Monian Composite Terrane, Precambrian and ?Cambrian, Wales

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Terranes of the Caledonian and Variscan orogens (adapted from Cope et al., 1992). P916145.
Generalised vertical section of the Monian Supergroup. P916146.


Folded low-grade metamorphosed sandstone with interbedded silty mudstone, South Stack Formation, Holy Island, Anglesey. P662388.

Minor folds, South Stack Formation, Holy
Introduction

The rocks on Anglesey were first referred to as Monian by Blake in the 19th century and it was this reference that caught the attention of Edward Greenly who, at the time, was working on the Precambrian rocks of the north-west Highlands of Scotland. Greenly resigned from the Survey in 1895 to study the rocks of Anglesey applying the techniques he had acquired in Scotland. His memoir was published by the Geological Survey in 1919 and was shortly followed by his map in 1920. The rocks that occupy the Monian Composite Terrane on Anglesey are referred to the Coedana Complex, the south-east Anglesey Blueschist Terrane and the Monian Supergroup; on Llŷn it is represented by elements of the Monian Supergroup.

Coedana Complex

The Coedana Complex forms a much denuded outcrop, south-west from Dulas Bay to the vicinity of Llanfaelog. It comprises sillimanite-bearing gneiss and amphibolite, which are intruded by the Coedana Granite. The complex includes the highest grade metamorphic rocks on the island, separating the greenschist facies Monian Supergroup, to the north-west, from the blueschist facies rocks, to the south-east. Because of the contrast in grade and the pressure-temperature conditions of formation, W Gibbons and co-workers have argued that these belts must have been generated in separate terranes and subsequently juxtaposed by faults. The north-west boundary of the complex is a post-Arenig brittle fault zone whereas the south-east boundary is a wide ductile zone.

The gneisses are coarse-grained, foliated rocks with light and dark bands, which E Greenly referred to as ‘acidic’ and ‘basic’, respectively. They consist of metasedimentary and metabasic gneisses with local development of migmatites. Zones of a distinctly schistose facies are common and ghosts of other lithological associations, such as limestone, graphitic shale and orthoquartzite, are also discernible. Metamorphic mineral assemblages indicate that the rocks were formed under middle or upper amphibolite facies conditions. Pelitic migmatites contain sillimanite ± almandine ± biotite ± oligoclase ± quartz ± ilmenite. Basic gneisses are mostly amphibolites with hornblende ± oligoclase ± biotite ± garnet ± clinopyroxene ± ilmenite ± quartz ± apatite ± sphene.

These variations led Shackleton to suggest that the gneisses were the result of the high-grade alteration of the Monian Supergroup. However, the Coedana Granite, the largest intrusion in the central Anglesey zone, is not deformed and U-Pb zircon ages indicate that igneous crystallisation took place at 614 ± 4 Ma. Greenly recognised four lithological types in the intrusion — the normal
granite, porphyritic granite, white mica granite and fine veins. The normal granite is generally pink and mottled with grey-green chloritic aggregates whereas the porphyritic granite is characterised by large orthoclase phenocrysts. The finer grained, white mica granite is a marginal facies to the main body and the finest grained granite generally occurs in veins. Although Greenly concluded that ‘the granite intruded and merged with the gneiss’, and that they were contemporary, clear relationships are not exposed. Fine-grained micaceous hornfelses, some bedded or banded, and quartzites are found at both contacts with the granite and as xenoliths within the granite. Greenly recorded some typical hornblende hornfels facies minerals consistent with a postulated depth of 3 to 7 km during emplacement. However, the structural and metamorphic evidence suggests that the granite emplacement postdated the gneisses. Locally, the south-eastern margin of the granite has been mylonitised by shearing associated with the high-strain zone.

**Blueschist Terrane**

The Blueschist Terrane forms a prominent belt on the south-east side of Anglesey, from the vicinity of Red Wharf Bay in the north-east to Newborough in the south-west. The belt was referred to as the Penmynydd Zone by Greenly, which he described as a zone of fine-grained mica schist with lenses of quartzite, foliated limestone, metagabbro and graphitic schist. The zone is characterised by strong deformation although some relict textures have survived in some of the larger bodies. More recent work has shown that the belt includes rocks of markedly different metamorphic grades, including ophiolitic epidote + sodic amphibole metabasites and phengitic metasedimentary rocks. Most importantly, the occurrence of blue amphibolite and lawsonite has been distinguished close to the eastern margin. Such rocks indicate high pressure and low temperature conditions which are commonly associated with subduction zones. Analyses of $^{40}$Ar/$^{39}$Ar amphibole and phengite data have yielded uplift ages of about 550 Ma for the blueschist event, and 590 Ma for an earlier greenschist metamorphism, possibly sub-sea floor alteration of ocean crust. Consequently, Greenly’s consideration that the association had been derived from the Gwna Group (see below) together with some acid volcanic rocks and granite is unlikely.

To the east, between Menai Bridge and Red Wharf Bay, the blueschist facies rocks are thrust over the Gwna mélangé (Monian Supergroup), and to the west they are separated from the mélangé by a steeply inclined mylonitic schist belt, the Berw Fault (P916145), with indications of sinistral transcurrent movement. The fault is the most westerly fault of the Menai Straits Fault System, a terrane boundary that was reactivated into brittle fault dis-placements throughout Phanerozoic time. It can be traced south-westwards into the Llŷn Shear Zone, on Llŷn, a mylonitic zone that juxtaposes the Gwna mélangé against the Sarn Complex at the north-western edge of the Avalonian terrane. Most of the rocks within the zone are steeply inclined, fine-grained, recrystallised schist and phyllite; both margins are gradational.

**Monian Supergroup**

The age of the Monian Supergroup on Anglesey has been the subject of controversy over many years. Progressively, its designation to the Precambrian has been claused with the possibility of it being Cambrian. Essentially the sequence is more intensely deformed and metamorphosed than the Cambrian sequence on the mainland. Even so, there is sufficient evidence to suggest that the original lithologies were broadly similar, which together with the sparse palaeontological evidence and the increasingly reliable radiometric dates makes the elevation of the Monian Supergroup into the Cambrian unavoidable.

The subdivisions of the Monian Supergroup are essentially those proposed by Shackleton. Earlier, Greenly recognised the Bedded Series, the Gneisses and the Coedana Granite, within the Mona
Complex, and considered that they each reflected successive periods of development. Thus, the Gneisses represented the floor on which the Bedded Series accumulated, and both were later intruded by the granites. Shackleton demonstrated a sharp increase in metamorphic grade from the Bedded Series into the Gneisses and argued persuasively that the latter were probably the highly metamorphosed representatives of the former.

The Monian Supergroup (P916146) comprises the Holy Island, New Harbour and Gwna groups, and is broadly equivalent to the Bedded Series of Greenly, who thought that the contacts between each unit in the lowest part of the succession were gradational and estimated a total thickness of some 6000 m. However, Shackleton recognised that although the sequence was continuous, the evidence of facing of the sedimentary structures indicated that it was upside down. The broad elements of Shackleton’s succession are generally agreed and these will be followed in this account.

The Holy Island Group has been subdivided into the South Stack, Holyhead and Rhoscolyn formations although the relationships between them remain ambiguous. The South Stack Formation, up to 400 m thick, is spectacularly exposed (P662388), (P662389) about South Stack on Holy Island (P916147) and less well exposed about Rhosgoch, south of Cemaes Bay, on the north side of Anglesey. It comprises a sequence of low grade metamorphosed, grey to white turbiditic sandstone with interbedded blue-grey silty mudstone; its base is not exposed. The turbiditic sandstones form flaggy to massive beds with graded bedding, parallel and cross-lamination and, in places, infilled scours at the base. They are interpreted as submarine outer fan deposits that accumulated in a basin considerably larger than the area enclosing the current outcrops. The possible occurrence of Skolithus-type burrows has raised the possibility of a Cambrian age. The most prominent vector of sediment derivation is from the north-west, and it has been proposed that the basin was bounded by a microcontinent in that direction.

The Holyhead Formation, up to 500 m thick, conformably overlies and is lithologically similar to the South Stack Formation. Exposure is restricted to Holy Island (P916147), where it consists of thick, interbedded, metamorphosed turbiditic sandstone and silty mudstone. Quartzites, generally 10 to 25 m thick, are subordinate, but include the Holyhead Quartzite, 150 to 200 m thick, which is correlated with a quartzite, 50 m thick, in the core of the Rhoscolyn Anticline. The quartzites are typically massive and generally structureless, but graded bedding and flute clasts are preserved in places. They are interpreted as coarse-grained turbidites from a major channel system in a mid- to inner-fan setting. Detrital zircons from the South Stack and Holyhead formations have yielded (SHRIMP) a depositional age of 501 ± 10 Ma. The Rhoscolyn Formation, up to 300 m thick, is dominated by turbiditic deposits with well-developed, plane parallel, convolute and cross-laminations indicating a more typical midfan facies.

The New Harbour Group forms the dominant outcrop across north-west Anglesey. Its thickness is estimated as up to 2500 m, but this is extremely conjectural because of the complex internal structures. In the south, the main component is highly deformed chlorite-mica schist with little evidence of the original lithologies or depositional environment. However, in the north, near Amlwch, the sequence is less deformed and metamorphosed. A lower argillaceous sequence, the Bodelwyn Formation, grades up into coarse- to fine-grained volcaniclastic sandstones, the Lynas Formation, in coarsening- and thickening-upward cycles. At some localities, as on Holy Island, thin beds of jasper, pillowd basalts and serpentinite bodies are recorded. The geochemical signature of the volcanic rocks indicates a subduction-related island arc setting.

The Skerries Formation forms three distinct outcrops in north Anglesey, about Church Bay, west of Cemaes Head and west of Bull Bay. All of these outcrops juxtapose the formation, probably in faulted contact, with New Harbour Group or Gwna Group strata. The formation has been subdivided into the Church Bay Tuffs, massive, tuffaceous silty mudstones, and the Skerries Grits, dominated by massive
poorly bedded volcaniclastic sandstones with subordinate conglomeratic layers and tuffaceous siltstone beds. The outcrop pattern and contrasting lithologies of the Skerries Formation have been attributed to the interdigitation of a proximal and more distal facies of the New Harbour Group. This interpretation is supported by the petrographical similarities between constituent formations, which indicate a similar provenance. The limited palaeocurrent data suggests that deposition occurred in a north-east–south-west-trending basin, on a fan that prograded from the north-west.

The Gwna Group is one of the most striking elements of Monian Supergroup stratigraphy. It forms two main outcrops, north of Malltraeth Bay, on Anglesey, and between Porth Dinllaen, on Llŷn, and Bardsey Island, where it is the main representative of the supergroup. The group is dominated by a mélangé, which contains allochthonous clasts, from millimetres to kilometres across, of a wide range of igneous rocks and sedimentary rocks in a sand- or mud-grade matrix. Greenly considered the mélangé to be a tectonic breccia, but Shackleton thought that its distribution, the largely unstratified matrix, and its relatively sharp contacts comprised persuasive evidence that it is an olistostrome or slide breccia resulting from lateral displacement. Locally, a crude, ghost-like internal stratigraphy within the dominant clast lithology can be determined. The emplacement of such a deposit was clearly initiated by a catastrophic event, possibly tectonic instability during closure of the basin in which the Monian Supergroup accumulated, causing uplift of the succession and its subsequent collapse. The possible Coedana Complex signature of some granitic clasts suggests the complex was exposed at the time of the disruption and, consequently, the mélangé was deposited after 614 ± 4 Ma.

In Cemaes Bay, north-west Anglesey, an outcrop of the Gwna Group comprises blue-grey silty mudstone with flaggy sandstone and ooidal and stromatolitic limestone bands, although it is possible that this apparently ordered sequence is itself a large raft. The stromatolites have been interpreted as late Precambrian or early Cambrian. Pillowed basalts, breccias and hyaloclastites are a common component throughout the entire Gwna Group outcrop and the exposures at Llanddwyn Island on Anglesey, and at Porth Dinllaen and Aberdaron on Llŷn, are particularly striking. The pillowed basalts generally contain jasper-filled cavities and, in the vicinity of fault planes, sheared limestone and dark blue-grey silicified mudstone clasts have been determined.

In Llŷn, the mélange is very well exposed in the coastal section between Porth Dinllaen and Trwyn Bychestyn, and it forms all of Bardsey Island (P662390). The mélange is estimated to be up to 3000 m thick and crude internal subdivisions, based on clast types, can be distinguished. Clasts of bedded, fine-grained volcaniclastic siltstone and sandstone (‘Gwyddel Beds’), up to 800 m across, are prominent at the south-western edge of Llŷn where, together with smaller clasts of quartzite, basalt, limestone and red mudstone, their distribution can be mapped out (P916148). Basaltic clasts of massive and pillowed lava, breccia and hyaloclastite are common throughout, and whole and fragmented basaltic pillows within a fine-grained micritic limestone matrix, as on Dinas Fawr, are particularly distinctive. Limestone clasts, clean white and bedded or dolomitised and brown, and pyritic lithologies are common; clasts of white quartzite and red mudstone, although not common, are easily discernible. Blocks of sheared lenticular granite, up to 100 m across, are recognised only in the cliff sections along the north-western and western coasts on Bardsey Island, and Wylfa Head. It has been proposed that there were two major collapse events in the emplacement of the mélangé and that ‘flow’ was directed towards the east, although this is difficult to substantiate. The wide range in composition of the clasts indicates sediments characteristic of an active plate margin and rocks of possible ‘exotic’ oceanic origin.

Much of the difficulty in interpreting the relationships of the various components of the Monian Supergroup is the result of deformation and metamorphism. Greenly considered the largest folds to be of the order of kilometres in wavelength and that the great folds seen in the cliff sections about South Stack lighthouse (Plate 4) were secondary. However the examination of any section through
the South Stack Formation shows that subsets of minor folds are common, and locally the intensity of associated thrusting has totally destroyed the original bedding. In such a context, a schistose texture is commonly well developed. More recent studies on Holy Island suggest that deformation and greenschist facies metamorphism developed in response to south-east-directed shear. The initial stages of deformation resulted in a bedding-parallel \( S_1 \) fabric and sigmoidal tension fissures. It was followed by south-east-verging \( F_2 \) folds, including the Rhoscolyn and Penrhyn Mawr anticlines (P916147), with north-west inclined foliation characterised by an \( S_2 \) pressure solution and crenulation schistosity. Finally, the ductile deformation was replaced by an episode of brittle, south-east-directed thrusting.

The ages of the deformation events continue to be controversial. The clearest stratigraphical evidence is that the supergroup is:

- unconformably overlain by Ordovician ( Arenig) sedimentary rocks that are less deformed and metamorphosed
- that boulders of New Harbour Group rocks occur in mid Ordovician ( Caradoc) conglomerates
- it contains possible Lower Cambrian acritarchs and stromatolites in the Gwna Group and possible trace fossils in the South Stack Formation

The general equivalence of the lithologies of the Monian Supergroup with both those of the Cambrian, south-east of the Menai Straits Fault System, and with the Cahore Group of south-eastern Ireland, has long been accepted. It is corroborated by the high-resolution microprobe data on zircons from the South Stack and Holyhead formations. Such a correlation would suggest that the separation of Avalonia from Gondwana did not take place until late Cambrian-early Ordovician times, and that the more intense deformation and metamorphism of the supergroup, in comparison with the Cambrian on the mainland, was the result of localised pre-Arenig shearing during amalgamation. However, the evidence remains that Anglesey basement-type rocks were incorporated into lowermost Cambrian sediments in Arfon and indicates their exposure and proximity at that time.

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