Glencartholm, Dumfries and Galloway

[NY 376 796]–[NY 375 807]

Introduction

Glencartholm is situated in Lower Carboniferous rocks (some 340 million years old) in the bed of River Esk (Figure 3.13), about 4 km north-west of Canonbie and 5.5 km SSE of Langholm, Dumfries and Galloway (see (Figure 3.7)a and (Figure 3.9). In addition to the remarkably diverse fossil fauna of arthropods (more than 30 species) and fishes that have made it famous, the fauna from Glencartholm comprises marine brachiopods and bivalves, and a diverse terrestrial flora is also known (Cleal and Thomas, 1995). It is a key site in studies of Carboniferous biotas and arthropod evolutionary history and is part of a network of Scottish lower Carboniferous sites that includes Foulden, Granton and East Kirkton (see (Figure 3.9)).

Fossils were first discovered at Glencartholm in 1879 by the collector A. Macconochie during work for the Geological Survey, as reported by Geikic (1881). The arthropods were first described by Peach (1882b,c, 1890), the fishes by Traquair (1881, 1884a,b, 1888a,b, 1890), and the plants by Kidston (1883, 1903). Further collecting took place in 1933–1936 by Moy-Thomas (Schram, 1983), when the use of explosives removed all the fossiliferous strata that were thought to be accessible at that time (Lumsden *et al.,* 1967). The geology of the area has been described by Peach and Horne (1903), Nairn (1956), Lumsden *et al.* (1967), Leeder (1974), and Cater *et at* (1989). No discussion of Carboniferous crustaceans or chelicerates is complete without a mention of the Glencartholm fauna, so this site was a prime candidate for inclusion in the list of GCR sites. The site itself, though suffering somewhat from inundation being close to the river water level, is nevertheless undamaged (except by some irresponsible collecting) and amenable to further research. Indeed, it would be an obvious site to be selected for a research project proposal. In addition to the fossil arthropod importance of this site, the area is also independently selected for the GCR for the Carboniferous–Permian Fish/Amphibia, Palaeozoic Palaeobotany, Carboniferous–Permian Igneous and Westphalian selection categories (Dineley and Metcalf, 1999, Cleal and Thomas, 1995, 1996 Stephenson *et al.,* 2003).

Description

The arthropod-bearing horizon, low in the Viséan succession, occurs as a thin unit within the Glencartholm Volcanic Beds (Figure 3.10), a sequence of tuffs, shales and sandstones at the base of the Upper Border Group of the Calciferous Sandstone (Lumsden *el al.,* 1967). In the section for the Langholm area, George *et al.* (1976, p. 42) showed these volcanic rocks to be largely Holkerian, possibly partly Asbian, in age, based on Foraminifera. The rocks are poorly exposed, but a complete section was provided by the Archerbeck Borehole (Lumsden and Wilson, 1961). This borehole, however, did not encounter the fossil beds of Glencartholm. British Geological Survey palaeontologists D.K. Graham and P.J. Brand located a shrimp bed at Glencartholm in 1971, which yielded essentially the same diversity of shrimps as the bed collected in the previous century and may represent the original band. The local extent of the Glencartholm fossil beds is unclear because of faulting at the site, and it had been assumed that the fossiliferous bed was worked out because explosives had been used for collecting (Lumsden *et al.,* 1967). However, Schram (1983) discovered similar fossiliferous shales and thin limestones 'some 20 paces north of the classic locality' containing an almost complete actinopterygian fish, *Acrolepis ortholepis,* the matrix and preservation of which were identified with that of the Shrimp Bed. However, the new section is separated from the original site by faulting and, though similar in many respects, the sedimentology and fauna differ sufficiently from Macconochie's section so that it is not clearhow the two are related. Thus, this important Lower Carboniferous arthropod-, fish- and plant-bearing site still awaits detailed study.

Peach and Horne's (1903) section at the collecting site showed two fossiliferous horizons: the Shrimp Bed, containing crustaceans, fishes and molluscs, and the Scorpion Bed, containing an extensive flora, as well as sparse crustaceans and arachnids. It is not possible, however, to distinguish these two elements in Macconochie's collections, or in the catalogue thereof, at the British Geological Survey in Edinburgh.

A nearby locality at Tarras Water Foot has been confused with Glencartholm. For example, Dineley and Metcalf (1999) stated that the fish from Tarras Water Foot are identical to those from Glencartholm, and mentioned that a separate locality could not be found during the survey by Lumsden *et al.* (1967). However, Størmer and Waterston (1968) reviewed the problem, and traced some of the confusion to Macconochie, who described his locality as 'River Esk, Glencartholm, Langholm at Foot of Tarras Water, 3 m. [4.8 km] S. of Langholm'. Later collectors, such as Jex and Stock, and Moy-Thomas, seem not to have distinguished separate outcrops along the Esk, which would explain why the fish faunas are similar. Similar confusion may well have occurred with the arthropods. Following Watson *et al.* (1948), Størmer and Waterston (1968) mentioned a locality in the Tarras Water just below the (now disused) railway bridge, about 2.5 miles (4 km) SSE of Langholm. Cater *et al.* (1989), following Leeder (1974), described a small outcrop in the river Esk, 1 km upstream from the main Glencartholm site (but the grid reference given refers to a place on the Tarras Water; however, the grid reference in this paper for Glencartholm is also erroneous). These authors also referred to another outcrop higher in the same (Whita) formation in the Tarras Water. The Whita Formation is older (Courceyan) than at Glencartholm (Holkerian), possibly yields a different arthropod fauna, and represent a different depositional environment than at Glencartholm (Cater *et al.* 1989). For these reasons it is proposed that the Glencartholm site be extended to include the river Esk section upstream to the Tarras Water and the lower reach of Tarras Water as far as the railway bridge, as a composite site.

Geological setting

The Glencartholm sequence is part of the Glencartholm Volcanic Beds within the Middle Border Group of southern Scotland, which roughly equates with the Fell Sandstone Group to the east and the lower part of the Oil Shale Group of the Scottish Midland Valley. The exposed section on the eastern bank of the River Esk is some 10 m long and 3 m high. The rocks dip to the south at about 15°, and the section is cut by three post-burial faults with known displacements (Cater *et al.,* 1989).

Cater *et al.* (1989) described the depositional environment in detail, on which this review is based. The sequence is transgressive, fining upwards from coarse, non-marine sandstones to fully marine shales (Figure 3.13). The basal 2 m consists of thinly plane-bedded, pebbly sandstones; the pebbles are mostly well-rounded vein quartz. The coarse sandstone is composed of metamorphic quartz, pyritic volcaniclastic material and perthitic feldspars. These fine up into finer-grained sandstones rich in volcanic ash and pyrite, some of the latter being of diagenetic origin. The sandy sediments pass up into generally thinly laminated and organic-rich, nodular cherty shales and cherty dolomicrites below an erosion surface. The only fossils recorded from this sequence are a few scales of the large euryhaline fish *Rhizodus,* found just below the erosion surface, and rare plant spores. The chert laminae show enterolithic and 'chicken-wire' textures. Microscopic lath-shaped pseudomorphs after anhydrite occur just below the erosion surface, and desiccation cracks are also present in the sequence. Abundant pyrite occurs at the edges of the chert layers.

The erosion surface (4.4 m above the base of the measured section) is overlain by a 10 cm intraclastic layer that fines upwards into laminated dolomicrites, containing quartz sand grains scattered along organic-rich laminae, and cherty laminae showing displacive textures. The dolomicrites are overlain by- over 1 m of dark micritic limestone, devoid of burrows or fossils. It is composed of non-ferroan calcite mud with large lensoid fenestrae and pseudomorphs after gypsum, and cut by ferroan and non-ferroan calcite veins. It is overlain by two erosion-surface-based, normal-graded, 10 cm thick units, each containing abundant and diverse derived ostra-cods including the brackish water *Beyrichiopsis plicata,* and non-ferroan micrite intraclasts set in organic-rich micrite. Several specimens of the shrimp *Tealliocaris* were found in the fine-grained top of one of these layers.

Above this is a gap of 1 m without exposure (about 6–7 m above the base of the measured section). A sequence of 5 m of black dolomitic silt-shales and silty dolostones, lacking burrows but containing an exceptionally well-preserved fauna of arthropods, fishes, ostracods and bivalves, follows. Some of the bivalves are of quasi-marine type, including articulated sped-mens of *Leiopteria hendersoni* and *Edmondia* sp. cf. *uniformis.* Fully marine fauna are rare, but include orthocones and echinoderms, representing 1% and 0.04% of the fauna, respectively (Schram, 1983). The sediments show indistinct organic-rich laminae, gradually passing into muddier layers; more dolomitic layers appear to have been slightly coarser-grained initially, and contain laminae rich in derived ostracods.

The interpretation of the basal sequence is one of volcaniclastic input from the Glencartholm Volcanic rocks mixed with vein quartz derived from the Southern Uplands and acid igneous material probably derived from the intrusive rocks of Galloway and Kirkcudbrightshire. The thin, normal-graded plane beds probably record deposition from sheet-floods, possibly at the toe of an alluvial fan. The distance from source of some of the clasts, and the presence of overlying subaqueous deposits (see below), suggests that this was a fan-delta fed by a large river. The fining-upwards transition to the cherty sediments records the abandonment of the fan-delta. The overlying sediments contain evidence of evaporites; the abundant pyrite probably resulted from bacterial reduction of sulphate evaporites. The pseudomorphs after anhydrite also indicate sulphate supply, either from the sea or from the oxidation of the pyrite-rich volcaniclastic rocks. The organic-rich laminae may have originated from algal blooms in shallow, ephemeral water bodies that were hostile to life, probably due to poor oxygenation. The remains of the fish *Rhizodus,* which may have exceeded 3 m in length, imply access to a large water body.

The sequence as a whole records deposition on a desiccating coastal mud-flat, marginal to a lake or the sea. The beds immediately above the erosion surface probably record the effects of a storm, which eroded the mud-flat and spread intraclastic debris across it; mud-flat deposition then resumed. The pseudomorphs after gypsum in the micritic limestone beds indicate that shallow evaporating conditions prevailed during its deposition. The non-ferroan calcite veins may record hydrothermal activity related to the Glencartholm Volcanic rocks. The overlying graded units are interpreted as storm deposits derived from peripheral muddy areas in which ostracods lived, and deposited in poorly oxygenated conditions that favoured the preservation of organic matter. The top part of the sequence represents a changeover to fully marine conditions, although the critical part of the transition is not exposed. The sediments were protected from wave activity; the more dolomitic layers may be low-energy (distal) storm deposits, preferentially dolomitized due to a slightly greater permeability than that of the enclosing mudrocks. It was in these poorly oxygenated, low-energy marginal marine to fully marine conditions that the diverse arthropod fauna of Glencartholm flourished.

The Whita Formation at Tarras Water Foot is part of the Lower Border Group of southern Scotland (Leeder, 1974). Only 2 m of well-exposed sediments crop out on the left bank of the Esk below a thick sandstone unit (Figure 3.13), but the lithologies and facies are essentially the same higher in the Whita Formation where it crops out in the Tarras Water. The Whita Formation is a stratigraphical/structural unit bounded by syn-sedimentary faults (Leeder, 1974).

The Tarras Water Foot sequence is interpreted as a coastal plain succession; lacustrine, crevasse-splay, stream-flood and fluvial distributary channel facies are represented. At the base of the sequence (Figure 3.13) are unoxidized, grey, mud-shales lacking burrows represents shallow, poorly oxygenated water without infauna. Desiccation cracks record periods of emergence, without plant colonization. Leeder (1974) observed pseudomorphs after halite in this facies, suggesting marginal marine or playa-lake conditions. The intercalated dolomicrites are mostly nodular, displacive early diagenetic cementstones recording poorly oxygenated, brackish conditions (estuaries or tidal flats). Cryptalgal laminated dolostones with fenestrae and desiccation cracks are also present, consistent with a stressful, periodically emergent coastal setting. The thin, ripple-laminated, silty sandstones are interpreted as crevasse-splay deposits derived from nearby river channels into low-lying interfluvial areas. The fining-upward part of Sandstone Unit 1 (Figure 3.13) is a typical point-bar deposit formed by lateral accretion. The coarse-grained lags are channel-base scour-fills. The wavy-laminated fine-grained sandstone capping this unit may be a crevasse-splay deposit formed after further subsidence of the flood-plain. The coarse upper part of Sandstone Unit 1 has an undulating, wave-rippled top and may represent a lacustrine storm deposit. During an initial storm-flood phase, sand and plant debris were carried into a shallow-water body. The deposit was partially re-worked by wave action during the waning storm stage. Sandstone Unit 2 consists of two separate shallow-water storm deposits similar to that described above. Coastal plain dolomitic mudrocks and splay sandstones cap the sequence, followed by a *c.* 4 m gap, and then over 3 m of coarse sandstones. Leeder (1974, plate 17, fig. 1) recorded a 1–5 m gap followed by 10 m of sandstones at this level. The sand body consists of upward-fining units; the thickness and coarseness of the trough cross-bedded units suggests that they were deposited in a major fluvial channel system, such as a distributary river crossing the coastal plain. The abundance of fluvial deposits, the lack of marine reworking (e.g. beach deposits) and of derived marine fossils indicates that most of the 'arras Water Foot sequence was deposited on an upper coastal plain beyond marine influence. However, in the absence of any apparent non-marine sulphate supply, the presence of pseudo-morphs after halite (Leeder, 1974), cementstones and cryptalgal laminated dolostones is also consistent with raised salinities in the lower part of the section that may record

limited marine influence.

The arthropod fauna

The arthropod fauna at Glencartholm is significant because the shrimp fauna (Figure 3.14) is the most prolific and diverse of all those in the Dinantian strata of northern Britain and the chelicerates include some unique and rare scorpions and bizarre eurypterids, and other forms.

Phylum ARTHROPODA

Subphylum Chelicerata

Order Xiphosura

Rolfeia fouldenensis Waterston, 1985

?Euproops sp.

Order Eurypterida

Adelophthalmus perornatus (Peach, 1882b): HOLOTYPE

?Pterygotus sp.

Woodwardopterus scabrosus (Woodward, 1887): HOLOTYPE

unidentified eurypterids

Order Cyrtoctenida

*Cyrtoctenus peachi Størmer & Waterston, 1968

Order Scorpiones

Anthracochaerilus palustris Kjellesvig-Waering, 1986: HOLOTYPE

Archaeoctonus glaber (Peach, 1882b): HOLOTYPE

Centromachus euglyptus (Peach, 1882b): HOLOTYPE

Eskiscorpio parvus Kjellesvig-Waering, 1986: HOLOTYPE

Gigantoscorpio willsi Størmer, 1963: HOLOTYPE

Loboarchaeoctonus squamosus Kjellesvig-Waering, 1986: HOLOTYPE

Pseudoarchaeoctonus denticulatus Kjellesvig-Waering, 1986: HOLOTYPE

Machyscorpio sp. Kjellesvig-Waering, 1986

unidentified scorpions

Subphylum Crustacea

Class Ostracoda

Bairdia sp.

?Beyrichiopsis

Tribolbina carnegiei Latham, 1932

cyprinidoidean myodocopid

Class Malacostraca

Subclass Phyllocarida

Sairocaris elongata (Peach, 1882a): LECTOTYPE

Subclass Hoplocarida

Bairdops elegans (Peach, 1908): LECTOTYPE

Crangopsis eskdalensis (Peach, 1882a): LECTOTYPE

Joanellia elegans (Peach): LECTOTYPE

Perimecturus parki (Peach, 1882a): LECTOTYPE

Subclass Eumalacostraca

Anthracocaris scotica (Peach, 1882a): LECTOTYPE

Anthracophausia dunsiana Peach

Belotelson traquairi (Peach, 1882a): LECTOTYPE

*Pseudogalathea macconochiei (Etheridge, 1879)

Pseudotealliocaris etheridgei (Peach, 1882a: LECTOTYPE

†*Tealliocaris* (Peach, 1908) unidentified malacostracans

Class Maxillopoda

Subclass Halicyna

Cyclus testudo Peach

*Also at Tarras Water Foot

† Only at Tarras Water Foot

Interpretation

The Glencartholm eurypterid fauna was first mentioned by Peach (1882b), who described *Adelophthalmus perornatus,* as a scorpion in the new genus *Glyptoscorpius.* However, because the genus was based on a suite of spec imens in different species, and the characters were either poorly preserved or meaningless, some confusion ensued in later revisions (see review in Størmer and Waterston, 1968). Bell (1922) recognized that another *Glyptoscorpius* species, *G. kidstoni* Peach, 1888, from Radstock, Somerset, was a eurypterid, and Waterston (1957) referred the genotype, *G. perornatus* from Glencartholm, and other species to the Eurypterida. Some specimens referred to *Glyptoscorpius* by Peach (1882b) from Glencartholm belong to *Gigantoscorpio* Størmer (1963) and to *Cyrtoctenus* Størmer & Waterston, 1968 (see below). Thus, *Glyptoscorpius* Peach, 1882b, is a junior synonym of *Adelophthalmus,* and its included species

have all found better homes elsewhere.

Størmer and Waterston (1968) erected the new order Cyrtoctenida, type genus *Cyrtoctenus,* for some strange, eurypterid-like arthropods with comb-like appendages on the abdomen. One specimen from Glencartholm belongs to *C. peachi* Størmer & Waterston, 1968. Waterston *et al.* (1985) referred cyrtoctenids to Eurypterida: Hibbertopteroidea, and this assignment was followed but Jeram and Selden (1994), but in the most recent systematic review of eurypterids, Tollerton (1989) recognized the order Cyrtoctenida as distinct from Eurypterida. The family Woodwardopteridae was erected by Kjellesvig-Waering (1959) for the Glencartholm eurypterid *Woodwardopterus scabrosus* (Woodward, 1887). Just recently, excavations by S. P Wood adjacent to the Glencartholm site have yielded a number of specimens of *Rolfeia fouldenensis,* the earliest known limuloid, previously known only from Foulden (see GCR site report in the present volume).

Scorpions from Glencartholm were first described by Peach (1882b), and later systematic revision was carried out by Petrunkevitch (1949, 1955). *Gigantoscorpio willsi* was described by Størmer (1963) in a fascinating study that included a description of nematodes and other decomposing organisms that had been feeding on the scorpion carcass before fossilization. In his posthumous review of fossil scorpions of the world, Kjellesvig-Waering (1986) re-described the Glencartholm scorpions and erected the new genera and species *Eskiscorpio parvus* Kjellesvig-Waering, 1986, *Loboarchaeoctonus squamosus* Kjellesvig-Waering, 1986, and *Pseudoarchaeoctonus denticulatus* Kjellesvig-Waering, 1986; he placed the last two gerna in a new family, Loboarchaeoctonidae Kjellesvig-Waering, 1986. However, re-study of the specimens led Stockwell (1989) to consider that *Loboarchaeoctonus* and *Pseudoarchaeoctonus* were synonyms of *Archaeoctonus,* and that Kjellesvig-Waering's family Loboarchaeoctonidae was a junior synonym of Archaeoctonidae Petrunkevitch, 1949. In a recent cladistic analysis of early scorpions sjeram, 1998), the Archaeoctonidae is subsumed within the family Proscorpiidae Scudder, 1885, in which *Archaeoctonus* is especially interesting because it is one of only two genera in this family (the other being *Labriscorpio* Leary, 1980, from the middle Carboniferous strata of Illinois) which occur in Carboniferous rocks, the others range from late Silurian to mid-Devonian in age. These genera represent late survivors of the early aquatic scorpions, and the inferred marginal marine environment of the Glencartholm beds in which *Archaeoctonus* occurs is in agreement with this. Stockwell (1989) suggested that *Eskiscorpio parvus* Kjellesvig-Waering, 1986, a tiny scorpion from Glencartholm, might be a juvenile of one of the other archaeoctonids at the same locality. However Jeram (1994b) could find no trace of typical archaeoctonid cuticle on the specimen and included it as *incertae sedis* in the suborder Mesoscorpionina Stockwell, 1989. In the same study, Jeram (1994b) placed the Glencartholm scorpions *Centromachus* and *Gigantoscorpio* in the Mesoscorpionina, so *Eskiscorpio* could represent a juvenile of one of these genera.

Among Crustacea (Figure 3.14), *Sairocaris elongata* is abundant at Glencartholm; a phyllocarid, it is a later representative of an early Palaeozoic diversity of bivalved Crustacea, before the true shrimps appeared in the Devonian Period (Briggs and Clarkson, 1990). *Cyclus,* a relatively common genus in non-marine Carboniferous rocks, has had a chequered systematic history, having been allied at various times with the trilobites, chelicerates, crustaceans, and as a separate subclass of trilobitomorphs (Schram *et al.,* 1997). A recent study of the cycloids of Mazon Creek (Schram *et al.,* 1997) concluded that the cycloids are indeed Crustacea, possibly a sister taxon to the copepods. These authors noted a variety of body forms within the Cycloidea; *C. testudo* from Glencartholm belongs in the *C. rankini* species group of somewhat flattened forms. They found no evidence for a parasitic ('fish louse') mode of life, but suggested that the range of body forms of cycloids compared to that found in the specialisms of Holocene small crabs;

Of the true shrimps (Hoplocarida and Eumalacostraca), *Crangopsis eskdalensis, Pseudotealliocaris etheridgei* are abundant, *Bairdops elegans, Anthracocaris scotica, Perimecturus parki, Anthracophausia dunsiana* and *Belotelson traquairi* are common, whereas *Pseudogalathea macconochiei* and *Joanellia elegans* are rare at Glencartholm (Schram, 1983). Briggs and Clarkson (1990) reviewed the radiation of late Palaeozoic shrimps. They concluded that taphonomy was a more important factor than biodiversity in accounting for the fossil record of Devonian–Permian shrimps: fossils were most-often preserved in marginal marine environments. The oldest-known shrimp occurs in Devonian strata, but in the Lower Carboniferous rocks the diversity exceeded 10 families, indicating a cryptic radiation. The fossil record of Palaeozoic shrimps reveals two major peaks in apparent diversity: Glencartholm (Viséan) and Mazon Creek, Illinois (Westphalian). Thus, Glencartholm represents the most important source of information on the first half of shrimp evolutionary history.

Briggs and Clarkson (1990) discussed the modes of life of Palaeozoic shrimps. The Glencartholm fauna, like those of Bear Gulch (Mississippian, Montana) and the Essex biota of Mazon Creek (Westphalian, Illinois), is dominated by carnivores; 67% of individuals at Glencartholm fall into this feeding category. *Perimecturus parki, Bairdops elegans, Anthracophausia dunsiana, Anthracocaris scotica,* and the phyllocarid *Sairocaris elongata* are rapacious carnivores, *Belotelson traquairi, Pseudogalathea macconochiei* and *Tealliocaris etheridgei* are scavengers or low-level carnivores, whereas the others are of uncertain feeding type.

Comparison to other faunas

The Glencartholm section ranges from fan-delta through coastal lagoon to fully marine (Cater *et al.,* 1989). Briggs and Clarkson (1989) discussed Schram's (1981) classification of Carboniferous crustacean communities. The near-shore marine community was characterized by Schram (1981) on the basis of Glencartholm, Bear Gulch, and the Essex fauna of the Mazon Creek biota. These faunas include the highest diversity of Carboniferous shrimps and the similarity between the crustacean assemblages is striking. Sedimentological evidence, however, indicates that the environment may have experienced more freshwater influence than formerly suggested. The Glencartholm section shows the greatest marine influence of all those yielding shrimps in the Dinantian rocks of Britain (Cater *et al.,* 1989), but fully marine taxa are rare (see above). This suggests that salinities fluctuated within brackish to near-normal marine. The Bear Gulch Limestone was deposited in a low-energy shallow water tropical basin (Williams, 1983; Factor and Feldmann, 1985). Although benthic organisms (including articulate brachiopods) are common, many normal marine taxa (e.g. corals, bryozoans and echinoderms) are absent. Lack of bioturbation indicates low oxygen levels below the sediment-water interface, and the proximity of non-marine and brackish-water deposits suggests a large freshwater input (Williams, 1983). Likewise, the Essex fauna lacks a number of typical stenotypic groups, although polychaetes are relatively abundant. Fusilinid foraminiferans, sponges, articulate brachiopods, anthozoan corals, bryozoans, crinoids and cephalopods are all absent or very rare (Baird *et al.* 1985, p. 264). In this case the assemblage probably occupied a semi-restricted estuarine embayment and salinities were lowered due to the influence of rivers (Baird *et al.,* 1985, p. 277). Thus, the three most complete examples of Schram's (1981) near-shore marine community, Glencartholm, Bear Gulch, and the Essex fauna, all represent conditions where salinity was probably lower than normal marine levels (Briggs and Clarkson, 1989).

Because of the Lower Carboniferous age of Glencartholm, this Fossil-Lagerstätte constitutes an important window on the evolutionary history of scorpions and eurypterids, which are otherwise sparsely represented in rocks of this age. This is especially true for the scorpions, which included both aquatic and terrestrial forms living together at this time (Jeram, 1994a).

Conclusions

Glencartholm has yielded the greatest diversity of Lower Carboniferous shrimps in the world, which, together with the younger Mazon Creek fauna of Illinois, represent the main source of information on shrimp evolution in the Palaeozoic Era. Seventeen crustaceans have been recorded, for half of which this site is the source of the type specimens; several are known only from Glencartholm. For the Chelicerata, especially scorpions and eurypterids, Glencartholm is scarcely less important. Fifteen species are known, for nine of which (all those identified to species level) this site is the source of the type specimens. Many of the collections are Victorian in age, but substantial excavations were carried out in the 1930s and 1960s. Exploratory trenching in the 1980s allowed a modern stratigraphical and sedimentological study to be carried out. Thus the palaeoecology and preservation of the arthropods is well known. This has led to good understanding of the environmental and ecological context of the faunal, and places it into a framework of Carboniferous arthropod faunas worldwide. Glencartholm is a major source of information in this context. The 1980s excavations also showed further potential of the site for more finds of fossil arthropods and more detailed palaeoecological research at this internationally rich and important fossil site.
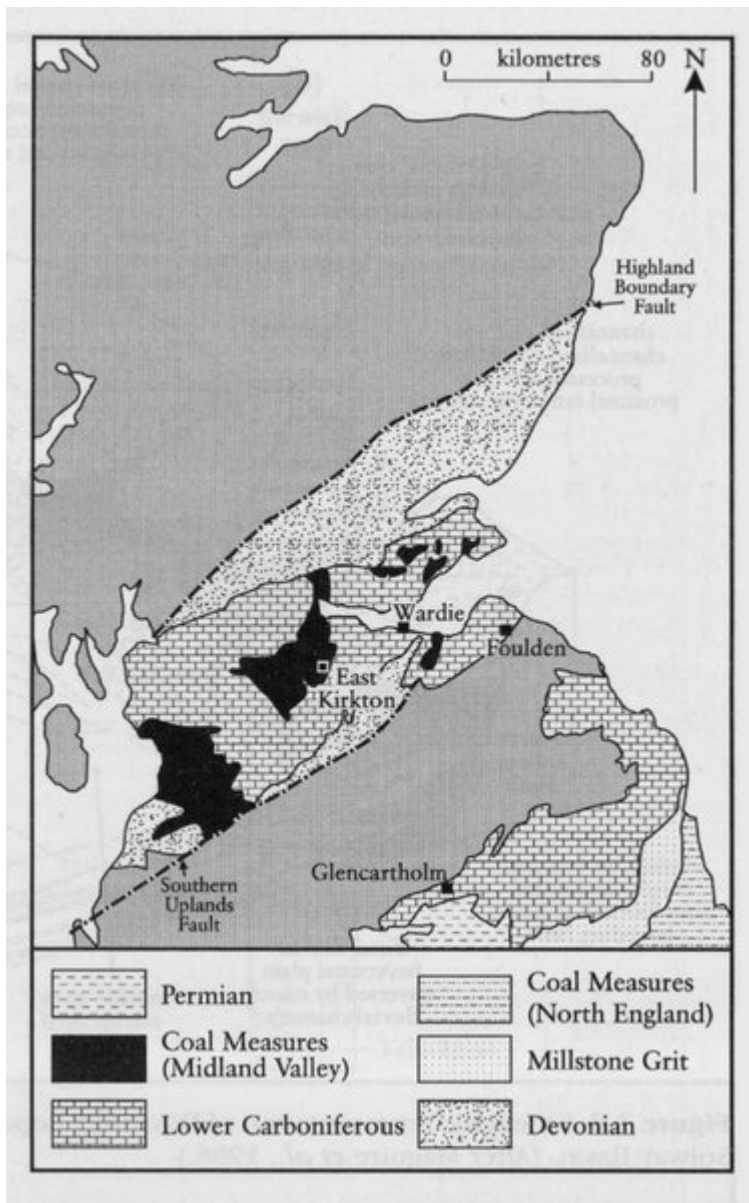
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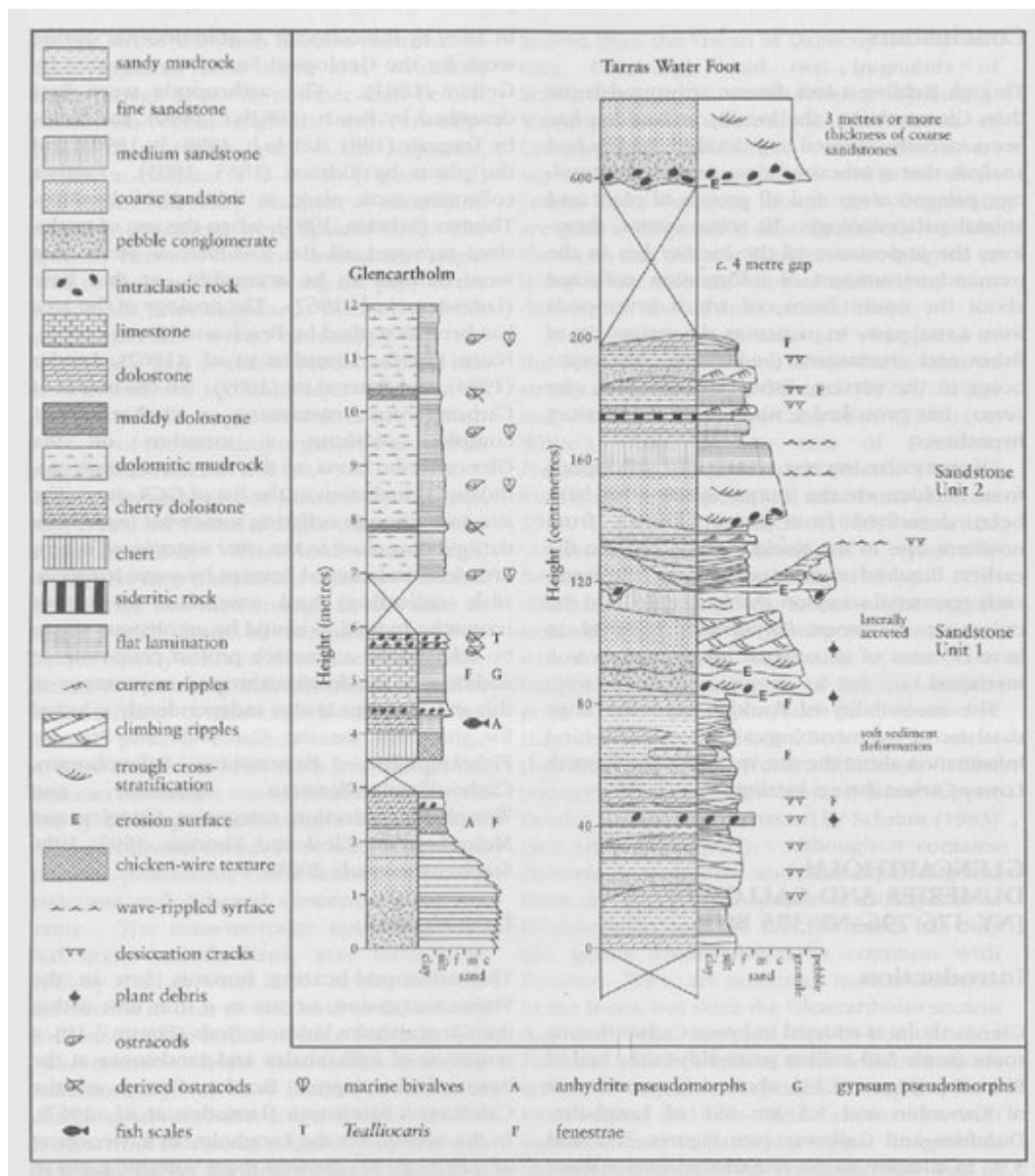
(Figure 3.13) Stratigraphical sections at Glencartholm and the nearby Tarras Water Foot. For discussion of localities, see text. (After Cater et al., 1989.)
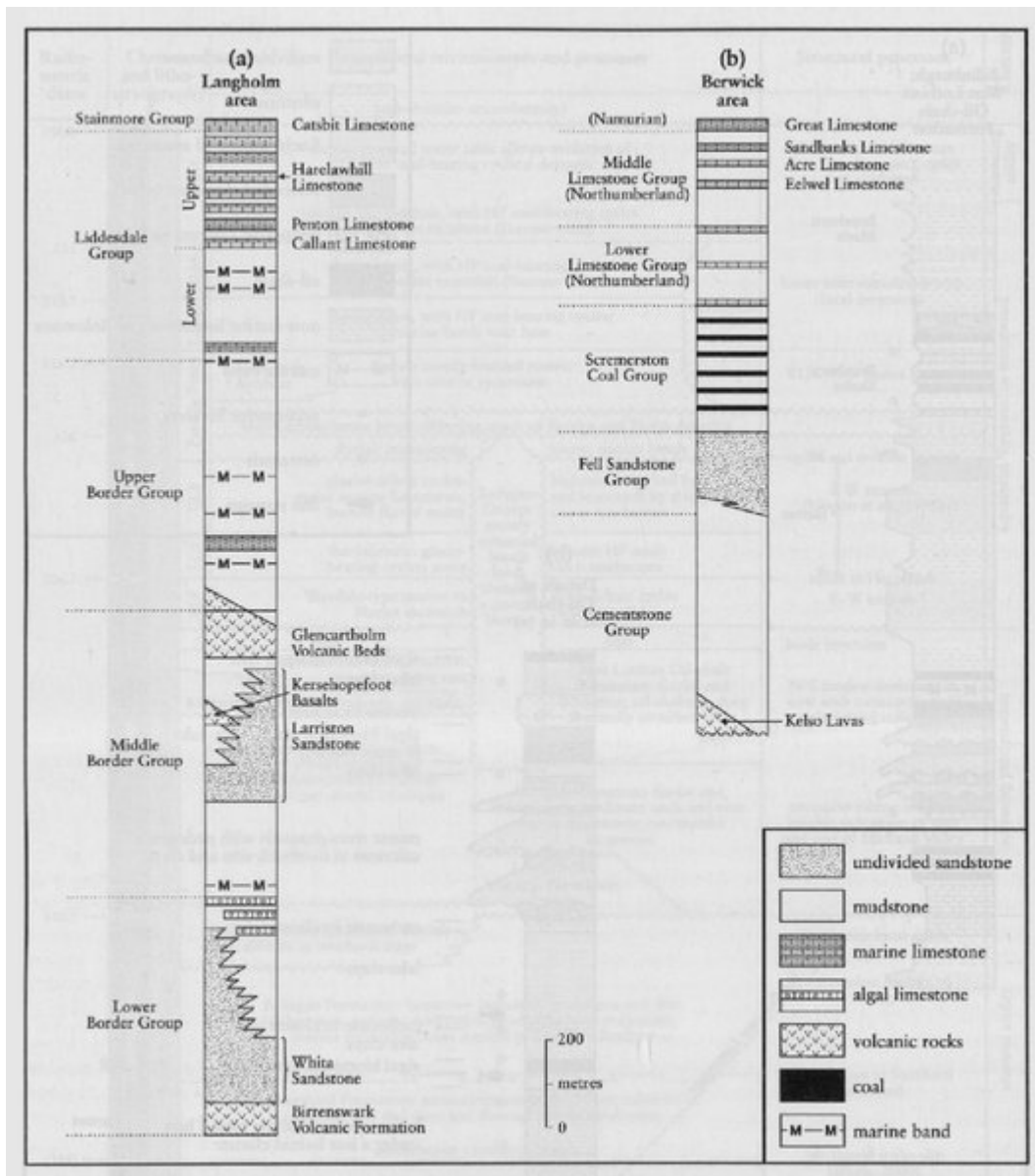
(Figure 3.7) Generalized vertical sections of the Dinantian successions in the Southern Borders (a) the Langholm area in the west and (b) the Berwick area in the east.

(Figure 3.9) Geological sketch map of southern Scotland and northern England with the positions of the Scottish Carboniferous GCR arthropod sites shown. Wardie is near to the Granton Shore GCR site.

Subsystems	Series	Radiometric dates	Stage	Microspore zone	Group	Midland Valley				Solway–Cheviot
						Ayrshire & Central	Fife	West Lothian	East Lothian	
Silesian	Westphalian C	308	Bolsovian	XI	Coal Measures	Upper Coal Measures				
		311		X						Aegiranum MB
	Westphalian B	313.5	Duckmantian	IX		Middle Coal Measures				Vanderbeckei MB
				VIII						
				VII						
	Westphalian A	316.5	Langsettian	5S		Lower Coal Measures			Lowstone MB	Subcrenatum MB
				FR						
			Yeadonian–Chokierian	KV		Passage Formation				
	Namurian	320		SO	Clackmannan Group					
		324	Arnsbergian	TK		Upper Limestone Formation			Castlecary Lst	Stainmore Group
									Orchard Lst	
									Index Lst	
			Pendleian	NC		Limestone Coal Formation				Cansbit Lst
		326.5			Bathgate Group					
			Brigantian	VF		Lower Limestone Formation			Top Hosie Lst	
									Hurlet Lst	
		331				Lawmuir Fmn	Pathead Formation			Liddesdale Group
						Kirkwood Fmn				
Dinantian	Viséan		Asbian	NM	Strathclyde Group		Sandy Craig Formation	West Lothian Oil-shale Formation	Aberlady Formation	
							Pittenweem Formation			Upper Border Group
				TC		Clyde Plateau Volcanic Formation	Anstruther Formation	Gullane Formation		
			Holkerian–Arundian					Arthur's Seat Volcanic Formation	Garleton Hills Volcanic Formation	Glencartholm Volcanic Beds
							Fife Ness Formation			Middle Border Group
		(342.5)	Chadian	Pu		Clyde Sandstone Formation				Lower Border Group
	Tournaisian		Courceyan	CM	Inverclyde Group	Ballagan Formation				
		(354)				Kinnesswood Formation				

(Figure 3.10) Lithostratigraphical and chronostratigraphical divisions of the Carboniferous Period in the Midland Valley and Southern Borders. Key marine bands (MB) and limestones (Lst) used in correlation are noted. No clear evidence for Chokierian or Alportian stages has been found in Scotland, possibly reflecting a mid-Carboniferous depositional break.
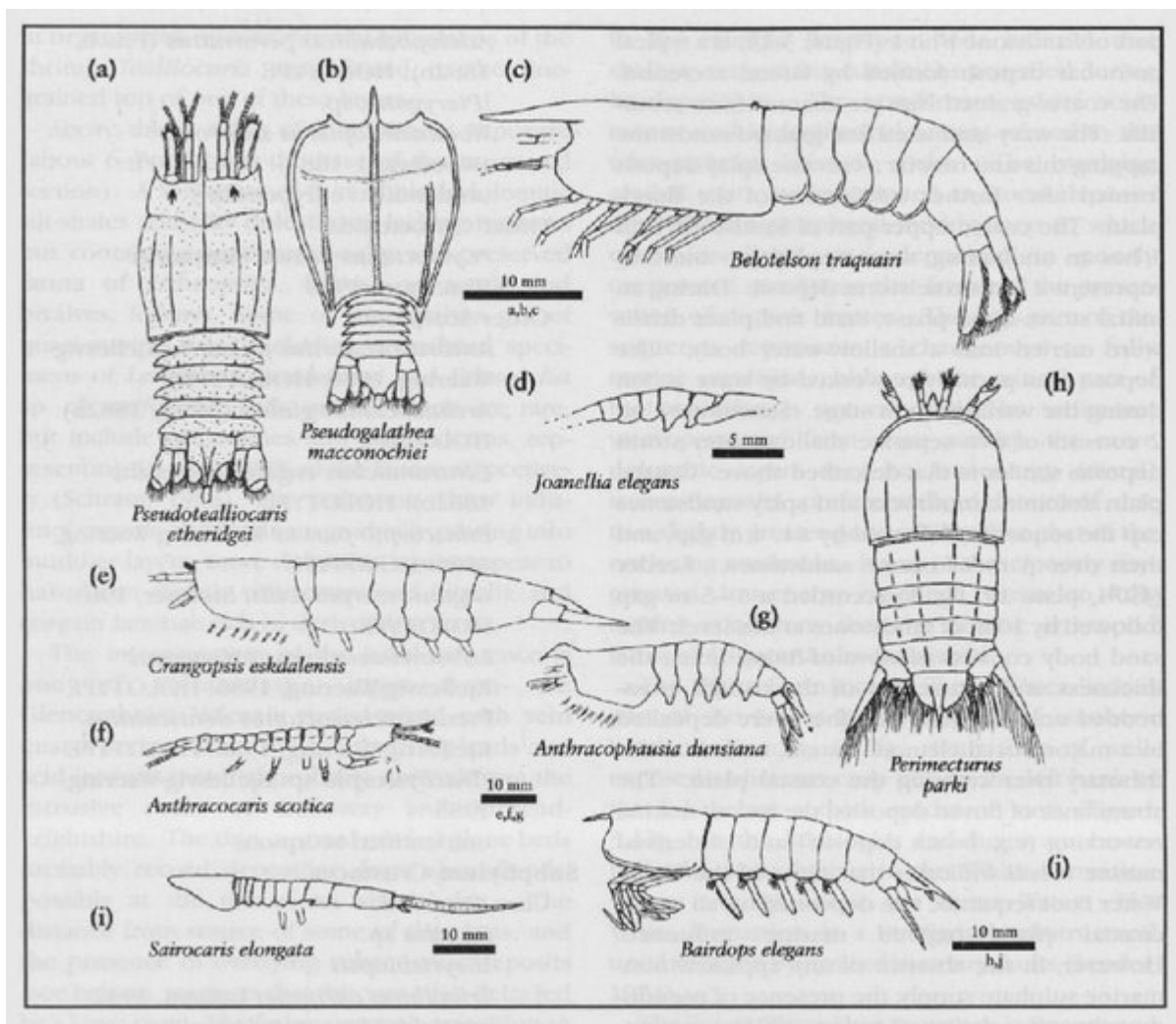
(Figure 3.14) Fossil shrimps from Glencartholm. (After Schram, 1981.)