Caledonian Structures of Shetland (CAL-STR-SD)

Block Description

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For Precambrian and Structural Geology GCR block descriptions and GCR site lists, visit https://jncc.gov.uk/gcr-blocks-precambrian-and-structural-geology

Introduction

The GCR sites selected for this GCR Block represent a major episode of Earth history that occurred as a result of the 'Caledonian Orogeny', lasting from about 500 million years ago (Ma) to around 360 Ma, which was a period of mountain building and continental collision that began in the Ordovician Period (which lasted from 495 to 440 Ma) and continued through Silurian (440–417 Ma) and Devonian (417–354 Ma) time, as represented by geological features present in Shetland; geological structures produced elsewhere by the same events are covered by other Blocks: the Caledonian Structures of the Southern Uplands, Caledonian Structures of the Lake District and Caledonian Structures of Wales, for both geographical and geological reasons. **See the GCR Blocks Caledonian Structures of the Lake District (CAL-STR-LD), Caledonian Structures of the Southern Uplands (CAL-STR-SU) and Caledonian Structures of Wales (CAL-STR-WL).**

Igneous rocks that formed as a result of the Caledonian Orogeny are encompassed by the **Caledonian igneous (CAL-IGN)** GCR Block.

There is at present no agreed definition of the term 'Caledonian', but is taken here to include all of the convergent tectonic and magmatic events arising from the closure of the 'proto-Atlantic' Iapetus Ocean in which many of the rocks of Late Proterozoic and early Palaeozoic age had been deposited. It therefore encompasses subduction beneath the continental margins; the accretion or obduction of oceanic crust and island-arc material onto these margins; and ultimate collision of the continents, uplift and development of extensional molasse basins. Within this broad orogenic framework many separate 'events' are identified, such as the 'Grampian Event' and the 'Acadian Event'.

For details of stratigraphy related to the Caledonian Orogeny see GCR Blocks for Ordovician, Silurian and Devonian Stratigraphy: **Arenig - Llanvirn (ARE-LLV); Arenig - Tremadoc (ARE-TRE); Caradoc-Ashgill (CAR-ASH); Llandeilo (LDO); Llandovery (LDY); Ludlow (LUD); Marine Devonian (MAR-DEV); Non-Marine Devonian (NMAR-DEV)**).

Tectonic setting and evolution

The Iapetus Ocean was created in Late Proterozoic time by the rifting and pulling apart of a large supercontinent known as 'Rodinia'. The opening started sometime around 650 million years (Ma) ago and by the beginning of Ordovician time, at 510 Ma, the ocean was at its widest development of possibly up to 5000 km across. On one side of the ocean lay the supercontinent of Laurentia, which is represented today largely by the Precambrian basement rocks of North America, Greenland, the north of Ireland and the Scottish Highlands. On the opposite side lay the supercontinent of Gondwana, consisting of the basements of South America, Africa, India, Australia, East Antarctica and Western Europe (including south Ireland, England and Wales). A separate continent, 'Baltica' (the basement of Scandinavia and Russia), was separated from Gondwana by an arm of the Iapetus Ocean, known as the 'Tornquist Sea'. The wide separation is supported by palaeontological data, which shows distinctly different faunal assemblages in the Lower Palaeozoic rocks of each continent and by palaeomagnetic interpretations.

The continental plates of Laurentia, Gondwana and Baltica started to converge during the early part of the Ordovician Period, initiating new tectonic and magmatic processes which marked the start of the Caledonian Orogeny. The Iapetus oceanic crust was consumed in subduction zones beneath oceanic island arcs and beneath the continental margins. Magma was being created by the melting of mantle and oceanic crustal material within and above the subduction zones and by melting within the thickened continental crust.

The generally accepted sequence and timing of events as the three plates converged is as follows.

• Closure of the Tornquist Sea between Eastern Avalonia and Baltica, followed by strike-slip movement along the Tornquist Suture.

• Anticlockwise rotation of Baltica, followed by convergence with Laurentia, with subduction beneath the ‘Scottish’ sector of the Laurentian margin and closure during early to mid-Silurian times.

• Oblique convergence of Eastern Avalonia with Laurentia, with subduction beneath the Laurentian margin, resulting in closure by the early Silurian in the ‘Irish’ sector and later, mid-Silurian closure in the ‘Scottish’ sector. The junction between the two fused plates passes through the Solway Firth in Britain and is known as the Iapetus Suture.

• Protracted continent–continent collision between Laurentia and Eastern Avalonia plus Baltica, with underthrusting beneath part of the Laurentian margin (?mid-Silurian to Mid-Devonian).

• Separation of a further microcontinent, Armorica, from the margin of Gondwana, which then collided with Eastern Avalonia during Early Devonian times (the Acadian Event).

• Sinistral re-alignment of terrane boundaries (?mid-Silurian to Mid-Devonian).

The Caledonian Orogenic Belt

The Caledonian–Appalachian Orogen can be traced (pre-Atlantic drift), for some 7500 km south-west to north-east, from south-eastern USA through the British Isles to Scandinavia, Greenland, and Ny Friesland. It is generally accepted that sedimentation and igneous activity took place at, or near, the margins of an ocean (the Iapetus) that separated the Laurentian and Gondwanaland plates, over a period from the Precambrian through the early Palaeozoic. From studies of fauna, sedimentary history, igneous activity, structural and metamorphic evolution, and palaeomagnetism on its two sides, it is considered that deformation of sediments and volcanic rocks, resulting from the episodic closure of the Iapetus Ocean, took place through the early Palaeozoic to culminate in continental collision during the early Devonian.

The British Caledonides–Scottish Highlands

In the British Isles, two groups of contrasting terranes are of long standing: the Scottish Highland Terranes (and Irish equivalents) with their early, 590–480 Ma Caledonian (= Grampian) deformation and metamorphism, and the Southern Upland, Lake District, and Welsh Terranes (and their Irish equivalents) dominated by late or end-Caledonian (= Acadian) deformation and low-grade metamorphism, dated around 400 Ma. The first of these areas itself has a complex history, but culminated with the Grampian Orogeny imposed on rocks ranging in age from Archaean basement (Lewisian) through the Proterozoic (Moine) to the Late Proterozoic to early Cambrian (Dalradian) cover. The principal deformation events took place before 490 Ma, resulting in polyphase folding, thrusting, and regional low- to high-grade metamorphism. Subsequent folding in this area has not been precisely dated, but it pre-dates intrusion of Upper Silurian to Lower Devonian granites and faulting on the Great Glen Fault system. Some of this late folding, and certainly the faulting, must correlate in time with the late-Caledonian deformation of other terranes.

Midland Valley

Between the Scottish Highlands and the Southern Uplands lies the enigmatic terrane of the Midland Valley. Apart from some indirect evidence here of a granulite basement, the oldest exposed rocks comprise the Lower Ordovician Ballantrae Complex, commonly interpreted as obducted Iapetus Ocean crust, with a complex and little-understood terrane history. These rocks are unconformably overlain by Middle Ordovician to Middle Silurian sediments which contrast strongly in their sedimentology and structural and metamorphic state with the rocks of the Southern Uplands. In the south-east of the Midland Valley, they are very weakly folded and appear to be conformable with the Lower Devonian, although folding preceded

Gedinnian Series deposition in the north-east in the Pentland Hills. The Middle Devonian is missing and the Upper Devonian is strongly unconformable on older rocks, with evidence, in this interval, of locally strong folding and faulting. Another element of the Midland Valley Terrane is a narrow zone of possibly ophiolitic rocks which parallels the Highland Boundary Fault: this has small areas of Arenig Series, Middle Ordovician and Upper Ordovician sediments, each apparently with a distinct structural history.

Southern Uplands The deformation events that are the subject of this GCR Block are generally construed to be the result of the closing of the Iapetus between the mid-Ordovician Period and the early Devonian, associated with marginally directed subduction zones. There have been many suggestions as to how both large-scale and small-scale structures may be related to these models. On the north-western margin, the arguments for NW-directed subduction in the Southern Uplands have been strengthened by the stratigraphical, sedimentological, and large-scale structural evidence. The distinctive stratigraphical and structural arrangement of these rocks has been used to argue for accretion above a descending oceanic plate. According to the accretionary prism model, deformation in the Southern Uplands, unlike that in the Lake District and Wales, would be expected to have developed throughout late Ordovician and Silurian times, perhaps culminating with the development of the finite cleavage in the early Devonian. Thus the upright SE-verging and steep reverse faults have been interpreted as original flat-lying, ocean-verging and NW-dipping thrusts respectively, which have been rotated into their present steep attitudes in the accretion process. The cleavage, which cuts across the folds, has been attributed to the late-stage closure of the Iapetus. However, there is still much debate concerning the detailed relationship of the structures observed, to the evolution of the supposed accretionary prism (a wedge-shaped pile of deformed rocks) above the subducting plate.