

## **The Fossil Record and the Cambrian Explosion Problem**

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The fossil record is now and always has been a great challenge for the Darwinian and Neo-Darwinian schools. If its principal characteristics can be shown to follow from the hypotheses of Neo-Darwinism, then the fossil record will be an important empirical confirmation of the theory. Indeed, the theory should be able to make predictions about it which can be verified by subsequent research. On the other hand, if emerging (and emerged) characteristics of the fossil record are not in accordance with predictions or inferences from the theory, then there is a problem. Unfortunately, the issues associated with the fossil record are widely misunderstood. We shall attempt to clarify the situation here.

First, observe that the gradualistic paradigm for change or *Phyletic gradualism*, which is an essential feature of the neo-Darwinian theory as it was for Darwin’s original version, should fill the fossil record with not just a few, but innumerable transitional forms. Indeed, constant transition, constant change, should be the main feature of the fossil record, since abrupt transitions or “saltations” are excluded from the theory because of their great improbability.

The number of intermediate varieties, which have formerly existed on the earth, (must) be truly enormous. Why then is not every geological formation and every stratum full of such intermediate links? Geology assuredly does not reveal any such finely graduated organic chain; and this, perhaps, is the most obvious and gravest objection which can be urged against my theory.<sup>1</sup>

The transitional forms problem, then, is not about any particular fossil, such as *Archaeopteryx*, and whether it is indeed “transitional”; rather, it is about the global question of the fossil record and why we do not see a continual record of transition, instead of the staccato rhythm of life forms actually observed, which abruptly come into existence, survive unchanged for millions of years, then disappear.

### ***The existence and distribution of transitional forms***

The evolution scenario envisioned by Darwin can only work one way: it must be the case that species gradually change, and eventually transform into another—a type of merging process, if you will. Then as the changes accumulate, that is, as the species continue to evolve and change, they become different genera. These likewise will continue to evolve and change, and become new families, and so forth. Now, this clearly implies that what one should see in the fossil record will depend on the time scale of one’s observations. In the short run, species will transition. On a longer time scale,

transitions between genera should be apparent, as the species transitions become too fast to see. Similarly, on a still longer time scale, families will transition, and so up to the highest taxa, phyla and perhaps kingdoms. It is important to understand that *under this paradigm, transitions between any taxonomic level (species, genera, family, order, class, or phylum) should be observed if one views the fossil record on the appropriate time scale.* The idea may perhaps be understood more easily in diagrammatic form, as shown in Figure 1a, b and c. In the figure, overlaps of taxa correspond to the sought-after transitional forms. Viewing the record on a small time scale would correspond to zooming in on the figure, so that only species and genera transitions can be seen, as shown in Figure 1a. On a medium time scale, transitions at the family and class level become prominent, but those at lower levels are harder to see, as shown in Figure 1b. Viewing the record on a large time scale would correspond to zooming out, so that genera and family transitions become invisible, and only higher taxa transitions can be seen, as shown in Figure 1c. (In the figure, only a small number of forms at each level is shown, due to space limitations. In reality, morphology would extend in multiple dimensions, and more than one new species could branch off from a given species, and similarly at higher levels.). It follows immediately that if one assumes the rate of speciation is approximately constant, then the time to generate higher-order taxa will increase exponentially as the level goes up. For example, if it takes 1,000 years to generate a new species, and 10 species are required for a new genus, 10 genera for a new family, and so forth, then the time to generate a new phylum would be  $1000 \times 10^5 = 100$  million years. Figure 2 shows what is actually observed in the fossil record, i.e., stasis. As one hard-nosed observer puts it:

The theoretical presumption of evolution [from] a common ancestor is not there in the insect record, just as it is not there for mammals, or for any other class of animal or division of plant. Still less is there evidence of evolution connecting different classes and subdivisions, subkingdoms or kingdoms. In 1860 it could be claimed with some plausibility that the record was seriously incomplete, and it could therefore be hoped that with increasing knowledge the more distant connections postulated by the theory would eventually be found. They have not been, and since geology has expanded enormously in scope over the past century, it now seems unlikely that the postulated connections will ever be found.<sup>2</sup>

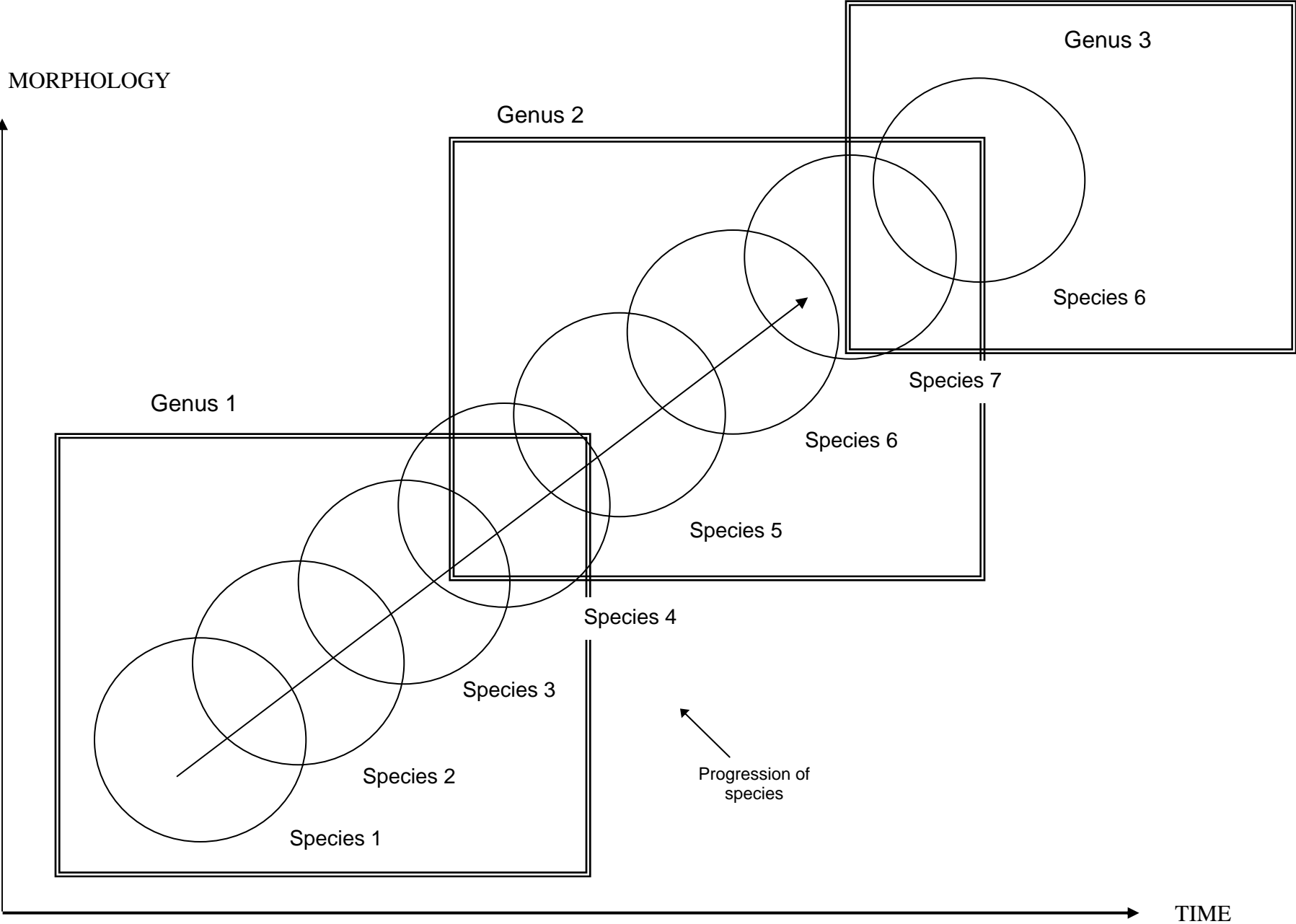


Figure 1(a). Schematic representation of progressive emergence of taxa and transitional forms according to Darwin's paradigm (Phyletic gradualism) at short time scale. Overlaps at each taxonomic level correspond to transitional

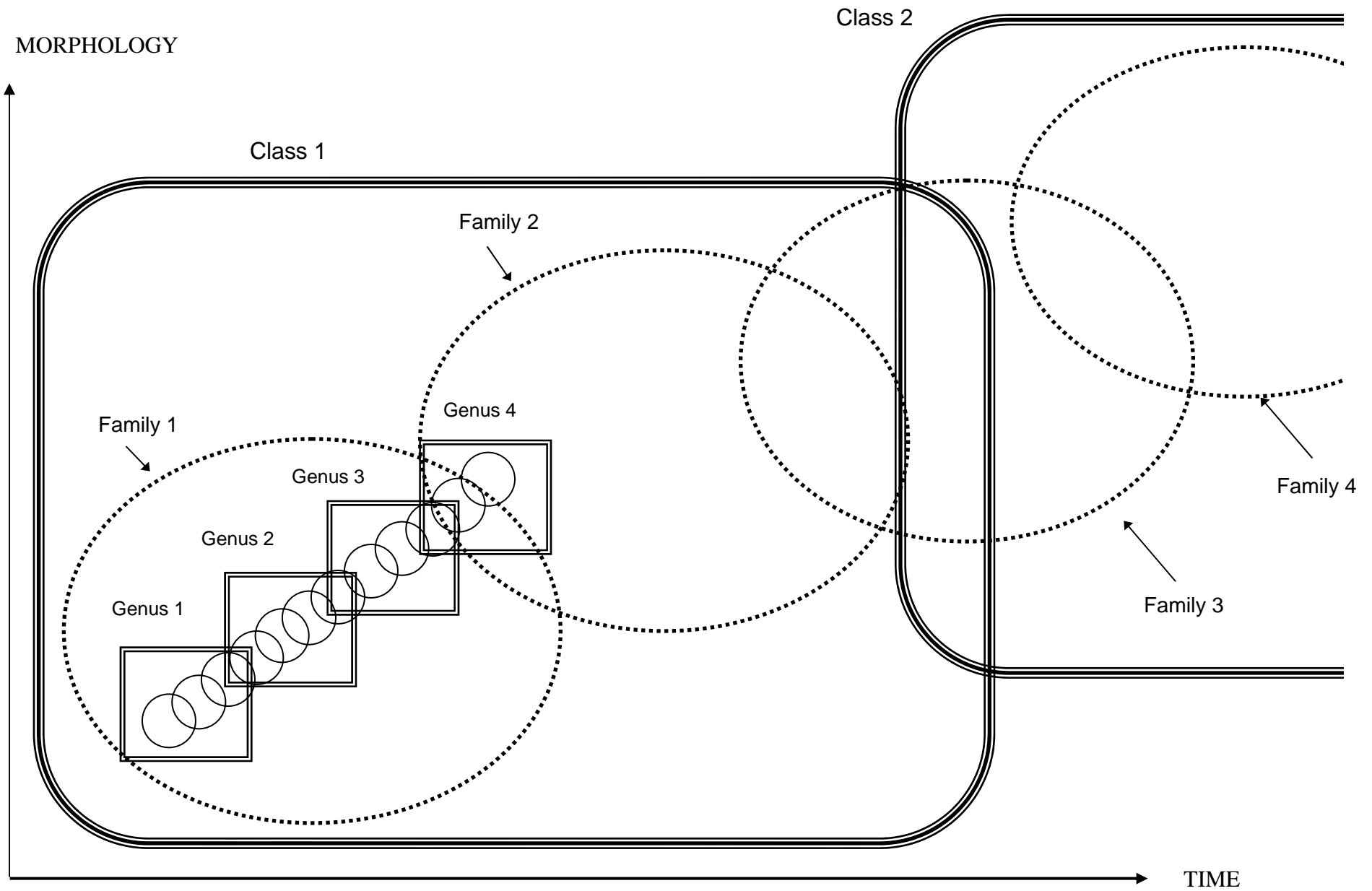


Figure 1(b). Schematic representation of progressive emergence of taxa and transitional forms according to Darwin's paradigm (Phyletic gradualism) at medium time scale. Overlaps at each taxonomic level correspond to transitional

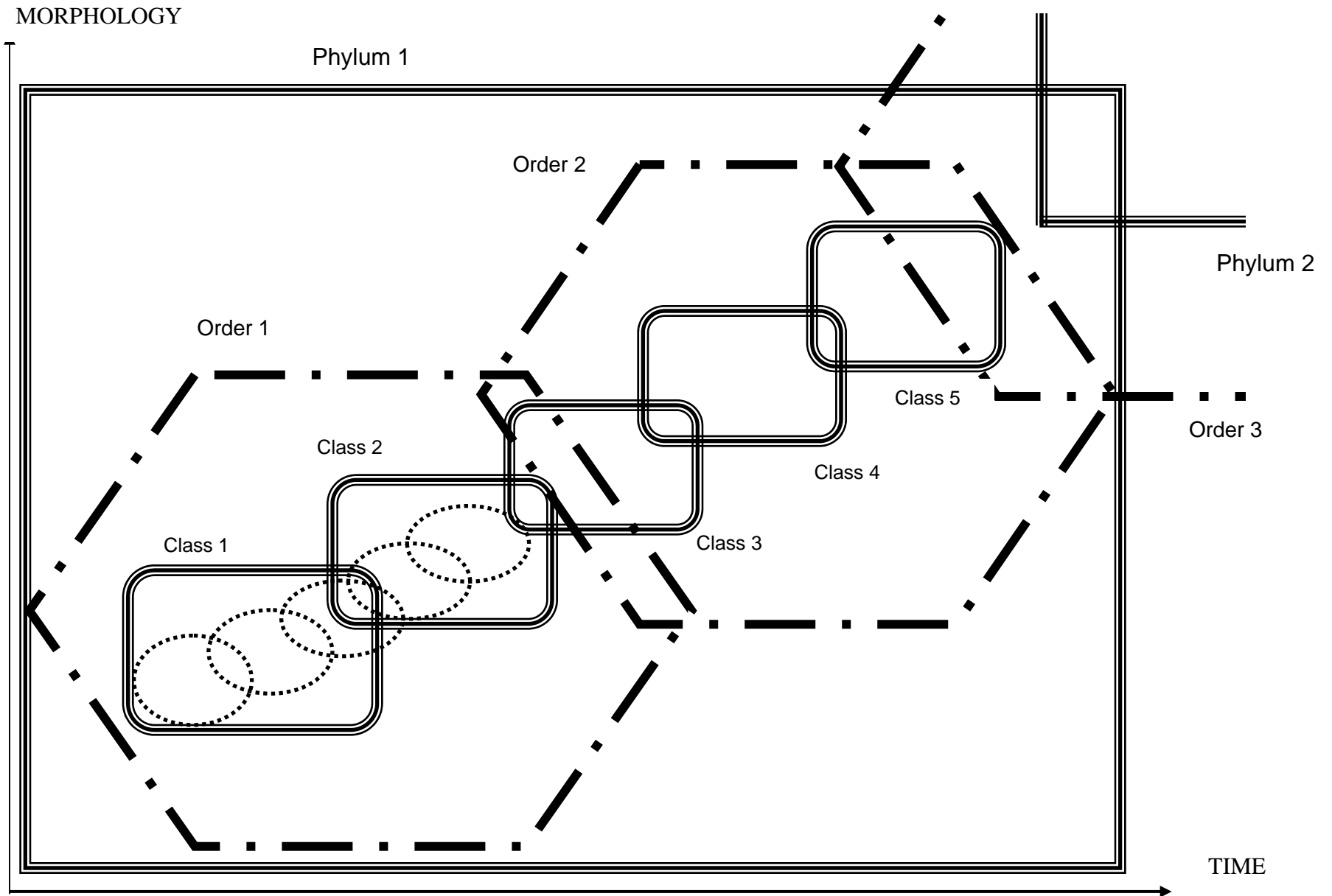


Figure 1(c). Schematic representation of progressive emergence of taxa and transitional forms according to Darwin's paradigm (Phyletic gradualism) at long time scale. Overlaps at each taxonomic level correspond to transitional

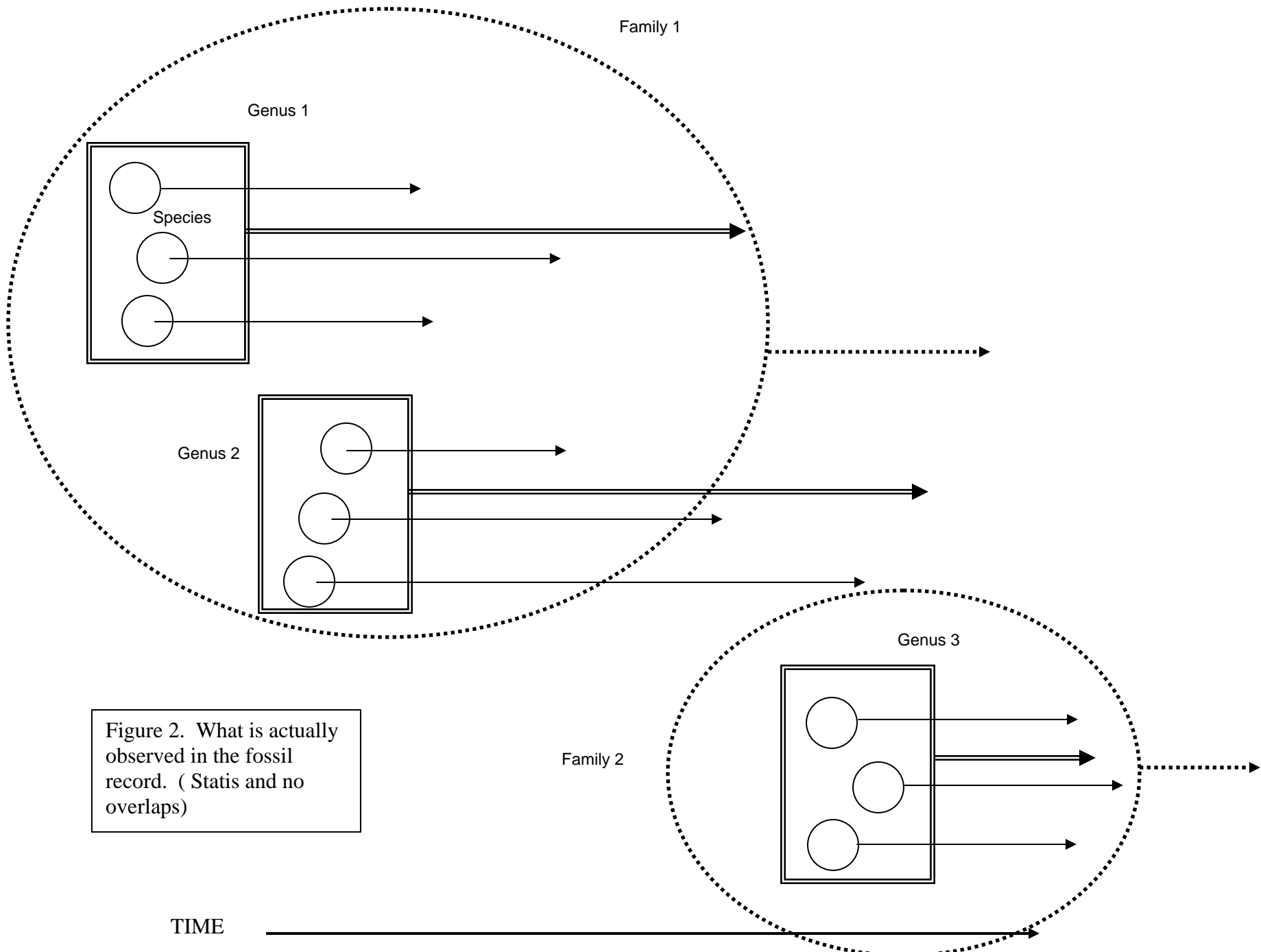


Figure 2. What is actually observed in the fossil record. (Statis and no overlaps)

As a practical matter, when confronted with this rather grave problem, the general policy of the neo-Darwinian school seems to be to just ignore it and hope that it goes away. A few stalwarts, however, have recognized that this is unacceptable and have tried to deal with it head-on. They have staked out six more or less incompatible approaches in their quest (itself an indication of the problem's magnitude):

- (1) The transitional forms did exist, but only for a short time, leaving no trace in the fossil record, so they can't be found.
- (2) The transitional forms are everywhere, and everything is a transitional form.
- (3) Our classification scheme makes them invisible
- (4) The transitional forms are there, we just can't see them because the fossil record didn't preserve enough.
- (5) We don't need the fossil record, so it doesn't matter.
- (6) (Darwin's original position) the missing transitional forms will eventually come to light when more of the fossil record is exposed. (Few if any subscribe to that notion any longer given the completeness of the fossil record, especially at the higher levels, as discussed in Chapter 2).

Let us review the two current positions in some detail, with a view to understanding from where their proponents are coming.

(1) *They existed but they're gone.* The defects in the fossil record have been widely acknowledged, and it is worthwhile reviewing the range of comments on it. First, David Raup, a believer in evolution though one who respects its critics, and who is a former curator of geology at the Field Museum of Natural History in Chicago:

Well, we are now about 120 years after Darwin, and knowledge of the fossil record has been greatly expanded ... ironically, we have even fewer examples of evolutionary transition than we had in Darwin's time. By this I mean that some of the classic cases of darwinian change in the fossil record, such as the evolution of the horse in North America, have had to be discarded or modified as a result of more detailed information ... So Darwin's problem has not been alleviated in the last 120 years and we still have a record which *does* show change but one that can hardly be looked upon as the most reasonable consequence of natural selection.<sup>3</sup>

Steven J. Gould, one of the founders of the Punctuated Equilibrium theory (and a member of the non-Darwinian evolution school, according to our classification), has commented:

The extreme rarity of transitional forms in the fossil record persists as the trade secret of paleontology. The evolutionary trees that adorn our textbooks have data only at the tips and nodes of their branches; the rest is inference, however reasonable, not the evidence of fossils. Yet Darwin was so wedded to gradualism that he wagered his entire theory on a denial of this literal record.... Paleontologists have paid an exorbitant price for Darwin's argument. We fancy ourselves as the only true students of life's history, yet to preserve our favored account of evolution by natural selection we view our data as so bad that we never see the very process we profess to study.<sup>4</sup>

Even stalwarts such as Simpson have conceded the difficulty:

...it remains true, as every paleontologist knows, that *most* new species, genera, and families and that nearly all categories above the level of families appear in the record suddenly and are not led up to by known, gradual, completely continuous transitional sequences.<sup>5</sup>

At some point, evolution and transitional forms should be visible, indeed, at many points:

No wonder paleontologists shied away from evolution for so long. It never seems to happen. Assiduous collection up cliff faces yields zigzags, minor oscillations, and the very occasional slight accumulation of change—over millions of years, at a rate too slow to account for all the prodigious change that has occurred in evolutionary history. When we do see the introduction of evolutionary novelty, it usually shows up with a bang, and often with no firm evidence that the fossils did not evolve elsewhere! Evolution cannot forever be going on somewhere else. Yet that's how the fossil record has struck many a forlorn paleontologist looking to learn something about evolution.<sup>6</sup>

Gould has also described the history of life forms once they emerge:

The history of most fossil species include two features particularly inconsistent with gradualism:

- 1) Stasis—most species exhibit no directional change during their tenure on earth. They appear in the fossil record looking much the same as when they disappear; morphological change is usually limited and directionless;
- 2) Sudden appearance—in any local area, a species does not arise gradually by the steady transformation of its ancestors; it appears all at once and 'fully formed'.<sup>7</sup>

It is important to note that the needed transitions do not appear at any taxonomic level:

[G]aps between higher taxonomic levels are general and large.<sup>8</sup>

Even Simpson, one of the creators of the "New Synthesis", acknowledges the problem:

This is true of all thirty-two orders of mammals...The earliest and most primitive known members of every order already have the basic ordinal characters, and in no case is an approximately continuous sequence from one order to another known. In most cases the break is so sharp and the gap so large that the origin of the order is speculative and much disputed...This regular absence of transitional forms is not confined to mammals, but is an almost universal phenomenon, as has long been noted by paleontologists. It is true of almost all classes of animals, both vertebrate and invertebrate...it is true of the classes, and of the major animal phyla, and it is apparently also true of analogous categories of plants.<sup>9</sup>

This null result is confirmed by others:

Most families, orders, classes, and phyla appear rather suddenly in the fossil record, often without anatomically intermediate forms smoothly interlinking evolutionarily derived descendant taxa with their presumed ancestors<sup>10</sup>.

The gaps in the fossil record are real, however. The absence of a record of any important branching is quite phenomenal. Species are usually static, or nearly so, for

long periods, species seldom and genera never show evolution into new species or genera but replacement of one by another, and change is more or less abrupt.<sup>11</sup>

Taxa recognized as orders during the (Precambrian-Cambrian) transition chiefly appear without connection to an ancestral clade via a fossil intermediate. This situation is in fact true of most invertebrate orders during the remaining Phanerozoic as well. There are no chains of taxa leading gradually from an ancestral condition to the new ordinal body type. Orders thus appear as rather distinctive subdivisions of classes rather than as being segments in some sort of morphological continuum.<sup>12</sup>

Others in “mainstream” science have reached conclusions that, if anything, are even stronger:

... many of the large populations should have been preserved, yet we simply do not find them. Small populations are called for, then, but there are difficulties here also. The populations must remain small (and undetected) and evolve steadily and consistently toward the body plan that comprises the basis of a new phylum (or class). This is asking a lot. Deleterious mutations would tend to accumulate in small populations to form genetic loads that selection might not be able to handle. Stable intermediate adaptive modes cannot be invoked as a regular feature, since we are then again faced with the problem of just where their remains are. We might imagine vast arrays of such small populations fanning continually and incessantly into adaptive space. Vast arrays should have produced at least some fossil remains also. Perhaps an even greater difficulty is the requirement that these arrays of lineages change along a rather straight and true course—morphological side trips or detours of any frequency should lengthen the time of origin of higher taxa beyond what appears to be available. Why should an opportunistic, tinkering process set on such a course and hold it for so long successfully among so many lineages? We conclude that the extrapolation of microevolutionary rates to explain the origin of new body plans is possible, but does not accord with the primary evidence.<sup>13</sup>

Some who wish to continue believing in evolution have found this problem so intractable that they have cut and run, joining one of the camps in the Meta-Darwinian school. And specifically, it is the jumping-off point for the Punctuated Equilibrium theory, which rejects the NDT on the basis of its failure to explain the gaps and jerkiness of the fossil record. As discussed in Chapter 8 of the book, this theory attempts to resolve the problem by postulating extremely rapid change during certain periods, with relatively few individuals involved, so the changes left no trace.

(2) *They're everywhere.* On the other side of the ring, most members of the NDT feel that the Punctuated Equilibrium approach gives away too much—the whole store, in fact—and have tried to finesse the problem by arguing that it is, in fact, a pseudo-problem since transitional forms are really abundant:

Each species, then, is intermediate in some sense of the word; all species possess primitive and derived characters.<sup>14</sup>

The National Academy of Sciences has weighed in with a blanket assertion that there is no problem, and that myriad transitional forms exist:

So many intermediate forms have been discovered between fish and amphibians, between amphibians and reptiles, between reptiles and mammals, and along the primate lines of descent that it often is difficult to identify categorically when the transition occurs from one to another particular species. Actually, nearly all fossils can be regarded as intermediates in some sense; they are life forms that come between the forms that preceded them and those that followed.<sup>15</sup>

The Academy is apparently oblivious to the direct contradiction between their position and that of a significant number of prominent researchers including those cited above. But that is not the important problem, which is, rather, whether the transitional forms exist as lineages. Indeed, it is clear that a major part of the difficulty here lies in the definition of a transitional form. A typical dictionary definition of “transition” is “movement, passage, or change from one position, state, stage, subject, concept, etc., to another”. In the context of evolution, this means evolving from one species (or higher taxon) to another, quite unambiguously; it does not mean simply sharing characteristics of two different taxa, as say, *Archeopteryx* shares characteristics of birds and reptiles because it has a tail and teeth. Such sharing does not make *Archeopteryx* transitional between reptiles and birds, any more than a hexagon is transitional between an octagon and a square because it has sides and encloses area. There is a serious confusion between transitional forms as *pattern recognition exercises* and transitional forms as *lineages*, as if the former were a substitute for the latter in evolution disputes. It is not, and we must keep our attention focused on the key question of *whether there is a path linking the hypothetical primordial ancestor with all subsequent life forms*:

The point is that any collection of objects can arbitrarily be placed into a continuum, with some identified as transitional. This, however, is not sufficient to establish actual evidence for common descent. There must, instead, be a discernible pattern of lineages giving the supposed transitionals credibility. The data must occur along a long, narrow trail...Once a [complete] lineage is determined, the transitional forms [should be] self-evident.<sup>16</sup>

So the reader, when he or she encounters the transition problem, must be sure that attention is focused on transitional forms in the sense of lineage, parent-to-offspring, and not as cases of pattern recognition.

(3) *Our classification scheme makes them invisible.*

This is another variant on the “they’re really there” theme.

(4) *We can’t see them.* They are there—we have a few, and the rest are invisible because the fossil record only discloses part of the morphology of organisms (~10%), and less of their functioning. This is a modern variant of Darwin’s original position, since abandoned. While true, it does not seem to have convinced many biologists or paleontologists, who obviously feel that enough has been preserved to determine that the sought-after transitions—many of which would have been very difficult—have not been found. Gould and Eldridge comment:

At the higher level of evolutionary transition between basic morphological designs [reflect in fossils], gradualism has always been in trouble, though it remains the “official” position of most Western evolutionists. Smooth intermediates between

*Bauplane* [body plans] are almost impossible to construct, even in thought experiments; there is certainly no evidence for them in the fossil record.<sup>17</sup>

Or in other words, the transitions would be too big to be consistently missed.

(5) *We don't need the fossil record anyway.* This is, of course, the sour grapes argument. Its proponents claim that evolution is now based on other sources of knowledge, such as genetics, biochemistry, and molecular biology, and that paleontology is thus expendable. Unfortunately, this doesn't really solve the problem, which is not whether we wish to use the fossil record to *support* the NDT, but whether it can be used *against* the NDT.

### ***The Cambrian Explosion***

Let us consider this problem further, in the context of the Cambrian Explosion. As is well-known, the Cambrian Explosion is the relatively short time in the Cambrian period during which nearly all phyla known today emerged. This has always been a problem for Darwinian and Neo-Darwinian evolution, because they are based on the paradigm of phyletic gradualism, according to which small changes accumulate slowly over time to give rise species and higher taxa. Thus most phyla should emerge late, not early, in the fossil record.

The early Cambrian fossil discoveries in China referenced above have led Chinese paleontologists to a rather different view of the history of life from that of the dominant Neo-Darwinian school. In particular, one fossil, dubbed *Haikouella* and dated as 530 million years old, has the beginnings of a notochord, far earlier than the previous candidate, *Pikaia*. This discovery has pushed back the date of the Cambrian explosion about 15 million years, causing it to become an even more acute problem for NDT (because the proposed mechanism of phyletic gradualism cannot generate innovations at anything approaching the required rate). Moreover, some of the excavations were in 580 million year old (Precambrian) phosphorous rock, where the Chinese found sponges and tiny embryos, but not the long-sought (and crucially important) predecessors of the animals representing the diverse phyla of the Cambrian explosion, which appeared about 40-50 million years later. These discoveries clearly indicate that *had the missing fossils existed, they would have been preserved*—seriously damaging the only credible argument as to why no one has found them. Did this powerful negative evidence cause the Neo-Darwinians to reconsider their position and admit that their theory might be wrong? Not much chance of that; in the mind of German biologist Dieter Walossek, who was trying to rally his colleagues, the facts are indeed irrelevant:

It doesn't matter if you find it [the missing fossil record] or not!...It's there! It's by law! All of the major taxa should have been there in the pre-Cambrian, whether proved or not!<sup>18</sup>

This is especially curious because we earlier had Ernst Mayr telling us that laws are not part of evolutionary science. Perhaps just when they're convenient...

But the spectacle only gets better. In their interpretation of the Cambrian explosion, the Chinese argue that the NDT cannot account for the speed, breadth, or uniqueness of this event. Instead, they believe that

...scientists should focus on the possibility that a unique harmony between forms of life allowed complex organisms to emerge. If all we have to depend upon is chance and competition, the conventional forces of evolution,...“then complex, highly evolved life, such as human, has no reason to appear.”<sup>19</sup>

This does not sit well with most Western scientists, already on edge about the problem. At a conference on the fossil discoveries held at Chengjian, Chinese scientists suggested that a variety of new hypotheses need to be investigated in order to explain the Cambrian explosion, including sudden seafloor changes, hydrothermal eruptions, and even intelligent design. The Western scientists couldn't take it, one of whom stood up and shouted, “This is not a scientific conference!”<sup>20</sup> When you don't like the facts, shoot the messenger. Even the Chinese Communist Party's own daily, *Guang Ming*, recognized the irony of the situation:

Evolution is facing an extremely harsh challenge. In the beginning, Darwinian evolution was a scientific theory...In fact, evolution eventually changed into a religion.<sup>21</sup>

The discoveries were reported in mainstream publications such as *Science*, but there was nary a word about negative implications for the NDT.<sup>22</sup> Always an explanation exists, in this case, traces of the missing ancestral creatures must be there somewhere: “These stem groups are all lurking down there, but we're just too dim to see them”.<sup>23</sup> The possibility that the dimness may be in the theory and not in our vision is not, as it seems, admissible.

Such examples once again demonstrate the troubling absence of a critical attitude toward the facts in evolutionary science, in contrast to virtually every other branch of science. Curiously, some members of the NDT, in their more candid moments, admit the problems, or at least some of them. But never in the context of “These are the problems our theory faces, and if we can't solve them, we must abandon the theory”. Consider these remarks of Richard Lewontin, a geneticist and leader of the Neo-Darwinian school:

We take the side of science in spite of the patent absurdity of some of its constructs, in spite of its failure to fulfill many of its extravagant promises of health and life, in spite of the tolerance of the scientific community for unsubstantiated just-so stories, because we have a prior commitment, a commitment to materialism. It is not that the methods and institutions of science somehow compel us to accept a material explanation of the phenomenal world, but, on the contrary, that we are forced by our *a priori* adherence to material causes to create an apparatus of investigation and a set of concepts that produce material explanations, no matter how counter-intuitive, no matter how mystifying to the uninitiated. Moreover, that materialism is an absolute, for we cannot allow a Divine Foot in the door.<sup>24</sup>

This quotation is especially interesting, because it reveals the extent to which the NDT is driven by ideology rather than facts and evidence. It is one thing to argue that only material causes are admissible in science; it is quite another to claim that, regardless of the absurdity of the explanations they produce, they must be maintained at all costs. The empirical possibility exists—and it is empirical—that materialistic explanations may be unable to account for all phenomena without recourse to unsubstantiated, counter-intuitive, forced, or absurd explanations. Such a dogmatic attitude is the very one which the NDT criticizes vehemently when attacking the Creationists, but the irony of the

situation seems lost on the Neo-Darwinians. Even occasional conferences where problems are aired and participants generally admit that key doctrines have failed, such as extrapolation of microevolution to macroevolution,<sup>25</sup> seem to have no impact on either the conduct of research or the presentation of the theory to students and the general public.

### ***A Way to Resolve the Cambrian Explosion Problem?***

Still, there may be a way out of the conundrum. Common Descent implies not only a telescoping series of relationships, but an historical chain, and a vision of how taxonomic categories—which reflect real architectural characteristics—have arisen over time. Thus the first vertebrate, which gave rise to an entire phylum, was itself a species, of course. Its descendants changed and innovated, giving rise to animals now classified as reptiles, birds, mammals, and so forth. In this manner, taxonomy is not fixed, even if the characteristics on which it is based correspond to specific architectures or structures. Common Descent and taxonomy are thus closely intertwined, and this ineluctable relationship furnishes a means to test the theory. Let us examine this situation carefully. The first chordate, whatever form it took, was itself a member of a new species at the time of its birth. At that time, there was no phylum *chordata*; the organism would have been labeled simply as new species, *chordata*, by a biologist, had there been any present to examine it. Some descendents of that first chordate presumably mutated, and one developed the segmented backbone of the vertebrata, others the characteristics of the cephalochordata and the urochordata. At that time, our time-travelling biologist would have pushed *chordata* up one level to a genus, and the descendants of that first chordate then would be classified into the species *vertebrata*, *cephalochordata*, and *urochordata*. Over eons, this process would repeat, and *chordata* would continue to be pushed higher and higher in the taxonomic scheme, as would the descendents of the first chordate. So *chordata* would become in turn a family, order, class, subphylum, and eventually a full-fledged phylum as changes and innovations accumulate, and descendents correspondingly multiply. Thus, as new animals evolve, taxonomic categories at all levels may need to be shifted. This implies, obviously, that the highest levels, such as phyla, should appear relatively late in the development of life—that is a consequence of common descent and gradual change: it just takes a long time for the required number of innovations to develop and accumulate such that large numbers of orders and classes can accumulate under a given phylum.

But, the upward mobility of taxonomic categories such as *chordata* also reveals the risks inherent in drawing conclusions from taxonomic data with respect to chronology. This is important, because some key arguments against evolution turn on the question of whether taxonomic data and classification reflect impossible chronological sequences (See chapter 5, below). As noted above, *chordata* did not appear in the chronological sequence of life forms as a *phylum*, but as a *species*. Taxonomic classifications such as phyla are abstract entities that encompass large numbers of particular organisms—living or dead—sharing certain architectural characteristics and features. One cannot hold a phylum in one's hand, of course; even if one holds the first primitive chordate, one is still holding an individual, not a phylum or even a species. So if a paleontologist today were to find the fossil of that first chordate, he or she would still classify it by today's scheme, as a member of the phylum chordata, a particular

subphylum, class, order, and so forth, down to the species level. This is because we now know about the myriad descendents of that first chordate, which all share its architectural innovation, and our classification reflects *architecture* not *historical individuals*. Considered as an architecture, the first chordate was obviously very successful; not all innovations are so, and few species are destined to be the parent of so many offspring and thus migrate up the classification level. Indeed, it is a fundamental problem of biology to understand the limits of architectures in this sense; have all of the possible ones been found, and do only details remain to be worked out? We shall not attempt to answer this question here, but merely point it out to the interested reader. In any case, the ability to account for the type of architectural changes reflected in our taxonomic system is a key test of any theory of evolution.

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<sup>1</sup> Charles Darwin, *Origin of the Species*, (Reprint of the first edition), Avenel Books, New York: Crown Publishers, 1979, p. 292.

<sup>2</sup> Hoyle, *op. cit.*, p. 107.

<sup>3</sup> Raup, David, "Conflicts Between Darwin and Paleontology," *Field Museum of Natural History Bulletin*, **50** (1), 1979, p. 24, 25.

<sup>4</sup> Gould, Steven J., "Evolution's Erratic Pace," *Natural History* **86**(5):14 (May, 1977).

<sup>5</sup> Simpson, George Gaylord, *The Major Features of Evolution*, New York: Columbia University Press, 1953, p. 360.

<sup>6</sup> Eldridge, Niles, *Reinventing Darwin*, New York: Wiley, 1995, p. 95.

<sup>7</sup> Gould, Steven J., "Evolution's Erratic Pace," *Natural History*, **86**, (May, 1977).

<sup>8</sup> Raff, R. A. and Kaufman, T. C., *Embryos, Genes, and Evolution: The Developmental-Genetic Basis of Evolutionary Change*, Bloomington: Indiana University Press, 1991, p. 35.

<sup>9</sup> Simpson, G. G. (1944), *Tempo and Mode in Evolution*, New York: Columbia University Press, 1944, p. 105, 107, 1944.

<sup>10</sup> Eldredge, Niles, *Macro-Evolutionary Dynamics: Species, Niches, and Adaptive Peaks*, New York: McGraw-Hill, 1989, p. 22

<sup>11</sup> Wesson, R., *Beyond Natural Selection*, Cambridge, MA: MIT Press, 1991, p. 45

<sup>12</sup> Valentine, J.W., Awramik, S.M., Signor, P.W., and Sadler, P.M., "The Biological Explosion at the Precambrian-Cambrian Boundary", *Evolutionary Biology*, Vol. 25, Max K. Hecht, editor, Plenum Press, New York and London, 1991, p.284

<sup>13</sup> Valentine, J., and Erwin, D. (1985) "Interpreting Great Developmental Experiments: The Fossil Record", *Development as an Evolutionary Process*, Rudolf A. Raff and Elizabeth C. Raff, Editors, Alan R. Liss, Inc., New York, pp. 95, 96

<sup>14</sup> Cracraft, Joel, "The Scientific Response to Creationism", in *Creationism, Science, and the Law: The Arkansas Case*, ed. by M.C. LaFollette, Boston: MIT Press, 1983, p. 146.

<sup>15</sup> National Academy of Sciences, *Science and Creationism*, Washington, DC: National Academy Press, 1999.

<sup>16</sup> Woetzel, David P., "Understanding Transitional Forms", *Creation Matters* **6**(2):3 (March/April 2001).

<sup>17</sup> Gould, Steven J., and Eldridge, N., "Punctuated Equilibria: The Tempo and Mode of Evolution Reconsidered", *Paleobiology* **3**:115-151 (quote from p. 147).

<sup>18</sup> Quoted in Heeren, Fred, "Paleontologic Agitprop?," *Insight*, 24 July 2000, p. 25.

<sup>19</sup> Heeren, Fred, "A little fish challenges a giant of science," *Boston Globe*, 30 May 2000.

<sup>20</sup> Heeren, Fred, "Paleontologic Agitprop," *op. cit.*

<sup>21</sup> Quoted in Heeren, Fred, "A little fish..." *op. cit.*

<sup>22</sup> Enserink, Martin, "Fossil Opens Window on Early Animal History," *Science* **286**:1829 (3 December 1999).

<sup>23</sup> Morris, Conway, quoted in Zimmer, Carl, "Fossils Give Glimpse of Old Mother Lamprey," *Science* **286**:1064-1065.

<sup>24</sup> Lewontin, Richard, 'Billions and billions of demons', *The New York Review of Books*, January 9, 1997, p. 31.

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<sup>25</sup> Lewin, Roger, "Evolutionary Theory Under Fire," *Science* **210**:883-887 (1980).