3. Structural terms including fault rock terms

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Introduction

A Study Group (SG), under the leadership of K. Brodie, was set up to look at nomenclature relating to structural terms. At an early stage a questionnaire was sent to around 60 structural geologists throughout the world, with a series of initial definitions. The response did much to guide the work of the SG and the SCMR in finalising its recommendations.

Background

Many of the definitions given below were adopted by the SCMR without difficulty; others gave rise to considerable debate. Problems arose for a variety of reasons, namely: the variable usage of terms across the geological community (e.g. gneiss and schist); terms such as slate and cleavage proved difficult because there are no similar terms in many non-English speaking countries; equally, the difference between cleavage and schistosity and the use of texture and microstructure proved major sticking points. In other cases it was difficult to differentiate between rock types solely on features observable in the field at hand-specimen scale or in thin section examination as required by the SCMR scheme (Schmid et al., this vol.). Also, although the SCMR scheme seeks to avoid terms based on processes wherever possible, this was not practical with many terms related to fault rocks (e.g. mylonite and cataclasite).

The following sections discuss the main problem areas and the basis that the SCMR used in deciding on its recommended definitions.

The terms schist, gneiss and granofels

The SCMR decided to base its systematic rock names on structural root terms with mineral qualifiers (Schmid et al., this vol.). One possibility would have been structural root terms based on grain size. However, although the sequence slate - phyllite - schist - gneiss could be used in this way, it was generally felt that these terms were too specific to be widely applicable and that there was an absence of other suitable names. The SCMR therefore decided that the most appropriate structural root terms were those reflecting the degree of fissility or development of schistosity in a rock. The terms selected for this purpose were schist, gneiss and granofels. These names are well entrenched in the literature and are generally acceptable as terms reflecting different degrees of fissility. However, the adoption of these names as purely structural based terms gave rise to considerable debate within the SCMR. The following section discusses the current definitions of these names and considers the advantages and disadvantages of their use as structural root terms.

Schist

The term schist is derived from the Greek schistos - to split and according to Tomkieff (1983) was first used by Pliny. In its simplest form schist can be regarded as a rock possessing a schistosity. In the English language, however, many workers differentiate between a slate which is a fine-grained rock possessing a well-developed schistosity and a schist which is a medium-grained rock with a good schistosity (e.g. Holmes, 1920; Spry, 1969; Barker, 1990).

The SCMR decided, however, that defining schist as a rock with a well-developed schistosity and thus making use of it as a structural-root term was acceptable within general usage. In this way schist becomes the systematic root term covering all rocks with a well-developed schistosity including slates and phyllites. These latter names, however, are still retained within the SCMR nomenclature scheme as recommended specific names (see, Schmid et al., this vol.)

Gneiss

Gneiss is thought to be a term originally used by miners in Bohemia for the host rock in which the metalliferous veins occurred. According to Tomkeieff (1983), it was first recorded by Agricola in 1556. The basis of modern usage was probably laid down by Werner (1786) who refined the list of components and defined gneiss as a feldspar-quartz- mica rock with a coarse schistosity (*dickschiefrig Gewebe*) or gneissosity.

In modern usage gneiss may be taken as a medium- to coarse-grained rock with a poorly developed schistosity, and feldspar and quartz as characteristic (to some, essential) components. The rock commonly has a banded structure reflecting compositional and/or structural variations. Gneiss is also generally presumed to be the product of medium- to high-grade metamorphism. Definitions of gneiss, however, vary greatly between authors, reflecting the emphasis they place on the various features. Two main areas of division may be considered.

a) *Mineral content and structure*

Schist has a better-defined schistosity than gneiss. This may be taken to reflect the mineral content: that is, schist is richer in phyllosilicates and poorer in granular minerals, such as quartz and feldspar, than gneiss. The emphasis placed on these interdependent criteria has polarised the definition of gneiss.

Much of European literature has built on the definitions of the early workers and places emphasis on the mineral content. As such, related definitions of gneiss regard feldspar + quartz as essential components. As an extension of this requirement Fritsch et al. (1967) proposed a boundary between gneiss and schist at >20% modal feldspar (see also, Lorenz, 1996).

Conversly, for other workers, particularly those writing in English, the definition of gneiss has evolved with an increasing emphasis on the structure (Winkler, 1974; Barth, 1978) and to some workers the mineral content is no longer regarded as an essential part of the definition (Harker, 1954; Bates & Jackson, 1987).

b) *The significance of banding*

The significance of banding in the definition of gneiss also varies, for example, Yardley (1989) notes: "English and north American usage emphasises a tendency for different minerals to segregate into layers parallel to the schistosity, known as gneissic layering; typically quartz and feldspar-rich layers segregate out from more micaceous or mafic layers. European usage of gneiss is for coarse, mica-poor, high-grade rocks, irrespective of their fabric".

Banding may be defined in a variety of ways; some workers place the emphasis on the alternation of schistose and granulose layers (Tyrrel, 1929; Bates & Jackson, 1987; Tomkeieff, 1983), while others regard mineral banding as the characteristic feature (Barker, 1990; Mason, 1978)

The SCMR debated these differences at length, particularly the requirement for feldspar + quartz in the definition of gneiss. However, the strong association in geological usage of gneiss as a rock possessing a poorer fissility than schist and the usefulness of gneiss as such a term proved decisive. Also, although this could be construed as showing a bias towards English-language usage, it was felt that this was acceptable because of the SCMR's decision to make its definitions in English.

The SCMR also noted that a structural-only definition did not exclude any rocks currently defined as gneiss. On the other hand a major concern for the SCMR was that a structure-only definition might include rocks that in current usage would never be considered as gneisses, for example, metasandstone of low metamorphic grade. In these cases it was felt that a guideline encouraging the use of protolith-based names would provide an adequate safeguard (Schmid et al., this vol.).

The SCMR chose the boundary between schist and gneiss based on the definition proposed by Wenk (1963, as given by Winkler 1974), namely: "When hit with a hammer, rocks having a schistose fabric (schists) split perfectly parallel to 's' into plates, 1-10 mm in thickness, or parallel to the lineation into thin pencil-like columns".

Granofels

Granofels was introduced by Goldsmith (1959) as a term to describe rocks in which schistosity was absent or virtually absent. Previously, the term granulite had been used but as it also had grade and lithological connotations it was generally considered unsuitable.

Cleavage and schistosity

Early workers distinguished slate and (slaty) cleavage from schist and schistosity. Although it was subsequently recognised that there was no significant difference between the two the four terms became well-established in English literature and are now in common usage. In some languages, however, the distinction between cleavage and schistosity and slate and schist is not made. In recognition of this latter position the SCMR discussed recommending ‘schistosity’ as a term to cover both cleavage and schistosity. This, however, proved impractical and both terms have been retained and defined as recommended terms. The basis of their use and definition is given below.

Cleavage is the property of a rock to split on a set of regular parallel or subparallel planes.

Cleavage was the subject of extensive study and discussion among early structural geologists and its classification was largely based on the assumed mechanism of its formation (see review in Wilson, 1961). This led to a great confusion of terms. In order to address this problem, Powell (1979) proposed a systematic classification based on morphological rather than genetic criteria. Powell’s scheme forms the basis of current definitions and is largely adopted here. Powell divided cleavage into continuous cleavage and spaced cleavage. Continuous cleavage is present throughout the rock at the grain-size scale and may be subdivided into fine continuous cleavage as found in fine-grained rocks, and coarse continuous cleavage as found in coarse-grained rocks. Spaced cleavage is subdivided into crenulation cleavage and disjunctive cleavage. The latter is developed independently of any pre-existing mineral orientation in the rock (e.g. fracture cleavage, pressure solution cleavage). (See below for full definitions of these terms.)

Schistosity is the preferred orientation of inequant minerals in a rock.

Schistosity, in some form, is present in most cleavage types. Only in certain disjunctive cleavages (e.g. fracture cleavage) is schistosity absent. Well-developed schistosity is characteristic of continuous cleavage and *is independent of grain size*. Thus, at the simplest level, all rocks with such a structure may be termed schists. However, it is common practice to refer to fine continuous cleavage as slaty cleavage and the associated rocks as slates.

Foliation

Foliated structure was used by Macculloch (1821) to denote a coarse mineral layering with a poor splitting: the equivalent, in modern terms, of gneissose structure. Darwin (1846) defined *foliation* and gave it the same meaning. This usage and meaning became established, particularly in British petrological literature (e.g. Harker, 1939; Fairbairn, 1948; see review in Wilson, 1961). In American literature, however, the term was generally taken to include schistosity and cleavage (e.g. Knopf & Ingerson, 1938; Turner & Weiss, 1963). This latter, wider meaning, is now prevalent (e.g. Spry, 1969; Tomkeieff, 1983; Park, 1983; Barker 1990; Davis & Reynolds, 1996) and is the one adopted by the SCMR. In this sense it is equivalent to *s-surface* (Turner & Weiss, 1963, p.97).

Structure, texture and fabric

The use of the terms structure, texture and fabric may give rise to ambiguity. This is particularly true when the same words in other languages may have different meanings.

Structure is the arrangement of the parts of a rock mass irrespective of scale, including spatial relationships between the parts, their relative size and shape and the internal features of the parts.

The term *fabric* is a translation of Sander's (1930) term *Gefüge*. Fabric was defined by Knopf & Ingerson (1938) as "the spatial data that governs the arrangement in space of the component elements that go to make up any sort of external form". In current practice these elemental parts are only considered as contributing to a fabric if "they occur over and over again in a reproducible manner from one sample of a rock to another" (Hobbs et al., 1976). This means that although the fabric of a body may be considered at any scale the term is normally used at the crystallographic or mineral aggregate scale. Thus, for example, the preferred orientation of inequant mineral grains will produce planar or linear fabrics.

The term *texture* is used in two ways. The commonest way is as a term for the spatial arrangement and relative size of mineral grains and their internal features (Spry, 1969). In this sense texture is synonymous with *microstructure* or at least certain aspects of microstructure.

On the other hand, in material science and increasingly for some geologists (e.g. Barker, 1990; Vernon, 2004) texture means the presence of preferred orientation. In this sense texture is synonymous with *microfabric.*

Given this dual use the SCMR recommends that only (micro)structure and (micro)fabric are used. If the term texture is used, its meaning should be made quite clear.

Fault rocks

While some fault rocks might be considered to fall outside the remit of metamorphic nomenclature, many undergo chemical as well as structural changes, and the deformation occurs within the P-T range of metamorphism. The definition of fault rocks is problematic and many of the definitions involve processes. Different minerals deform in different ways depending on the temperature conditions, this precludes definitions of fault rock terms that are mineralogically based. The definitions presented are systematic and general.

As might be expected, **mylonite** proved difficult to define. Since its original definition by Lapworth (1885) there have been many nomenclature schemes proposed for mylonites and related rocks (e.g. Quensel, 1916; Knopf, 1931; Spry, 1969; Higgins, 1971; Sibson, 1977). More recently a Penrose conference on mylonites (Tullis et al., 1982) failed to arrive at an agreed definition of a mylonite, mainly because of the problem of knowing if, for example, plastic processes have been involved in the grain size reduction. Commonly detailed microstructural analysis of thin sections is required which makes it difficult to apply these definitions on a hand specimen scale. The definition given below is non-genetic from the point of view of the mechanism of deformation. The definition of mylonite also covers cohesive foliated cataclasites and this is in recognition of the fact that, in many cases, these are difficult to distinguish in the field. It is sometimes difficult to look at a very fine-grained fault rock in the field and know whether it is an ultramylonite, an ultracataclasite or indeed a pseudotachylite. Any division on the basis of percentage of crystal plasticity vs brittle deformation is not practical using thin sections let alone from field observations. In addition, grain-size sensitive flow is being recognized as an important deformation mechanism in many mylonites. Thin section observation may allow more specific terms or qualifiers to be applied. A review of the historic perspective of the nomenclature and classification of fault rocks is provided in Snoke et al. (1998).

Deformed **ultramafic rocks** have there own descriptive terminology (e.g. Boullier & Nicolas, 1975; Harte, 1977) that grew from detailed petrographic studies of kimberlite xenoliths. Many of these terms can be replaced with more general terms such as mylonite and cataclasite, and have not been re-examined by the SCMR.

These examples serve to illustrate the considerable difficulties that have arisen within the SCMR in attempting to erect a practical and widely acceptable scheme. Some notes are included after particular definitions in order to explain the reasoning behind the recommended definition. In considering the definitions it is important to remember that they may be a compromise but one that is hopefully workable.

All the terms given below fall into the SCMR category of ‘recommended names’ as defined by Schmid et al. (this vol.).

Definitions: 1. Main structural terms. A full list is given in the glossary

Structure: *The arrangement of the parts of a rock mass irrespective of scale, including spatial relationships between the parts, their relative size and shape and the internal features of the parts.*

The terms micro-, meso- and mega- can be used as a prefix dependent on the scale of the feature.

Microstructure: *Structure on the thin section or smaller scale.*

Mesostructure: *Structure on the hand specimen scale.*

Megastructure: *Structure on the outcrop or larger scale*.

Texture: (a) *The relative size, shape and spatial interrelationship between grains and internal features of grains in a rock*.

(b) *The presence of a preferred orientation on the microscope scale.*

Note: the use of ‘texture as defined in (a) above is common in geological literature (e.g. Spry, 1969), and as such is synonymous with *microstructure*. Because of this widespread usage the SCMR decided to accept ‘texture’ as a recommended term. However, in material science and in some languages ‘texture’ is used as defined in (b) above (e.g. Barker, 1990; Vernon, 2004) and as such is synonymous with *microfabric* The SCMR encougrages the use of (micro)structure and (micro)fabric to avoid ambiguity. If ‘texture’ is used then its meaning must be clear.

Fabric: *The relative orientation of parts of a rock mass*.

This is commonly used to refer to the crystallographic and/or shape orientation of mineral grains or groups of grains, but can also be used on a larger scale. Preferred linear orientation of the parts is termed *linear fabric*, preferred planar orientations *planar fabric*, and the lack of a preferred orientation is referred to as *random fabric*.

Foliation: *Any repetitively occurring or penetrative planar feature in a rock body.*

Examples include:

-layering on a centimetre or less scale

-preferred planar orientation of inequant mineral grains

-preferred planar orientation of lenticular or elongate grain aggregates

More than one kind of foliation with more than one orientation may be present in a rock. Foliations may become curved or distorted. The surfaces to which they are parallel are called *s-surfaces*. More precise terms should be used wherever possible.

Schistosity: *A preferred orientation of inequant mineral grains or grain aggregates produced by metamorphic processes.*

A schistosity is said to be well developed if inequant grains or grain aggregates are present in a large amount and show a high degree of preferred orientation. If the degree of preferred orientation is low or if the inequant grains or grain aggregates are only present in small amounts the schistosity is said to be poorly developed. See general comment above.

Schistose structure: *A type of structure characterised by a schistosity that is well developed, either uniformly throughout the rock or in narrowly spaced repetitive zones such that the rock will split on a scale of one centimetre or less.*

Gneissose structure: *A type of structure characterised by a schistosity which is either poorly developed throughout the rock or, if well developed, occurs in broadly spaced zones, such that the rock will split on a scale of more than one centimetre.*

Gneissosity: Synonymous with and to be replaced by gneissose structure.

Granofelsic structure: *A type of structure resulting from the absence of schistosity such that the mineral grains and aggregates of mineral grains are equant, or if inequant have a random orientation. Mineralogical or lithological layering may be present.*

Cleavage: *The property of a rock to split along a regular set of parallel or sub-parallel closely spaced surfaces*.

More than one cleavage may be present in a rock. See general comment above.

Continuous cleavage: *A type of cleavage characterised by the preferred orientation of all the inequant mineral constituents of a rock, and in which the cleavage planes are developed at the grain-size scale.*

See general comment above.

Spaced cleavage: *A type of cleavage in which the cleavage planes are spaced at regular intervals and separated by zones known as microlithons. The structure is visible by the unaided eye*.

See general comment above.

Disjunctive cleavage: *A type of spaced cleavage that is independent of any pre-existing mineral orientation in the rock.*

See general comment above.

Slaty cleavage: *A type of continuous cleavage in which the individual grains are too small to be seen by the unaided eye.*

Spaced schistosity: *A type of spaced cleavage characterised by regularly spaced zones with schistose structure that are structurally distinct from, and separating rock layers (called microlithons). The structure is visible by the unaided eye*.

Fracture cleavage: *A regular set of closely spaced parallel or subparallel fractures along which the rock will preferentially split.*

Crenulation cleavage/schistosity: *A type of spaced cleavage developed during crenulation of a pre-existing foliation, and orientated parallel to the axial plane of the crenulations*.

Crenulation: *A type of regular folding with a wavelength of one centimetre or less.*

Lineation: *Any repetitively occurring or penetrative visible linear feature in a rock body.*

It may be defined by:

-alignment of the long axes of elongate mineral grains (=*mineral lineation*)

-alignment of elongate mineral aggregates

-parallelism of hinge lines or small scale folds (=*crenulation lineation*)

-intersection of two foliations (=*intersection lineation*)

-slickenside striations or fibres.

More than one kind of lineation, with more than one orientation, may be present in a rock. Lineations may become curved or distorted. The lines to which they are parallel are called l-lines. Where possible the type of lineation should be indicated.

Fracture: *A general term for any break in a rock mass, whether or not it causes displacement*.

Fracture includes cracks, joints and faults.

Slate: *An ultrafine- or very fine-grained metamorphic rock displaying slaty cleavage.*

Slate is usually of very low metamorphic grade, although it may also occur under low-grade conditions.

Phyllite: *A fine- to medium-grained metamorphic rock characterised by a lustrous sheen and a well-developed schistosity resulting from the parallel arrangement of phyllosilicates.*

Phyllite is usually of low metamorphic grade.

Schist: *A metamorphic rock displaying schistose structure.*

For phyllosilicate-rich rocks the term schist is commonly used for medium- to coarse-grained varieties, whereas finer-grained rocks may be given the more specific names *slate* or *phyllite*.

The term schist may also be applied to rocks displaying a linear fabric rather than a schistosity, but in which the rock will split on a scale of one centimetre or less. In which case the expression *'lineated schist'* is applied.

Gneiss: *A metamorphic rock displaying a gneissose structure.*

The term gneiss may also be applied to rocks displaying a dominant linear fabric rather than a gneissose structure, but in which the rock will split on a scale of more than one centimetre. In which case the term *'lineated gniess'* is applied.

Granofels: *A metamorphic rock displaying a granofelsic structure.*

For granofels containing layers of different composition the term '*layered (or banded) granofels'* may be used.

Definitions: 2. Fault rock terms (see Fig. 3.1)

Fault: *A fracture surface along which rocks have moved relative to each other*.

Fault zone: *A zone of sheared, crushed or foliated rock, in which numerous small dislocations have occurred, adding up to an appreciable total offset of the undeformed walls. All gradations may occur between multiple fault planes and single shear zones.*

Fault rock: *Rock formed as a result of deformation in a fault zone*.

Mylonite: *A fault rock which is cohesive and characterised by a well developed schistosity resulting from tectonic reduction of grain size, and commonly containing rounded porphyroclasts and lithic fragments of similar composition to minerals in the matrix*.

Fine scale layering and an associated mineral or stretching lineation are commonly present. Brittle deformation of some minerals may be present, but deformation is commonly by crystal plasticity. Mylonites may be subdivided according to the relative proportion of finer-grained matrix into *protomylonite, mesomylonite* and *ultramylonite*.

When the protolith is known terms such as *mylonitised granite, granite mylonite* or *granite-derived mylonite* can be used.

Note: in the field it is often not possible to distinguish a foliated fault rock formed by brittle deformation (foliated cataclasite) from one formed by crystal plastic or grain boundary sliding processes, or a combination of different deformation mechanisms. Hence these are all defined in the field by the term mylonite.

Protomylonite: *A mylonite in which less than 50% of the rock volume has undergone grain size reduction.*

Mesomylonite: *A mylonite in which more than 50% and less than 90% of the rock volume has undergone grain size reduction.*

Note: As mylonite is the general term, to be consistent it is necessary to have a prefix for the more specific term intermediate between proto- and ultramylonite.

Ultramylonite: *A mylonite in which more than 90% of the rock volume has undergone grain size reduction.*

An ultramylonite need not be 'ultra' fine grained.

Augen Mylonite: *A mylonite containing distinctive large crystals or lithic fragments around which the foliated fine-grained matrix is wrapped, often forming symmetric or asymmetric trails.*

Blastomylonite: *A mylonite that displays a significant degree of grain growth related to or following deformation.*

Phyllonite: *A phyllosilicate-rich mylonite that has the lustrous sheen of a phyllite.*

Cataclasite: *A fault rock which is cohesive with a poorly developed or absent schistosity, or which is incohesive, characterised by generally angular porphyroclasts and lithic fragments in a finer-grained matrix of similar composition.*

Generally no preferred orientation of grains of individual fragments is present as a result of the deformation, but fractures may have a preferred orientation. A foliation is not generated unless the fragments are drawn out or new minerals grow during the deformation. Plastic deformation may be present but is always subordinate to some combination of fracturing, rotation and frictional sliding of particles.

Cataclasite may be subdivided according to the relative proportion of finer-grained matrix into *protocataclasite, mesocataclasite* and *ultracataclasite.*

Protocataclasite: *A cataclasite in which the matrix forms less than 50% of the rock volume.*

Mesocataclasite: *A cataclasite in which the matrix forms more than 50% and less than 90% of the rock volume*.

Note: As cataclasite is the general term, to be consistent it is necessary to have a prefix for the more specific term intermediate between proto- and ultracataclasite.

Ultracataclasite: *A cataclasite in which the matrix forms more than 90% of the rock volume.*

Fault Breccia: *A medium- to coarse-grained cataclasite containing >30% visible fragments.*

Fault Gouge: *An incohesive, clay-rich fine- to ultrafine-grained cataclasite, which may possess a schistosity and containing <30% visible fragments. Lithic clasts may be present.*

Pseudotachylite: *Ultrafine-grained vitreous-looking material, usually black and flinty in appearance, occuring as thin planar veins, injection veins or as a matrix to pseudo-conglomerates or breccias, which infills dilation fractures in the host rock.*

REFERENCES

Agricola (Bauer, G.), 1556. De re metallica, Libri XII, posthumous edition illustrated by H.R. Manuel. *Frobenius, Basel*, 538pp. (1st edn in 1530)

Barker, A.J., 1990. Introduction to Metamorphic Textures and Microstructures. Blackie. 162pp.

Barth T.F.W., 1978. In, McGraw-Hill Encyclopedia of the Geological Sciences, (ed., Lapedes, D.N.). McGraw-Hill. 915pp.

Bates R.L. and Jackson J.A 1987. Glossary of Geology (3rd edition). American Geological Institute, Virginia, 788pp.

Boullier, A.M. & Nicolas, A. 1975. Classification of textures and fabrics from peridotite xenoliths from South African Kimberlites. Physics and Chemistry of the Earth, (eds. Ahrens, L.H., Dawson, J.B. Duncan, A.R. & Erlank, A.J.), **9,** 467-475. Pergamon Press.

Darwin, C. 1846. Geological observations in South America. Smith, Elder & Co. 279pp

Davis, G.H& Reynolds, S.J. 1996. Structural Geology of Rocks and Regions (2nd edition). Wiley. 776pp

Fairbairn, H.W. 1949. structural Petrology of Deformed. Addison-wesley. 344pp.

Fritsch, W., Meixner, H., andWieseneder, H. 1967. Zur quantitativen Klassification der kristallinen Schiefer. Neues. Jahrb. Mineral. Monatsch, 364-376.

Goldsmith, R., 1959. Granofels, A New Metamorphic Rock Name. J. Geol., **67**, 109-110.

Harker, A. 1939. Metamorphism (2nd edition) Methuen. pp362

Harker, A., 1954. Petrology for Students (8th edition). Cambridge University Press.283pp.

Harte, B. 1976. Rock nomenclature with particular relation to deformation and recrystllisation textures in olivine-bearing xenoliths. Journal of Geology, **85**, 279-288.

Higgins, M.W. 1971. Cataclastic Rocks. USGS Prof. Paper. **687**, 97pp.

Hobbs, B.E., Means, W. D. and Williams, P.F. 1976. *An Outline of Structural Geology*. Wiley 571pp.

Holmes, A. 1920. A nomenclature of Petrology. Allen and Unwin. 284pp.

Knopf, E.B. 1931. Metamorphism and Phyllonitisation. Am. Jour. Sci., **21**, 1-27.

Knopf, E.B. and Ingerson, E**.** 1938. Structural Petrology. Mem Geol. Soc. Am., 6, 270pp.

Lapworth, C. 1885. The Highland Controversy in British Geology: its causes, course and consequences. Nature, **32**, 558-559.

Le Maitre R.W. (ed) 1989. A classification of igneous rocks and glossary of terms. Blackwell Sci. Publ., 193pp.

Le Maitre R.W. (ed) 2002. A classification of igneous rocks and glossary of terms (2nd edition). Cambridge University Press. 236pp.

Lorenz, W. 1996. Gneisses and Mica Schists. Chem. Erde, **56**, 79-94.

Macculloch, J. 1821. *Geological classification of rocks*. Longman, Hurst, Rees, Orme and Brown. 655pp.

Mason, R. 1978. Petrology of the Metamorphic Rocks. Allen and Unwin. 254pp.

Park, R.G. 1983. Foundations of Structural Geology.Blackie. 135pp.

Powell, C.McA. 1979 A morphlogical classification of Rock Cleavage. Tectonophysics, 58, pp21-34.

Quensel, P. 1916. Zur Kenntnis der Mylonitbildung, erläutert an Material aus dem Kebnekaisegebiet. *Bull. Geol. Inst. of the Univ. of Uppsala*, **15**, pp91-116.

Sander, B. 1930. Gefügekunde der Gesteine. Springer. 352pp.

Schmid R., Fettes D., Harte B., Davis E., and Desmons J., 2007. A systematic nomenclature for metamorphic rocks. 1. How to name a metamorphic rock. Recommendations by the IUGS Subcommission on the systematics of metamorphic rocks. SCMR website (www.bgs.ac.uk/SCMR).

Sibson, R.H. 1977. Fault rocks and fault mechanisms. Journal of the Geological Society (London) 133, 191-213.

Snoke, A.W., Tullis, J. & Todd, V.R. 1998. Fault-related Rocks: A Photographic Atlas. Princeton Univ. Press.

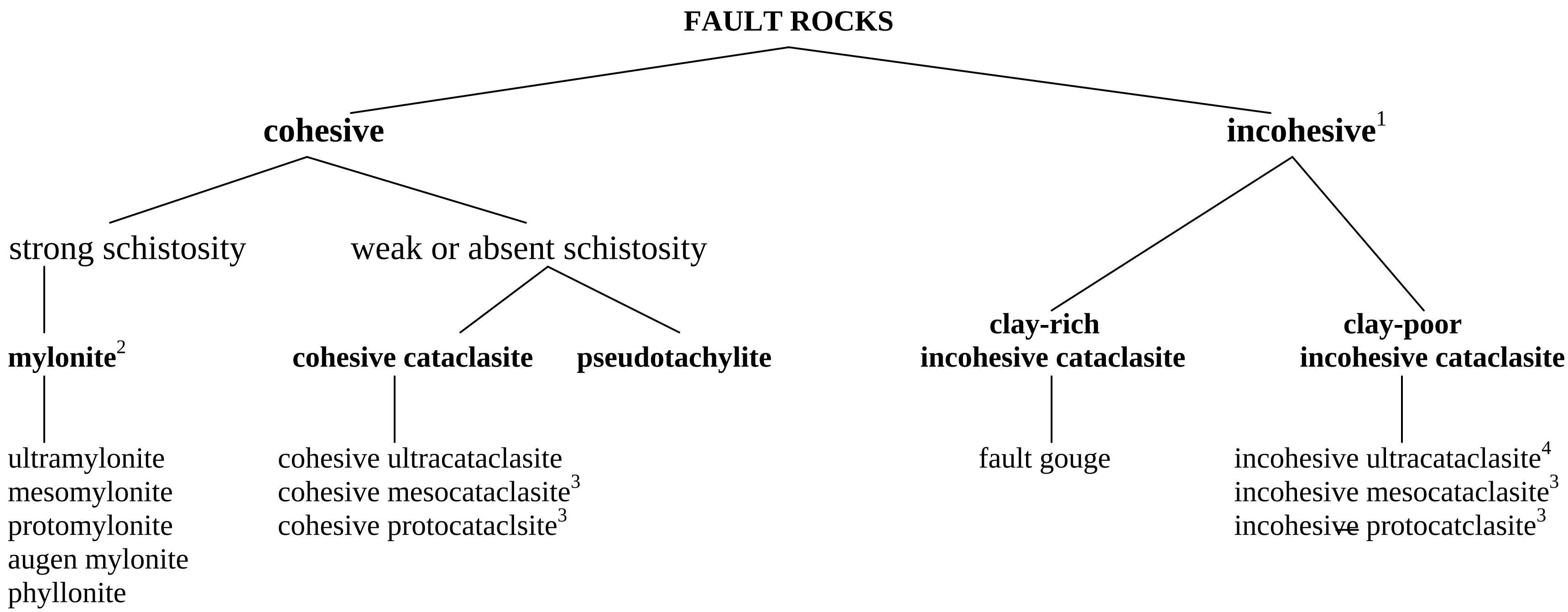
Spry,A. 1969. Metamorphic Textures. Pergamon Press, Oxford. 350pp.

Tomkeieff S. I., 1983. Dictionary of Petrology, (eds. Walton E. K., Randall B.A.O., Battey M. H. and Tomkeieff, O.). Wiley. 680pp.

Tullis, J., Snoke, A.W. & Todd, V.R. 1982. Significance and petrogenesis of mylonitic rocks. Geology, **10**, 227-230.

Turner, F.J. and Weiss L.E. 1963. *Structural analysis of metamorphic tectonites*. McGraw-Hill. 545pp.
Tyrrell, G.W., 1929. The Principles of Petrology (2nd edition). Methuen. 349pp.
Vernon, R.H. 2004. A Practical |Guide to Rock Microstructure. Cambridge 592pp.
Wenk, C. 1963 Neues Jahrb. Mineral. Monatsch. 97-107
Werner, A.G., 1786. Kurze Klassification und Beschreibung der verschiedenen Gebirgsarten. Abhandlungen der Böhmischen Gesellschaft der Wissenscafen, **1**, 272-297.
Wilson, G. 1961. The tectonic significance of small scale structures, and their importance to the geologist in the field. Annales de la Soc. Géol. de la Belgique, 84, pp423-548.
Winkler, H.G.F., 1974. Petrogenesis of Metamorphic Rocks (4th edition). Springer-Verlag. 334pp.
Yardley, B.W.D. 1989. An Introduction to Metamorphic Petrology. Longman. 248pp

Fig. 2.3.1. Organogram for fault rocks



1. incohesive (incoherent, friable, uncemented): capable of being broken into component granules with fingers or with the aid of a pen knife.
2. cohesive and foliated cataclasite is indistinguishable in the field from a mylonite.
3. coarse-grained cataclasite may also be termed ‘fault breccia’ (with the prefix cohesive or incohesive).
4. incohesive very fine grained ultracataclasite may also be termed ‘fault gouge’.

Note: the incohesive rock names may be subdivided into foliated and non-foliated varieties.