# Biostratigraphy

*Microfossils and Geological Time*

Using fossils to tell geological time, biostratigraphy balances biology with geology. In modern geochronology – meaning timescale-building and making correlations between oceans, continents and hemispheres – the microfossil record of speciations and extinctions is integrated with numerical dates from radioactive decay, geomagnetic reversals through time, and the cyclical wobbles of the Earth-Sun-Moon system. This important modern synthesis follows the development of biostratigraphy from classical origins into petroleum exploration and deep-ocean drilling. It explores the three-way relationship between species of micro-organism, their environments and their evolution through time as expressed in skeletons preserved as fossils. This book is essential reading for advanced students and researchers working in basin analysis, sequence stratigraphy, palaeoceanography, palaeobiology and related fields.

BRIAN MCGOWRAN worked as a governmental and consultant geologist-palaeontologist in Australia, New Guinea and the southwest Pacific for several years. For three decades he was an academic, teaching and supervising in a wide range of the Earth sciences, and he has held visiting positions at the Universities of Vienna and Princeton and at the Geological Survey of Austria. His previous publications include technical books on geological excursions through the famous and touristic Cenozoic outcrops of southern Australia, as well as over 200 journal articles. Oceanic drilling in the Indian Ocean in the early days of the Deep Sea Drilling Project anchored his long-time interest in the history of the Cenozoic Era and especially on the interplay through geological time of the three environmental realms – the terrestrial and oceanic realms, and the shallow seas spilling across the continental margins, the neritic realm, in between. His main focus in recent years has been the geological record of southern Australia, a locale that has had the front-row seat witnessing the birth and development of the Southern Ocean, engine room of the cooling planet during the Cenozoic Era.

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*Geological Time*

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For the six women in my inner universe:

Fiona, Heidi, Lisi, Rosi, Jasmine

and

Susi

# *Contents*

# *Preface*

Some geologists and palaeontologists recount their awakenings as occurring while collecting minerals and rocks, or when suddenly seeing – really seeing – fossils in rocks for the first time. Others chose geology to fill in the fourth subject in first-year science, as not much more than a happy accident. Many of the teachers at my high school were of the Depression generation for whom teaching was the main career option before the war, and some were indeed excellent in the mathematics-science area. But becoming a successful junior cricketer was more important to me than becoming a scientist. In those days science for the A-stream comprised physics, chemistry and maths, all of which held some interest for me, but that was all. Botany or physiology were for girls, and evolutionary biology and geological time remained as much a shrouded mystery for my generation as it was for our otherwise well-educated antecedents. I came upon W. W. Norton's *Physical Geology* (1915) by chance at the age of 16 – it had belonged to an aunt who did Geology I with Douglas Mawson – and I became entranced with theories of the landscape and its history which, together with other natural history and human history, were quite absent from my formal education. When I should have been studying for the public exams, I was digging around in the geology section of the Adelaide public library.

Without being very self-aware about it, I was groping towards the realization that Earth and life evolution and history were what really mattered. There were unsettling experiences on the way – my first-ever Geology I practical was on wooden models of crystals and the first zoology lectures were on the chemistry of carbohydrates. This was the old inductionist philosophy at work – begin with the atoms and molecules and work up to grand notions such as Earth history or organic evolution, no matter that it is they that make their sciences autonomous (I encountered that word only years later). I learned a lot from rather few people and more from chatting with some of them than sitting through lectures.

Another life-bending experience was a summer in the Bureau of Mineral Resources in Canberra after second year – the field veterans advised me that palaeontology was women's work and tended not remunerate as well as the managing of field-mapping parties did (because camp leaders managed cooks and drivers and palaeontologists did not). Constructive encouragement from numerous geologists and palaeontologists when Australian Geological Surveys and academic departments were strong was the best education possible for a young, naïve and brash enthusiast. Education was a bit patchy, but discovering the soul of geology in rock relationships and Earth history surely compensated for the gaps. I owe Martin Glaessner and Mary Wade incalculably for encouraging voraciously wide, curiosity-led reading. Pettijohn's sediments, Marshall Kay's geosynclines and Kuenen's marine geology were exciting enough in the mid 1950s, but pale in retrospect compared to the Big Three of the second Darwinian revolution in evolutionary biology, the modern synthesis – Dobzhansky's *Genetics and the Origin of Species* (1937), Mayr's *Systematics and the Origin of Species* (1942), and Simpson's *Tempo and Mode in Evolution* (1944).

My first research was in Cambrian stratigraphy and field mapping before entering micropalaeontology, not answering any great calling or foreseeing a powerful research programme but for the (perceived) money and a confused dream of singing calypsos on Trinidadian beaches one day. Instead, I became very interested in the microanatomy, taxonomy and stratigraphy of the foraminifera. With no scanning electron microscope and no computer drafting, we did our own thin sections, washing and picking, drawing and photography of specimens and plate preparation for publication (my amateurish drawings became embedded in the main reference works of the field). Writing a thesis on the Mesozoic–Cenozoic boundary in Australia, publishing too little of it, and becoming a consultant to exploration was followed by an appointment to supervise the Palaeontology Section in the Geological Survey of South Australia – all of which gave me an abiding respect for how applied palaeontology interacted with mapping and drilling and for the workings of organizations outside the ivory tower. And here we are.

### About this book

George Gaylord Simpson prefaced his *Principles of Animal Taxonomy* with this quote from A. J. Cain: 'Is it not extraordinary that young taxonomists are trained like performing monkeys, almost wholly by imitation, and that in only the rarest cases are they given any instruction in taxonomic theory?' So, too in biostratigraphy – how do we expound our subject? There are those with horrible memories of having to memorize lists of index fossils, for example of the British

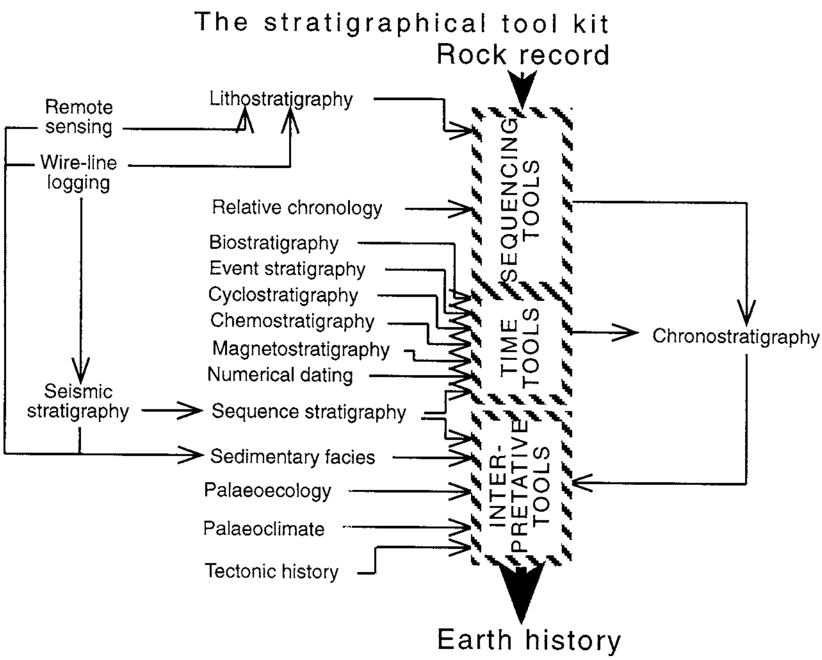


**Figure 0.1** From the rock record to Earth history: the context of modern biostratigraphy in the stratigraphic tool kit with its three boxes of sequencing, time and interpretive tools (Doyle and Bennett, 1997, with permission). The modern kit is more complex in its available technologies than were the kits of earlier times. Biostratigraphy is not the only biology feeding into this kit of sequencing tools, time tools and interpretative tools transforming the rock record into earth history. Nor is it desirable to constrain the scope of the term 'biostratigraphy' to fossil ranges and zones. For example: event stratigraphy contains many bioevents as well as physical events; and chemostratigraphy relies heavily on an understanding of the biology of the organisms that record chemical signals in their fossilizable skeletons.

or the German Mesozoic; and many will have been lost to geology forever, for that feat of memory. Is there any more to biostratigraphy than that – than determining fossils and testing their constant ranges, over and over again, and doing an inventory of the various combinations prefixing '-zone'? What could be more empirical than the building of a fossil succession in the absence of a coherent theory of that succession, as in the early nineteenth century? Fossils are where you find them – a guide fossil remains a guide fossil only until it has been discovered in the wrong place. All very inductive, all very solemn and, well, excitement-challenged. Modern stratigraphy and biostratigraphy reside in a more complex and integrated 'tool kit' employed more ambitiously (Fig. 0.1).

What is the meaning of 'biostratigraphy', the word itself? The best, most comprehensive still modern exposition is Teichert's (1958). According to

Teichert, the word itself seems to have been introduced by Louis Dollo in 1904 to cover 'the entire research field in which paleontology exercises a significant influence upon historical geology', and biostratigraphy thus defined would now embrace several other palaeodisciplines – all of those concerned with the reasons why fossils are found where they are – Jukes's (1862) factors of environment, geography and time (Chapter 1). Diener's *Grundzüge der Biostratigraphie* (1925) covered all of this. Biostratigraphy was defined later as palaeontological stratigraphy, or as stratigraphy with palaeontological methods. (A corollary was: sedimentology is stratigraphy without the fossils.) Teichert outlined the three aspects of the study of fossiliferous stratified rocks thus: (i) their division into locally mappable units, (ii) the local sequence of fossil assemblages in the rock units, and (iii) the correlation of the rocks through the evidence of their contained fossil assemblages. We find that little had changed by the 1970s in the *International Stratigraphic Guide*, in which biostratigraphy was defined as 'the element of stratigraphy that deals with the remains or evidences of former life in strata and with the organization of strata into units based on their fossil content' (Hedberg, 1976). It is clear enough, and reasonable, that the geology of fossils receives more emphasis in biostratigraphy than does the biology of fossils, for biostratigraphers work in a geological environment. Even so, a recent and forward-looking definition is interdisciplinary (Simmons *et al.*, 2000): 'Biostratigraphy is the study of the temporal and spatial distribution of fossil organisms.'

Biotaxonomy and biostratigraphy are two of the quintessentially historical-scientific disciplines, linked through their bonds in the fact and theories of organic evolution at geological timescales; and linked too in their common concerns with historical contingencies – the emergence and the extinction of countless species, for a start. An enquiry into biostratigraphy should include our correlations and age determinations. What are we actually employing under the appellation 'fossils' – species or higher taxa, or biocharacters? This question confronts the evolutionary dualism of taxic evolution and transformational evolution (Eldredge, 1979), which (I find) is a useful way to approach the question of what we actually correlate with (Chapter 4). Why, for example, have biostratigraphers had a cavalier attitude toward fossil population samples and what was once known as the 'species problem'? (Known, that is, in palaeontology; the species problem still thrives in philosophy (Chapter 8).) Can we have finely split, index-fossil 'species' simultaneously with taxa sufficiently robust to contribute to the rejuvenating field of the fossil record in macroevolution? Or will we make a clean break with the clutter of the Linnaean system of classification and identification and go down the road of some kind of 'operational taxonomic unit' (in the charmless neologism of the 1960s: Hull, 1988) more amenable to the accountancy of the computer age? Also surviving is the ancient question of why some fossils or groups empirically seem to be more useful than others – the opposite of the 'living fossil'. There is yet another hoary problem of interest and (I think) importance: are there natural biostratigraphic units? I refer to the perceptions of fossil assemblages as remains of ancient communities and to the search for punctuations of the fossil succession, both subsumed at times under 'ecostratigraphy', which implies something beyond the dry empiricism of selecting and baptizing zone fossils. This is drawn together in Chapters 4 and 6 – biostratigraphy and biohistorical theory.

But the results of Phanerozoic organic evolution comprise a vast and sprawling panorama of body fossils and trace fossils and their assemblages. There has to be a selection of material. Easily the best approach is via the record revealed by the Deep Sea Drilling Project (DSDP) and the Ocean Drilling Project (ODP) and their forerunners in subsurface geology and basin analysis driven by petroleum exploration. I am referring to marine micropalaeontology in the later Phanerozoic eon and mostly in the Cenozoic Era. Certainly the planktonic foraminifera and other phyto- and zoo-protists have no monopoly over our changing insights into biostratigraphy in recent decades. But they do have a dominating physical presence in the literature at the cutting edge of the disciplines, just as they are retrieved in their thousands in cores from the depths of continental and oceanic basins, in the latter often actually constituting their own sediment. And so I justify Chapter 2 on the biostratigraphy of fossil foraminiferal microplankton, from its beginnings in the zonation and correlation of the deepwater sediments of the Alpine mountain belts to the modern worries about succession – homotaxy – and diachrony. Modern biostratigraphy sits in more complex conceptual and technological contexts than did its antecedents (Fig. 0.1) and zonations have to be integrated into modern geochronology, as in Chapter 3.

Likewise, the polemics over fossils and time have continued into the microfossil domains, although there are signs – more than signs – of a mounting impatience with the old arguments over the synonymy or otherwise of biostratigraphy with chronostratigraphy. Just as some would sidestep species on their way into automated methods of correlation, so too is the zone being subverted in the 'age models' of modern palaeoceanography. Meanwhile, Chapter 7 on biostratigraphic and chronostratigraphic classification is an opportunity to parade case histories from the Cenozoic. The topics here have many connections with the topics of Chapter 3 and the division is somewhat arbitrary. Nor need we adhere to the cases from the marine record. The successions of macro- and micro-mammals not only have an intrinsic worth and interest, but their interactions with the marine successions are an essential part of the enquiry. Ages and stages are used more freely in the pre-Cenozoic, and probably increasingly in the Cenozoic, not least due to the rise of sequence stratigraphy.

As Sir Karl Popper advocated tirelessly, the inductivist model of science, whereby we collect data and draw conclusions from it, is not very useful or stimulating or realistic. No: we always have theories and biases influencing our choice of observations and our perception of 'facts', and biostratigraphy is no different. We do not simply identify, range, zone and correlate in a tedious induction – for we have stubborn, crazy, powerful and pet ideas about tectonism, climatic change, or evolutionary relationship whose triumph or tragedy can depend utterly on the fragility or robustness of the chronology or correlation. Be it in the mode of 'time's arrow' or 'time's cycle' (Gould, 1987), there is a feedback between biostratigraphy and the reasons why it is being carried out. As the historical sciences evolve, the critical and interesting questions change, and our *Weltanschauung* changes. Much of that shift in world view demands renewed scrutiny of the chronology, including greater chronological refinement, and it is now commonplace that fossils alone have not nearly the information for correlation that is available synergistically from their integration with various physical signals. And there is more: there is the choice of an agnostic approach or a thoroughly committed approach towards the nature of the stratigraphic record. Hence *systemic stratigraphy*, a timely resurrection of an earlier merging of history with its controlling chronology, is the central topic of Chapter 5, where we consider the use of Quaternary-style reversible events in the pre-Quaternary, of the integration of fossil events with physical events in event stratigraphy, and of a stratigraphic record consisting of cycles.

We can heal the split between the so-called index fossils and the so-called facies fossils (Fig. 0.2). Fossils carry signals of genealogy and ecology on the one hand, and age and environment of the other. The former ('sequence biostratigraphy') is strengthened in the context of the latter ('evolutionary palaeoecology'). It is difficult or impossible to draw a line anywhere in this diagram to exclude something as non-biostratigraphic. Among the various kinds of microfossil comprising the contents of micropalaeontology (e.g., Glaessner, 1945; Pokorny, 1963; Haq and Boersma, 1978; Brasier, 1980; Bignot, 1985; Lipps, 1981, 1993), the foraminifera are particularly broad in the range of their signals (Fig. 0.3).

This book has had a prolonged gestation and I have accumulated numerous debts of gratitude more wide-ranging than its subject matter and production. I have learned the hard way what many authors learn that way – assistance in all kinds of tangible ways is fine and indispensible, and acknowledgments feel inadequate as one struggles to articulate them. But deep approval of what one is trying to do is on a higher plane. I have benefited from uplifting of that kind ever since I was at school, and the following short list omits some wise and kind people. For early and strong encouragement in Earth and life history and in thinking about biostratigraphy: Martin Glaessner, Mary Wade, David Taylor,

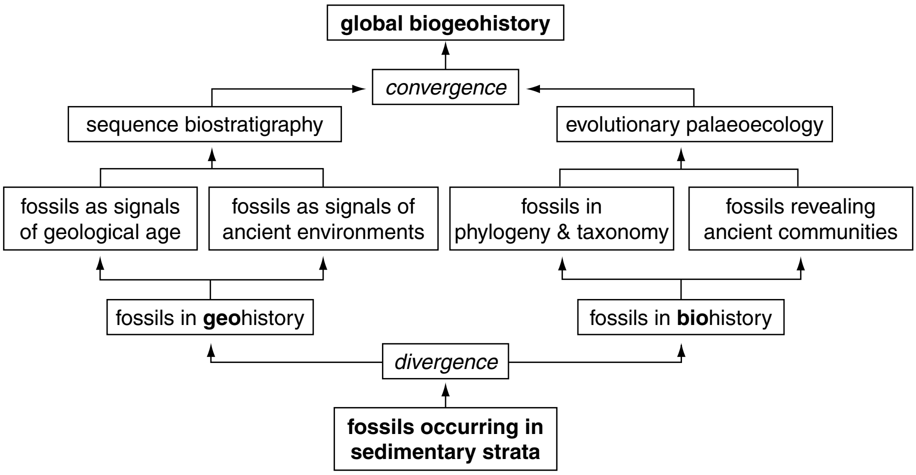


**Figure 0.2** From fossils to biogeohistory: pathways diverging and subsequently reunited. The divergence near the base is between fossils in geology and fossils in biology. Within the former, or 'applied palaeontology,' the age/facies split arose from the eighteenth-century question: is that fossil informing us about the age or the depositional environment of this stratum? Hence the two streams, classical biostratigraphic zones progressing (left stream) and progressing concepts in eco- and sequence-stratigraphic events and units (right stream). Sequence biostratigraphy unites the two streams in the modern synthesis of sequence stratigraphy and exogenic biogeohistory (Chapter 5). Evolutionary palaeoecology unites morphology and systematics with community reconstruction at timescales beyond the reach of ecology (Chapter 6). The whole diagram is pervaded with the need for age-control, hence for biostratigraphy.

Roye Rutland, Al Fischer and Bill Berggren. For the cross-disciplinary excitement in the early days of deep-ocean drilling: John Sclater and Steve Gartner. Colleagues and students: Nell Ludbrook, Murray Lindsay, Wayne Harris, Clinton Foster, Rob Heath, Mike Hannah, Geoff Wood, Stephen Gallagher, Guy Holdgate. Collaborations keeping me going in the day-to-day stuff: Amanda Beecroft, Graham Moss and – now well into our second decade of genially apportioned research and writing – Qianyu Li. (Among their scientific efforts, the good people in the room next door helped me into the computer age.) Drafts were read by Graham Moss, Qianyu Li, Marie-Pierre Aubry, Bill Berggren and Al Fischer. I deeply appreciate not only their constructive criticisms but especially their enthusiasm and encouragement. Qianyu Li's help with the array of figures was immense. Sally Thomas at Cambridge University Press was enthusiastic and decisive at all times in getting this project accepted, patiently advising its author and transmuting the manuscript into a book. It has been a pleasure and an education to work with Sally, Carol Miller, and their colleagues.

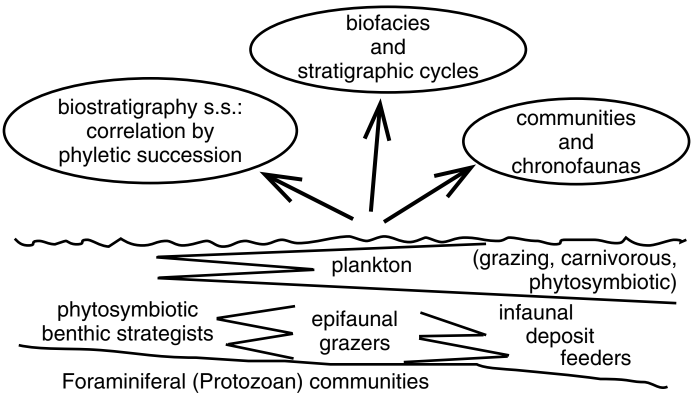


**Figure 0.3** Reasons for studying the foraminifera. Benthics comprising a mix of epifaunal, infaunal and photosymbiotic strategists fossilize together with planktonics, themselves possessing a range of strategies in lifestyle (often overlapping). Their understanding was driven by classical biostratigraphy s.s. (i.e., correlation and age determination based on the reconstructed ordination of speciations and extinctions), and biofacies (fossil assemblages signalling environments and environmental change and cyclicity). These streams have been united recently in sequence stratigraphy and the search for cycles in the rock record. The flipside of these 'geological' drives is the 'palaeobiological' question of ancient communities and their long-timescale equivalents, chronofaunas – which question unites the three balloons. Not shown: foraminiferal shells carry isotopic signals (mainly $\delta^{18}O$, $\delta^{13}C$, $^{87}Sr/^{86}Sr$, but there are others). (McGowran and Li, 2002, with permission.)

Pervading all this was the powerfully supportive presence of Susi McGowran – believing shrewdly in the book and its author in the dark moments and slothful patches, being patient and stinging as necessary, listening to the gripes and doubts in the lows and the enthusiasms and exultations in the highs, and believing in life after biostratigraphy.

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