How to use stratigraphic terminology in papers, illustrations, and talks

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ABSTRACT: Some writers, speakers, and students have problems with clear usage of stratigraphic terminology, a topic made more acute by the appearance of the complex 1983 North American Stratigraphic Code, its 2005 revision, and new editions of the International Stratigraphic Guide. The basic categories of stratigraphic units are: 1) material; 2) non-material; 3) hybrid. Examples are the well-known rock (lithostratigraphic), time (geochronologic), and time-rock (chronostratigraphic) units, respectively. Biostratigraphic units (biozones) are used to describe and correlate time-rock units. Lesser-known categories include magnetostratigraphic, lithodemic, pedostratigraphic, diachronic, and unconformity-related units. Sequence-stratigraphic nomenclature, still developing, is in a state of turmoil at present.

Both formal and informal stratigraphic units are recognized. All words in formal units are capitalized, except for species names in biozones. Only the geographically derived name in informal units is generally capitalized. Inadequate distinction between time and place words, both formal and informal, leads to unnecessary confusion. Misuse of early versus lower, late versus upper, and Ma for Myr is epidemic.

Web sites and publications such as lexicons, geologic time scales, and correlation charts are recommended as initial sources of stratigraphic information. Naming, revising, and abandoning formal stratigraphic names are governed by specific rules for names to be accepted. In illustrations of stratigraphic units, it is important to distinguish clearly between scales of time and position. Strata are not measured in years, or time in meters!

INTRODUCTION

Since publication of the latest revision of the North American Stratigraphic Code [North American Commission on Stratigraphic Nomenclature (NACSN 2005)], I have been asked to revise and update my previously published papers on using stratigraphic nomenclature (Owen 1978, 1987) which have proved useful to writers, speakers, and students who strive for clear usage of stratigraphic nomenclature, including formal terms, informal conventions, and in illustrations. The 2005 North American Stratigraphic Code (hereafter referred to as the Code) is much the same as the 1983 North American Stratigraphic Code (NACSN 1983), except for the completely revised section on biostratigraphic units. Stratigraphic nomenclature was expanded during 1983 to include formal units for non-stratified rocks that do not conform to the Law of Superposition, so the recommendations in this paper also may be of interest to geologists working with non-stratified rock types.

This paper concentrates on the North American Stratigraphic Code (NACSN 2005), but authors working on areas outside North America should consult the International Stratigraphic Guide (Salvador 1994; Murphy and Salvador 1999), hereafter referred to as the Guide. Essays to update the topics of the published Guide chapters are being written during 2008-2009 by groups of authors for the International Subcommission on Stratigraphic Classification (ISSC). Plans are to issue these separately in the journal, *Newsletters on Stratigraphy,* and they may lead to a new edition of the Guide. Current information may be found at the ISSC web site: http://users.unimi.it/issc.

The purposes of this paper are: 1) to summarize, in plain language, the currently available types of formal stratigraphic units and their usage; emphasizing the most-commonly used units, and 2) to review some informal conventions that are standard procedure in stratigraphic writing and editing, but which are not written in the Code, Guide, or any other readily available source.

CATEGORIES OF STRATIGRAPHIC UNITS

In stratigraphic work, two fundamental categories of units are recognized: 1) material units, based on actual bodies of rock; 2) non-material units, based on the abstract concept of geologic time. A hybrid of these two categories, the chronostratigraphic unit, is also recognized. A chronostratigraphic unit is an actual body of rock that serves as the referent for the interpreted geologic time during which that body of rock was deposited.

Well-known Units

For most geologists composing papers, the old "Holy Trinity" of stratigraphic units (Schenck and Muller 1941) (Table 1) that students are supposed to learn will suffice: 1) lithostratigraphic units (= material rock units); 2) geochronologic units (= abstract time units); 3) chronostratigraphic units (= hybrid time-rock units). For simplicity, these three units are called **rock, time,** and **time-rock** units in this paper. Biostratigraphic units are similar to lithostratigraphic units, in that they consist of a material body of rock, but they are defined on their fossil content rather than rock type, and they are used to determine and correlate relative age. They have been called zones, informally, but the formal term, biozone, is less commonly confused with other kinds of zones. Time and time-rock units provide a dual classification of intervals of geologic time, and the rock bodies that formed during the same time interval. Thus, they share the same boundaries, but with different category names to eliminate con-

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fusion of time and spatial concepts (i.e., Jurassic Period vs. Jurassic System). See Table 1, columns 1 and 2.

Recently, a group of British stratigraphers (Zalasiewicz et al. 2004), in their effort to simplify the stratigraphy of time, proposed eliminating the time-rock unit categories (Eonothem, Erathem, System, etc.) altogether, replacing them with the time unit categories (Eon, Era, Period, etc.), and combining the time and rock concepts into a single category they called chronostratigraphy. Soon thereafter, a group of members of the Comité Français de Stratigraphie (Odin et al. 2004) published a similar proposal to eliminate the dual classification, but they used a mixture of geochronologic and chronostratigraphic unit category names (Era, System, Stage, etc.). These proposals have not found acceptance in North America [see the objections of Heckert and Lucas (2004) and Bassett et al. (2004) to the Zalasiewicz et al. (2004) proposal], although they are more popular among some European stratigraphers. See the paper by Ferrusquia et al. in this volume for more discussion of the value of time-rock units.

The status and relationships of time-rock and biozone units is slightly controversial. Separate terms for each category are well-established in official codes and guides, but a few dissenters maintain that time-rock units are unnecessary because they are based on biozones (Weidmann 1970; Hancock 1977; Johnson 1979; Watson 1983; and Witzke et al. 1985). Biostratigraphic units were revised in the 2005 Code, so they now are in close agreement with those of the Guide. The fundamental unit is still the Biozone, but five types of biozones are now recognized: range, interval, lineage, assemblage, and abundance biozones. Biozones contain an unrepeated sequence of fossil taxa produced by unidirectional organic evolution. Their relative age is interpreted from their contained fossils. Although biozones are effective for interpreting time-rock relationships, their boundaries are not as synchronous as those of time-rock units.

Although the above controversies about time-rock and biozones units are interesting, most authors will find it prudent to adhere to the North American Code, which has been adopted for editorial use by many publishers, or the Guide for other continents.

Less-known Units

Several new types of stratigraphic units (Table 2) were first established in the 1983 Code and have been retained in the 2005 Code. All have been used in at least some publications since then, but are less-known than the well-known units. Most of these units are used almost exclusively by the special interest group that proposed them, although some have greater potential usage. These less-known units are summarized here. However, the reader seriously interested in using them should consult the appropriate specialist literature. Some geologists may encounter these units in their work, so they should be aware of them.

Magnetostratigraphic Units

These units are based on remnant magnetic polarity in rocks. In the Code, they consist of three types of stratigraphic units comparable to the "Trinity" of well-known units: 1) magnetopolarity units, similar to lithostratigraphic units; 2) polarity-chronologic units, similar to geochronologic units; 3) polarity-chronostratigraphic units, similar to chronostratigraphic units (Table 2).

Lithodemic Units

A companion to the familiar lithostratigraphic unit, which is restricted to generally stratified, tabular rock bodies conforming to the Law of Superposition, is the lithodemic unit, a generally unstratified body of intrusive, metamorphic, or highly deformed rock not generally conforming to the Law of Superposition. Many geologists working with these types of rocks are now using lithodemic nomenclature (examples may be found in papers and geologic maps in Canada and Finland). A few hard-core stratigraphers valiantly oppose usage of stratigraphic nomenclature for unstratified rocks. However, many formally named, unstratified rock bodies predate lithodemic nomenclature (e.g., Manhattan Schist) and have been used on published geologic maps since the early days of geologic mapping.

Where lithodemic units consist of two or more genetic classes of rock (e.g., igneous and metamorphic), the unranked lithodemic unit, Complex, should be used. For a unit consisting of two or more classes of rock that are intermixed due to deformation or tectonic interleaving, the term, Structural Complex, may be applied. For a unit consisting of extrusive volcanic rocks, related intrusions, and their weathering products, the term, Volcanic Complex, may be applied.

Pedostratigraphic Units

The pedostratigraphic unit, a buried layer of soil with developed soil horizons (formally called a geosol), is also a companion to a lithostratigraphic unit. Geosols are underlain and overlain by other lithic units. Pedostratigraphic units of the 2005 Code are not the same as the now abandoned soil-stratigraphic units of the 1970 revised Code (ASCN 1970). Also, pedostratigraphic terms are not used for modern or unburied soils. Most pedostratigraphic units are Quaternary, but sub-Quaternary ones have been recognized. Sequence stratigraphers commonly use ancient soils (paleosols) to recognize unconformities, but they typically do not bother with naming them as formal geosols. Many ancient soils are treated informally. Pedostratigraphic nomenclature and recognition of ancient soils is a complex subject; the interested reader is referred to the 2005 Code (p. 1559-1560 & 1576-1578) and references therein.

Diachronic Units

The 1983 Code formalized, for the first time, the diachronic unit, a temporal unit that consists of the unequal time spans represented by types of material units (Table 2). Although it has long been recognized that most lithostratigraphic and many biostratigraphic units are time-transgressive from place to place, no formal terminology has been available to indicate this diachroneity. Some geologists working with Quaternary deposits have found diachronic units useful, but few examples have been published.

Unconformity-related Units

The most debated category of stratigraphic unit during the last three decades or so is the unconformity-related unit, which has been given several different names (Table 3), both formal and informal. Many of our major time-rock subdivisions used today that were defined during the early years of geology, including many of the systems at their original locations, are bounded by unconformities, although they are not formally classified on that basis. Currently, one of the most prominent fields of geology is sequence stratigraphy, which is based on unconformity related units called sequences. The term sequence for an uncon-

TABLE 1
Hierarchy of well-known stratigraphic units in the Code listed in decreasing order of rank. Fundamental units, which are in bold type, are the original, necessary rank within each category. Other ranks are optional. Units on the same row in columns 1-3 are of equivalent rank, but units in column 4 are completely independent of the rank of units in columns 1-3.

1. Geochronologic (time)[1, 2]	2. Chronostratigraphic (time-rock)[3]	3. Biostratigraphic (Biozone)	4. Lithostratigraphic (rock)
Eon	Eonothem		Supergroup
Era	Erathern		Group
Period	**System**		**Formation**
Epoch	Series		Member (also, Lens, Tongue, Bed, or Flow)
Age	Stage		
Chron[4]	Chronozone[5]	**Biozone**	
		Subbiozone	

formity-bound unit dates from Sloss et al. (1949). Sequence stratigraphic terminology is still informal and in a state of turmoil. Sequences are defined in several different ways.

The earliest proposal to formally recognize unconformity-related units was that of Chang (1975), who named them **synthems.** The ISSC (International Subcommission on Stratigraphic Classification) adopted the term synthem as the basic unit of formal unconformity-bounded units (Salvador 1994). They were defined as "A body of rocks bounded above and below by specifically designated, significant and demonstrable discontinuties in the stratigraphic succession…" (Salvador 1994, p 46). NACSN (1983) had previously established a similar unit called an **allostratigraphic** unit, defined as "…a mappable body of rock that is defined and identified on the basis of its bounding discontinuities." Some details of usage of allostratigraphic units were modified in the 2005 Code.

Early workers in seismic stratigraphy (Vail et al. 1977) borrowed the term **sequence** of Sloss et al. (1949) and called it a depositional sequence, recognized on a seismic section by its bounding unconformities (or correlative conformities). This unit has also been called a seismic sequence. Sloss (1963) viewed the sequence as a major lithostratigraphic unit bounded by unconformities, but Vail et al. (1977) emphasized its chronostratigraphic significance. Later, the genetic stratigraphic sequence of Galloway (1989) was defined by maximum-flooding surfaces as boundaries rather than unconformities, but these surfaces may be locally unconformable, mostly due to non-deposition. All types of sequences are still treated informally. Currently, the most contentious issue about sequences seems to be the choice of which surface to trace as an approximation of the correlative conformity, which has no physical characteristic itself. Many workers, sometimes called the "Exxon school", tend to use a mixture of empirical and theoretical surfaces to bound or subdivide a sequence, especially on seismic profiles. Others, mostly workers who emphasize outcrop and well-log data, tend to use empirical surfaces such as in the T-R sequence of Embry and Johannessen (1992) to bound or subdivide a sequence. For details on these two contrasting approaches, see the series of short papers by Embry (2008-2009) and a longer paper by Catuneanu et al. (2009). Nevertheless, the ability to trace a sequence throughout a depositional basin by extending it beyond the point where unconformities become conformable has been very valuable in stratigraphic analysis.

Authors should take advantage of the wide choice of potentially useful unconformity-related stratigraphic units, but the diversity of concepts and usages is complex. So, take care. The debate over which type (or types) of unconformity-bounded unit that may eventually gain general acceptance should be interesting to follow, and the debate has become acrimonious (See http://strata.geol.sc.edu.) Currently, sequences are most used; synthems are uncommonly used; allostratigraphic units are moderately used. A recent paper by Räsänen et al. (2009) proposes that allostratigraphic units be the principal stratigraphic unit used for Quaternary glacial deposits with lithostratigraphic units being subordinate to them.

Unconformity and Hiatus Terminology

Although terminology of unconformities and their associated time significance is not formally addressed in the Code, much confusion of this terminology exists, so it is addressed here. Well established terms for different kinds of unconformities, such as angular unconformity, disconformity, and nonconformity rarely have usage problems. The general term, unconformity, has meant a surface formed by erosion, non-deposition, or both for many years, although most unconformities are formed primarily by erosion. Van Wagoner et al (1988) tried to redefine an unconformity for use in sequence stratigraphy as a subaerial erosion truncation surface, possibly with correlative submarine erosion, but excluding non-deposition; however, the classic definition prevails. The term, **paraconformity** (Dunbar and Rodgers 1957, p. 119), is commonly used for an unconformity without discernible evidence of erosion, possibly formed by non-deposition. A **diastem** (non-sequence in some British usage), although originally and unfortunately defined as "minor undetected breaks in the sedimentary record" (Barrell 1917), now means either a paraconformity with very little time gap or an unconformity with localized erosion such as in the case of a channel-base diastem. The terms lacuna, hiatus, and vacuity are used for the interpreted time gap at an unconformity (unconformities are real stratigraphic contacts, not interpreted time gaps). The term, **lacuna** was defined by Gignoux (1955, p. 15-16) as a broad term for the interpretive *time* unrecorded in the stratigraphic record at an unconformity. A lacuna consists of two specific parts (Wheeler 1958): 1) the **erosional vacuity** (or, simply, **vacuity**) (Wheeler 1958, p. 1057) or time unrecorded due to erosion of previously deposited strata, and 2) the **hiatus** (Grabau 1906a, p. 90, and 1906b, p. 616) or time unrecorded due to non-deposition of strata. This distinct original meaning

TABLE 2
Hierarchy of less-known stratigraphic units, listed in decreasing order of rank. Fundamental units, which are in bold type, are the original, necessary rank within each category. Other ranks are optional. Lithostratigraphic units, although well-known, are repeated here to show corresponding rank with other lithic units.

I. Magnetostratigraphic units:			
A. Polarity-Chronologic	**B. Polarity-Chronostratigraphic**		**C. Magnetopolarity**
Polarity Superchron	Polarity Superchronozone		Polarity Superzone
Polarity Chron	**Polarity Chronozone**		**Polarity Zone**
Polarity Subchron	Polarity Subchronozone		Polarity Subzone
II. Lithic units, an informal grouping of the following three formal units:			
A. Lithostratigraphic	**B. Lithodemic**		**C. Pedostratigraphic**
Supergroup	Supersuite	Complex[1]	
Group	Suite		
Formation	**Lithodeme**		**Geosol**
Member; Lens; Tongue			
Bed; Flow;			
III. Diachronic units:			
Episode	Diachron		
Phase			
Span			
Cline			

[1]. Complex is an unranked unit of two or more genetic classes of rock (i.e., igneous and metamorphic). It is comparable to a Supersuite or Suite in rank.

of hiatus as non-deposition only is being lost because many geologists, especially North Americans and sequence stratigraphers, have commonly used hiatus as the equivalent of lacuna, perhaps because it was used in that way by Blackwelder (1909) in a well known paper on unconformities. Perhaps, using a new term, **non-depositional hiatus,** would preserve the distinction between erosional vacuity and hiatus. As a practical matter, however, in many studies, we do not have enough data to differentiate between non-deposition and erosion.

Other Units

New categories of stratigraphic units are formalized from time to time, and others are abandoned when they seem to serve no practical purpose after a trial period. For example, the geologic-climate units of the revised Code (ACSN 1970) were omitted in the 1983 and 2005 Codes. On the other hand, formal recognition of hydrostratigraphic units (e.g., aquifers) has been discussed by NACSN, but no proposal has been accepted. Geologists wishing to petition NACSN should follow the procedures outlined in its bylaws (Owen et al. 1985, and Owen et al., this volume). Many changes in the Code have originated from outside petitions, so don't be bashful.

CAPITALIZATION: FORMAL VERSUS INFORMAL NAMES

Many writers seem confused about the conventions for capitalization of stratigraphic names, but speakers never encounter this problem except in preparing slides. The rule is simple: **All words in every formally named stratigraphic unit begin with capital letters except for the specific name in a biozone.** This rule has been in effect since the 1961 Code (ACSN 1961), so be aware of this in papers published before 1961. All of the ranks of stratigraphic units listed in Tables 1, 2, and 3 are formal, except for the sequence-stratigraphic units (sequences). For example, the Whitewater Arroyo Shale Tongue of the Mancos Shale, in northwestern New Mexico, is contained within the Cenomanian Stage, which was deposited during the early part of the Late Cretaceous Epoch. However, in some instances, stratigraphic units are used informally, even if they have geographic names, especially in subsurface work (the X bentonite, upper Hackberry sand, etc.). For example, a widely recognized subsurface Pennsylvanian rock unit in the Arkoma Basin is known as the Spiro sandstone (note the initial lowercase letter in sandstone), an informal basal Atokan unit not to be confused with the Spiro Sandstone (note the initial uppercase letter in Sandstone), a formal Desmoinesian rock unit recognized on the surface in the same area. Such duplication of the geographic part of stratigraphic names should be avoided for obvious reasons, but it does occur.

Geochronologic and Chronostratigraphic Units

The most troublesome instance of capitalization problems of stratigraphic names usually involves geochronologic/chronostratigraphic units. Most Phanerozoic Period/System and Epoch/Series names, and some boundaries, (most exceptions are among Cambrian and Ordovician subdivisions, which are incomplete as of this writing) have been formally proposed and agreed upon by appropriate international organizations. See Gradstein et al. 2004 (or http://www.stratigraphy.org/scale04.pdf) and Ogg et al. 2008 for the international geological time scale and USGS Geologic Names Committee 2007 (or http://pubs.usgs.gov/fs/2007/3015/) for the U.S. geologic time scale. These International and U.S. geological time scales are in close, but not perfect agreement. Therefore, authors may write Middle Devonian, Late Cretaceous, and so on, with some confidence. But, the U.S. scale recognizes the Tertiary, and the international scale does not. The status and lower boundary of the Quaternary is in spirited dispute as of this writing (see Aubry and others 2005, and Salvador 2006). Also, some Epochs/Series (e.g., Paleocene, Eocene, etc. in the Cenozoic) and nearly all

TABLE 3
A. Hierarchy of unconformity-related units, listed in decreasing order of rank. Fundamental units, which are in bold type, are the original, necessary rank within each category. Other ranks are optional.

Unconformity-related units, an informal grouping of the following units:
A. Allostratigraphic (these units are formal in the Code, and moderately used)
Allogroup
Alloformation
Allomember
B. Unconformity-Bounded (these units are formal in the Guide, but uncommonly used)
Supersynthem
Synthem
Subsynthem
C. Sequence-stratigraphic (these units are informal, but are the most commonly used)
Sequence (depositional sequence; T-R sequence; genetic stratigraphic sequence)

Ages/Stages (Frasnian, Cenomanian, etc.) have formal, given names and are capitalized. However, be aware that vague terms such as late/upper Paleozoic and middle Cretaceous are informal. Most Periods/Systems are formally subdivided into Early/Lower, Middle, and Late/Upper, except the Cretaceous, which has no Middle. The Silurian and Permian are divided into named formal Epochs/Series, so that Early/Lower, Middle, and Late/Upper are not formally used. Also the Oligocene and Pliocene Epochs/Series are divided into only Early/Lower and Late/Upper. Subdivisions of Ages/Stages (early/lower Frasnian, late/upper Cenomanian, etc.) are informal. The geological time scales cited above are based on marine biostratigraphic zonation, but many vertebrate paleontologists working with nonmarine strata use stages based on terrestrial fossils. The North American land mammal ages (Lancian, Puercan, etc.) and similar zonation schemes on other continents have been used, but they are not well calibrated to the marine stages in most cases (see Woodburne 2004; Alroy, http://www.nceas.ucsb.edu/~alroy/TimeScale.html).

Geochronologic/chronostratigraphic nomenclature in the Precambrian has been evolving from mostly informal toward formal geochronologic units during recent decades, but almost all chronostratigraphic units still remain informal. Only the uppermost system, the Edicaran, has been defined with a stratotype. However, names have been adopted for the underlying nine Proterozoic periods (Plumb 1991, Fig. 1), but these nine currently are defined chronometrically, so they are periods, not systems (i.e. Cryogenian Period, etc.). The Archean Eon is only subdivided into eras (i.e. Neoarchean Era, etc.)—no period names have been selected yet. See the table of Boundary Stratotypes on the ICS web site (http://www.stratigraphy.org/) for Precambrian and Phanerozoic names. Incidentally, Precambrian (Cryptozoic) has no designated rank other than being above the eon category.

If you use the modifiers early, middle, or late with Precambrian or its subdivisions, they are informal and should not be capitalized (i.e., early Archaean, late Proterozoic, middle Precambrian, etc.). The Hadean eon is also informal, and neither boundary has been formally defined, although listed as ~4600 Ma and ~4000 Ma (http://www.stratigraphy.org/) The term, Precambrian, was formally adopted to replace the term, pre-Cambrian because of its common usage, but this results in an apparent absurdity if it is ever to be used chronostratigraphically (i.e., "Precambrian eonathems"), or lithostratigraphically (super-Precambrian rocks, etc.). Another absurd expression relating to this adoption, "post-Precambrian", has been pointed out by Hofmann (1992) in discussing his objections to the adopted Precambrian time scale (Plumb 1991). Does anyone know of a geographic locality named Precambrian that we can adopt as a type locality for the Precambrian? Although not formally adopted, the alternate, but suppressed term, Cryptozoic, harmoniously fits in with Phanerozoic for the rest of geologic time, and it rhymes with Proterozoic, Paleozoic, Mesozoic, and Cenozoic, just in case you want to write geopoetry.

In some situations, an author may wish to use formal terms in an informal way, usually because definitive data are lacking. For example, one might want to place a rock unit approximately in the upper part of the Cretaceous, without really knowing whether some part of it might be slightly lower than the formally defined Upper Cretaceous Series. An author should clearly state that this inexact usage is intended, and use a vague term such as "the upper part of the Cretaceous" (preferably not "upper Cretaceous"). Also, remember that, in oral presentations, the listener has no idea whether upper Cretaceous is capitalized and used formally or not, unless it is clearly indicated on a slide shown simultaneously. Imprecise usage can be confusing, especially if condoned by authors, reviewers, or editors who are careless with capitalization, so it should be avoided.

TIME WARPS AND PITFALLS—THE ENIGMA OF TIME AND PLACE WORDS!

For some strange reason, a geologist who never refers to "upper Tuesday" or the "late peninsula of Michigan" in everyday life will readily take keyboard, pen, or microphone in hand and inform other geologists about the thickness of the Late Jurassic or the events that occurred during the Upper Cretaceous! You can find examples of such incorrect usage in almost any journal issue. I shall spare the reader of all except my favorite example. Did you hear about the writer who managed to publish a whole paper about the events that occurred between the Late Jurassic and the Early Cretaceous (reference not cited for kindness)? Authors who are careless in usage of time and place words run the risk of implying that their carelessness may extend to data collection, analyses, and conclusions, as well. Don't demonstrate ignorance of the difference between time and place by writing or speaking about early/late rocks and lower/upper/deep time!

In discussing the age relationships of fossils, the clearest terminology would be to refer to fossils as lower, middle, and upper, as in Upper Cretaceous fossils. In discussing the living organisms that later became fossils, the clearest terminology would be early, middle, and late, as in Late Cretaceous dinosaur behavior. We do distinguish between paleoecology and ecology, so why not fossils and living organisms? Some living paleontologists disagree with this recommendation, but nothing has been heard or read from their dead subjects of study.

Authors of most papers concerning ancient rocks are involved in reconstructing geologic history. Thus, events that occurred during a specific time interval in a certain paleogeographic location are being interpreted from evidence contained in the presently existing stratigraphic record. Therefore, an author should be extremely careful to differentiate clearly between the events (time-bounded) and the locations (space-bounded). In formal and even informal stratigraphic nomenclature, differentiation between time words and place words is fairly straightforward. Early and late clearly refer to time, and lower and upper clearly refer to location in space. Some confusion may occur with middle, because, unfortunately, it is used in both sets of nomenclature ("medial" has been suggested as the equivalent time term, but it is rarely used).

Exceptions

A few exceptions to the above rules on time and place words in stratigraphic nomenclature exist.

Lithodemic Units

Rock bodies that do not generally conform to the Law of Superposition (lithodemic units) are referred to by using geochronologic terms (early, middle, and late) rather than by chronostratigraphic terms (lower, middle, and upper), because lithodemic units generally depend on crosscutting relationships for relative ages and isotopic data for numerical ages rather than superposition. Thus, younger rock bodies can be under older rock bodies in normal conditions. This convention generally applies to intrusive, highly metamorphosed, or highly deformed rock bodies. Tabular volcanic rock bodies do follow the Law of Superposition and should be addressed much like tabular bodies of sedimentary rock.

The Precambrian

Precambrian geochronometric units are rarely translated into equivalent chronostratigraphic units, because they depend on isotopic ages for their definition. However, conventional chronostratigraphic units based on stratotypes can be recognized in the Precambrian, even though they may not be dated by biochronology. Stratigraphers of the Precambrian often debate the geochronometric method, based on isotopic ages, versus the chronostratigraphic method, based on stratotypes, of subdividing the Precambrian (e.g., Hedberg 1974; Bleeker 2004). Conventional lithostratigraphic units such as the Belt Supergroup are defined in the Precambrian in exactly the same way as in the Phanerozoic. Historically, the term **Series** (now used only as a chronostratigraphic unit) was used as a high-rank lithostratigraphic unit in the Precambrian, but a valid lithostratigraphic term, such as **Supergroup** is necessary today.

Terraces

A third exception is at the other extreme of the geologic time scale. Late Cenozoic-age terraces of all kinds are conventionally referred to by time terms (early, middle, and late) because the older terraces lie topographically above younger terraces. For example, it may be confusing to refer to an early Pleistocene terrace as lower Pleistocene, because the early Pleistocene terrace is topographically higher than a late Pleistocene terrace.

TABLE 4
Informal time and Place words.

Time	Place
late	upper
middle (medial)	middle
early	lower
young(er)	high(er)
old(er)	low(er)
post-	super-
pre-	sub-
after	above, over
before	below, under
when	where
then	there
now	here
while	whereas
sometime(s)	someplace(s)
often, frequent	abundant, common
occasionally	locally
during	in

Other Time and Place Words

After an author has mastered the correct usage of stratigraphic nomenclature, the correct usage of other time and place words may be even more difficult. Many of these other words may be used rather vaguely in both temporal and spatial contexts in everyday English, but in reconstructing geologic history from the stratigraphic record, these words are best used in only one context to avoid confusion. Some common misusages follow.

Use of a term such as *pre-Dakota unconformity* implies that the Dakota Sandstone is a time unit. Use *of pre-Cretaceous unconformity* implies that the unconformity is a synchronous surface. One should use the term *sub-Dakota* (or *sub-Cretaceous) unconformity* instead, because the unconformity is a surface at the base of the Dakota Sandstone and the base of the Cretaceous strata (or preserved part of the Cretaceous System). Do not be afraid to use the prefix *super-(e.g., super-Jurassic unconformity);* it is the opposite of *sub-*. Time words should be used with vacuities, hiatuses, and lacunas. In the previous example, where basal Upper Cretaceous strata lie unconformably on uppermost Upper Jurassic strata, one could correctly refer to the Early Cretaceous lacuna, hiatus, or vacuity, if referring to events, such as erosion or climate change, that occurred during a time unrepresented in the local stratigraphic record. Also, a lithostratigraphic name should not be used in a time sense (e.g., "Dakota time") unless you want to imply that the boundaries of the lithostratigraphic unit are time-parallel. Few are! Also, some geographic names are not appropriate for time or time-rock units—for example, a time unit named after the town of Upper Sandusky, Ohio, or a time-rock unit named after the town of Early, Texas, could be very confusing.

Pairs of commonly used time and place words are in Table 4. Careful attention paid to this rather short, incomplete list can improve clarity of writing and speaking and may help convince your audience that you know what you are talking or writing about. Knowing what time it is and where things are now is important—it should be just as important during the past at paleogeographic locations. Although you may use some of the words in Table 4 rather loosely in everyday speaking and writing, use them very precisely for geologic history and data.

Also, be careful of verb tenses. Use the past tense in discussing geologic history, but use the present tense in discussing current conditions.

LITHOSTRATIGRAPHIC NAMES

The operational units for most geologists are the lithostratigraphic units, mainly groups, formations, members, and informal units. Lithostratigraphic units outnumber all the named geochronologic/chronostratigraphic units by several hundred times. In the U.S., approximately 40,000 lithostratigraphic units have been named, but no more than approximately 200 geochronologic/chronostratigraphic names are ever used. Little significant change in the methods of usage of lithostratigraphic nomenclature has occurred during recent years. Therefore, geologists should be proficient in using lithostratigraphic nomenclature, treated in the following paragraphs.

Information Sources

Because of the sheer number of lithostratigraphic names, authors may become bewildered and may need a source for information on lithostratigraphic nomenclature, especially when first working in unfamiliar geographic areas or sections of the stratigraphic column. A recently published, large-to intermediate-scale geologic map or report on the general geology of the area of interest is usually a good place to start. Alternatively, for the U.S., the set of 20 Correlation of Stratigraphic Units of North America (COSUNA) charts (AAPG 1983-1986) provides 570 stratigraphic columns throughout the U.S., excluding Hawaii (Childs 1985). For Canada, a similar, but older, set of four correlation charts was published by the Geological Survey of Canada (Douglas 1967, part C). These correlation charts for the U.S. and Canada essentially replace the series of 16 correlation charts published by the G.S.A. between 1942 and 1960, which may be useful for historical purposes. A list of stratigraphic names, useful because it is compiled by geographic area, is in Wilson et al. (1959). This list is noteworthy, although outdated, because it includes lithostratigraphic units in Mexico, Central America, Greenland, and some islands, as well as the U.S. and Canada. Swanson et al. (1981) provide a newer list, with references, but it is arranged by lithostratigraphic name and covers only the U.S.

If you already know the lithostratigraphic names in an area, but need historical data and examples of usage, for the U.S., the Geolex database of the U. S. Geological Survey (http://ngmdb.usgs.gov/Geolex) is good and is periodically updated. Published sources include the *Lexicons of Geologic [Stratigraphic] Names of the U.S.* (Wilmarth 1957; Keroher et al. 1966; Keroher 1970; Luttrell et al. 1981, 1986). The Lexicons, except for the first two, cover only new names introduced since the previous edition, with very few exceptions. The 1986 Lexicon covers new lithostratigraphic names proposed from 1976 through 1980. For later data, the U.S.G.S. published periodic updates on changes in its usage of lithostratigraphic nomenclature in the *Bulletin* series from 1980 to 1994 under the title, *Stratigraphic Notes.*

Geolex must be used for later changes. Some state and provincial geological surveys also publish catalogs of lithostratigraphic nomenclature. For Canada, the WebLex database (http://cgkn.net/weblex/weblex_e.pl) similar to Geolex, is also a good source. Published sources in Canada include the CSPG (Canadian Society of Petroleum Geologists) Lexicon Series: volumes 1 (Arctic Archipelago), 2 (Yukon-Mackenzie), 4 (Western Canada), and 6 (Atlantic region) of a planned six have been issued on CD-ROM to date. For Mexico, a new stratigraphic lexicon web site has recently been established (http://coremi01.coremisgm.gob.mx/lexicoes/) by El Servicio Geológico Mexicano. Compilation is in progress, so the list of names is incomplete for now.

Please understand that there is no official organization that approves or rejects lithostratigraphic names in the U.S., Canada, or Mexico—all of the above sources are historical. The NACSN establishes categories of stratigraphic units and procedures for usage, but it does not approve individual lithostratigraphic names. It is up to each individual geologist to follow the rules set in the Code and to use appropriate lithostratigraphic names and categories. We do not need lawyers and judges to determine valid lithostratigraphic usage—peer-review works rather well in most cases. Debates about lithostratigraphic names need not be useless—they often lead to additional data and understanding of the stratigraphy.

Changing Nomenclature

An author sometimes finds it necessary to change previously existing lithostratigraphic nomenclature. Specific rules for making changes should be followed to reduce confusion. The Code (Articles 3 to 30) and Guide (p. 17-24) contain these rules and should be studied before proposing changes in nomenclature. Even when no change is proposed for an an existing lithostratigraphic unit, it is good procedure to cite the original reference naming the unit (see the Lexicons or databases) and a recent paper in which the usage you are following is well described. This advice is especially apt for controversial or poorly known units.

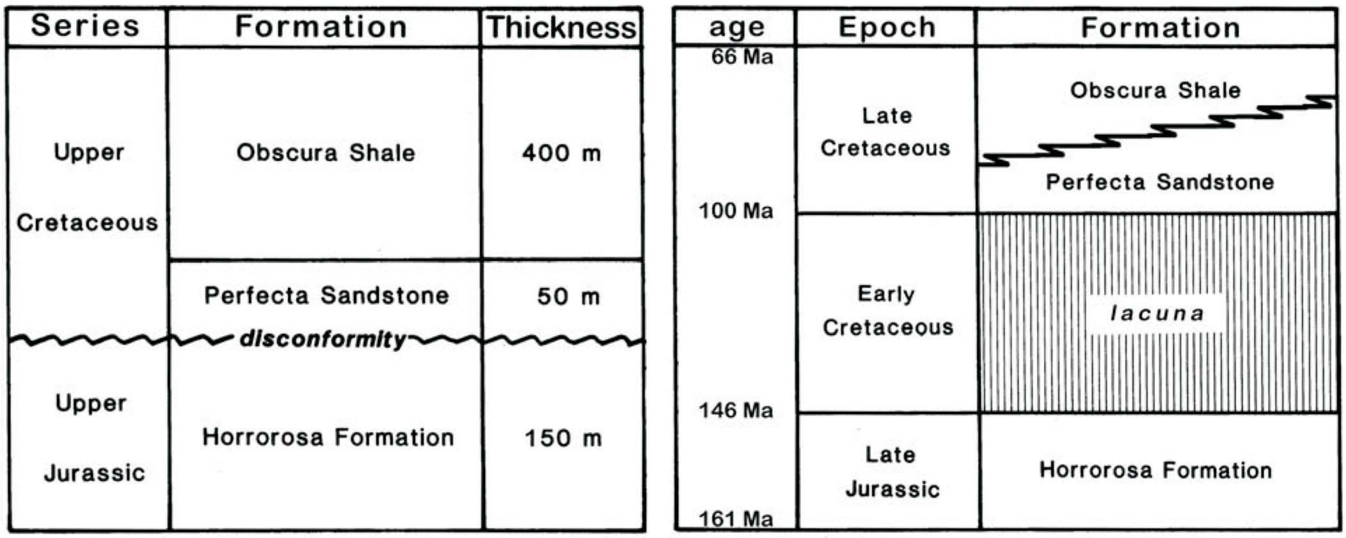
New Names

If you must propose a new name, a detailed procedure must be followed. Casual mention of "the sand exposed at Cut and Shoot, Texas" does not formally name the "Cut and Shoot Sand."

The first problem encountered is usually the choice of a geographic name. You will probably find that many of your favorite choices have already been used and, therefore, are unavailable. Studying published maps of the area of interest should suggest potential names, and studying Lexicons, databases, and other literature should give you an idea of whether your potential names are already in use. Some writers have had to go to the extreme of formally naming geographic features in certain areas in order to have newly available names for lithostratigraphic units.

In North America, the Geologic Names Committee of the USGS in Reston, Virginia, the Committee on Stratigraphic Nomenclature of the Geological Survey of Canada in Ottawa, and El Servicio Geológico Mexicano in Pachuca, Hidalgo, keep records and respond to inquiries on lithostratigraphic names. Some state, provincial, and other surveys or committees also perform similar functions. Authors are responsible for researching previously used and available lithostratigraphic names and must not expect editors to do this for them.

After finding an appropriate, available name, the author must publish the following information on the new unit in a recognized scientific medium: 1) intent to formally name; 2) category



TEXT-FIGURE 1
Stratigraphic units in the Ficticia area, New Texico. Illustration on left is appropriate for vertical scale of thickness; illustration on right is appropriate for vertical scale of geologic time. Note that chronostratigraphic units are used with thickness, but geochronologic units are used with geologic time. Ma, not Myr, is used for age before the present (see section on numerical age/duration data below).

and rank; 3) name and type locality; 4) stratotype; 5) lithologic description; 6) definition of boundaries; 7) historical background; 8) dimensions, shape, and geographic distribution; 9) age; 10) correlation; 11) genesis. The first eight categories are to describe the unit; the last three are useful inferences. These requirements are taken from the Code—the Guide has similar requirements. Measured sections, well logs, maps, and other illustrations generally accompany the description of a new unit. An exact location of the stratotype is very important. Any attempt to name a new unit in a talk, abstract, unpublished thesis or dissertation, open-file report, map explanation, the popular press, a legal document, an internet post, or other inadequate publication is invalid according to the Code (Article 4). One example of inadequate publication is a field-trip guidebook issued only to participants. Publication in a permanent electronic journal or a publication issued on a CD-ROM, DVD, or similar medium is considered a recognized scientific medium and is valid. This does not include posts on impermanent web pages.

Revising Names

Believe it or not, revising (or abandoning) an existing lithostratigraphic unit requires attention to the same eleven topics listed in the preceding paragraph. Perhaps the intent is to discourage changes!

Most revisions of existing units involve changing boundaries. The Code (NACSN. 2005, fig. 2) illustrates several different types of boundaries, but it is important to remember that boundaries of lithostratigraphic units are based *only* on lithologic change (even if gradational). Age boundaries, interpretations of depositional environments, and taxonomy of included fossils are not valid factors in defining lithostratigraphic unit boundaries. However, the presence of fossils may be considered an aspect of lithology as in some coquina beds or chalks made up of microfossils. Great care should be taken in establishing and revising boundaries of lithostratigraphic units—boundaries should be chosen that are not just locally convenient, but recognizable over the entire geographic extent of the unit. Unfortunately, stratigraphers sometimes argue more about the boundaries than about what is between them! Authors are urged to be conservative in proposing boundary changes. If several authors propose different boundaries for the same unit, we are probably better off to start over with new units if there is no consensus.

Before going to the trouble of naming, revising, or abandoning a unit, authors should consider using informal nomenclature, especially if innovative or controversial ideas are involved.

Abandoning Units

Geologists rarely go to the trouble of abandoning units, except in the process of revising and naming new ones. Thus, many units fade away from disuse. However, formal abandonment of lithostratigraphic units may be necessary in order to clean up nomenclature. To abandon a unit formally, the eleven categories listed above must be addressed.

Justifications for abandoning a formal unit include: 1) synonymy or homonymy; 2) improper definition or category (e.g., defining a lithostratigraphic unit by chronostratigraphic criteria); 3) long-term disuse or obsolescence; 4) flagrant misuse or Code violations; 5) impracticability. If a unit is formally abandoned, recommendations should be made for nomenclature to be used in its place.

Authors should be careful not to abandon units when they only intend to restrict the unit from their study area—the unit may be valid and quite useful elsewhere. Also, just because two geographically separated units are found to be equivalent, it is not necessary to abandon one. There may be good reasons for retaining both names.

An abandoned unit must be completely abandoned, including its stratotype. Also, abandoning a stratotype abandons the name of the unit as well. Reinstatement or reuse of an abandoned name for another stratigraphic unit is rare, but possible.

Changing Rank

Changing the rank of a lithostratigraphic unit is a relatively simple process and does not require attention to the eleven categories listed above, because neither the boundaries nor the geographic name of the unit changes. For example, a formation may become a member, or a group, and vice versa. Similar rank changes may also be accomplished easily in lithodemic, magnetopolarity, and allostratigraphic units. Rank changes in geochronologic/chronostratigraphic units, particularly those of major rank, are much more troublesome and usually require submission to international committees, such as the IUGS International Commission on Stratigraphy (ICS) and its subcommisions and working groups. For example, the December 2007 issue of *Episodes*, published by IUGS., contains a paper discussing the global standard names defining the base of the Cambrian System at the base of the Terreneuvian Series and Fortunian Stage in Newfoundland (Landing et al. 2007)

The main criterion controlling rank changes in material units is practicality. For example, if a group in one geographic area changes laterally so that it has no separately mappable formations in an adjacent area, reduce its rank to formation in the latter area. A thin, inconspicuous member of a formation in one area may become so thick and distinctive in a second area that it is raised to formational rank in the second area, but it retains the same geographic name. An established formation may be subdivided into new formations, and the established formation may be raised to group rank. Also, the same continuous member may occur in two or more formations.

Some pitfalls to avoid in rank changing are 1) changing the boundaries of an existing unit; 2) using the same name for a rank and for one of its components (e.g., the Dakota Formation in the Dakota Group, which, unfortunately, is an actual usage).

STRATA GRAPHICS

In papers that treat several lithostratigraphic units or any complexity of chronostratigraphy, a stratigraphic illustration such as a columnar section, stratigraphic table or figure, correlation chart, or stratigraphic cross-section is generally necessary. A computer program, TSCreator (Van Couvering and Ogg 2007), for constructing stratigraphic illustrations with a chronostratigraphic and biostratigraphic database is available on the ICS web site (http://www.tscreator.com/). In preparing stratigraphic illustrations, note carefully that time-rock units are preferentially used in illustrations with rock units, especially where the vertical scale represents thickness, either linear or relative (text-fig. 1). A column entitled, Age, should not be used with a vertical scale of thickness (a year is not 365 meters long). Unconformities and ordinary rock-unit contacts are shown as lines separating adjacent, abutting rock units in such illustrations (text-fig. 1). Because capitalization is used to distinguish between formal and informal stratigraphic units, using all capital letters for stratigraphic names in illustrations is undesirable because it results in a loss of precision and possible confusion.

In stratigraphic illustrations with a vertical scale representing geologic time, either millions of years before present (Ma) or relative time (e.g., Late Jurassic), geochronometric or geochronologic units are used instead of chronostratigraphic units (text-fig. 1). In these illustrations, the ages, not the thicknesses of rock units, are shown. A lacuna, hiatus, or vacuity ("time gap"), represented by an unconformity in the rocks, is illustrated as an actual gap in the illustration (text-fig. 1, right), in contrast to a wavy line between abutting units used for an unconformity (text-fig. 1, left).

The simple suggestions in the above two paragraphs, if followed, should convince your audience that you know, graphically at least, that strata are not measured in years, or time in meters. Inattention to detail in strata graphics is apparently widespread, as a perusal of recent publications in a wide variety of journals has demonstrated.

NUMERICAL AGE/DURATION DATA

In papers that deal with isotopic age or other quantifiable age data, a few minor, but troublesome, terminology problems regarding numerical ages can occur. First, according to the Code, use of the nouns "isotopic age" or "numerical age" instead of the nouns "date" or "absolute age" is recommended. Second, the term **calibration** should be used for the special form of designating chronostratigraphic boundaries in terms of numerical ages.

Authors need to be aware of conventions for abbreviating numerical ages. The Code and Guide recommend the following abbreviations for numerical ages in years before the present: ka = 10^3; Ma = 10^6; Ga = 10^9. The prefixes k, M, and G are borrowed from the International System of Units (SI); however, time in years is not an SI unit, and time in years ago is not an SI concept. Incidentally, the duration of an annum is a modern year and the present refers to AD 1950. Qualifiers such as "ago" or "before the present" are redundant after the above formal abbreviations, because duration from the present to the past is indicated by their use. Avoiding the use of m.y.a./m.y.b.p.-type abbreviations for ages is recommended. However, authors should remember that the formal Ma-type abbreviations are not used for the duration of an interval of geologic time that does not extend to the present; in such cases, the informal abbreviations, y., k.y., m.y., and b.y. (or preferably yr, kyr, Myr and Gyr, see Aubry et al., this volume) are used. The Code (Article 13c) and Guide (Salvador 1994, p.1 6) specify this distinction. For example, the numerical age boundaries of the Late Cretaceous Epoch are calibrated at 99.6 Ma and 65.5 Ma (Gradstein et al.; 2004), but the duration of the Late Cretaceous Epoch is 34.1 Myr (99.6 – 65.5), not 34.1 Ma (which was during Late Eocene time)—many authors make this mistake—don't join them. Think of it this way: I may have a class that meets from 3:00 to 4:00 PM, but the duration of that class is 1 hour.

Very young numerical ages have added complications. Authors may need to express what kind of year is being used: ^{14}C year, calendar year, varve year, etc. The abbreviations b2k (before AD 2000) and BP (before AD 1950) are used by some authors.

CONCLUSION

With the appearance of the 2005 Code and the second edition of the Guide, formal stratigraphic nomenclature has undergone significant expansion, even into nonstratified rocks, but sequence-stratigraphic nomenclature still remains informal and debatable. Authors should be aware of the distinction between material and nonmaterial stratigraphic units, and authors may need to consider some of the less-known stratigraphic units as well as the old, well-known ones.

Authors must strive for clarity, consistency, and correct usage of both formal and informal terminology because of the complex interrelations between time and space interpreted from the presently existing stratigraphic record. Be careful with early versus lower and late versus upper. All of our geologic data ultimately comes from the geologic record; therefore, treat the source carefully, and don't call the record or its interpretation by the wrong names.

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