Organic evolution and natural stratigraphical classification

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Typological stratigraphy persisted up to the early 1940's, when it gave way to gradualistic concepts. Because world-wide periodicity of evolutionary events and their functional relations to crustal disturbances were denied, it was decided to define geological time divisions by a set of time-planes marked by agreed reference points. Actually, evolution is discontinuous at the molecular, population, species and community levels. Evolution of the whole biosphere depends on periodicity of tectonic and climatic events which add to general environmental instability and alter adaptive strategies. The perception of geological time is derived from the succession of unique litho- and biosphere events which serve as a base of natural stratigraphical classification. Correlation is based on the parallelism of cliseres and chronoclines. Their homotaxial members are recognized as coenozones and phenozones. Standard stratigraphical boundaries are materialized in local boundaries defined by historical events of high 'confidence level'. Nominotypes designated for nomenclatural procedures need not coincide with the boundary reference points; otherwise they would hamper further development of stratigraphical classification.

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Working as a stratigrapher in the Far East, I found it difficult to reconcile my results with the ideas of chronostratigraphy put forward by Schenk & Müller, Hedberg and other authors who still dominate stratigraphical theory. Contrary to what was said by Laffitte *et al.* (1972), chronostratigraphy is not one of several methods of equivalent status based on different categories of stratigraphical characters, like lithostratigraphy or biostratigraphy, but rather a principle of stratigraphical classification. I found myself essentially in agreement with much older, in fact pre-Darwinian, theory, customarily cast aside now as altogether obsolete and naive. In this paper I attempt to explain why I see this theory as not so naive. It seems appropriate also to discuss the nature of stratigraphical theory.

Stratigraphical theories

In stratigraphy, the 'before than–later than' relations of historical events are inferred from the 'below–above' relations of strata observed in geological sections. However, in many cases superposition is not immediately evident, and the theory is needed to tell the temporal relations from the rock characters, i.e. to carry out stratigraphical correlation.

In all historical sciences, a theory is essentially a generalized restatement of a history (of the sedimentation history in the case of stratigraphy). The first stratigraphical theories were proposed by Lehmann, Arduino, Linnaeus, Bergman, Werner and other 18th Century scientists. They stated that, with the lapse of time, the diagenesis and diastrophism of sediments decreased, the proportion of volcanic rocks and marine deposits diminished, and the frequency of fossils increased. Giraud-Sulavy had noticed that the proportion of extant taxa among fossils increased upwards, and Lyell developed this theory with respect to the Tertiary rocks (his method still has some applications, e.g., in palaeobotany, though the Palaeocene floras have higher percentages of extant taxa than do those of the Eocene, see Wolfe & Barghoorn 1960). Darwin considered the biological progress engraved in the fossils as a possible basis for stratigraphical theory, yet insisted that younger members of a group were not inevitably more advanced.

These early theories were too abstracted from real history to be applied for practical purposes, so stratigraphers have preferred the purely empirical approach of William Smith, consisting in enumeration of guide fossils in successive strata. European stratigraphical classification was developed in this way, but when this appeared as an international scale, it was charged with theoretical meaning not only of what happened in a particular area, but also of what should happen elsewhere. In other words, this scale assumed the significance of a stratigraphical theory, substantiated by observation of the parallel successions of faunas and floras in different countries and coupled with the ideas of Cuvier (catastrophic transgressions) and Buffon (biotic changes in relation to geological and climatic disturbances).

It was suggested later that the successions of organic forms throughout the world were homotaxial, but not synchronous. The concepts of Cuvier and Buffon have been severely criticized, and many stratigraphers have deprived the international scale of its theoretical meaning, considering it as no more than a set of conventional reference points or a convenient language. Different interpretations of the international scale marks the major split among stratigraphers. The history of sedimentation is conceived by some of them as a succession of episodic events, while others see it as a continuum.

Natural *versus* artificial classification

Actual continua defy any attempt at natural classification: only a conventional, artificial classification is possible; while the gaps between distinct clusters, even if filled with some transitional entities, allow natural division. Thus, two major schools of stratigraphers may be defined also as supporters of either natural or artificial classification.

The early history of stratigraphy was completely dominated by essentialism. Werner had defined formations by typical lithogenic characters, and his follower William Smith added to them the standard sets of fossils. This concept was challenged by Lyell and Darwin who attributed all sharp boundaries and sudden changes to local gaps in the record. In 1887 Neumayr said that geological systems were not natural entities, as conceived by earlier authors, but arbitrary divisions established for convenience. Many years later Hedberg (1948) said that the systems were needed 'for the sake of intelligent intercommunication of thought'. It was stated repeatedly that 'had the initial stratigraphic divisions been made in another continent (not in Europe) a quite different classification would no doubt have resulted'. For instance, the American Mississippian and Pennsylvanian were confronted with the European Carboniferous and Permian (Rastall 1944). Unfortunately for this particular argument, Europe and North America formed a single continent according to the pre-drift arrangement. Thus, stratigraphical discrepancy was caused by the different professional training of European and American geologists rather than by the different Palaeozoic histories of their countries.

Another of Neumayr's (1887) arguments was that organic evolution is continuous and indivisible into natural periods. This was reiterated by Hedberg who believed that 'throughout the history of the earth organic evolution, when looked at as a whole, has taken place very gradually. There have been accelerations and retardations in individual groups, but considering, all types of organisms there is little basis for localizing time divisions to particular point in the earth's history on the grounds that they coincide with particularly marked changes in life forms'. Indeed, the dinosaurs and ammonites perished at the Maestrichtian–Danian boundary, but *Lingula* survived and, thus, considering all types of organisms, nothing particular has happened. But is this a proper way of considering evolution as a whole?

Evolution as a whole

From several definitions of evolution I would choose this: any transgression of identity at a selected level of biotic organization is evolution. It does not connote progress or irreversibility and is concurrent with the fact that evolution means different things to molecular biologists and palaeontologists who have different ideas of identity.

At the molecular level, rates of evolution have been claimed to be uniform (clock model: Zuckerkandl & Pauling 1965). These uniform rates signified either a steady ticking of the molecular clock or a comparable number of jerks within a given time interval. More detailed studies (e.g. Goodman & Moore 1973) revealed that molecular evolution was rather jerky, with periodical speeding of substitution rates after macromutational events.

At population level, identity (the Hardy-Weinberg equilibrium) is transgressed by mutations, genetic drift and natural selection. Many mutations are preserved by such mechanisms as frequency-dependent selection and superdominance. While the selectionist–neutralist controversy is far from settled, it is clear that many mutations are of very little effect on fitness. One can suppose that under canalizing selection, the expression of these mutations has been neutralized to lessen segregation load. In populations with even distribution of allele frequencies, genetic drift caused random fluctuations, but in the case of uneven distribution it speeded fixation of the most frequent allele. In classical genetics, industrial melanism of the pepper moth and variation of banding pattern in land snails have illustrated, first, genetic drift and, later, visual selection. Now it is evident that climate is the major controlling factor in both cases (Jones 1973; Creed 1975). In general, both drift and canalizing selection acted against any spontaneous change, and evolution of populations occurred only when selection pressure was altered by intermittent environmental changes. This is relevant to the 'environmental' *versus* 'evolutionary' dilemma of many stratigraphers (e.g. van Hinte 1969: 'a succession of phylozones is the most reliable tool in correlation and age determination, because it directly reflects the irreversible evolution of life on earth providing maximum exclusion of the environmental factor').

Palaeontological species were conceived as conventional in nature because of their gradual transition from ancestral species to descendant ones. However, descriptions of gradual change of characters along chronoclines are infrequent and can in most cases be ascribed to replacement of ecotypes not necessarily resulting in speciation. The 'punctuated equilibrium' model of Eldredge & Gould (1972) is more consistent with palaeontological facts.

Since the appearance of reproductive isolation is not accompanied by considerable increase of mutation distance (Dobzhansky 1974), one can suppose that speciation is gradual. This may signify instead that allozymic variation is not the major source of speciation. Gene rearrangements and saltationary increase in repeated DNA redundancy might have been more important sources of evolutionary novelties. The initial saltationary steps have altered the preexisting pattern of genetic polymorphism, and, as a consequence of this, the intraspecific mutation distances are, as a rule, much larger than the interspecific (Avise 1975). Periods of catastrophic selection are especially favourable for the establishment of saltants (Lewis 1958; Carson 1975).

The higher grade of biotic organization – the community – is believed by some authors to be fairly stable in the climax state, while others insist that it is changing continuously and is never the same as before. The identity of communities as 'classes', not 'individuals', depends on criteria by which they are recognized. If a community is defined by its dominant forms, then community evolution is manifested by replacement of these dominant forms. If the Mesozoic deciduous forest of Siberia is understood as a community dominated by the ginkgoalean and czekanowskialean trees, then this community maintained its identity for 100 million years, from the mid-Triassic to the mid-Cretaceous, when it was changed instantaneously, its dominants winnowed or subdued. Community evolution is most spectacularly jerky, and the replacement of major communities results in change of the biosphere, i.e. evolution as a whole.

Dominance and frequency changes are often denied as being of stratigraphical value because they are 'environmental', not 'evolutionary'. However, evolution is not insensible to the frequency changes which might trigger simultaneous evolutionary episodes in different lineages.

It has been repeatedly claimed that, because of different rates of evolution, there would be as many natural biostratigraphical classifications as there are groups of fossils. However, no such thing as an intrinsic evolution rate exists, and evolutionary episodes in different lineages can be synchronized by phenomena affecting general selective environment (see below). Of course, it would be preposterous to insist on exact correlation of evolutionary rates. They are not correlated even between various parts of a single organism, which nevertheless evolves as a whole.

Crustal disturbances

Before 1940, most texts on earth history claimed that crustal disturbances 'lead to a period of accelerated evolutionary change' (Schuchert & Dunbar 1933) or 'stimulate the sluggish evolutionary stream to quickened movement' (Lull 1947). Then the converse statement, denying any causal relations between tectonic episodes and evolution, rapidly became a commonplace of historical geology. This inversion stemmed from classical population genetics and from the notion of permanent tectonic activity.

Gilluly (1973) claimed steady plate motion, but it was decisively shown to be intermittent, and Vogt *et al.* (1971) stated that 'three major events in the history of North Atlantic fall close to period boundaries which therefore are not merely stratigraphic boundaries whose significance is restricted to Europe'. They related the changes of the spreading pattern to periodical discharge from mantle plumes. Other authors suggested periodical disturbances of the earth rotation as the major force beneath plate motions (see Krassilov 1976a).

Any plate motion inevitably interfered with other plates. The repatterning of sea-floor spreading was broadly synchronous in all major oceans. It caused synchronous orogenies (e.g. the mid-Devonian orogeny in the Caledonian, Appalachian, Cordilleran, Uralian, Caucasian and other fold belts: Boucot *et al.* 1974; Khain 1975; Leonov 1976), regressions of epeiric seas (Flemming & Roberts 1973) and climatic changes (Kennett & Watkins 1970).

The epochs of the Mesozoic and Cenozoic eras roughly correspond to climatic cycles with the temperature minima falling at the beginning of each epoch (Krassilov 1973, 1975). Important megaevolutionary events coincided either with major glaciations (e.g. the appearance of Ediacaran metazoans, of the first chordates in the Ordovician, of cordaitalean and glossopteridalean deciduous forests in the late Namurian, of the tundra-steppe biome in the Pleistocene), or with the maximum spread of red-bed climates (the appearance of progymnosperm forests and tetrapods in the mid-Devonian, of therapsid fauna in the Permian, of grasslands in the Miocene).

The temporal range of the therapsid fauna corresponded to the time of Pangaean integrity in the Permian and early Triassic. While Pangaea was rifted in the mid-Triassic, therapsids gave way to dinosaurs. The pro-mammals and pro-angiosperms appeared simultaneously. The modern continents had been outlined in the Neocomian, and this was also the time of the first therians and angiosperms (Lillegraven 1974; Hughes 1976). They increased in number, again simultaneously, in the Albian, and achieved dominant status when the modern structure of the lithosphere was laid down towards the end of the Cretaceous.

It has been said that temporal relations between evolutionary events and orogenies are of little importance because some crustal disturbances are always close at hand, within at most 50 m.y. (Simpson 1949). Though synchronism was more precise than that, it did not prove functional relations and many authors had questioned any relations of this kind, except that migration routes had been altered. Sea-level fluctuations affected many species and caused extinctions through 'loss of habitat' (Newell 1963, etc.). However, the extinction of major dominant groups controlling various habitats cannot be easily explained this way. A general theory of interaction between geological revolutions and organic evolution was advanced by Wallace (1855), who proceeded from comparison of tropical and temperate biota and postulated that environmental instability caused by crustal movements had decreased biotic diversity. However, the time was not ripe for the appreciation of his ideas.

Levins (1968) has discussed alternative adaptive strategies in heterogenous fine-grained environments. One of them is the selection of a single genotype allowing extensive phenotypic plasticity and doing moderately well in all grains. The other is the segregation of specialized genotypes for each grain. The choice of one or another strategy apparently depends on the stability of the environment. Different meanings of stability are discussed by many authors (e.g. Lewontin 1969). Climatic seasonality, depending on astronomical as well as geological factors, is probably the best measure of stability (stability is different from long-term constancy: tropical and deep water environments are stable, but inconstant). Homoselected populations are favoured in an unstable environment, while polymorphism increases along with environmental stability. Progressive specialization of ecodemes filling multiple niches leads to a coarse-grained pattern.

Tense competition for resources (K-selection) in a constant environment results in character displacement, increased species diversity and ecosystem complexity; while reduction of biotic diversity in an unstable environment causes extinctions, character release and strong selection for high reproductive rates (r-selection), which will also affect developmental time (MacArthur & Wilson 1967). Acceleration of growth rates and telescoping of successive morphogenic events are major sources of evolutionary novelty.

Thus, episodes of drift and climatic changes coincided with evolutionary events because they added to general environmental instability, disturbing the balance between K- and r-selection (Valentine 1971a, b), altering adaptive strategies and reversing heteroselection and specialization trends.

Correlation

Correlation in stratigraphy is traditionally conceived as time-correlation, that is, the demonstration of synchroneity in terms of either 'relative' or 'absolute' time. 'Relative' time is understood as the time defined by the periodic (though not necessarily regular) process of organic evolution. 'Absolute' time is defined by the regularly periodic (varve deposition or formation of growth rings) or non-periodic (decay of radioactive minerals) processes of uniform rate translated into years. The 'absolute' time of geologists has not necessarily been understood as Newtonian absolute time, though, as Miller (1965), Kitts (1966) and other authors have pointed out, some confusion actually occurred.

Because world-wide periodicity of evolutionary events was denied, it was decided to define 'relative' time by a set of agreed 'time-planes' marked by designated reference points in stratotype sections. Correlation in this context means a recognition of events equidistant in time from the nearest reference time-plane. This procedure has completely inverted the logic of stratigraphical classification. In traditional classification, historical events had been clustered, and then the corresponding time-intervals were defined; while in modern chronostratigraphy, time is subdivided first and then the conventional time divisions are imposed on the sequence of events, irrespective of their internal unity. Thus, such segments of the standard scale as Jurassic or Cretaceous are divisions, not units (Harland *et al.* 1972). This new concept brought with it the rather questionable notion of ideal time planes (see Kitts 1966) and complete departure of the international standard scale from local 'rock stratigraphy'. Because evolution as a whole is not continuous, may not the older concept of relative time and natural classification be preferable?

It has been claimed that 'every bit of evidence provided by evolutionary theory, and by the observations which may be adduced in support of this theory, compels us to conclude that the recognizable effects of evolution, far from being "felt over the world at the same time" are restricted to limited areas on the surface of the earth' (Kitts 1966). However, ecosystem evolution, or syngenesis, is causally related to tectonic and climatic events felt over the world (which follows from current concepts of lithosphere and atmosphere), and different ecosystems responded to these events in a similar way. The question as to whether these responses are synchronous depends on relative velocities of 'signals', i.e. causal chains triggered by tectonic or climatic events. There is compelling evidence that turnovers in marine and terrestrial ecosystems occurred close in time. The last ammonites and dinosaurs were found in the same beds, such as the Lance Formation. The delay in response of marine ecosystems to changes of water temperature amounts to several thousand years (Pisias *et al.* 1975), but in terms of the pre-Holocene time scale the response can be described as instantaneous. Thus, it is theoretically permissible to derive time from world-wide syngenetic events. In other words, the perception of geological time is derived from a succession of unique litho- and biosphere states defined by periodic tectonic and syngenetic events. This succession may serve as a base of stratigraphical classification. The sections of such a classification are units in the sense that their internal unity is provided by interaction along interwoven causal chains. Correlation means that two spatially separated events are shown to be contemporaneous, i.e. by virtue of their characteristics they belong in the same unit of earth history. Thus defined, correlation is falsifiable and independent of imaginary time planes.

Interaction of events proves that they happened together, and 'events are simultaneous not because they occupy the same moment of time but amply because they happen together' (Whitrow 1961). The galls on fossil leaves indicate that certain insects and plants were contemporaneous. Since the traces of interaction are studied by palaeoecologists, correlation is essentially an ecological task, and the term 'ecostratigraphy' (in the sense of Hedberg 1958, not Schindewolf 1950) is fully warranted (see Martinsson 1973).

Though 'radiometric ages' are at present more useful for estimating duration than 'darwins' or 'paulings', their application for stratigraphical correlation inevitably invokes circular reasoning (O'Rourke 1976). Radiometric age is meaningful in stratigraphy only when the sampled rock is attributed to a certain unit, that is, after correlation is achieved.

Whitrow (1961) has shown that chronology is blurred by repeated attempts either to eliminate time or to thrust on it the properties of space. In geology, the most vigorous attempt to eliminate time was the steady-state theory of Lyell (ironically Lyell claimed full awareness of the time factor to be his privilege over the Cuvierians), and modern chronostratigraphy is a continuation of the same trend of thought. Time can be defined non-reductionally as a trace of directional movement in the memory of a system. Specifically, geological time is a trace of irreversed global change in the geological record.

Much confusion has arisen from an inability to discriminate between time and clock. Any relatively constant process can serve as a time measure, or clock. I am not aware of any geological clock which can be conceived, on theoretical grounds, as an absolute clock. The aprioristic idea of the fossil record as a 'natural chronometer' which stemmed from De Luc and Lyell (see the excellent historical essay by Rudwick 1972) is an especially persistent stratigraphical fallacy. 'The geomagnetic clock appears not to be a phenomenon separate and independent of geological processes, but may have common cause with geology, in the earth's mantle' (Irving & Pullaiah 1976:61). And radiochronometry depends on such episodic geological events as eruptive activity, or emergence of plutonic bodies over the critical isotherm (Salop 1963), or deposition of glauconitic beds.

The moments of geological time are defined by coexisting events, i.e. those events for which before and after relations are indeterminable. Geological moments are not without duration (not point-like). Their duration depends upon properties inherent in both geological movement and the geological record. There is also a third component, related to the exactness of encoding the record. This third component (but not the first two) can be diminished by improvement of stratigraphical techniques.

That the earth's crust did not fold gradually but was deformed by sudden release of internal stresses was recognized by Élie de Beaumont as early as 1829. Le Pichon *et al.* (1973) suggested spasmodic jumps of seismic zones even in response to a constant rate motion of plates. The history of the geomagnetic field is conceived as a succession of quasistatic states periodically disturbed by rapid reversals (McElhinny 1973). Similar non-linearity is characteristic of the response of the atmosphere to any coercive agent (Bryson *et al.* 1970). Thus, homeostatic properties of all systems involved in geological movement determined its jerky character, which was reflected in the succession of geological moments.

Boundaries

Natural classification consists of units (not divisions in the sense of Harland *et al.* 1972), which correspond to universally recognized stages of the evolution of the biosphere, or to successive palaeobiospheres. Its boundaries are drawn along transitions (statoecotones, cf. Krassilov 1970) from one equilibrial state to another. Since these boundaries are objectively defined by inversions of relative importance values of dominant species, no agreed limits are needed. Because a succession of rocks registers the history of sedimentation, not the mythical 'passage of time', hiatuses are seen not as gaps in the record, but as records of non-depositional events, which are often incorporated in the characteristic of a boundary: the Maestrichtian–Danian boundary is characterized by an almost world-wide hiatus.

A geological section bears historical information and, like the genetic code, is composed of repeated and unique sequences. The repeated sequences (such as alluvial cyclothems) indicate some auto-regulating process, while the unique sequences show that sedimentary equilibrium was disturbed. Thus, unique sequences stand out as reference points and their significance, or 'confidence level' (Kauffman 1970), depends on historical events referred to them. Biotic events are favoured as being the most sensitive indicators of the ecosystem turnovers. Reference beds of the highest confidence level define major stratigraphical boundaries, subject to periodical revisions in respect of additional information or changing interpretation of earth history.

The search for appropriate neostratotypes now in progress is no doubt useful. It draws attention to the most complete classical sections and sponsors their careful study. But the goal of this work – the boundaries fixed by 'golden spikes' – if achieved, would stagnate stratigraphical classification. For example, the calcarenite G–G in the type section of Santa Maria di Catanzaro is accepted as the lower boundary stratotype of the Pleistocene. However, all stratigraphically meaningful events – the extinction of *Discoaster brouweri*, the appearance of *Hyalinea balthica*, etc. – occurred in the 'sandy Calabrian' below the stratotype, and *Globorotalia truncalinoides* was found either below or much above it (admittedly not an 'evolutionary appearance'). Berggren & Van Couvering (1974) vaguely suggested correlation of the reference bed with the reversed split in the Olduvai Normal Event, though actually it may be placed elsewhere in the Matuyama Reversed Epoch. Thus, the confidence level of the G–G bed is very low and the 'sandy Calabrian' is a much better choice. The appearance of *H. balthica* indicates climatic change as a cause of biotic events. However, Berggren & Van Couvering are strongly against use of the 'ecologically controlled' *H. balthica* and against any reference to climatic changes as well. They state that boundaries are not determined by convenience: 'They are. They exist.' They certainly exist but, as in the case of G–G, their existence may be of very little consequence.

Homotaxis and diachroneity

Homotaxis, or parallel development of regional biota – 'this great fact of the parallel succession', as Darwin phrased it – had served as the basis of international stratigraphical correlation until Darwin and Huxley claimed that homotaxial biota were not contemporaneous. They proceeded from the assumption that the modern biota of southern continents, especially of Australia, were like the Cretaceous or Tertiary biota of Europe. This was not substantiated by direct geological observations, but rather arose from the notion that marsupials were predecessors of placentals. It is true that in the Cretaceous, North America was richer in marsupials than at present, but its biota as a whole were a far cry from that of modern Australia. In the Tertiary, the marsupial fauna of Australia underwent diversifications and extinctions together with the eutherian faunas of northern continents (Lillegraven 1972). The study of plant successions in the Quaternary of the southern continents convinced Lennart von Post that his law of regional parallelism (different plant communities responded synchronously and much in the same way to climatic changes) was of world-wide application (see Cranwell & von Post 1936). The modern vegetation of New Zealand was often compared with the late Mesozoic plant communities of northern countries. However, Mildenhall (1975) reported *Eucalyptus* and *Acacia* from the Tertiary of New Zealand. It appears that the 'Mesozoic aspect' was acquired only very recently. Rattenbury (1962) suggested that the tropical element of New Zealand vegetation was repeatedly segregated from hybridizing 'Rassenkreisen' during the Pleistocene. Modern studies (e.g. Waterhouse 1973) show that it is still possible to infer contemporaneity from homotaxis.

W. B. Wright (1926) based his idea of diachroneity on the observation that successive zonal species (of goniatites) replaced one another laterally, away from the stratotype area. He regarded the zonal species 'as absolute indices of the passage of time'. If so, there was no escape from the conclusion that some similar fossiliferous beds were deposited at different times. The alternative possibility that zonal species belonged to different 'depth communities', or were engaged in other patterns of catenic distribution (Krassilov 1974), was not seriously considered. Belief in diachroneity is backed by the assumption that any rock sequence was produced by continuous migration of facies; this is the law of Golovkinsky and Walther, recently championed by Shaw (1964). However, a migration of facies was caused by some change in depositional environment which was not simply transferred intact from place to place. A layer deposited during more than one moment of geological time (as defined above) was never demonstrated, neither is it theoretically conceivable, because deposition of a layer is an elementary event in stratigraphy.

Zones

There are many kinds of zones based on the time ranges of taxa or communities, partial ranges, or their overlaps. It is essential for natural stratigraphical classification that spatially separated rock sequences belong in the same unit, not because they fall in the same selected species range (the idealized boundaries based on total ranges are undetectable, and partial ranges are admittedly diachronous) or yield a combination of fossils corresponding to a zonal assemblage (which is typology par excellence), but because they occupy corresponding positions in the parallel sequences of events. Among the sequences to be compared the ones most important for stratigraphy are cliseres and chronoclines. The cliseres, or chronocoenoclines, are defined as the sequences of climax ecosystems replacing each other in response to crustal or climatic disturbances. The cliseres are divided into coenozones (see Krassilov 1974).

The chronoclines are often conceived as lineages, or ancestor–descendant lines, though actually they are rather sequences of character states, or phenes. Thus, the successive parts of a chronocline defined by particular character states are *phenozones*. According to the law of homologous variation (Vavilov 1922), the same alleles can be fixed in populations of closely related or even distantly related species. Changes of general selective environment cause similar shifts of allele frequencies in isolated populations resulting in parallel chronoclines. Golubovsky *et al.* (1974) has described simultaneous rises of certain allele frequencies in numerous fairly isolated *Drosophila* populations scattered over the vast territories of Siberia, Central Asia and the Far East. They referred to this phenomenon as the 'mutation fashion'.

I believe that parallel successions of mutation fashions, though differently interpreted, are at the root of many zonal correlation systems. A mutation fashion may be perceived by palaeontologists as the appearance and instantaneous spread of a new species or higher taxon. In local classifications, phenozones are essentially concurrent with morphotype zones (Sylvester-Bradley 1958; Kauffman 1970). However, phenozones transgress taxonomic divisions and allow much wider correlation. One of the first and most refined systems of phenozones was worked out by Pavlov (1907), who used homologous variation in the highly polymorphous species of *Buchia* for correlation of Upper Jurassic strata. He clearly understood the nature of the biological process under this correlation, though, like Neumayr, he gave a specific name to each phenon. Pavlov has observed the swells of particular phene frequencies in many contemporaneous populations flowing together in the 'mighty stream of life'. These swells gave their characteristic aspect to successive chronofaunas. Soergel (1912) has described parallel chronoclines of the European and Asiatic elephants in much the same words (*Entwicklungstrom*).

The stepwise 'trigonization', simultaneously embracing several bivalve chronoclines (Newell & Boyd 1975), is a spectacular example picked from modern literature. In plants, the 'entire leaf' phene arose among the ginkgophytes in the Late Triassic (*Ginkgoites lunzensis*) and was kept at low frequencies through the Jurassic and Neocomian. Considerable increase occurred in the Aptian and Albian and then, again simultaneously, in the European, North American and Asiatic lineages (*Ginkgo spitsbergensis* Manum, *G. wyomingensis* Manum, *G. tsagajanicus* Samylina) in the Danian (see Krassilov 1972, 1976b). It was held that *Gigantopteris* occurred in the Permian floras of China and U.S.A., thus, giving evidence of trans-Pacific land connections. According to Kon'no & Asama (1956), the Asiatic and American '*Gigantopteris*' belonged in different lineages and acquired the coherent leaf type by parallel evolution. However, the 'gigantopteridalean leaf' phene had appeared in the Shansi Series of China (*Emplectopteris* and *Emplectopteridium*) and in the Leonardian of North America (*Gigantopteridium*), in both cases correlated on independent evidence.

International and regional classifications

The regional stratigrapher is supposed to define existing divisions of rocks and then to relate them to the international scale which stands for standard reference. Thus, regional classification can be conceived as natural and the international standard scale as artificial, at least outside the stratotype area.

In his pioneering paper on the 'dual classification', Williams (1894) claimed that it was a bold step when the New York state geologists discarded extra-typological Wernerian classification and described the New York rocks 'just as they found them', with new names and new classifications. But the formations were not time-divisions, because they overlapped and replaced each other laterally, while in the time-scale the divisions formed a regular succession. Thus, the local rock-scale is independent of the standard time-scale and is related to it by means of fossils. While Williams' reasoning is largely sound, his conclusions are questionable. One could argue that the gross lithological characters are simply not enough for general-purpose stratigraphical classification (except perhaps a preliminary one) and that a complex lithogenic, palaeoecological and evolutionary approach would make the dual classification superfluous.

Schenk & Müller (1941) revived the ideas of Williams in more categorical and logically more vulnerable form. They said that a geologist defines rock units as he finds them in the field, without bias concerning their ages. He maps the rock-masses, not time-intervals or organic remains. 'He rarely finds it possible or relevant to his problem to show the exact relations of the cartographic units in his area to similar units in Europe, Asia, Africa, or even to units in less distant regions.' Contrary to this, a biostratigrapher deals with time boundaries established primarily on a palaeontologic basis and independent of facies. The success of these ideas in the middle of the 20th century is remarkable because they, in fact, carry us back to the 'Grauwacke Slate' of British geologists before 1851, and to the famous Sedgwick–Murchison controversy which stemmed from lumping together masses of superficially similar rocks irrespective of their fossil content. Stratigraphy aims at temporal relations of rocks and it is precarious to map 'rock masses' with no regard to their ages.

The field geologist is seldom so lucky as to find out the sequential relations of all rocks in his area without reference to adjacent areas or more distant regions. The standard scale comes into sight much earlier than the regional classification is completed. It must also be remembered that William Smith proposed his biostratigraphical method for purposes of local classification and cartography. It is preposterous to speak of organic remains as independent of facies. These and other inconsistencies are characteristic of all works backing the 'dual nature' of stratigraphical classification.

In natural classification, divisions of the standard scale reflect major discontinuities in evolution of the lithosphere and the biosphere. These world-wide discontinuities should be evident in any local record. If the boundaries of local stratigraphical units are of the highest confidence level, they are bound to coincide with units of the standard scale. Otherwise they are ill-defined. Conversely, if the standard scale does not fit regional classifications, it is not up to its theoretical stature and must be revised. The standard scale arises, as does natural regional classification, biased by incompleteness of local records and errors of individual workers. It is then subjected to step-by-step improvement while the experience of many regional classifications is synthesized.

One can argue that spectacular events such as the Messinian crisis in the Mediterranean are of regional importance only. But if the crisis had been caused by inversion of the inflow and outflow currents (Sonnenfeld 1975), it might have been seen as one of responses to pronounced cooling felt (though less catastrophically) all over the world.

The field geologist may find it convenient to draw the boundaries below some conglomerates or bentonites with no regard to their confidence level. However, he must be aware that any compromise between the theoretically sound decision and the immediately convenient one makes the regional classification less natural and, thus, diminishes its heuristic value and utility.

Conclusions

Darwin prophesied the decline of the 'noble science of geology' (that is, palaeontology and stratigraphy), and it is undeniable, in Rudwick's words (1972:264), 'that palaeontology was withdrawing more and more from the position of intellectual importance that it had held in the public mind earlier in the century'. Darwin contributed to its decline not by demonstrating the discouraging imperfection of the fossil record (which he, in fact, failed to do), but by his long-standing reductionist view of natural selection as competition between organisms against a steady-state geological background. Only recently was it realized that causal explanation of evolution should be sought not at a biotic but at a higher geobiotic level of organization and that the 'survival of the fittest' is a tautology unless the trend of geological development is specified.

The gradualistic concept of evolution stemmed from ignorance of such general system properties as homeostasis. Resilience of a system is directly related to its complexity. The more complex a system is, the more discontinuously it evolves, and the layered rocks are a paradigm manifestation of this character of geobiological evolution.

Chronostratigraphy has challenged the traditional typological classification which underestimated variation of stratigraphical characters. The chronostratigraphical school claims continuous variation of stratigraphical characters and gradual evolution. The international stratigraphical scale is conceived as a succession of arbitrary reference time planes, fixed in stratotypes and independent of opinions about earth history. The sections of this scale are divisions in the sense that they have no internal unity. Rocks are placed in a division because their ages fall between corresponding time planes.

An alternative interpretation of the evolution of the biosphere as a sequence of equilibrial states, periodically disturbed by geodynamic events, allows natural stratigraphical classification. Perception of geological time is derived from the succession of palaeobiospheres. The international scale is conceived as the current stratigraphical theory, summing up the experience of many local classifications. The internal unity of its sections depends on the stability of dominant biological (as well as geochemical and geomagnetic) characters. Geological age is defined by these characters. Events are contemporaneous if they belong in the same palaeobiosphere.

Classification can be seen as a frame of reference and common language. Arbitrary classifications suffice for this purpose. However, classifications also embody our understanding of nature. In the latter case, there is nothing arbitrary about them; they are more informative, but also riskier, because there is not only some true content, but inevitably also some false content. Chronostratigraphical and ecostratigraphical classifications reflect reductionist and holistic views of evolution respectively, and stratigraphy is apparently the only field where the problem of reduction is not just of philosophical significance but also of some practical significance.

References

Avise, J. C. 1975: Systematic value of electrophoretic data. *Syst. Zool. 23*, 465–481.

Berggren, W. A. & Van Couvering, J. A. 1974: The Late Neogene: Biostratigraphy, geochronology and paleoclimatology of the last 15 million years in marine and continental sequences. *Palaeogeogr. Palaeoclimatol. Palaeoecol. 16*, 1–216.

Boucot, A. J., Dunkle, D. H., Potter, A., Savage, N. M. & Rohr, B. 1974: Devonian orogeny in western North America? A fish and other fossils. *J. Geol. 82*, 691–708.

Bryson, R. A., Baerreis, D. A. & Wenland, W. M. 1970. The character of late-glacial and post-glacial climatic changes. *In:* Pleistocene and present environments of the central Great Plains. *Dep. Geol. Univ. Kansas Spec. Publ. 3*, 53–74.

Carson, H. L. 1975: The genetics of speciation at the diploid level. *Am. Nat. 109*, 83–92.

Cranwell, L. M. & Post, L. von 1936: Pleistocene pollen diagrams from the southern hemisphere. I. New Zealand. *Geogr. Ann. 18*, 308–333.

Creed, E. R. 1975: Melanism in the two spot ladybird: the nature and intensity of selection. *Proc. Roy. Soc. Lond. 190B*, 135–148.

Dobzhansky, T. G. 1974: Genetic analysis of hybrid sterility within the species *Drosophila pseudoobscura*. *Hereditas 77*, 81–88.

Eldredge, N. & Gould, S. J. 1972. Punctuated equilibria: an alternative to phyletic gradualism. *In* Schopf, T. J. M. (ed.): *Models in Paleobiology*, 82–115. Freeman & Cooper, San Francisco, California.

Flemming, N. C. & Roberts, D. G. 1973: Tectono-eustatic changes in sea level and seafloor spreading. *Nature 243*, 19–22.

Gilluly, J. 1973: Steady plate motion and episodic orogeny and magmatism. *Bull. Geol. Soc. Am. 84*, 499–514.

Golubovskij, M. D. *et al.* (Голубовский, М. Д., Иванов, Ю. Н., Захаров, И. К. и Берг, Р. Л.) 1974: Исследование синхронных и параллельных изменений генофондов в природных популяциях плодовых мух *Drosophila melanogaster*. [Study of synchronous and parallel changes of gene pools in the natural populations of *Drosophila melanogaster*.] *Генетика 10*, 73–81.

Goodman, M. & Moore, G. W. 1973 (1974): Phylogeny of hemoglobin. *Syst. Zool. 22*, 508–532.

Harland, W. B. *et al.* 1972: A concise guide to stratigraphical procedure. *J. Geol. Soc. 128*, 295–305.

Hedberg, H. D. 1948: Time-stratigraphic classification of sedimentary rocks. *Bull. Geol. Soc. Am. 59*, 447–462.

Hedberg, H. D. 1958: Stratigraphic classification and terminology. *Bull. Am. Assoc. Petrol. Geol. 42*, 188–189.

Hedberg, H. D. 1964: Definition of geological systems. *Rept. 22 Sess. (Intern. Geol. Congr.,) India 18*, 1–26.

Hughes, N. F. 1976: *Palaeobiology of Angiosperm Origins.* 242 pp. Cambridge University Press, Cambridge.

Jones, J. S. 1973: Ecological genetics and natural selection in molluscs. *Science 182*, 546–552.

Irving, E. & Pullaiah, G. 1976: Reversals of the geomagnetic field, magnetostratigraphy, and relative magnitude of paleosecular variation in the Phanerozoic. *Earth Sci. Rev. 12*, 35–64.

Kauffman, E. G. 1970: Population systematics, radiometrics and zonation–a new biostratigraphy. *North Am. Paleont. Convention, Chicago, 1969, Proc. A* 612–665.

Kennett, J. P. & Watkins, N. D. 1970. Geomagnetic polarity change, volcanic maxima, and faunal extinction in the

South Pacific. *Nature 227*, 930.

Khain, V. E. (Хаин, В. Е.) 1975: Основные этапы тектоно-магматического развития Кавказа: опыт геодинамической интерпретации. [Major stages in the tectonomagmatic evolution of the Caucasus: an attempt at a geodynamic interpretation.] *Геотектоника 1*, 13–27.

Kitts, D. B. 1966: Geologic time. *J. Geol. 74*, 127–146.

Kon'no, E. & Asama, R. 1956: On pinnate fround of *Gigantopteris whitei* Halle from the Lower Shihhotse Series, Shansi, with special comparison to *Gigantopteris americana* White. *Jap. J. Geol. Geogr. 27*, 157–160.

Krassilov, V. A. (Красилов, В. А.) Палеоэкосистемы. [Palaeoecosystems.] *Изв. АН СССР, сер. геол. 12*, 97–101.

Krassilov, V. A. (Красилов, В. А.). 1972: *Мезозойская флора реки Буреи.* [*Mesozoic flora of the Bureja River.*] 151 pp. Наука, Москва.

Krassilov, V. A. 1973: Climatic changes in Eastern Asia as indicated by fossil floras. I. Early Cretaceous. *Palaeogeogr. Palaeoclimatol. Palaeoecol. 13*, 261–273.

Krassilov, V. A. 1974: Causal biostratigraphy. *Lethaia 7*, 173–179.

Krassilov, V. A. 1975: Climatic changes in Eastern Asia as indicated by fossil floras. II. Late Cretaceous and Danian. *Palaeogeogr. Palaeoclimatol. Palaeoceol. 17*, 157–172.

Krassilov, V. A. (Красилов, В. А.) 1976a: Тектоника плит и ротационный режим планеты. [Plate tectonics and the rotation regime.] *Изв. АН СССР, сер. геол. 1*, 74–82.

Krassilov, V. A. (Красилов, В. А.) 1976b: Цагаянская флора Амурской области [Tsagajan flora of the Amur Province.] Наука, Москва.

Laffite, R., Harland, W. B., Erlen, H. K., Blow, W. H., Haas, W., Hughes, N. F., Ramsbottom, W. H. C., Rat, P., Tintant, H. & Ziegler, W. 1972: Some international agreement on essentials of stratigraphy. *Geol. Mag. 109*, 1–15.

Leonov, Ju. G. (Леонов Ю. Г.) 1976: Тектоническая природа девонского орогенеза. [Tectonic nature of the Devonian orogeny.] 193 pp. Недра, Москва.

Le Pichon, X., Francheteau, J. & Bonin, J. 1973: Plate tectonics. *Development in Geotectonics 6*. 300 pp. Elsevier, Amsterdam.

Levins, R. 1968: *Evolution in Changing Environments.* 120 pp. Princeton University Press, Princeton, New Jersey.

Lewis, H. 1958: Catastrophic selection as a factor in speciation. *Evolution 16*, 257–271.

Lewontin, R. C. 1969: The meaning of stability. *In: Diversity and Stability in Ecological Systems. Brookhaven Symposia in Biology 22*, 13–24.

Lillegraven, J. A. 1972: Ordinal and familial diversity of Cenozoic mammals. *Taxon 21*, 261–274.

Lillegraven, J. A. 1974: Biogeographical considerations of the marsupial-placental dichotomy. *In* Johnston, R. F. *et al.* (eds.): *Annual Review of Ecology and Systematics 5*, 263–285.

Lull, R. S. 1947: *Organic Evolution.* 744 pp. Macmillan, New York.

MacArthur, R. H. & Wilson, E. O. 1967: *The Theory of Island Biogeography.* 203 pp. Princeton University Press, Princeton, New Jersey.

Martinsson, A. 1973: Editor's column: Ecostratigraphy. *Lethaia 6*, 441–443.

McElhinny, M. W. 1973: *Palaeomagnetism and Plate Tectonics.* 358 pp. Cambridge Univ. Press, Cambridge.

Mildenhall, D. C. 1975: Palynology of the *Acacia*-bearing beds in the Komako district, Pohangia Valley, North Island, New Zealand. *New Zeal. J. Geol. Geophys. 18*, 209–228.

Miller, T. G. 1965: Time in stratigraphy. *Palaeontology 8*, 113–131.

Neymayr, M. (Неймайр, М.) 1887: *История Земли.* [*History of the earth*, Russian translation, 1900.] 848 pp. Просвещение, С.-Петербург.

Newell, N. D. 1963: Crises in the history of life. *Sci. Am. 208*, 76–92.

Newell, N. D. & Boyd, D. W. 1975: Parallel evolution in early Trigoniaceae bivalves. *Bull. Am. Mus. Nat. Hist. 154*, 53–162.

O'Rourke, J. E. 1976: Pragmatism versus materialism in stratigraphy. *Am. J. Sci. 276*, 47–55.

Pavlov, A. P. 1907: Enchainement des aucelles et aucellines du crétacé. *Nouv. Mem. Soc. Natur. Moscou 17*, 1–93.

Pisias, N. G., Heath, G. R. & Moore, T. C. Jr. 1975: Lag time for oceanic responses to climatic change. *Nature 256*, 716–717.

Rastall, R. H. 1944: Palaeozoic, Mesozoic and Kainozoic: a geological disaster. *Geol. Mag. 81*, 159–165.

Rattenbury, J. A. 1962: Cyclic hybridization as a survival mechanism in the New Zealand forest flora. *Evolution 16*, 348–363.

Rudwick, M. J. S. 1972: *The Meaning of Fossils. Episodes in the History of Palaeontology.* 287 pp. MacDonald, Elsevier, New York and Amsterdam.

Salop, L. I. (Салоп Л. И.) 1963: Геологическая интерпретация данных аргонового определения абсолютного возраста горных пород. [Geological interpretation of the argon dating of rocks.] *Геология и геофизика 1*, 3–21.

Schenk, H. G. & Müller, S. W. 1941: Stratigraphic terminology. *Bull. Geol. Soc. Am. 52*, 1419–1429.

Schindewolf, O. H.: *Grundlagen und Methoden der paläontologischen Cronologie.* 152 pp. Berlin.

Shaw, A. B. 1964: *Time in Stratigraphy.* 365 pp. McGraw-Hill, New York.

Simpson, G. G. 1949: Rates of evolution in animals. *In* Jepsen, G. L. *et al.* (eds.): *Genetics, Paleontology and Evolution*, 205–228. Princeton University Press, Princeton, New Jersey.

Soergel, W. 1912: *Elephas trogonterii* Pohl. und *Elephas antiquus* Falc. *Palaeontographica 70*, 1–114.

Schuchert, C. & Dunbar, C. O. 1933: *A Textbook of Geology 2*. 3 ed., New York.

Sonnenfeld, P. 1975: The significance of Upper Miocene (Messinian) evaporites in the Mediterranean Sea. *J. Geol. 83*, 287–311.

Sylvester-Bradley, P. C. 1958: The description of fossil populations. *J. Paleontol. 32*, 214–235.

Valentine, J. M. 1971a: Resource supply and species diversity patterns. *Lethaia 4*, 51–61.

Valentine, J. M. 1971b: Plate tectonics and shallow marine diversity and endemism, an actualistic model. *Syst. Zool. 20*, 253–264.

van Hinte, J. E. 1969: The nature of biostratigraphic zones. *Proc. Int. Conf. Planktonic Microfossils 1, Geneva, 1967*, 267–276.

Vavilov, N. I. 1922: The law of homologous series in variation. *J. Genet. 12, 1.*

Vogt, P. R., Johnson, G. L., Holcombe, T. L., Gilg, J. G. & Avery, O. E. 1971: Episodes of sea-floor spreading recorded by the North Atlantic basement. *Tectonophysics 12*, 211–234.

Wallace, A. R. 1855: On the law regulating the appearance of new species. *Ann. Mag. Nat. Hist. September issue*, 1–27. *Russian translation, 1878*, S.-Petersbourg.

Waterhouse, J. B. 1973: Permian brachiopod correlations

of South-East Asia. *Bull. Geol. Soc. Malaysia 6*, 187–210.
Whitrow, G. J. 1961: *The Natural Philosophy of Time.* 324 pp. Nelson, Edinburgh.
Williams, H. S. 1894: Dual nomenclature in geological classification. *J. Geol. 2*, 145–160.
Wolfe, J. A. & Barghoorn, E. S. 1960: Genetic changes in Tertiary floras in relation to age. *Am. J. Sci. 258A*, 388–399.
Wright, W. B. 1926: Stratigraphic diachronism in the Millstone Grit of Lancashire. *Rept. Brit. Ass. Adv. Sci.* 354–355.
Zuckerlandl, E. & Pauling, L. 1965: Evolutionary divergence and convergence in proteins. *In* Bryson, V. & Vogel, H. J. (eds.): *Evolving Genes and Proteins*, 97–116. New York Acad. Press, New York.

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