Published by Princeton University Press, 41 William Street, Princeton, New Jersey 08540

In the United Kingdom:
Princeton University Press, Guildford, Surrey

Library of Congress Cataloging in Publication Data will be found on the last printed page of this book

ISBN 0-691-08356-8

Clothbound editions of Princeton University Press books are printed on acid-free paper, and binding materials are chosen for strength and durability. Paperbacks, although satisfactory for personal collections, are not usually suitable for library rebinding

Designed by Publication Graphics Ltd., Wellington, New Zealand
Typeset by Quickset Platemakers Ltd., Christchurch, New Zealand
Printed in the United States of America by Princeton University Press, Princeton, New Jersey

To

Dov Ospovat, *in memoriam*

and

Sydney Smith, mentor of us all

1

GOING THE LIMIT: TOWARD THE CONSTRUCTION OF DARWIN'S THEORY (1832–1839)

Howard E. Gruber

As a cognitive psychologist, my forays into the history of science have as their ultimate aim to contribute something to the psychology of thinking and the psychology of creativity. I hoped to learn from historical studies, and enrich my own rather crabbed, often Philistine field. In the course of this effort, my students and I found ourselves developing what we now call, quite provisionally, an "evolving systems approach to creative work" (Gruber 1980a, b).

In this view, creative work is seen as a purposeful growth process. Much work on the psychology of creativity reveals a certain tropism toward monolithicity. In such diverse ideas as: one great insight, one ruling passion, one overarching metaphor — there is a common term, *one*. In contrast, our work has persistently revealed a striking pluralism of events and processes. For Darwin there were many insights, each with a complex inner structure; rather than representing a break with his own past, they reflect the ongoing function of the evolving system of thought (Gruber 1981a). Similarly, there are many influences, several candidates for his "father figure", many metaphors (Gruber 1978), and many enterprises.

In addition to this emphasis on growth and pluralism, we stress the idea of creativity as *purposeful* work. Since it always seems to take a long time, the creative individual must go to some lengths to organize the conditions of life that make possible such continued work. If it were easier, faster, and more straightforward than experience shows to be the case, spontaneity might be enough. But if it were so easy, fast and straightforward, many would accomplish the same thing, and we would not deem it so creative. In the real world, then, purpose is indispensable for creativity.

The person doing creative work exhibits the continuous interplay of three loosely coupled sub-systems: the organizations of knowledge, of purpose, and of feeling. This interplay is displayed with particular clarity when the thinker undertakes to push ideas to their extremes, to abandon cautious middle-of-the-road strategies and instead to test the limits of his innovations. Sailing to the edge of one's intellectual world does not happen by accident: it requires deep knowledge and a sense of direction. It is, moreover, so taxing an effort that it requires intellectual courage and, if not the ability to enjoy life at the edge, at least the resolve to endure it.

The current status of Darwin studies provides an object lesson in the density and complexity of a creative thought process. Instead of being apologetic that we, the collectivity of Darwin scholars, have written so much, we ought to brace ourselves for the probable future. The history and philosophy of science, cognitive science and developmental psychology have reached a promising confluence. The idea that the work of hermeneutic interpretation is a legitimate part of our enterprise has at least taken hold, and description is becoming thicker and thicker. We are, I think, growing more skilled in relating the internal history of science to wider issues in personal psychology and social history. Out of all this will emerge a new generation of Darwin studies, and during its gestation we should all be very patient. Newell and Simon, in their book *Human Problem Solving*, analyze the thinking of one subject solving one problem, thinking aloud while he did it. The subject took twenty minutes. The analysis covers 100 pages (Newell and Simon 1972).

The study of Darwin's thinking is many orders of magnitude more complex. He was solving not one problem but many. The problems were not chosen for him but by him as part of a broader effort to construct a new point of view. He faced a double task. On the one hand, he had to make the best possible use of a wide array of professionally accepted, normalized scientific knowledge. On the other hand, he had to organize his efforts so as to raise and answer questions hardly dreamt of within that conventional framework. To understand Darwin's thinking, we must study the connections between these quite different aspects of his work — his intellectual navigation in well-charted scientific waters and his explorations of the farthest horizons.

I. Networks of Enterprise

If we are to deal with the complexities of a creative life we absolutely must develop some methodical ways of surveying it as a whole. As we go deeper and deeper into detail, we need to avoid losing our sense of direction. One orienting device that I have proposed is the *network of enterprise* (Gruber 1977). This is a diagrammatic way of examining the creative person's organization of purpose by depicting all of the activities of the person as they are connected in time. It permits us to see both the continuity within and the diversity among simultaneous ongoing activities. I use the term

enterprise to suggest something larger than a problem or project; it has no necessary termination, and the stock of projects within it are usually renewed in order to keep it functional. Of course, at any given time some enterprises are dormant or less active than others.

As it happens, quite independently of my work, Sandra Herbert in her edition of Darwin's *Red Notebook* has published some excellent diagrams that capture the same idea in a simple and illuminating way (Herbert 1980, pp. 14–17). Although a number of colleagues (and I, too) have drawn up networks of enterprise for Darwin, I believe the best reasonably complex diagram currently available was drawn by Martin Rudwick (Rudwick 1982b). This was constructed in such a way as to show that Darwin's network was not only a set of activities, but an agenda. More specifically, it was a plan for the sequence in which his different enterprises would rise from the privacy of Darwin's mind to the level of public disclosure.[1] Needless to say, a network of enterprise has other dynamic properties. For example, one enterprise can steer another, distract attention from another, provide thought-forms and metaphors useful in other contexts.

More broadly still, the network of enterprise represents the organization of purpose for the creative person. As such, since he or she is more or less aware of its structure, it is a fundamental part of the self-concept.

In Darwin's case, as the present essay and for that matter this entire volume show, it is indispensable to see each part of his activity in relation to the others. Ideas or actions which seem ambiguous in a narrow context are clarified as the frame is widened. The point is not so much that we the interpreters clarify Darwin's meaning, but rather that we come to understand how Darwin, over time, disambiguated himself.

II. The Shape and Function of Controversy

As the fund of solid scholarship mounts, disagreements emerge. If the reconstruction of thought processes were an art form, these differences could simply be allowed to stand. As things are, there is an increasing convergence and even collaboration among relevant disciplines concerned with the growth of scientific knowledge: social history, history of science, philosophy of science, cognitive psychology, and the sociology of knowledge. There is even some hope that this confluence is producing a science of science, in which issues can be settled, questions really answered, and knowledge accumulated. So a productive strategy for dealing with differences should be sought.

At present there seem to be two main strategies at work. I want to describe them and propose a third. For want of better terms I will call them *the cave*, *the shadow box*, and *the solution tree*.[2]

The cave strategy is simply the pessimistic subjectivism inherent in believing that we are all looking at mere shadows of the world, and all from the same station point. We can never decide what is really there: if differences arise they can never be resolved. Since we all see the same shadows, any differences must have a subjective origin. The best solution is to accept our fate.

The shadow box strategy. In Plato's cave there is only one source of illumination and only one wall on which shadows are projected. Imagine, instead, a box with an unknown object in it, with two sources and two screens, and hence two station points. Now if two observers begin by disagreeing about what is in the box, they may discover that they are looking at two different shadows of the same thing. They may be able to settle their differences by synthesizing their two perspectives.

In the cave strategy:
"triangle" versus "circle" → disagreement
In the shadow box strategy:
"triangle" x "circle" → "cone!"

I have done this experiment in the laboratory. People can solve quite complex problems fairly soon. But first they must get over the egocentric tendency to discount the other person's report; they must build up trust and a shared descriptive language. For all its merits and its resemblance to some moments in scientific work, the shadow box strategy, or the strategy of multiple perspectives, has two limitations. First, there are really innumerable perspectives and no finite number will tell all. For example, convexities appear nicely in shadows, but to detect concavities other exploratory devices must be introduced. Second, the strategy assumes that there is one unchanging reality, and that a more powerful synthesis will eventually reveal it.

But suppose this is not the case. Suppose, for example, that there is not one Darwin and one sequence of ideas he entertained, waiting to be discovered . . . but many! This thought leads to the third strategy — and beyond.

The solution tree. Investigators of problem solving have for some time been interested in an approach which entails mapping out all of the possible solutions to a problem, separately from observations of actual solutions produced by experimental subjects. Armed with such a set of possible pathways one can then more easily identify the one actually chosen. This approach, like the other two, assumes that there is, for a given thinker, only one pathway. Moreover, it requires that the investigator know more than the experimental subject. This is not a good model for us, for a reason that we all tacitly accept — we may not be able to think about the problem in hand *as well* as Darwin, much less generate all possible solutions. The solution tree strategy may be appropriate for understanding an experimental

subject solving a relatively simple, closed problem — where all the rules and conditions are set by the experimenter. But it seems inapplicable for understanding creative scientific thinking, where the limits of the problem and the rules of the game are all constantly changing.

And yet there is a gleam of light in the solution tree approach. It is plausible that a man like Darwin explored many pathways, found partial solutions to numerous problems, and often found several solutions to the same problem. Each successful move would increase his confidence in the general approach that was guiding him. Each *un*successful move, remembered, would increase his knowledge of the intellectual terrain over which he was moving — and by the same token, increase his confidence in his developing point of view.

As lived by Darwin then, there is not a simple pathway to be charted, but a set of them. If we want to know the moves Darwin actually made, knowledge of the set of moves potentially open to him may be enormously helpful.[3]

But how can we get such knowledge? Must we surpass Darwin? I think not. This is where our pooled knowledge and effort are useful. Instead of each rejecting the other's contributions and vaunting our own as better, we can look at each attempt as one of the many moves necessary to fill out the solution tree. Any description of Darwin by a reasonably competent person is a candidate for inclusion in the solution tree. Moreover, descriptions of *anyone* else working in the same domain (Lamarck, Erasmus Darwin, Lyell, Owen, Hooker, etc.) are also plausible candidates. So we can and do generate a greatly expanded solution tree, far exceeding our individual capacities. All we need is respect for each other and the patience to organize our combined efforts in such a fashion.

But our use of the solution tree need not be restricted to finding the *one* pathway Darwin followed. The approach I am proposing is inherently phenomenological. We want to reconstruct Darwin's thinking as *he* experienced it.[4] He had the time, the energy, and the absence of smugness that allowed him to explore widely in the set of possible solutions. He had also the technique of note making, developed in a powerful way, to help him re-explore, retrace the pathway taken.[5] For him, vagrant thoughts were less ephemeral than for most, because he was committed to writing them down. Finally, he believed that "the subjective probability" of an hypothesis increases as the number of partial proofs, following different lines, rises.

III. The Voyage Begins

When Darwin set out in the *Beagle*, it took him a while to get his sea legs and longer still to find his feet as a professional naturalist moving towards the life in science we know him for. Even then he remained vulnerable to *mal de mer* and to a certain *mal d'esprit* reflected in remarks such as

> This multiplication of little means & bringing the mind to grapple with great effect produced is a most laborious & painful effort of the mind . . . (C75)

During the voyage, alongside his scientific notes he kept a diary of all sorts of narratives and personal feelings (but nothing too intimate to publish in the *Journal* he may have already been contemplating). There were in the *Diary* many observations pertinent to what would eventually play a major role in his evolutionary theories, and become a distinct enterprise in its own right — his reflections on *homo sapiens*. A few early entries in this *Diary* reveal his state of mind, his plans, and some of his basic orientation at the time (Darwin 1934).

On 13 December 1831, two weeks before the *Beagle* weighed anchor, he wrote a brief sketch of plans for work during the voyage.

> I am often afraid I shall be quite overwhelmed with the number of subjects which I ought to take into hand. It is difficult to mark out any plan & without method on shipboard I am sure little will be done. The principal objects are 1st, collecting, observing & reading in all branches of Natural history that I possibly can manage. Observations in Meteorology, French & Spanish, Mathematics, & a little Classics, perhaps not more than Greek Testament on Sundays. I hope generally to have some one English book in hand for my amusement, exclusive of the above mentioned branches. If I have not energy enough to make myself steadily industrious during the voyage, how great & uncommon an opportunity of improving myself shall I throw away. May this never for one moment escape my mind & then perhaps I may have the same opportunity of drilling my mind that I threw away whilst at Cambridge. (*Diary*, p. 14)

Thomas Huxley, writing his resolutions at a similar stage — the beginning of the voyage of the *Rattlesnake* — was far more specific and more professionally crisp (Huxley 1935, pp. 16–17). Perhaps Darwin's initial looseness and openness was a great asset, when coupled with certain other attributes.

On 11 January 1832, sailing from Tenerife to Cape Verde Islands, he has been working hard with his marine catches.

> *January 11th*. I am quite tired having worked all day at the produce of my net. The number of animals that the net collects is very great & fully explains the manner so many animals of a large size live so far from land. Many of these creatures, so low in the scale of nature, are most exquisite in their forms & rich colours. It creates a feeling of wonder that so much beauty should be apparently created for such little purpose. (*Diary*, p. 23)

Presumably, his nets caught mostly small organisms, so he realizes there is a good food supply for larger ones. Here, then, is Darwin thinking about the food chain, very early. Note also the ease with which he steps back from his own assumption of functional order to enjoy "a feeling of wonder" at the apparent lack of purpose in the beauty of the natural world. On 28 February 1832 he records his early reactions to tropical scenery:

> But these beauties are as nothing compared to the Vegetation; I believe from what I have seen Humboldt's glorious descriptions are & will for ever be unparalleled: but even he with his dark blue skies & the rare union of poetry with science which he so strongly displays when writing on tropical scenery, with all this falls far short of the truth. The delight one experiences in such times bewilders the mind; if the eye attempts to follow the flight of a gaudy butter-fly, it is arrested by some strange tree or fruit; if watching an insect one forgets it in the stranger flower it is crawling over; if turning to admire the splendour of the scenery, the individual character of the foreground fixes the attention. The mind is a chaos of delight, out of which a world of future & more quiet pleasure will arise. I am at present fit only to read Humboldt; he like another sun illumines everything I behold. (*Diary*, p.39)

Darwin sees himself going beyond "the chaos of delight". His cathexis with nature is deepening. He shows his strong sense of connection with Humboldt, whose writings had enthralled him during his student days. But even Humboldt "falls far short of the truth". Again we see Darwin's ability to stand away from the things he admires, and to go beyond the moment. I believe this passage records the moment when Darwin began to construct his metaphor of the "entangled bank", which became the organizing principle of the celebrated closing passage of *The Origin of Species*.

On 18 December 1832 he recorded his first reactions to a primitive group, the Indians of Tierra del Fuego: "I would not have believed how entire the difference between savage and civilized man is. It is greater than between a wild and domesticated animal, in as much as in man there is great power of improvement" (*Diary*, p. 119). In this and other passages Darwin conveyed his vivid sense of the strangeness of these "inconceivably wild" people. These entries also reveal his commitment to the ideal of progress and show him aware of the vast transformations possible within a species.

IV. 1832–1834: Darwin Assimilates Lyell's Principles

Throughout the voyage, Darwin's major activity, by a long margin, was in the field of geology. During the first two years, the main manifest event in Darwin's development was his reading of Lyell's *Principles of Geology* (1830–1833), moving toward the increasingly explicit decision to reject the catastrophist geology he had learned from his teacher Adam Sedgwick, in favor of Lyell's uniformitarianism. Each theory had something to say about physical geology and something to say about the relations among geology, paleontology, and biogeography.

As Hodge has recently emphasized, the theoretical situation in geology then called for systematic search for fossils, with or without benefit of Lyell's *Principles* (Hodge 1982). And we see that Darwin sprang into action on this front early in the voyage. He went out looking for fossils and he made exciting finds. Although there is a clear distinction between the two positions, it is not hard and fast. There are slow processes in Sedgwick's and fast ones, even floods, in Lyell's. There are extinctions in both, and both rely on some mysterious "creation" to replace the lost species.

In the field of physical geology, the matter is clear. Darwin became a uniformitarian, we may even say Lyell's disciple. It took him perhaps two years to accomplish this transition (Gruber and Gruber 1962).

Paleontology played an important role in Lyell's physical geology. From fossil evidence one could reason about the probable course of geological events. Finding beds of seashells on mountain tops suggested the former residence of the sea: either the mountains have been upraised or the sea level has subsided. Further reasoning and evidence of the same kind could decide the matter. An exciting array of issues could be dealt with in this manner.

Matters are much harder to interpret when we see Darwin using the same range of evidence to settle the biological questions of the extinction of some species and the appearance of others. Modern scholars can take the same remark to show that Darwin was coming "to face directly general difficulties in Lyell's account of extinction" (Hodge 1982, p. 35), or "a convinced Lyellian, which means he was committed to (1) the immutability of species; (2) local extinction and local creation as opposed to catastrophism; (3) extinction proceeding gradually by the successive deaths of individuals; (4) the concept of local species distribution" (Kohn 1980, p. 71).

This passage and its alternative interpretations are worth examining. It is a part of his Geological Notes, a few pages written in February 1835 and later removed to be filed with notes on South American geology. In the nearly 1400 pages of geological notes Darwin made during the voyage, this passage may be his first (and almost only) extended discussion of issues mentioned above. Although its interpretation has occasioned some disagreement, a few major points can be summarized.

1. Darwin rejects the idea of a single "diluvial débâcle" as the cause of extinction. He is also skeptical about a series of such events as the likely cause.
2. He is dubious about changes in climate as the cause of extinction.

3. He is interested in the compensatory relationship of regions of elevation and regions of subsidence.
4. He accepts Lyell's metaphor, likening the death of species to the death of individuals, both as natural processes.
5. He extends the metaphor to include both the "gradual birth and death of species". While the phrase, "gradual birth" occurs only once, and almost in passing, it is hard to ignore: Darwin is not only a future evolutionist, he has a past, through contact with the ideas of his grandfather, of Grant, and of Lamarck.
6. After this one *lapsus linguae* he reverts to the more Lyellian formulation, "successive births must repeople the globe". This phrase happens also to echo one of his grandfather's poems (Erasmus Darwin 1803, Canto IV).
7. He probably believes that in the order of nature which "the Author of Nature has now established" the number of species remains approximately constant.

In spite of numerous ambiguities, it seems to me that we can sum up Darwin's most general ideas about extinction at this time as lying within a certain range on a number of issues.

Extinction. Definitely occurs. Sudden débâcles rejected as cause. Possible mechanisms: species senescence, disadaptation due to environmental change.

Approximate constancy in number of species. Accepted as an explicit but unexamined premise.

Replacement of old species by new ones. Follows from the above. Possible mechanisms: "successive births" or "gradual births". Both are vague terms, and it must be noted that the apposition of "gradual" considerably modifies the metaphor of "birth".

In the theories then current, species death could be Sedgwick-sudden, or Lyell-gradual disadaptation, or Brocchian senescent.[6] Do we have Darwin becoming an evolutionist as early as February 1835?

On balance, I think not. All the other evidence points the other way. Kohn would probably accept the interpretation Hodge has now given the passage, as I do. Darwin was dealing with the issue of extinction in a somewhat confused way. He could not interpret his own fossil findings without more expert help, which he received later (see below). The passage does represent the beginning of his rather longstanding commitment to *some version* of the species senescence idea.

There are several versions, and Darwin probably vacillated among them. But to my mind we should not negotiate away these differences of interpretation. They reflect something important — the ambiguities in Darwin's position at *every* point in his development. He was skillful and creative in using ambiguity productively, both to help him get on with what could be settled and to suggest openings. He was capable of living with ambiguity. Also he could sustain ambivalence, entertain several theories during the same period. Closer and closer study of Darwin's thinking should not be aimed at finding the one right pathway that correctly describes his route. He had the time to explore a number of paths. So should we.

I do not say all this in an especially conciliatory spirit, although I see nothing wrong with that. Rather, I wish to underline the value of many eyes, many minds, many station points. The way toward understanding sometimes passes through choice and other times through synthesis.

What can we now say of Darwin's commitment to Lyell? Let us review what we know.

In 1832 his unseen mentor and hero was still undoubtedly Humboldt. By sometime in 1833 he had assimilated enough Lyellian geology to reject, with increasing resolution, throughout 1833–1834, his earlier training in catastrophist ways of thought, especially concerning physical geology.

Sometime after receiving it in April 1834, Darwin began to read and absorb volume III of Lyell's *Principles*. Not long after, Darwin began to think along Lyellian lines with regard to a group of related issues connecting biogeography, and paleontology with uniformitarian geology, all under the aegis of a creationist (albeit multiple creationist) point of view. These commitments are expressed mainly in Darwin's geological notes of February 1835. And it must be noted that this is not a very rich record compared with the documentation we have on other matters. Furthermore, it must be noted that even this commitment was more than a little "iffy".

By December 1835 we have Darwin (a) criticizing Lyell's theory of coral reefs and (b) questioning the immutability of species. It should be noted that even a firm belief in mutability of species would not necessitate espousal of evolution. Although there are still many points of agreement between Darwin and Lyell on biological questions, the atmosphere of discipleship, which lasted between two and three years, has dissipated. When Darwin steps off the *Beagle* in 1836 he is on his own.

Among Darwin scholars, there is good measure of agreement about the theoretical outcome of the voyage for Darwin's progress. To be sure, an older generation of scholars may have believed in a sudden eureka experience in or just beyond the Galapagos experience. But it is now widely recognized that there was during the voyage no grand "Aha!" about the idea of evolution, not to speak of the mechanism of natural selection. In spite of much theoretical and personal growth, Darwin had still a long way to go.

V. Coral Reefs: A Theoretician Upward and Outward Bound

There are two themes that appear and reappear throughout most of Darwin's

life, adaptation as both state and process, and continuity through transformation. Both make an early appearance in a surprising place: Darwin's theory of the formation of coral reefs, which he worked out in December 1835, before visiting the coral islands of the Pacific toward the end of the voyage.

Adaptation can be thought of in two ways. On the one hand it refers to a steady state, in which the different parts of a system are so formed that they function in harmony with each other. On the other hand, it refers to a process in which adaptive change in one part of the system compensates for change in some other part. Darwin's coral reef theory argued that a series of local compensatory changes in the growth of coral organisms generates, in the long run, a continuous series of forms of coral reef. The coral organism flourishes within a certain distance of the ocean surface. As the bottom sinks, due to the action of large-scale geological processes, the live coral flourishes at a new level. Meanwhile, a corresponding increment is added to the column of dead coral. As the reef column grows upward and outward, its interaction with the rough and tumble of the sea changes in ways that account for the ultimate shape of the reef. Under different conditions, different types of reef are formed. These are not sharply distinguished but, Darwin argued, grade into each other. Thus, a series of smooth changes in outward physical forces produced a continuous series of forms: fringing reefs, barrier reefs, and coral atolls.

This theory bears a striking *formal* resemblance to the theory of evolution through natural selection. The similarities have been pointed out independently by Gruber and Gruber (1962), and by Ghiselin (1969). First, both theories contain a principle of population growth, e.g. the coral organism does not grow beyond some limiting distance from the ocean surface. In both cases the limiting principle is described by Darwin as a *struggle* — in the case of coral formations, a struggle "between the two nicely balanced powers of land and water". Second, both theories combine this limiting principle with geological ideas to explain the major facts of geographical distribution. Thus the hypothesis that a pattern of regions of subsidence of the Pacific floor (together with other geological factors) determines the places in which the coral organism grows and forms reefs. Third, both theories generate a continuous series of forms where other theories posited only certain classes. Thus for example, ". . . barrier reefs, when encircling islands, are thus converted into atolls, the instant the last pinnacle of land sinks beneath the surface of the ocean."[7]

This coral episode is important for a number of reasons. First, it shows Darwin as a confident theoretician: extrapolating not only from observations but from his own prior theoretical work; formulating the theory before ever seeing a coral reef. It shows Darwin thinking on a global scale: over wide spaces, coordinating the elevation of continental land masses with the subsidence of remote ocean floors; over long periods of time, imaginatively reconstructing the formation of reefs through the interaction of geological and biological processes. It shows Darwin comfortably handling the complexities of a multi-level theory that requires: close knowledge of a small invertebrate organism; clear thinking about the consequences of its colonial mode of life in relation to its environment; working out the reef building effects of periods of elevation and subsidence; connecting all this with a still hypothetical picture of geological processes on a global scale.

Second, it shows Darwin in December of 1835 forming a theory that disagrees with one advanced by Lyell. This did not represent a sharp break with Lyellian thinking, as Lyell was quick to admit, in expressing his admiration for Darwin's idea. Nevertheless it does show that Darwin felt free to criticize his still unseen mentor.

Third, the theory expresses Darwin's interest in a more general theme, the way in which living organisms transform both their own immediate environment, and the earth in general. This "life makes land" theme was made evident in 1837 when Darwin published two papers bearing on it, the May 31st paper on the formation of coral reefs (*CP* 1:46–49, 1837) and the November 1st paper on the formation of vegetable mould through the action of earthworms (*CP* 1:49–53, 1837). The joint occurrence of the two papers, the fact that the earthworm paper seems to come out of nowhere, and the fact that both topics were taken up at later times — all this argues for the idea that the coral theory was not an isolated event, but one related to Darwin's general point of view and embodied in an enduring theme.

Since the term *adaptation* is generally used to refer to morphological and behavioral changes in the organism, the reader may question my use of it to refer to a system of compensatory changes maintaining an invariant. The key point is that Darwin's thinking, from an early date, was permeated with the idea of self-regulating systems. In the eighteenth century there had been a marked increase in the development of self-regulating machines. During the same period the concept of society as a self-regulating system became prominent in the work of Adam Smith and others. The American constitution was constructed as a system of "checks and balances". Although Darwin never used the analogy between natural selection and man-made feedback devices, Alfred Russel Wallace did. In his 1858 paper, presented for him at the Linnaean Society, he wrote of natural selection, "The action of this principle is exactly like that of the centrifugal governor of the steam engine, which checks and corrects any irregularities almost before they become evident . . ." (Wallace 1858b).

How like the "nicely balanced powers" in Darwin's coral reef theory!

Nevertheless, Darwin's first theory of evolution — whether we take Gruber's, Hodge's, or Kohn's version of it (or all of them as there was not necessarily only one at a time . . .) — does not have a formal structure

of the kind described above. An adequate account of Darwin's intellectual development should deal with that rather surprising inconsistency.

Darwin's actual visit to the coral islands was a significant event, providing him with the opportunity to make observations supporting his already constructed theory. His increase in self-confidence as a theoretician is reflected in an entry in the *Diary*. As the *Beagle* sailed away from Keeling Island on 12 April 1836, he wrote:

> In the morning we stood out of the Lagoon. I am glad we have visited these Islands: such formations surely rank high amongst the wonderful objects of this world. It is not a wonder which at first strikes the eye of the body, but rather after reflection, the eye of reason. (*Diary*, p.400)

The sense of self Darwin experienced at this time is expressed in a letter to his sister Caroline, written 29 April 1836. He mentions his work on coral formations and remarks, "The idea of a lagoon island, 30 miles in diameter being based on a submarine crater of equal dimensions, has always appeared to me a monstrous hypothesis" (Darwin 1945, pp. 138–139). This was Lyell's idea that he was rejecting. Later on in the letter he writes of his plans to live in London and work as a geologist, "It is a rare piece of good fortune for me, that of the many errant (in ships) Naturalists, there have been few, or rather no, Geologists. I shall enter the field unopposed."

With the theoretical equipment and empirical knowledge we have now described, it might seem as though Darwin was in a good position to move toward a theory of evolution, and that that theory would be one involving an equilibration model of the kind he already knew well, having created it himself. But there were obstacles to be removed. Chief among them were Darwin's belief, although somewhat shaken, in the immutability of species and his inability to interpret his own puzzling biogeographical and paleontological materials. These two kinds of issues were closely related, and their resolution would, it has been argued, make an evolutionist of Darwin. How were they resolved? And did their resolution suffice?

VI. The Self-Construction of a Transformationist

It is now widely agreed among Darwin scholars that when Darwin stepped off the *Beagle* he was not yet an evolutionist. Although our knowledge of the immediately post-voyage period is quite incomplete, Sandra Herbert's publication of the *Red Notebook* is an important landmark in scholarship for this period (*RN*). And Frank Sulloway (1982a, b, c, 1983) has now done a masterful job of tracking down and organizing the empirical work that moved Darwin toward transmutationism. Sulloway speaks of Darwin's "conversion" but I prefer to think of it as "self-construction" — for three reasons. First, for the whole period from about February 1835 to July 1837 Darwin seems to be moving in a direction, making a set of choices, constructing a point of view and applying it over a wide range of phenomena. Second, at any given time his belief system is assembled out of many components, each with considerable inner structure and all fitted together with some care, albeit not always perfectly coherently. Third, conversions come to an end, constructions do not — and there seems to be no end point in Darwin's activity in any of the enterprises or themes in question. This lack of finish means also that there are always loose ends and ambiguities, continually re-animating the creative process.

The reader may object to my description of movement toward a rather vague goal as purposeful. I grant that Darwin's purposes are not always clear. But remember, we are not speaking of history or of evolution; abstract criticisms of teleology are not at issue here. Human beings do have purposes, and they need to organize their work. The very concept, *work*, is saturated with the idea of purpose. Goal, purpose, plan, aspiration, self-concept, ideal self — these are fundamental human attributes. For years, I have wanted to become a pacifist; I may someday achieve that aim. What is wrong with thinking that Darwin, especially given his family history, may have wanted to become an evolutionist, may have been consciously aware that some intellectual moves took him in that direction and others did not?

During the voyage Darwin collected wonderful material. He later wrote that the relation between fossil and living forms in South America and the facts of geographical distribution, especially the peculiar array of species he found in the Galapagos, were critical in swaying him toward evolution (*Autobiography*, pp. 118–119). But he was not, during the voyage, in a position to use these materials in an evolutionary theory. He was not competent enough in anatomy to make the necessary analyses of his fossils; nor was he enough of a systematist to solve the classificatory problems his far-ranging collections posed. His Galapagos collections were not complete, many specimens were initially misclassified, and the famous tortoises and finches were not adequately labeled to know which island they came from. To some extent these problems were due to Darwin's lack of expertise. But also, he lacked the evolutionary perspective that would have led him to collect and label more assiduously, island by island in the Galapagos. As he put it, "I never dreamed that islands, about fifty or sixty miles apart, and most of them in sight of each other, formed of precisely the same rocks, placed under a quite similar climate, rising to a nearly equal height, would have been differently tenanted" (*Journal of Researches* 1845, p. 394).

To take the next step Darwin needed to fit three ideas together: first, the idea that one species could be transmuted into another; second, the

idea that the repetition of such a process could accumulate over geological time to produce large differences; and third, the idea that this scenario, played out on a world scale, with organisms constantly migrating to new environments and becoming isolated from their forebears, could produce the whole system of organic nature.

To establish transmutability, the small differences among related species on the different islands of an archipelago would be ideal material. This step requires that the specimens be differentiated from each other as belonging to different species, and yet classified together as belonging to the same genus. Moreover, if the fundamental biogeographical connection is to be made, the specimens collected must be correctly labelled as to their location. For the birds of the Galapagos Archipelago, the collaboration of the ornithologist John Gould was indispensable, and the work was done between January 4th and early March, 1837. The ornithological findings broke the "species barrier" (Sulloway's phrase): there was no longer an intrinsic limit keeping variation within the boundaries (on which Lyell had insisted) of the species. Other zoologists contributed to the new picture, but Gould's work was the most important.

But establishing the transmutability of species would not lead to a full-scale evolutionary conclusion unless coupled with the more general changes that could only be observed over wider reaches of space and time. Regarding geological time, the paleontological work of Richard Owen was the key collaborative effort. This work began in December 1837. Almost immediately, Owen was able to pronounce that Darwin's fossils included a rodent (*Toxodon*) the size of a rhinoceros and an anteater (*Scelidotherium*) the size of a horse. These and other findings were communicated to Lyell. In his presidential address to the London Geological Society on 17 February 1837, Lyell summarized Owen's findings. He showed how these results dramatically confirmed the law of the succession of types: on large continents, existing species and extinct ones are closely related anatomically. This law really has two parts: first, new species closely resemble the ones they are replacing; and second, the difference between species sufficiently separated in time can become very great.

It should be noted that this law was by no means a new discovery.[8] Why did its confirmation now help move Darwin toward an evolutionist commitment? Perhaps the dramatic confirmation, using his *own* fossil specimens, and the attendant recognition he received, provoked him to think more about it. This highlighting of a known idea took place just as other key results of the voyage were coming into focus, and it was, after all, the integration of such widely different classes of data into a new synthesis that became Darwin's role.

The third class of data growing out of the zoologists' processing of the *Beagle* specimens has to do with the issue of representative species. Darwin revealed some awareness of this idea in his celebrated ornithological notebook in a passage (now dated by Sulloway as written June or July 1836) mainly on the birds of the Galapagos, but also mentioning the foxes of the Falkland Islands. Darwin was struck by the point that organisms "slightly differing in structure and filling the same place in Nature" could be found in different places. But that famous note remains ambiguous, in good part because Darwin injected the phrase, "I must suspect they are only varieties." Only if this suspicion was removed would "such facts . . . undermine the stability of species." The suspicion was not alleviated until early 1837, when the zoological results of the voyage poured in. Extended over a wider scale, Darwin's intuition (as against his prudent "suspicion") was richly confirmed. At a taxonomic level higher than species, there is a broad pattern of resemblances between the forms found in neighboring regions. The greater their isolation from each other — in time, reinforced by space and other barriers — the greater the differences. But islands typically have a general relation of similarity to nearby continents in their flora and fauna.

In the *Red Notebook*, this idea is conveyed in an odd phrase: ". . . new creation affected by Halo of neighboring continent . . ." (*RN* 127, written mid-March, 1837). In one possible reading, Darwin is suggesting that a geographic region somehow imposes a character on its organic productions. In his discussion of this passage, where Darwin wrote "peculiar plants created", Sulloway has added "[by colonization and gradual transmutation]". This is a plausible interpretation of Darwin's meaning, but certainly not the only possibility.

Thus, to assimilate his zoological work of the voyage to his emerging scheme, Darwin had to clarify the relations among three quite different classes of results. No one of them alone required an evolutionary explanation. Even all of them together could be assimilated to other theoretical schemas.

Sulloway has argued convincingly that the new information that Darwin gained from the expert processing of the *Beagle* specimens is not sufficient to account for his turn toward evolutionism; others sharing the same knowledge, indeed responsible for producing it, did not move in the same direction as Darwin. Sulloway attributes the difference to Darwin's "genius". I will not discuss here whether "genius" is an adequate explanatory concept (see Gruber 1982). However that question is decided, we must try, as well as possible, to understand what other moves Darwin was making that would lead him to the turn he took.

The *Red Notebook* may offer some help. Most scholarly attention has been centered on the frankly evolutionary or proto-evolutionary passages in the second half of it, written probably from the end of May 1836 to the close of the voyage. But here I want to draw attention to the first half, which deals mainly with more strictly geological issues.

VII. Going the Limit

What strikes me in the *Red Notebook* is an aspect of his style of thought. He is interested in pushing ideas to their limits, in making global generalizations. He writes of the need to focus on one region (for him, America), then to draw parallels with what is known about Europe, and finally to draw conclusions "applicable to the world" (*RN* 18). Since he knows how marine organisms capture lime, and he believes that this has gone on for a very long time, he asks, "How does it come that all Lime is not accumulated in the Tropical oceans detained by organic powers. We know the waters of the oceans are all mingled" (*RN* 29–30).

He is interested in the relation between very small events and their accumulation to great effects, sometimes not such obvious ones. Thus he tries to explain how gradual processes can lead to coastal steps (*RN* 39–41). He returns to this point a little later: "Mr Lyell . . . considers that successive terraces mark as many distinct elevations; hence it would appear he has not fully considered the subject" (*RN* 60). The more general idea of a qualitative leap emerges in another form in a reference to an experiment by Humphrey Davy showing that a small electric charge on a ship's copper bottom (produced by a bi-metallic contact) prevents fouling: "From Sir H. Davy experiment on the copper bottom, we see a trifling circumstance determines whether an animal will adhere to a certain part" (*RN* 95).

The question of scale occurs over and over in different forms. In writing of the flow of seemingly solid earth, he writes, "Mountains, which in size are grains of sand, in this view sink into their proper insignificance; as fractures, consequent on grand rise, & angular displacement, consequent of injection of fluid rock. — Try on globe, with slip paper a gradually curved enlargement" (*RN* 48). His mind moves eagerly from one scale to another: "Volcanos must be considered as chemical retorts" (*RN* 78). Within a few pages he remarks on "immense time", "immense areas", and "stupendous mass" (*RN* 107–109).

The idea of systems of compensating variables comes up repeatedly. He is fascinated by proposals that the system of volcanic action is a global system of subterranean forces. A line of volcanos in the Cordilleras could have "originated . . . from a fissure in a deep & therefore weak part of the ocean's bottom" (*RN* 10). The system of variables captured in the phrase "deep and therefore weak" deserves reflection.

Thus, while still on the voyage he was perfecting a style of thought in which (a) ideas are pushed to both their limits, such as the very great and the very small; (b) relationships are worked out between these extremes, and are often not obvious; and (c) since the limits in question include time as well as space, matter, and energy, the question of ultimate origins is never very far away.

We do not know just when the note on the inside cover was written, but it was appropriate for Darwin to place it at the front of the *Red Notebook*.

> The living atoms having definite existence, those that have undergone the greatest number of changes towards perfection (namely mammalia) must have a shorter duration, than the more constant: This view supposes the simplest infusoria same since commencement of the world.
> (*RN*, inside front cover)

VIII. The First Notebook on Transmutation

We now turn to the beginning of the B *Notebook*, a momentous step for Darwin. Darwin announces that something is happening. He begins a new notebook. He names it *Zoonomia*, the title of his grandfather's evolutionist essay (Erasmus Darwin 1794-1796). Most important is the change of style. The first thirty pages or so are no longer a miscellany of jottings, but a connected series of reflections. I will take the passage a few pages at a time. On the whole, within the passage, late ideas are added to or combined with earlier ones; revisions and rejections come later.

B 1–5. 1. Adaptive change is necessary. This is nowhere stated but assumed throughout.

2. The function of the life-cycle is to make adaptive change possible. "Generation" is used to refer to the cycle of reproduction, maturation, and death. "There may be unknown difficulty with *full grown* individual with fixed organisation thus being modified, — therefore generation to adapt and alter the race to *changing* world. On other hand, generation destroys the effect of accidental injuries, which if animals lived for ever would be endless . . . Therefore final cause of life" (*B* 4–5).
3. If the young must be born, this is taken to imply the necessity of death. In other words, the population remains approximately constant.
4. Variation is necessary for adaptive change. Two mechanisms are discussed, sexual reproduction and direct response to environmental circumstances. The latter is *not* the Lamarckian idea of inheritance of acquired characteristics. Rather, by some unspecified mechanism, change is induced during reproduction. For example, "seeds of plants sown in rich soil, many kinds are produced . . ." (*B* 3).
5. Variation must be disseminated to a whole population. The theory is not about individual adaptation but about populations and species. This is accomplished by sexual reproduction: "With this tendency to vary by generation, why are species all constant over whole country [?] Beautiful law of intermarriages partaking of characters of both parents and then infinite in number" (*B* 5).
6. There is an explicit denial of the efficacy of asexual reproduction as an agent in this process of adaptive change: the offspring are uniform. This leaves a question unsolved: Did Darwin think that asexual organisms do not evolve? Did he think that all organisms are at least occasionally sexual? Or was the denial not so absolute, perhaps a rhetorical device to accentuate the value of sexual reproduction? These questions are confused with that of the significance of the opening lines, on pages *B* 1 and *B* 2. Kohn (1980, p. 84) takes them to be a clear and succinct summary of a passage in Erasmus Darwin's *Zoonomia*. I fail to see such a close resemblance, and see the passage as a still rather confused paraphrase and extension of a passage in the *Red Notebook* (*RN* 132), with a reference to *Zoonomia*. But we do not need to settle these questions in order to agree on the others. This opening passage strongly suggests Darwin's aspiration for a theory that would go from monad to *homo sapiens*: from "the original molecule" to "civilized man". Both phrases occur here.

B 6–13. These pages deal with the wider consequences of the initial moves. Darwin begins to discuss the set of resemblances and differences that form a taxonomic system broad and flexible enough to encompass island-to-island differences in an archipelago, representative species in different regions of a continent, and the peculiar pattern of resemblances (which he had earlier called a "halo") between a continent and a nearby island in their flora and fauna. Both geographical and sexual isolating mechanisms are mentioned.

B 14–17. The relation between the extinct and extant animals of a region is cited. Historical geology is brought to bear. "Countries longest separated — greatest differences" (*B* 15).

B 18–23. The issues of the limits of the system, and the direction of evolution come into focus: "Each species changes. Does it progress [?] Man gains ideas. The simplest cannot help becoming more complicated; and if we look to first origin there must be progress" (*B* 18). So far as direction goes, Darwin is cautious but clear: there must be progress.

So far as the first limit of the system, its origin, is concerned, Darwin makes two points about monads, or simplest living forms. First, if monads are constantly formed, there would be lawful similarities among them, due to prevailing worldwide conditions. Second, if monads have a specifiable, finite existence, then their derivatives share this duration in lawful ways.

7. Isolating mechanisms, geographical and sexual, are necessary to stabilize species change.
8. The metaphor likening the life-cycle of a species to that of an individual, which appeared much earlier in his thinking, is reiterated. "There is nothing stranger in death of species, than individuals" (*B* 22).

9. Not only population, but the number of species remains approximately constant.
10. The taxonomic system is a branching one. "Organized beings represent a tree, irregularly branched; some branches far more branched, — hence general. As many terminal buds dying as new ones generated" (*B* 21). Notice that these "buds" must vary, since the intent of the metaphor is to describe the evolution of new species, so they are not the literal buds of a real tree in Erasmus Darwin's *Botanic Garden.*

One of the vexed points in pages 1–23 is the status of extinction. Darwin clearly implies a system of nature in which extinction is both a lawful phenomenon and a formal requirement if new species arise while the species number remains constant. But what is the mechanism of extinction? The phrase, "death of species" states the problem but not the mechanism. There is only a hint of the idea of cumulative disadaptation. The idea of species senescence is not expressed here. Only the idea that I have called "monad life span" — with the rider that the monad includes the things it becomes — is clearly stated. It seems to me that one plausible reading of the passage in question is this: Mammalia have evolved the most from their monadic origins; that is, they have undergone the most change. Species longevity is inversely proportional to amount of change undergone; "Hence shortness of life of mammalia" (*B* 22). Built into this reading is the idea that the monad life span is being shared among its derivatives. So in spite of the copious criticisms Hodge and Kohn have heaped on me, I stand unrepentant on this point. For a brief period Darwin entertained the monad life span idea as a mechanism of extinction. Recognizing this idea is important in order to see the significant change Darwin soon underwent. Whether Darwin at this time relied on monad life span, species senescence, or cumulative disadaptation due to environmental change — or some combination of them — it is clear that he was unsatisfied with his position. And it is reasonably clear that he moved soon to what I have called the idea of "becoming" (Gruber 1981b): unless species change they "die" (*B* 61–63).

Most important of all, the branching model emerged together with these considerations, and it deserves attention. The series of tree (and coral) diagrams in the B *Notebook* evolved over the years into the only diagram in the *Origin*, and the one that was used to explicate the important idea of divergence. At this early time, I believe Darwin saw branching evolution as a good way to describe the empirical facts of taxonomy, biogeography, and paleontology. Moreover, he had some trace of the idea of the exponential growth function implicit in any branching model, and this was soon to become quite explicit. Except for the phrase "*irregularly branched*" (Darwin's italics) and a certain feel of the whole thirty pages, there is little to suggest that Darwin had a clear view of the probablistic view of nature that would eventually justify the branching model.

IX. From Monad to Man

If the theoretical issues at stake for Darwin and his contemporaries could have been contained within the shift from within-species *variability* to between-species *mutability*, their lives would have been much simpler. But it was not hard for them to see that once the "species barrier" was broken, an explosive theoretical change might set in. In the pre-Darwinian debate, the issues of evolution and of the natural origin of life were considered as twin (Farley and Geison 1974). In *Zoonomia*, for example, Erasmus Darwin dealt with them together.[9] In the 1850s, in his Species Notebook, Lyell remarked repeatedly that transformationism could not be contained at either end of the scale. He took some solace in Lamarck's view (as compared with Darwin's) that monads were still being constantly produced by spontaneous generation; this squared with his uniformitarian conscience (Lyell 1970, p. 124-125). Thinking about both limits together was not restricted to the Darwins and Lyell. In 1860, Leonard Jenyns wrote to Darwin, perceptively noting that in the *Origin* Darwin had gone to both extremes. In the conclusion of the *Origin* Darwin wrote plainly and vigorously: "probably all the organic beings which have ever lived on this earth have descended from some one primordial form, into which life was first breathed" (*Origin*, p. 484). Only a few pages later he wrote, far more prudently, "Light will be thrown on the origin of man and his history" (*Origin*, p. 488). Jenyns pointed this out and centered his objections on exactly this issue, the *scope* of Darwin's theoretical aims.[10]

But the shape of these conclusions in the *Origin* is quite different from the shape of Darwin's career as a whole. Faced with the prospect of both "going the whole Monad" and "going the whole Ourang", he made a lop-sided decision. He decisively dropped the issue of the origin of life. It is simply not present in his later work. The trenchant sentence in the *Origin* quoted above represents an abstract conviction, not a program of work. But at the other end of the scale, circumspect as he was in the *Origin*, he labored mightily and took a clear stand, early in the M and N *Notebooks*, and much later in *Descent* and *Expression*. When was this asymmetrical decision made? In the B *Notebook*, both ends of the scale are moderately well represented, although neither was his main preoccupation. In the Spring of 1838 he wrote, "The intimate relation of Life with laws of chemical combination, & the universality of latter render spontaneous generation not improbable" (*C* 102e). Meanwhile, the C *Notebook* was full of remarks about *homo sapiens* and by July 1838 he began the M *Notebook*, on man, mind, and materialism. In several places in the transmutation notebooks Darwin reiterated his mysterious idea, "If all men were dead, then monkeys make men. — Men make angels" (*B* 169). But nowhere do "monads make monkeys". Here again we see Darwin's use of deferral and ambiguity. He put one question firmly aside, and buried the other in his notebooks. And yet, when the time came, anticipating his readers' question "It may be asked how far I extend the doctrine of the modification of species" (*Origin*, p. 483), opening the section quoted above, he answered in his odd mixture of forthrightness and circumspection.

We have seen how Darwin experimented with the idea that the longevity of a species is inversely proportional to its position in the scale of nature: the more evolved species, i.e., mammalia, have the shortest species life span. This idea soon gave way to a quite different formulation.

> ?Law: existence definite without change, superinduced or new species. Therefore animals would perish if there was nothing in country to superinduce a change? (*B* 61)

In this new formulation, *amount* of change is not mentioned as a consideration. On the one hand, the particular change must be in some sense adaptive. On the other hand, change itself is necessary. Fortunate is the species that inhabits a region where something will "superinduce a change". Although stated here between question marks, the idea is reiterated several times and soon becomes quite definite:

> If *species* generate other *species*, their race is not utterly cut off: — like golden pippins, if produced by seed, go on, — otherwise all die. —the fossil horse generated in S. Africa zebra — and continued, — perished in America. (*B* 72–73)

In the sense that one species is transformed into another, the first is the parent of the second — and in the making of it enjoys a "second life", the phrase Darwin used in his notes on marriage and having children (*Autobiography*, Keegan and Gruber 1983). This does away with any clear meaning that might be assigned to the species life span idea and its variant, monad life span.

Dropping the ideas of species life span, monad life span, and original monads from his thinking was an important step, tantamount to a decision to deal with the system of nature as an ongoing system, and to avoid questions of ultimate origins. But there were numerous vacillations and backslidings, and it was not until May 1839 that he could write unambiguously, "My theory leaves quite untouched the question of spontaneous generation" (*E* 160).

X. Toward Natural Selection

Here the story diverges in a number of ways. Intricate as each path may be, I can only summarize briefly.

First, there is the main line — from the explorations in the B *Notebook* in July 1837 to the moment some fifteen months later when he read Malthus's *Essay on Population* (Malthus 1826) and formulated the principle of evolution

through natural selection. Insisting too much on the singular and climactic nature of this moment misses important points. There was the work he had to do to arrive at 28 September 1838. Then there was the work of the moment. As Kohn (1980) has nicely shown, the "moment" of insight had a complex inner structure. Darwin wrote and then, probably immediately, rewrote his ideas. I believe that in the initial version there is a predominant tendency to take species, and in the rewrite to take the individual as the unit of analysis.

The work of the moment also included the task of significantly transforming Malthus's ideas (Keegan and Gruber 1983). The latter anthropocentrically dichotomized the world into a human population tending to increasing geometrically and a food supply increasing arithmetically. For Darwin, the food was also organisms, all with a potential for exponential population growth, unless checked. So generalizing and de-centering went hand in hand. Moreover, Malthus wrote within a context of social theory in which the complex interrelationships among human sexuality, population growth, and social class differences were matters of intense controversy. Darwin abstracted one key idea out of this context and turned it upside down — from the scourge of humanity to the motor of evolution. The first mention of Malthus in the M and N *Notebooks* occurs in an entry made between 4 and 7 October 1838, only a few days after the great moment. It has nothing much to do with the population principle, but deals with Malthus's other preoccupation, sexual continence. The first and probably only suggestion of the principle of natural selection in the M and N *Notebooks* occurs on about 16 March 1839:

> N.B. According to my view marrying late, will make average of life longer. — for short-lived constitutions will then be cut off. (*N* 67)

Second, there is the issue that went underground for so long, the question of divergence. The early B *Notebook* pages strongly suggest the fact of divergence. But why? As Janet Browne has shown (Browne 1980), when Darwin came back to this question in the 1850s, the language he used resembled that of the B *Notebook*. What he did not settle in 1837–1838 was the *reason* for divergence: what makes it necessary? It is widely agreed that it was not until the 1850s that he succeeded in answering that question to his own satisfaction (Browne 1980; Schweber 1980; Ospovat 1981; Kohn this volume).

Third, there is the seeming tangent — the initial exploration of the evolution of mind, recorded in the M and N *Notebooks*. This was not only an effort to extend the theory of evolution to one of its limits, but also to use the limiting case — a "frontier instance", Darwin called it (*N* 49) — to solve problems within the theory of evolution. This is a subject still largely unexplored.

Fourth, there is the disputed issue of artificial selection. Several authors have argued that Darwin came to natural selection via artificial selection. It is true that in the C *Notebook* and the D *Notebook* before Malthus there is much about plant and animal breeding. But it now seems clear that Darwin was investigating the work of breeders in order to find clues to the mechanism of variation: in some way, breeding under artificial conditions was thought to disturb the natural process of sexual reproduction. Nevertheless, this process of steeping himself in the subject was fruitful; when he did arrive at the idea of natural selection, he could then turn around 180° and use artificial selection as a small scale demonstration of the principle. Even this seemingly small step took some months.

While the model of artificial selection may have been a stepping stone on some of the possible paths to natural selection, it was not a necessary way station. As late as 1858, Alfred Russel Wallace arrived at natural selection while explicitly denying the relevance of results of artificial breeding.

Conclusion

I think it is at least tacitly agreed that Darwin's development was a true epigenesis: a series of structures with each phase growing out of the previous, always in interaction with new circumstances provided by a changing scientific and social environment. No one has suggested that when Darwin set out on the voyage he knew exactly where he was going, or that when he began the First Transmutation Notebook the theory of evolution through natural selection was a foregone conclusion. At the same time, Darwin's intellectual activity was far from random exploration. Starting at some early point, he seems to have been moving in a direction. In part this direction was given by certain family traditions, in part by broader historical currents to which he was exposed, and in part by his opportune encounter with Lyell's *Principles*. The voyage itself seems to have evoked in him a strong tendency to be that kind of natural historian who goes beyond local description and explanation to generalize on a world-wide scale. Perhaps we should say that the voyage reinforced a tendency already evident in his pre-*Beagle* admiration for Humboldt's *Personal Narrative*. The combination, tradition × education × circumnavigation, made a global thinker of the young naturalist.

As Darwin's sense of purpose emerged, it rapidly became more and more complex. We have summed up and surveyed this pattern in the "network of enterprise" — a diagrammatic way of showing the simultaneous development of a number of strands of scientific work. One of the themes of this essay has been the need to make sense out of this diversity.

Throughout this early period, we see the emergence and spread of a number of thought-forms. Among the most prominent is the summing of small effects over many iterations to produce large, often surprising results:

"the multiplication of little means" that Darwin found such a "laborious and painful effort of the mind" (C 75). This idea involved, for Darwin, the movement from one time-scale to another, from the scale of localized events to the scale of their long-range consequences. So the scale of time and space intellectually available profoundly affects the significance of such summative processes. For Darwin, this scale rapidly became geological in time and global in space.

A second very general thought-form we see emerging in Darwin's work is the equilibration model. Each natural phenomenon hovers around some value governed by a host of factors. Departures from this value provoke an equilibrating process. This is not quite the same as a static "balance of nature" since from an early point Darwin was thinking of a *changing* world, so this re-equilibration was a moving process, as shown dramatically in his theory of coral reef formation.

A third characteristic of Darwin's thought was to think in terms of the whole range of phenomena within whatever domain was in question. Just as geological processes were happily generalized on a world scale, when he saw his first Tierra del Fuegian he immediately thought of the whole range from wild animal to civilized man. When he encountered, in his reading of Lyell, the idea of the "death" of species, he wondered also about their "birth". If one was gradual, why not the other? Moreover, he often thought about the connection between the very small and the very great.

This characterization helps to understand Darwin's evident tendency, at the beginning of his thinking about evolution, to raise questions about the scope of the theory: What is the function of birth and death of individuals? Of species? Can one theory go all the way from simplest living being to most complex, from monad to man?

There has been a valuable trend, in writing about Darwin, to "normalize" his life — to show how he became a true professional, how his work depended on that of other true professionals. This is important if we are to demystify, as far as possible, his achievements. This procedure is likely to accentuate that part of his thinking which was in the solid middle-of-the-range of scientific work.

At the same time, this normalized picture of Darwin de-emphasizes that part of his thinking in which he was testing the limits, exploring the possible scope of his theory. But the scope he achieved was a fundamental part of his contribution. Darwin was a revolutionary thinker. We need to understand what forms of thought he used that permitted him to consider so deeply and so unflinchingly the whole range of possibilities.

Notes

1. Rudwick and I have had a fruitful exchange on the matters covered here. On the relation between public and private science, see also my essay, "The Many Voyages of the *Beagle*" (Gruber 1981b, 259–299).
2. For the cave, see Plato, *The Republic*, Book VII; the shadow box experiments are work in progress; the solution tree, or search tree, is discussed in Newell and Simon (1972).
3. For an approach to playful exploration of micro-worlds as a way of mastering a domain, see Papert (1980).
4. For discussions of the phenomenological approach see Gruber (1981c) and Gruber (1980).
5. He was specifically trained in keeping notebooks by his teachers at Edinburgh University; and Erasmus Darwin's *Commonplace Book* (Ms at Down House) contains a lengthy preface explaining the connection between the practice of recording one's experiences and the empirical philosophy of John Locke; see *Darwin on Man* (Gruber 1981c, 21-22).
6. Both Hodge (1982) and Kohn (1980) concur on the Brocchian source of the species senescence idea. Lyell discussed it and disagreed with it in Vol. III of *Principles*, which Darwin read during the voyage. Lyell learned of it from, and cited the Italian geologist, Giovanni Battista Brocchi. I see no reason to doubt the importance of Brocchi in the story. But I would add that at least one key part of the idea, the gradual deterioration over generations, of grafted apples — an example Darwin alluded to, metaphorically, repeatedly for many years — can be found in Erasmus Darwin's poetry, spelled out in full in a prose note. What is more, the context it occurs in is the poet's celebration of the value and power of sexual love. This attitude was a Darwin family tradition. Erasmus Darwin, *The Temple of Nature or, the Origin of Society: A Poem with Philosophical Notes* (London: Johnson, 1803, posthumous), Canto II, p. 57.
7. In most respects the above description of Darwin's coral reef theory is very close to the version I wrote in *Darwin on Man* (Gruber 1981c).
8. For a brief account of its history see Eiseley (1958, 161–166).
9. Erasmus Darwin, *Zoonomia*, Section XXXIX, "Of Generation". See also the *Temple of Nature*, "Additional Note I", which is an essay on spontaneous generation of simple organisms. The sections of this poem have the following titles: Canto I, "Production of Life"; Canto II, "Reproduction of Life"; Canto III, "Progress of the Mind"; Canto IV, "Of Good and Evil".
10. Jenyns' letter is reprinted in *Lyell's Scientific Journals* (Lyell 1970: 349–351).

Special Note: Writing this essay was completed during a stay at the Institute for Advanced Study, whose hospitality I gratefully acknowledge. I thank Martin Rudwick and Doris Wallace for helpful comments. The idea of *thought-form* is being elaborated in a doctoral dissertation by Robert T. Keegan on Darwin's unpublished "Diary of an Infant".

2

THE WIDER BRITISH CONTEXT IN DARWIN'S THEORIZING

Silvan S. Schweber

Home is where one starts from. As we grow older
The world becomes stranger, the pattern more complicated
Of dead and living.
. . . .
We must be still and still moving
Into another intensity
For a further union, a deeper communion . . .
In my end is my beginning.

T. S. Eliot, *Four Quartets*, 'East Coker' V

Introduction

The *Origin of Species* was the culmination of Darwin's theorizing of the previous twenty years. Its unique role in delineating the subsequent debates over all aspects of evolution account for the enduring interest in the construction of the *Origin* and the intellectual and other factors that helped shape its final form. We know from Darwin's correspondence that he saw himself as constantly engaged in "species-work" during the period from 1840 to 1854. It was "far-distant work" but he did indicate to several of his correspondents that he intended to write a book on the species question, though he would "not publish on the subject for several years" (for example, LL (NY) 1: 392, 394-395). My aim is to trace the development of Darwin's understanding of the divergent pattern of evolutionary history, particularly the mechanism of divergence.

I see the dynamical explanations that Darwin advanced in the *Origin* as the amalgamation of two great insights. The first occurred in the Summer of 1838, and consisted in the apprehension of the Malthusian mechanism. It led to natural selection, and was the high point of Darwin's theorizing following his voyage on the *Beagle*. The second was gleaned in the mid 1850s and resulted in the principle of divergence. The Malthusian principle reflects a deterministic, quantitative, Newtonian mechanistic conceptualization of the world; the principle of divergence is modeled after the Scottish