Chapter 2 Stratigraphic Principles and Correlation

"Science committs suicide when it adopts a creed."

Huxley

INTRODUCTION

This chapter is designed to teach you some of the basics of the most commonly used methods of stratigraphic correlation. Correlation can be defined as establishing the relationship between any two groups of rocks. The relationships can be based on any criteria. Common ones include rock type, fossils, age, soils, unconformities, and magnetic properties, among others. A full list of formal methods and types of correlation are the purpose of the North American Stratigraphic Code (NACSN, 1983) and the International Stratigraphic Guide (ISSC, 1976). Krumbein and Sloss (1963, p. 332) summarize correlation as follows: "*Correlation is an essential element of most stratigraphic investigations and typically occupies a major portion of a stratigrapher's time. Without correlation, facies relationships, and others ..., would be meaningless and the rational treatment of the analytical aspects of stratigraphy would be impossible.*" The code further defines correlation as "*a procedure for demonstrating correspondence between geographically separated parts of a geologic unit*".

Table 2.1 illustrates various stratigraphic units proposed by the North American Stratigraphic Code and the International Code of Stratigraphic Nomenclature. Four of these units, lithostratigraphic, biostratigraphic, chronostratigraphic and geochronologic, have been used extensively in past stratigraphic work. In this chapter we hope to teach you some of the basic criteria which distinguishes these four units. In the process of understanding these criteria and the nature of the units, we will master the procedures inherent in correlation. These procedures will also help you to understand and use the other types of stratigraphic units (e.g. magnetopolarity, pedostratigraphic, unconformity bounded, etc.) if you should have the need to use them.

PRINCIPLES AND METHODS

Before discussing the different kinds of stratigraphic units and how and why they are correlated, it may help to analyze a conceptual model that shows how three of these units relate to one another. The conceptual model that probably best portrays this interrelationship is the prograding delta. Figure 2.1 depicts this model in cross section. Notice how at any one time, the depositional surface has four kinds of sediment on it. Landward to seaward these are: marsh mud or peat, delta front sand, prodelta silt, and offshore clay. At some time, the delta has built seaward, or prograded, but the surface distribution of sediments with respect to the water level remains the same. If this process continues indefinitely, then horizontal beds of different sediment types will form a kind of *layer cake* stratigraphy - i.e., a clay layer overlain by a silt layer, and so on.

Early geologists, the so-called *pancake thinkers*, interpreted such stratigraphy as a period of clay deposition followed by a period of silt deposition. However, as the delta model clearly shows,

Table 2.1. Classification of stratigraphic units from the North American Stratigraphic Code (NACSN, 1983) with the addition of the Unconformity-bounded stratigraphic unit from the International Subcommission on Stratigraphic Classification (ISSC, 1987).

I. Material Units	
A. **Lithostratigraphic**	**Formation**
B. Lithodemic	Lithodeme
C. Magnetopolarity	Polarity Zone
D. **Biostratigraphic**	**Biozone**
E. Pedostratigraphic	Geosol
F. Allostratigraphic	Alloformation
G. **Unconformity-Bounded Stratigraphic Unit**	**Synthem**
II. Units Related to Geologic Age	
A. Time Units	
1. **Geochronologic**	**Period**
2. Polarity-Chronologic	Polarity Chron
3. Diachronic	Episode
B. Material Units Deposited during Specified Time Spans	
1. **Chronostratigraphic**	**System**
2. Polarity-Chronostratigraphic	Polarity Chronozone

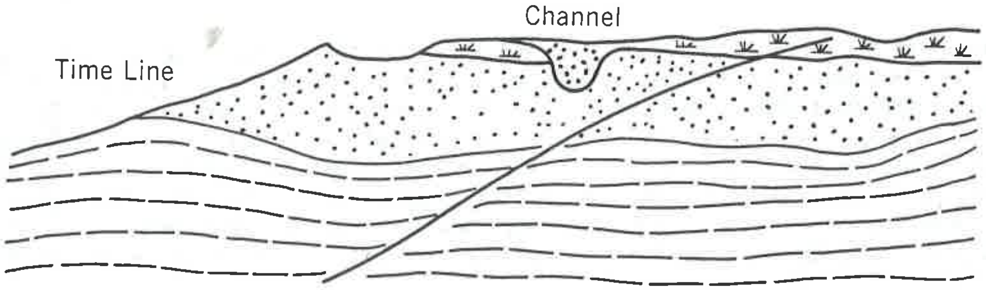


Figure 2.1. Various lithologic units generated from the progradation of facies of a delta. Note that time lines transgress lithologic units. From W. J. Fritz and J. N. Moore, 1988, *Basics of Physical Stratigraphy and Sedimentology*, Wiley, New York, Fig. 9.2, p. 279. Copyright © 1988. Reprinted by permission of John Wiley & Sons, Inc.

the boundaries between lithologies have no connection whatsoever with time! In fact, it is just the opposite from the *pancake thinker's* claim, i.e. all lithologies are being deposited all of the time rather than first one type followed by a second and so on.

This idea of simultaneous deposition of various sediment types paraphrases one of the basic theorems of stratigraphy, first put forth by Johannes Walther (1893-1894). Walther's Law states that within a given sedimentary cycle, the same succession of facies that occurs laterally is also present in vertical successions. Lithostratigraphic units, therefore, are defined solely on lithologic characteristics. Associating lithostratigraphic units with time intervals can be deceiving, especially where time stratigraphic markers are absent. Only rarely ,do lithologic boundaries represent isochronous surfaces; they are usually *time-transgressive.*

How is it possible, then, to construe time from strata? Let's go back to Figure 2.1. If, for example, a volcanic eruption took place the day after the artist drew the delta picture, ash may have covered the whole depositional surface, regardless of the different lithologies previously deposited there. With continued progradation of the delta, this deposit could become covered and would constitute a buried *time-line.* This widespread volcanic ash bed is an example of a synchronous chronostratigraphic unit.

Fortunately for mankind (but unfortunately for stratigraphers), volcanic eruptions occur only sporadically (even so they have claimed over 325,000 lives in the past 365 years) in geologic time and only in certain geologic provinces. Fossils can provide another means for establishing or at least interpreting time-stratigraphic units. Although the geologic range of a given species can also transgress time from one locality to another, they are rarely as time transgressive as lithostratigraphic units. Biostratigraphy, therefore, acts as the practical, though theoretically imprecise, chronostratigraphic tool for stratigraphers. However, when working with fossils, the stratigraphic code mandates that the rock units characterized by fossil be called biostratigraphic units. Thus, the establishment of time is an interpretation of the biostratigraphic zones.

Unfortunately, radiometric dating does not often provide a useful means of establishing detailed chronostratigraphic units. Most radiometric dating techniques must be applied on high grade metamorphic or igneous rocks that do not occur in abundance in sedimentary sequences. However these can provide useful geochronologic information when lava flows, ash, dikes, sills and the like are present. Also carbon 14 dating is very useful in time correlation in strata that contains organic carbon less than 100,000 years old.

The procedures of correlation, whether they concern individual beds or entire rock sequences, demand a rigorous systematic classification scheme which arranges bodies of rock or unconsolidated sediments into units based on their inherent properties and attributes. By analogy, *equivalency* must preempt our correlating apples with oranges.

One need only ponder the thought of thousands of scientists rummaging through and describing the surficial materials of the Earth to understand the need for uniform standards and common procedures in defining and classifying rock bodies, their fossils, and time spans represented by them. Today, stratigraphic codes or guides serve the purpose of standardizing the classification and formal nomenclature of these rock bodies.

Today most countries have various stratigraphic codes that are adapted to suit the needs of establishing the stratigraphy of that area. The International Stratigraphic Guide (International Subcommission on Stratigraphic Classification, 1976, 1987a, 1987b) is an attempt to standardize stratigraphic classification around the world and the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983) for North America. The North American Code was first published in 1933 (Committee on Stratigraphic Nomenclature, 1933) and has been revised several times. The latest (1983) revision was engineered to be as consistent as possible with the International Stratigraphic guide. However, some differences do exist. For example, the ISG prefers to treat non-stratified rock bodies as lithostratigraphic units whereas the NACSN prefers to separate these plutonic and high grade metamorphic rocks as separate units called lithodemic Stratigraphic units (ISSC, 1987b; NACSN, 1983). In this lab manual, we rely on the North American Stratigraphic Code (1983) published by the North American Commission on Stratigraphic Nomenclature (NACSN) in the AAPG Bulletin.

The indented passages in the following pages are excerpts from the code designed to teach you the rudiments of stratigraphic classification. These have been quoted directly from North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code, American Association of Petroleum Geologists Bulletin, vol. 67, p. 841-875 with the permission of the American Association of Petroleum Geologists. These excerpts are not comprehensive, nor intended as such. Their inclusion here serves as a brief review of the traditional units employed in correlation. Please refer to these exhaustive documents (references are included in the bibliography) for any further elucidation of the principles inherent to stratigraphic classification and correlation. The entire text of the NASC has been reprinted in various introductory texts such as Krumbein and Sloss (1963), Boggs (1986), and Fritz and Moore (1988).

A. Material Units

LITHOSTRATIGRAPHIC	LITHODEMIC	MAGNETOPOLARITY	BIOSTRATIGRAPHIC	PEDOSTRATIGRAPHIC	ALLOSTRATIGRAPHIC
Supergroup	Supersuite (Complex)				
Group	Suite (Complex)	Polarity Superzone			Allogroup
Formation	*Lithodeme*	*Polarity zone*	*Biozone* (Interval, Assemblage or Abundance)	*Geosol*	*Alloformation*
Member (or Lens, or Tongue)		Polarity Subzone	Subbiozone		Allomember
Bed(s) or Flow(s)					

B. Temporal and Related Chronostratigraphic Units

CHRONO-STRATIGRAPHIC	GEOCHRONOLOGIC GEOCHRONOMETRIC	POLARITY CHRONO-STRATIGRAPHIC	POLARITY CHRONOLOGIC	DIACHRONIC
Eonothem	Eon	Polarity Superchronozone	Polarity Superchron	
Erathem (Supersystem)	Era (Superperiod)			
System (Subsystem)	*Period* (Subperiod)	*Polarity Chronozone*	*Polarity Chron*	*Episode*
Series	Epoch			Phase (Diachron)
Stage (Substage)	Age (Subage)	Polarity Subchronozone	Polarity Subchron	Span (Diachron)
Chronozone	Chron			Cline

*Fundamental units are italicized.

Table 2.2. Categories and ranks of units defined in the North American Stratigraphic Code. From North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code, *American Association of Petroleum Geologists Bulletin*, 67, Table 2, p. 852. Reprinted by permission of the American Association of Petroleum Geologists.

Tables 2.1 and 2.2 depict categories of units for some of the categories of units recognized by the NASC. Again, our principle concern here will be the lithostratigraphic, biostratigraphic, chronostratigraphic, and geochronologic units. The following general definitions distinguish these four units:

1) A **LITHOSTRATIGRAPHIC UNIT** is a stratum or body of strata, generally but not invariably tabular, which conforms to the Law of Superposition and is distinguished and delimited on the basis of lithic characteristics and stratigraphic position. Example: Navajo Sandstone.

2) A **BIOSTRATIGRAPHIC UNIT** is a body of rock defined and characterized by its fossil content. Examples: *Discoaster multiradiatus* Interval Zone.

3) A **CHRONOSTRATIGRAPHIC UNIT** is a body of rock established to serve as the material reference for all rocks formed during the same time span. Example: Devonian System.

4) A **GEOCHRONOLOGIC UNIT** is a division of time distinguished on the basis of the rock record preserved in a chronostratigraphic unit. Example: Devonian Period.

The establishment of a formal stratigraphic unit of any category and rank requires that the unit in question be thoroughly described and a type section (stratotype) designated. The type section must have a specific geographic locality that has both good exposure and accessibility to the unit (unit stratotype) as well as good contacts with adjacent units (boundary stratotype). Examples are shown in Figure 2.2. In addition, the unit must be thoroughly described in an acceptable scientific publication. Following are two articles from the code that speak to the formal designation of stratigraphic units.

> ARTICLE 3. Requirements for Formally Named Geologic Units. Naming, establishing, revising, redefining, and abandoning formal geologic units require publication in a recognized scientific medium of a comprehensive statement which includes: (i) intent to designate or modify a formal unit; (ii) designation of category and rank of unit; (iii) selection and derivation of name; (iv) specification of stratotype (where applicable); (v) description of unit; (vi) definition of boundaries; (vii) historical background; (viii) dimensions, shape, and other regional aspects; (ix) geologic age; (x) correlations; and possibly (xi) genesis (where applicable). These requirements apply to subsurface and offshore, as well as exposed units.

> ARTICLE 8. Stratotypes. The designation of a unit or boundary stratotype (type section or type locality) is essential in the definition of most formal geologic units. Many kinds of units are best defined by reference to an accessible and specific sequence of rock that may be examined and studied by others. A stratotype is the standard (original or subsequently designated) for a named geologic unit or boundary and constitutes the basis for definition or recognition of that unit or boundary; therefore, it must be illustrative and representative of the concept of the unit or boundary being defined.

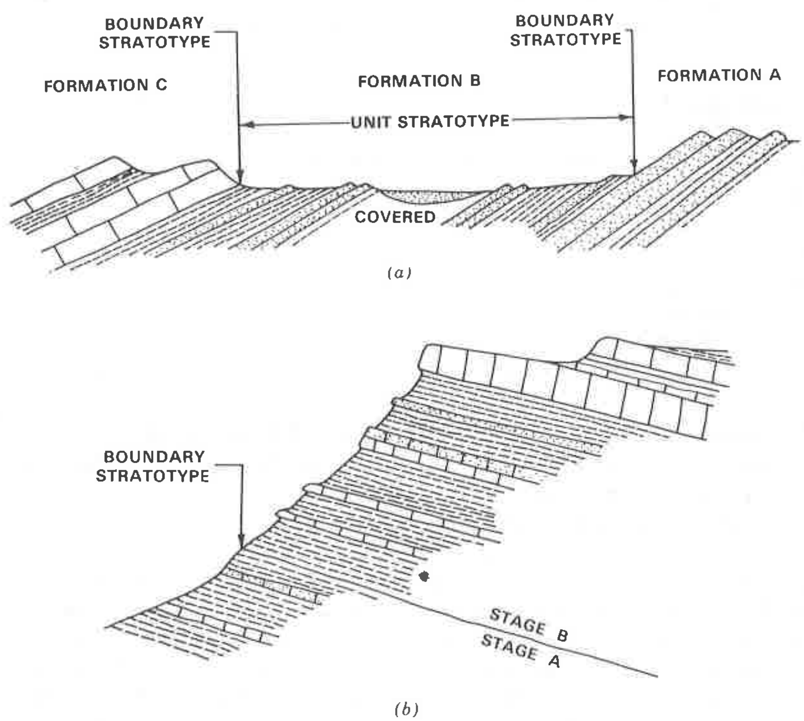


Figure 2.2. Illustration of the placement of Unit Stratotype and Boundary Stratotype for (a) lithostratigraphic unit and (b) biostratigraphic unit. From International Subcommission on Stratigraphic Classification, H. D. Hedberg (Ed.), 1978, *International Stratigraphic Guide*, Wiley, New York, Fig. 2, p. 25. Copyright © 1978. Reprinted by permission of John Wiley & Sons, Inc.

LITHOSTRATIGRAPHIC UNITS

Nature and Boundaries:

ARTICLE 22. Nature of Lithostratigraphic Units. A lithostratigraphic unit is a defined body of sedimentary, extrusive igneous, metasedimentary, or metavolcanic strata which is distinguished and delimited on the basis of lithic characteristics and stratigraphic position. A lithostratigraphic unit generally conforms to the Law of Superposition and commonly is stratified and tabular in form.

(d) Independence from Inferred Geologic History. Inferred geologic history, depositional environment, and biologic sequence have no place in the definition of a lithostratigraphic unit, which must be based on composition and other lithic characteristics... The fossil content of a lithostratigraphic unit is a legitimate lithic characteristic; for example, oyster-rich sandstone, coquina, coral reef or graptolite shale.

(e) Independence from Time Concepts. The boundaries of most lithostratigraphic units may transgress time horizons, but some may be approximately synchronous. Inferred time-spans, however measured, play no part in differentiating, or determining the boundaries of any lithostratigraphic unit...

ARTICLE 23. Boundaries. Boundaries of lithostratigraphic units are placed at positions of lithic change. Boundaries are placed at distinct contacts or may be fixed arbitrarily within zones of gradation (Fig. 2.3a). Both vertical and lateral boundaries are based on the lithic criteria that provide the greatest unity and utility.

Ranks of Lithostratigraphic Units

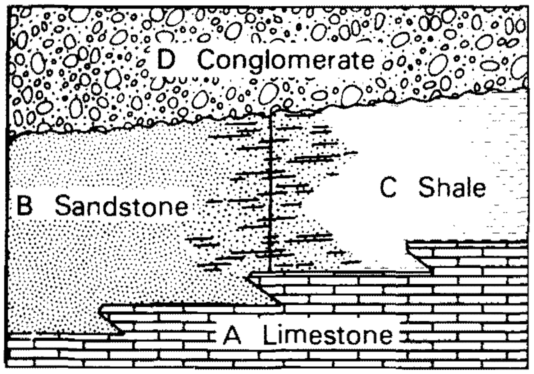
Below is a hierarchical classification scheme showing sets and subsets of the fundamental lithostratigraphic unit, the FORMATION

- Supergroup
  - Group
    - **Formation**
      - Member
        - Bed

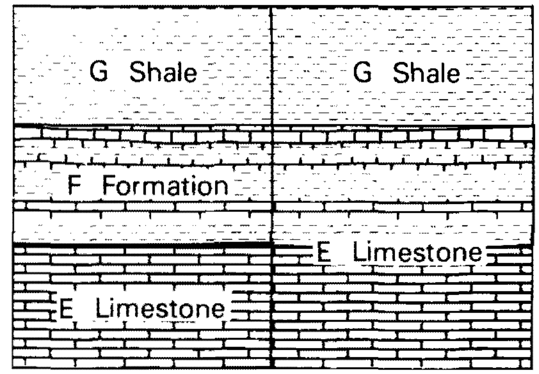
ARTICLE 24. Formation. The formation is the fundamental unit in lithostratigraphic classification. A formation is a body of rock identified by lithic characteristics and stratigraphic position; it is prevailingly but not necessarily tabular and is mappable at the Earth's surface or traceable in the subsurface.

ARTICLE 25. A member is the formal lithostratigraphic unit next in rank below a formation and is always a part of some formation. It is recognized as a named entity within a formation because it possesses characteristics distinguishing it from adjacent parts of the formation. A formation need not be divided into members unless a useful purpose is served by doing so. Some formations may be divided completely into member; others may have only certain parts designated as members; still others may have no members. A member may extend laterally from one formation to another.

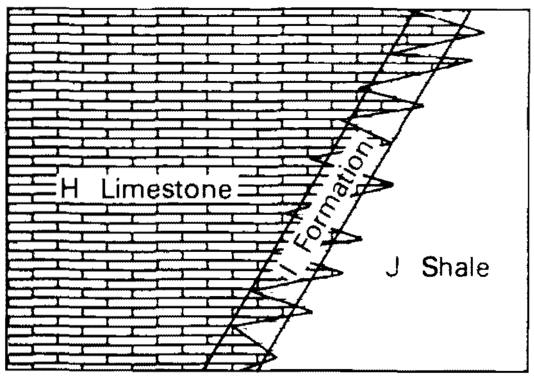
(b) Lens and Tongue. - A geographically restricted member that terminates on all sides within a formation may be called a lens (lentil). A wedging member that extends outward beyond a formation or wedges ("pinches") out within another formation may be called a tongue.



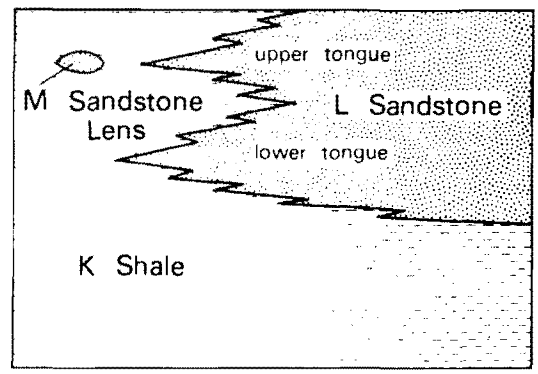
A.--Boundaries at sharp lithologic contacts and in laterally gradational sequence.



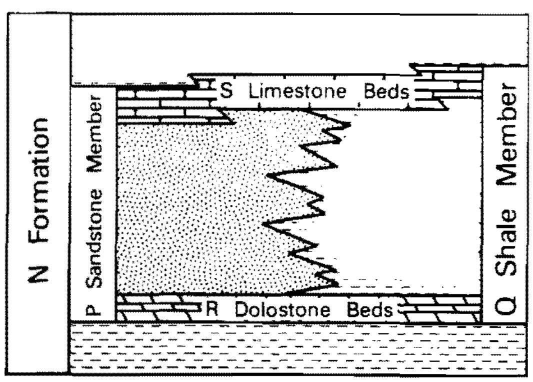
B.--Alternative boundaries in a vertically gradational or interlayered sequence.



C.--Possible boundaries for a laterally intertonguing sequence.



D. Possible classification of parts of an intertonguing sequence.



E.--Key beds, here designated the R Dolostone Beds and the S Limestone Beds, are used as boundaries to distinguish the Q Shale Member from the other parts of the N Formation. A lateral change in composition between the key beds requires that another name, P Sandstone Member, be applied. The key beds are part of each member.

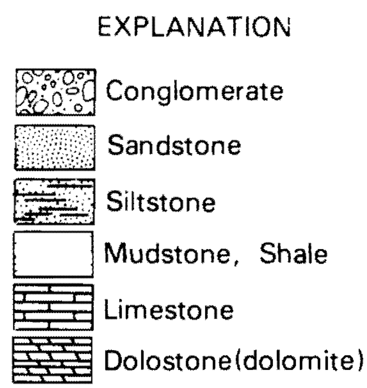


Figure 2.3. Examples of various lithostratigraphic boundaries and classification. From North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code, *American Association of Petroleum Geologists Bulletin*, 67, Fig. 2, p. 852. Reprinted by permission of the American Association of Petroleum Geologists.

ARTICLE 26. Bed(s). A bed, or beds, is the smallest formal, lithostratigraphic unit of sedimentary rocks.

(a) limitations - The designation of a bed or a unit of beds as a formally named lithostratigraphic unit generally should be limited to certain distinctive beds whose recognition is particularly useful...

(b) Key or marker beds - A key or marker bed is a thin bed of distinctive rock that is widely distributed. Such beds may be named, but usually are considered informal units. ...

ARTICLE 28. Group. A group is the lithostratigraphic unit next higher in rank to a formation; a group may consist entirely of named formations, or alternatively, need not be composed entirely of named formations.

(a) Use and content - Groups are defined to express the natural relationships of associated formations. They are useful in small-scale mapping and regional stratigraphic analysis.

ARTICLE 29. Supergroup. A supergroup is a formal assemblage of related or superposed groups, or groups of formations. Such units have proved useful in regional and provincial syntheses. Supergroups should be named only where their recognition serves a clear purpose.

Lithostratigraphic nomenclature. Following are various articles from the code that dictate the ways that lithostratigraphic units are formally named.

ARTICLE 30. Compound Character. The formal name of a lithostratigraphic unit is compound. It consists of a geographic name combined with a descriptive lithic term or with the appropriate rank term, or both. Initial letters of all words used in forming the names of formal rock-stratigraphic units are capitalized.

(b) Use of simple lithic terms. - The lithic part of the name should indicate the predominant or diagnostic lithology, even if subordinate lithologies are included. Where a lithic term is used in the name of a lithostratigraphic unit, the simplest generally acceptable term is recommended (for example, limestone, sandstone, shale, tuff, quartzite). Compound terms (for example, clay shale) and terms that are not in common usage (for example, calcirudite, orthoquartzite) should be avoided. Combined terms, such as *sand and clay,* should not be used for the lithic part of the names of lithostratigraphic units, nor should an adjective be used between the geographic and the lithic terms, as *Chattanooga Black Shale* and *Biwabik Iron-Bearing Formation.*

(c) Group names. - A group name combines a geographic name with the term "group," and no lithic designation is included; for example, San Rafael Group.

(d) Formation names. - A formation name consists of a geographic name followed by a lithic designation or by the word *formation.* Examples: Dakota Sandstone, Mitchell Mesa Rhyolite, Monmouth Formation, Halton Till.

(e) Member names. - All member names include a geographic term and the word *member;* some have an intervening lithic designation, if useful; for example, Wedington Sandstone Member of the Fayetteville Shale. Members designated solely by lithic character (for example, siliceous shale member), by position (upper, lower), or by letter or number, are informal.

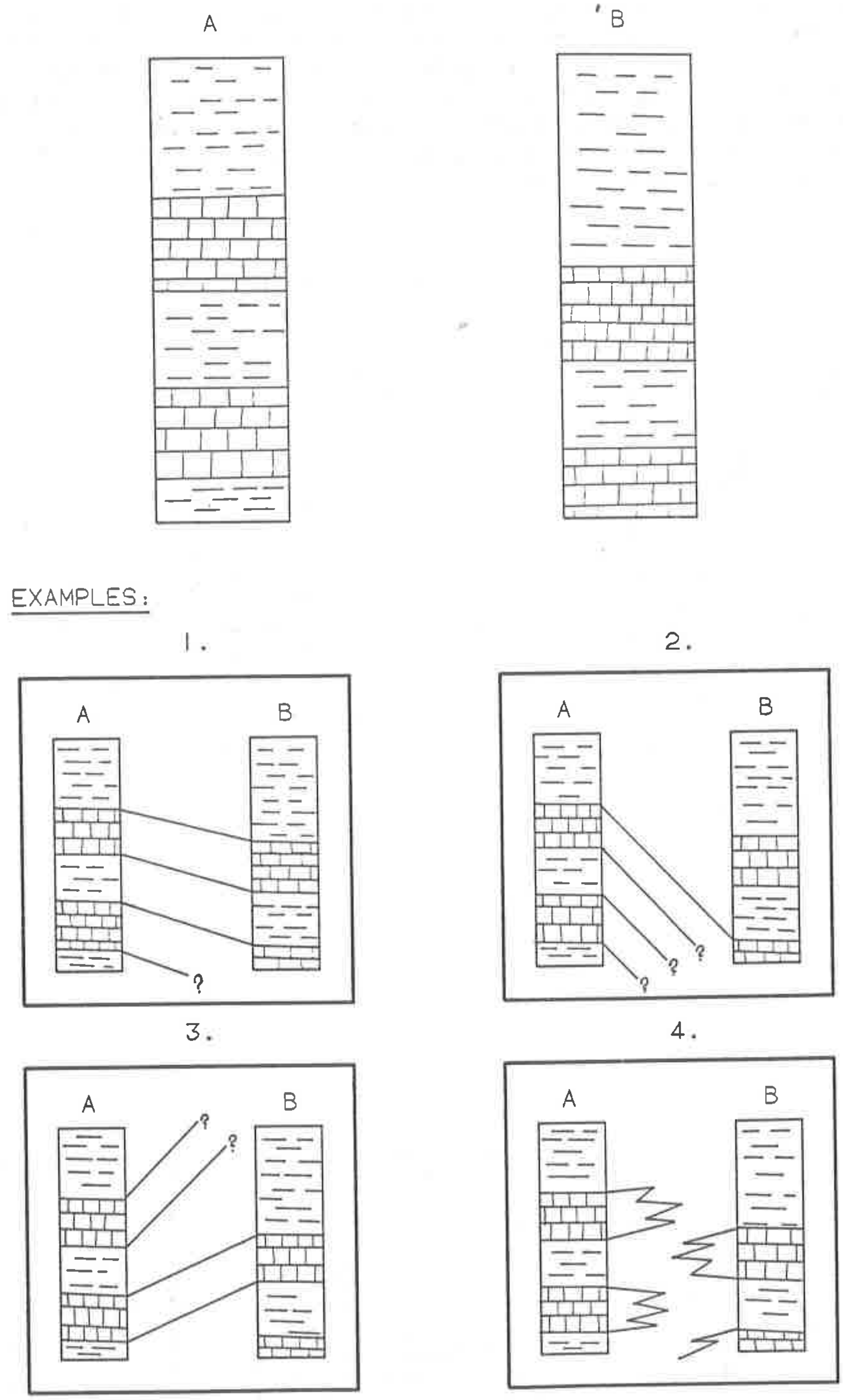
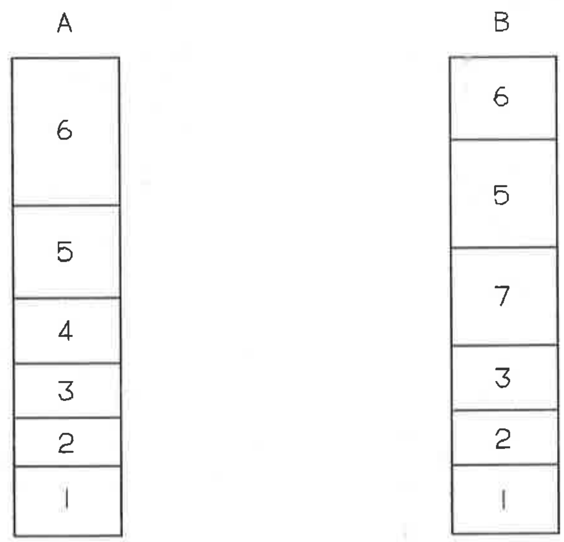


Figure 2.4. Correlation diagram showing four possible correlations.

Ideally, it would be nice to physically trace rock units between measured sections and thereby gain detailed control on lateral changes. Almost always, though, stratigraphers must make correlations from incomplete data sets like widely spaced wells, roadcuts or natural outcroppings. The exercise of correlation, therefore, becomes necessarily subjective and several ways often exist to correlate a given set of sections. Figure 2.4 gives an example of a correlation exercise that has at least four possible solutions. In such situations, with multiple possible correlations, it becomes necessary to rely on other data where it exists. Perhaps there are distinctive sedimentary structures in one limestone but not in the others. Or maybe, while on the outcrop the geologist noticed that all the limestone beds were discontinuous lenses that pinched out before the next section. All such clues will make the stratigraphers decisions easier and will allow the correlation to more closely approximate what exists in nature. Unless one has compelling evidence to do otherwise it is best to apply Occams Razor. That is to cut out the most complicated solutions and choose the simplest solution.



EXAMPLES:

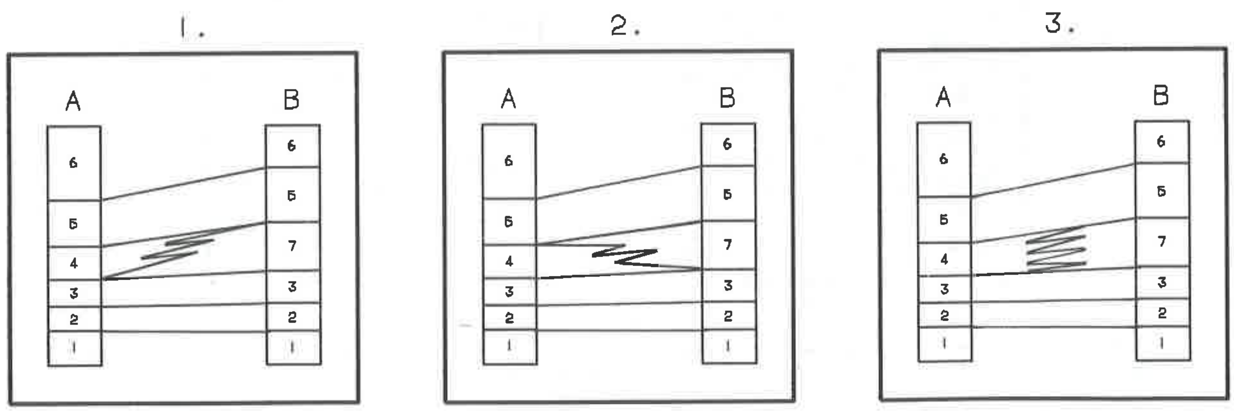


Figure 2.5. Correlation diagram showing three possible ways to show or interpret the interfingering of units 4 & 7.

Cases will arise when a stratigrapher wishes to be noncommittal and make a very conservative interpretation. Take the example given in Figure 2.5. Most units correlate in a straight-forward manner. Note, however, that unit 4 must somehow correlate with unit 7. There are three ways that 4 and 7 could interfinger. In the absence of other data, the most conservative correlation would be the third. Schematic interfingering in this case implies to the reader that the exact way that units 4 and 7 interfinger is unknown but is assumed to be a simple lateral gradation.

Let's look a bit closer at this zone of interfingering. What if, at some later date, a new well or roadcut is located through this interval, and a stratigrapher is sent to measure the section and name the units. Between units 3 and 5 the stratigrapher counts three intervals of unit 7 and two intervals of unit 4. According to Article 22(c) of the North American Stratigraphic Code, one is not allowed to repeat unmodified names of formal units in a stratigraphic sequence. This is known as the classical stratigraphic dilemma. The choices are: 1) name the rocks in question Unit 4 and break out five members; 2) name the interval as Unit 7 and break out five members; or 3) rename lithologies. As long as the stratigrapher is familiar with Article 23, any of the three choices will be acceptable. Note however, that the Stratigraphic Code recommends option 3, above.

The pertinent part of ARTICLE 23(b) reads as follows:

> "... *Where a unit changes laterally through abrupt gradation in or intertonguing with a markedly different kind of rock, a new unit should be proposed for the new rock type. An arbitrary lateral boundary may be placed between the two units. Where the area of lateral integration or intertonguing is sufficiently extensive, a transitional interval of interbedded rocks may constitute a third independent unit (Fig. 2.3c). Where tongues (Article 25(b)) of formations are mapped separately or otherwise set apart without being formally named, the unmodified formation name should not be repeated in a normal stratigraphic sequence, although the modified name may be repeated in such phrases as "the lower tongue of the Mancos Shale" and "upper tongue of the Mancos Shale."*"

A final word on graphic procedures. The tops and bottoms of sections measured in the field or boreholes were probably chosen arbitrarily at the limits of exposure or the bottoms of boreholes. Therefore, the tops and bottoms of correlation diagrams should not themselves be correlated unless they are known to coincide with lithologic contacts. It is acceptable to have correlation lines truncated by diagram boundaries.

BIOSTRATIGRAPHIC UNITS

Nature and boundaries

ARTICLE 48. - Nature of Biostratigraphic Units. A biostratigraphic unit is a body of rock defined or characterized by its fossil content. The basic unit in biostratigraphic classification is the biozone, of which there are several kinds.

(b) Independence from lithostratigraphic units. - Biostratigraphic units are based on criteria which differ fundamentally from those of lithostratigraphic units. Their boundaries may or may not coincide with the boundaries of lithostratigraphic units, but they bear no inherent relation to them.

(c) Independence from chronostratigraphic units. - The boundaries of most biostratigraphic units, unlike the boundaries of chronostratigraphic units, are both characteristically and conceptually diachronous. An exception is an abundance biozone boundary that reflects a mass-mortality event. The vertical and lateral limits of the rock body that constitutes the biostratigraphic unit represent the limits in distribution of the defining biotic elements. The lateral limits never represent, and the vertical limits rarely represent, regionally synchronous events. Nevertheless, biostratigraphic units are effective for interpreting chronostratigraphic relations.

ARTICLE 49. - Kinds of Biostratigraphic Units. Three principle kinds of biostratigraphic units are recognized: *interval, assemblage and abundance* biozones.

Remark: (a) Boundary definitions. - Boundaries of interval zones are defined by lowest and/or highest occurrences of single taxa; boundaries of some kinds of assemblage zones (Oppel or concurrent range zones) are defined by lowest and/or highest occurrences of more than one taxon; and boundaries of abundance zones are defined by marked changes in relative abundances of preserved taxa.

ARTICLE 50. - Definition of Interval Zone. An interval zone (or subzone) is the body of strata between two specified, documented lowest and/or highest occurrences of single taxa.

Remarks. (a) Interval Zone types. - Three basic types of interval zones are recognized... (Fig. 2.6).

1. The interval between the documented lowest and highest occurrences of a single taxon... (Fig, 2.6A).

2. The interval included between the documented lowest occurrence of one taxon and the documented highest occurrence of another taxon... (Fig. 2.6B).

3. The interval between documented successive lowest occurrences or successive highest occurrences of two taxa... (Fig. 2.6C).

ARTICLE 51. - Definition of Assemblage Zone. An assemblage zone is a biozone characterized by the association of three or more taxa. It may be based on all kinds of fossils present, or restricted to only certain kinds of fossils.

(b) Assemblage zone types. - In practice, two assemblage zone concepts are used:

1. The *assemblage zone* (or cenozone) of ISSC (1976, p. 50), which is characterized by taxa without regard to their range limits... (Fig. 2.7, this manual). Recognition of this type of assemblage zone can be aided by using techniques of multivariate analysis. Careful designation of the characterizing taxa is especially important.

2. The *Oppel zone*, or the *concurrent range zone* of ISSC (1976, p. 55, 57), a type of zone characterized by more than two taxa and having boundaries based on two or more documented first and/or last occurrences of the included characterizing taxa... (Fig. 2.7a).

ARTICLE 52. - Definition of Abundance Zone. An abundance zone is a biozone characterized by quantitatively distinctive maxima of relative abundance of one or more taxa...

Ranks of Biostratigraphic Units:

ARTICLE 53. - Fundamental Unit. The fundamental unit of biostratigraphic classification is a biozone.

Remarks. (a) Scope. - A single body of rock may be divided into various kinds and scales of biozones or subzones... Such usage is recommended if it will promote clarity, but only the unmodified term *biozone* is accorded formal status.

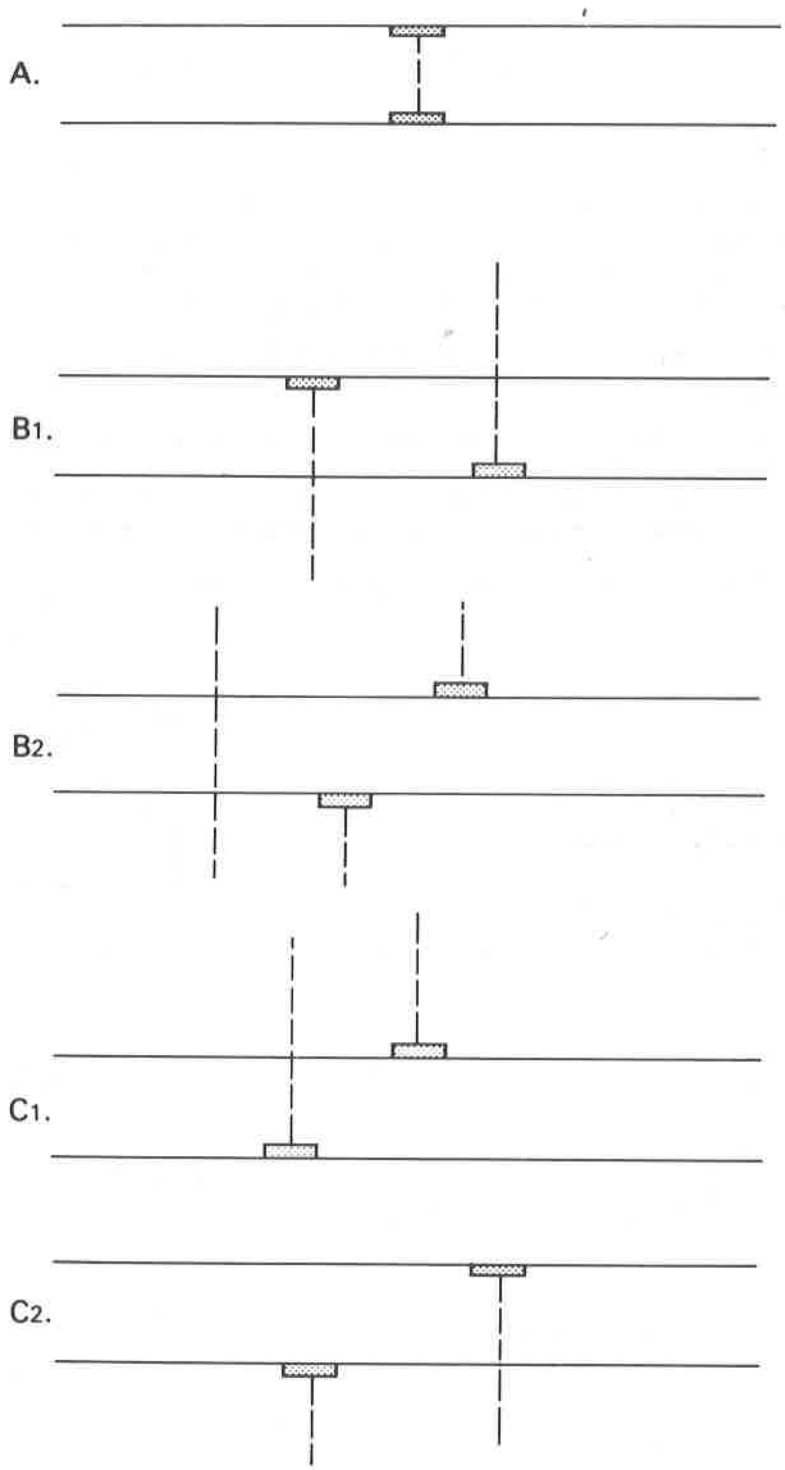


Figure 2.6. Various examples of biostratigraphic interval zones. Vertical lines indicate ranges of taxa; bars indicate lowest or highest documented occurrences. From North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code, *American Association of Petroleum Geologists Bulletin*, 67, Fig. 4, p. 863. Reprinted by permission of the American Association of Petroleum Geologists.

(b) Divisions. - A biozone may be completely or partially divided into formally designated sub-biozones (subzones), if such divisions serve a useful purpose.

Biostratigraphic Nomenclature

ARTICLE 54. - Establishing Formal Units. Formal establishment of a biozone or subzone must meet the requirements of Article 3 and requires a unique name, a description of its content and its boundaries, reference to a stratigraphic sequence in which the zone is characteristically developed, and a discussion of its spatial extent.

Remarks. (a) Name. - The name, which is compound and designates the kind of biozone, may be based on:

1. One or two characteristic and common taxa that are restricted to the biozone, reach peak relative abundance within the biozone, or have their total stratigraphic overlap within the biozone. These names most commonly are those of genera or subgenera, binomial designations of species, or trinomial designations of subspecies...

2. Combinations of letters derived from taxa which characterize the biozone...

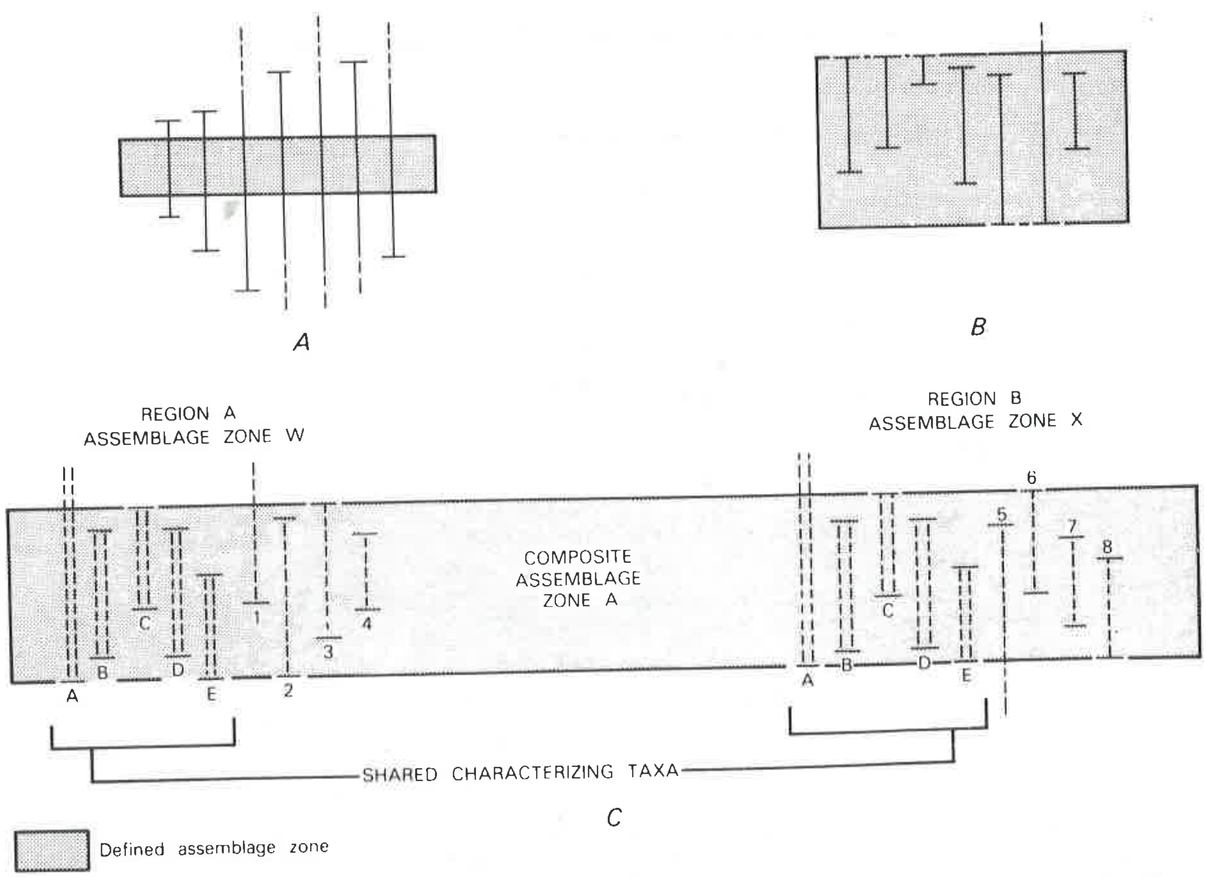


Figure 2.7. Examples of biostratigraphic assemblage zones. From North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code, *American Association of Petroleum Geologists Bulletin*, 67, Fig. 5, p. 864. Reprinted by permission of the American Association of Petroleum Geologists.

CHRONOSTRATIGRAPHIC UNITS

Nature and Boundaries

ARTICLE 66. - Definition. A chronostratigraphic unit is a body of rock established to serve as the material reference for all rocks formed during the same span of time. Each of its boundaries is synchronous. The body also serves as the basis for defining the specific interval of time, or geochronologic unit (Article 80), represented by the referent.

Remarks. (a) Purposes. - Chronostratigraphic classification provides a means of establishing the temporally sequential order of rock bodies. Principle purposes are to provide a framework for (1) temporal correlation of the rocks in one area with those in another, (2) placing the rocks of the Earth's crust in a systematic sequence and indicating their relative position and age with respect to earth history as a whole, and (3) constructing an internationally recognized Standard Global Chronostratigraphic Scale.

(b) Nature. - A chronostratigraphic unit is a material unit and consists of a body of strata formed during specific time span. Such a unit represents all rocks, and only those rocks, formed during that span.

ARTICLE 68. - Correlation. Demonstration of time equivalence is required for geographic extension of a chronostratigraphic unit from its type section or area. Boundaries of chronostratigraphic units can be extended only within the limits of resolution of available means of chronocorrelation, which currently include paleontology, numerical dating, remnant magnetism, thermoluminescence, relative-age criteria (examples are superposition and cross-cutting relations), and such indirect and inferential physical criteria as climatic changes, degree of weathering, and relations to unconformities. Ideally, the boundaries of chronostratigraphic units are independent of lithology, fossil content, or other material bases of stratigraphic division, but, in practice, the correlation of geographic extension of these boundaries relies at least in part on such features. Boundaries of chronostratigraphic units commonly are intersected by boundaries of most other kinds of material units.

Ranks of Chronostratigraphic Units

ARTICLE 69. - Hierarchy. The hierarchy of chronostratigraphic units, in order of decreasing rank, is eonothem, erathem, system, series, and stage. Of these, system is the primary unit of world-wide major rank; its primacy derives from the history of development of stratigraphic classification. All systems and units of higher rank are divided completely into units of the next lower rank... The rank and magnitude of chronostratigraphic units are related to the time interval represented by the units, rather than to the thickness or areal extent of the rocks on which the units are based.

ARTICLE 77. - Nomenclature. A formal chronostratigraphic unit is given a compound name, and the initial letter of all words, except for trivial taxonomic terms, is capitalized. Except for chronozones, names proposed for new chronostratigraphic units should not duplicate those for other stratigraphic units.

Remarks. (a) Systems and units of higher rank. - Names that are generally accepted for systems and units of higher rank have diverse origins, and they also have different endings (Paleozoic, Cambrian, Cretaceous, Jurassic, Quaternary).

(b) Series and units of lower rank. - Series and units of lower rank are commonly known either by geographic names (Virgilian Series, Ochoan Series) or by names of their encompassing units modified by the capitalized adjective Upper, Middle, and Lower (Lower Ordovician)...

GEOCHRONOLOGIC UNITS

Nature and Boundaries

ARTICLE 80. Definition and Basis. Geochronologic units are divisions of time traditionally distinguished on the basis of the rock record as expressed by chronostratigraphic units. A geochronologic unit is not a stratigraphic unit (i.e., it is not a material unit), but it corresponds to the time span of an established chronostratigraphic unit (Articles 65 and 66), and its beginning and ending corresponds to the base and top of the referent.

Ranks and Nomenclature of Geochronologic Units:

ARTICLE 81. Hierarchy. The hierarchy of geochronologic units in order of decreasing rank is *eon, era, period, epoch*, and *age*. *Chron* is a non-hierarchical, but commonly brief, geochronologic unit. Ages in sum do not necessarily equal epochs and need not form a continuum. An eon is the time represented by the rocks constituting an eonothem; era by an erathem; period by a system; epoch by a series; age by a stage; and a chron by a chronozone.

Correlation of Terms Used for Geologic Time and Time-Rock Units

Time-Rock Units	Time Units
Eonothem	Eon
Erathem	Era
System	Period
Series	Epoch
Stage	Age

Table 2.3. Correlation of terms used for time rock (chronostratigraphic) and time (geochronologic) units. From W. J. Fritz and J. N. Moore, 1988, *Basics of Physical Stratigraphy and Sedimentology*, Wiley, New York, Table 1.2, p. 31.

Please refer to Table 2.3 for a visual correlation of chronostratigraphic and geochronologic units.

ARTICLE 82. - Nomenclature. Names for periods and units of lower rank are identical with those of the corresponding chronostratigraphic units; the names of some eras and eons are independently formed. Rules of capitalization for chronostratigraphic units (Article 77) apply to geochronologic units. The adjectives Early, Middle, and Late are used for the geochronologic epochs equivalent to the corresponding chronostratigraphic Lower, Middle and Upper series, where these are formally established.

CORRELATION

Because there are a number of different types of stratigraphic units, correlation diagrams vary in style, organization, magnitude and scope of material included. Indeed, the number of variations may be as profound as the multitude of geologic settings. Figure 2.8 illustrates the steps used in establishing a simple lithologic correlation between two measured sections. Use this information as an aid to making your own correlations in the exercises at the end of this chapter. You may also wish to refer to examples of correlation diagrams shown in Figures 2.9 and 2.10.

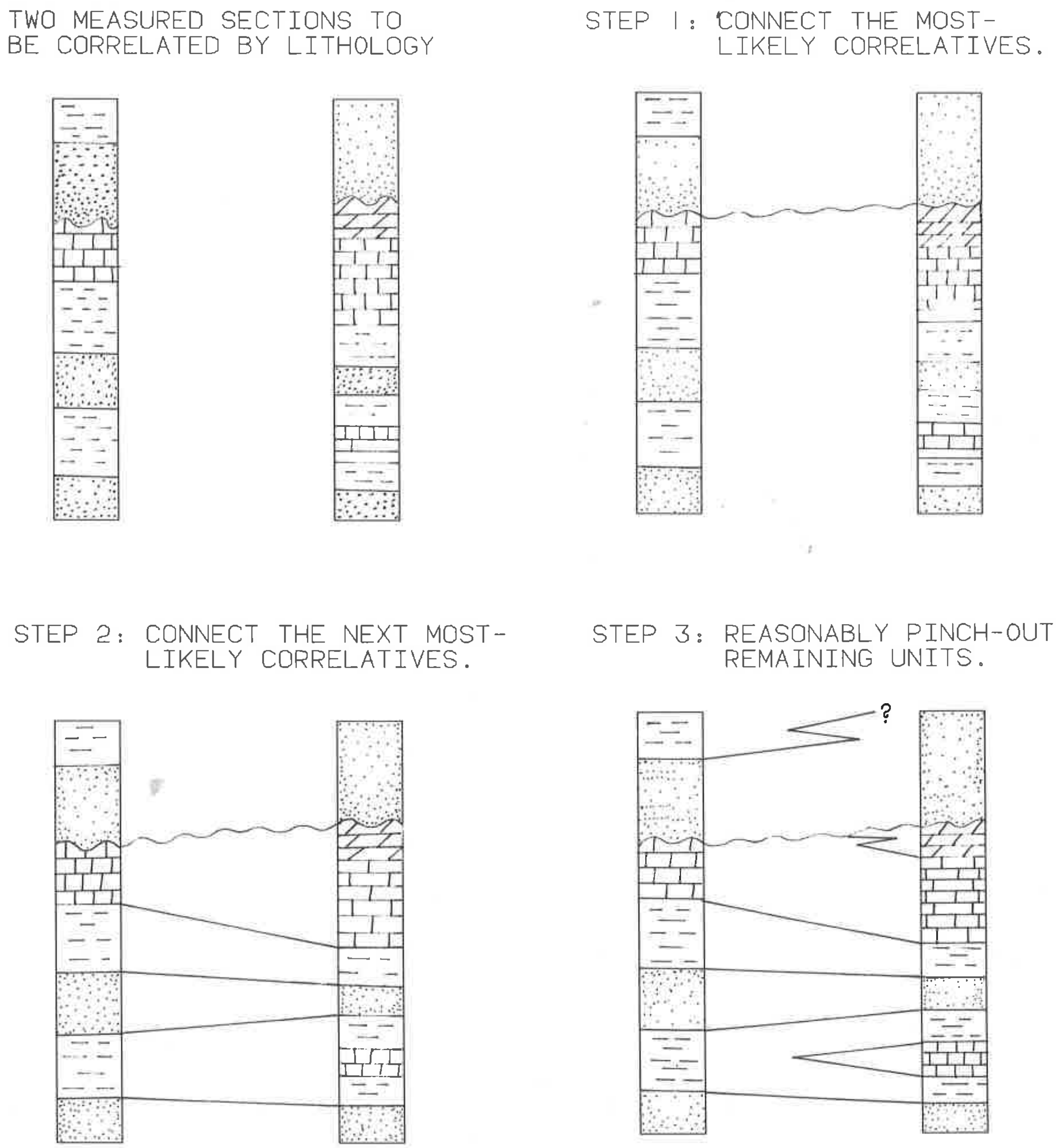


Figure 2.8. Procedure for constructing a correlation diagram

UNCONFORMITIES

Breaks in the stratigraphic record, called unconformities, are important in establishing correlations among rock sequences. An important concept is that unconformities are physical rock surfaces that result from periods of non-deposition or from uplift, folding, erosion and renewed deposition. The amount of time missing from such a contact or surface is called a hiatus. Recently the International Subcommission on Stratigraphic Nomenclature has formalized correlations based on unconformities into Unconformity Bounded Stratigraphic Sequences (ISSC 1987) with a basic subdivision called a *Synthem*. However, many other stratigraphers have long used the criterion of unconformities in establishing stratigraphic packages (Sloss, 1963; Chang, 1975; Vail and Mitchum, 1977; Vail and others, 1977a, 1977b).

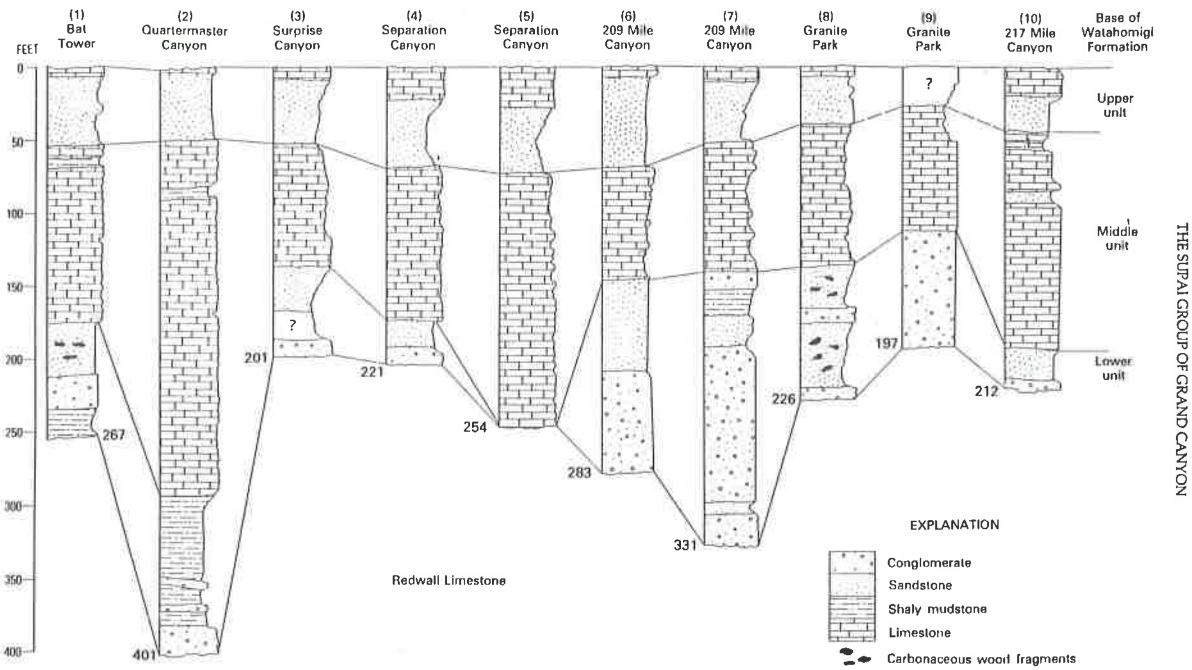


Figure 2.9. Example of a correlation diagram, the Supai Group in the Grand Canyon region. From Billingsley and McKee (1982).

Most stratigraphers place unconformities into one of four subdivisions (Fig. 2.11) as follows:

1. **Angular Unconformity**: An erosional surface separating tilted strata below from strata parallel to the erosional surface above.

2. **Disconformity**: An erosional surface separating two sequences of parallel strata from one another.

3. **Paraconformity**: A non depositional surface separating two parallel sequences of strata from one another. Nondeposition is inferred by evidence of missing time other than erosion, such as gaps in the fossil record.

4. **Nonconformity**: An erosional surface separating sedimentary strata above from nonstratified igneous or metamorphic rocks below.

Unconformities are physical surfaces separating two packages of rock and are therefore a special kind of lithologic contact, and should be treated differently than normal conformable contacts during correlation exercises. Unconformities should not necessarily be viewed as isochronous surfaces and have no more time significance than the lithologic boundaries of the prograding delta of Figure 2.1.

Just as the nature of lithologic contacts change laterally, so can surfaces of an unconformity. Figure 2.12 shows how rock units along the Colorado front range change laterally from an angular unconformity near the range at the area of maximum uplift and deformation into a disconformity and finally a conformable sequence in the center of the basin.

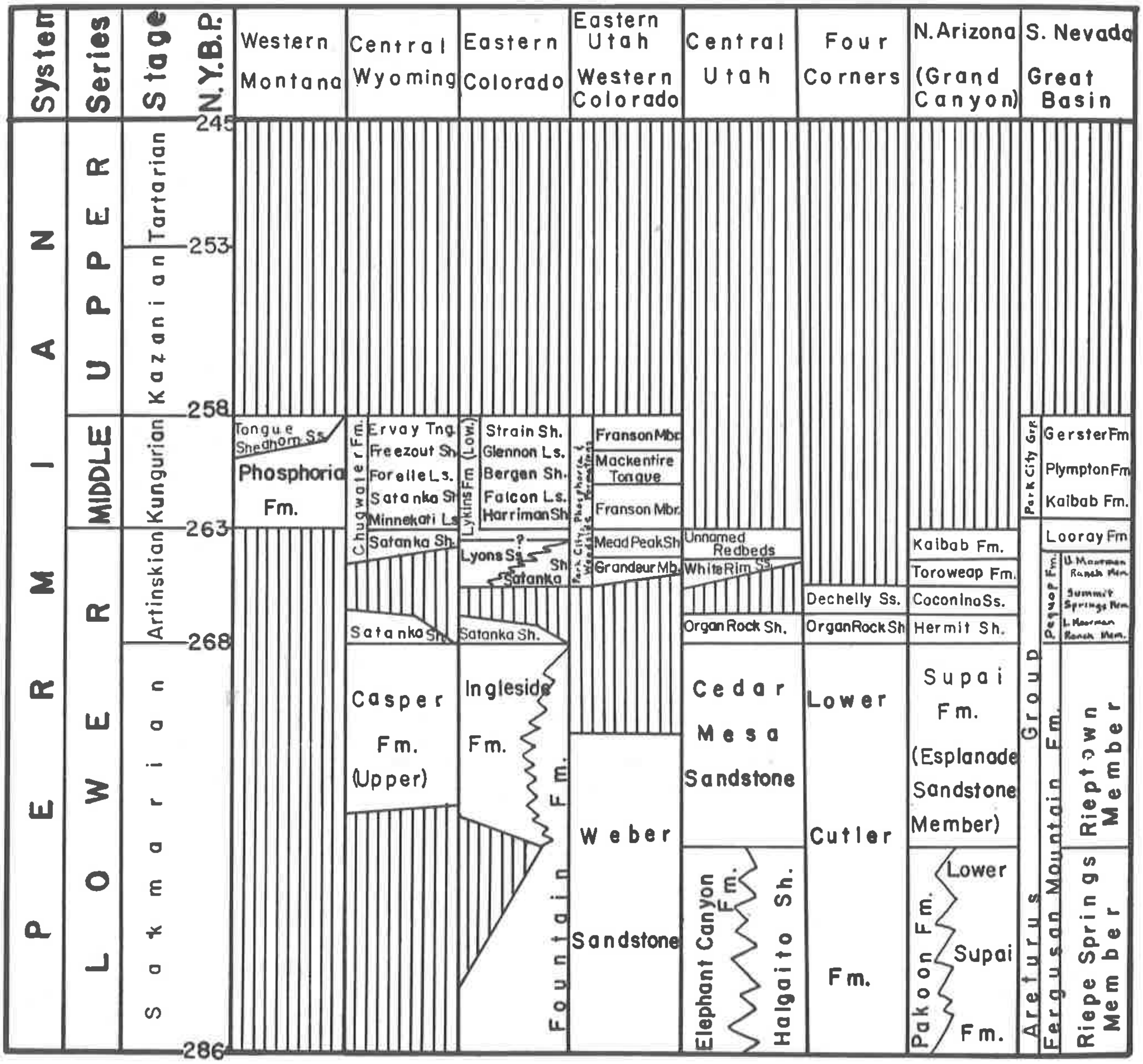


Figure 2.10. Chronostratigraphic and lithostratigraphic correlation diagram for the Permian System of the Western United States.

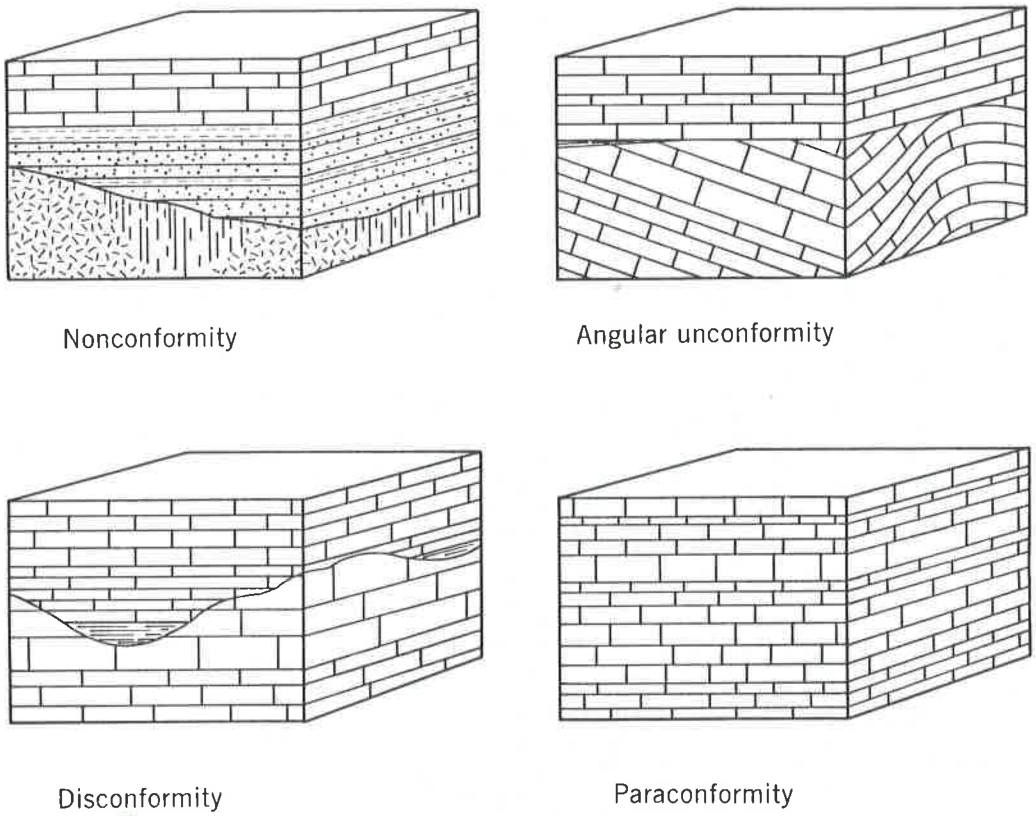


Figure 2.11. Diagram illustrating the four basic types of unconformities. From C. O. Dunbar and J. Rodgers, 1957, *Principles of Stratigraphy*, Wiley, New York, Fig. 57, p. 117. Copyright © 1957. Reprinted by permission of John Wiley & Sons, Inc.

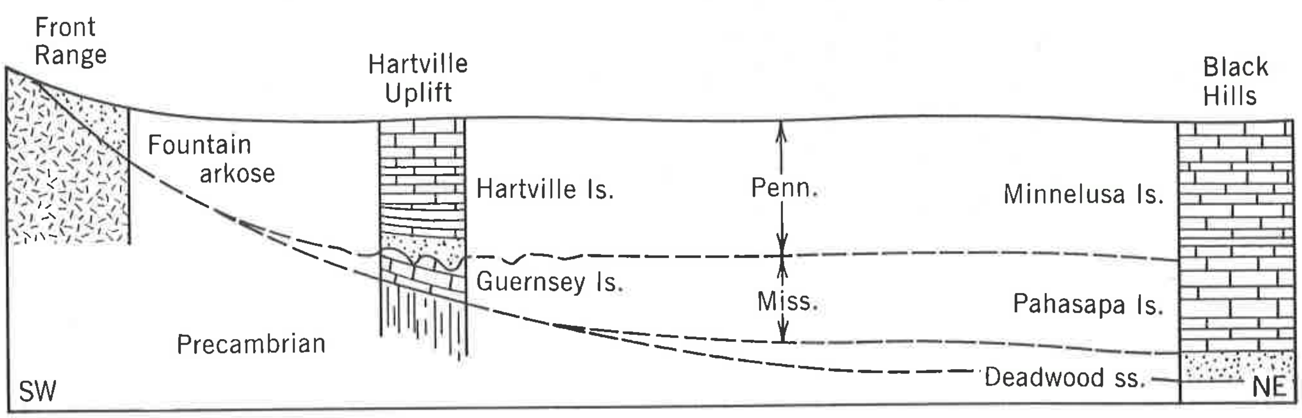


Figure 2.12. Variable expression of an unconformity at the base of the Pennsylvanian system in southeastern Wyoming from uplift into the depositional basin. From C. O. Dunbar and J. Rodgers, 1957, *Principles of Stratigraphy*, Wiley, New York, Fig. 64, p. 123. Copyright © 1957. Reprinted by permission of John Wiley & Sons, Inc.

Because unconformities often form from erosion they commonly cut across contacts of lithostratigraphic, biostratigraphic and time-stratigraphic units. Following is a quotation from the recent proposal of the ISSC (1987) to formalize the concept of unconformity-bounded stratigraphic units into a basic subdivision called a synthem. Figure 2.13 shows the character of various types of synthems.

"An unconformity-bounded unit is a body of rock bounded above and below by specifically designated discontinuities in the stratigraphic succession (angular unconformities, disconformities, and so on), preferably of regional or interregional extent. Being bounded by stratigraphic discontinuities is the single diagnostic criterion used to establish and recognize unconformity-bounded units; they should be extended only as far as both of its bounding unconformities are identifiable. Unconformity-bounded units can be composed of diverse kinds of any class or classes of rocks - sedimentary, igneous, metamorphic, or any combination of two or more of these classes. Neither the lithologic character of the rocks that compose the unit, nor their fossil content, nor the time span it represents, however, enters into its definition and recognition. Unconformity-bounded units, therefore, are not lithostratigraphic, biostratigraphic, or chronostratigraphic units. They are what their names indicates - unconformity-bounded units, a distinct and separate kind of stratigraphic unit that requires separate recognition. The basic unconformity-bounded unit is the synthem. Synthems are given geographic names derived from features at or near the location where the unit is well developed."

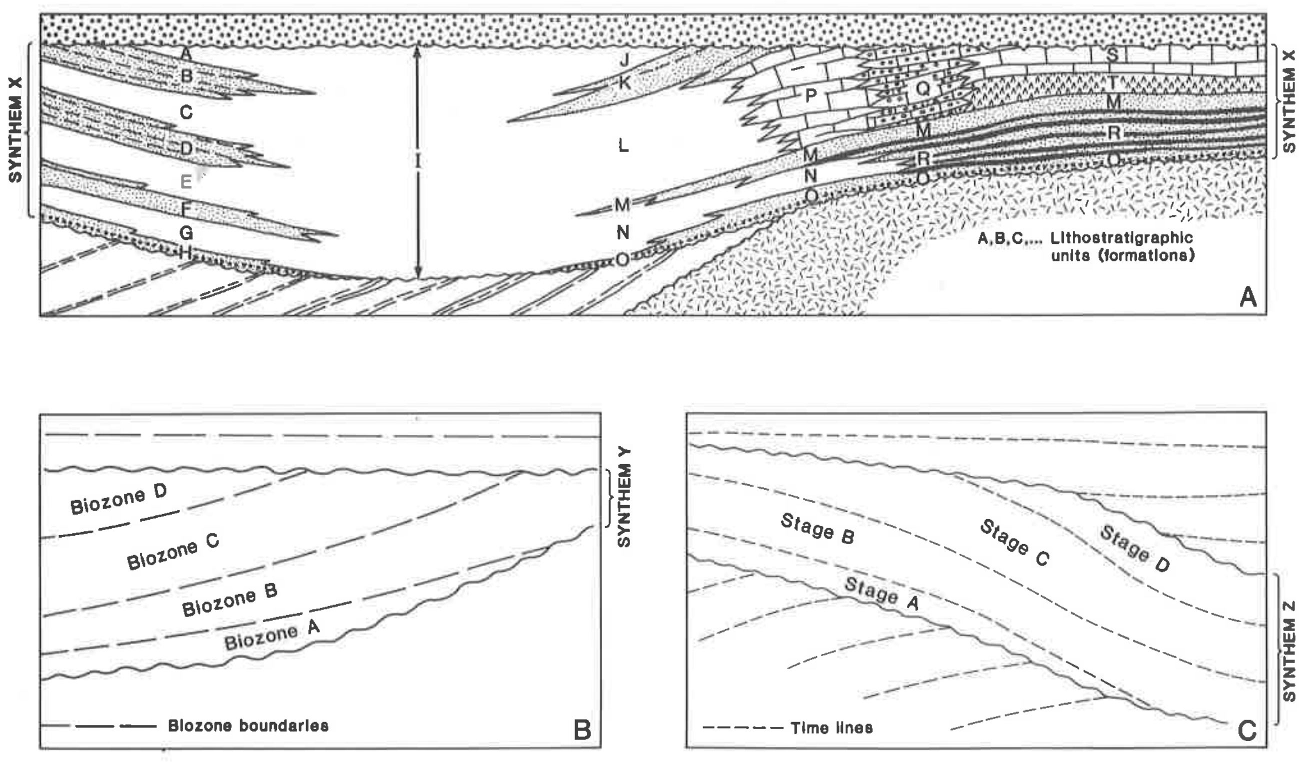


Figure 2.13. Relationship of unconformity-bounded units and (a) lithostratigraphic units, (b) biostratigraphic units, and (c) chronostratigraphic units. From International Commission on Stratigraphic Classification (Amos Salvador, Chairman), 1987, *Geological Society of America Bulletin*, 98, Fig. 1, p. 235.

SUMMARY

Correlation is the methodology of establishing the relationship among various rock units. As we have seen from the North American Stratigraphic Code, the relationship may be established based on a number of criteria. Common means of establishing relationships include fossils (biostratigraphic correlation) time (chronostratigraphic correlation), rock type (lithostratigraphic correlation) unconformities (unconformity bounded sequences of ISSC, 1987). Other means include magnetic properties of rocks, seismic studies, and others. Thus, correlation requires a thorough understanding of the formal stratigraphic units on which it is based. Also, the accuracy of correlation is based, in a large part, on the accuracy of field notes or other primary data.

The following exercises are designed to allow you to practice various types of stratigraphic correlation. In a manual such as this it would be impossible to include examples of every type of correlation. Thus, we have chosen and designed exercises that illustrate principles that can be applied to correlation of various types of stratigraphic units.

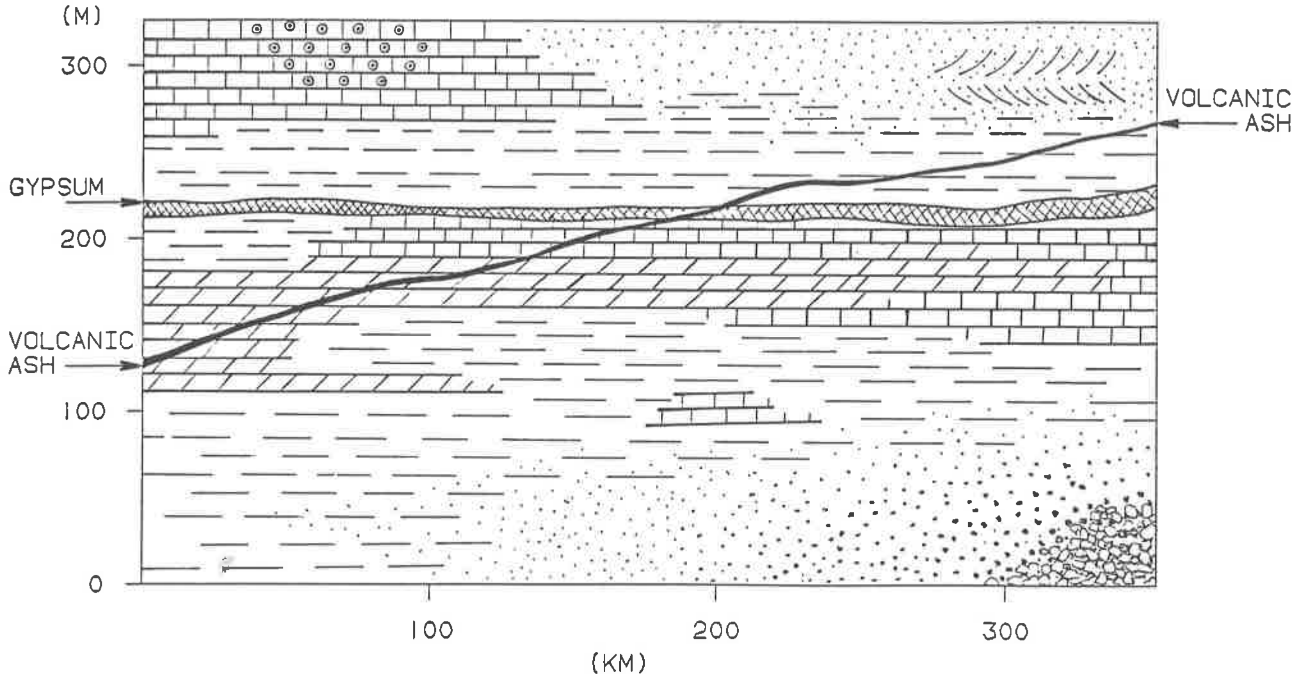
OUTSIDE READING

Boggs (1986); Committee on Stratigraphic Nomenclature (1933); Fritz and Moore (1988); International Subcommission on Stratigraphic Classification (1976, 1987a, 1987b); Krumbein and Sloss (1963); Miall (1983); North American Commission on Stratigraphic Classification (1983); Owen (1978, 1987); Sloss (1963); Vail and Mitchum (1977); Vail and others (1977a, 1977b).

EXERCISES FOR CHAPTER 2

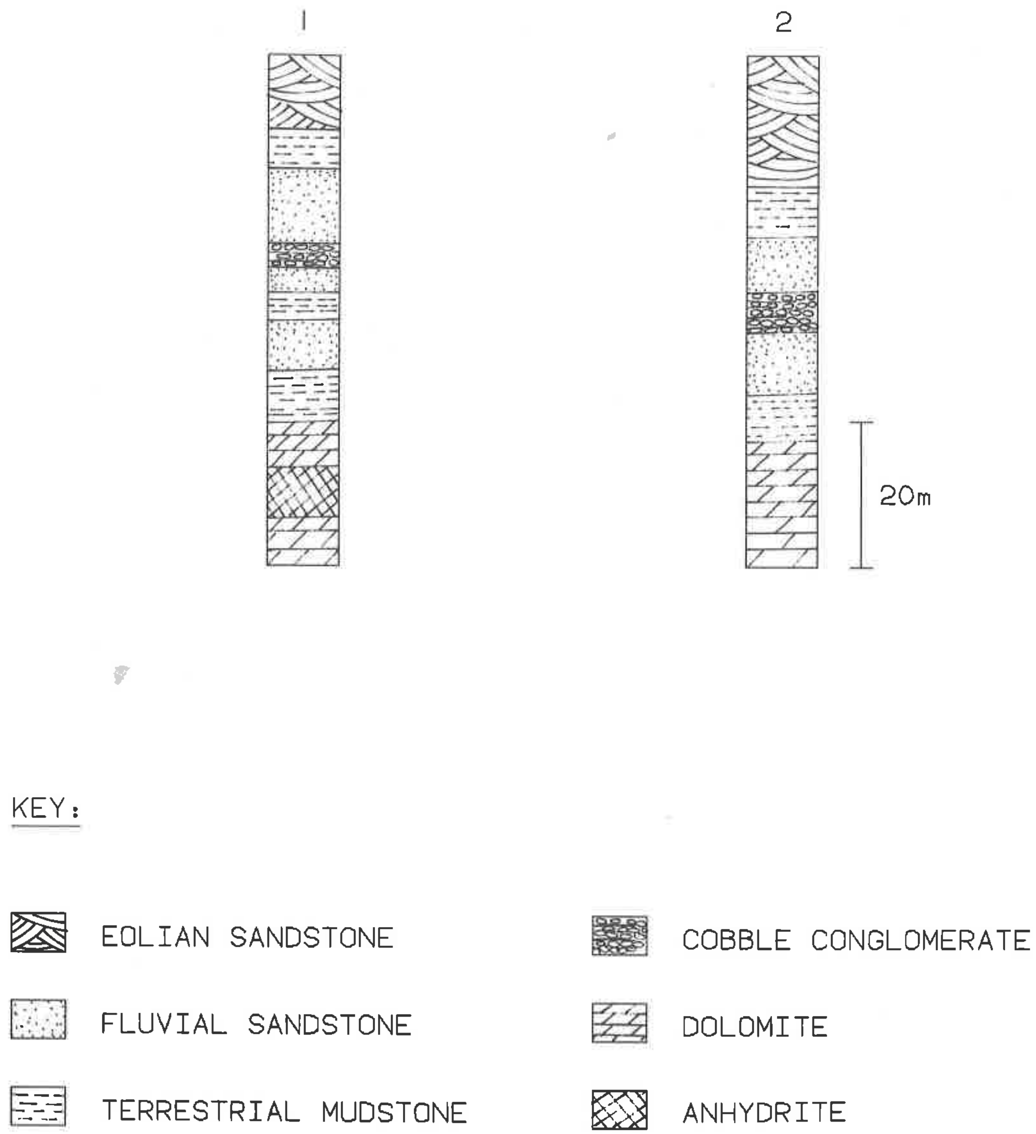
Exercise 2.1

As an example of how to use the stratigraphic code, divide this figure into formal lithostratigraphic units. Use various colored pencils to designate beds, members, formations or groups as needed. Consult the appropriate portions of the stratigraphic code for help.



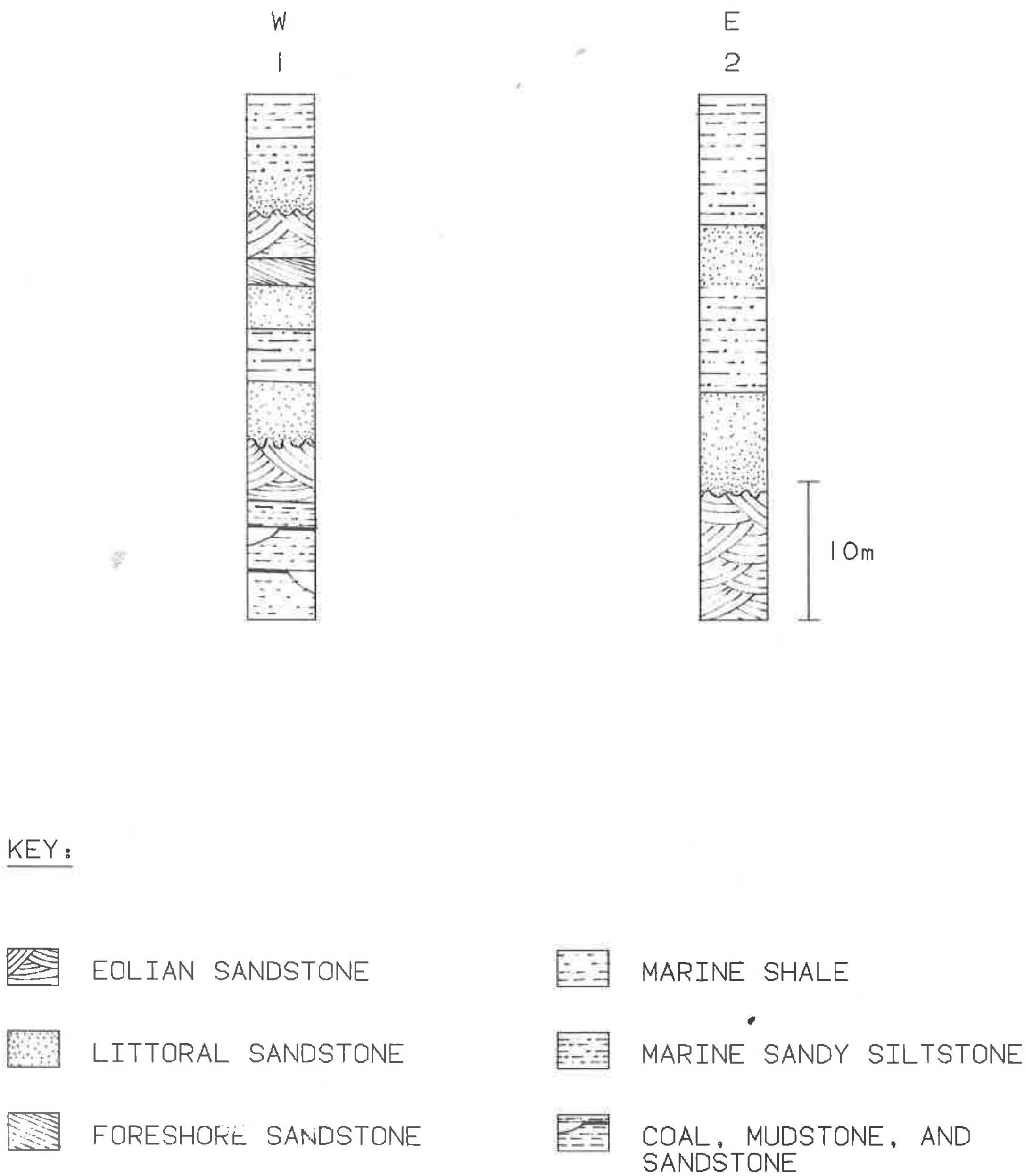
Exercise 2.2

Correlate the stratigraphic columns in the following problem. From which direction was the coarse clastic sediment derived?



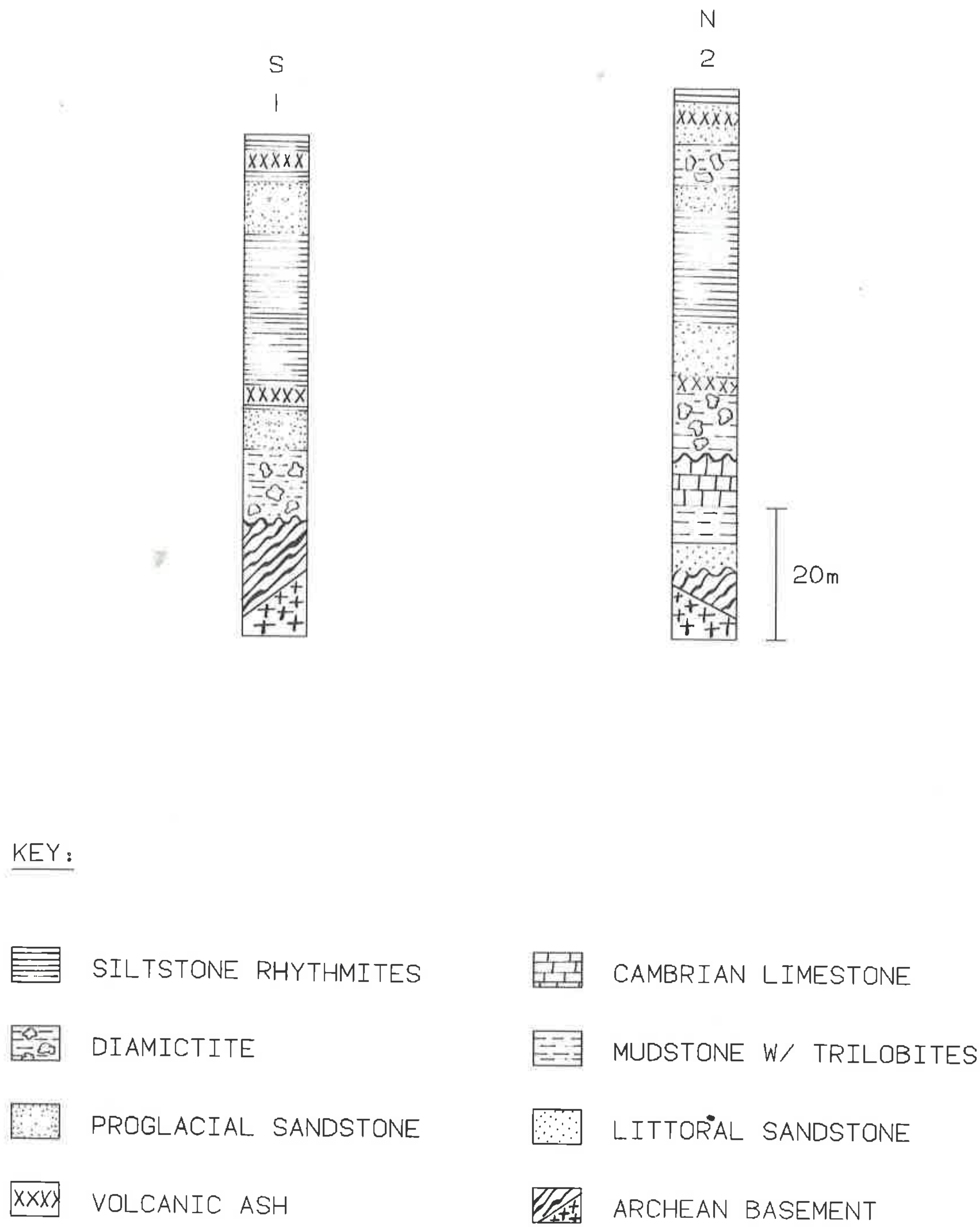
Exercise 2.3

Correlate the following stratigraphic columns. Which direction is landward? Why is there only one unconformity in the eastern column? What was happening in the east while erosion was occurring in the west?



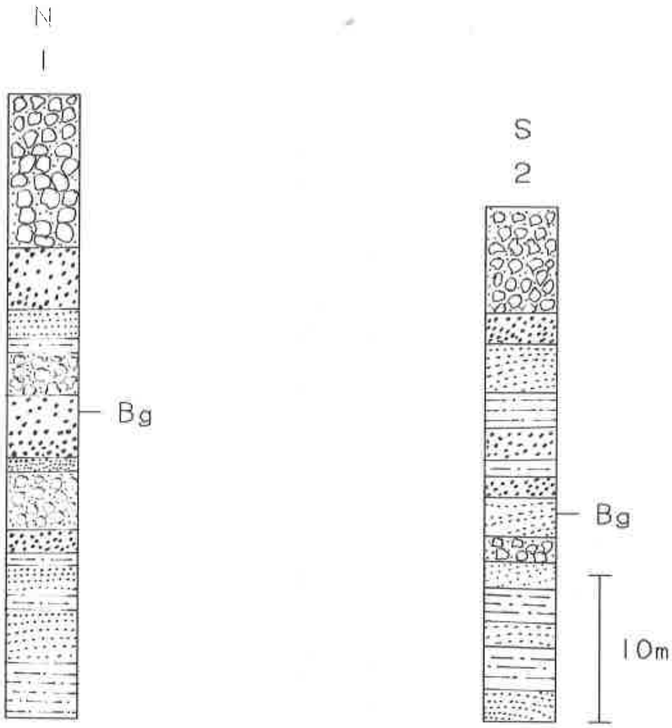
Exercise 2.4

Correlate the following measured sections. From what direction does the till appear to be derived? Do your chronostratigraphic correlations support this?



Exercise 2.5

Correlate the following two measured sections. Is this a prograding sedimentary sequence? From what direction was the sediment derived? Is this sequence marine or non-marine in origin? What two fundamental controlling factors may be responsible for this overall coarsening upward sequence?



KEY:

V. THICK-BEDDED MASSIVE SANDSTONE

CONGLOMERATE

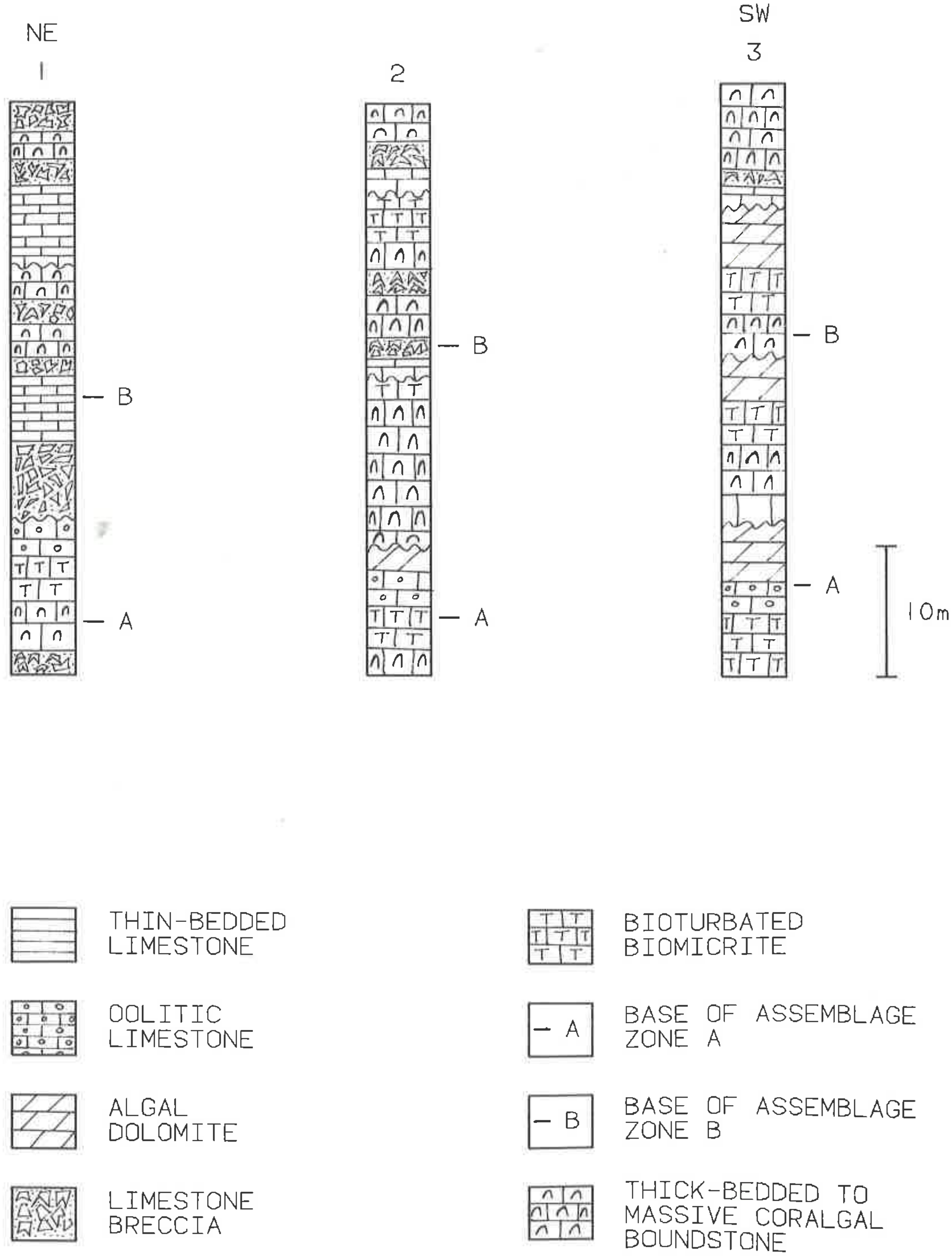
HEMIPELAGIC MUDSTONE W/ THIN SILTSTONE INTERBEDS

Bg BASE OF BACULITIES GRANDIS INTERVAL ZONE

V. THIN CROSS-BEDDED SANDSTONE W/ MINOR MUDSTONE DRAPES

Exercise 2.6

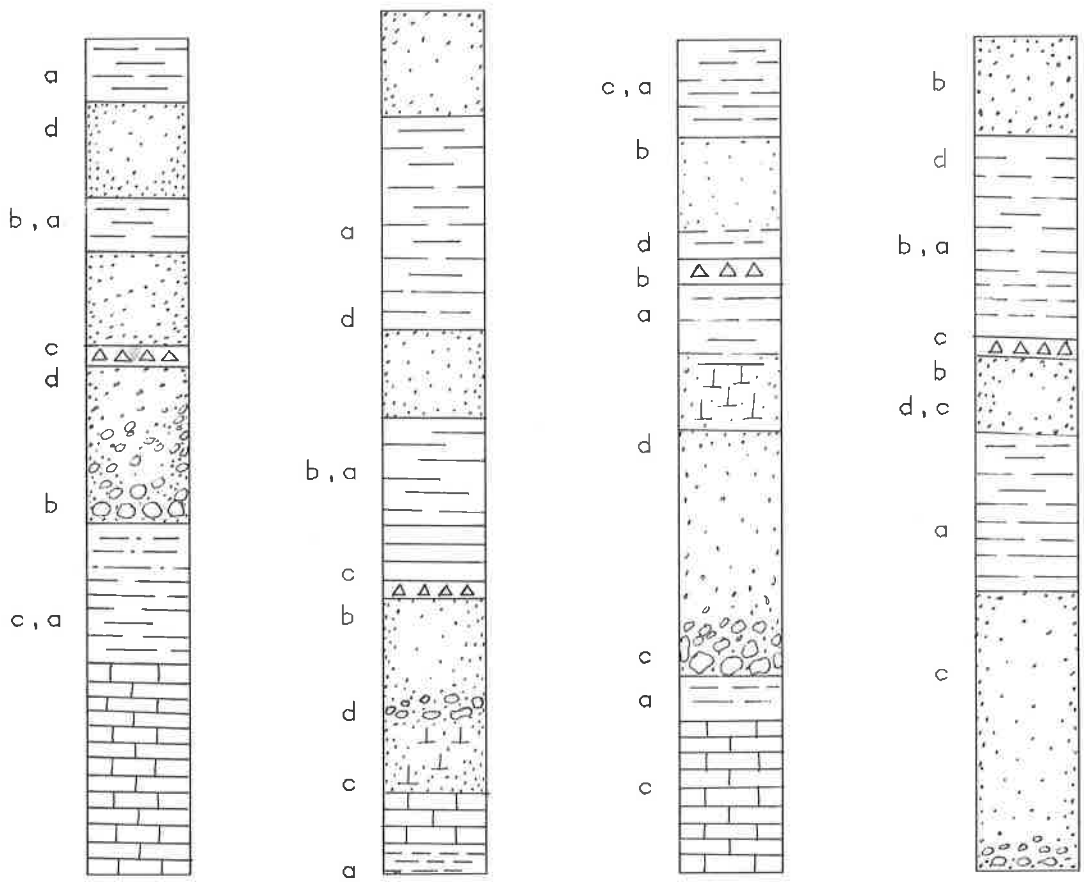
Correlate the following three measured sections. How does the oldest unconformity bounded sequence (below the first unconformity) differ from the two unconformity bounded sequences above, e.g., are they progradational, retrogradational, or ...? Are sediment distributions (in this system) more likely a result of sediment supply or changes in relative sea level? Which direction would you sail if you were heading to sea? In the context of Walther's Law, apply your understanding of this rock sequence to decipher the depositional environment in which the limestone breccia was formed.



Exercise 2.7

Correlate this figure by assemblage zone or overlapping range zones (concurrent range zone of ISSC) of fossils a, b, c, d; by lithology; and, by time. Write a short paragraph explaining your correlations. Use various colored pencils to keep the units separate. Are any of the lithologic units time equivalent? Which? Do any of the fossils appear restricted to a particular environment? If so, which? What effect would this have on its use as an index fossil? Why?

Hint: For this problem the letters give locations where the fossils were found. Because you only have the information given here you can use this diagram to determine the observed or documented highest and lowest stratigraphic occurrence for each.

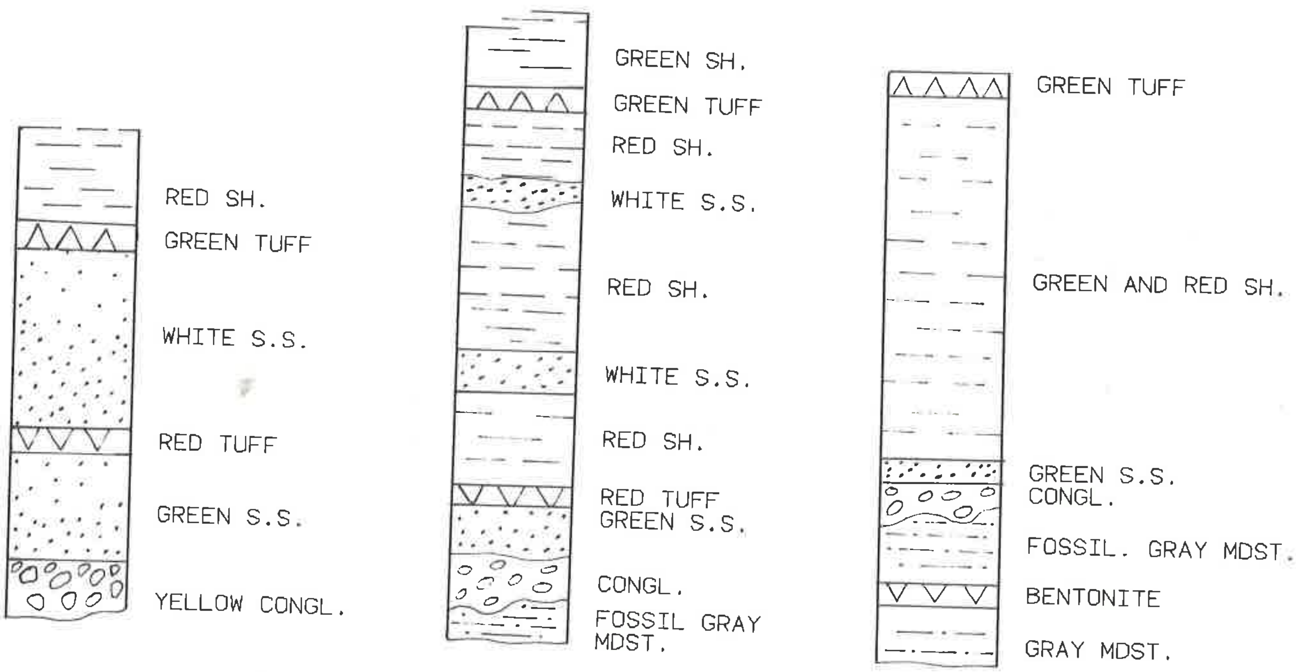


ΔΔΔΔ = VOLCANIC ASH

Exercise 2.8

Correlate the following three columns by:
a) time - use solid lines
b) lithology - use dashed lines

Explain and discuss the reasons for your correlations.



Exercise 2.9

As an exercise and practice to see how well you have mastered the principles of correlation and rules of stratigraphy as established by the International Stratigraphic Guide and/or the North American Stratigraphic Code read an article published in a major journal that deals with the establishment of a new stratigraphic unit or one that correlates stratigraphic sections. Prepare a critique of how well you think the rules of stratigraphy were followed. Articles that have served well for this type of report in our courses include: Cloud and Glaessner (1982); Fassett (1973); Ludvigsen and Westrop (1985); Prosh and McCracken (1985).