UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

CONCEPTS OF CLASSIFICATION AND NOMENCLATURE FOR SURFICIAL DEPOSITS

By

Richard B. Waitt, Jr.

Open-File Report

81- 28

CONTENTS

ABSTRACT

Alpine-glacial deposits and many other surficial accumulations are routinely divided into relative-age classes by the criteria of relative geographic position, geomorphology, and weathering and soils, rather than by lithostratigraphic and biostratigraphic criteria that are bases of the 1961 and 1970 Code of Stratigraphic Nomenclature. The Code contains no provision for formal naming of local material units that are distinguished primarily on relative geographic position of attendant landforms and on time-dependent criteria. Consequently some surficial units named since 1961 have been improperly designated as lithostratigraphic units. The term "formation" has been applied to at least two different categories of surficial units: it does not reveal the nature of a surficial unit so designated and disguises one class of units as something it is not.

To avoid the implication that surface-defined alpine-morainal, outwash-terrace, stream-terrace, marine-terrace, pluvial-shoreline, and certain other surficial units are lithostratigraphic units, a category of practical "para-chronogeographic" units drawn from precedent is proposed that distinguishes the surficial units from lithostratigraphic units. For regional correlation an additional broader category of material units is proposed analogous to "glacial stages" (in the time-rock sense) prior to publication of the Code. Both categories of units are of practical use not only for Quaternary glacial deposits, but for certain glacial, alluvial, pluvial, coastal, and other surficial deposits of any age.

Surficial geologists should engage in a comprehensive discussion of principles of classification and nomenclature for surficial deposits. Only after a thorough, published discussion widely among practicing surficial geologists should revision of existing procedures be undertaken. Meanwhile, an informal code of surficial nomenclature may be composed that is founded broadly on principles that have been the bases for classification and nomenclature of surficial deposits since the days of T. C. Chamberlin.

INTRODUCTION

Historic perspective

From the beginnings of glacial geology in North America, surficial deposits have been grouped and divided by relative age, the main criteria for classification having been relative geographic position of depositional landforms and sediments, their geomorphic expression, and their degree of weathering and erosion. Thus T. C. Chamberlin (1882) delineated a rudely contemporaneous series of moraine segments from Cape Cod to Saskatchewan. These morainal deposits were distinguished in the Midcontinent from other lithologically similar glacial deposits by their relative northward position and by a lengthy hiatus inferred from surficial weathering and geomorphic criteria. Chamberlin referred the deposits to time intervals called "epochs". Leverett (1899, 1902) renamed the time intervals "glacial stages" and called the deposits of each stage a "drift," some divided into "moraines." This procedure was followed by early investigators of alpine-glacial deposits in the Rocky Mountains and has since changed only in degree. In glaciated terrane throughout the American West, units are objectively divided by inferred relative age; morphology is and has been a guiding influence in cartography.

Although field procedures for classifying surficial deposits have not changed substantially since the 19th century, the Code of Stratigraphic Nomenclature [the Code] (American Commission on Stratigraphic Nomenclature [ACSN], 1961) fundamentally changed procedures for formal classification and naming of deposits. Frye and Richmond (1958) discussed the chronostratigraphic nature of many Quaternary units and outlined fundamental differences between them and lithostratigraphic units. Richmond (1959) discussed differences between the principles and practices used to classify surficial deposits and sedimentary rocks (p. 663-664). But he also stated (p. 665-668) that Quaternary division and classification should follow the standard procedures of lithostratigraphy and chronostratigraphy--procedures that had been tailored over the years by and for sedimentary-rock stratigraphers (Schenck and Muller, 1941; Hedberg, 1952; Cohee and others, 1956). Despite criticism from several workers in the Midcontinent (Leighton, 1958, Bretz and others, 1959), the Code (ACSN, 1961) recommended the same classification and nomenclatural procedures for surficial deposits as for sedimentary-rock strata. These procedures are also recommended by Hedberg and others (1976).

The 1961 and 1970 Code did not formally recognize a category of units that is indispensible to surficial mapping as being stratigraphic units, a position discussed by Richmond (1962b). However, because the Code addresses the entire stratigraphic range of deposits, it is generally the only guideline used in naming surficial deposits. I contend that chronogeographic or para-chronogeographic units (defined below), which differ from any class of units acknowledged by the 1961 or 1970 Code, are bona fide stratigraphic units. Although glacial geologists have long mapped local para-chronogeographic units, there is no commonly accepted terminology to accomodate them. To apply the Code one must either refer the local material units to the climate-stratigraphic category or disguise them in lithostratigraphic names. A common alternative has been to declare surficial units to be informal, which avoids the restrictions of the Code but has caused a variety of terms to be applied to a single type of unit.

Definition of para-chronogeographic unit

Frye and Willman (1962) proposed the term "morphostratigraphic unit" to distinguish in ice-sheet terrain in Illinois units of the general type discussed herein. But relative geographic position of landforms is far more the distinguishing criterion than is form, the units generally are not strata (*sensu stricto*) as seen and *defined* in the field, but they do have a relatively narrow temporal meaning. I therefore propose instead the term "chronogeographic unit." The boundaries of a chronogeographic unit, however, are not necessarily strictly time parallel, and a more accurate term would be "para-chronogeographic" unit (see Wheeler and others, 1950, p. 2364). In the remainder of the paper I use the term "para-chronogeographic" when referring to a unit of earth material, but the more economical term "chronogeographic" when speaking of principles or concepts.

A para-chronogeographic unit is defined and characterized by certain properties and restrictions:

1. The unit is a three-dimensional body of sediment defined by observable physical features.
2. The unit is defined by one of a succession of similar landforms (a) at distinctly different altitudes or heights above a valley floor or other base level or (b) at distinctly different distances from a source. The distinction from neighboring para-chronogeographic units depends on lateral geographic relations. Examples are the bodies of sediment underlying moraines, stream terraces, or shoreline terraces.
3. The top of a unit is delineated by a depositional surface that developed *pari passu* with accumulation of the sediment and is roughly contemporaneous throughout its extent. Commonly a soil of roughly consistent characteristics persists along the surface; the soil is generally more developed than soils on lower adjacent surfaces and less developed than soils on higher adjacent surfaces.
4. The base of a unit is the base of the deposit underlying a defining landform, down to an unconformity, a buried soil, or other demonstrably older surface.
5. As most para-chronogeographic units are lithologically heterogeneous and are laterally variable, no one type section is definitive. A para-chronogeographic unit consisting of several facies can be represented by a type area or several type sections linked by a common depositional surface.
6. Para-chronogeographic units differ from lithostratigraphic units in that (a) the unit commonly comprises several lithologic facies, (b) the unit may be lithologically identical to adjacent para-chronogeographic units, (c) lithology is not a primary criteria of distinction between units, and (d) the practical defining criteria are relative lateral positions in map, view rather than contrast in texture or lithology of incised strata viewed in section.
7. Para-chronogeographic units differ from chronostratigraphic units in that (a) the contacts with older and younger para-chronogeographic units are defined in map rather than section view and (b) the boundaries dividing para-chronogeographic units are not necessarily strictly isochronous. Most para-chronogeographic units, however, are bounded above and below by inferred hiatuses; such a unit is thus temporally restricted and is nowhere contemporaneous with older or younger such units.

8. Para-chronogeographic units differ from climate-stratigraphic units in being material units and in being readily applicable to various nonglacial deposits.

Para-chronogeographic units are not stratigraphic units in the strictest sense, that of being defined within a succession of strata exposed in section. But they are stratigraphic units in that they are objectively defined bodies of material ranked by relative age. Section-defined stratigraphic units are ranked by relative age by the principal that in a succession of superposed strata, an underlying layer of rock is older than an overlying layer. Para-chronogeographic units are ranked by relative age by a parallel principal: in a succession of undissected deposits distinguished primarily by depositional landforms, the more distant from the agent of deposition, or the higher above local base level, generally is older than the closer or lower deposits. (There are exceptions, such as overridden moraines). In places where sectional exposures of para-chronogeographic units are available, commonly some strictly stratigraphic evidence can be found to support the chronogeographic division. In some places units may be divided on either lithostratigraphic or chronogeographic criteria, or both (e.g., Richmond, 1962a). Where the chronogeographic criteria are the principal or only means of definition of units, though, the units should not be confounded with lithostratigraphic or chronostratigraphic names.

Relation to proposed (1981) alterations to Stratigraphic Code

This report is a much-revised manuscript originally written in 1978 and which began informal circulation in January 1979. In November 1979 at the Geological Society of America Annual Meeting, a summary of these proposals was presented to the Quaternary Advisory Group, who along with other committees appointed by the North American Commission on Stratigraphic Nomenclature were considering opinion prior to offering alterations to the 1970 Code of Stratigraphic Nomenclature. Copies of my manuscript (1979 version) were also circulated to the Quaternary Advisory Group. Although I submitted the manuscript for publication in late 1979, new priorities caused by the 1980 eruptions of Mount St. Helens have delayed my full consideration of reviewers' criticisms for almost two years. Meanwhile the Code committees have come forth with proposed amendments. My 1979 proposal was among those considered by the composers of the proposed amendments to the Code.

The draft of the proposed-amended Code (North American Commission on Stratigraphic Nomenclature, 1981) includes two new catagories of units, "ectostratigraphic units" and "diachronostratigraphic units," that would between them partly fill voids in the 1970 Code that are addressed by the present report. Although I think these proposals are a step in the right direction, I cannot entirely agree with them. (But the proposals may be altered by criticism solicited by the Stratigraphic Commission). It is inappropriate in this prior, independent document to specifically discuss the new proposed amendments, which should be done in the manner solicited by the Stratigraphic Commission. My proposals are similar in some respects but differ considerably in others from the proposed amendments to the Code. The present report does provide detailed reasons and rationale for some sort of substantial change in existing procedures for formal classification and nomenclature for surficial deposits.

Time is long overdue for a thorough discussion of stratigraphic principles and nomenclature for surficial deposits. In contrast to a literature spanning a century on principles of stratigraphy for dissected layered rock, discussion of stratigraphic principles for undissected surficial deposits is very sparse. The present report is just one of many opinions that should be aired and should be fully considered by the entire community of surficial geologists before amendments to present procedures are formally adopted.

NATURE OF STRATIGRAPHIC UNITS

Lithostratigraphy and chronostratigraphy

Figure 1A illustrates the fundamental distinction between lithostratigraphic and chronostratigraphic units in stratified sedimentary rock (Caster, 1934; Moore, 1947; Rodgers, 1948; Rubey, 1948; Teichert, 1958; Wheeler, 1958). The horizontal dashed lines represent "ideal" isochronous surfaces bounding conformable chronostratigraphic units (facies tracts) 1 through 5. During each successive time interval a gravel lithosome (Krumbein and Sloss, 1961, p. 300-302) merges with a contemporaneous sand lithosome that in turn merges with contemporaneous mud and calcareous lithosomes (all separated by thin solid lines). After such sediments have been consolidated, uplifted, and deeply dissected, the A Conglomerate, B Sandstone, C Shale, and D Limestone are distinguished and defined by lithology. The practical and objective units of mapping and stratigraphic division thus are lithostratigraphic formations (separated by thick solid lines); lesser tongues may be designated members--as the K (shale) Member and the L (conglomerate) Member of the B Sandstone. At both the formation and member ranks, rocks are grouped by lithologic likeness and are divided by lithologic unlikeness. In buried strata depositional geomorphology cannot be a criterion for division of these units: the intersection of the ancient depositional with the modern erosional surface is but a line, of which only trifling segments are exposed.

Figure 1 near here

Chronogeography

> <u>Physiography bears the same relation to Quaternary geology as paleontology bears to stratigraphy in general. By its aid formations of similar composition but unlike age may be distinguished</u>.
>
> --Atwood and Mather, 1932.

Alpine-glacial deposits

Figure 1B illustrates the common procedure of grouping and dividing alpine-glacial deposits. A body of till (t) commonly is traced downvalley into outwash gravel (g) and thence into outwash sand (s), inwash sidestream debris, lacustrine mud, or nonglacial sediment. These lithologic and genetic facies are ideally linked by a common depositional surface defining a downvalley succession of landforms: moraine, outwash terrace, stream terrace (dashed lines). The depositional surface ceased to develop when the glacier receded from the moraine, when the mainstream concurrently cut below the outwash plain, and when sidestreams consequently cut below inwash surfaces. The surface connecting the several facies is a relic of their contemporaneity. The morphologically linked ensemble of till, outwash gravel and sand, and inwash debris--a facies tract--may be grouped as a named unit, the X Drift; a similar ensemble of landform-linked deposits upvalley, or at lower altitude in the same valley segment, is a younger facies tract that may be assigned a different name, the Y Drift. The deposits are thus divided and named not by lithologic unlikeness but by age differences that are objectively inferred from relative geography, geomorphology, and weathering criteria. Lithologic facies are commonly distinguished within each facies tract: the X Drift comprising till (Xt), outwash gravel (Xg), and outwash sand (Xs) facies.

In a truly lithostratigraphic division of the imbricate sequence of Figure 1B, most of the till (T Formation) would be separated from most of the gravel (G Formation), as indicated by the thick solid line. The N (gravel) Member might be distinguished within the T Formation, as discussed above for the lithostratigraphic units in Figure 1. Any such surficial glacial sequence can be divided by lithologic or lithostratigraphic criteria alone. But rarely is such a sequence divided by lithostratigraphic boundaries that steeply transgress time when objective geographic, geomorphic, and weathering criteria are at hand by which to classify and map material units by relative age. Lithologically unlike materials in surficial accumulations generally are differentiated within relative-age divisions. Till, gravel, and mud are facies that may be distinguished and mapped within each of facies tracts X, Y, and Z.

In some reports published since 1961 (e.g., Richmond, 1962a; Porter, 1976; Scott, 1977), alpine-glacial deposits have been divided into so-called "lithostratigraphic" units. But the nature of these units is shown by Figure 1, if the boundary between units 3 and 4 is considered a fundamental division that separates unit groups I and II. If I and II are designated "formations", and 1, 2, and 3 are "members" of "Formation I" and 4 and 5 "members" of "Formation II"--that essentially is the manner in which the alpine-glacial sequences were divided and named. If A, B, and C are valid formations and K and L legitimate members, as they are according to stratigraphic principles recommended by the Code, I and II cannot be formations, nor can 1 through 5 be members. The "members" of these alpine-glacial sequences are facies tracts, and the "formations" are successions of facies tracts: they are chronostratigraphic units by the traditional principles of stratigraphy.

Glacial geologists delineate material units inferred to be segregated from one another by lacunae, whether or not unconformities are evident in the field. A lacuna is inferred largely or wholly from evidence not available in bedrock stratigraphy--topographic unconformities, for example, or objective differences in weathering, soil, vegetation, or geomorphic character. A drift distinguished by these criteria generally is not lithologically distinctive and commonly its relation to neighboring drifts cannot be seen in vertical section. Doubtless many such drift bodies are strata piled one atop another, but only rarely are drifts defined on the basis of a vertical sequence of strata. Such a drift nonetheless has a particular chronologic significance.

In many alpine valleys till, outwash gravel, and lacustrine sediment each occur within units distinguished by relative geographic position and by geomorphic and weathering criteria. Two successive moraines, each composed of an identical suite of materials, manifest two para-chronogeographic bodies of sediment. Similarly two terraces underlain by lithologically identical material manifest two para-chronogeographic bodies of sediment. The two moraines or the two terraces will be classed as separate para-chronogeographic units or grouped as a single para-chronogeographic unit depending on whether or not they exhibit significantly different weathering, soils, or other time-dependent characteristics (Blackwelder, 1931; Sharp, 1969; Burke and Birkeland, 1979; Birkeland and others, 1979).

Excluding weathering and soil criteria, lithologic differences between alpine drifts are due to the relative positions of the drifts to bedrock bodies. A diagnostic character of a drift in one place may not persist throughout the map unit. In the Yakima Valley, Washington, for example, the terminal till and moraines of Porter's (1976) Swauk Prairie "Member" contain clasts from the Miocene Yakima Basalt Subgroup and Ellensburg Formation, whereas the terminal till and moraines of the Indian John "Member" do not. The drifts are lithologically different because the Swauk Prairie ice advanced far enough downvalley to cross the contact of the Yakima and Ellensburg, but the Indian John ice did not. Despite this fundamental lithologic difference between the two drifts on the floor of the main valley, the lateral deposits of the two "members" on the valley sides are distinguished from one another despite that neither unit contains clasts from the Yakima or Ellensburg: in those places the two units are lithologically identical. Probably no glacial geologist would dispute the intent or utility Porter's division--a division objectively based on relative geographic position, continuity of distinctive landforms, and degrees of postdepositional weathering and erosion, a division that distinguishes two units of clearly unlike age. But these units are not lithostratigraphic "members" of a type recognized by the Code.

The upper and lower boundaries of alpine-glacial and other surface-defined units may be somewhat diachronous. Because most alpine-glacial units are bounded by inferred lacunae, however, there are relatively narrow limits to their diachrony. Certainly the boundaries of the "drifts" in Figure 1B are a great deal less diachronous than the boundaries between "formations" of that sequence if it were divided according to lithostratigraphic principles. Although certainly not "ideal" chrononstratigraphic units, many glacial, pluvial, coastal, and other surficial units are thus more chronostratigraphic in nature than they are lithostratigraphic.

Degree of weathering is not a lithologic character. -- Some investigators have regarded differences in surface weathering to be lithologic phenomena that may be used to divide alpine-glacial deposits into lithostratigraphic units. But weathering products are time-dependent, are derived in situ, are younger than the alloclastic deposits on which they formed, and are imposed as a discontinuous veneer on the deposits. Boulder frequency, pitting, weathering rinds, soils, lichen growth, and other such criteria are a family of relative-age characteristics distinct from the lithologic constitution beneath the weathered veneer.

Some icesheet deposits

Chronogeographic procedures have been the basis of division of late Wisconsin deglacial sequences in some icesheet terranes. Willman and Frye (1970) divided late-Wisconsin ridged moraines, imbricate sheets of ground moraine, and outwash of the Lake Michigan lobe in Illinois into "morpho-stratigraphic" units called "drifts." In principle this classification is similar to the classification of Leverett (1899): both are based on the relative geographic positions of till bodies manifested by end moraines. Similarly, in the Puget Lowland the surficial Sumas Drift is distinguished from the surficial Vashon Drift by its relatively more northern geographic position (Armstrong and others, 1965). In southern New England, late Wisconsin outwash trains graded to lacustrine deposits and small end moraines have been divided into "sequences," "morphological sequences," or "morphosequences"--units that have become a primary basis for mapping and dividing deglacial ice-sheet deposits throughout the region (Jahns, 1953, 1966; Shafer, 1965, 1968; Koteff, 1970, 1974, 1976; Koteff and Pessl, 1981). Near the coasts of Baffin Island, Labrador, and Newfoundland, glacial deposits and regoliths of weathered bedrock are divided on the basis of differences in degrees of weathering. The lower boundaries of these weathering zones are mappable over substantial regions (Pheasant and Andrews, 1973; Brookes, 1977; Grant, 1977). The procedure for division is similar to that of distinguishing the limits of variously aged drifts in alpine regions. In each of these widely separated regions, icesheet drifts and outwash bodies are thus distinguished mainly by criteria of chronogeography rather than of lithostratigraphy.

Nonglacial surficial deposits

Nonglacial surficial deposits in many regions commonly are divided chronogeographically and thus have classification and nomenclatural needs similar to those of surficial alpine-glacial deposits. In contrast to the thickly superposed deposits in a basin of accumulation, stream-valley deposits in a degradational region are preserved not because of burial by younger sediment, but because the streams incise the deposits. The process eventually results in a series of stream-beveled rock terraces overlain by gravel, the oldest terrace and gravel being the highest above the present stream, and the successively younger at successively lower heights. Gilbert (1877), Bradley (1936), Mackin (1937), and Hunt and others (1953a) articulated and developed this paradigm, the fundamental basis for mapping and age-classification of nonglacial surficial stream deposits throughout the American West.

Mackin (1937), Ritter (1967), and Moss (1974), and others divided alluvium in drainages in the Bighorn Basin, Wyoming into the deposits of many individual terraces grouped by Mackin into 6 height classes. Variations in lithology of the gravel underlying the terraces within a drainage are small except where the basin itself has changed because of stream capture. Division of the alluvium is based on objective geographic, geomorphic, and weathering criteria. The name "Fenton Pass Formation," although formalized for deposits of Mackin's Tatman bench (Rohrer and Leopold, 1963; Rohrer, 1964), is no more a lithostratigraphic unit according to Article 4 of the Code than are other surficial "formations" cited above and below.

Alluvial deposits in the San Joaquin Valley, California customarily have been divided into "formations" and "members" (Piper and others, 1939; Davis and Hall, 1959; Marchand and Allwardt, 1981). These lithologically heterogeneous units, scarcely seen in vertical section, are defined and distinguished by relative heights of terraces and on the bases of weathering, soil, and geomorphic criteria. Their names should indicate their distinction by geographic and time-dependent criteria rather than incorrectly implying that the units conform to Article 4 of the Code.

The distinction by relative geographic position into relative-age groups has been and is the principal mode of classification of surficial alluvial deposits in other areas. Alden (1932, 1953), Bradley (1936), Hunt and others, (1953a), Malde (1953), Hansen (1955), Skipp and Peterson (1965), Schmidt (1977), Soward (1975), and Hawley and others (1976, p. 252) are among hundreds of reports that exemplify these principles as applied over the years in regions and landscapes variously different than the Bighorn and San Joaquin basins.

Quaternary pluvial-shoreline deposits in the Lake Bonneville basin were first informally divided on a chronogeographic basis. Gilbert (1890) referred the deposits of four named "shorelines" to four identically named lake "stages" and "epochs". Hunt and others (1953b), however, named the deposits of each lake "stage" a "formation", whose lithologically distinct facies were designated "members". Morrison (1965) also defined deposits of the lake "stages" as "formations"; but his named "members" are the deposits of lake "substages" while his facies are called facies. "Member" thus was used unequally in these latter two reports, in neither conforming to the definition of a "member" in the Code. Morrison in fact stated (p. 14) that his units do not conform to standard lithostratigraphic procedures, but that each "formation" was defined as the deposit of a certain lake stage (age)--which is to say that despite their names, these units are either (para-)chronogeographic or (para-)chronostratigraphic units. The newly named Ridgeland Formation (Horn, 1979) continues the same philosophy of nomenclature.

Late Cenozoic marine-shoreline deposits along the California coast have been distinguished mainly by the relative altitude of the terraces that they form or underlie (Davis, 1933; Birkeland, 1972; Bradley and Griggs, 1976; K. R. Lajoie, oral commun., 1979). Some of these deposits are known by such names as the Battery Formation (Maxon, 1933; Back, 1957), but each of the units has a similarly heterogeneous lithology and is distinguished by relative geographic position and by various relative-age and chronologic criteria. Deposits of seven named transgressions along the Alaskan coast (Hopkins and others, 1965; Hopkins, 1973) are similarly chronogeographic in nature. The Atlantic coastwise terrace sequence between Virginia and Florida (Richards, 1965; Flint, 1971, p. 589), which although in places has been divided into units called "formations" and "members," has been divided mostly on chronogeographic principles.

Along the unglaciated segment of the Columbia River and tributaries, Pliocene-Quaternary mass-wastage deposits and the unique deposits of Lake Missoula catastrophic floods are divided and classified by relative height above valley floors and other chronogeographic criteria (Waitt, in press). A mainly chronogeographic (but said to be lithostratigraphic) classification applied to Quaternary morainal, stream-terrace, and marine-terrace deposits is the basis of the 20 "formations" of the cartographic system devised for 1:250,000 mapping by the New Zealand Geological Survey (Suggate, 1965).

These many examples from a variety of nonglacial Quaternary terranes show that principles of chronogeographic classification are not confined to glacial deposits but apply in general to various, widely distributed surficial terranes.

PAST NOMENCLATURAL PRACTICES

A precedent embalms a principle —Benjamin Disraeli

Landforms and deposits, now often regarded as mutually exclusive categories, in the past were commonly wedded by a term like "moraine" or "terrace." "End moraine" refers to a ridge, but only one composed of glaciogenic debris. "Moraine" not only was a principal division of Quaternary deposits of some of the earliest geologic maps in western United States (Hayden, 1877, pl. 13; Hayden and others, 1883, pl. 5; Salisbury, 1906a, 1906b), but continues to designate divisions in some glacial sequences (Crandell, 1967; Hamilton and Porter, 1975; Mayewski, 1975; Mercer, 1976). Most authors who through the years have used "moraine" have intended it to refer not only to a landform but also to a deposit.

In accumulations of drift lithostratigraphic units commonly have not been distinguished from para-chronostratigraphic units, even though it is routine to do so in stratified-rock stratigraphy. Following Chamberlin's principles from the Midcontinent, early alpine-glacial maps in the West (Salisbury, 1906a, 1906b, Atwood, 1909; Capps, 1909) divided deposits into older and younger drifts, older and younger moraines, higher and lower terraces, deposits of older and younger glacial epochs--all chronogeographic distinctions. Blackwelder (1915) distinguished his Pinedale, Bull Lake, and Buffalo drifts in Wyoming by relative positions of moraines and terraces and by degree of weathering and geomorphic character inferred to be time dependent. Blackwelder (1915) did not define his terms, but he did in 1931 with a crisp sentence (p. 869) unambiguously distinguishing "age" for time, from "stage" for time-rock. Blackwelder (1915) qualified each of the nouns "stage," "epoch," "drift," and "moraine" with each of the relative-age terms "Pinedale," "Bull Lake," and "Buffalo"; he thus embalmed the principle that the four categories merely distinguish different aspects of a single deposit that accumulated during a particular time interval.

Later investigators continued to divide alpine-glacial deposits primarily on the basis of relative age and for easy communication to borrow the age names for other aspects of the units. In western Montana Alden (1953, Pl. 1) distinguished surficial deposits mainly by relative geographic position and depositional geomorphology. The terms "deposits," "drift," "moraines," and "glaciers" are all modified by the relative-age terms "Wisconsin," "Iowan," and "Illinoian." Alden's definitions of units depend on lateral relations rather than on vertical stratigraphy, and his major divisions are thus para-chronogeographic units. Sharp (1960) grouped glacial deposits in the Trinity Alps, California into four age categories called "substages." Relative-age names modify "episodes," "events," "glaciations," "moraines," "till," and "substages." Criteria used to differentiate the relative-age groups were relative geographic position of moraines, topographic expression, weathering, soils, and only lastly stratigraphic relations ("rarely seen").

INFLUENCE OF CODE OF STRATIGRAPHIC NOMENCLATURE

After publication of the Code of Stratigraphic Nomenclature in 1961, some investigators began to divide undissected surficial deposits into units said to be lithostratigraphic. Some workers recognized the generally chronostratigraphic nature of their units, but the chronostratigraphic units of the Code are "in practice" based on lithostratigraphic or biostratigraphic units; the Code further implies that lithostratigraphy may be for local mapping purposes, but chronostratigraphy is for regional or larger use (ACSN, 1961, Art. 26b). Table 1 illustrates a variety of nomenclatural procedures that have been applied to glacial sequences that are similar in nature and in means of distinction. The diversity in nomenclature since 1961 reflects the ambiguity of the Code when applied to surficial glacial deposits.

Table 1 near here

In stratified rock, rock units have been distinguished in concept and nomenclature from time units and from time-rock units for almost a century (Powell, 1890; Williams, 1894; Renevier, 1901; Willis, 1901; Committee on Stratigraphic Nomenclature, 1933; Caster, 1934; Schenck and Muller, 1941; Moore, 1947; Hedberg, 1951, 1952; Woodring, 1953; Rodgers, 1954; Cohee and others, 1956; Teichert, 1958; Wheeler, 1958; ACSN, 1961). In glacial-stratigraphic nomenclature, however, rock and time concepts were closely linked before 1961. After 1961 some surficial geologists defining para-chronogeographic units began to use lithostratigraphic terminology. Thus Richmond (1962a), using mainly relative geographic position of deposits and various time-dependent criteria, divided mountain-glacial deposits into formally named formations subdivided into members. Suggate (1965), Porter 1976), and Scott (1977) named glacial sequences similarly, a procedure apparently advocated by Flint (1957, p. 274-276; 1971, p. 372). But regardless of what these units are called, they are of the same ilk as those of Chamberlin (1882), Salisbury (1906a, 1906b), Atwood (1909), Capps (1909), Matthes (1930), Blackwelder (1931), Sharp (1938, 1960), and Alden (1953).

After publication of the Code most geologists continued to rank glacial deposits explicitly by inferred relative age and continued to refer to landforms and deposits by the same name as designates the time interval during which the deposits and landforms originated. Sharp and Birman (1963), Sharp (1969, 1972), Pierce and others (1976), Porter (1976), and Waitt (1979, in press) thus variously referred to "glaciers," "glaciation," "ice," "moraines," "till," "outwash," "deposits," and "age" with relative-age names such as Tioga and Tahoe, Pinedale and Bull Lake, Lakedale and Kittitas. Of the published names Tioga Till, Tioga Drift, Tioga Glaciation, Tioga stage, Tioga age, and Tioga moraines, are they all approximately synonymous or do some belong solely to one or another class of units? Many geologists would consider Tioga Till and Tioga Drift as lithostratigraphic designations, Tioga Glaciation as geologic-climate (or glacial-stratigraphic), Tioga moraines as informal geomorphic or "morphostratigraphic," and Tioga stage and Tioga age--Blackwelder's (1931) only defined terms--as obsolete. Blackwelder in fact used most of these terms; his contexts show that he intended them all as chronologic, chronogeographic, or chronostratigraphic designations--"Tioga moraines," for example, having been a descriptive ad hoc variation on his chronostratigraphic "Tioga stage". The 1933 code (CSN, 1933, Art. 18c) acknowledged the multiple use of a geographic name for a deposit and its cognate depositional landforms, but the present Code (ACSN, 1970, Art. 10, 11c) discourages the practice.

PROPOSED MODIFICATION OF NOMENCLATURAL PROCEDURES

A complaint among surficial geologists about the Code of Stratigraphic Nomenclature is that the rules for defining lithostratigraphic units are too restrictive. But because many alpine-glacial and some other surficial deposits are more nearly chronostratigraphic than lithostratigraphic in nature, it seems to me that Articles 4 and 5 of the Code are irrelevant to defining and naming such units. Many so-called formations," "drifts," and "members" of surficial sequences ignore the requirements and transgress the prohibitions for lithostratigraphic units, and they are thus improper lithostratigraphic units. But the chronostratigraphic sections of the Code do not prohibit any of the relative-age and numerical-age criteria commonly employed in the division of glacial and alluvial sequences.

Because the principal criteria in distinguishing alpine-glacial and some other surficial units are irrelevant to bedrock mapping and stratigraphy, surficial deposits require classification and nomenclatural procedures different than those for classification and naming of dissected, stratified sedimentary rock. I propose a para-chronogeographic catagory and a para-chronostratigraphic category specifically to accomodate units of any age that are surface defined. Table 2 shows the hierarchal relation of the proposed units to presently recognized units. Like the stratigrapher of dissected sedimentary rock who divides superposed strata, the surficial geologist objectively divides surficial deposits into material units of local to regional significance.

Table 2 near here

Local para-chronogeographic units

Within a drainage basin or subregional area the surficial geologist needs descriptive, geomorphically and geographically defined material units ranked by relative age. Such a para-chronogeographic unit in alpine-glacial deposits would comprise moraines and attendant outwash terraces, and in pluvial- or glacial-lake basins would comprise a heterogeneous suite of shoreline deposits underlying a terrace. For glacial and genetically related deposits I propose _drift_ as the fundamental unit, its divisions _subdrifts_ (Table 3). For smaller mountain ranges a single terminology may apply to the entire range or to several adjacent ranges; within a large mountain range each major group of drainage basins may acquire locally designated drifts and subdrifts. It would not be improper to attach the chronogeographic adjective to a landform that developed _pari passu_ with accumulation of the drift. "Lakedale moraines" or a "Lakedale terrace" thus would be allowed variants of the para-chronogeographic name "Lakedale Drift"--the moraines and terraces, after all, being the very criteria by which the drift is distinguished from neighboring units. The term "drift" is inappropriate for nonglacial deposits such as of shorelines, alluvial fans, and stream or marine terraces. A term like "terrace alluvium"--hinting of the defining landform and its dominant lithology--may do for alluvial sequences (Table 3). Such sequences of heterogeneous bodies of sediment of any genesis are individually distinguished by relative height or lateral geographic relations and are packaged and divided according to inferred time relations.

Table 3 near here

Regional para-chronostratigraphic units

The surficial geologist needs a para-chronostratigraphic nomenclature for regional use, like the "Bull Lake stage," originally applied to a region in Wyoming and afterward extended through a large part of the Rocky Mountains; or like the "Bonneville stage" (chronostratigraphic sense), applied to a regionally distributed suite if shoreline deposits.

I propose to use "set" and "subset" (Table 4) in the chronostratigraphic sense that "stage" was used in the Sierra Nevada (Blackwelder, 1931), in the Midcontinent (Kay, 1931; Kay and Leighton, 1933; Leighton, 1960; Willman and Frye, 1970), and in New Zealand (Suggate, 1965). The surficial regional designations may retain a genetic adjective like "glacial" or "alluvial," as was widely the practice with the term "stage" earlier this century (CSN, 1933, Art. 2a). Hypothetical examples of this terminology are the <u>Pinedale Glacial Set</u> (Rocky Mountains alpine), the <u>Provo Shoreline</u> (or <u>Lacustrine?</u>) <u>Set</u> (Lake Bonneville basin), the <u>Modesto Alluvial Set</u> (Great Valley), the <u>Cody Alluvial Set</u> (Bighorn Basin), or the <u>Santa Cruz Marine Set</u> (California coast).

Table 4 near here

Interregional to global chronostratigraphic units

Finally, the surficial geologist, like the bedrock stratigrapher, needs a chronostratigraphic terminology for interregional to global grouping of contemporaneous surficial deposits of various origins. The existing chronostratigraphic section of the Code seems suitable for that purpose. The term "Wisconsin," originally intended for subregional use in the Midcontinent, has been transplanted widely in North America. Whether used in Wisconsin, eastern Pennsylvania, southern California, or British Columbia, "Wisconsin" is generally understood to include the interval roughly 75,000 to 10,000 yr B.P. The chronostratigraphic term "Wisconsinan Stage" <u>could</u> be a standard to designate nonglacial as well as glacial accumulations of these ages anywhere in North America.

Application

Table 5 illustrates an application of this three-tiered system. The practical working units (A columns) are surface-defined para-chronogeographic units, proxy for the column-defined lithostratigraphic units of deeply dissected strata. Because the local names are independent of perceived relations to any regional para-chronostratigraphic unit, a future change in correlation to such a unit will not entail changes in local names. The names in any of the A columns may be shifted up or down with respect to other A columns or to any of the B columns without changing definitions of the local names in the area from which they derived.

Table 5 near here

Local para-chronogeographic sequences may be amalgamated into or correlated with regional para-chronostratigraphic units (B columns), including those for alluvial, lacustrine, or coastal terranes. The various regional para-chronostratigraphic units at last are correlated with or amalgamated into continental or global chronostratigraphic standards (C and D columns). Because the regional para-chronostratigraphic names are independent of the continental or global names, the units of the B columns can be shifted up or down with respect to other B columns or to any of the C and D columns without upsetting the utility of the regional names within that particular region.

Discussion

Many elements of this proposed system have been drawn from precedents. This system would standardize principles of classification and terminology for local para-chronogeographic units (A columns) and to broaden the use of regional para-chronostratigraphic units (B columns). It advocates standardization of practices that, while some have decades or a century of precedents, are far from universally applied to surficial deposits at present, among them:

1. that local, regional, and continental surficial units be named as <u>material</u> units;
2. that material units based on relative geographic position of landforms and on geomorphic and weathering criteria be recognized as a class separate from lithostratigraphic units as defined by the Code;
3. that such local, practical, objectively defined units be named from the local evidence, rather than from perceived relations to regional or continental standards;
4. that appropriate local para-chronogeographic and regional para-chronostratigraphic units be acknowledged for alluvial, lacustrine, and coastal deposits, as well as for glacial deposits.

This discussion does not imply that all the names of the A columns of Table 5 need be formalized, only that where a formal terminology of surface-defined deposits is desired for practical, objective, subregional mapping or stratigraphy, the names need not conform to the inappropriate Article 4 of the Code. For clear communication, though, there should be <u>some</u> standards of classification and nomenclature appropriate to these units.

A CODE OF SURFICIAL NOMENCLATURE

The first requisite in a cartographic system is such breadth and elasticity that it shall not trammel the investigator in the expression or interpretation of phenomena.

--John Wesley Powell, 1888.

One must use common sense in deciding what in the long run will most effectively promote clarity, understanding, and progress.

--International Subcommission on Stratigraphic Classification, 1976

Units of rock, time-rock, soil, morphology, and time-rock-geography each are classifications based on different criteria of division. the last three are the most useful for practical mapping of undissected or sparsely dissected surficial deposits, whereas the Code contains only certain interpretations of the first three classes, interpretations that are particularly suited to deeply dissected strata.

The time-tested criteria doubtless will continue to be used in the practical analysis of surficial deposits and chronogeography will continue to be an important class. These units need a separate nomenclature in order that they not be confounded with authentic lithostratigraphic or other types of units. The term "formation" in a stratified-rock context specifies a certain class of units. The same term has been used to designate different types of surficial units and therefore does not reveal the nature of a surficial unit so designated. Worse, one class of surficial units is sometimes masqueraded as something it is not.

Para-chronogeographic units are strata insofar as the bodies of sediment composing successive moraines or terraces commonly are perceived to be imbricated or nested one atop another. But because the stratigraphic relations are only sparsely exposed, and because where exposed the contact between superposed identical sediment bodies may be indistinguishable, the practical defining criteria of these surficial deposits are lateral and altitudinal relations. Para-chronogeographic units as defined therefore may not be considered strata (*sensu stricto*) and thus may not necessarily fall within the purview of a stratigraphic commission (Richmond, 1962b; Lohman and others, 1963).

Many people recognize the incompleteness of the Code of Stratigraphic Nomenclature for classification and nomenclature of surficial deposits. There are seeds of a renewed published discussion on the subject (Birkeland and others, 1979; Nelson and Locke, 1981) and a review continues for possible revision of the Code. However, a lengthy published discussion by the entire community of practicing surficial geologists is needed before significant additions to existing guidelines are made. Rather than hastily amending the present Code, and thereby gracing ill-considered precepts and nomenclature with formal recognition, surficial geologists should perhaps compose a temporary, informal code of surficial nomenclature, a code comprehending material geographic and morphologic units, as well as stratigraphic units *sensu stricto*, that collectively have been the basis for the classification of surficial deposits in North America since the days of T. C. Chamberlin. After an appropriate period of trial application, the truly useful and widely acceptable elements of this informal code could then be proposed for formal incorporation into the North American Code of Stratigraphic Nomenclature.

ACKNOWLEDGMENTS

Elements of this paper, originally an informal essay, have been discussed with surficial and bedrock geologists since 1977. Since January 1979 various drafts of this manuscript have been submitted to about 50 surficial geologists, the majority from the USGS. Roughly half of these responded with thoughtful comments, some of which affected this paper. These individuals far too numerous to acknowledge separately I graciously thank for their helpful discussion. For particular discussion of the nature of certain surficial units I thank K. L. Pierce and S. C. Porter. For particularly critical reviews and discussion of one or another draft of the manuscript I thank Dwight R. Crandell, David M. Hopkins, David S. Fullerton, Rudolf W. Kopf, and Gerald M. Richmond.

REFERENCES

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U. S. Geological Survey Professional Paper 174, 133 p.

Alden, W. C., 1953, Physiography and glacial geology of western Montana and adjacent areas: U. S. Geological Survey Professional Paper 231, 200 p.

American Commission on Stratigraphic Nomenclature (ACSN), 1961, Code of Stratigraphic Nomenclature: American Association of Petroleum Geologists Bulletin, v. 45, p. 645-665.

American Commission on Stratigraphic Nomenclature (ACSN), 1970, Code of Stratigraphic Nomenclature, American Association of Petroleum Geologists, Tulsa, Oklahoma.

Armstrong, J. E., Crandell, D. R., Easterbrook, D. J., and Noble, J. B., 1965, Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington: Geological Society of America Bulletin, v. 76, p. 321-330.

Atwood, W. W., 1909, Glaciation of the Uinta and Wasatch Mountains. U. S. Geological Survey Professional Paper 61, 96 p.

Atwood, W. W. and Mather, K. F., 1932, Physiography and Quaternary geology ofthe San Juan Mountains, Colorado: U. S. Geological Survey Professional Paper 166, 176 p.

Back, W., 1957, Geology and ground-water features of the Smith River Plain, Del Norte County, California: U. S. Geological Survey Water-Supply Paper 1254, 76 p.

Birkeland, P. W., 1972, Late Quaternary eustatic sea-level changes along the Malibu coast, Los Angeles County, California: Journal of Geology, v. 80,p. 432-448.

Birkeland, P. W., Colman, S. M., Burke, R. M., Shroba, R. R., and Meierding, T. C., 1979, Nomenclature of alpine glacial deposits, or, What's in a name?: Geology, v. 7, p. 532-536.

Blackwelder, E., 1915, Post-Cretaceous history of the Mountains of central westen Wyoming, Part III: Journal of Geology, v. 23, p. 307-340.

Blackwelder, E., 1931, Pleistocene glaciation in the Sierra Nevada and Basin Ranges: Geological Society of America Bulletin, v. 42, p. 865-922.

Bradley, W. H., 1936, Geomorphology of the north flank of the Uinta Mountains: U. S. Geological Survey Professional Paper 185-I, p. 163-204.

Bradley, W. C. and Griggs, G. B., 1976, Form, genesis, and deformation of central California wave-cut platforms: Geological Society of America Bulletin, v. 87, p. 433-449.

Bretz, J H. and others, 1959, Application of stratigraphic classification to the Quaternary: American Association of Petroleum Geologists Bulletin, v. 43, p. 674-675.

Brookes, I. A, 1977, Geomorphology and Quaternary geology of Codroy lowland and adjacent plateaus, southwest Newfoundland: Canadian Journal of Earth Sciences, v. 14, p. 2101-2120.

Burke, R. M. and Birkeland, P. W., 1979, Reevaluation of multiparameter relative dating techniques and their application to the glacial sequence along the escarpment of the Sierra Nevada, California: Quaternary Research, v. 11, p. 21-51.

Capps, S. R., Jr., 1909, Pleistocene geology of the Leadville quadrangle, Colorado: U. S. Geological Survey Bulletin 386, 99 p.

Caster, K. E., 1934, The stratigraphy and paleontology of northwestern Pennsylvania, Part I--stratigraphy: Bulletin of American Paleontology, v. 21, no. 71, 185 p.

Chamberlin, T. C., 1882, The bearing of some recent determination on the correlation of the eastern and western terminal moraines: American Journal of Science, v. 124, p. 93-97.

Cohee, G. V. and others, 1956, Nature, usage, and nomenclature of rock-stratigraphic units: American Association of Petroleum Geologists Bulletin, v. 40, p. 2003-2014.

Committee on Stratigraphic Nomenclature (CSN), 1933, Classification and nomenclature of rock units: Geological Society of America Bulletin, v. 44, p. 423-429.

Crandell, D. R., 1972, Glaciation near Lassen Peak, northern California: U. S. Geological Survey Professional Paper 800-C, p. 179-188.

Crandell, D. R. and Miller, R. D., 1974, Quaternary stratigraphy and extent of glaciation in the Mount Rainier region, Washington: U. S. Geological Survey Professional Paper 847, 59 p.

Davis, W. M., 1933, Glacial epochs of the Santa Monica Mountains, California: Geological Society America Bulletin, v. 44, p. 1041-1133.

Davis, S. N. and Hall, F. R., 1959, Water quality of eastern Stanislaus and northern Merced Counties, California: Stanford University Publications in Geological Sciences 6, p. 1-112.

Flint, R. F., 1957, Glacial and Pleistocene geology: New York, John Wiley & Sons, 553 p.

Flint, R. F., 1971, Glacial and Quaternary geology: New York, John Wiley & Sons, 892 p.

Flint, R. F. and Moore, R. C., 1948, Definition and adoption of the terms stage and age: American Association of Petroleum Geologists Bulletin, v. 32, p. 372-375.

Frye, J. C. and Richmond, G. M., 1958, Problems in applying standard stratigraphic practice in nonmarine Quaternary deposits: American Association of Petroleum Geologists Bulletin, v. 42, p. 1979-1983.

Frye, J. C. and Willman, H. B., 1962, Morphostratigraphic units in Pleistocene stratigraphy: American Association of Petroleum Geologists Bulletin, v. 46, p. 112-113.

Frye, J. C., Willman, H. B., Rubin, M., and Black, R. F., 1968, Definition of Wisconsinan Stage: U.S. Geological Survey Bulletin 1274-E, 22 p.

Gilbert, G. K., 1877, Geology of the Henry Mountains: U. S. Geographical and Geological Survey of the Rocky Mountain Region, 160 p.

Gilbert, G. K., 1890, Lake Bonneville: U. S. Geological Survey Monograph 1, 438 p.

Grant, D. R., 1977, Altitudinal weathering zones and glacial limits in western Newfoundland, with particular reference to Gros Morne National Park: Geological Survey of Canada Paper 77-1A, p. 455-463.

Hamilton, T. D., and Porter, S. C., 1975, Itkillik glaciation in the Brooks Range, northern Alaska: Quaternary Research, v. 5, p. 471-479.

Hanson, W. R., 1955, Geologic map of the Flaming Gorge quadrangle, Utah-Wyoming: U. S. Geological Survey Geologic Quadrangle Map GQ-75.

Hawley, J. W., Bachman, G. O., and Manley, K., 1976, Quaternary stratigraphy in the Basin and Range and Great Plains provinces, New Mexico and western Texas, in Mahaney, W. C., ed., Quaternary stratigraphy of North America, Dowden, Stroudsburg, Pennsylvania, Hutchinson & Ross, p. 235-272.

Hayden, F. V., 1877, Geological atlas of Colorado: U. S. Geological Survey of the Territories.

Hayden, F. V., Holmes, W. H., Peale, A. C., St. John, O., Endlich, F. M., and Leffman, H., 1883, Geologic map of portions of Wyoming, Idaho, and Utah: U. S. Geological Survey of the Territories 12th Annual Report, Pl. 2.

Hedberg, H. D., 1951, Nature of time-stratigraphic units and geologic-time units: American Association of Petroleum Geologists Bulletin, v. 35, p. 1077-1081.

Hedberg, H. D., 1952, Nature, usage, and nomenclature of time-stratigraphic and geologic time units: American Association of Petroleum Geologists Bulletin, v. 35, p. 1627-1638.

Hedberg, H. D. and others, 1976, International Stratigraphic Guide: New York, John Wiley & Sons, 200 p.

Hopkins, D. M., 1973, Sea level history in Beringia during the past 250,000 years: Quaternary Research, v. 3, p. 520-540.

Hopkins, D. M., MacNeil, F. S., Merklin, R. L., and Petrov, O. M., 1965, Quaternary correlations across the Bearing Strait: Science, v. 147, p. 1107-1114.

Horn, R. V., 1979, The Holocene Ridgeland Formation and associated Decker Soil (new names) near Great Salt Lake, Utah: U. S. Geological Survey Bulletin 1457-C, p. 1-11.

Hunt, C. B., Averitt, P., and Miller, R. L., 1953a, Geology and geography of the Henry Mountains region, Utah: U. S. Geological Survey Professional Paper 288, 234p.

Hunt, C. B., Varnes, H. D., and Thomas, H. E., 1953b, Lake Bonneville--geology of northern Utah Valley, Utah: U. S. Geological Survey Professional Paper 256-A, p. 1-99.

Jahns, R. H., 1953, Surficial geology of the Ayer quadrangle, Massachusetts: U. S. Geological Survey, Geologic Quadrangle Map GQ-21.

Jahns, R. H., 1966, Surficial geologic map of the Greenfield quadrangle, Franklin County, Massachusetts: U. S. Geological Survey, Geologic Quadrangle Map GQ-474.

Kay, G. F., 1931, Classification and duration of the Pleistocene period: Geological Society of America Bulletin, v. 42, p. 425-466.

Kay, G. F. and Leighton, M. M., 1933, Eldoran epoch of the Pleistocene period: Geological Society of America Bulletin, v. 44, p. 669-674.

Koteff, C., 1970, Surficial geologic map of the Milford quadrangle, Hillsborough County, New Hampshire: U. S. Geological Survey, Geologic Quadrangle Map GQ-881.

Koteff, C., 1974, The morphologic sequence concept and deglaciation of southern New England: in Coates, D. R., ed., Glacial geomorphology: Binghamtom, State University of New York, p. 121-144.

Koteff, C., 1976, Surficial geologic map of the Nashua North quadrangle, Hillsborough and Rockingham Counties, New Hampshire: U. S. Geological Survey, Geologic Quadrangle Map GQ-1290.

Koteff, C. and Pessl, F. Jr., 1981, Systematic ice retreat in New England: U. S. Geological Survey Professional Paper 1179, 20 p.

Krumbein, W. C. and Sloss, L. L., 1961, Stratigraphy and sedimentation: W. H. Freeman, San Francisco, 660 p.

Leighton, M. M., 1958, Principles and viewpoints in formulating the stratigraphic classification of the Pleistocene: Journal of Geology, v. 66, p. 700-709.

Leighton, M. M., 1960, The classification of the Wisconsin glacial stage of the north-central United States: Journal of Geology, v. 68, p. 529-552.

Leverett, F., 1899, The Illinois glacial lobe: U. S. Geological Survey Monograph 38, 817 p.

Leverett, F., 1902, Glacial formations and drainage features of the Erie and Ohio basins: U. S. Geological Survey Monograph 41, 802 p.

Leverett, F., 1929, Moraines and shore lines of the Lake Superior basin: U. S. Geological Survey Professional Paper 154-A, p. 1-72.

Lohman, K. E. and others, 1963, Function and jurisdictional scope of the American Commission on Stratigraphic Nomenclature: American Association of Petroleum Geologists Bulletin, v. 47, p. 853-855.
Mackin, J. H., 1937, Erosional history of the Bighorn Basin, Wyoming: Geological Society of America Bulletin, v. 48, p. 813-893.
Malde, H. E., 1953, Surficial geology of the Louisville quadrangle, Colorado: U.S. Geological Survey Bulletin 996-E, p. 217-257.
Marchand, D. E. and Allwardt, 1981, Late Cenozoic stratigraphic units, northeastern San Joaquin Valley, California: U. S. Geological Survey Bulletin 1470, 70 p.
Matthes, F. E., 1930, Geologic history of the Yosemite Valley: U. S. Geological Survey Professional Paper 160, 137 p.
Maxon, J. H., 1933, Economic geology of portions of Del Norte and Siskiyou Counties, northwesternmost California: California Journal of Mines and Geology, v 29, p. 123-160.
Mayewski, P. A., 1975, Glacial geology and late Cenozoic history of the Trans-Antarctica Mountains, Antarctica: The Ohio State University, Institute of Polar Studies, Report 56.
Mercer, J. H., 1976, Glacial history of southernmost South America: Quaternary Research, v. 6, p. 125-166.
Moore, R. C., 1947, Nature and classes of stratigraphic units: American Association of Petroleum Geologissts Bulletin, v. 31, p. 519-528.
Morrison, R. B., 1965, Quaternary stratigraphy of eastern Jordan Valley, south of Salt Lake City, Utah: U. S. Geological Survey Professional Paper 477, 80 p.
Moss, J. H., 1974, The relation of river terrace formation to glaciation in the Shoshone River basin, western Wyoming: in Coates, D. R., ed., Glacial geomorphology: State University of New York, Binghamton, p. 293-314.
Nelson, A. R. and Locke, W. M., III, 1981, Quaternary stratigraphic usage in North America: a brief survey: Geology, v. 9, p. 134-137.
Nelson, A. R., Millington, A. C., Andrews, J. T., and Nicols, H., 1979, Radiocarbon-dated upper Pleistocene glacial sequence, Fraser valley, Colorado Front Range: Geology, v. 7, p. 410-414.
North American Commission on Stratigraphic Nomenclature (NACSN), 1981, Draft North American Stratigraphic Code: unpublished printing distributed by Canadian Society of Petroleum Geologists, Calgary, Alberta.
Pheasant, D. R. and Andrews, J. T., 1973, Wisconsin glacial chronology and relative sea level movements, Narpaing , western Wyoming: in Coates, D. R., ed., Glacial geomorphology: Binghamton, State University of New York, p. 293-314.
Pierce, K. L., Obradovich, J. D., and Friedman, I., 1976, Obsidian-hydration dating and correlation of Bull Lake and Pinedale Glaciations near West Yellowstone, Montana: Geological Society of America Bulletin, v. 87, p. 703-710.
Piper, A. M., Gale, H. S., Thomas, H. E., and Robinson, T. W., 1939, Geology and ground-water hydrology of the Mokelumne area, California: U. S. Geological Survey, Water-Supply Paper 780, 230 p.
Porter, S. C., 1970, Quaternary glacial record in Swat Kohistan, West Pakistan: Geological Society America Bulletin, v. 81, p. 1431-1446.
Porter, S. C., 1976, Pleistocene glaciation in the southern part of the North Cascade Range, Washington: Geological Society of America Bulletin v. 87, p. 61-75.
Porter, S. C., 1979, Quaternary stratigraphy and chronology of Mauna Kea, Hawaii--a 380,000-yr record of mid-Pacific volcanism and ice-cap glaciation (summary): Geological Society of America Bulletin, v. 90, Part I, p. 609-611.

Powell, J. W., 1888, Methods of geologic cartography in use by the United States Geological Survey: Third International Geological Congress, 1885, Compte Rendu, p. 221-240.
Powell, J. W., 1890, Conference on map publication. U. S. Geological Survey Tenth Annual Report, Part I, p. 56-79.
Renevier, E., 1901, Commission Internationale de Classification Stratigraphique: Eighth International Geological Congress, 1900, Compte Rendu, p. 192-203.
Richards, H. G., 1965, Pleistocene stratigraphy of the Atlantic coastal plain: in Wright, H. E., Jr. and Frey, D. G., eds., The Quaternary of the United States, Princeton, Princeton University Press, p. 129-133.
Richmond, G. M., 1960, Glaciation of the east slope of Rocky Mountain National Park, Colorado: Geological Society of America Bulletin, v. 71, p. 1371-1382.
Richmond, G. M., 1962a, Quaternary stratigraphy of the La Sal Mountains, Utah: U. S. Geological Survey Professional Paper 324, 135 p.
Richmond, G. M., 1962b, Morphostratigraphic units in Pleistocene stratigraphy: American Association of Petroleum Geologists Bulletin, v. 46, p. 1520-1521.
Richmond, G. M. and Fyles, J. G., 1964, Amendment of Article 31, Remark (b) of the Code of Stratigraphic Nomenclature on misuse of the term "stage": American Association of Petroleum Geologists Bulletin, v. 48, p. 710-711.
Richmond, G. M. and Waldrop, H. A., 1972, Surficial geologic map of the Pelican Cone quadrangle, Yellowstone National Park and adjoining area, Wyoming: U. S. Geological Survey Miscellaneous Geologic Investigations Map MI-638.
Richmond, G. M. and others, 1959, Application of stratigraphic classification and nomenclature to the Quaternary: American Association of Petroleum Geologists Bulletin, v. 43, Pt. I, p. 663-675.
Ritter, D. F., 1967, Terrace development along the front of the Beartooth Mountains, southern Montana: Geological Society of America Bulletin, v. 78, p. 467-484.
Rodgers, John, 1948, Discussion of nature and classes of stratigraphic units: American Association of Petroleum Geologists Bulletin, v. 32, p. 376-378.
Rodgers, John, 1954, Nature, usage, and nomenclature of stratigraphic units: a minority report: American Association of Petroleum Geologists Bulletin, v. 38, p. 655-659.
Rohrer, W. L., 1964, Geology of the Tatman Mountain quadrangle, Wyoming: U. S. Geological Survey Geologic Quadrangle Map GQ-311.
Rohrer, W. L. and Leopold, E. B., 1963, Fenton Pass Formation (Pleistocene?) Bighorn Basin, Wyoming: U. S. Geological Survey Professional Paper 475-C, p. 45-48.
Rubey, W. W., 1948, Discussion of nature and classes of stratigraphic units: American Association of Petroleum Geologists Bulletin, v. 32, p. 378-380.
Rutter, N. W., 1972, Geomorphology and multiple glaciation in the area of Banff, Alberta: Geological Survey of Canada Bulletin 206, 54 p.
Salisbury, R. D., 1906a, Glacial geology of Bald Mountain-Dayton Folio: U. S. Geological Survey, Geologic Atlas of the United States 141.
Salisbury, R. D., 1906b, Glacial geology of Cloud Peak-Fort McKinney Folio: U. S. Geological Survey, Geologic Atlas of the United States 142.
Schenck, H. G., and Muller, S. W., 1941, Stratigraphic terminology: Geological Society of America Bulletin, v. 52, p. 1419-1426.

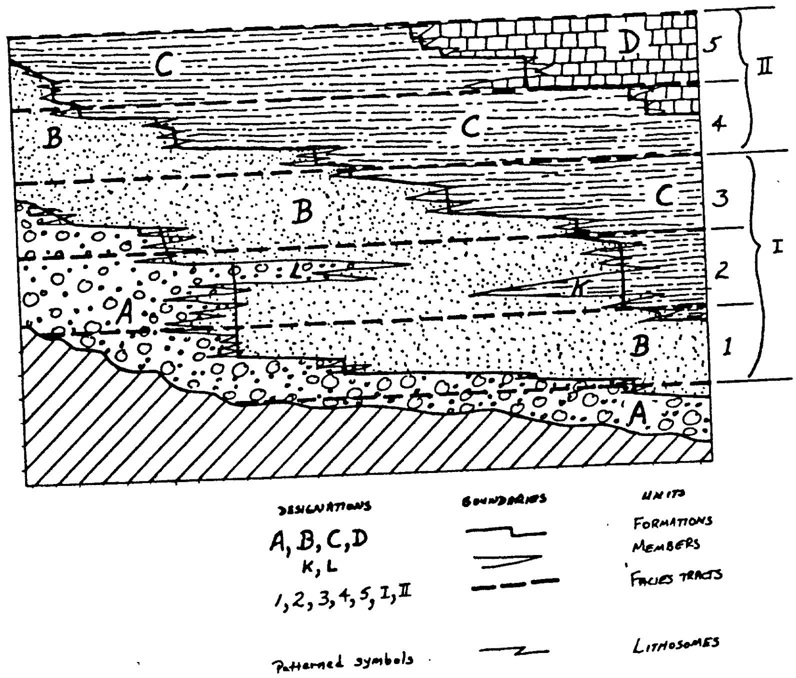
Schmidt, D. L. and Mackin, J. H., 1970, Quaternary geology of Long and Bear Valleys, west-central Idaho: U. S. Geological Survey Bulletin 1311-A, 22 p.
Scott, W. E., 1977, Quaternary glaciation and volcanism, Metolius River area, Oregon: Geological Society of America Bulletin, v. 88, p. 113-124.
Shafer, J. P., 1965, Surficial geologic map of the Watch Hill quadrangle, Rhode Island-Connecticut: U. S. Geological Survey Geologic Quadrangle Map GQ-410.
Shafer, J. P., 1968, Surficial geologic map of the Ashway quadrangle, Connecticut-Rhode Island: U. S. Geological Survey Geologic Quadrangle Map GQ-712.
Sharp, R. P., 1938, Pleistocene glaciation in the Ruby-East Humboldt Range, northeastern Nevada: Journal of Geomorphology, v. 1, p. 296-323.
Sharp, R. P., 1960, Pleistocene glaciation in the Trinity Alps of northern California: American Journal of Science, v. 258, p. 305-340.
Sharp, R. P., 1969, Semiquantitative differentiation of glacial moraines near Convict Lake, Sierra Nevada: Journal of Geology, v. 77, p. 68-91.
Sharp, R. P., 1972, Pleistocene glaciation, Bridgeport basin, California: Geological Society of America Bulletin, v. 83, p. 2233-2260.
Sharp, R. P. and Birman, J. H., 1963, Additions to classical sequence of Pleistocene glaciations, Sierra Nevada, California: Geological Society of America Bulletin, v. 74, p. 1079-1086.
Skipp, B. and Peterson, A. D., 1965, Geologic map of the Maudlow quadrangle, southwestern Montana: U. S. Geological Survey, Miscellaneous Geologic Investigations Map MI-452.
Soward, K. S., 1975, Geologic map of the Rock Reef quadrangle, Cascade County, Montana: U. S. Geological Survey Geologic Quadrangle GQ-1240.
Suggate R. P., 1965, Late Pleistocene geology of the northern part of the South Island, New Zealand: New Zealand Geological Survey Bulletin 77, 91 p.
Teichert, Curt, 1958, Concepts of facies: American Association of Petroleum Geologists Bulletin, v. 42, p. 2718-2744.
Waitt, R. B., Jr., 1979, Late Cenozoic deposits, landforms, stratigraphy, and tectonism in Kittitas Valley, Washington: U. S. Geological Survey Professional Paper 1127, 18 p.
Waitt, R. B., Jr., in press, Surficial deposits and geomorphology, in Tabor, R. W. and others, Geologic Map of the Wenatchee 1:100,000 quadrangle, Washington: U. S. Geological Survey Miscellaneous Field Investigations Map MF-1311.
Wheeler, H. E., 1958, Time stratigraphy: American Association of Petroleum Geologists Bulletin, v. 42, p. 1047-1063.
Wheeler, H. E., Scott, W. F., Bayne, G. W., Steele, G., and Mason, J. W., 1950, Stratigraphic classification: American Association of Petroleum Geologists Bulletin, v. 34, p. 2361-2365.
Williams, H. S., 1894, Dual nomenclature in geological classification: Journal of Geology, v. 2, p. 145-160.
Willis, B., 1901, Individuals of stratigraphic classification: Journal of Geology, v. 9, p. 557-569.
Willman, H. B. and Frye, J. C., 1970, Pleistocene stratigraphy of Illinois: Illinois Geological Survey Bulletin 94, 204 p.
Woodring, W. P., 1953, Stratigraphic classification and nomenclature: American Association of Petroleum Geologists Bulletin, v. 37, p. 1081-1083.

FIGURE CAPTION

Figure 1. (A) Lithostratigraphic and chronostratigraphic units in a conformable stratified-rock sequence.

(B) Schematic cross section of moraine and outwash sequences in an alpine valley, showing relation of para-chronogeographic units to hypothetical lithostratigraphic units.

(A)


C
D
5
II
4
B
3
I
2
1
A
K
L
DESIGNATIONS
BOUNDARIES
UNITS
A, B, C, D
FORMATIONS
K, L
MEMBERS
1, 2, 3, 4, 5, I, II
FACIES TRACTS
Patterned symbols
LITHOSOMES

(B)

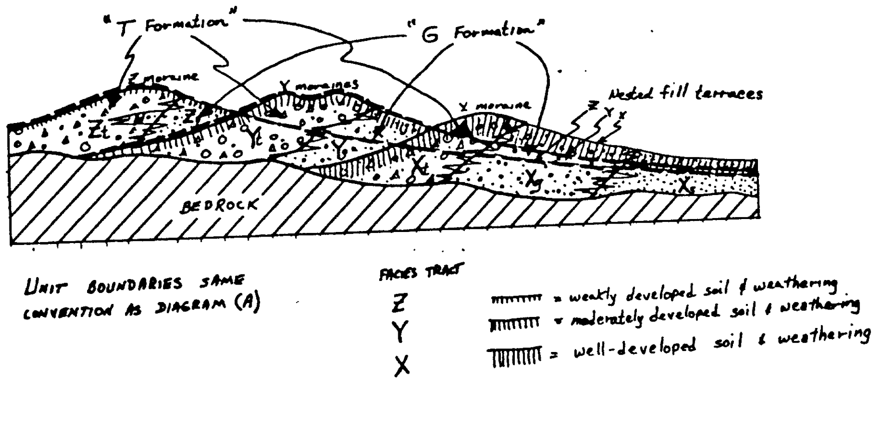

"T Formation"
"G Formation"
Z moraine
Y moraines
X moraine
Nested fill terraces
BEDROCK
UNIT BOUNDARIES SAME CONVENTION AS DIAGRAM (A)
FACIES TRACT
Z
Y
X
= weakly developed soil & weathering
= moderately developed soil & weathering
= well-developed soil & weathering

FIGURE 1

Table 1.--Nomenclature for glacial deposits (surface defined)

	Non-material	Material	Non-material		Material					
Stage rank	Stage	Glacial stage (drift)	referred to Glaciation	referred to Glaciation	Drift or Till	Drift	Drift	Formation	Drift	Moraines
Substage rank	Substage	(Substage)	referred to Stade	referred to advance		moraines or sediment	(Member)	(Member)	phase	-----
Examples:	Leverett, 1899, 1929 Salisbury, 1906a, 1906b Atwood and Mather, 1932 Matthes, 1930	Blackwelder, 1931 Kay, 1931 Leighton, 1960 Sharp, 1960 Porter, 1979	Richmond, 1960 Richmond and Waldrop, 1972 Crandell and Millar, 1974 Pierce et al., 1976 Sharp 1969, 1972	Rutter, 1972 Nelson _et al._, 1979 Luckman and Osborn, 1979	Richmond, 1964 Crandell, 1972	Hamilton and Porter, 1975 Crandell, 1967	Porter, 1970 Porter, 1976	Richmond, 1962a Suggate, 1965 Scott, 1977	Waitt, 1979	Mayewski 1975 Mercer, 1976

Table 2.--Proposed units and hierarchal relation to existing units of Code

Existing		Proposed		Existing		
Non-material	Material				Non-material	Material
Climate-stratigraphic (regional)	Lithostratigraphic (local-regional)	Glacial Para-chronogeographic (local-regional)	Non-glacial Para-chronostratigraphic (regional)	Chronostratigraphic (inter-regional)	Geologic time (global)	Soil-Stratigraphic
Glaciation (Interglaciation)	Formation	Drift *	glacial or alluvial or marine or pluvial Set *	Stage	Epoch	Soil
Stade and Interstade	Member	Subdrift *	glacial or alluvial or marine or pluvial Subset *		Age	

* Expanded classification including units for nonglacial deposits shown on Table 3 and Table 4.

Table 3.--Proposed hierarchal nomenclature for local to subregional surficial para-chronogeographic units

Rank	Environment	
	Glacial	Alluvial, Marine, or Pluvial
Set	Drift	Terrace alluvium
Subset	Subdrift	Terrace suballuvium
Sub-subset	Moraine or Terrace or Sequence	Terrace

Table 4.--Proposed hierarchal nomenclature for regional para-chronostratigraphic units

Rank	Environment				
	Alpine glacial	Ice sheet	Alluvial	Marine shoreline	Fluvial shoreline
Superset	Glacial Superset	Glacial Superset	Alluvial Superset	Marine Superset	Fluvial Superset
Set	Glacial Set	Glacial Set	Alluvial Set	Marine Set	Fluvial Set
Subset	Glacial Subset	Glacial Subset	Alluvial Subset	Marine Subset	Fluvial Subset

Table 5.--*Hypothetical application of proposed nomenclatural system, showing relation of local, regional, continental, and global units.*

D	A	A	A	B	B	C	B	A		A		A		A		A		A		A		A		B	C	D
GLOBAL CHRONOSTRAT.	← LOCAL PARA-CHRONOSTRATIGRAPHIC UNITS →			REGIONAL PARA-CHRONOSTRAT.	REGIONAL PARA-CHRONOSTRAT.	CONTINENTAL CHRONOSTRAT.	REGIONAL PARA-CHRONOSTRAT.	← LOCAL PARA-CHRONOGEOGRAPHIC UNITS →																REGIONAL PARA-CHRONOSTRAT.	CONTINENTAL CHRONOSTRAT.	GLOBAL CHRONOSTRAT.
	Greybull valley Wyo.	Shoshone Valley, Wyo.	Rock Cr. Wyo.	Bighorn Basin Wyoming	Rocky Mountains	North America	Eastern Cascade Range	Mount Rainier WA		Yakima Valley WA		Wenatchee Valley WA		Wallowa Mountains OR		Metolius R. OR		Trinity Alps CA		No. Sierra Nevada CA		So. Sierra Nevada CA		Eastern Sierra Nevada	North America	
	TERRACE ALLUV.	TERRACE ALLUV.	TERRACE ALLUV.	Alluvial Set	Glacial Set	Stage	Glacial Set	Drift	Subdrift	Drift	Subdrift	Drift	Subdrift	Drift	Subdrift	Drift	Subdrift	Drift	Subdrift	Drift	Subdrift	Drift	Subdrift	Glacial Set	Stage	Isotope Stage
Pleistocene		C	Re	Cody	Pinedale	Wisconsinan	Lakedale	E		L	H [illegible] B	L	5 4 3 [illegible]		W T	C	C S		M R A	T		Ti	H Ta Ti	Tioga	Wisconsinan	II IV
						Sangamonian																			Sangamonian	5
Series	E	P	B	Powell	Bull Lake	Illinoian	Kittitas	H		K	I S	P		J		J		S		D		Ta		Tahoe	Illinoian	VI
			Ro																			M				
	Y	K	M	Mesa		Kansan	Lookout Mountain	W		LM		B		C		A				H		S		Sherwin	Kansan	
Pliocene? Series?	T			Tatman																		M		McGee		
Miocene Series							Thorp (Alluvial Set)			T (terrace alluv.)																