers before flight (Fig. 2). Then we could look at the transition from water to land and the establishment of the tetrapods, which started with the discovery of very early land animals in Devonian strata in Greenland in the last century but has had the final touches added just in the last few years with the discovery of *Tiktaalik* in Arctic Canada, which offers an almost perfect link between limb and fin, bone by bone, according to Neil Shubin. Or I could describe the many important species of fossil plants that have been discovered by my colleague Dianne Edwards in the Welsh Borderland–this time from the late Silurian; these "John the Baptists" prepared the way for other organisms to cross from water to land. Plants came first, arthropods (the ancestors of insects and spiders) followed, and they in turn were food for vertebrates, but all-in-all the whole suit of organisms was provided with a comparatively safe haven compared with the waters from which they emerged. Life took advantage of the opportunities, as it always seems to do. Or I could make much of the details of the human tree which have come to light in the last fifty years as fossil after fossil has been discovered after Raymond Dart's initial intuition. The African origin of our species is accepted by 95% of anthropologists–and for anthropologists that is a pretty good measure of agreement. The point is that Darwin's shortages have now, mostly, been supplied–whether it was a whale with legs (found), a dinosaur with feathers (found), or a fish with fingers (found) –I am glad to say.

But that is not to say that everything has been discovered, thank goodness. Otherwise we palaeontologists might just as

Fig. 2. Feathered dinosaur or "dinobird."

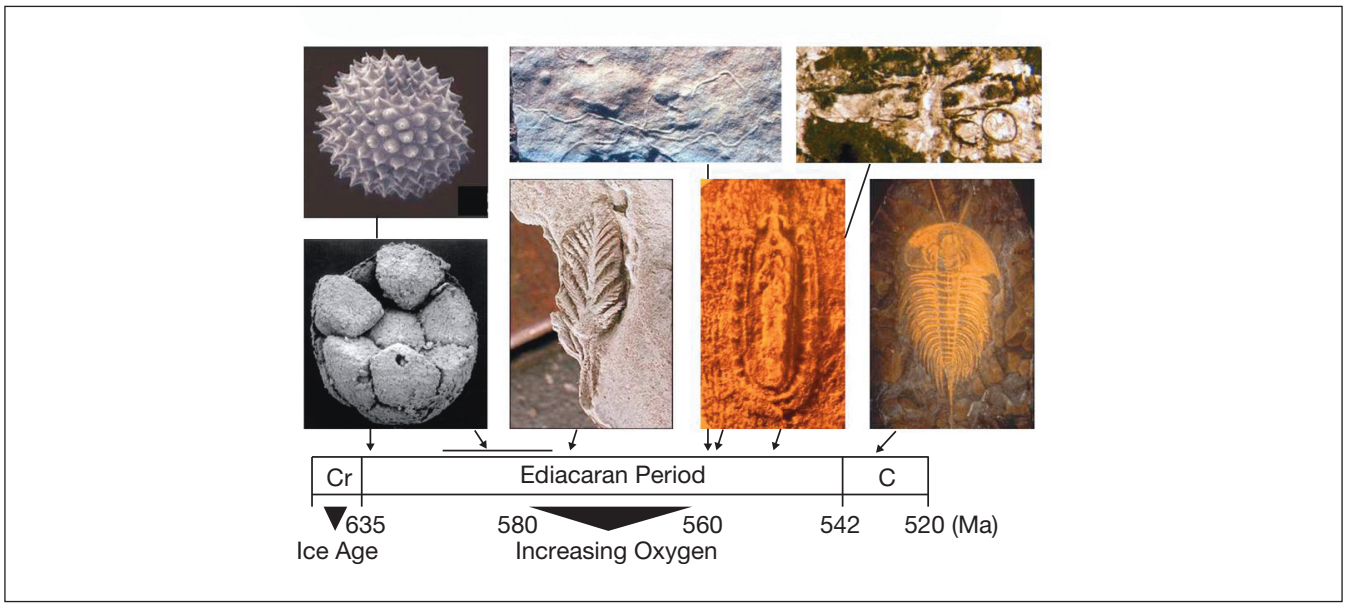

Fig. 3. Ediacaran-Cambrian animal radiation.

well pack up our bags. There are still mysteries to be solved. To take just one example, the Class Insecta, which is the most species-diverse group by far and therefore certainly not a trivial matter. We have known for some time that flightless insects were already present among the early terrestrial plant communities, such as springtails not so different from those that can be found around the average Cambridgeshire pond. But we still do not know in detail how flying insects evolved, although there are plenty of controversial ideas because truly convincing transitional forms have not yet been discovered as fossils. In recent years there has been a revival of the idea that the ancestor of the insects would be some kind of crustacean; this replaces the idea with which I was brought up, that the ancestor was closer to a centipede. Molecular evidence has provided an important series of new insights in this debate, which makes the point that science is always open to reinterpretation when new kinds of evidence arrive. I might add that these controversies still provide the favoured habitat of those who believe in Intelligent Design. Wherever there is an unsolved problem, adherents of this view move into a particular space, claiming the operation of the guiding hand at that point in the story.

Then, too, that realm of mystery to Darwin, the Precambrian, has been illuminated in so many ways. Far from being devoid of fossils, they are there in abundance if one knows where to look. The story of the change from a world dominated by prokaryotes (lacking organised nuclei) at 3.5 billion years ago to the appearance of eukaryotes with nuclei and of sexually differentiated organisms at about 1300 million years ago, and thence to complex organisms that achieved large size 700 million years later is both a tribute to Darwinian intuition and a story of surprises. It has become clear that the world evolved, and life with it. Oxygenation of the atmosphere would not have happened without photosynthesising microorganisms operating over hundreds of millions of years. Atmospheric change made animals possible. When living analogues of ancient stromatolite mounds were discovered in Shark's Bay, Western Australia, the biochemist joined hands with the geochemist to work out how the cycling of crucial nutrients and elements provided global control of the evolution of the atmosphere. That in turn controlled when animals could become large, and set the scene for subsequent evolution–a story that is almost too neat. But then there are the Ediacaran animals, those large, but still mysterious organisms that populated the oceans a few tens of millions of years before the Cambrian (Fig. 3). I had the pleasure of visiting Mistaken Point in Newfoundland last year to see these strange things for myself. Well they certainly do not resemble comfortable common ancestors of younger organisms and I think you would have difficulty claiming one of these curiosities as the urbilaterian that allegedly lies at the Clapham Junction of evolution of most animal life. They are, in short, a delightful surprise, and I am sure Darwin would have been as intrigued by them as we are.

But then we arrive at the Cambrian evolutionary explosion, which is still the most extraordinary threshold in the history of life even despite the many discoveries in the Precambrian. The conventional story is that the major groups of organisms (the phyla) appeared with great rapidity at 542 million years ago. Many of them acquired preservable skeletons then or shortly afterwards, and even those that did not are preserved thanks to a range of special fossil sites that protected the remains of marine animals that lacked skeletons–the most famous locality being the Burgess Shale in British Columbia (Fig. 4). My professor in Cambridge, Harry Whittington, sealed his reputation working on the Burgess Shale and a whole generation of his students have become nearly as famous working on the Burgess animals that Harry passed on to them in the 1970s. New discoveries in China and Greenland have added another huge gallery of fossil animals to the Cambrian exhibition. My own animals, the trilobites, have been dethroned in the process as the most primitive arthropods. Darwin would probably have assumed that they were the basal arthropods, if only because at the time of the *Origin* hard-shelled trilobites provided the only

Fig. 4. Satellite image of Burgess Shale quarry in British Columbia's Yoho National Park, Canada. The shale-covered fossil quarry is pale beige-grey (NASA Earth Observatory).

evidence of the Phylum Arthropoda in the Cambrian. Well, now there are several dozen other kinds of arthropods and their relatives and these make for other candidates for the early links in the chain. Organisms now rather obscure, like relatives of the velvet worm *Peripatus*, were prolific in the Cambrian, but perhaps that was only to be expected. The important point is that scientists can understand these Cambrian faunas in an evolutionary context. Some of them are strange-looking animals and were described as "weird wonders" and the like: there were claims that they represented many extinct phyla, an idea that achieved prominence thanks to Stephen Jay Gould's 1989 bestselling book *Wonderful Life*. Not many scientists go along with that now, and many of the strange animals of the Cambrian are now understood as extinct members of what are termed stem lineages; in other words, relatively familiar animals under construction embellished with peculiarities all their own. But they have been subsumed into the Darwinian paradigm.

From these beginnings we go onward and upwards through time and through those earthly "ages" of fish and reptiles that Darwin already knew: the land was colonised and so was the air; forests and reefs came and went; the whole delirious diversity of life; and the "human age" at last. The extinction of forms less adapted; the proliferation of forms better adapted: the whole increasing complexity of life apparently defying the second law of thermodynamics driven by the motor of natural selection. In this great adventure was the end point to eventually arrive at Darwin's "tangled bank"? You will recognise the famous quotation from the end of the *Origin*: "It is interesting to contemplate an entangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent on each other in so complex a manner, have all been produced by laws acting around us."

Not that life's history was truly a simple onward and upward scenario. Now we know better than did Darwin about the mass extinction events that punctuated–or should I say punctured? –that succession of "intermediate forms". The events at the end of the Palaeozoic era removed 90% of the marine species from the Earth, and all but a few tough generalists from the land. The late-Cretaceous extinction 180 million years later was less severe, but everyone knows that the end of the dinosaurs on land and of the ammonites in the sea–and many more organisms besides–reset the cast of characters that would take life's history onward into the Cenozoic. Many scientists believe that the world froze over almost completely in the later Precambrian, with all the traumatic implications for life that such an event entails. If I can put it teleologically, there was no particular sin committed by those organisms that failed to survive these catastrophes, nor apparently any special virtue that carried survivors through. An organism might die out because it was simply too large, or ate something that itself was endangered, or simply because it lived in a habitat that vanished with the drastic conditions with which extinction events are invariably associated, be they meteorite impacts, drastic climate changes, ocean anoxia, or some particularly nasty combination of several of these factors.

I do not suppose anyone would object to the broadest possible history of life I have just outlined other than the most diehard creationist. What I have *not* talked much about yet is what it all means, if indeed it means anything at all. Personally, I have tended to avoid the topic. Ten years ago I concluded my own history of the biosphere by saying "there are no trite moral lessons, nor are homilies desirable about cycles of history which are destined to come around once more." But if you accept what I have said about Darwin then the scientist in his role as hero might almost be *required* to impart meaning. Somehow Darwin's conclusion in the *Origin* does not seem to have quite the satisfying punch of, say: "Man is born free, but everywhere he is in chains!" Darwin rather modestly concluded that the processes behind evolution will lead to "Divergence of Character and the Extinction of less-improved forms." Well, I can spin that a little without doing too much violence to his language to say that evolution will lead to "improvement" and improvement certainly carries with it the notion of advance. There will be a direction to life history and that direction will, to put is as vaguely as possible, be in some way forwards in time and upwards through design towards some ultimate, if unreachable perfectability.

But let us stop here for a moment. Because if it is really the case that the major extinction events operated in some arbitrary way upon what Darwin termed the "extinction of forms" then these *external* circumstances may have made the "improvement" or otherwise of the organisms beside the point. Were it not for a giant meteorite impact dinosaurs would have carried on happily enough; nor was there an "improvement" possessed by, say, crocodiles and turtles that allowed them to survive while dinosaurs perished. Maybe they were just lucky enough to require less food for long periods.

Darwin's "improvements"

Not everybody is as cautious about discerning meaning, or drawing conclusions from the history of life as Darwin (or me). I

can crystallise two extremes of attitude according to the emphasis placed on those controls on life's trajectory I have just described. First, there is the view that external events, like mass extinctions, or even random extinctions, have been the main drivers of what we see in life's history. Its shape, in short, is largely a matter of contingency. This view is perhaps most readily associated with the late Stephen Jay Gould. He expounded it in his book that I mentioned above, *Wonderful Life*, which is about the Cambrian explosion and the Burgess Shale fauna, based on the work of Harry Whittington and his colleagues. As an international bestseller, it made all the scientists described in the book famous. Gould was already famous but it certainly made him a lot wealthier. One of the main theses of *Wonderful Life* is that if one, rather than another of the "weird wonders" that thrived in the Cambrian had become extinct, possibly by mere random chance, then the shape of life might well have had an utterly different trajectory. Put in terms of a metaphor that became very popular, Gould said that if the tape of life were to be run again, the outcome might have been very different.

Then we have a completely opposite view which holds that despite the vicissitudes of earthly events, however drastic, the course of life would, given time enough, run through its course in exactly the same fashion. And I mean, *exactly*, even to the extent of the eventual evolution of critical intelligence in a bipedal animal with good binocular vision. Put another way, everything, from the Cambrian evolutionary explosion to the appearance of consciousness, was an inevitable consequence of life's appearance on planet Earth and the first self-replicating cell. The tape was destined to play a particular narrative, and that narrative was assuredly progressive–an "improvement" of a special kind. This idea, which is essentially the antimatter to Gould's matter, is particularly promulgated by my former friend Professor Simon Conway Morris, one of Whittington's students in the heady years of the Burgess Shale investigations. Palaeontologists of my vintage will remember Simon unveiling some of the odder animals in the Burgess fauna at conferences, originally claiming them as representing hitherto unknown animal phyla. I do not want to trace his transmogrification from being the beneficiary of Gould's particular praise to the scourge of everything Gould stood for–although I believe that psychology of a not-particularly Freudian kind has something to do with it. But it is worth exploring how two professors looking at the same apparent narrative based largely on fossil evidence can come to absolutely different conclusions and sell them to the waiting public under such magisterial titles as *Life's Solution* (the title of Conway Morris' book). Both authors would claim Darwin's blessing while pointing out ways in which the old man was not quite the ticket.

Both views start from the base of undeniable facts. For Conway Morris the overwhelmingly important fact is the frequency of convergent evolution (convergence) in the fossil record and among living organisms. Convergence is a matter of striking similarities of form having arisen on separate evolutionary pathways. An old favourite, although there are differences in innervation, is that the octopus eye and the higher vertebrate eye are similarly constructed. The forms of trees and of corals have been independently evolved on several occasions; so have truffles. The list goes on and on. Systematists like me are challenged by it because we are always trying to discover the real evolutionary relationships, which may not be clearly revealed by the more blatant similarities. Cladists call such resemblances homoplasies and they are everywhere in evolution. The conventional explanation for these resemblances is that designs in nature have to be "fit for purpose". If you were a plant you must compete with other plants for light; one way of winning is to grow upwards, away from the competition, and spread your chloroplasts as if on outstretched hands; but in doing that you have to overcome mechanical problems in supporting your foliage and in transporting water. The solution is to become a tree with a mechanically strengthened trunk containing water and nutrient transport systems. It is an engineering problem but one that is constrained by the raw materials available–and the genes that can handle it. There is no question of a plant making its vessels out of iron. Even biochemicals like haemoglobin appear convergently because they are the logical outcome of a cellular toolkit. Evolution does not simply make things up from scratch.

So the argument goes that the repeated appearance of even complex structures supports an innate progression operating within the range of habitats presented on Earth. Taking to the air provides an opportunity, for example, and many organisms will indeed take that opportunity, for all that the details of wing construction are different in bats, birds and pterosaurs, not to mention insects. That life does rise to new opportunities is perfectly reasonable, it seems to me, and surely Darwin would agree. But can you extend the argument to the point that the appearance of a human is *inevitable*, where consciousness will ineluctably arrive? As if the goal of Darwin's "improvements" had to be something very like ourselves? According to Conway Morris the answer to both these questions is "yes", and at this point God enters the argument. The appearance of thinking beings is what the whole process is about; as he put it recently "the universe is actually the product of a rational Mind and evolution is simply the search engine that in leading to sentience and consciousness allows us to discover the fundamental architecture of the universe." Ahem. This is Conway Morris' answer to the question of direction in evolution–the reason for what Darwin modestly proclaimed as "improvement". We are here to recognise, and presumably worship, the first cause. If the dinosaurs had not gone extinct then maybe they rather than us would have finished up as the intelligent bipeds (he quotes an amusing science fiction book to this effect, with approval). They would eventually have converged on the human form. The tape plays out regardless of the slings and arrows of historical circumstance.

The blogosphere treatment of Conway Morris' ideas is pretty harsh; he stands accused of being a somewhat cryptic adherent to the views of Intelligent Designers. He himself has always strenuously denied this, and I think I do sympathise with him that he does not actually claim that a "hidden hand" is working behind critical stages in the evolutionary process. I would rather dub his viewpoint Inevitable Design. The earliest history entails the latest outcome. There is only one tape. Odd-

ly enough, in a religious context his views are remarkably like those of the Gnostic heretics, who claimed that the Fall in the garden of Eden and the knowledge of Good and Evil was not sinful because without it there would have been no resurrection: the former entailed the latter. As the medieval carol "Adam lay ybounden" put it:

> Ne had the apple taken been,
> The apple taken been,
> Ne had never our ladie,
> Abeen heav'ne queen.
>
> Blessed be the time
> That apple taken was,
> Therefore we moun singen.
> Deo gracias!

So, naturally enough, to Conway Morris the Gouldian view is anathema. Furthermore, Gould was himself the leading representative of a hated cohort: the atheist/humanist liberal intellectuals; those who have what Conway Morris has repeatedly termed an "arid" take on life, the universe and everything. As for Darwin–well, descent with modification is essential for Inevitable Design to work, and presumably natural selection acts as a kind of motor that keeps the tape turning onwards. I am slightly hard put to see how this works on the ground, as it were, but we will have to give it the benefit of the doubt.

On the very other hand, Gould brought out his ideas of contingency particularly from his reading of the results of the Burgess Shale. Recall that the Cambrian lies early on in metazoan evolution, early enough (as Gould claimed) to have in the sea at the time various additional animal designs as different as any that separate the animal phyla today. Many of these "blueprints" for further evolution perished; so Gould figured, not implausibly, that had extinction picked out other candidates (maybe the ancestor of all today's crustaceans and insects, for example) then the subsequent course of life might have been completely different. If one fork in the path of life were followed rather than another, who knows what organisms would have arisen? A somewhat similar argument might be applied to mass extinction events, as I have already mentioned. In Gould's view, natural selection works its wonders in creative times–like the invasion of land–but the whole scenario can be reset by external events: meteorites, de-oxygenation or even by chance extinctions. However, it is important to record that since the publication of Gould's *Wonderful Life* re-examination of the Cambrian weird wonders have shown that they are better understood as primitive members related to living groups rather than as the possessors of uniquely peculiar characteristics. If one rather than another had gone extinct, then maybe the future of life would *not* have been so different after all. And new discoveries over the last decade have shown that at least some of the Cambrian animal types lived on for millions of years. Gould's extinctions were probably just a matter of ignorance of geologically younger soft-bodied faunas, a few of which we know nowadays.

It is as well to remind ourselves at this point that both these opposing views, Gould's and Conway Morris', are buttressed by considering almost exactly the same evidence. In my view, this is where the same philosophical considerations that applied for Sigmund Freud come back into the picture. The point is surely that neither the idea of the convergent fate of life history nor the idea of contingency can actually be tested by "re-running" the tape of time. It is not an experiment that can ever be done outside the mind of the savant. It is non-science (I am tempted to say nonsense). It is not any more scientifically possible than re-running human history to describe what might or might not have happened had Hitler won the Second World War. It is intriguing, but it is the stuff of novelists and conspiracy theorists, not scientists. However, it is possible to closely examine what happened over mass extinction events, This is a matter of gleaning facts, and many such facts have indeed been accumulated over the last two decades that prove how tightly squeezed life was at the end of the Permian, to give but one example. On this score I would say the contingent scenario was more capable of examination than the "Inevitable" scenario.

But perhaps I have not been quite fair at this point. There is a way of testing the Inevitable Design idea, but only outside the solar system. Conway Morris asserts the likelihood of life evolving to the same pattern elsewhere in the universe (and more possible planets are recognised each year), in which case the appearance of extraterrestrial intelligent bipedal beings in Trafalgar Square would offer proof of this scenario. Astrobiology is a fashionable branch of science just now, and this idea has probably had more than a fair draught of the oxygen of publicity. For myself, I think it has more than a smack of the cargo cults of Vanuatu about it, perpetual waiting for proof of something that is itself a supposition, and probably implausible. But I could be proved wrong tomorrow; I wonder what odds the bookies would write for me?

So let us return finally for another bite at the question of Darwin's "improvement". After all, the scientist's saint almost invariably had the right judgement. He did not claim a monopoly on the meaning of life but the bits he looked at were always illuminated.

I believe that one can objectively identify some direction in life's history and if you want to call it "improvement" I am not going to baulk at it too strongly. This direction results from two elements in evolution by natural selection, to one of which Darwin devoted his genius; that is, co-evolution, the mutual jacking-up of adaptations. Darwin famously explored the connection between pollinating insects and orchids (one might say more generally insects and angiosperms), a relationship that promoted a wondrous increase in richness of designs in both and ultimately increased the likelihood of cross-pollination. Almost the complement of that sort of co-evolution is what has been characterised by Geerat Vermeij as the "arms race" between predator and prey. Vermeij demonstrated how molluscs and other organisms were forced to improve (right word) their defensive armour or other strategies in response to more efficient predation by heavily clawed crabs or efficient boring snails–and this happened during the Cretaceous, and not immediately after a mass extinction. This was evolution as a creative force. After the extinction of the dinosaurs the faster me-

tabolism of mammals (and the need for more food per unit time) must surely have entailed more complex neural networks. Greater sophistication in the hunters would have stimulated greater sensitivity in the hunted. The fact that, however you define it, "clever" animals have appeared in several lineages, including crows, dolphins and primates, is merely the top end of a general "improvement". I cannot absolutely prove it, but if brain size relative to body weight is any indication then the Cenozoic world is a smarter world than the Jurassic world. Let us not be too restrictive about our definition of improvement; anyone who has a cat will know the perfection of their hunting skills (and presumably the associated neural networks) but will also acknowledge how maddeningly stupid they can be. But I think we can reasonably allow for brain-led directional change.

Then there is the property or propensity of life to build up complex systems like coral reefs from simpler components which in turn provide habitats and niches for hundreds of other organisms. We know this has happened repeatedly through geological time. We probably only know a fraction of the species tucked away in a thousand niches in the rainforests even now. Well, this is another sort of advancement, and it may be one that is interrupted only by contingent factors like climate change. Also, it is important to say that none of this kind of advancement implies that all less "improved" organisms died out; rather, many are accommodated within the "tangled bank" perfectly happily. The soil harbours many small organisms that have been around more than 350 million years since the Devonian.

Coda

So I think I can summarise by saying that Darwin's "improvements" do indeed have meaning. I prefer to summarise it all by saying that life becomes richer over its long history. The habitat breakthroughs (e.g. water to land) were the most obvious part; emergent systems like reefs and forests less obvious, perhaps, but most creatively enriching. The natural state of the biological world operating through natural selection is one of maximising species richness. Extinction events interrupt and divert this process, giving new organisms the chance to contribute to subsequent richness; stressable ecologies like reefs are extinguished but then rebuild, often using different organisms as building blocks. But there *is* a sense of forward development– or "improvement" as the saint would have put it.

At last we can come back to consciousness; we humans are the first time that this arose on earth, so it cannot be argued that it is just another potential example of convergence. Inevitable? This is where we need to look once more at the fossil record. Although I have stressed that many structures do indeed appear convergently more than once, there are still plenty of unique structures–one-offs that, as it were, evolution tossed up but never repeated. You could argue that there are convergences between porpoises and Jurassic ichthyosaurs, for example, but where is the modern equivalent of the flexible-necked *Plesiosaurus* and *Pliosaurus*, which were already well-known in Darwin's day? Or take my own particular organism, the long extinct trilobites. They had uniquely constructed eyes with lenses made of calcite–lenses that are unique in the animal kingdom. Their eyes were compound eyes like those of many other arthropods; it is just that the trilobites took them off into a unique direction. The eye of *Phacops* is unique. I could give you lots of other examples, but the point is this: we do not know whether the evolution of consciousness is a one-off or not. We do know that it has not happened before, and it could be the product of unique circumstances in Africa when a selective premium was placed on pushing the development of the brain in a particular direction. Given what I have said about a general hike in "smartness" in the Cenozoic, well, maybe humankind was just one of the those "trilobite eye diversions" off the common trend. It also seems to me very unlikely that if mankind and the mammals became extinct that (say) crows would pop exactly into that vacant consciousness niche. We parted company from the ancestors of the crows 250 million years ago, and it seems extraordinarily presumptuous of me to assume that crow consciousness (if that ever came to pass) would be anything like our own.

About the author

Richard Fortey is a palaeontologist and writer. He studied at the University of Cambridge where he became Bachelor of Science and later obtained his Ph.D. in Geology. He has been a researcher at the Natural History Museum of London for more than 30 years. His research interests are trilobites and graptolites, especially Ordovician, their systematics, evolution and mode of life (a subject on which he is world authority); Ordovician palaeogeography and correlation; arthropod evolution, and especially the origin of major groups; and the relationships between divergence times as revealed by molecular evidence and the fossil record. He is a fellow of the Royal Society since 1997 and was elected President of the Geological Society of London for the period 2006-2008. He has published many articles in scientific journals and has written several books explaining all his knowledge to the general public. In 1993 *The Hidden Landscape* was named Natural World Book of the Year. He won the Lewis Thomas Prize for Science Writing 2003. In 2006 he was given the Linnean Medal, and he is the 2006 holder of the Royal Society's Michael Farady Prize for the public communication of science. Other bestselling books include *Life: An Unauthorised Biography. A Natural History of the First Four Billion Years of Life on Earth* (1997), *Trilobite!: Eyewitness to Evolution* (2000), *The Earth: An intimate History* (2004) and *Dry Store Room no.1* (2008).