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Holocene relative sea levels and coastal changes in the lower Cree valley and estuary, SW Scotland, U.K.

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ABSTRACT: Changes in Holocene (Flandrian) relative sea levels and coastal geomorphology in the lower Cree valley and estuary, SW Scotland, are inferred from detailed morphological and stratigraphical investigations. A graph of relative sea level changes is proposed for the area. Rising relative sea levels during the early Holocene were interrupted at *c*. 8300–8600 ^{14}C years B.P. (*c*. 9400–9900 calibrated years B.P.), when an extensive estuarine surface was reached at *c*. −1 m O.D., after which a fluctuating rise culminated at *c*. 6100–6500 ^{14}C B.P. (*c*. 7000–7500 calibrated years B.P.) in a prominent shoreline and associated estuarine surface measured at 7·7–10·3 m O.D. A subsequent fall in relative sea level was followed by a rise to a shoreline at 7·8–10·1 m O.D., exceeding or re-occupying the earlier shoreline over much of the area after *c*. 5000 ^{14}C B.P. (*c*. 5,800 calibrated years B.P.), before relative sea level fell to a later shoreline, reached after *c*. 2900 ^{14}C B.P. (*c*. 3100 calibrated years B.P.) at 5·5–8·0 m O.D., following which relative sea levels fell, ultimately reaching present levels. During these changes, a particular feature of the coastline was the development of a number of barrier systems. The relative sea level changes identified are compared with changes elsewhere in SW Scotland and their wider context is briefly considered.

KEY WORDS: Diatoms, foraminifera, glacio-isostasy, morphology, ostracoda, particle size, pollen, shoreline, stratigraphy.

This paper describes the application of morphological, lithostratigraphical and biostratigraphical techniques in determining changes in both relative sea levels and coastal geomorphology in an estuarine area which has experienced glacio-isostatic uplift. The environmental context and deposits in which the techniques have been employed are sufficiently consistent to enable a detailed picture of these changes in the area to be gained, providing an additional perspective on the pattern of Holocene (Flandrian) relative sea levels more widely in Scotland.

1. The area

The lower Cree valley and estuary lie at the head of Wigtown Bay, on the northern shore of the Solway Firth, SW Scotland (for location, see Fig. 1). Rising in the Southern Uplands, the Cree drains southward and becomes tidal at Newton Stewart, where the lower valley reaches the estuary. In this area, the river is flanked by the raised estuarine sediments of the carselands, which contain detailed evidence for Holocene relative sea level changes. The carselands are widely covered by the remains of ombrogenous peat mosses, which although partially cleared mainly during the eighteenth and nineteenth centuries (e.g. Boyd 1792; Duncan 1795; Young 1841; Reid 1841; Richardson 1841; Picken in press), still constitute some of the largest lowland peat mosses in Scotland. South of the mouth of the Cree, along the shores of Wigtown Bay, small areas of carseland are also found along the lower reaches of the River Bladnoch and the Moneypool Burn. Wigtown Bay is a macrotidal environment, the tidal station at Kirkcudbright Bay, in an analogous situation to the east, recording a Spring tidal range of 6.70 m (see Table 1). It is believed likely that the depositional environment of the Holocene sediments discussed in this paper would have involved a similar Spring tidal range, although no estimates of Holocene tidal ranges in the area have so far been made (Lloyd *et al.* 1999).

2. Previous work

The glacio-isostatic setting of the Cree was established by the beginning of the twentieth century, Wright (1914) placing SW Scotland within the area of the differentially uplifted '25-foot beach', which he subsequently identified as diachronous from an interpretation of archaeological evidence in neighbouring areas (Wright 1925, 1928, 1934). The ice load reflected by the uplifted 'beach' is likely to have exhibited a surface slope southwards across the area, as is implied by studies depicting an ice margin withdrawing northwards during deglaciation (e.g. Sissons 1967). Recent models of land uplift in Scotland during the Late Devensian and Holocene (e.g. Sissons 1967, 1974, 1983; Donner 1970; Jardine 1982; Firth *et al.* 1993; Lambeck, 1993, 1995; Smith *et al.* 2000) depict uplift declining southwards across the area reflecting the likely pattern of ice sheet loading.

Detailed studies of raised shoreline distribution and relative sea level changes in the lower Cree valley and estuary were undertaken largely after the broad pattern of glacio-isostatic uplift had been postulated. In 1975, from a study of raised shorelines along the northern shore of the Solway Firth and an analysis of radiocarbon determinations on biogenic material within the carseland sediments (listed in Table 3), Jardine concluded that Holocene relative sea levels were occupying

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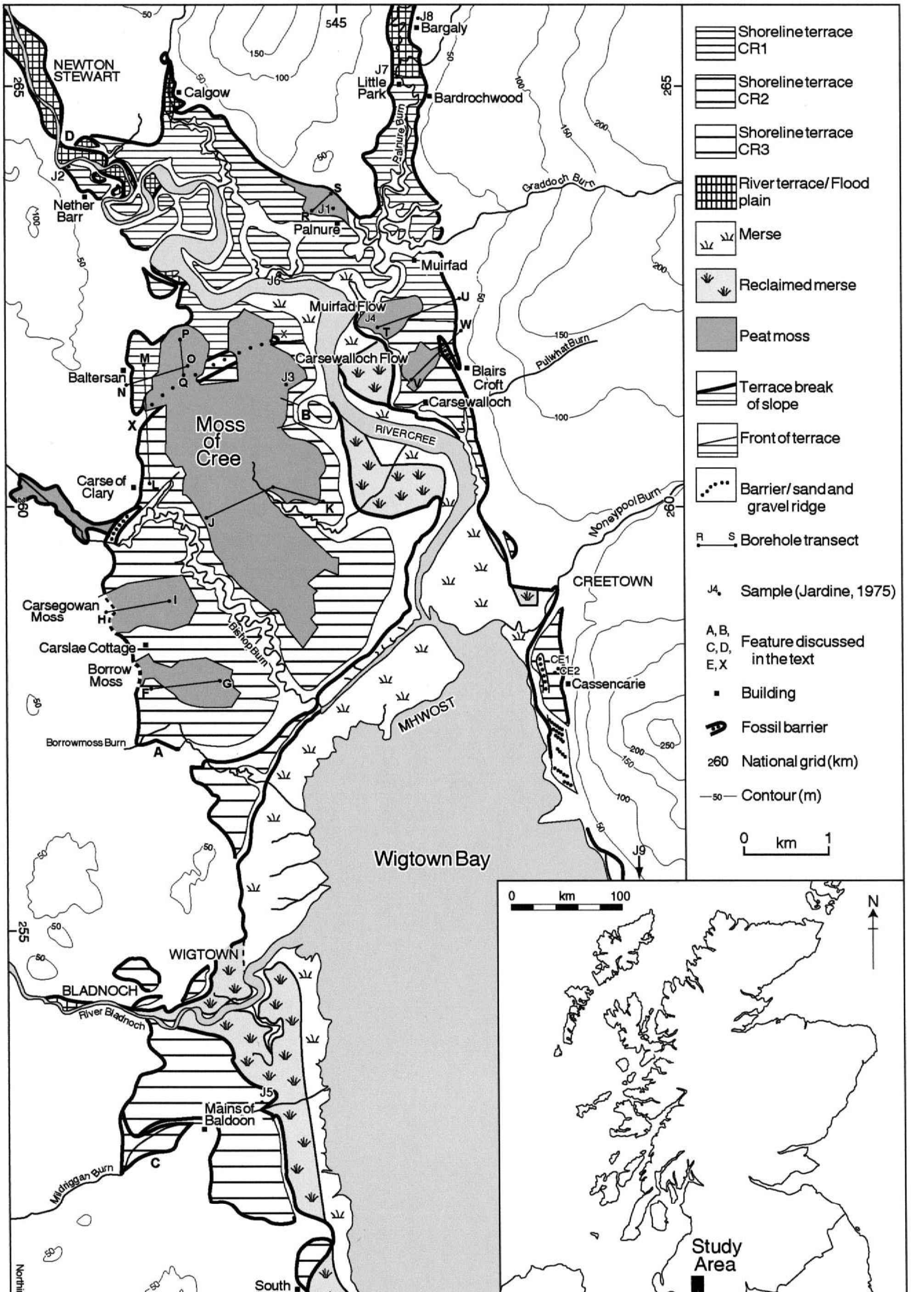

Figure 1 Generalised morphological map of the features discussed, with locations of the borehole transects undertaken. Inset: location of the area.

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Table 1 Tide levels relative to the O.D., in metres, at Kirkcudbright Bay (Admiralty Hydrographic Department 1996)

Lat. 54° 48′, Long. 4° 04′						
Mean High Water Springs	Mean Low Water Springs	Spring Tide Range	Mean High Water Neaps	Mean Low Water Neaps	Neap Tidal Range	Mean Tide Level
3·80	−2·90	6·70	2·20	−1·30	3·50	0·45

much of the lower Cree valley and estuary by *c*. 8000 ^{14}C years B.P., and did not begin to withdraw from much of the area until *c*. 5000 ^{14}C years B.P., subsequently falling to within 1 m of present levels by *c*. 2000 ^{14}C years B.P.

Jardine's (1975) conclusions were at variance with work being undertaken elsewhere in Scotland at the time, which indicated that Holocene relative sea levels had culminated nearer to 6000 ^{14}C years B.P. (e.g. Sissons & Brooks 1971) and in 1989 Haggart, in a review of the evidence for relative sea level change in the eastern Solway Firth, cast doubt on the validity of some of the ^{14}C dates there used by Jardine (1975) as relative sea level index points, maintaining that Holocene relative sea levels in that area (and by implication in the Solway Firth as a whole) had probably culminated before *c*. 6600 ^{14}C years B.P. However, Smith *et al.* (2000), in a paper describing preliminary results of an empirical study on patterns of Holocene glacio-isostatic land uplift in mainland Scotland, in which they identified isobases for three shorelines, suggested that the pattern for the Cree area disclosed two shorelines reached in the middle Holocene, the earlier shoreline estimated to have been reached at *c*. 5800–6850 ^{14}C years B.P. and the later and, over much of the area, higher, feature dating from 2000–4200 ^{14}C years B.P. Isobases for these shorelines are shown in Figure 2.

A difficulty which has been encountered in reconstructing relative sea level changes for the area has been the lack of microfossil studies, as Haggart (1989) observed. Apart from pollen analysis of middle Holocene sequences in cores from Moss of Cree by Moar (1969) and Brown & Heslop (1979), there are no published systematic microfossil studies which record the environment in which the Holocene relative sea level changes in the area took place. There appear to have been no previous studies detailing coastal changes which may have occurred as a consequence of relative sea level changes or other processes in the Cree valley and estuary.

3. Methodology

The approach taken in the present work was one in which detailed morphological studies, including the measurement of the altitude of former shore features, was undertaken, informing the selection of sites for stratigraphical work. Stratigraphical work in turn involved basic stratigraphical survey to determine the broad sequence of estuarine and terrestrial sedimentation, followed by the selection of boreholes for detailed lithostratigraphical and biostratigraphical studies with the aim of identifying the environment of deposition of the sediments studied and of obtaining radiocarbon-dated sea level index points from conformable contacts. The particle size characteristics of the minerogenic sediment studied were examined in detail from the deepest borehole made (CW14, see below), which passed through all types of estuarine sediment examined here. From four deep boreholes, two on each side of the valley, (CC2, CCT2, P6 and CW14), multiproxy microfossil analysis was undertaken using foraminifera, ostracoda and pollen analysis, whilst from eleven shallower boreholes (BM12, BM13, CM3, CM4, CM8, MC1, MC16, MC23, CW1, CW2, BC4/2) pollen and/or diatom analysis was employed to determine the content and continuity of intercalated peat and minerogenic horizons.

4. Techniques

4.1. Morphological mapping and survey

The carselands and related features were mapped morphologically at a scale of 1:10000 using standard geomorphological mapping techniques (see e.g. Sissons *et al.* 1966). Following this, the altitudes of all terraces, together with present-day mudflats and saltmarshes, were measured along their lengths at 50 m intervals from British Ordnance Datum Newlyn (O.D.) using a Total Station. To ensure comparability, only the highest point on a feature was measured at each 50 m interval. This generally corresponded to the inner (inland) margin, but where this margin was marked by a depression or channel, a line of altitudes was taken seaward to identify the highest point. Surface peat was avoided in these measurements, as were stream fans or anthropogenically-disturbed ground. Over 3000 altitudes were measured. All boreholes were also levelled to O.D. In the text of this paper, all altitudes are given in terms of O.D. and High Water Mark of Ordinary Spring Tide (HWMOST) at Kirkcudbright Bay, the latter value being shown in parentheses.

The altitude data obtained in this work are subject to a number of errors as discussed by Sutherland (1981) and Gehrels *et al.* (1996). These may be summarised as surveying errors, errors associated with the relationship of the point being measured to former tidal levels, and errors due to settlement or compaction of sediment. Surveying errors are estimated at ±0·021 m following Sutherland (1981), whilst errors relating to former tidal levels are assumed to have been no more than the range of the present-day tidal mudflat inner margin altitudes, in view of the estuarine location, following Smith *et al.* (2000). Over the 92 mudflat inner margin altitudes obtained, the range amounted to ±0·63 m. In the case of settlement or compaction, it is assumed that this will have primarily affected the peat and similar biogenic sediments, and to have amounted to between 68% and 40% of the sediment thickness, following Cullingford *et al.* (1980). For transgressive contacts, the whole of the peat layer beneath the minerogenic sediment has been assumed to have been affected. In the case of regressive contacts, the effect has been estimated based upon stratigraphical studies at similar sites (e.g. at Fraserburgh, see Smith *et al.* 1982). At these latter contacts, the full range of compaction is assumed to have affected the underlying peat where the minerogenic layer is 0·5 m thick or less, whilst a linear scale of compaction from 100% to 0% of the full range has been applied where the minerogenic layer ranges from 0·51 m to 2·50 m thickness. Examples of compaction estimates are given in Table 2.

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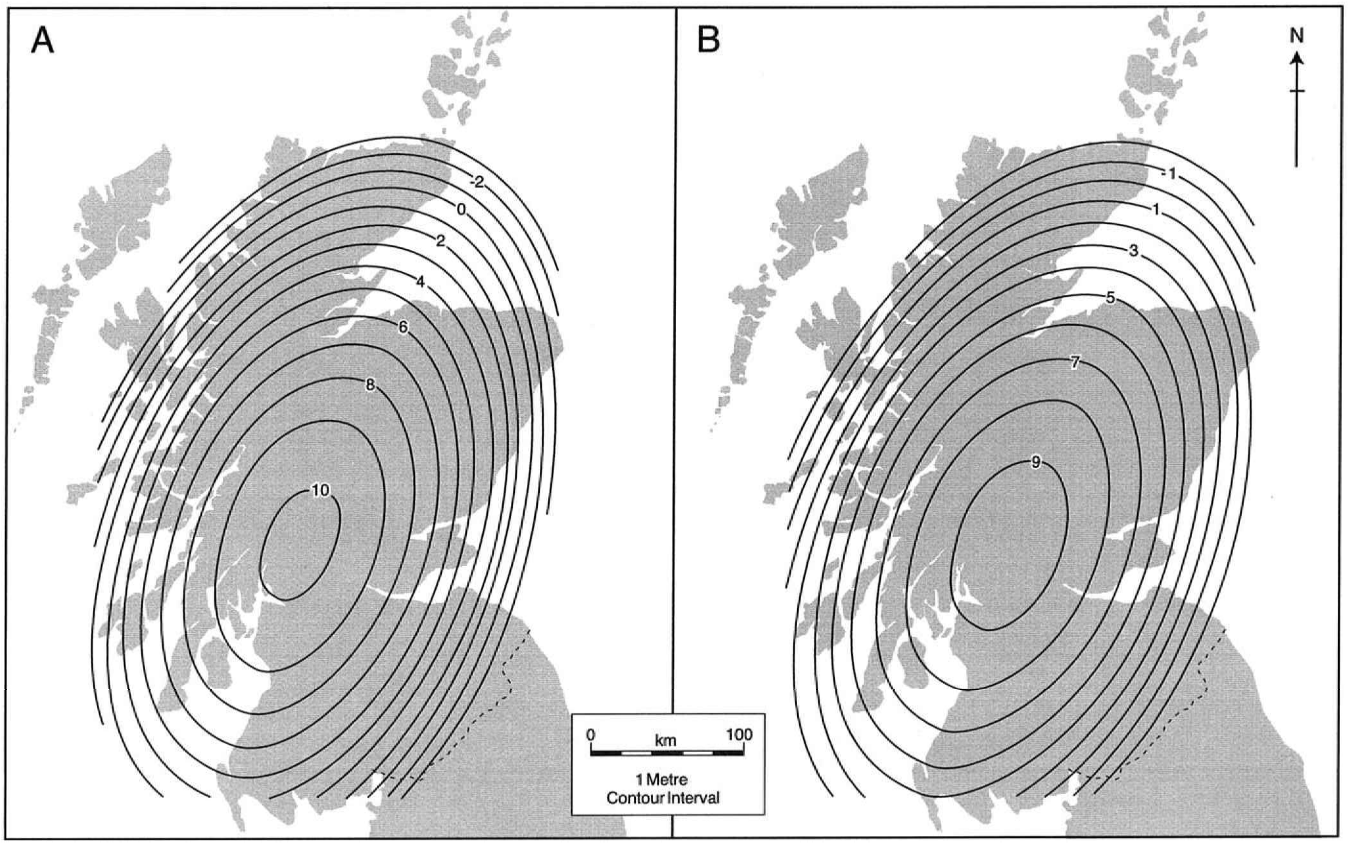

Figure 2 Isobase maps for the Main Postglacial Shoreline (A) and Blairdrummond Shoreline (B), after Smith *et al.* (2000).

These altitudinal error measures are applied to radiocarbon-dated horizons in Tables 3 and 4 and have been applied in the construction of a relative sea level graph described below, but have not been applied in the graphs of shoreline measurements presented here. However, in summaries of shoreline heights given in this paper, surveying and tidal level errors have been included.

4.2. Coring and stratigraphical description

The stratigraphy of selected sites was initially determined using a manually operated gouge sampler. Boreholes selected for detailed analysis were then made using a 'Russian-type' (Jowsey 1966) sampler through the surface peat and powered percussion-type systems through the intercalated minerogenic sediments and peat beneath. The stratigraphy of each of these cores was then recorded in detail in the laboratory prior to sampling. The thickness of the estuarine sequences in the area necessitated boreholes of up to 21 m depth, rather deeper than in most Holocene estuarine sequences so far recorded in Scotland (for comparison see e.g. Smith *et al.* 1992, 1999). 218 boreholes were made.

4.3. Particle size analysis

Particle size distributions were determined for the estuarine sediments at intervals through the deepest core (CW14). A laser granulometer, a Malvern Mastersizer 2600, was used. The accuracy of this approach to particle size is discussed in Shi (1995). Particle size composition and mean particle size were initially measured from 5 mm-thick samples taken every 10 cm from 1·30 m depth to 15 m depth, and every 20 cm thereafter.

Table 2 The method used in this paper for calculating the likely effects of peat compaction on index point altitudes derived from boreholes

Example 1: Transgressive Contact					
Altitude of Contact, O.D.	Peat Thickness Directly Below Contact	Peat Compaction at 68%	Peat Compaction at 40%	Altitude Range Due to Compaction	
10 m	2 m	+1·36 m	+0·8 m	11·36-10·8 m	
Example 2: Regressive contact, where the transgressive layer is between 0·51 m *and* 2·5 m *thick*					
Altitude of Contact, O.D.	Peat Thickness of Layer Directly Beneath Transgressive Layer	Thickness of Transgressive Layer	Peat Compaction as a Proportion of 68%	Peat Compaction as a Proportion of 40%	Altitude Range Due to Compaction
10 m	2 m	1 m	$68 \times \frac{1}{2{\cdot}5} = 27{\cdot}2\% = 0{\cdot}54$ m	$40 \times \frac{1}{2{\cdot}5} = 16\% = 0{\cdot}32$ m	10·54-10·32 m

At regressive contacts where the transgressive horizon is < 0·51 m *thick, compaction estimates are as for transgressive contacts; where the transgressive horizon is* > 2·5 m *thick, no compaction estimate is applied.*

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Table 3 Previously published radiocarbon dates relating to relative sea level changes in the Cree area (Jardine, 1975), with estimated height ranges of the samples, based upon the error measures used in the present paper

Location (Figure 1)	Grid Reference (NX)	Lab. Code	^{14}C age, B.P., 1σ	Calib 4 age, B.P., 2σ	Material Dated	Height of Contact O.D.	Stratigraphical Position	Regressive (R) or Transgressive (T) Contact	Estimated Height Range, (O.D.)		Reference
									Max.	Min.	
J1	4500·6360	Birm-189	6240 ± 240	7583–6528	Wood	6·38	Wood in 0.05 m peat above silt	R?	7·03	5·73	Shotton & Williams 1971
J1	4500·6360	Birm-415	6540 ± 120	7654–7249	Peat	6·38	0.05 m Peat above silt	R	7·03	5·73	Shotton *et al.*, 1974
J2	4160·6400	Q-639	6159 ± 120	7316–6730	Wood	4·25	Wood in silt		4·90	3·60	Godwin & Willis 1962
J3	4450·6140	I-5513	4000 ± 100	4826–4153	Peat	8·35	0.25 m Peat above silt	R	9·00	7·70	Buckley 1973
J4	4530·6200	SRR-26	4746 ± 50	5594–5323	Wood	7·92	Wood in 0.05 m peat above silt	R?	8·57	7·27	Harkness & Wilson 1973
J5	4400·5300	I-5068	2290 ± 95	2209–2062	Shell	5·15	*Cerastoderma* sp in sand		5·80	4·50	Jardine 1975
J6	4430·6260	I-5514	6325 ± 120	7958–6911	Wood	4·30	Wood in silt		4·95	3·65	Buckley 1973
J7	4500·6570	Birm-219	7450 ± 200	8625–7866	Wood	6·34	Wood in peat layer in silt		6·99	5·69	Shotton & Williams 1971
J8	4620·6650	Birm-188	7960 ± 350	9596–8032	Wood	6·30	Wood in peat elow silt	T?	6·95	5·65	Shotton & Williams 1971
J9	4820·5550	GU-374	2027 ± 108	2311–1714	Shell	5·24	*Cerastoderma* sp. in silt		5·89	4·59	Ergin *et al.* 1972

Where initial investigation revealed strong variations in particle size, re-sampling at a 5 cm interval was carried out; this was the case for 2–2·4 m and 4·7–4·9 m depth.

4.4. Microfossil analyses

These analyses followed a well-established, routine protocol to analyse a combination of microfossils, involving pollen analysis, diatom analysis, and analysis of foraminifera and ostracoda. In this study, microfossil analyses have been used both to determine broad changes in the environment of deposition of the estuarine and marine sediments studied, and to determine the presence or absence of depositional lacunae, thus assisting in the determination of changes in relative sea level (Wells 1999).

All microfossil samples were prepared using conventional procedures with a minimum of 300 microfossils counted at each level, except in sediments where the microfossils were poorly preserved.

Sub-samples of 0.5 cm thickness and either 1 g or 2 g wet weight were prepared for pollen analysis using the procedure described by Barber (1976) and identified using pollen keys and a modern type slide collection (Andrew 1984; Faegri *et al.* 1989; Moore *et al.* 1991). Fossil diatom assemblages were analysed from boreholes B1 and B2 to determine the nature of the change from estuarine to terrestrial sedimentation. Sediment samples of 0.5 g wet weight were taken every 2 cm across the contact horizons and prepared for analysis using standard techniques (Barber & Haworth 1981). Diatom identification followed Cleve-Euler (1951–1955), Hendey (1964), Hustedt (1927–62) and Krammer & Lange-Bertalot (1991).

Given the deep sedimentary sequences that flank the Cree Estuary, 1 cm-thick samples of approximately 10 g were analysed down core, initially every 50 cm, for foraminifera and ostracoda. The sampling resolution was then increased where distinct faunal changes were taking place. Samples for foraminifera and ostracoda analysis were boiled to break down the sediment before being wet-sieved and oven-dried. Once dried, each sample was then sieved through a 112 μm-aperture mesh and the larger portion was analysed quantitatively for each of the faunal groups. The smaller portion was scanned to record additional information associated with juvenile populations. Identifications were based upon Haynes (1973, 1981) and Murray (1979). The identification of the ecomorphotypes of *Elphidium excavatum* and *Ammonia beccarii* were undertaken using the definitions of Miller *et al.* (1982) and Murray (1979) respectively. Ostracod identification was based on Mizen (1986), Athersuch *et al.* (1989), Henderson (1990), Griffiths (1995) and from unpublished records held by Dr A. Wood, Coventry University.

4.5. Microfossil data presentation

The microfossil data are presented in summary diagrams drawn using Tilia version 2.0.b.4 and Tilia.graph. Microfossil assemblage zones were constructed using CONISS (Grimm 1991, 1991-1993). Parts of the cores where microfossils were absent are designated as 'barren zones'. Pollen data are presented as percentages of total land pollen (TLP), excluding spores and aquatics. Spores and aquatics are also expressed as a percentage of total land pollen. A cross denotes values of $\leq$ 1% TLP. Plant nomenclature follows Stace (1991) and takes into account the problems of categorising plant species on the basis of their pollen morphology (Bennett *et al.* 1994). Summary curves for trees and shrubs (constituting arboreal pollen, AP); and dwarf shrubs and herbs (non-arboreal pollen, NAP) are shown.

Diatoms are presented as percentages of total populations. Diatom species are divided into classes based on life form and salinity as advocated by Vos & de Wolf (1988). Foraminifera and ostracoda are presented in total numbers and are grouped on the basis of changes in water salinity. The foraminifera are separated into five categories (after Murray 1979): marsh, brackish, brackish/marine, marine (inner shelf) and marine

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Table 4 Radiocarbon dates obtained during this work

Relative Sea Level Index Point No.	Sample No.	Borehole No.	Grid Reference (NX)	Lab. Code (Beta-)	^{14}C Age, B.P., 1σ	Calib 4 Age, B.P., 2σ	Sample Thickness (m)	Height at Contact, O.D.	Depth from Surface, m	Stratigraphical Position	Material Dated	Transgressive (T) or Regressive (R) Contact	Estimated Height Range, (O.D.)	
													Max.	Min.
1	C1	BM12	4319·5800	120961	3380 ± 70	3829–3467	0·02	8·44	2·97	Peat above silt	Peat	R	9·09	7·79
2	C2	BM13	4343·5776	120962	3470 ± 80	3963–3483	0·02	7·96	3·30	Peat above silt	Peat	R	8·61	7·31
	C3	CM3	4223·5887	84189	3050 ± 60	3383–3077	0·02	9·60	3·33	Peat above silt	Peat	R	10·25	8·95
3	C4	CM4	4239·5890	83746	4050 ± 90	4830–3261	0·02	9·23	3·82	Peat above silt	Peat	R	9·88	8·58
4	C5	CM8	4302·5898	83747	3680 ± 60	4222–3835	0·02	8·97	2·87	Peat above silt	Peat	R	9·62	8·32
5	C6	MC1	4327·5987	83750	4050 ± 50	4809–4416	0·02	8·98	2·26	Peat above silt	Peat	R	9·63	8·33
6	C7	MC16	4974·6063	83751	4330 ± 80	5261–4654	0·02	8·21	2·55	Peat above silt	Peat	R	8·86	7·56
7	C8	MC23	4296·6176	96320	5030 ± 110	5991–5588	0·03	9·16	3·70	Peat above silt	Peat	R	10·06	8·74
8	C9	MC23	4296·6176	96321	5770 ± 90	6782–6323	0·03	9·09	3·77	Peat beneath silt	Peat	T	9·99	8·67
9	C10	MC23	4296·6176	96322	6470 ± 80	7560–7251	0·03	8·86	4·00	Peat above silt	Peat	R	9·51	8·21
10	C11	CC2	4271·6025	96323	8600 ± 90	9888–9439	0·03	2·43	7·15	Peat beneath silt	Peat	T	3·50	2·13
11	C12	P6	4491·6363	105932	6100 ± 70	7209–6752	0·03	8·66	0·60	Peat above silt	Peat	R	9·31	8·21
12	C13	P6	4491·6363	96326	8190 ± 80	9426–9000	0·03	−1·13	10·63	Peat beneath silt	Peat	T	0·23	−1·19
13	C14	P6	4491·6363	96327	8310 ± 100	9528–9026	0·02	−1·15	10·70	Peat above silt	Peat	R	0·50	−1·80
14	C15	BC4/2	4637·6223	100919	6800 ± 130	7929–7430	0·03	7·16	2·58	Peat above silt	Peat	R	8·16	6·80
15	C16	BC4/2	4637·6223	100918	7210 ± 120	8319–7761	0·03	7·09	2·65	Peat beneath silt	Peat	T	8·09	6·73
16	C17	BC4/2	4637·6223	100917	7510 ± 310	9029–7684	0·03	6·96	2·80	Peat above silt	Peat	R	7·71	6·39
17	C18	BC4/2	4637·6223	100916	7240 ± 90	8276–7868	0·03	5·86	3·87	Peat beneath silt	Peat	T	6·66	5·32
18	C19	BC4/2	4637·6223	100915	7830 ± 110	9007–8393	0·03	5·81	3·93	Peat above silt	Peat	R	6·46	5·16
	C20	BC4/2	4637·6223	100914	7820 ± 80	8982–8413	0·04	3·49-3·45	6·24-6·28	Peat between silt layers	Peat		4·26	2·90
19	C21	BC4/2	4637·6223	96324	8400 ± 80	9535–9146	0·03	0·88	8·85	Peat beneath silt	Peat	T	2·44	0·77
20	C22	CW1	4573·6152	83748	3810 ± 70	4417–3982	0·02	8·59	2·62	Peat above silt	Peat	R	9·24	7·94
21	C23	CW6	4611·6172	83749	4010 ± 80	4813–4244	0·02	8·94	1·27	Peat above silt	Peat	R	9·59	8·29
22	C24	CW14	4610·6181	96325	8580 ± 80	9711–9439	0·03	−0·51-0·54	10·68-10·71	Peat above silt	Peat	R	0·11	−1·22
	C25	CW14	4610·6181	92209	9680 ± 50	11197–10788		−9·37-9·32	19·54-19·59	*Cerastoderma edule* shell	Shell		−8·67	−10·02

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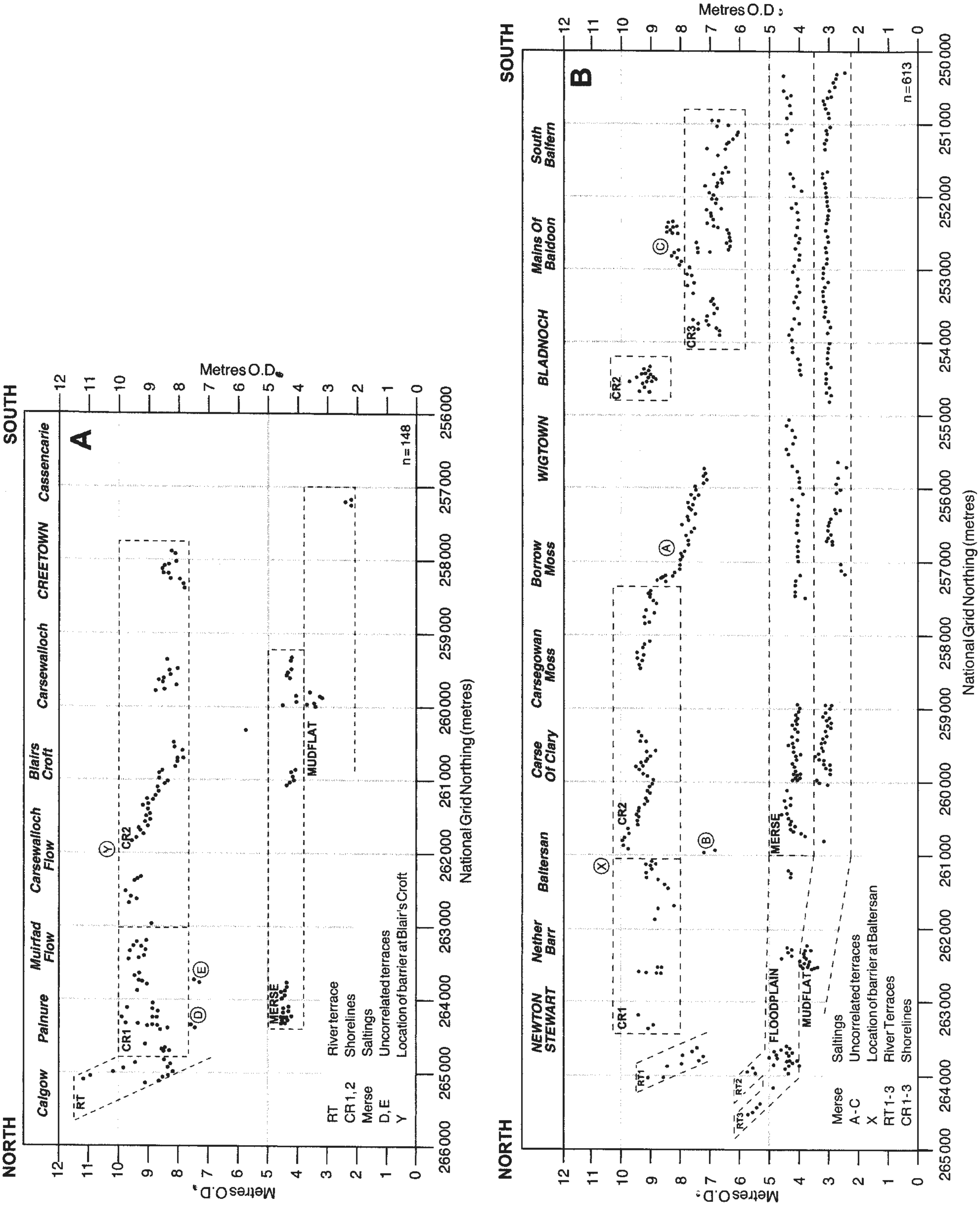

Figure 3 Terrace altitudes plotted along a N-S axis for the left bank of the Cree (A) and right bank (B).

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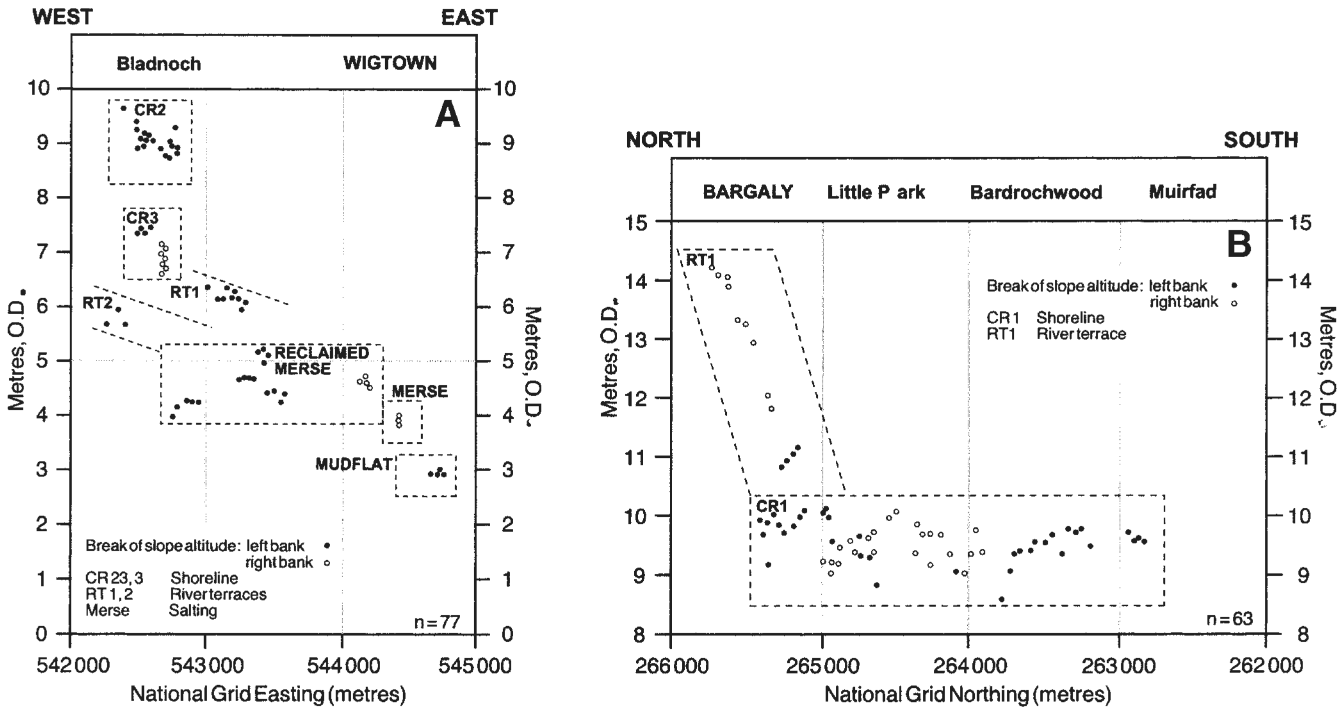

Figure 4 Terrace altitudes for (A) the river Bladnoch valley, plotted along a W–E axis and (B) the Palnure Burn valley, plotted along a N–S axis.

(planktonic), whilst ostracoda are grouped informally into the following categories: freshwater, freshwater (low salinity), brackish, marine/brackish and marine.

4.6. Radiocarbon dating

Radiocarbon assay was undertaken by Beta Analytic Inc. Peat samples were 2–3 cm thick, taken from 10 cm-diameter half cores obtained with a modified 'Russian-type' peat sampler or from 5 cm-diameter piston cores. In the case of the piston cores, the outer 2–4 mm of the sampled core sections was removed to avoid contamination. Where wood, visible rootlets, or stems and rhizomes of *Phragmites* were present in the peat they were extracted from the sample. One sample dated was of shell. Details of all the radiocarbon dates obtained in this study are given in Table 4, which gives the CALIB 3 rev. 4.2, equivalent of each date using the intercept method (Stuiver & Reimer 1993; Stuiver *et al.* 1998). In the text of this paper dates are given in their radiocarbon age B.P. (before present) to one standard deviation, with the calibrated range equivalent B.P. to two standard deviations in parentheses, thus 8580 ± 80 (9711–9439). Approximate ages are given in their radiocarbon age B.P. with the calibrated equivalent B.P. in parentheses, thus *c*. 7900 (*c*. 8600).

5. Morphology

Figure 1 is a generalised morphological map of the area. Arguably the most distinctive features are the carselands, below which lie extensive saltmarshes (locally known as merse) and, at low tide, the widespread mudflats, whilst up-valley, river terraces occur. The carselands are locally remarkably flat, and where they reach the valley sides a sharp break of slope occurs. However, significant features may be observed in the carseland surface. Breaks of slope at Borrow Moss (Fig. 1, feature A), and in the Bladnoch and Moneypool Burn valleys define the limits of separate carseland surfaces. Abandoned river channels and former tidal creeks, especially up-valley from Muirfad Flow, define former drainage patterns. Along the edge of the carselands near Creetown and farther north at Blairs Croft on the eastern side of the area and at Carse of Clary and Baltersan on the western side, ridges of sand and gravel occur. South of Cassencarie on the eastern side of the estuary these ridges collectively form a low, undulating area, but elsewhere they are partly buried beneath the carseland sediments. The ridge at Baltersan (Fig. 1, feature X) is particularly extensive, running north-eastward for almost 2 km towards the Cree. Together with the ridge at Blairs Croft lying on the opposite side of the valley, this ridge forms a barrier system which effectively constricts the passage of the river through the carselands. The detail of the carseland surface and its constituent features is locally buried beneath the surface peat mosses, but where these mosses occur, carseland features have been traced in boreholes and ditch sections.

In Figures 3 and 4, measured altitudes for the terrace breaks of slope (or locally highest point), together with merse and mudflat altitudes, are plotted along a north–south axis for the features on each bank of the Cree and for the Palnure Burn, and along a west–east axis for the River Bladnoch valley. These plots disclose the down-valley slope of the river terrace altitudes, contrasting with the other terraces present. The shoreline terraces (CR1, 2, 3) are discussed below. The consistency of the mudflat and merse (saltings) altitudes is evident from the graphs. On the merse, localised breaks of slope occur seaward of the inner margin, as was recognised by Marshall (1962a, b). However, these do not amount to more than 30 cm below the inner margin altitude, and can rarely be traced for more than a few tens of metres. They have been measured, but not plotted here. Reclaimed merse altitudes have also been measured. They generally lie *c*. 0·2–0·5 m above unreclaimed merse. They have not been plotted here, except for the River Bladnoch valley, where they constitute most of the merse area. The mudflat inner margin lies at an altitude of 2·5 m to 3·5 m (−1·3 m to −0·3 m) before rising to 4·0 m (0·2 m) at its extreme up valley limit, whilst the unreclaimed merse inner margin lies at an altitude of 3·6 m

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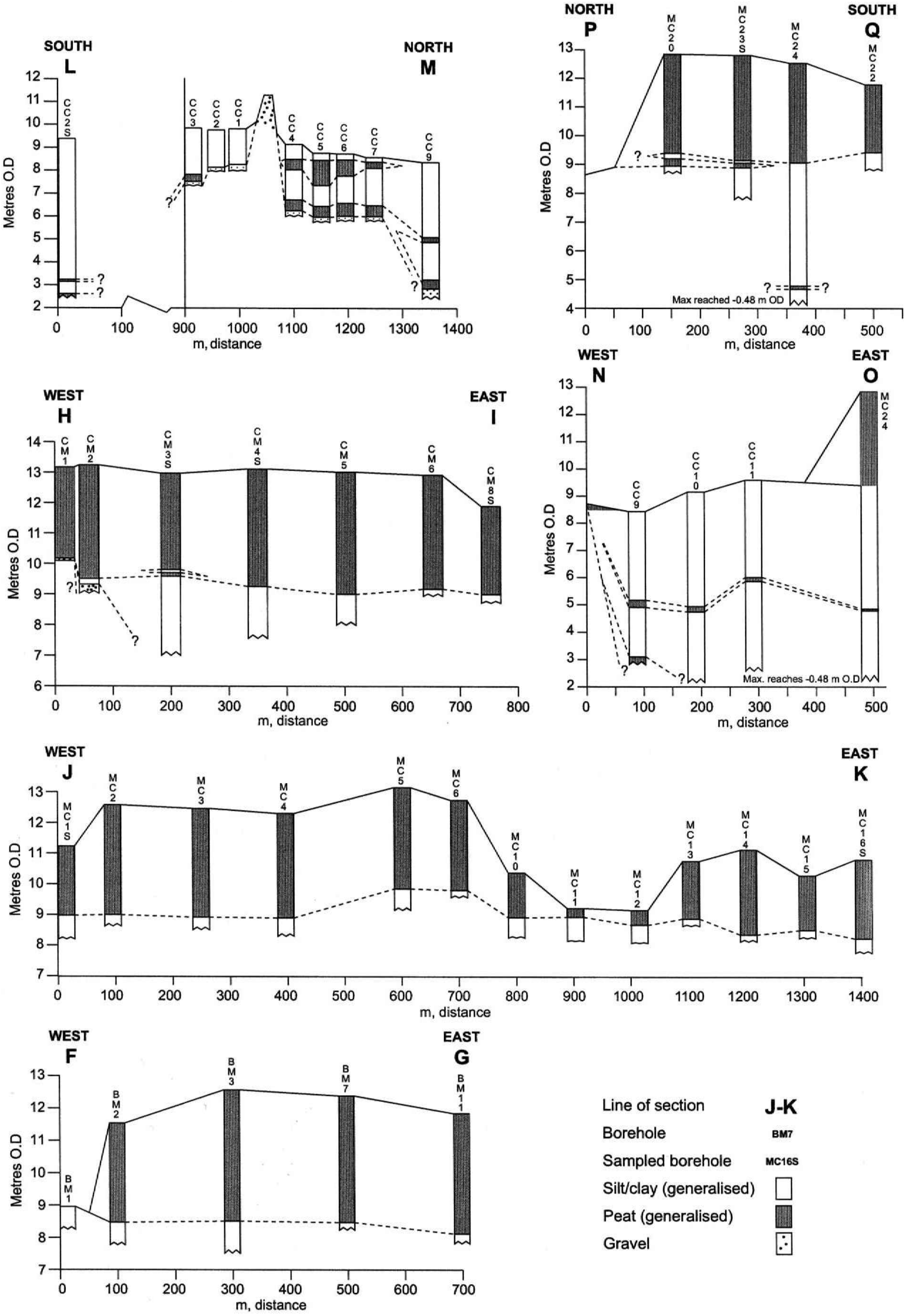

Figure 5 Borehole transects west of the river Cree.

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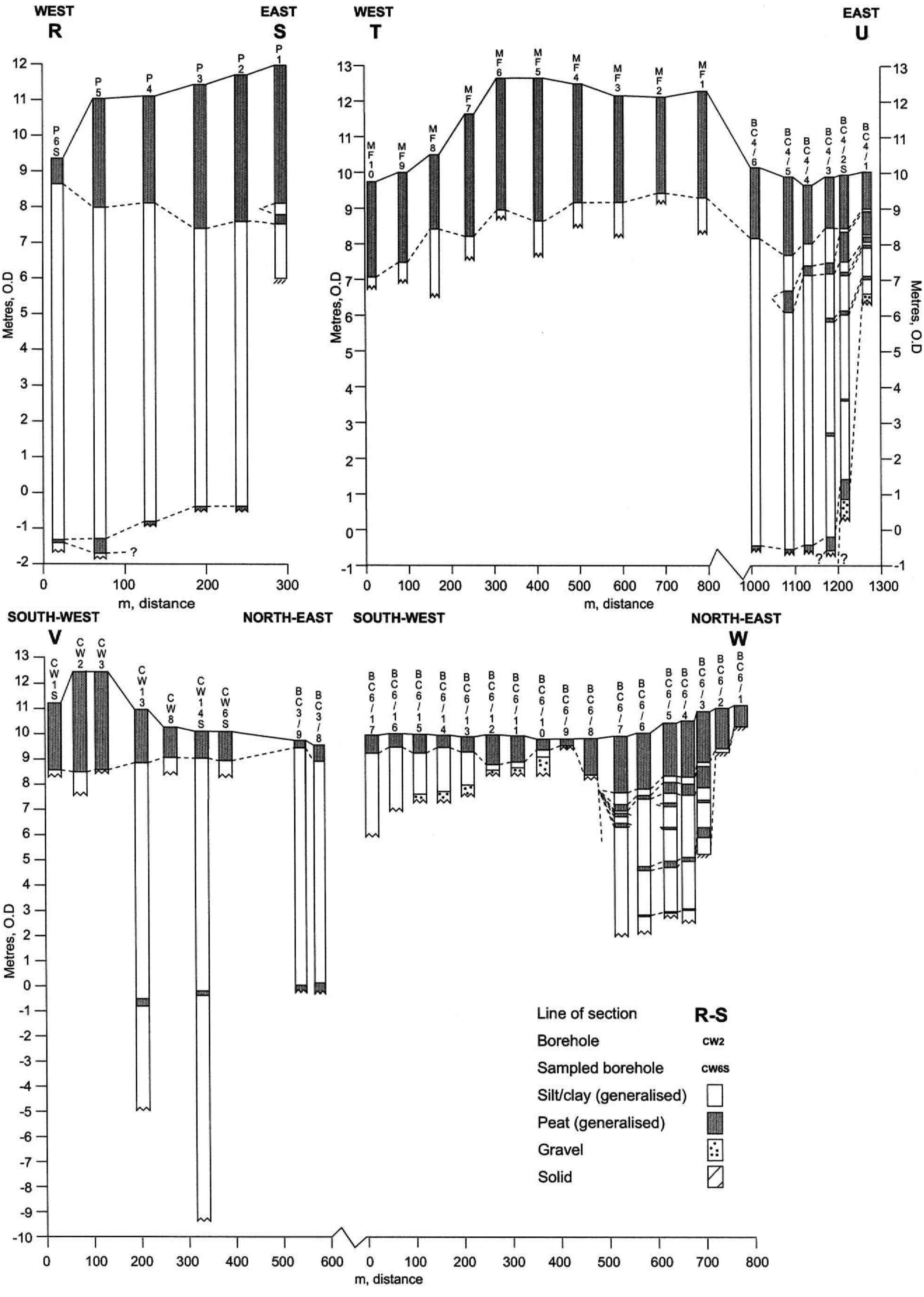

Figure 6 Borehole transects east of the river Cree.

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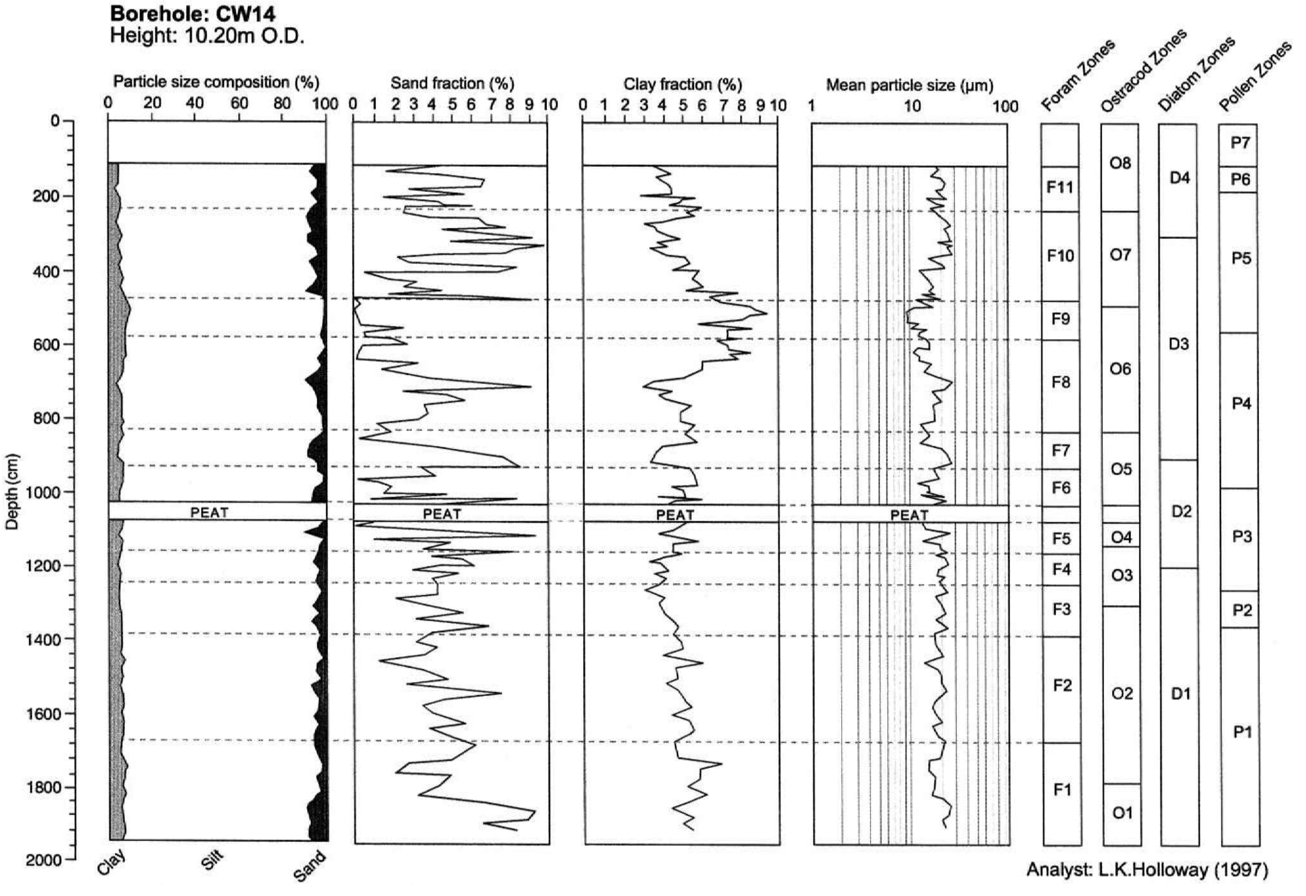

Figure 7 Particle size diagram for core CW14. Microfossil zones are also shown.

to 4·7 m (−0·2 m to 0·9 m) before merging into the floodplain terrace. These ranges include the estimated variation for possible survey errors discussed above.

6. Stratigraphy

The borehole transects taken are located on Figure 1 and generalised stratigraphies are shown in Figures 5 (for transects west of the Cree) and 6 (for transects east of the Cree). The stratigraphy is broadly consistent across the valley. The lowest sedimentary unit encountered is a grey silt (boreholes P6, P5, transect R–S; boreholes CW13, CW14, transect V–W), the surface of which lies at 1–1·5 m(−3·8–5·3 m). This is covered by up to 0·3 m of an extremely compacted peat, the top of which is also reached in boreholes P2–P4 (transect R–S), BC4/3–BC4/6 (transect T–U) and CC9 (transects N–O, L–M). This compact peat rises up the valley side in transects N–O, T–U and V–W to appear as a surface peat. Within this valley side peat, several lenses of carseland deposits occur locally, thus at Blairs Croft six transects parallel to BC6/1–BC6/17, transect V–W (the six transects are not shown here), confirm the sequence over at least 200 m. However, in places (e.g. transects L–M and N–O) clearance of the surface peat has removed the highest lens, notably in transect P–Q, where the carseland surface revealed is of a lower lens. On the surface of the carselands, the peat mosses (see transects P–Q, H–I, N–O, J–K, F–G, R–S, T–U and V–W) are up to 4 m thick. In transects T–U and V–W the surface of these mosses appears to have been lowered by partial clearance.

The relationship between the carseland sediments and peat, and the sand and gravel ridges shown in Figure 1 at Baltersan (X) and Blairs Croft is depicted in transects L–M and V–W respectively. The ridges are locally obscured beneath peat, but they generally reach 1–2 m above the adjacent carseland surface, and descend beneath the carse as they approach the river Cree. Beneath the carse, the layers of silt and peat end abruptly against the ridge gravels and sands, while the ridges themselves are asymmetrical; with the steepest slope facing up-valley. Exposures in the ridges disclose well-sorted, sometimes imbricated gravels, and it seems likely that they are barrier systems formed by marine action. However, as far as the borehole transects show, no deposits of sand and gravel extend into the adjacent sediments, (such as might have been expected from washover effects), implying that the ridges may have formed under higher energy conditions before much of the carseland silts accumulated, a conclusion supported by the borehole evidence of at least 7 m of carseland sediments resting upon the ridge flanks. The ridge at Carse of Clary appears to be similar, but here boreholes additionally suggest that sand and gravel deposits locally underlie the carseland sediments more widely, raising the possibility that these three ridges could be the visible elements of more widespread ridges beneath the carseland deposits.

7. Particle size analysis

Figure 7 depicts the particle size profile for the minerogenic sediments in borehole CW14, transect V–W. Particle size composition is broadly similar throughout. Silt predominates, comprising 82–94% of the total population, with neither clay nor sand exceeding 10% at any level. Mean particle size is 17·98 μm, with a maximum of 25·56 μm at 720 cm depth and a minimum of 8·85 μm at 520 cm depth. The similarity in the

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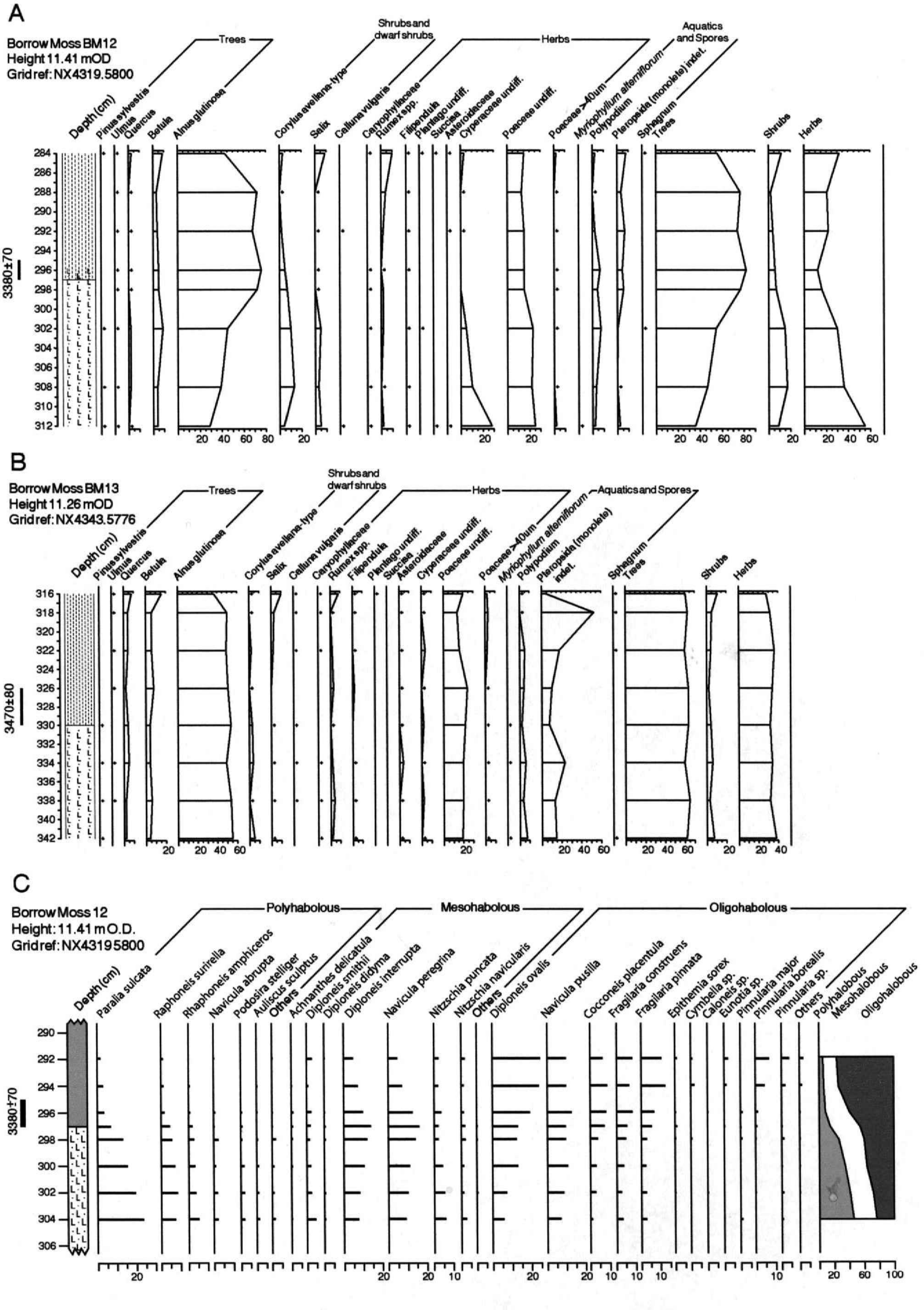

Figure 8 Microfossil data from Borrow Moss, covers BM12 and BM13: (A) Pollen diagram of selected taxa between 284 cm and 312 cm from borehole BM12; (B) Pollen diagram of selected taxa between 316 cm and 342 cm from borehole BM13; (C) Diatom diagram of selected species from borehole CM12 between 290 cm and 304 cm.

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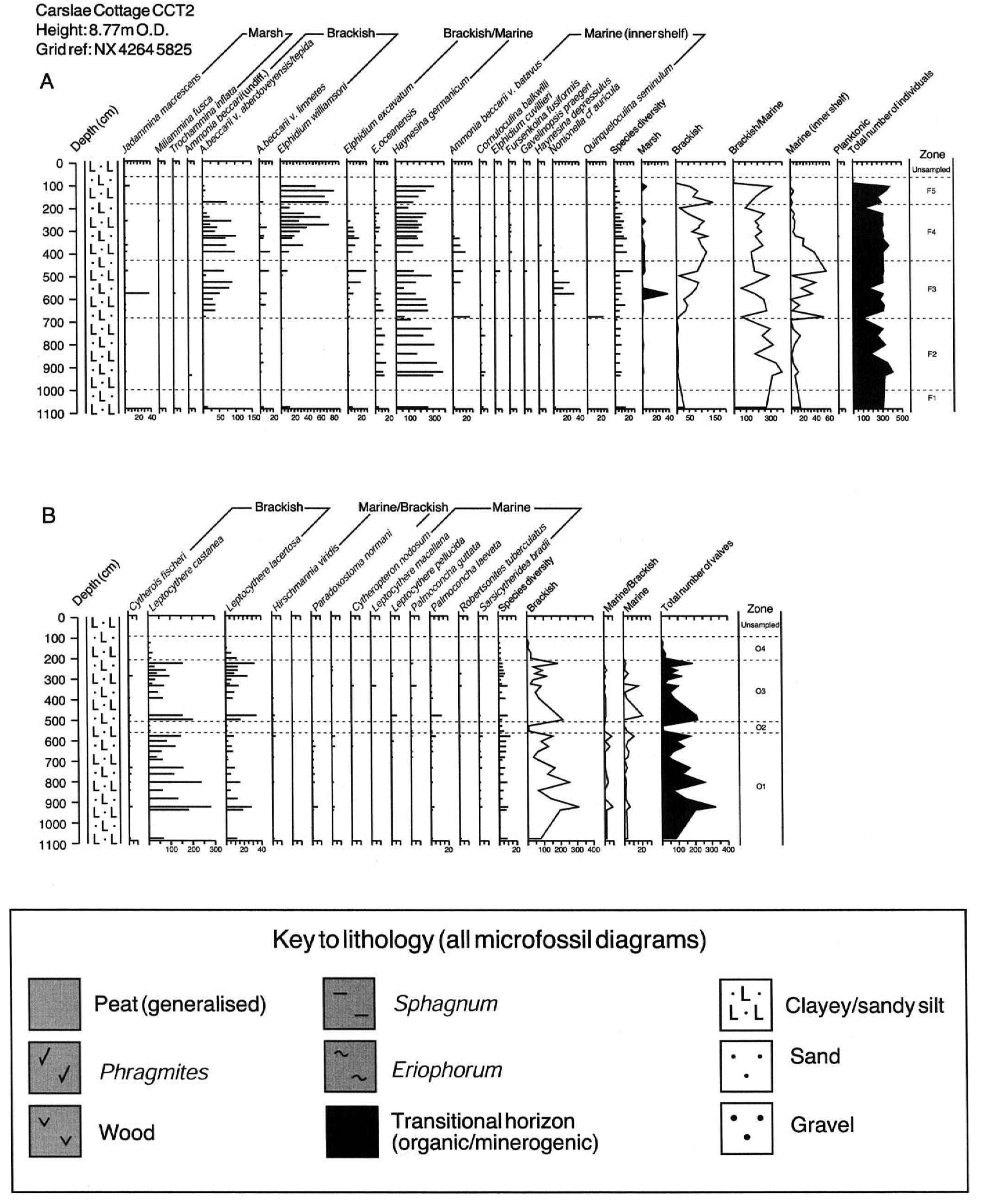

Figure 9 Microfossil data from Carslae Cottage: (A) Selected foraminifera from CCT2; (B) Selected ostracoda from CCT2. Lithology key shown in Fig. 9 applies to Figs. 8–19b.

particle size composition for all horizons analysed indicates that these minerogenic sediments accumulated in a broadly comparable environment under a similar regime of sedimentation.

However, it is possible to identify episodes of subtle but distinct changes in particle size profile through this sequence which may reflect changes in water depth, possibly in response to relative sea level changes. The most marked of these is an

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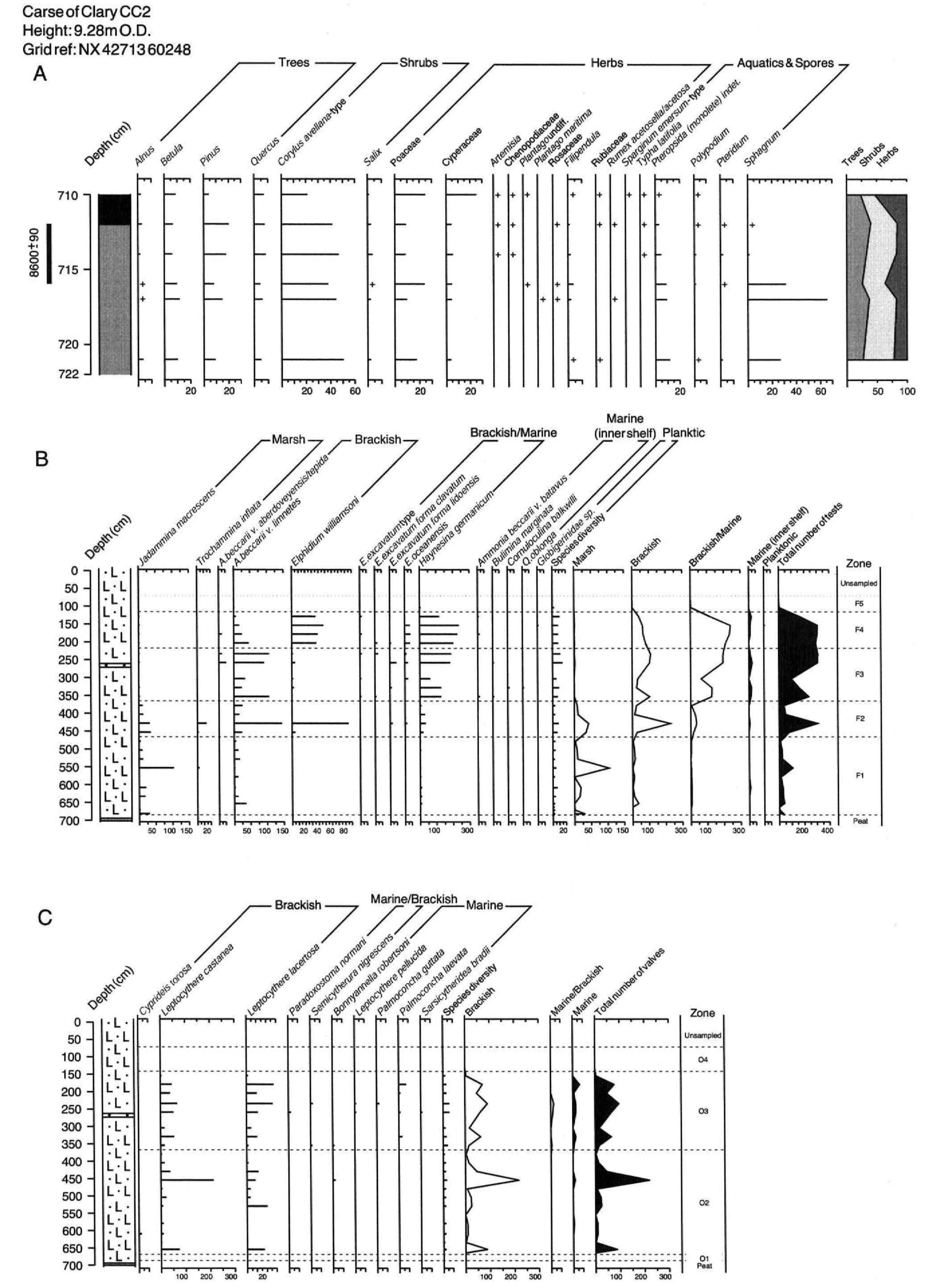

Figure 10 Microfossil data from Carse of Clary: (A) Pollen diagram of selected taxa between 710 cm and 722 cm from borehole CC2; (B) Foraminifera diagram of selected species from borehole CC2; (C) Ostracoda diagram of selected species from borehole CC2.

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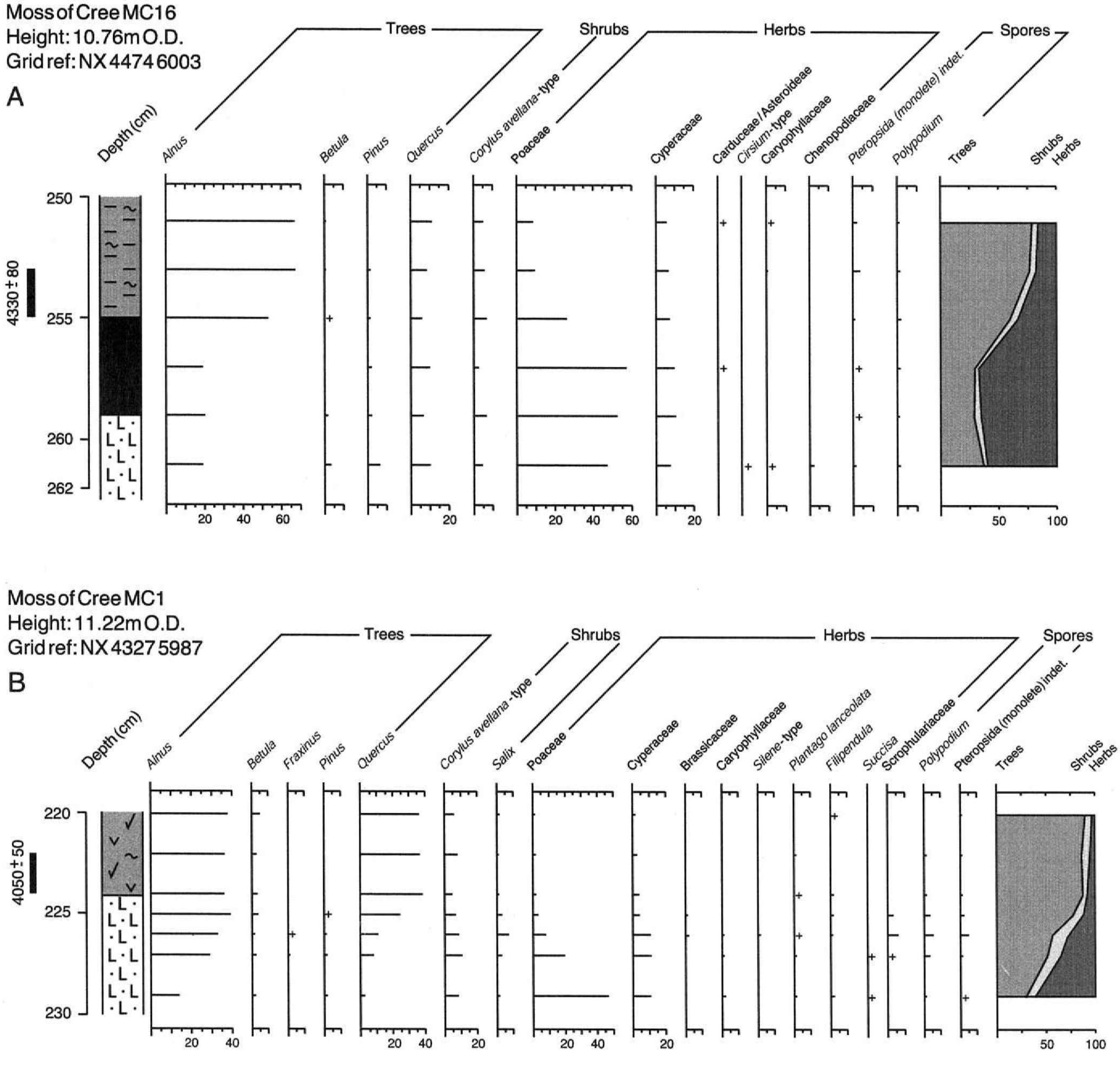

Figure 11 Microfossil data from the Moss of Cree: (A) Pollen diagram of selected taxa between 250 cm and 262 cm from borehole MC16; (B) Pollen diagram of selected taxa between 220 cm and 230 cm from borehole MC1.

episode of finer particle size accumulation between 4·1 m and 7·0 m depth, shown by a peak in the clay fraction and a corresponding dip in the sand fraction. Over this episode mean particle size falls to 13·32 μm.

8. Microfossil analysis

8.1. Borrow Moss: cores BM12 and BM13

Figure 8 shows the results of analyses of both pollen (Fig. 8A, B) and diatoms (Fig. 8C) at boreholes BM12 and BM13. Both pollen and diatoms indicate a continuous sequence of environmental changes with no major hiatus in the record. The pollen spectrum (Fig. 8A, B) discloses relatively high frequencies of Poaceae and Cyperaceae in the basal clayey silt which, with the presence of Caryophyllaceae, Asteroidiaceae and Chenopodiaceae, indicate saltmarsh conditions locally. In the peat, increases in *Sphagnum* and Pteropsida indicate the transition to freshwater marsh conditions. The increases in the representation of *Betula, Quercus* and *Salix*, taken with the slightly decreased amounts of Poaceae and Cyperaceae in the peat, probably reflect the spread of woodland as the deposition of the clayey silt ended in the area.

The diatom record for Borrow Moss was examined at each borehole across the contact between the base of the surface peat and underlying estuarine sediments. Figure 8C shows the sequence at borehole BM12. The record from both boreholes is similar. From the estuarine sediments, the diatom assemblages are dominated by polyhalobous planktonic species including *Paralia sulcata*, with high numbers of *Rhaphoneis surirella* and *Rhaphoneis amphiceros.* These diatoms are representative of the estuarine nature of the sediment. This is further confirmed with a range of brackish and brackish marine taxa, including *Nitzschia navicularis, Diploneis smithii* and *Navicula peregrina* which inhabit the intertidal mudflats. As the change to organic sedimentation above is approached, the diatom assemblage becomes dominated by more brackish species (*Diploneis interrupta*) and a range of freshwater and fresh-brackish

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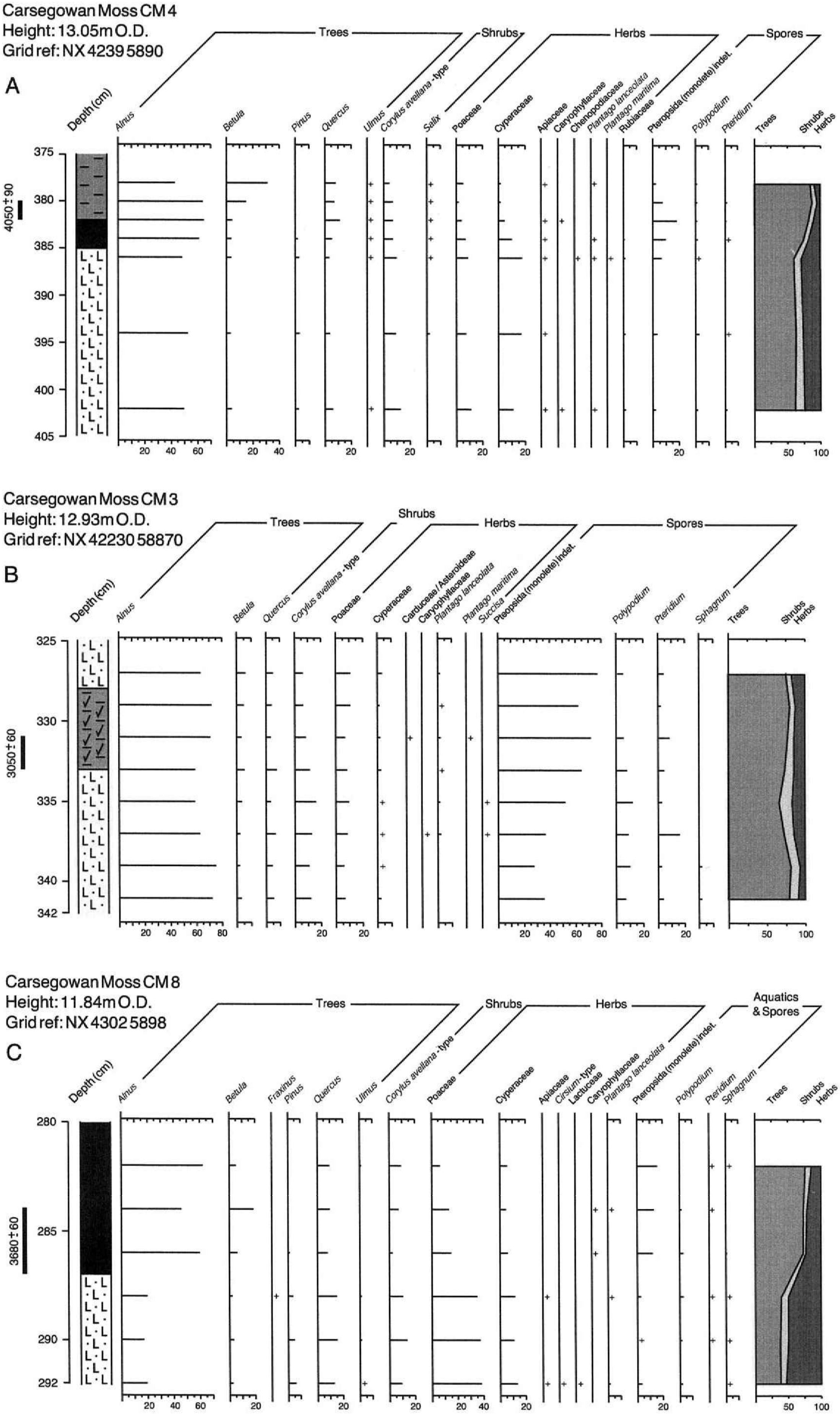

Figure 12 Pollen diagram of selected taxa from Carsegowan Moss: (A) Borehole CM4 375–405 cm; (B) borehole CM3 325–342 cm; (C) borehole CM8 280–292 cm.

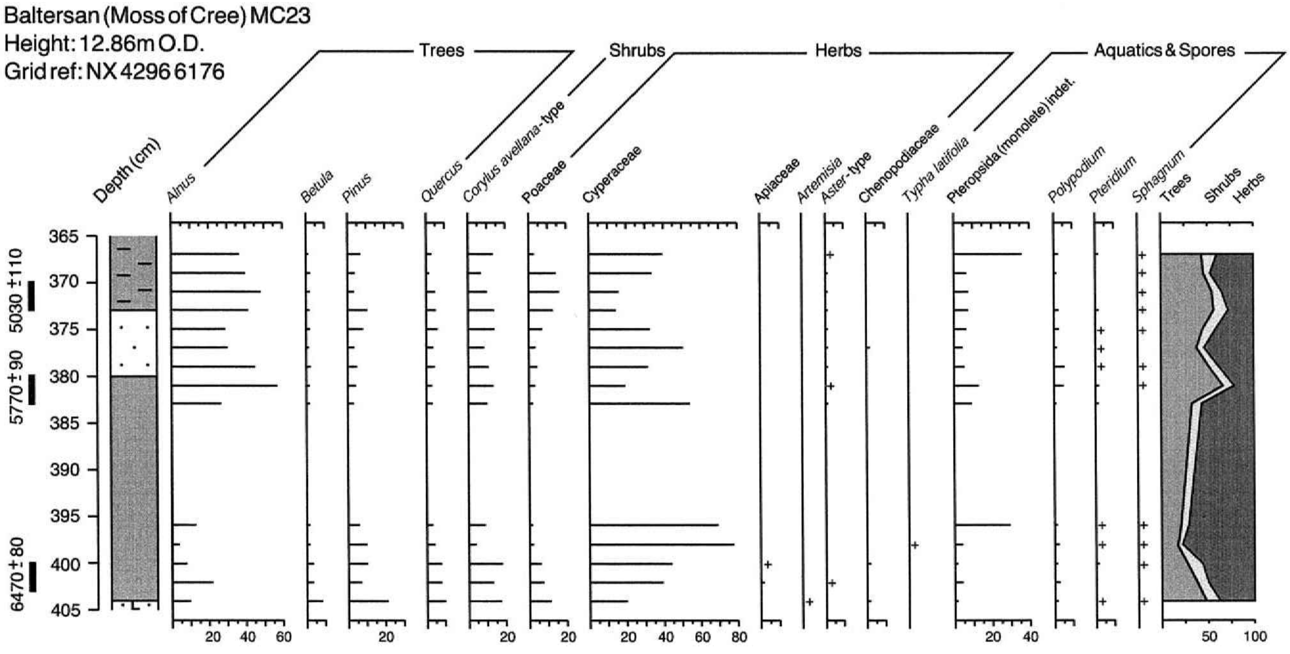

Figure 13 Pollen diagram of selected taxa between 365 cm and 405 cm from Baltersan (Moss of Cree), borehole MC23.

taxa, including *Diploneis ovalis, Navicula pusilla* and *Fragilaria* sp. This is in accordance with a gradual change from marine intertidal conditions to the deposition of organic sediments in an environment of reducing marine influence. Radiocarbon dates obtained from 2 cm-thick samples of peat from transitional horizons in the diatom records, where a predominantly marine intertidal environment is replaced by a freshwater-brackish or freshwater environment at each borehole, gave 3380 ± 70 (3829–3467) (borehole BM12, sample C1) and 3470 ± 80 (3963–3483) (borehole BM13, sample C2) (Table 4).

8.2. Carslae Cottage: core CCT2

Figure 9 depicts the frequencies of foraminifera (A) and ostracoda (B) identified at borehole CCT2. Throughout the sequence, foraminifera abundance is generally high, with counts of over 300 tests possible in the majority of levels, whereas ostracoda numbers are less abundant. The foraminifera and ostracoda record an estuarine environment which has experienced fluctuations in salinity, largely as a result of the variable influence of marine waters. The basal part of the core represents a brackish low intertidal mudflat (zones F1 and F2), indicated by the presence of *Haynesia germanicum, Elphidium excavatum* and *Ammonia beccarii* species (Fig. 9A), with a greater influence from open marine waters between 1000 cm and 685 cm. Subtidal mudflats possibly formed during zone F3. Low intertidal mudflats with a greater marine influence are suggested for zones F4 and F5, as species such as *Haynesia germanicum, Elphidium williamsoni* and *Ammonia beccarii* dominant. Ostracod frequencies (Fig. 9B) broadly concur with this environmental regime, with the brackish-loving *Leptocythere lacertosa* and *Leptocythere castanea* dominant, indicating a probable change from a low intertidal mudflat environment at the base of the core to a brackish intertidal mudflat, then possibly a high intertidal mudflat towards the top.

8.3. Carse of Clary: core CC2

The stratigraphic sequence at Carse of Clary commences with a basal peat, the top of which is dated at 8600 ± 90 (9888–9439) (Table 4, sample C11). The pollen data analysed from the buried peat suggest that dryland areas supported mixed woodland comprising *Betula, Pinus, Corylus* and *Quercus* with a *Pteridium* understory (Fig. 10A). Terrestrial conditions are indicated by high *Sphagnum* spore percentages. These diminish towards the top of the peat, as the influence of open water, possibly increasingly saline, is suggested by rising Poaceae and Cyperaceae pollen percentages and the occurrence of non-arboreal pollen and spore taxa such as *Artemisia*, Chenopodiaceae, *Plantago* undiff. and *Sparganium emersum*-type. The changes recorded in the pollen diagram suggest a gradual change from terrestrial peat to a possible saltmarsh. This is followed by the deposition of estuarine silt of the carse. The foraminifera and ostracoda records in this estuarine silt (Fig. 10B, C) indicate that these minerogenic sediments accumulated in an increasingly open estuarine environment, with marine influence slowly increasing through the sediment column. First, a terrestrial or perhaps saltmarsh environment could be inferred from the presence of basal peat and the lack of foraminifera. Above the peat, a saltmarsh environment with *Jadammina macrescens* gives way to more brackish influences, with *A. beccarii v. limnetes*, and brackish ostracods *L. lacertosa* and *L. castanea.* From about 465 cm, the foraminifera and ostracoda suggest a transition to a mudflat. A brackish influence increases in zones F2 and O2 (Fig. 10B, C) and by zone F3 brackish/marine indicators, including *H. germanicum, E. williamsoni, A. beccarii v. limnetes,* and in zone O3 *Palmoconcha laevata,* are present. Foraminifera zone F4 is one of a low intertidal mudflat environment, and with marine (inner shelf) species now present, a further increase in brackish/marine indicators (particularly *H. germanicum* and *E. williamsoni*) suggests a more open estuarine environment.

The lack of preservation of these microfossils towards the top of the core precludes any conclusion as to any decline in marine influence prior to the removal of an estuarine environment when the site became beyond tidal influence. The radiocarbon date for the top of the buried peat might reflect the commencement of estuarine deposition at this site, although the foraminifera and ostracoda record is equivocal and it is possible that an erosional peat horizon has been dated.

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8.4. Moss of Cree: cores MC1 and MC16

The age at which deposition of the minerogenic sediments ceased at Carse of Clary is unknown. Two radiocarbon dates of 4050 ± 90 (4830–4261) (C4) and 4330 ± 80 (5261–4654) (C7) (Table 4) for the base of peat overlying the carse at two locations on the Moss of Cree (Fig. 5, boreholes MC1 and MC16), at a similar altitude to the carse surface at Carse of Clary, may be a general indication (see below). The pollen data (Fig. 11A, B) across the upper estuarine silt/peat contact at both sites suggest a gradual change from an estuarine saltings to alder carr: Poaceae and Cyperaceae pollen values, and Chenopodiaceae at MC16, decline as *Alnus* percentages increase. The increase in *Quercus* and *Corylus avellana*-type pollen at borehole MC1 suggests oak and hazel woodland had established itself on drier, local soils. The development of woodland cover may account for the demise of other non-arboreal pollen and spore taxa (e.g. Caryophyllaceae, Scrophulariaceae, *Plantago lanceolata*, *Polypodium* and Pteropsida (monolete) indet.).

8.5. Carsegowan Moss: cores CM3, CM4 and CM8

The age of the upper contact between the carse and overlying peat is dated to the mid–Holocene at three locations across Carsegowan Moss (Fig. 1). At boreholes CM3, CM4 and CM8 (Fig. 12 A–C), the base of the upper peat has been radiocarbon-dated to 3050 ± 60 (3383–3077), 4050 ± 90 (4830–4261) and 3680 ± 60 (4222–3835) (respectively samples C3, C4, C5, Table 4). High *Alnus* pollen percentages at each site suggest that the area supported alder carr with a fern, polypody understory on damper substrates, whilst an oak–birch–hazel woodland occupied drier ground. Across the contact, the existence of a wet, marsh environment is suggested by the presence of a range of herbaceous taxa such as Poaceae, Cyperaceae, Rubiaceae and Apiaceae. The age variation is puzzling, given that CM3 has the highest and most landward contact, and it is believed that an hiatus may be present between the cessation of carse deposition and commencement of peat accumulation at this borehole, although the pollen record provides no corroborative evidence. CM4 and CM8 are progressively farther from the carse margin, and the contacts are closer in age, with the younger contact at CM8 being at a slightly lower altitude. They are considered more reliable regressive contact dates.

8.6. Baltersan, Moss of Cree: core MC23

Two silt/peat intercalations were examined by pollen analysis at Baltersan, on the edge of the Moss of Cree (Fig. 1). The stratigraphic context is shown in Figure 5. No hiatuses are evident in the pollen data (Fig. 13) across these sedimentary changes. *Alnus* pollen indicates the development of alder carr with a pine–oak–hazel woodland established on drier ground. The peat appears to have supported a sedge-rich vegetational community.

8.7. Palnure: core P6

The microfossil record from Palnure (Figs 14, 15) records gradual changes across the horizons examined. Foraminifera (Fig. 14A) indicate that the top of the basal silt and overlying peat appear to have accumulated in a saltmarsh environment, with *Jadammina macrescens* and *Miliammina fusca* well represented. The radiocarbon date of 8310 ± 100 (9528–9026) (Table 4, sample C14) from the base of the peat thus probably marks a conformable contact. The saltmarsh environment is indicated throughout the peat, but as the overlying silt is encountered this gradually changes to more estuarine conditions, with *H. germanica* and *E. oceanensis* (zone F2) and ostracoda *Cyprideis torosa* and *Leptocythere castanea* (Fig. 14B, zone O2). A date from the top of the peat of 8190 ± 80 (9426–9000) (Table 4, sample C13) may reflect a similarly conformable contact to the basal contact date mentioned above. The pollen record across this peat horizon (Fig. 15A) also supports gradual change in sedimentation, with no major change in individual taxa. The high Poaceae and Cyperaceae pollen values, combined with the occasional grain of Chenopodiaceae, *Plantago maritima* and *Aster*-type, suggests the buried peat was not completely free of saline conditions. Pollen and spores of *Filipendula, Lithrum salicara*-type, *Isoetes*, *Mentha*-type, and Rubiaceae suggest that this organic sediment represents a grass and sedge rich marsh.

Above the base of the silt overlying the buried peat, the foraminifera record (Fig. 14A) discloses a broadly deepening then shallowing environment, with some fluctuations. Brackish conditions are notable near the base of the silt in zone F5, which is characterised by *Ammonia beccarii var. limnetes* and *Elphidium williamsoni*, supported by the more sparse ostracod record for the same horizon, in zone O4 (Fig. 14B). This environment is subsequently replaced by a lower–upper saltmarsh environment from zones F6 to F8, demonstrated by increased representation of *J. macrescens* and *Trochammina inflata*. Above these horizons the overlying peat increases and although no foraminifera or ostracoda were found from the basal contact of this deposit, the pollen record (Fig. 15B) implies that it is likely to be conformable. Diminishing saline influence (for example in the reduction of Poaceae, *Aster*-type and Chenopodiaceae pollen) is registered up-core as saltmarsh is succeeded by terrestrial *Sphagnum* peat with pockets of alder carr. A radiocarbon date from the base of this peat of 6100 ± 70 (7209–6752) (Table 4, sample C12) is believed to closely record the removal of estuarine conditions from this site.

8.8. Carsewalloch Flow: cores CW14, CW1 and CW6

The main core examined at Carsewalloch Flow (Figs 1, 6) was CW14, which reaches a depth of 21·5 m. This core was analysed for diatoms, pollen, foraminifera and ostracoda (Figs 16A-C, 17A-B) as well as particle size (Fig. 7, above, which also shows the microfossil zonation). Shells of *Cerastoderma edule* found at 19·54-19·59 m-depth yielded a radiocarbon age of 9680 ± 50 (11197–10788) (Table 4, sample C25). Corrected for 'old carbon', after Sutherland (1983), the radiocarbon age would be *c.* 9250 (*c.* 10700). An organic horizon at 1060–1082 cm includes a peat 3 cm thick, with transitional zones above and below this (see Fig. 16C) containing relatively low levels of organic material. The peat was submitted in its entirety for radiocarbon assay, giving a date of 8580 ± 80 (9711–9439) (Table 4, sample C24).

The microfossil record in CW14 indicates no apparent hiatus up-core to the base of the surface peat. Below the organic horizon in the sequence (i.e. between 1957 cm and 1082 cm), the environment of deposition indicated by the foraminifera (Fig. 17A) and ostracoda (Fig. 17B) is tidal/estuarine, typified by the presence of the foraminifera *H. germanica* and *E. oceanensis* and the brackish ostracoda *Leptocythere castenea* and *Leptocythere lacertosa.* Open marine influence decreases up-core to the organic horizon until a lower saltings terrace environment, with the presence of *J. macrescens* and the loss of marine (inner shelf) species such as *Cornuloculina balkwilli* and *Quinqueloculina* sp. in zone F4, possibly continued in the largely barren zone F5, is indicated. The diatoms and dated mollusc shell in this sequence below the organic horizon indicate a habitat broadly similar to that of the foraminifera and ostracoda assemblages. Marine plankton, marine tychoplankton and marine epi-

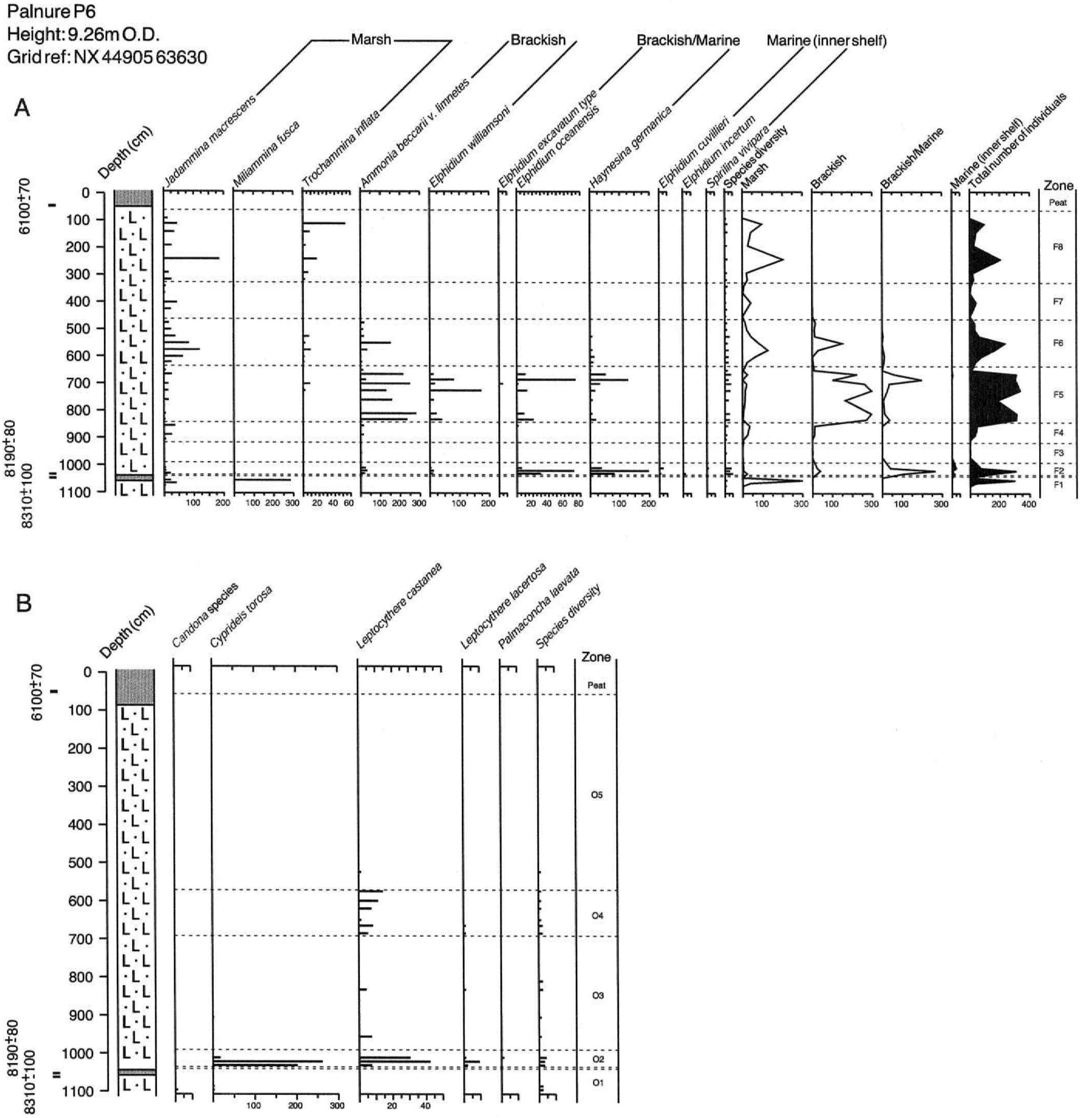

Figure 14 Foraminifera and ostracoda data from borehole P6, Palnure: (A) Foraminifera diagram of selected species; (B) Ostracoda diagram of selected species.

phytes are well represented in diatom zones D1 and D2 before starting to decrease in zone D3, as the percentages of more brackish/freshwater diatoms increase (Fig. 16A). The pollen data from this lower part of CW14 (Fig. 16B) suggest that in the early Holocene, woodland dominated dryland areas around the Cree estuary. This woodland underwent several compositional changes. A *Corylus* scrub/woodland dominates zone P1 and it is co-dominant with *Pinus* during zone P2, while a mixed woodland has developed by zone P3. High Poaceae pollen percentages, combined with intermittent increases in Cyperaceae and the presence of a variety of non-arboreal taxa and spores such as *Aster*-type, Chenopodiaceae, Caryophyllaceae, Pteropsida (monolete) indet. and *Sparganium emersum*-type characterise the organic horizon peat that is present in pollen zone P3. The presence of such taxa may be indicative of a saltmarsh and/or terrestrial peat. Thus, taken together, the microfossil data from the silt below the organic horizon indicate a gradual change from an estuarine to a saltmarsh environment, and it is believed that the radiocarbon date of 8580 ± 80 relates more closely to the conclusion of this episode than the commencement of overlying sedimentation.

Directly above the organic horizon, the silt contains microfossil assemblages indicative of a mudflat or inner shelf environment, the foraminifera record containing both brackish (*Ammonia beccari* var. *limmetes* and *Elphidium williamsoni*)

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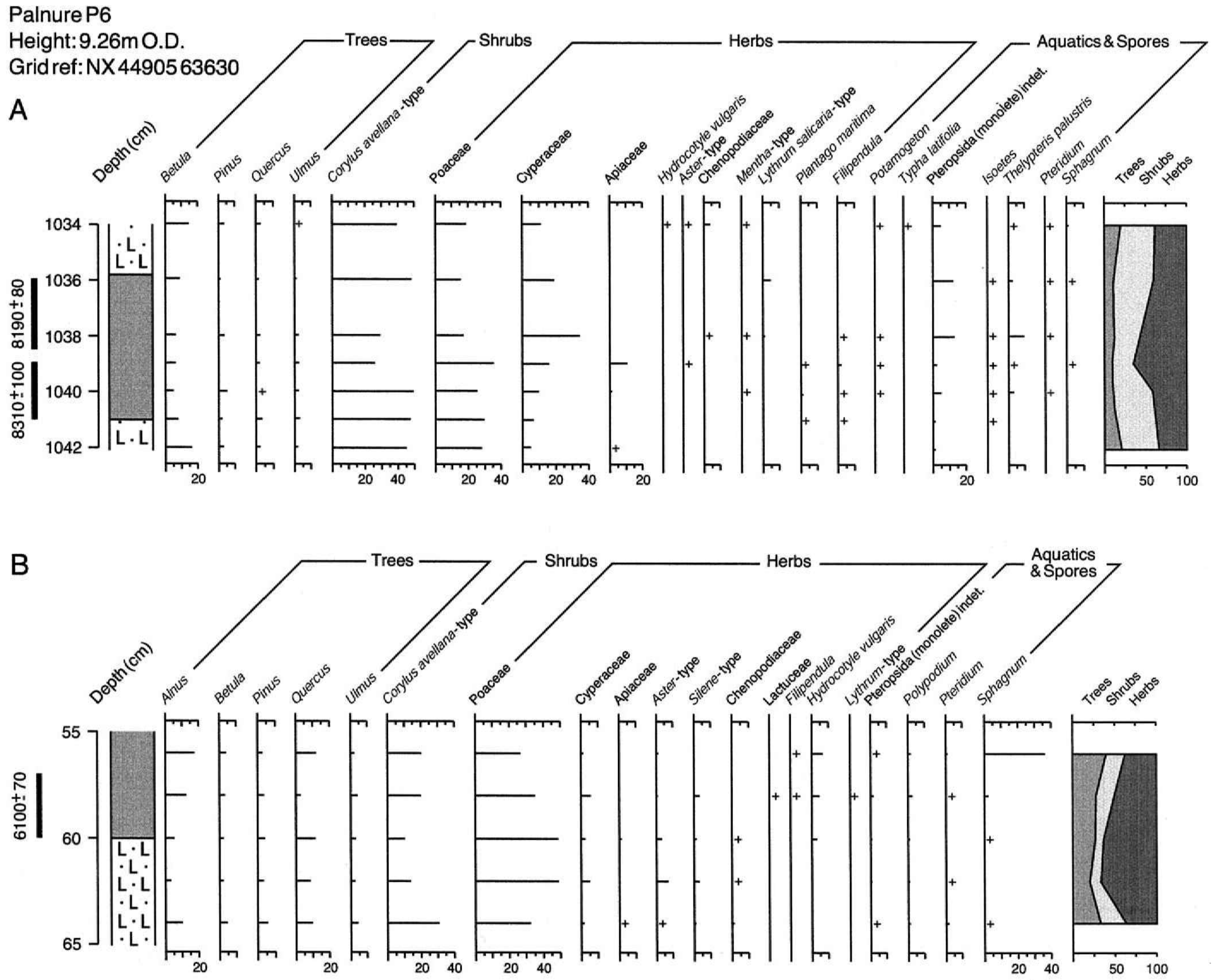

Figure 15 Pollen data from borehole P6, Palnure: (A) Pollen diagram of selected taxa between 1034cm and 1042cm; (B) Pollen diagram of selected taxa between 55cm and 65cm.

and brackish/marine (*Elphidium oceanensis*) forms (Fig. 17A, zone F6), and the diatom record marked by the marine *Paralia sulcata* (Fig. 16A, zone D5). Above these levels, the foraminifera record discloses fluctuations in water depth, as marsh and brackish tolerant forms are replaced by brackish/marine forms (such as *Haynesina germanica* in zone F10) before becoming again more prominent. Overall, there is a shallowing sequence, with *J. macrescens* and *T. inflata* being notable directly below the surface peat.

The surface peat in CW14 marks the end of estuarine sedimentation and the commencement of a terrestrial environment. The age of the silt/peat contact is unknown. The dramatic rise in *Alnus* values directly below the contact (Fig. 16B, zone P6) would seem to imply an age of *c*. 7500 radiocarbon years B.P., taking account of evidence from the Southern Uplands (Birks 1993; Jones & Stevenson 1993), Brighouse Bay (Wells *et al*. 1999) and Blairs Croft in this study. However, at CW14 the *Alnus* values may have been suppressed by *Pinus* pollen, which is known to be preferentially preserved in marine and estuarine conditions (Traverse & Ginsberg 1966), and the foraminifera and ostracoda records (Fig. 17A, B) clearly demonstrate such conditions at the horizon sampled. Nevertheless, in view of these uncertainties, the possibility of an hiatus before the accumulation of surface peat at this site cannot be excluded.

Just to the south of CW14, at core CW6 and core CW1 farther west (Fig. 18A, B), the change from the estuarine silt to surface peat is radiocarbon-dated to 4010 ± 80 (4813–4244) and 3810 ± 70 (4417–3982) respectively. Both pollen records from these sites suggest that alder carr is well established on Carsewalloch Flow by the mid- to late-Holocene, with mixed woodland comprising *Betula*, *Quercus* and *Corylus* occupying drier ground. At CW1, Poaceae pollen percentages fall dramatically as *Betula* pollen values increase. Similar but less dramatic changes are recorded at CW6, suggesting that a grass-dominated estuarine saltings community has been replaced by terrestrial peat that supports birch on Carsewalloch Flow. It is suggested that at CW1 and CW6 no hiatus is indicated and that the ^{14}C dates mark a gradual change from estuarine sedimentation to the accumulation of peat.

8.9. Blairs Croft: core BC4/2

The core taken at Blairs Croft was barren of ostracoda and there were insufficient foraminifera to identify zones. Microfossil analysis was largely confined to pollen analysis, the samples concentrated across changes in stratigraphy (Fig. 19A, B). The stratigraphic context of this core is shown in Figure 6 (transects T–U and V–W). This is supported by four other transects in the vicinity (not shown here). A basal peat is

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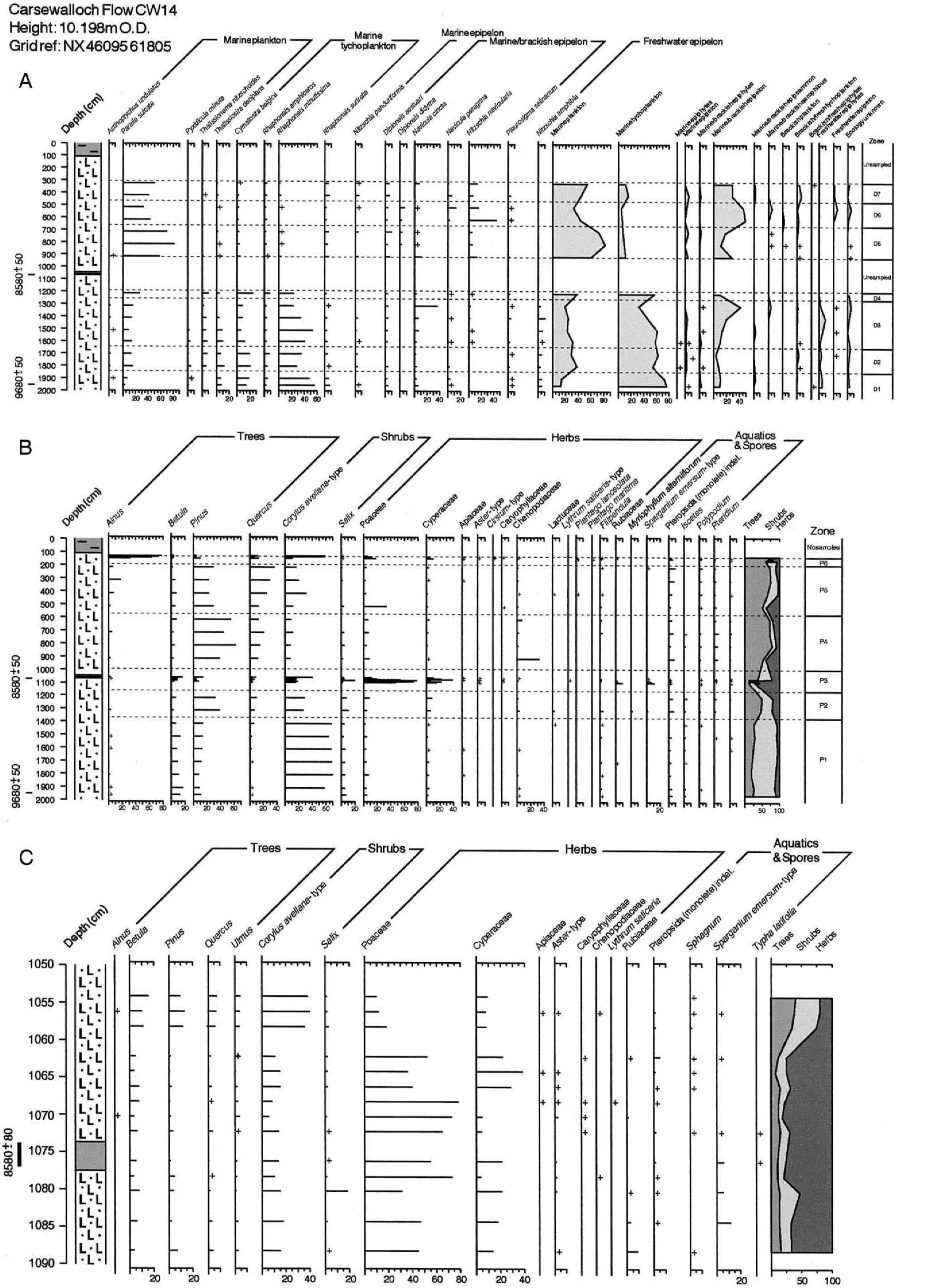

Figure 16 Selected diatom and pollen data from borehole CW14, Carsewalloch Flow: (A) Diatom diagram of selected species; (B) Pollen diagram of selected taxa; (C) Pollen diagram of selected taxa between 1050 cm and 1090 cm.

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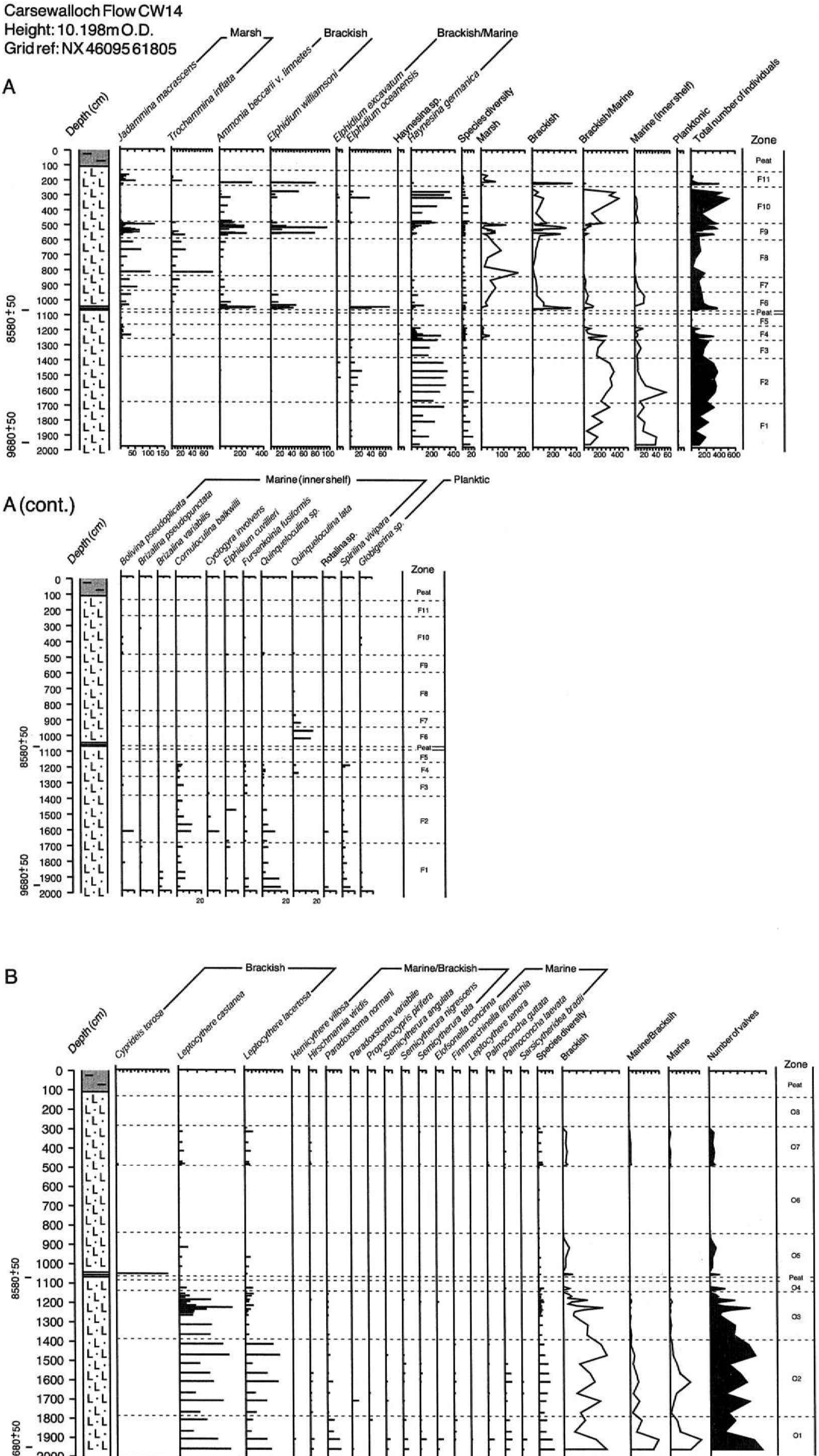

Figure 17 Selected foraminifera and ostracoda data from borehole CW14, Carsewalloch Flow: (A) Foraminifera diagram of selected species; (B) Ostracoda diagram of selected species.

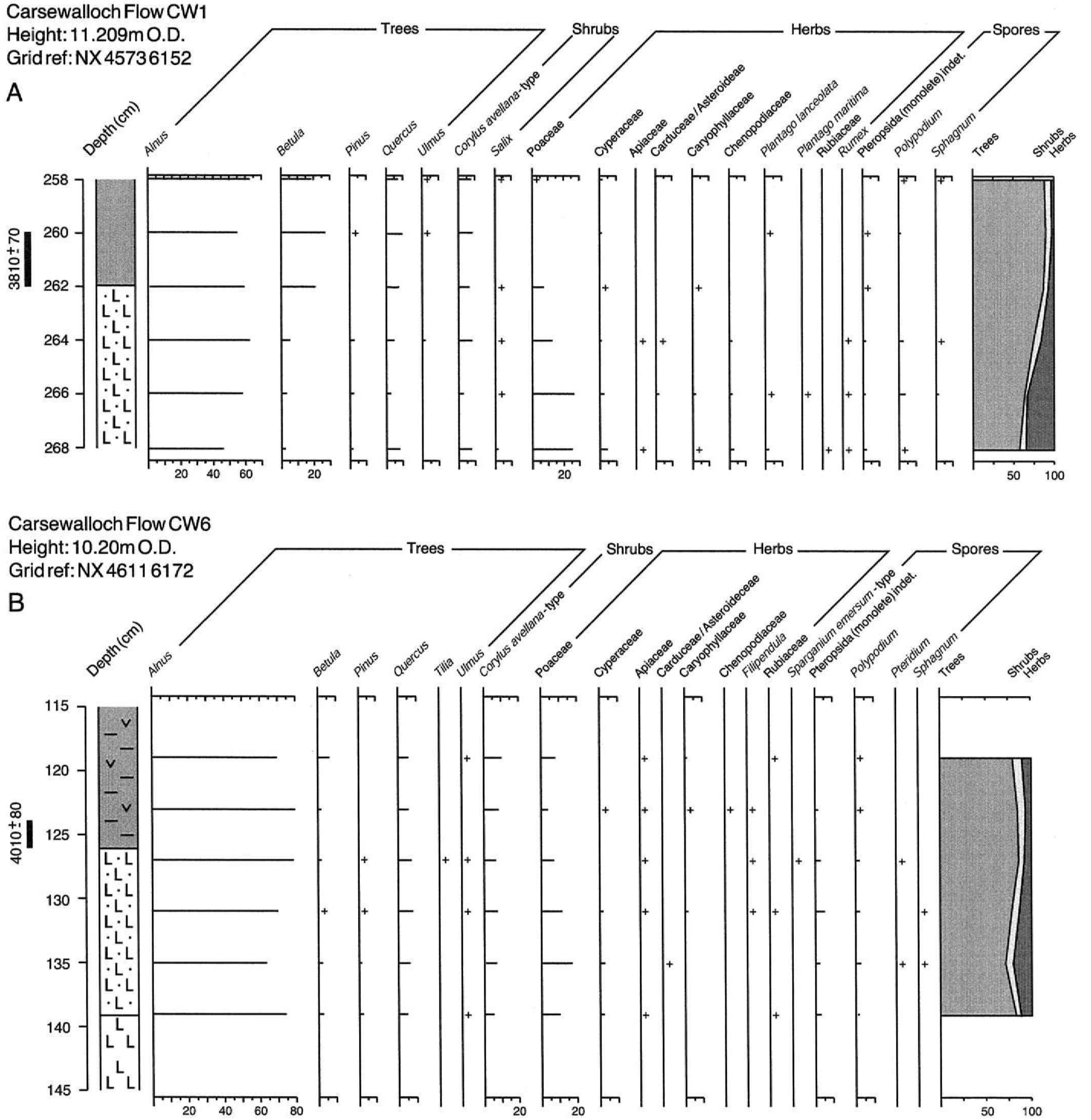

Figure 18 Pollen diagrams of selected taxa for boreholes CW1 and CW6, Carsewalloch Flow: (A) Borehole CW1, 258–268 cm; (B) Borehole CW6, 115–140 cm.

overlain by silt containing four peat layers, then succeeded by surface peat (Fig. 6).

The top of the basal peat in the sequence is radiocarbon-dated to 8400 ± 80 (9535–9146) (Table 4, sample C21). In the pollen spectrum, (Fig. 19A) the decline in *Sphagnum* spores and the increased representation of Chenopodiaceae pollen from near the top of the peat suggests an increase in salinity at the site, therefore suggesting that the date marks the advent of marine influence. The persistence of high percentages of Cyperaceae and Poaceae pollen, combined with the presence of taxa such as Apiaceae and *Isoetes* suggest that a sedge-rich freshwater marsh plant community was established locally. The occasional presence of the marsh foraminifera *J. macrescens* is recorded at intervals in the silt above the basal peat between 885 cm and 628 cm, indicating that the area around Blairs Croft may have never deepened below a lower saltings environment as this silt accumulated.

The deposition of silt is interrupted between 628 cm and 624 cm by the accumulation of the lowest of the four peat horizons. This thin peat horizon is radiocarbon-dated in its entirety to 7820 ± 80 (8982–8413) (Table 4, sample C20). The pollen record across this peat (Fig. 19B) suggests that it supported freshwater marsh vegetation (for example, high Poaceae, *Isoetes*), although some taxa more commonly associated with saltmarsh are occasionally recorded (Chenopodiaceae and *Aster*-type). The lack of marked changes in the pollen spectrum across this peat suggests that it accumulated conformably above the silt below, and was conformably

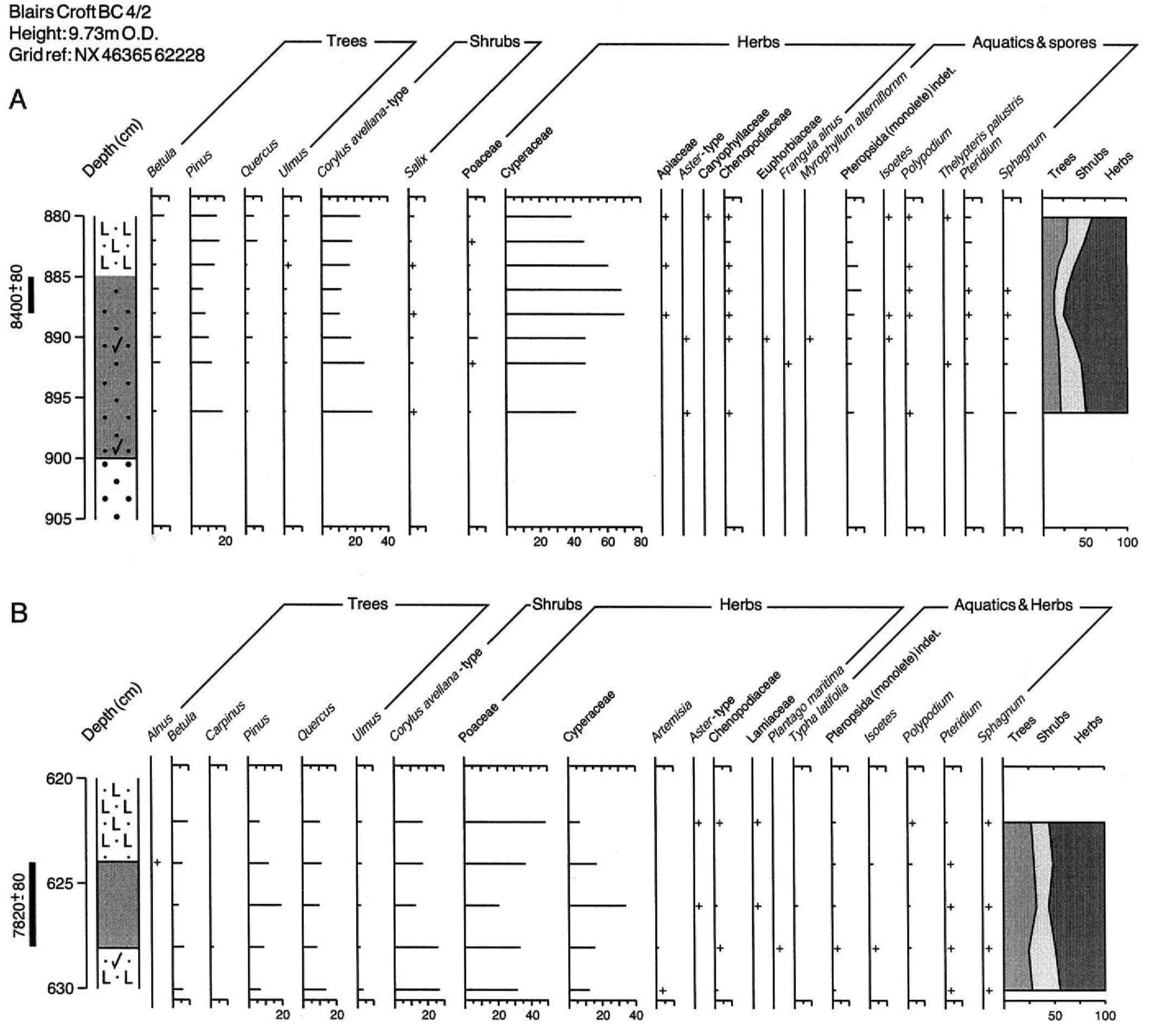

Figure 19 Pollen diagrams of selected taxa from Blairs Croft: (A) 875–905 cm; (B) 620–630 cm; (C) 375–400 cm; (D) 240–285 cm.

succeeded by the overlying silt. This marshy environment possibly persisted during the deposition of the overlying silt, as the foraminifera *J. macrescens* is recorded, albeit in low numbers, at 470 cm to 471 cm and 450 cm to 451 cm. The occurrence of the foraminifera *H. germanica* and *A. limnetes* indicate the presence of a lower saltings terrace or intertidal mudflat close by. The three peat horizons above lie between 398 cm and 378 cm, 280 cm and 264 cm and 258 cm to 154 cm (Fig. 19C, D). Radiocarbon dates of 7830 ± 110 (9007–8393) (base, 390–393 cm depth) and 7240 ± 90 (8276–7868) (top, 384–387 cm) were obtained for the lowest of these horizons; 7510 ± 310 (9029–7684) (base, 277–280 cm) and 7210 ± 120 (8315–7761) (top, 265–268 cm) for the middle horizon and $6,800 \pm 130$ (7929–7430) (base, 255–258 cm) for the upper horizon. Notwithstanding the problem of the reversal of radiocarbon dates in the sequences recorded here, it appears that the four organic horizons within the silt above the basal peat accumulated sometime between 7830 ± 110 (9007–8393) and after 6800 ± 130 (7920–7430). The pollen record suggests that these peats all supported a wet, marsh plant community dominated by Poaceae and Cyperaceae, combined with a range of herbaceous taxa, including *Filipendula* and Rubiaceae. The presence of *Potamogeton* implies that open pools of water existed on the marsh, whilst the regular occurrence of Chenopodiaceae and *Aster*-type pollen suggests that saltmarsh was established close by. The relatively higher percentages of *Alnus* between 398 cm and 378 cm suggest that alder carr established itself as the second of these organic horizons accumulated, although this fluctuated through the sequence as sedge-rich communities developed. However, the relative stability of other tree taxa suggests that no lacunae exist during these stratigraphic changes. The peats above 280 cm record the re-establishment of an alder carr. The radiocarbon dates through this sequence broadly concur with the rise of alder in other pollen diagrams in the region (see microfossil data for Carsewalloch Flow, above).

No sampling for microfossils or radiocarbon was undertaken across the upper silt horizon (144–154 cm depth) or surface peat.

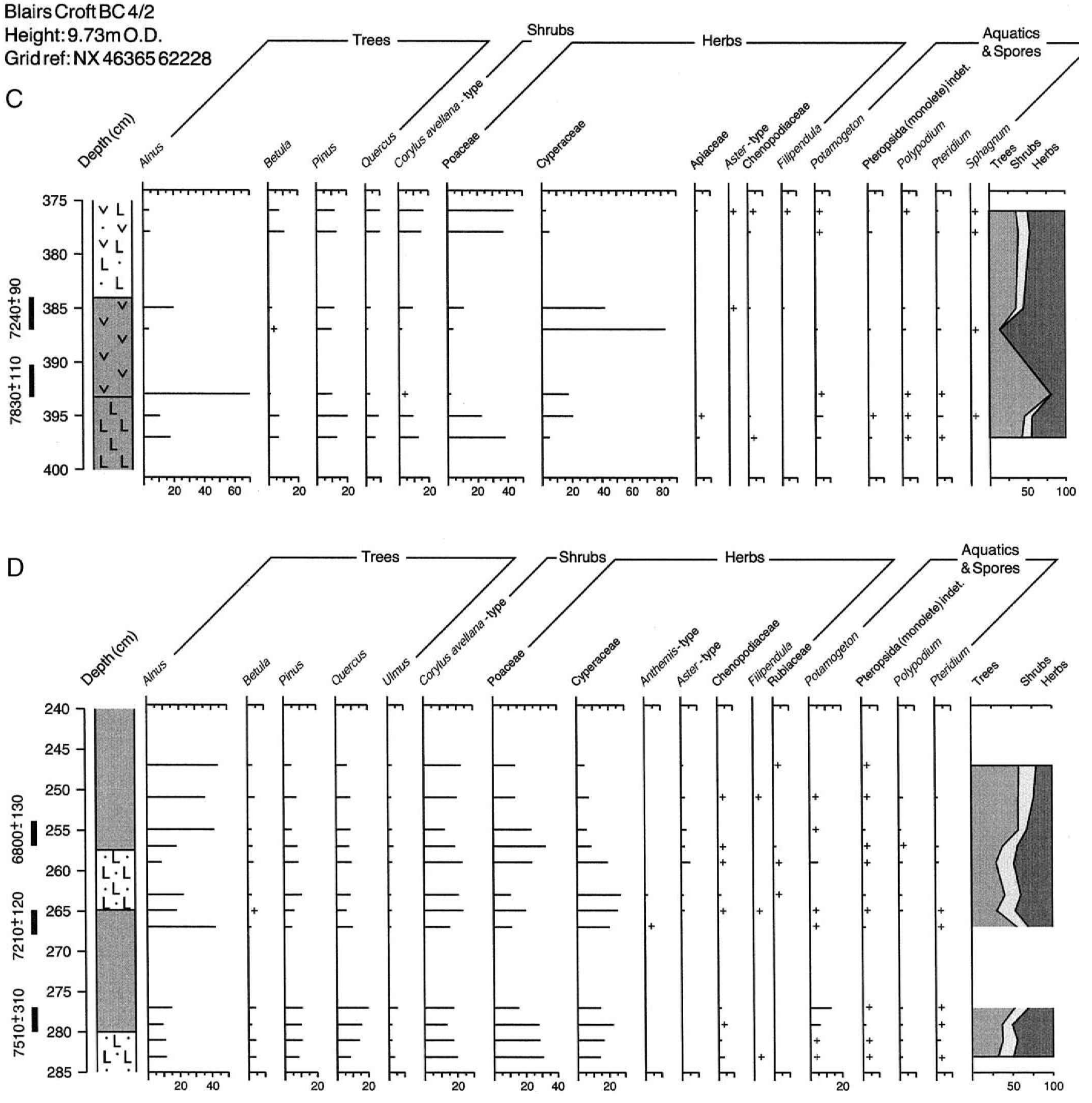

Figure 19 Continued.

These horizons, however, relate closely stratigraphically to similar horizons at CW14 and CW6, to the W (see above).

9. Interpretation: relative sea levels

9.1. A graph of relative sea level changes

Figure 20 is a graph of those radiocarbon dated points considered sea level index points (see Table 4). Each point is represented by an error box, its age limits set at two standard deviations about the mean and its altitude limits determined from the error measures outlined earlier in this paper. Both limits can be obtained from Table 4. The sequence of changes in relative sea level in the area probably occurred within the error box margins of the graph, and the likely trend of relative sea level changes is indicated by a single line. The changes are inferred as follows:

9.1.1. Early Holocene relative sea levels. The earliest episode recorded is that of the accumulation of estuarine silt widely in the area from at least as early as *c.* 9250 (*c.* 10700) (Table 4, sample C25, borehole CW14) (corrected for 'old' carbon). As the silt accumulated, the estuary was becoming progressively more shallow until a saltmarsh surface was formed. Boreholes P6 and CW14 record this surface at respectively 0·23 m to −1·19 m (−3·57 m to −4·99 m) and 0·11 m to −1·22 m (−3·69 m to −5·02 m) with nearby boreholes (P5, CW13 and BC4/3) providing corroborating evidence of these altitude ranges. Sea level index points for the base of the peat at borehole P6 (index point 13), 8310 ± 100 (9528–9026) and at

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borehole CW14 (index point 22), 8580 ± 80 (9711–9439), overlap at two standard deviations.

9.1.2. Start of the middle Holocene marine transgression. The peat overlying the saltmarsh surface of the basal silt can be traced rising up the valley sides in transects T–U and V–W (Fig. 6), and probably became widespread across the area. However, at lower levels this peat subsequently became overwhelmed by a renewed accumulation of estuarine silt. At borehole P6, index point 12 records this as having begun at 8190 ± 80 (9426–9000) at an altitude of 0·23 m to −1·19 m (−3·57 m to −4·99 m). On the western side of the area at borehole CC2, this event appears to have occurred earlier but at a higher altitude, index point 10 recording 8600 ± 90 (9888–9439) at 3·50 m to 2·13 m (−0·30 m to −1·67 m). The greater altitude of the older index point 10, taken with the uncertainty about the microfossil record at the base of the silt overlying that index point, reported above, suggests that this point may possibly date an erosional horizon. For this reason, index point 12 is preferred as an indication of relative sea level change at this time. Jardine (1975) maintained that the sea was invading the Palnure valley by 7960 ± 350 (9596–8032) at 6·95 m to 5·65 m (3·15 m to 1·85 m) (Fig. 1, sample J8, Table 3), although given the standard error of the date it cannot be closely compared with index points 10 and 12.

9.1.3. Variations in the middle Holocene transgression. It seems likely that marine inundation during the transgression was variable in the area. In boreholes CC1, CCL2 and CW14, the foraminifera and ostracoda records through the silt above the basal peat indicate a broadly shallowing but fluctuating water depth. In particular, each borehole records an episode of deepening water towards the top of the sequence (particularly marked in CW14), where a distinct increase in the clay content of the sediment occurs. Farther north, at Baltersan and Blairs Croft, fluctuations in the transgression are marked by intercalations of peat and silt at the valley sides (transects L–M and N–O (Fig. 5), T–U and V–W (Fig. 6)).

The sequences at Blairs Croft (Fig. 1, Fig. 6, transect T–U, boreholes BC4/1–6) and Baltersan (Fig. 1, Fig. 5, transects N–O and P–Q, boreholes CC9–11 and MC20, MC22–24) are probably characteristic of changes more widely in the area. At Blairs Croft, the intercalations in borehole BC4/2 (Figs 6, 19) record that estuarine sedimentation, which had reached the site at about 8400 (9400), was interrupted on four occasions, the lower three of which are dated around 7800 (8700), 7800 (8700)–7200 (8000) and 7500 (8400)–7200 (8000) and after 6800 (7700). The closeness of the dates for the lower three intercalated peat horizons, and the overlaps between three of these dates, notwithstanding the large standard deviations involved, probably indicates only brief interruptions in estuarine sedimentation at this valley side location. However, the likelihood of variations in relative sea level around these ages elsewhere in the area is supported by Jardine's (1975) radiocarbon date of 7450 ± 200 (8625–7866) for a peat horizon within the carseland silts in the Palnure valley (Fig. 1, sample J7, Table 3). The culmination of the last episode of estuarine sedimentation at Blairs Croft, although not dated, may correlate with the carseland surface beneath nearby Carsewalloch Flow and Muirfad Flow on the basis of stratigraphy and altitude (e.g. see Fig. 6 transects T–U and V–W). The date of 4746 ± 50 (5594–5323) (Fig. 1, sample J4, Table 3) at an altitude of 8·57 m to 7·27 m (4·77 m to 3·47 m) obtained by Jardine (1975) for the base of the peat at Muirfad Flow, although not supported by microfossil analysis, supports limiting ages obtained from CW1 and CW6 for this last event.

At Baltersan, two silt intercalations in the valley side peat (Fig. 5, transect N–O) can be traced beneath the adjacent Moss of Cree, in which a third and higher intercalation is present (Fig. 5, transect P–Q). In the sequence at borehole MC23 (Figs 5, 13), apparently continuous according to the pollen record, the date of the index point for the regressive overlap from the most extensive silt horizon (Table 4, index point 9, Fig. 13) overlaps at two standard deviations with the highest dated horizon at Blairs Croft (Table 4, index point 14, Fig. 19C, D), whilst index point 7 (Table 4, Fig. 19C, D) for the regressive overlap from the last intercalation indicates that this event may equate with the regression from the highest silt horizon at Blairs Croft, overlapping at two standard deviations with the Muirfad Flow date of Jardine (1975) referred to above.

Notwithstanding the water depth variations and intercalations in the Baltersan and Blairs Croft areas reported above, the evidence towards the head of the carseland area appears to indicate a less variable sequence. At Palnure (Fig. 1), the silt which accumulated over the basal peat at index point 12 does contain some evidence of fluctuating water depths (see Figs 14, 15), but this is not marked and there is no evidence of a deepening episode near the top of the sequence. Instead, index point 11 at borehole P6 records the culmination of a shallowing sequence as surface peat began to accumulate at 6100 ± 70 (7209–6752) at an altitude of 9·31 m to 8·21 m (5·51 m to 4·41 m), and no later intercalations are present. It is supported by dates from the same horizon in a nearby borehole (Fig. 1, sample J1, Table 3) of 6540 ± 120 (7654–7249) for peat and 6240 ± 240 (7583–6528) (Fig. 1, sample J1, Table 3) for twigs at 7·03 m to 5·73 m (3·23 m to 1·93 m) obtained by Jardine (1975). The date obtained in this study for this last marine regression recorded at Palnure (Table 4, index point 11), falls only marginally outside the two standard deviation limit of the date at Baltersan for the regression there (Table 4, index point 9).

The evidence for the mid-Holocene marine transgression can therefore be interpreted as indicating that the event was locally variable and culminated earlier nearer the head of the carselands, and later farther south.

9.1.4. Mid-Holocene marine regression. South of the Baltersan and Blairs Croft areas, index points disclose a widespread regressive overlap beneath the surface peat. Index points 1, 2, 3, 4, 5, 6, 20 and 21 disclose marine regression between *c.* 4500 and *c.* 3400 (*c.* 5300 to *c.* 3600), although the overall range of altitude of these index points, at 10·25 m to 7·31 m (6·45 m to 3·51 m), implies a relatively slow rate of change. The ages of the index points are supported by the Muirfad Flow date of Jardine (1975) referred to above and additionally by a date of 4000 ± 100 (4826–4153) (Fig. 1, sample J3, Table 3) from Moss of Cree, obtained by Moar (1969).

10. Interpretation: shorelines and coastal change

10.1. The changing coastal landscape

As the relative sea level changes outlined above took place, the coastal landscape evolved, with shore features being formed, then buried beneath later accumulations or abandoned as relict features. On the basis of the stratigraphical and morphological evidence disclosed in this paper, the pattern of coastal change would appear to include the following elements:

10.1.1. Buried coastal features. During the early Holocene, at least 12 m of estuarine sediment accumulated between −12·5 m O.D. and *c.* −0·5 m O.D. at the site of borehole

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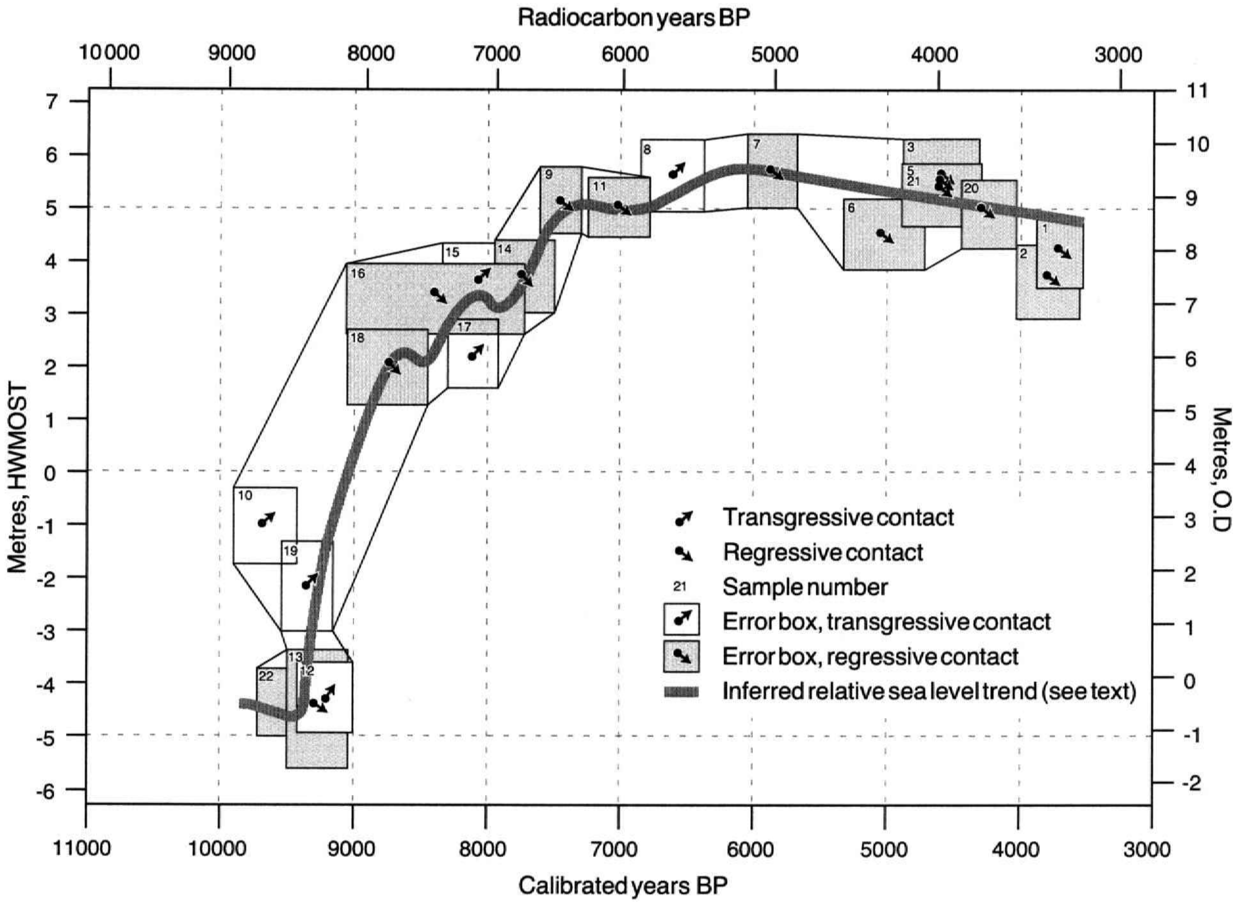

Figure 20 A graph of relative sea level change for the lower Cree Valley and estuary.

CW14. The particle size and microfossil profile of the sediment is consistent with it forming part of a locally extensive and gradually shallowing estuarine accumulation with no apparent breaks in sedimentation within the deposit. The indication is of a falling relative sea level from at least as early as *c*. 9250 (*c*. 8700), followed by a locally widespread saltmarsh surface which probably lies beneath much of the present-day carseland area, in view of the fact that the surface is reached in boreholes relatively close to the present carseland margin. Regression from this surface at *c*. 8300–8600 (*c*. 9300–9700) left an estuarine surface at *c*. −1 m (*c*. −5 m) widely covered by peat.

More detail is known of the features and sedimentary accumulations which developed during the subsequent rises in relative sea levels. By *c*. 8100 (*c*. 9200), estuarine silt had once again begun to accumulate in the area, across the peat-covered earlier surface, as large areas were re-occupied by estuarine waters. However, the pattern of accumulation across the area varied in response to variations in the overall relative sea level rise and to coastal morphology. The development of sand and gravel barriers aligned obliquely to the estuary sides had probably begun either as the earlier estuarine sediments accumulated, or at least at an early stage in this renewed episode of estuarine development, since at some locations (e.g. borehole CC9) nearly 7 m of estuarine sediments rest upon barrier gravels (the maximum thickness of estuarine sediments accumulating during this relative sea level rise is recorded as 9.5 m at borehole P6). These barriers may have formed under more open, high-energy conditions than those that subsequently developed, since they ultimately became largely buried beneath the accumulating estuarine silt, and the lack of evidence of wash-over effects suggests that they became relict, inherited features as extensive tidal mudflats developed.

However, the Baltersan–Blairs Croft barrier probably played an influential role in the accumulation and distribution of estuarine silt during the marine transgression. On the seaward side of the barrier, the foraminifera and ostracoda record through the minerogenic sediments in boreholes at Carslea Cottage (CCT2), Carse of Clary (CC2) and Carsewalloch Flow (CW14) indicate fluctuations in water depth (a conclusion probably supported by the particle size record at CW14), whilst on the landward side of the barrier, borehole transects at Baltersan and Blairs Croft disclose intercalations of estuarine silt and peat. It is suggested here that the episodes of shallowing water on the seaward side equate with the development of peat on the landward side. The continued deposition of minerogenic sediment seaward of the barrier during shallowing episodes would have been facilitated at least in part by the tendency of such sediment to be delivered mainly up-valley by tidal action. This process of sediment supply may be observed today in the lower reaches of Cree, where silt preferentially accumulates against the downstream side of obstructions in the estuary.

The last fluctuation in water depth recorded in CC2, CCT2 and CW14 appears to have been the most significant one, but it seems likely that the event was restricted up-valley of the Baltersan–Blairs Croft barrier and produced only a relatively shallow accumulation of silt there (e.g. see Fig. 5, transect P–Q, boreholes MC20 and MC23). On the other hand, the relative sea level reached probably persisted for a longer period than the earlier events. This was probably mainly due to the effect of a slowing in the overall rate of relative sea level rise as evident from Figure 16.

10.1.2. Visible raised shorelines The earliest visible raised shoreline to have been reached in the area is CR1 (Figs 1, 3, 4). The stratigraphically-consistent regressive surface lying below the highest minerogenic intercalation at Baltersan and Blairs Croft (Figs 1, 5, 6) and dated there at *c.* 6400–6800 (*c.* 7500–8000) can be seen to emerge north of the Moss of Cree as the highest visible surface (Fig. 5, transect P–Q) and is correlated with the highest regressive surface at Palnure (Fig. 6, transect R-S), there dated at *c.* 6100 (*c.* 7200). The extensive carselands on both sides of the Cree at Palnure and in the Palnure Burn valley (Fig. 1) are correlated with this shoreline, which lies within an altitude range of 7·7 m to 10·3 m (3·9 m to 6·5 m) (Figs 3, 4), merging up-valley into a river terrace.

The second visible raised shoreline is CR2 (Figs 1, 3, 4). This is associated with the highest carseland surface south of the Baltersan-Blairs Croft barrier system, and with the carseland areas at Bladnoch, near Wigtown and Cassencarie, near Creetown (Figs 1, 3, 4). This carseland is less dissected than that associated with CR1 and sea level index points indicate regression from it between *c.* 5000 and 2900 (*c.* 6000 and 3100). It may extend along the river Cree for some distance north of Muirfad Flow (Fig. 1), since Jardine (1975) obtained a radiocarbon date for wood within silt at the river bank of 6325 ± 120 (7458–6911) (Fig. 1, sample J6, Table 3), demonstrating that at that locality the carse surface above is younger than that date. The similar date, 6159 ± 120 (7316–6730) obtained by Jardine (1975) for wood from a river bank section near Nether Barr (Fig. 1, sample J2, Table 3) is from the face of a lower terrace in the carselands, probably related to a lower shoreline than CR2. Shoreline CR2 lies within an altitude range of 7·8 m to 10·1 m (4·0 m to 6·3 m), and overlies CR1 south of the Baltersan-Blairs Croft ridges.

The lowest raised shoreline is CR3 (Figs 1, 2, 3). This is only found in the south of the area, although the fragments of carseland terrace along the river at B, D and E (Fig. 1) may correlate with it. CR3 lies at 5·5 m to 8·0 m (1·7 m to 4·2 m), and where it meets CR2, at Borrowmoss Burn (Fig. 1A) a distinct surface slope occurs (Fig. 3A). At C (Figs 1, 3), the surface of CR3 rises into an embayment probably reflecting the delivery of sediment along the Mildriggan Burn (Fig. 1). The age of CR3 has not been determined in this study. In 1975, Jardine reported a radiocarbon date of 2290 ± 95 (2709–2062), on shells of *Cerastoderma edule* lying at an altitude of 5·80 m to 4·50 m (2·0 m to 0.7 m) at Mains of Baldoon (Fig. 1) from a ditch in the carselands associated with CR3, though given the habitat range of the mollusc (Peacock (1993) describes it as ‘littoral’, but comments that it has been found down to −46 m), this constitutes only a general indication. Across the valley at Hollanbank, south of Cassencarie (Fig. 1), the same molluscan species found in a terrace of sand and gravel at 5·89 m to 4·59 m (2·09 m to 0·79 m) was dated by Ergin *et al.* (1972) at 2027 ± 95 (2311–1714). These dates and their altitudes broadly support the inference that CR3 is younger than the youngest regressive contact index point date on CR2 (index point 1, 3380 ± 70 (3829–3467)).

The altitudes for all three relict shorelines identified in the Cree area, CR1, 2 and 3, do not disclose statistically-acceptable slopes from the horizontal, when plotted in a range of planes of projection thought likely to span that normal to the isobase trend for middle Holocene shorelines as illustrated in the several models of glacio-isostatic uplift for Scotland referred to earlier in this paper. The most likely reason is that the data lie along the long axis of the oval-shaped area of isostatic uplift commonly described in these models, possibly rendering the likely slope too gentle to have been identified for the distances over which the shorelines have been traced in the Cree area.

11. Comparison with other locations in SW Scotland

In recent years, detailed studies of Holocene relative sea level changes at sites in SW Scotland have been made by Jardine (e.g. 1975, 1980), Huddart *et al.* (1977), Bishop & Coope (1977), Lloyd *et al.* (1999) and Smith *et al.* (2000), and preliminary results of recent work published in a Quaternary Research Association Field Guide (Tipping 1999) by Dawson *et al.* (1999), Haggart (1999), Lloyd (1999) and Wells & Smith (1999). The results of these studies, taken with the evidence from the Cree area, indicate a broadly consistent pattern of relative sea level change.

The identification of an early Holocene shoreline dating from *c.* 8300 to *c.* 8600 (*c.* 7300–7700) at 0 m O.D. to −1.0 m O.D. in the Cree area is consistent with the stratigraphy reported from a borehole near Carsethorn, on the Nith estuary, where Holocene marine sedimentation is recorded as having been in progress at that site at below −2 m O.D. (Jardine 1975). The transgression which followed regression from the early Holocene shoreline in the Cree area, recorded as having begun by *c.* 8100 to *c.* 8300 (*c.* 9200 to *c.* 9400), is corroborated by maximal age dates of 8400 ± 200 (9890–8818) and 8420 ± 150 (9697–9027) from Girvan (Jardine 1975), and more particularly by transgressive contact sea level index point dates of 7950 ± 62 (9011–8595) and 7794 ± 61 (8748–8415) from Redkirk Point (Lloyd *et al.* 1999).

Several studies indicate that the transgression may have been interrupted by episodes of regression. Jardine (1975, 1980) maintained that in the eastern areas of the Solway Firth, the transgression was episodic, resulting in a number of disconformities within the apparently continuous carseland silts there and more particularly in a conspicuous layer of organic detritus within the carse silts extending over 160 m west of Newbie Cottages. More recently, Haggart (1999) identified an episode of marine regression between 7220 ± 70 (8175–7872) and 6790 ± 90 (7790–7483) during a widespread marine transgression at Pict’s Knowe, in the Nith valley, whilst Lloyd *et al.* (1999) identified a regressive–transgressive overlap sequence at Priestside Flow, east of the Lochar Water, which they dated to between 7302 ± 68 (8284–7964) and 7033 ± 57 (7963–7700). These observations indicate that the fluctuations in the transgression identified at Blairs Croft may be of a more than local significance.

Over much of the Solway Firth coastline east of the Cree estuary, the highest Holocene marine regressive surface is dated at older than *c.* 6,000. Thus, Jardine (1975) recorded dates of 6470 ± 280 (7912–6692) and 6645 ± 120 (7685–7307) for the base of peat overlying the carseland surface at Midtown and at Nether Locharwoods in the Lochar valley (the date of 5410 ± 160 (6498–5775) recorded from Horseholm, in the same area, was from the base of peat resting upon a surface 3 m lower than at the other two sites and is not strictly comparable). More acceptable dates for this regressive contact were obtained by Lloyd *et al.* (1999) from Priestside Flow, east of Milltown, of 6087 ± 186 (7420–6493), and on the southern side of the Solway Firth, from Boustead Hill, of 6202 ± 83 (7287–6808). These dates are similar to those obtained for the regressive surface associated with shoreline CR1 in the Cree area (at Palnure, Baltersan and Blairs Croft).

Evidence in support of the subsequent transgressive and regressive overlaps occurring in the Cree area is evident from other studies in SW Scotland. At Newbie Cottages, east of Priestside Flow, Jardine (1975) concluded that the transgression did not cease earlier than *c.* 5600 (*c.* 6500), a conclusion supported by dates from the highest Holocene marine regressive overlap on the southern side of the Solway Firth (Huddart *et al.* 1977). Recently, Dawson *et al.* (1999) have re-

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examined the site at Newbie Cottages and have identified a conformable episode of marine regression and terrestrial sedimentation within the carse deposits which they date at between 6590 ± 65 (7585–7340) and 6015 ± 60 (7005–6679), and date the overlying regressive content of the carse surface there at 4795 ± 50 (5609–5331), thus providing evidence that a late Holocene marine transgression occurred there at a comparable date to the event recorded in the Cree area.

Several visible Holocene shoreline terraces have been reported in the Solway Firth (e.g. Marshall 1962a, b; Jardine 1980), although there is little detailed height information and correlations cannot therefore be made with the Cree sequence. Interestingly, Lloyd *et al.* (1999), comparing both northern and southern coasts at the head of the Solway Firth, maintain that there is evidence for differential crustal movement, the highest Holocene regressive overlap in the north lying at a higher altitude than in the south.

12. The wider context

The apparently widespread saltmarsh surface and inferred shoreline identified in the area as dating from *c.* 8300–8600 (*c.* 9400–9700) is tentatively correlated with the Low Buried Beach beneath the Forth (*c.* 8500 (*c.* 7500)) and Tay (*c.* 8800 (*c.* 10000)) carselands (e.g. Sissons 1966; Cullingford *et al.* 1980). No equivalents of the High or Main Buried Beaches (e.g. Sissons *et al.* 1966) have so far been found in the Cree area. The evidence from the Palnure site in this paper indicates that regression from this buried saltmarsh surface and shoreline was short-lived in a similar manner to the regression from the Low Buried Beach in the Forth and Tay. The date for commencement of the subsequent transgression at Palnure, *c.* 8100 (*c.* 9300), is close to dates for the commencement of the Main Postglacial Transgression in the Forth, Tay and other areas in eastern Scotland (Sissons 1974), and the event in the Cree is therefore correlated with that widespread feature of relative sea level change during the Holocene in Scotland.

The variations in the Main Postglacial Transgression identified at Blairs Croft have no equivalent outside the Solway Firth in Scotland and it is therefore not known whether they are secular or purely local or regional events. However, the possibility that the Main Postglacial Transgression involved some variation may be realistic given the likely origin of the event, involving the deglaciation of global ice masses with the periodic release of water from ice-dammed lake complexes (e.g. Fairbanks 1989; Blanchon & Shaw 1995; Leverington *et al.* 2000).

The shoreline reached at *c.* 6100–6800 (*c.* 7000–7700) in the Cree area (CR1) is here correlated with the Main Postglacial Shoreline elsewhere in Scotland (e.g. Smith 1997), and reflects a slowing in the rise of the Main Postglacial Transgression, such as has been observed elsewhere (e.g. Smith *et al.* 1985), whilst the later shoreline, CR2, which partially overlaps CR1, is correlated with the Blairdrummond Shoreline of Smith *et al.* (2000), although in comparison to these other locations, the evidence in the Cree area is particularly detailed. Several locations around the Scottish glacio-isostatic centre have been shown to disclose evidence of at least one transgressive overlap exceeding the Main Postglacial Shoreline, as summarised by Smith (1997), for example at Wick (Dawson & Smith 1997) and on Skye (Selby *et al.* 2000). The lowest shoreline, CR3, may correlate with one of the lower shorelines found in, for example, the Forth (Smith 1968), Tay (Cullingford 1972) or Inner Moray Firth (Firth & Haggart 1989).

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