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TERMINOLOGY FOR STRATIFICATION AND CROSS-STRATIFICATION IN SEDIMENTARY ROCK*

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TERMINOLOGY FOR STRATIFICATION AND CROSS-STRATIFICATION IN SEDIMENTARY ROCKS

By Edwin D. McKee [1] and Gordon W. Weir [2]

ABSTRACT

A terminology is suggested for stratified and cross-stratified rock units that will aid the field geologist in describing these structures. Qualitative terms, describing the character of rock layering, are stratification, stratum, cross-stratification, cross-stratum, set, co-set, and composite-set. Quantitative terms, applying to the thickness of stratification, are very thick-bedded, thick-bedded, thin-bedded, very thin-bedded, laminated, and thinly laminated. Quantitative terms, applying to the thickness of splitting units, are massive, blocky, slabby, flaggy, shaly, platy, and papery.

A classification of cross-stratification based primarily on the character of the lower bounding surface of a set of cross-strata is suggested. Features of secondary importance in this classification are the shape of set of cross-strata, the attitude of the axis, the symmetry of the cross-strata with respect to the axis, the arching of the cross-strata, the dip of the cross-strata, and the length of individual cross-strata.

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INTRODUCTION

Stratification is layering in rocks; it is the most common and characteristic structure of most sedimentary rocks. Stratification differs widely in form and size. A large vocabulary with which to describe these differences has developed. Many terms applicable to stratification have been used in different senses by different authors. A vagueness, overlapping, and confusion of terms has resulted.

The purpose of this paper is to present a classification and a terminology of stratification that will aid the field geologist to describe easily and exactly differences in the primary structure. To review the historical development of the terminology of stratification and the many terms and definitions that have been proposed would unduly lengthen this paper. Even a casual reading of current descriptive and reference literature, however, reveals many terms with several definitions.

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A clear distinction should be made between three basically different groups of terms: first, qualitative terms such as stratification, cross-stratification, stratum, and cross-stratum that are concerned with the attitude and relation of rock layers without regard to scale; second, quantitative terms such as thick-bedded, thin-bedded, and laminated that are concerned with the thickness of stratification; and, third, quanitative

terms such as massive, slabby, and flaggy that are concerned with the thickness of splitting within stratified units. Thickness of layering and thickness of splitting may differ greatly; terms applying to these two properties should not be used interchangeably.

TERMINOLOGY OF STRATIFICATION

General

The need for adequate terms in describing and comparing in detail varieties of stratification and cross-stratification is apparent to any geologist who has attempted to analyze these structures. The terms proposed in this paper are based on structures represented in formations that have been examined in the field.

Qualitative terms

For an understanding of the relation between the qualitative terms presented below, reference to Table 1 and to Figure 1 is recommended.

Stratification is the general term for layering in rocks. By definition it refers both to the process of stratifying and the state of being stratified, but in this paper it is used in the latter sense only. No implication is made concerning the thickness of the individual layers involved. The adjective stratified is applicable to any layered sedimentary rock.

A stratum is a single layer of homogeneous or gradational lithology deposited parallel to the original dip of the formation and separated from adjacent strata or cross-strata by surfaces of erosion, non-deposition, or abrupt change in character. Stratum is not synonymous with the terms bed or lamination but includes both. These terms carry definite thickness connotations as explained in the next section of this paper.

Cross-stratification is the arrangement of layers at one or more angles to the original dip of the formation. A cross-stratified unit is one with layers deposited at an angle to the original dip of the formation. "Cross-bedding" and "cross-lamination" have been used by many authors as synonymous with cross-stratification, but it is here proposed to restrict the terms cross-bedding and cross-lamination to a quantitative meaning depending on the thickness of the individual layers, or cross-strata (Tab. 2).

A cross-stratum is a single layer of homogeneous or gradational lithology deposited at an angle to the original dip of the formation and separated from adjacent layers by surfaces of erosion, non-deposition, or abrupt change in character (Fig. 1; Table 1). "Cross-bed" and "cross-lamina" have been used as synonyms for cross-stratum, defined above, but, as proposed in this paper, they should be restricted to a quantitative meaning. A cross-bed is greater than 1 cm in thickness and a cross-lamina less (Table 2).

A set is a group of essentially conformable strata or cross-strata, separated from other sedimentary units by surfaces of erosions, non-deposition, or abrupt change in character (Fig. 1). It is the smallest and most basic group unit. The term "cross-bed" has been used in this sense by some authors, but, as here proposed, this term should apply to a single cross-stratum and should be restricted to a quantitative meaning based on the thickness of the cross-stratum (Table 2).

In some deposits, two or more minor sets (or subsets) of cross-strata occur within a larger more prominent set. The minor sets may be due to slight variations in direction or capacity of transporting agent filling a single scour depression or to oversteepening and cascading on the lee side of a sand dune. No formal name is hereby proposed for such minor sets, but their occurrence is recognized.

Table 1. - Relationship between qualitatives* terms for stratification

	Horizontally stratified	Cross-stratified
Basic unit; single layer	Stratum	Cross-stratum
Group of strata (or cross-strata) in conformable series	Set (of strata)	Set** (of cross-strata)
Layer composed of two or more sets		Co-set
Layer compounded from strata and cross-strata		Composite-set

* No size or thickness connotation is intrinsic in these terms.

** Minor sets of cross-strata, within larger sets, are present in some formations due to slight depositional changes as in degree or direction of dip. No name is here proposed for such variations.

Table 2. - Comparison of quantitative terms used in describing layered rocks.

Cm = .3937 inch

Stratification		Cross-Stratification		Thickness	Splitting Property
Very thick-bedded	"Beds"	Very thickly cross-bedded	"Cross-beds"	Greater than 120 cm	Massive
Thick-bedded		Thickly cross-bedded		120 cm (about 4 ft.) to	Blocky
Thin-bedded		Thinly cross-bedded		60 cm (about 2 ft.) to	Slabby
Very thin-bedded		Very thinly cross-bedded		5 cm (about 2 in.) to	Flaggy
Laminated	"Laminae"	Cross-laminated	"Cross-laminae"	1 cm (about 1/2 in.) to	Shaly (claystone, siltstone) Platy (sandstone, limestone)
Thinly laminated		Thinly cross-laminated		2 mm (paper thin) or less	Papery

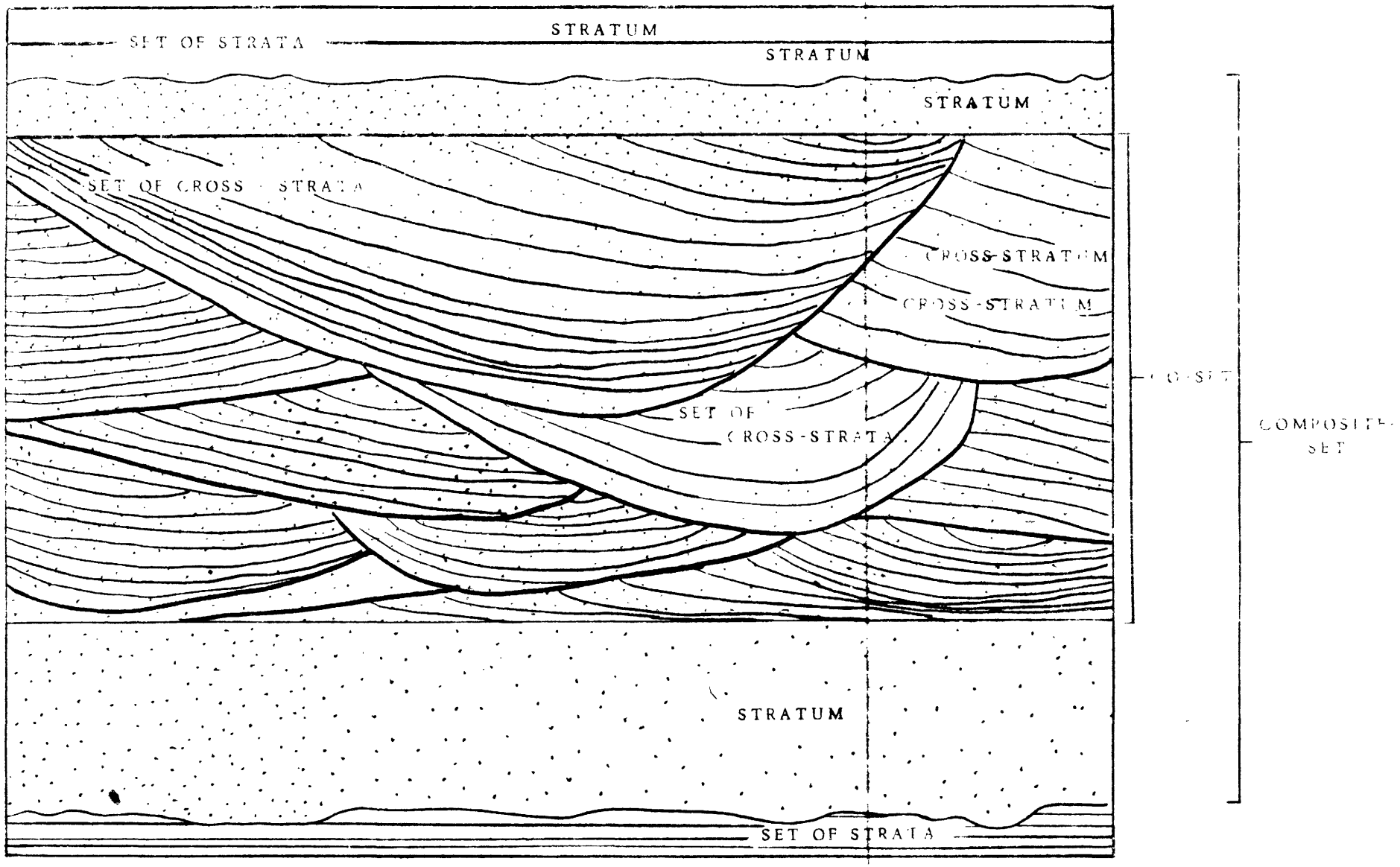


Figure 1. - Terminology of stratified and cross-stratified units

The term co-set is proposed for a sedimentary unit made up of two or more sets of cross-strata, separated from other strata or cross strata by original flat surfaces of erosion, non-deposition, or abrupt change in character (Fig.1).

The term composite-set is proposed for large sedimentary units that are compounded from both stratified and cross-stratified units. Thus, a composite-set is a sedimentary unit having similar or gradational lithology and consisting of horizontal strata together with co-set of cross-strata (Fig. 1; Table 1).

Quantitative terms

Bedding and lamination, as defined in this paper, are terms denoting the thickness of strata. The terms bed and bedding may be applied to any stratum or stratification of thickness greater than 1 cm; lamina and lamination may be applied to any stratum or stratification 1 cm or less in thickness. Similarly, cross-bed and cross-bedding may be applied to any cross-stratum or cross-stratification of thickness greater than 1 cm; cross-lamina and cross-lamination may be applied to any cross-stratum or cross-stratification 1 cm or less in thickness (Table 2).

As adjectives with specific limits it is suggested that very thick-bedded be applied to strata greater than 120 cm thick, thick-bedded to strata 60 to 120 cm (or about 2 to 4 feet) thick, thin-bedded to strata 5 to 60 cm (or about 2 inches to 2 feet) thick, very thin-bedded to strata 1 to 5 cm (or about 1/2 inch to 2 inches) thick, laminated to strata 2 mm to 1 cm thick, and thinly laminated to strata 2 mm thick or less -- that is, paper-thin.

As pointed out previously, "bedding" and "lamination" should not be confused with terms pertaining to the property of splitting. Terms describing splitting properties are not discussed in this paper, but Table 2 compares the quantitative terms proposed for stratification with those that may be used to describe the splitting properties.

CLASSIFICATION OF STRATIFIED UNITS

General

A proposed classification of stratified units is presented in Table 3. This table is essentially an outline for describing strata. Except for dimensional and directional measurements, all important elements of stratification are indicated in it. A summary of its essential features follows.

The lower surface of the stratified unit (stratum, set, or co-set, depending upon the unit being considered) is either erosional or non-erosional and this feature determines whether sedimentation was effectively continous or discontinuous.

The apparent shape of the stratification unit is of next importance. "Lenticular," "wedge-shaped," and "tabular" are, of course, only qualitative terms, inasmuch as all sedimentary units are somewhat lenticular. "Irregular" refers especially to such sedimentary masses as bioherms.

Table 3. - General classification of stratified units

Character of lower surface of stratification unit	Apparent shape of stratification unit	Internal (primary) structure of stratification unit
1. Erosional	1. Lenticular	1. Structureless
	2. Wedge-shaped	2. Irregular
2. Non-erosional	3. Tabular	3. Contorted */
	4. Irregular	4. Ripple-laminated **/
		5. Horizontally stratified
		6. Cross-stratified

*/ See Fairbridge (1946)
**/ See McKee, E. D. (1939)

The nature of the internal structure of the stratification unit is a third major division in the classification. It includes (1) structureless units, (2) irregular strata such as many reef types, (3) contorted beds due to slumping or pre-consolidation deformation, (4) ripple lamination, (5) horizontal stratification, and (6) cross-stratification. Most of these internal, primary structures have been thoroughly described and evaluated in the recent literature (Fairbridge, 1946; McKee, 1939); a notable exception is cross-stratification.

Although not included in Table 3, dimensional and directional measurements are part of a complete and thorough description of stratified units. Thickness and, in some places, lateral extent of a stratum may be measured. If lenticularity is apparent, it may be practicable to determine the trends of the lines of convergence and of the line of maximum thickness of the stratum. Similarly, it may be practicable to determine the preferred orientation, where present, of internal structures. Measurement of such trends may help define the direction of deposition.

Cross-stratification

The lack of an adequate classification and terminology for cross-stratification has been a serious handicap in detailed studies of this structure. The requirements for an adequate classification are (1) that it be inclusive, (2) that it make a clear distinction between types, and (3) that it be easy to apply in field study.

Descriptive terms most commonly applied to cross-stratification units are "angular" and "tangential." "Torrential" and "regular" have been used as synonymous with "angular." Angular, torrential, and regular are terms applied to cross-strata that appear in section as nearly straight lines meeting the underlying surface at high angles. The term "tangential,"

on the other hand, is applied to cross-strata that appear in section as smooth arcs meeting the underlying surface at low angles. "Angular" cross-stratification, as used, generally implies deposition by water; "tangential" cross-stratification, as used, generally implies deposition by wind. This supposed relationship between genesis and angular or torrential type is not substantiated by experimental studies or by observations of structures in modern deposits.

Attempts have been made to classify cross-stratification according to manner of deposition. Such a classification is seldom all-inclusive, but the fundamental difficulty is that few criteria are known by which the mode of formation of cross-stratification can be determined. For example, cross-stratification of dunes and sand bars may be similar. Perhaps after a thorough study of cross-stratification in modern sediments and older rocks, a feasible genetic classification may be developed. In the present state of knowledge the most workable classification is one that is purely descriptive.

The classification presented here is a modification of one suggested by McKee (1948) and illustrated in part by Kiersch (1950). Nomenclature is based on physical characteristics rather than on genesis. The classification is presented in Table 4 and Figure 2. Pseudo-cross-stratification and variations in horizontal stratification are not included in this classification.

The classification is based on (1) the character of the lower bounding surface of the set of cross-strata, (2) the shape of the set of cross-strata, (3) the attitude of the axis of the set of cross-strata, (4) the symmetry of the cross-strata about this axis, (5) the arching of the cross-strata, (6) the dip of the cross-strata, and (7) the length of individual cross-strata.

According to this outline there are three major types of cross-stratification, depending upon the character of the lower bounding surface of the set of cross-strata. For ease of reference, each of these major types is assigned a name. (1) Any set of cross-strata whose lower bounding surface is not a surface of erosion but one of non-deposition or change in character is here called a simple set of cross-strata. It is formed by deposition alone. (2) Any set of cross-strata whose lower bounding surface is a planar surface of erosion is here called a planar set of cross-strata. It results from beveling and subsequent deposition. (3) Any set of cross-strata whose lower bounding surface is a curved surface of erosion is here called a trough set of cross-strata. It results from channeling and subsequent deposition (Fig. 2). Thus, the basic criterion that determines the type of cross-stratification is the character of the lower bounding surface of the set of cross-strata -- whether this surface is erosional or not, and, if erosional, whether it is plane or curved.

The term "festoon," first applied by Knight (1929) to sandstones of the Casper formation in Wyoming, is a variety of trough cross-stratification. This type consists essentially of elongate semi-ellipsoidal troughs that crosscut each other so that only portions of each unit are preserved and, in section, a festoon-like appearance results. In this variety, cross-strata are concave upward and conform to the shapes of the troughs.

Various names other than those proposed in this paper have been used in geological literature for types of cross-stratification. Some names are considered inappropriate because they imply genesis. Examples are "torrential" and "delta" cross-stratification. Others, such as "compound," have been discarded in this paper because the name, although used for the planar type (Lahee; 1941), could apply equally well to the other two basic types and therefore is a source of confusion. If used at

all, "compound" cross-stratification should apply to a combination of the basic types.

Designation of the type of cross stratification, as described in preceding paragraphs, is dependent upon the character of the lower bounding surfaces of sets of cross-strata. There are no restrictions based on dimensions, number of imbricating units, convexity or concavity of the filling cross-strata, or agency of formation, for the determination of the basic three types.

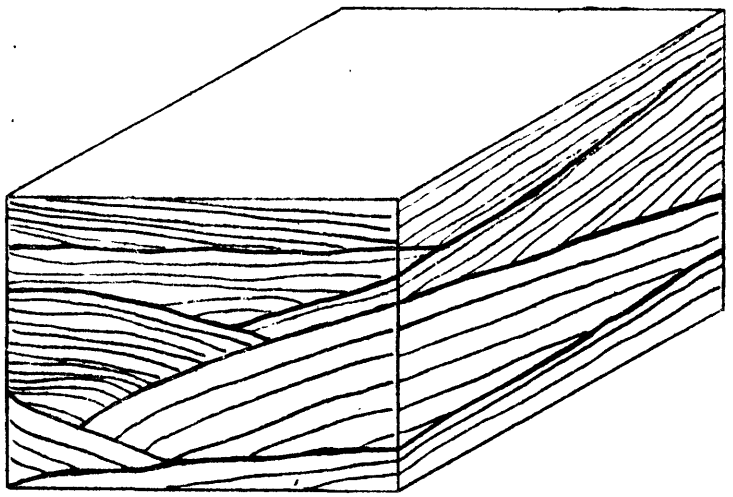
A second element considered in the proposed classification is the shape of each set of cross-strata. By "lenticular" is meant that the boundary surfaces are converging and that at least one is curved. By "wedge-shaped" is meant that the bounding surfaces are planar and converging. By "tabular" is meant that the bounding surfaces are planar and essentially parallel. In simple cross-stratification sets are generally lenticular or wedge-shaped. In planar cross-stratification sets form tabular or wedge-shaped units. In trough cross-stratification, by definition (curved surfaces of erosion) sets are always lenticular.

A set of cross-strata that is either lenticular or wedge-shaped may be further differentiated on the basis of its axis -- the trace of a line on the lower bounding surface that marks the thickest part of the set as originally deposited. The axis may be characterized as plunging or non-plunging. Also, the set of cross-strata may be characterized (1) as "symmetric" if the cross-strata correspond in size and shape on opposite sides of the axial plane, or (2) as "asymmetric" if this correspondence is lacking.

Differentiation in some types of cross-strata may also be made on the presence or absence and, if present, on the direction of curvature of

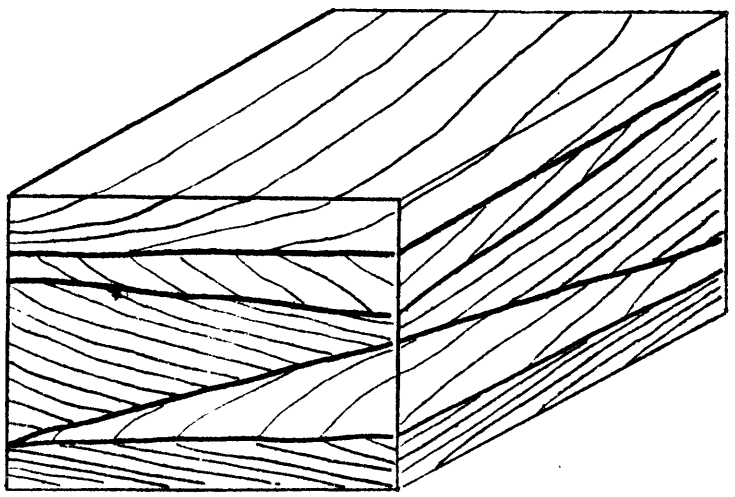
Table 4. - Classification of cross-stratified units

Character of lower boundary surface of set of cross-strata	Shape of sets of cross-strata	Attitude of axis of set of cross-strata	Symmetry of set of cross-strata	Arching of cross-strata	Dip of cross-strata	Length of cross-strata
1. Non-erosional surfaces (simple cross-stratification)	1. Lenticular	1. Plunging	1. Symmetric	1. Concave	1. High angle	1. Small scale
2. Planar surfaces of erosion (planar cross-stratification)	2. Tabular	2. Non-plunging	2. Asymmetric	2. Straight	2. Low angle	2. Medium scale
3. Curved surfaces of erosion (trough cross-stratification)	3. Wedge-shaped			3. Convex		3. Large scale



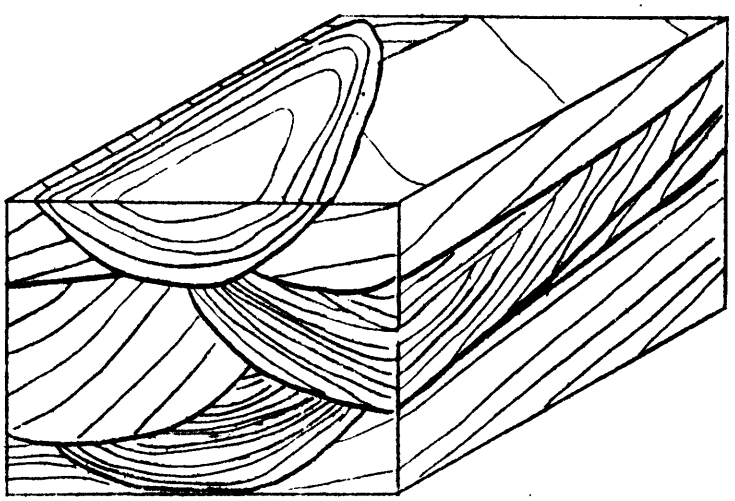
SIMPLE
CROSS-STRATIFICATION

The lower bounding surfaces of sets are non-erosional surfaces.



PLANAR
CROSS-STRATIFICATION

The lower bounding surfaces of sets are planar surfaces of erosion.



TROUGH
CROSS-STRATIFICATION

The lower bounding surfaces of sets are curved surfaces of erosion.

FIGURE 2
Basic elements of classification of cross-stratification

individual cross-strata. If the cross-strata arch upward, they are referred to as "convex"; if they arch downward, they are described as "concave." If, as rarely is the situation, the cross-strata are not arched, they are termed "straight." Concave cross-strata undoubtedly are most common and have long been used as a criterion for telling top from bottom in sedimentary rocks (Shrock, 1948, p. 251-253).

A distinction among cross-strata can be made on the basis of degree of inclination. Cross-strata having an average maximum inclination above 20 degrees may arbitrarily be considered "high angle"; cross-strata having an average maximum inclination less than 20 degrees may arbitrarily be considered "low angle."

For designating the relative magnitude of cross-stratification the following terminology is recommended:

(1) Small scale cross-stratification = cross-strata less than 12 inches in length.

(2) Medium scale cross-stratification = cross-strata 1 to 20 feet in length.

(3) Large scale cross-stratification = cross-strata more than 20 feet in length.

The purpose of this classification of cross stratification is to facilitate description, as well as to provide a measure of standardization. The classification focuses attention on the most important features of cross-stratification, and thus may encourage a better understanding of the structure. Standardized descriptions may bring out relationships between types of cross-stratification and specific environments.

SUMMARY AND CONCLUSIONS

This paper is written with the aim of standardizing and defining the qualitative and quantitative terms applicable to stratified and cross-stratified units. Qualitative terms have been defined (Table 1). The difference between terms applicable to the thickness of stratification and of splitting has been noted and the limits of these quantitative terms have been suggested (Table 2). A classification of cross-stratification with three main divisions based on the character of the lower bounding surface of the cross-stratified unit and with numerous subordinate divisions based on other characteristics has been presented (Table 4).

The ultimate conclusions of this paper are not the writers', but the reader's. It is for the reader to further test this terminology and classification by application in the field and to determine its value in facilitating description.

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