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Biogeohistory and the development of classical biostratigraphy
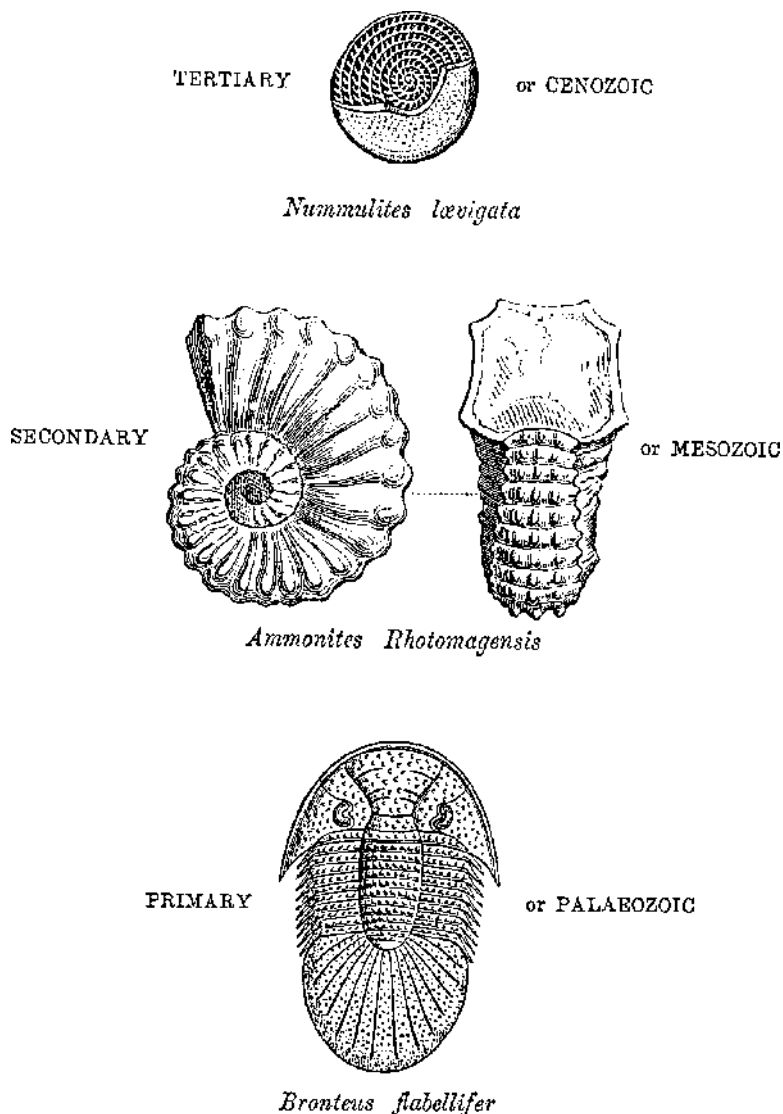
Summary

The science of geology emerged from eighteenth-century tensions between the notion of Earth-as-machine and the notion of a recoverable Earth history. Fossils had a central role in identifying formations for mapping, in building and testing a succession of life, in reconstructing ancient environments, and most of all in developing the perception that similarity among assemblages of fossils indicates similarity in geological age. There followed the ecological facies concept and the chronological zone concept, both pre-evolutionary. This chapter takes these themes up to the mid twentieth century when the stratigraphic *Guide* was in preparation and planktonic microfossils were about to dominate the biostratigraphy of the Cenozoic Erathem.

Introduction

Fossils record the fleeting tenure of species as members of the Earthly biosphere. This nagging fact made more sense of the rock relationships in the exposed parts of the Earth's crust, extracting more order from an apparently chaotic jumble, than did any other observation or speculation on rocks, or any exploration and development of mineral resources. The presence of fossils in sedimentary strata could reveal a succession of ancient faunas and floras. Simultaneously, the same observations could be used to define and recognize groups of strata: thus we have both biohistory and geohistory. Sedimentary strata containing trilobites seemed to occur above strata lacking fossils (themselves sitting on the deformed crystallines), and below other strata containing ammonites. Then there was yet another group of strata lacking ammonites but

TERTIARY   or CENOZOIC

Nummulites lævigata

SECONDARY   or MESOZOIC

Ammonites Rhotomagensis

PRIMARY   or PALAEOZOIC

Bronteus flabellifer

Figure 1.1 The fossil-based geological time scale: frontispiece of Lyell's *Student's Elements of Geology* (Lyell, 1871). Trilobites, ammonites, and the large rock-forming foraminifer *Nummulites* characterize the Palaeozoic, Mesozoic and Cenozoic Eras, respectively.

containing nummulites, the 'petrified lentils' observed by the travelling chronicler Herodotus in the blocks comprising the Egyptian pyramids. The three kinds of fossil symbolized the three divisions of the fossil record for Sir Charles Lyell, as shown here (Fig. 1.1) in the frontispiece of *The Student's Elements of Geology* (1871): the Primary or Palaeozoic, Secondary or Mesozoic, and

Tertiary or Cenozoic. That edition of the *Elements* was published about a quarter of a century after the three eras of Earth history were secured on the evidence of their fossil record and no longer on their mineralogy or lithology, and by then Lyell had accepted, ever so tardily, organic evolution as the explanation of fossil succession and its pre-eminent utility in the correlation and classification of strata.

An account of the origins of biostratigraphy, of the science and the arts of using fossils for chronological correlation and geological age-determination, can begin at one of the truly natural turning points in the story. Towards the end of the eighteenth century, James Hutton was discovering deep time, Georges Cuvier was demonstrating once and for all the fact of organic extinction, and geology was rapidly being established as an empirical discipline which would include the systematic mapping of the rocks exposed at the surface of the Earth. That was also the time that the ideas of *pre*history, *bio*history and *geo*history took hold in the collective Judaeo-Christian intellect. Although all of these notions had forerunners and precursors – 'precursoritis' usually leads us back to classical antiquity – Hancock (1977) deemed it necessary to reassert one of the great mainstays of the textbooks on historical geology, at least in the English-speaking world – that the science of biostratigraphy was founded by William Smith, that he owed nothing much of significance to earlier writers, and that the importance of his work is greater than that of any subsequent contributor to the theory of our science.

Significance of fossils

Why does a fossil occur where it does in a sedimentary stratum? Beyond the taphonomic questions of the preservation or destruction of organic remains – fossilization itself – there are the three factors of environment, geography and time. That the three factors have long been known is exemplified in this summary from the textbook by J. Beete Jukes (1862):

1)   First of all, within the same biological province there may have been differences in the 'stations', to use the naturalists' phrase, that is, the place where the fossil was buried may have been at the time either sea or fresh-water, deep or shallow water, near shore or far from it, having a muddy or a sandy bottom, or being a sea clear of sediment, and the fossils entombed at these different stations of the province may have varied accordingly.

2)   Secondly, we may pass from one 'province' to another, the two provinces having been inhabited by different but contemporaneous groups of species.

3)   Thirdly, there may have been a difference in 'time', during which a general change had taken place in the species, those formerly existing having become extinct, and others having come into existence that had not previously appeared on the globe.

It was the first of these, the ecological factor, that was appreciated the earliest, by the Greeks and the men of the Renaissance (Rudwick, 1972; Mayr, 1982). For Leonardo da Vinci and others, a sedimentary rock containing fossil shells like modern shells signified the former presence of the sea, no matter that the modern sea was many leagues' distant. Indeed, James Hutton, the discoverer of deep time (Gould, 1987), was well aware of the significance of fossils – but not as signals of time and history. There is 'not a shred of suggestion that fossils might record a vector of historical change, or even distinctness of moments in time. Fossils, to Hutton, are immanent properties of time's cycle' (Gould, 1987). Instead, the incorporation of fossils into subsequently lithified sediments indicated the operation of heat; and their presence in rocks in continents well above sea level indicated uplifting. Thus we have crucial evidence for the existence of the restorative force necessary for completing each geological cycle. Last, petrified wood was eroded from continents in earlier cycles and hence are clues to the former existence of plants (Gould, 1987). All of these inferences had their basis in ecology and environment, not in history and surely not in any perception of distinctive biological changes during geological time. And Gould probed further, suggesting that our antecedents' awareness of fossil forms not found in the living state merely revealed their ignorance of the modern biota and that this was not just an ahistorical stance but an active denial of history by Hutton.

For Teichert (1958) the science of stratigraphy developed in a logical way. First, there was the recognition and interpretation of physical characteristics of sedimentary rocks, with emphasis on *lithostratigraphy* from Steno to Werner, in the seventeenth and eighteenth centuries. Then there was recognized the orderly and meaningful succession of fossil floras and faunas in sequences of sedimentary strata, and the development of *biostratigraphy* since William Smith. The third step was the recognition of the contemporaneity of dissimilar rocks and fossil assemblages and the subsequent development of the *facies* concept from Gressly in 1838 to Mojsisovics in 1879. *Lithostratigraphy, biostratigraphy, facies*: 'modern stratigraphy rests securely on these three basic achievements of the human mind' (Teichert, 1958). Figure 1.2 exemplifies the complication and apparent falsification of the fossil record in that the primacy of the first or the third of those factors is not always clear. The related fossil species *a* and *b* are confined to different environments reflected by two sedimentary facies. At any one locality *a* is always below *b* and will be considered to be older, but in fact *a* and *b* are contemporaneous species.
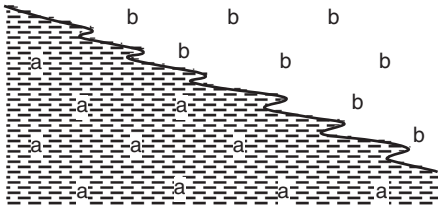
Figure 1.2 Fossils and lithology: time or environment? Two facies-bound species are consistently superposed *a* below *b*, but actually are contemporaneous – an unscaled pattern of diachrony cited by Simpson (1951) as an 'example of complication and apparent falsification of the fossil record'. Some would restrict this diachrony to within a third-order sequence (Chapter 5).

Biostratigraphy itself developed as a discipline essential to the growth of historical science on a three-part foundation (McGowran, 1986a). The three pedestals were: (i) the recognition of successional assemblages of fossils in successional strata; (ii) the successful testing and confirmation of that succession in other localities and other regions; and (iii) the perception that similarity among assemblages of fossils indicates similarity in geological age.

Laudan (1976, 1987, 1989) reassessed what the first of those points means. Is it the succession of faunas in successional sedimentary formations – on the grounds of superposition – that is important, or is it the identification of each formation by its fossil content – the sorting out, the reliable identifying of otherwise confusingly similar but separate and distinct clay strata, say, which are always exposed as discontinuous outcrops and excavations? The two aspects of fossil content are not so much contradictory as differing in emphasis. Where does the *identification* of individual formations of strata end and the *correlation* of formations begin? In the standard accounts, William Smith's use of fossils in stratigraphy may have begun in the former endeavour but established the latter. His subsequent celebrants, beginning with his canonization by Adam Sedgwick in 1831, identified Smith as the person most of all responsible for the overthrow of the neptunist stratigraphies of the eighteenth century, based as they were on a perceived, consistent succession of lithology and mineralogy. This preeminence of fossils in correlation, linked to the independence of fossils from sedimentary facies in what came later to be called the Phanerozoic Eon, was stated most clearly by John Phillips in 1829, and 'this conception can scarcely can have been foreign to William Smith ten years earlier, though we seldom find it formulated' (Arkell, 1933). Arkell continued, interestingly, 'It is only occasionally that a gleam of light reveals the inner working of men's minds about this time, for the output of a great

mass of important descriptive matter was engaging most of their attention' – they knew about the temporal significance of fossils but they were too busy exploiting it to write in general terms about it.

But Laudan claimed that Smith's actual work was based instead on the following convictions – the constant *order* of strata and the constant individual *properties* of strata including mineral content, fossil assemblage and, most importantly, topographic expression. Smith's real contribution (in this view) was in tracing and mapping the course of strata from outcrop to outcrop in England rather than in establishing the use of fossils in identifying the strata. In the Paris Basin, Cuvier and Brongniart showed that the Alluvial of the neptunists was a complex succession of formations that could be traced over 120 km and more by means of the consistent succession of their fossils. In both of these programmes credited with establishing historical geology and history biology based in sound biostratigraphy, then, successional assemblages were established as a fact of biohistory that could be confirmed in different sections of sedimentary strata.

Now contemplate Fig. 1.3 and Fig. 1.4, highly idealized and simplified versions of transgression-regression cycles, and quite anachronistic in being cartoons more at home in the twentieth century than in the early nineteenth, being based on Israelsky's (1949) oscillation chart which has some basis in reality (e.g. Poag, 1977, Fig. 4) (although clearly pre-sequence stratigraphy; see Chapter 5). In Figure 1.3 three distinct biotic realms produce fossil assemblages namely plant (non-marine), mollusc (neritic) and foraminifer (offshore). They can be utilized in two distinct ways – to identify and to discriminate those strata in distant locales, along with lithological and mineralogical criteria; and to demonstrate faunal and floral succession in which the higher respective assemblages must be younger by superposition. Note too that within each assemblage there are waxing and waning distributions producing 'time-transgressive' or *diachronous* configurations. The dualism of identification and age demands some consideration of the meaning of *correlation*. Broadly, in stratigraphy, to correlate is to show correspondence in character and in stratigraphic position. That includes the tracing of stratigraphic units between discontinuous outcrops, or through the subsurface from one control section to another using lithological, physical and/or palaeontological criteria. Several authors have advocated that broad use of the term (e.g. Shaw, 1964; Hedberg, 1976), but it refers rather to the *identification* of sedimentary formations, their boundaries, and included members and horizons. More restrictively and more appropriately, according to some (e.g. Rodgers, 1959; Raup and Stanley, 1978), correlation means *chrono*correlation – establishing the time-equivalence of two spatially separate stratigraphic units (McGowran, 1986a).
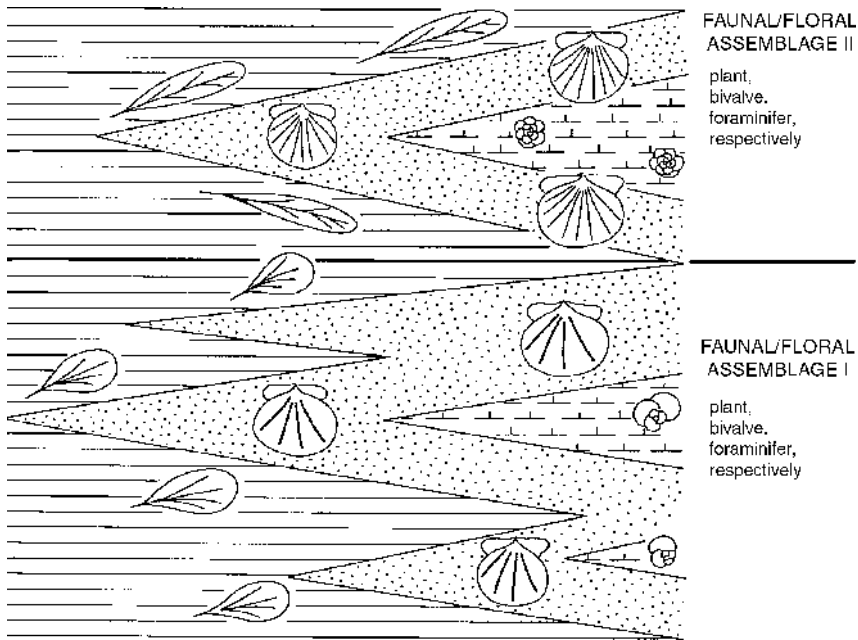
Figure 1.3 Fossil succession in three biofacies in a pattern of transgression-regression (McGowran, 1986a). This sketch was contrived to demonstrate two things – lateral movement of non-marine, neritic and marine biofacies in response to environmental shifts but also a change in time, allowing recognition of two successional assemblages within each biofacies. Concurrence of the three ensuing boundaries at the heavy line might be a kind of coordinated stasis (Chapter 6).

We can follow this matter of fossil assemblages and their chronological significance a little further in Figure 1.4, where there are fossil assemblages that follow shifting lithologies (thus shifting environments in life) as in Figure 1.3, in contrast to assemblages that do not so shift. The latter category is illustrated by three successional assemblages of pollen grains whose mutual boundaries cut across lithological boundaries because pollens are blown out to sea (we ignore here such complications as subsequent destruction by oxidation); it is illustrated too by assemblages of planktonic foraminifera whose mutual boundaries likewise cut across lithologies where elements of the living communites come inshore. There are two concepts here. First, there is the concept of *facies* which appeared in the 1820s, on lateral intergradations in lithology (Young and Bird in England; Amos Eaton in New York) and on the observation that the same fossils can occur in different lithologies (Brongniart in France). Brongniart realized the tremendous possibilities afforded by this independence of some fossil distributions from lithological facies (Hancock, 1977) – the

palynomorphs

planktonic
foraminifera

ZONE III

ZONE C

ZONE II

ZONE B

ZONE A

ZONE I
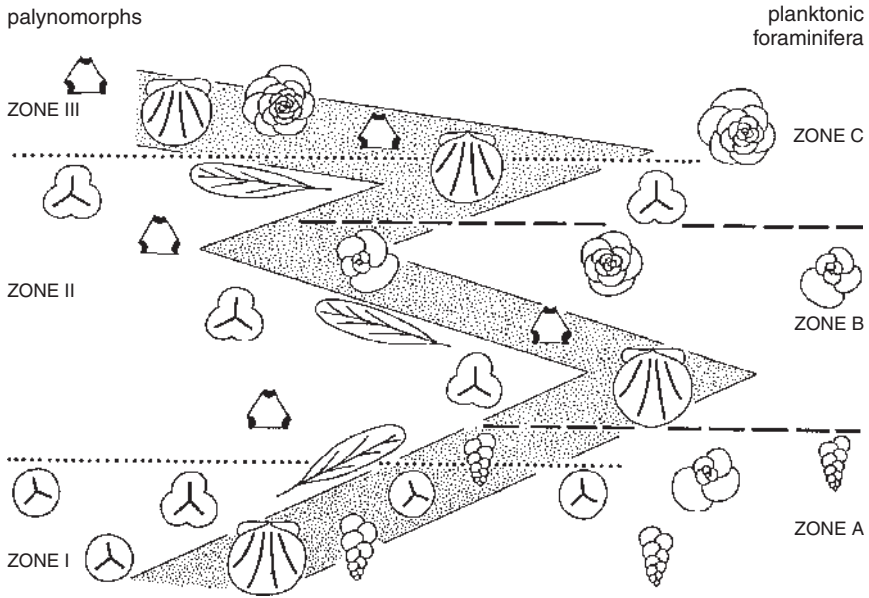
Figure 1.4 Biofacies migrations (non-marine, inshore, offshore) as in Fig. 1.3, with two sets of biozones based on the fossils of mobile and relatively facies-independent organisms (McGowran, 1986a). Two sets of three biozones can be recognized on the highest occurrences respectively of pollens (dotted lines) and planktonic foraminifera (dashed lines). Nothing in this diagram proves that biozone boundaries are 'time-parallel' but it is a reasonable and testable working assumption that they come close to that situation.

possibilities of (in subsequent jargon) long-distance *chronological biostratigraphic correlation*. This is the second concept (McGowran, 1986a).

Zones and zonation through a century

Laudan (1982) identified a turning point in the 1820s in the advent of Smith's nephew and protégé, John Phillips:

> In deciding to use fossils as the key to the succession, Phillips was altering the whole basis of mapping. On Smith's map, a band of uniform color represented strata with particular geographical positions and similar surface features, and in addition, Smith assumed without question, a similar place in the succession, similar lithology and similar fossils. On Phillips' map, however, the bands of uniform colour represented strata containing the same fossils, and therefore, he assumed, *occupying the same place in the succession whatever their lithology* (emphasis added).
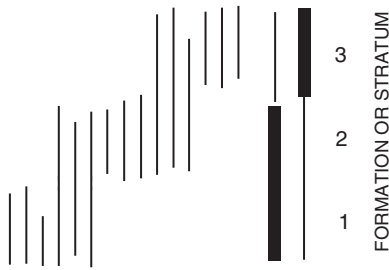
"That a formation or stratum may differ from all those
above it, by the presence or absence of certain species,
and from all those below it, by the presence or absence
of other species:
"That it may contain some particular species, unknown
either above or below. We may add, that formations and
strata differ by the relative abundance or paucity of
their imbedded fossils."
                                                        John Phillips, 1829

Figure 1.5 This hypothetical range chart is a reasonable rendering of Phillips's (1829) verbal summary (McGowran, 1986a).

By 1829 Phillips himself could state bluntly:

> for since it thus appears, that a few shells brought from a quarry, are data sufficient to determine the geological relations of the rock, we are entitled to conclude, that in a given district the age and position of certain strata, or groups of strata, are infallibly indicated by their organic contents. These researches, commenced by Mr Smith in England, have been extended with the same results over all parts of Europe, and a large portion of America, and therefore it is concluded that strata, or groups of strata, are to be discriminated in local regions, and identified in different countries, by their imbedded organic remains

Figure 1.5 shows visually Phillips's (verbal) conclusions as quoted therein (McGowran, 1986a). The 'formation or stratum' would appear to be a biostratigraphic zone except for the anachronism – such formalizing of fossil successions simply did not happen yet. It is instructive to consider an authoritative textbook account twenty-odd years later. As quoted already, J. Beete Jukes outlined the constraints on fossil distribution; he used a sketch (Fig. 1.6 herein) to discuss them. 'Let there be', wrote Jukes, 'a great series of rocks divisible into three groups *A*, *B*, and *C*, each with alternations of argillaceous, arenaceous, and calcareous strata. Each lithology in *A* will contain characteristic fossil assemblages *a*, *b*, and *c*, respectively, which also will recur so that the assemblage
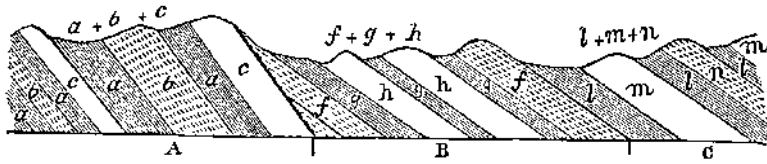
Figure 1.6 Hypothetical fossil succession in a 'great series of rocks' (Jukes, 1862, Fig. 105). Strata are grouped into *A*, *B* and *C*. Each group contains recurring lithologies characterized by (also recurring) fossil assemblages (*a*, *b* and *c* in group *A*). In the higher groups of strata, the still-recurring lithologies contain new fossil assemblages which recur for a time in their turn ($f+g+h$ in *B*; $l+m+n$ in *C*).

overall for group *A* will be $a+b+c$. But as we pass up into group *B* we will encounter a different set of assemblages, $f+g+h$ in their respective lithologies, even though those lithologies may be indistinguishable from their counterparts in group *A*. And likewise for assemblages $l+m+n$ in group *C*.' Jukes's point was that there are two reasons for differences among fossil assemblages – environmental contrasts and the lapse of geological time: what he called *the law of the distribution of fossils*. Interestingly, Jukes began this discussion with three groups of strata but he does not end it with any zonation, or any other classification of fossil distribution, even though the detailed collecting with reference to stratal position, and that careful biotaxonomy on which progress depends, had been proceeding in various parts since the 1820s.

For Jukes did not refer to the work of Albert Oppel, published in 1856–58 and identified in due course as the 'birth of biostratigraphy as a separate discipline' (Hancock, 1977). What was special about the work of this man 'who was to place the whole science of stratigraphical geology on a new footing and to breathe new life into it' (Arkell, 1933) and then died, even younger than Mozart? Adapted from a figure by Berry (1977, Fig. 1), Figure 1.7 is intended to illustrate Oppel's principle of biostratigraphic zonation. There are two noteworthy points. First, the column is composite, representing a district in which several exposed sections of strata contribute to the succession – the process of piecing a succession together is there right at the beginning; and likewise with the ranges of carefully collected and identified fossils. Second, there are two ways in which the zones labelled I to IV are distinguished. The zone I/II boundary, for example, is in the vicinity of three last appearances and two first appearances of species. Each of those species can contribute to the recognition of that boundary in some other district if so required. Also, however, the association of species characterizes each zone. That is, we have here both *assemblage* criteria and *boundary* criteria. It is the first point that is the more important – Oppel emphasized that whilst the correlation of groups of strata had been achieved, 'it has not been
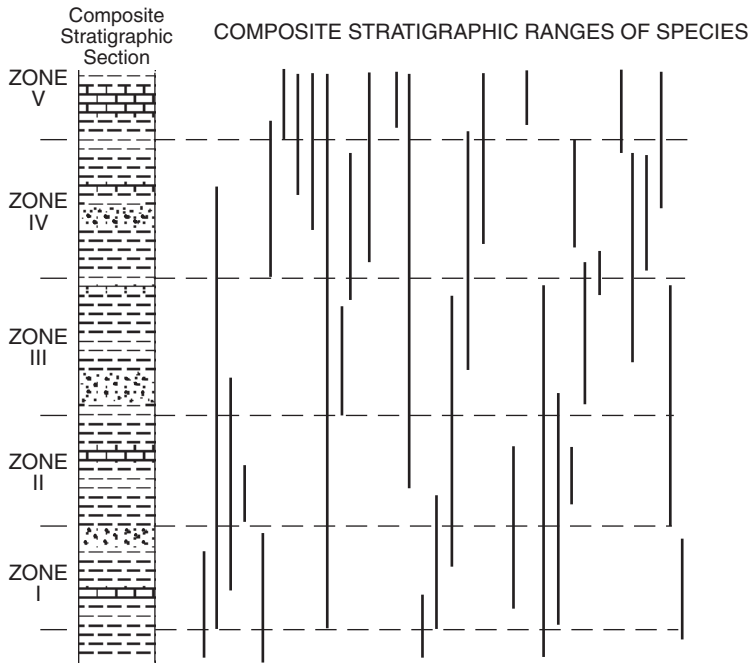
Figure 1.7 Oppel's principle of zonation (McGowran, 1986a, based on Berry, 1977). The section and the range chart are both composite for the district or region. The divisions labelled zones are clear enough – but were Oppel's zones in the rocks (the 'British' view) or were they idealized or abstracted, temporal terms (the 'German' view)?

shown that each horizon, identifiable in any place by a number of peculiar and constant species, is to be recognized with the same degree of certainty in distant regions. This task is admittedly a hard one …' (from Arkell, 1933). And from these regional profiles one may develop the ideal profile, of which '… the component parts of the same age in the various districts are characterized always by the same species' (from Arkell, 1933). Oppel did not tease out the somewhat pedantic classification of zones, as happened later; and, indeed, he neither invented nor anywhere defined what he meant by a zone (Arkell, 1933). There was already a respectable list of forerunners to Oppel in the study of fossils in strata (e.g. Arkell, 1933; Moore, 1941, 1948; Conkin and Conkin, 1984; among many), but to him

> … is due not the credit for the inception of the zonal idea, but for a very great refinement in its use, and, most important of all, for emancipating the zones from the thralls both of local facies, lithological and palaeontological, and of cataclysmic annihilations, thus giving

> them an enormous extension and transferring them from mere local records of succession to correlation-planes of much wider (theoretically universal) application (Arkell, 1933).

'For we have here the beginnings of a detailed and generally applicable time scale, abstracted from local lithological and paleontological considerations', said Arkell, who made a striking comparison with the affairs of men:

> Before it geological history had been as confused as the history of Assyria and Babylonia at the time of the city-kingdoms, each with its own local chronology, overlapping those of its neighbours. Since Oppel, historians have been provided with an orderly system of dynasties, subdivided into reigns, and even in countries as distant as the Himalayas it has been possible to discern marks appropriate to the periods when the more important of the dynasties held sway, although the influence of the individual reigns was not always felt outside North-Western and Central Europe.

For Schindewolf (1950, 1993) palaeontological zonation is chronology – a 'purely temporal' system and not actually stratigraphy; he was certain that both d'Orbigny and Oppel assigned a temporal, abstract meaning to 'zone', and he rejected the spatial concept of a zone comprising the actual rocks with their fossils.

Since the times of Oppel and with one major exception remarkably little has happened in the field of zonation, *sensu stricto*. Consider Figure 1.8, which summarizes various kinds of biozone defined and discussed by the International Subcommission of Stratigraphic Classification (ISSC) (Hedberg, 1976) – a century and more later (McGowran, 1986a). The zones fall largely into three general types: (i) there is the 'distinctive natural assemblage' which allows grouping of strata into an *assemblage zone*; (ii) the range or ranges of selected taxa give us *range zones* including the various kinds of interval zones, whose distinction is rather pedantic; (iii) fluctuations in the abundance of a taxon give the *acme-zone* (of 'lesser importance'). There is little here that was unknown to Oppel. Arkell's (1933) superb discussion of the topic devoted most space to the changes in abundance on which Buckman based the hemera – the first unit of geologic time using the acme of a taxon. Probably the major advances in the late nineteenth century were Charles Lapworth's on Ordovician–Silurian graptolites (Fortey, 1993) – but these were applied in unpacking structural complexity. Indeed, Fortey emphasized the durability of biostratigraphic data in contrast to the contingencies of structural and palaeo-geographic inference.
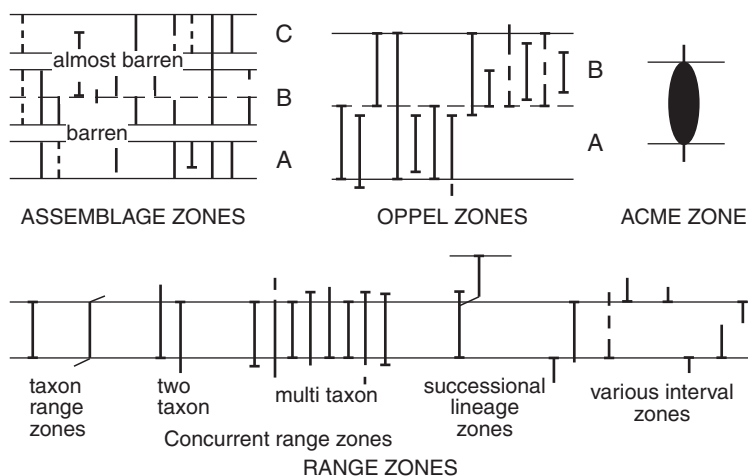
Figure 1.8 Kinds of biostratigraphic zones, redrawn from ISSC figures (Hedberg, 1976; McGowran, 1986a).

But lurking in Figure 1.8 are two examples of a notion not available in any cogent way to Oppel, even though it was to erupt towards the end of the same decade – the notion of organic evolution and consequently of ancestor-descendant relationships among species and the shape of their genealogy, or *phylogeny*. There is quite a difference between a range zone, of whatever stripe, based on rigorous, comprehensive collecting, identification of species and compilation of species' ranges, and a range zone based on the phyletic emergence of a species from its ancestor and its subsequent extinction. Likewise, it is one thing to to define a zonal boundary on the top of the range of a species in the local rocks, and quite another to define it on that species' extinction (although the acceptance of the fact of extinction preceded acceptance of the fact of phylogenetic origin by half a century) (McGowran, 1986a). Although in both cases one might reasonably expect the field observations cumulatively to approach the evolutionary interpretation asymptotically, there is a major conceptual shift involved.

But 74 years after the publication of *On the Origin of Species*, Arkell spent very little time on lineage zones. Although studies such as the lineage zonation based on the evolution of the Late Cretaceous echinoid *Micraster* date back to the 1890s, they do not seem to have loomed large in Jurassic biostratigraphy by the 1930s. On the other hand, Arkell did focus on the difference between the 'total' range of a taxon on which the biozone is based, and the 'local' range in the rocks, which gives the teilzone. If the time-equivalent of the biozone is the biochron (Table 1.1), then 'The ideal biochron is as elusive as the ideal hemera';

Table 1.1 *Zones (assemblage and single species) and their chronological equivalents*
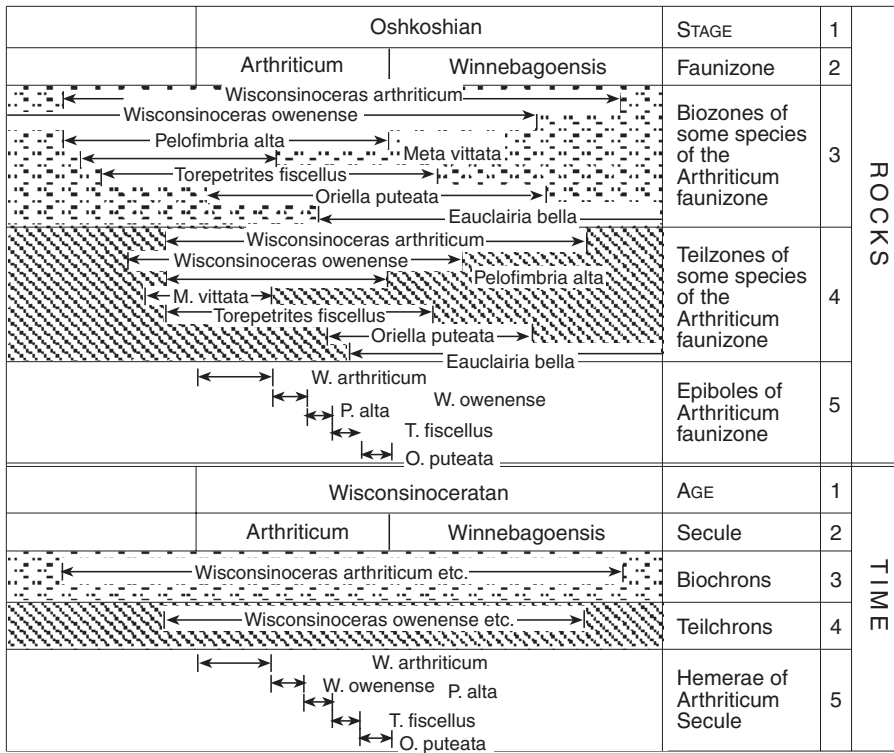
Basis	Stratal term	Chronological term
Zones based on assemblages		
acme or duration	faunizone	secule or moment
	(German Faunenzone)	(Zeitmoment or Zonenmoment)
Zones based on single species		
acme	epibole	hemera (Blützeit einer Art)
absolute duration	biozone	species-biochron (Absolute Lebensdauer einer Art)
local duration	teilzone	teilchron (Locale Existenzdauer einer Art)

From Arkell (1933), with permission.

and, we can dispense with the local range-zone, the teilzone, 'only when we are able to deal with lineages' – but, 'Unfortunately, opportunities for making use of lineages in zonal work are extremely rare'.

We find a closely similar outlook and assessment in Moore's review of stratigraphical palaeontology (1948). 'The concept of biozones seems to have little practical value, inasmuch as the total range of the guide fossil controls definition; the observed vertical distribution of most fossil organisms varies from place to place, and total range always is difficult to determine with certainty.' Moore gave us a comprehensive if fictitious sketch of taxa and ranges to show the relations of time divisions and their equivalents based on fossil invertebrates (Fig. 1.9). It is revealing to one inured in the use of microfossil zones and datums (Chapter 2) to see how Moore's chart treats biozones–biochrons and especially teilzones–teilchrons. Thus, the total local or 'absolute' range is treated for each taxon. There is no discussion here of the notion of lining up – *ordinating* – events from different taxa in succession – first and last appearances; tops and bottoms of the teilzones – so that that succession can be subjected to test elsewhere and the nagging problem of incomplete ranges can be resolved. Perhaps that is the most telling illustration of the difference between the essentially neritic fossil record, including the remains of mobile and often highly mobile organisms, and the mostly bathyal and oceanic fossil successions to be considered in Chapter 2.

Even so, there is no clear caesura from the noble traditions of invertebrate fossil biostratigraphy to the newer notions of micropalaeontology. We shall see that there is more in common between the classical times of the discipline and the present than we proselytes tend to remember (see also Kleinpell, 1979).

|				
Oshkoshian		Stage	1	
Arthriticum | Winnebagoensis		Faunizone	2	
Wisconsinoceras arthriticum — Wisconsinoceras owenense — Pelofimbria alta — Meta vittata — Torepetrites fiscellus — Oriella puteata — Eauclairia bella		Biozones of some species of the Arthriticum faunizone	3	ROCKS
Wisconsinoceras arthriticum — Wisconsinoceras owenense — Pelofimbria alta — M. vittata — Torepetrites fiscellus — Oriella puteata — Eauclairia bella		Teilzones of some species of the Arthriticum faunizone	4	
W. arthriticum — W. owenense — P. alta — T. fiscellus — O. puteata		Epiboles of Arthriticum faunizone	5	
Wisconsinoceratan		Age	1	
Arthriticum | Winnebagoensis		Secule	2	
Wisconsinoceras arthriticum etc.		Biochrons	3	TIME
Wisconsinoceras owenense etc.		Teilchrons	4	
W. arthriticum — W. owenense — P. alta — T. fiscellus — O. puteata		Hemerae of Arthriticum Secule	5	

Figure 1.9 Relationships of time-rock and time divisions defined mainly or wholly on fossil invertebrates (Moore, 1948, Fig. 5, with permission). Moore's caption continues: 'The divisions of varying rank are designated by fictitious stratigraphic and paleontologic names, which are nonexistent in literature. They are intended to illustrate concepts in zonation and corresponding segmentation of geological time.'

Schindewolf (1950, 1993) acknowledged the applied and economic impact of micropalaeontology (Croneis, 1941) but stoutly rejected any claims of a new and revolutionary methodology, of epistemological autonomy, or of it being '*the* paleontology of the future'.

Whilst Moore (1941) was presenting a splendid, still relatively early example of the power of microfossil (foraminiferal) zones dipping seawards in the Tertiary of the US Gulf Coast region (Fig. 1.10), problems were accumulating in perceiving distinctions between facies fossils and chronologically significant fossils. Among several examples appreciating this divergence, the paper by Lowman (1949) is outstanding in its imaginative use of the dense subsurface sampling of the US Gulf Coast and its exploiting the actualistic link between modern and ancient patterns in foraminiferal distribution and biofacies. The appreciation of such patterns was not new but the sheer accumulation of both
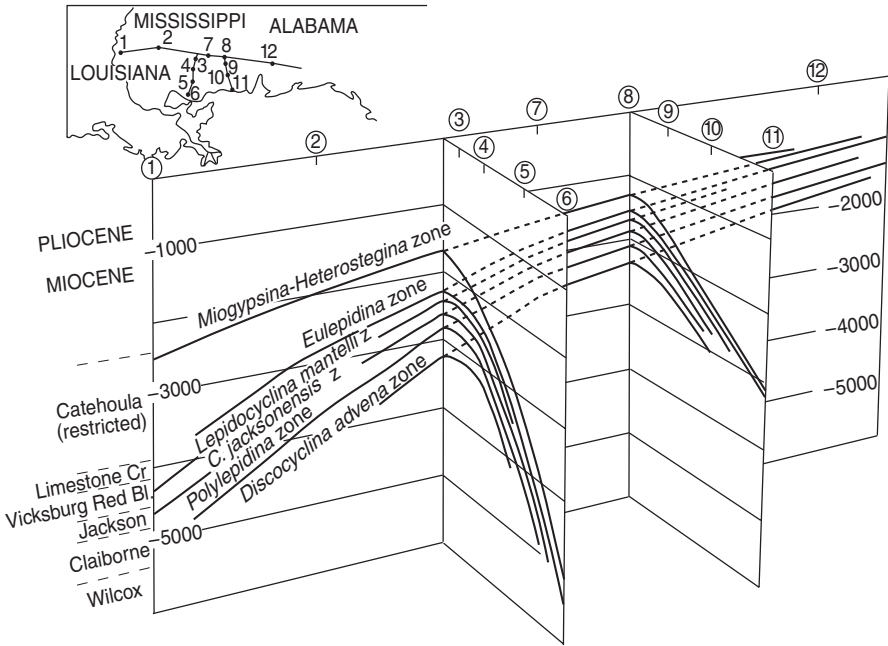
Figure 1.10 Foraminiferal zones in the subsurface, Eocene–Miocene, US Gulf Coast (Moore, 1941, Fig. 12, with permission). The genera are large, photosymbiotic, warm-water, benthic forms. The succession is consistent, along strike and downdip, and could be used in rotary cuttings, not just cores.
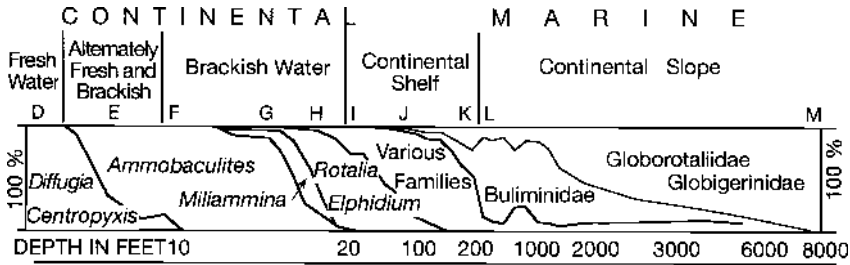

Figure 1.11 Percentage abundances of foraminifera delineating modern biofacies in a composite profile, Mississippi delta and Gulf of Mexico (from Lowman, 1949, Fig. 12, with permission). The pattern was built by connecting bar graphs at each station D to M.

samples and specimens was overwhelming. Lowman demonstrated the biofacies belts from freshwater environments to the slope (Fig. 1.11); if sea level rose or fell, not too fast for the communities to keep up, then biofacies must be diachronous (Fig. 1.12). Thus an updip-downdip section (Fig. 1.13) will display a 'climb' across bedding planes in the downdip or seaward direction by the
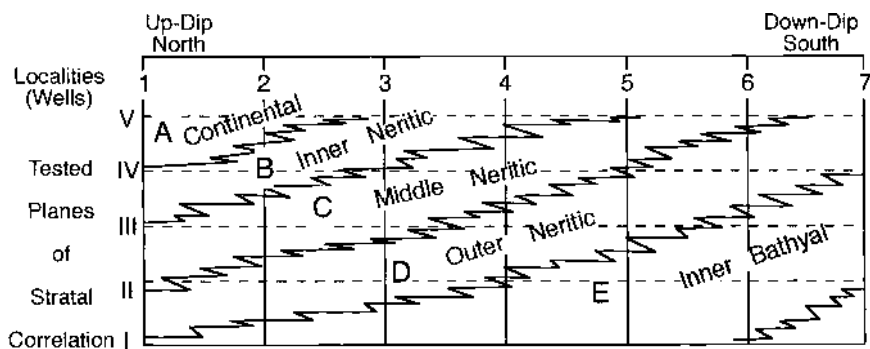
Figure 1.12 Diachronous biofacies 'climbing' in downdip direction as they cross 'tested planes of stratal correlation' I–V during sustained regression (Lowman, 1949, Fig. 28, with permission). The facies could be rapidly determined in the Oligocene and Neogene using the broad modern pattern shown in Figure 1.11.
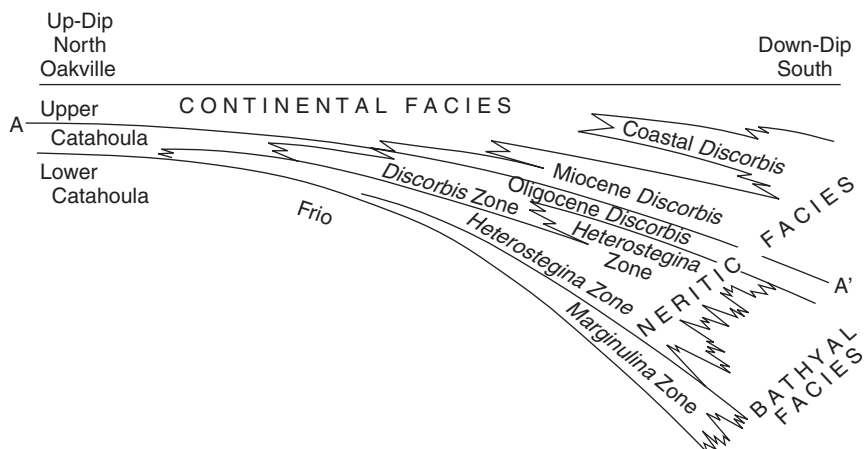

Figure 1.13 'Climbing' downdip (seaward direction) by the (benthic foraminiferal) *Heterostegina* and *Discorbis* zones is illustrated in an Oligo-Miocene depositional unit (Lowman, 1949, Fig. 3, with permission).

Discorbis and *Heterostegina* zones, based on two prominent genera of neritic benthic foraminifera. A generalized sketch demonstrated a perceived distinction between the environmentally more robust species, longer-ranging and distributed more widely, and the narrowly constrained guide species (Fig. 1.14). Another, emphasizing the penetration of neritic facies by richly fossiliferous spikes from the bathyal realm (Fig. 1.15), foreshadowed the notion of the maximum flooding surface, forty years later (as pointed out by Loutit *et al.*, 1988). Most of the intervening years were devoted to the development of the
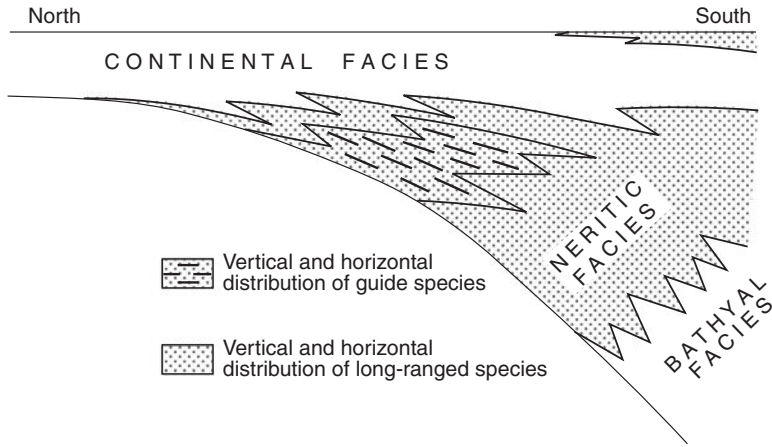
Figure 1.14 'Diagrammatic cross-section of a cyclical sedimentary unit, showing the distribution of long-ranging species and guide species' (Lowman, 1949, Fig. 26, with permission).
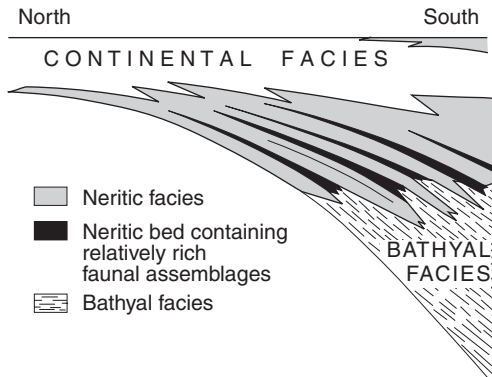
Figure 1.15 'Diagrammatic cross-section of cyclical sedimentary unit, showing distribution of richly fossiliferous streaks (black) in neritic facies' (Lowman, 1949, Fig. 27, with permission). This figure was used by Loutit *et al.* (1988) to illustrate the notion of condensed sections and flooding surfaces (Chapter 5).

'true' index fossils – the microplankton – and so this split between 'facies fossils' and 'index fossils' was perpetuated. We deal with the plankton beginning in Chapter 2, but we return to this dichotomy in Chapter 5. Lowman's superb demonstration of foraminiferal biofacies in space and time is a natural point to conclude this selective outline of 'classical' biostratigraphy.