The Dalradian rocks of Scotland: glossary and terminology

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G.1 Geochronology

The time-scale and chronostratigraphical names used throughout this volume are from *A Geologic Time Scale 2004* (Gradstein *et al*., 2004). Wherever possible, interpretations of age are based upon the most recent radiometric dates, which are almost always by U-Pb analysis of zircons or, rarely, monazites. Determinations by other radiometric methods provide additional information but are interpreted with more caution or are included for historical interest.

G.2 Lithological nomenclature

The nomenclature of metamorphic rocks in this volume broadly follows the recommendations of the British Geological Survey's Rock Classification Scheme (Robertson, 1999). It also draws upon some parts of the Recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Metamorphic Rocks (Fettes and Desmons, 2007). However, the nature of the GCR is such that the site reports draw heavily upon previous literature, to which the reader is frequently referred. Hence, some more-radical changes in nomenclature that would make comparison with previous work confusing have been avoided.

Historically in the Grampian Highlands, the names used to describe units of metasedimentary rock have been dependent upon metamorphic grade and the ease with which primary sedimentary features can be identified. Thus in the South-west Grampian Highlands, where metamorphic grade is generally low, many authors have used sedimentary rock terms (e.g. mudstone, siltstone, sandstone), with or without the prefix 'meta'. In an ideal world this would be the preferred scheme. However, where the rocks are more metamorphosed, the terms pelite, semipelite, psammite and quartzite have been used to represent argillaceous to arenaceous clastic protoliths. Use of the latter scheme, first proposed by Tyrrell (1921), is almost unique to the British Isles, has not been recommended by the IUGS (Fettes and Desmons, 2007), and will almost certainly be phased out in the future. Some attempt has been made to rationalize the two 'schemes', at least within individual chapters of this volume, but total consistency has proved to be impractical for various pragmatic reasons.

Some commonly used names have been abandoned because they are no longer approved in any modern-day sedimentary-rock scheme. For example, the term 'grit', beloved of Highland geologists since the earliest days, becomes 'pebbly sandstone' or 'microconglomerate' under this regime, and 'arkose' becomes 'feldspathic sandstone'.

Regardless of metamorphic grade, relatively pure metacarbonate rocks consisting essentially of recrystallized carbonate minerals are referred to as ‘metalimestone’ or ‘metadolostone’. The term ‘marble’ is rarely found in modern descriptions and tends to be used as an informal general term for a decorative metacarbonate rock. Calcsilicate rocks represent originally impure calcareous (or magnesian) carbonate rocks and contain a high proportion of calcium-magnesium-silicate minerals such as tremolitic amphibole, grossular garnet, epidote, zoisite and idocrase. Such rocks grade into metasedimentary ‘para-amphibolites’.

The textural terms 'slate', 'phyllite', 'schist' and 'gneiss' have commonly been used as rock names and are still approved by the IUGS and BGS schemes for use where the nature of the protolith is uncertain. However, they impart no information about the composition of the rock and hence the preferred terminology restricts their use to textural qualifiers, giving priority to root names based upon composition e.g. ‘slaty metamudstone’ or ‘slaty pelite’, rather than ‘pelitic slate’. This principal has been followed throughout this volume wherever possible.

Restrictions on the use of non-approved rock names do not apply to lithostratigraphical names, into which they are commonly incorporated by historical precedence and in order to maintain consistency (e.g. Ballachulish Slate Formation, Ben Ledi Grit Formation).

The terminology of igneous rocks follows the IUGS-approved scheme of Le Maitre et al. (2002), with slight modifications following the BGS Rock Classification Scheme of Gillespie and Styles (1999). Metamorphosed igneous rocks are classified, wherever possible, by adding the prefix ‘meta’ to the name of their protolith (eg. metabasalt, metadolerite, metagranite). Where the protolith cannot be identified, general descriptive terms such as ‘hornblende schist’ or ‘amphibolite’ are used. The term ‘epidiorite’, formerly used for various metamorphosed basic rocks has been abandoned.

For the names of minerals, the reader is referred to standard textbooks.

G.3 Nomenclature and numbering of structures related to phases of deformation

Identifiable episodes of deformation have been termed D1, D2, D3 etc. in order of decreasing age. Folds that can be related to specific deformation phases are numbered F1, F2, F3 etc. Corresponding cleavages and other planar structures are numbered S1, S2, S3 etc. and primary bedding is numbered S0. Lineations are likewise numbered L1, L2, L3 etc.

However, not all of the deformation episodes are necessarily developed in all areas and, even within individual areas, the multiplicity of workers has resulted in differences in numbering of structural events. Consequently inconsistencies in the nomenclature of structural phases are common when comparing detailed studies of separate areas. Authors undertaking regional syntheses have attempted to solve this problem by disregarding phases of deformation whose effects can be shown to be of local extent only. The regional phases are then numbered to produce a sequence of major events recognizable over wide areas and accepted by most authors. Thus, for example, the sequence D1 to D3 identified in the regional synthesis of the South-west Highlands by Roberts and Treagus (1977c), differs numerically from that used in detailed, more local studies within the same area by Roberts (1974; 1976) and Treagus (1974). The issue of local fold phases that are difficult to date or seem to be additional to the regional phases was addressed by Treagus (2000) by the use of lower case letters, such as De and Dt to represent Errochty and Trinafour fold phases respectively in the Schiehallion area. Even with this rationalization, problems still exist on a regional scale with the result that different nomenclatures have been applied by various authors.

One major problem arises from a variation in the number of recognizable major phases across the Tay Nappe. D1 and D2 are widespread events recognized by most authors. However, a D3 event, responsible for refolding of the Tay Nappe in the Tummel Steep Belt, for example, becomes difficult to distinguish farther to the north-west. Consequently, workers in the Central Grampian Highlands and southern parts of the Northern Grampian Highlands, such as Roberts and Treagus (1977c; 1979), Thomas (1979; 1980) and Treagus (1987) recognized only D1 and D2 as definite nappe-forming and nappe-modifying events and later upright folds such as the Ben Lawers Synform, termed by them D3, were regarded as part of a post-nappe phase. Workers in areas to the south-east (e.g. Harris *et al*., 1976; Bradbury *et al*., 1979; Harte *et al*., 1984; Mendum and Fettes, 1985) recognized three nappe forming or modifying events (D1, D2, D3) and hence their

main late-tectonic phase, responsible in particular for the Highland Border Downbend, is D4. It is still not clear whether structures such as the Ben Lawers Synform correlate with D3 or D4 structures father to the south-east but the D1–D4 nomenclature is more generally applicable and hence will be adopted in this volume unless stated otherwise.

G.4 Use of the stereographic projection

The equal-area stereographic projection, whose use in structural geology was popularized by Coles Phillips (1954), remains the best tool for representing the orientation of planes and lines in three-dimensional space. Although it is possible to project planes and lines onto either the lower or the upper surface of a sphere, it has become conventional to use only the lower hemisphere; the equal-area projection of that hemisphere onto a two-dimensional plane is known as a stereogram or stereoplot.

On the stereogram, a plane is represented by a great circle, and a lineation by a point; if many planes are to be plotted they are best recorded as poles (a pole is a line drawn at right angles to the plane that uniquely defines the dip, dip direction, and strike of the plane)(Figure G.1)a. Plotting of the two main geometrical features of minor folds, the axial plane and hinge, is illustrated in (Figure G.1)b.

In areas of tilted or folded strata, the pattern defined by the poles to bedding, for example, most commonly forms one of two distinctive patterns. Either the points cluster in a single group (a point distribution), or they are spread out along a great circle path and define a girdle (Figure G.1)c and (Figure G.1)d. A cluster represents the variation in orientation of a single surface or horizon, for which the computed mean is commonly quoted, together with the number of observations (N). In the case of the girdle, a best-fit great circle for the dataset is computed (i.e. the plane containing the poles to the bedding; (Figure G.1)d), with the pole to this plane giving the attitude of the major fold axis.

G.5 Glossary

This glossary aims to provide simple explanations of all but the most elementary geological terms used in Chapter 1 and in the Introduction and Conclusions sections of site descriptions. It also includes many of the more important terms encountered in other sections of the volume. *The explanations are not intended to be comprehensive definitions, but concentrate instead on the way in which the terms are used in this volume*. Bold type indicates a further glossary entry.

A-type: refers to an igneous rock, usually a granite, with **alkaline** characteristics; an alkali granite.

Accretion: used in a tectonic context to describe the process whereby sections of usually oceanic crust become attached to the margin of a craton or pre-existing terrane during plate collision.

Acritarch: hollow organic walled microfossils of uncertain biological affinities, but most might be algal cysts.

Agglomerate: a **pyroclastic** rock with predominently rounded **clasts** greater than 64 mm in diameter.

Alkaline: describes igneous rocks that contain more sodium and/or potassium than is required to form feldspar and hence contain, or have the potential to contain (i.e. in the **norm**), other alkali-bearing minerals such as feldspathoids, alkali pyroxenes and alkali amphiboles.

Allochthonous: describes a body of rock that has been transported from where it was originally formed to its present position by tectonic processes.

Alluvial: **proximal** terrestrial depositional environments containing a spectrum of **mass-flow** (debris-flow) and stream-flow (**fluvial**) deposits.

Amphibolite: a dark-green rock composed largely of amphibole, typically hornblende, possibly with some plagioclase. Most amphibolites are metamorphosed **mafic** igneous rocks (ortho-amphibolites), but some are metamorphosed calcareous sedimentary rocks (**para-amphibolites**).

Amygdale: a gas bubble cavity in an igneous rock that has been infilled later with minerals.

Anatexis: describes partial melting of a pre-existing rock

Anticline: a fold in which the oldest strata lie in the core of the fold, irrespective of whether the fold closes upwards, downwards or sideways.

Antiform: a fold with **limbs** that converge upwards (upward closing), either in strata where the direction of **younging** in the stratigraphical sequence is not known, or where the strata have been previously inverted so that the fold is an upward-closing syncline. In areas of multiphase folding, all upward closing post-F1 folds should strictly be termed antiforms because of the likely presence of both upward- and downward-facing earlier structures.

Aphyric: textural term, applied to igneous rocks that lack relatively large, conspicuous crystals (**phenocrysts**) compared with the grain size of the groundmass (or non-**porphyritic**).

Aplitic: describes relatively finer grained areas, or typically veins, usually of **felsic** material, within an igneous rock

Appinitic: describes coarse-grained **ultramafic** and **mafic** igneous rocks, characterized by the presence of abundant hydrous mafic minerals, particularly amphibole, and by distinctive whole-rock geochemistry.

Ash-fall tuff: lithified **pyroclastic** fall deposit with grain size less than 2 mm in diameter.

Augen: large, generally ovoid crystals within a foliated matrix. The foliation wraps around the augen to give a characteristic texture. (From German for ‘eyes’.)

Autochthonous: describes a body of rock that formed approximately in its present position in contact with its basement.

Axial planar cleavage or foliation: a **cleavage** or **foliation** that is orientated parallel to the **axial plane** of a fold or set of folds.

Back-arc basin: the region adjacent to a **subduction**-related **island arc**, on the opposite side of the arc from the trench and subducting plate. Stresses in the back-arc region are typically extensional.

Basement: The oldest rock units recognized in a given area; usually a complex of metamorphic and/or igneous rocks that underlies a sedimentary or metasedimentary succession.

Basic: describes igneous rocks relatively rich in the ‘bases’ of early chemistry (MgO, FeO, CaO, Fe_2O_3); silica (SiO_2) is relatively low (nominally 45 – 52%).

Basin (i.e. sedimentary basin): a region of prolonged subsidence of the Earth’s surface.

Bedding: a feature of sedimentary rocks, in which planar or near-planar surfaces known as bedding planes indicate successive depositional surfaces formed as the sediments were laid down.

Biostratigraphy: the stratigraphical subdivision of sedimentary or metasedimentary rocks based on their fossil content.

Blastomylonite: a type of **mylonite** in which **porphyroclasts** and matrix have undergone recrystallization, normally synchronous with the deformation.

Boudinage: the process whereby a competent bed or layer surrounded by less competent layers is subject to extension and separates into ‘boudins’, which have the cross-section appearance of a ‘string of sausages’, separated by the less competent material.

Breccia: rock composed of angular and subangular broken fragments greater than 2 mm in diameter; can be volcanic, sedimentary or **fault**-related.

Brittle fault: a fault that has developed at low enough temperatures and pressures that the rocks adjacent to the fault have become broken and ground up by **cataclasis**, rather than undergoing recrystallization (contrast with **ductile**).

Buckle fold: fold formed in response to end loading of a competent layer, e.g. bed, vein, igneous sheet.

Calc-alkaline: describes a suite of igneous rocks, characterized chemically by the steady decrease in iron content relative to silica during evolution of the magma; typical of magmas generated at destructive plate margins during **orogenesis**.

Calcsilicate: referring to calcium- and/or magnesium-silicate minerals, or to metamorphic rocks that are rich in those minerals but contain few or no carbonate minerals.

Cataclasis: fine-scale brecciation, fracturing, crushing and rotation of mineral grains under **brittle** conditions, without significant chemical reconstitution. A cataclastic rock has no foliation.

Chert: a microcrystalline or cryptocrystalline sedimentary rock composed dominantly of silica.

Chevron fold: a fold with an angular **hinge** and near-planar **limbs**, the limbs commonly being of approximately equal length (symmetrical).

Chronostratigraphy: the correlation and subdivision of sedimentary and volcanic rock units and their metamorphosed equivalents on the basis of their relative ages. The hierarchy of chronostratigraphical units is erathem, series, system and stage, which correspond to the geological time units era, period, epoch and age.

Clast: a fragment in a rock.

Cleavage: plane of incipient parting in a rock, produced by the preferred alignment of platy minerals such as mica in response to confining pressure during deformation and accompanying low-grade metamorphism.

Coaxial: describes parallel linear structures, especially fold axes and related **lineations** arising from different phases, plunging by the same amount and towards the same direction.

Comagmatic: describes igneous rocks that are considered to have been derived from the same parent **magma**, or at least from the same source region, at the same time and under identical physical and chemical conditions.

Complex: a large-scale spatially related assemblage of mixed rock units (igneous, metamorphic and sedimentary), with complicated inter-relationships, various ages and diverse origins.

Concretion: a hard, compact mass, commonly spheroidal or ovoid, in a sedimentary rock, formed by precipitation of a cementing mineral (commonly carbonate) around a nucleus during deposition or more commonly during subsequent burial and **diagenesis**.

Conglomerate: a sedimentary rock with a significant proportion of **clasts** greater than 2 mm in diameter, set in a finer-grained groundmass (normally sandstone or siltstone). The clasts are typically rounded to subangular pebbles, cobbles and boulders.

Country rock: rock that has been intruded by an igneous rock or replaced by a mineral vein etc.

Crenulation cleavage: a type of **spaced cleavage** developed by the microfolding (crenulation) of an earlier **cleavage** or **schistosity**.

Cross-bedding: a structure in sedimentary rocks, notably sandstones, that was formed due to current action by the migration of ripples or dunes on the sediment surface. Cross-bedding can be formed in **alluvial**, tidal or aeolian environments.

Crust: The outermost layer or shell of the Earth, above the **mantle**. It consists of two parts: a **basic** layer, which forms the oceanic crust and underlies the continents at depth; and a layer of dominantly **silicic** rocks, which forms the thickest, upper part of the continental crust.

Crustal shortening: compression of the **crust** resulting in shortening on a regional scale, normally in the plane of the earth's surface.

Culmination: highest point on a structural surface or linear structural feature, where the dip or plunge reverses its direction.

Cumulate: an igneous rock formed by the accumulation of crystals in a magma chamber.

Depleted mantle: **mantle** that has been depleted in **incompatible elements**, through **partial melting**.

Detrital zircon: a zircon crystal within a sedimentary deposit or rock. Detrital zircons can be dated by **radiometric dating** methods to provide information about the age of their source rocks. Hence, they can provide a maximum age limit for deposition of the sedimentary unit.

Dextral: the sense of **strike-slip** displacement along a **fault** that has had right lateral movement; i.e. to an observer standing on one side of the fault, the rocks on the other side appear to have been displaced to the right.

Diagenesis: the process of consolidation, mineral growth, recrystallization and other processes leading to lithification of unconsolidated sediment to form rock.

Diamictite: a sedimentary rock that consists of a fine-grained matrix with much coarser clasts, such as pebble-bearing mudstones and matrix-supported conglomerates. Diamictites show poor or no sorting and are commonly, but not exclusively, of glacial origin.

Diatexite: rock that has been almost, but not completely, melted, commonly with only refractory minerals remaining.

Distal: far from the source.

Dolerite: medium-grained rock of basaltic composition; used herein as a synonym of microgabbro.

Dolostone: a carbonate-rich sedimentary rock largely composed of the mineral dolomite (calcium-magnesium carbonate).

Ductile: a type of deformation that occurs at relatively high temperature and/or pressure, where the rocks deform by distributing the strain smoothly throughout the deforming mass, typically by recrystallization and grain boundary migration processes.

Dyke: a body of igneous rock emplaced as a steep, generally near-vertical sheet, and normally discordant to the structure of its host rocks.

Enclave: an inclusion; one rock type enclosed within another.

Epidiorite: An obsolete term, widely used in the Grampian Highlands, for fine- to medium-grained basic meta-igneous rocks at medium to high grades of metamorphism, where the mineralogy becomes comparable to that of a diorite i.e. hornblende plus plagioclase of andesine composition.

Euhedral: describes a mineral grain, such as a **phenocryst**, with well-formed crystal faces.

Extensional tectonics: the term used for tectonic processes where the **crust** is under extension, for example in an orogenic collapse or continental rift setting.

Extrusive: refers to igneous rocks that have been extruded onto the Earth's surface, rather than being intruded beneath the surface (**intrusive**).

Facies: the characteristic features of a rock unit, including rock type, mineralogy, texture and structure, which together reflect a particular sedimentary, igneous or metamorphic environment and/or process.

Facing: the direction towards which a rock unit, layer or structure youngs. Facing can be applied to folds, cleavages and even faults. A fold faces in the direction normal to its axis, along the axial surface and towards the younger beds (Figure G.2).

Fault: A fracture or zone of fractures in the Earth's **crust** across which the rocks have been displaced relative to each other.

Felsic: describes light-coloured minerals (*fe*ldspar/*fe*ldspathoid and *si*lic*a*) or an igneous rock containing abundant proportions of these minerals; the opposite of **mafic**.

Felsite: a field term for glassy and fine-grained **felsic** igneous rocks.

Fluvial: describes a depositional system related directly to stream-flow deposition (i.e. rivers and streams), within a more-general **alluvial** system.

Fold axial plane: see **fold axial surface**.

Fold axial surface: the surface that joins the hinge lines of a fold occurring in successive folded surfaces (Figure G.3). Where the surface is planar or near-planar, it is commonly referred to as an **axial plane**.

Fold axis: strictly describes an abstract feature i.e. the line that when moved parallel to itself generates a fold. It is also used to describe the feature derived from a stereographic projection (i.e. a pi-axis). However, it is commonly used loosely as a synonym for **fold hinge** (Figure G.3).

Fold hinge: the trace of the fold **axial surface** (or axial plane) on a folded surface. Measured in the field as the line along which a change occurs in the amount and/or direction of dip of a folded surface; the area with the smallest radius of curvature (Figure G.3).

Fold limb: the part of the fold between one hinge and the next; the area with a larger radius of curvature (Figure G.3).

Fold interference pattern/structure: the complex geometry created where early folds have themselves been deformed and re-orientated by later folds.

Foliation: the planar arrangement of textural and mineralogical components within a rock. In metamorphic rocks, generally formed during deformation and metamorphism of the pre-existing bedding or other primary fabric.

Footwall: the block of rock immediately below any non-vertical **fault**, **thrust** or **slide**.

Foreland: the stable region in front of an orogenic belt, which has not been significantly affected by the deformation and metamorphism. The rocks in the orogenic belt are normally thrust and overfolded towards the foreland.

Gneiss: Coarse-grained metamorphic rock with a compositional layering known as gneissose layering, typically defined by paler coloured quartz- and feldspar-rich layers and darker coloured layers of **mafic** minerals. Gneisses are formed by segregation and mineral growth during metamorphism at high grades.

Graben: an elongate down-faulted crustal block commonly bounded by two normal **faults** or fault systems and with a marked topographic expression. A half-graben is bounded on one side by a **fault** or fault system.

Graded bedding: describes a bed in a sedimentary rock that has a progressive change in particle size from top to bottom. Most common is a sequence with coarse grains at the bottom and fining upwards.

Granofelsic: refers to a recrystallized, medium- to coarse-grained quartzofeldspathic rock, commonly a **psammite**, with little or no foliation or lineation.

Greywacke: a coarse-grained and poorly sorted sedimentary rock composed of angular to subangular fragments in a sandy, silty or clayey matrix. Normally deposited from turbidity currents.

Hangingwall: the block of rock immediately above any non-vertical **fault**, **thrust** or **slide**.

Hinge-zone: the zone around a **fold hinge**.

Hornfels: a well-baked, hard, splintery rock resulting from thermal (contact) metamorphism.

Hyaloclastite: A **pyroclastic** rock composed of angular fragments of glass, formed when **magma** is rapidly quenched and shattered on entering water.

Hydrothermal: describes the reaction of hot water with rocks, resulting in changes in mineralogy and chemistry (cf. **metasomatism**).

Imbricate zone: consists of slices of rock displaced by successive **thrust faults** within a **thrust belt**, which commonly form a structure like stacked roof tiles.

Incompatible elements: trace elements that are not readily accepted into the crystal structure of common rock-forming minerals during the crystallization of **magma** and hence are concentrated preferentially into the remaining liquid. They are also concentrated in the first liquids produced during **partial melting**.

Inlier: strictly, an area of older rocks enclosed within a sequence of younger rocks. Where the sequences are inverted, or where boundaries between the distinct sequences are all structural dislocations (especially low-angle **thrust faults** or **slides**), the term ‘structural inlier’ is commonly used, irrespective of the relative ages.

Intermediate: applied to an igneous rock that is transitional between **silicic** and **basic** (i.e. SiO_2 between 52% and 63%).

Intrafolial: literally “within the foliation”; a term used to describe isolated, tight to **isoclinal** folds that typically have **axial planes** parallel to the **foliation** of the rock. The folds generally affect only a few layers of the rock succession and can even be confined to a single layer.

Intrusive: refers to igneous rocks that have been intruded into older rocks beneath the Earth’s surface, rather than being extruded onto the surface (**extrusive**).

Island Arc: a chain of islands formed largely of volcanic rocks and volcaniclastic sedimentary rocks, commonly with a core of associated plutonic rocks, that formed above a **subduction zone**.

Isoclinal fold: a fold with parallel **limbs**.

Joint: a fracture in a rock across which there has been no noticeable displacement.

Juvenile: applied to material that has been derived directly from the melting or **partial melting** of **crust** or **mantle**.

Keratophyre: an altered fine- to medium-grained **felsic** igneous rock (originally a trachyte or microsyenite), consisting essentially of albite with minor chloritized **mafic** minerals.

Kink fold: a fold with planar **limbs** and a markedly angular **hinge**.

Lamination: very fine layering.

Lamprophyre: mineralogically and geochemically distinctive group of largely medium-grained igneous rocks characterised by abundant **phenocrysts** of **mafic** minerals, with **felsic** minerals largely confined to the groundmass. Allied to coarse-grained **appinitic** rocks.

Lava: molten rock at the Earth's surface (contrast with **magma**).

Lee (side): the steep slope of a ripple or dune bedform where sediment 'avalanches' from the top.

Leuco: prefix to denote a *relatively* light-coloured variant of a rock-type.

Leucocratic: *absolute* term to describe light-coloured igneous rocks based upon the modal proportions of **mafic** minerals being within the range 0 – 35%.

Leucosome: Lighter coloured, igneous-looking layers composed of **felsic** minerals in a **migmatite**, formed by segregation from or **partial melting** of the original rock.

Limestone: a sedimentary carbonate rock consisting largely of the mineral calcite (calcium carbonate).

Lineation: a linear structure in a rock; any linear fabric element. It can result from a number of processes including aligned mineral growth, intersection of cleavage and bedding, minor folding, stretching, or fault movement.

Listric: refers to a **normal fault** whose dip decreases downwards.

Lithosphere: the outer layer of the solid Earth, including the **crust** and upper part of the **mantle**, which forms tectonic plates.

Lithostratigraphy: the stratigraphical subdivision and correlation of sedimentary and volcanic rock units and their metamorphosed equivalents based on their lithology, stratigraphical position and affinities. Units are named according to their perceived rank in a formal hierarchy, namely supergroup, group, formation, member and bed. The fundamental unit is the formation.

Mafic: describes dark-coloured minerals, rich in *ma*gnesium and/or iron (*Fe*), **or** an igneous rock containing substantial proportions of these minerals, mainly amphibole, pyroxene or olivine; the opposite of **felsic**.

Magma: molten rock beneath the Earth's surface.

Mantle: part of the interior of the Earth, beneath the **crust** and above the core.

Mass-flow: the transport, down slope under the force of gravity, of large, coherent masses of sediment, tephra or rock; commonly assisted by the incorporation of water, ice or air.

Megacryst: a large crystal, occurring within an igneous rock or more rarely a metamorphic rock, which is notably larger than the surrounding minerals in the groundmass or matrix.

Mélange: a chaotic rock unit, characterized by the lack of internal continuity of contacts between component blocks and including fragments of a wide range of composition and size.

Meta-: prefix added to any rock name (lithology) to indicate that it has been metamorphosed e.g. metabasalt is a metamorphosed basalt.

Metamorphic aureole: an area of rocks around an igneous intrusion that has undergone metamorphism due to the increased temperatures created by the intrusion of **magma**. Also commonly referred to as a **thermal aureole** or simply an aureole.

Metamorphic facies: an expression of a specific range of metamorphic conditions, in particular temperature and pressure, as determined from sets of mineral assemblages (Figure G.4). Unlike **metamorphic zones**, which relate to

specific lithologies, metamorphic facies are applicable to all lithologies, although their names are derived from mineral assemblages in rocks of basaltic composition.

Metamorphic grade: widely used to indicate relative conditions of metamorphism; either as informal references to low, medium or high grade, with increase in temperature and/or pressure; or related to a specific **metamorphic zone** e.g. biotite-grade, sillimanite-grade etc.

Metamorphic isograd: in theory, any line connecting points of equal **metamorphic grade**, but in practise usually marks the incoming during **prograde** metamorphism of a key mineral, especially one that characterizes a **metamorphic zone**.

Metamorphic zone: an area or volume defined by the presence of a metamorphic index mineral or set of minerals in rocks of a specified composition (e.g. in metamudstones or in basic meta-igneous rocks).

Metasomatism: the process of chemical change and mineralogical replacement due to the introduction of different elements through fluid circulating in the rocks.

Micro: prefix added to the name of any coarse-grained igneous rock to indicate a medium-grained variety e.g.microgabbro is a medium-grained rock of gabbroic mineralogy.

Microfossil: a fossil that is of such a size that it can only be identified by use of a microscope.

Microlithon: in **spaced cleavage**, microlithons are the tabular to lenticular, millimetre- to centimetre-thick rock domains that lie between the cleavage domains. They are generally quartz and feldspar rich and either lack cleavage or have only poor cleavage development.

Mid-ocean ridge basalt (MORB): type of **tholeiitic** basalt, generated at mid-ocean ridges. A world-wide, voluminous basalt type widely used as a fundamental standard for comparative geochemistry.

Migmatite: a partially melted layered rock having an overall metamorphic appearance, generally consisting of light-coloured layers (**leucosome**) of igneous-looking **felsic** minerals, and darker layers (melasome), richer in **mafic** minerals.

Monoform: large- or medium-scale fold with one steep and one shallow-dipping limb in a sequence in which the way up of the beds is not known. Similar to monocline, where the way up is known.

Mudstone: a clastic sedimentary rock composed of very fine-grained clay and silt particles (grain size < 0.032 mm).

Mullion: an architectural term, adopted to describe a combination of **lineations** and **fold hinges**, which appear as a series of centimetre- to metre-scale columnar structures on the surface of a bed or layer.

Mylonite: A coherent, thinly layered rock, formed in a zone of intense **ductile** deformation where pre-existing grains in the rock have been deformed, recrystallized, and reduced to a grain size of 0.05 mm or less.

Nappe: a large recumbent fold or a coherent body of rock, with its margins bounded by thrust faults or shear-zones, either of which has been moved a considerable distance from its original location. (see also allochthonous).

Normative composition: a theoretical mineralogical composition of an igneous rock obtained by recalculation of the whole-rock chemical composition; useful for classification purposes and for comparison with experimental studies of **magma** crystallization.

Normal fault: an extensional high-angle **fault** (dip over 45°) on which the **hangingwall** has moved downwards relative to the **footwall**.

Obduction: the overriding/overthrusting of oceanic **crust** on to the leading edge of continental **lithosphere** during plate collision.

Ophiolite: an ordered sequence of related **ultramafic** rocks, gabbros, sheeted **dykes** and basalt **lavas** that originated through the generation of oceanic **crust**.

Orogenesis: crustal thickening following the collision of tectonic plates and resulting in magmatism, folding, thrusting and accretion, leading to regional uplift and mountain building. A period of orogenesis may be referred to as an orogenic event or as an orogeny, and the resulting area of rocks affected by these processes constitutes an orogenic belt.

Orthogneiss: a **gneiss** with an igneous **protolith**.

Orthoquartzite: a clastic sedimentary rock composed originally almost exclusively of quartz sand (over 90% quartz).

Outlier: strictly, an area of younger rocks completely surrounded by older rocks. Where the sequences are inverted (as in the Flat Belt of the Tay Nappe), or where an upper unit of restricted outcrop lies upon a low-angle **thrust fault** or **slide**, the term ‘structural outlier’ is commonly used, irrespective of the relative ages.

Palaeocurrent: a wind or water current direction that existed at the time of deposition of sedimentary rocks, and that can be inferred from sedimentary structures.

Palaeogeography: the study of the configurations of continents and oceans and their physical geography during geological history.

Palaeomagnetism: the variation in the Earth’s magnetic field over time. When rocks that contain magnetic minerals are deposited, the orientation of the Earth’s magnetic field is locked within the rocks and can be used to study the movement of tectonic plates.

Para-amphibolite: an **amphibolite** with a sedimentary **protolith**.

Paragneiss: a gneiss with a sedimentary protolith.

Partial melting: the incomplete melting of a rock to produce a **magma** that differs in composition from the parent rock.

Passive margin: a continental margin formed following rifting and continental rupture that is not the site of convergent tectonic processes. Passive margins generally contain marine sedimentary sequences.

Pegmatite: a very coarsely crystalline igneous-textured rock, typically a vein, **dyke** or sheet but also as irregular patches. Most commonly the minerals are **felsic** but used strictly the term has no mineralogical connotation.

Pelite: used here, and historically in the Scottish Highlands, for a rock, rich in mica, which formed by metamorphism of a sediment rich in clay minerals (a metamudstone).

Phenocryst: a crystal in an igneous rock that is larger than those of the groundmass, usually having crystallized at an earlier stage.

Phyllite: describes a rock with a strong **cleavage**, intermediate in texture between **slate** and **schist**, characterized by growth of new sericite, chlorite and locally biotite. Most commonly applied to pelites and semipelites but in theory can be applied to any **protolith**.

Phyllonite: a very platy type of **mylonite**, formed by deformation and recrystallization of rocks rich in mica and chlorite.

-phyric: as in ‘plagioclase-phyric’, a **porphyritic** rock containing **phenocrysts** of plagioclase.

Picrite: a magnesium-rich igneous rock (MgO greater than 18%), generally appearing as an olivine- and/or pyroxene-rich variety of a gabbro, dolerite or basalt.

Pillow lava: subaqueously erupted **lava**, usually basaltic in composition, comprising an accumulation of smooth pillow shapes produced by rapid chilling.

Plunge: the orientation of a **fold hinge/axis** or other linear structure, expressed as its angle below the horizontal (measured in degrees in a vertical plane) and its azimuth or compass direction.

Pluton: an intrusion of igneous rock, generally of kilometre-scale or larger, that has been emplaced at depth in the Earth's **crust**.

Porphyritic: textural term for an igneous rock in which larger crystals (**phenocrysts**) are set in a finer grained or glassy groundmass.

Porphyroblast: a newly grown mineral in a metamorphic rock that is significantly larger than most minerals in the matrix.

Porphyroclast: a relict, resistant, large crystal or rock fragment within a foliated rock. Common in **mylonites** where the rock has had its overall grain size reduced by deformation processes.

Porphyry: a field term for an igneous rock that contains **phenocrysts** within a fine-grained groundmass of indeterminate composition; usually preceded by a mineral qualifier indicating the type of **phenocryst** present; e.g. feldspar porphyry.

Prograde: metamorphism during which the temperature and/or pressure is progressively increasing. See **retrograde**. Also used to describe the advance of a sedimentary feature such as a delta.

Protolith: the source rock from which a new rock was formed, either by metamorphism to form a metamorphic rock, or by melting to form an igneous rock.

Proximal: near to the source.

Psammite: used here, and historically in the Scottish Highlands, for a rock, rich in quartz and feldspar with some micas, formed by metamorphism of a sandstone (a metasandstone or meta-arenite).

Pseudomorph: a replacement product, usually crystalline and consisting of one or more minerals, that retains the distinctive original shape of the parent crystal.

Ptygmatic fold: normally a single layer or vein, tightly folded in a lobate manner in a less-competent schistose matrix.

Pyroclastic: describes unconsolidated deposits and rocks that form directly by explosive ejection from a volcano.

Quartzite: used here, and historically in the Scottish Highlands, for a rock composed largely of quartz grains, formed by metamorphism of a pure sandstone (a meta-orthoquartzite).

Radiometric dating: Measuring the age of rocks using the rate of decay of radioactive isotopes contained within minerals in the rock. Sometimes referred to as isotopic dating.

Recumbent fold: an overturned fold with a near-horizontal **axial plane**.

Restite: the material remaining after **partial melting**.

Retrograde: metamorphism in which minerals that formed at relatively high temperature and/or pressure are converted to those characteristic of lower grades.

Rift: a defined area of crustal extension and thinning, typically bounded by **normal faults**. A rift may eventually rupture the continental **crust**, allowing the development of new oceanic **lithosphere**, to become an ocean. A failed rift is one in which extension has been insufficient to produce oceanic material.

Rift basin: a depositional **basin** resulting from crustal extension.

Rift–drift transition: the evolution of a continental **rift** into a **passive margin** following the development of new oceanic **lithosphere**.

Rodding: a type of lineation, formed by elongate structures that are monomineralic and not formed from the original rock, most commonly of quartz.

S-type: refers to an igneous rock, usually a granite, that formed by the **partial melting** of sedimentary or metasedimentary rocks.

Sandstone: a clastic sedimentary rock made up mainly of quartz and feldspar, between 0.032 and 2 mm in grain size.

Schist: a foliated metamorphic rock with a **schistosity**. A textural term that can be combined with compositional or mineralogical terms to specify the type of schist.

Schistosity: the subparallel alignment of grains, most commonly of micas, but also of other minerals, e.g. hornblende, talc, etc., to form a tectonic **foliation**, enabling the rock to split readily into thin flakes or laminae.

Selvedge: marginal zone to a rock mass having a distinctive feature or composition. Commonly refers to the fine-grained margin of an intrusion or to a concentration of **mafic** minerals adjacent to **leucosomes** in **migmatites** and migmatic rocks.

Semipelite: used here, and historically in the Scottish Highlands, for a metasedimentary rock, with roughly equal amounts of siliciclastic grains (quartz and feldspar) and micas, which formed from a sedimentary rock dominantly composed of silt.

Serpentinization: the hydrothermal alteration of **ultramafic** rocks in which the **mafic** minerals are replaced by a range of hydrous secondary minerals, collectively known as serpentine.

Serpentinite: a rock dominantly composed of serpentine-group minerals.

Shearing: Deformation of a rock body by the sliding or translation of one part relative to another part, in response to an applied stress. The deformation can be **brittle** or **ductile** dependent on the strain rate, temperature, pressure, presence of fluids, rock mineralogy, etc. Shearing can occur across a single fault-plane, across **shear-zones**, or it can affect kilometre-thick rock sequences.

Shear-zone: a near-planar zone of intense **shearing**, with deformation generally by **ductile** processes.

Sheath fold: a fold with a tubular shape in three dimensions, resulting from the marked variation in the **plunge** of the **fold axis** through some 180°. In cross-section on two-dimensional surfaces sheath folds are commonly manifest as closed ovoid structures.

SHRIMP: refers to ‘Sensitive High-Resolution Ion MicroProbe’. An in-situ method of measuring isotope concentrations in polished thin sections or polished sections of rocks.

Silicic: used to describe igneous rocks rich in silica (SiO_2 more than 63%). Preferred alternative to traditional term ‘acid’.

Siliciclastic: describes a sedimentary or metasedimentary rock composed dominantly of clasts of silicate minerals.

Sill: a tabular body of igneous rock, originally intruded as a subhorizontal sheet and generally concordant with the **bedding** or **foliation** in the **country rocks**.

Siltstone: a clastic sedimentary rock made up of silt-sized grains (between 0.004 and 0.032 mm).

Sinistral: the sense of **strike-slip** displacement along a **fault** that has had left lateral movement; i.e. to an observer standing on one side of the fault, the rocks on the other side appear to have been displaced to the left.

Slate: describes a fine-grained rock with a very strong, very regular, closely spaced penetrative **cleavage**, enabling it to be split into thin parallel sheets (slates). Most commonly applied to **pelites** and **semipelites** but in theory can be applied

to any **protolith**.

Slickenside: Linear grooves and ridges formed on a **fault** plane as rocks move against each other.

Slide: strictly any fault making a very low angle with original **bedding** but nowadays used almost exclusively for extensional faults (lags), commonly on the long upper limbs of **recumbent folds** and excising elements of the succession. A lag is the opposite of a compressional **thrust fault**.

Spaced cleavage: a type of **foliation** defined by closely spaced micaceous cleavage surfaces, or less commonly fractures (termed cleavage domains), that divide the rock into a series of fine-scale quartzofeldspathic tabular bodies (termed rock domains). Includes **crenulation cleavage**. In rocks of low metamorphic grade, spaced cleavage is commonly the result of pervasive pressure-solution processes.

Spilite: a pervasively altered basalt, commonly in a sub-marine environment, due to conversion of the plagioclase to albite, together with other hydrous mineralogical changes.

Steatite: a massive, typically pale grey-green, fine-grained rock consisting largely of the magnesium silicate minerals talc and magnesite.

Stereoplot: stereographic projection of structural data. Also known as a sterogram. See (Figure G.1) and accompanying text.

Stoss (side): the gentle, up-current side of a ripple or dune beform. See also **lee** side.

Strike-slip: a term used to describe a **fault** on which the sense of movement is parallel to the strike of the fault.

Subduction: the process of one lithospheric plate descending beneath another during plate convergence. Subduction occurs along a narrow belt, termed a subduction zone. Where an oceanic plate is subducted beneath a continental plate, a trench is formed.

Supercontinent: A large landmass that forms from the convergence of multiple continents. Such supercontinents have formed at various periods in the geological record, e.g. Rodinia in Mesoproterozoic times.

Syncline: a fold in which the youngest strata lie in the core of the fold, irrespective of whether the fold closes downwards, upwards or sideways.

Synform: a fold with **limbs** that converge downwards (downward closing), either in strata where the direction of **younging** of the stratigraphical sequence is not known, or where the strata have been previously inverted so that the fold is a downward-closing anticline. In areas of multiphase folding, all downward closing post-F1 folds should strictly be termed synforms because of the likely presence of both upward- and downward-facing earlier structures.

Tectonothermal event: an event in which rocks are heated and metamorphosed at depth in the crust due to tectonic processes; most commonly as a result of **orogenesis**.

Terrane: a fault-bounded body of oceanic or continental **crust** having a geological history that is significantly distinct from that of contiguous bodies.

Tholeiitic: describes a suite of silica-oversaturated igneous rocks, characterized chemically by strong iron enrichment relative to magnesium during the early stages of evolution of the **magma**; formed in extensional within-plate settings, at constructive plate margins, and in **island arcs**.

Thermal aureole: see **metamorphic aureole**.

Thermal relaxation: in a zone of rifting, upwelling **mantle** rises beneath the base of the **crust**, which becomes stretched and thinned. Following the end of rifting, this hot mantle material will gradually cool and contract, causing subsidence

over a wider area, and generating a thermal relaxation **basin**.

Thrust fault: a compressional reverse **fault** making a low-angle (less than 45°) with original **bedding** and placing older rocks over younger rocks, repeating elements of the succession. Typically occurs on the short lower limbs of **recumbent folds**. The opposite of an extensional lag or **slide**.

Thrust belt: a zone where a series of **thrust faults** crop out at the Earth's surface marking a major area of translation linked to an orogenic belt.

Tillite: a lithified glacial till ('boulder clay').

TIMS: refers to 'Thermal Ionization Mass Spectrometry' (also known as 'Isotope Dilution Thermal Ionization Mass Spectrometry' or ID-TIMS). A method of measuring isotope concentrations involving grain selection (usually zircon or monazite) and dissolution in acid.

Trace fossil: a sedimentary structure that was formed by a living organism.

Transcurrent: describes predominantly horizontal relative movement across a large-scale, steeply dipping **fault** or **shear-zone** (see also **strike-slip**).

Transgression: the spread or extension of the sea over land areas, commonly due to a relative sea-level rise.

Transpression: crustal shortening as a result of oblique compression across a >transcurrent fault

> or shear-zone.

Transtension: crustal extension as a result of oblique tension across a **transcurrent fault** or **shear-zone** leading to localised **rifts** or **basins**.

Tuff: a **pyroclastic** rock derived from volcanic ash and made up of fragments with average grain size less than 2 mm.

Turbidite: a clastic sedimentary rock formed by deposition from a **turbidity current**.

Turbidity current: an underwater, gravity-controlled, density flow laden with suspended sediment, which produces a characteristic graded sedimentary unit showing a range from sand and gravel at the base to silt and mud at the top.

U-Pb dating: measurement of the amounts of lead daughter products that result from the decay of various isotopes of uranium to calculate a radiometric age for a rock. Zircon and monazite are the common minerals dated. See **SHRIMP** and **TIMS**.

Ultrabasic: describes an igneous rock with a silica content less than that of **basic** rocks (less than 45% SiO_2).

Ultramafic: describes an igneous rock in which dark-coloured, **mafic** minerals (amphibole, pyroxene, olivine) comprise more than 90% of the rock.

Unconformity: a contact between two rock units of significantly different ages, representing a significant gap in the geological time record.

Vergence: direction of relative movement or rotation of layers in an asymmetrical fold pair. Also the direction of overturning of folded layers, e.g. towards the south. (Figure G.3).

Vesicle: a gas bubble cavity, usually in a **lava** or shallow intrusion.

Volcaniclastic: generally applied to a clastic rock containing mainly material derived from volcanic activity, but without regard for its origin or environment of deposition (includes rocks formed directly by explosive eruption from a volcano, and sedimentary rocks containing transported volcanic debris).

Xenolith: a rock fragment that is alien to the igneous rock in which it is found. Commonly refers to blocks of country rock included within intrusions.

Younging: the demonstration of the direction in a sedimentary or volcanic sequence in which younger strata can be found.

Figures

(Figure G.1) Simplified examples of the use of the equal-area stereographic projection (lower hemisphere) to represent geological structures:

1. representation of a bedding plane as a great-circle trace and as a pole.
2. representation of a fold hinge line (fold axis) as a point, lying on the axial plane (great circle).
3. example of a point distribution, defined by poles to gently dipping beds, mean dip = 05°.
4. example of a girdle distribution of poles to bedding, with a best-fit great circle, and its pole (fold axis).

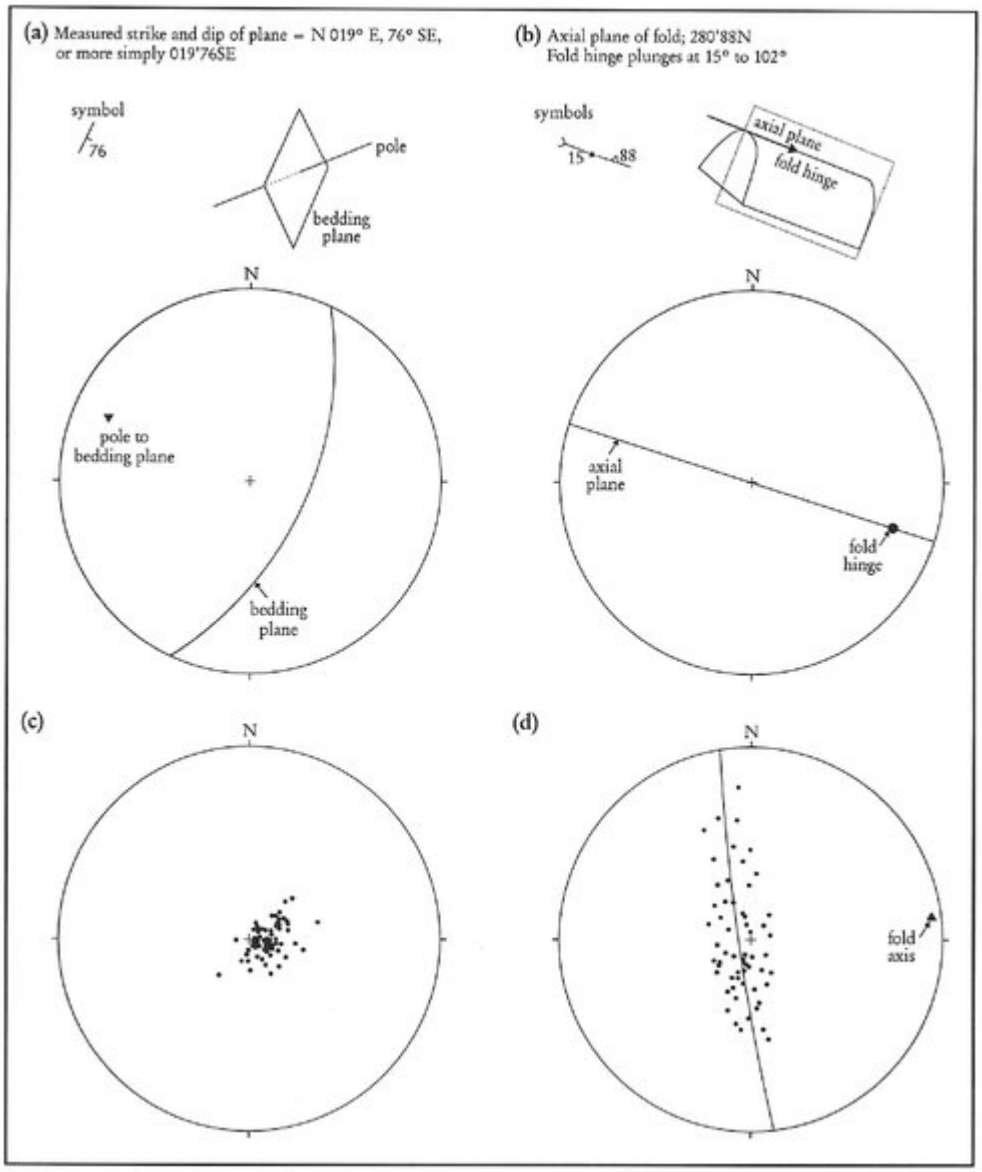
(Figure G.2) Diagram to illustrate the concept of ‘facing’ direction of folds, introduced by Shackleton (1958) as a means to describe the structural ‘way-up’ of strata. Shackleton defined ‘facing’ geometrically as ‘the direction normal to the fold axis, along the axial plane, and towards the younger beds’. Thus a synclinal synform is described as ‘upward facing’, whereas an anticlinal (i.e. inverted) synform is ‘downward facing’. Asymmetrical and recumbent folds have a sideways component of facing which is an important descriptive parameter, and which has commonly been used to infer the direction of tectonic transport.

(Figure G.3) Fold terminology:

1. single inclined fold pair illustrating the basic fold nomenclature (from McClay, 1987);
2. fold train showing the change from upright to recumbent fold and the concept of an enveloping surface (from McClay, 1987);
3. terms to describe the tightness of folds (from McClay, 1987);
4. Asymmetrical minor folds showing Z, S and M symmetry and their typical relationship to larger scale antiformal and synformal structures (from McClay, 1987);
5. Fold profile showing direction of vergence of an asymmetrical fold (from Bell, 1981);
6. Geometry of coaxially refolded folds showing F1 and F2 major folds and related minor fold structures. Note how minor F1 folds change vergence across F1 fold axial traces but maintain a consistent vergence across the F2 fold axial traces, whilst changing their facing from upwards to downwards. Minor F2 folds change their vergence across the F2 axes (after Bell, 1981);
7. Geometry of orthogonally refolded folds. Note that both F1 and F2 folds change vergence across F2 fold axes but not facing direction (arrows indicate facing direction of F1 folds) (after Bell, 1981).

(Figure G.4) Pressure/Depth–Temperature diagram showing the fields of metamorphic facies (Yardley, 1989) Abbreviations: a-e–albite-epidote, hbl–hornblende, hfls–hornfels, preh-pump–prehnite-pumpellyite, px–pyroxene.

References



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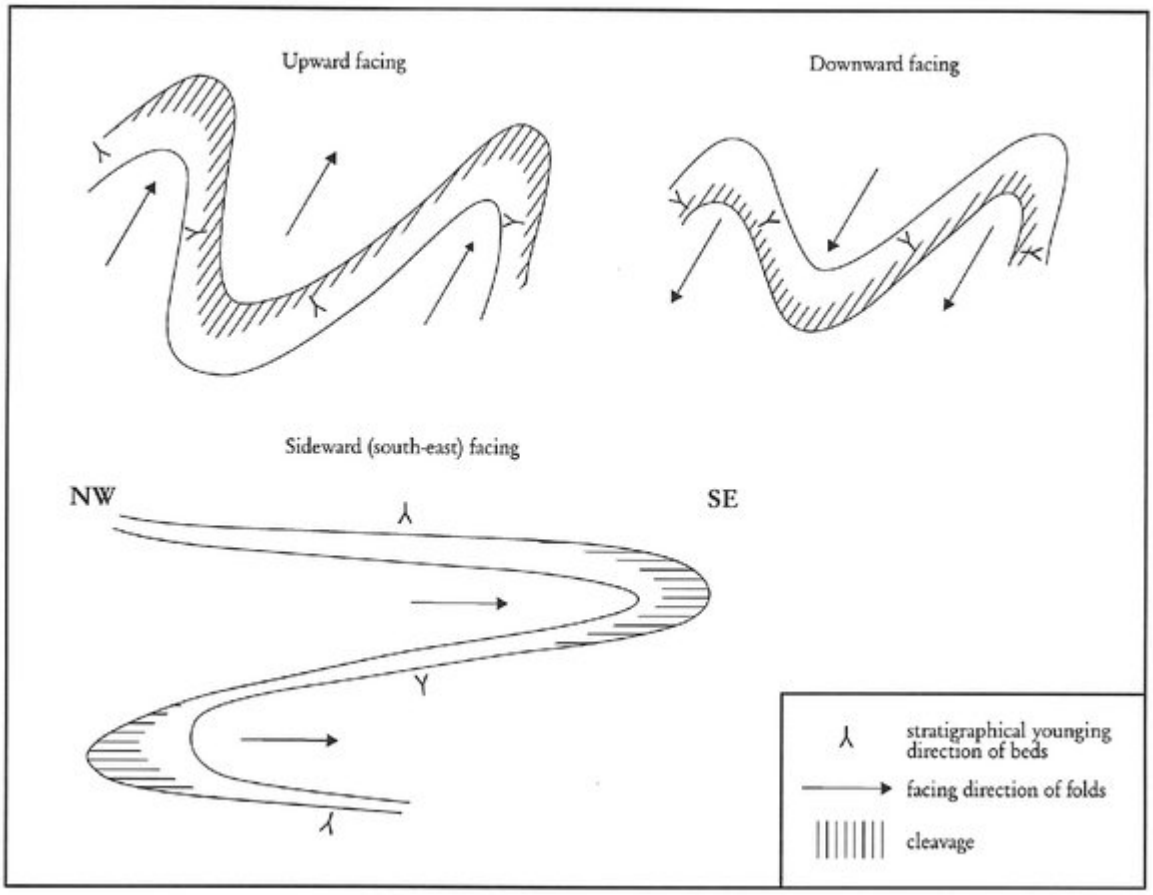

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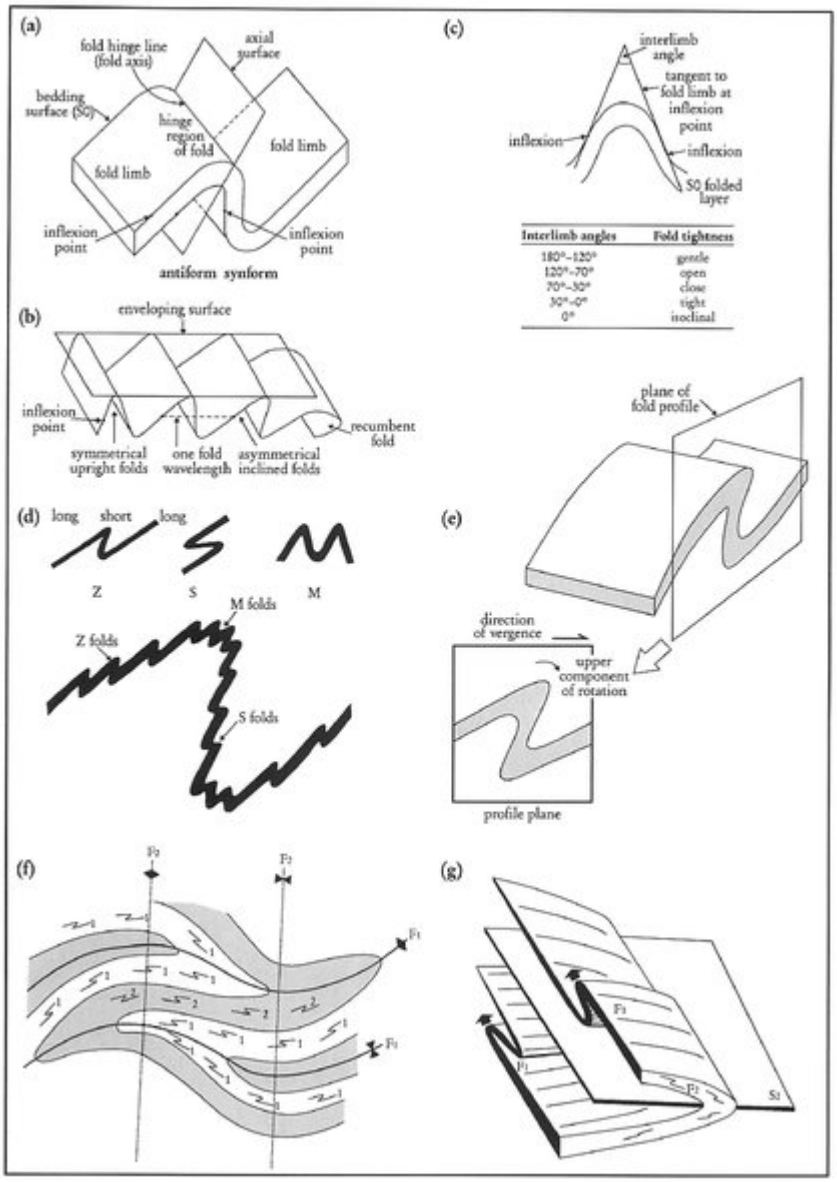

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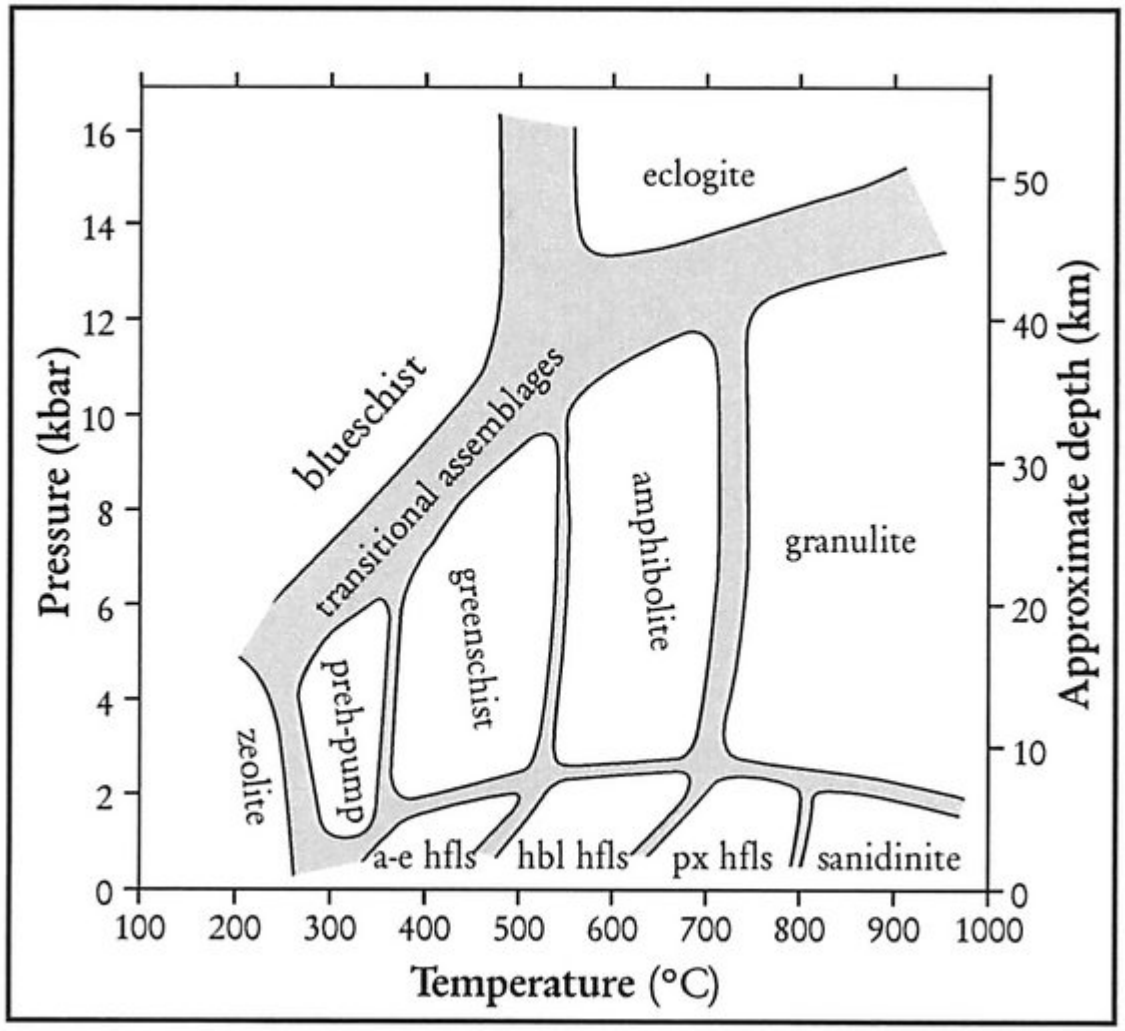

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