

# HOMOTAXY AND BIOSTRATIGRAPHICAL THEORY

by G. H. SCOTT

**ABSTRACT.** The principal problem in biostratigraphical theory is a justification for using fossils to identify isochronous horizons. Biostratigraphers establish the sequential order of fossil events but there is no theoretical justification for equating constancy in stratigraphical position (homotaxy) with constancy in time of deposition. The problem is important as the way in which it is solved greatly influences the direction of biostratigraphical research. A partial solution is to use homotaxy as a weak test for diachroneity. Events that do not maintain invariant stratigraphical order are regarded as diachronous. While surviving events are not shown to be isochronous the amount of potential diachroneity throughout their individual distributions is inversely related to their stratigraphical spacing. The closer are homotaxial events in stratigraphical space the less they have wandered in time. Thus a major objective of biostratigraphical research should be to make tests of homotaxis more rigorous by raising the density of events.

SINCE William Smith the principal role of biostratigraphers has been to provide classifications of strata useful for estimating time of deposition. Historical geology requires a chronological framework to study ancient geographies and the sequential classifications established with fossils have long been used for this purpose. Indeed, the advent of radiometric and palaeomagnetic chronologies, in which time is directly estimated, has not diminished the utility of biostratigraphical data and there are now interesting applications of fossils as surrogate criteria for datum planes determined by quantitative techniques for measuring age. Cenozoic biostratigraphy, for example, has progressed to the stage where appearances and extinctions of taxa, calibrated at only a few sites with radiometric or magnetostratigraphic chronologies, are used as datum planes expressed in years (e.g. Ryan *et al.* 1974; Poore *et al.* 1984) that are recognized at locations far distant from the sites of calibration. Resolutions of less than 10 000 years have been claimed for such datum planes (Thierstein *et al.* 1977; Berggren and van Couvering 1978). To the bystander, these applications suggest that biostratigraphy has come of age and that the isochronous surfaces envisaged by the *International Stratigraphic Guide* (Hedberg 1976) can be accurately estimated by fossils.

While utility itself may be a justification, there is little theory to underwrite biostratigraphical practice. Further, over a long period there have been denials that fossils can accurately estimate time. A trenchant early critic was Huxley (1862) who argued that occurrences of taxa in fixed order from section to section (the common feature of biostratigraphical classifications since William Smith) did not imply that each datum or unit was isochronous. As correspondence in position did not imply contemporaneity, he alleged by way of demonstration that, 'for anything that geology or palaeontology are able to show to the contrary, a Devonian fauna and flora in the British Islands may have been contemporaneous with Silurian life in North America, and with a Carboniferous fauna and flora in Africa' (Huxley 1862, p. xlv). Modern critics (e.g. Miller 1965; Drooger 1974; Watson 1983), while less dismissive than Huxley, have continued to wrestle with the problems of using fossils to define isochronous surfaces. Kitts (1966) made a detailed investigation of the problem, viewing the events of the biostratigrapher as biological signals which were transmitted from specific centres. Because biological signal velocities (rates of dispersal) are variable and cannot be determined intrinsically from the data, he concluded that 'simultaneous with' relationships cannot be derived from fossils.

The impasse in biostratigraphical theory is that the intrinsic palaeobiological and stratigraphical data for an individual event do not enable its isochroneity to be established. There is no rationale for

progressing from event ordering to event dating. The *International Stratigraphic Guide* states (p. 88) that 'biostratigraphic correlation is one of the most useful approaches to time correlation if used with discretion and judgment', repeating an earlier view (p. 63) that correlation is a matter of judgement. It also mentions 'subtle paleontological discrimination' (p. 88) but in none of the discussions are clear guidance or objective rules given for identifying the most reliable datum planes. The idealistic way in which the *Guide* equates fossil datum planes with isochronous surfaces is echoed in some texts. Krumbein and Sloss (1963, p. 370) wrote that 'Chronospecies and "chronogenera" include the most obvious index fossils, since the synchronism of their range zones may be established without serious doubt'. In like vein, Donovan (1966, p. 32) found it 'inconceivable, in view of what we now know of evolution and dispersal, that a long and complex series of faunal changes should occur at different times in different places'. Certainly, there are grounds for making such assertions but where is the theory that allows them to be tested with biostratigraphical evidence? Other authors (e.g. Dunbar and Rodgers 1957; Weller 1960; Raup and Stanley 1978) focus more on the imperfections of palaeobiological events as time indices. Yet these 'realists' also fail to confront the problem: how to identify the best events for time correlation?

In overview, there is no theory to allow a set of ordered events to be tested for isochroneity with biostratigraphical data. The problem has existed since the advent of biostratigraphy and is ignored or glossed over in the vast majority of the biostratigraphical literature. I believe that this is unsatisfactory as the direction of biostratigraphical research is intimately related to the way in which the gap between sequence and time is to be bridged. Here I outline one approach which, rather than trying to find isochronous events directly, seeks to identify the least diachronous.

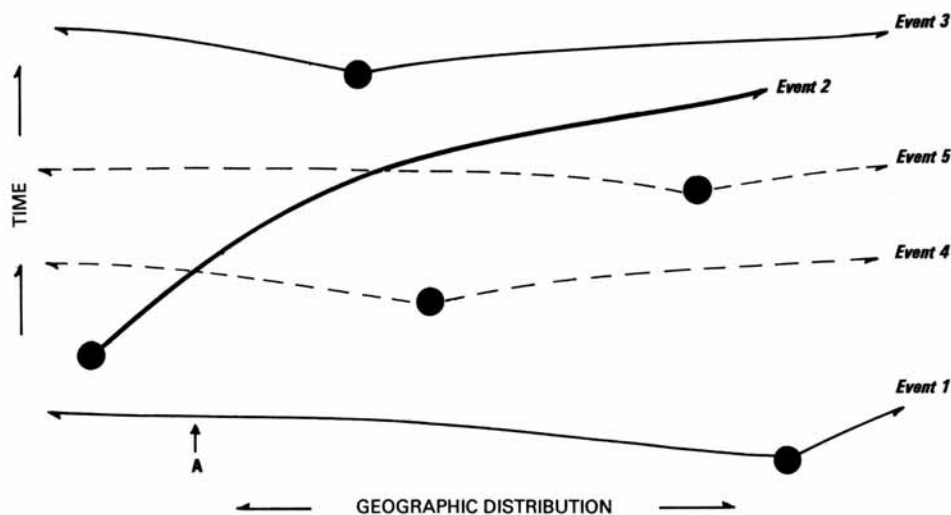
#### A PARTIAL SOLUTION

Perhaps ironically for Huxley, a basis for biostratigraphical theory lies in his concept of homotaxis. To Huxley (1862) it signified similarity in orders of stratigraphical events without implication of contemporaneity, and he used it with some relish to demolish time stratigraphical correlation with fossils. Huxley was correct in contending that an order of events, maintained from section to section, does not entail that each was isochronous throughout its occurrences. Nevertheless, he did not explore some implications of his concept. Let us simply define as homotaxial those events that occur in fixed stratigraphical order with respect to selected neighbouring events. As graphical representations show, order invariance does not necessarily identify an event as isochronous. Homotaxial events potentially include strictly isochronous events (e.g. those caused by instantaneous global catastrophes) as well as diachronous events that are insufficiently time transgressive to intersect with their immediate neighbours. Conversely, non-homotaxial events include those diachronous events that are time transgressive to the extent that they produce inversions of order. Relative to the time stratigraphical objective, non-homotaxial events can be rejected as certainly unsuitable. Thus the problem focuses on homotaxial events; these may vary considerably in the amount of undetected diachroneity. Huxley denied that this class of event was applicable in time stratigraphy. This is substantially correct given the biogeographical model he implied in which, over a long period (Silurian to Carboniferous), taxa originated in one region and slowly migrated in the same direction to others. But in any model in which events may arise at various geographical loci (text-fig. 1) and disperse at different rates in different directions, homotaxial events will include those that are potentially the most accurate estimators of time. The operational task is to identify the least diachronous.

While tests using various stratigraphical, physical, or chemical techniques are sometimes feasible, it is important from the standpoint of biostratigraphical theory to identify procedures that simply depend on stratigraphical relationships (the intrinsic data of biostratigraphy).

The primary procedure relates to the stratigraphical spacing of homotaxial events and tries to force them into the class of non-homotaxial events. Text-fig. 1 shows a homotaxial triplet (Events 1, 2, 3). Events 1 and 3 are well behaved in the time domain as they dispersed rapidly. Event 2 did not, but it will still be regarded as a homotaxial event as it does not intersect with the adjacent Events 1 and 3.

## EVENT SPACING AND HOMOTAXY



TEXT-FIG. 1. Initially, only biostratigraphical Events 1, 2, 3 are known. They maintain homotaxy throughout their joint occurrences. Event 4 is recognized subsequently and it is found that the upward sequence 1-4-2-3 is maintained over most of the region in which they occur jointly. However, in the vicinity of A the order of Events 4 and 2 inverts. Evidence from Event 5 helps establish that Event 2 is strongly diachronous. The slow dispersal of Event 2 was unrecognized when the event set consisted only of Events 1, 2, 3. Decreasing the stratigraphical spacing of events will raise the chance of detecting the most diachronous events provided that the origins of events and their dispersal directions and rates are variable.

Consideration of an additional event (4, perhaps newly recognized) shows that while it maintains homotaxy with Events 1 and 3 it fails with Event 2. At this stage which of Events 2 and 4 is the more diachronous is unknown and further events, such as 5, may be needed to reject Event 2.

Interpolation of additional events in homotaxial sets should tend to eliminate the most diachronous. Thus attempts to falsify the hypothesis that a set of events is homotaxial become increasingly rigorous as event spacing declines. As testing relies only on hypotheses about event orders, there is no indication of the variation in age of events that survive testing. They are not shown to be isochronous, neither is their diachroneity definitely established. Nevertheless, for particular sedimentary regimes, those that are closest in stratigraphical space may be expected to best approximate isochronous horizons.

The signal model (Kitts 1966) provides another perspective on selection of events. Here, events are considered to be transmitted away from a local geographical origin. Speciation by allopatry is an excellent example but some extinctions (such as those caused by an environmental change moving along a geographical gradient, progressively eliminating populations) also conform. The significance of geographical extent is that it provides a test of signal velocity. Any event whose transmission time is slower than those of its neighbours is liable not to maintain its order in the sequence (Event 2 in text-fig. 1). Whether it does so depends on several factors, including its proximity (in time) to the

neighbouring event with faster velocity, and on variation in its own velocity. This may be considerable. For example, zooplankton populations tend to be watermass bounded (McGowan 1971). Within one watermass, biological events are rapidly distributed by physical circulation. But the spread of a taxon to a neighbouring watermass is often a trial and error process. Thus some signals (e.g. first appearances) may terminate near the boundary (possibly indicating that founder populations in the adjacent watermass failed to establish). On the other hand, a successful invasion may lead to rapid expansion over the whole of the new territory.

While estimates of ancient signal velocities are speculative, it is obvious that variation in signal velocity is the more likely to be revealed the greater the area over which homotaxis is checked. It is not simply the global taxa that are the least diachronous, it is those that dispersed most rapidly throughout their entire geographical range. The effectiveness of the geographical test is related to event spacing. If events are widely spaced, velocities are only weakly testable via consideration of geographical distributions. Rather, its effectiveness increases as event spacing decreases. Generally, events that maintain homotaxial order over the widest area at the minimum available stratigraphical spacing are likely to be the least diachronous.

#### DISCUSSION

Given suitable distributions of event origins and dispersal routes, tests of homotaxy are potentially capable of eliminating all but strictly isochronous events. In this respect the argument simply supports the utility of sequence classifications long used by biostratigraphers in their quest for time. Additionally, however, the formulation raises issues in contemporary theory and practice that would otherwise not be clearly perceived.

1. Testability. Like Donovan (1966), we may appeal to evolutionary theory to 'guarantee' that certain events are isochronous or, like the *International Stratigraphic Guide*, we may cloak our selections under the shrouds of 'discretion' and 'judgment'. The merit of building a theory around homotaxy is that it emphasizes practical testing procedures. Biostratigraphy is not an art, despite the writings of the *International Stratigraphic Guide*.

2. Integration of data. Events used in biostratigraphy come from sources as diverse as protists and vertebrates. However, the potential value of this diversity is rarely realized in biostratigraphical applications. The systematics of groups well represented in the Cenozoic record, for example, have recently been greatly refined, often with large increases in the number of useful biostratigraphical events recognized. Yet this research has been paralleled by the multiplication of biostratigraphical classifications which use only events in one group (e.g. Martini 1971; Riedel and Sanfilippo 1978; Blow 1979). While all represent major advances, no single classification necessarily uses events that are the least diachronous. In general, this will be the integrated set as it will contain the most closely spaced events.

Integration implies more than finding the stratigraphical position of diatom species C relative to coccolith species H in one or two sequences. To fully utilize advances in the systematics of Cenozoic planktonic microfossils the positions of individual events need to be compared with those of their nearest stratigraphical neighbours throughout regions of joint occurrences. While biogeographical compatibility largely controls the severity of testing, any reduction in event spacing while maintaining homotaxy enhances the value of the datum planes for time stratigraphy. There is an increasing effort to correlate events in various planktonic microfossil groups (e.g. Hornibrook and Edwards 1971; Ikebe and Chiji 1981; Abbott 1984) but is testing really rigorous?

3. Stratotypes. The *International Stratigraphic Guide* vigorously promoted the function of stratotypes and type localities as standards for the definition and recognition of stratigraphical units. It views a stratotype (p. 27) as 'the standard of reference on which the concept of the unit is uniquely based'. Thus biostratigraphical units (p. 63) are 'extended away from their type localities by biostratigraphic correlation'. Similarly, the boundaries of stages (chronostratigraphical unit, p. 71) 'as they are extended away from the boundary stratotypes should be in principle isochronous'. Further, the Guide states (p. 86) that 'Only after the type limits (boundary stratotypes) of a chrono-

stratigraphic unit have been established can the limits be extended geographically beyond the type section'.

These views conflict with the theory advocated here. While it is valuable to have a locality that serves as a name bearer for a datum or unit, homotaxial theory does not require any locality to serve as a standard endowed with special status. Homotaxis is recognizable only by occurrences of events in the same order in several sequences. The order of events in one section without reference to the order of the same events in other sequences is completely irrelevant in a homotaxial scheme. Rather than initially identifying a standard and correlating outward from that site, as the *Guide* suggests, a homotaxial datum, or unit, can only be recognized after inspection of events in several sequences. From a different viewpoint Hay (1974) reached a similar conclusion. The equal status of sequences in homotaxial schemes is implied in the test procedure for order invariance. Any sequence in which the order of an event is not maintained becomes crucial in determining the status of the event, irrespective of its relationships in the stratotype.

I suggest that methodological emphasis on stratotypes is misplaced. Biostratigraphy is built on selection of events, not selection of sections.

Biostratigraphers have long advocated the utility of fossils to identify synchronous horizons and independent methods of dating are now establishing that some palaeobiological events in fact dispersed extremely rapidly. Such results, however encouraging, do not resolve the problem of identifying synchronous horizons when only data on the order of events are available. While there may not be a full solution to this problem the value of my formulation is that it points to a coherent approach to event selection and identifies research objectives that should improve biostratigraphical resolution. Rightly, some will say that the procedures are commonplace, used by all biostratigraphers. Nevertheless, the way they may be used to bridge the gap between order of events and age of events is insufficiently recognized either in practice or in the literature.

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