Chapter 2: Defining and classifying nonstratiform units: a morphogenetic approach

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Chapter 2 deals with nonstratiform units, i.e. those mappable rock bodies that lack primary stratification, including intrusions, bodies formed by deformation and/or metamorphism, and bodies of 'mixed' genetic class. The chapter follows the guidance contained in the BGS Rock Unit Classification System (BRUCS) of Gillespie and Leslie (2021) which combines a new morphogenetic approach for nonstratiform units with the well-established lithostratigraphy approach for stratiform units (Chapter 1), thereby providing a robust but pragmatic methodology for defining, classifying and naming all rock bodies revealed by conventional geological mapping. The supplementary online materials provided here include a table of the requirements for providing a comprehensive description of a formal nonstratiform unit (reproduced from Chapter 2), and two worked examples from geological settings that are distinct from – and complement – those provided in Chapter 2 of this volume. Neither of the worked examples presented here includes a comprehensive breakdown of how the various units were identified, classified and named; the reasoning and methodology used in that process are generally similar to that described for the worked examples included in Chapter 2.

Other online items associated with the book *Deciphering Earth's History: the Practice of Stratigraphy* can be found at https://geolsoc.figshare.com/DEH

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Table S2.1: Duplicate of Table 2.4 describing the requirements for providing a comprehensive description of a formal nonstratiform unit

Requirement	**Details**
Full name	The full formal name, e.g. Iapetus Ocean Ophiolite Superassemblage.
Class and rank	The class and rank of the hierarchy in which the unit is classified (e.g. Tectonometamorphic unit; Rank 4).
Parent unit	The related unit in the next highest rank of the hierarchy, if applicable.
Child unit(s)	The related unit(s) in the next lowest rank of the hierarchy, if applicable.
Geographical extent	A description of the known or inferred extent of the outcrop. The description should be text-based and should make use of place / feature names on topographic maps and a coordinate reference system where appropriate. Maps can be included where this is helpful.
Evidence for 3D form	If the unit has been classified in Rank 6 or Rank 5 according to its 3D form (e.g. as a sill, pluton, or intrusion), what evidence was used?
Evidence for spatial distribution	If the unit has been classified in Rank 5, 4, or 3 according to the spatial distribution of its component units (e.g. as a block-swarm, package, intrusion-swarm, or centre), what evidence was used?
Evidence for distinctive features	If the unit has been classified in Rank 4 or 3 according to the distinctive features displayed by its component units (e.g. as an ophiolite, ring-complex, or volcano-complex), what evidence was used?
Evidence for genetic relationship	If the unit groups related units, what evidence for a genetic relationship was used?
Geological character	A brief description of the geological character of the unit (which can include the component parts [if applicable], lithology, deformation state, etc.), and some indication of how representative the current understanding is.
Nature of boundary	A brief description of the nature of the boundary (intrusive/faulted/chilled margin/not observed etc.), if this has not been provided adequately in the description(s) of component units.
Type locality / Reference localities	Details of the precise location and character of a type locality and/or one or more reference localities. In all cases, the description should include some indication of how representative the exposure is. A type locality or reference locality is not required for a unit of Rank 5 or higher, if such localities are identified for the main component units.
Chronostratigraphical age	The chronostratigraphical division or range of the unit, and a brief description of the evidence (e.g. field relations or geochronological age).
Historical origins and revisions of nomenclature	The description should: i) indicate the source of the definition ii) list previous (now obsolete) nomenclature, citing key references iii) note if the unit is a combination of multiple locally named units iv) indicate what has been included in the new unit if it constitutes all or part of an earlier-named unit or units.
Key references	A list of important references describing the unit, or some part of it.

Worked example S2.1: the mixed-class Anglesey Supercomplex, Wales

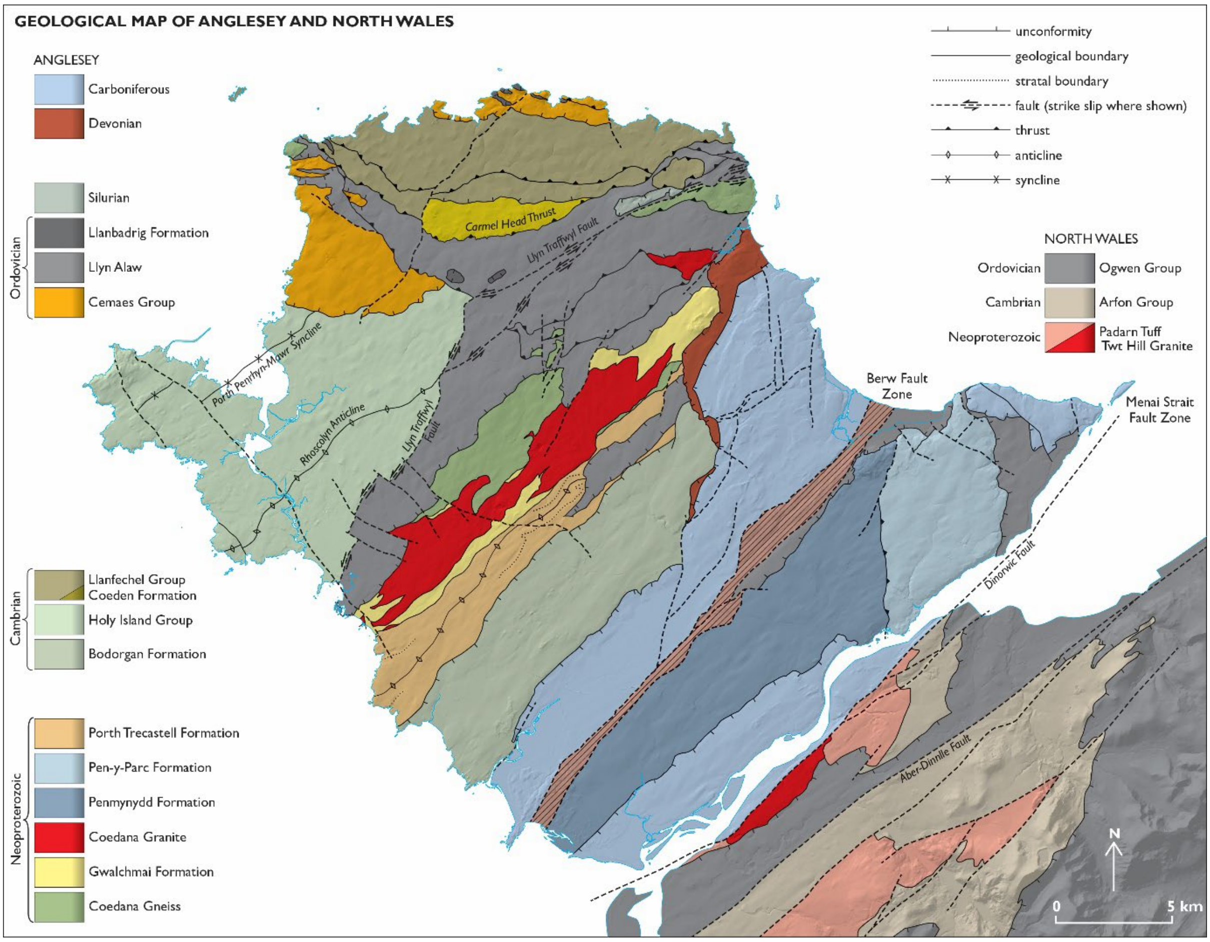

Figure S2.1: Geological map of Anglesey and adjacent North Wales. (Originally produced by the BGS. Contains British Geological Survey Background IPR © UKRI.)

Mixed-class units are inherently geologically variable and often geologically complicated. The island of Anglesey, situated off north-west Wales in the British Caledonides (Figure S2.1), comprises a complex collage of previously formally and informally classified units of Neoproterozoic and Early Palaeozoic igneous rocks and metasedimentary successions. Schofield *et al.* (2020) now describe the tectonic evolution of Anglesey in the context of the Appalachian–Caledonian Orogen, underpinning that modern interpretation with a new stratigraphical framework developed during geological survey revision mapping. Unlike the worked examples in Chapter 2, this worked example does not include a comprehensive breakdown of how the various units were identified, classified and named (but see the worked examples included in Chapter 2); more details on the geological issues and their resolution are provided in Schofield *et al*. (2020). The numerous historically recognized components of Anglesey geology can now be resolved into a number of individual mappable units, the majority of which are recognized to be of essentially lithostratigraphical character, namely the Lynn Alaw, Porth Wen, Cemaes, Llanfechel, and Holy Island groups (Figure S2.2). These units are tectonically interleaved with two tectonometamorphic packages assigned to the Mona Gneiss Assemblage, and with the Coedana Granite Pluton (Schofield *et al.* 2020). These revisions of Anglesey geology have shown that the previous array of formal, semiformal and informal units can in fact be resolved into a number of lithostratigraphical formations and groups associated with subsidiary tectonometamorphic units and intrusions. A number of the lithostratigraphical unit are present in more than one of the tectonically-bound terranes identified by Schofield *et al*. (2020). Nevertheless, the tectonic evolution of each terrane is different from its neighbour, satisfying identification as a terrane. When considered as a whole, the pre-Devonian geology of Anglesey undoubtedly presents an essentially 'mixed-class' character; as such, all of the constituent units identified to date are classified within a single mixed-class parent unit at Rank 1, the Anglesey Supercomplex.

	BRUCS classification			
Terrane	**Rank 4**	**Rank 3**	**Rank 2**	**Rank 1**
Amlwch Terrane	Llanbadrig Formation		Lynn Alaw Group	**Anglesey Supercomplex**
	Torllwyn, Porth Cynfor, and Porth Llanlleiana formations		Porth Wen Group	
	Porth Swtan and Porth Trefadog formations		Cemaes Group	
	Cemlyn Bay, Porth y Ysgraff, and Bodelwyn formations		Llanfechel Group	
	Coeden Formation		Holy Island Group?	
Porth y Felin Terrane	Porth Swtan and Porth Trefadog formations		Cemaes Group	
	Rhosneigr, Capel Parc, Portobello, Treiorworth, and Pen y Foel formations		Lynn Alaw Group	
	New Harbour, Rhoscolyn, Holyhead, and South Stack formations		Holy Island Group	
	Carmel Head Gneiss Package		Mona Gneiss Assemblage	
Aberffraw Terrane			Lynn Alaw Group (undiv.)	
	Bodorgan Formation			
	Porth Trecastell Formation			
Penmynydd Terrane	undivided strata		Lynn Alaw Group	
	Baron Hill Formation			
	Pen y Parc Formation			
	Penmynydd Formation			
Coedana Terrane (including ***Coedana Granite Pluton****, Rank 5)*	Traeth Lligwy, Porth y Mor, Traeth Bach, and Bodafon formations		Brynrefail Group	
	Cooper Mine, Parys Mountain Volcanic, Llanbadrig, Mynydd Eilian, Capel Parc, Porthygwichiad, Porth y Nant, and Mynydd y Garn formations		Lynn Alaw Group	
	Mynydd Bonafon and Gwalchmai formations		Lynn Maelog Group	
	Llandrygarn Gneiss Package		Mona Gneiss Assemblage	

Figure S2.2: BRUCS-compliant classification of the mixed-class Anglesey Supercomplex, constructed using the methodology of Gillespie and Leslie (2021), and as described in Chapter 2 of this volume. The colours used here denote unit class, as set out in Fig. 2.1 and applied throughout Chapter 2. Units classified in the lowest ranks (6 and 5) are omitted here for clarity; no subgroups have been identified to date hence Rank 3 is unused. No stratigraphical or tectonostratigraphical order is implied by the way units are arranged in this figure, which merely illustrates the hierarchical relationships of the units identified. Note that the structurally distinct and fault-bound terrane designations of Schofield *et al.* (2020) can be set alongside for context and comparison but are not a constituent part of the BRUCS classification.

The terminology used in BRUCS should not be confused with terrane nomenclature or used directly in terrane analysis, even where the extent of a classified unit (e.g. a complex, assemblage, supercomplex or supergroup) coincides wholly with a terrane, or where a terrane fulfils the criteria for a mixed-class unit as in the example of Anglesey. Stratiform and/or morphogenetic units may occur in more than one terrane but share in the distinct geological evolution of each. Indeed, a boundary between two complexes (for example) may be tectonic, intrusive or unconformable, but only in the first case could it qualify as a terrane boundary (e.g. Coney 1980). However, terrane names (such as those presented in Schofield *et al*. 2020) can be set alongside a BRUCS classification to provide context and comparison, as shown for Anglesey in Figure S2.2.

Worked example S2.2: large-scale tectonostratigraphy, East Greenland Caledonides

Allochthonous thrust sheets that may be of very substantial regional extent, and can contain km-scale thicknesses of imbricated or 'stacked' bedrock units, present a challenge for a hierarchical classification system such as BRUCS (Gillespie and Leslie 2021). Individual thrust sheets can comprise multiple stratiform units and/or intrusions and, while the allochthonous sheets are indeed tectonometamorphic units in the BRUCS nomenclature, the mappable units they contain often are not. Tectonostratigraphic(al) units are recognized by geological organizations in Scandinavia (e.g. Kumpulainen, 2017), but not in the existing International Subcommission on Stratigraphic Classification (ISG) and North American Stratigraphic Code (NASC) guidance and recommendations, as discussed in Chapter 2 of this volume. Mapped allochthonous thrust sheets in the UK (e.g. in the Northwest Highlands of Scotland) have largely been classified using the hierarchy for lithostratigraphical units, and BRUCS currently does not contain a hierarchy for tectonostratigraphical units. In some situations – particularly where the geology consists of large- or regional-scale, stacked allochthonous sheets, and where it would be beneficial in terms of achieving the objectives of mapping and classification – it may be appropriate to use a hierarchy of tectonostratigraphical units (using Kumpulainen (2017) for example) alongside the other hierarchies in BRUCS.

The large-scale tectonostratigraphy of the East Greenland Caledonides can be divided up into a number of distinctive thrust sheets, allochthons, and parautochthonous foreland windows, all thrust westwards onto the Caledonian Foreland (Higgins and Leslie 2008). Whilst the regional-scale mapping resolution of the East Greenland Caledonides does arguably reflect the relatively remote nature of this Arctic region, the published overall understanding should be regarded as robust, but has not been formally classified according to any of the published Scandinavian literature. A BRUCS-compliant classification hierarchy can be readily developed for the principal geological units already identified (Higgins and Leslie 2008), Figure S2.3 provides a visual representation of the current understanding, placing those BRUCS-compliant unit names alongside the published tectonstratigraphical nomenclature, and a possible classification of units that follows the scheme of Kumpulainen (2017), thus providing a useful foundation perhaps on which to plan further investigation and ultimately build a more mature classification overall.

<table>
<tr><th>Published Tectono-stratigraphy/ structural domain, after Higgins and Leslie (2008)</th><th colspan="4">Possible classification of 'tectonostratigraphical units', based upon Kumpulainen (2017)</th><th colspan="6">BRUCS classification</th></tr>
<tr><th></th><th>Rank 4</th><th>Rank 3</th><th>Rank 2</th><th>Rank 1</th><th>Rank 6</th><th>5</th><th>Rank 4</th><th>3</th><th>Rank 2</th><th>Rank 1</th></tr>
<tr><td rowspan="6">Franz Joseph allochthon</td><td rowspan="6">Franz Joseph Small Thrust Sheet</td><td rowspan="6"></td><td rowspan="11">East Greenland Nappe</td><td rowspan="6"></td><td></td><td></td><td></td><td></td><td>Kong Oscar Fjord Group</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>Tillite Group</td><td></td></tr>
<tr><td rowspan="4"></td><td rowspan="4"></td><td></td><td rowspan="4"></td><td>Andrée Land Group</td><td rowspan="4">Eleonore Bay Super-group</td></tr>
<tr><td></td><td>Ymer Ø Group</td></tr>
<tr><td></td><td>Lyell Land Group</td></tr>
<tr><td></td><td>Nathorst Land Group</td></tr>
<tr><td rowspan="3">Hagar Bjerg Thrust Sheet</td><td rowspan="3"></td><td rowspan="3">Hagar Bjerg Thrust Sheet</td><td rowspan="3"></td><td>Unnamed 'Older Granites'</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td></td><td rowspan="3"></td></tr>
<tr><td></td><td>Unnamed groups in the Krummedal (& Smallefjord) supracrustal sequences</td></tr>
<tr><td>Unnamed layers of Palaeoproterozoic orthogneiss (with mafic dyke intrusions)</td><td></td></tr>
<tr><td rowspan="2">Niggli Spids Thrust Sheet</td><td rowspan="2"></td><td rowspan="2">Niggli Spids Thrust Sheet</td><td rowspan="2"></td><td></td><td></td><td></td><td></td><td>Unnamed groups in the Krummedal supracrustal sequence</td><td></td></tr>
<tr><td>Unnamed layers of Palaeoproterozoic –Archaean ortho-gneiss and infolded layers of supracrustal rocks</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">Foreland and parautoch-thonous foreland windows</td><td rowspan="5"></td><td rowspan="5"></td><td rowspan="5"></td><td rowspan="5"></td><td></td><td></td><td>Målebjerg Formation</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Slottet Formation</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>Tillite Group</td><td></td></tr>
<tr><td>Layers of Supra-crustal rocks (Charcot Land and Eleonore Sø successions)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Unnamed layers of Palaeoproterozoic orthogneiss</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Figure S2.3: The published tectonostratigraphical divisions of the southern part (70°N to 76°N) of the Caledonian Orogen in East Greenland (left-hand column, after Higgins and Leslie 2008), set alongside: a possible classification of tectonostratigraphical units (centre columns) that follows the scheme of Kumpulainen (2017); and a BRUCS-compliant classification (right hand columns) of the principal lithostratigraphical, tectonometamorphic and mixed-class units that can be recognized in published accounts of the geology. The numerous individual formations making up the groups in the Franz Joseph allochthon are not listed here for simplicity. Note that the term 'East Greenland Nappe' and the terms assigned in this example to its constituent parts have not previously appeared in the literature and are not being formally proposed here; they are merely presented as examples of appropriate nomenclature.

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