Darwin as a Geologist – Biographical Reflections

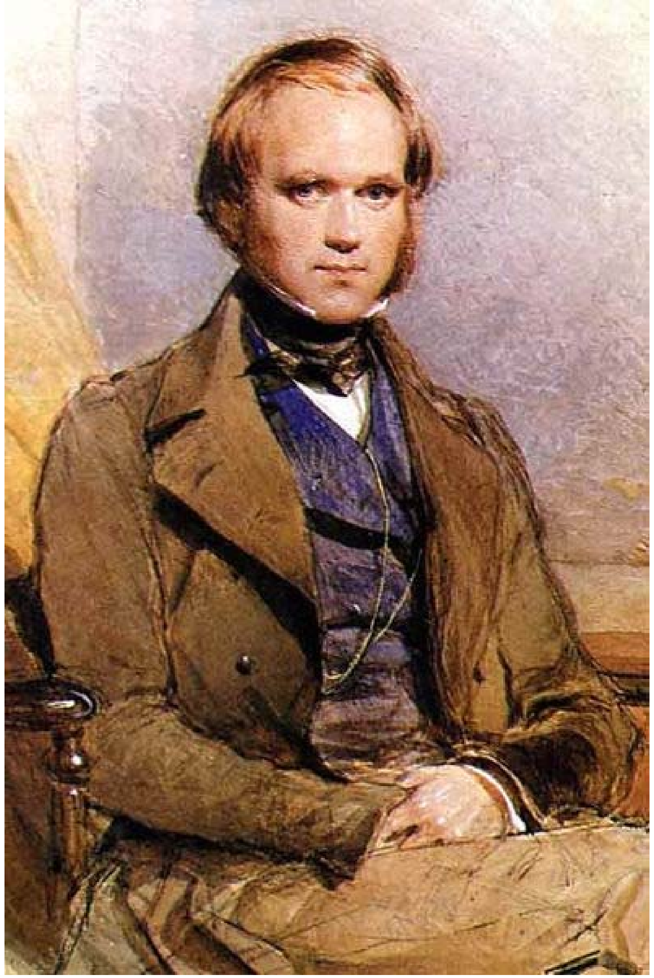
<u>Introduction</u>

Charles Darwin's reputation, in the minds of both the general and the scientific public, rests primarily on his position as a biologist. His name is permanently linked to the concepts of biological (including human) evolution, and to the controversies that surrounded the publication of the *Origin of Species* in 1859.

However, as the bicentenary of his birth (2009) approaches, it is salutary to recognize that, as a young scientist, Darwin considered himself as much a geologist as any other category of natural scientist. The early exposure he had had to geological thinking meant that he approached the phenomena he encountered during the *Beagle* voyage with a keen eye to processes acting on the earth – both in fine detail, and on a much larger scale. The fossil collections he made on that voyage honed the intuitions, which, later in life, matured to underpin his thinking on the transmutation of species. Indeed, in the words of John Wesley Judd, Darwin's 'geological confidante' in his later years, '*It is not too much to say that, had Darwin not been a geologist, the "Origin of Species" could not have been written by him'.*

Darwin was recognized as a geologist early in his career. Shortly after his return from the *Beagle* voyage he was embraced by the geological fraternity, represented by the prestigious Geological Society of London. He was elected to the Society's council, and appointed one of its secretaries in 1838. In 1859 he was awarded the Society's highest honour, the Wollaston Medal, for his contributions to understanding the growth of coral reefs, the history of uplift of the Andes and of the Chilean coast, and for work on glacial boulders in Britain and for fossil barnacles. Sandra Herbert (2005) in her comprehensive study of Darwin as a geologist, echoes John Wesley Judd when she refers to 'geological moorings' for the '*Origin of Species'.*

In the present essay, I have attempted to present, in narrative form, something of the influences on Darwin's thinking as a geologist. The account begins with his early education, then records his responses to the geology he encountered on the *Beagle* voyage, and finally moves to the way in which geological concepts influenced his thinking about biological processes in his 'post – *Beagle*' years. In order to maintain a narrative quality, the paper draws heavily on the splendid biography of Darwin published by Adrian Desmond and James Moore in the 1990s. This is an outstanding publication, by authors who are themselves historians of science and palaeontologists – and who were able to draw upon some of the14,000 pieces of correspondence that Darwin accumulated.



The young Darwin. Watercolour portrait of Charles Darwin, painted by George Richmond, late 1830s. From *Origins.* Richard Leakey and Roger Lewin (public domain).

<u>Education and Early Influences</u>

The irony of Darwin's success as a geologist was that he had had very little formal training in the subject. While this might be true, the exposure that he had in his early years was somewhat intense. And geology was a popular subject, even among the general public.

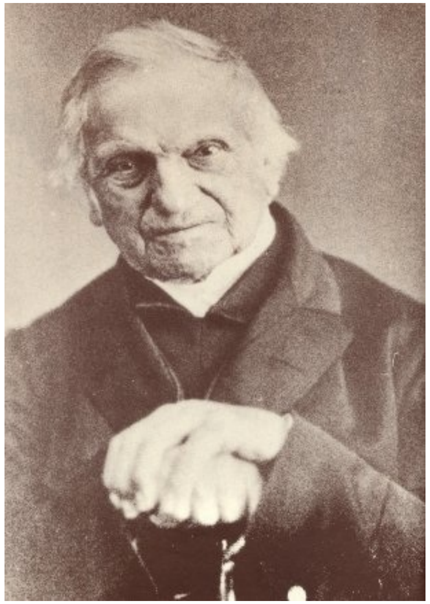
At the University of Edinburgh, where he studied from 1825, before he dropped out of his medical course, Darwin attended lectures by one Robert Jameson, who was a Champion of Werner's Neptunist theory

> …..'*Jameson was famous as a 'Neptunian' geologist: he taught that the rock strata had been precipitated from a universal ocean. Darwin had already heard an opposite view from Professor Hope (the chemistry Professor Thomas Hope). Hope told his students that the granites had crystallized from a white-hot molten mass. The question – were the rocks solidified crust or muddy sediment – was of long standing. Too long, in fact: it had run its course elsewhere. But Hope and Jameson prolonged the set-piece debate in Edinburgh, to the delight of the students, whose fees provided the inducement. 'It would be a misfortune if we all had the same way of thinking', Jameson admitted. 'Dr Hope is decidedly opposed to me, and I am opposed to Dr Hope, and between us we make the subject interesting'.*
>
> *And yet Jameson's course was immensely popular, and Darwin learned from it. It was popular almost in spite of Jameson, who had all the flair of a master reading a roll call. Geology was what the audience came to hear. The subject was in vogue; it was practical and popular with the town's tradesmen, and in Darwin's year 200 attended, from students to city silversmiths and surveyors. The course was as comprehensively assorted as the audience. There was something for the jewellers and farmers as well as the students; mineralogy and meteorology, geology and natural history. Perhaps little more if one looked, given Jameson's Lamarckian paper, one wonders what Charles made of his closing lectures on the 'Origin of the Species of Animals'.*
>
> *Jameson met his students three times a week for practicals in the museum. Here he described exhibits, especially the minerals; and Darwin assiduously studied these, scribbling notes in his textbook and checking specimens against those in his own 'Cabinet' He also learned the sequence of the rock strata, from the Scottish Old Red Sandstone to the Downs Chalk, and how to read them like the pages of a book.'* (Desmond & Moore, p.41).

And yet Jameson's lectures were incredibly dull. And in his autobiography Darwin reported ….'*the sole effect they produced on me was the determination never as long as I lived to read a book on Geology or in any way to study the science. Yet I feel sure that I was prepared for a philosophical treatment of the subject' (Autobiography, p.52).*

Unable to face a medical career, Darwin ended up in Cambridge – his father having determined that the church was probably the best calling for an aimless son – a 'haven for dullards and dawdlers', as he thought. A country parish would probably be his ultimate reward.

In Cambridge a variety of interests opened to him. He was much influenced by the Reverend Paley's view of creation, wherein God would reveal himself in the miracles of nature; his interest in botany was sparked by his friendship with John Henslow, and it was Henslow who introduced him to the geology professor Adam Sedgwick, with the thought that a geological training was what the young Darwin needed, to keep up his interest in natural history.



The elderly Sedgwick
See www.sedgwickmuseum.org

Again, reading from the Desmond and Moore biography.

> ' *For his part, Darwin was fired up by Sedgwick's lectures that spring. They were incomparably better than Jameson's at Edinburgh, which he had hated. Sedgwick's reminded him of Humboldt, Herschel, and Paley, wrapped into one. They opened up new vistas of God's world, exposed the grandeur of creation. 'What a capital hand is Sedgewick for drawing large*

cheques upon the bank of time!' Darwin marvelled. As for space, the professor revealed how much more of the globe remained to be conquered. 'It strikes me' Darwin reflected, 'that all our knowledge about the structure of our Earth is very much like what an old hen wd know of the hundred acre field in a corner of which she is scratching.'

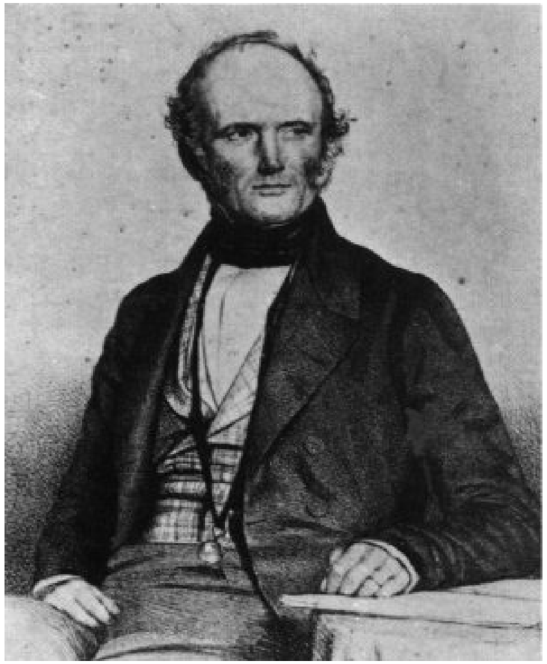
The summer was to see more serious field work. Darwin left Cambridge in June for London, where he bought his first geological instrument, a clinometer, for measuring the angle of inclined rock strata. Back home he put it to use, piling
'all the tables in my bedroom,, at every conceivable…direction' and then sizing up their angles like 'any Geologist going could do'. He even ventured into the
countryside to try his hand at mapping Shropshire. (Desmond & Moore, p.94).

In August 1831 we find him on a geological tour of Wales with Adam Sedgwick, who was studying the rocks that he would later define as the Cambrian System….

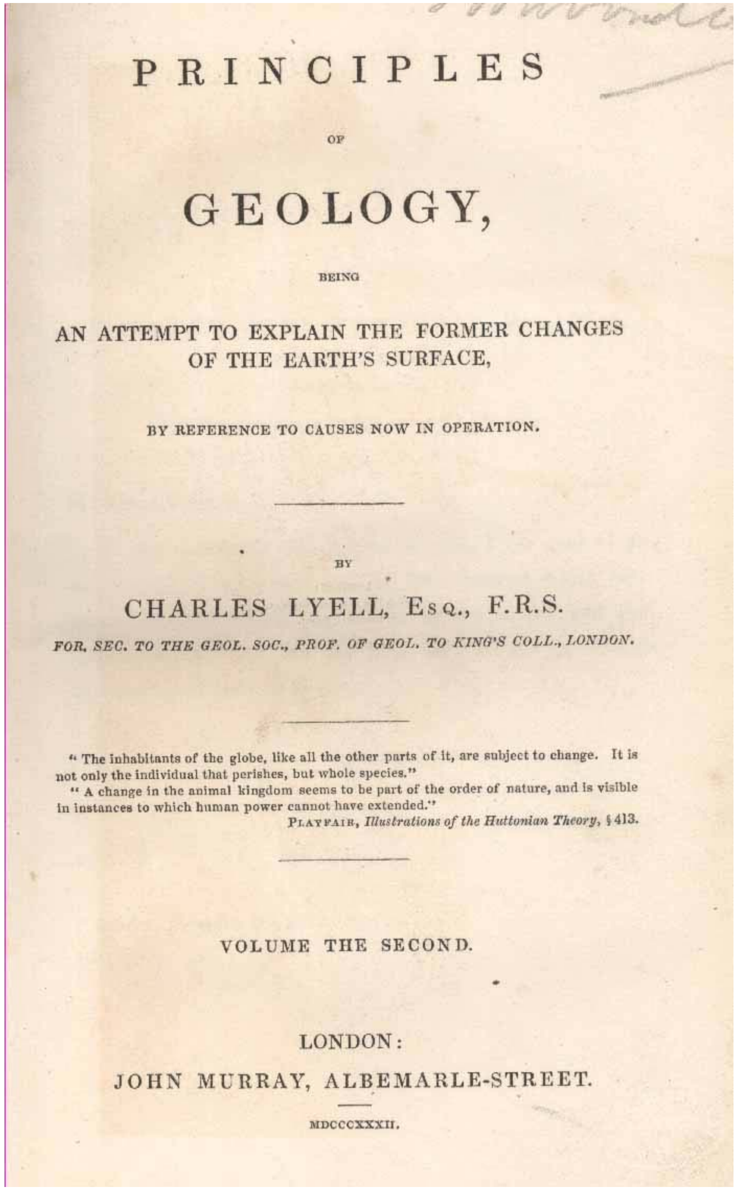
'*For the Professor it was an expedition long overdue. Wales was becoming an area of enormous geological importance. Sedgwick had run into the problems of sorting out the oldest rocks of northern England. Strata seemed to be missing, like the pages of a book, and he guessed that equivalent ones would turn up in the rugged Welsh mountains. If he could find those ancient fossil-bearing rocks below the Old Red Sandstone, he could put the opening pages back into the geological book, enabling the history of life to be read from scratch'.*
……'That week Sedgwick hammered his way cross country from Cambridge, preparing for the Welsh invasion by chipping at conformable strata en route. He arrived in Shrewsbury tired and sore, and the next day drove off with Darwin under menacing skies, heading north into the Vale of Clwyd.
……'And serious geology was what Darwin learned in Sedgwick's on-the-spot tutorials, as well as the skills that books could never impart.The clinometer came in handy, and Sedgwick checked the accuracy of Darwin's measurements. In less than a week he learned how to identify specimens, interpret strata, and generalize from his observations. It was the best crash course in geological practice, and Darwin hardly missed a trick, developing intellectual muscle as he burned off the flab. Sedgwick sent him off to collect rock samples and to check the stratification. When they met up, Darwin reported that he had found no Old Red Sandstone in the Vale of Clwyd. This contradicted the national geological map, and Sedgwick's discussions made him 'exceedingly proud'.

Before they left the hills and headed for the coast, Darwin had fallen for the romance of geology.' (Desmond & Moore, p.96)

Arriving back in Cambridge, on 29th August, Darwin found a fat envelope awaiting him. He discovered, on opening it, that he was being offered a passage on a voyage around the world. He had been recommended by his Cambridge mentor, John Henslow, as naturalist for the forthcoming Beagle voyage under Captain Fitzroy. Darwin was considered suitable for the position more for his gentlemanly background than for his skills as a naturalist. Fitzroy had expressed a wish to have as his companion a 'well-bred gentleman' who could relieve the isolation of his command, and share the captain's table. As a welcoming gift, Fitzroy gave Darwin the first volume of Charles Lyell's *Principles of Geology*', which had been published the year before.



Charles Lyell from Wikipedia



PRINCIPLES

OF

GEOLOGY,

BEING

AN ATTEMPT TO EXPLAIN THE FORMER CHANGES OF THE EARTH'S SURFACE,

BY REFERENCE TO CAUSES NOW IN OPERATION.

BY

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" The inhabitants of the globe, like all the other parts of it, are subject to change. It is not only the individual that perishes, but whole species."

" A change in the animal kingdom seems to be part of the order of nature, and is visible in instances to which human power cannot have extended."

PLAYFAIR, *Illustrations of the Huttonian Theory*, § 413.

VOLUME THE SECOND.

LONDON:

JOHN MURRAY, ALBEMARLE-STREET.

MDCCCXXXII.

Cover page of 'Principles of Geology'
2nd Edition, John Murray, London

Geology and the Beagle voyage

We next find Darwin's references to geology with respect to St Iago, in the Cape Verde Islands, some 300 miles off the African coast – a wretched place, he had read, and described as an 'excrescence of desolate volcanic hills'. But it was the first landing of the voyage, and Darwin, who had suffered intensely from sea-sickness, was relieved to be walking on solid ground.

From the tide pools on the coast he collected brilliantly coloured sponges and exquisite corals, but …

> '*What enthralled him most was the volcanic terrain. Walking alone over sun-scorched plains strewn with 'black and burnt rocks' was ecstasy, his imagination running riot on nature's primeval forces. The barrenness and solitude forced all mortal thoughts from his mind; he was left facing earth's awesome power.*
>
> *He spotted something odd – a horizontal white band running through the rocks, about thirty feet above sea-level. It was made of compressed shells and corals, and continued as far as the eye could see. Obviously the whole area had once been under water, but why not now? Darwin, fascinated, took up the challenge.*
>
> *Sedgwick in North Wales had inducted him into Cambridge style geology – a science of violent crustal movements, wrenching strata, and mountain thrusts.*
>
> *But how had this seashell band arrived at this height above the ocean? Lyell's*
> *'Principles of Geology' could help here…..Lyell pictured a world constantly and slowly changing, with the past no more violent than the present – so that today's climates, volcanic activity, and earth movements are all that we need to explain the ancient world. Crustal movements balance one another; land rises in one area as it falls in another, not cataclysmically, as Sedgwick thought, but gradually.*
>
> *Was Lyell right? Thousands of miles from Cambridge, Darwin thought for himself. It was impossible that the sea itself had fallen; a lower Atlantic was unimaginable in St Jago's volcanic lifetime. So had the island risen slowly or abruptly? He inspected the oyster band again. It was practically intact, showing no sign of catastrophic violence. And it varied in height above sea-level along its length, suggesting secondary subsidence in places. St Jago, at least, seemed to prove Lyell's point. Darwin started to view the world as slowly and gradually changing.*
>
> *With his notepads filling up, Darwin now realized that he could make a serious contribution to geology. He even imagined writing his own book on*

the subject, based on the countries he would visit. (Desmond & Moore, p.117)

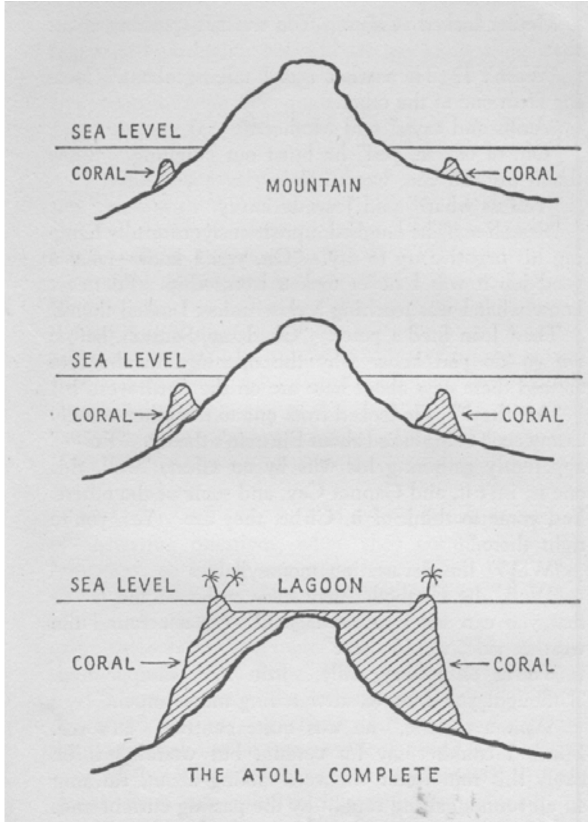
He did, of course, come to write three books on the subject – the first on the structure and distribution of coral reefs; one on his geological observations in South America, and another on volcanic islands.

While the observations that he made on the Beagle voyage, and his geological mode of thinking, were no doubt highly influential in his thinking as a biologist, and influenced his contemplation of biological processes (and more of that later), in the strictly geological literature I think it is fair to say that it was his analysis of the origin of coral reefs, published in 1842, that made the most impact.

Darwin, coming under the influence of Lyell, was prepared to see the earth as being in a kind of steady state, where uplift, subsidence, erosion and deposition were in balance.

On coral reefs…

> *'Darwin coupled in his mind this dramatic evidence of elevation with accompanying subsidence and deposition. Thus he hypothesized, before actually seeing them, that coral reefs of the Pacific developed on the margins of subsiding land masses, passing through the three stages of fringing reef, barrier reef, and atoll.'* (From Leo Laporte, 1996)
>
> ' *No other work of mine was begun in so deductive a spirit as this; for the whole of the theory was thought out on the west coast of South America before I had seen a true coral reef. I had therefore only to verify and extend my views by a careful examination of living reefs. But it should be observed that I had during the two previous years been incessantly attending to the effects on the shores of S. America of the intermittent elevation of the land, together with the denudation and deposition of sediment. This necessarily led me to reflect much on the effects of subsidence, and it was easy to replace in imagination the continued deposition of sediment by the upward growth of coral. To do this was to form my theory of the formation of barrier reefs and atolls.* (Autobiography,p.98,99, quoted in LaPorte,1996).
>
> *When the Beagle visited the Cocos Islands in the Indian Ocean more than a year later, Darwin was able to test his hypothesis of reef formation 'by examining the very interesting, yet simple structure and origin of these islands…These low, insignificant coral-islets stand and are victorious…thus do we see the soft and gelatinous body of a polyp…conquering the great mechanical power of the waves'* (Voyage, p.457, 459).



Darwin's Coral Reef Theory. Darwin believed that corals grow on the sides of a slowly subsiding volcanic island. They continue to grow upwards, at rates fast enough to keep up with the subsidence, and form a coral ring with a central lagoon - an atoll - after the island has subsided below sea level.(based on Hatfield 1948). Corals do not grow well in the enclosed lagoon because of poor nutrient supply.

Further comments on the Cocos Reefs come from Desmond and Moore…

'The reef itself he ranked 'among the wonderful objects of this world'. He spent days up to his waist, making notes on brain corals and the fishes darting in and out…….Under the microscope these living corals posed more of a problem: however hard he looked, he could not see any discrete polyp animals. They seemed to consist of a mass of 'fleshy matter' spread 'over the whole surface'.
Moreover, the stony framework of the coral appeared to grow as it did in the encrusting algae. He was now convinced that the lowest animals and plants practically touched at this primitive level. He had come round to the

position of his Lamarckian teacher Robert Grant ten years earlier; the plant and animal kingdoms had a common starting point' (Desmond & Moore, p.182).

It is interesting to learn that the interest in coral reefs came also from the higher ranks of the naval hierarchy.

> *The sea lords had instructed Fitzroy to use any means 'that ingenuity can devise of discovering at what depth the coral formation begins'. He too was looking for clues to the reef's origin. A mile out he took soundings, but even here the sea floor had dropped away. The line was fed out 7000 feet, and still it did not touch bottom. The reef was clearly built on an oceanic mountain top. The 'circular wall' of coral had risen as the mountain had submerged, leaving only a vivid green lagoon, as Darwin's theory had predicted.* (Desmond & Moore p.183)

Over one hundred years later, Darwin's theory of reef building was empirically confirmed. As noted by the marine geologist James Kennett, Darwin's theory required two basic tenets; that the sinking of volcanic islands was sufficiently widespread to account for the distribution of atolls; and that coral growth can be rapid enough to keep pace with the subsidence (see Kennett 1982). The drilling of coral atolls has shown the assumptions to be well-founded. At Eniwetok a thickness of some 1500 metres of coral limestone was shown to overlie basaltic rock; at Bikini, 800 metres of reef limestones overlie the basalts. Beside the bore on Eniwetok the American geologist Harry S. Ladd erected a sign saying 'Darwin was right!' (see also Herbert 2005).

<u>The Beagle in South America</u>

The *Beagle*'s track took them down the east coast of South America, including to the Falkland Islands, then around Cape Horn – or rather through the Beagle Channel, tracking past Tierra del Fuego – and up the west coast past Chile, thence to the Galapagos and across the Pacific.

It is probably appropriate to report here something of Darwin's fossil collecting in South America. There is little doubt that the entire voyage had given him both a temporal and a spatial dimension in his thinking when he later came to consider the origins, and transmutations, of species.

At first, Darwin was in some trepidation as to whether he would find any good fossils in South America. He was galled that the French collector d'Orbigny had been working in the area for six months, picking up plum specimens for the Paris Museum. But his fears were unfounded…..

> *'On 22nd September 1832 he was scouring the bay at Punta Alta, ten miles from the Beagle. Checking some low cliffs, he spotted the fossilized bones of a colossal extinct mammal. Excitedly, he disinterred teeth and a thigh bone from the quartz and pebble gravel and loaded the pack horses. The Captain was laconic and twitted his companion, smiling at 'the cargoes of apparent rubbish' being carried up the gang plank……*
>
> *Darwin returned the next day and found a huge skull 'embedded in a soft rock'….The best part of the following day was spent 'packing up the prizes'. He knew little of mammal fossils, such Brobdingnagians least of all. His best guess was that they were 'allied to the Rhinoceras'. ……On the 25th he found yet more bones. Many were nothing to look at, huge and shattered, and others on the beach had been rolled by the waves. But they were precious. In all England there was only one giant South American fossil – a ground sloth just acquired by the College of Surgeons.*
>
> *On 8 October he was back, prying out a jawbone. Its one tooth was characteristic, and revealed it to be a megatherium, a huge ground-living relative of the sloth. Nearby were six-inch polygonal plates, and he mentally amalgamated all the finds to come up with an 'ante-diluvial' armour coated cow-sized sloth. He wondered how the bones had arrived there, indeed how the embedding gravels had been formed. Perhaps a flood of 'extreme violence' had swept over the pampas, washing bones and pebbles before it?*
>
> *Lyell might not have approved, but then Henslow had warned him off Lyell's gradualist extremism.'* (Desmond & Moore, pp.128 – 29).

Darwin's collecting was not of course, confined to fossils. Among living fauna, his collections of birds included the South American ostrich, or rhea, which, apart from providing Christmas dinner for the crew, was to feature largely in Darwin's thinking on the transmutation of species. In his notebooks, he recorded the distribution of two living forms, and was to draw on these as he contemplated the geographical shifts in species. The bird collections were a feature of his naturalising along the Patagonian coast.

But more fossil collecting followed, and further south…

> '*When the Beagle dropped anchor at Port St Julian in January 1834 – 110 miles further south – he searched again. It was a wasteland, devoid of fresh water, and the only large mammal – the guanaco – could drink from the salt lakes. Again, in the cliffs on the harbour's edge he found bits of spine and a complete hind leg of 'some large animal, I fancy a Mastodon'.* (Desmond & Moore, p.145).

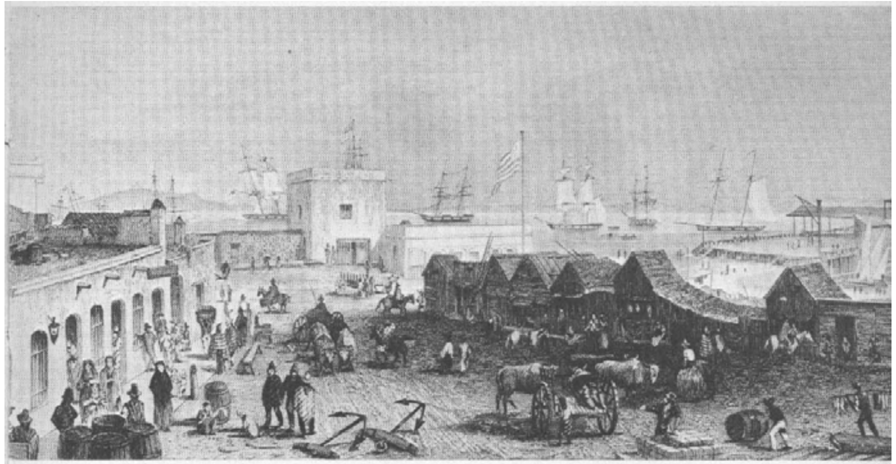
The bones he collected at St Julian, which at the time he said he had no idea to what animal they belonged, were later identified by Richard Owen as belonging

to species of gigantic llama…Darwin referred later to these as the extinct Guanaco. This occurrence he used to reinforce his notion of descent – exploring the relationship between these and the living species.
Lyell, in his address to the Geological Society of London in 1837, a mere three years after the collection of the fossils, developed the notion of succession, in relation to the vertebrates collected by Darwin and identified by Owen. Thus Owen reported….

> '*These fossils…establish the fact that the peculiar type of organization which is characteristic of the South American mammalia has been developed on that continent for a long period, sufficient at least to allow the extinction of many large species of quadrupeds…'*

(There have been controversies concerning Owen's identification, but they are irrelevant here.)

Another point that arises from the geological address is the idea of extinction as one of the forces shaping life. According to Sandra Herbert, it was in one of his notebooks that Darwin wrote ' *The more I think, the more convinced I am, that extinction plays a greater part than transmutation'* . This was the geologist speaking, and the concept is one that palaeontologists and biologists would be comfortable with today.
But to return to the narrative of the voyage…the Beagle headed north again, back to Montevideo. There, a treat awaited Darwin. In the post was a copy of the second volume of Charles Lyell's *Principles of Geology.* But this book was very different from the first, where Lyell had speculated about past landscapes, and the evidence for their slow and gradual change. In the second, he tackled the question of whether animals and plants had become modified to match their physical surroundings – was there some way in which they could be slowly transformed to match changes about them? Lyell could see no such mechanism – in his view, each species was adapted to its place of origin – its birth spot, or 'centre of creation', reflecting an idea developed earlier by Carl Linnaeus. Changes in the surrounds would exterminate, not transform the species. Darwin could appreciate this, having excavated the remains of the giant sloth, *Megatherium.*



Mole and customs house at Montevideo. Drawing by Augustus Earle.

Montevideo. Etching by Augustus Earle.

Lyell wrote persuasively…

> '*It was a sprightly, brilliantly written book, a lawyer's book, piled with clever arguments against the idea that life had evolved and could be represented as a family tree. Can all animals trace their ancestry back to a single stem? Lyell answered no, appalled at the thought of a chimpanzee in the family, of an ape aspiring to the 'attributes and dignity of man'. He went further, arguing that the history of life on earth had been completely misunderstood. The sequence of fossils from ancient times showed no overall progress towards humanity….but Lyell had at least posed the question of how species die and are reborn.* (Desmond and Moore, p.131)

Thence the *Beagle* voyaged to the Galapagos, whose volcanic cones reminded Darwin of an industrial wasteland, or '*the iron furnaces near Wolverhampton'*.

Further geologising followed on the *Beagle* voyage. In the Falkland Islands Darwin identified a sandstone bearing brachiopods or lamp shells, that reminded him of the older sequences in Wales; this was an opportunity to compare ancient faunas from widely separate parts of the globe. He travelled inland by horseback in Chile, to the volcanic sequences of the Andes; he experienced the devastation of the earthquake that destroyed Concepcion, noting that it was but a few feet of upward thrust that had caused such damage.

Concepcion : post-earthquake ruins.
www.britannica.com/EBcheckedftopic-art/151902.

After the *Beagle*

In London, after the end of the five-year expedition, Darwin wrestled with all the implications of what he had seen and recorded in such detail. He threw himself into a number of projects. Writing up the Journal of the voyage was completed in two years. His first paper dealt with the uplift of Chile, indeed of the whole South American coast, and reflected Lyell's views of uplift being balanced by a sinking Pacific. His paper was read to the Geological Society of London on January 4th, 1837. In 1838 he began work on his volume on the genesis of coral reefs, which was published in 1842. The volume on volcanic islands appeared in 1844; that on *Geological Observations in South America* in 1846. (For an evaluation of Darwin's volume on South American geology see the critical introduction by John W.Judd; www.darwin-literature.com).

He was elected to the Council of the Geological Society, and, somewhat reluctantly, served as its Secretary for three years from 1838 - some say this was the only 'proper job' that Darwin ever had! The attempts to recruit Darwin into the inner circle of what was a somewhat elite and influential scientific society reflect a recognition of his value as a collector and observer. But it was Darwin's view of the world, from an essentially geological perspective, that clearly influenced his thinking, and that of his contemporaries, on the nature of change in the biological world. This is evident from Charles Lyell's presidential address to the Society in 1837, when he used Darwin's fossil faunas to point out their relationship to their living counterparts.

But for Darwin himself, it was the geological mode of thinking that provided him with the wider context within which to consider the transmutation of species. He could visualise the formation of new species in space – the geographical aspect, and he had become accustomed to thinking temporally – seeing changes, descent, through time. As Sandra Herbert has noted;

> '*The two processes were tied together by the notion of succession; as one species succeeded another across space, so one species succeeded another in time. When Darwin discussed this idea in his Red Notebook, he had particular species in mind: on the geographical side most especially, the two South American rheas; on the temporal side, the fossil bones he believed – following Owen's advice – to be an extinct guanaco…….The examples that he chose have their own complexities, but the key point to emphasize is the comparison he drew between change over time and change over space.'* Herbert, p.320.

Within this framework of thought, he was also forced to confront the nature of time – specifically the length of time through which these processes of change might occur. The issue of the availability of time – how much was there for changes in life forms to have occurred - was but one aspect of the geological record that clearly troubled Darwin as he developed his theory of Natural Selection. This is clear from *The Origin of Species*, where he devoted two chapters to the imperfections of the geological record. It is unfortunate that it is the doubts expressed by Darwin regarding the record of the rocks - as described below - that have been seized on by proponents of intelligent design and creationism!

In Chapter 10 of the 'Origin', Darwin headed one section 'On the lapse of time'. In this part of the text he wished to argue against he view that '*time cannot have sufficed for so great an amount of organic change, all changes having been effected slowly.'*

Sandra Herbert calls this a 'defensive manoeuvre' on Darwin's part.
To substantiate his argument – that there is a sufficiency of time for evolutionary processes to have been active – Darwin turned again to Lyell. And the methodology he invoked was that of the rates of denudation of strata. Lyell supplied the description of the key geological site that Darwin used to come up

with a figure. This was the Weald in southern England, an area bounded by the chalk of the North and South Downs.

In his '*Principles of Geology*' Lyell described five formations in the area, all laid down, he thought, at the bottom of the sea. These were later forced up into a dome, whose crown was cut off by erosion, so that the presently visible beds were the result of denudation of the crown. All of these processes would have required vast amounts of time; Lyell, however, did not have a figure for this. But Darwin did supply a calculation, which he said would have been roughly 300 million years. He arrived at this using a hypothetical rate for the sea to denude a 500 foot cliff at the rate of one inch each century. Then he calculated how much time it would take for the sea to erode formations 1100 feet thick and extending for some 22 miles.

Darwin drew too on the work of Andrew Ramsay, from the British Geological Survey, who had an encyclopaedic knowledge of the formations of British geology, including their thickness. Essentially, Darwin's approach continued to be one wherein he converted thicknesses of strata into passages of time. Not unnaturally, his approach drew criticisms. In particular, he was accused of neglecting the fact that strata of differing hardness would erode at different rates, and would be affected by a variety of processes. In the rapidly published second edition of the *Origin*, Darwin gave new figures for the rate of denudation of the Weald, and reduced the time for deposition significantly; in the third and following editions, he dropped the estimates entirely. Darwin warned Lyell of the critics – Lyell was preparing to assign ages to the passage of time of the glacial ages; Darwin wrote to him in 1860;

> *' Having burnt my fingers so consumedly with the Wealden, I am fearful for you…take care of your fingers, to burn them as severely as I have done, is most unpleasant'* (quoted in Sandra Herbert, p. 352).

In his notebooks and publications, Darwin sidestepped the issue of the age of the earth completely. But, it is important to note that, given the degree of attention that the *Origin* attracted – its 'book of the moment' status, Darwin's estimates for the length of time encompassed by the Wealden strata did serve to focus attention on the duration of past time. And it pressed a number of eminent scientists towards its quantification. For some 40 years after the publication of the *Origin,* the issue rested with stratigraphers and physical scientists. With the discovery of radioactivity at the beginning of the 20th century, the quest to quantify the age of the earth took new directions, and scientists such as Lord Kelvin entered the lists. But it is noteworthy that accelerated interest in the issue of time was provoked by publication of the *Origin of Species.*

Of interest to current thinking is that the need for a 'long lapse of time' may in many cases be redundant, and evolutionary change has been measured and seen to occur over very short time intervals. Among Galapagos finches it may occur in spans as short as decades (see the work of Peter R. Grant). Evolutionary change among colonising cohorts of cane toads in Australia may be another example where change is discernible over very short intervals, with success in invading new territory being linked to increases in toad leg length, through the more 'athletic' toads breeding with each other (see www.canetoadsinoz.com.) But for Darwin, '*Evolution occurring in nature on so short a timescale as to be susceptible to human measurement…'* lay outside even his imagination (Sandra Herbert, p. 347).

Other aspects of the rock record continued to trouble Darwin. Of the fossil record itself he asked '*Why then is not every geological formation and every stratum full of intermediate links? Geology assuredly does not reveal any such finely graduated organic chain; this, perhaps is the most obvious and serious objection which can be urged against the theory….The explanation lies, I believe, in the extreme imperfection of the fossil record.'* (Origin of Species, Ch.10).

The absence of intermediate forms he essentially explained away by recourse to geological processes – which included processes acting in both time and space. Erratic periods of subsidence during the accumulation of fossil remains would have been a factor. To have a perfect gradation between forms in the upper and lower parts of a formation would have required continuous deposition, sufficient, he said, to observe the slow processes of modification, but sedimentary accumulation has always been intermittent.

Another problem lies, he claimed, quite rightly, in the conventions of palaeontogical classification, wherein what might have been intermediate forms are classed by taxonomists as distinct species. Darwin could find no explanation either for the sudden appearance of groups of species. The 'Cambrian explosion' was one such event (although he didn't call it that). But he noted the need for progenitors of the main animal groups to be identified. Perhaps, he suggested, the preceding world was subjected to more rapid and violent conditions which may have induced more rapid changes in organisms. Such conditions may also have obliterated their remains.

Also, he persistently noted, we know only a small part of the world with accuracy – our palaeontological collections are meagre.

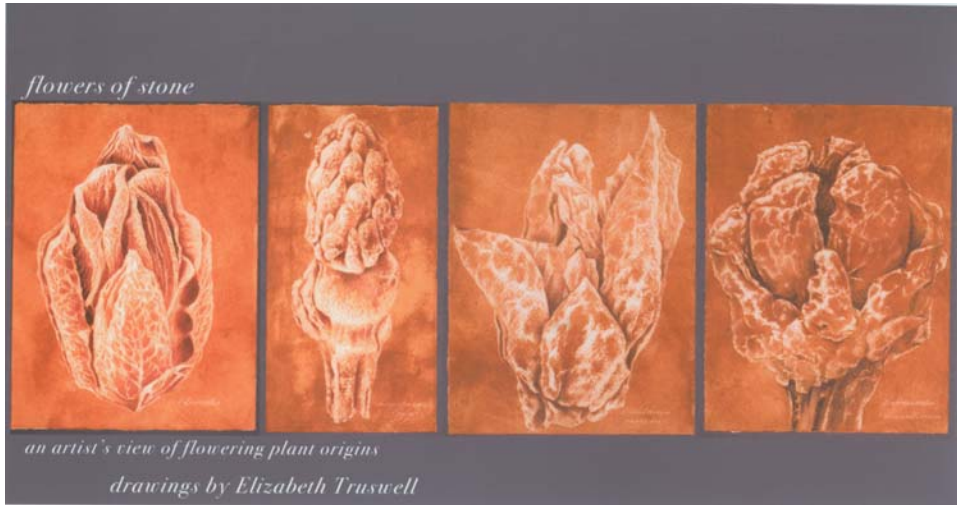
We now know so much more about the fossil record compared to Darwin. We have an understanding of the life forms of the Precambrian – both in the form of body fossils and chemical fingerprints that reinforce knowledge from morphologies alone.

Moreover, there are instances of transitional forms preserved as fossils. Such examples are drawn both from within and between formations. In deposits known to be of more-or-less continuous deposition, there are clear examples of variations within species. In the Cretaceous chalk of southern England and France, deposited within only a few breaks over a 15 million year interval, irregular sea-urchins (echinoids) show variation that is probably linked to local habitats. As long ago as the late nineteenth century studies of the echinoid genus *Micraster* had shown gradual changes in the form of the test between successive populations at different levels within the chalk. A modal shift in the occurrence of characters appears to have occurred through a continuous series of intermediates (for a summary see Nichols (1959)). It is within such deep sea depositional sites, which typically have more frequent interruptions in deposition than shallow water environments, that such variation (? speciation) can be observed; the graptolites of the Early Palaeozoic provide another such example.

Eon	Era	Period	Epoch	Age*
PHANEROZOIC	CAINOZOIC	Quaternary	Recent	0.01
			Pleistocene	1.8
		Tertiary	Pliocene	5.3
			Miocene	23.5
			Oligocene	36.7
			Eocene	58.0
			Paleocene	66.4
	MESOZOIC	Cretaceous		144
		Jurassic		213
		Triassic		248
	PALAEOZOIC	Permian		286
		Carboniferous		354
		Devonian		408
		Silurian		434
		Ordovician		505
		Cambrian		590

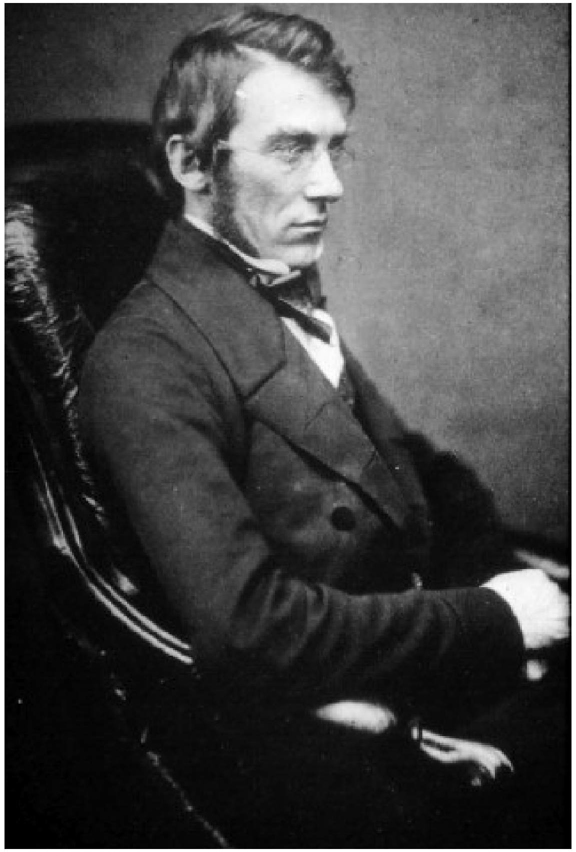
Geological timescale. The columns on the left show the major Eras, with, to their right, the well-known Periods, followed by Stages, and ages in millions of years (*), according to currently accepted calibrations. (Based on *An Australian Phanerozoic Timescale,* 1996; Australian Geological Survey Organisation; Oxford University Press).

Another frequently quoted example of what might be viewed almost as Darwin's frustration with the fossil record, relates to the origin of the angiosperms – the flowering plants that dominate much of today's vegetation. The rapid rise of this group to ecological dominance during the Cretaceous period has long been regarded as a puzzle. Darwin's comment concerning this observed phenomenon is much quoted; *'The rapid development as far as we can judge of all the higher plants within recent geological times is an abominable mystery''* - this in a letter o J.D.Hooker dated 22nd July 1879. The fossil record over the last 50 years has provided a much clearer picture of the diversification of this major group, particularly through the recovery and examination of (often minute) fossil flowers. The picture, however, is still one of an unparalleled burst of diversification during the Cretaceous. Phylogenetic studies may suggest an older origin for the group,as yet unsubstantiated by the fossil record. But the issue of angiosperm origins still remains, and molecular analyses of living plants do not reflect the full diversity of the group in the past (see Friis et al 2008).



Exhibition: *The Stone Flowers.*
CSIRO Discovery Centre, Canberra, November 2007

One further area where Darwin turned to geology for an explanation of observed features of natural history was that of the past and present distribution of species. He much favoured Lyell's uniformitarian approach, visualising processes occurring now as having had primacy in the past. But perhaps he was even more of a stabilist than Lyell, in that he saw continents as being essentially governed by very long-term motions – these he would have seen only as vertical movements. He had little patience with those who claimed otherwise in trying to understand the distribution of species – his good-natured disputes with the botanist Joseph Hooker on these issues have been well documented. The concept of land-bridges, or of an Atlantis continent that rose and fell through time brought forth some scornful rejoinders.



Joseph Hooker in the 1850s. National Portrait Gallery, London**.**

Again, from the Desmond and Moore biography (p.441) we find…

> *' He also became het up again about supercontinents as more naturalists jumped on the bandwagon. Wollaston was connecting Madiera to the mainland, others were conjuring up a lost Pacific land, and the old Atlantis was still below the waves. Darwin 'fairly exploded' on the subject: "my blood gets hot with passion & runs cold alternately."*

It was so absurd. Add up all the lost continents and 'half the present ocean was land within the period of living organisms'. And did the extensions help? Why the absence of Australian Banksia plants in New Zealand if they were formally connected? And couldn't ice-sheets pushing animals and plants down from the Arctic explain the common American and European forms? And why were old continental strata never found on mid-oceanic islands?'

His irritation with what he saw as the unsupported views of others was expressed at a time (1856) when he saw himself as under pressure to produce the *Origin*. (It may also be related to the fact that Emma, his wife, was expecting their 10th child!).

Darwin's view, that it was not legitimate to move continents around willy-nilly, nor to propose land bridges between them in a random fashion, lead to his experiments with other means of dispersal. He noted the presence of hatchling snails on a dead duck's foot; he tried to float seeds in salt water, with what he called 'disastrous results'. Seed-eating birds offered him better possibilities, and he began to collect bird droppings; but still germination results were poor …'*All nature is perverse, and will not do as I wish it'…* (see p.444 in Desmond and Moore).

Joseph Hooker's interests, and his problems in seeking an explanation, arose from his survey of the vegetation of sites in high southern latitudes. He had travelled as naturalist on James Clark Ross' voyage (1839 -1843) to Antarctica and the sub-Antarctic islands, and was much struck by the similarities between plant taxa in Tasmania, New Zealand, southern South America and islands of the sub-Antarctic, such as Kerguelen.

The views of Darwin and Hooker on dispersal methods are often seen as divergent, so it is of interest to note that they were not so far apart in explaining these distributions. Darwin seems to have been in agreement with Hooker on the idea that a common source region might be invoked to explain these high latitude floras. In Chapter 12 of the *Origin of Species*, he wrote;

'*The facts seem to indicate that distinct species belonging to the same genera have migrated in radiating lines from a common centre; and I am inclined to look in the southern, as in the northern hemisphere, to a former and warmer period, before the commencement of the Glacial period,when the Antarctic lands now covered by ice, supported a highly peculiar and isolated flora'*.

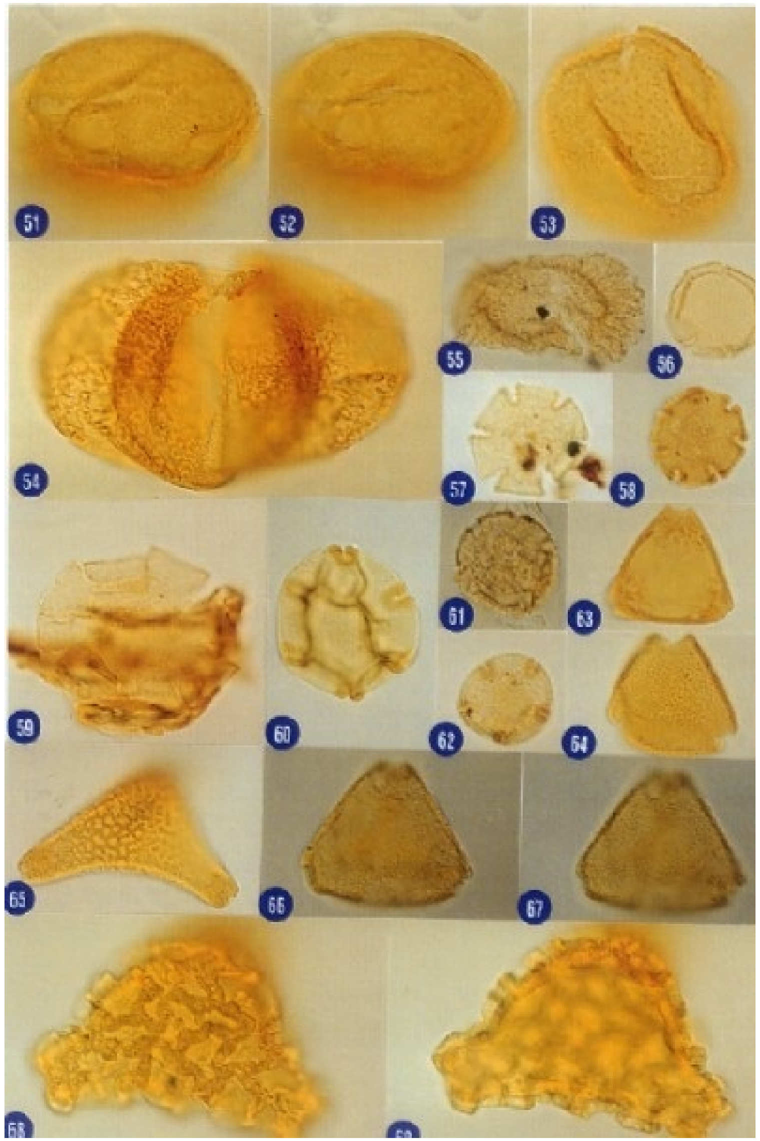
These words were written before the advent of plate tectonics, which provides an understanding of lateral, as well as vertical movements of continents.

They were written before there was any real understanding of the chronology of glaciations in both southern and northern hemispheres, and, significantly, before the discovery of fossil plants in Antarctica. Now, the former presence of a forest cover on Antarctica is well known from the record of both plant macrofossils and pollen.

The documented evidence now shows that this near-polar flora was neither peculiar nor isolated, originating, as it did, from formerly widespread Gondwanan floras. The record shows that, during the Tertiary, with the breakup of Gondwana, and shortly before the formation of the present icecap, the Antarctic flora bore considerable resemblance to the modern cool temperate rainforests of Tasmania, New Zealand and southern South America.

These were dominated by a canopy formed by the Southern Beech, *Nothofagus*, and the southern conifers, the Podocarpaceae, with Proteaceae and other families prominent in the understory (see Figure below depicting Antarctic fossil pollen).

Antarctica is now viewed both as a source and as a migration route for elements of these now widely separated southern floras (see summary papers such as Truswell (1990) and Hill and Scriven (1995)).



Fossil pollen: Eocene of Prydz Bay, Antarctica.
Nos.51 – 53 represent pollen of Araucariaceae; 54 – 55 that of the southern conifers Podocarpaceae; 56 – 62 that of the Southern Beech, *Nothofagus*, and 63 – 69 pollen of Proteaceae.

While, as Sandra Herbert has noted – it would require some historical imagination for a modern reader to enter into Darwin's understanding – one cannot help but imagine with what eagerness , both as geologist and biologist, he would have embraced these modern ideas. A large scale theory such as plate tectonics, which unifies so much observational geology, would have appealed to his need for a synthesising view; and contemporary reconstructions of past vegetation based on the accumulation of a huge amount of fossil data, would have been confirmed – indeed reinforced for him - the value of this traditional discipline.

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