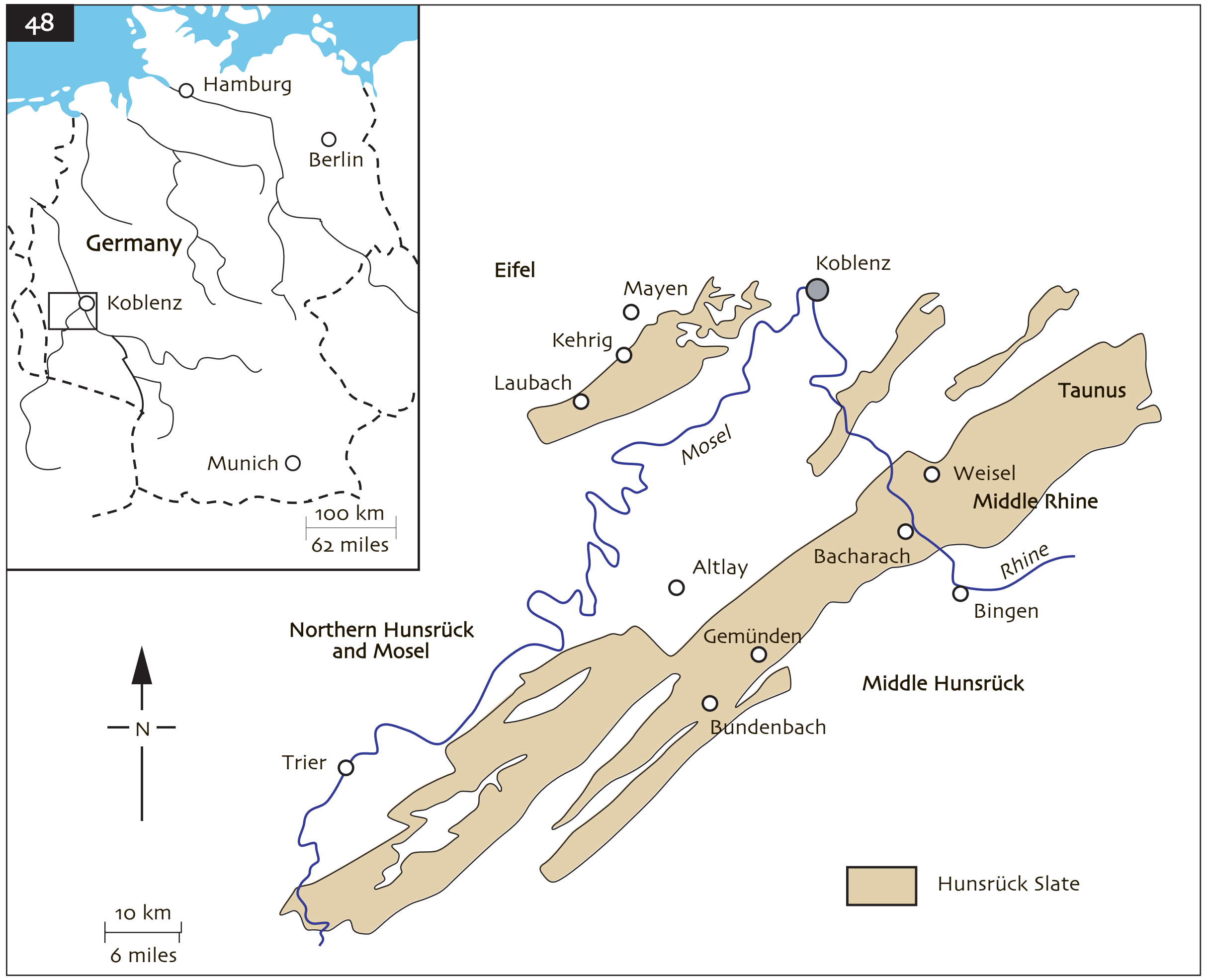
History of discovery and exploitation of the Hunsrück Slate

The Hunsrück Slate has been an important source of roof slates for several centuries in the Rheinisches Schiefergebirge (Slate Mountains) of the Rhine and Mosel valleys (**48**). Certainly the slate was used in Roman times as evidenced from numerous Roman sites in west Germany, but the earliest documented evidence of mining in this area comes from the fourteenth century (Bartels *et al.*, 1998). Extensive mining continued throughout the succeeding centuries, but the Industrial Revolution of the late eighteenth century saw a huge expansion in the production of roofing slates. Slate was exported along the Rhine and Mosel rivers, but a collapse in the industry during the German depression (1846–49) led to poverty and hardship in the mining settlements.

Economic revival and a new sense of nationalism after the Franco-Prussian war of 1870–71 led to renewed growth in the slate industry and extensive mines were developed by the bigger companies. In the early twentieth century deeper shafts were sunk, railways were employed and the use of technology generally increased. Production continued through the years of the Second World War into the 1960s, but competition from synthetic and cheaper imported slate has since led to a decline. In recent years only one mine (Eschenbach-Bocksberg Quarry) has been operating in the Bundenbach region and, since 1999, this has merely been preparing imported slate from Spain, Portugal, Argentina and China and has ceased mining local rock.

The mining of the Hunsrück Slate was vital to the discovery of its fossils. Although they are not uncommon, fossils are only readily recognised by handling large quantities of rock and many of the fine specimens on display in museums were originally found by the slate splitters. The first scientific paper on these fossils was by Roemer (1862) who described and illustrated asteroids and crinoids from the Bundenbach region. Distinguished German palaeontologists such as R. Opitz (1890–1940), F. Broili (1874–1946), R. Richter (1881–1957) and W. M. Lehmann (1880–1959) made extensive studies of Hunsrück fossils from the 1920s to the 1950s, but Lehmann's death, coupled with the decline in the slate industry, led to a corresponding decline in research, especially as few new specimens were being discovered.



48 Locality map to show the Hunsrück Slate region in the Rheinisches Schiefergebirge of western Germany (after Bartels *et al.*, 1998).

At the end of the 1960s Wilhelm Stürmer, a chemical physicist and radiologist at Siemens Corporation, combined these skills with his interest in palaeontology and developed new methods of examining the Hunsrück fossils using X-rays (Stürmer, 1970). His beautiful radiographs of unprepared slates, using soft X-rays (25–40 KV) and stereoscopic exposures combined with high-resolution films and image processing, show intricate detail of soft tissue not revealed by conventional techniques (**49**, **50**). More recently Günther Brassel and Christoph Bartels have continued the work of Stürmer (Bartels and Brassel, 1990). Bartels *et al.* (1998) give an extensive bibliography for all of this research.

49 Radiograph of the starfish *Helianthaster rhenanus* (DBMB). Width approx. 150 mm (6 in).

50 Radiograph of the arthropod *Cheloniellon* (BKM). Width 120 mm (4.8 in).

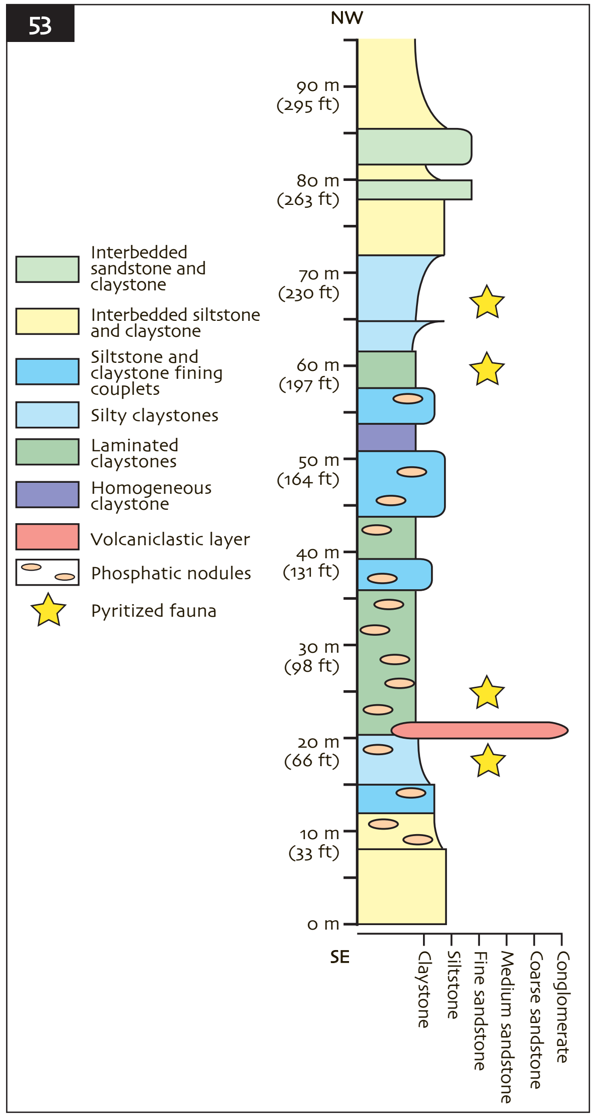
Stratigraphic setting and taphonomy of the Hunsrück Slate

The Hunsrück Slate (Hunsrückschiefer) is a thick sequence of muddy marine sediments of Lower Devonian age which by low-grade metamorphism have been altered to slates. The sequence should strictly be regarded as a facies, rather than a stratigraphic unit, as the deposition of mud was diachronous, beginning earlier in the north-west and migrating south-eastwards. The precise age of the slate is therefore variable, but ranges from late Pragian to early Emsian and is therefore approximately 390 million years. Its outcrop in the Hunsrück hills (**51**, **52**) occurs in a belt approximately 150 km (90 miles) in length and covers an area of 400 square km (150 square miles).

Deposition of the mud occurred in a narrow north-east–south-west offshore marine basin lying between the recently uplifted Old Red Sandstone Continent to the north and the Mitteldeutsche Schwelle (see Chapter 10, p. 101) to the south. Immediately after its uplift, at the end of the late Silurian/early Devonian Caledonian Orogeny, large volumes of sand and muddy detritus were shed into rivers and transported south. Finer sediment was carried in suspension and deposited offshore in the Central Hunsrück Basin. The total thickness of the Hunsrück Slate has been estimated at 3,750 m (12,300 ft) (Dittmar, 1996), although the roofing-slate sequence in the area around Bundenbach and Gemünden is somewhat less than 1,000 m (3,300 ft) (**53**).

51 The Hunsrück hills near Fischbach in the Rheinisches Schiefergebirge of western Germany.

52 Underground mining of the Hunsrück Slate at Herrenberg Mine, Bundenbach.



53 Generalized log of part of the Hunsrück Slate sequence in the Bundenbach area (after Sutcliffe *et al.*, 1999).

During the subsequent Variscan Orogeny of the Carboniferous Period the muddy sediments were subjected to low-grade metamorphism, producing the characteristic slaty cleavage. On the limbs of the folds, such as in the Bundenbach–Gemünden area, the cleavage lies parallel to the bedding enabling the fossils to be revealed.

The ecological setting of the Hunsrück Slate biota has only recently been investigated in detail. The presence of photosynthesizing red algae and the well-developed eyes of certain fish and arthropods (Stürmer and Bergström, 1973; Briggs and Bartels, 2001), suggest that the community was living within the photic zone, i.e. less than 200 m (650 ft) below sea level (Bartels *et al.*, 1998). Average sedimentation rates have been estimated at only 2 mm (0.08 in) per year, but Brett and Seilacher (1991) suggested that rapid sedimentation occurred episodically, caused by tropical storms disturbing sediment in shallower water and sending sediment-laden turbidity currents down into deeper water. Communities living on the muddy sea floor were quickly overcome and buried, explaining the dominance of benthic organisms.

Earlier authors (e.g. Koenigswald, 1930) suggested that the currents transported communities from the area in which they were living into a hostile environment favourable for preservation, exactly as postulated for the Burgess Shale (Chapter 2). However, the burial of crinoids with rooting structures *in situ* and the preservation of syndepositional arthropod trails confirm that the Hunsrück community was living in the area in which it was fossilized, and that it was buried in life position (Sutcliffe *et al.*, 1999).

The bottom waters were clearly well oxygenated allowing the benthic community to become established, including a thriving infauna, as shown by diverse trace fossils. Preservation of soft tissue requires that it is not disturbed by burrowers after burial, so the sediment must have rapidly become anoxic and inhospitable, eliminating both benthos and scavengers. Burial events were, however, only of limited lateral extent, maybe confined to a few hundred square metres (several hundred square feet) (Bartels *et al.*, 1998, p. 50), and living communities survived adjacent to them.

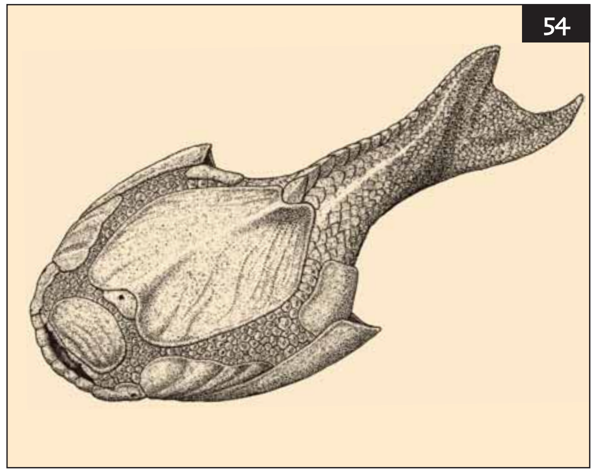
The preservation of the Hunsrück Slate fossils is remarkable in that mineralized skeleton and unmineralized soft tissue have both been preserved by the process of pyritization. Moreover, fragile skeletons (of echinoderms, for example) are often preserved as complete, articulated individuals. Soft tissue preservation, which includes arthropod limbs, eyes and intestines and the tentacles of cephalopods, is confined to four restricted horizons within the thick Hunsrück sequence in the Bundenbach Gemünden area only (**53**). Elsewhere the sequence yields the same taxa, but preserved as fragmented or disarticulated hard parts only. Conditions for rapid pyritization must only have existed for limited periods of time within a restricted area.

Pyritization of soft tissue is unusual in the fossil record; the only other Fossil-Lagerstätten to show such preservation are Beecher's Trilobite Bed (Ordovician) of New York State, and the Jurassic beds of La Voulte-sur-Rhône in France. Briggs *et al.* (1996) showed that the pyritization of soft tissue can only occur in exceptional circumstances of sediment chemistry when there is a low organic content, but a high concentration of dissolved iron. When a carcass is buried in such sediment, sulphate-reducing anaerobic bacteria break down its organic matter producing sulphide. The high concentration of iron in the sediment converts this to iron monosulphide. Finally, aerobic bacteria convert this by oxidation to pyrite. If the organic content of the sediment is too high the dissolved iron precipitates in the sediment and not in the carcass.

The pyrite that preserves the soft tissue of the Hunsrück Slate fossils thus grew as the tissue decayed, but unfortunately microstructure is not preserved as it is when the tissue is replaced by calcium phosphate (see Chapter 11, p. 114). Fossils are usually compressed, but pyritization does preserve some relief, which is not usually the case in argillaceous deposits such as the Burgess Shale (Chapter 2). It has been shown by Allison (1990) that, although the formation of pyrite initially involves reduction, it also requires oxidation at a later stage, and therefore occurs in the upper layers of the sediment near the aerobic–anaerobic interface.

Description of the Hunsrück Slate biota

Fish. As Bartels *et al.* (1998, p. 229) pointed out, the Hunsrück fossils provide an unrivalled picture of the diversity of fish in early Devonian seas. Four of the five main groups of fish are present with only the chondrichthyans, which had not yet evolved, unrepresented. Most of the fish present are agnathans and placoderms. Agnathans are represented by *Drepanaspis* (**54**), which is locally abundant and suggests temporary brackish conditions, and the much rarer *Pteraspis.* The flattened form of *Drepanaspis* suggests that it was nektobenthic and that it was easily caught in the

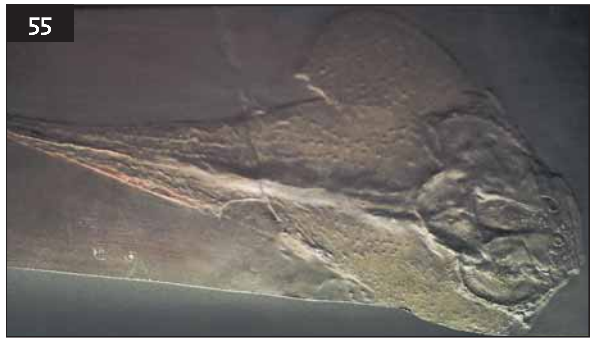


54 Reconstruction of *Drepanaspis.*

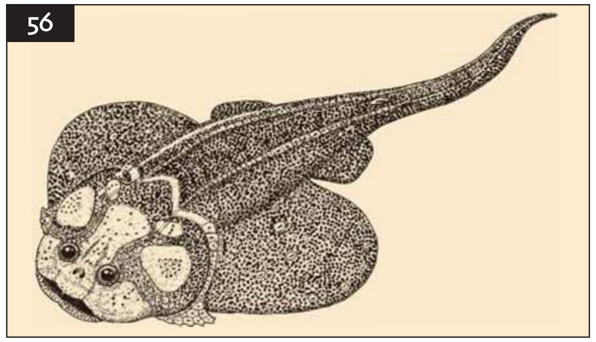
turbidity flows. Placoderms comprise several genera, such as *Gemuendina* (**55**, **56**) and *Lunaspis*, but are less common. The former was shaped like a modern ray and was probably also a bottom dweller – some individuals are up to 1 m (3 ft) long. Acanthodians are known from their fossilized spines up to 40 cm (16 in) long and are common in the Eifel region. Finally, a single specimen of a sarcopterygian (lobe-finned fish) represents the earliest record of a lungfish.

Echinoderms. 'Starfish' (including asteroids and ophiuroids) are perhaps the most familiar and most abundant Hunsrück fossils and are often found intact with the soft skin preserved between the arms. Asteroids (true starfish) comprise some 14 genera, most with five arms, but some (e.g. *Palaeosolaster*, **57**) had more than 20. *Helianthaster* (**49**, **58**) was one of the largest asteroids known, with 16 arms up to 20 cm (8 in) long. Ophiuroids ('brittle-stars'), also with 14 genera, are sometimes very common, such as the graceful *Furcaster* (**59**) and *Encrinaster* (**60**), with their long slender arms. Crinoids are also common (**61**), but echinoids, blastoids, cystoids and holothuroids ('sea-cucumbers') are rare. Almost all of the 65 species of crinoids were sessile forms attached to the substrate and many of the Hunsrück specimens are preserved intact and articulated.

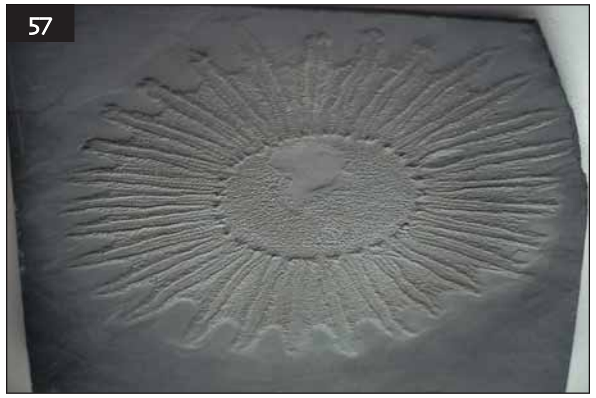
Annelids and arthropods. The polychaete worms ('bristle worms') of the Hunsrück Slate (e.g. *Bundenbachochaeta*, **62**) fill the gap between those of the Burgess Shale (Chapter 2) and Mazon Creek (Chapter 6); these entirely soft-bodied animals are rarely fossilized. Arthropods are spectacular with soft-part preservation of appendages and internal organs. The three major aquatic groups, trilobites, crustaceans and chelicerates, are all represented and there are also some enigmatic arthropods (such as *Mimetaster* with a star-shaped dorsal shield [**63**, **64**], and *Vachonisia* with a carapace like a large brachiopod; Stürmer and Bergström, 1976), which recall the more ancient body plans of some of the Burgess Shale arthropods (Chapter 2). They are important for they prove that successors of the archaic Burgess arthropods did survive at least until Devonian



55 The placoderm fish *Gemuendina stuertzi* (SM). Length 220 mm (8.7 in).

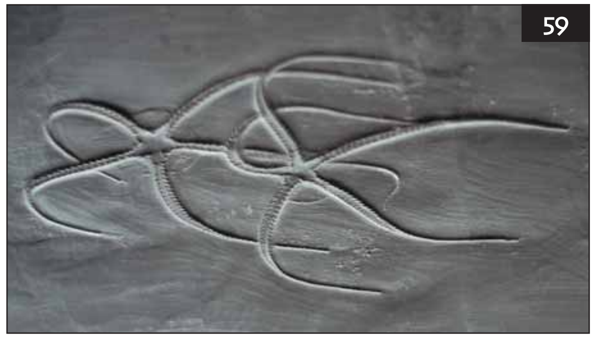


56 Reconstruction of *Gemuendina*.



57 The starfish *Palaeosolaster gregoryi* (BKM). Width approx. 250 mm (10 in).

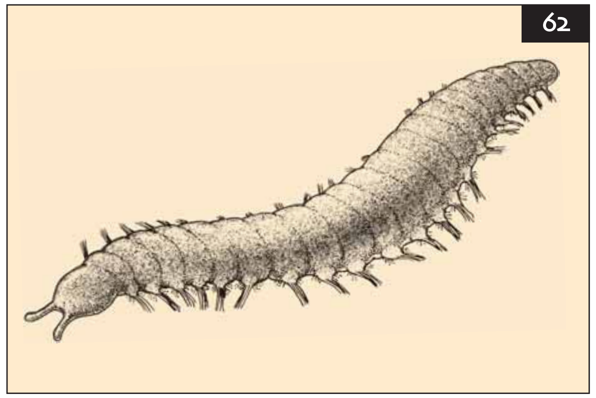
58 The starfish *Helianthaster rhenanus* (BM). Width approx. 150 mm (6 in).



59 The brittle star *Furcaster palaeozoicus* (BM). Length of arms approx. 75 mm (3 in).

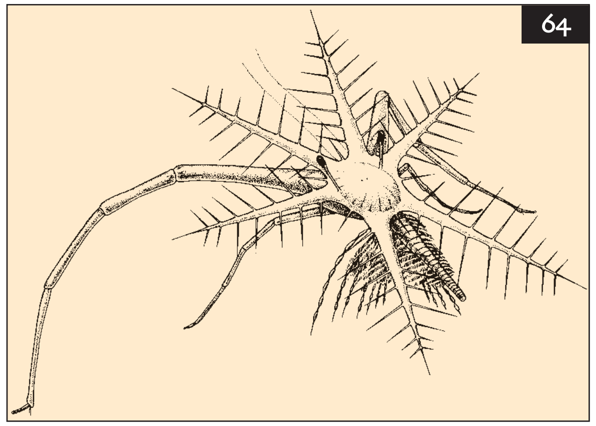
60 The brittle star *Encrinaster roemeri* (MM). Maximum width 120 mm (4.8 in).

61 The crinoid *Imitatocrinus gracilior* (BKM). Length of arms approx. 60 mm (2.4 in).



62 Reconstruction of *Bundenbachochaeta*.

63 The enigmatic arthropod *Mimetaster hexagonalis* (PC). Width of specimen (left to right) 46 mm (c. 2 in).



64 Reconstruction of *Mimetaster*.

times (Briggs and Bartels, 2001). Trilobites are numerous, dominated by the phacopids (e.g. *Chotecops*, **65**), but crustaceans are much rarer, the most common being the bivalved malacostracan *Nahecaris* (**66**, **67**). The chelicerates include rare xiphosurans, eurypterids and scorpions, as well as the only known fossil sea spiders (pycnogonids). The last group is represented in the Hunsrück fauna by the remarkable *Palaeoisopus* (**68**, **69**) with a limb span of up to 40 cm (16 in).

Other invertebrates. None of the other invertebrate groups form dominant members of the Hunsrück fauna, but several groups are represented. Siliceous sponges (cf. *Protospongia*) are restricted to two genera, but cnidarians are more variable. They include chondrophorans ('by-the-wind-sailors'), solitary rugose corals (common Devonian types such as *Zaphrentis*, **70**), colonial tabulate corals (e.g. *Pleurodictyum* and *Aulopora*), scyphozoan conulariids and ctenophores ('comb jellies' or 'sea gooseberries'). Molluscs include gastropods, bivalves and cephalopods, the latter being an important element, mainly comprising orthoconic nautiloids and goniatites. Brachiopods (some with the soft pedicle preserved; see Südkamp, 1997) and bryozoans are also relatively common.

Plants. The calcareous alga *Receptaculites* is the only autochthonous marine plant. Fragments of terrestrial vascular plants also occur, washed out to sea from the coast, including members of the rhyniophytes (see Chapter 5).

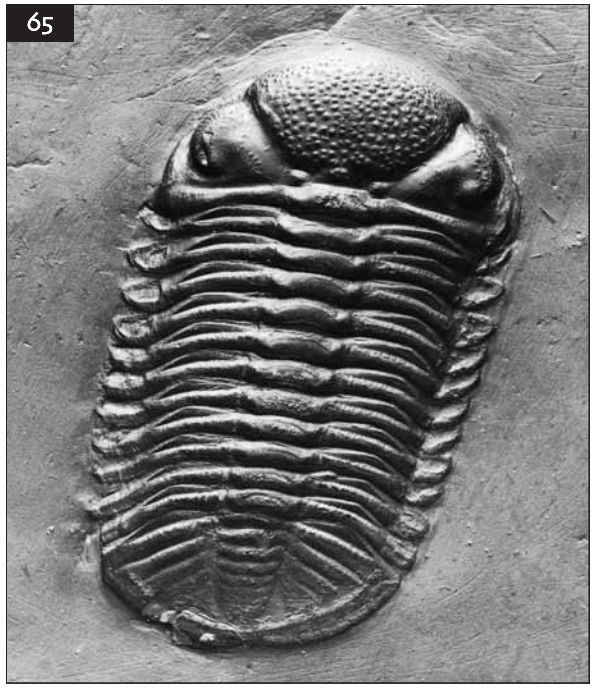
Trace fossils. These include coprolites (from fish), epifaunal tracks (of arthropods, ophiuroids and fish), mobile infaunal traces (of bivalves, echinoderms and polychaetes), and constructed infaunal burrows (Sutcliffe *et al.*, 1999).

Palaeoecology of the Hunsrück Slate

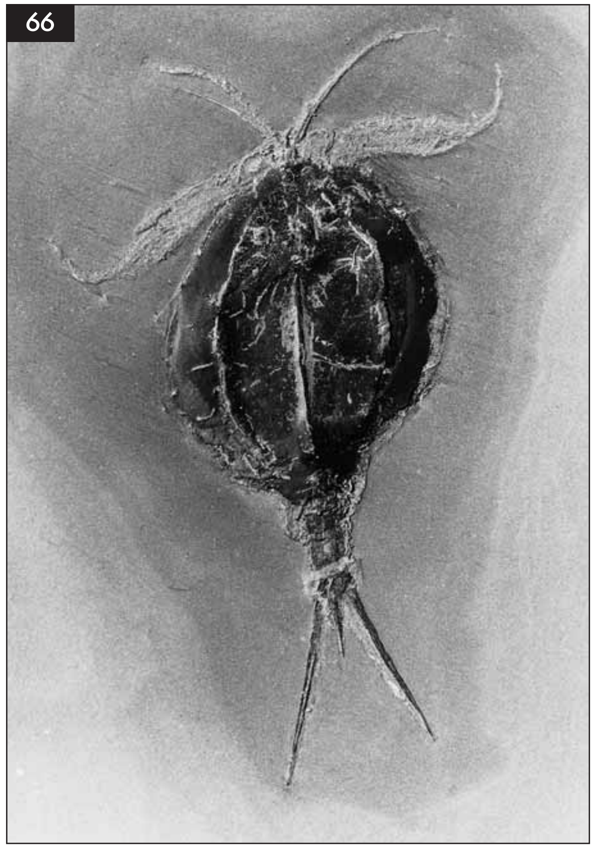
The Hunsrück Slate, like the Burgess Shale (Chapter 2), represents a marine, benthic community living in, on, or just above the muddy seabed of an offshore basin situated at about 20°S. Bottom waters were oxygenated and subjected to currents and, as at Burgess, the presence of photosynthesizing algae suggests that the depth was certainly less than 200 m (650 ft).

No statistical analysis of the Hunsrück Slate biota has been attempted, but of the 400 species of macrofossils described, the majority were certainly benthic. A small percentage consisted of benthic infauna, living in the sediment itself, as shown by pyritized burrows such as *Chondrites*, and the infaunal traces of deposit feeders such as the polychaete worm *Bundenbachochaeta* together with some bivalves and echinoderms.

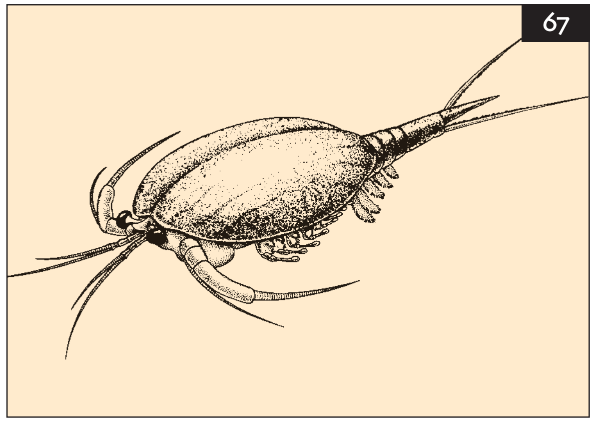
The majority of Hunsrück animals consist of benthic epifauna, living on the sediment surface, the sessile epifauna being dominated by meadows of crinoids, with sponges, corals, conulariids, brachiopods and bryozoans, plus most of the bivalves. These animals shared the seabed with calcareous receptaculitid algae. The vagrant epifauna, walking or crawling across the seabed, was dominated by starfish (asteroids and ophiuroids) and arthropods (trilobites, crustaceans, chelicerates and the archaic forms), but also included some gastropods.



65 The phacopid trilobite *Chotecops* sp. (DBMB). Length 85 mm (3.4 in).

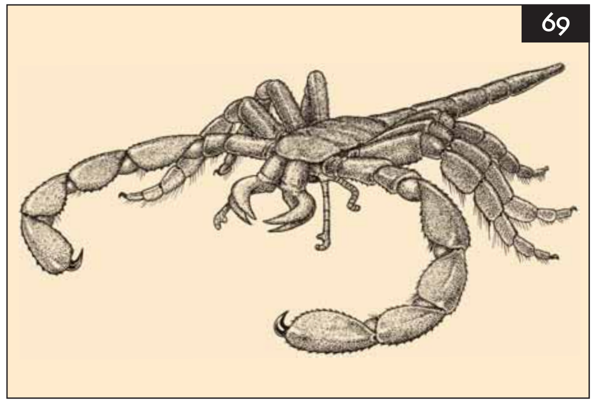


66 The crustacean *Nahecaris stuertzi* (DBMB). Total length 157 mm (6.2 in).



67 Reconstruction of *Nahecaris*.

68 The sea spider *Palaeoisopus problematicus* (BKM). Length of longest leg approx. 180 mm (7 in).



69 Reconstruction of *Palaeoisopus*.

70 The rugose coral *Zaphrentis* sp. (DBMB). Width of calyx 48 mm (c. 2 in).

Animals living higher in the water column were generally able to escape the storm-induced mud flows, but nektobenthic animals (near-bottom swimmers) are represented by some of the agnathan and placoderm fish, such as *Drepanaspis* and *Gemuendina*, with their flattened, ray-like bodies. Planktonic floaters include the cnidarian chondrophorans and ctenophores, while the active nektonic swimmers include orthocone nautiloids, goniatites, acanthodian fish and the arthrodire placoderms up to 2 m (6 ft) long.

Trophic analysis identifies the full range of feeding types including: filter feeders, dominated by the crinoids and sponges; deposit feeders, including the gastropods, polychaetes, some arthropods (such as the enigmatic *Mimetaster* and *Vachonisia*), and possibly the starfish (their large mouths suggest that they were deposit feeders unlike modern predators: Bartels *et al.*, 1998, p. 43). Other arthropods were either scavengers, such as the phyllocarid crustacean *Nahecaris*, with its robust mandibles, or predators such as the giant sea spider, *Palaeoisopus*, which was armed with large chelicerae, or pincers, and probably preyed on crinoid meadows (Bergström *et al.*, 1980). The largest predators were undoubtedly the orthoconic nautiloids, plus the shark-like acanthodians and the arthrodire placoderms, which possibly preyed on orthocones. All of the cnidarians would have captured small organisms with their tentacles.

Comparison of the Hunsrück Slate with other Devonian fish beds

Gogo Formation, Western Australia

This locality in the Kimberley district of north-west Australia has yielded an exceptional fauna of fossil fish from a late Devonian marine (reef) setting. First discovered in the 1940s, the fossils are preserved in limestone concretions which formed during early diagenesis, thus preventing compaction and preserving the fish uncrushed in three dimensions (compare with