HELMSDALE

B.M. Cox

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Introduction

The Helmsdale GCR site spans *c*. 17 km of coastal exposures from near Kintradwell north-eastwards to Dun Glas on the north-east coast of Scotland (Figure 5.9). The narrow outcrop of Kimmeridgian strata represents almost the youngest part of a virtually complete Jurassic succession that is probably over 2 km thick, one of the thickest in the UK (Barron, 1989). The Kimmeridgian strata were deposited along the westernmost active margin of the fault-controlled Inner Moray Firth Basin, which underlies the present-day Moray Firth. The principal western bounding fault of the basin, with major downthrow to the east, is the Helmsdale Fault (Wignall and Pickering, 1993). The Jurassic sediments are downfaulted against Moinian granulites, Helmsdale Granite (Silurian–Early Devonian) and Old Red Sandstone (Macdonald and Trewin, 1993). The outcrop has attracted interest since Murchison (1829b) reported the presence of ‘boulder beds', which are now believed to have been deposited at the foot of the Jurassic submarine fault scarp of the Helmsdale Fault. Other early investigators include Cunningham (1841), Miller (1854), Ramsay (1865), Judd (1873) and, later, Blake (1902b), Seward (1911), Seward and Bancroft (1913), Woodward (in Seward, 1911), MacGregor (1916), Norton (1917), Lee (in Read *et al*., 1925), Bailey *et al*. (1928) and Bailey and Weir (1932). Discovery of oil in the North Sea Basin, where many of the oilfields occur in similar structural settings, and, in particular, the proximity of the Beatrice Oilfield, led to a resurgence of interest in the Helmsdale outcrop, and during the past 25 years there has been a further spate of publications, including a review by Neves and Selley (1975), and papers by Brookfield (1976), Lam and Porter (1977), Riley (1980), Pickering (1984), van der Burgh and van Konijnenburg-van Cittert (1984), Hurst (1985), van de Burgh (1987), Barron (1989), Roberts (1989), Tyson (1989), Trewin (1990), Wignall and Pickering (1993), and a field guide by Macdonald and Trewin (1993).

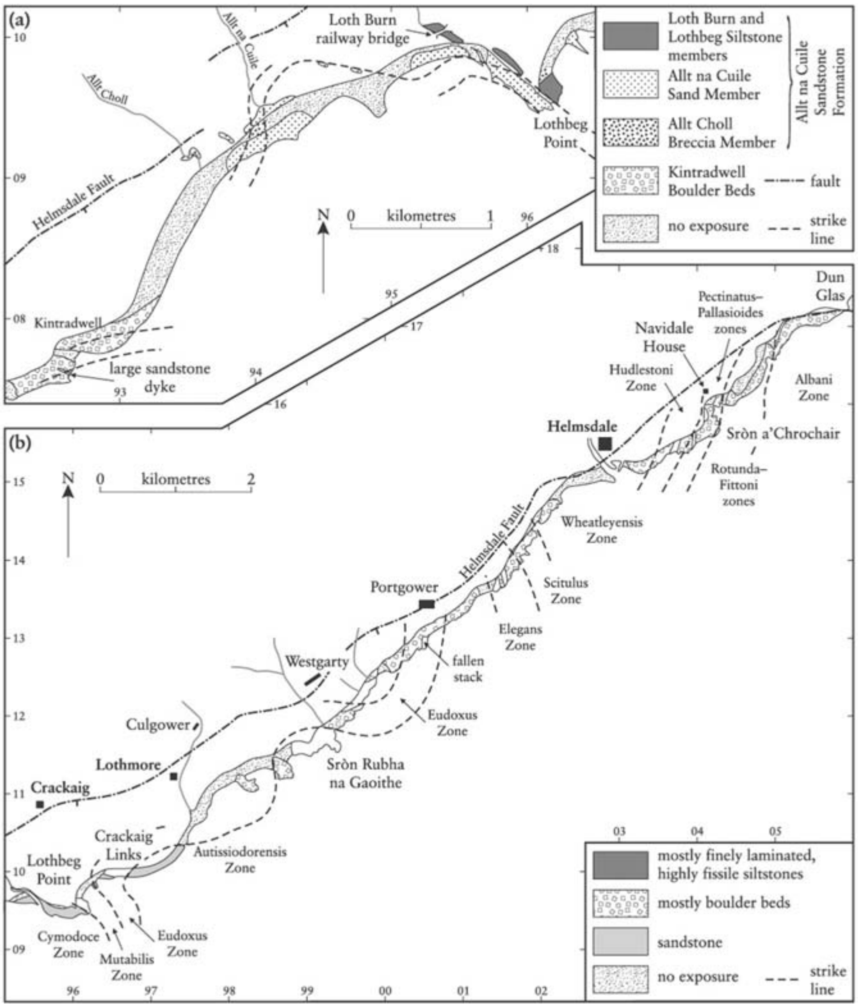

Figure 5.9: Sketch map of the mainly Kimmeridgian outcrop between (a) Kintradwell and Lothbeg Point, and (b) Lothbeg Point and Dun Glas (after Wignall and Pickering, 1993, figs 10 and 17).

Description

The Kimmeridgian outcrop, up to a kilometre wide, displays a complex array of boulder beds interdigitating with dark mudstones, siltstones and sandstones, which generally become younger to the north-east. Minor faults with throws of up to several metres are common and the whole succession has been deformed by simple open, gently plunging folds (Pickering, 1984; Barron, 1989). Three main lithostratigraphical units are recognized, the Kintradwell Boulder Beds (*c*. 85 m thick), overlain by the Allt na Cuile Sandstone Formation (*c*. 120 m) and then the Helmsdale Boulder Beds (*c*. 800 m) (Pickering, 1984; Wignall and Pickering, 1993). As defined by Pickering (1984), the Allt na Cuile Sandstone included the Loth River Shales of Brookfield (1976) and Lam and Porter (1977). Wignall and Pickering (1993) divided the Allt na Cuile Sandstone into four members: the Allt Choll Breccia, the Allt na Cuile Sand, the Loth Burn Siltstone and the Lothbeg Siltstone (Figure 5.10). The following notes are based mainly on Wignall and Pickering (1993), with additional information from Macdonald and Trewin (1993).

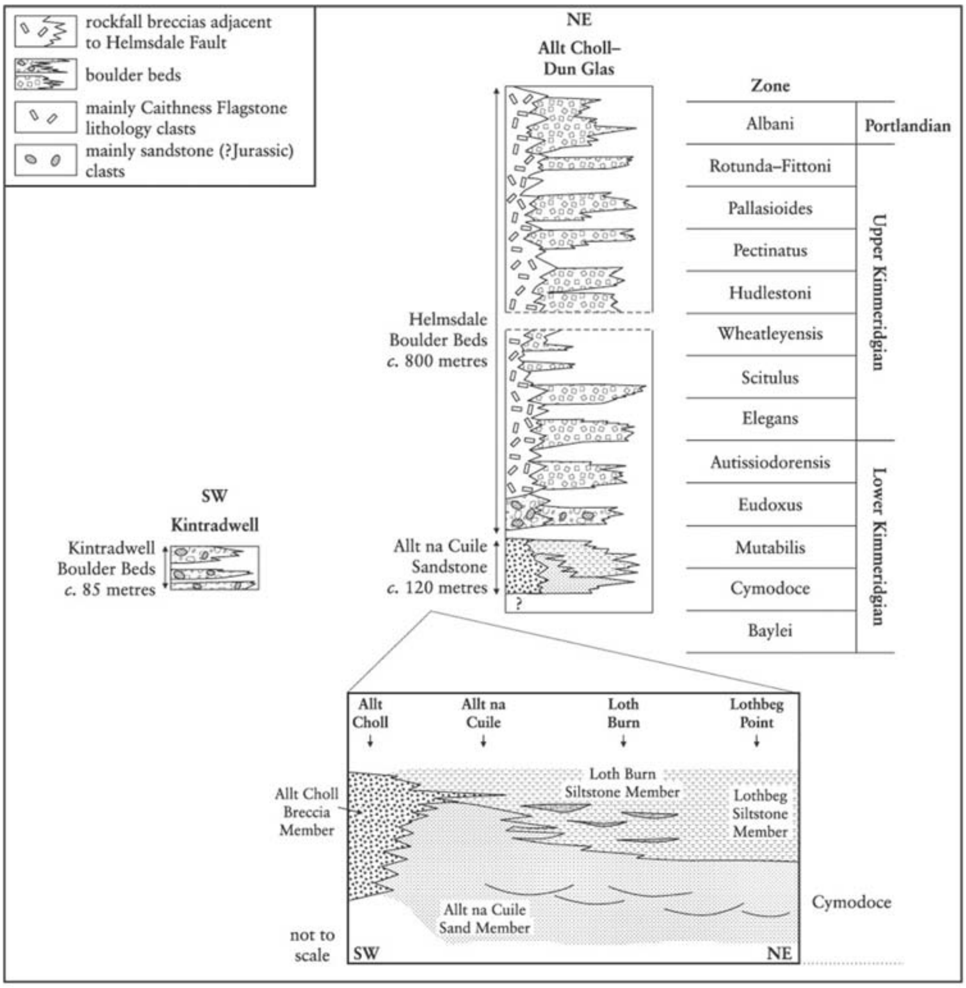

Figure 5.10: Schematic sections showing the main stratal units of the Helmsdale GCR site (based on Macdonald and Trewin, 1993, fig. 2 and Wignall and Pickering, 1993, fig. 15).

At the southern end of the GCR site (NC 929 077), well-developed lenticular boulder beds (matrix-supported conglomerate) of the Kintradwell Boulder Beds are interbedded with finely laminated, highly fissile siltstones and thin sandstones. Many compaction features occur around the large boulders (Figure 5.11) and synsedimentary deformation features are common in the interbedded strata, notably abundant small-scale, closely spaced faults, low-angle or bedding-parallel shears, clastic dykes, sediment slides and slide folds. The boulders are angular to rounded and composed of parallel laminated and cross-bedded white or grey sandstone (quartz arenite). A large (up to 7 m diameter) boulder of bedded sandstone is prominent on the shore. Wignall and Pickering (1993) reported the ammonite *Amoeboceras subkitchini* Spath common in the siltstones and, at the southern end of the section, *Rasenia evoluta* Spath and *Amoeboceras kitchini* Salfeld.

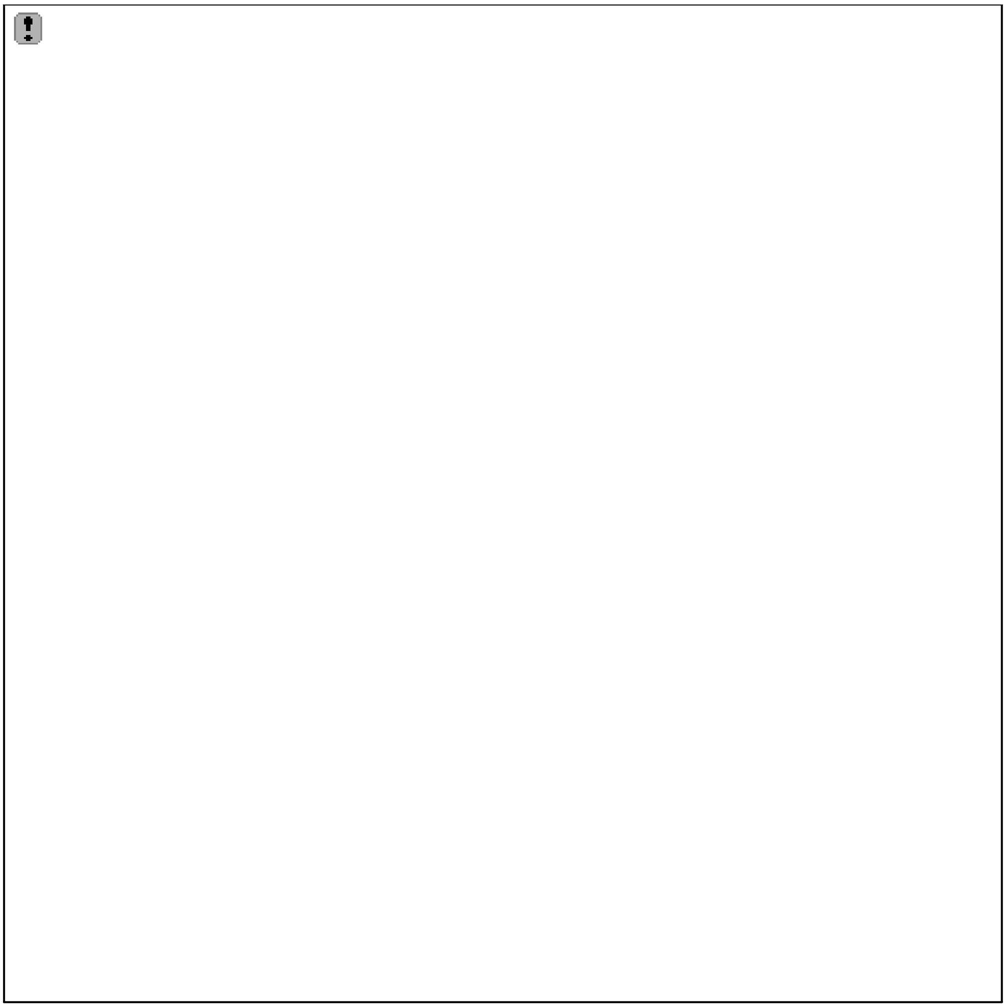

Figure 5.11: Kintradwell Boulder Beds at Kintradwell showing compaction features around the large boulders. (Photo: C1980, reproduced by kind permission of the Director, British Geological Survey ©NERC.)

Between the southern end of the GCR site and Lothbeg Point (NC 960 096), there is a series of disconnected foreshore exposures including the type and only section of the Allt na Cuile Sandstone Formation. At Allt Choll, the Allt Choll Breccia Member comprises 25 m of very coarse breccia in an unconsolidated, fine-grained quartz sand matrix. The clasts range up to several metres in diameter and consist of poorly lithified quartz arenites. Locally, the breccia is interbedded on a *c*. 3 m scale with sandstones of the Allt na Cuile Sand Member, and it dies out eastwards over a distance of *c*. 500 m. Foreshore exposures of the Allt na Cuile Sand at Allt na Cuile show planar-laminated sands alternating with intensely burrowed horizons. Distinct burrows are not generally discernable but in some beds there is a vertical fabric probably representing *Skolithos* or *Arenicolites*. There are rare discrete shelly beds, mostly composed of fragmented bivalves, serpulids and echinoid spines. The lower beds of the member are seen again on the foreshore immediately south of the Loth Burn railway bridge where bioturbation is more clearly picked out because of the presence of carbonaceous plant material. Trace fossils include *Rhizocorallium*, *Planolites*, *Monocraterion* and *Chondrites*. At Lothbeg Point, the Allt na Cuile Sand comprises burrowed, clean sandstones with rare, thin, dark siltstones. These pass upwards into more structureless, thick-bedded sandstones with erosional-based sands and sand packets. The overlying Loth Burn Siltstone, comprising a series of lenticular sandstones less than 2 m thick interbedded with finely laminated, highly fissile siltstones, is seen in the banks of the Loth Burn on either side of the railway bridge. The fauna is mainly restricted to isolated nests of the bivalves *Liostrea multiformis* (Koch) and *Buchia concentrica* (J. de C. Sowerby), although Arkell and Callomon (1963) recorded an ammonite fauna of *Amoeboceras* and various ‘raseniids'. At Lothbeg Point, a broad wave-cut platform exposes the Lothbeg Siltstone, which appears to be a lateral equivalent of the Loth Burn Siltstone but without the lenticular sandstones. The 30 m thick section is dominated by finely laminated and fissile, dark-grey siltstones with rare interbedded pale-grey mudstone laminae up to 2 mm thick. There are two horizons of giant carbonate-cemented concretions up to 0.4 m thick and 2 m in diameter, and a 3 m thick interval of sand and silt interbedded on a centimetre to millimetre scale (the 'tiger-stripe' facies), which shows wet-sediment deformation structures such as slump folds and small-scale synsedimentary faults. The ammonites *Amoeboceras kitchini* and *Rasenia lepidula* (Oppel) occur throughout much of the section, with *Rasenia evoluta* in the basal metre. The basal two metres of the Lothbeg Siltstone contain the bivalves *Buchia concentrica*, *Liostrea multiformis* and *Parainoceramus*. Plant fragments, dominated by ferns, cycads and conifer needles, are abundant in the siltstones.

There is a short gap in exposure north-east of Lothbeg Point but between Crackaig and Dun Glas (ND 058 172), the Helmsdale Boulder Beds are exposed almost continuously. Bed thicknesses are generally between 0.5 and 1 m but may range from a few centimetres up to tens of metres. Most of the boulder beds contain giant, subangular to subrounded clasts, mainly of Devonian Caithness Flagstone lithologies, and Jurassic material including silicified wood and coral fragments in a heterogeneous fine-grained matrix. The largest clast is the famous 'fallen stack' of Bailey and Weir (1932) near Portgower; it has dimensions of at least *c*. 45 m by 27 m (Figure 5.12). In places, the boulders appear to have sunk up to some tens of centimetres into the underlying fine-grained lithologies, which comprise interbedded sandstones and siltstones but no true mudstones or black shales. The sandstones vary from a centimetre to more than a metre in thickness, and range from quartz arenites to greywackes. Some are rich in shell detritus, others in plant material. Unlike the uncemented sands of the Allt na Cuile Sandstone Formation, the sandstones are tightly cemented by coarsely crystalline calcite. The siltstones are planar interlaminated with fine sand on a 1–5 mm scale; where they are interbedded with somewhat thicker sandstones (up to 3 cm), the so-called 'tiger-stripe' facies is again developed. Wet-sediment deformation features are common throughout the formation, including synsedimentary normal and reverse faults on various scales, slide folds, slumps, clastic dykes as both mud and sand injections, convolute bedding, and dish and pillar structures. A diverse, calcareous fauna, dominated by thick-shelled bivalves, is present in the matrix of the boulder beds throughout the formation. The bivalves include oysters (*Liostrea*, *Nanogyra* and rarer *Lopha*), pectinids (*Chlamys* and *Radulopecten*), very thick-shelled *Isognomon* riddled with lithophagid borings, large trigoniids and small astartids. Gastropods, belemnites, serpulids, echinoids, crinoids and brachiopods are also present as well as rare blocks of the coral *Isastrea*. In the interbedded laminated siltstones, there is a well-preserved but more limited fauna of *Liostrea multiformis*, rare nests of *Buchia concentrica*, and rare *Plagiostoma*. Rare and poorly preserved ammonites from the formation include *Amoeboceras (Euprionoceras) kochi* Spath, *Pectinatites (Arkellites)*, and *Pavlovia concinna* (Neaverson).

Figure 5.12: The 'fallen stack' in the Helmsdale Boulder Beds near Portgower. (Photo: C1975, reproduced by kind permission of the Director, British Geological Survey ©NERC.)

Near Dun Glas, the Helmsdale Fault itself is exposed on the foreshore near the mouth of Allt Briste. The rocks in the fault zone are intensely fractured, sheared and veined such that the original lithologies are hard to recognize.

Interpretation

According to Pickering (1984), the boulders in the Kintradwell Boulder Beds are probably derived from older Jurassic formations, such as the Callovian–Oxfordian Brora Arenaceous Formation, which were reworked in the littoral zone. The beds show abundant evidence of synsedimentary deformation and, according to Wignall and Pickering (1993), the Helmsdale Fault was active during their deposition although the rarity of older Jurassic clasts suggests that only a small part of the Jurassic succession was exposed on the fault scarp, and/or the earlier Jurassic sediments were not then lithified. A low-diversity bivalve fauna of *Buchia concentrica* and *Liostrea multiformis* in the siltstone matrix indicates oxygen-restricted conditions of deposition but where these taxa occur in a more diverse assemblage, including the bivalves *Nicaniella* cf. *eathiensis* (Waterston), *Palaeonucula*, *Parainoceramus* and *Solemya* cf. *woodwardiana* Leckenby, and the gastropod *Semisolarium*, almost normal bottom-water oxygen levels can be inferred. The presence of this latter assemblage in laminated sediments, which are typically associated with very low oxygen levels, suggests very high sediment accumulation rates. Rapid sedimentation is also indicated by the presence of small escape structures, probably of bivalves, at the lower contact between sandstone and siltstone beds (Wignall and Pickering, 1993).

Pickering's (21.0308) interpretation of the Allt na Cuile Sandstone Formation as having accumulated in a large submarine canyon–channel incised into the slope associated with the

Helmsdale Fault scarp has been accepted by all subsequent authors. Of these, Trewin (1990) suggested that the Allt Choll Breccia probably formed as a rockfall breccia at the base of the steep-walled proximal canyon. Wignall and Pickering (1993) agreed, in essence, with these ideas but suggested that the area between Allt Choll and Allt na Cuile, where the otherwise straight outcrop of the Helmsdale Fault is displaced by about 500 m to the south-east, may have been preferentially exploited as a conduit for the transport of sandy shelf sediments to the downfaulted basin. The accumulation of sediment, comprising amalgamated channel sand bodies that became gradually smaller down-dip, built out to the east for a distance of at least 2 km but Wignall and Pickering (1993) noted that there is no evidence to suggest a radially distributed and well-organized set of submarine fan environments that would warrant the use of the term 'fan'. The diverse trace-fossil suite in the lower beds indicates that bottom-water oxygen levels were initially normal but the rapid fining-upwards shown by the higher beds, associated with a drastic decline in oxygen values (inferred from the lack of benthos), probably indicates a deepening of the sea.

In the Helmsdale Boulder Beds, the boulder beds themselves show classic features of submarine debris-flow and rockfall–slide processes. According to Wignall and Pickering (1993), the 'fallen stack' at Portgower is most likely to have been emplaced by rockfall and downslope sliding only a few hundred metres from the submarine cliff. They interpreted those isolated boulders that did not sink into the finer-grained beds below them, as the product of non-depositing debris flows or as ejected 'out-runner' blocks at the snouts or lateral margins of debris flows. Sedimentary structures suggest that the sandstones of the Helmsdale Boulder Beds were deposited from turbidity currents, but the finely laminated siltstones represent sedimentation by several different processes, the main one being deposition from dilute, muddy, turbidity currents, with hemipelagic and pelagic background sedimentation. According to Wignall and Pickering (1993), the 'tiger-stripe' facies likewise results from episodic deposition from thin, probably dilute, sandy turbidity currents and muddy turbidity currents, with hemipelagic– pelagic background sedimentation. The fauna in the matrix of the boulder beds is considered to be allochthonous and indicates a shallow, fully oxygenated shelf environment west of the Helmsdale Fault; the presence of corals suggests warmth. The corals occur as isolated colonies, with no indication of the presence of reefs on the upthrown side of the fault. The dominance of sessile epifauna rather than vagile infauna suggests sediment-starved, stable substrate conditions where the influx of sand was fairly infrequent (Wignall and Pickering, 1993). On the other hand, the fauna of the laminated siltstones is considered to be autochthonous. Wignall and Pickering (1993) suspected that the main ways by which the usually anoxic bottom-waters became briefly sufficiently oxygenated to support an impoverished fauna was from occasional turbidity currents carrying warmer and more oxygen-rich water with the sediment from the shelf into deep water.

The ammonite faunas have never been comprehensively reported but the records, recently assessed by Wignall and Pickering (1993), are sufficient to establish a nearly complete Kimmeridgian zonal sequence, from the Lower Kimmeridgian Cymodoce Zone through to the oldest (Albani) zone of the Portlandian (Figure 5.10). These authors concurred with the assessment of the zonal succession made by Barron (1989) on the basis of dinoflagellate cysts. Based largely on the unpublished ammonite data in Linsley (1972), with later refinement by Macdonald (1985) and Barron (1989), an approximate outcrop map of the zones was presented by Barron (1989) and Wignall and Pickering (1993) (Figure 5.9). The ammonite faunas reported from the Kintradwell Boulder Beds are indicative of the Cymodoce Zone. Neves and Selley (1975) thought that these beds were younger than the Allt na Cuile Sandstone but most subsequent authors have suggested that they are slightly older (Roberts, 1989; Tyson, 1989); Wignall and Pickering (1993) showed that they are equivalent in age to most of the Allt na Cuile Sand Member (Figure 5.10). The relationship one to another of the various members of the Allt na Cuile Sandstone Formation, which have mainly discontinuous outcrops, was not clearly demonstrated until the latter authors' work. Brookfield (1976) and Gregory (1989) both reckoned that the Allt na Cuile Sand Member was overlain by the Lothbeg Siltstone Member, which is clearly demonstrated at Lothbeg Point, but Wignall and Pickering (1993) showed that the latter member also grades laterally into the sandstones to the west via the Loth Burn Siltstone (Figure 5.10). The ammonites recorded from the Lothbeg Siltstone indicated to Wignall and Pickering (1993) that it represents the youngest part of the Cymodoce Zone and the Mutabilis Zone (Brookfield, 1976; Gregory, 1989). Arkell and Callomon (1963) recorded an ammonite fauna from the Loth Burn Siltstone indicative of the oldest part of the latter zone, and a fauna of similar age has been collected from loose blocks, probably from the top of the Allt na Cuile Sand Member, at Allt na Cuile (Brookfield, 1976; Wignall and Pickering, 1993). The Helmsdale Boulder Beds range from the Mutabilis Zone to the top of the Albani Zone of the lowest Portlandian but the ammonite faunas are not well known (Spath, 1935; Birkelund and Callomon, 1985). Wignall and Pickering (1993) reckoned that they had substantiated the presence of the Eudoxus, Elegans, Hudlestoni and Rotunda–Fittoni zones. Linsley (1972) and Lam and Porter (1977) had suggested that the Scitulus Zone was faulted out at Gartymore and that the Hudlestoni Zone, although present in the Helmsdale area, was not exposed (Barron, 1989). However, from structural and sedimentological data, MacDonald (in Barron, 1989) reported that the section was assumed to be continuous with only part of the Wheatleyensis Zone unexposed at Helmsdale and no evidence of faulting at Gartymore, although angular disconformities were present on the Helmsdale to Navidale and Gartymore foreshores.

Within the framework of the ammonite zonation, Wignall and Pickering (1993) presented a depositional history of the Kimmeridgian succession that started with deposition of the oldest Kimmeridgian strata (Kintradwell Boulder Beds and Allt na Cuile Sandstone) on the downthrown side of an already active Helmsdale Fault (Figure 5.13). At this time, the water depth in the downfaulted area was probably not very great, and the submarine fault scarp was probably only a few (?ten) metres high. Subsidence on the Helmsdale Fault probably accelerated towards the end of Cymodoce Zone times leading to rapid deepening, and headward erosion and steepening of the Allt na Cuile channel– canyon complex. Late in Mutabilis and Eudoxus Zone times, further rapid deepening led to permanent anoxia. By this time, much of the older Jurassic succession had probably been stripped off the footwall to reveal Middle Old Red Sandstone lacustrine facies (Caithness Flagstone), which constitutes most of the clasts in the Helmsdale Boulder Beds. The height of the scarp must have been greater than 50 m and water depths at the foot of the fault scarp-slope must have exceeded 200 m by mid Eudoxus Zone times when a broad shallow shelf had developed on the upthrown side of the fault. From then onwards, sediment reached the foot of the fault scarp-slope as a series of sediment slides, debris flows, avalanches and turbidites that alternated with quieter water hemipelagic–pelagic sedimentation. The substantial reduction in plant detritus in the youngest beds led Wignall and Pickering (1993) to speculate that in Rotunda Zone times, the climate, which earlier in the Kimmeridgian had been humid and supported a rich and varied terrestrial flora (Seward, 1911; Seward and Bancroft, 1913; van de Burgh and van Konijnenburg-van Cittert, 1984; van de Burgh, 1987), had become more arid.

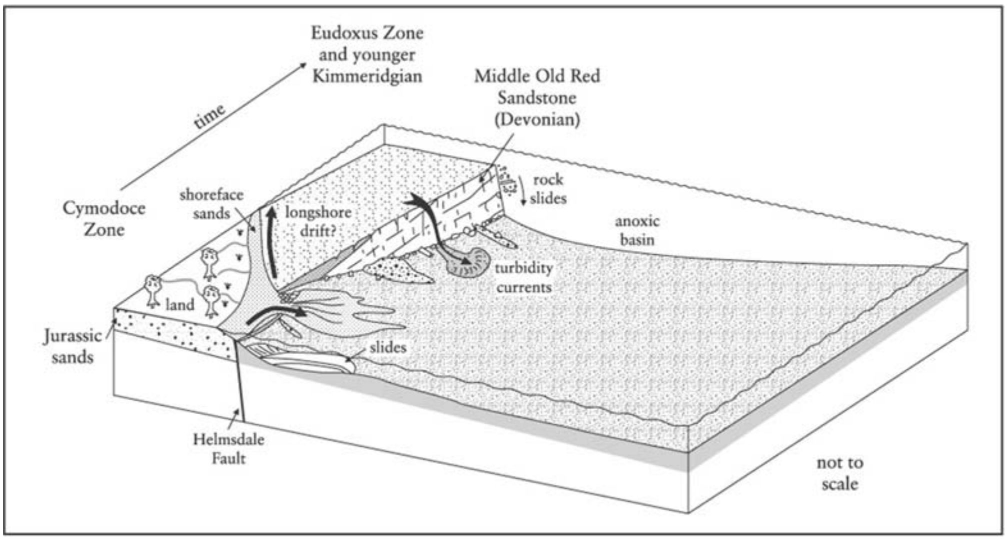

Figure 5.13: Simplified reconstruction of depositional conditions adjacent to the Helmsdale Fault during the Kimmeridgian (after Wignall and Pickering, 1993, fig. 21).

Conclusions

The narrow outcrop of Kimmeridgian strata on the coast of north-east Scotland, which comprises the GCR site known as 'Helmsdale', is the most extensive Kimmeridgian outcrop in

Britain apart from that on the Dorset coast (see Chapter 2). It shows a virtually complete Kimmeridgian zonal succession, including the youngest zones and the basal zone of the overlying Portlandian strata, which are otherwise known only in Dorset. It also provides one of the best examples of fault-controlled sedimentation in the British Mesozoic record. The Kimmeridgian beds were deposited at the western active margin of a major half-graben controlled by downthrow on the Helmsdale Fault. The succession provides good sedimentological analogues for several North Sea oilfields. Boulder beds and the millimetre- to centimetre-scale interbedded sandstones and siltstones known as 'tiger stripe' facies, comparable to those that characterize the coastal outcrop, are also known from boreholes in the Moray Firth, Witch Ground Graben and Viking Graben. The site is thus a most important one for sedimentological and stratigraphical studies, offering a 'window' on the economically important subsurface geology of the North Sea.

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