Chapter 3 The Llandovery Series

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Introduction

The lowest series of the Silurian System is named the Llandovery Series, after the town of Llandovery in South Wales. The base of the series is coincident with the base of the Silurian System, and was defined in 1984 by the Ordovician–Silurian Boundary Working Group of the International Commission on Stratigraphy (ICS) at the base of the *acuminatus* graptolite biozone at Dob's Linn in the Southern Uplands of Scotland (see (Figure 1.2), and description of the GCR site at Dob's Linn). The history leading to this decision and to the decisions of the Silurian Subcommission of the ICS regarding stages within the Llandovery Series has been fully documented by Holland (1989).

The term 'Llandovery Series' was introduced by Murchison (1839), and is effectively synonymous with the 'Valentian Series' of Lapworth (1876c). For many years it was customary to use the latter term for the graptolitic facies of the earliest Silurian, such as the succession in the Southern Uplands of Scotland (e.g. Jones, 1909, 1921), while the former term was applied to shelly sequences such as that at Llandovery (Jones, 1925). The history of usage of the two names was discussed by Toghill (1969), who advocated dropping the term 'Valentian Series' in favour of the earlier name. The use of the name 'Llandovery Series' was ratified at the International Geological Congress in 1984 (Holland, 1985).

There are three stages within the Llandovery Series, the Rhuddanian, Aeronian and Telychian stages (Cocks *et al.,* 1984; Bassett, 1985). The base of the Rhuddanian Stage is coincident with the base of the Llandovery Series and the base of the Silurian System, and is defined at the GCR site at Dob's Linn. The bases of the Aeronian and Telychian stages are defined within the Llandovery type area, at the GCR sites of Trefawr Track and Fron Road, respectively, although there has been some debate regarding these definitions (e.g. Temple, 1988). The division of the Llandovery Series into these three stages supersedes the earlier proposal for four named stages (Cocks *et al.,* 1970).

Palaeoenvironmental setting

The palaeogeography and palaeoenvironments of the British Silurian have been summarized in a number of publications, most recently by Bassett *et al.* (1992), and are also outlined in Chapter 1 of this volume (see also (Figure 3.1)). The early Llandovery was marked by a general eustatic rise in sea level following the glacial episode in the latest Ordovician (see (Figure 1.4)), and by a slow recovery of biotic diversity, which had been depleted by the extinction events associated with the glaciation. In the Welsh Basin, Llandovery history is marked by a pulsed transgression of the sea eastwards and south-eastwards across the margins of the Midland Platform (see (Figure 1.9)a). The progressive flooding of the coastal areas is evident at several GCR sites in Wales and the Welsh Borderland, which record the varying times of deposition of the first Silurian marine sediments, and the nature of the deeper-water deposits that succeeded them (Ziegler *et al.,* 1968b). Benthic faunal communities, dominated by brachiopods, have proved particularly useful in tracing the progress of this Llandovery transgression, and have enabled recognition of temporary local regressive episodes (Ziegler *et al.,* 1968a; Ziegler *et al*., 1968b). By the end of the Llandovery epoch, much of the Welsh Borderland area, which was emergent during the latest Ordovician, had been inundated. In the deeper parts of the basin, deposition was dominated by turbidity flows, initially mostly generated from the eastern or south-eastern margin of the basin; from the early Telychian, however, the major source of turbidity currents shifted to the south-south-west. Deposition was controlled by major faults within the basin, with subsidence making space for thick accumulations of turbidites (Wilson *et al.,* 1992). In quieter areas of the basin and between the turbidite systems, hemipelagic shales were deposited, sometimes with rich graptolite faunas. In comparison with much of the Ordovician, Llandovery times in the Welsh region were relatively volcanically quiescent, although lava and ash flows are evident in the Skomer Volcanic Group of west Pembrokeshire and in the succession in the Tortworth Inlier. Other evidence of some continuing volcanic activity is found in the occurrence of bentonite bands in many areas.

In the Lake District Basin, mudstone deposition was dominant throughout the Llandovery, with anoxic black graptolitic shales particularly prevalent in sections of Rhuddanian strata. In the lower part of the Aeronian Stage, paler non-graptolitic mudstones become interbedded with the black shales; Rickards (1964, 1989a) suggested that these represent brief periods of oxic bottom conditions. This alternation continues through the Aeronian, with fine turbiditic sands, perhaps generated from a reactivated horst, coming into many sections in the uppermost part of the stage. Black shales become thinner and more infrequent in Telychian sections, which are dominated by pale mudstones, regarded at least in part to represent distal turbidites by Rickards (1964, 1989a). The changes in bottom oxygenation here and elsewhere have been related to a model of alternating greenhouse (secundo) and coldhouse (primo) climatic conditions; in primo states there would have been vigorous vertical circulation in oceanic and marginal basins, with consequent oxygenation of deeper waters, whereas secundo states were characterized by stagnant oceans with deepwater anoxia Oeppsson, 1990; Aldridge *et al.,* 1993a).

To the north of the Iapetus Suture, in Scotland, a diachronous thrust stack of greywackes and deep-marine graptolitic mudstones occurs to the south of the Southern Uplands Fault (see (Figure 1.6)). These represent an accretionary accumulation of sediments that built up during the late Ordovician and Llandovery on the northern margin of the ocean or of an associated back-arc basin. North of this, in the Midland Valley area, Llandovery sedimentation is represented in a suite of marine to non-marine successions, deposited in narrow sub-basins generated by strike-slip activity (Williams and Harper, 1988; Phillips *et al.,* 1998). In the Girvan sub-basin much of the sequence was deposited in relatively deep water, with graptolitic shales and turbidites or storm-generated sandstone bodies characteristic; some horizons with shelly fossils, particularly at the bottom of the succession, testify to shallow water or offshore shelf conditions. The deepening through the Llandovery in this area relates to the general eustatic rise in sea level also recognized in the Welsh Basin. In the Pentland Hills area, at the south-eastern end of the Midland Valley, marine deposition also occurred in a sedimentary basin that was physically or ecologically isolated from other parts of the region; faunal similarities, however, suggest that there was a link between this area and Balto-Scandia. Evidence of brackish water conditions during the Llandovery is found in the succession exposed in the Lesmahagow Inlier, in the south-central part of the Midland Valley, where laminated siltstones contain gastropods, eurypterids, phyllocarids and agnathan fishes.

Subsurface Llandovery strata are also known from boreholes to the east of the Midland Platform, in East Anglia and Kent. The sediments here include turbidites and graptolitic shales, suggestive of a basinal environment (see Bassett *et al.,* 1992).

Biostratigraphy

The primary fossil group for biostratigraphy in the Llandovery is the graptolites. The standard biozonal scheme (Rickards, 1976, 1989b; see (Figure 1.2)) has been modified recently by the recognition of additional biozones and the division of some biozones into sub-biozones (Figure 3.2). Conodonts, acritarchs, chitinozoans and brachiopods also provide valuable biostratigraphical information, although a considerable amount of work remains to be done to tie zonations based on these groups into the graptolite scheme.

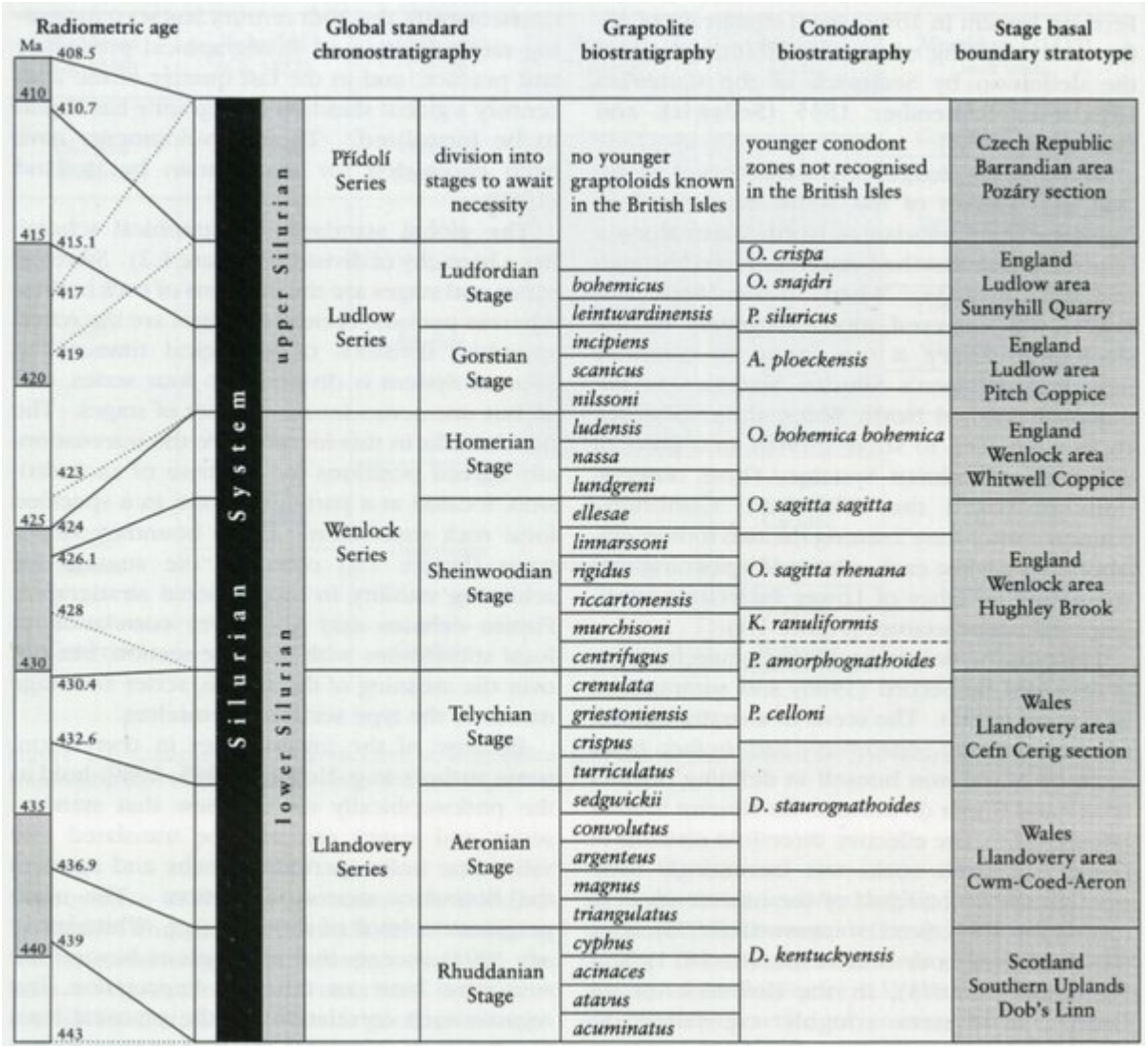
Site selection

GCR sites have primarily been selected to illustrate the range of Llandovery palaeoenvironments documented above. Localities in the Welsh Basin are representative of the shelf, basin margin and basinal depositional environments and their characteristic biotas, and also record the progressive transgression of the sea across the Midland Platform. The sites in the Lake District together provide coverage of the lithostratigraphical and biostratigraphical changes in the area through the Llandovery Epoch, and illustrate the major regional variations. The network of localities in the Southern Uplands of Scotland illustrate the early Silurian stratigraphy of this ancient continental margin, and exemplify the exposures that have led to the different interpretations of its depositional and tectonic history. Finally, the Midland Valley localities demonstrate the various environments, from deep marine to brackish water, developed in this area and allow comparison with the very different successions developed in the Southern Uplands immediately to the south.

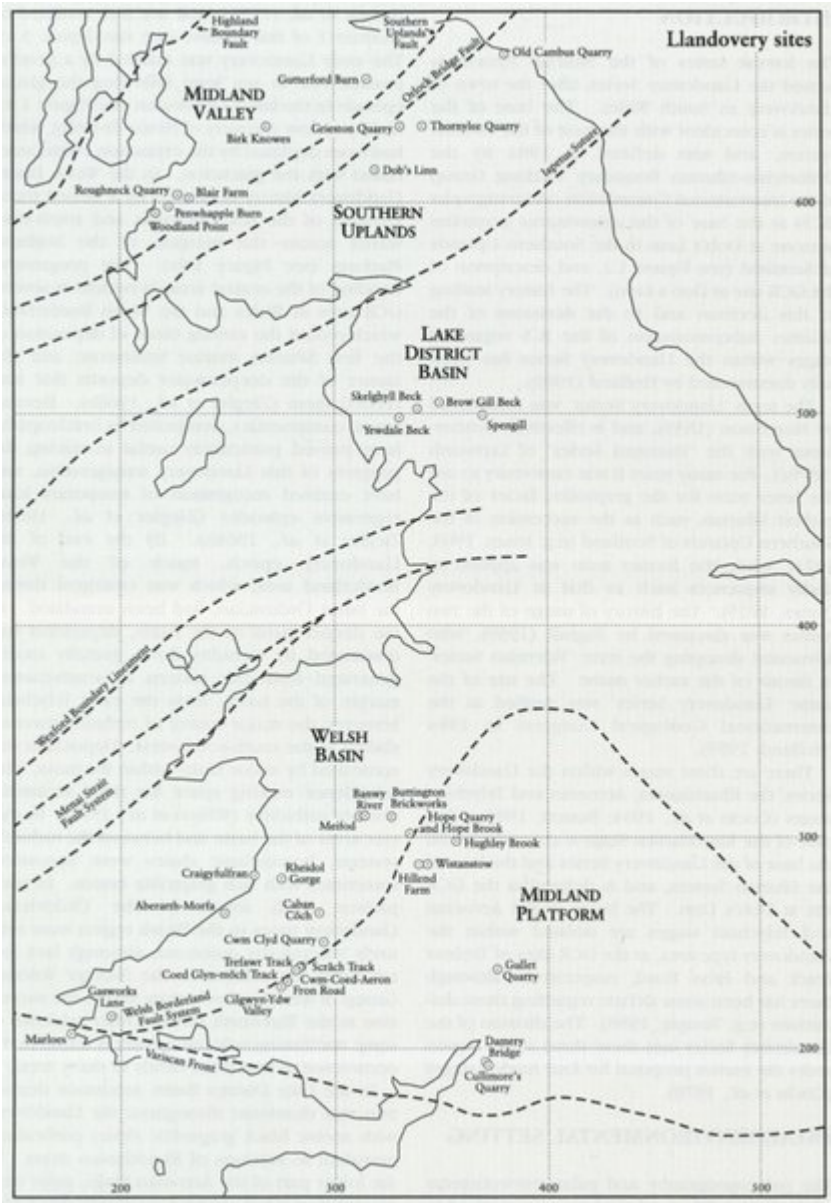
Another important criterion for a number of sites is their international significance; the international stratotypes for the base of the Silurian System and for the bases of all the Llandovery stages are defined at GCR localities. In addition, several sites are international reference points for biostratigraphical schemes. Some sites are also important because of their well-known, abundant or exceptionally preserved fossils, and others are of historical importance in our evolving knowledge of early Silurian geology.

Several of the sites (Hughley Brook, Buttington Brickworks, Marloes, Banwy River) continue into Wenlock strata, and are also described in the Wenlock section of this volume. The Sawdde Gorge site, which is included in the Wenlock and Ludlow sections, also includes some Llandovery strata at its base; these are briefly described in the Wenlock section.

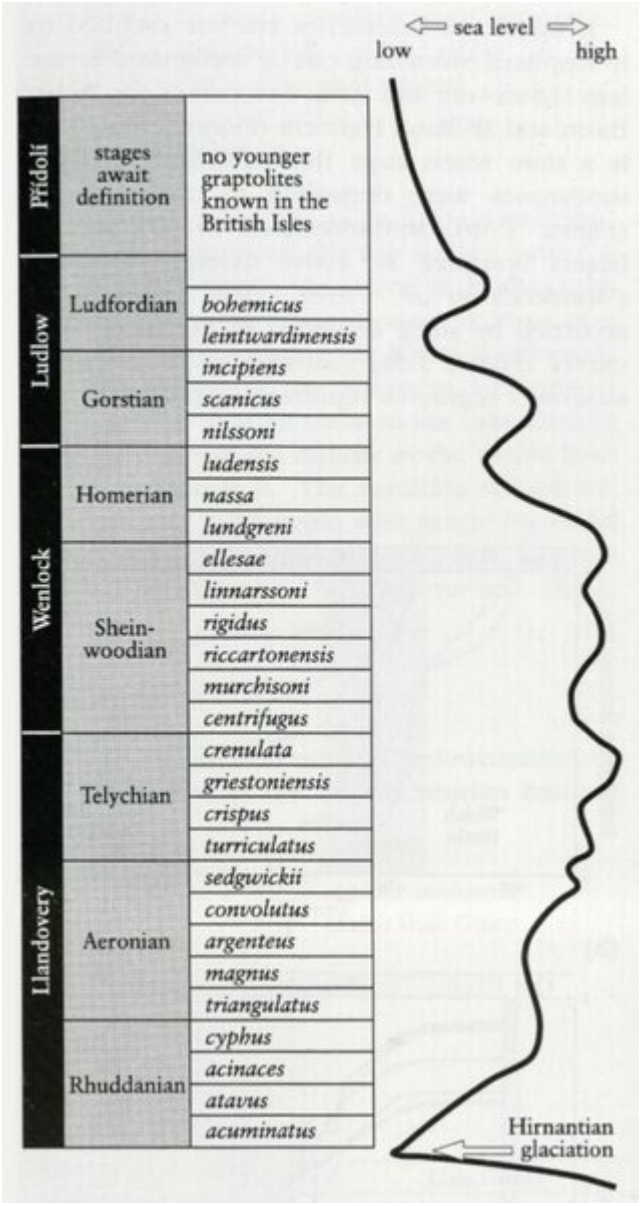
References



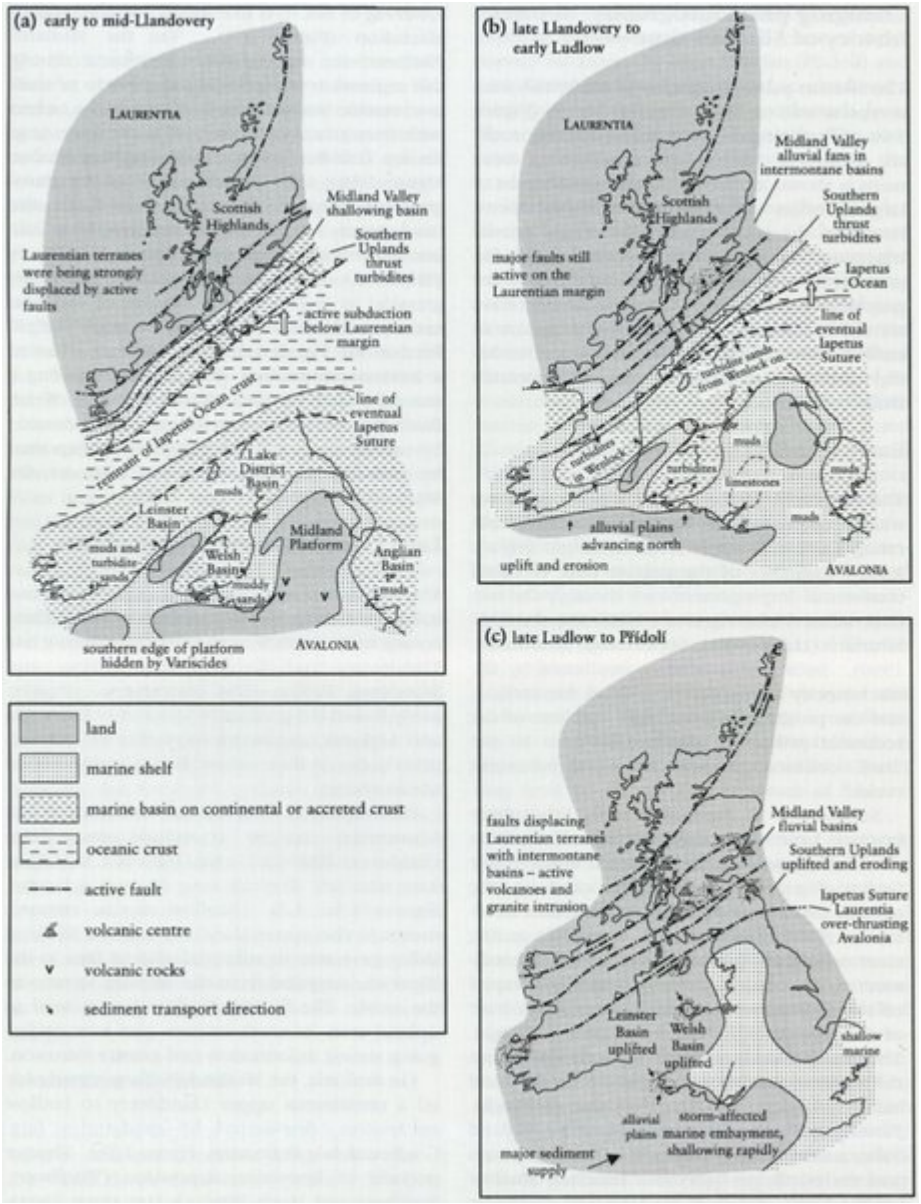
(Figure 1.2) The global standard stratigraphy and a graptolite biostratigraphical zonation, calibrated against two recent chronometric scales derived from radiometric age determinations.



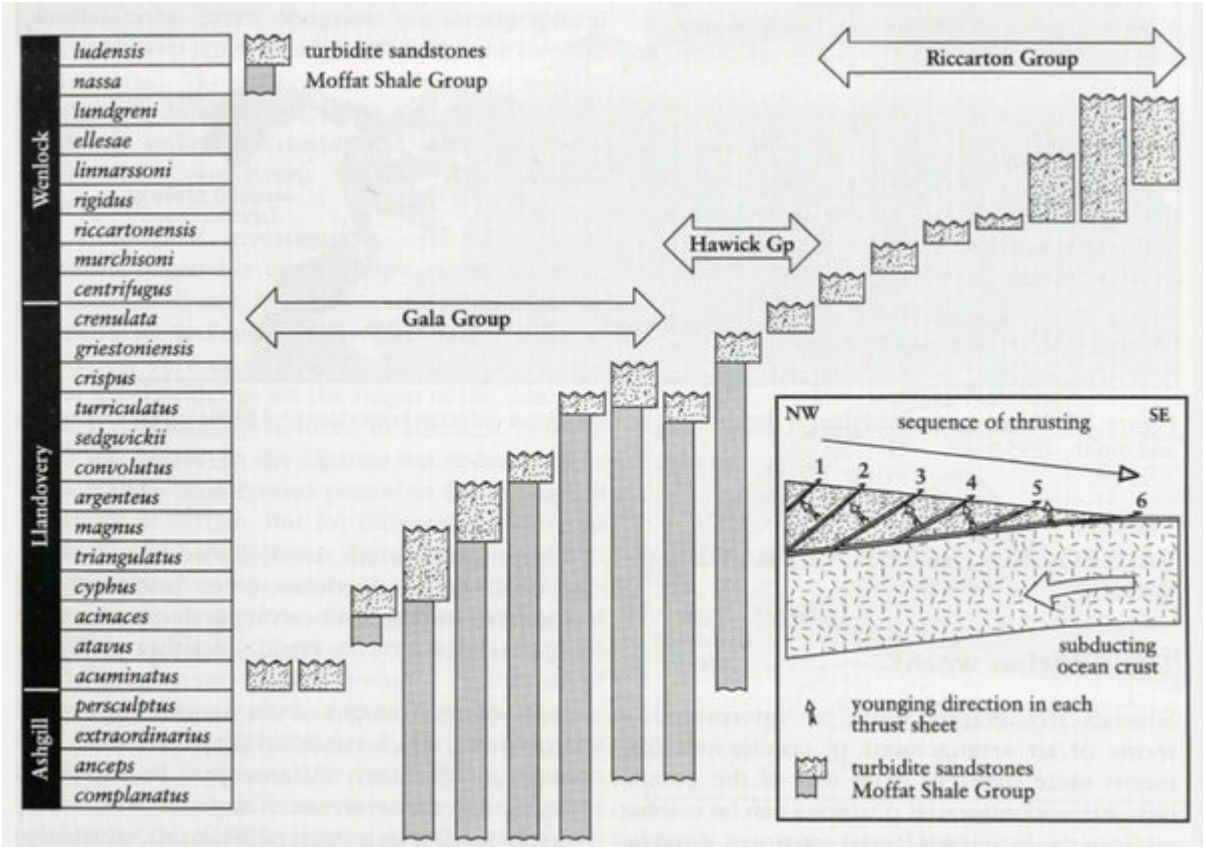
(Figure 3.1) Distribution of the Geological Conservation Review sites for the Llandovery Series, set against the palaeogeographical elements of Silurian Britain.



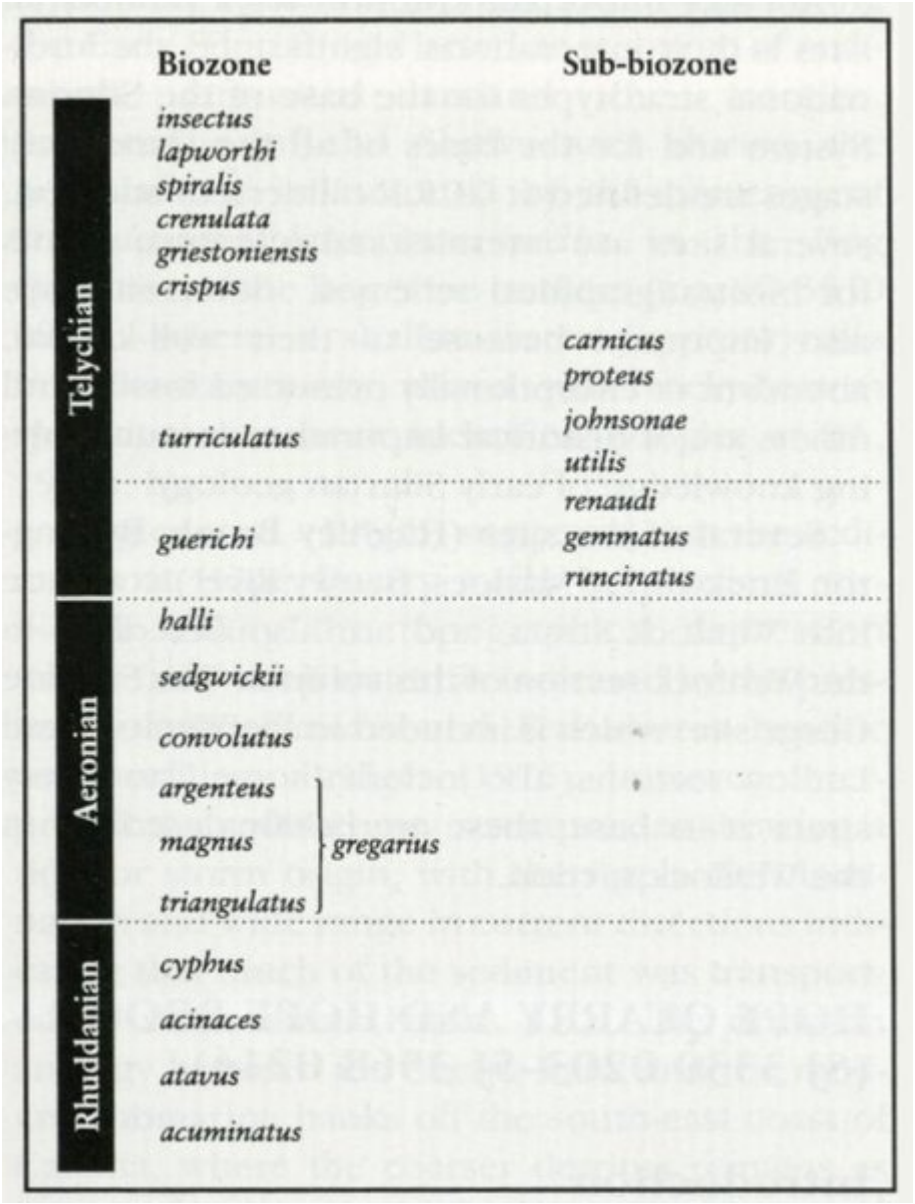
(Figure 1.4) A global sea-level curve for Silurian time (after Johnson et al., 1991).



(Figure 1.9) Palaeogeographical maps of Britain for three intervals of Silurian time: (a) early to mid-Llandovery, (b) late Llandovery to early Ludlow, (c) late Ludlow and P■ídolí.



(Figure 1.6) The stratigraphical columns of successive tectonic slices across the south-west end of the Southern Uplands of Scotland (after Rushton et al., 1996). Inset shows the geometry of an accreting sedimentary prism.



(Figure 3.2) Graptolite biozonation in the Llandovery Series of Britain, after Rickards (1976, 1989b), Loydell (1991, 1993), Loydell and Cave (1993, 1996) and Zalasiewicz (1994).