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Classification of sediments and sedimentary rocks

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This volume was prepared for BGS use, and is released for information; comments on its applicability for wider use would be welcome and should be sent to the Rock Classification Scheme Coordinator, Dr M T Styles, British Geological Survey, Keyworth, Nottingham NG 12 5GG.

1 INTRODUCTION

The purpose of this report is to present a classification for lithified and unlithified sediments that is logical, systematic, hierachial and uses clearly defined, unambiguous names. Although classification systems for igneous rocks have been published (International Union of Geological Sciences, Subcommission on the Systematics of Igneous Rocks), a unifying scheme for classifying sedimentary rocks and their unlithified equivalents has not yet been formulated. Existing sediment and sedimentary rock nomenclature has been developed on a wide range of criteria, such as composition, texture and other physical attributes, as well as depositional environment, genetic relationship and local economic importance. As a result, sediment and sedimentary rock terminology tends to be inconsistent and lacking in basic general guidelines.

Sediments and sedimentary rocks occur as a continuum of types with no clear boundaries between them. However, certain types of sediments and sedimentary rock group naturally together. These natural groups of sediments and sedimentary rock have been classified separately by different authors, and invariably these individual classification schemes do not take account of schemes for other sediment and sedimentary rock types with which these sediments overlap. For example, sandstones, limestones and ironstones have all been classified separately, although in nature they overlap both in composition and in place of occurrence. Additionally the compositional boundaries used to classify unlithified sediments are commonly different to those for their lithified equivalents. A consistent, workable classification for all sediments and sedimentary rock needs a set of unifying boundary conditions: this classification scheme therefore attempts to do this.

There are four principal reasons for standardising the classification and nomenclature procedures for sediments:

- to ensure that all BGS geologists use the same approach to sediment and sedimentary rock classification and nomenclature, thereby reducing potential sources of confusion and misunderstanding over the meaning of particular rock names
- to make all sediment and sedimentary rock names descriptive. This will make the names more informative to both specialist and non-specialist users, and will allow any sediment to be easily placed into its position in the hierarchy
- to develop a classification scheme which unifies the compositional boundaries of unlithified sediments with those of sedimentary rocks
- to produce a hierarchical classification scheme and a logical approach to sediment nomenclature. A sediment classification scheme with a hierarchical structure has three principal benefits. Firstly, it is a 'user-friendly' system in that the wide range of sediment types are divided and classified in a logical manner. Secondly, guidance on how to classify and name sediments can be varied according to the level of information available to the user — the more information available, the higher is the level of the hierarchy at which the rock can be classified and named. Thirdly, it is a convenient system to input, store and retrieve data on a computer database

The scheme is designed primarily for classifying and naming sediments, and is essentially descriptive. Names that have genetic meaning or connotation, as well as those names that are more suitable for describing rock units rather than individual rocks, have been excluded. Using the scheme presented here, it should be possible to classify and name any sediment or sedimentary rock without knowledge of its field setting and without making assumptions about its mode of origin. A genetic approach to classification was not adopted for the following reasons:

- it is less informative about the mineral/chemical composition of the rock/sediment
- the information required to make an interpretation of rock genesis is not always available to the geologist
- ideas about petrogenesis change with time, generally more frequently than does the approach to describing the mineral/chemical features of rocks

To successfully construct and maintain an efficient computer database for sediments and sedimentary rocks the approach adopted for classification and nomenclature must be applied consistently by all who use it. The system will not work unless the scheme recommended here is followed rigidly. Clearly there will be a transition period in which users must become accustomed to employing terms which may differ from 'established' terms with which they are familiar. However, it must be emphasised that a fundamental objective of this rock classification exercise is that all geologists should be able to use it, regardless of which country they are in, regardless of the level of information available to them, and regardless of their geological background. For this reason many local (usually parochial) names for sediments and sedimentary rocks have been replaced with more descriptive names.

The approach to rock nomenclature described here has some drawbacks in that sediment and sedimentary rock names may be longer than equivalent 'traditional' terms, and also the scheme introduces new 'rules' for the use of qualifier terms and hyphens. However, it must be stressed that fundamental objectives of this new rock classification scheme are that it must be suitable for the storage, search and retrieval of rock names on a computer database, and it must also minimise potential sources of confusion among geologists as to what particular terms mean, or signify. For these reasons the removal of synonyms and the introduction of rigid guidelines for constructing descriptive rock and sediment names using qualifier terms and hyphens are necessary measures (see Section 1.3).

1.1 Principles of this classification scheme

- The term 'sediment' is taken to describe an unlithified sediment.
- Sediments and sedimentary rocks should not be classified according to the environment of deposition. Sediment and sedimentary rock nomenclature is based as far as possible on actual, descriptive attributes, <u>not</u> interpretative attributes. It is therefore essentially non-genetic. Genetic terms or parochial names may be used as a qualifier, but an approved classification term must also be given.
- The classification follows fundamental geological relationships and is based on natural groups of sediments and sedimentary rocks.
- The primary classification of sediments and sedimentary rocks is based on their compositional attributes present at the time of deposition. This allows sediments to be classified by the same compositional boundaries as sedimentary rocks.

- All classes are separated by boundary conditions such as proportions of clasts or grain size.
- Each class of sediments and sedimentary rocks has a number of hierarchical levels to allow simple categorisation or the assignation of a more detailed specific name. Qualifiers may be used to denote specific attributes at any level.
- The classification scheme is based on schemes and terms which are currently in use to describe sediments. There are many different classification schemes for natural groups of sediments: wherever possible the most widely accepted schemes have been incorporated into this classification.
- As far as possible, the scheme permits definition of group names without recourse to petrological or geochemical analysis.

1.2 Summary of the structure and development of the classification scheme

The sediment and sedimentary rocks classification scheme consists of 11 categories. Eight categories are based on the dominant component of the modal composition of the sediment or sedimentary rock at the time of deposition. The composition and abundance of diagenetic components should not affect the classification. For example, a sandstone is classified according to the composition of its detritus rather than its cement. The only exception to this rule are sedimentary rocks that are purely diagenetic in origin, for example 'chert'. The ninth category is based on the grain size or crystal size and enables a sediment or sedimentary rock to be given a simple classification even if the composition is not known. Category 10 covers sediments and sedimentary rocks that consist of more than one primary compositional component. Category 11 includes volcaniclastic sediments and sedimentary rocks.

The sediment and sedimentary rocks classification schemes are:

i) Siliciclastic sediments and sedimentary rocks
ii) Carbonate sediments and sedimentary rocks
iii) Phosphate-sediments and phosphorites
iv) Iron sediments and ironstones
v) Organic-rich sediments and sedimentary rocks
vi) Non-carbonate salts
vii) Non-clastic silica-rich sediments and sedimentary rocks
viii) Miscellaneous hydroxide, oxide and silicate sediments and sedimentary rocks
ix) Sediments and sedimentary rocks based on grain size or crystal size
x) Hybrid sediments and sedimentary rocks
xi) Sediments and sedimentary rocks with volcaniclastic debris

All categories except hybrid sediments and sedimentary rocks and organic-rich sediments and sedimentary rocks require a sediment to have at least 50% of that component by volume. A sediment or sedimentary rock which comprises more than one primary compositional component, with no component forming more than 50%, should be classified as a hybrid sediment or sedimentary rocks. This category includes sediments and sedimentary rocks comprising two equal components as well as multicomponent sediment and sedimentary rocks where each main component forms less than 50% of the sediment or sedimentary rock. Sediments and sedimentary rocks classified as rich in organic-matter should have a sufficiently high organic component to have a noticeable effect on the lithology. The problems associated with a volumetric definition of organic rocks is discussed in Section 6. To choose the correct classification scheme, the flow diagram on Figure 1 should be consulted.

Wherever possible, each category is primarily subdivided into sediments and sedimentary rocks. Sedimentary rocks composed of detrital grains may be simply classified by using qualifiers to describe their grain size, for example *sand-grade* **limestone**. More detailed classification schemes based on texture and/or composition are available for the assignation of root names.

Many of the classification schemes are based on grain size. The British Geological Survey (BGS) grain size scheme (Figure 13) has been adapted from Wentworth's (1922) grain size scale. Although the grain size terms should be used to describe the size of a clast of any composition, there is presently some confusion because the terms tend to be associated with siliciclastic clasts. To overcome this problem, the classification scheme requires all root names based on grain size to be clarified by reference to the clast composition. This rule applies mainly to clastic sediments which are classified according to grain size. They are primarily subdivided into gravels, sands and muds, and the grain size term is prefixed with a reference to their composition. For example, a sediment consisting of sand-grade lime clasts is given the root name <u>**lime-sand**</u>. To prevent any confusion, sediments composed of silicate particles should also include the prefix **silicate-** in the root name, for example, <u>**silicate-sand**</u>. A **silicate-** prefix should also be given to mudstones, sandstones and conglomerates to clarify their composition. The **silicate**_prefix is required for the database but could be dropped in descriptive text if the composition of the sedimentary rock is clear. This rule also applies to qualifiers describing grain size of additional clast types (for guidelines see Section 13.3.1).

Because sediments and sedimentary rocks characteristically show considerable variety and have a large range of attributes a classification scheme can only assign a general name. To amplify either the group name or the more specific root name, qualifiers can be added.

Throughout this report all sediment and rock group names are shown in **bold** type and root names are shown in <u>**bold type and underlined**</u>. Qualifiers are shown in *italics* and are separated by commas. (It is emphasised that this is for guidance to the reader and is not suggested for general use.)

1.3 Constructing a sediment or sedimentary rock name

The sediment and sedimentary rock classification scheme assigns each distinct sediment type a unique root name. Further refinement of the sediment or sedimentary rock name is achieved by prefixing one or more qualifier terms to the root name. Qualifiers may be added to any level of the classification scheme, see Section 13.1. There are strict guidelines for the use of qualifiers that describe grain size of either predominant or subordinate components, and they should be followed carefully to prevent any confusion arising over the composition of the clasts. Qualifiers that are recommended for use with certain sediment types are noted at appropriate points in the text. Compound root names and qualifiers composed of two terms are hyphenated. However, qualifiers are not linked to the root name with a hyphen. To avoid any potential source of confusion in the use of hyphens a rigid scheme for their use has been adopted.

1.4 Use of hyphens in rock names

Standardisation of the use and placement of hyphens in sediments and sedimentary rock names is vital if search and retrieval systems on computer databases are to be used efficiently and successfully, and to minimise potential confusion among geologists as to what particular names mean or signify. For example, correct use of hyphens will enable compound group/root names (e.g. **lime-packstone**) to be distinguished readily from group/root names with separate qualifiers (e.g. *calcareous* **iron-packstone**). The following guidelines for the use and placement of hyphens are proposed:

- a group/root name that consists of more than one word must be hyphenated, for example **lime-mud**, to show that it is a compound name
- hyphens must not be used between qualifiers and root/group names, for example *sandy* **limestone**
- commas must be used to link two or more qualifiers applied to a group/root name, for example *porous, calcareous* **sandstone**
- hyphens must be used to link compound qualifiers composed of two terms, for example *calcite-cemented* or *poorly-sorted*
- when using hyphens to join terms the trailing vowel should be omitted if followed by another vowel. For example the 'i' of the prefix 'calci' should be omitted if followed by a term such as 'ooidal', for example *calc-ooidal*

2 SILICICLASTIC SEDIMENTS AND SEDIMENTARY ROCKS

Siliciclastic sediments and sedimentary rocks are defined as those in which clastic fragments derived from pre-existing siliceous rocks form more than 50% of the sediment or rock. This group is further subdivided on the basis of grain size into rudaceous (> 2 mm), arenaceous (32 µm to 2 mm) and argillaceous (< 32 µm) classification categories:

- rudaceous — sediments with over 25% of the clasts larger than 2 mm
- arenaceous — sediments that are predominantly 32 µm to 2 mm, with less than 75% of the clasts smaller than 32 µm, and less than 25% larger than 2 mm
- argillaceous — sediments with over 75% of the clasts smaller than 32 µm

To keep the siliciclastic scheme consistent with the other sedimentary classification schemes, it is recommended that all siliciclastic sediments with a grain size term as part of their root name are given the prefix **silicate-** in the name. This is to avoid confusion over terms such as 'sand' which have been used to refer to both grain size and siliciclastic clasts (see Section 1). The **silicate-** prefix is required for database purposes but could be dropped in descriptive text if the composition of the sediment or sedimentary rock is clear.

Siliciclastic sediment or sedimentary rocks which contain over 10% volcanic debris may be classified under the sediment and sedimentary rock classification scheme or the igneous classification scheme. The scheme used should depend on the user's emphasis; it is recommended that rocks from an obviously volcaniclastic sequence should be classified under the igneous scheme (Gillespie and Styles, 1997).

2.1 Siliclastic rudaceous sediments and sedimentary rocks

Siliciclastic rudaceous sediments and sedimentary rocks contain more than 50% siliciclastic fragments. They are coarse grained and composed of clasts derived from pre-existing rocks of which over 25% are coarser than 2 mm (adapted from Greensmith, 1978 and Tucker, 1991). A flow diagram summarising the hierarchial classification of siliciclastic rudaceous sediments and sedimentary rocks is shown on Figure 2; see also Section 2.1.3.

2.1.1 Siliciclastic rudaceous sediments

All siliciclastic rudaceous sediments are given the group/root name **silicate-gravel**.

Rudaceous sediments can be given a more precise name by using qualifiers. Recommended qualifiers are described in Section 2.1.3.

Rudaceous sediments that are non-sorted and contain a wide range of clast sizes can be given a specific root name-**diamicton**. The strict descriptive definition relates to range of particle size and not to relative abundance of any or all size classes (Fairbridge and Bourgeois, 1978). These sediment types therefore traverse the boundary of siliciclastic rudaceous, arenaceous and argillaceous sediments. They can be classified by the same root name under any of the schemes. The scheme chosen should depend on the predominant grain size. They should be classified as a rudaceous sedimentary rock only if over 25% of the fragments are coarser than 2 mm.

2.1.2 Siliciclastic rudaceous sedimentary rocks

All rudaceous sedimentary rocks are given the group/root name **silicate-conglomerate.**

Rudaceous sedimentary rocks can be given a more precise name by using qualifiers. Recommended qualifiers are described in Section 2.1.3.

Conglomerates that are non-sorted and contain a wide range of clasts can be given a specific root name — **diamictite**. The strict descriptive definition relates to range of particle size and not to relative abundance of any or all size classes (Fairbridge and Bourgeois, 1978). These rock types therefore traverse the boundary of siliciclastic rudaceous, arenaceous and argillaceous rocks. They can be classified by the same root name under any of the schemes. The scheme chosen should depend on the predominant grain size. They should be classified as a rudaceous sedimentary rock only if over 25% of the fragments are coarser than 2 mm.

2.1.3 Recommended qualifiers

Grain Size

The predominant grain size can be clarified by prefixing with a term such as *pebble-grade* (see Section 13.2.1).

Grain fabric

Qualifiers can be used to indicate whether the sediment is matrix or clast supported (see Section 13.2.7).

Variety and composition of clast types

Qualifiers can be used to describe whether the sediment has a variety of clast types (polymictic) or comprises one clast type (oligomictic). The composition of the clasts may also be defined (see Section 13.3.1).

Clast morphology

Qualifiers to describe the roundness of clasts are given in Section 13.2.6. Conglomerates made of angular clasts should be given an 'angular' qualifier. The term 'breccia' may be used as a synonym of *angular* **silicate- conglomerate** but its use should be restricted to describe conglomerates made of sharply angular clasts. The term breccia has not been included as a root name because its use relies on the determination of clast shape, a factor that is not used for definition elsewhere in the sedimentary classification scheme. Clast shape is not used because its determination is very subjective and unlikely to be consistent between users.

2.2 Siliclastic arenacoeus sediments and sedimentary rocks

Siliciclastic arenaceous sediments and sedimentary rocks contain more than 50% siliciclastic fragments. The clasts should be predominantly 32 µm to 2 mm, with less than 75% of the clasts smaller than 32 µm and less than 25% of the clasts larger than 2 mm. Siliciclastic arenaceous sediments and sedimentary rocks may contain some lithic fragments, but the majority of the grains are individual crystals, abraded to various degrees. Qualifiers are used to describe any additional components. However, siliciclastic arenaceous sediments and sedimentary rocks with a wide range of other clast sizes may require a specific root name. These are described below, in Sections 2.2.1 and 2.2.2.

It may be difficult to determine whether siliciclastic grains are the most abundant clast type in sediments and sedimentary rocks with a high proportion of carbonate cement and carbonate grains. If it is not possible to determine the abundance of siliciclastic grains in hand specimen, the sediment may have to be classified according to the most abundant component (which may include cement). If the carbonate and siliciclastic components appear to be in equal amounts, the sediment should be classified as a hybrid sediment (see Section 12). This classification can be changed following petrological investigation if necessary.

A flow diagram summarising the hierarchical classification of siliciclastic arenaceous sediments is shown on Figure 3; see also Section 2.2.3.

2.2.1 Siliciclastic arenaceous sediments

All arenaceous sediments are given the group/root name **silicate-sand**.

Arenaceous sediments can be given a more detailed classification by using qualifiers to describe the predominant grain size (grain size scale is shown on Figure 13.), for example *coarse* **silicate-sand**. Other recommended qualifiers are described in Section 2.2.3.

2.2.1.1 Poorly sorted siliciclastic arenaceous sediments

Sediments that are poorly sorted and contain a wide range of clast sizes can be given a specific root name — **diamicton**. The strict descriptive definition relates to range of particle size and not to relative abundance of any or all size classes (Fairbridge and Bourgeois, 1978). These sediment types therefore traverse the boundary of siliciclastic rudaceous, arenaceous and argillaceous sediments. They can be classified by the same root name under any of the schemes. The scheme chosen should depend on the predominant grain size. They should only be classified as an arenaceous sediment if the clasts are predominantly 32 µm to 2 mm.

Non-sorted sands may also be described using qualifiers. Sands with a wide range of particles within the arenaceous grain size fraction (32 µm to 2 mm) can be given the qualifier *poorly-sorted*. The presence of a subordinate clast size can be described using an appropriate qualifier, for example *silici-pebbly* **silicate-sand**.

2.2.2 Siliciclastic arenaceous sedimentary rocks

All siliciclastic arenaceous sedimentary rocks are given the group name **silicate-sandstone**.

If the user requires a simple classification, the sediment should be classified as a **silicate-sandstone** with qualifiers used to describe the predominant grain size (grain size scale is shown on Figure 13), for example *fine* **silicate-sandstone**. Other recommended qualifiers are described in Section 2.2.3.

A more detailed classification scheme is based on the silicate sandstones composition. Root names are also available to classify non-sorted silicate-sandstones (see Section 2.2.2.2).

2.2.2.1 Classification of siliciclastic arenaceous sedimentary rocks using composition

The classification scheme is based on the composition of the detrital grains and has been adapted from the classification of Pettijohn et al (1987). The basis for the scheme is shown on Figure 4. There are two levels of classification:

The scheme primarily divides the sandstones on the proportion of matrix (fine-grained interstitial material) into **arenites** (0 to 15% matrix) and **wackes** (15 to 75% matrix). These names can generally be applied with a high degree of accuracy in the field.

A more detailed classification is made on the proportion of quartz, feldspar and lithic fragments in the arenaceous grain size fraction. Figure 4 shows how the arenites can be more accurately classified as **quartz-arenite**, **subfeldspathic-arenite**, **feldspathic-arenite**, **sublithic-arenite** and **lithic-arenite** and the wackes can be more accurately classified as **quartz-wacke**, **feldspathic-wacke** and **lithic-wacke**. This level of differentiation is only recommended following thin section analysis, or if the composition is absolutely clear without thin section analysis. The type of lithic fragments in **lithic-wackes** and **lithic-arenites** can be described using qualifiers, for example a *mudstone-clast* **lithic-wacke** or a *meta-clast* **lithic-arenite** (see Section 13.3.4.

To use the compositional classification scheme accurately, any diagenetic components or crystal clasts other than quartz and feldspar should not be included. Following modal analysis the amount of matrix, quartz, feldspar and lithic fragments should be recalculated to 100%. Polycrystalline quartz (chert) should be included as lithic fragments. The type and degree of cementation can be identified by the use of a qualifier (see Section 13.4:).

2.2.2.2 Poorly sorted siliciclastic arenaceous sedimentary rocks

Sedimentary rocks that are non-sorted and contain a wide range of clast sizes can be given a specific root name — **diamictite**. The strict descriptive definition relates to range of particle size and not to relative abundance of any or all size classes. (Fairbridge and Bourgeois, 1978). These rock types therefore traverse the boundary of siliciclastic rudaceous, arenaceous and argillaceous sedimentary rocks. They can be classified by the same root name under any of the schemes. The scheme chosen should depend on the predominant grain size. They should only be classified as an arenaceous sedimentary rock if the clasts are predominantly 32 µm to 2 mm.

Non-sorted sandstones may also be described using qualifiers. Sandstones with a wide range of particle sizes within the arenaceous grain size fraction (32 µm to 2 mm) can be given the qualifier *poorly-sorted*. The presence of a subordinate clast size can be described using an appropriate qualifier (see Section 13.3.1*)* for example *silici-pebbly* **silicate-sandstone.**

2.2.3 Recommended qualifiers

Group and root names from the siliciclastic arenaceous sediments and sedimentary rocks classification scheme can be enhanced by the use of qualifiers. Although any important feature of a silicate-sand or silicate-sandstone can be described with qualifiers, the following are recommended.

Qualifiers to describe grain size

The predominant grain size can be clarified by prefixing with a term such as 'coarse', for example *coarse* **silicate-sandstone** (see Section 13.2.1. If the sediment or sedimentary rock contains a subsidiary component of non-arenaceous siliciclastic clasts, this may also be defined, for example *silici-pebbly* **silicate-sandstone.** More details are given in Section 13.3.1.

Qualifiers to describe composition of any non-siliciclastic clasts

The presence of non-siliciclastic particulate components can be described using qualifiers (see Section 13.3.1). For example a silicate sandstone with calcite clasts is described as a *calciclastic* **silicate-sandstone**. If it is necessary to specify the grain size of the non-siliciclastic clasts the 'clastic' may be replaced by the grain size term, for example *calci-pebbly* **silicate sandstone**.

If the siliciclastic and non-siliciclastic components appear to be in equal amounts, the sediment should be classified as described in Section 11. It may be difficult to determine whether siliciclastics are the most abundant clast type in sediments and sedimentary rocks with a high proportion of carbonate cement and carbonate grains. If it is not possible to determine the abundance of siliciclastics in hand specimen, the sediment may have to be classified according to the most abundant component (which may include cement). This classification can be changed following petrological investigation if necessary.

2.3 Siliciclastic argillaceous sediments and sedimentary rocks

Siliciclastic argillaceous sediments and sedimentary rocks contain more than 50% siliciclastic fragments. At least 75% of the clasts should be less than 32 µm. This may include both silt grade (4 to 32 µm) and clay grade (< 4 µm) particles. Root names are determined by the proportion of silt to clay. Qualifiers are generally used to describe any additional components. However, siliciclastic argillaceous sediments and sedimentary rocks with a wide range of additional clast sizes require a specific root name. These are described in Section 2.3.1.

The classification of siliciclastic argillaceous sediments and sedimentary rocks with an evident organic component is described in Section 2.3.2. A flow diagram summarising the hierarchial classification of siliciclastic argillaceous sediments and sedimentary rocks is shown on Figure 5. Recommended qualifiers are summarised in Section 2.3.3.

All siliciclastic argillaceous sediments are given the group name **silicate-mud**.

All siliciclastic argillaceous sedimentary rocks are given the group name **silicate-mudstone**.

Root names are determined by the proportion of silt to clay. The criteria are demonstrated on Table 1.

2.3.1 Siliciclastic argillaceous sediments and sedimentary rocks with a wide range of other clast sizes

Argillaceous sediments and sedimentary rocks that are poorly-sorted and contain a large proportion (up to 25% volume) of gravel-grade clasts (> 2 mm) can be given a specific root name. Unlithified types are called **diamicton** and lithified forms **diamictite**. The strict descriptive definition relates to range of particle size and not to relative abundance of any or all size classes (Fairbridge and Bourgeois, 1978). These sediment types therefore traverse the boundary of siliciclastic argillaceous and rudaceous sediments and sedimentary rocks. They can be classified by the same root name under any of the schemes. The scheme chosen should depend on the predominant grain size. They should only be classified as an argillaceous sediment or sedimentary rock if more than 75% of the clasts are smaller than 32 µm.

The presence of a subordinate clast size can also be described using an appropriate qualifier, for example *silici-pebbly* **silicate-mudstone** (see Section 13.3.1).

2.3.2 Siliciclastic argillaceous sediments and sedimentary rocks with organic matter

Siliciclastic argillaceous sediments and sedimentary rocks with an evident organic component can be classified in two ways. The sediments and sedimentary rocks should usually be classified as a silicate-mud or silicate-mudstone and given a qualifier to describe the organic component. However, if the user wishes to focus on the organic component, the sediment

Table 1 Criteria for classifying silicate-muds and silicate-mudstones (after Twenhofel, 1937, and Tucker, 1991).

Percentage clay-size constituents	> 50 % clay	< 50 % clay	Not known group name
Hand description of unlithified sediment	Demonstrates plastic properties*	Abundant silt visible with hand lens and has a gritty texture	
Root name	**silicate-clay**	**silicate-silt**	**silicate-mud**
Hand description of lithified sediment	Extremely fine grained with homogeneous appearance	Abundant silt visible with hand lens	
Root name	**silicate-claystone**	**silicate-siltstone**	**silicate-mudstone**

* Plasticity of clays is the ability of the wet material to be shaped and to have the strength to hold the shape after the deforming pressure is removed (Fairbridge and Bourgeois, 1978).

may be classified using the parallel scheme for organic-rich sediments and sedi rocks (see Section 6.3). Recommended qualifiers for describing organic components include: *organic*, *carbonaceous*, *sapropelic* and *kerogenic.* Guidelines for the use of these qualifiers are given in Section 13.3.3

2.3.3 RECOMMENDED QUALIFIERS

Group and root names from the siliciclastic argillaceous sediments and sedimentary rocks classification scheme can be enhanced by the use of qualifiers. Although any important feature of a silicate-mud or silicate-mudstone can be described with qualifiers, the following are recommended.

Qualifiers to describe grain size of non-argillaceous siliciclastic clasts

The presence of non-argillaceous siliciclastic clasts can be described using qualifiers (see Section 13.3.1). For example a mudstone with siliciclastic pebbles would be described as a *silici-pebbly* **silicate-mudstone**.

Qualifiers to describe composition of non-siliciclastic clasts

The presence of non-siliciclastic clasts can be described using qualifiers (see Section 13.3.1). For example a silicate-mudstone with calcite clasts should be described as a *calciclastic* **silicate-mudstone**. If it is necessary to specify the grain size of the non-siliciclastic clasts the 'clastic' may be replaced by the grain size term, for example *calci-pebbly* **silicate-mudstone**. If the non-siliciclastic clasts are of an argillaceous grain size then a general reference to their mineralogy can be made, for example a *calcareous* **silicate-mudstone**.

Qualifiers to describe lamination and fissility

Qualifiers can be used to describe bedding characteristics, for example a *fissile* **silicate-mudstone**. Terms are defined in Section 13.5.2.

3 CARBONATE SEDIMENTS AND SEDIMENTARY ROCKS

Carbonate sediments are defined as those where the carbonate component forms more than 50% of the sediment. For a rock to be termed a carbonate sedimentary rock, the 50 % carbonate criterion should not include any carbonate cement in an originally non-carbonate rock. If it is difficult to distinguish carbonate clasts from carbonate cement in hand specimens, it can be assumed that a sediment which is dominantly composed of carbonate should be classified as such. This classification can be changed following petrological investigation if necessary.

The classification of carbonate sediments and sedimentary rocks with an evident organic component is described in Section 3.1.4.

The carbonate may comprise calcium carbonate, magnesium carbonate or sodium carbonate. There are three broad categories of carbonate sediments, defined on the basis of the carbonate composition.

- Lime-sediments and limestones:
  the dominant carbonate mineral is calcium carbonate in the form of calcite, aragonite and/or vaterite. Vaterite is a metastable hexagonal form of calcium carbonate. It is exceptionally rare and it is unlikely that it would ever occur as the main mineral.
- Dolomite-sediments, dolostones, and magnesite-stones:
  the dominant carbonate mineral is magnesium carbonate in the form of dolomite, ankerite and/or magnesite.
- Sodium carbonate sedimentary rocks:
  the dominant carbonate mineral is sodium carbonate.

Qualifiers can be used to describe carbonates of an intermediate composition (see Section 13.3.2). For example:

dolomitic is used as a qualifier where dolomite makes up 10 to 50 % of carbonate within a limestone

calcareous is used as a qualifier where calcium carbonate makes up 10 to 50 % of a dolomite, or more precisely a *calcitic* or *aragonitic* qualifier

3.1 Lime-sediments and limestones

A flow diagram summarising the hierarchial classification of lime-sediments and limestones is shown on Figure 6.

3.1.1 LIME-SEDIMENTS

The lime-sediment classification scheme includes all sediments composed of calcite and/or aragonite.

All lime-sediments are given the group name **lime-sediment.**

Two classification schemes are available to give root names to lime-sediments. The first scheme is based on the grain size of the sediment. The second scheme is designed to classify limestones composed dominantly of one constituent.

3.1.1.1 Classification of lime-sediments according to grain size

The grain size classes are defined in the same way as the siliciclastic sediments:

- gravel — over 25% of the clasts larger than 2 mm
- sand — clasts predominantly 32 µm to 2 mm, with less than 75% of the clasts smaller than 32 µm and less than 25% larger than 2 mm
- mud — over 75% of the clasts smaller than 32 µm

The composition of the carbonate is used as a prefix to the grain size term and hyphenated, for example **lime-sand**. If it is known that the carbonate is composed dominantly of calcite then the prefix is **calcite-**, if it is dominantly of aragonite, then the prefix is **aragonite-** and if the composition of the carbonate is not known the prefix **lime-** should be used. If the sediment comprises more than one type of carbonate, it can be classified according to the dominant component and the lesser component described with a qualifier, for example *calcitic* **aragonite-sand**. The criteria for classifying carbonate sediments are demonstrated in Table 2.

3.1.1.2 Classification of monogranulate lime-sediments

If the lime-sediment is composed almost entirely of one type of allochem, shell or micro-organism, then the group name or root name can be prefixed with the component. Examples include **shell-lime-sediment**, **crinoid-lime-sediment** and **ooid-lime sand**.

3.1.1.3 Recommended qualifiers

The lime-sediment group and root names can be given qualifiers to describe grain size, composition of any non-carbonate components, clast (allochem) type and fossil content. More details on the use of qualifiers in classifying lime-sediments are given in Section 3.1.5.

Table 2 Classification of lime- sediments according to grain size.

It should be noted that when the terms **-gravel**, **-sand** and **-mud** are combined with a compositional prefix (e.g. **lime-sand**) they do not have a siliciclastic connotation but refer to grain size only (see Sections 1.2 and 13.3.1)

Grain size	Composition		
	Dominantly calcite	Dominantly aragonite	Unspecified
Rudaceous (> 2 mm)	**calcite-gravel**	**aragonite-gravel**	**lime-gravel**
Arenaceous (32 µm–2 mm)	**calcite-sand**	**aragonite-sand**	**lime-sand**
Argillaceous (< 32 µm)	**calcite-mud**	**aragonite-mud**	**lime-mud**

3.1.2 Limestones

Sedimentary rocks which are composed dominantly of calcium carbonate are given the group name **limestone**.

The carbonate component in limestones is usually composed of calcite, but may be aragonite. Aragonite cements and clasts are rarely preserved in ancient limestones since the mineral is metastable. However, some recent limestones consist predominantly of aragonite. If it is known that aragonite forms more than 50% of the carbonate component then the group name **limestone** can be prefixed with aragonite, for example **aragonite-limestone**. If a smaller amount of aragonite is present (< 50%) then *aragonitic* may be used as a qualifier to the group name, for example *aragonitic* **limestone**. Although the group name **limestone** is assumed to be composed of calcite, it may be clearer when classifying recent sediments to prefix the group name with calcite, for example **calcite-limestone**.

Qualifiers may be used to describe any features that are considered important. More details on the use of qualifiers in classifying limestones are given in Section 3.1.5.

If the user requires only a simple classification, the rock should be classified as a **limestone** and qualifiers used to describe the predominant grain size or crystal size. For example, a limestone composed of sand grade clasts can be described as a *sand-grade* **limestone** (see Section 13.2.1), whereas a limestone composed of fine crystals can be described as a *fine-crystalline* **limestone** (see Section 13.2.2). In the geological literature there are some commonly used rock names that have a grain size connotation, for example calcirudite.. Although these terms are not in the classification scheme they may be used as synonyms. The following synonyms are recommended:

- calcilutite can be used as a synonym of *mud-grade* **limestone**
- calcarenite can be used as a synonym of *sand-grade* **limestone**
- calcirudite can be used as a synonym of *gravel-grade* **limestone**, *pebble-grade* **limestone** *cobble-grade* **limestone** etc.

Two classification schemes are available to give root names to limestones. The first scheme is based on the textural classification of Dunham (1962) as modified by Wright (1962), to accommodate diagenetically altered limestones. The second scheme is designed to classify limestones composed dominantly of one constituent (see Section 3.1.3).

3.1.2.1 Classification of limestones using texture

The limestones are primarily divided on their depositional, biological or diagenetic texture following the classification schemes of Dunham (1962), Embry and Klovan (1971) and Wright (1992). Descriptions of clast and cement type derived from Folk's (1962) classification scheme can be used as qualifiers to enhance the root names (see Section 3.1.5).

The original names suggested by Dunham (1962) and others are prefixed with **lime-**, or, if the exact mineralogy of the rock is known **calcite-** or **aragonite-.** This is to distinguish the limestones from phosphorites and ironstones which have been given a similar textural classification scheme. The full compound root name (e.g. **lime-packstone**) will be required for the database, but the **lime-**, **calcite-** or **aragonite-** may be dropped in descriptive text if it was clear that the author was referring to a sequence of limestones.

The classification scheme is shown in Table 3. The main differences between this scheme and the original classifications of Dunham (1962), Embry and Klovan (1971) and Wright (1992) are:

- The classification scheme follows Dunham (1962) in equating matrix with mud-grade carbonate. However the upper size limit of mud is here defined at 32 µm to be consistent with the rest of the sedimentary scheme (see Figure 13).
- Dunham (1962) defined wackestones as having more than 10% grains, and mudstones as having less than 10% grains. Wackestones are now defined as having less than 75% matrix (mud-grade carbonate) whereas mudstones have more than 75% matrix. This is to make the scheme consistent with other sedimentary classification schemes and enables easier classification of hybrid sediments.
- Embry and Klovan (1971) introduced the terms floatstone and rudstone to describe coarse-grained (more than 10% grains larger than 2 mm) wackestones and grain-supported limestones. These terms have not been included because they describe a texture already covered by the classification. The grain size can be described using an appropriate grain size adjective (see Section 13.2.1) for example *gravel-grade* **lime-packstone.**
- The term 'bafflestone' introduced by Embry and Klovan (1971) is interpretive and therefore not included in this classification scheme.
- Wright (1992) introduced a number of diagenetic classes, for example condensed fitted grainstone. Not all of these have been retained in this classification scheme. This is because the classification scheme is based on depositional attributes rather than diagenetic features. Diagenetic features are usually added as qualifiers to the root name. However, the distinction can become blurred in carbonates as a result of diagenesis or where cements were precipitated contemporaneously with deposition of lime-clasts. As a result specific root names are required to describe some limestones with a diagenetic texture. The terms 'sparstone' and 'microsparstone' have been retained

to describe limestones with obliterative diagenetic textures. However, the crystal sizes recommended by Wright (1992) have been altered to make them consistent with the crystal sizes used through the rest of the sedimentary classification scheme (see Section 3.1.5, Table 5.). The class of limestones with non-obliterative diagenetic textures termed 'cementstones' by Wright (1992) have also been retained but renamed as **pseudosparstones**. This is to prevent any confusion with the informal term applied to limestones used in cement making. The terms 'condensed fitted' and 'fitted' have not been included as root names as the rocks can be classified as **grainstones** and the diagenetic term used as a qualifier, for example *condensed-fitted* **grainstone** (see Section 3.1.5). Root names and qualifiers describing diagenetic textures can be accurately used only after petrological study.

Definition of textural classes

The different root names are shown using the prefix **lime-**, this may be replaced by **calcite-** or **aragonite-** if the exact mineralogy of the rock is known**.**

Depositional textural classes

- Matrix-supported carbonates
  Matrix refers to mud-grade material that is smaller than 32 µm in diameter.

  lime-mudstone — rock composed of greater than 75 % mud-grade (< 32 µm) calcite
  lime-wackestone — matrix-supported carbonate rock containing less than 75 % mud-grade (< 32 µm) calcite

- Grain-supported carbonates
  lime-packstone — grain supported with intergranular spaces filled by matrix
  lime-grainstone — grain supported with little matrix

Biogenic textural classes

- **lime-boundstone** — the original components were bound and encrusted together by the action of plants and animals in the position of growth (e.g. reef limestones)
- **lime-framestone** — a type of reef rock consisting of a rigid framework of colonies, shells or skeletons. Internal cavities are filled with fine sediment

Diagenetic textural classes

These classes can be accurately used only after petrological study:

- **lime-pseudosparstone** — a limestone composed almost totally of a divergent radial fibrous calcite cement in which grains or in-situ biogenic material do not constitute a framework. The calcite pseudospar occurs as in-situ botryoidal masses commonly found in the core of algal mounds and probably formed from early diagenetic alteration of aragonite masses (Mazzullo and Cys, 1979). The diagenetic process does not cause any alteration to the depositional or biological texture

- **lime-sparstone** — limestones composed of obliterative sparry calcite crystals, typically in inequant, blocky mosaics, with a crystal size larger than 32 µm
- **lime-microsparstone** — similar to a sparstone but with 4 to 32 µm crystal size. Crystals are resolvable under optical microscope
- **lime-microstone** — similar to a sparstone but with crystals smaller than 4 µm. Crystals are not resolvable under an optical microscope

Recommended qualifiers

It is recommended that root names from the textural classification of limestones are given qualifiers to describe the cement, clast types, diagenetic textures, grain size and fossil content. More details on the use of qualifiers in describing lime-sediments and limestones are given in Section 3.1.5.

Table 3 Classification of limestones using texture. Modified from Dunham (1962), Embry and Klovan (1972) and Wright (1992).

DEPOSITIONAL				BIOLOGICAL	
Contains matrix (silt and clay < 32 µm)			Lacks matrix		
Matrix–supported		Grain-supported		In-situ organisms	
> 75% matrix	< 75% matrix			Encrusting binding organisms	Rigid organisms dominant
lime-mudstone	**lime-wackestone**	**lime-packstone**	**lime-grainstone**	**lime-boundstone**	**lime-framestone**

DIAGENETIC				
Non-obliterative		Obliterative		
Texture of limestone visible	Main component is spherulutic calcite cement	Sparite crystals (> 32 µm)	Microsparite crystals (4–32 µm)	Micrite crystals (< 4 µm)
Use appropriate root name and qualifier	**lime-pseudosparstone**	**lime-sparstone**	**lime-microsparstone**	**lime-microstone**

3.1.3 Monogranulate limestones

Limestones which are composed almost entirely of one type of allochem or micro-organism can be classified according to Table 4.

Table 4 Classification of limestones comprising one type of allochem.

Dominant component	Rock name
ooids	**ooid-limestone**
pisoids	**pisoid-limestone**
oncoids	**oncoid-limestone**
microoncoids	**microoncoid-limestone**
peloids	**peloid-limestone**
microncoid	
shells	†**shell-limestone**

The term chalk should only be used to describe limestones which are friable and porous. Indurated forms of chalk should be classified as limestones and qualified as *chalky*.

†'shell' may be replaced with fossil type, e.g. crinoid-limestone

Recommended qualifiers

Chalk may be qualified by a description of the main fossil type (e.g. *foraminiferal* **chalk**). If more than one microfossil is present the minor component should be listed first.

3.1.4 Lime-sediments and limestones with organic matter

Lime-sediments and limestones with an evident organic component can be classified in two ways. The sediments and sedimentary rocks should usually be classified as a lime-sediment or limestone and given a qualifier to describe the organic component. However, if the user wishes to focus on the organic component, the sediment may be classified using the parallel scheme for organic-rich sediments and sedimentary rocks (see Section 6.3). Recommended qualifiers for describing organic components include: *organic*, *carbonaceous*, *sapropelic* and *kerogenic*. Guidelines for the use of these qualifiers are given in Section 13.3.3.

3.1.5 Recommended qualifiers

Group and root names from the lime-sediment and limestone classification scheme can be enhanced by the use of qualifiers. Although any important feature of a lime-sediment or limestone can be described with qualifiers, the following are recommended:

Qualifiers used to describe grain size

The predominant grain size can be clarified by prefixing with a grain size adjective (see Section 13.2.1), for example *pebble-grade* **calcite-gravel** or *coarse* **lime-sand**. If the sediment or rock contains a subsidiary component of different sized lime clasts this may also be defined, for example *lime-pebbly* **lime-sand**.

Qualifiers used to describe composition of any non-carbonate components

The presence of non-carbonate particulate components can be described using qualifiers (see Section 13.3.1). For example a limestone with phosphate clasts can be described as a *phosphaclastic* **limestone**. If it is necessary to specify the grain size of the non-carbonate clasts the 'clastic' may be replaced by the grain size term, for example *phospha-pebbly* **limestone**.

Qualifiers used to describe clast (allochem) type

The presence of allochems can be described using qualifiers. Allochem types comprise *bioclasts*, *lithoclasts*, *intraclasts*, *ooids*, *pellets*, *peloids* and *spastoliths* and are defined in Section 13.3.5.

Qualifiers used to describe fossil component

A general term such as *bioclastic* or the most abundant fossil types can be used as a qualifier, for example *crinoidal* **lime-sand**.

Qualifiers used to describe carbonate cements

Carbonate cements are defined according to their crystal size following the terminology introduced by Folk (1962). To ensure consistency between the carbonate specific terms and crystal size terms used elsewhere in the classifcation scheme, Folk's boundary conditions have been amended. The new crystal sizes are easier to define using a microscope (see Table 5).

Qualifiers used to describe diagenetic textures specific to limestones

These qualifiers are specific to limestones and are taken from Wright's (1992) textural classification scheme.

- *condensed* — this term can be applied to grainstones where pressure solution has caused many grain contacts to consist of stylolites. The texture is non-obliterative
- *fitted* — this term can be applied to grainstones where virtually all the grain contacts consist of microstylolites. The texture is largely non-obliterative

Qualifiers used to describe a texture with genetic connotations

There are a number of limestones which have been given a genetic name in the literature. Such names are interpretative and therefore not included in the classification scheme. However, if the mode of origin of the rock is known and needs to be highlighted, the genetic name may be used alongside the

Table 5 Definition of carbonate crystal-size qualifiers.

Crystal size	optical properties	limestone crystal-size qualifiers	Dolomite crystal-size qualifiers	crystal-size terms used elsewhere in classification
> 32 µm	crystals normally sand-grade	*sparite*	*dolosparite*	*very-fine-crystalline*
4–32 µm	crystals resolvable with optical microscope	*microsparite*	*dolomicrosparite*	
< 4 µm	crystal unresolvable under optical microscope	*micrite*	*dolomicrite*	*cryptocrystalline*

formally defined classification term as a synonym or informal genetic qualifier, for example *tufa* **limestone**. Classification by the rock's physical and textural properties should still be made whenever possible. The most common genetic qualifiers associated with limestones are *tufa*, *travertine* and *calcrete*; these are defined in Section 13.6. If the rock is a modern day superficial deposit with an obvious mode of origin it may be classified in the superficial deposit scheme (McMillan and Powell, 1999) and given a genetic name.

3.2 Dolomite-sediments, dolostones and magnesite-stones

Dolomite-sediments, dolostones and magnesite-stones are defined as carbonate sediments which are dominantly (> 50%) composed of a magnesium carbonate in the form of dolomite ($CaMg(CO_3)_2$), ankerite ($Ca_3 (Mg_2Fe) (CO_3)_6$) or magnesite ($MgCO_3$). A flow diagram summarising the hierarchial classification of these sediments is shown on Figure 7.

3.2.1 Dolomite sediments

The dolomite-sediment classification scheme includes all sediments composed dominantly of dolomite or ankerite.

All dolomite-sediments are given the group name **dolomite-sediment.**

A more detailed classification scheme is based on the sediment's grain size. The classes are defined in the same way as the siliciclastic sediments:

- gravel — over 25% of the clasts larger than 2 mm
- sand — clasts predominantly 32 µm to 2 mm, with less than 75% of the clasts smaller than 32 µm and less than 25% larger than 2 mm
- mud — over 75% of the clasts smaller than 32 µm

The composition of the carbonate is used as a prefix to the grain size term and hyphenated. If it is known that the carbonate is composed dominantly of ankerite then the prefix is **ankerite**- otherwise the prefix **dolomite** should be used. If the sediment comprises of more than one type of carbonate, it should be classified according to the dominant component with the lesser component described with a qualifier, for example *calcitic* **dolomite-sand**. The criteria for classifying dolomite-sediments are demonstrated in Table 6.

Table 6 Classification of unlithified dolomite-rich sediments according to grain size.

Grain size	Composition	
	Dominantly dolomite	Dominantly ankerite
Gravel (> 2 mm)	**dolomite-gravel**	**ankerite-gravel**
Sand (32 µm–2mm)	**dolomite-sand**	**ankerite-sand**
Mud (< 32 µm)	**dolomite-mud**	**ankerite-mud**

When the terms **-gravel**, **-sand** and **-mud** are combined with a compositional prefix (e.g. **dolomite-sand**) they do not have a siliciclastic connotation but refer to grain size only (see Sections 1.2 and 13.3.1).

Recommended qualifiers

The dolomite-sediments group and root names can be given qualifiers to describe grain size, composition of any non-carbonate components, clast (allochem) type and fossil content. The use of qualifiers in classifying dolomite-sediments, follows the guidelines given for lime-sediments (see Section 3.1.5).

3.2.2 Dolostones

Sedimentary rocks which are composed dominantly of dolomite or ankerite are given the group name **dolostone**.

The carbonate component in dolostones is usually composed of dolomite, but may be composed of ankerite. If it is known that ankerite forms more than 50% of the carbonate component then the group name **ankeritestone** is given. If a smaller amount of aragonite is present *ankeritic* may be used to qualify the group name.

Qualifiers may be used to describe any features that are considered important. The use of qualifiers follows the guidelines given for limestones (see Section 3.1.5).

Table 7 Classification of dolostones with a depositional or biological texture.

depositional texture				biological texture	
contains matrix (silt and clay < 32 µm)			lacks matrix		
matrix-supported		grain-supported			
> 75% matrix	< 75% matrix			encrusting binding organisms	rigid organisms dominant
dolomite-mudstone	**dolomite-wackestone**	**dolomite-packstone**	**dolomite-grainstone**	**dolomite-boundstone**	**dolomite-framestone**

Table 8 Classification of dolostones with a diagenetic texture

non-obliterative diagenetic texture		obliterative diagenetic texture		
texture of dolostone visible	main component is spherulutic calcite cement	sparite crystals (> 32 µm)	microsparite crystals (4–32 µm	micrite crystals (<4m)
Use root name to describe depositional texture and qualifiers to describe diagenetic texture (see below)	**dolomite-pseudosparstone**	**dolomite-sparstone**	**dolomite-microsparstone**	**dolomite-microstone**

If the user requires only a simple classification, the sediment should be classified as a dolostone and qualifiers used to describe the predominant grain size or crystal size. For example, a dolostone composed of sand-grade clasts can be described as a *sand-grade* **dolostone** (see Section 13.2.1), whereas a dolostone composed of fine crystals can be described as a *fine-crystalline* **dolostone** (see Section 13.2.2 and Figure 13.).

The classification scheme for giving higher level root names to dolostones, follows the textural classification given for limestone. Two classifaction schemes are available to give higher level root names to dolostones. The first scheme is based on the textured limestone classification (see Section 3.2.2.1). The second scheme is designed to classify dolostones composed dominantly of one constituent (see Section 3.2.2.2).

3.2.2.1 Classification of dolostones using texture

The dolostone textural classification follows the limestone textural classification scheme. The composition of the carbonate is used as a prefix to the textural term and hyphenated. If it is known that the carbonate is composed dominantly of ankerite then the prefix is **ankerite-** otherwise the prefix **dolomite-** should be used. The root names and main features are summarised in Tables 7 and 8, but the limestone scheme should be consulted for more detailed descriptions of the different textures (see Section 3.1.2.1).

Recommended qualifiers

Root names from the dolostone textural classification can be given qualifiers to describe the cement, clast types, diagenetic textures, grain size and fossil content. The use of qualifiers in classifying dolostones, follows the guidelines given for limestones (see Section 3.1.5).

3.2.2.2 Monogranulate dolostones

Dolostones which are composed almost entirely of one type of allochem or micro-organism can be classified according to Table 9.

Table 9 Classification of dolostones comprising one type of allochem.

Dominant component	Sediment name
ooids	**ooid-dolomite**
pisoids	**pisoid-dolostone**
oncoids	**oncoid-dolostone**
microoncoids	**microoncoid-dolostone**
peloids	**peloid-dolostone**

3.2.3 Magnesite-stones

Sedimentary rocks composed of magnesite are very rare and the few known examples are formed as primary precipitates. Unlithified equivalents are not known. All rocks composed of magnesite are given the group name **magnesite-stone**. No higher level root names are considered necessary.

3.3 Na carbonate sedimentary rocks

The Na carbonate sedimentary rocks are primary precipitates and do not have an unlithified equivalent. They are classified as follows:

- **thermonatrite** ($Na_2CO_3.H_2O$) — forms orthorhombic crystals and efflorescent crusts
- **natron** ($Na_2CO_3.10H_2O$) — usually in solution, but also forms monoclinic crystals and efflorescent crusts
- **trona** ($Na_2CO_3.NaHCO_3.2H_2O$) — monoclinic crystals form in fibrous or columnar layers and masses
- **gaylussite** ($Na_2CO_3.CaCO_3.5H_2O$) — monoclinic flattened wedge-shaped crystals

4 PHOSPHATE-SEDIMENTS AND PHOSPHORITES

Phosphate-sediments and phosphorites are defined as those sediments and sedimentary rocks which have more than 50% phosphate minerals. These may be phosphates of calcium, aluminium or iron (equivalent to about 18 to 21% wt P_2O_5 depending on the nature of the phosphate minerals present). A flow diagram summarising the hierarchical classification of phosphate-sediments and phosphorites is shown on Figure 8.

4.1 Phosphate-sediments

All phosphate-sediments are given the group name **phosphate-sediment.**

A more detailed classification scheme is based on the sediment grain size. The classes are defined in the same way as the siliciclastic sediments:

- gravel — over 25% of the clasts larger than 2 mm
- sand — clasts predominantly (32 µm to 2 mm, with less than 75% of the clasts smaller than (32 µm and less than 25% greater than 2 mm
- mud — over 75% of the clasts smaller than (32 µm

The grain size term is prefixed with **phosphate-**, for example **phosphate-sand**. The classification criteria are demonstrated in Table 10.

Recommended qualifiers

The phosphate-sediment group and root names can be given qualifiers to describe grain size, composition of any non-phosphate components, and clast (allochem) type. More details are given in Section 4.3.

4.2 Phosphorites

All lithified phosphate-rich sediments are given the group name **phosphorite**.

Qualifiers may be used to describe any features that are considered important. More details on the use of qualifiers in classifying phosphorites are given in Section 4.3.

Table 10 Classification of phosphate-sediments according to grain size

Gravel (> 2 mm)	**Phosphate-gravel**
Sand (32 m–2 mm)	**Phosphate-sand**
Mud (< 32 µm)	**Phosphate-mud**

It should be noted that when the terms **-gravel**, **-sand** and **-mud** are combined with a compositional prefix (e.g. **phosphate-sand**) they do not have a siliciclastic connotation but refer to grain size only (see Sections1.2 and 13.3.1).

If the user requires only a simple classification, the sediment should be classified as a phosphorite and qualifiers used to describe the predominant grain size or crystal size. For example, a phosphorite composed of sand-grade clasts can be described as a *sand-grade* **phosphorite** (see Section 4.3). The term 'phospharenite' is commonly used in the geological literature, and although 'phospharenite' is not included in the classification it may be used as a synonym of *sand-grade* phosphorite.

Phosphorites and carbonates have many textural similarities and can be classified in a similar way. Two classification schemes are available to give higher level root names to phosphorites. The first scheme is based on the textural limestone classification and Cook and Shergold's (1986) phosphorite classification (see Section 4.2.1). The second scheme is designed to classify phosphorites composed dominantly of one constituent (see Section 4.2.2).

Phosphate-rich deposits of sediments formed from the excrement of birds or bats can be given the root name **guano**.

4.2.1 Classification of phosphorites by texture

The phosphorite textural classification follows the textural limestone classification scheme (see Section 3.1.2.1) and the phosphorite classification scheme of Cook and Shergold (1986). The classification scheme is summarised in Table 11, but the limestone scheme should be consulted for more detailed descriptions of the different textures.

Any of the qualifiers referred to in Section 4.3 can be used to enhance the root names.

4.2.2 Monogranulate phosphorites

Phosphorites which are composed almost entirely of one type of allochem or micro-organism can be classified according to Table 12.

4.3 Recommended qualifiers

Qualifiers used to describe grain size

The predominant grain size can be clarified by prefixing with a grain size adjective (see Section 13.2.1, for example *cobble-grade* **phosphorite** or *coarse* **phosphate-sand**. If the sediment contains a matrix or a subsidiary component of different sized phosphate clasts this may also be defined, for example a phosphate-sand with cobble-grade phosphate clasts is described as a *phospha-cobbly* **phosphate-sand.**

Qualifiers used to describe composition of any non-phosphate components

The presence of non-phosphate particulate components can be described using qualifiers (see Section 13.3.1). For example a phosphorite with limestone clasts can be described as a *calci-clastic* **phosphorite**. If it is necessary to specify the grain size of the non-phosphate clasts the 'clastic' may be replaced by the grain size term, for example *calci-pebbly* **phosphorite**.

Table 12 Classification of phosporites comprising one type of allochem.

Dominant component	Sediment name
ooids	**ooid-phosphorite**
pisoids	**pisoid-phosphorite**
oncoids	**oncoid-phosphorite**
microoncoids	**microoncoid-phosphorite**
peloids	**peloid-phosphorite**

Qualifiers used to describe clast (allochem) type

The presence of allochems can be described using qualifiers. Allochem types comprise *bioclasts*, *lithoclasts*, *intraclasts*, *ooids*, *pellets*, *peloids* and *spastoliths* and are defined in Section 13.3.5.

Qualifiers used to describe crystal size

The crystal size of crystalline phosphorite can be defined using qualifiers, for example *cryptocrstalline* **phosphorite**. Crystal sizes are defined in Figure 13.

4.4 Rocks rich in secondary phosphate

Some rocks are rich in phosphate due to the precipitation of secondary apatite in the weathering profile. In the geological literature these rocks are sometimes given the name 'phoscrete'. This term is not included as a formally defined classification term as it is interpretative and genetic. Such sedimentary rocks should be classified solely on their compositional attributes at the time of deposition. A 'phoscrete' could therefore be classified as a *phosphate-cemented* **silicate-conglomerate** or a *phosphate-cemented* **limestone** depending on the type of host rock. However, if the rock's mode of origin is known and needs to be highlighted, the genetic name may be used alongside the formally defined classification term as a synonym or informal genetic qualifier, for example *phoscrete*, *phosphate-cemented* **silicate-conglomerate**. Classification by the physical and textural properties of the rock should still be made. If the rock is a modern day superficial deposit with an obvious mode of origin it may be classified according to the scheme *The classification of artificial (man made) and natural superficial deposits* (McMillan and Powell, 1999) and given a genetic name.

Table 11 Textural classification of phosphorites.

<table>
<tr><td colspan="5">Depositional texture recognisable</td><td rowspan="4">Depositional texture not recognisable</td></tr>
<tr><td colspan="3">Contains matrix
(silt and clay < 32 µm in diameter)</td><td>Lacks matrix</td><td rowspan="3">Components bound together by action of plants and animals in the position of growth</td></tr>
<tr><td colspan="2">Matrix-supported</td><td colspan="2" rowspan="2">Grain-supported</td></tr>
<tr><td>> 75% matrix</td><td>< 75% matrix</td></tr>
<tr><td>phosphate-mudstone</td><td>phosphate-wackestone</td><td>phosphate-packstone</td><td>phosphate-grainstone</td><td>phosphate-boundstone</td><td>phosphorite
(use qualifiers to describe crystal size)</td></tr>
</table>

5 IRON-SEDIMENTS AND IRONSTONES

Ironstones and iron-sediments are defined as those sediments which have more than 50% iron-bearing minerals (ironstones should have greater than 15 weight per cent iron; Young, 1989). The complex mineralogy of most ironstones means that any attempt to classify on the basis of even the most common phases would result in an unwieldy name. However, qualifiers may be used to add any mineralogical information to the group and root names that the user considers important (see Section 5.4). A flow diagram summarising the hierarchical classification of iron-rich sediments is shown in Figure 9.

The classification of banded ironstones is discussed in Section 5.3.

5.1 Iron-sediments

All iron-sediments are given the group name **iron-sediment**.

A more detailed classification scheme is based on the sediments grain size. The classes are defined in the same way as the siliciclastic sediments:

- gravel — over 25% of the clasts larger than 2 mm
- sand — clasts predominantly 32 µm to 2 mm, with less than 75% of the clasts smaller than 32 µm and less than 25% greater than 2 mm
- mud — over 75% of the clasts smaller than 32 µm

The grain size term is prefixed with **iron** and hyphenated, for example **iron-sand**. The classification criteria are demonstrated in Table 13.

Table 13 Classification of unlithified iron-rich sediments according to grain size.

Gravel (> 2 mm)	**iron-gravel**
Sand (32 µm–2 mm)	**iron-sand**
Mud (< 32 µm)	**iron-mud**

It should be noted that when the terms **-gravel**, **-sand** and **-mud** are combined with a compositional prefix (e.g. **phosphate-sand**) they do not have a siliciclastic connotation but refer to grain size only (see Sections 1.2 and 13.3.1).

Recommended qualifiers

The iron-sediment group and root names can be given qualifiers to describe grain size, composition of any non-ferruginous components, and clast (allochem) type. More details are given in Section 5.4.

5.2 Ironstones

All lithified iron-rich sediments are given the group name **ironstone.**

Qualifiers may be used to describe any features that are considered important. More details on the use of qualifiers in classifying ironstones are given in Section 5.4.

If the user requires only a simple classification, the sediment should be classified as an ironstone and qualifiers used to describe the predominant grain size or crystal size. For example, an ironstone composed of sand grade clasts can be described as a *sand-grade* **ironstone** (see Section 5.4).

Ironstones have many textural similarities to carbonates and phosphorites and can be classified in a similar way. Two classification schemes are available to give higher level root names to ironstones. The first scheme is based on the textural limestone classification, Young's (1989) ironstone classification and Cook and Shergold's (1986) phosphorite classification. The second scheme is designed to classify ironstones composed dominantly of one constituent (see Section 5.2.2.).

5.2.1 Classification of ironstones by texture

The ironstone textural classification follows the textural limestone classification scheme (see Section 3.1.2.1). The classification scheme is summarised in Table 14, but the limestone scheme should be consulted for more detailed descriptions of the different textures.

Any of the qualifiers referred to in Section 5.4 can be used to enhance the root names.

5.2.2 Monogranulate ironstones

Ironstones which are composed almost entirely of one type of allochem or micro-organism can be classified according to Table 15.

Table 15 Classification of ironstones comprising one type of allochem.

Dominant component	Sediment name
ooids	**ooid-ironstone**
pisoids	**pisoid-ironstone**
oncoids	**oncoid-ironstone**
microoncoids	**microoncoid-ironstone**
peloids	**peloid-ironstone**

Table 14 Textural classification of ironstones.

<table>
<tr><td colspan="5">Depositional texture recognisable</td><td>Depositional texture not recognisable</td></tr>
<tr><td colspan="3">Contains matrix
(silt and clay < 32 µm in diameter)</td><td>Lacks matrix</td><td rowspan="3">Components bound together by action of plants and animals in the position of growth</td><td rowspan="3"></td></tr>
<tr><td colspan="2">Matrix-supported</td><td colspan="2" rowspan="2">Grain-supported</td></tr>
<tr><td>> 75% matrix</td><td>< 75% matrix</td></tr>
<tr><td>iron-mudstone</td><td>iron-wackestone</td><td>iron-packstone</td><td>iron-grainstone</td><td>iron-boundstone</td><td>ironstone
(use qualifiers to describe crystal size)</td></tr>
</table>

5.3 Banded ironstones (laminated ironstones)

The terms 'banded iron formation' or 'iron formation' have been used to describe a stratigraphical unit and should therefore not be used to classify a sediment type. A banded ironstone is composed of silica-rich and iron-rich laminae (< 10 mm) or bands (> 10 mm). It should only be classified as an ironstone if the iron-mineral content exceeds 50%. The rock name should be given qualifiers to describe the banding/lamination as well as the composition of the subordinate bands/laminae, for example *banded, siliceous* **ironstone**. If the rock contains less than 50% iron minerals it should be classified under the non-clastic silica-rich schemes (see Section 8) a chert and given appropriate qualifiers, for example *banded-ferruginous* **chert**.

5.4 Recommended qualifiers

Qualifiers used to describe grain size

The predominant grain size can be clarified by prefixing with a grain size adjective (see Section 13.2) for example *pebble-grade* **ironstone** or *fine* **iron-sand**. If the sediment contains a matrix or a subsidiary component of different sized iron clasts this may also be defined, for example an iron-sand with pebble-grade calcite clasts is described as a *calci-pebbly* **iron-sand**. The **iron-** can be replaced by a specific iron mineral, for example **sideritic-.**

Qualifiers used to describe composition of any non-ferruginous components

The presence of non-ferruginous particulate components can be described using qualifiers (see Section 13.3.1). For example an ironstone with limestone clasts can be described as a *calciclastic* **ironstone**. If it is necessary to specify the grain size of the non-ferruginous clasts the 'clastic' may be replaced by the grain size term, for example *calci-pebbly* **ironstone**.

Qualifiers used to describe clast (allochem) type

The presence of allochems can be described using qualifiers. Allochem types comprise *bioclasts*, *lithoclasts*, *intraclasts*, *ooids*, *pellets*, *peloids* and *spastoliths* and are defined in Section 13.3.5.

Qualifiers used to describe crystal size

The crystal size of crystalline ironstones can be defined using qualifiers, for example *medium-crystalline* **ironstone**. Crystal sizes are defined in Figure 13.

Qualifiers used to describe bands and laminae

The presence of laminae (< 10 mm) or bands (> 10 mm) can be described using qualifiers. If the laminae or bands are of a non-ferruginous composition this may also be defined with a qualifier, for example *laminated, silicious* **ironstone.**

Qualifiers to describe type of iron mineral

The recommended mineralogical nomenclature for iron minerals is described in Section 13.3.2.

5.5 Rocks rich in secondary iron

Some rocks are rich in iron because secondary iron has precipitated in the weathering profile. In the geological literature these rocks are sometimes given the name 'ferricrete'. This term is not included as a formally defined classification term as it is interpretative and genetic. Such sedimentary rocks should be classified solely on their compositional attributes at the time of deposition. A 'ferricrete' could therefore be classified as an *iron-cemented* **silicate-conglomerate** or an *iron-cemented* **limestone** depending on the type of host rock. However, if the rock's mode of origin is known and needs to be highlighted, the genetic name may be used alongside the formally defined classification term as a synonym or informal genetic qualifier, for example *ferricrete, iron-cemented* **silicate-conglomerate**. Classification by the physical and textural properties of the rock should still be made. If the rock is a modern-day superficial deposit with an obvious mode of origin it may be classified in the superficial deposit scheme *The classification of artificial (man-made) and natural superficial deposits* (McMillan and Powell, 1999) and given a genetic name.

6 ORGANIC-RICH SEDIMENTS AND SEDIMENTARY ROCKS

Sediments and sedimentary rocks rich in organic-matter are defined as those where the organic content is sufficiently high to have a noticeable effect on the lithology. A definition based on a greater than 50% volumetric abundance of organic matter is not possible because historically the definitions of sediments and sedimentary rocks rich in organic-matter have been based on their quality as fossil fuels. The humic coal series is defined on the abundance of inorganic residue (ash) following combustion, whereas oil shales are defined as those sediments which yield oil on destructive distillation. Coals were defined by the National Coal Board (1972) as those with less than 40% ash (by weight air dried). This definition can be tied in with the rest of the sedimentary classification scheme by slightly altering it to allow coals to have less than 50% ash or more than 50% organic matter. The total organic carbon content (TOC) as determined by combustion can vary in sapropelites (oil shales) from less than 1% to over 80%. Therefore many sapropelites (oil shales) have more than 50% siliciclastics or lime-clasts and should really be defined as silicate-muds and silicate-mudstones or lime-muds and lime-mudstones (see Sections 2.3, 3.1. However, if the user wishes to focus on the organic content, such sediments may be classified under the alternative scheme, see Section 6.3 Inorganic sediments and sedimentary rock rich in sapropelic matter.

Because the exact definitions of organic sediments and sedimentary rocks depend on analytically determined data, detailed visual descriptions of the different types of organic sediments are given. Sediments can be reclassified following analysis if necessary.

The main types of organic sediments and sedimentary rocks are the humic coal series, the sapropelic coal series and the inorganic sediments and sedimentary rocks rich in sapropelic matter. Each series relates primarily to the type of organic matter and amount of inorganic components but are also influenced by the type of decomposition the organic matter has undergone. The main sediment types and sedimentary rocks in each series are summarised in Table 16. The different series are transitional and because they grade into each other it is hard to define boundaries. It is also not possible to define a type of sediment or sedimentary rock by its total organic carbon (TOC) because this increases from its unlithified to lithified state due to concentration of the organic carbon as water is driven off. For instance 'oil shales' usually have between 8 to 55% TOC whereas their modern analogues only have 2 to 7% TOC.

A flow diagram summarising the hierarchial classification of organic-rich sediments and sedimentary rocks is shown on Figure 10.

This section has been compiled by adapting and integrating definitions from a number of references: Gallois (1979), Hutton et al. (1981), International Committee for Coal Petrology (1963), National Coal Board (1972), Parnell (1988), Stach (1975), Talbot (1988), Tucker (1991) and Ward (1984).

6.1 Humic coal series

The humic coal series develops from peat, which is an unlithified heterogeneous mixture of a wide range of plant debris. Lithified humic deposits are given the group name 'coal'. They are visibly stratified, consisting of layers or bands of organic matter of varying appearance with individual layers usually no more than a few centimeters in thickness (Ward, 1984). The humic coal series has less than 50% inorganic residue (ash) by weight air dried, following combustion. Humic coals have a low hydrogen content.

The humic coal series is initially subdivided into humic coals, which have less than 15% ash, and impure humic coals which have 15 to 50% ash. Sediments and sedimentary rocks which have more than 50% ash but enough humic matter to affect the lithology can be given a carbonaceous qualifier and classified according to the dominant component.

6.1.1 Classification of humic deposites by rank of coalification

The pure humic coal series can be simply subdivided into:

- unlithified form — **peat**
- lithified form — **coal**

The sediment series is subdivded further on the degree of lithification, and rank of coalification. There is no group name available for unlithified forms. More detailed classification schemes exist for coals of particular economic importance.

The rank of the coal series is determined by the carbon and volatile content (see Table 16), but the different stages can be readily recognised by their physical attributes.

Table 16 Classification of humic deposits by rank with approximate values of various parameters used to estimate rank. Adapted from Tucker (1991) and Stach (1975). The following physical attributes are associated with the different ranks of humic deposits:

Carbon content % dry ash-free	Volatile content %	Rank stages of humic Coal series
< 60	> 63%	**peat** (unlithified)
60–75	46–63%	**lignite**
75–90	14–46%	**bituminous coal**
> 90	< 14%	**anthracite**

- **peat** — an unconsolidated deposit of semi-carbonised plant remains, with individual plant remains commonly seen with the unaided eye. Peat has a yellowish brown to brownish black colour, is generally of a fibrous consistency and can be plastic or friable. In its natural state it can be cut and has a very high moisture content (> 75%, generally > 90%). It can be distinguished from lignite by the fact that the greater part of its moisture content can be squeezed out by pressure (e.g. in the hand)
- **lignite** — a consolidated, dull, soft brown to black coal with many readily discernible plant fragments set in a finer grained organic matrix. Tends to crack and fall apart on drying. For a more precise subdivision and definition see Section 6.1.1.1
- **bituminous-coal** — black, hard and bright coal, which typically breaks into rectangular lumps. For a more precise subdivision and definition see Section 6.1.1.2
- **anthracite** — A hard black coal with a semi-metallic lustre and semiconchoidal fracture. It ignites with difficulty and burns without smoke

6.1.1.1 Classification of humic lignites

- **brown-lignite** — brown with a dull or earthy lustre; many are banded with a fibrous structure
- **black-lignite** — dark brown to black with a silky lustre, much harder than brown lignites

Humic lignites are macroscopically similar to sapropelic lignites. Sapropelic lignites may possibly be distinguished by their homogenous, non-stratified appearance. If differentiation is difficult humic lignites could be identified by their low hydrogen content.

6.1.1.2 Classification of humic bituminous coals

The bituminous coals can be subdivided in two ways. The first scheme is based on lithotypes which are macroscopically recognisable bands of coal seams (Stopes, 1919). This scheme can be used for describing individual specimens or discrete horizons within a coal seam. The second scheme, introduced by Diessel (1965) describes the brightness of the coal, and should be used in the field to describe megascopically distinct layers of coal seams.

Classification of bituminous coals according to lithotypes

Definitions of the different lithotypes follow those given by Ward (1984).

- **vitrain** — black, glassy, vitreous coal. It occurs as thin bands, commonly less than 6 or 8 mm in thickness. It is usually very closely jointed and breaks into cubic pieces generally with a conchoidal fracture
- **clarain** — consists of bright to semi-bright bands of finely laminated coal. Clarain generally exhibits an overall silky lustre, and commonly contains fine vitrain bands alternating with a duller attrital groundmass
- **fusain** — black, soft, friable coal which closely resembles charcoal. It easily disintegrates into a black, fibrous powder. A hard form of fusain that has been impregnated with mineral matter can be found in some coals
- **durain** — dark grey to black bands with a dull to slightly greasy lustre. The material is relatively hard compared to other lithotypes, and tends to break into large blocky fragments. Durain may be confused with impure coal which is also dull and hard, but it can be distinguished by its lower density

Classification of bituminous coals according to brightness

- **bright-coal**
- **banded-bright coal**
- **banded-coal**
- **banded-dull coal**
- **dull-coal**

6.1.2 Classification of the impure humic coal series

The impure humic coal series contains 15 to 50% ash (approximately equivalent to 50 to 85% organic matter).

Lithified forms are termed **impure-coals**. Qualifiers may be used to describe the mineral impurites which are usually in the form of siliciclastics, pyrite, siderite or carbonate.

The unlithified analogue of impure-coal is termed a **sandy-peat** or **muddy-peat**. The root name depends on the mineral component.

The composition and form (disseminated, nodular etc) of the mineral impurities can be described using qualifiers. Impure coals with clay disseminated throughout the organic matter are given the specific root name **bone coal**. Bone coal can be recognised by its dull appearance and grey streak.

6.2 Sapropelic coal series

The sapropelic coal series develops from sapropel which is an organic mud containing concentrations of miospores (spores and pollen) and algae. Lithified sapropelic coals have a homogeneous texture, are characteristically massive and commonly display conchoidal fractures. The structures of algae, miospores and other fine plant remains are usually quite well preserved. Sapropelic coals have a high hydrogen content. The sapropelic coal series has less than 50% inorganic residue (ash) by weight air dried, following combustion.

The sapropelic coal series is initially subdivided on the degree of lithification and rank of coalification. A more detailed classification is based on the type of organic matter.

6.2.1 Classification of sapropelic coal series by degree of lithification and rank

The rank of the sapropelic coal series is determined by the carbon and volatile content (see Table 17), but the different stages can be readily recognised by their physical attributes.

The sapropelic coals are of limited economic importance and are not subdivided into the bituminous and anthracite rank stages which are commonly applied to the humic coals.

The following physical attributes are associated with the different ranks of the sapropelic coal series:

- **sapropel** — an unlithified dark, pulpy, fine organic mud containing concentrations of algae and miospores that is more or less identifiable. It is recommended that the term sapropel is used in preference to terms such as gyttja, dy, afja, forna etc which have been used inconsistently and haphazardly in the past. Qualifiers may be used to describe the dominant components, for example *alga* or *miosporal*

Table 17 Classification of sapropelic coals by rank. Adapted from Tucker (1991) and Stach (1982).

Carbon content % dry ash free	Volatile content %	Rank stages of sapropelic coal series
< 60	> 63%	**sapropel** (unlithified) **coorongite**
60–70	52–63%	**sapropelic lignite**
> 70	< 52%	**sapropelic coal**

- **coorongite** — rubber-like, highly resilient structureless algal deposit
- **sapropelic lignite** — Sapropelic lignites are macroscopically similar to humic lignites. It may be possible to distinguish sapropelic lignites by their homogeneous, non-stratified appearence. If differentiation is difficult sapropelic lignites can be accurately differentiated by chemical analysis
- **sapropelic coal** — characteristically fine grained, faintly bedded to homogeneous and massive. They are generally dark in colour with dull to greasy lustre and typically display conchoidal fractures. For a more precise subdivision and definition see following section.

6.2.1.1 Classification of sapropelic coals

Sapropelic coals are subdivided by type of organic matter and other physical properties.

- **cannel-coal** — dull black, waxy lustre, homogeneous, concoidal fracture, rich in miospores with very little alginite. Macroscopic examination shows no stratification. Microscopic examination shows that compared with humic coals the macerals are more intimately mixed and at the same time are finer and more uniformly grained. Moreover cannel coal frequently shows a uniform microstratification and is more homogeneous in structure than humic coal. Siderite is commonly abundant in cannel coals. Those in which siderite exceeds clay minerals are given a *sideritic* qualifier (they are classified under the ironstone classification scheme if siderite becomes the dominant component)
- **boghead-coal** — similar to cannel coals but browner and rich in alginite with very few miospores. They appear unstratified on macroscopic examination. Microscopic examination shows that boghead coal consists of alginite and very finely dispersed inertinite and vitrinite. The proportion of alginite can vary widely. Boghead coals are sometimes referred to as torbanites. This term is not recommended for usage

Table 18 Classification of inorganic sediments and sedimentary rocks rich in sapropel.

Sediments		Sedimentary rocks		
TOC	Sediment type (depends on type of inorganic matter)	TOC	Sedimentary rock type (depends on type of inorganic matter and sapropelic matter)	
			sapropelic matter rich in algae	sapropelic matter rich in miospores
0.5–3%	*sapropelic* **silicate-mud** *sapropelic* **lime-mud**	1–8%	*kerogenic* **silicate-mudstone** *kerogenic* **limestone**	*sapropelic* **silicate-mudstone**
3–100 %	**sapropel** (qualifiers may be given to describe inorganic component)	8–50%	**sapropelite**	**cannel-mudstone**
		> 50%	see classification of sapropelic coals	

There is a continuous range of transitional stages between boghead coal and cannel coal with both alginite and miospores present. Intermediate types can be called:

- **boghead-cannel coal** — miospores > alginite
- **cannel-boghead coal** — alginite > miospores

6.3 Inorganic sediments and sedimentary rocks rich in sapropelic matter

Inorganic sediments and sedimentary rocks have a higher abundance of inorganic matter than the sapropelic-coal series. They can be classified according to their main inorganic component and given a sapropelic qualifier, for example *sapropelic* **silicate-mudstone**. However, if the user wishes to focus on the organic component, the sediment or rock can be classified according to the following guidelines:

The sediment or sedimentary rocks can be classified according to their type of sapropelic matter, that is algae or miospores (spores and pollen). The majority of sediments and sedimentary rocks in this group are rich in algae and form the sapropelite (oil shale) series. The term 'oil shale' is considered misleading and it is recommended that it is replaced by 'sapropelite'. Inorganic sediments and sedimentary rocks rich in miospores are relatively rare but form the cannel-mudstone series. Sediments and sedimentary rocks from the sapropelite series are generally described by their total organic carbon (TOC) as determined using a LECO combustion furnace. The definition of the different classes is summarised on Table 18. Explanation of the classification is given below.

6.3.1 Classification of unlithified inorganic sediments rich in sapropelic matter

Sapropelites and cannel mudstones are both derived from the unlithified fine organic mud termed sapropel. These sapropels contain more inorganic matter and plant matter than the sapropels that form sapropelic coals. No distinction is presently made between the sapropels that are likely to form sapropelites (rich in algae) and cannel mudstones (rich in miospores) to those that form sapropelic coals. The sapropels likely to form sapropelites and cannel-mudstones have a higher inorganic content and it is recommended that they are given *muddy* or *calcareous* qualifier to describe the inorganic component, for example *muddy* **sapropel**. Qualifiers can also be used to describe the dominant type of organic matter, for example *alga* **sapropel** and *miosporal* **sapropel**.

Research into sapropels thought to form oil shales (sapropelites) indicates that the TOC can be quite variable: 2 to 7% in the eastern Mediterranean (Anastasakasis and Stanley, 1984), 7 to 11% in the deep water anoxic sediments from Lake Tanganyika (Degens et al., 1971) and 3 to 26% on the south-west African Shelf (Demaison and Moore, 1980). It is recommended that sediments classified as sapropels should have at least 3% TOC. It is not clear how high the TOC has to be before a sapropel would form a coal rather than a sapropelite.

Siliciclastic and calcareous sediments and sedimentary rocks with 0.5 to 3% sapropelic matter should be classified according to their main component and given a sapropelic qualifier, for example *sapropelic* **lime-mud**.

6.3.2 Classification of inorganic sedimentary rocks rich in sapropelic matter

Inorganic sedimentary rocks rich in sapropel are classified according to their type of organic matter. Sapropelites are rich in alginite, whereas cannel mudstones are rich in miospores.

6.3.2.1 Classification of sapropelites (oil shales)

The term 'oil shale' is misleading because most of the organic content is in the form of kerogen which only yields oil artificially on heating or, naturally, under the action of the geothermal gradient and overburden pressure in the earth's crust. It is recommended that the term 'oil shale' is replaced by **sapropelite** which is a more appropriate name for a rock that is a type of lithified *muddy* **sapropel.**

The TOC of sapropelites has been reviewed by Hutton et al. (1980). The TOC content can vary from less than 1% to as much as 81% in a sapropelite from Tasmania, although most sapropelites fall in the range of 8 to 55% TOC. It is recommended that the lower limit of the sapropelites should be 8% TOC and the upper limit 50% TOC. Sedimentary rocks rich in alginite with greater than 50% TOC should be classified as a **sapropelic coal** or more specifically **boghead-coal**.

Siliciclastic and calcareous sedimentary rocks with 1 to 8% TOC should be classified according to their main component and given the qualifier *kerogenic*, for example *kerogenic* **silicate-mudstone**.

A sapropelite can be recognised in hand specimen by its bituminous smell and by the curled sliver of rock produced when it is scraped with a pen knife (information from Dr B M Cox, 1997). This definition may not distinguish between *kerogenic* **silicate-mudstones** and **sapropelites** and it is possible that sediments and sedimentary rocks would have to be reclassified following the determination of TOC.

Subdivision of sapropelites according to the properties of the organic matter

Sapropelites can be given a more detailed classification by reference to the properties of the organic matter:

- **telalginite** — organic matter is present in large discretely occurring algal bodies. This term was introduced by Hutton et al. (1980)
- **lamalginite** — algal matter occurs in very thin laminae cryptically interbedded with mineral matter. This term was introduced by Hutton et al. (1980)

6.3.2.2 Classification of cannel-mudstones

The organic component in a **cannel-mudstone** consists predominantly of miospores. The TOC should be between 8 and 50%. If it has more than 50% TOC it should be classified as a sapropelic coal or more specifically a cannel coal. Sediments and sedimentary rocks with less than 8% TOC should be classified according to their main component and given the qualifier *sapropelic*, for example a *sapropelic* **silicate-mudstone**.

7 NON-CARBONATE SALTS

The non-carbonate salt group is a non-genetic term for what are commonly called evaporite minerals. The root name is derived from the dominant mineral species (e.g. halite) and given the suffix **-stone**. For example **gypsum-stone** should be used rather than gypsum. In addition to the compositional classification there are a number of sediment names that are used to describe detrital salt deposits, these are discussed in Section 7.2. Non-carbonate salts are commonly present in a host rock. The host rock may consist of other non-carbonate salts or other types of sediment. Recommendations for their classification are discussed in Section 7.3. Recommended qualifiers are described in Section 7.4.

A flow diagram summarising the classification of non-carbonate salts is shown on Figure 11.

7.1 Sedimentary rocks composed of non-carbonate salt

All **non-carbonate salts** are given one group name

Salts can be divided into sulphates, chlorides and borates:

Sulphates

The sedimentary rocks consisting mainly of sulphate minerals are:

- **gypsum-stone** — gypsum ($CaSO_4.2H_2O$) is a soft mineral with a number of different crystal habits; colour varies
- **anhydrite-stone** — anhydrite ($CaSO_4$) has orthorhombic crystals, and is usually white
- **barite-stone** — barite ($BaSO_4$) has orthorhombic, heavy, colourless to yellow tabular crystals. Also occurs in granular form or compact masses
- **polyhalite-stone** — polyhalite ($K_2MgCa_2(SO_4)_4.2H_2O$) has pink or red triclinic crystals, in compact lamellar masses
- **kierserite-stone** — kierserite ($MgSO_3$) has white monoclinic crystals
- **kainite-stone** — kainite ($KMgCl\ SO_4.3H_2O$) has white monoclinic irregular granular masses

Chlorides

The sedimentary rocks consisting mainly of chlorides are:

- **halite-stone** — halite (Na Cl) has massive granular cubic crystalline forms, and a salty taste
- **sylvite-stone** — sylvite (KCl) has colourless or white cubic crystals; and occurs in crystalline, massive and granular form
- **carnallite-stone** — canallite ($KMgCl_3.6H_2O$) is a white to reddish orthorhombic mineral

Borates

The main boron-bearing minerals are:

- **borax-stone** — borax ($Na_2B_4\ O_7.10H_2O$) has white prismatic crystals with tinges of blue, green or grey
- **kernite-stone** — kernite ($Na_2B_4O_7.4H_2O$) has white, massive crystals
- **ulexite-stone** — ulexite ($NaCaB_5O_9.8H_2O$) is a white, globular mineral with a fibrous internal structure
- **colemanite-stone** — colemanite ($Ca_2B_6O_{11}.5H_2O$) occurs as colourless or white prismatic crystals or as granular masses

7.2 Detrital deposits of salts

The detrital salt deposits are classified in a similar manner to other detrital sediments and sediment rock.

7.2.1 Unlithified detrital salt deposits

The root name should include reference to the grain size and the composition. Examples of sediments include:

- **gypsum-sand** — a sediment composed of sand-sized (32 µm to 2 mm) particles of gypsum.
- **gypsum-gravel** — a sediment composed of gravel-sized (> 2 mm) particles of gypsum.

7.2.2 Lithified detrital salt deposits

The rock should be classified according to its dominant mineral species using one of the root names recommended in Section 7.1. Qualifiers can be used to describe the predominant grain size. For example a gypsum-stone composed of sand-grade clasts can be described as a *sand-grade* **gypsum-stone**.

A more detailed description could be given by reference to the depostional texture. Terms are taken from the textural limestone classification scheme (see Section 3.1.2.1). Common examples are:

- **gypsum-grainstone** — a grain supported sedimentary rock composed of sand-sized (32 µm to 2 mm) particles of gypsum with little matrix
- **gypsum-packstone** — a grain-supported sedimentary rock composed of sand-sized (32 µm to 2 mm) particles of gypsum with intergranular spaces filled by matrix

Detrital deposits of other non-carbonate salts should be named in a similar manner.

7.3 Non-carbonate salts present in a host sediment

Sedimenttary rocks that comprise two or more types of non-carbonate salts

If two types of non-carbonate salts are equal in abundance they should be classified as a hybrid sediment (see Section 11. Both types of non-carbonate salts should be used in the root name and joined by a slash, for example **gypsum/anhydrite-stone**. If one type of non-carbonate salt is dominant then this should be used as the root name and the other non-carbonate salt used as a qualifier, for example a *halite* **gypsum-stone** has more gypsum than halite. In both cases a qualifier (see Section 7.4) should be used to describe the textural relationship of the two non-carbonate salts, for example a *laminated* **gypsum-anhydrite-stone.**

Sedimentary rocks that comprise a non-carbonate salt mixed with a different sedimentary rock type

Rocks which contain a non-carbonate salt mixed with a different type of sedimentary rock should be classified only as a non-carbonate salt if this is the most abundant component. Otherwise they should be classified according to the most abundant component, and the non-carbonate salt used as a qualifier for example *anhydrite* **dolostone**. If the different sediment types are equal in abundance they should be classified as a hybrid sedimentary rock (see Section 11). Both sediment types should be used in the root name and joined by a slash, for example **dolostone/anhydrite-stone**. In both cases a qualifier (see Section 7.4) should be used to describe the textural relationship of the different sediment types, for example *laminated, calcareous* **halite-stone**.

7.4 Qualifiers to describe the physical properties of non-carbonate salts

Non-carbonate salts can occur within a host sediment or as a pure mineral. Qualifers can be used to describe the mineral texture, crystal form, crystal size and if relevant, the textural relationship with the host sediment.

Qualifiers to describe mineral texture and crystal form of non-carbonate salts

The following qualifiers are recommended for use where appropriate.

Selenitic: clear, colourless monoclinic crystals or large crystalline masses that cleave into broad folia; term is generally applied to gypsum.
Palmate: crystals radiate from a common centre.
Discoidal: disc shaped crystals.
Rosette (desert rose): crystalline aggregate resembling a rose.
Porphyrotopic: large crystal in a finer-grained matrix.
Alabastrine: small to large interlocking crystals.
Fibrous: fibrous with a silky lustre (satin spar).
Lath shaped: lath shaped crystals.
Chevron texture: impurities and bubbles arranged in a chevron pattern.

Qualifiers to describe crystal size

The crystal size of crystalline non-carbonate salts can be defined using qualifiers, for example *medium-crystalline* **gypsum-stone**. Crystal sizes are defined in Figure 13.

Qualifiers to describe the relationship of non-carbonate salts with host sediment

The following textural terms can be used to describe the textural relationship of non-carbonate salts with the host sediment.

Enterolithic: ribbons of intestine like folds.
Chicken-wire: irregular nodules (usually of anhydrite) separated by thin stringers of sediment.
Contorted-bedded: bedded non-carbonate salts in which some highly deformed beds are associated with undeformed ones.
Ropy-bedded: bedded non-carbonate salts in which all the beds have been deformed.
Laminated: thin discrete layers of sediment.
Highly-distorted: non-carbonate salts have been so intensely deformed that the original structure is no longer recognisable.
Brecciated: rock composed of angular fragments of evaporite.
Polygons: halite crust breaks up into a polygonal arrangement.
Tepees: inverted 'v' fold at the edge of a large polygon.

These terms are commonly used to describe non-carbonate salts, but may be used for other sedimentary rocks where appropriate.

If a qualifier is used to describe both the the mineral texture/crystal form as well as the textural relationship with the host sediment then the mineral texture/crystal form qualifier should follow the textural relationship with host sediment qualifier, for example *enterolithic, fibrous* **anhydrite-stone**.

8 NON-CLASTIC SILICEOUS SEDIMENTS AND SEDIMENTARY ROCKS

Non-clastic siliceous sediments are defined as those which are composed of more than 50% silica of biogenic or chemical origin. Qualifiers are used to describe additional components. The classification is based upon the stage of the mineralogical transformation of silica, the type of silica and, if recognisable, the type of biogenic matter. Many non-clastic siliceous sediments contain clay or calcareous matter, which can be described using qualifiers. If the sediment contains more than 50% clay or carbonate it should be classified accordingly and given the qualifier *siliceous*. Non-clastic siliceous sediments generally appear in the geological record as bedded or nodular types. The type of deposit can be referred to with a qualifier (e.g. *nodular* **chert**) but this should not affect the actual classification of the sediment type. The classification of silica-dominated banded ironstones is discussed in Section 8.3. Comments regarding the classification of rocks rich in secondary (diagenetic) silica are given in Section 8.5.

A flow diagram summarising the hierarchical classification of non-clastic siliceous sediments is shown on Figure 12.

This classification scheme has been compiled by adapting definitions and classifications from IIjima and Utada (1983), the lithological classification scheme adopted for use by the JOIDES Planning Committee (see for example Roberts et al., 1984) and Tucker (1991).

8.1 Non-clastic siliceous sediments

All non-clastic siliceous sediments are given the group name **siliceous-ooze**.

Oozes have little strength and are readily deformed under the finer or broad blade of a spatula (Roberts et al., 1984). Detailed analysis by X-ray powder diffractogram would show the silica to be composed of amorphous opal, frequently referred to as opal-A.

They may be given a more detailed root name on the basis of their biogenic fossil type into:

- **radiolarian-ooze** — predominantly composed of radiolaria
- **diatomaceous-ooze** — predominantly composed of diatoms
- **sponge-spicular-ooze** — predominantly composed of sponge spicules

8.2 Non-clastic siliceous sedimentary rocks

Non-clastic siliceous sedimentary rocks are initially subdivided into three main categories on the basis of their porosity. The sediments are then classified according to their type of silica and the dominant kind of biogenic fossil.

8.2.1 Non-clastic siliceous sedimentary rocks usually with porosities of 50% to 90%

This group includes sediments formed of biogenic silica and those formed of non-biogenic silica. Detailed analysis by X-ray powder diffractogram would show the silica to be composed predominantly of opal-CT.

- **diatomite** — composed dominantly of diatoms
- **radiolarite** — composed dominantly of radiolaria
- **spiculite** — composed dominantly of sponge spicules
- **sinter** — lightweight, porous, white, opaline variety of silica

8.2.2 Non-clastic siliceous sedimentary rocks usually with porosities of 15% to 30%

Siliceous rocks in this group have the texture, lustre and conchoidal fracture of porcelain. All rocks in this group are given the group name **porcellanite.**

A more detailed root name can be given according to the type of silica. It may not be possible to accurately use this classification without X-ray analysis.

- **opaline-porcellanite** — silica includes amorphous silica (opal-A), opal CT, low-cristobalite and tridymite
- **quartzose-porcellanite** — silica consists predominantly of quartz

8.2.3 Non-clastic siliceous sedimentary rocks usually with porosities of less than 10%

Siliceous rocks in this group are dense, very hard and have a vitreous lustre. All rocks in this group are given the group name **chert.**

A more detailed root name can be given according to the type of silica. It may not be possible to accurately use this classifcation without X-ray analysis.

- **opaline-chert** — silica includes amorphous silica (opal-A), opal CT, low-cristobalite and tridymite
- **quartzose-chert** — silica consists predominantly of quartz (88 to 98%)

A number of root names are available to describe distinctive sediment types:

- **jasper** — a form of red silica, the colour is due to the presence of haematite
- **flint** — a nodular form of grey/black chert. This term is restricted to nodules of chert present in Cretaceous chalk
- **agate** — translucent cryptocrystalline quartz; this is a variegated chalcedony, commonly mixed or alternating with opal and characterised by banded colours

8.3 Silica-dominated banded ironstones

The terms 'banded iron formation' or 'iron formation' have been used to describe a stratigraphical unit and should therefore not be used to classify a sediment type. A banded ironstone is composed of silica-rich and iron-rich laminae (< 10 mm) or bands (> 10 mm). It should only be classified as a non-clastic siliceous sedimentary rock if the non-clastic silica content exceeds 50%. The sediment should be given qualifiers to describe the banding/lamination as well as the composition of the subordinate bands/laminae, for example *banded, ferruginous* **chert**. If the rock contains less than 50% non-clastic silica minerals it should be classified under the ironstone scheme as an **ironstone** and given appropriate qualifiers, for example *banded-siliceous*.

8.4 Recommended qualifiers

Qualifiers to describe siliceous biogenic components

The presence of recognisable biogenic components can be described using qualifiers. Siliceous biogenic components usually comprise either diatoms, radiolaria or sponge spicules. If more than one biogenic component is present, the minor component is listed first, for example a *radiolarian, diatomaceous* **chert**.

Qualifiers to describe type of sedimentary structures

If bedding structures are visible the chert may be given the qualifier *bedded*. Bedded cherts are biogenic in origin and may be further classified by using qualifiers to describe the biogenic component. The qualifier describing the biogenic component is considered more important and should directly precede the root name, for example *bedded, radiolarian* **chert**. If the chert is nodular it may be given the qualifier *nodular*.

8.5 Sedimentary rocks rich in secondary silica

Some rocks are rich in silica because of secondary (diagenetic) processes. These should be classified under the host rock classification scheme. However, there are some commonly used terms in the literature relating to rocks rich in secondary silica:

- **silcrete** — a conglomerate consisting of surficial sand and gravel cemented into a hard mass by silica
- **ganister** — (seat earth): a hard, fine-grained quartzose sandstone found below coal seams. It is composed of subangular quartz particles cemented with secondary silica, and can be distinguished from chert by its granular texture

These terms are not included as formally defined classification terms as they are interpretative and genetic. Such sedimentary rocks should be classified solely on their compositional attributes at the time of deposition. Therefore a 'silcrete' should be classified as a *silica-cemented* **silicate-conglomerate** and a 'ganister' as a *silica-cemented* **silicate-sandstone**. However, if the rock's mode of origin is known and needs to be highlighted, the genetic name may be used alongside the formally defined classification term as a synonym or informal genetic qualifier, for example *silcrete, silica-cemented* **silicate-conglomerate**. Classification by the physical and textural property of the rock should still be made. If the rock is a modern day superficial deposit with an obvious mode of origin it may be classified according to the superficial deposit scheme *The classification of artificial (man made) and natural superficial deposits* (McMillan and Powell, 1999) and given a genetic name.

9 MISCELLANEOUS HYDROXIDE, OXIDE AND SILICATE SEDIMENTS AND SEDIMENTARY ROCKS

Hydroxide, oxide and silicate sediments and sedimentary rocks are subdivided into two main groups: monomineralic aluminium-silicates and hydroxides and oxides of iron and alumina.

9.1 Monomineralic aluminium-silicates

Monomineralic aluminium silicates take the form of clays or claystones. The criteria on which they are named is shown in Table 19.

These names are synonymous with terms such as china clay, fuller's earth and bentonite, but such terms are not recommended for use because of their stratigraphical and industrial implications. However, if such terms are appropriate they may be used as a synonyms:

- china clay can be used as a synonym for **kaolinite-claystone**
- fuller's earth and bentonite can be used as synonyms for **smectite-claystone**

Table 19 Classification of monomineralic aluminium-silicicates.

Component name	Unlithified sediment name	Lithified sediment
illite kaolinite smectite unspecified mineral	**illite-clay** **kaolinite-clay** **smectite-clay** **'mineral-type'-clay**	**illite-claystone** **kaolinite-claystone** **smectite-claystone** **'mineral-type'-claystone**

9.2 Hydroxides and oxides of iron and alumina

The classification of hydroxides and oxides of iron and alumina is based upon the state of hydration of the silicate minerals.

lithomarge — consists essentially of hydrated silicates of alumina or kaolinite minerals

bauxite — predominantly hydrated aluminium oxides with iron oxides and other impurities

10 SEDIMENTS AND SEDIMENTARY ROCKS BASED ON GRAIN SIZE OR CRYSTAL SIZE

If the composition of a sediment is unknown it may be simply classified by reference to its clast or crystal size.

10.1 Clastic sediments

Sediments composed of clasts can be classified according to their grain size. The classes are defined in the same way as the siliciclastic sediments. The main grain size subdivisions are:

- over 25% of the clasts larger than 2 mm
  classify as a **gravel-grade-sediment**
  or **gravel-grade-sedimentary rock**
- clasts predominantly 32 µm to 2 mm, with less than 75% of the clasts smaller than 32 µm and less than 25% larger than 2 mm
  classify as a **sand-grade-sediment**
  or **sand-grade-sedimentary rock**
- over 75% of the clasts smaller than 32 µm
  classify as a **mud-grade-sediment**
  or **mud-grade-sedimentary rock**

A more detailed grain size classification may be given. The clast sizes are defined in Figure 13. The clast terms (e.g. pebble or medium-sand) should be suffixed with **-grade-sediment** or **-grade-sedimentary rock** as shown above.

10.2 Crystalline sediments

Sediments composed of crystals can be classified according to their crystal size. The different crystal sizes are defined in Figure 13. The crystal term should be suffixed with **-crystalline sediment**. For example a rock with crystals between 32 µm and 250 µm can be classified as a **fine-crystalline-sedimentary rock** and a rock with crystals smaller than 4 µm can be classified as a **crypto-crystalline-sedimentary-rock**.

11 HYBRID SEDIMENTS AND SEDIMENTARY ROCKS

A sediment which comprises more than one primary compositional component, with no component forming more than 50%, should be classified as a hybrid sediment. Classification is divided into two parts:

11.1 Sediment or sedimentary rock comprising two equal components

This classification would generally be applied in the field when it is not possible to determine whether one component forms more than 50%.

Sedimentary rocks should be given a name formed by joining the group names associated with the different clast types. The names should be joined by a slash (/) and given in alphabetical order, for example **limestone/silicate-sandstone** or **ironstone/phosphorite**. The grain size may be referred to with a qualifier, for example *sand-grade* **limestone/phosphorite**.

Names for unlithified hybrid sediments should be formed in a similar way, for example **lime-sediment/phosphate-sediment**. The name can be abbreviated by dropping the first 'sediment', for example example **lime/phosphate-sediment**. The grain size may be referred to by using a qualifier, for example *pebble-grade* **lime/silicate-sediment**. Alternatively, the grain size of the hybrid sediment can be referred to by joining the grain size based root names rather than the group names, for example **lime-gravel/silicate-sand.**

If detailed modal analysis of a representative thin section indicated that one component is greater than 50% the sediment could be re-classified under the appropriate classification scheme.

11.2 Sediment or sedimentary rock comprising three or more components

A sediment or sedimentary rock comprising three or more components which form more than 5% but less than 50% of the sediment should be given the name **hybrid-sediment** or **hybrid-sedimentary-rock**. This may be prefixed with qualifiers to describe the different clast compositions and grain size.

The terms used to describe different clast and mud compositions should follow the guidelines given in Section 13.3.1 and summarised here.

- Clasts (silt-grade and above) are described using their composition with a 'clast' suffix. The most common are *siliciclast*, *phosphaclast*, *ferruclast*, *doloclast*, *aragoclast*, *calciclast* and for an unspecified calcareous clast *carbonate-clast*.
- Muds are described using their composition with a muddy suffix. The most common are *ilicimuddy*, *phosphamuddy*, *ferrumuddy'*, *dolomuddy*, *aragomuddy*, *calcimuddy* and for a unspecified calcareous mud *carbonate-muddy*.

A typical name would be a *phosphamuddy, calciclastic, siliciclastic* **hybrid-sediment.** If the sediment comprises only clasts, the name may be abbreviated by dropping all but the last 'clast' suffixes and joining the different composition types with a hyphen, for example *phospha-calci-silici-clastic*-**hybrid-sedimentary-rock.**

Terms to describe the grain size of the sediment should follow these guidelines.

- If the clasts are in the same grain size range then it is only necessary to describe the overall grain size grade, followed by a list of clast compositions, for example *sand-grade, phosphaclastic, ferruclastic, calciclastic* **hybrid-sedimentary-rock**.
- If the different clast compositions are of different grain sizes the root name should be prefixed with *poorly-sorted*, for example *poorly-sorted, phosphaclastic, ferruclastic, calciclastic* **hybrid-sediment**.

The different clast types should be put in ascending order with the name of the most abundant mineral closest to the root name. For example a sediment with 20% iron clasts, 35% lime clasts and 45% siliciclastic clasts can be described as a *ferruclastic, calciclastic, siliciclast* **hybrid-sediment**.

12 SEDIMENTS AND SEDIMENTARY ROCKS WITH VOLCANICLASTIC DEBRIS

The classification of rocks and sediments with abundant volcanic debris is covered in detail in the Classification of igneous rocks (Gillespie and Styles, 1997) and only a brief summary is given here.

The term volcaniclastic is a general term including any clastic material composed in part or entirely of volcanic fragments formed by any particle-forming mechanism. Pyroclasts however are 'primary' particles formed as a direct result of volcanic action. Sediments or rocks containing more than 75% pyroclasts are classified as pyroclastic, and special terms such as **ash** and **tuff** are used. Those containing 75 to 25% pyroclasts are classified as tuffites. Names are formed by combining an appropriate term from the sedimentary classification scheme with the prefix **tuffaceous-**. To determine the correct sedimentary classification the pyroclasts should be included as a siliciclastic component. For example, a sand-grade clastic rock comprising of 100% siliciclasts of which at least 25% are pyroclasts should be given the root name **tuffaceous-silicate-sandstone**. A limestone with 40% pyroclast should be given the root name **tuffaceous-limestone**. Sediments and rocks containing less than 25% pyroclasts but greater than 10% volcanic debris can be described by combining an appropriate term from the sedimentary classification scheme with the prefix **volcaniclastic**-, for example **volcaniclastic-mudstone**. It is pointed out that a rock consisting of 100% volcanic debris that had been weathered, transported and deposited would be classified as volcaniclastic as the volcanic particles are no longer 'primary' pyroclasts. The qualifiers tuffaceous and volcaniclastic should only be used as outlined above.

13 QUALIFIER TERMS

Qualifier terms may be given as prefixes to sediment and sedimentary rock names at any hierarchical level in the classification, in order to make the name more specific. Qualifiers can be used to describe features such as the detrital composition, cementation and physical properties of the sediment. The qualifiers given in this section are not intended to be exhaustive, but merely serve as examples of how qualifiers should be used in constructing a sediment name. Qualifiers not listed here can also be used, provided their presence in the sediment or sedimentary rock name is considered important.

13.1 Guidelines for applying qualifiers

- Qualifiers should only be used where they are contributing information of value to the sediment name. For example, a qualifier describing clast composition and/or grain size should only be used where the relevant clast type is not implicit in the sediment name.
- The number of qualifiers should be kept to a minimum to avoid rock names becoming too cumbersome or complex. However, some sediments, particularly those with a number of different clast types, can be described satisfactorily only by using several clast-type qualifiers with a root name.
- Qualifier terms that consist of more than one word should be hyphenated to show that they are a compound word, for example *fine-grained*. If more than one qualifier term is given they should be linked by commas, for example *cemented*, *phosphaclastic* **sandstone**. Hyphens should not be used to link qualifiers with root name (see Section 1.4).
- Qualifiers are used as a prefix to the group or root name in the following order: physical properties and structures other than grain size, cementation, fossil types or subordinate clast compositions, grain size. If more than one fossil or compositional qualifier is used, the name of the most abundant component should appear closest to the root name. For example, *a calciclastic, phosphaclastic* **silicate-sandstone** should have more phosphaclasts than calciclasts.
- It is neither possible or desirable to have all observable petrographic features built into a rock name. Ultimately, the choice of what qualifiers to use will depend on the individual, and will probably be governed largely by factors that have direct relevance to the rocks in the sampling area or to the study for which the rocks are being collected or mapped.

13.2 Qualifiers to describe physical properties of the sediment

The following is a list of qualifiers that could be used to describe the physical properties of the sediment. Descriptions of the physical properties of sediments and sedimentary rocks involve consideration of grain size and grain size parameters, grain morphology and fabric, induration, porosity.

13.2.1 Qualifers to describe grain size in clastic sediments

The grain size scale is shown in Figure 13.

A more detailed description of rudaceous grade sediments and sedimentary rocks can be made by prefixing the group or root name with a term such as *boulder-grade*, for example *cobble-grade* **gravel** or *pebble-grade* **phosphorite**.

The grain size of arenaceous and argillaceous grade sediments and sedimentary rocks is often referred to in the root name, for example **silicate-sandstone**. A more detailed description can be made by adding qualifiers to describe whether it is *coarse*, *fine* or *very-fine*. These terms should not be suffixed with 'grained'. This is to avoid any confusion with the igneous and metamorphic classification schemes which use terms such as 'coarse-grained' and 'medium-grained' to describe different grain sizes to those defined for sedimentary clasts.

If the root name does not infer the grain size, then an indication of the grain size may be made by prefixing the sediment name with a term such as *sand-grade*, for example *sand-grade* **limestone**.

13.2.2 Qualifiers to describe crystal size of crystalline sediments

The term *crystalline* may be applied to certain sedimentary rocks composed entirely of contiguous crystals (Bates and Jackson, 1987) such rocks include cherts, evaporites and some limestones. The term can be clarified by referring to the crystal size. Crystal sizes are the same as those used to describe igneous and metamorphic rocks. These are defined in Figure 13.

13.2.3 Qualifiers to describe textural maturity

The textural maturity of a sediment or sedimentary rock can be determined by the grain morphology and the degree of sorting. Definitions are from Tucker (1992).

- *texturally immature* — sediments and sedimentary rocks with much matrix, poor sorting and angular grains
- *texturally mature* — little matrix, moderate to good sorting and subrounded to rounded grains
- *texturally supermature* — no matrix, very good sorting and well-rounded grains

13.2.4 Qualifiers to describe sorting characteristics

A measure of the degree of sorting of particle size in a sediment is usually based on the statistical spread of the frequency curve of particle sizes. Folk (1974) considered that the most representative measure is the Inclusive Graphic Standard Deviation (IGSD) and defined a sorting scale based on this parameter, as follows:

Qualifier	IGSD (ϕ units)
very well-sorted	< 0.35
well-sorted	0.35–0.5
moderately well-sorted	0.5–0.71
moderately-sorted	0.71–1.0
poorly-sorted	1.0–2.0
very poorly-sorted	2.0–5.0
extremely poorly-sorted	> 5.0

13.2.5 Qualifiers to describe variety of clast types

Qualifiers describing the variety of clast types are sometimes used in the description of rudaceous sediments and sedimentary rocks.

- *oligomictic* — a clastic sedimentary rock composed of one clast type
- *polymictic* — a clastic sedimentary rock composed of more than one type of particle or clast

13.2.6 Qualifiers to describe grain/clast morphology

The roundness of clastic grains can be described using one of the categories of roundness shown on Figure 14. For example a sandstone with well-rounded grains should be described as *well-rounded* **sandstone.**

13.2.7 Qualifiers to describe grain fabric

References to the grain fabric may be included in the root name. For example para-conglomerate and lime-wackestone are matrix suppported, whereas orthoconglomerate and lime-packstone are grain supported. Other references to the sediment fabric may be made using qualifiers but such qualifiers, should only be given when the fabric is considered a significant feature of the sediment. Fabrics which may warrant description include:

- *imbricated* — tabular or disc-shaped pebbles overlap each other, dipping in an upstream direction
- *loosely packed* — seen in unconsolidated, well sorted sands
- *tightly packed* — seen in poorly sorted sands

If the sediment name makes no reference to the grain content then this may be described:

- *matrix supported* — arenaceous or rudaceous grade clasts are floating in a matrix
- *grain supported* — arenaceous or rudaceous grade clasts are in contact with little or no matrix

13.2.8 Qualifiers to describe degree of induration

Qualifiers describing the degree of induration may sometimes be relevant. These include:

- *friable* — a rock that crumbles easily
- *indurated* — a very hard rock, either from cementation or intergranular solution

13.2.9 Qualifiers to describe distribution of minerals/fossils in the sediment

Qualifiers can be used to describe the distribution of minerals, chemical precipitates and fossils throughout the sediment. Terms include:

- *banded*
- *layered*
- *disseminated*
- *nodular*

13.3 Qualifiers to describe primary composition

The classification scheme allows all sediments to be given names which provide information about the predominant primary composition. Qualifiers may be used to describe the presence of clasts and muds of different compositions to the main component, allochems, fossils, lithic clasts, organic and mineralogical components. These qualifiers should only be added to a group or root name if the user considers that they describe a component that forms a significant part of the sediment. A systematic approach to determining whether reference to an additional component should be made is complicated because their significance can vary according to the nature of the sediment.

13.3.1 Qualifers to describe composition and grain size of subordinate clast types

Clasts (particles of silt-grade and above) are described using their composition with a ‘clast’ suffix. The most common clast types are *siliciclast, phosphaclast, ferruclast, doloclast, aragonoclast, calciclast,* and for an unspecified calcareous clast *carbonate-clast.*

To describe the grain size of the clasts the ‘clast’ suffix can be replaced by a grain size term, for example *phospha-pebbly* (further examples are given on Table 20). It should be noted that all grain size terms refer to grain size only and do not have a siliciclastic connotation. To prevent any confusion about the composition of the clasts, all grain size terms should be prefixed with a reference to the composition. For example, a limestone with sand-sized siliciclastic particles should be described as a *silici-sandy* **limestone**.

All grain size terms should be prefixed with a reference to the clast composition. This is to prevent any confusion about the composition of the clasts.

If the user wishes to describe a subordinate grain size component of the same composition as the main component then the grain size of the main component must also be described. For example, a sand-grade phosphorite with pebble-sized phosphate particles should be described as a *phospha-pebbly, sand-grade* **phosphorite**.

A list summarising the qualifying terms associated with some of the more common clast types is given in Table 20.

13.3.2 Qualifiers to describe additional mineralogical components

When no reference to grain size is required, a general reference to a subordinate mineralogical component may be made. These qualifers refer to the primary constituents of the rock rather than to secondary (diagenetic) components. The more common mineralogical components are given below.

Table 20 Examples of qualifiers used to describe clast composition, grain size and their abundance in the sediment.

Component	Qualifier
unspecified phosphate clasts	*phosphaclastic*
phosphate allochems e.g. peloid	*phospha-peloidal*
phosphate allochems e.g. ooid	*phosph-ooidal*
rudaceous-grade phosphate clast	*phospha-gravelly*
pebble-grade phosphate clast	*phospha-pebbly*
sand-grade phosphate clast	*phospha-sandy*
silt-grade phosphate clast	*phospha-silty*
mud-grade phosphate clast	*phospha-muddy*
unspecified primary phosphate component	*phosphatic*
unspecified silicate clasts	*siliciclastic*
cobble-grade silicate clast	*silici-cobbly*
pebble-grade silicate clast	*silici-pebbly*
sand-grade silicate clast	*silici-sandy*
silt-grade silicate clast	*silici-silty*
mud-grade silicate clast	*silici-muddy*
unspecified primary silici component	*silicic*
unspecified calcite clasts	*calciclastic*
calcite allochems e.g. Ooids	*calc-ooidal*
calcite allochems e.g. bioclasts	*calci-bioclastic*
cobble-grade calcite clast	*calci-cobbly*
pebble-grade calcite clast	*calci-pebbly*
sand-grade calcite clast	*calci-sandy*
silt-grade calcite clast	*calci-silty*
mud-grade calcite clast	*calci-muddy*
unspecified primary calcite component	*calcitic*
unspecified carbonate clasts	*carbonate-clastic*
carbonate allochems e.g. ooids	*carbonate-ooidal*
carbonate allochems e.g. oncoid	*carbonate-oncoidal*
cobble-grade carbonate clast	*carbonate-cobbly*
pebble-grade carbonate clast	*carbonate-pebble*
sand-grade carbonate clast	*carbonate-sandy*
silt-grade carbonate clast	*carbonate-silty*
mud-grade carbonate clast	*carbonate-muddy*
unspecified primary carbonate component	*calcareous*

Examples are given using clasts of phosphate, silicate, calcite, and carbonate. The term 'carbonate' should be used where more than one type of carbonate is present, or when the user is unable to identify the type of carbonate

This is not intended to be an exhaustive list and other mineral terms may be used as qualifiers where appropriate.

- qualifiers to describe siliciclastic components — *siliciclastic*
- qualifiers to describe carbonate components — *calcareous* (general term for unspecified carbonate), *aragonitic, calcitic, dolomitic*
- qualifiers to describe clay minerals — *chloritic, illitic, kaolinitic, smectitic*
- qualifiers to describe mica group — *micaceous* (general term for unspecified mica), *muscovitic, biotitic, glauconitic*
- qualifiers to describe feldspar group — *feldspathic* (general term for unspecified feldspar)
- qualifiers to describe iron minerals (adjectives taken from Young, 1989) — *ferruginous* (general term for unspecified iron minerals), *berthieroidal* (adjective for material bearing, or rich, in berthieroid minerals (berthierine or chamosite), *chamositic, berthierinic, pyritic, sideritic, sphaerosideritic*
- qualifiers to describe other non-silicates — *gypsiferous, phosphatic, potassic, aluminous*

13.3.3 Qualifiers to describe additional organic components

The following qualifers may be used:

- *organic* — a term to describe undefined visible organic matter
- *carbonaceous* — a term to describe visible carbon and/or humic material
- *kerogenous* — a term to describe fossilised insoluble organic material, which can be converted to petroleum products by distillation
- *sapropelic* — a term to describe sediments and sedimentary rocks with organic matter consisting mainly of algal or spore matter
- *miosporal* — a term to describe sediments and sedimentary rocks with organic matter consisting mainly of spores and pollens
- *alga* — a term to describe sediments and sedimentary rocks with organic matter consisting mainly of algae

13.3.4 Qualifiers to describe lithic clasts

The list of possible lithic clasts includes all approved rock names from the sedimentary, igneous and metamorphic classification schemes and is thus not included here. The qualifier should comprise the lithology followed by the suffix '-clast'. For example a sandstone with mudstone clasts should be described as *mudstone-clast* **sandstone.** Metamorphic or igneous clasts may be referred to as *metaclasts* and *igneous-clasts*.

13.3.5 Qualifiers to describe allochem component

Allochems are common to carbonates, phosphorites and iron-rich sediments, but may also be found in other sediments. When allochems or fossils are of the same composition as the host rock, no compositional qualifier is needed and it is recommended that the allochems and fossils should be described using their adjective, for example *ooidal* or *crinoidal*. When allochems are of a different composition to that used to classify the sediment, the allochem name should be prefixed with a reference to the composition. For example, a phosphorite with iron peloids should described as a *ferru-peloidal* **phosphorite** and a sandstone with calcite ooids should be described as *calc-ooidal* **sandstone**. The allochems are divided into coated grains and clasts.

Coated grains

Following the recommendations of Young (1989) coated grain names should have an -'id' termination, with the adjectives based on an -'idal' ending (ooidal, pisoidal, etc.). One exception are spastoliths, the root (spastos) is an adjective, so the '-lith' ending for the granule should be used rather than the '-id' ending.

- *ooidal* from ooid — a coated grain with a cortex that is smoothly and evenly laminated. A nucleus is usually evident and may be of different composition to the cortex. They are typically spherical or ellipsoidal in shape with the degree of roundness increasing outwards. There are no obvious biogenic structures (Tucker and Wright, 1990)
- *pisoidal* — from pisoid: grain similar to ooid, but greater than 2 mm in diameter (Young, 1989). Use the term pisoid in preference to pisolith
- *oncoidal* — from oncoid: coated grain with a cortex of irregular, partially overlapping laminae. They are typically irregular in shape and may exhibit biogenic structures. Some forms lack a distinct nucleus. Oncoids are generally larger than 2 mm (Tucker and Wright, 1990)
- *microoncoidal* — from microoncoid: grain similar to an oncoid, but smaller than 2 mm in diameter (Tucker and Wright, 1990)
- *peloidal* — from peloid: a grain with an average size of 100 to 500 um, composed of microcrystalline carbonate. They are generally rounded or subrounded, spherical, ellipsoidal to irregular in shape and internally structureless. The term pellet is commonly used to describe peloids. Whilst this is a correct term to describe grains that are faecal in origin it is difficult to distinguish faecal grains from non-faecal. It is therefore recommended that the term peloid is used to describe all structureless grains of the above description (Tucker and Wright, 1990)
- *spastolithic* — from spastolith: plastically deformed ooid (Rastall and Hemingway, 1940). The outer cortical laminae may have been replaced by siderite or a phosphate mineral prior to the deformation; this may undergo brittle deformation around the plastically deformed inner part of the ooid giving rise to a characteristic sigmoidal egg-shell spastolith (Kearsley, 1989)

Clasts

Adjectives to describe clasts should have an -'ic' termination (for example bioclastic)

- *intraclasts* — fragments of typically weakly consolidated sediment reworked from within the area of deposition (Folk, 1959)
- *lithoclasts* — fragments of lithologies not represented in the associated environments (Tucker and Wright, 1990)
- *bioclast* — fragments of skeletal grains. If the type of fossil can be identified, the specific term should be used in place of 'bioclast' (for example *crinoidal* **limestone** as opposed to *bioclastic* **limestone**)

13.3.6 Qualifiers to describe fossil content

The fossil content of a sediment can be described using qualifiers. The more common fossil types are given below. This is not intended to be an exhaustive list and other fossils may be used as qualifers where appropriate.

- *fossiliferous* — qualifier to describe significant presence of fossils
- *shell* — qualifier to secribe significant presence of shells
- *spicular, Coral, Brachiopod, Gastropod, Bivalve, Belemnite, Crinoid, Echinoid* — qualifiers to describe animal fossil groups
- *protozoan, Radiolaria, Foraminifera* — qualifiers to describe protozoan fossil groups
- *alga, Coccolith, Diatom* — qualifiers to describe plant fossil groups

13.4 Qualifiers to describe cementation

The mineralogy of the cement should not be included in the determination of the classification of a sediment. However, the mineralogy of the cement can be referred to using qualifiers. To distinguish the cement from a detrital component, the qualifier should comprise the composition, followed by the suffix *-cemented*. For example a sandstone with calcite cement should be described as a *calcite-cemented* **sandstone**.

The more common cements are given below. This is not intended to be an exhaustive list and other types of cement may be used as qualifiers where appropriate.

- qualifiers to describe level of cementation —
  loosely cemented
  cemented
  well-cemented: the cement has bound the sediment into a rigid, dense mass
- qualifiers to describe more common cements —
  silica cemented
  silicified: term to describe the replacement of existing minerals and filling of pores by silica
  c*arbonate-cemented:* term to describe cement of unspecified carbonate composition
  calcite-cemented
  dolomite-cemented
  siderite-cemented
  gypsum-cemented

13.5 Qualifiers to describe sedimentary structures

Descriptions of sedimentary structures should not be used as qualifiers. References to the sediment structure should normally be included in the sediment description. However, qualifiers may sometimes be useful to describe the presence of bioturbation, and in a field classification qualifiers could be used describe the sediment's stratification and parting.

13.5.1 Qualifiers to describe bioturbation

The amount of bioturbation can be indicated by one of the following terms (modified from Reineck (1967), Drosser and Bottjer (1986, 1989, 1991) and Pemberton et al. (1992).

- *slightly-bioturbated* — discrete, isolated trace fossils, up to 10% of original bedding disturbed
- *moderately-bioturbated* — 10 to 40% of original beddding disturbed, burrows generally isolated, but locally overlap

- *highly-bioturbated* — last vestiges of bedding discernible; approximately 40 to 60 % disturbed, burrows overlap and are not always well defined
- *intensely-bioturbated* — bedding is completely disturbed, but burrows are still discrete in places and the fabric is not mixed
- *completely-bioturbated* — bedding is totally obliterated

13.5.2 Qualifiers to describe stratification and parting

Qualifiers to describe the stratification and parting are taken from the following scheme (modified from Ingram (1954) and Potter et al. (1980).

Thickness of unit (millimetres)	Qualifier to describe stratification	Qualifier to describe parting
No apparent internal structure	*massive-bedded*	*massive*
> 1000	*very-thick-bedded*	*massive*
300–1000	*thick-bedded*	*blocky*
100–300	*medium-bedded*	*blocky*
30–100	*thin-bedded*	*slabby*
10–30	*very-thin-bedded*	*slabby*
5–10	*thick-laminated*	*flaggy*
1–5	*medium-laminated*	*platy*
0.5–1	*thin-laminated*	*fissile*
< 0.5	*very-thin-laminated*	*papery*
General term	*bedded or laminated*	

13.6 Genetic terms

A number of sediment names that have genetic implications exist in the geological literature. These terms should not be used to classify a sediment. However, such terms may be valid for discussion purposes when the genetic origin needs to be highlighted. The terms may be used alongside the formally defined classification terms as synonyms or informal genetic qualifiers, for example *tufa* **limestone**. The terms should precede the full descriptive term, for example *calcrete, calcite-cemented* **silicate-conglomerate**. The term '*calcrete* **silicate-conglomerate**' is ambiguous.

13.6.1 Genetic terms applied to mudstones

- *Bentonite* — a soft, plastic, porous, light-coloured rock composed essentially of clay minerals from the smectite group plus colloidal silica, and produced by chemical alteration of volcanic ash.
- *Brick Earth* — a loam or earth suitable for making bricks; specifically a fine-grained brownish deposit consisting of quartz and flint mixed with ferruginous clay and found on river terraces as a result of reworking by water of windblown material.
- *Fuller's Earth* — a clay consisting largely of hydrated aluminium silcates (e.g. smectite), it has a high proportion of water and little plasticity. It is formed by in-situ decomposition of igneous rocks containing a high proportion of glass.
- *Tonstein* — a band of mudstone composed dominantly of kaolinite and associated with coal seams.
- *Ooze* — a fine-grained pelagic sediment consisting dominantly of calcareous or siliceous organic remains.

13.6.2 Genetic terms applied to arenaceous and rudaceous sediments

- *Olistrostrome* — a mappable, stratigraphical unit of a chaotic mass of heterogenous materials (such as blocks and muds) that accumulated as a semifluid body by submarine gravity sliding or slumping of unconsolidated sediments.

13.6.3 Genetic terms applied to concretionary deposits associated with springs, streams and lakes

- *Tufa* — a thin, surficial, soft, spongy, semifriable incrustation around the mouth of springs, seeps or streams carrying calcium carbonate in solution and exceptionally as a thick deposit along lake shores.
- *Travertine* — a hard dense variety of tufa. It also occurs in caves as stalactites and stalagmites (synonymous with calcareous sinter).

13.6.4 Genetic terms applied to rocks of a pedogenic origin

- *Alcrete* — indurated deposit consisting predominantly of accumulation of aluminium sesquioxides
- *Ganiste*r — a hard, fine-grained, quartz-arenite, cemented with silica and possessing a splintery fracture. Traces of roots visible. It is associated with coal seams.
- S*eat-earth* — a term for a bed of rock underlying a coal seam; it represents the soil that supported the vegetation from which the coal was formed. A highly siliceous seat earth is known as *ganister.*
- *Duricrust* — a general term for a hard crust on the surface of, or layer in, the upper horizons of a soil in a semiarid climate. See also *silcrete, ferricrete, calcrete, caliche.*
- *Silcrete* — a conglomerate consisting of surficial sand and gravel cemented into a hard mass by silica. Also see *duricrust.*
- *Ferricrete* — a conglomerate consisting of surficial sand and gravel cemented into a hard mass by iron oxide derived from the oxidation of percolating solutions of iron salts. Also see *duricrust.*
- *Caliche* — a reddish brown to white calcareous material of secondary accumulation, commonly found in layers on or near the surface of stony soils of arid and semiarid regions, but also occurring as a subsoil deposit in subhumid climates. It may occur as a thin, friable horizon within the soil, but more commonly it is up to a metre or more in thickness, impermeable and strongly indurated. It is composed largely of a calcareous cement, in addition to such materials as gravel sand and mud. Also see *duricrust.*
- *Calcrete* — a conglomerate consisting of surficial sand and gravel cemented into a hard mass by calcium carbonate. See also *duricrust* and *caliche,*
- *Laterite* — a highly weathered red subsoil rich in secondary oxides of iron and/or aluminium, nearly devoid of base metal compounds and primary silicates, and commonly with quartz and kaolinite. It develops in tropical and warm-temperate climates.

13.6.5 Genetic terms applied to ironstones

- *Bog ironstone* — a soft spongy and porous deposit of limonite, impregnated with plant debris, clay and clastic material. It is formed in bogs, marshes and shallow lakes by precipitation from iron-bearing waters and by the oxidising action of algae, iron bacteria or the atmosphere.

- *Blackband ironstone* — a dark variety of mud ironstone containing siderite clasts and sufficient carbonaceous material (10 to 20%) to make it self-calcining (Bates and Jackson, 1987).

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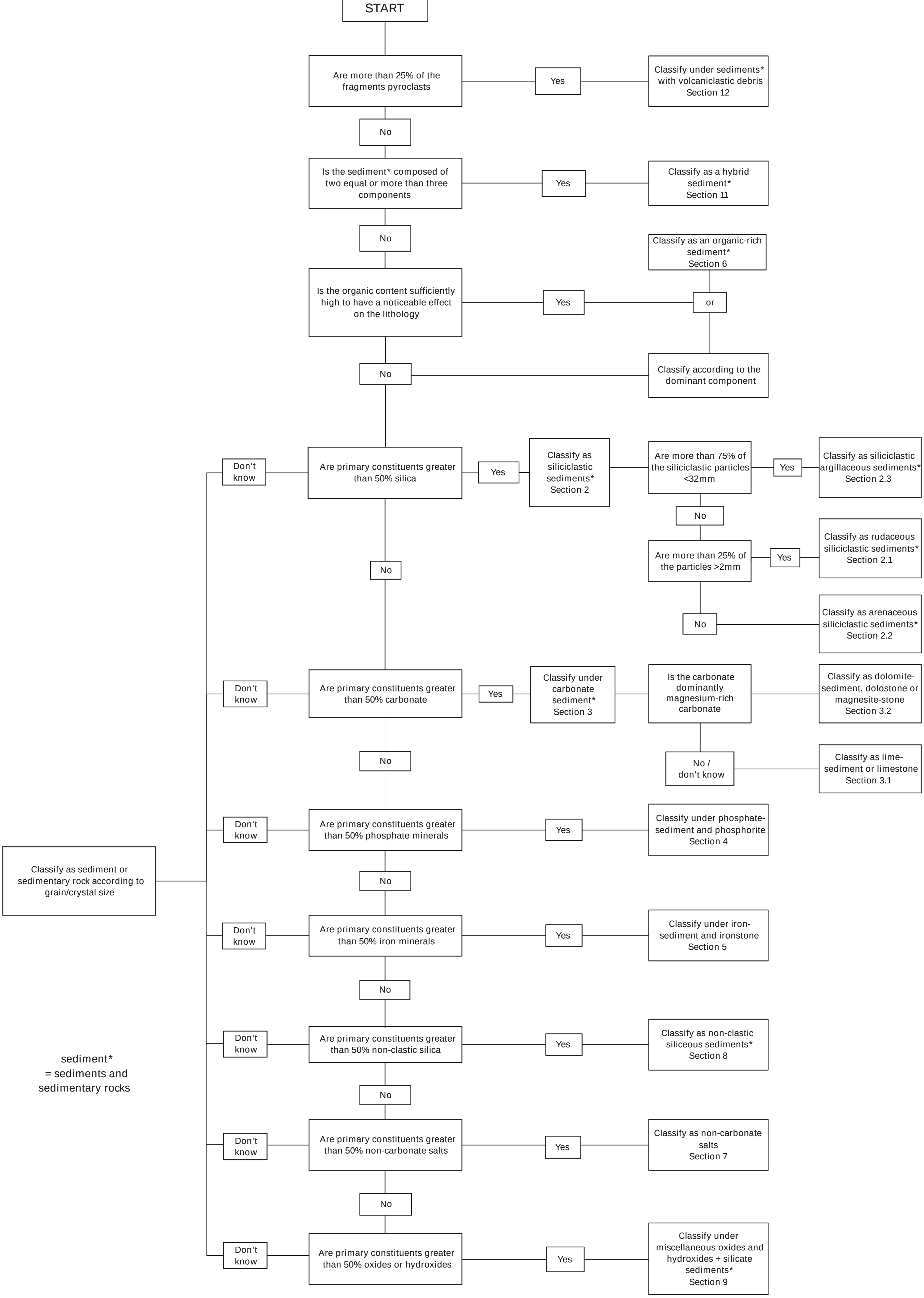

Figure 1 Flowchart for the classification of sediments and sedimentary rocks.

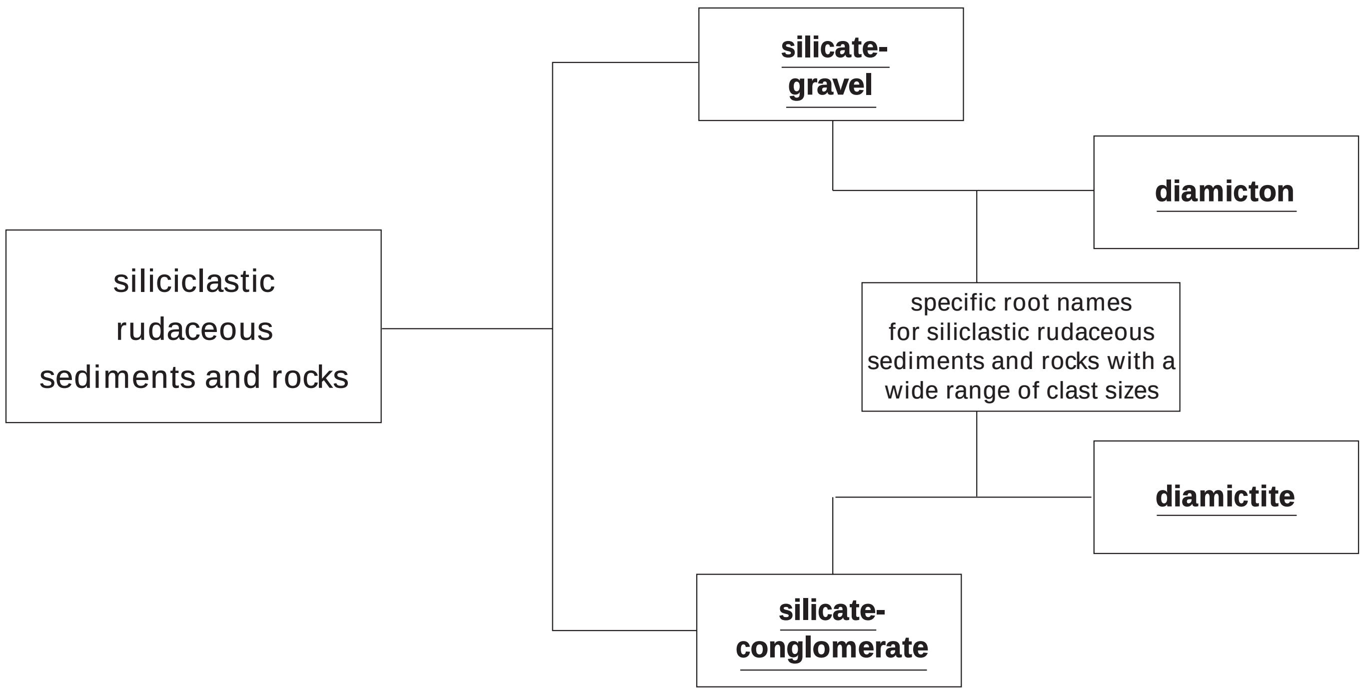

Figure 2 Classification of siliciclastic rudaceous sediments and rocks.

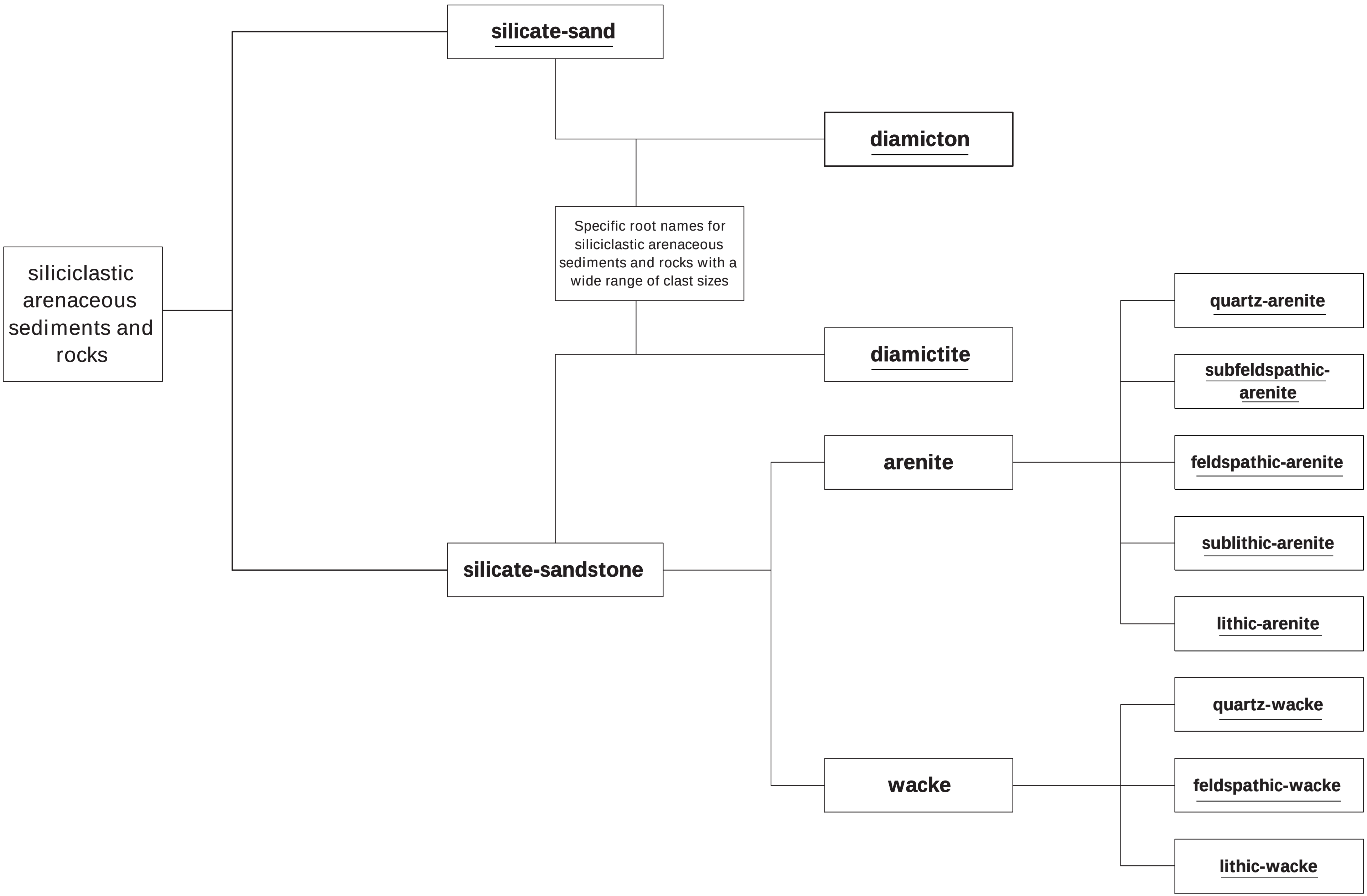

Figure 3 Classification of siliciclastic arenaceous sediments and rocks.

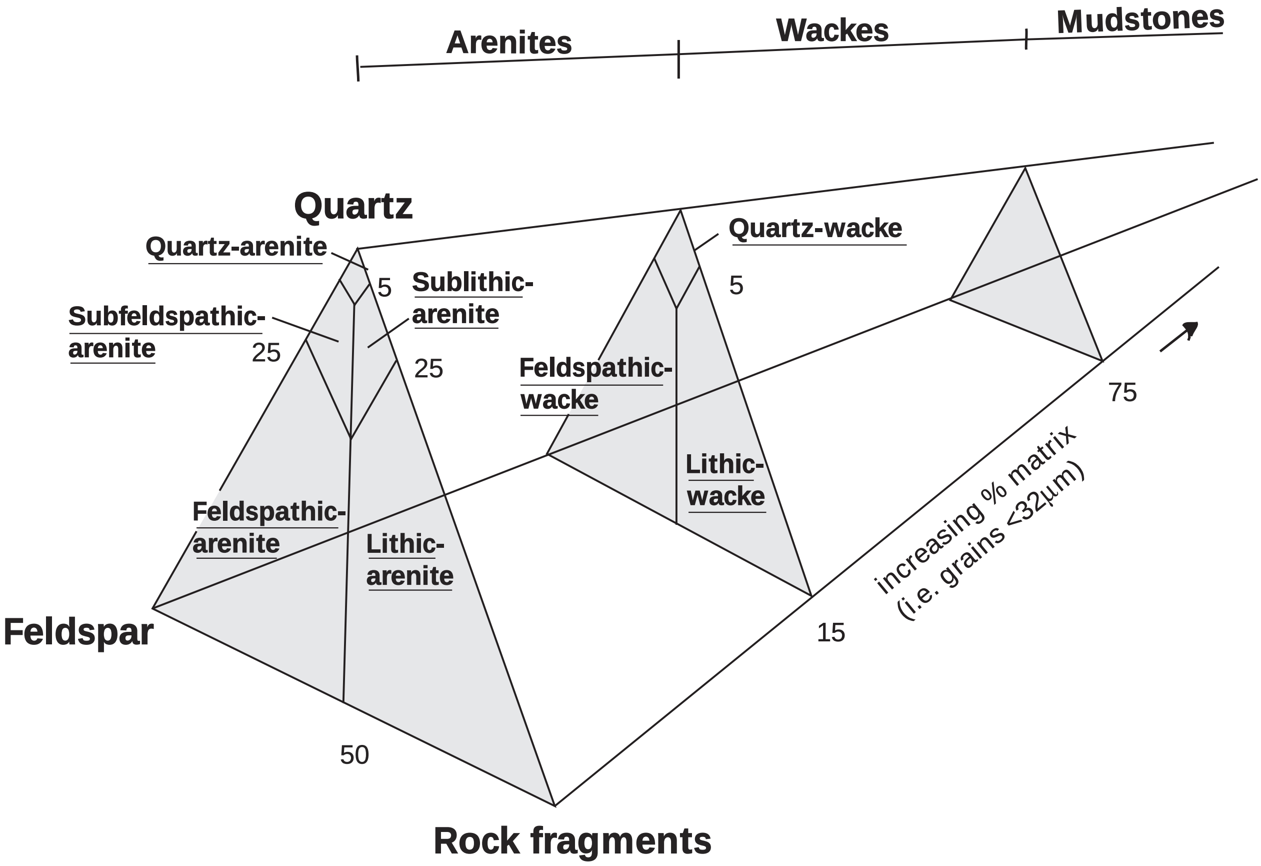

Figure 4 Classification of siliciclastic arenaceous sedimentary rocks according to composition. Adapted from Pettijohn et al. (1987).

Figure 5 Classification of siliciclastic and argillaceous sediments and rocks.

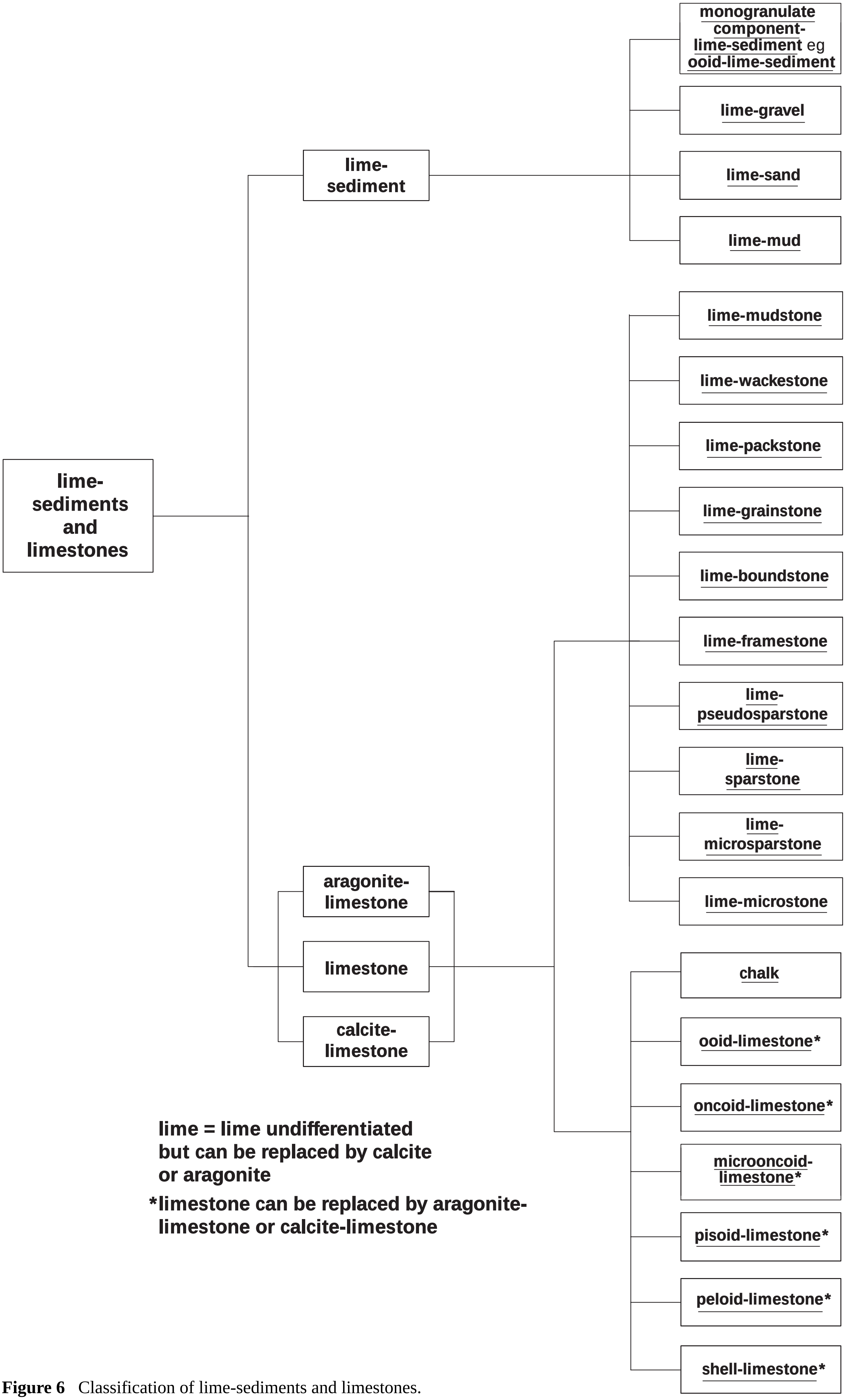

Figure 6 Classification of lime-sediments and limestones.

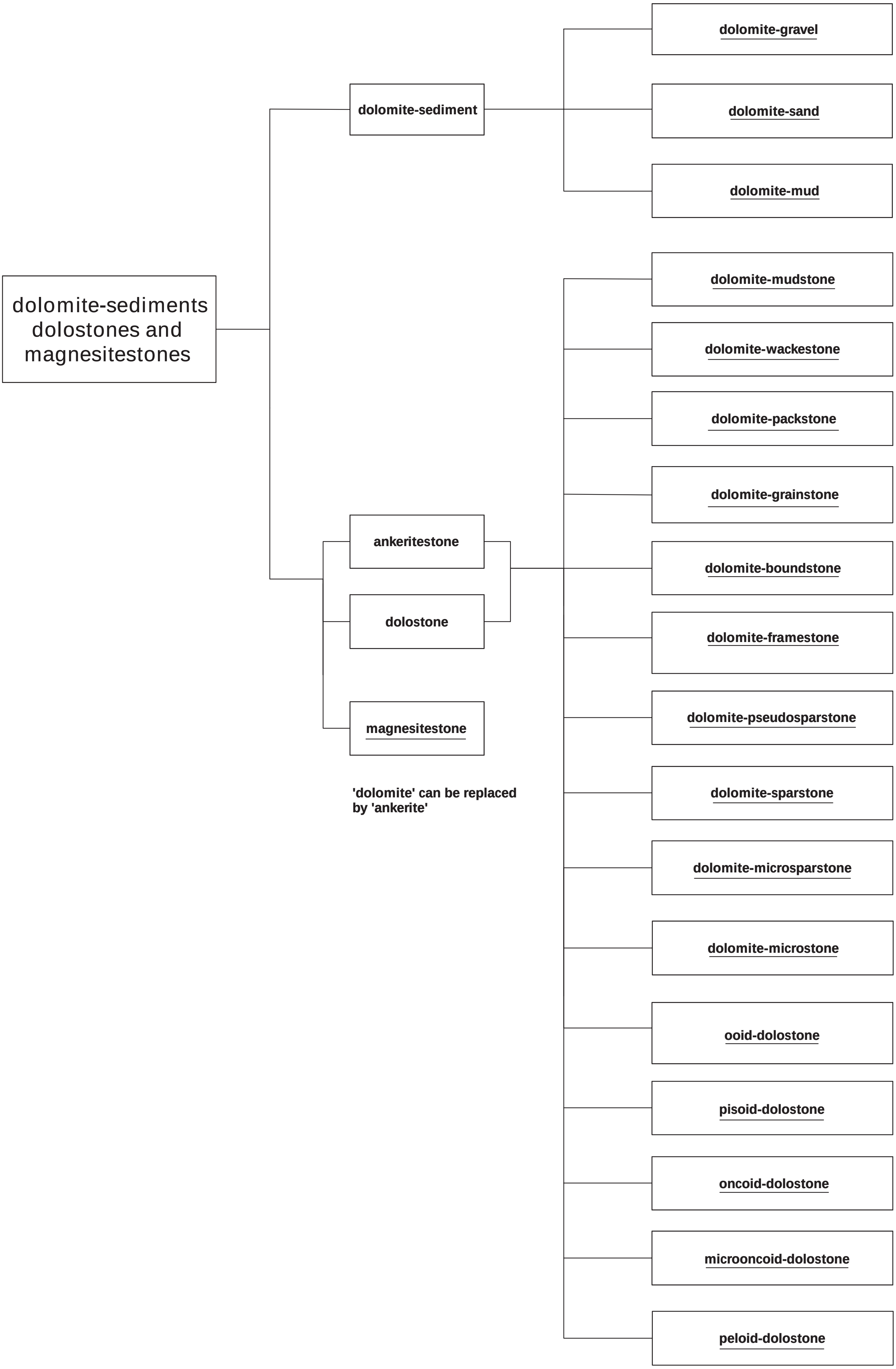

Figure 7 Classification of dolomite-sediments and dolostones.

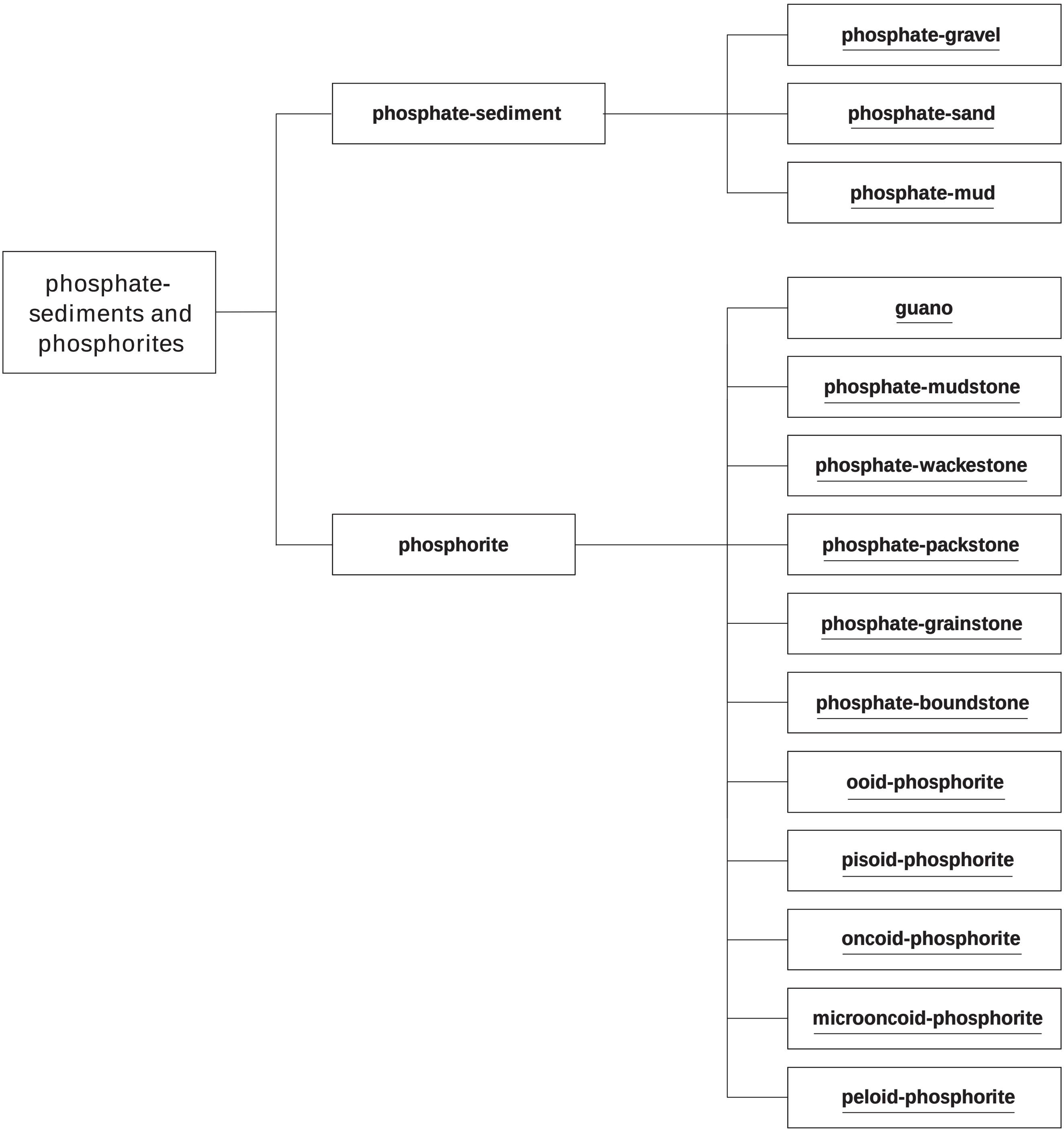

Figure 8 Classification of phosphate-sediments and phosphorites.

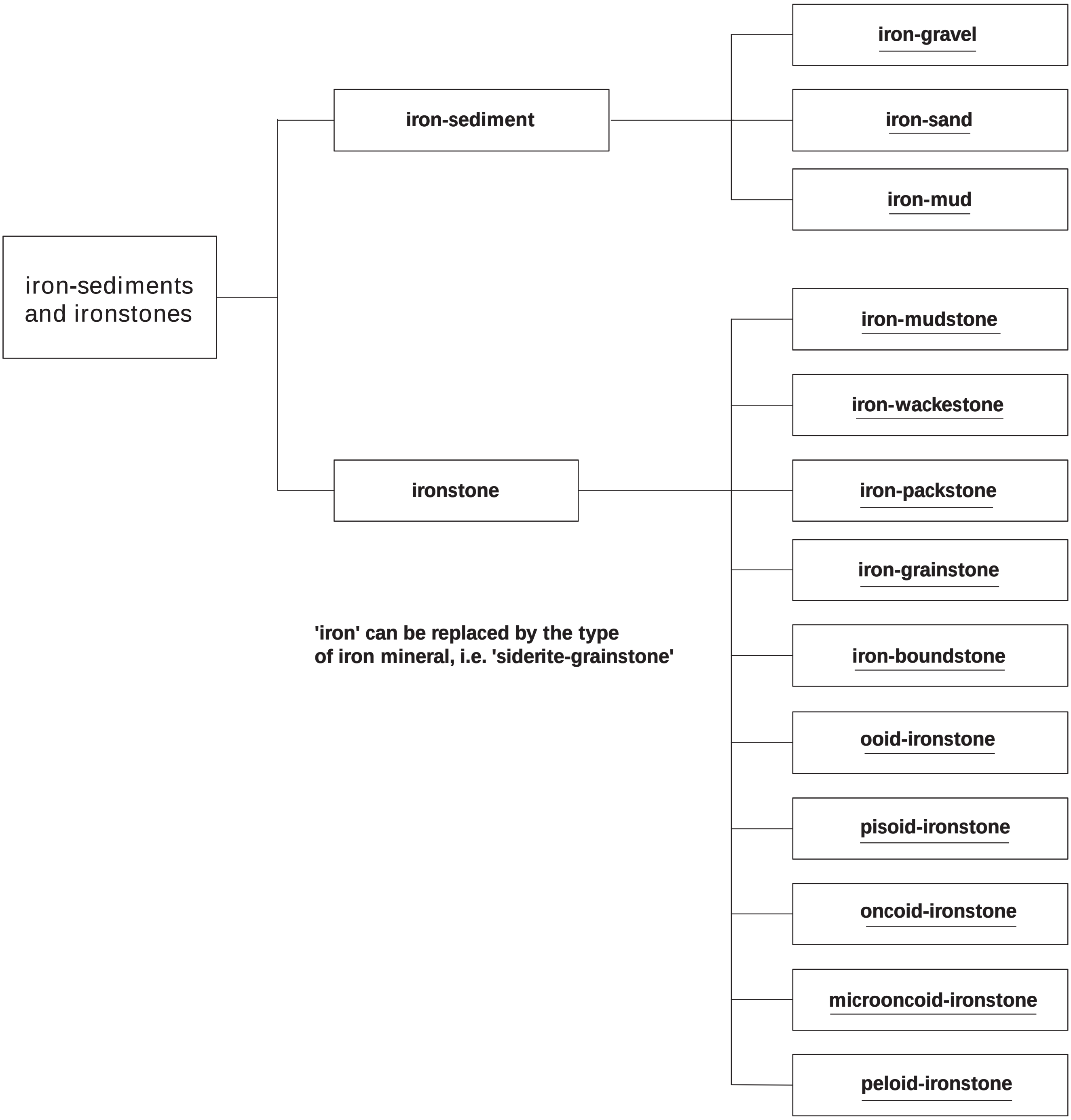

Figure 9 Classification of iron-sediments and ironstones.

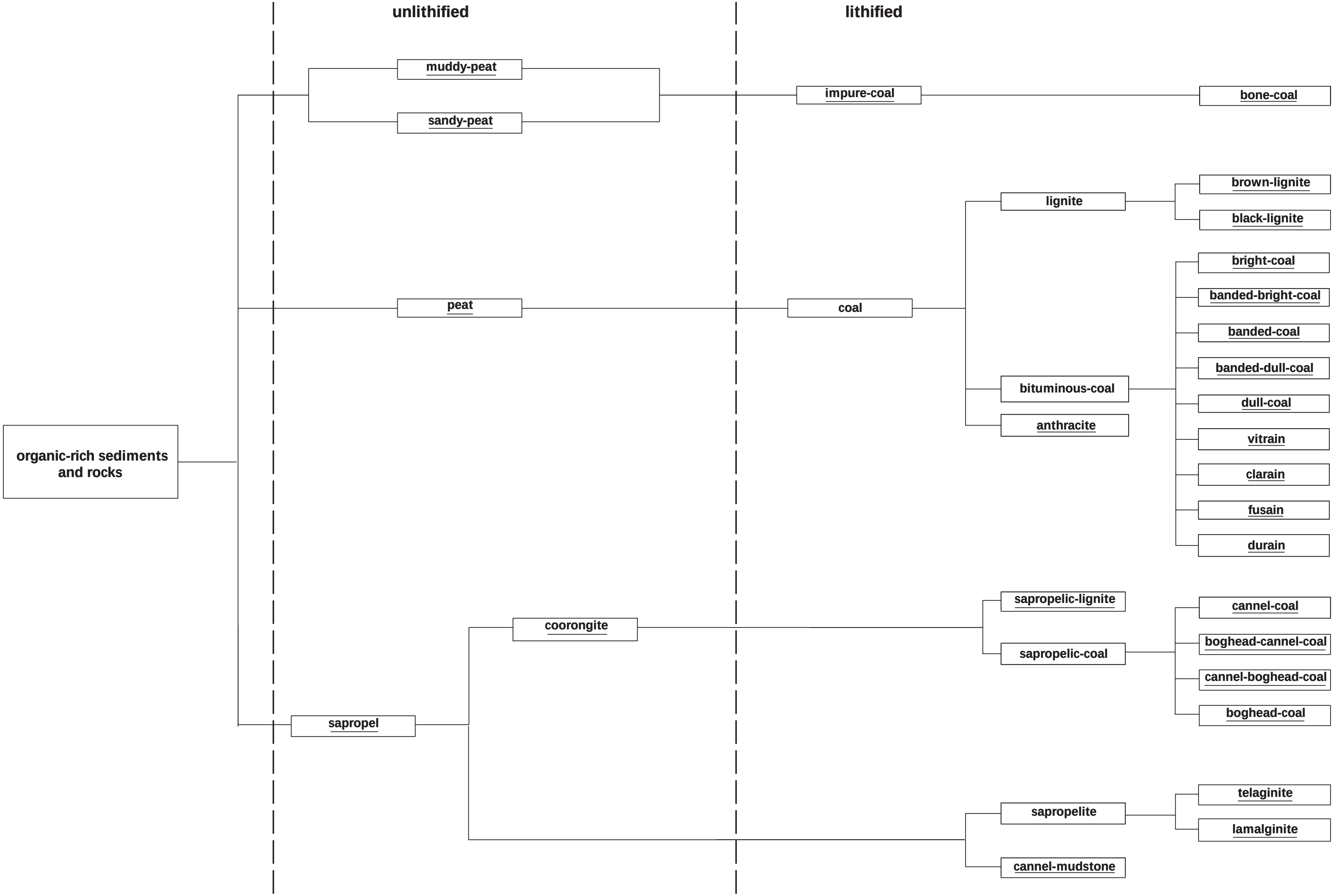

Figure 10 Classification of organic-rich sediments and rocks.

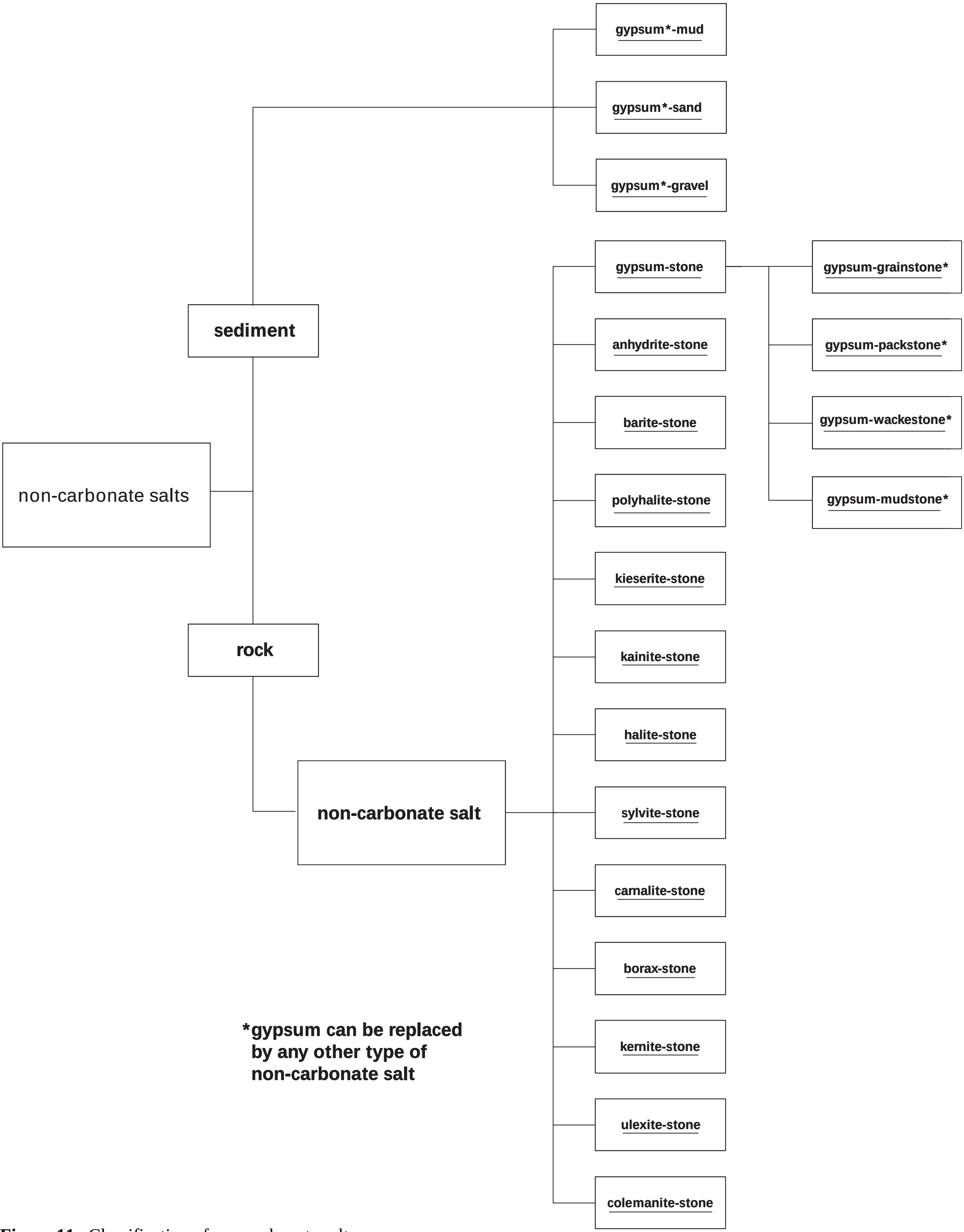

Figure 11 Classification of non-carbonate salts.

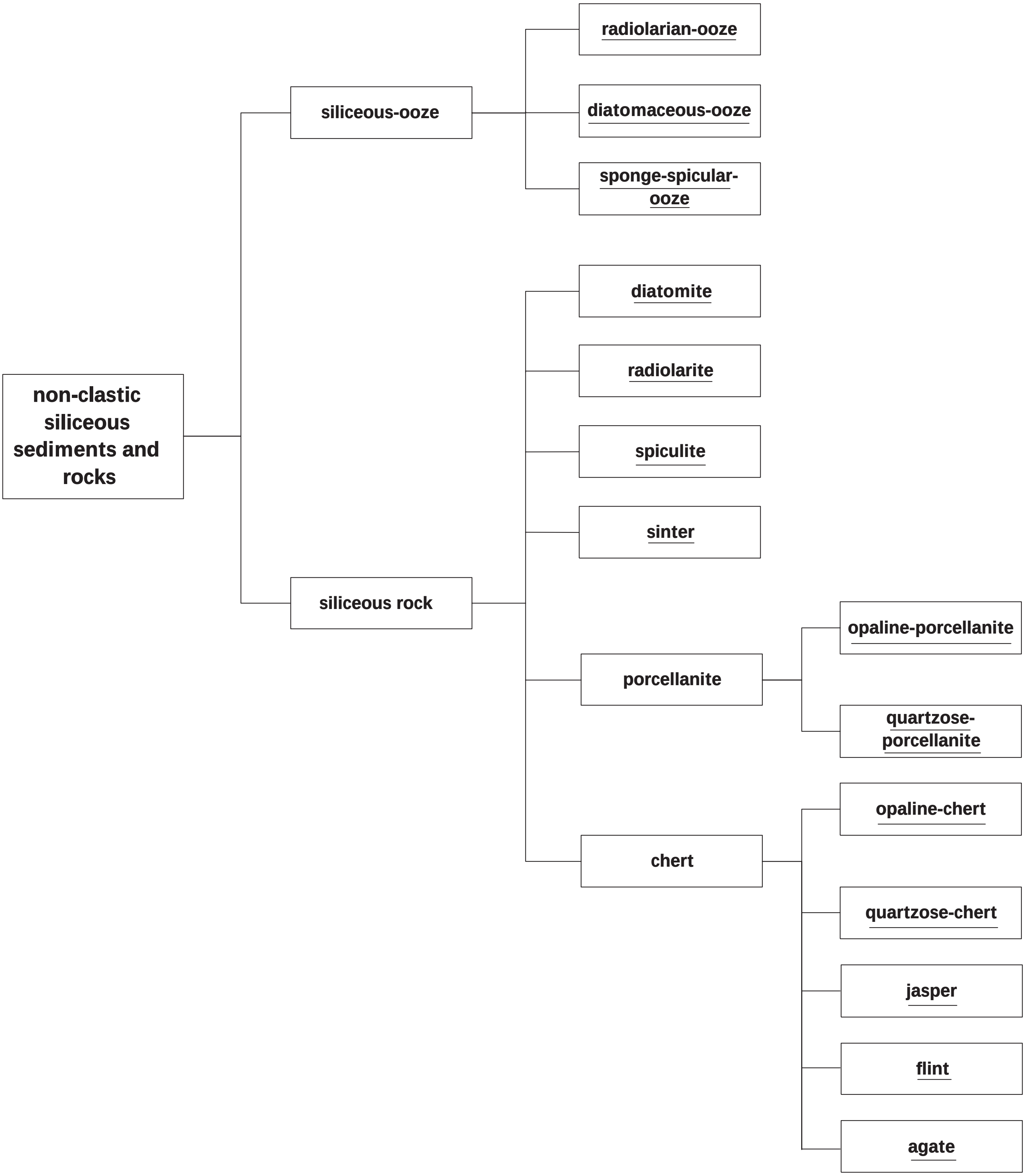

Figure 12 Classification of non-clastic silicaceous rocks.

Phi units	Clast or crystal size in mm. Log scale	Sedimentary clasts		Volcaniclastic fragments	Crystalline rocks, igneous, metamorphic or sedimentary
		boulders	GRAVEL	blocks and bombs	very–coarse–grained very–coarse–crystalline
–8	256	cobbles			
–6	64	pebbles		lapilli	
–4	16				coarse–grained coarse–crystalline
–2	4	granules			
–1	2	very–coarse–sand	SAND	coarse–ash–grains	medium–grained medium–crystalline
0	1	coarse–sand			
1	0.5 (1/2)	medium–sand			
2	0.25 (1/4)	fine–sand			fine–grained fine–crystalline
3	0.125 (1/8)	very–fine–sand			
5	0.032 (1/32)	silt	MUD	fine–ash–grains	very–fine–grained very–fine–crystalline
8	0.004 (1/256)	clay			cryptocrystalline

Figure 13 BGS grain-size scheme (based on Wentworth, 1922).

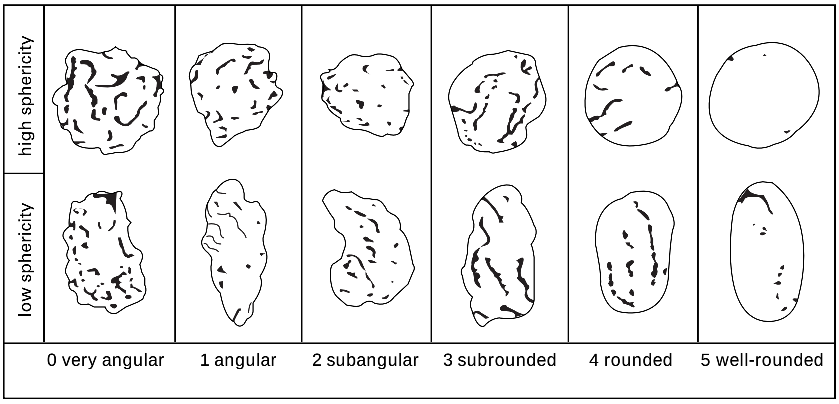

Figure 14 Categories of roundness for sediment grains (after Powers, 1953; Tucker, 1991 and Pettijohn et al., 1987).