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STRATIGRAPHIC UNITS IN SPACE AND TIME

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ABSTRACT. The physical basis for stratigraphy should be restricted to surface-accumulated (sedimentary and volcanic) rocks; intrusive igneous, metamorphic, and other post-depositionally emplaced bodies should be excluded.

Relationships involve at least a four-dimensional space-time continuum which, for ease of concept and convenience of graphic portrayal, may be subdivided into two three-dimensional frameworks: (1) a spatial framework in which all intrinsically *objective* (physical and biostratigraphic) units are defined; and (2) a framework with lateral spatial dimensions and a vertical temporal dimension, in which all *subjective* (time-stratigraphic) units are defined.

Transposition (with appropriate distortion) of the objective, spatial elements to the subjective, space-time framework (or *vice versa*) provides bases for integration and potentially complete historical interpretation. Moreover, such an integrated system, insofar as it may be dimensionally valid and otherwise logically constructed, tends to induce consideration of various essential relationships which commonly have been disregarded in stratigraphic analyses and historical interpretations.

Present geologic knowledge and practices imply that four basic principles and numerous distinctional factors or criteria must be satisfied. The principles are superposition, faunal succession, base-level, and datum variance. Among the distinctional criteria are subjectivity and objectivity; physical, bio-, and time-stratigraphic; environmental ("ecostratigraphic") and non-environmetal control; natural and arbitrary configuration; mode of contiguity (vertical, lateral, and intertongued); mappability and scale; lithology; unconformity; evolution; "uniformity" and heterogeneity; barrenness; lateral variation (facies); deposition, non-deposition, and erosion (stratigraphic cycle); tangibility; and continuity versus discontinuity.

Although the number of factors appears unwieldly, if the physical, bio- and time-stratigraphic categories are shown on one co-ordinate axis, and if the other factors, as additional bases for unit configuration, are appropriately applied to the other, a reasonably simple, dual (space and space-time) classification may be constructed.

INTRODUCTION

A principal objective of many stratigraphers has been to keep concepts and terminology "simple and practical." Indeed, these would be worthy aims, if the science could advance within the simplicity of a framework largely developed a century ago, and if the tendency to justify the *status quo* by fettishing the word "practical" does not actually lead to malpractice.

Hedberg (1958) has recently expressed this desire for simplicity, although he properly included *verity* and *utility* as other essential attributes. He pointed out that: "Stratigraphic terminology, like stratigraphic classification is . . . . only a means to an end [but that] it plays a very important role in stratigraphic thinking."

To realize the aims of verity and utility, however, terminology must reflect the validity and adequacy of stratigraphic concepts and procedures, in the interest of creative thinking and communication. From this viewpoint an attempt is made to bring together a space-time framework, incorporating essential principles, concepts, procedures, and terminology. Because the "mental crutch" of classification is involved (fig. 1), the approach follows the devious course of numerous factors or kinds of criteria and their influence on the designation of units.

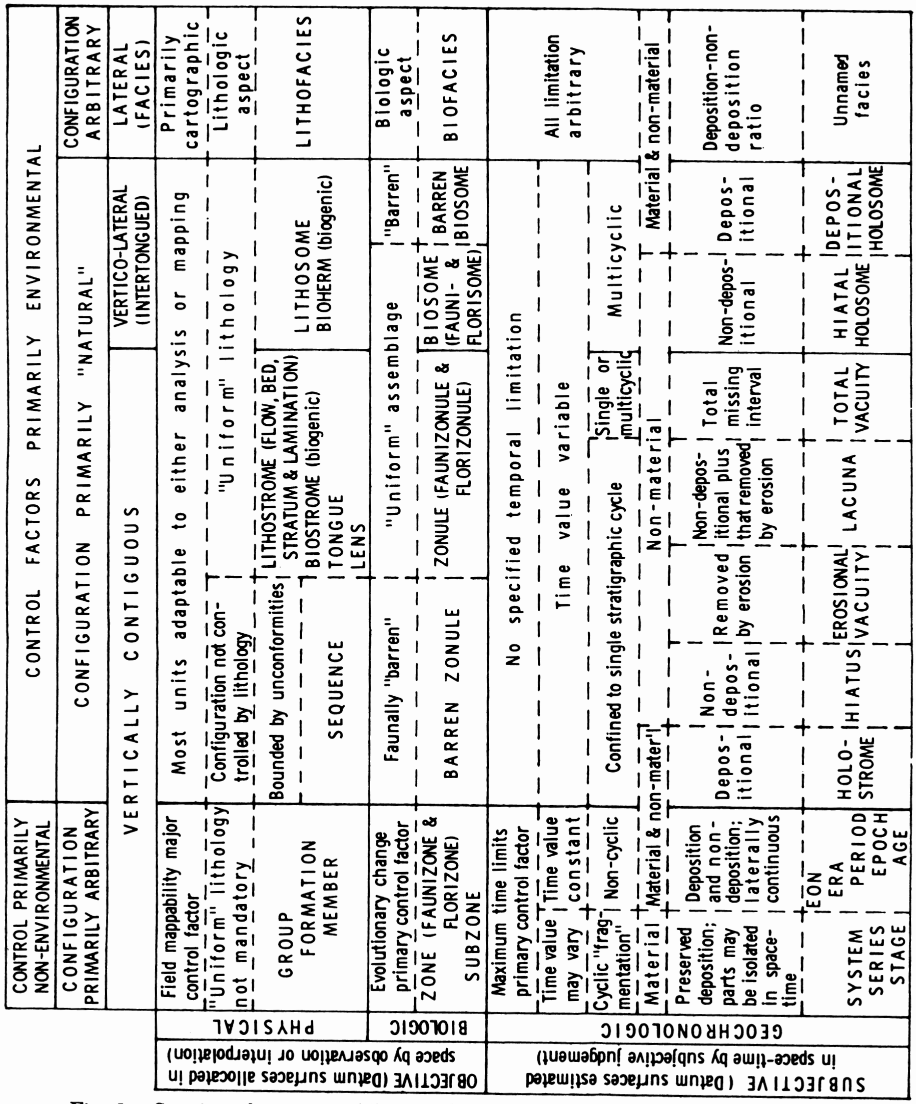

Fig. 1. Stratigraphic units. All capitalized categories on left (SUBJECTIVE, OBJECTIVE, GEOCHRONOLOGIC, *etc.*) apply to right, *through entire chart*, between horizontal solid lines concerned. All capitalized categories at top (CONTROL PRIMARILY ENVIRONMENTAL, VERTICALLY CONTIGUOUS, *etc.*) apply below, *through entire chart*, betwen the vertical solid lines concerned. All categories described in lower-case letters apply below, *only to next horizontal solid line*, between vertical lines (solid or dashed) concerned.

NATURE OF STRATIGRAPHY

Regardless of the universal desire for simplicity, the numerous variable stratigraphic factors and relationships can be expressed only in a complex framework—a four-dimensional continuum which may be conceived with reasonable facility, but which nevertheless defies imagination. If this disquieting thought has created a dilemma, it is one which can no longer be ignored. We must either adapt some kind of "non-Euclidean" geometry in order to portray the complex, or we must employ a device within the realm of familiarity which will permit us to deal in the customary three dimensions. Because the former does not appear to lie within the scope of the profession's (and the writer's) present capabilities, it is assumed that the latter is more feasible. This appears to be attainable by: (1), defining all physical and biostratigraphic (objective) entities in a three-dimensional spatial framework; and (2), defining all time-stratigraphic (subjective) entities in a framework consisting of two lateral spatial dimensions and a vertical dimension in time.

Such a dual system is not as simple as the single three-dimensional spatial scheme into which, with persistent futility, we have attempted to cram the troublesome fourth dimension. Williams (1894) and others since have observed the need for such a dual system, but elements of the two sub-systems have been confused, and their dimensional characteristics generally have not been envisaged. Most of the space-time relationships were illustrated by Blackwelder (1909), but his significant concepts have not received their deserved consideration. Although Williams' observation was injected into the classification by Schenck and Muller (1941), most of Blackwelder's implications have escaped proper notice for a half-century.

Why has an integrated four-dimensional system continued to remain elusive? In line with the tendency to maintain "simplicity and practicality" of concept and terminology, all geologists have "learned" that there are only two fundamental laws in stratigraphy, superposition and faunal succession (and it may be argued that these two are merely differing expressions of a single law relating to vertical succession). If these were the only laws involved, stratigraphy would indeed be simple—so simple, in fact, that the entire stratal "sphere" would consist of a series of concentric layers. The varied relationships, however, can only be explained in terms of at least two additional principles (baselevel and datum variance), the implications of which demand a more complex system.

Stratigraphy is variously defined, but among recent authors, Dunbar and Rodgers (1957) refer to the subject as:

> . . . . the study of stratified rocks . . . . originally spread as sheets over a surface of accumulation. [It includes] the study of such layered igneous rocks as ash falls and lava flows, and of metamorphic rocks insofar as they reflect the original sedimentary [or volcanic] character—a definition in agreement with the statement of the U.S.S.R. Interdepartmental Stratigraphic Committee (Rotay, et al., 1956).

Stratigraphic units should *directly* relate to surface-accumulated rocks; and if stratigraphy is to have any restriction in the vast realm of geology, entities more directly related to other geological phenomena should be excluded.

The American Commission on Stratigraphic Nomenclature (1956, p. 2000-2006) cited the time-honored and useful rock classes: sedimentary, igneous, and metamorphic; and implied that all units of each are rock-stratigraphic. Such an all-encompassing view not only needlessly flouts the oldest and most fundamental law (superposition), but it also confuses stratigraphy with petrology, and gives rise to illogical practices. The distinction between surface-deposited (stratigraphic) layers and postdepositionally emplaced rocks is fundamental; post-depositionally emplaced bodies, regardless of whether they may be petrologically classed as igneous, metamorphic, or "sedimentary" (sandstone dikes and salt intrusions), should not be regarded as stratigraphic units. The Dunbar and Rodgers and Russian definitions carry the inescapable implication that the law of superposition must obtain. It is believed that this simple test serves to distinguish stratigraphic from non-stratigraphic units.

Wheeler and Beesley (1948) referred to stratigraphy as being 'four-dimensional. Stainforth (1958) stated: "Accepting as we must, that sedimentary [and volcanic] rocks form a four-dimensional continuum, this very word tells us why stratigraphic classification and nomenclature remain in a debatable state." Schenck and Muller (1941) opened the door to this four-dimensional concept, not only by pointing out the distinction between "time" and lithic units, but also by introducing a time-stratigraphic category. However they confused the dimensional aspects of the problem, as did Wheeler and Beesley (1948), by assuming identity of biostratigraphic and time surfaces. Hedberg (1948) appears to be the first to emphatically disparage the traditional belief that biostratigraphy is a wholly reliable basis for determining synchrony. In a paper based largely on this view, Wheeler, et al. (1950) made an abortive attempt to reconcile the various concepts by proposing the term "para-time-rock" for any biostratigraphic or lithologic units that are deemed to "approach synchrony." The American Commission on Stratigraphic Nomenclature (1952, p. 1628) disregarded this ill-considered proposal, and gave long-overdue recognition to the distinction of the biostratigraphic and temporal divisions. The Commission thus recognized four principal kinds of units—rock-stratigraphic, biostratigraphic, time-stratigraphic, and "geologic time" units. Three of these four have been accepted and discussed as primary categories in papers on lithostratigraphy (Wheeler and Mallory, 1956), on biostratigraphy (Wheeler, 1958a), and on time stratigraphy (Wheeler, 1958b).

Each of these three was approached with emphasis on the dimensional relationships. Both physical and biostratigraphic units are mutual but distinctive occupants of the same three-dimensional spatial framework and are designed to account for total stratigraphic space. It logically follows that a category must be designed to potentially account for total stratigraphic space-time. But if it is not feasable to deal singly with the four-dimensional continuum, the conclusion seems inescapable that here also a three-dimensional framework must be employed. In time-stratigraphy, the same geographic points are involved. Thus the two lateral dimensions are common to all phases of stratigraphy. This leaves the vertical as the time dimension of the three dimensional space-time framework.

From this point of view it may be seen that there is neither a place nor a need for "geologic time" units in the non-stratigraphic sense proposed by the American Commission on Stratigraphic Nomenclature (1952, p. 1628-1629). The notion of "non-stratigraphic time" in stratigraphy is as dimensionally invalid and useless as would be the concept of a "purely biologic ("non-stratigraphic") zone. Time has no meaning in stratigraphy unless it is first tied to the spatial record and then substituted for its vertical dimension. Thus the units involved (period, epoch, and age) are both three-dimensional and time-stratigraphic (of which time is but a single dimension). Like all other time-stratigraphic units, they have a vertical dimension measurable in terms of time; and like all stratigraphic units of any kind, their lateral dimensions are spatial. Period, epoch and age differ from other time stratigraphic units only in their constant time values and their potential world-wide continuity.

Most of this discussion up to this point, either directly or indirectly, involves dimensional relationships. In this regard, it is noteworthy that the general disregard for principles other than superposition-faunal succession has given rise to terminology which not only futilely attempts to substitute three dimensions for the necessary four, but also which commonly reflects thinking in terms of only a single dimension.

KINDS OF STRATIGRAPHY CRITERIA

Physical Stratigraphy

As indicated in the foregoing discussion, the Stratigraphic Commission and others, in recent years, have recognized lithostratigraphic, biostratigraphic, and time-stratigraphic as three fundamentally differing kinds of first-order categories. Units of the "lithostratigraphic" category indeed consist of rock, but some of the criteria by which units are distinguished are other than lithologic. For this reason, the term physical stratigraphic seems more appropriate for this first category. Among the more important criteria used in the designation of physical units are: lithologic character (lithosome and lithofacies); unconformities (sequence); and mappability, including lithology and physiographic expression (group, formation and member).

Biostratigraphy

If individual fossils are viewed as representatives of their respective taxa, they occur disseminated through the rocks in a manner which delineates the stratigraphic spatial distribution of that taxon. Such three-dimensional distribution patterns may be viewed either by themselves, or with regard to the dimensional configuration and contiguity of their various associations in stratigraphic space. The resulting units are truly biostratigraphic, for they are based on fossils as biologic rather than lithologic criteria.

Time-Stratigraphy

An appreciable segment of the geological profession has implied in recent years and, in some cases, continues to hold that "fossils at present provide the only evidence for the placing of rocks in a world-wide geologic time scale" (Teichert, 1957, p. 2575). This notion has been challenged by Hedberg (1948 and 1951), Wheeler, et al. (1950), The American Commission on Stratigraphic Nomenclature (1952), and Woodring (1953), among others, but appears to remain one of the most strongly contested major issues in the entire "classification controversy."

Another review of the evidence is not justified here. It should suffice to restate that all *objective* datum surfaces are intrinsically variable in their relation to stratigraphic time surfaces. This does not belittle the value of biostratigraphy as a basis for temporal correlation. Instead, it merely implies that this most widely employed approach to dating should be augmented by other objective criteria, and above all, that biostratigraphic and physical criteria should be fully integrated.

Objective and Subjective Criteria

The American Stratigraphic Commission (1957, fig. 1) indicated that all stratigraphic units may be placed into one or the other of two categories on the basis of their essential objectivity or subjectivity. The Commission pointed out that biostratigraphic units, together with lithostratigraphic, and other physically based units, are "dominantly objective units [in the sense that they are] based largely on observation and measurement [and that chronostratigraphic units belong in a category of] dominantly subjective units based largely on interpretation." This conclusion is obviated by the subjective nature of the temporal dimension in a space-time framework.

Hedberg (1958, p. 1883-85) has made a special point of this distinction.

Environment

The spatial distribution of the various specific types of sedimentary and volcanic rocks is entirely controlled by the space-time distribution of *environmental* factors. The same may be said for some kinds of biostratigraphic entities, the spatial distribution of which is primarily influenced by the ever-changing distribution of ecologies (Moore, 1957).

Whether environment influences configuration of some time-stratigraphic units depends on one's definition of time-stratigraphy. If time-stratigraphic units include all three-dimensional entities related to the stratal record, and defined in a framework consisting of two lateral space dimensions and a vertical temporal dimension, such units, because they are designed to account for total space-time must include, not only the preserved stratal record in space-time, but also such entities as interpreted deposition and non-deposition. Obviously, the configuration of such entities is the consequence of space-time migration of depositional, non-depositional, and erosional environments.

"Natural" and Arbitrary Limitation

The notion is common that most stratigraphic units denote the more significant events of depositional history; that is, that the boundaries between units mark the more important responses to change through geologic time. This is true in some cases; and it would be desirable that it were true in every case. Some of the most widely employed units, however, are primarily designed to fulfill special needs, with the result that their boundaries are arbitrarily defined in such fashion that the natural configurations are obscured.

Sequences are defined by their bounding unconformities, and lithostromes depict the distribution of "uniform" lithologies. Configurations of such units are largely natural. Formations, however, are defined for their mappability and may be decidedly arbitrary.

Similarly, a given biostratigraphic zonation represents only one of several possible arbitrary subdivisions based on taxon ranges; while zonules and biosomes based on "uniformity" of assemblage are "natural" in configuration.

In time-stratigraphy, boundaries between units of constant time value must be established arbitrarily; and those between time-variable units occurring within maximum time limits (such as system, series, and stage) are in part arbitrary and in part natural. Configuration of all other space-time units is controlled by natural phenomena such as deposition, non-deposition and erosion.

Contiguity

Stratigraphers have been reluctant to conceive and accept dimensional relationships other than those involving vertical succession. Nevertheless, intertonguing of certain lithic, paleobiologic, or time-stratigraphic units is the inevitable consequence of datum variance; and the baselevel concept (Barrell, 1917) cannot be divorced from units based on interpreted space-time distribution of deposition and nondeposition. In addition, designation of laterally contiguous facies units has been demonstrated to have special utility in certain phases of stratigraphic analysis.

Configuration of all stratal entities relates directly to the modes of contiguity; that is, whether the units are vertically, vertico-laterally, or laterally contiguous. Distinction among various units in each of the three categories (physical, biostratigraphic, and geochronologic) depends on recognition of these dimensional relationships.

Mappability, Scale, and other "Purpose" Considerations

Cohee (American Comm. on Stratigr. Nomen., 1956, p. 2014) and associates have stated:

> Since the early days of geologic mapping in this country the need of stratigraphic units for cartographic purposes has been recognized, and these fundamental units have been considered formations. . . . . it is recommended that the concept of mappability be considered an essential feature in the definition of a formation.

We should endorse these views on mappability, not only with regard to formation, but also group and member. This endorsement should not imply, however, that other stratigraphic units which are amenable to map portrayal should not be mapped.

One aspect of scale affects configuration; that is, recognition or nonrecognition of stratal layers. Wheeler and Mallory (1956, fig. 4) illustrated the deliberate use of the arbitrary cut-off as a necessary expedient involving arbitrary assignment of certain intertongued layers in the designation of formations. They implied that all such intertongued lithostromal bodies are individually recognized and assigned to their respective lithosomes. In many cases, however, if this procedure is carried to the extreme of recognizing each thin bed and lamination, the consequent configurations would be both impossible to achieve and undesirable as workable units. In other words, as an effect of scale, many thin layers that are recognized in concept must be individually disregarded in practice. This recognition factor may also apply in biostratigraphy and time-stratigraphy.

Lithology

Lithology is used in four differing senses in its influence on the delineation of those physical units to which it applies.

Specific lithologies are of primary and direct concern in defining such units as lithostrome, lithsome, group, formation and member; whereas *lithologic aspect* is derived statistically as the basis for the definition of laterally variant (lithofacies) units. Such aspect, of course, depends on the number, kinds, and relative proportions of specific lithologies present.

Among the above-mentioned lithic units, the configuration of lithostrome and lithosome is controlled solely by their lithologic "uniformity", while group, formation, and member may be *variant* in that they may comprise arbitrary assemblages of various specific lithologies. The fact that some formations and members may be lithologically uniform is coincidental, for such uniformity is not among their inherent characteristics.

The term *uniform*, as used here requires definition. In the case of some units, the uniformity is characterized by relative purity of both composition and texture; whereas others possess uniformity by virtue of their lithologic heterogeneity. A unit comprising thin intercalations of limestone and siltstone may be regarded as uniform, but only by the afore-mentioned non-recognition (as units) of its differing components. This kind of uniformity could not exist, except for the scale-factor. For example, a body consisting of a succession of glacially varved clays may be designated as a mappable unit of uniform lithology, and may be so employed at most map scales. However, it may not be regarded as uniform in the large-scale view of a glaciologist who locally is concerned with the detail of its individual laminations.

Unconformities

The significance of unconformities was appreciated by most of the founders of stratigraphy to the extent that most of the systems were originally defined by their unconformable relationships. The catastrophist concept and its outgrowth the diastrophist concept, in turn were the products of this early recognition of the role of unconformities in historical interpretation. In recent years, however, Wheeler (1947), Wheeler and Beasley (1948), Gilluly (1949), Spieker (1956), and others have disparaged (with a considerable measure of success) the long-standing notions that unconformities tend to be world-wide, and that, as manifestations of diastrophism, they constitute "the fundamental basis for subdivision of the geological record". Although the unconformity has been losing its traditional role in time-stratigraphic classification, it was not immediately given its deserved consideration for another.

Sloss, Krumbein and Dapples (1949) defined the term *sequence*, and designated several examples, all of which, in the regions under consideration, are bounded by unconformities. Gignoux (1955), in part, employed the term *stage* in this same sense. The American Commission on Stratigraphic Nomenclature (1957, p. 1877) included unconformities among its list of bases for classification. Moreover, many of the units shown on the Geological Map of the U.S.S.R. (Nalivkin, 1956), are of this kind.

These unconformity-based units are necessary, not only because of their direct value in physical stratigraphy, but also because they are essential, as a framework of reference, to the concept and derivation of a number of different varieties of time-stratigraphic units (Wheeler, 1958b).

Biologic Factors

Evolution.—The importance of evolution as one of the bases for subdivision and classification is appreciated by all geologists. Agreement is general that this continuous and irreversible process should be employed as a factor in the control of configuration and contiguity of certain kinds of units. However, a significant point of disagreement concerns the fundamental nature of units so defined. In accord with The American Commission on Stratigraphic Nomenclature (1952 and 1957), the writer agrees that these are biostratigraphic units, and that the criteria involved may not serve directly to delineate time-stratigraphic units, as recently advocated by Jeletzky (1956), for example.

Faunal "Uniformity".—In general, the same kinds of problems exist regarding faunal uniformity as are encountered in lithologic uniformity, except for the additional factor of evolution. However, as the writer has previously indicated, (Wheeler, 1958a), the evolution factor may be minimized by the proper selection of units (zonules). In other words, in spite of evolution, as long as the environment remains constant in a given depositional situation, the plexus or organisms will tend to remain relatively constant. "Uniformity" of assemblage, as of lithology, must be permitted to imply either relative purity or heterogeneity, as the case demands.

"Barrenness".—Because fossils are unknown in some segments of the stratigraphic record, or because of the absence of fossils of the kinds that are otherwise employed in a given biostratigraphic subdivision, the American Commission on Stratigraphic Nomenclature (1957, p. 1880), has recommended use of the term *barren zone* for such faunally negative units. The writer, however, has pointed out that evolution is the primary control factor in zonation and that barrenness is the consequence of environmental influences (Wheeler, 1958a, p. 651). From this it may be concluded that only zonules and biosomes may be barren, and that the term barren zone is therefore inappropriate.

Biologic Aspect.—In the foregoing discussion of lithology as a factor in configuration, laterally variant lithologic aspect units (lithofacies) are mentioned. Similarly, ratios involving two or more laterally intergrading paleobiologic associations may serve to delineate biofacies. The writer's previous discussion of biofacies units (Wheeler, 1958a, p. 650) does not need repeating here. The present purpose is merely to point out the role of biologic aspect as another of the many factors in stratigraphic unit configuration.

Temporal Limitation

Arbitrary Temporal Limitation.—It has become evident in recent years, that the boundaries between units of constant time value ultimately must be established arbitrarily within continuous depositional successions. These arbitrarily defined time-datum surfaces are the boundaries between such space-time units as period, epoch, and age. Hence, these units may be regarded as universally present, arbitrary slices of total stratigraphic space-time.

Variable Temporal Limitation.—The above mentioned units of total space-time comprise a space-time framework in which "bodies" comprising the preserved stratigraphic record, interpreted erosional removal, and interpreted of such subjectively delineated time-stratigraphic "bodies" are obviously time-variable.

Stratigraphic Cycle and Baselevel Concept

It is a generally neglected fundamental that geologic history at any given place comprises an alternating succession of depositional and non-depositional episodes. From this viewpoint, any properly constructed, time-stratigraphic column is cyclic.

The stratigraphic cycle has been defined as comprising "the entire space-time 'volume' represented by both the surface accumulation (holostrome) and non-depositional (hiatus) interpreted for the interval separating two successive unconformities" (Wheeler, 1958b). Its tangible manifestation, therefore, is in every case a sequence in the restricted sense. Implied in this definition, however, is more than mere deposition followed by nondeposition, for all such cycles involve, during the nondepositional phase, at least some erosional removal of strata belonging to the depositional phase; and in many cases all tangible evidence of the cycle may be locally, and sometimes regionally, erased. Such removal, nevertheless, does not imply absence of the cycle, because complete interpretation of geologic history anywhere must involve, among other things, the interpretation of the entire succession of stratigraphic cycles, regardless of whether they may be locally represented in the present record.

These are not the "sedimentary cycles" envisaged by Gignoux (1955, p. 18). As his term indicates, Gignoux's cycle is only sedimentary. It is, essentially, a specific variety of sequence in the restricted sense. The stratigraphic cycle, however, is more than sedimentary in that it is time-stratigraphic in nature; it includes the post-depositional lacuna as well as the sequence (it is thus partially subjective); and it may embody marine sediments, non-marine sediments, volcanic rocks, or their various combinations. In other words it is a complete time-stratigraphic cycle extending at any given place from the initiation of accumulation, through its cessation, and through the subsequent phase of non-deposition, to the place-time beginning of the depositional phase of the next succeeding cycle. Fully interpreted geologic history is possible only where the complete succession of such cycles can be envisaged. These cycles and their phases, in turn, can only be fully appreciated in terms of the baselevel concept.

Barrell (1917, p. 778) stated:

> . . . . the sediments [and volcanics] whose interpretation form the basis of earth history have been characteristically deposited with respect to a nearly horizontal controlling surface. This surface of control is baselevel, but for continental and marine [and volcanic] deposits the baselevel is determined by different agencies and is a word of more inclusive content than the sense in which it has generally been used by physiographers as a level limiting the depth of fluviatile erosion. Sedimentation as well as erosion is controlled by baselevel, and baselevel, local or regional, is that surface toward which the external forces strive, the surface at which neither erosion nor sedimentation takes place.

This definition, which the writer believes to be both valid and fundamental, has been generally misinterpreted. In contrast with popular concept, baselevel is neither a "horizontal plane" nor can it be defined solely in terms of sea-level or relationships on the sea floor. At any given moment its intersection with the surface of the lithosphere on one profile may be, say, a thounon-accumulation. These may be subjectively allocated in the interest of complete historical interpretation. The boundaries (and hence the configurations) sand feet above sea-level and a thousand miles inland; while on another it may be a fifty fathoms below sea-level and fifty miles off-shore. On some profiles baselevel may alternately rise and fall to intersect the lithosphere surface at a number of different points. Moreover, baselevel should not be conceived solely in its relationships to either erosion or aggradation alone, for its significance is best appreciated in stratigraphy, sedimentation, or geomorphology if it is conceived as a "surface at which neither erosion nor sedimentation [can take] place". Actually, the position of any point on the surface at any given time, relative to baselevel, is controlled by the increment and transport-energy relationship. It makes no difference whether the increment is organically or otherwise chemically generated, whether it is erosionally derived, or whether it is a direct product of volcanic activity. Nor does it matter whether the transport medium is water, ice, or atmosphere. The position of a given surface point. relative to baselevel, depends simply on whether the increment exceeds, equals, or is less than that which the energy can move. From this viewpoint, baselevel, like other geological conditions, is in a continual state of space-time flux.

Baselevel and the related grade concept are of fundamental importance in time-stratigraphy and therefore in stratigraphic analysis and historical interpretation. The writer has shown previously that insofar as they may be accurately delineated, the continuous space-time shift of the points of grade is marked by the boundaries between depositional and hiatal units (Wheeler, 1958b, p. 1061). The baselevel concept and the related concept of the stratigraphic cycle are required for an understanding of the derivation and configuration of most time-stratigraphic units, to say nothing of their influence in physical and biostratigraphy. Some time-stratigraphic units, for example, are invariably confined to the space-time "volume" of a single stratigraphic cycle; some are in all cases multicyclic; one may be either uni- or multicyclic; some may be "fragmented" or separated into disconnected parts by cyclic consequences; and some units are non-cyclic.

Tangibility

The American Commission on Stratigraphic Nomenclature (1952, p. 1629) stated that time-stratigraphic units are material units and that "geologic time units" are non-material and non-stratigraphic. Wheeler (1958b, p. 1059), in disagreement, has argued that the only kind of time which is of use to the stratigrapher must have stratigraphic control, that all units involving a dimension in time are time-stratigraphic, and that the content of such space-time units may be entirely material, entirely non-material, or partly material and partly non-material, depending on their definitions. Again, it is assumed that the aim in time-stratigraphy is to potentially account for total stratigraphic space-time, just as it is in both physical and biostratigraphy to account for all stratigraphic space. If so, preserved depositional entities defined by their positions in the space-time framework are material units; entities interpreted either as the space-time value of non-deposition, or as former deposits later removed by erosion, are non-material units; and entities such as either "restored" deposition or those with constant time value may be in part material and in part non-material. Hence, tangibility is not only a primary factor in determining the space-time configuration of preserved tangible bodies, but is also a factor without which the shape of non-material units could not be envisaged.

Deposition, Non-deposition, and Erosion

All material stratigraphic units, of course, occur in consequence of deposition, whether they be physical, biostratigraphic, or geochronologic. Furthermore, the present configuration of units in each of the three categories may be in part controlled by post-depositional erosion. Only in time-stratigraphy, however, are non-deposition and erosional removal represented "volumetrically." Satisfactory historical interpretation is not possible without envisaging units the estimated space-time configuration of which is controlled by preserved deposition, original deposition, non-deposition, erosional removal, deposition plus non-deposition, and non-deposition plus ersional removal.

Lateral Continuity and Discontinuity

Only one category of stratigraphic units has potential world-wide continuity. Eon, era, period, epoch, and age may be envisaged as being universally present in the space-time stratigraphic sphere. The Jurassic Period, for example, is present everywhere with precisely the same vertical (time) value and successional position.

All other kinds of stratigraphic units, however, may be laterally discontinuous. Such lateral discontinuity is of two kinds—natural limitation by "pinch-out" (or "cut-out") and arbitrary limitation by the arbitrary cut-off. In physical stratigraphy, both formations and lithostromes, for example, may be terminated by either pinch-out or arbitrary cut-off (Wheeler and Mallory, 1956) ; and sequences may be terminated arbitrarily or they may be "pinched out (actually cut out) wherever the upper bounding unconformity truncates the lower one (Wheeler, 1958b, fig. 2). In biostratigraphy, zonules may be terminated in either manner, and zones may discontinue laterally by the cut-off (Wheeler, 1958a, fig. 2). Moreover, one may readily envisage that zones are also subject to termination by variance of its boundary surfaces, or by erosional truncation. These same conditions have been shown to apply in the case of vertically successive time-stratigraphic units, with the above-mentioned exception (Wheeler, 1958b). Finally, all somal units, by their very nature, are subject to multiple "pinch-out"; and all facies units are terminated laterally by arbitrary cut-off.

Thus the lateral continuity of eon, era, period, etc., and the discontinuity or intermittency of all other stratigraphic units are factors in their distinction and dimensional configuration.

Datum-Surface Variance

Geologic literature gives many examples of angular relation between rock unit boundaries and "time horizons." Because Wheeler and Beesley (1948, p. 82-84) concluded that this relationship is intrinsically variable in all cases, they called it the "principle of temporal transgression." Presence of the word *temporal* appeared to distinguish this connotation of transgression from that of Grabau (1907) and others, who have used the words *transgression, transgress, transgressive*, and *transgressional* to imply marine advance as opposed to *regression* or marine retreat.

This notion of *temporal transgression* was expressed at a stage of stratigraphic thinking when only rocks and time appeared to be involved—a stage characterized by assumed parallelism of time- and biostratigraphic datum surfaces, and a few months before Hedberg's (1948, p. 456) observation that: "The time value of stratigraphic units based on fossils will fluctuate from place to place in much the same manner as the time value of a lithologic formation may vary." More recently, the American Commission on Stratigraphic Nomenclature (1957, p. 1878) recognized this variation by noting that biostratigraphic units may be "roughly parallel with rock-stratigraphic and time-stratigraphic units, but they do not necessarily conform to such units nor are they necessarily restricted by the boundaries of such units." Thus it has become evident that this intrinsic variance applies to any two stratigraphic datum surfaces of any kind or kinds (except among time-stratigraphic surfaces of constant time value when viewed in the subjective, space-time framework). Thus, it is also evident that because this transgression involves more than mere time differential, the word "temporal" is inappropriate. Without this modifier, however, use of the term transgression in this sense would be an obvious source of confusion. Therefore, the *principle of datum variance* is proposed in terminological substitution.

Datum variance is of major significance among the causes of dimensional configuration. Except for this factor, the Wernerian concept of universal concentric lithostratigraphic spheres would obtain, and all stratigraphy would be of the "layer-cake" variety. It is for this reason alone that the principle of datum variance must be included with the baselevel concept, superposition, and faunal succession to provide the foundation for a sound stratigraphic system.

CONCLUSION

It is intended that the foregoing brief discussion of the nature of stratigraphy and some of its more important components may serve to demonstrate the immensity and dimensional complexity of the subject, even though, as recommended, its tangible manifestations may be restricted to the surface-accumulated geologic record.

If it is true that acceptable stratigraphic intelligence and practice must incorporate at least four basic principles rather than the generally recognized two, if the numerous and variable factors employed to date as bases for envisaging and designating stratigraphic units are to continue in use or perhaps expand to greater utility, and if the consequent classification and terminology are to possess the desired qualities of verity and utility, they cannot at the same time be characterized by the degree of simplicity that a segment of the profession currently appears to be demanding. In essence, it is the writer's conviction that the inducement of creative thinking and the conveyance of ideas, in any field of human endeavor, are greatly enhanced if terminology and nomenclature or other symbolism is permitted to keep pace (or catch up) with development of concepts and techniques. In numerous cases stratigraphers have unsuccessfully attempted to reconcile the increasing need for a more precise language, on the one hand, and the ever-present clamor for simplicity, on the other. This inevitably gives rise to the "Humpty Dumpty" approach cited by Hedberg (1958, p. 1883) by which "a word . . . . means just what I choose it to mean." Fortunately, stratigraphic thinking and practice have advanced to the point where a few basic terms will no longer suffice for the present, not to mention the need for better expression in the interest of future progress.

The fact must be made clear, however, that the writer holds no serious brief for any of the ordination accepted or suggested in these pages, as terms embodying a greater degree of validity and utility may be proposed—or better, if a system possessing the necessary attributes can be significantly simplified. The most that presently can be claimed for this classification is that it comprises a preliminary attempt to construct a dimensionally sound, skeletal, unified, stratigraphic system, in the development of which an effort has been made to incorporate as much as possible of existing notions and terminology. And in the last analysis, if this attempt or any small part of it may be used as an effective springboard for more significant developments in this complicated field, it will have served its intended purpose.

Although the publication space available for this report does not allow inclusion of their verbal definitions, the implied stratigraphic units, together with the principle bases for their distinction, are shown in the accompanying classification (fig. 1).

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