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 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 limestones 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 6.3)c,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 intra-formational 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 a 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 manly 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 Carrickfergus 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 manly 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.

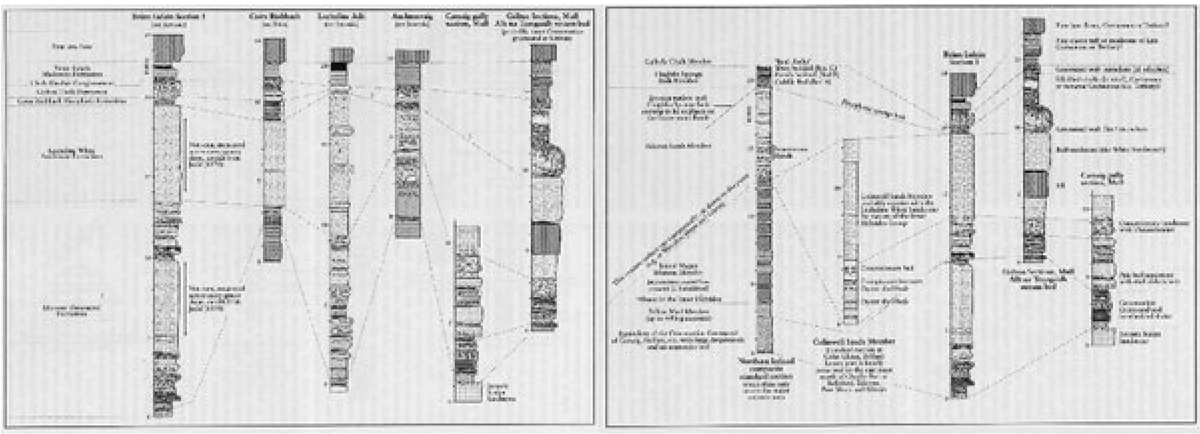
In addition, there may have been a large hiatus in deposition here between the Turonian and Santonian ages (Ilsede Tectonic Phase), and then between the Santonian and Campanian ages, and again between the early and Late Campanian (Wernigerode and Peine tectonic phases). The reworked Cretaceous material 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.

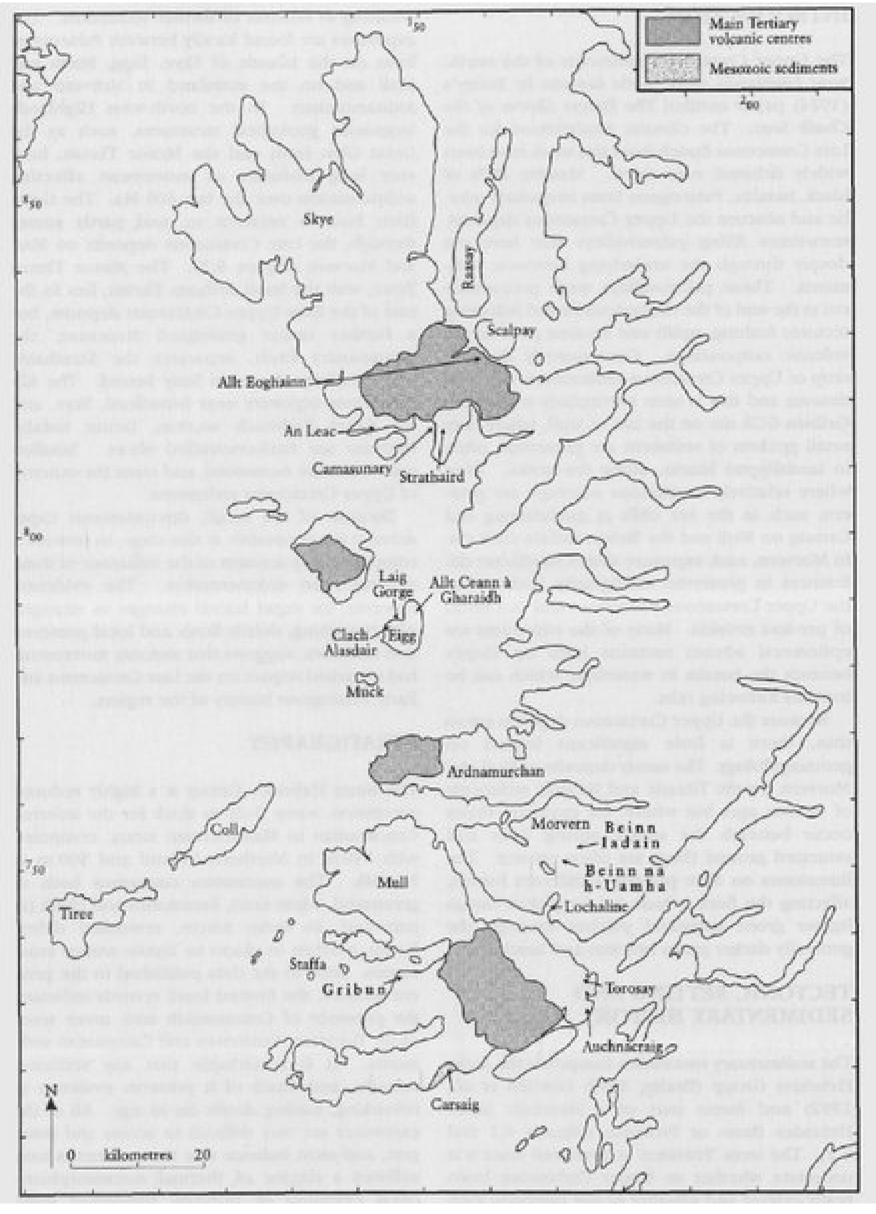
A further key aspect of the Inner Hebrides succession is the possibility that the sediments, including the matrix enclosing reworked chalk and/or the first lava flows of the Thulean Province, may transgress the Cretaceous–Palaeogene (K/P) boundary. Although Bailey *et al.* (1924) and Lee and Bailey (1925) 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 (Daman) 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.

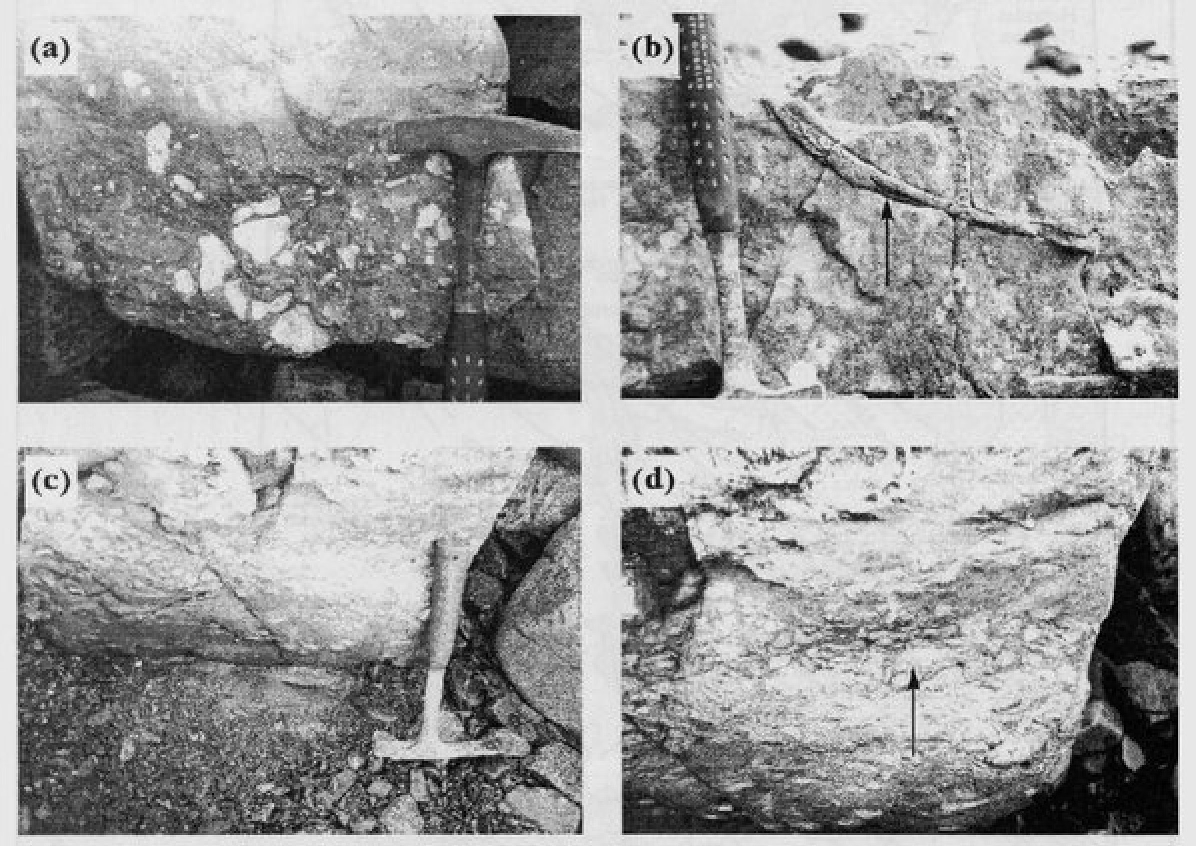
References



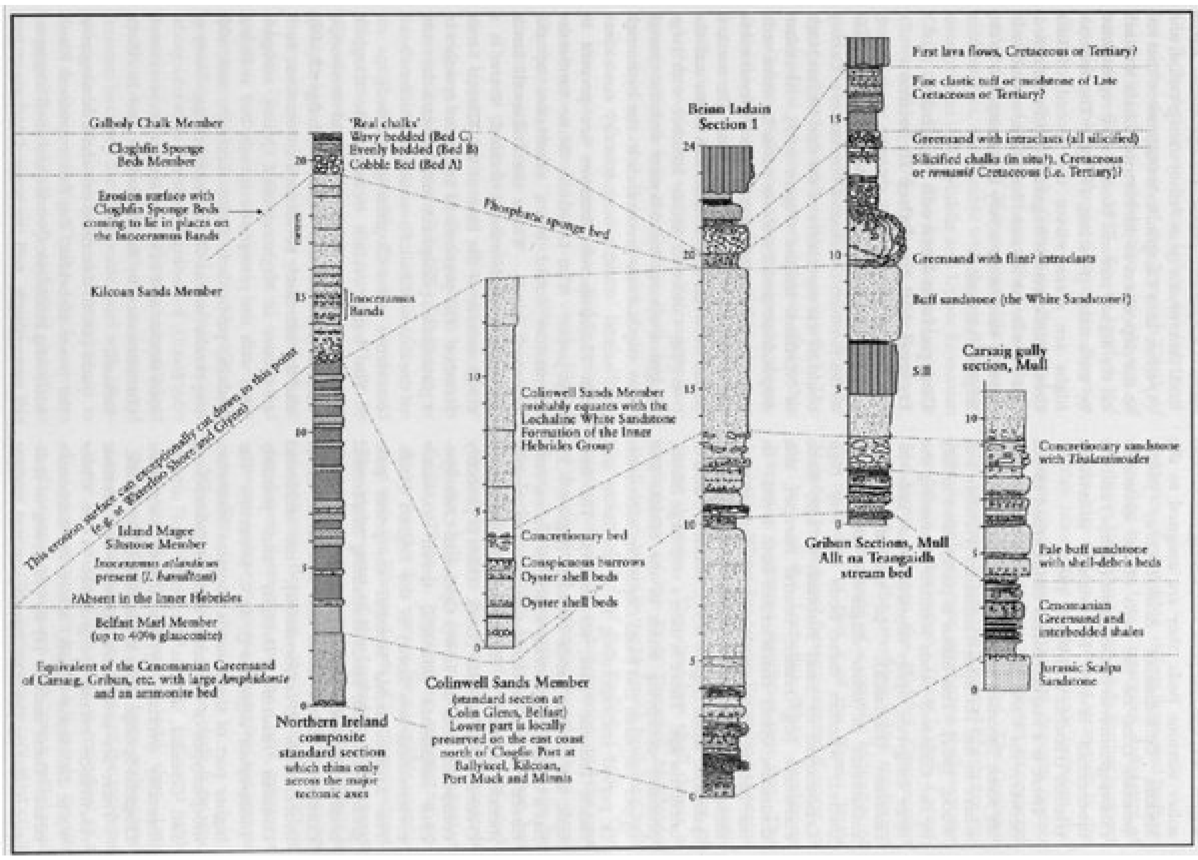
(Figure 6.34) Correlation of the Upper Cretaceous GCR sites in the Inner Hebrides at Morvern, Argyll (Beinn Iadain and Lochaline) and at Auchnacraig, Carsaig, and Gribun, Mull. Note the restructuring of the lithostratigraphy of the Inner Hebrides Group.



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



(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 6.35) 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 ladain phosphatic sandy marl, and the Cloghfin Sponge Beds of Northern Ireland. These beds are followed by the onset of real chalk in both areas.