British Upper Cretaceous Stratigraphy

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Chapter 6

Inner Hebrides Group, north-west Scotland

INTRODUCTION

The Upper Cretaceous sediments of the north-west Highlands were made famous by Bailey's (1924) paper entitled *The Desert Shores of the Chalk Seas*. The climatic implications for the Late Cretaceous Epoch from this work have been widely debated ever since. Massive cliffs of black, basaltic, Palaeogene lavas irregularly overlie and obscure the Upper Cretaceous deposits, sometimes filling palaeovalleys that have cut deeply through the underlying Mesozoic sediments. These palaeovalleys were presumably cut at the end of the Cretaceous Period following tectonic faulting, uplift and erosion prior to the volcanic outpourings. Consequently the outcrop of Upper Cretaceous sediments is not continuous and this is seen particularly well at the **Gribun** GCR site on the Isle of Mull, where only small pockets of sediment are preserved, often in landslipped blocks, along the strike. Even where relatively continuous outcrops are present, such as the sea cliffs at Auchnacraig and Carsaig on Mull and the **Beinn Iadain** GCR site in Morvern, each exposure shows significant differences in preserved stratigraphy both within the Upper Cretaceous succession and as a result of pre-lava erosion. Many of the exposures are ephemeral stream sections high up slopes beneath the basalts in waterfalls, which can be torrents following rain.

Because the Upper Cretaceous deposits are so thin, there is little significant impact on geomorphology. The sandy deposits of Mull and Morvern overlie Triassic and Jurassic sediments of various ages but where, for example, shales occur beneath the sands, spring lines and saturated ground (bog) are often present. The limestones on Skye provide a different habitat, affecting the flora, which can be picked out as lighter green grassland patches amongst the generally darker green bracken and heather.

TECTONIC SETTING AND SEDIMENTARY HISTORY

The sedimentary succession comprises the Inner Hebrides Group (Braley, 1990; Lowden *et al.*, 1992) and forms part of a Mesozoic Inner Hebrides Basin or Province (Figures 6.1 and 6.2). The term 'Province' is preferred since it is uncertain whether an Upper Cretaceous basin really existed and whether or not inversion took place in the late Lower Cretaceous Epoch resulting in erosion of former sediments. The exposures are found locally beneath Palaeocene lavas on the islands of Skye, Eigg, Staffa and Mull and on the mainland in Morvern and Ardnamurchan. In the north-west Highlands large-scale geological structures, such as the Great Glen Fault and the Moine Thrust, have very long histories of movement affecting sedimentation over the last 400 Ma. The Great Glen Fault is adjacent to, and partly passes through, the Late Cretaceous deposits on Mull and Morvern (Figure 6.2). The Moine Thrust Zone, with the basal Kishorn Thrust, lies to the east of the Skye Upper Cretaceous deposits, but a further major geological structure, the Camasunary Fault, separates the Strathaird outcrops from those on Soay Sound. The Allt Strollamus exposure near Broadford, Skye, and the Coire Riabhach section, Beinn Iadain, Morvern are fault-controlled slices. Smaller-scale faults are numerous, and cross the outcrop of Upper Cretaceous sediments.

Because of the small, discontinuous exposures, it is not possible at this stage, to provide a comprehensive account of the influence of these structures on sedimentation. The evidence, however, for rapid lateral changes in stratigraphy, reworking, debris flows and local preservation windows, suggests that tectonic movements had a marked impact on the Late Cretaceous and Early Palaeogene history of the region.

STRATIGRAPHY

The Inner Hebrides Group is a highly reduced succession, some 2–20 m thick for the inferred Cenomanian to Maastrichtian strata, compared with 110 m in Northern Ireland and 500 m in Norfolk. The succession comprises beds of greensand, white sand, limestones and chalk (in part and, in some places, reworked debris flows), overlain in places by lignite and/or mudstones. Prior to the data published in the present account, the limited fossil records indicated the presence of Cenomanian and, more tenuously, Turonian, Santonian and Campanian sediments. It is remarkable that any sediment remains, and much of it presents evidence of reworking, casting doubt on its age. All of the exposures are very difficult to access and interpret, and most indicate that the sediments have suffered a degree of thermal metamorphism, often calcining or burning important fossil evidence.

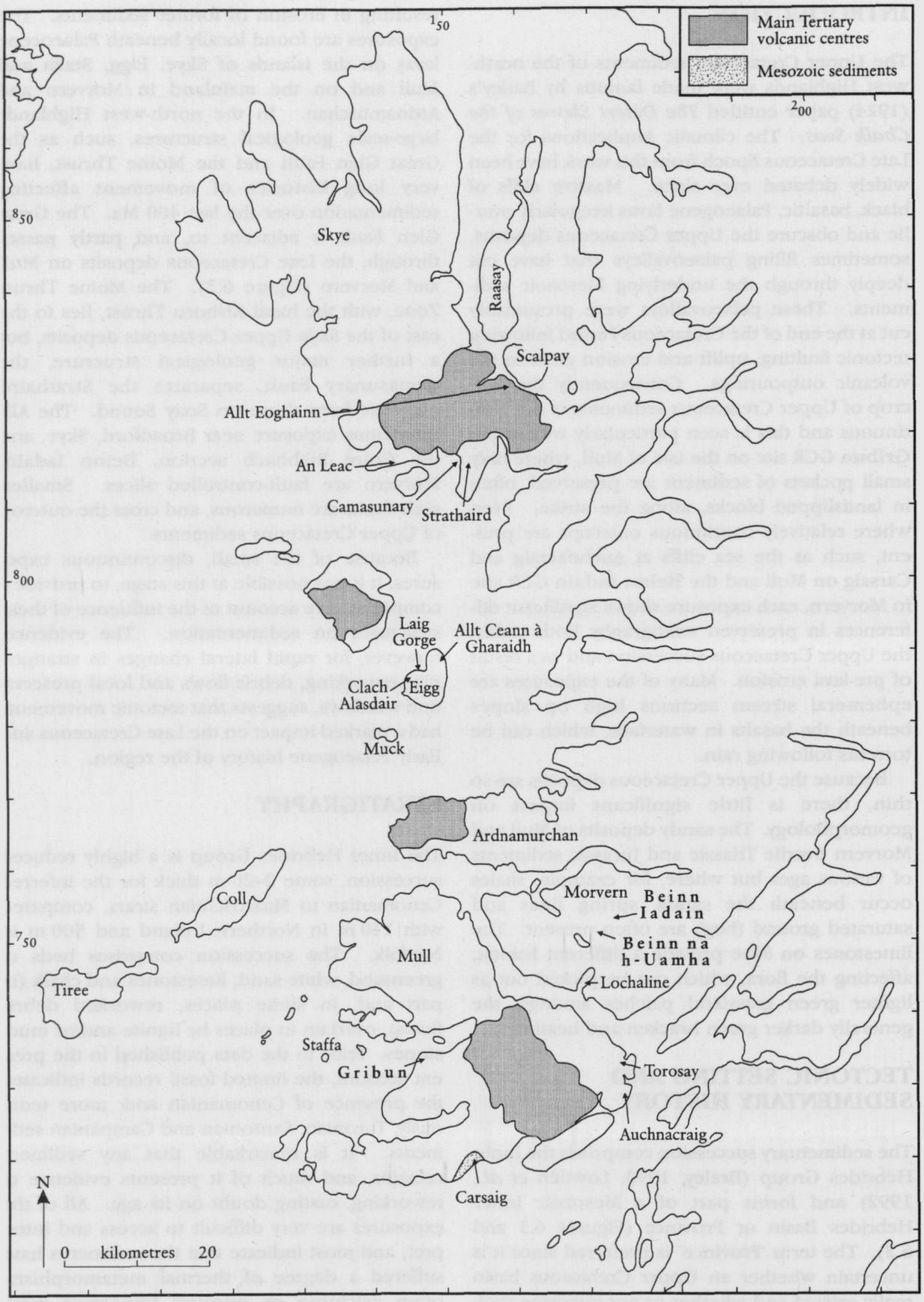


Figure 6.1 Main Upper Cretaceous localities in the Inner Hebrides Province; GCR sites are in bold type face.

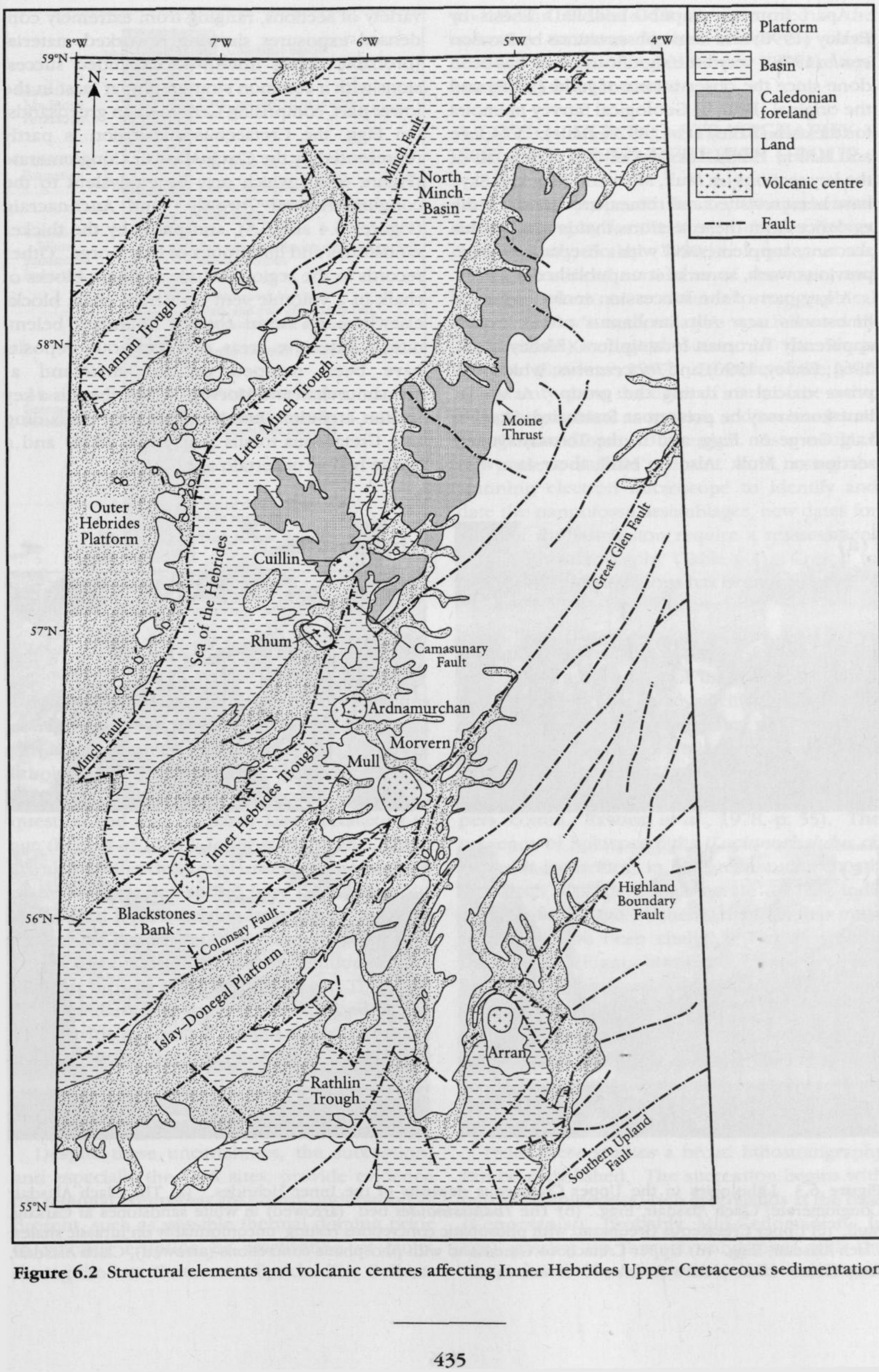


Figure 6.2 Structural elements and volcanic centres affecting Inner Hebrides Upper Cretaceous sedimentation.

Apart from an unpublished PhD Thesis by Braley (1990) and some observations by Rawson *et al.* (1978), very little significant work has been done since the observations of Judd (1878) and the original [British] Geological Survey memoirs for the area (Bailey *et al.*, 1924; Bailey, 1924; Lee and Bailey, 1925). As part of this review, all of the key sections on Mull, Morvern, Eigg and Skye have been revisited and remeasured, and it is the evidence from these sections that is used in this account, supplemented with observations from previous work, some of it unpublished.

A key part of the succession includes 5 m of limestones near Allt Strollamus on Skye with apparently Turonian foraminifera (Richey *et al.*, 1961; Braley, 1990) and *Inoceramus*, which may prove crucial to dating the group. A similar limestone may be present at Strathaird, Skye, in Laig Gorge on Eigg, and in the Torosay Quarry section on Mull. Also on Mull, there is a wide variety of sections, ranging from extremely condensed exposures showing reworked material (probable debris flows), to expanded successions with a common stratigraphy, at least in the lower part, comprising Cenomanian greensands. On Eigg, the Cretaceous succession is partly represented by the Clach Alasdair Conglomerate (Figure 6.3a), which may be equivalent to the conglomerate at Torosay and Auchnacraig (Figures 6.4 and 6.5), and partly by the thicker sandstones and limestones of Laig Gorge. Other records in the region include remnant blocks of chalk in a volcanic vent on Arran; chalk blocks elsewhere on Arran contain abundant belemnites. Extensive areas of Cretaceous deposits have been mapped on the mainland at Ardnamurchan and Morvern where there is a key section at **Beinn Iadain** apparently containing Late Cretaceous fossils (e.g. Judd, 1878) and a lignite bed of uncertain age.

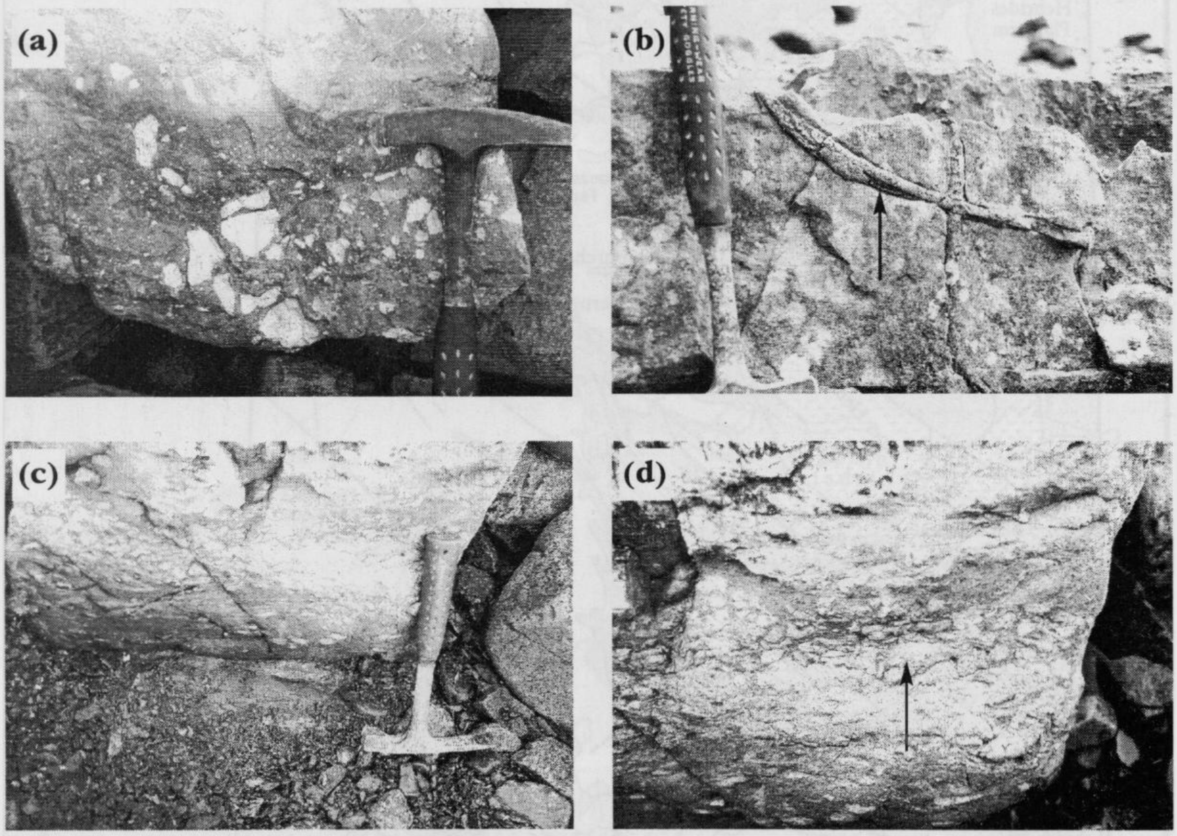


Figure 6.3 Lithologies in the Upper Cretaceous deposits of the Inner Hebrides. (a) The Clach Alasdair Conglomerate, Clach Alasdair, Eigg. (b) The *Thalassinoides* bed (arrowed) in white sandstones at Carsaig, Mull. (c) Upper Cretaceous Greensand with phosphatic concretions resting unconformably on Jurassic shales, Clach Alasdair, Eigg. (d) Upper Cretaceous Greensand with phosphatic concretions (arrowed), Clach Alasdair, Eigg. (Photos: R.N. Mortimore.)

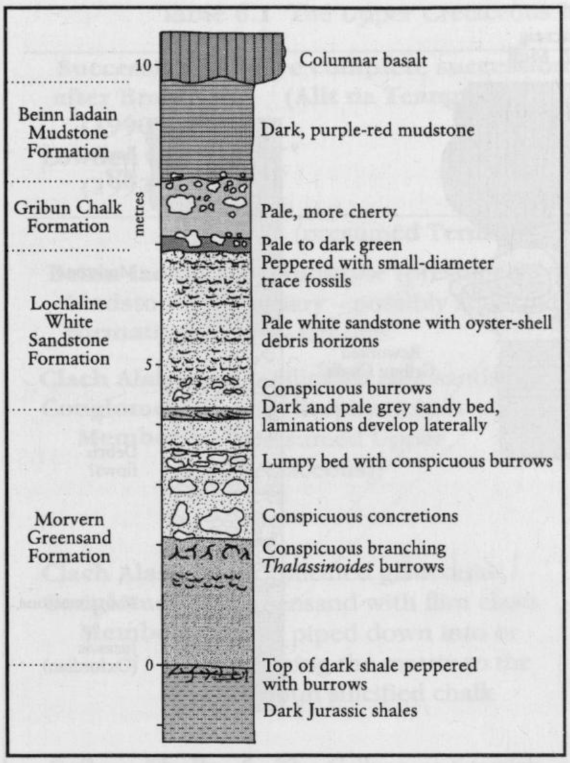


Figure 6.4 The Auchnacraig Section 1, Mull (see also Figure 6.5).

Much of the dating of the succession remains controversial, as diagnostic fossils have not yet been obtained from all of the different lithologies. Even the date of the onset of vulcanism at the top of the section is open to question and may be partly Late Cretaceous in age (Kent *et al.*, 1998; Jolley *et al.*, 1998). There are also lignites that are of uncertain age because many of the pollen spores have been burnt-out by the heat from overlying lavas. Only the basal part of the succession, which largely comprises shelly glauconitic sands, can confidently be dated as broadly Cenomanian in age. There are some similarities in fossil occurrences and lithologies with equivalent sediments in Northern Ireland where the metamorphism is of lower grade and different character. Hence Northern Ireland provides key evidence for unlocking the Hebridean succession.

Despite these uncertainties, the succession, and especially the GCR sites, provide evidence for regional events that are poorly understood at present, such as possible thermal doming prior to volcanic eruption or reactivation of faults during the Late Cretaceous Epoch. The **Gribun** and **Beinn Iadain** GCR sites are used as the reference sections against which the other sections in the Inner Hebrides Province are compared and contrasted.

A LITHO- AND BIO-STRATIGRAPHY FOR THE INNER HEBRIDES GROUP

Judd (1878) proposed the first comprehensive lithostratigraphy for the Inner Hebrides Group. Subsequently, Braley (1990; in Lowden *et al.*, 1992) introduced a number of new units and arranged them in a different stratigraphical order. Braley's nomenclature was followed by the British Geological Survey in the Rhum Memoir (Emeleus, 1997). Because of the great uncertainty about the dates of many of the units, this stratigraphical succession and nomenclature has remained open to question. As a result of the present authors' current work, using the scanning electron microscope to identify and date the nannofossil assemblages, new dates for parts of the succession require a reassessment of the lithostratigraphy (Table 6.1). Critical to these new interpretations has been the dating of the greensands with phosphates at **Gribun** (Mull), **Beinn Iadain** (Morvern) and Clach Alasdair (Eigg), which indicate a Late Coniacian or Early Santonian age for these deposits, overlain by Early Campanian silicified pale chalks. Such an age for the phosphates was suggested by Reid (unpublished letters to Dr C.V. Jeans) who dated sponges from the Beinn Iadain section collected by Jeans and Platten (Jeans, pers. comm.; Rawson *et al.*, 1978, p. 55). The presence of holococcoliths (*Lucianorhabdus* cf. *cayeuxii* Deflandre) in the greensands beneath the Clach Alasdair Conglomerate on Eigg indicates a similar age. Other sediments that must originally have been chalks at Torosay (Mull), Laig Gorge (Eigg), Strathaird (Skye) and Allt Strollamus (Skye) are now cemented dark blue-grey limestones containing abundant coccoliths. Some of these limestones contain nannofossil assemblages indicative of an Early Campanian age (e.g. the nannofossils *Prediscosphaera serrata* Noël and *Micula staurophora* (Gartner) Stradner)).

From these studies a broad lithostratigraphy can be established. The succession begins with oyster (*Amphidonte*)-rich greensands at the base (Cenomanian, probably Mid-Cenomanian, in age) passing up through sandstones with the trace fossil *Thalassinoides*, and calcareous

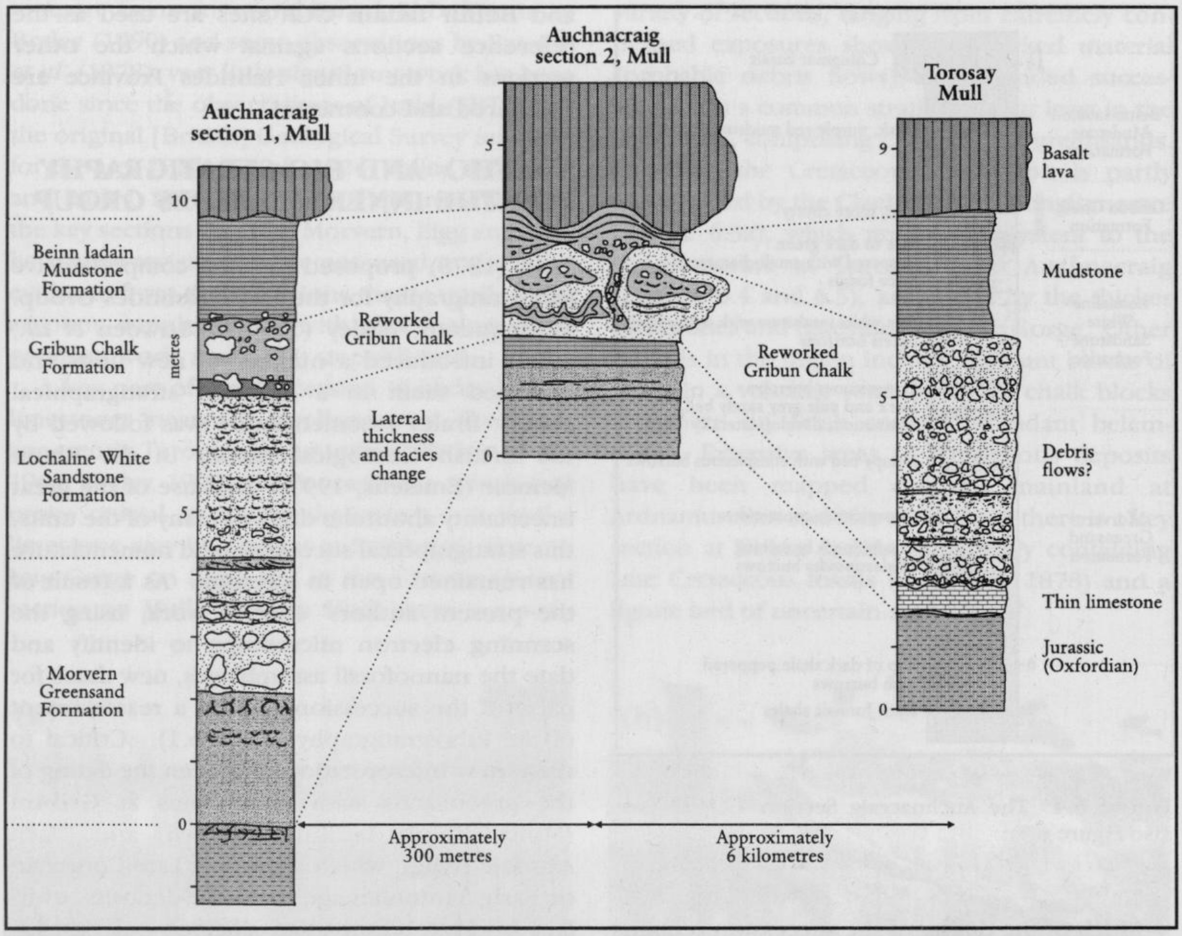


Figure 6.5 Lateral variation in the Upper Cretaceous stratigraphy on Mull illustrated by the Auchnacraig sections and the nearby Torosay section. These sections are near the Great Glen Fault. See also Figure 6.4 for notes on the beds.

concretions, immediately followed by oyster (*Rhynchostreon*)-rich beds with a special form of serpulid (the septagonal *Hepteris*) which, elsewhere in Europe, is typical of the shallow water sediments that equate with Jefferies' Bed 4 of the Plenus Marls Member. These serpulid and *Rhynchostreon* oyster-rich sands are overlain by the Lochaline White Sandstone Formation (probably Turonian–Coniacian in age) and then a greensand at the top with phosphates of latest Coniacian or Early Santonian age. Silicified chalks and limestones of Late Santonian–Early Campanian age follow and are in turn overlain by another phase of greensands containing reworked chalk and flint conglomerate. The final part of the succession contains mudstones, shales and lignites and possibly (as on Eigg), reworked earlier lava flows.

The GCR sites contain much of the evidence for this succession but lack the limestones rich in coccoliths. The localities with limestones on Eigg and Skye can be linked to the GCR sites to provide a more complete picture of the Inner Hebrides Group.

GRIBUN, ISLE OF MULL (NM 454 328–NM 451 332)

Introduction

It was the Gribun Chalk that caught the imagination when first recorded by Judd (1878). This startlingly white bed, close to the roadside in the Gribun 'boulders' (Figures 6.6 and 6.7), contrasts with the dark lavas of Tertiary age on the surrounding cliffs. Prior to Judd, the presence of Mesozoic rocks in this part of Scotland had been largely dismissed as irrelevant to Scottish

Table 6.1 The Upper Cretaceous Inner Hebrides Group Succession in Mull.

Succession after Braley (1990); Lowden *et al.* (1992);	More complete succession (Allt na Teangaidh)	Less complete succession (Torosay Track)	Variations Torosay Quarry	Variations Feorlin Cottage Carsaig
	Lava (presumed Tertiary)	Lava		Lava
Beinn Iadain Mudstone Formation	8. Mudstone (presumed Tertiary – possibly argillized ash); laterites	Mudstone	Top of section unknown	Mudstone with lignite
Clach Alasdair Conglomerate Member	7. Silicified pale sandstone with flint intraclasts (presumed Upper Cretaceous);	Flint conglomerate in sandy matrix showing evidence of debris flows	Flint conglomerate at the top	Flint conglomerate
Clach Alasdair Conglomerate Member	6. Silicified glauconitic greensand with flint clasts also piped down into or forming the matrix to the Gribun silicified chalk	Possible thin dark-grey limestone with planktonic foraminifera	Thick dark grey limestone in Torosay Quarry	Thick wedge of white sandstone on top of chalk conglomerate at Feorlin Cottage
Gribun Chalk Formation	5. The Gribun or Scottish Chalk, in places with hints of internal bedding, containing inoceramid shell debris bands, sponges etc. (the inoceramids are Cretaceous but may be reworked as silicified chalks into younger greensand; or the chalk may represent silcrete formation first in the Late Cretaceous, then the Tertiary?)	Resting on Rhaetic, Lias or Oxfordian	Resting on Oxfordian	Chalk conglomerate
	4. Glauconitic greensand with flint intraclasts			
Lochaline White Sandstone Formation	3. Pale buff sandstone (the White Sands)			Thick white sandstone
	2. Laminated and concretionary sandstone with oyster shell beds and *Thalassinoides* burrow bed			
Morvern Greensand Formation	1. Cenomanian greensand with marly units in expanded sections and containing Lower and/or Middle Cenomanian fossils. Basal pebble bed			
Unconformity	Upper Cretaceous resting on Lias or Oxfordian sediments			Base of section unknown

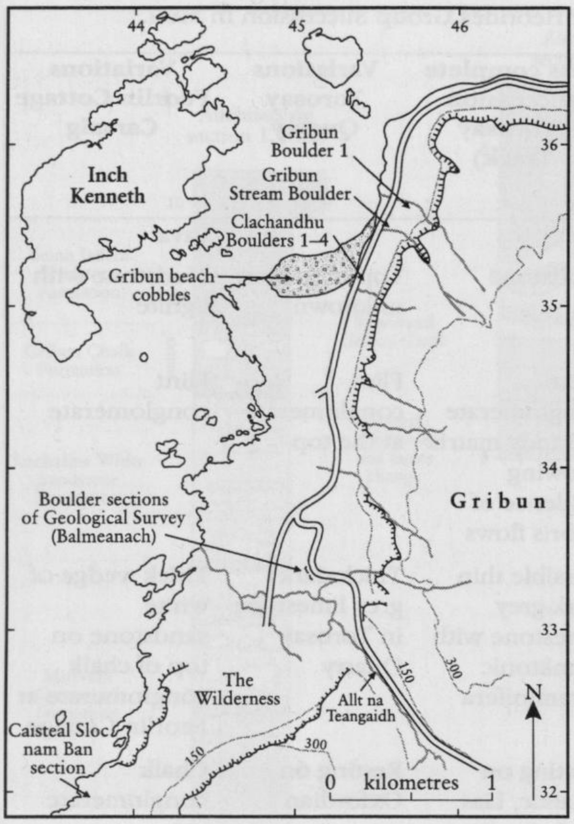


Figure 6.6 The Upper Cretaceous GCR sites at Gribun, Mull.

geology. It is now recognized that the history of movement on the major tectonic structures of the Highlands, the Great Glen Fault and the Moine Thrust–Camasunary Fault (Figure 6.2), has also to consider the evidence provided by the Upper Cretaceous rocks, especially at Gribun and the local network of sections on Mull.

Gribun is a relatively low-lying agricultural area of fields and pastures on Mesozoic sediments (mainly Triassic), with low sea cliffs and marine rock platforms to the west, contrasting with the vertical stark, black, Tertiary basalt cliffs forming the high ground to the east. Ancient landslips litter the base of the cliffs bringing down isolated remnants of the thin Cretaceous sediments, capped by basalts, to low levels adjacent to the road. The steep torrents flowing from the high plateau above sometimes bring down spreads of coarse debris (mostly boulder size) to cover some sections (fanglomerates). At other times the torrents erode into older fans revealing the underlying rock, providing generally small and incomplete sections. Some exposures recorded in earlier times, for example on the beach near Clachandhu, have remained buried for many years and have not been re-exposed (1998–1999).

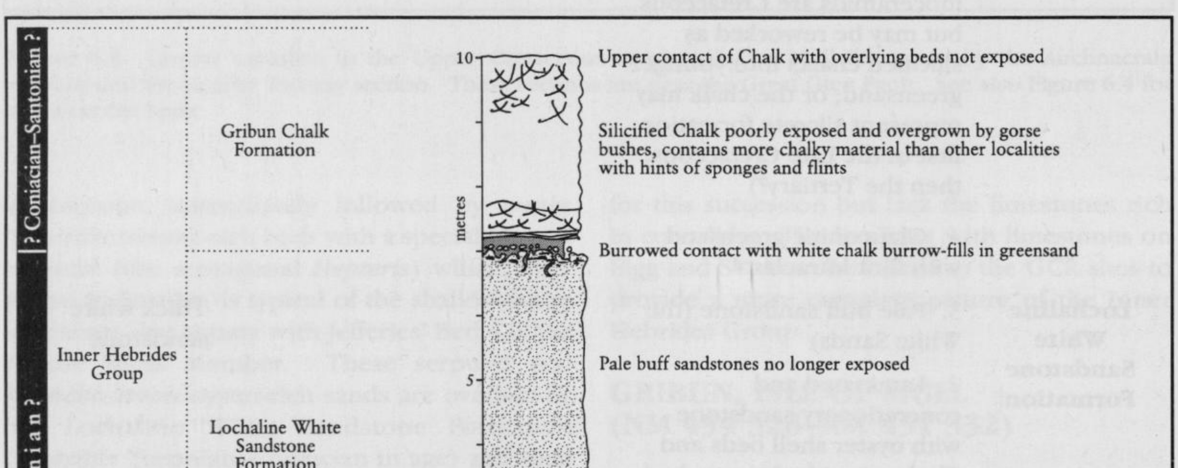


Figure 6.7 Gribun landslip section, (sometimes known as the 'Gribun Boulder' – Gribun Boulder 1, in the present volume).

The entire Gribun area has been selected for the GCR. The site includes the whole Mesozoic section, which comprises thin remnants of parts of the Trias, Jurassic and Upper Cretaceous deposits resting on Moine Schists. No Lower Cretaceous rocks have been recorded. The Upper Cretaceous succession occurs in four main groups of exposures; Group I, about 10 m thick, is at the northern end of the site in landslipped 'boulders' near Clachandhu (Figure 6.6). Group II is again in landslipped (but rolled) boulders adjacent to, and below, the road at Balmeanach. Group III is the most complete section, about 18 m thick, at Allt na Teangaidh, forming the walls of a narrow defile cut by a stream beneath the lavas. Group IV exposures of 'chalk' are present to the south, in The Wilderness, at Caisteal Sloc nam Ban (Figure 6.6).

Description

Judd (1878) was the first to recognize Upper Cretaceous deposits in the western Highlands and to describe the succession at Gribun. He additionally identified a section on the island of Inch Kenneth (Figure 6.6; Figure 6.15c, p. 450) where he thought Upper Greensand rested directly on his '*Poikilitic Series*' or Trias (1878, p. 732) and considered that the lower part, forming a conglomerate of quartzitic pebbles, was derived directly from underlying gneisses (Moine Schist). The upper part of the Upper Greensand comprised '...ordinary glauconitic sands' with abundant exogyrine oysters, serpulids and sponges characteristic of these beds that he regarded, on the basis of sections at Carsaig (Figure 6.1), as equivalent to the English Lower Chalk. Judd also recognized that the 'Scottish Chalk' was largely siliceous and '... crushed out from beneath the overwhelming masses of basaltic lava that cover all the secondary (i.e. Mesozoic) strata...'. Judd had thin sections of the siliceous chalk made and analysed by Professor T. Rupert Jones (in Judd, 1878, p. 739), who identified foraminifera (sample No. 4, poorly preserved *Globigerina*), inoceramid prisms and sponges. In particular, Judd emphasized the 'pseudomorphism' of the original calcareous chalk by silica. He was aware of Sorby's work, which had shown the extremely fine-grained, coccolithic nature of chalk (see Chapter 1). On the basis of an overview of the Scottish Chalk at many localities (see **Beinn Iadain** GCR site report, this volume), Judd equated this part of the succession with the Upper Chalk of England, particularly because of the presence of inoceramid prisms ('similar to beds around London at Charlton near Woolwich in the *Inoceramus*-zones', 1878, p. 739).

The [British] Geological Survey (Bailey *et al.*, 1924; Lee and Bailey, 1925) could not agree with Judd on the occurrence of Upper Cretaceous strata on Inch Kenneth, re-interpreting these as Triassic in age, but recognized his Upper Greensand and Chalk at several places within the Gribun GCR site. Bailey *et al.* (1924, pp. 56–7) considered much of the Chalk to be *remanié* Cretaceous and possibly of Tertiary age.

The exposures of Upper Cretaceous strata at the Gribun GCR site illustrate lateral change in the succession typical of the entire Inner Hebrides outcrop. The sections form discontinuous small exposures, mostly disturbed by landslipping, over a distance of some 6 km north to south. It is uncertain whether all the rocks described are Cretaceous in age or whether some of the reworked silicified chalk and flint conglomerate, sandstones and mudstones are Early Tertiary (Palaeogene) in age. It is also uncertain whether the first lavas are latest Cretaceous or earliest Palaeogene in age. There is, at present, no adequate field evidence or dating to determine the ages of all the rocks. The first lava flow throughout the area is conspicuously columnar jointed and is considered to be the same as the Staffa flow forming Fingal's Cave, which can be seen on a clear day from Gribun.

Lithostratigraphy

Group I exposures: the Gribun Boulder 1 (NM 457 357)

The first Gribun section is in low cliffs east of the road on the south side of the first steep mountain stream south of 'The Bungalow' (Figures 6.6 and 6.7). The stream passes in a culvert under the road debouching in the centre of the beach. This so-called 'boulder' is in fact a series of landslip masses, broadly retaining stratigraphical integrity and comprises four small exposures within one outcrop. The exposures are all uphill, some 50 m east of the road and the dip of all the strata exposed in these landslip masses is consistent and about 10°– 20° to the east. The first exposure nearest the stream is hidden under a mass of gorse bushes but can be dug out to reveal the basal contact of the Gribun silicified chalk with the underlying glauconitic and slightly phosphatic greensand. The contact appears to be burrowed with white 'chalk' occurring in lenses or millimetre diameter burrow-fills in the topmost greensand. It is a complex contact with some of the chalk appearing to be in the form of reworked fragments.

The upper beds of the Gribun Chalk Formation were overgrown at the time of writing and would require extensive excavation, but a mass of white 'chalk' is still visible some 15 m south and 5 m higher towards the crest-line of the landslip masses. This second exposure does not show the top contact of the Gribun chalk with the red mudstones above; this contact is seen best in the Gribun Stream Boulder and the Clachandhu Boulders (see below). Nevertheless, real sponge and burrow-replacement flints do seem to be present in this Gribun chalk exposure. There are also hints of other shell fragments including ghosts of silicified inoceramid shells, echinoid spines, and sponges such as *Porosphaera*. Part of the difficulty with interpretation is the intense fracturing of the chalk by a joint set (10 joints per 100 mm, trending east) and the degree of alteration (silicification) of the whole mass. Some fragments 'appear' to be quite chalky! There is a hint of a stratigraphy in the detailed structure (layers of dark black flaser marly wisps) and colour changes from dark grey to fawn to pale green upwards. Millet-seed sand grains fill the spaces between 'silicified chalk' fragments and are particularly evident in the fawn coloured and uppermost parts of the succession.

Below this highest chalk exposure, but not in a continuous section, is the third exposure, a sandstone block of medium to fine 'white' sands with oyster-shell debris bands and calcareous, weathered-out concretions. The fourth exposure or 'boulder' is the lowest and is also a sandstone, again not in a continuously exposed section with the higher blocks. This lowest exposure contains a conspicuous basal pebble bed of rounded quartz pebbles in a sandy micaceous bed, also containing oyster-shell bands. It is assumed that the last three exposures, from the uppermost chalk to the basal pebble bed, represent a continuous outcrop, albeit only partially exposed, and that measurements across the dip therefore, give a true thickness for the total section (Figure 6.7).

These four exposures together comprise the 'Gribun Boulder' section of Braley (1990) and were measured during the 1998 field season and re-checked in 1999.

Group I exposures: the Gribun Stream Boulder (NM 456 355)

A more complete, well-washed Gribun Chalk Formation section, with overlying red mudstones, is present in a large 'boulder' in the bed of the second mountain stream south of 'The Bungalow' (Figures 6.6, 6.8–6.11). This stream also runs under the road in a culvert and debouches onto the beach, carrying numerous blocks of the eroded, silicified Gribun Chalk Formation, which are spread across the beach at this point. The section is some 50 m upstream from the culvert. During the winter of 1998–1999 the stream power was sufficient to expose (or re-expose) this section, which was covered by boulders in 1998. The strata in the 'boulder' appears to dip in the same direction to the east at about the same angle as the other Group I exposures, suggesting that stratigraphical integrity has been retained.

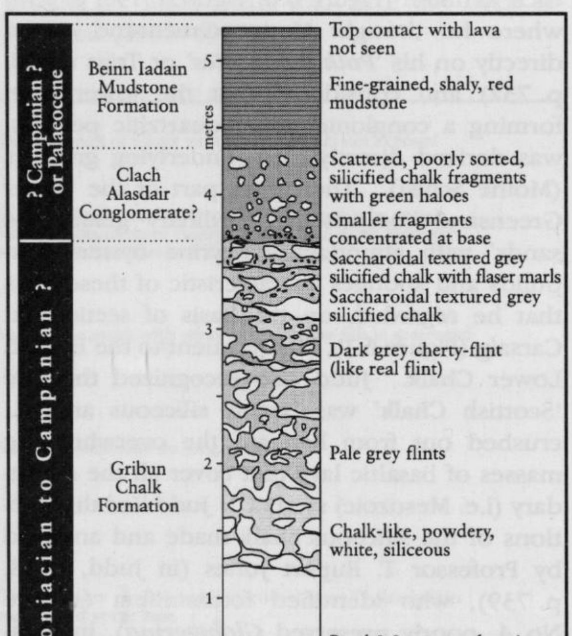


Figure 6.8 The stratigraphy of the Gribun Stream Boulder, which exposes beds stratigraphically above Gribun Boulder 1.

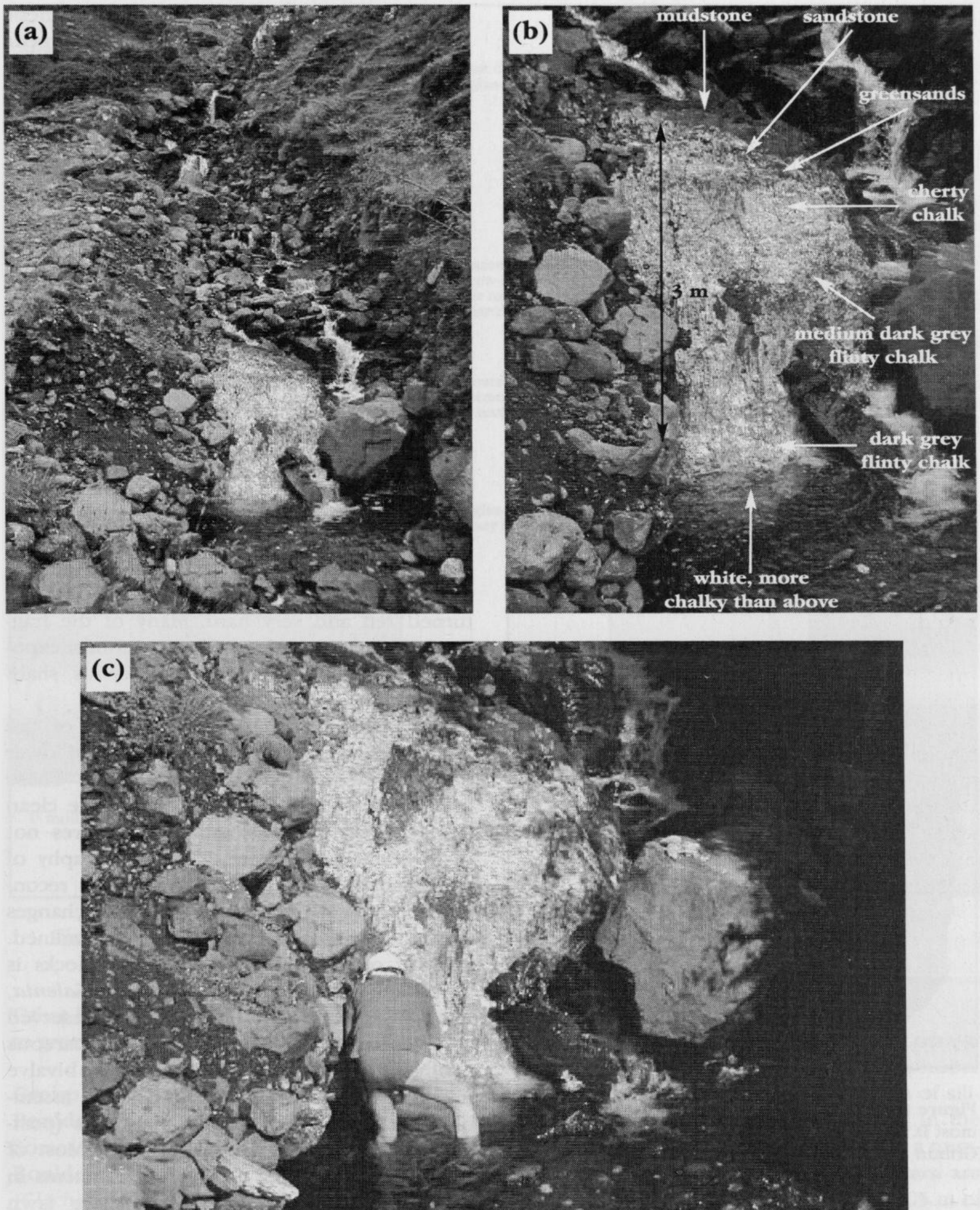


Figure 6.9 The Gribun Stream Boulder illustrating the stratigraphy of the Chalk and its contact with the overlying sandstones, conglomerate and mudstones. Note, on figure (b) the mudstone is altered, hard (red) and shaly; the sandstone is altered, hard and red, with flint/chalk conglomerate; the greensands have partly turned red forming a flaser structure in the topmost chalk; the cherty chalk is fawn-coloured with saccharoidal silicified, millet-seed sand-fills around the chalk; the dark grey flinty chalk looks like typical flint. (Photos: R.N. Mortimore.)

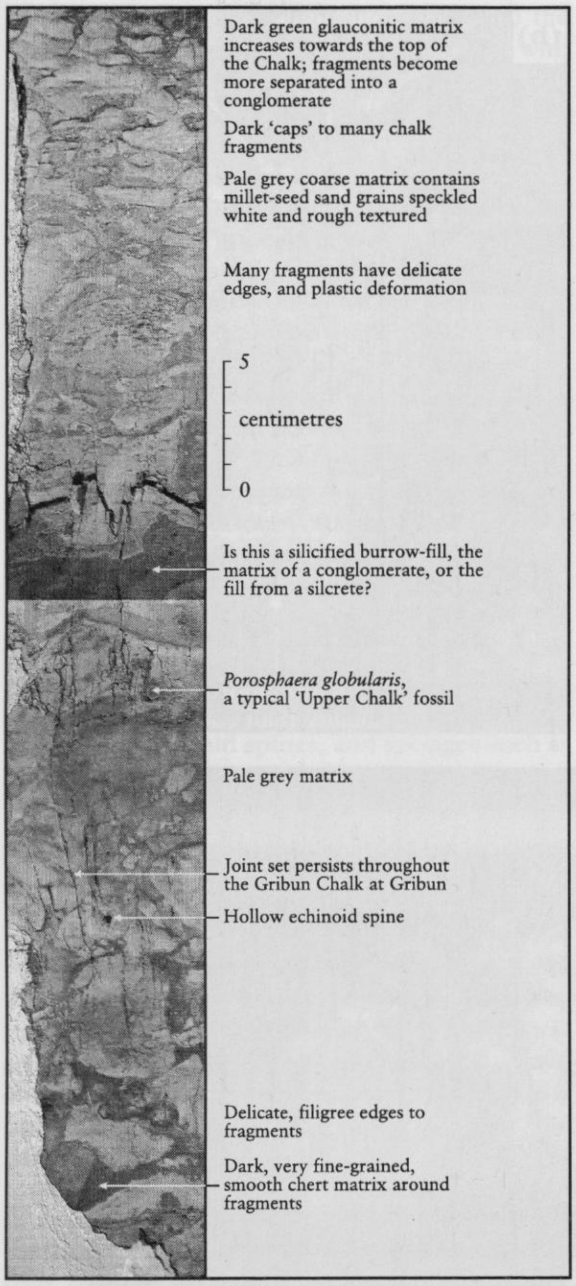


Figure 6.10 Cut slabs showing details of the uppermost 0.5 m of the Gribun Chalk Formation from the Gribun Stream Boulder, Mull.

When measured in July 1999 (Figures 6.8 and 6.9), the basal beds of chalk were underwater but some 4.0 m of Chalk and 1.0 m of red mudstones were recorded. As hinted at in the Gribun Boulder 1 description above, a stratigraphy within the Chalk is evident, based on changes in colour and fine structure. Again the intense, easterly striking joint set (10 per 100 mm) and the alteration/diagenesis make interpretation difficult. The basal beds exposed, (*c.* 0.50 m thick) were very 'chalk-like', being white and powdery. These grade upwards into pale grey, cherty chalk (0.75 m), then dark grey cherty chalk (0.4 m, like real flints), overlain by a 0.25 m thick bed of fawn coloured, saccharoidal cherty chalk. The saccharoidal structure is imparted by millet-seed quartz sand grains between the more cherty chalk with sponge flints, and the whole layer is silicified. This is overlain by a 0.20 m thick unit of silicified chalk with wavy interlacing dark marly wisps (griotte or flaser texture) with hints of fossil fragments in the marly wisps. The flaser layer grades up into a conglomerate of reworked silicified chalk fragments (size ranges from 130 × 50 mm to 10 × 5 mm and sand-size). Although poorly sorted, there is a crude reverse grading with the largest fragments forming a 100 mm-thick layer on top of the bed. There is then a 0.25-m thick layer of more scattered fragments (some rounded, some angular) in a sandy matrix, the whole turned red and very hard. Many of the fragments have green haloes. The uppermost exposure comprises 0.6 m of fine micaceous, shaly, red mudstone.

Many small boulders and pebbles of the Gribun Stream Boulder section are found lower down the stream bed and on the beach. These have been studied in detail because the clean fragments yield fossils and rock textures not easily studied elsewhere. The stratigraphy of the silicified chalk fragments is easily reconstructed once the stratigraphical colour changes in the main boulder have been determined. The list of fossils from these loose blocks is significant and includes the sea urchin *Salenia*, many long echinoid spines, well-preserved sponges including the globular calcareous sponge *Porosphaera*, inoceramid bivalve fragments and brachiopods. The total assemblage is indicative of a Late Cretaceous (post-Turonian), probably Santonian, age. Most of the fossils were found as silicified fragments in the dark flinty layer and the pale fawn saccharoidal layer. The textures in the silicified chalk illustrated typical burrow-replacement flint formation, especially in the darker beds, which included the trace fossil *Zoophycos*, suggesting that this succession was once a typical chalk-like deposit. Several boulders of the wispy, flaser-textured bed, in places stained deep red, confirm the presence of this texture.

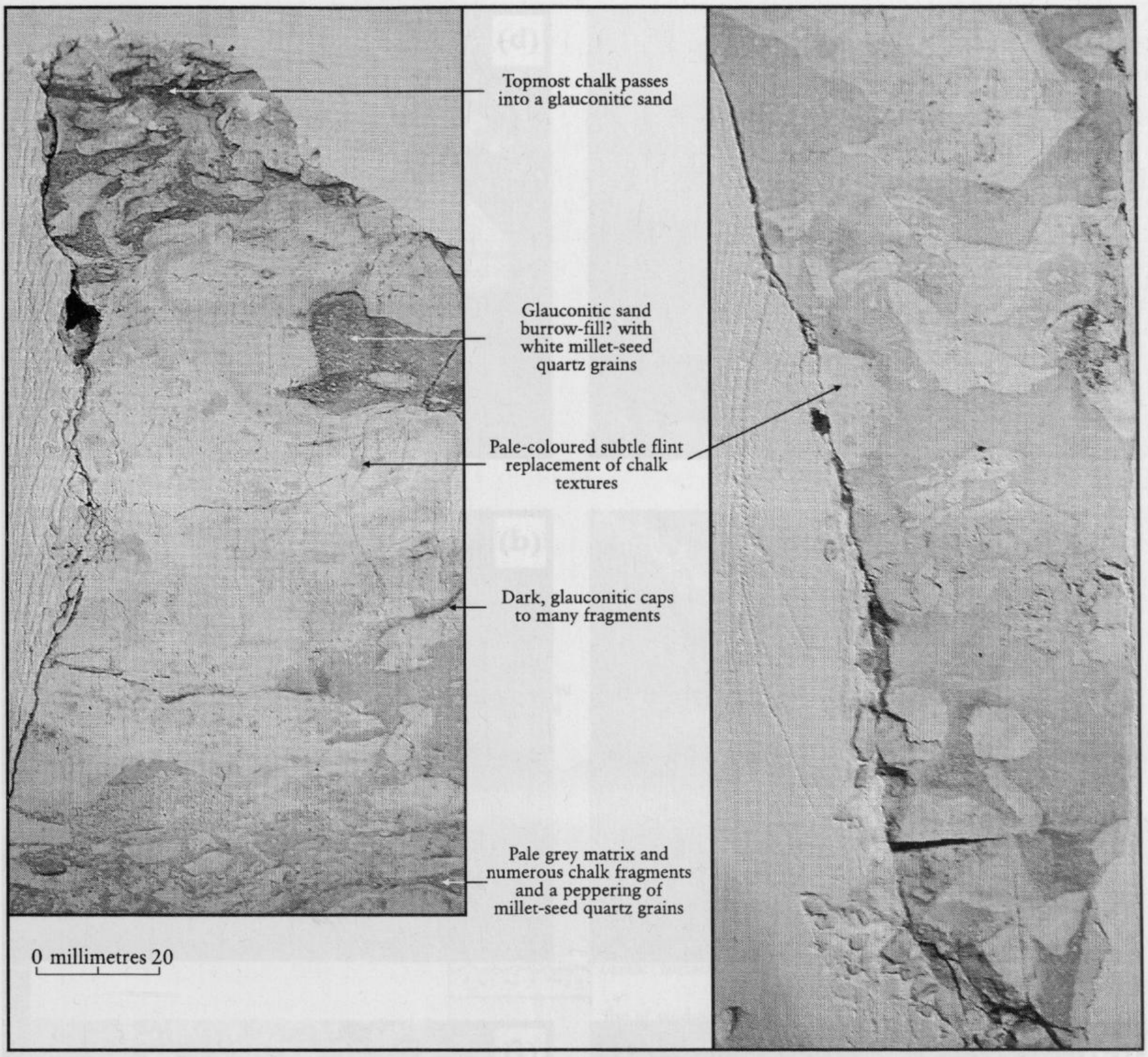


Figure 6.11 Second cut slab of the Gribun Chalk Formation from the Gribun Stream Boulder, Mull.

Other boulders include the change downwards to greensand at the base of the chalk.

Group I exposures: the Clachandhu Boulders

Some 200 m south of the Gribun Stream Boulder section is a holiday cottage (Clachandhu Cottage), behind and south of which, and only some 20 m east of the road, are three boulders of Gribun Chalk Formation (Figures 6.12 and 6.13), all with red mudstone on top of the Chalk. All of the Clachandhu Boulders show the same intense jointing seen in the Gribun Boulder 1 exposures and the Stream Boulder sections in the silicified chalk. The internal stratigraphy of the chalk in these boulders is also similar.

First Boulder behind Clachandhu Cottage (NM 4550 3533): This lichen-covered boulder (Clachandhu Boulder 1) exposes 1.05 m of silicified chalk in the lower part. Cavities in the middle of this section contain fossils, and a number of examples of the sponge *Porosphaera* are present as round, silicified balls. The 1.05 m of chalk is overlain by a 0.30 m unit of silicified chalk-conglomerate in a millet-seed, quartz-sand matrix. The matrix becomes a glauconitic greensand towards the top. Red, shaly mudstone (0.2 m preserved), rests on the greensand.

Second Boulder behind and just south of Clachandhu Cottage (NM 4550 3531): The base of the Second Boulder (Clachandhu Boul-

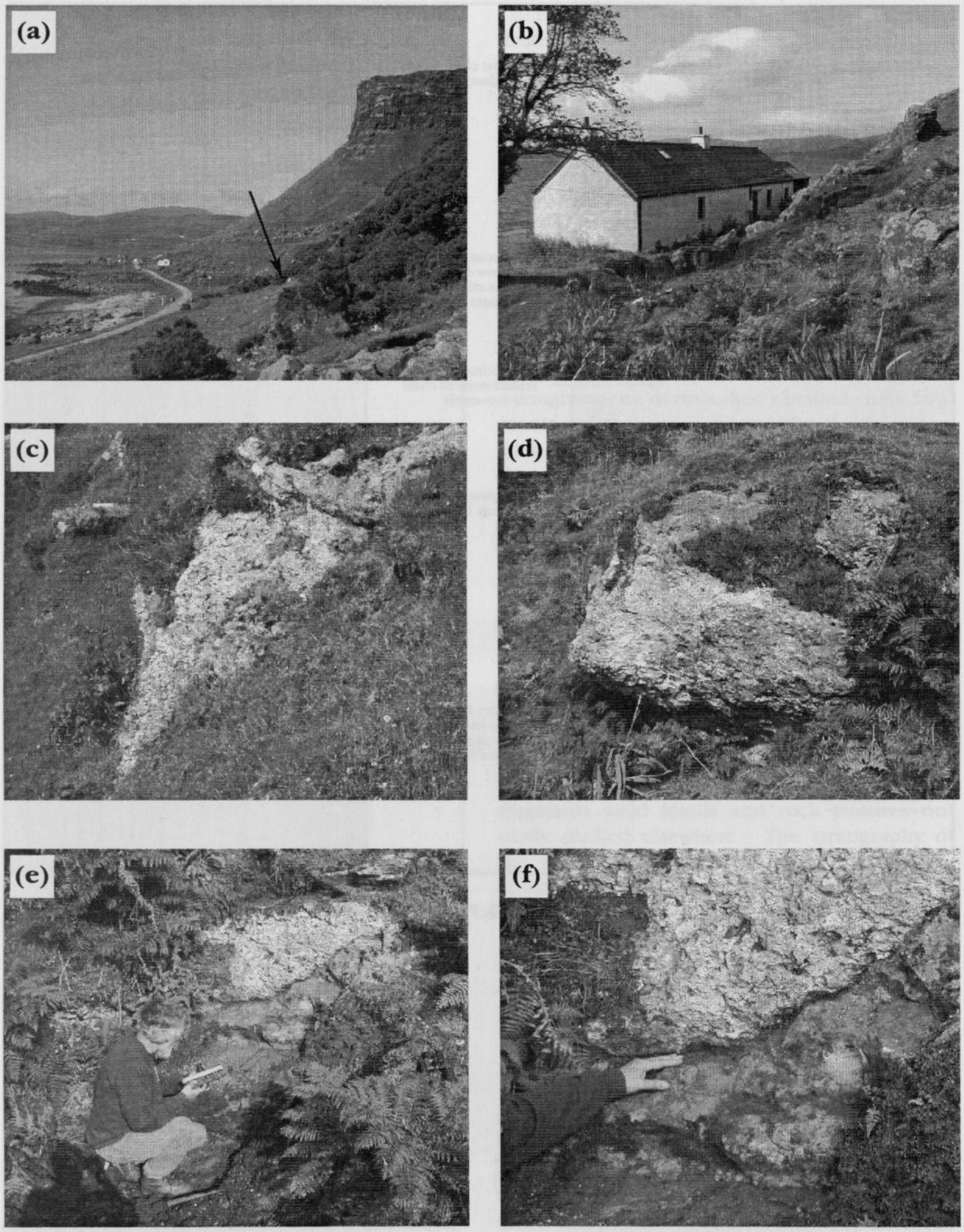


Figure 6.12 Group I exposures. (a) Northern end of Gribun Boulder 1 (arrowed). (b–f) The Clachandhu Boulders, behind Clachandhu Cottage, at the northern end of Gribun, Mull; (b) Clachandhu Cottage, with the Clachandhu Boulders behind; (c) The First (northernmost) Boulder (Clachandhu Boulder 1), immediately behind cottage; (d) the Second (central) Boulder (Clachandhu Boulder 2) showing the Chalk–red shale contact; (e, f) The Third (most southerly) Boulder (Clachandhu Boulder 3), adjacent to fence showing the contact between greensands and silicified chalk. (Photos: R.N. Mortimore.)

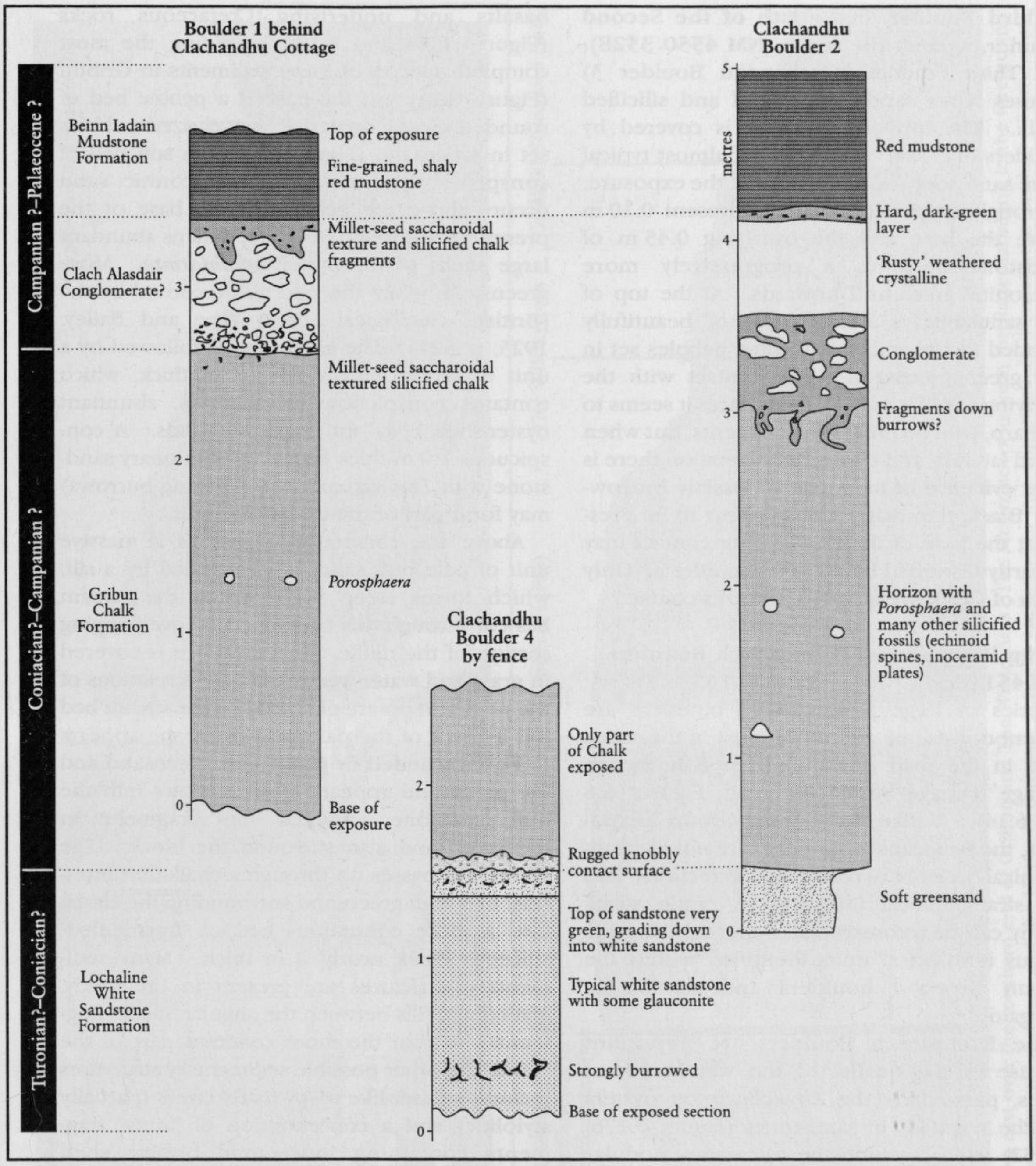


Figure 6.13 The stratigraphy of the Clachandhu Boulders at Gribun, Mull. Details of the beds are not as clear as in the Gribun Stream Boulder.

der 2) is heavily undercut by weathering, possibly representing a softer chalky layer. Above this softer unit is 1.10 m of silicified chalk with *Porosphaera* in the middle part and other unidentified fossil fragments in the lower half. The top of the silicified chalk appears to contain a wispy, marly (flaser) layer, and to be burrowed, with debris and fragments from the overlying conglomerate filling the apparent burrows. The conglomerate is about 0.2 m thick, overlain by a rusty-weathered crystalline bed, 0.25 m thick, with a 0.03 m thick, hard greenish bed at the top, followed upwards by 0.30 m of red, shaly mudstone.

Third Boulder, just south of the Second Boulder, against the fence (NM 4550 3528): The Third Boulder (Clachandhu Boulder 3) exposes white sands, greensand and silicified Chalk. The top of the Chalk is covered by boulders of basalt. A thin bed of almost typical white sandstone forms the base of the exposure. A strongly burrowed surface is present 0.10 m above the base and the overlying 0.45 m of sandstone becomes a progressively more glauconitic greensand upwards. At the top of this sandstone is a thin layer of beautifully rounded quartz grains with some pebbles set in very green greensand. The contact with the overlying Chalk is not clear. In places it seems to be sharp, with no mixing of sediments, but when traced laterally and cleared of vegetation there is some evidence of mixing and possible burrowing. Black, thin marly wisps appear to be present at the base of the Chalk. The contact may be partly disturbed by the landslip effects. Only 0.5 m of Chalk is exposed above this contact.

Group II exposures: Balmeanach Boulders (NM 451 333)

A series of large air-weathered boulders are present downslope and to the west of the sharp bend in the road downhill from Balmeanach Cottage (cottage beside the road, Figures 6.6 and 6.14). Unlike the Gribun Group I exposures, the Balmeanach Boulders are not in stratigraphical order, have rolled in all directions, and lack stratigraphical integrity. A crude stratigraphy can be reconstructed by recognizing the various lithological units identified within the Gribun Group I boulders and at Allt na Teangaidh.

The Balmeanach Boulders are important because of the quality of the weathered-out fossils, particularly the *Rhynchostreon* oysters and the serpulids in sandstones (Figure 6.17b, p. 452) which include the calcareous nodular and conspicuous *Thalassinoides* trace fossil beds. No Chalk boulders are present but the evidence for the continuation of these sandstones beneath the Chalk in the wider Gribun area is useful.

Group III exposures: Allt na Teangaidh (NM 453 328)

The mountain stream called Allt na Teangaidh runs across the basalt lava plateau towards the north-west, parallel to the road. At the edge of the plateau it cuts a narrow defile through the basalts and underlying Cretaceous rocks (Figures 6.14 and 6.15), providing the most complete section of these sediments in Gribun (Figure 6.16). At the base is a pebble bed of rounded mostly quartzitic, gravel-sized pebbles set in greensand (Figure 6.17a). A soft bed of conspicuously dark green, glauconitic sand occurs above the pebbles at the base of the present exposure (1998) and contains abundant large shells of the oyster *Amphidonte*. More greensand below this bed was recorded by the [British] Geological Survey (Lee and Bailey, 1925, p. 121). The greensand is followed by a unit of sandstone, nearly 1.0 m thick, which contains conspicuous laminations, abundant oyster-shell beds and many serpulids. A conspicuous 1.0 m thick bed of concretionary sandstone with *Thalassinoides* (branching burrows) may form part of the underlying unit.

Above the concretionary bed is a massive unit of pale buff sandstone, intruded by a sill, which forms steep walls where the stream has cut through this narrow, partly overhanging section of the defile. The exposure is covered in grass and water-weeds. The field relations of the next unit up are obscured by the stream bed but a block of the pale buff sandstone appears to be surrounded by glauconitic greensand and the greensand appears to fill burrows into the buff sandstone. Angular 'flint' fragments in the greensand also surround the block. The greensand passes up through a chalk-flint intraclast bed with greensand surrounding the clasts, into a more continuous bed of 'fragmented' siliceous chalk nearly 2 m thick. Many sedimentary structures are present in the sandy, glauconitic fills between the angular 'chalk' fragments. Within the more coherent part of the 'chalk' are other possible sedimentary structures including flaser-like wispy marly layers (partially stylolitic) and a concentration of 'flinty' fragments containing inoceramid bivalve shell debris.

A thin greensand unit (about 0.2 m thick) overlies the chalk and is partly piped down into the top of it. This layer also contains 'flint' intraclasts and these continue upwards into a bed of pale sandstone (millet-seed sands?). The final complex unit beneath the lavas contains two beds (Figure 6.16), the first in the stream bed is a dark purple unit of fine mudstone(?) with orange-stained joints, and this is overlain by a paler purple bed, possibly a mudstone or a volcanic tuff.

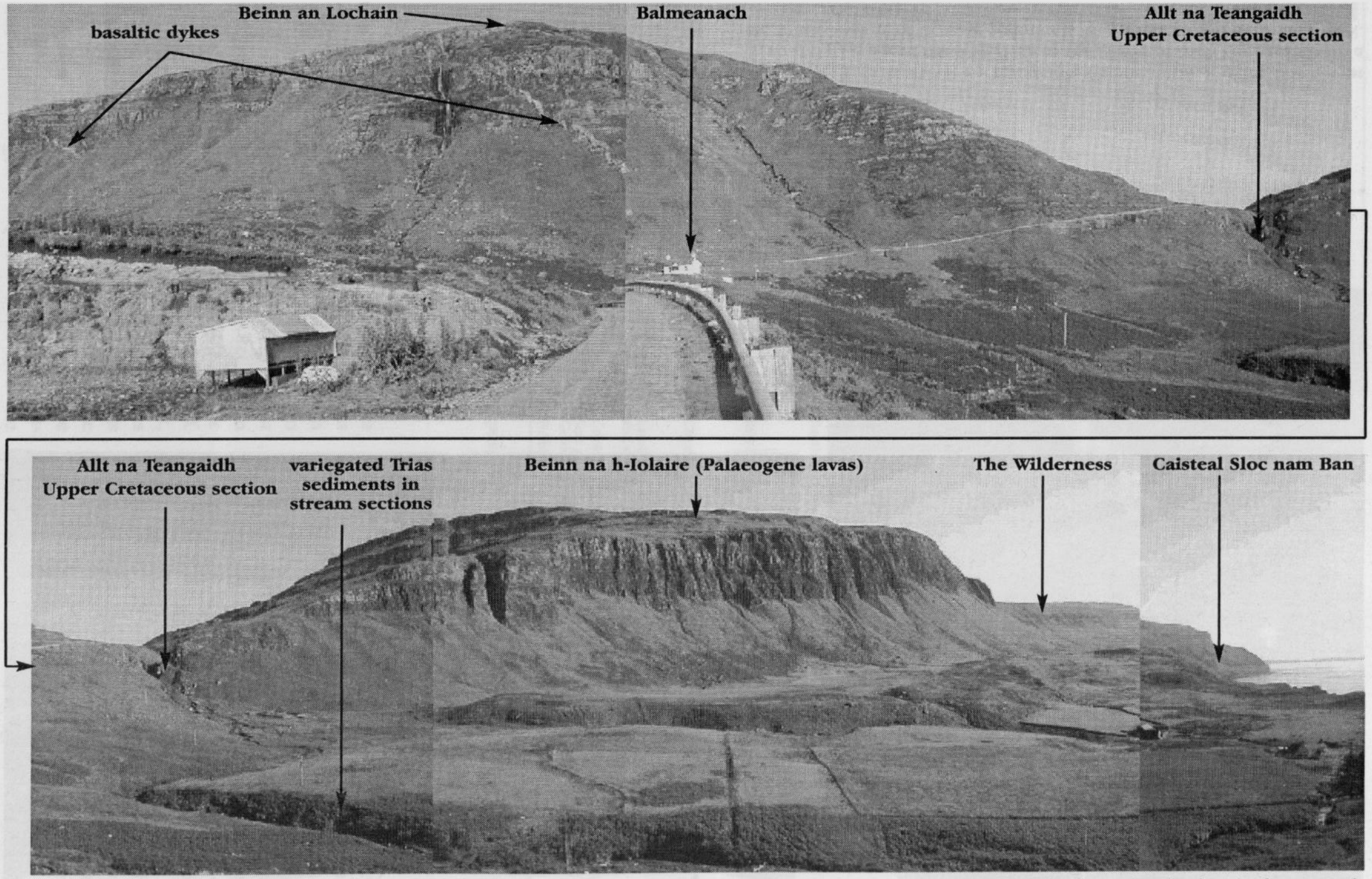


Figure 6.14 Panoramic view looking east over the southern end of Gribun and The Wilderness. The Mesozoic rocks form the flatter farmland in the foreground. Tertiary basaltic lavas form the high crags and plateaus and the Upper Cretaceous deposits are found in intermittent slivers beneath the basalts. (Photomosaic: R.N. Mortimore.)

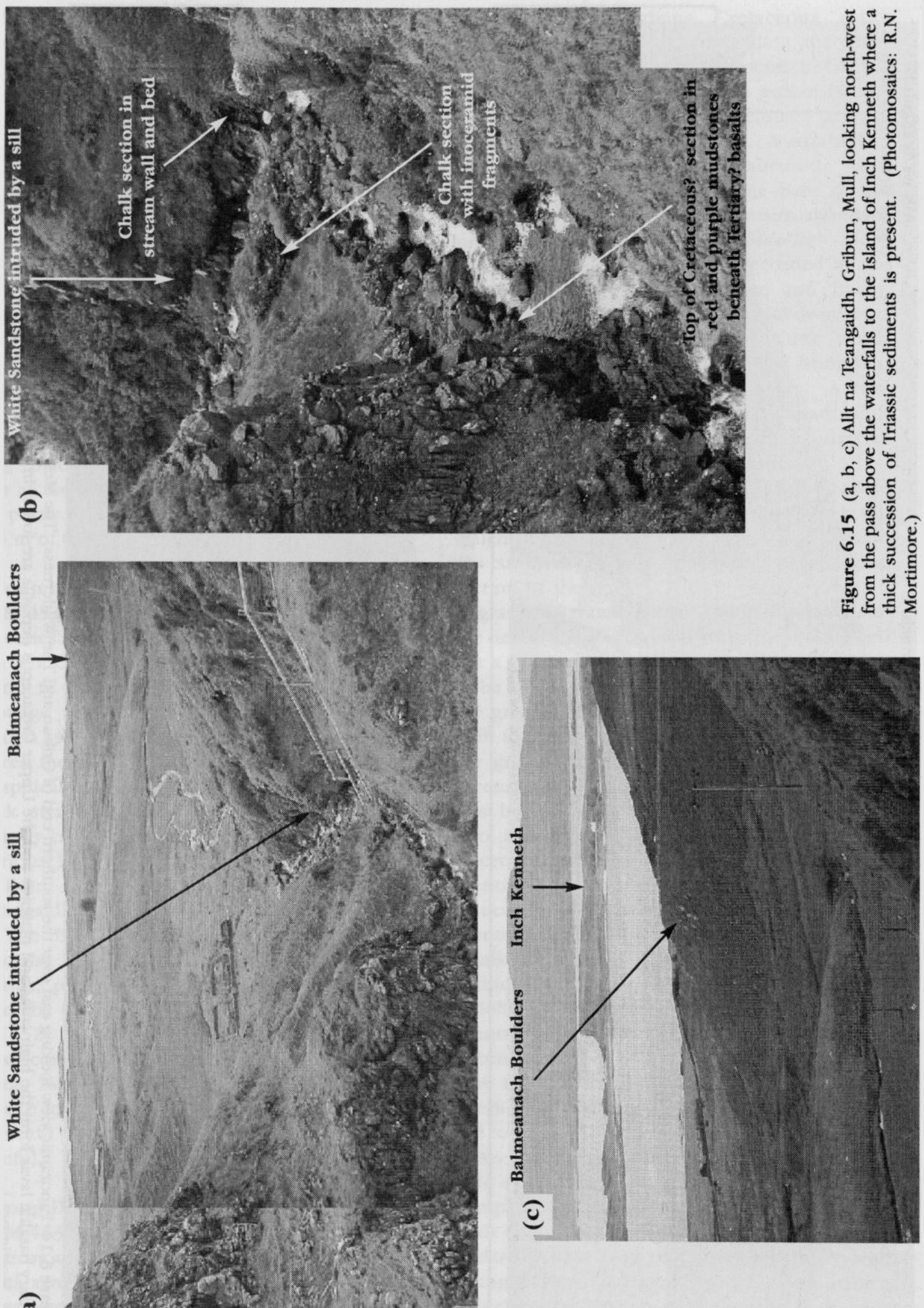


Figure 6.15 (a, b, c) Allt na Teangaidh, Gribun, Mull, looking north-west from the pass above the waterfalls to the Island of Inch Kenneth where a thick succession of Triassic sediments is present. (Photomosaics: R.N. Mortimore.)

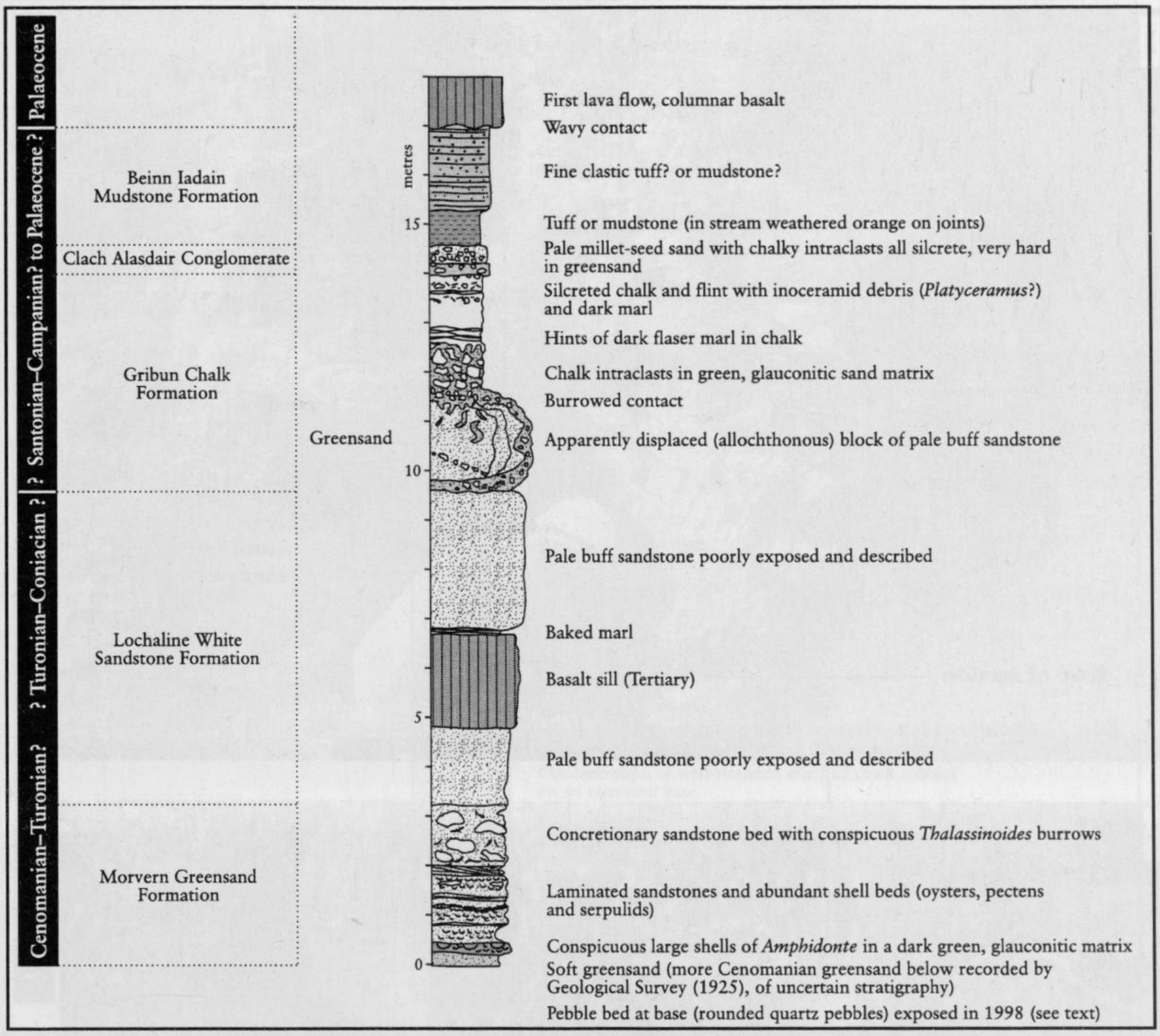


Figure 6.16 The Gribun Group III exposures, Allt na Teangaidh stream bed, Mull.

Group IV exposures: Caisteal Sloc nam Ban (NM 431 312)

A long walk from Balmeanach Farm south through The Wilderness (Figure 6.14), past McKinnon's Cave, leads to a stream section with several waterfalls. The best route is to keep to high ground and not follow the cliff top. Just south of McKinnon's Cave is a fine section in Triassic rocks where several streams join before forming a spectacular waterfall over the sea cliff. Equally spectacular sills and dykes are present, cutting through the sediments. This location is best identified by the two huge gullies or clefts in the basalt cliffs, forming the backwall to The Wilderness, down which the streams tumble from the plateau above. There are no Cretaceous or Palaeogene deposits here and the Caisteal Sloc nam Ban section is about one kilometre farther south.

In contrast, the Caisteal Sloc nam Ban section comprises only one stream emanating from the plateau above. Below the point where the stream falls over the lowest of the basalt lavas there is a wet, weed- and algal-covered stream-bed section, partially buried by boulders, revealing a 2 m thick flint conglomerate of red and green coloured 'real' flint cobbles and pebbles set in a very hard, cemented matrix. This flint conglomerate is separated by some 20 m from the next exposure below (Figure 6.18) by the boulder-strewn stream-bed. The stream then crosses coarse- to medium-grained, cross-bedded white sandstone that also forms the lip of the next waterfall (Figure 6.18). In the

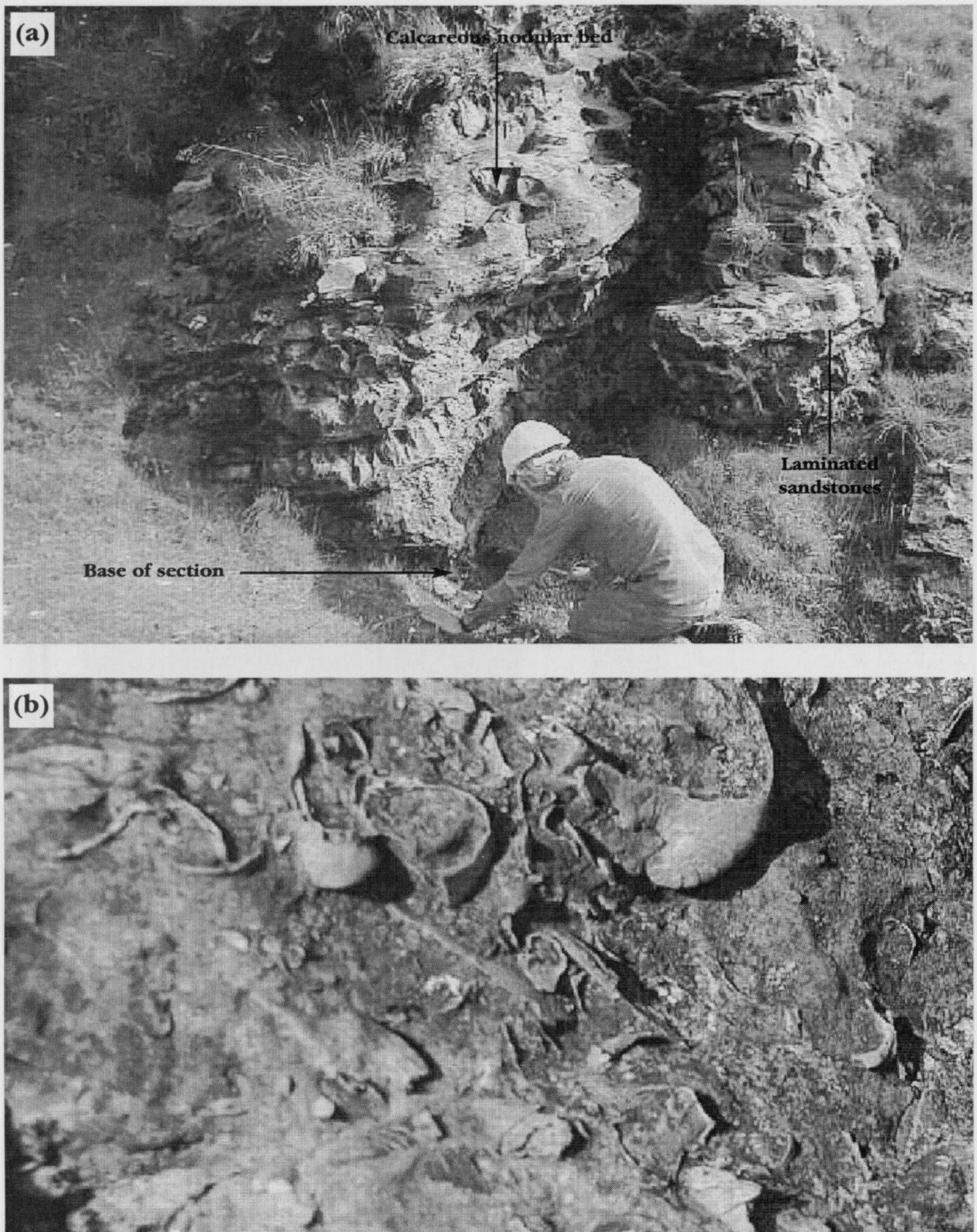


Figure 6.17 Details from the Gribun sandstones. (a) Base of the Allt na Teangaidh section; greensands pass up into laminated beds and the calcareous nodular bed. (b) Abundant *Rhynchostreon* oyster horizon in a Balmeanach sandstone boulder. (Photos: R.N. Mortimore.)

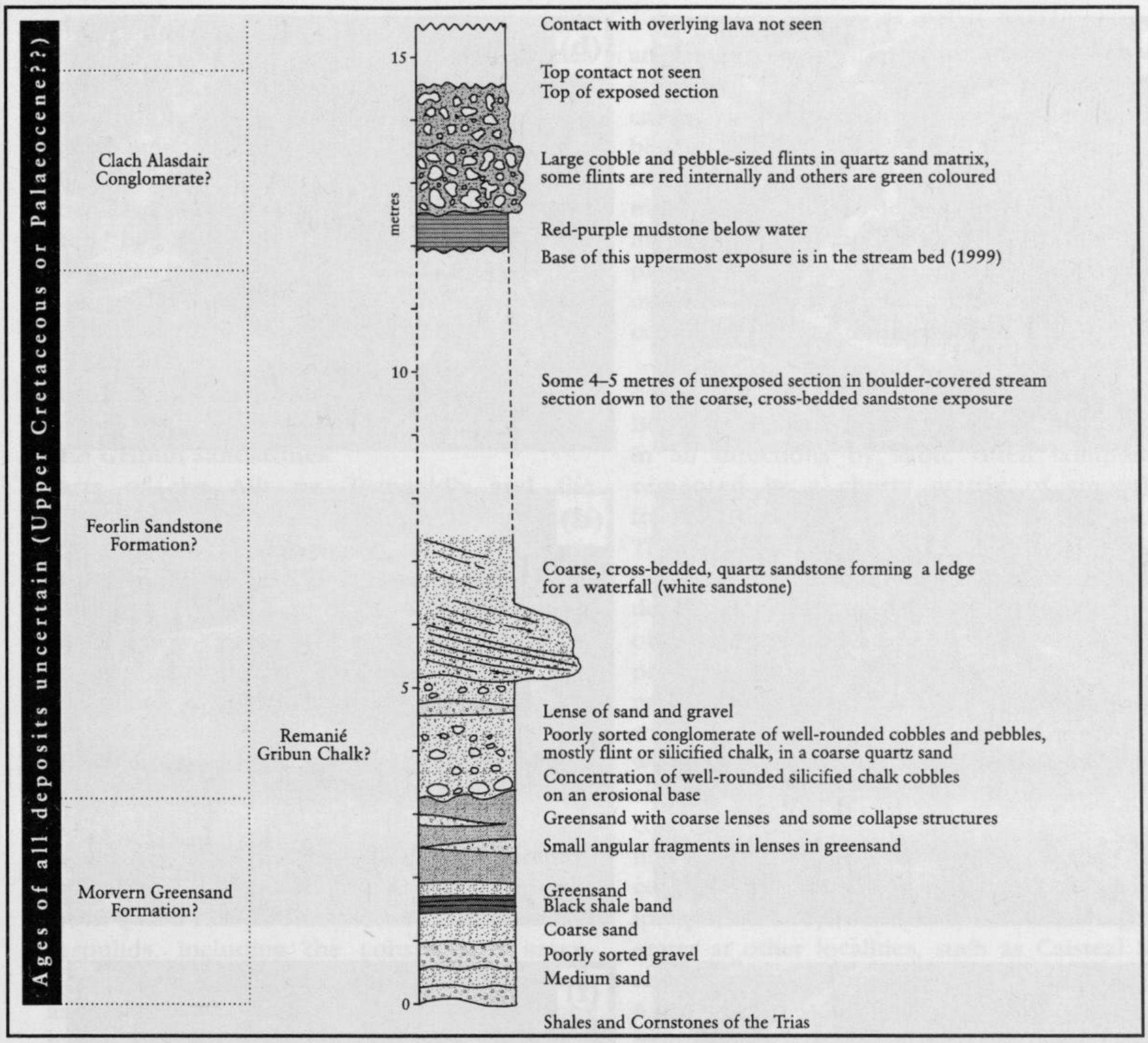


Figure 6.18 The Caisteal Sloc nam Ban section in The Wilderness, Mull. Section drawn as a weathered profile of the rock exposure, not as a sedimentological grain-size profile.

undercut beneath the waterfall is a spectacular chalk conglomerate comprising lenticular lenses of chalk fragments with quartz pebbles, interbedded with coarse sand and gravel lenses (Figure 6.19). Beneath the chalk conglomerate is a 1.40–1.50 m thick greensand with thin wedge-shaped lenses of coarser white chalk fragments, underlain by two black shale seams. Below these shale seams are greenish-coloured Triassic coarse sandstones with lenses of white fragments that are derived from the Triassic cornstones.

The whole of the conspicuous chalk conglomerate forms a lense half a metre thick on the south bank of the stream and two metres thick on the north side.

Biostratigraphy

There are no diagnostic macrofossils recorded from any of the Gribun sections but the large *Amphidonte* in the basal greensands at Allt na Teangaidh suggest a (Middle?) Cenomanian age for these lowest beds (see discussion below). Serpulids within the basal beds of the Lochaline White Sandstone Formation suggest a Late Cenomanian Plenus Marls Bed 4 age. Nannofossil evidence from the silicified chalks in the Gribun Stream Boulder suggests a possible Santonian–Early Campanian age for at least part of the Gribun Chalk Formation. This dating is supported by the record of the benthic foraminifera *Gavelinella thalmanni* (Brotzen)

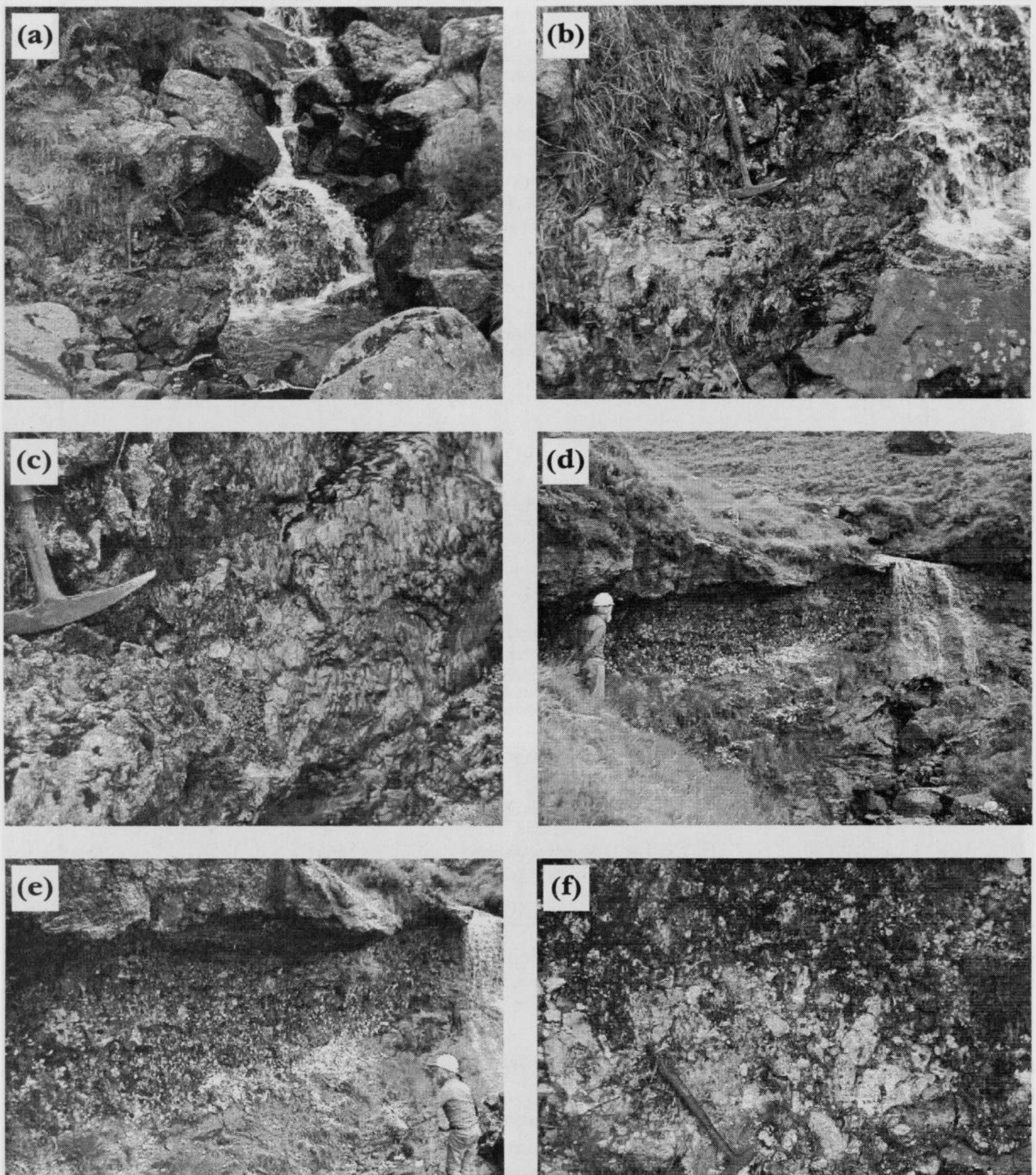


Figure 6.19 The most southerly Upper Cretaceous? or basal Palaeocene section in Gribun at Caisteal Sloc nam Ban, Mull, showing two conglomerates separated by a thick 'white', millet-seed sandstone unit. The lower conglomerate is a mixture of silicified chalk fragments and well-rounded quartz pebbles and cobbles, all poorly sorted, and containing sand/gravel lenses. The upper conglomerate is primarily composed of flints including red flints. (a, b, c) Upper section beneath Tertiary basalts, the poorly sorted flint conglomerates including red and green coloured flints. (d, e, f) Lower section with the waterfall on the white sandstone and the under-cut section in a silicified chalk quartz sand and gravel deposit, which thickens in a wedge from beyond the waterfall towards the geologist. Many Upper Cretaceous fossils are present in the reworked chalky material. (Photos: R.N. Mortimore.)

and *Stensioeinena exsculpta gracilis* Brotzen (Rawson *et al.*, 1978 p. 56). These two species both have a late Santonian–Early Campanian range but their co-occurrence points more to an Early Campanian date (H. Bailey, pers. comm., 2001). On this evidence, the main mass of the Lochaline White Sandstone Formation would then be latest Cenomanian, Turonian or Coniacian in age.

It would not be possible to interpret the Gribun sections, fully or reliably, without comparing them with sections elsewhere on Mull and on the mainland in Morvern.

The Gribun sandstones

Parts of the Allt na Teangaidh and the Clachandhu Boulder sections can be correlated with sections at Carsaig on the south coast of Mull (Figure 6.27, p. 462, Figure 6.34, p. 471). Greensands at the base of the sections containing probably Cenomanian age *Amphidonte* are common to both areas. At Carsaig (Figure 6.20), a number of exposures (Figures 6.21–6.25) show great variation in thickness and structure of the greensands. In the big coastal cliff localities towards Malcolm's Point, rhythmically bedded marly layers interbedded with greensand bands, are packed full of shells and common unspecified ammonites. Oyster-shell debris layers in quartz-rich pale sandstones with abundant serpulids, including the conspicuous seven-sided serpulid, *Hepteris*, are also present in both areas, overlain by the concretionary sandstone with conspicuous *Thalassinoides* burrows. Fallen boulders near Rubh' a' Chromain contain spectacular weathered-out burrows (Figure 6.3). The overlying pale-buff sandstone forms a conspicuous feature in the cliffs at Carsaig (Figures 6.25 and 6.26a) and is similar in appearance to the Allt na Teangaidh exposure at Gribun. The age of this unit is uncertain.

The Gribun Chalk Formation

The Caisteal Sloc nam Ban section is crucial in interpreting the Gribun Chalk Formation. This most southerly exposure in the Gribun shows the silicified chalk as a complex of intraclasts set in a sandy (in places, greensand) matrix, resting on greensands that in turn rest on the Rhaetian succession. Bailey *et al.* (1924), described this exposure as *remanié* Cretaceous and it appears to be a reworked 'mélange' of material (Figure 6.19). Traced northwards, the Chalk appears to be a more competent unit at Allt na Teangaidh, with possible internal sedimentary structures and inoceramid shell beds, but sands and greensands still occur as piped-down, or let-down, cavity-filling laminations between the silicified blocks. In the Clachandhu Boulders the Chalk is still a fragmented mass of peculiar silicified fragments, but contains less sand, and could be interpreted as either in-situ chalk silicified in place (a possible silcrete) or as a reworked mélange with very little matrix (further discussed in the final interpretative section).

Bailey *et al.* (1924, pp. 55–6) gave a graphic description of the chalk of the Clachandhu Boulders section; '...silicified chalk is traversed in all directions by sand, often completely cemented by a cherty matrix of smoother fracture than that replacing the chalk itself...'. This was a crucial locality for Bailey, providing evidence for him of in-situ silicification in desert conditions (a silcrete that he related to observations made on current silicification processes in the Kalahari Desert). This interpretation was supported by the presence of well-rounded quartz grains of 'millet-seed' sand, which he considered characteristic of desert conditions. The reworking of chalk as a 'flint-conglomerate' at many localities suggested to him that silicification had occurred in the Cretaceous Period. Bailey *et al.* (1924, pp. 56–7), interpreted many of the reworked flint conglomerates at other localities, such as Caisteal Sloc nam Ban and Auchnacraig (Loch Don) (Figures 6.1, 6.4 and 6.5), as *remanié* Cretaceous set in a matrix of Early Tertiary deposits. They considered silicification of these conglomerates on top of the Chalk at Carsaig and Loch Don to have resulted from continuing desert, silcrete-forming, conditions in Early Tertiary times. These are challenging ideas that need to be considered alongside the causes of reworking and the presence of mudstones and lignites in the beds above the Chalk (see below).

The Gribun mudstones

The chalk at Gribun is succeeded by further thin sandstone units with silicified chalk intraclasts (angular), followed by a mudstone unit. The origin of this mudstone is controversial. It could represent a deeper-water clastic phase as a result of subsidence, or could be due to argillization of tephras following earliest volcanic activity in the area (Bailey *et al.*, 1924, p. 59). Pre-eruption thermal doming may have developed local limestone (chalk) platforms and

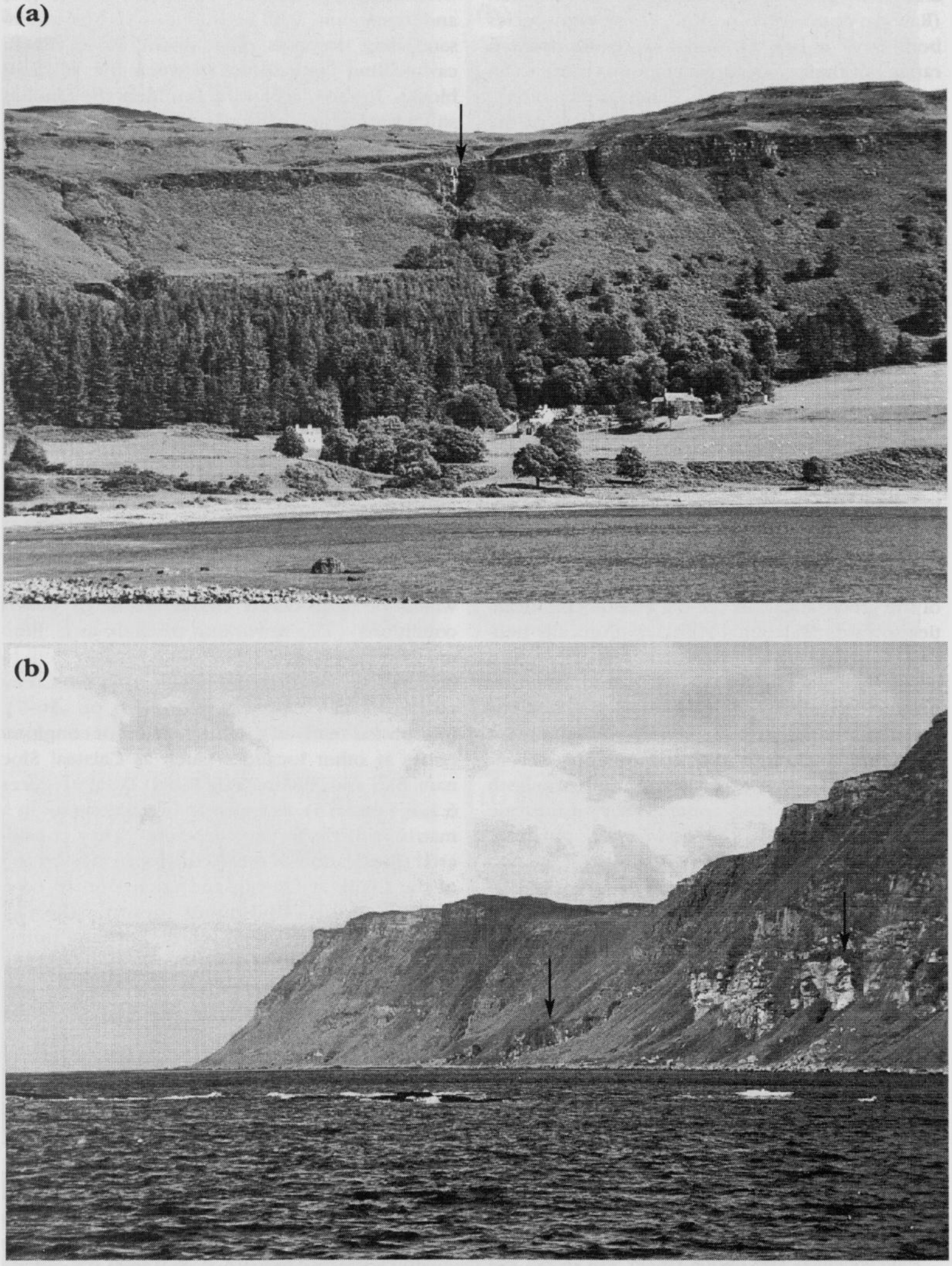


Figure 6.20 Two views of the Carsaig sections. (a) Sections above Carsaig House include the waterfall (arrowed). (b) Upper Cretaceous sections (arrowed) north-west of Carsaig beneath basalts and above Jurassic sandstones and shales. (Photos: R.N. Mortimore.)

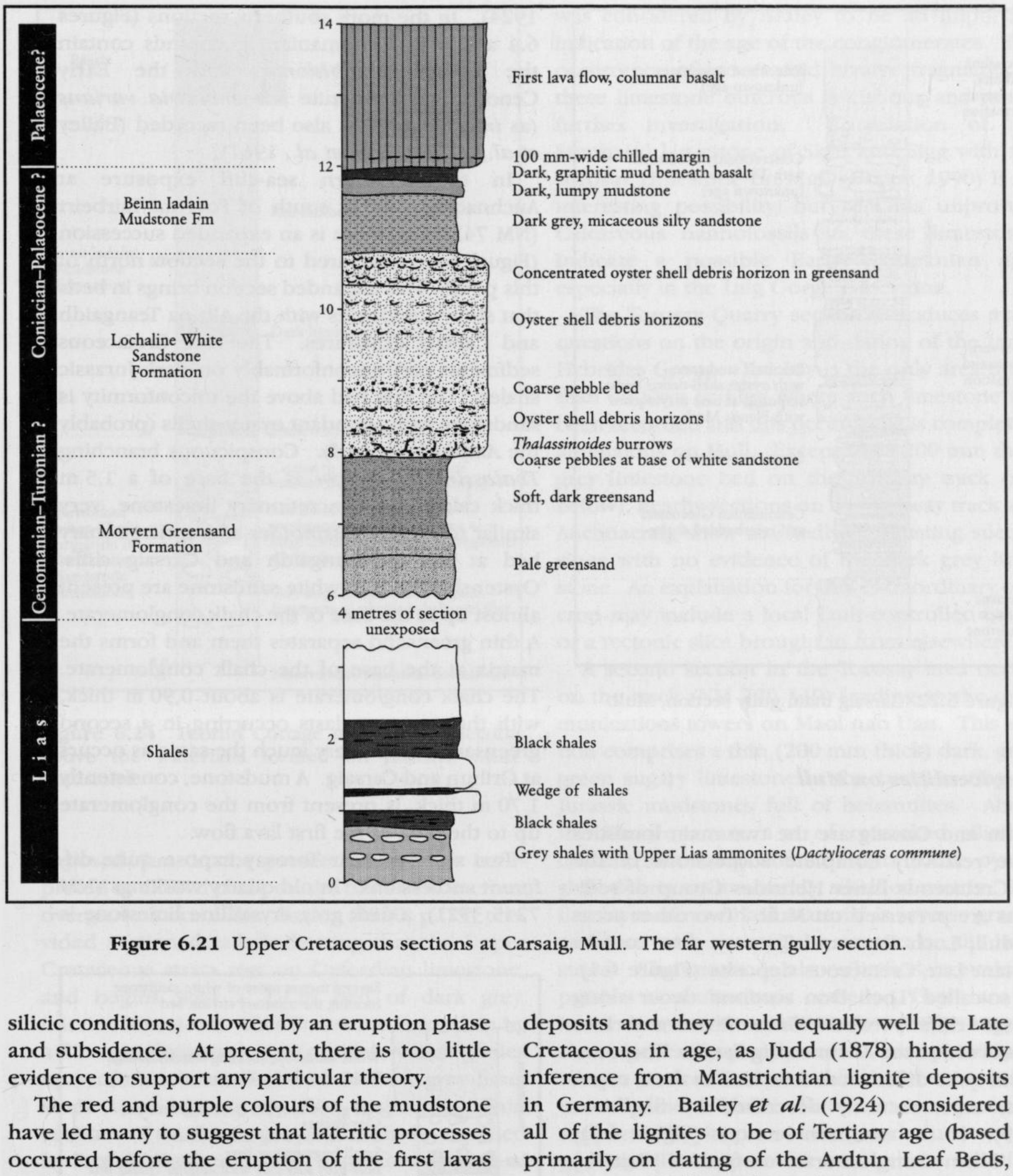


Figure 6.21 Upper Cretaceous sections at Carsaig, Mull. The far western gully section.

silicic conditions, followed by an eruption phase and subsidence. At present, there is too little evidence to support any particular theory.

The red and purple colours of the mudstone have led many to suggest that lateritic processes occurred before the eruption of the first lavas (Judd, 1878; Bailey *et al.*, 1924; Lee and Bailey, 1925).

Lignite beds

At Carsaig there are lignite beds apparently interbedded with the earliest lava flows but also possibly beneath the lavas. These lignites locally form bright coals, seen as fallen blocks on the beach. The lignites are generally presumed to be Early Tertiary in age although there has been no satisfactory dating of these deposits and they could equally well be Late Cretaceous in age, as Judd (1878) hinted by inference from Maastrichtian lignite deposits in Germany. Bailey *et al.* (1924) considered all of the lignites to be of Tertiary age (based primarily on dating of the Ardtun Leaf Beds, south-west Mull) and used the presence of lignites to suggest that warm moist conditions predominated. Recent results from dating the Ardtun Leaf Beds and other lignites on Mull (Simpson, 1961; Bell and Jolley, 1997, 1998; Kerr and Kent, 1998) all indicate an Early Tertiary age for the top of the Lower Group of lavas, leaving open the possibility of an earlier age for the base of this group, including some of the sediments interbedded with the lavas.

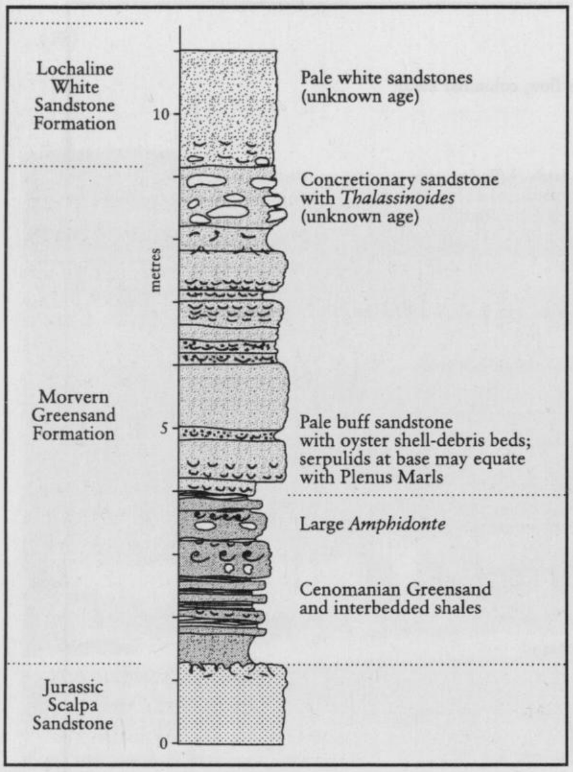


Figure 6.22 Carsaig main gully section, Mull.

Other localities on Mull

Gribun and Carsaig are the two main localities where relatively complete successions of the Late Cretaceous Inner Hebrides Group of sediments are preserved on Mull. Two other areas on Mull, Loch Don and Torosay, also contain remnant Late Cretaceous deposits (Figure 6.1). The so-called 'Loch Don sections' occur along the sea cliffs between Grass Point and Port Donain within the Auchnacraig Estate. There are several quite different successions in these exposures, most recently described by Skelhorn (1969). In the northern sections (Figure 6.5), the 'Flint Conglomerate' of the [British] Geological Survey (Bailey *et al.*, 1924, p. 58; Lee and Bailey, 1925, p. 118) is incorporated in a sandy matrix, the whole bed resting on Lias without any intervening Cenomanian greensand or Lochaline White Sandstone Formation. Reworked oyster-shell debris is common and the bed contains contorted laminae and many other sedimentary structures. Above the conglomerate, the 'mudstone' is very dark, often difficult to distinguish from the overlying lava, and contains fragments of flint and black shale (Bailey *et al.*, 1924). In the more southerly sections (Figures 6.4 and 6.5), Cenomanian greensands contain the typical *Amphidonte*, and the Early Cenomanian ammonite *Schoenbachia varians* (as *intermedia*) has also been recorded (Bailey *et al.*, 1924; Richey *et al.*, 1961).

In the southern sea-cliff exposure at Auchnacraig, 100 m south of Port na Tairbeirt (NM 742 294), there is an expanded succession (Figure 6.4), compared to the section north of this point. This expanded section brings in beds that show similarities with the Allt na Teangaidh and Carsaig exposures. The Late Cretaceous sediments rest unconformably on dark Jurassic shales. The first bed above the unconformity is sandstone with abundant oyster shells (probably the *Amphidonte* bed). Conspicuous branching *Thalassinoides* follow at the base of a 1.5 m thick calcareous concretionary limestone, very similar to the *Thalassinoides* and concretionary bed at Allt na Teangaidh and Carsaig cliffs. Oyster-shell beds in white sandstone are present almost up to the base of the chalk conglomerate. A thin greensand separates them and forms the matrix at the base of the chalk conglomerate. The chalk conglomerate is about 0.90 m thick, with the topmost clasts occurring in a second greensand matrix, very much the same as occurs at Gribun and Carsaig. A mudstone, consistently 1.70 m thick, is present from the conglomerate up to the base of the first lava flow.

Two sections near Torosay expose quite different successions. In old quarry workings (NM 7245 3521), a dark grey, crystalline limestone is

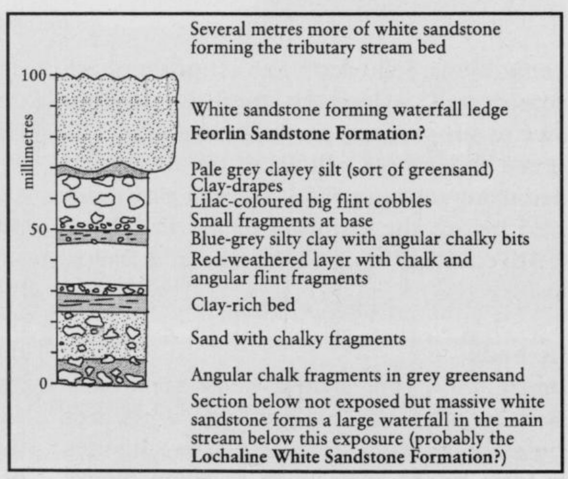


Figure 6.23 Feorlin Cottage tributary stream section on the east side of Abhainn na Feorlin section under the waterfall, below the road, Carsaig, Mull.

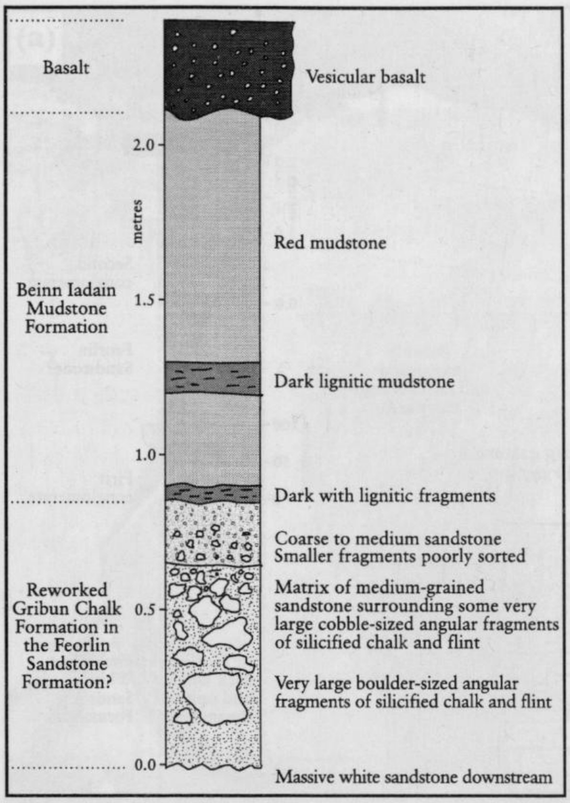


Figure 6.24 Feorlin Cottage main stream section above the waterfalls formed on massive white sandstone.

exposed that, in the present account, is interpreted as altered chalk on the basis of numerous overgrown coccoliths. Braley (1990, p. 79) provided section details indicating that the Upper Cretaceous strata rest on Oxfordian limestone, and begins with a 2.1 m bed of dark grey, micritic limestone. This limestone is overlain by a flint conglomerate, 0.40 m thick, which grades upwards into a second bed of dark grey limestone containing sparse flint fragments. Thin sections of this limestone (some kindly supplied by Prof. R. Skelhorn) show many foraminifera of Late Cretaceous aspect, but they are taxonomically indeterminate. Braley (1990) correlated this bed with the apparently similar Strathaird Limestone on the Isle of Skye and in Laig Gorge, Eigg, which contained better-preserved foraminifera indicating a Turonian age. The Skye and Eigg examples were dominated by calcispheres and planktonic foraminifera including *Hedbergella praehelvetica* (Trujillo), a Lower and Middle Turonian species. The presence of flint conglomerate below and above the limestone was considered by Braley to be an important indication of the age of the conglomerates. The occurrence of inoceramid bivalve fragments in these limestone outcrops is curious and needs further investigation. Correlation of the Strathaird Limestone of Skye and Eigg with the Torosay Limestone on Mull (Braley, 1990) is an interesting possibility, but remains unproven. Calcareous nannofossils in these limestones indicate a possible Early Campanian age, especially in the Laig Gorge Limestone.

The Torosay Quarry section introduces many questions on the origin and dating of the Inner Hebrides Group. Torosay is the only area other than on Skye or Eigg where such limestone has been recorded and this occurrence is completely anomalous on Mull. Except for a 200 mm thick grey limestone bed on the Torosay track (see below), nearby sections on the Torosay track and Auchnacraig show markedly contrasting successions with no evidence of the dark grey limestone. An explanation for this extraordinary outcrop may include a local fault-controlled basin, or a tectonic slice brought in from elsewhere.

A second section in the Torosay area occurs on the track (NM 720 349) leading to the communications towers on Maol nan Uan. This section comprises a thin (200 mm thick) dark, grey-green sugary limestone at the base, resting on Jurassic mudstones full of belemnites. Above the limestone are 4 m of reworked silicified chalks (flint conglomerate) and some oyster-shell debris set in a sandy, silicified matrix. The first layer of reworked material is reverse graded and rests with an irregular contact on the limestone. The matrix is also silicified, containing patches of chalcedonic cement. There are six horizons of white, silicified, mostly angular clasts, generally poorly sorted, but possibly all reverse graded. It is probable that this reworked unit represents debris flows, an interpretation supported by the poor sorting and crude reverse grading. The uppermost unit between the flint conglomerates and the first lava flow is a dark purple mudstone, ~2 m thick.

Fault control of sedimentation

Each locality on Mull shows significant differences in the Inner Hebrides succession. The most condensed, reworked deposits on the north side of Auchnacraig and on the Torosay track are close to the Great Glen Fault (Figure 6.2). There may also have been local troughs in which sedi-

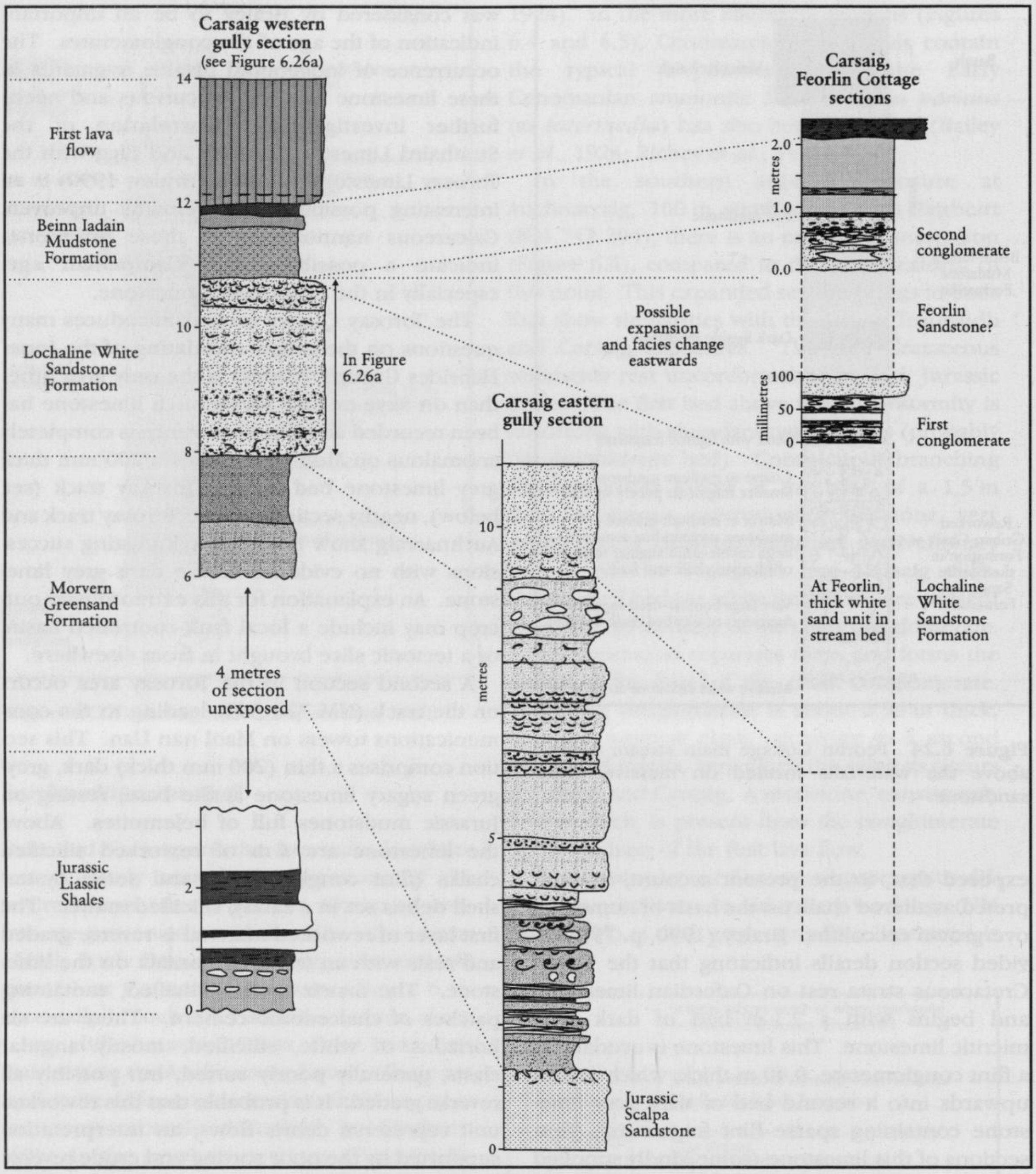


Figure 6.25 Possible correlation of the Upper Cretaceous sections at Carsaig, Mull.

ments such as the Torosay Limestone formed. Variation in thickness and lithology along the Carsaig cliff sections between Carsaig Bay and Malcolm's Point may also indicate local, fault control of sedimentation. Similarly, the variation in the thickness and composition of the sediments in the Gribun sections, notably the mélange in the most southerly, Caisteal Sloc nam Ban section, indicates rapid changes in this sedimentary environment, if indeed all the sections are Late Cretaceous in age.

Conclusions

Gribun, complemented by the local sections on Mull, together expose the eight main rock units comprising the Late Cretaceous(?) Inner Hebrides Group on Mull (Table 6.1). Apart from

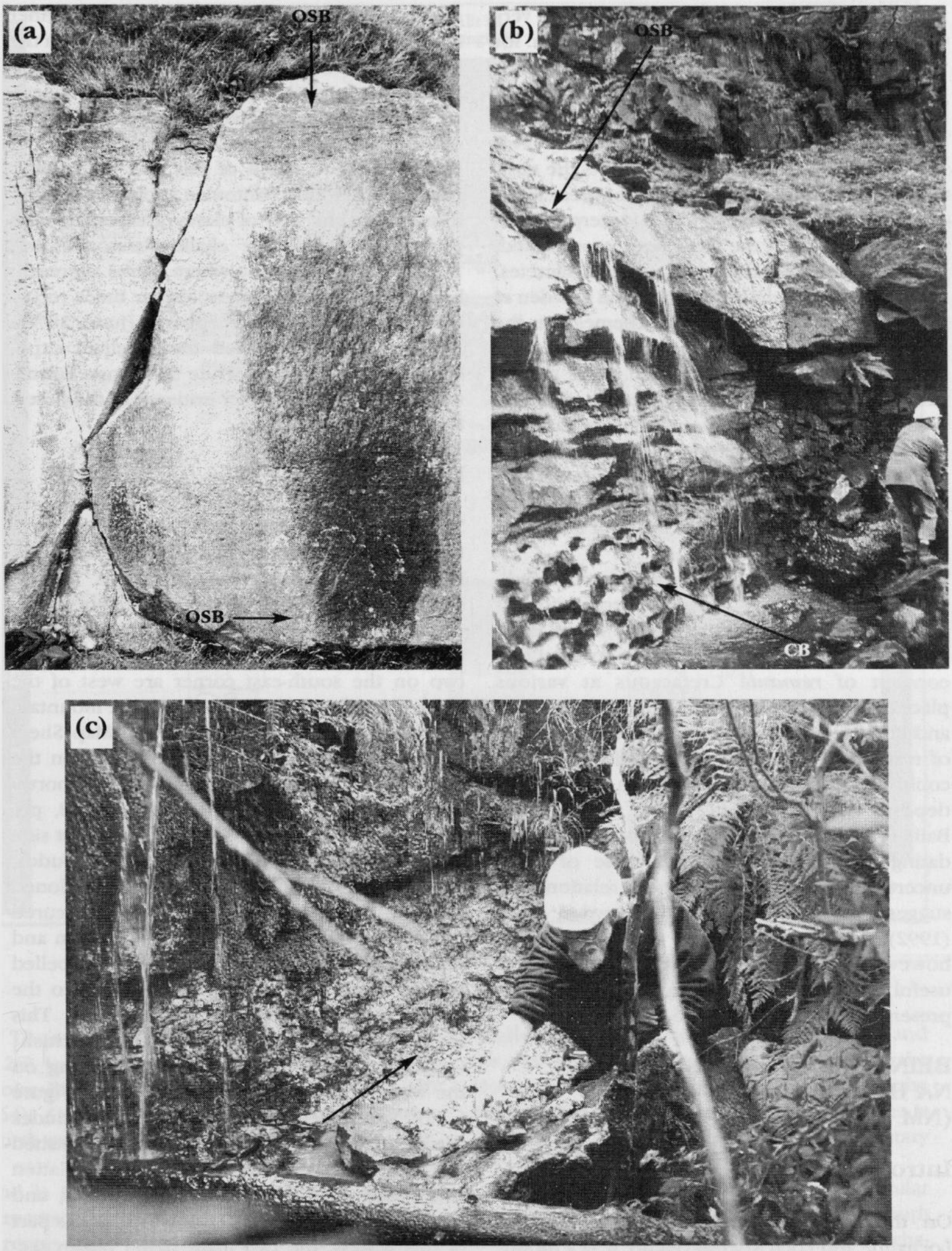


Figure 6.26 Three Carsaig exposures. (a) North-west of Carsaig, abundant oyster-shell beds (OSB) at the top, and base of, the sandstone are arrowed (see also Figure 6.25, western gully section). (b) Above Carsaig House, showing an abundant oyster-shell bed (OSB) at the top of the sandstone, and a concretionary bed (CB) at the base of the sandstone. (c) Feorlin Cottage upper stream section. An upper band of chalk/flint separating two sandstone units is arrowed. (Photos: R.N. Mortimore.)

the Cenomanian greensands there is, as yet, very little evidence for dating the sediments or for including all of them in the Cretaceous and/or Tertiary systems. It was the strikingly white Gribun Chalk Formation (Judd, 1878) in contrast to the dominating dark rocks of the Tertiary lavas that first attracted attention. Now it is the environment of sedimentation that is of great interest, stimulated by Bailey's (1924) interpretation of desert shores of the chalk seas, represented, so he thought, by millet-seed sands and silcretes.

Missing from the Braley (1990) and Lowden *et al.* (1992) lithostratigraphical schemes are the greensands that form conspicuous thin beds at the base and top of the Chalk. The overall succession represents three phases of transgression, possibly onto unconformable surfaces, represented by, respectively, the Middle? Cenomanian *Amphidonte* greensands, the greensands beneath the Chalk (possibly Santonian) and the greensands at the top of the Chalk (of unknown age).

The absence of good dating and detailed sedimentological analyses makes interpretation of this group of rocks very difficult. There is increasing evidence, however, to support Bailey's concept of *remanié* Cretaceous at various places. The Caisteal Sloc nam Ban, Auchnacraig and Torosay track sections all contain evidence of reworking, possibly by debris flows. These could be either Late Cretaceous or Tertiary deposits and Bailey *et al.* (1924), and Lee and Bailey (1925) are not clear or consistent in their dating of these deposits. Because of these uncertainties, the stratigraphical relationships suggested by Braley (1990) and Lowden *et al.* (1992) (see Table 6.1) must remain in doubt; however, their stratigraphical terminology is useful and is, where possible, adopted in the present volume (e.g. Figure 6.27).

BEINN IADAIN AND BEINN NA H-UAMHA, MORVERN (NM 670 541–NM 689 528, NM 68)

Introduction

On the Scottish mainland, to the north of Lochaline and Loch Arienas (Figure 6.1) a mountainous wilderness composed primarily of Moine Schists, is capped on the highest peaks by thin elements of Mesozoic sediments and Tertiary lavas. Beneath the lavas on two of these mountains, Beinn Iadain and Beinn na h-Uamha, are exposures of the Upper Cretaceous Inner Hebrides Group, probably more complete in the former than anywhere else. It was at Beinn Iadain that Judd (1878) and Scott (1928) collected (inferred) Campanian belemnites (possibly *Belemnitella mucronata*) from a thin bed of chalk (to Scott, much of this was real chalk). Later, in the 1960s, Santonian sponges were collected from the bed of clayey greensands with phosphates under the chalk (Rawson *et al.*, 1978). It is also an area where lignite is present beneath the mudstones, in former times recognized as coal seams by shepherds (Judd, 1878). Bailey (1922) interpreted the excellent exposures of the Lochaline White Sandstone Formation in this area as further evidence of the desert shores of the chalk seas.

Description

The mountains of Beinn Iadain and Beinn na h-Uamha include several exposures of the Inner Hebrides Upper Cretaceous Group (Figure 6.28). Approached from the west by the estate track from Kinloch (NM 658 558), the Beinn Iadain sections occur in three main exposures, two on the south-east corner are west of the marked north–south fault crossing the mountain (British Geological Survey 1:50 000 Map Sheet 52(E), Strontian). The other section is on the west side of a deep stream gully on the north-east side of the mountain. Judd's (1878, pp. 735–6) original section is on the south-east side of Beinn Iadain (spelt Beinn-y-Hattan by Judd), and is directly north of the shielings (abandoned shepherds' cottages) in a currently obscured exposure (NM 694 549), partly in a stream and waterfall. Currrently the best exposure (labelled Section 1 on Figure 6.28) is above and to the west of the ruined shielings (NM 692 551). This section was also studied by the [British] Geological Survey (Bailey, 1922, reporting on the work of Simpson and Manson) (see Figure 6.29). Subsequent work on this section includes the records of Scott (1928, p. 169), unpublished sections and collections of Jeans and Platten with fossil identifications by Reid (1968), and Braley's unpublished PhD thesis (1990). As part of this review, the two main Beinn Iadain sections on the south-east side were visited (1998–1999) and remeasured and sampled, in order to establish the current state of the exposures around the mountains and to attempt to date the succession.

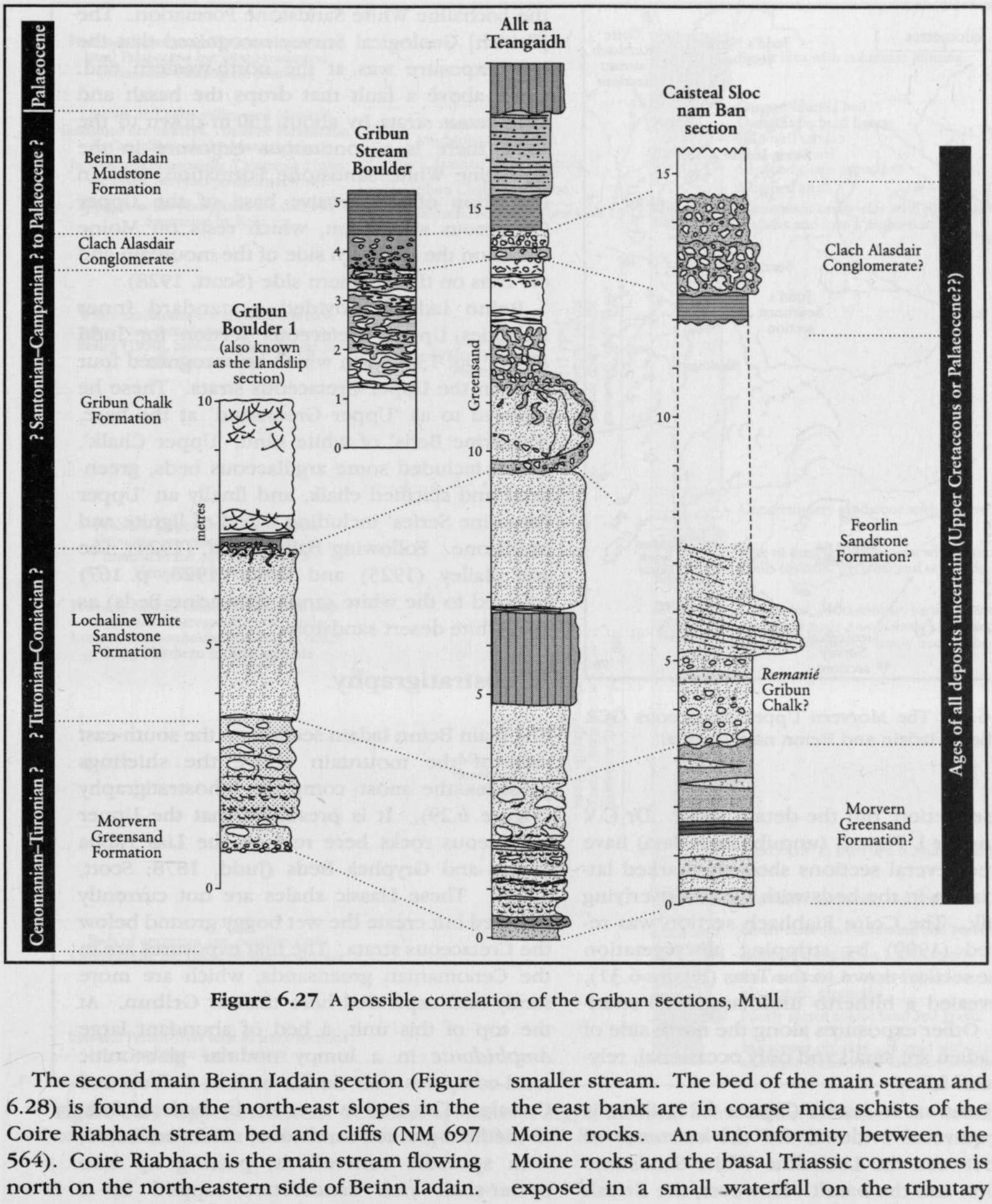


Figure 6.27 A possible correlation of the Gribun sections, Mull.

The second main Beinn Iadain section (Figure 6.28) is found on the north-east slopes in the Coire Riabhach stream bed and cliffs (NM 697 564). Coire Riabhach is the main stream flowing north on the north-eastern side of Beinn Iadain. It cuts a steep-sided valley into Moine Schists and is joined by a number of small tributary streams (Figure 6.30). One of these smaller streams joins from the west where it flows off basalts along the edge of a small fault-controlled outlier of Mesozoic rocks. The Upper Cretaceous exposure here is a small fault-controlled outlier on the steep west bank of the main stream below the confluence with a smaller stream. The bed of the main stream and the east bank are in coarse mica schists of the Moine rocks. An unconformity between the Moine rocks and the basal Triassic cornstones is exposed in a small waterfall on the tributary stream.

Judd (1878, pp. 734–5) recorded a similar succession at Coire Riabhach to that at the south end of the mountain, albeit with thinner Lochaline White Sandstone Formation, overlying oyster-rich greensands and argillaceous greensands resting on Lias and Trias. This broadly agrees with the description given below. Braley (1990) recorded the higher part of what is presumably

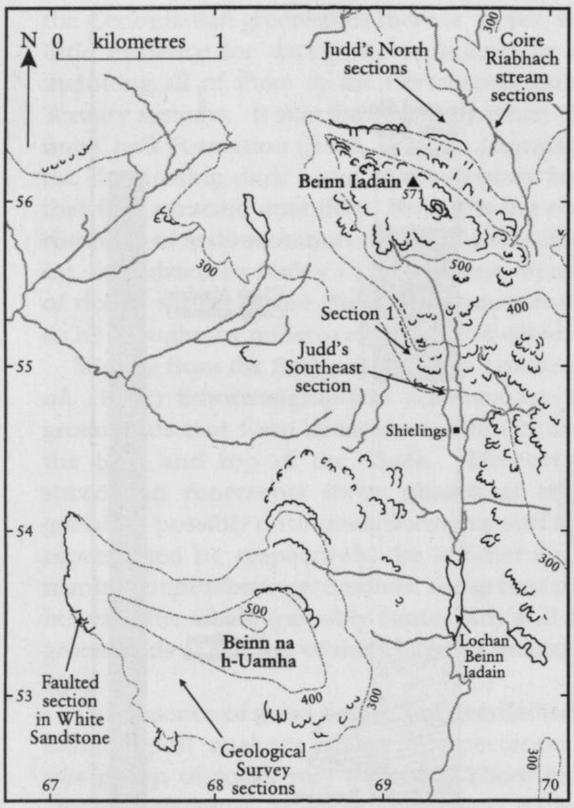


Figure 6.28 The Morvern Upper Cretaceous GCR sites at Beinn Iadain and Beinn na h-Uamha.

the same section, but the details differ. Dr C.V. Jeans and Dr I. Platten (unpublished data) have measured several sections showing marked lateral variation in the beds with lignites overlying the chalk. The Coire Riabhach section was re-measured (1999) by stripping all vegetation from the section down to the Trias (Figure 6.31). This revealed a hitherto undocumented stratigraphy. Other exposures along the north side of Beinn Iadain are small and only occasional, relying on cliff falls.

On Beinn na h-Uamha (Figure 6.28) there is no unequivocal evidence for the existence of Chalk between the Lochaline White Sandstone Formation and the basalt. However, the British Geological Survey 1:50 000 (Strontian) Geological Map shows the existence of (supposed Tertiary) sediments with lignites beneath the lavas, and the memoir (Bailey *et al.*, 1924) implies that the basalts are underlain by mudstones everywhere in the surrounding area, including the sections at Lochaline.

The south-east and north-west ends of Beinn na h-Uamha have provided good exposures of the Lochaline White Sandstone Formation. The [British] Geological Survey recognized that the best exposure was at the north-western end. Here, above a fault that drops the basalt and Cretaceous strata by about 150 m down to the west, there is a continuous exposure in the Lochaline White Sandstone Formation, and an indication of the erosive base of the Upper Cretaceous succession, which rests on Moine Schist on the southern side of the mountain and on Trias on the northern side (Scott, 1928).

Beinn Iadain provided a standard Inner Hebrides Upper Cretaceous section for Judd (1878, pp. 734–5), in which he recognized four beds in the Upper Cretaceous strata. These he referred to as 'Upper Greensand' at the base, 'Estuarine Beds' of white sand, 'Upper Chalk', which included some argillaceous beds, greensand and silicified chalk, and finally an 'Upper Estuarine Series' including a bed of lignite and mudstone. Following Bailey *et al.* (1924), Lee and Bailey (1925) and Scott (1928, p. 167) referred to the white sands (Estuarine Beds) as the 'White desert sandstone'.

Lithostratigraphy

The main Beinn Iadain section on the south-east side of the mountain above the shielings provides the most complete lithostratigraphy (Figure 6.29). It is presumed that the Upper Cretaceous rocks here rest on the Lias Pabba Shales and Gryphea Beds (Judd, 1878; Scott, 1928). These Liassic shales are not currently exposed but create the wet boggy ground below the Cretaceous strata. The first exposures are in the Cenomanian greensands, which are more sandy and expanded here than at **Gribun**. At the top of this unit, a bed of abundant large *Amphidonte* in a lumpy nodular glauconitic sand compares with similar beds at **Gribun** and Carsaig. This bed is overlain by beds of fine- to medium-grained sandstone, some laminated, with sporadic concretions, passing up into oyster-shell rich sandstones capped by a concretionary sandstone with *Thalassinoides* burrows. The Lochaline White Sandstone Formation above is poorly exposed but forms a massive 5–6 m thick bed, which becomes weakly glauconitic towards the top.

The most variable part of the succession lies above the Lochaline White Sandstone Formation. At Beinn Iadain Section 1, a thin glauconitic sandy clay packed with weathered, brown

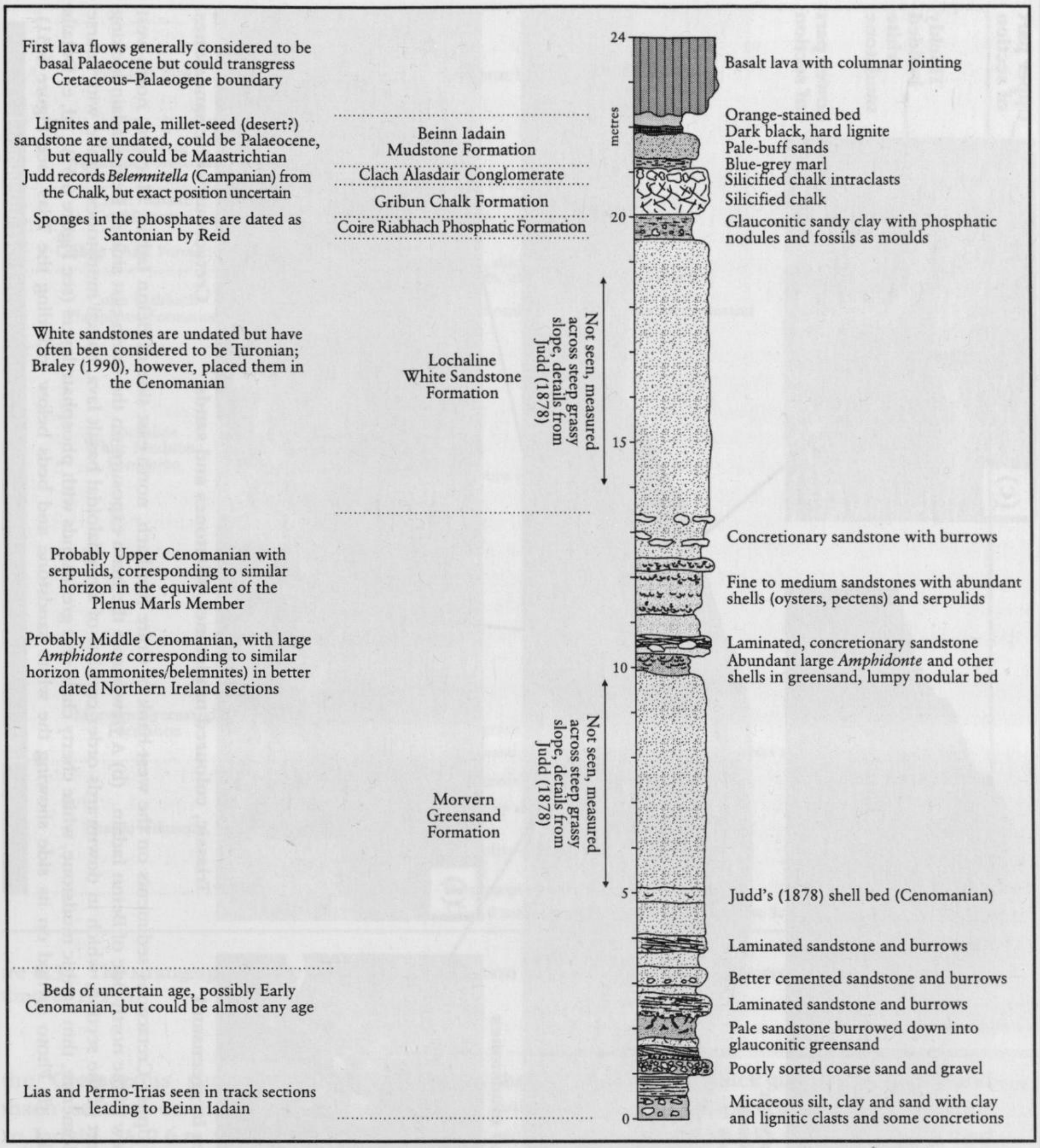


Figure 6.29 Upper Cretaceous GCR Sites at Morvern, Argyll, the main Beinn Iadain section on the south-east corner. (Figure 6.28, Section 1; re-measured 1998 by R.N. Mortimore and C.J. Wood.)

phosphate clasts including sponges, internal moulds of brachiopods and bivalves, and sharks teeth is intercalated between the Lochaline White Sandstone Formation and the overlying silicified chalk. The basal contact is burrowed, but the nature of the contact with the overlying chalk is unclear. As at other localities, the chalk is silicified, but Scott (1928) noted that the degree of silicification changes within the exposure, some chalk appearing to be softer, leaving a white powder when handled, and more like a real chalk. At the top of the 1 m-thick chalk is a variable succession, which, in the most complete section, comprises a thin layer of silicified chalk intraclasts in a greensand matrix, overlain by thin units of grey marl, pale buff sandstone, dark black lignite and orange mudstone.

It is uncertain which bed is actually the base

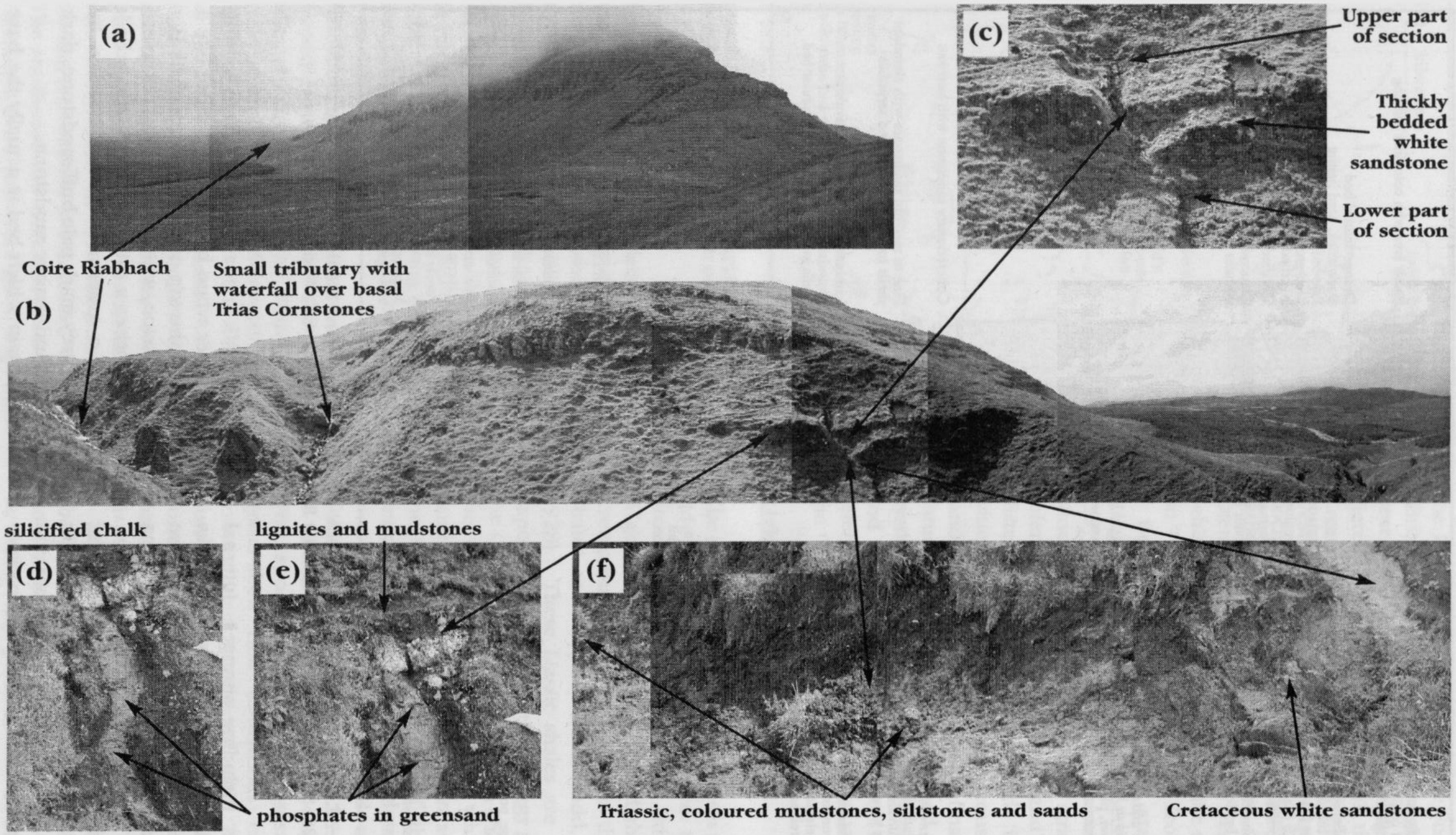


Figure 6.30 Small, faulted outlier of Upper Cretaceous sediments on the west bank of Coire Riabhach, north-east side of Beinn Iadain, Morvern, north-west Highlands, Scotland. (a) Panoramic view of the north side of Beinn Iadain. (b) A view across the main exposure on the north-east side of Beinn Iadain looking south-west. (c) Detail of the upper part of the section, which in downwards order consists of amygdaloidal basalt lava, baked mudstones, lignite with coarse flint pebbles, sandstone and flint conglomerate, thin lignitic mudstone, white cherty chalk and greensands with phosphate layers (see Figure 6.31). (d, e) Details of the conspicuous rib of white chalk. (f) Photo turned on its side showing the white sandstone and beds below including the Trias (see Figure 6.31). (Photomosaics: R.N. Mortimore.)

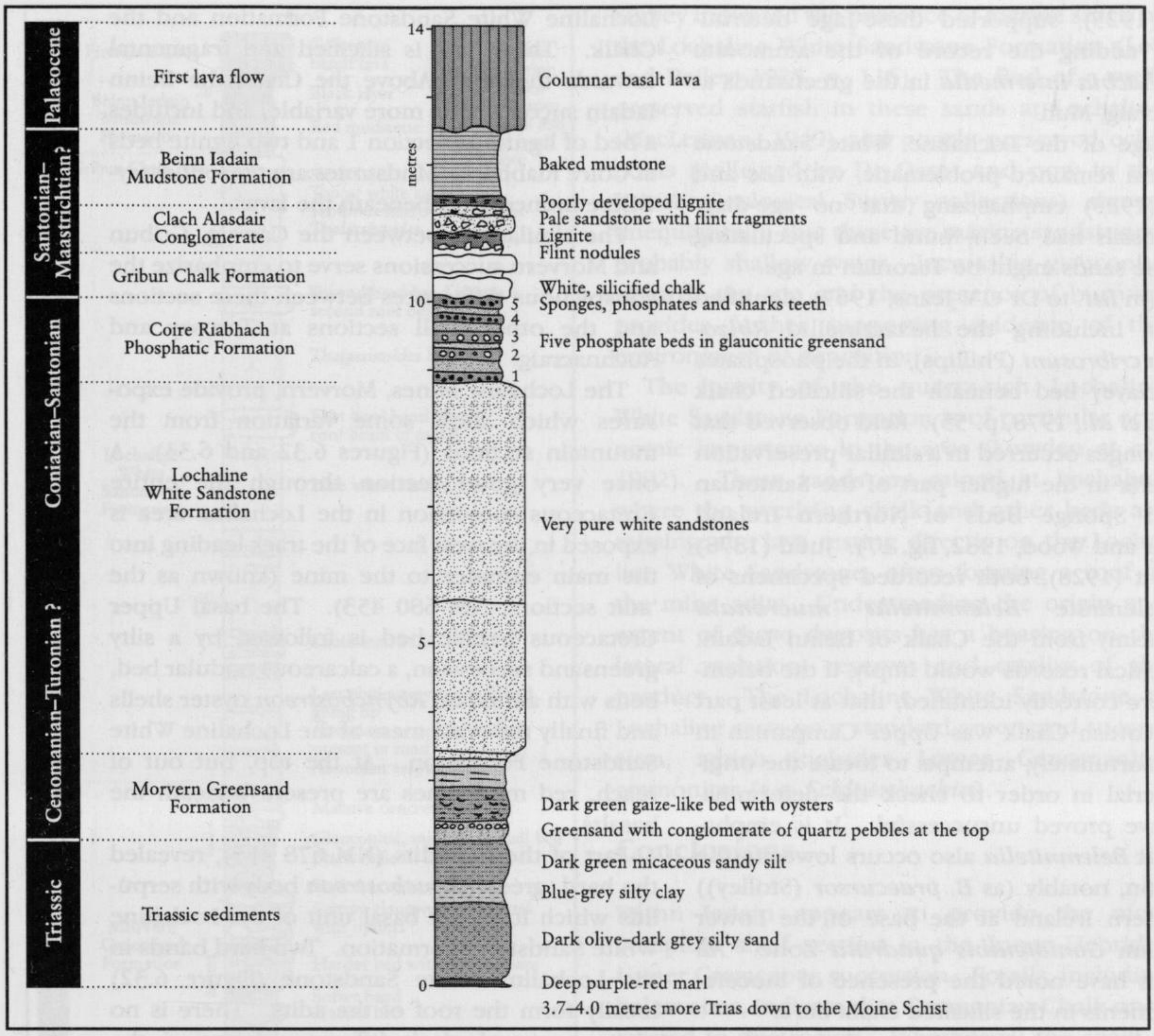


Figure 6.31 The stratigraphy of the Coire Riabhach stream section, Beinn Iadain, Morven. (Measured by R.N. Mortimore, 1999.)

of the Cretaceous succession in the Coire Riabhach section on the north-east slopes of Beinn Iadain. A 0.6 m thick, dark green, micaceous and glauconitic, sandy silt with wavy laminations overlies what is presumed to be the top Triassic blue-grey, silty clay. This is succeeded by a thin (0.3 m thick) pebble bed of well-rounded quartz pebbles in a 0.3 m thick true glauconitic greensand which could also be the basal Upper Cretaceous bed. The overlying 0.5 m thick dark green, gaize-like lithology contains oyster shells. This bed grades progressively upwards into the very thickly bedded white sandstone, here about 3 m thick, which forms a buttress along the side of the valley. The next bed above is of particular importance for stratigraphical correlation as there is an unusually thick glauconitic greensand with five well-developed phosphate horizons rich in sponges and sharks teeth. The silicified chalk is very thin (0.25 m), and is capped by a flint conglomerate and a lignitic bed overlain by a pale sandstone that contains further scattered flint fragments. Another thin lignite above is succeeded by 1 m of mudstones up to the first lava.

Biostratigraphy

Judd recognized the age of the Cenomanian greensands at Carsaig and **Gribun** on Mull, and found similar fossils (mostly oysters) at Beinn Iadain. Bailey *et al.* (1924), and Lee and

Bailey (1925), supported these age determinations, adding the record of the ammonite *Schloenbachia intermedia* in the greensands at Auchnacraig, Mull.

The age of the Lochaline White Sandstone Formation remained problematic, with Lee and Bailey (1925) emphasizing that no age-diagnostic fossils had been found and speculating that these sands might be Turonian in age.

Reid (in *litt.* to Dr C.V. Jeans, 1967) identified sponges, including the hexactinellid *Rhizoposterion cribrosum* (Phillips), in the phosphates in the clayey bed beneath the silicified chalk (Rawson *et al.*, 1978, p. 55). Reid observed that these sponges occurred in a similar preservation and matrix in the higher part of the Santonian Cloghfin Sponge Beds of Northern Ireland (Fletcher and Wood, 1982, fig. 17). Judd (1878) and Scott (1928), both recorded specimens of the belemnite *Belemnitella mucronata* (Schlotheim) from the Chalk of Beinn Iadain. These critical records would imply, if the belemnites were correctly identified, that at least part of the Scottish Chalk was Upper Campanian in age. Unfortunately, attempts to locate the original material in order to check the determinations have proved unsuccessful. It is emphasized that *Belemnitella* also occurs lower in the succession, notably (as *B. praecursor* (Stolley)) in Northern Ireland at the base of the Lower Campanian *Gonioteuthis quadrata* Zone. All observers have noted the presence of inoceramid fragments in the silicified chalk here.

From the intraclast beds upwards to the lavas there are no satisfactory dates and these could therefore be either Upper Cretacous or Tertiary sediments.

Interpretation

The Upper Cretaceous succession on the mountain sections of Morvern at Beinn Iadain and Beinn na h-Uamha show great similarities with correlative sections on Mull (Figure 6.34, p. 471), particularly the **Gribun** Clachandhu boulders and Allt na Teangaidh sections, and Carsaig. This similarity occurs in the Cenomanian greensands, the buff laminated, concretionary sandstone with *Thalassinoides*, the Lochaline White Sandstone Formation, the greensands below the Chalk, and the flint conglomerate above, partly in greensand. As on Mull, there is a glauconitic bed (here more clayey at Beinn Iadain Section 1) between the Lochaline White Sandstone Formation and the Chalk. The Chalk is silicified and fragmental towards the top. Above the Chalk the Beinn Iadain succession is more variable, and includes a bed of lignite at Section 1 and two lignite beds at Coire Riabhach. Mudstones are present everywhere immediately beneath the lavas.

The similarities between the Carsaig, Gribun and Morvern successions serve to emphasize the conspicuous differences between these sections and the other Mull sections at Torosay and Auchnacraig.

The Lochaline Mines, Morvern, provide exposures which show some variation from the mountain sections (Figures 6.32 and 6.33). A once very good section through the entire Cretaceous succession in the Lochaline area is exposed in the west face of the track leading into the main entrance to the mine (known as the 'adit section', NM 680 453). The basal Upper Cretaceous pebble bed is followed by a silty greensand succession, a calcareous nodular bed, beds with abundant *Rhynchostreon* oyster shells and finally the main mass of the Lochaline White Sandstone Formation. At the top, but out of reach, red mudstones are present beneath the basalts.

Part of the old adits (NM 678 455), revealed the hard, green *Rhynchostreon* beds with serpulids which form the basal unit of the Lochaline White Sandstone Formation. Two hard bands in the Lochaline White Sandstone (Figure 6.32) locally form the roof of the adits. There is no obvious petrological difference between the hard bands and the main sandstone.

There is little extra fossil information to support the age dating of the Upper Cretaceous deposits in this region. Cenomanian ammonites (*Schloenbachia*) confirm the age of the Morvern Greensand Formation but no diagnostic fossil records exist for beds above the Greensand. The ages of the Lochaline White Sandstone Formation and the highest beds remain controversial.

Judd (1878) interpreted all the beds between the Cenomanian Morvern Greensand Formation and the chalk (Table 6.1) as estuarine (his 'Lower Estuarine beds'). In contrast, Bailey (1924) interpreted the Lochaline White Sandstone Formation as derived from sand blown into the sea from a desert because of its incredible purity and the presence of 'millet-seed' quartz grains, considered typical of desert conditions. The continued presence of similar millet-seed grains in the sands between the silicified chalk clasts,

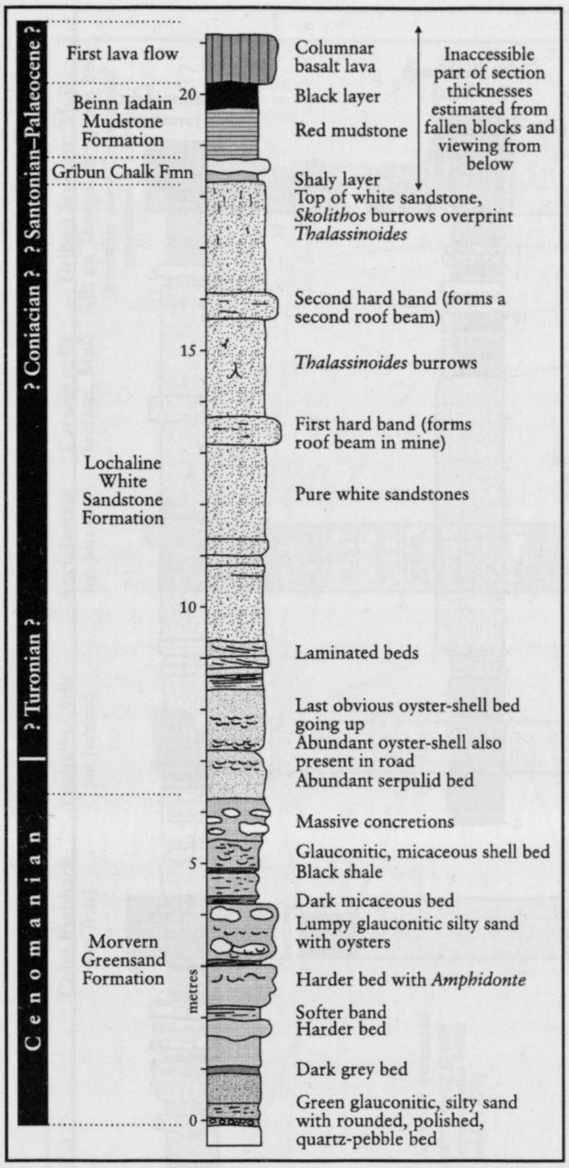


Figure 6.32 The Upper Cretaceous deposits of the Lochaline Mine Adit section, Lochaline, Morvern. The Gribun Chalk Formation probably incorporates the Clach Alasdair Conglomerate and lignites.

and the silicification of the chalk itself, led Bailey to suggest that desert conditions continued to the top of the succession (i.e. into the Tertiary deposits). He considered the silicification to be a soil-forming process (a silcrete) similar to the processes seen in the present day Kalahari Desert. For Bailey, this explained the angular, fragmental nature of the chalk, which was then reworked in overlying layers as a flint conglomerate.

Other evidence from the [British] Geological Survey indicated the presence of marine shells in the Lochaline White Sandstone Formation (Lee and Bailey, 1925, p. 116). The find of a well-preserved starfish in these sands at Lochaline (MacLennan, 1949) and poorly preserved echinoids (collected by Dr Oates and now in the British Geological Survey collections) shows, unequivocally, that these are marine sandstones, probably shallow water. Increasing glauconite towards the top and the presence of burrows provides further supporting evidence of the environment of deposition.

The purity of the quartz-rich Lochaline White Sandstone Formation is of particular economic importance in the area (Lowden *et al.*, 1992). These sands are mined at Lochaline where the overlying chalk and other beds are missing, the lava resting directly on the Lochaline White Sandstone, often forming a roof to the mine adits. Understanding the origin and extent of these deposits has a bearing on the lateral variation, reserves and quality of the product. The Lochaline White Sandstone at Lochaline rests on a standard greensand succession, which includes Lower Cenomanian ammonites (e.g. *Schloenbachia*).

Conclusions

Beinn Iadain appears to provide the most complete shelf section in the Inner Hebrides Upper Cretaceous succession. Fossils, including belemnites, indicate that Campanian Chalk once existed in this region. Whether all the chalk is now *remanié* Cretaceous in a Tertiary matrix remains to be proved. The Morvern stratigraphy confirms and complements observations made at **Gribun**, Mull.

GENERAL REVIEW OF THE INNER HEBRIDES GROUP

The sediments forming the Inner Hebrides Group are an extraordinarily reduced representative of the Upper Cretaceous Series (Figure 6.34). A major hiatus is evident between the Jurassic (Corallian being the youngest rocks below the hiatus) and Upper Cretaceous strata. This is greater than the hiatus between the Upper Cretaceous and the Tertiary deposits. As recognized by Judd (1878) and Bailey (1924), the great transgression of the Late Cretaceous Epoch only just managed to submerge parts of the Scottish Highlands. However, the units of

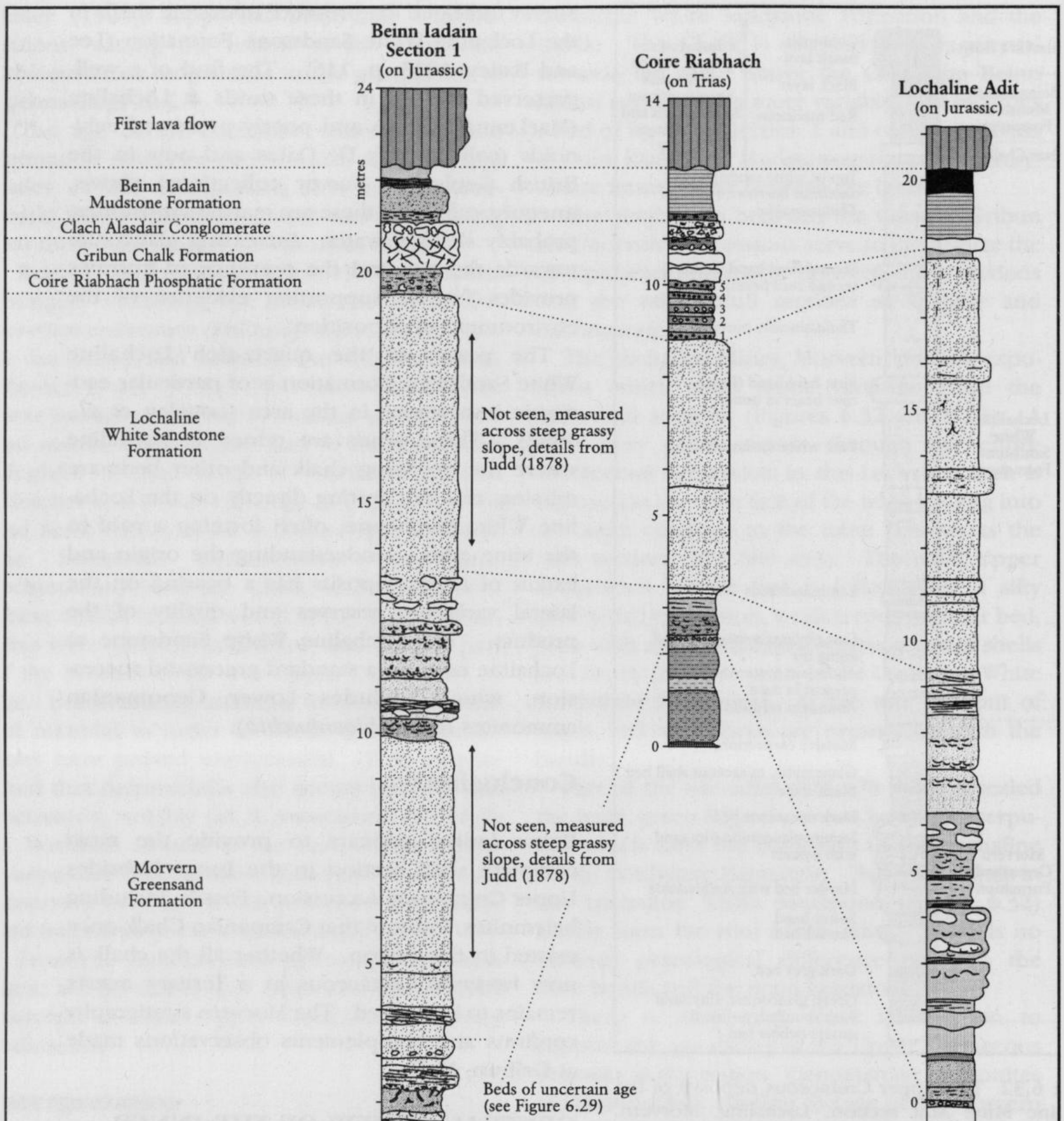


Figure 6.33 Correlation of the Upper Cretaceous GCR sites at Morvern, Argyll, the main Beinn Iadain sections linked to Lochaline.

rock that are preserved provide evidence both for pulses of sea-level fluctuation and for tectonic reworking. Dating these events requires a wider network of sections than is available in the Inner Hebrides. In particular, as Lee and Bailey (1925, p. 116) realized, the Late Cretaceous sediments of Northern Ireland provide crucial evidence to support interpretations in the Inner Hebrides.

While the Mull and Morvern sections are dominated by clastic sediments, there are sections on Eigg (Laig Gorge), and Skye (Strathaird and Allt Strollamus) that are mostly limestone successions. These dark grey lime-

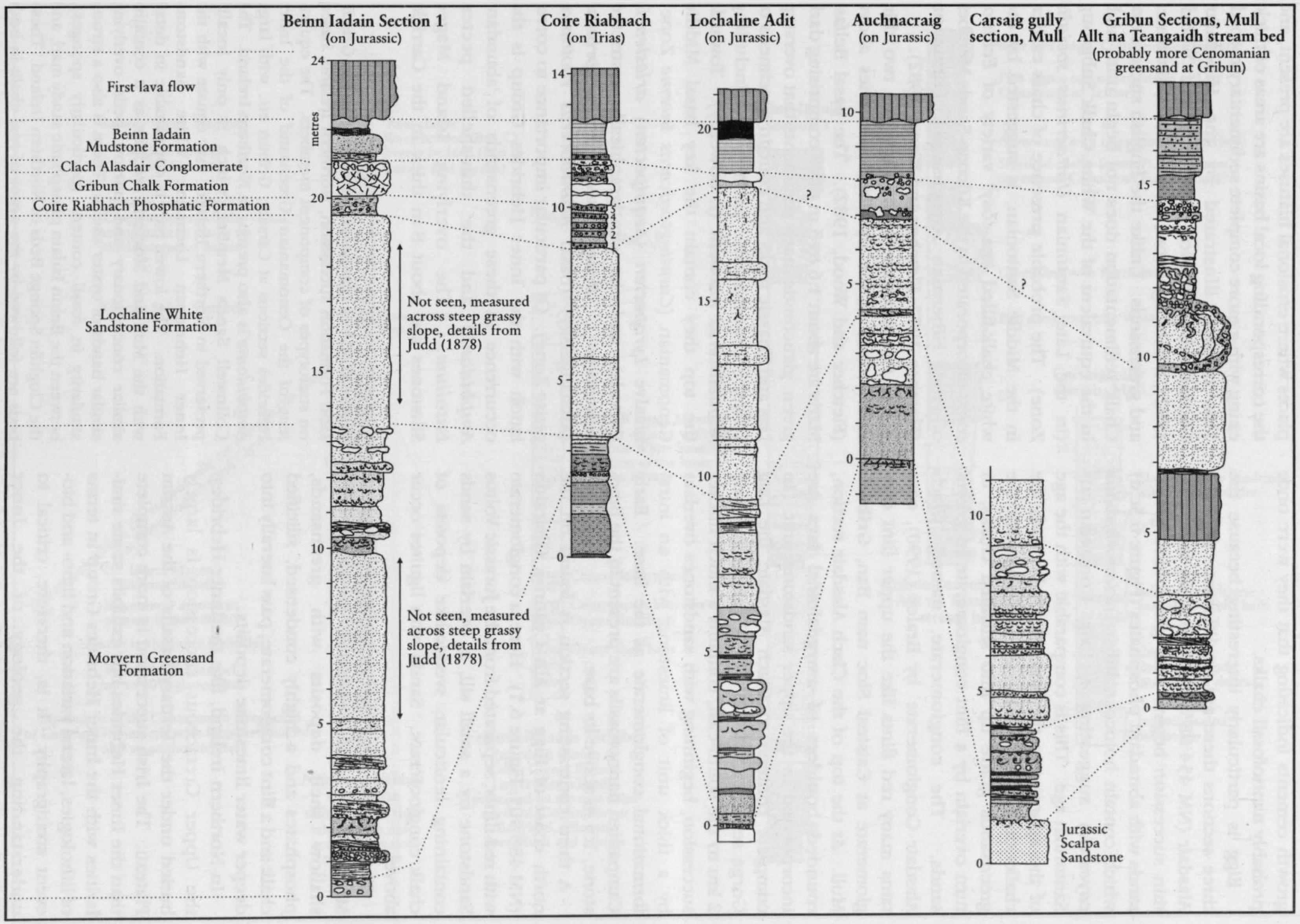


Figure 6.34 Correlation of the Upper Cretaceous GCR sites in the Inner Hebrides at Morvern, Argyll (Beinn Iadain and Lochaline) and at Auchnacraig, Carsaig, and Gribun, Mull. Note the restructuring of the lithostratigraphy of the Inner Hebrides Group.

stones contain abundant nannofossils with overgrowth cements indicating that they were once probably nannofossil chalks.

Eigg is particularly interesting because the three sections there are so different. At Clach Alasdair (NM 454 883; Figure 6.1) an incredibly thin succession begins with glauconitic greensands with abundant phosphates (Figure 6.3c,d) which contain holococcoliths (*Lucianorhabdus cayeuxii*) suggesting a Late Coniacian or Santonian age. This is comparable with the age of the sponges in the greensands beneath the chalks on **Beinn Iadain**. At Clach Alasdair the greensands grade up into silicified chalks, in turn overlain by a flint conglomerate in greensands. The conglomerate, named 'Clach Alasdair Conglomerate' by Braley (1990), contains many red flints like the upper flint conglomerate at Caisteal Sloc nam Ban, **Gribun**, Mull. At the top of the Clach Alasdair section, rounded boulders of amygdaloidal lava are incorporated in the upper sandstone unit. In complete contrast to Clach Alasdair, the Laig Gorge section (NM 473 875; Figure 6.1), some 2 km to the south-east, contains a much thicker succession, beginning with sandstones overlain by a thick unit of limestone with an intraformational conglomerate at the base. Early Campanian nannofossils are present in the limestone, 1.5 m above its base.

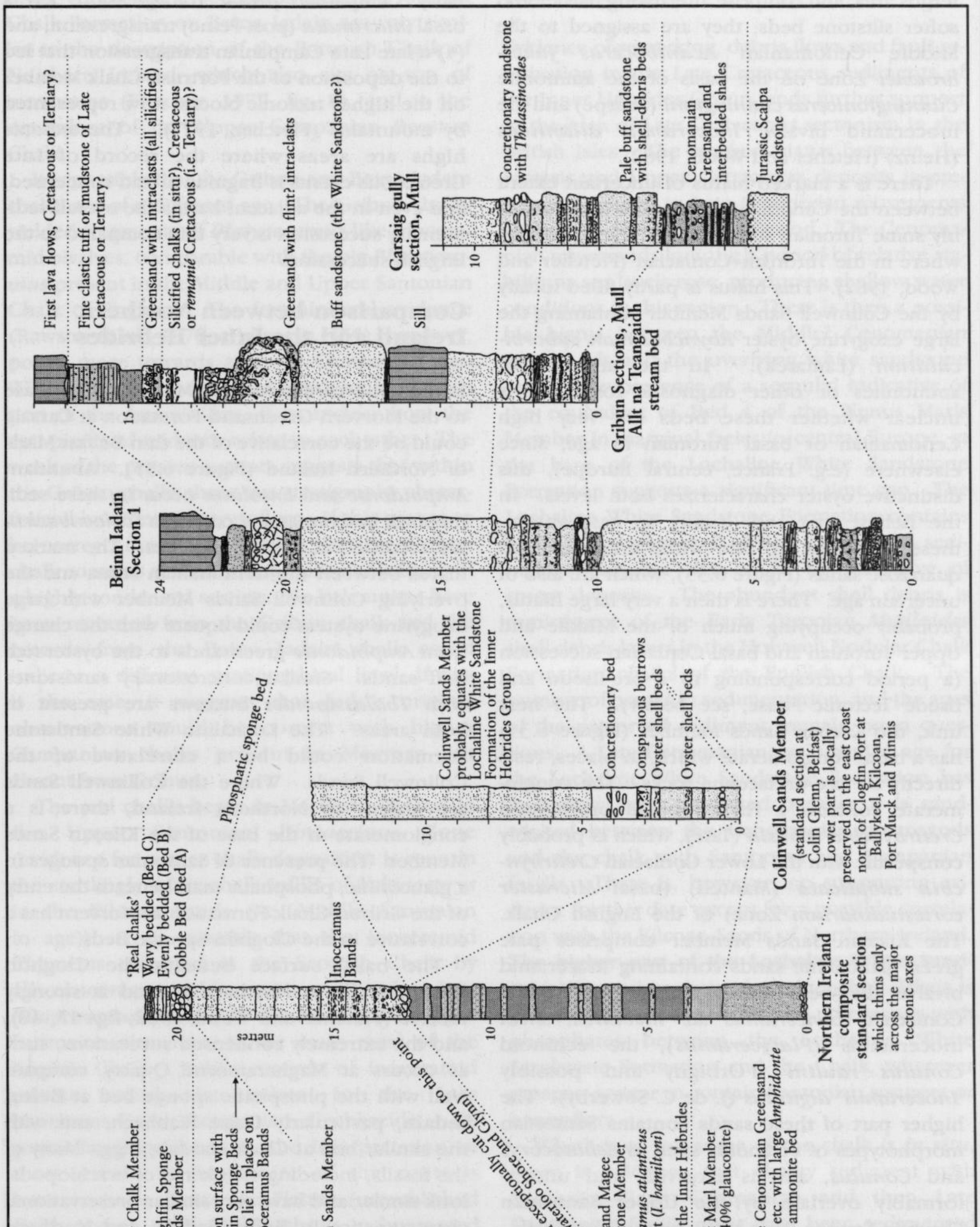
A third contrasting section is found on the north coast of Eigg at Allt Ceann à Gharaidh (NM 488 905; Figure 6.1). Here, a conglomerate with red flints, separated from the Jurassic Voltos Sandstone by a small sill, is overlain by sands containing lenticular, wedge-like deposits of chalk conglomerate. Sands with lignites occur above.

These three Eigg sections mirror those on Mull in the lateral variation present. Very shallow shelf deposits with greensands, phosphates and a highly condensed, silicified chalk and a flint conglomerate, pass laterally into deeper water limestone deposits.

In Northern Ireland, like the Inner Hebrides, the Upper Cretaceous succession is largely buried under the Tertiary basalts of the Antrim Plateau. The Irish succession is more complete than the Inner Hebrides but exhibits some similarities with the Inner Hebrides Group in terms of lithologies, lateral variation and litho- and bio-event stratigraphy. It is, therefore, critical to understanding the geology of the Inner Hebrides Group (Figure 6.35). In Northern Ireland, tectonically-controlled massifs are places where erosional hiatuses are present, and the corresponding local basins are areas of thickening with a more complete sedimentary record. This is well illustrated by the Hibernian Greensand Formation (Fletcher and Wood, 1982), a heterogeneous unit of marls, siltstones and greensands. Unlike the English succession, Chalk sedimentation does not begin until high in the equivalent of the White Chalk Subgroup (in the Late Santonian *Uintacrinus socialis* Zone). The probable presence of chalk earlier, in the Middle Santonian, is suggested by the white chalk-filled 'tea-cosy' variety of *Echinocorys* incorporated in the Kilcoan Sands Member of the Hibernian Greensands Formation (Fletcher, 1977; Fletcher and Wood, 1982).

The Cenomanian Stage comprises two thin units, marls at the base and siltstones above (Fletcher and Wood, 1982). The basal Belfast Marls are about 1.6 to 3 m thick comprising dark green, glauconitic marly sediments that overstep Lias and Triassic rocks and contain specimens of Lower Cenomanian ammonites including *Mantelliceras mantelli* (J. Sowerby). Towards the top they contain the key basal Middle Cenomanian (*Cunningtoniceras inerme* Zone) bivalve *Lyropecten* (*Aequipecten*) *arlesiensis* (Woods), and the stratigraphically restricted belemnite *Praeactinocamax primus* (Archangelsky) (basal *Acanthoceras rhotomagense* Zone). Of particular importance to correlation with the Inner Hebrides Group is the occurrence in these greensands of abundant *Amphidonte* and the thin-shelled pecten *Entolium*. The overlying Island Magee Siltstones are about 8 m thick in the Carrick-

Figure 6.35▸ A composite Antrim Hibernian Greensand Formation succession, Northern Ireland, based on stratotypes of component members. The equivalent of the Cenomanian Greensand of the Inner Hebrides sections at Carsaig, Gribun etc. with large *Amphidonte* is also present in Northern Ireland. The Colinwell Sands Member, which is only locally preserved in Northern Ireland, may equate with the Inner Hebridean Lochaline White Sandstone Formation. The lower part is correlatable in detail with the Mull and Morvern sections as it contains similar concretionary and burrow beds overlying similar bands of oyster shells. There is also a strong similarity in fossil content (particularly sponges), between the Beinn Iadain phosphatic sandy marl, and the Cloghfin Sponge Beds of Northern Ireland. These beds are followed by the onset of real chalk in both areas.


Galboly Chalk Member
Cloghfin Sponge Beds Member
Erosion surface with Cloghfin Sponge Beds coming to lie in places on the Inoceramus Bands
Killoan Sands Member
The erosion surface (e.g. at Waterloo Shore and Glynn) can exceptionally cut down to this point
Island Magee Siltstone Member
Inoceramus atlanticus present (I. hamiltoni)
Absent in the Inner Hebrides
Belfast Marl Member (up to 40% glauconite)
Equivalent of the Cenomanian Greensand of Carsaig, Gribun, etc. with large amphidonte and an ammonite bed
'Real chalks'
Wavy bedded (Bed C)
Evenly bedded (Bed B)
Cobble Bed (Bed A)
metres
Inoceramus Bands
Northern Ireland composite standard section which thins only across the major tectonic axes
Phosphatic sponge bed
Colinwell Sands Member probably equates with the Lochaline White Sandstone Formation of the Inner Hebrides Group
Concretionary bed
Conspicuous burrows
Oyster shell beds
Oyster shell beds
Colinwell Sands Member
(standard section at Colin Glenn, Belfast)
Lower part is locally preserved on the east coast north of Clogfin Port at Ballykeel, Kilcoan, Port Muck and Minnis
Beinn Iadain Section 1
Gribun Section, Mull
Allt na Teangaidh stream bed
Carsaig gully section, Mull
Sill
First lava flows, Cretaceous or Tertiary
Fine clastic tuff or mudstone of Late Cretaceous or Tertiary
Greensand with intraclasts (all silicified)
Silicified chalks (in situ?), Cretaceous or remanié Cretaceous (i.e. Tertiary)?
Greensand with flint intraclasts
Buff sandstone (the White Sandstone?)
Concretionary sandstone with Thalassinoides
Pale buff sandstone with shell-debris beds
Cenomanian Greensand and interbedded shales
Jurassic Scalpa Sandstone

fergus area, and comprise alternating harder and softer siltstone beds; they are assigned to the Middle Cenomanian *Acanthoceras jukesbrownei* Zone on the basis of the ammonite *Cunningtoniceras cunningtoni* (Sharpe) and the inoceramid bivalve *Inoceramus atlanticus* (Heinz) (Fletcher and Wood, 1982).

There is a marked hiatus of uncertain extent between the Cenomanian deposits (plus possibly some Turonian strata) and an interval somewhere in the Turonian–Coniacian (Fletcher and Wood, 1982). This hiatus is partly filled locally by the Colinwell Sands Member containing the large exogyrine oyster *Rhynchostrean suborbiculatum* (Lamarck). In the absence of ammonites or other diagnostic fossils, it is unclear whether these beds are very high Cenomanian or basal Turonian in age, since elsewhere (e.g. France, central Europe), this distinctive oyster characterizes both levels. In the Belfast area and, locally, in east Antrim, these beds pass up into white unfossiliferous quartzose sands (Figure 6.35), which are also of uncertain age. There is then a very large hiatus, probably occupying much of the Middle and Upper Turonian and basal Coniacian succession (a period corresponding to a pre-Ilsede and Ilsede Tectonic Phase, see below). The next unit, the Kilcoan Sands Member (Figure 6.35) has a basal conglomerate which, in places, rests directly on pre-Cretaceous rocks. The conglomerate contains a rhynchonellid brachiopod *Cretirhynchia robusta* (Tate), which is probably conspecific with the Lower Coniacian *Cretirhynchia subplicata* (Mantell) (basal *Micraster cortestudinarium* Zone) of the English Chalk. The Kilcoan Sands Member comprises pale green glauconitic sands containing inoceramid bivalve shell-beds which include the Middle Coniacian *Volviceramus* aff. *involutus*, sheet inoceramids (*Platyceramus*), the echinoid *Conulus raulini* d'Orbigny and possibly '*Inoceramus*' *digitatus* (J. de C. Sowerby). The higher part of these sands contains Santonian morphotypes of echinoids such as *Echinocorys* and *Conulus*, and is erosively and unconformably overlain by the Upper Santonian Cloghfin Sponge Beds at the base of the Chalk.

There are several transgressive and tectonic reactivation events recognizable in the Ulster White Limestone (Chalk) above the Santonian strata. These include (1) an onlapping of sediments during the Late Santonian and earliest Campanian times (the Grobkreide facies); (2) an Early Campanian *pilula* transgression; (3) a basal *mucronata* (post-Peine) transgression; and (4) a late Late Campanian transgression that led to the deposition of the Portrush Chalk Member on the higher tectonic blocks, now represented by mountains (Fletcher, 1977). The tectonic highs are areas where the record of Late Cretaceous events is fragmental and condensed, and even in the adjacent basins the overall sedimentary succession is very thin compared to the English succession.

Comparison between Northern Ireland and the Inner Hebrides

In the Cenomanian rocks of Mull, the marly base to the Morvern Greensand Formation at Carsaig could be the correlative of the thin Belfast Marls of Northern Ireland (Figure 6.35). Abundant *Amphidonte* and *Entolium* occur in these sediments in both areas and common *Schloenbachia* are recorded at several localities. The marked hiatus between the Cenomanian strata and the overlying Colinwell Sands Member with large exogyrine oysters could equate with the change from *Amphidonte* greensands to the oyster-rich buff sands. Similar concretionary sandstones with *Thalassinoides* burrows are present in both areas. The Lochaline White Sandstone Formation could be a correlative of the Colinwell Sands. Where the Collinwell Sands are absent in Northern Ireland, there is a conglomerate at the base of the Kilcoan Sands Member. The presence of Santonian sponges in a glauconitic, phosphatic marl beneath the entry of the Gribun Chalk Formation in Morvern has a correlative in the Cloghfin Sponge Beds.

The basal surface beneath the Cloghfin Sponge Beds in Northern Ireland is strongly erosive (Fletcher and Wood, 1982, figs 17, 18), and the extremely condensed successions, such as occurs at Magheramorne Quarry, compare well with the phosphatic sponge bed at **Beinn Iadain**, particularly Coire Riabhach, and with the similar bed at Clach Alasdair, Eigg. Many of the fossils, including steinkerns of brachiopods, look similar and have very similar preservational characteristics in **Beinn Iadain** and Northern Ireland.

Judd (1878) described two chalk lithologies in the Inner Hebrides, the first contained fossils including belemnites, corals and shell fragments of inoceramids, and the second had many inoceramid prisms. Judd's (1878) records of belemnites, corals and inoceramids from the Gribun Chalk Formation on Beinn Iadain are very similar to the description of the Portrush Chalk of Northern Ireland, which also sits on top of mountains (Fletcher, 1977, fig. 8), and is the equivalent of the Upper Campanian Beeston Chalk.

It is possible that the Gribun and Beinn Iadain chalks are of a different age. The Gribun chalks yielded fragments of *Platyceramus*-like inoceramid bivalves, comparable with the big *Platyceramus* present in the Middle and Upper Santonian Chalk of England. The foraminiferal evidence (Rawson *et al.*, 1978; and see p. 455), however, points more towards a Lower Campanian age. Without knowing the exact stratigraphical position of the foraminifera, it is unclear how the two pieces of evidence relate to each other. The work of the present authors suggests that within the Gribun chalks there is a stratigraphy characterized by different nannoflora. If this proves to be correct, then it is possible that the Gribun chalk contains several stratigraphical horizons in a highly condensed section. No belemnites have been recorded from the Gribun chalk and the records from the Beinn Iadain chalk could indicate a different stratigraphical level. If this is the case, it suggests that Judd's original observations could be correct with higher Campanian chalks present in Morvern but absent from Gribun.

The real chalks begin in Northern Ireland in the Upper Santonian *Uintacrinus* Zone (evidence for earlier chalk deposition is seen in the startlingly white-chalk infills of *Echinocorys* in the Kilcoan Sands (i.e. Middle Santonian in age)). It is possible that the inoceramid fragments recorded in the Scottish Chalk by all observers could equate with abundant *Platyceramus* present in the Middle and Upper Santonian elsewhere in the main mass of the English Chalk. Judd's records of inoceramid prisms could also relate to the Late Santonian–Early Campanian Grobkreide. Of particular importance to the interpretation of these events is the nature of the contacts between beds. Jeans and Platten (unpublished field notes, 1966–1967) show a burrowed contact between the glauconitic marl with phosphates and the underlying white sandstones as well as the overlying Chalk. Such contacts suggest that original soft sediment interfaces were present, though this could not be confirmed during recent fieldwork.

Conclusions

Evidence of reworking, debris flows and fault reactivation in the Late Cretaceous sediments of the Inner Hebrides Group lends further support to the idea of Late Cretaceous tectonism in the British Isles. The marked hiatus between the Jurassic and Upper Cretaceous deposits is presumably related to Late Cimmerian movements at the end of the Jurassic Period. The Cenomanian greensands indicate a period of relative stability as sea levels rose, producing shallow water conditions in this region. There is then a possible hiatus between the Middle? Cenomanian greensands and the overlying white sandstone units. The presence of a serpulid indicative of the equivalent of Bed 4 of the Plenus Marls Member in marginal facies in central Europe, at the base of the Lochaline White Sandstone Formation suggests a significant time gap. The Lochaline White Sandstone Formation contains broken-up oyster-shell debris layers and sedimentary laminae that could be indicative of storm deposits. The abundant shell debris is reminiscent of the Early Turonian *Mytiloides* shell debris layers in the Holywell Nodular Chalk Formation chalks of the English Chalk. The number of breaks in sedimentation, and the ages of the preserved sediment, remain open questions. A Late Cenomanian or Turonian age for the Lochaline White Sandstone Formation has frequently been suggested because it is sandwiched between the Cenomanian greensands and the chalk with Santonian and Campanian fossils. There is, however, no supporting evidence for this date except for a possible correlation with the Kilcoan Sands of Northern Ireland. The higher part of the Lochaline White Sandstone Formation above the oyster-shell debris is generally barren of shells. The greensands with phosphates between the Lochaline White Sandstone Formation and the Chalk, wherever present, appear to contain Santonian sponges or nannoflora.

Whether or not some of the chalk is ***in situ***, there is evidence that chalky sediment with Santonian–Early Campanian and then Late Campanian fossils must have been sedimented somewhere in the region. Many of the localities show that much of the chalk is reworked as a flint conglomerate set in a sandy matrix, usually a glauconitic greensand with some millet-seed quartz grains. The conversion to silicified chalk must pre-date the reworking, since many of the fragments are angular, almost brecciated. In more complete sections, such as **Beinn Iadain**, lignitic mudstones are found above the sandstones that rest on the chalk, followed by mudstones beneath the lavas. The origin of these sediments is also uncertain. Many studies, including Bailey *et al.* (1924) and Bell and Jolley (1998), have considered some of the mudstones to be altered volcanic ash. These beds could, however, also be seen as a fining-upwards cycle from the flint conglomerates to the mudstones, part of a debris flow sequence. More detailed work on the sedimentology is required.

In addition, there may have been a large hiatus in deposition here between the Turonian and Santonian ages (Ilsede Tectonic Phase), and then between the Santonian and Campanian ages, and again between the early and Late Campanian (Wernigerode and Peine tectonic phases). The reworked Cretaceous material found at places such as Torosay and Auchnacraig may be Late Cretaceous and/or Tertiary in age, possibly reflecting debris flows generated during either Subhercynian or Laramide tectonism. Auchnacraig and Torosay, where maximum condensation and disruption of the sediments occurs, lie close to the Great Glen Fault, suggesting continued movement on this structure in the Late Cretaceous Epoch. The presence of extremely localized lithologies, such as the Torosay Limestone, may also reflect a tectonically transported slice, as this sediment seems to be completely out of place with respect to adjacent sections.

Of equal interest is the evidence for climatic conditions in the Late Cretaceous and Early Palaeogene times presented in Bailey's *Desert Shores of the Chalk Sea* (Bailey, 1924). Bailey considered the presence of millet-seed sand grains in the Lochaline White Sandstone Formation and in the greensand below, within, and above the chalk, as well as the silicification of the chalk (silcrete formation), to be evidence of desert conditions. Others (Lowden *et al.*, 1992) have not supported Bailey's interpretation but the presence of possible silcretes in the Inner Hebrides might be compared with the occurrence in south-east Devon of silicified chalk (Haldon Greensand, Chapters 1 and 3). Bailey also considered the red and purple mudstones commonly present between the chalks and the basalt lavas to be lateritic. The presence of alumnite and basalumnite between the chalk and Tertiary deposits in southern England, for example at Newhaven, is also considered, by some, to be evidence of lateritic conditions. Others (e.g. Wilmot and Young, 1985) have suggested a post-depositional, diagenetic model for these alumnites, related to ground water movement. Lignites and lateritic mudstones above the chalk suggest hot tropical conditions rather than a desert. To accept Bailey's contention, the Late Cretaceous Epoch, at least from the Turonian to the Campanian, would have to have experienced desert conditions followed by hot, wet, tropical conditions, possibly in latest Cretaceous times or in the Early Palaeogene. This indicates a dramatic climatic change towards the end of the Cretaceous.

A further key aspect of the Inner Hebrides succession is the possibility that the sediments, including the matrix enclosing reworked chalk and/or the first lava flows of the Thulean Province, may transgress the Cretaceous–Palaeogene (K/P) boundary. Although Bailey *et al.* (1924) and Lee and Bailey (1925) considered the reworked, silicified chalk (flint conglomerate), lignites and the mudstones beneath the lavas to be Tertiary in age, there has been no supporting evidence for this. Dates obtained from the Ardtun Leaf Beds on Mull, which are interbedded with, and some tens of metres above, the first lava flows, range from 55 Ma (Bell and Jolley, 1997) to 60 Ma or >60 Ma (Mussett, 1986). Bell and Jolley (1997, 1998) recognize the same palynological species found in the Ardtun Leaf Beds in lignites beneath the lavas on Mull. This would suggest a Palaeogene (Danian) age for these deposits, but current work has yet to be published to support this interpretation.

Although thin and incomplete, the Scottish Upper Cretaceous Inner Hebrides succession provides supporting evidence for tectonic, sea-level and climatic controls on sedimentation in the British Isles. The GCR sections at **Gribun** and the mountains of **Beinn Iadain** and **Beinn na h-Uamha**, combined with the evidence from the Carsaig sections, are critical to interpreting this succession.