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Review No 108

Coastal processes and management of Scottish estuaries
VI. The Firth of Clyde

Callum R Firth and Phillip E F Collins

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13.3 Loch Ryan

13.3.1 Sea Defences

Large sections of this coastline are currently protected and the demand for additional defences may increase as relative sea level rises. Where seawalls front the shoreline, they may promote the loss of fronting beaches as sea level rises, since scour is likely to be enhanced by increasing water depths. At isolated sites it may be better to reposition road systems or allow individual buildings to collapse into the sea. Along the eastern and southern shore the sea defences are already in place and little further impact would be introduced by maintaining these features.

13.3.2 Land Claim and Managed Retreat

At present no claimed land has been identified in the Loch Ryan area. Although there is some scope for claiming land at the head of the Loch there are no plans to undertake such development. With rising sea levels the position of the coastline in this area will tend to remain static due to the steep shoreline or the current sea defences. The area also has limited potential for managed retreat, since natural processes could achieve the same result with no input from society. The recommendation is thus to allow as much as the coastline as possible to continue to evolve naturally in this area.

13.3.3 Sand and Gravel Extraction

No sand and gravel are extracted in this area although the extensive deposits in the vicinity of Stranraer represent a potential source of material. Such deposits could be developed away from the coast and so there is no reason why the coastal sediments should be exploited.

13.4 Isle of Arran and Outer Clyde Coastline

13.4.1 Sea Defences

Much of the Kintyre and Arran coastlines consist of rock cliffs and it is unlikely that coastal defences will be greatly extended in these regions. Localised sections of the coast are protected, mainly alongside villages, and as sea level rises it would seem likely that the current structures may need to be upgraded. None of these structures greatly effect longshore sediment transport or limit sediment supply to the coastal zone and as a result they are not seen as a major concern.

In contrast, the Ayrshire coastline is already heavily defended due to the extensive erosion that is taking place. It seems likely that as sea level rises so the sea defences will be extended, particularly along the golf links. Greater attention will be paid to stabilising the dunes and at some localities beach nourishment may be practised. It is unlikely that these defences will greatly alter the character of the coastal zone although the construction of sea walls may promote enhanced coastal erosion.

13.4.2 Land Claim and Managed Retreat

The only area of land claim lies near the mouth of the River Irvine where a limited area of land now lies protected behind embankments. New wetlands have developed in front of the embankments and these systems seem to have a high sediment supply. It is highly likely that the wetlands will keep pace with any future rise in sea level, but they will need space to migrate landward. Since the systems will be under pressure form rising sea levels further

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Focus on Firths Project
Overall Objectives

The Scottish estuaries or "Firths" contain a wealth of natural features (both geomorphological and ecological) which are sensitive to environmental changes and human impacts (Carter and Woodroofe, 1994). At the same time current research into climate change (IGCP95 1996, Great Britain 1997) suggests that during the next 100 years sea-level and climate will probably alter and as a result it is vital that the impact of such changes on the coastal communities and resources of Scotland are evaluated. For these reasons Scottish Natural Heritage has developed a national initiative, termed the "Focus on Firths" project, to assess the impact of future environmental and human changes on coastal regions and to develop plans for their sustainable management. In such plans it is essential to evaluate both the landforms and the physical processes which influence their development since these factors largely control the distribution and composition of habitats and biological communities. In particular a sound knowledge of the nature and extent of recent patterns of accretion and erosion is required if areas at risk from coastal erosion or flooding are to be identified and appropriate management plans developed.

One of the major aspects of the "Focus of Firths" project is the preparation of management frameworks for Scottish Firths. A precursor to such plans is an in depth assessment of the physical processes operating in each of the estuaries since this provides the necessary background against which management options can be developed.

The principal aim of this report is to provide an audit of the contemporary and Late Quaternary (last 11,000 years) coastal landforms and processes present in the Firth of Clyde region. The scientific value, distinctiveness and contribution of these features to the character of the Scottish coastline is also assessed together with their sensitivity to future environmental changes. The report is largely based upon published and unpublished literature which was supplemented by material gathered during one week of fieldwork in the area.

It should be noted that for many sections of the coastline there is very little or even no information available relating to the coastal geomorphological processes. Such a lack of information, which is highlighted in the text, thus limits the recommendations that can be made and it is essential that this report is read with this context in mind.

1.0 INTRODUCTION

1.1 Objectives

The objectives of this report are:

a) to briefly review the geological and physiological setting of the Firth of Clyde region.

b) to review the current understanding of geomorphological/hydrodynamic processes within the estuary in relation to tides, winds, waves, currents, and storm surges.

c) to review the nature of contemporary and Late Quaternary coastal landforms and sedimentary environments within the estuary.

d) to identify patterns of erosion and accretion, sediment sources, sinks and transport pathways within the estuary.

e) to outline the effects of society on the marine geomorphological environment and to make recommendations for the management of threatened landforms.

f) to assess the national importance of the geomorphological features in the estuary and evaluate their contribution to the overall landscape character of the Scottish coastline.

g) to review current knowledge relating to former and future changes in relative sea level and climate in Scotland.

h) to evaluate the possible impacts of environmental changes on the landforms, geomorphological processes and ecological habitats within the estuary.

i) to review the options available to manage environmental change within the estuary and to highlight areas worthy of further geomorphological research.

1.2 Geological and geomorphological setting

The Firth of Clyde represents the largest estuary in western Scotland, which consists of a broad embayment together with a series of fjord lochs (Loch Ryan, Loch Fyne, Loch Long, Loch Riddon, Loch Striven, Holy Loch, Loch Goil, Gare Loch) (Fig. 1.1). The Clyde extends some 140 km south-south-west from Clachan (head of Loch Fyne) into the North Channel, between Scotland and Northern Ireland, its outer limits (for the purpose of this report) being placed at the Mull of Kintyre in the west and Corsewall Point in the south. The outer section of the estuary consists of a broad NNE-SSW aligned embayment (*circa* 50km wide) which extends from the mouth to Skipness Point in the west and Farland Head in the east. Within this embayment lie the isles of Arran and Ailsa Craig and the small north-south aligned embayment of Loch Ryan. The inner section of the estuary consists of a number of narrow fjords and the islands of Bute, Inchmarnock, Great Cumbrae and Little Cumbrae. Loch Fyne, in the west is the longest of the fjords, extending some 70km inland but only reaching a maximum width of 6km. Farther east are the smaller fjords of Loch Riddon, Loch Striven, Holy Loch, Loch Goil and Loch Long which rarely exceed 1 km in width. In contrast the Inner Clyde forms a broader embayment which is aligned north-south between Farland Head and Dunoon and then takes on a west-east alignment to its head in Glasgow (Fig. 1.1).

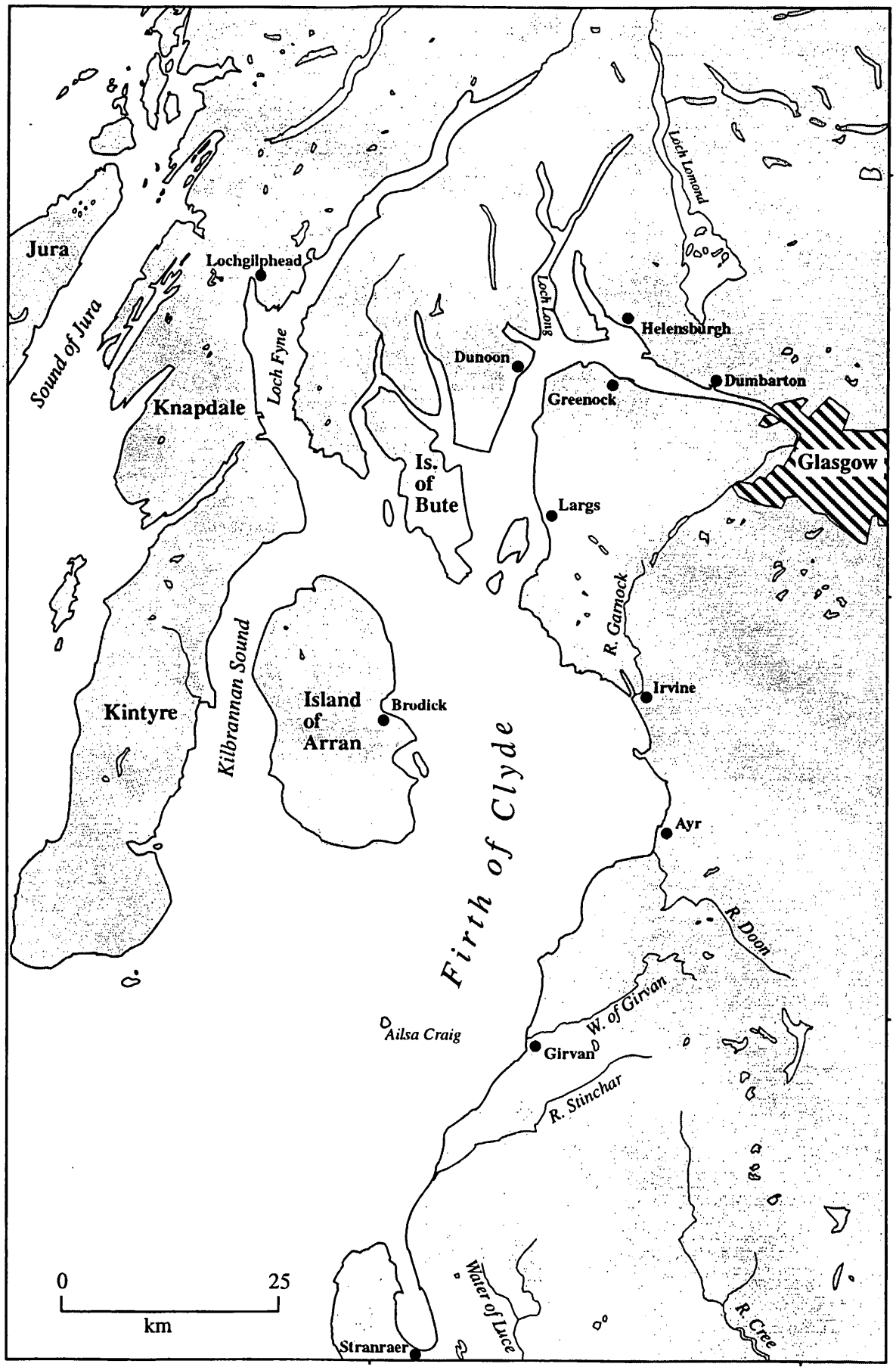


Fig.1.1 Firth of Clyde: Site locations

Bathymetric maps (Admiralty Charts; Ritchie 1975; British Geological Survey., 1997) indicate a complex pattern with deep channels extending into the narrow fjords. The major channels have been generated by the scouring action of ice (Sissons 1967), which has created locally-enclosed deeps with shallower seaward terminations (Fig. 1.2). Deep channels (150m) are located to the east and west of the Isle of Arran and these join together and extend northwards into Loch Fyne where the water locally reaches a depth of 164m near Lochgilphead and 150m offshore of Strachur. Similarly water depths in excess of 50m are common in most of the other fjords and this clearly contrasts with the shallow Firths which characterise the eastern and southwest coasts of Scotland.

The most significant rivers which flow into the Clyde (Stinchar, Water of Girvan, Doon, Ayr, Irvine, Clyde, Endrick Water) are all located in the east and they drain to the eastern shoreline of the estuary (Fig. 1.2). Most of these rivers flow across low relief, drift covered landscapes and as a result sediment delivery to the coastal zone is usually moderate. In contrast, the western shoreline and fjord coasts are associated with small river basins but the steep gradients combined with high rainfall can result in significant inputs of sediment at the mouth of each river.

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The physical landscape surrounding the Clyde largely reflects the underlying solid geology (Fig. 1.3), with areas of low ground being underlain mainly by Carboniferous and Permian sandstones and occasionally limestones and the higher ground being associated with igneous or Precambrian metamorphic rocks (British Geological Survey, 1997). Areas of high ground such as northern Arran (874), the Cowal Penninsula (locally rises to 1011m at Beinn Ime) and the region south of Ayr are underlain by granite, Dalradian schists and Lower Palaeozoic rocks which result in steep coastal slopes. In contrast the Upper Palaeozoic rocks which characterise the lowlands of Glasgow and Ayr provide more gentle coastal slopes.

1.2.1 Bedrock Geology

The Clyde region is divisible into three geological regions, the Southern Uplands, the Midland Valley and the Highlands, each being separated by major NE-SW trending faults: the Southern Uplands Fault and the Highland Boundary Fault (Fig. 1.3). Rocks associated with the Southern Uplands lie south of Girvan and consist of deep-water marine sandstones and slates of Ordovician age and the Ballantrae Igneous Complex. The rocks were laid down under oceanic conditions and were subsequently folded as the former Iapetus Ocean closed (Greig 1971).

To the north of this between the Southern Uplands and Highland Boundary Fault lies the Midland Valley (Cameron & Stephenson 1985). The oldest rocks in this area consist of the Devonian sandstones and conglomerates between Girvan and Ayr, Saltcoats and Cloch Point and the southern part of the Isle of Bute and the southeastern tip of the Kintyre Peninsula. These rocks formed by the erosion of the mountains that emerged when the Iapetus Ocean closed and they were deposited under continental conditions. Between Ayr and Saltcoats the coast is formed of the Carboniferous Coal Measures which consist of well-bedded alternations of sandstone, siltstone, coals and seat earths. The rocks indicate fluctuations between shallow marine and terrestrial environments associated with changing

sea levels. Farther north in the vicinity of Glasgow extensive Carboniferous and Permian volcanics are present, which indicate considerable volcanic activity within this region at the time. To the west is the Isle of Arran with its Tertiary granite intrusion in the north and Permo-Triassic sandstones with numerous dykes and sill intrusions in the south. The island also contains minor outcrops of later Mesozoic rocks including chalk which suggest that much of the region lay beneath the ocean and would have been covered by this rock (Richey 1961). Subsequent uplift during the Tertiary linked with the volcanic intrusions of the time may have provided the initial landscape from which the current drainage system has been derived and later modified by glacial action (Sissons 1967, 1976).

To the north of the Highland Boundary Fault lies the Highlands and the Precambrian metamorphic rock of Dalradian age (Johnstone 1966). These rocks are mainly metamorphosed marine sediments which produce a rugged coastline and often steep coastal gradients. The rocks display a strong southwest to northeast trend which is partly reflected in the alignment of some of the inner fjords.

1.2.2 Quaternary history and landforms

A wide range of landforms is present in the Clyde region, reflecting a variety of environmental conditions and changes in these conditions over time. Much of the landscape above high water includes elements inherited from earlier phases of landform development. In contrast, the intertidal and subtidal zone contains a number of morphological elements which are sensitive to even relatively minor environmental conditions and which reflect processes active at present or in the very recent past.

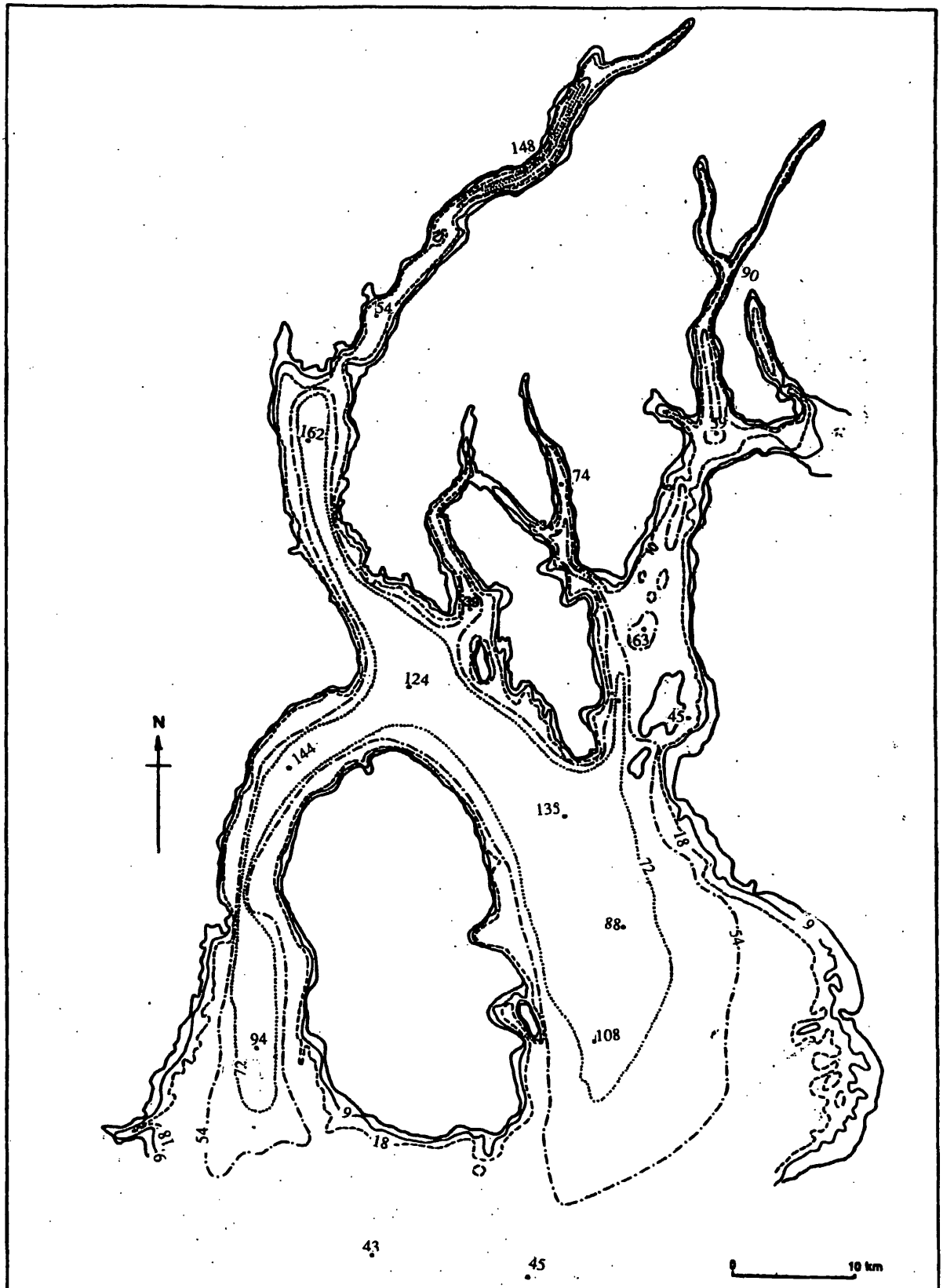
Little research appears to have been completed on the long-term evolution of the Clyde region but it is suggested that the current drainage divide between the Clyde and Forth was in place prior to the Quaternary (Sissons 1967, 1976). Similarly it is believed that during the Tertiary the Midland Valley formed a topographic low in comparison to the higher ground to the south and north although there is limited evidence to support this. Many of the existing valleys were no doubt formed prior to the glacial period and have subsequently been modified by glacial processes

Much of the landscape in the Clyde area is a result of Quaternary processes. The fjords of the Cowal Peninsula radiate outwards from the centre of ice accumulation and they probably formed during the repeated glaciations that characterised the Quaternary Epoch. Major ice streams would have extended from Rannoch Moor southwards along lochs Fyne, Long and Lomond and over a series of glaciations they generated the fjord landscape.

During the period of the last glacial episode, the Late Devensian *circa* 30-10,000 years before present (B.P.), ice advanced into the Clyde from the north and south, with a convergence zone just north of the Southern Uplands Fault (Sutherland 1984). The evidence suggests that ice initially expanded from the Highlands and then later from the Southern Uplands. At the time of maximum glaciation (*circa* 18,000-20,000 yrs B.P.) the whole region was covered in ice and models (Boulton *et al.* 1991) have suggested that it may have been up to 1000m thick and extended westwards beyond Islay into the North Atlantic.

The initial stages of deglaciation are not recorded within the Clyde region, although the lack of earlier Errol beds suggests that much of the area may have remained covered by an ice dome centred over Arran with ice flowing eastwards across Ayrshire and westwards across the Kintyre peninsula (Boulton *et al.* 1991). Rapid deglaciation of the region appears to have taken place as a consequence of calving of icebergs as the ice front receded towards the inner fjords (Bishop and Dickson 1970). Much of the area was certainly ice free by about 13,000 yrs. B.P. (Sutherland 1981, 1984, Peacock and Harkness 1990) by which

time marine sediments were being deposited within much of the outer estuary. The ice sheet stabilised at the mouth of many of the fjords and within localised valleys on Arran (Gemmell 1973) and a minor readvance of ice may have occurred (Sutherland 1981, 1984) within Loch Fyne, this being referred to as the Otter Ferry Stage (Fig. 1.4). It is noteworthy that the mouth of the inner Clyde remained blocked by ice but the sea was able to penetrate into Glasgow via the Lochwinnoch Gap (Peacock 1970). These ice margins were usually associated with large volumes of sediment being delivered to the coastal zone and thus represent a major sediment source for modern coastal processes. It has been suggested (Peacock 1970, Sutherland 1981) that whilst the ice remained at these locations relative sea level fell as a consequence of continued crustal uplift. As a result when the ice started to retreat into the inner Firth's relative sea level was markedly lower and so the highest Lateglacial raised shorelines within the inner lochs often occur at markedly lower altitudes than those at the mouth.



1. Isobaths in meters
2. Loch Goil, Loch Fyne, Loch Long, and Loch Striven have depths of water too great to be shown by isobaths in the space available Spot depths are shown to indicate order of depth
3. 36m line ommited for the same reason

Figure 1.2 The Firth of Clyde bathymetry (Ritchie, 1975)

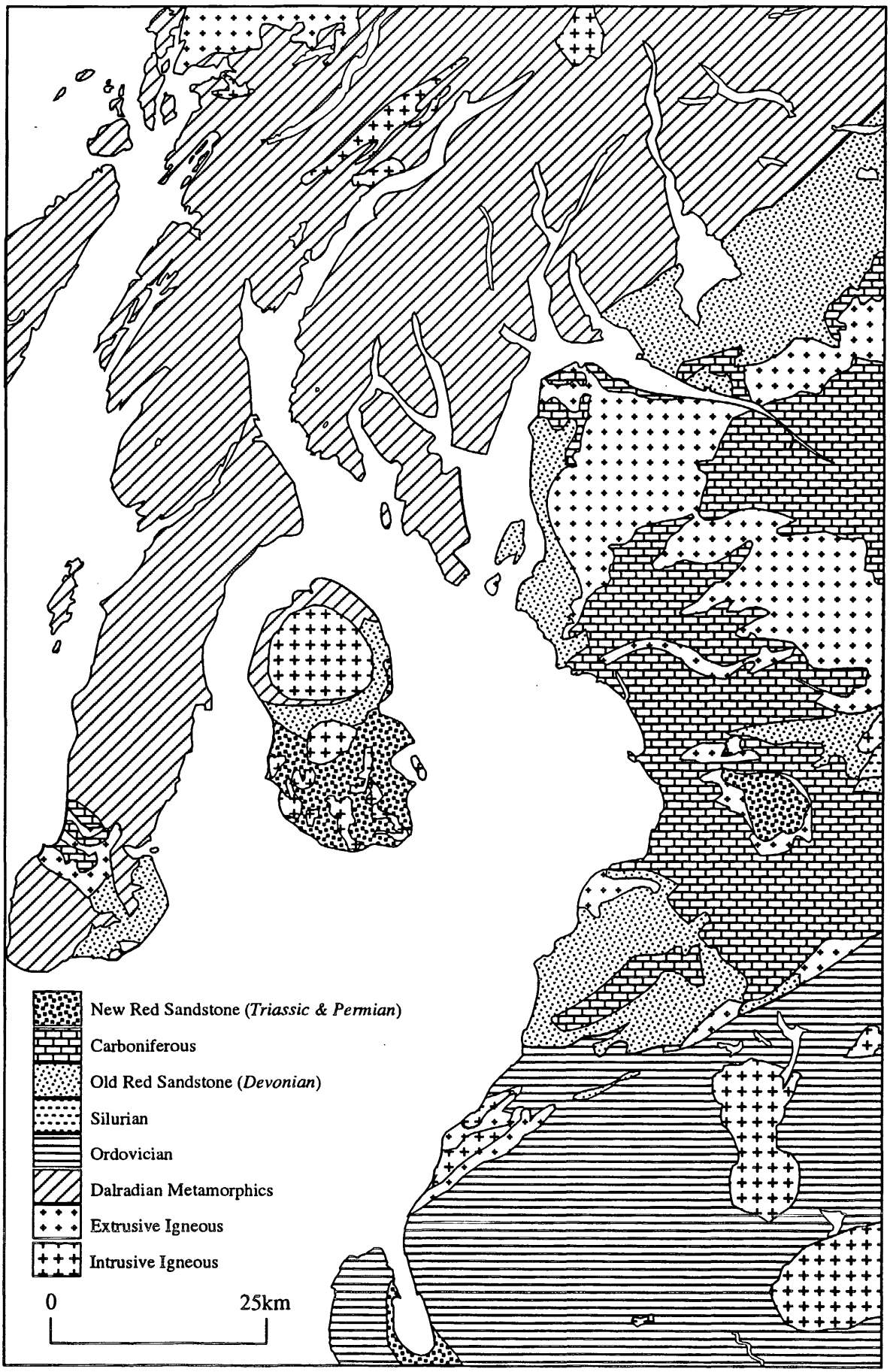


Figure 1.3: Firth of Clyde Region: Bedrock geology

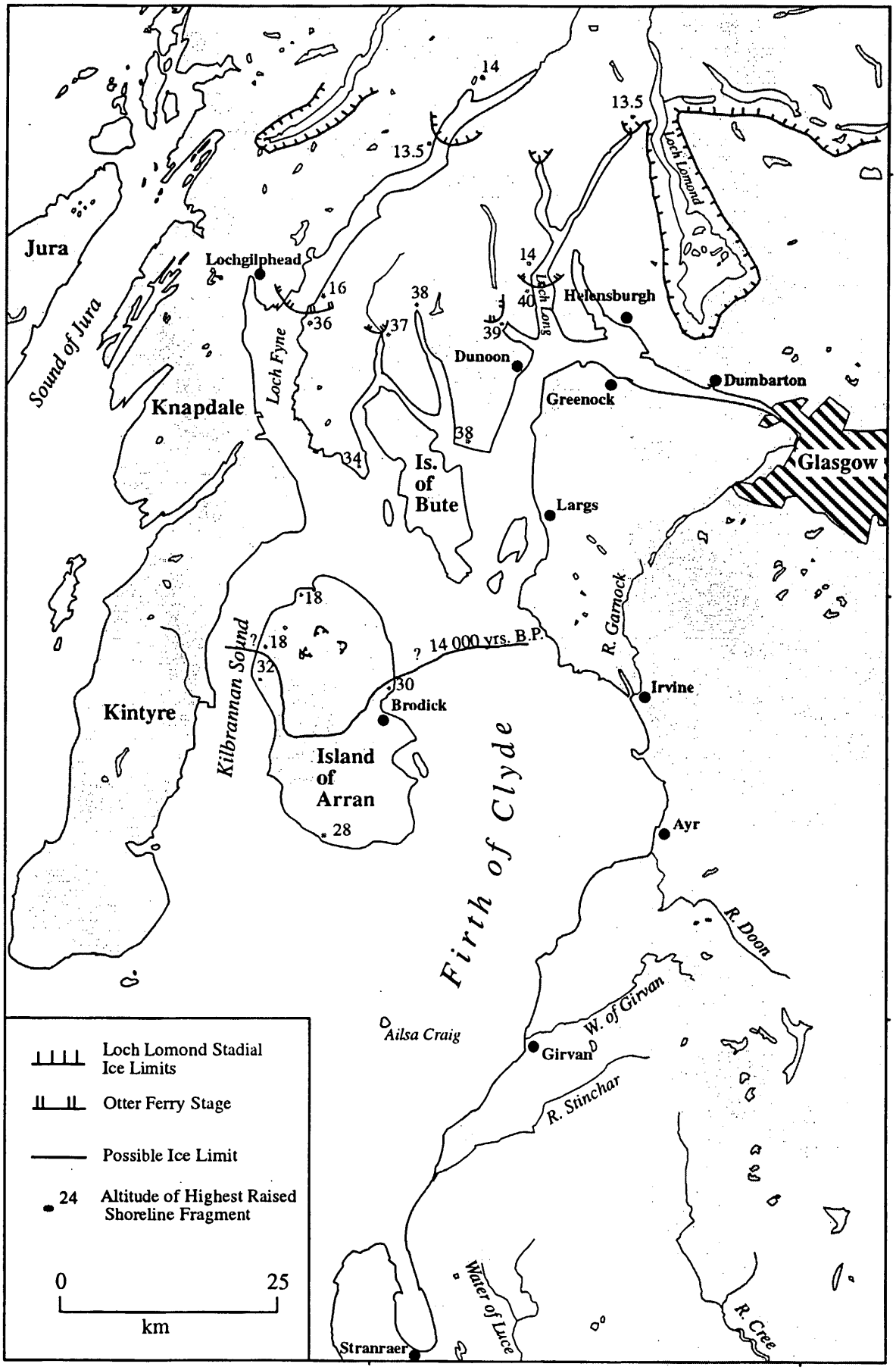


Fig.1.4 Quaternary Geology of Firth of Clyde Region

At around 13,000 yrs B.P. the cold arctic conditions were replaced by a milder climate of the Lateglacial Interstadial (13,000-11,000 yrs B.P.), as the oceanic polar front in the North Atlantic migrated to the north of Scotland. Although the passage of the front may have initially stimulated the re-advance of ice it subsequently resulted in the rapid disintegration of the remaining ice masses which retreated rapidly into the fjords and as a consequence limited volumes of sediment were deposited within the coastal zone. There is no conclusive evidence to suggest that all the ice melted during this period and some authors (Sissons 1976) have suggested that residual ice masses may have remained in the Highlands. It is however extremely likely that most of the sea lochs became ice free as evidenced by the extensive distribution of Clyde Beds throughout the area (Peacock 1983, 1989). In the inner fjords sea level certainly fell to within a few metres of present level (Peacock *et al*, 1977, 1978; Sutherland 1984) and lay below present in the outer part of the estuary.

At around 11,000 yrs. B.P. the climate declined and there was a return to arctic conditions for approximately 1,000 years, know as the Loch Lomond or Younger Dryas Stadial. The oceanic polar front migrated south of the British Isles and marine sediments with a restricted high arctic marine fauna were deposited around the coasts (Peacock *et al.* 1978). The period was characterised by a phase of glacier advance with glaciers moving southwards into the Clyde region along Loch Lomond, Loch Fyne and Loch Long and developing in corries in Arran (Gemmell 1973) and the Southern Uplands (Cornish 1984). These glaciers reached their maximum extent (Fig. 1.4) after 10,500 yrs. B.P. (Rose *et al.* 1988) and may have retarded crustal uplift or even re-depressed the crust (Boulton *et al.* 1991, Firth *et al.* 1993) to the extent that relative sea level rose near the ice margin. The periglacial conditions of the period resulted in extensive coastal erosion and the formation of a coastal platform (Main Rock Platform) backed by a shoreline known as the "Main Lateglacial Shoreline" (Sissons 1974). This feature is glacio-isostatically tilted so that it descends in altitude from 9m near the head of Loch Fyne to 0m at the southern end of the Mull of Kintyre (Gray 1978, 1995; Firth *et al.* 1993). Some evidence does suggest however that this feature may have been formed earlier and was only re-trimmed during this period (Browne *et al.* 1983). The Main Rock Platform and backing cliff is by far the most prominent Quaternary feature in the coastal zone and in many areas it dominates the coastal profiles. At the Head of Loch Fyne and within Loch Long and Loch Goil sections of cliff and platform occur within the Stadial ice limits. Sutherland (1981, 1984) suggested that these features formed prior to the ice advance and have subsequently been exhumed, which indicates that such features can be preserved beneath an ice sheet and so the possibility that they formed prior to the Late Devensian is tenable. The Loch Lomond Stadial came to an abrupt end at *circa* 10,000 yrs B.P. with rapid climatic amelioration which marked the start of the Holocene period and this resulted in the rapid backwasting and final decay of the glaciers.

1.3 Scientific Importance of the Firth of Clyde Region

The coastline of the Firth of Clyde is one of contrast since parts of it are heavily developed and used by society and other sections consist of largely natural shorelines where human impacts are minimal. The area contains a wide range of protected sites of national and international importance for geological, biological and ornithological reasons (Fig. 1.5).

1.3.1 Loch Ryan

The Loch Ryan area is a Marine Consultation Area and contains part of the Western Southern Uplands environmentally sensitive area, 1 SSSI and two Areas of Regional Scenic Significance.

The whole of Loch Ryan has been designated as a Marine Consultation Area which indicates that SNH gives particular attention to the quality of the marine environment and

encourages the local community to be aware of conservation issues within the area. Similarly the land to the eastern shoreline is given particular attention since it forms part of the Western Southern Uplands Environmentally Sensitive Area. The northern part of this coast together with the outer Rhinns coastline have also been designated as Areas of Regional Scenic Significance with the strong presumption that development should be limited. The area does however only contain one Site of Special Scientific Interest (SSSI), namely Corsewall Point to Milleur Point which covers some 60ha and is important for biological and geological reasons.

1.3.2 Arran and the Firth of Clyde

The Firth of Clyde is the largest estuary on the west coast of Scotland and as a result it contains a complex variety of features. A significant proportion of the shoreline lies within Regional Scenic Areas or regional Scenic Coasts and the area contains 38 SSSIs, and 30 Geological Conservation Review sites.

All of the south Ayrshire coast and the parts of the east Kintyre coast have been designated as Regional Scenic Coasts. In addition the Heads of Ayr, the Renfrew Hills, North & Central Arran and the Mull of Kintyre have been designated as Regional Scenic Areas and the rest of the coasts of Arran and Kintyre have been designated as Preferred Conservation Areas. Such designations indicate the scenic value of the coastlines involved and indicate that development would be inappropriate.

Of the 17 SSSIs selected for their biological importance (Table 1.1) one, Ailsa Craig, is a Special Protection Area important for the gannets and to a lesser extent the lesser black-backed and herring gulls. The other sites contain a wide range of habitats ranging from coastal grasslands, through dune systems to shingle beaches. In addition there are a further 17 SSSIs which have been selected for their geological significance (Table 1.2). These sites contain a range of rock types of Precambrian-Quaternary age, the most important of which are the Girvan to Ballantrae Coast section with its obducted ophiolite sequence and Tertiary intrusive dykes and sills on Arran (Drumadoon-Tormore and Dippin Head).

The area also contains two Royal Society for the Protection of Birds (RSPB) sites (Horse Isle and Inner Clyde) for breeding seabirds and waterfowl and winter grounds. In addition there are two Scottish Wildlife Trust sites at Parkhouse Community Nature Reserve and Carradale Point.

1.3.3 Isle of Bute and the Cowal Penninsula

This area contains a National Nature Reserve, 9 SSSIs, a Marine Consultation Area and extensive sections of coastline noted for their scenic value.

By far the most important site in the area is Mealdarroch National Nature Reserve which forms part of the Tarbert to Skipness Coast SSSI (Table 1.1, Fig. 1.5). The site contains ancient broad-leaved woodland and a variety of vascular plants in the humid narrow ravines. The woodland extends from sea level up to 150 m and illustrates marked altitudinal zonation. Another site of particular scientific interest is the Ruel Estuary which provides a largely natural transition from marine to terrestrial ecosystems.

The northern part of the Isle of Bute and the surrounding shores of Loch Riddon and the Kyles of Bute have been designated by SNH as a National Scenic Areas. The rest of the Isle of Bute and South Cowal are designated as Regional Scenic Areas whilst upper Loch Fyne, Long Long and Loch Goil are Regional Scenic Coasts (Fig. 1.5). Due to the scenic value of these areas there is a strong presumption against development. Large sections of

the remaining coast have been designated as Preferred Conservation Areas and thus industrial projects (oil-/gas- related) are considered inappropriate. The Head of Loch Fyne has also been designated as a Marine Consultation Area and thus the local community is encouraged to be aware of marine conservation issues in the area.

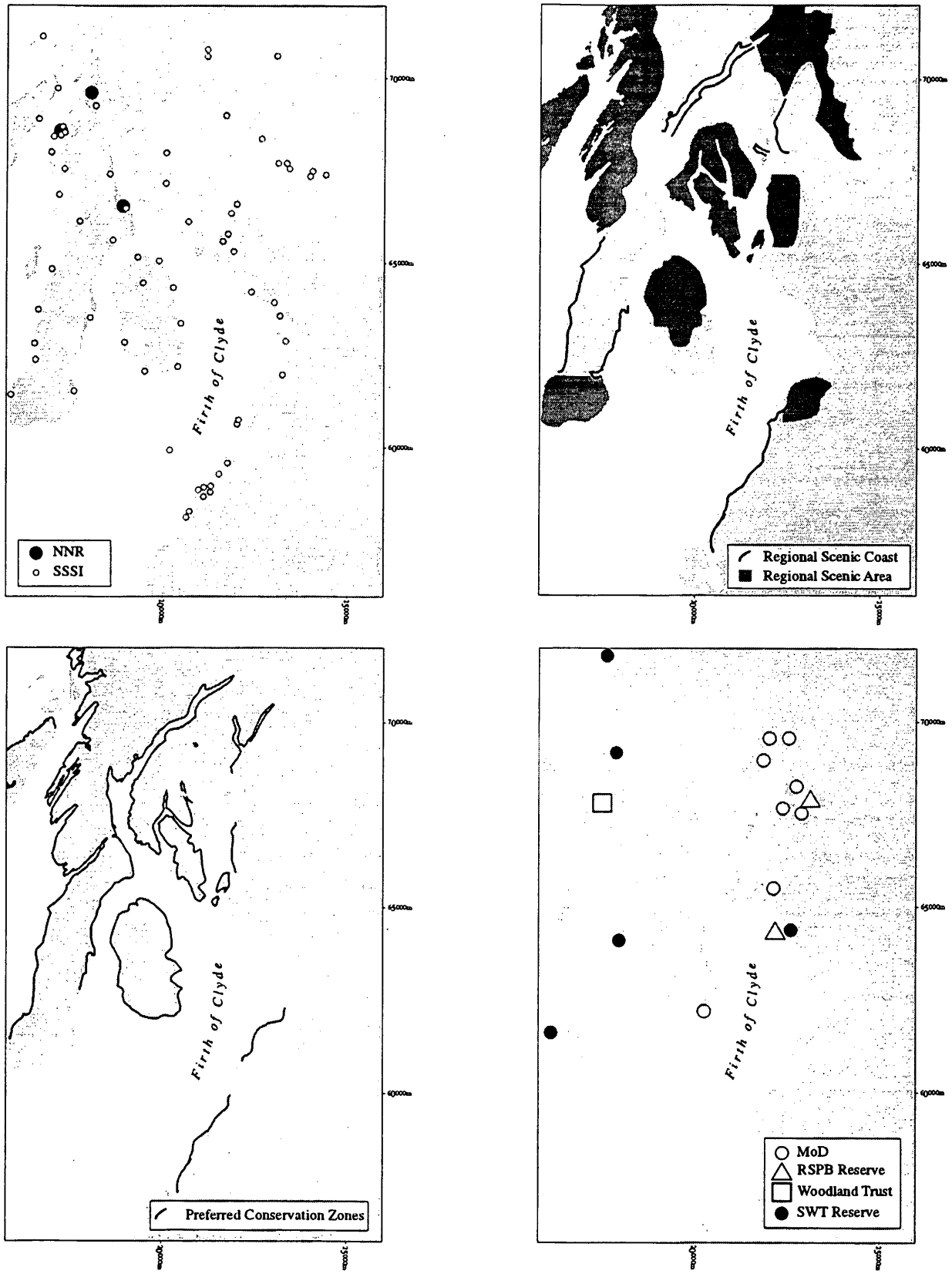


Figure 1.5: Firth of Clyde Region: Sites of Special Scientific Interest and other coastal areas of scenic/biological interest. (Barne *et al.*, 1997)

Table 1.1: SSSIs of biological interest in the Firth of Clyde area

SSSI Biological Site	Area	Scientific Interest
Ballantrae Shingle Beach	34ha	Shingle spit habitat, breeding colony of little tern
Bennane Head Grassland	74.1ha	Coastal grasslands, wide variety of plants & butterflies
Ailsa Craig	104.4ha	Rocky shores, 4th largest gannetry in UK.
Maidens to Doonfoot	224.5ha	Cliffs support coastal deciduous woodland and a variety of coastal habitats with rare insect species.
Turnberry Dunes	77.7ha	Sandy beach & dunes with rare beetles.
Troon Golf Links and Foreshore	149.6ha	Dune and beach system with important roosting and wintering grounds for birds.
Western Gailes	93.7ha	Dune system which includes northern limit of many beetle and fly populations.
Bogside Flats	253.8ha	Saltmarsh and mudflat habitats used by wintering birds
Portencross Coast	478ha	Variety of coastal habitats, best mudflats for wildlife & waders in the Clyde.
Kames Bay	4.6ha	Intertidal marine biology
Ballochmartin Bay	18.9ha	Coastal habitats important for teaching marine biology
Erskine to Langbank	545.2ha	Extensive mudflats supports wintering waders and wildfowl
Dumbuck Foreshore-Pillar Bank	819.5ha	Saltmarshes and mudflats which support wading birds and are internationally important for redshank and shelduck.
Ardmore point	134.8ha	Saltmarsh and mudflats important for a range of waterfowl and winter waders.
Claonaig Wood	55.4ha	Native oakwood and beach marsh.
Torrisdale Cliff	27.8ha	Ash and elm native woodland, with diverse bird community
Balnabraid Glen	109.4ha	Valley alder wood with rocky coast of national importance.
Clauchlands Point-Corrygills	47.3ha	Coastal habitats: beach-head saltmarsh to alder/willow woodland
North End of Bute	934.1ha	Native deciduous woodland and moorland habitats and exceptionally high diversity of breeding birds (70 in all)
Ruel Estuary	341.7ha	Excellent example of transition from estuarine to terrestrial habitats
Artilligan and Abhain Strathain Burns	62.7ha	Coastal oak and birch woodlands
Tarbert to Skipness Coast	592.3ha	Ancient broad-leaved woodland with altitude zonation and variety of vascular plants.

Table 1.2: SSSIs of geological interest in the Firth of Clyde area

SSSI Geological Site	Area	Scientific Interest
Corsewall Point to Milleur Point	60.3ha	Lower Palaeozoic congolmerates
Sgavoch	6.2ha	Ordovician Igneous: Ballantrae pillow lavas
Girvan to Ballantrae Coast Section	89.2ha	Ordovician Igneous: Ballantrae obducted ophiolite series
Ailsa Craig	104.4ha	Tertiary riebeckite microgranite: ice flow indicator
Turnberry Lighthouse to Port Murray	24.4ha	Lower Devonian Igneous: andesite pillow lavas
Maidens to Doonfoot	224.5ha	Devonian-Permo-Carboniferous igneous and sedimentary: variety of igneous rocks and structures
Ardrossan to Saltcoats Coast	53.7ha	Permo-Carboniferous igneous: intrusive sills
Portencross Coast	478ha	Devonian sediments & volcanics; excellent section of Main Rock Platform and cliff.
Largs Coast	7.7ha	Non marine Devonian: braided stream deposits
Dumbarton Rock	4.4.ha	Permo-Carboniferous igneous: volcanic plug
Laggan	6.6ha	Palaeozoic Palaeobotany: fossil flora in volcanic ashes
Corrie Foreshore and Limestone Mines	13.3ha	Devonian-Permian sedimentary: range of sedimentary rocks and structures.
Dippin Head	18.4ha	Tertiary Igneous: basic sills
Drumadoon-Tormore	77.5ha	Permo-Trias & Tertiary Igneous: range of sedimentary rocks and structures intruded by dykes
North Newton Shore	9.2ha	Non-marine Devonian: historically important unconformity between Precambrian and Old Red Sandstone
South Coast of Arran	218.3ha	Tertiary Igneous: main Arran Dyke swarm of inter-national importance.
Ardmore Point	134.8ha	Upper Palaeozoic: contact between Upper and Lower Old Red Sandstone.
Rhu point	0.11ha	Quaternary: Clyde Beds deformed and overlain by tills of Loch Lomond Stadial age.
Clauchlands Point to Corrygills	47.3ha	Tertiary Igneous: crinanite sill & major teaching site
Strone Point, North Loch Fyne	3.8ha	Dalradian: isoclinal folds in quartzites & phyllites.

2.0 COASTAL PROCESSES AND SEDIMENTATION PATTERNS

2.1 Tides

The Firth of Clyde has been classified as a mesotidal area, with tides at the head of the firth being described as semi-diurnal (high tides every 12 hours) (Pethick 1984, Pugh 1987). Detailed tidal records have been kept for Millport and Portpatrick (Emery & Aubery 1990) although tidal ranges are also predicted for a number of secondary ports (Admiralty 1994). Hydrological models indicate that the Spring tidal range increases towards the head of the estuary from 2.3 m at Campbeltown to 3.1 m at Inveraray/Garelochhead/Arrochar (Fig. 2.1, Table 2.1). The amplitude of the Spring tides is about 1.6 times that of Neaps. Mean Sea Level is relatively uniform throughout the area but tends to decline towards the head of the fjords.

Table 2.1. Predicted tidal range at primary (*) and secondary ports in the Firth of Clyde region (derived from Admiralty, 1994).

Site	MHWST	MLWST	Spring Tidal Range	MHWNT	MLWNT	Neap Tidal Range
Campbeltown	1.61	-0.99	2.6	1.11	-0.49	1.6
E.Loch Tarbert	1.58	-1.12	2.7	1.18	-0.62	1.8
Inveraray	1.68	-1.42	3.1	1.38	-1.12	2.5
Millport	1.78	-1.12	2.9	1.18	-0.62	1.8
Rothesay	1.78	-1.22	3.0	1.28	-0.62	1.9
Wemyss Bay	1.78	-1.12	2.9	1.28	-0.52	1.8
Greenock	1.78	-1.22	3.0	1.28	-0.62	1.9
Coulport	1.78	-1.32	3.1	1.28	-0.72	2.0
Lochgoilhead	1.68	-1.32	3.0	1.18	-0.72	1.9
Arrochar	1.78	-1.32	3.1	1.28	-0.72	2.0
Helensburgh	1.78	-1.22	3.0	1.28	-0.72	1.9
Rhu	1.78	-1.22	3.0	1.28	-0.62	1.9
Garelochhead	1.78	-1.32	3.1	1.28	-0.62	1.9
Irvine	1.5	-1.2	2.7	1.0	-0.7	1.7
Ayr	1.5	-1.0	2.5	1.1	-0.4	1.5
Girvan	1.7	-1.0	2.7	1.2	-0.5	1.7

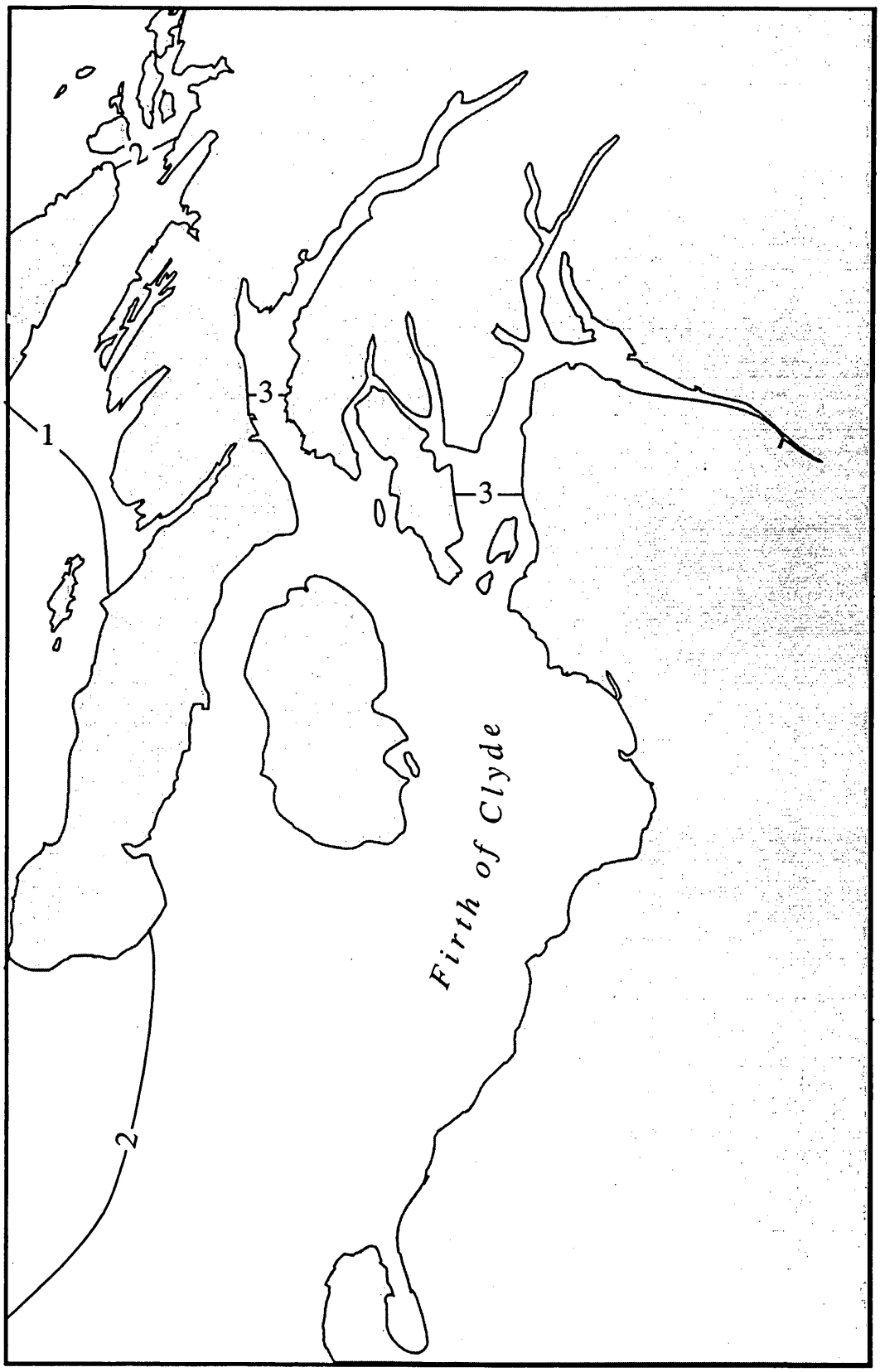


Fig 2.1 Mean Spring tidal ranges (m) of the Firth of Clyde Region (Barne *et al.*, 1997)

Predicted tidal curves derived from Hydrological models (Admiralty 1993) suggest that flood and ebb tides in the Firth are relatively symmetrical. Most of the water movement occurs at the surface since the flow of deeper water is often restricted by the sill at the mouth of the estuary and at the mouth of each fjord. Dense saline and relatively stagnant water can thus collect in the glacially deepened troughs.

2.2 Winds

The climate of the Firth of Clyde has been monitored at a number of climate stations, including Prestwick and Abbotsinch (Wallingford 1996; British Geological Survey 1997) Such land based climate stations however only provide a general assessment of the weather conditions over the estuary. At the same time patterns of air flow in individual embayments can vary greatly.

To a large extent, the climate of the region is dominated by westerly airstreams and cyclonic weather systems that move across the area from the Atlantic Ocean. In the outer Firth westerly and southerly winds tend to dominate particularly in winter months (Fig. 2.2). In the summer months the stations indicate more varied wind patterns, this illustrating the impact of local topography. Air flow within the fjords has not been accurately monitored but it is highly likely that the air tends to flow along rather than across these features.

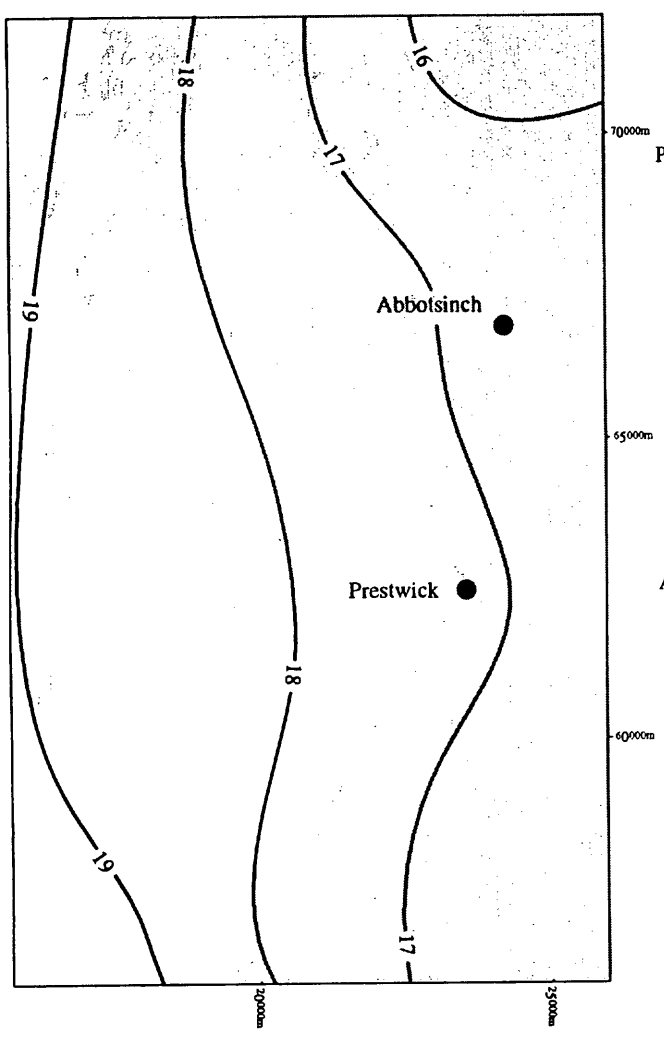
Strong winds may be experienced from all directions but are most frequent in the sector northwest through west to southwest. On average the region experiences 7-15 gales each year and these tend to come from the west and southwest. These gales are at their strongest in the Outer Firth and have a more limited impact within the enclosed fjords.

In terms of the Firth of Clyde coastline, the typical airstreams have markedly different effects along different sections of the shoreline. Along the Kintyre Peninsula and the eastern coast of Arran the winds predominantly blow offshore. In contrast along the Ayrshire coast and western Arran the winds tend to blow onshore. For many of the enclosed lochs winds tend to either blow parallel to the shore for Loch Ryan, Loch Fyne and Loch Long and across the fjords for Loch Riddon, Loch Striven, Gare Loch and Holy Loch. Such patterns have no doubt been of considerable influence in determining the distribution of dune fields and current coastal erosion within the region.

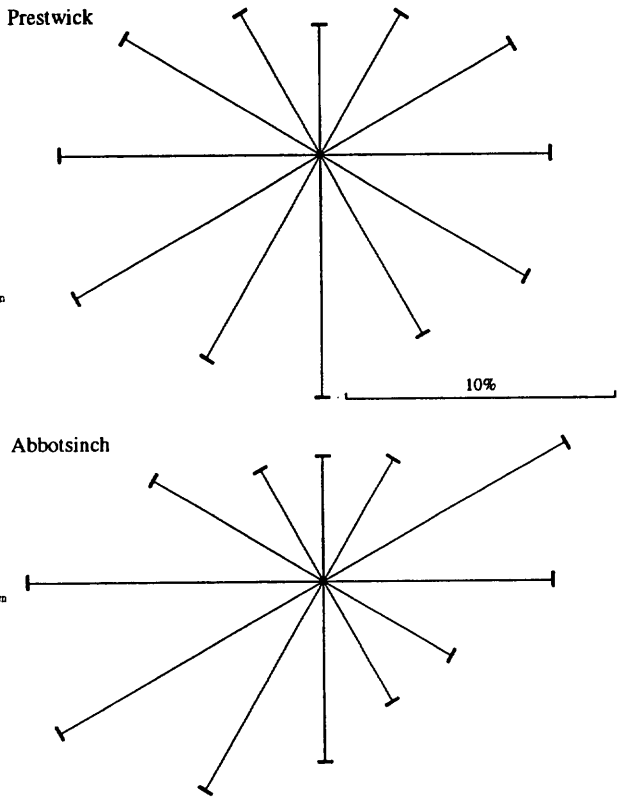
2.3 Waves

The enclosed nature of the Firth of Clyde combined with the narrow fjords severely limits the wave field effecting the coastline of this area. As a result the height and direction of waves reaching the coast are highly dependant on the dominant wind direction. For limited sections of the coastline (the southern shore of the Kintyre Peninsula) the fetch can exceed 300 km, when the wind blows from the south along the Irish Sea. For other areas the fetch rarely exceeds 100 km and is often less than 10km. As a result the wave spectrum in the Firth of Clyde is primarily composed of waves generated within the confines of the estuary.

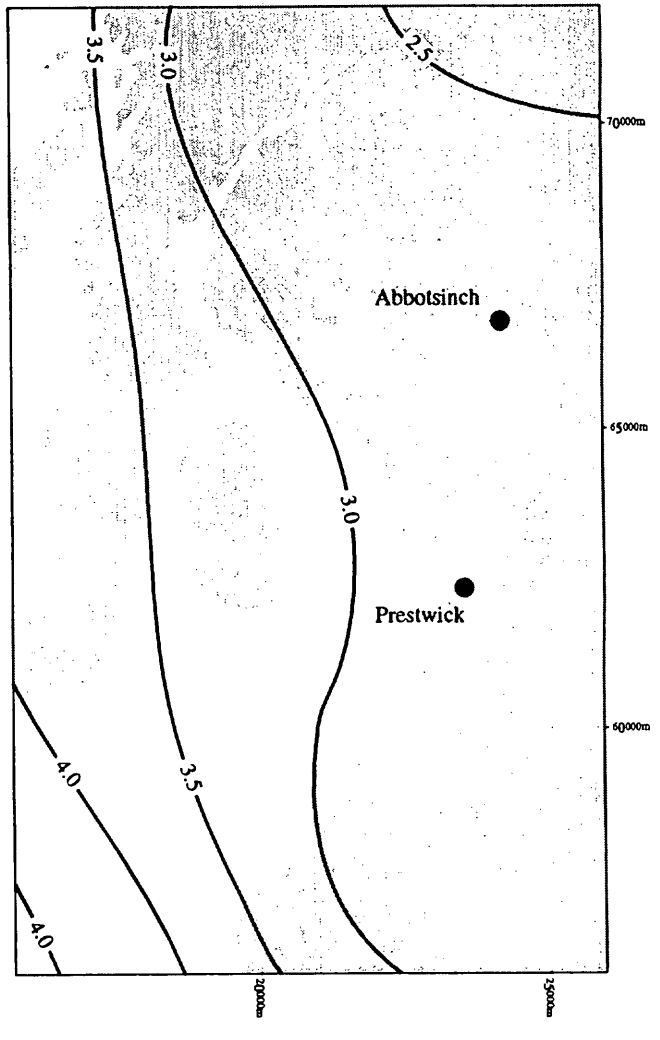
For the outer estuary wave heights exceed 2 m for 10% of the year and are less than 0.5 m for 75% of the year (Draper 1991), although maximum wave heights of 3 m may occur (CRPB, 1976). Detailed modelling and measurement of the wave climate has been undertaken for the Ayrshire coast (HR Wallingford 1996). The data indicate that the majority of waves in this region come from the southwest and west. In the offshore zone the waves rarely exceed 1.6m in height whilst in the inshore zone they rarely exceed 1.2m in height. The area is also not greatly effected by swell waves, since they rarely extend into the area from the Irish Sea.



Hourly mean windspeed (m/s)
exceeded for 0.1% of time.



Wind roses for Preswick
and Abbotsinch



Hourly mean windspeed (m/s)
exceeded for 75% of time.

Figure 2.2: Hourly wind speeds and directions for the Firth of Clyde Region (Barne *et al.*, 1997)

Along the fjord coasts the wave magnitude will be limited. The limited fetch available combined with reduced wind speeds results in small waves, with wave heights rarely exceeding 0.7m. There is often a marked contrast between wave climate at the mouth and within the fjords and as a consequence the nature of coastal forms will reflect the marked reduction in wave energy.

2.4 Currents

The behaviour of currents in estuaries and nearshore areas is governed by tidal movements, together with residual (non-tidal) currents driven by winds and density gradients. Since the Firth of Clyde has a medium tidal range tidally induced currents dominate the nearshore zone. Waves also produce currents in this area but there is limited information available.

2.4.1 Tidal Currents

The moderate tidal range in the Firth of Clyde results in weak currents. Within the inner estuary the tidal currents are very weak with velocities below 0.5m/s in the inner estuary and as low as 0.2m/s in the fjords (Sager & Sammler 1968). In the outer Firth maximum tidal currents rise to 3.5m/s at the Mull of Kintyre this being associated with the high currents of the North Channel (Fig. 2.3). The flood tide originates along the north coast of Ireland and flows in a south easterly direction through the North Channel across the mouth of the Outer Firth of Clyde and down the western coastline of the Rhinns of Galloway (HR Wallingford 1996) The ebb tide is a reversal of the flood tide. On both the flood and ebb tides there is a lag of circa 1 hour between the main tidal stream beginning and the corresponding flood or ebb flow within the outer Firth. On the flood the tidal stream divides around Bennane Head, with one part flowing north into the outer Firth of Clyde and the other south into the North Channel. The main flood direction is to the north along the Ayrshire and Kintyre coastlines. The northward flow tends to continue along the Ayrshire coast for up to one hour after the main ebb stream has started, whilst along the Kintyre coast the reversal of water flow occurs sooner. As a result there is slight anti-clockwise rotation of tidal currents for a short period just after high water within the outer Firth. These currents are however weak and they are probably incapable of transporting significant quantities of sediment (HR Wallingford 1996).

2.4.2 Wave-Generated Currents

Wave-generated currents are formed when waves approach the shoreline at an oblique angle. As the waves approach the shoreline, they are refracted and, in some circumstances, they can end up aligned parallel to the shoreline when they break. Farther offshore, the wave spectrum can produce a net movement of water from which onshore and along-shore fractions of movement can be calculated (Komar 1976; Pethick 1984). Perkins (1968) and CRAB (1976) have studied the wave-generated currents in the Firth of Clyde region. They suggest that that the patterns of movement are complex as a result of marked salinity variations within the water columns. In general in the inner Firth freshwater tends to move seaward with a flow of saltwater landward along the seabed. Since the wind and hence the waves in the region arrive dominantly from the southwest and west flows of water towards the north east are common. The velocities of flow are however very low and produce an insignificant movement of sand but plastics and other floating debris may be readily transported into the estuary from the Irish Sea to be deposited in Irvine Bay (Bowden 1955).

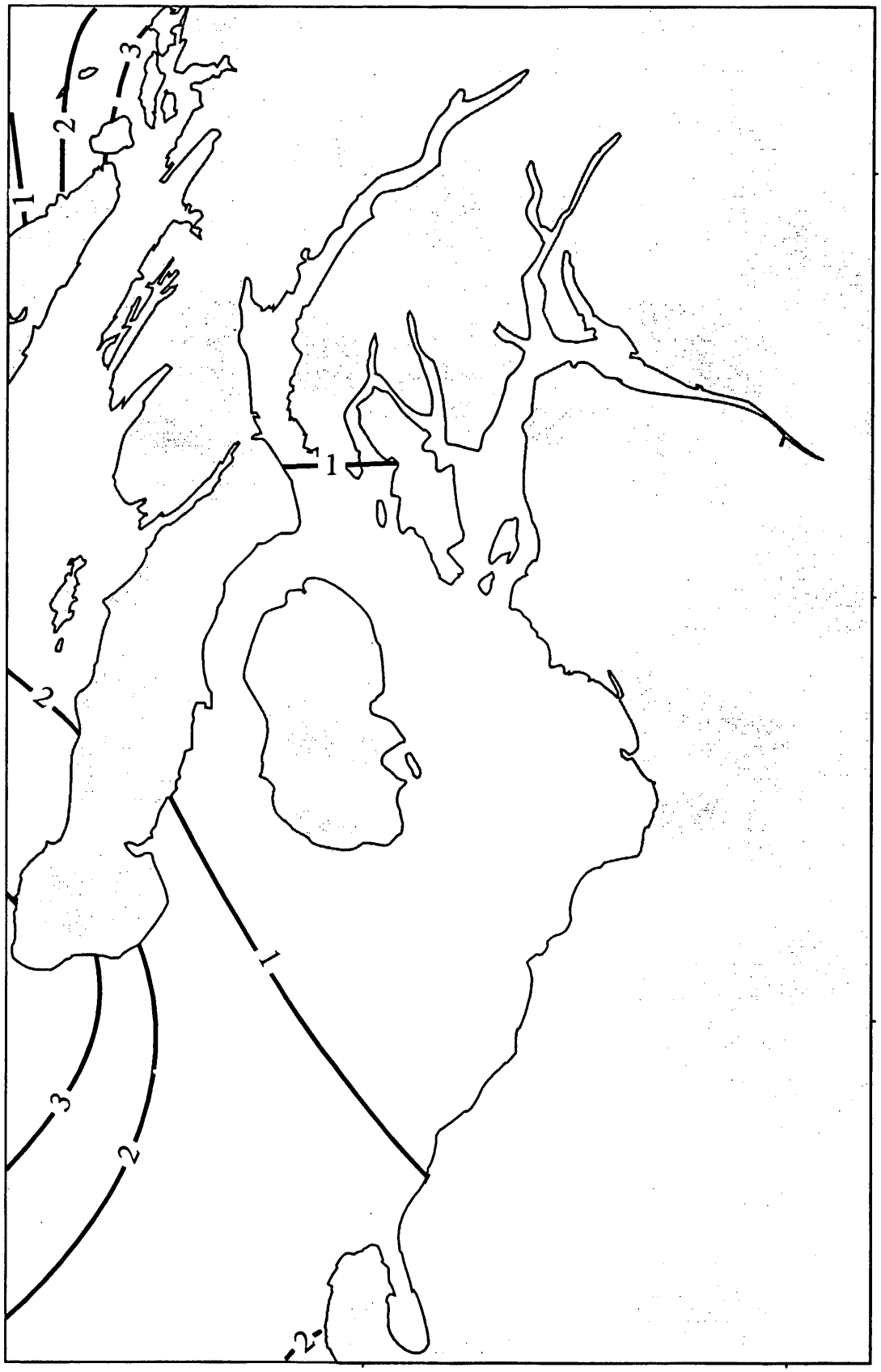


Fig 2.3 Mean spring tidal currents (ms^{-1}) in the Firth of Clyde (Barne *et al.*, 1997)

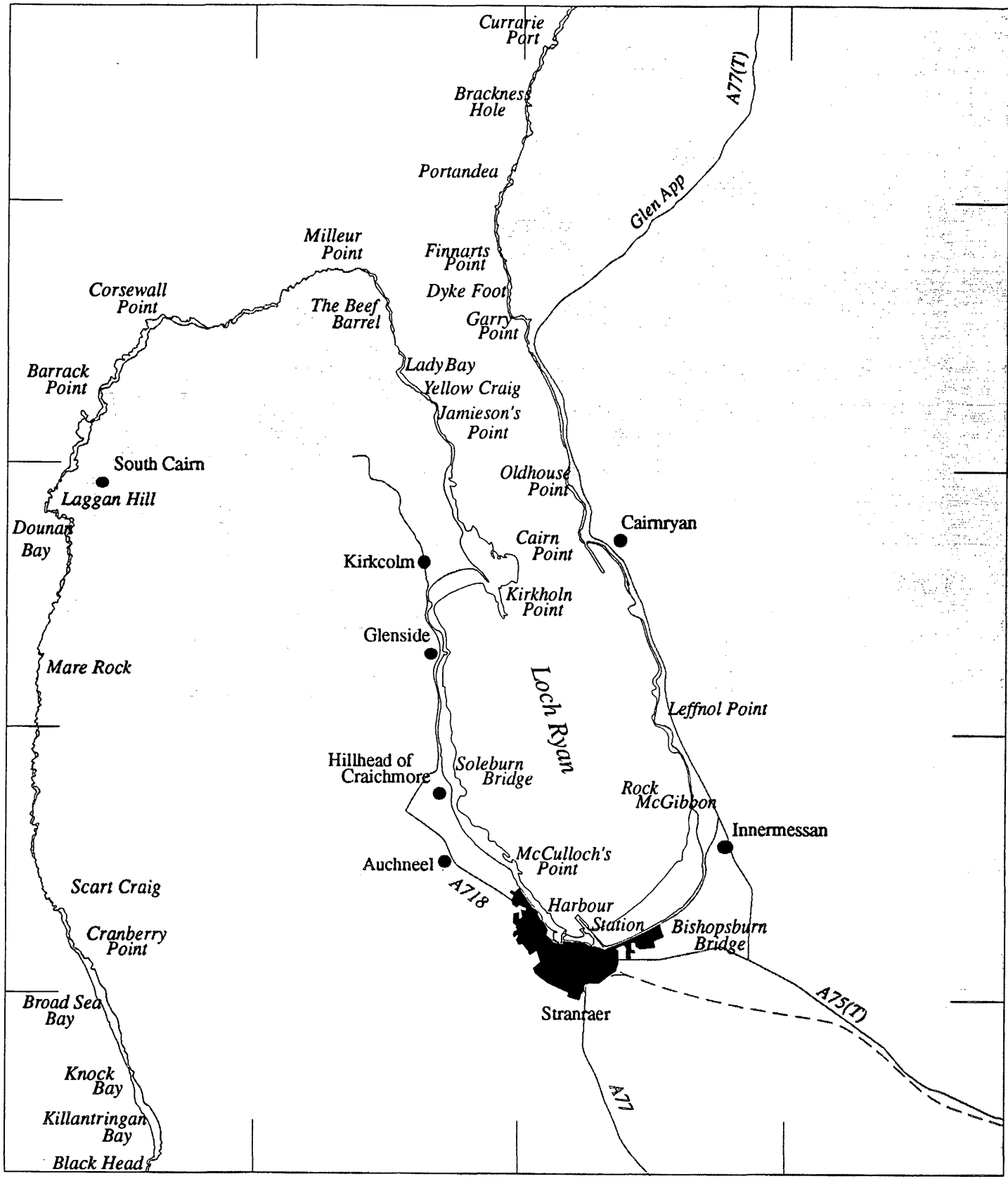


Fig 4.1 Loch Ryan: Site Map

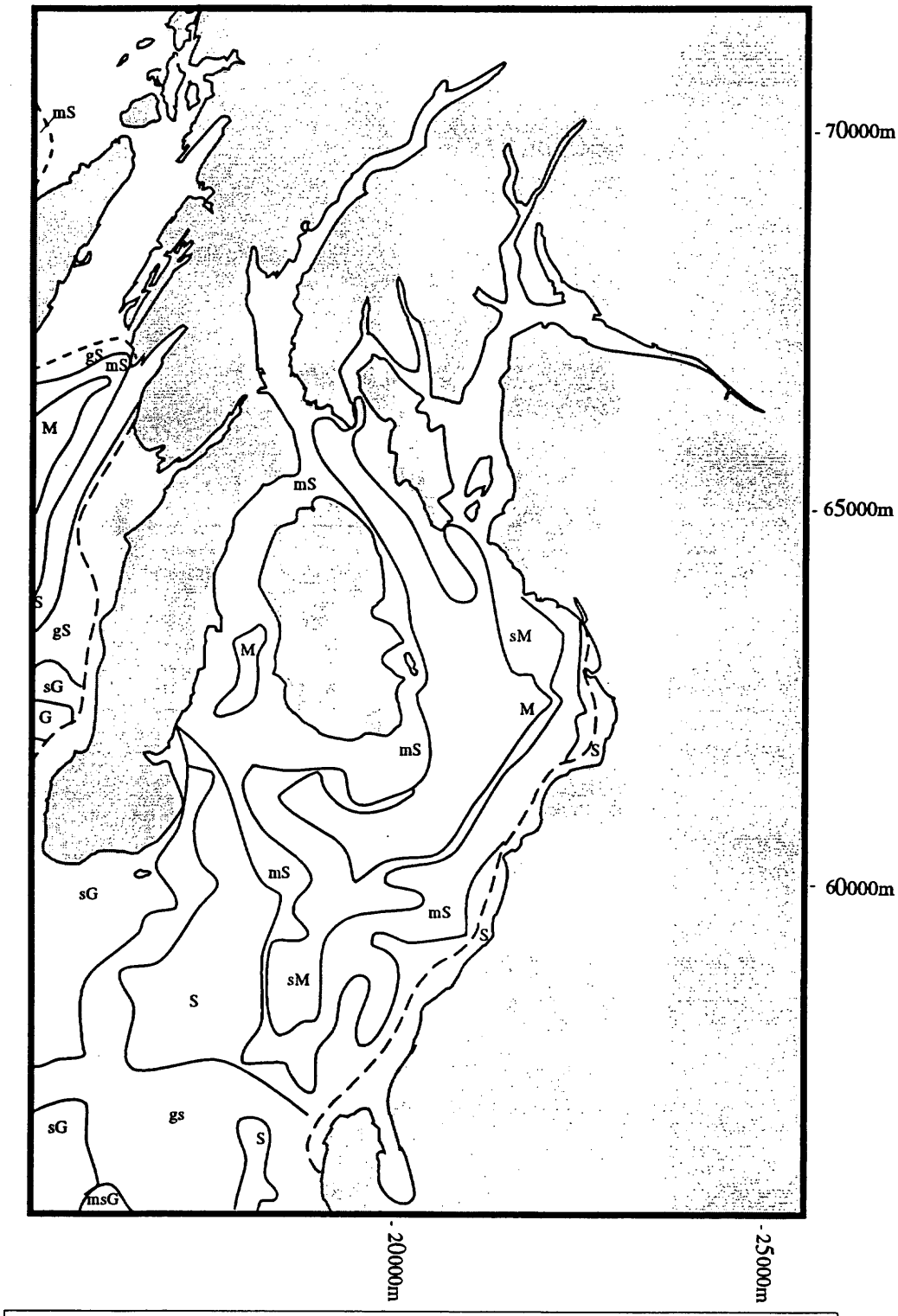


Fig. 2.4 Firth of Clyde Sea-Bed Sediments.

Based upon *Geological Map of the United Kingdom, Ireland and the adjacent continental shelf: North and South sheets (pair) (1991), 1:1 000 000* by permission of the British Geological Survey, IPR/27-32C British Geological Survey. © NERC. All rights reserved.

At a few locations society has been an active source of coastal sediments. For example coal mining waste was dumped on the shore near Stevenston and has subsequently been reworked to form small spits in this region. At other locations quarry/building rubble is being deposited along the shoreline to overcome problems of erosion (e.g. Seamill). This coarse material is subsequently becoming rapidly incorporated into the coastal system as the shoreline continues to erode.

3.0 COASTAL LANDFORMS

3.1 Introduction

Geological and geomorphological studies of the Clyde region date back into the 19th Century with some of the sites being particularly important in terms of glacial theory (e.g. Agassiz 1841). The area has attracted some interest in terms of Quaternary environmental changes, sea level changes and long term coastal evolution (e.g. Peacock 1970; Peacock *et al.* 1978; Gray 1978, 1995; Sutherland 1981; Rose *pers. Comm.*). In contrast, the contemporary coastal landforms of the area have attracted very little attention in terms of their distribution and the processes that are forming them, other than the inventories produced by Ritchie & Crofts (1973), Ritchie (1975) and Mather (1979). These inventories although detailed are now dated. The published material was insufficient to provide the detail required to outline the coastal landforms in the Clyde region, and, as a result, it was supplemented by reference to air photographs and one week's fieldwork by P E F Collins and C R Firth. The latter involved fieldwalking of sections of the coastline, recording the landforms and any evidence of erosion or deposition. The fieldwork was carried out in January 1988 directly after a major storm and as a result considerable evidence of coastal erosion was identified. Care was thus taken to ensure that minor examples of coastal erosion were not confused with evidence which indicated that prolonged periods of erosion had been taking place.

The Firth of Clyde represents a mosaic of contrasting coastal environments, with a number of narrow embayments leading from the main estuary. As a result the estuary has been sub-divided into a number of smaller sections for the purpose of this report. The divisions proposed have attempted to link together areas in which similar coastal features and processes were identified. On this basis the region has been divided as follows (Fig. 3.1):

Loch Ryan	Corsewall Point to Currarie Port
Ayrshire Coastline	Currarie Port to Farland Head
Inner Clyde Estuary	Farland Head to Barons Point (includes Gare Loch)
Isle of Arran	
Cowal Peninsula	Barons Point to Skipness Point (the fjord lochs)
Kintyre Coastline	Skipness Point to Mull of Kintyre

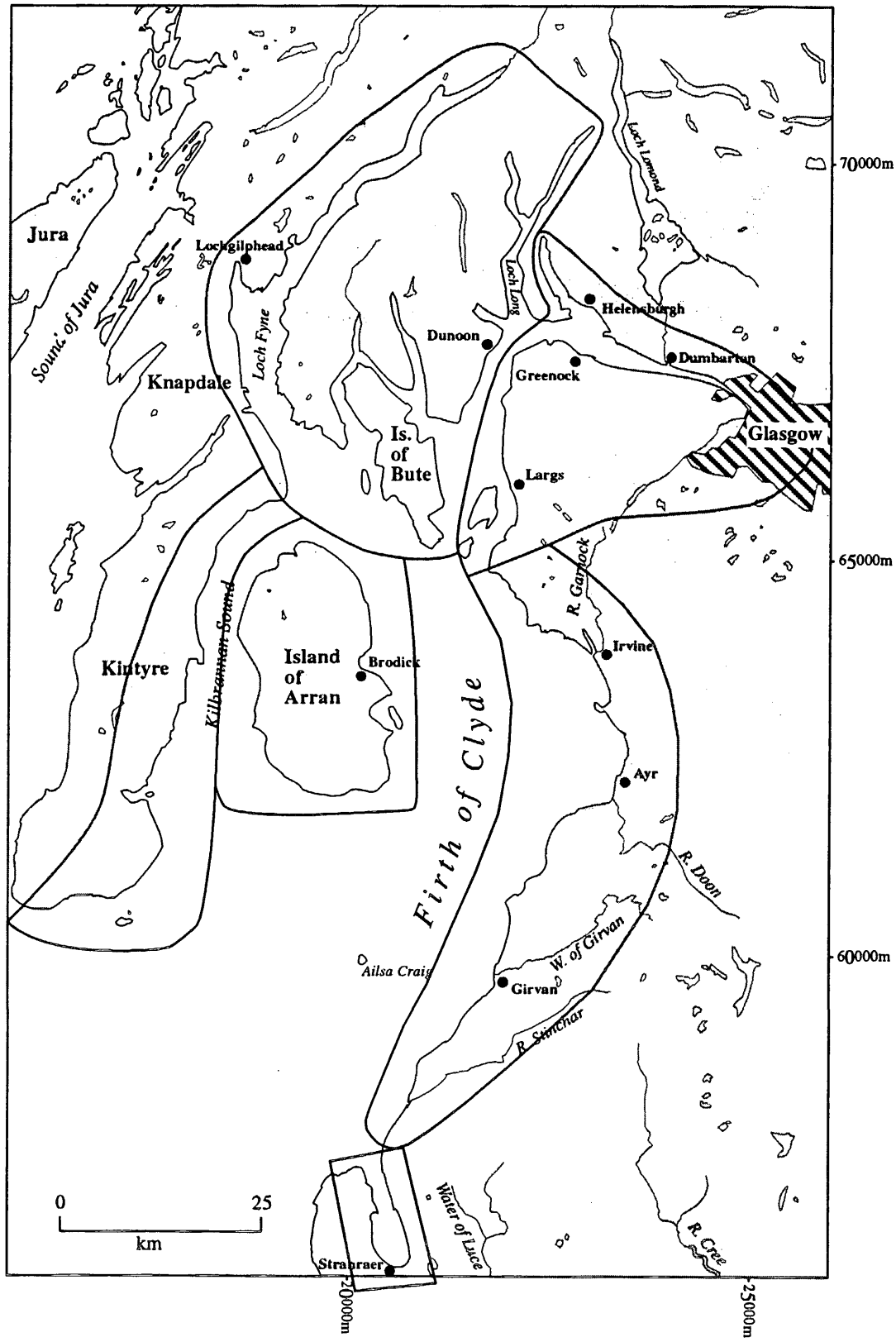


Figure 3.1 : Firth of Clyde region: Sub-areas

4.0 LOCH RYAN

4.1 Introduction

The Loch Ryan area extends from Corsewall Point (NW975734) in the west to Currarie Port (NX062773) in the east, which mark the outer edge of this NNW-SSE aligned embayment. The embayment is some 12.5 km long and 2.5 km wide at its mouth but some 4km wide at its head (Fig. 4.1). The main settlement in the area is Stranraer (NX060610) which is a main terminal for ferry services to Northern Ireland. The head of the embayment is marked by a wide sandy beach, and a series of small cuspate forelands lie along its margins. In contrast the mouth of the Loch is characterised by rock platforms and cliffs. Landward of the shoreline a variety of Holocene marine features are present.

Geomorphological literature for this area is limited (Mather 1979) and tends to concentrate on the depositional features in the area. As a result large sections of the coastline were visited this being aided by the road system which follows the shoreline in much of the area.

4.2 Contemporary landforms and sedimentary environments

4.2.1 Rock Platforms

Bedrock is exposed in the intertidal zone in many places along the exposed, outer part of this area (Fig. 4.2). In places this rock falls steeply into the sea, for example at Garry Point on the northern side of the mouth of Glen App (NX048728) or only a narrow platform is present. Wider rock platforms do not exist within the Loch itself. Immediately to the west of this coastal cell a wider platform is present is present in certain embayments. At Moidoch Hole (NW973701) and Lady Bay (NX027718) for example, it can be traced laterally beneath adjacent units of sediment and appears to be an exhumed landform. Investigations at these sites, beginning with a field visit in January 1994, (Firth and Collins unpubl.) suggest that this veneer is largely of Mid-Late Holocene age. If the conclusion that rock platforms elsewhere in the Clyde are periglacial rather than wave-abraded (see section 6.2.1 below) then this platform must have formed during the last cold stage, or earlier.

4.2.2 Sand and Gravel Beaches

Beaches are generally confined to the head of Loch Ryan and the mouths of rivers (Fig. 4.2). Gravel bars and spits are present across the mouths of Glen App, where the river flow has been impounded to form a wooded wetland.

Within Loch Ryan, a series of shingle and sand spits occur on both the east and west shores which indicate net sediment transport into the loch. Morphologically similar earlier Holocene landforms are present at slightly raised levels immediately inland of the active features. The largest of these, at Kirkcolm, extends a considerable distance into Loch Ryan. Small sandy beaches are present at Lady Bay and Portbeg. At the head of the loch, in front of Stranraer, is a gently sloping sand and shingle beach. Larger clasts present locally on the surface may suggest that some of the sediment here is the winnowed remnant of fluvio-glacial/glacial sediments. This is modified on its eastern side by a small gravel fan associated with a stream at Innermessan (NX083631) and the Stranraer ferry harbour on the west (NX060613). Despite the lochside shingle spits, there is no real indication of high energy shingle accumulation, such as storm ridges, at the southern end of Loch Ryan. This may reflect circulation of water currents back out of the loch. Dredging possibly also may have had an influence.

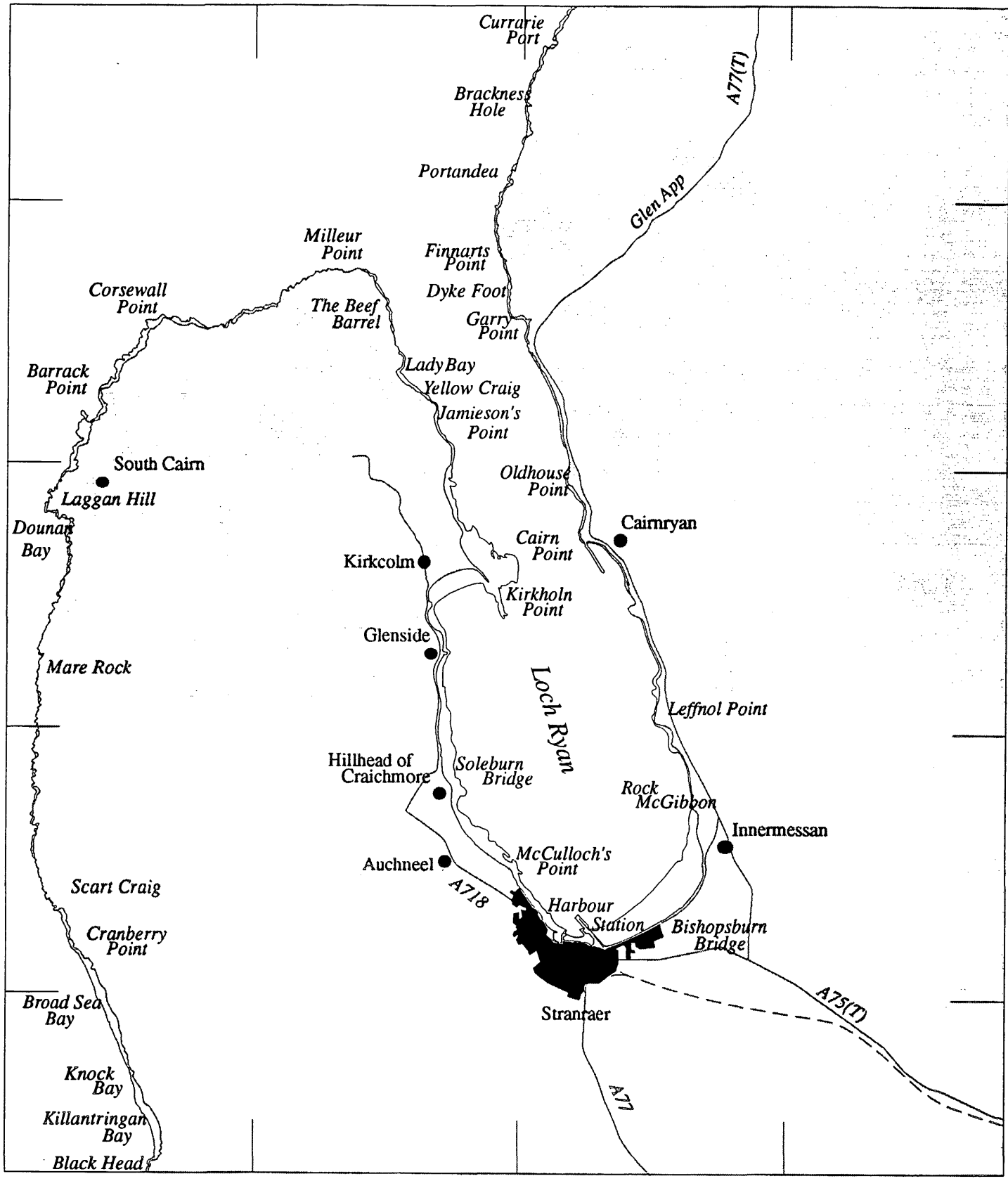


Fig 4.1 Loch Ryan: Site Map

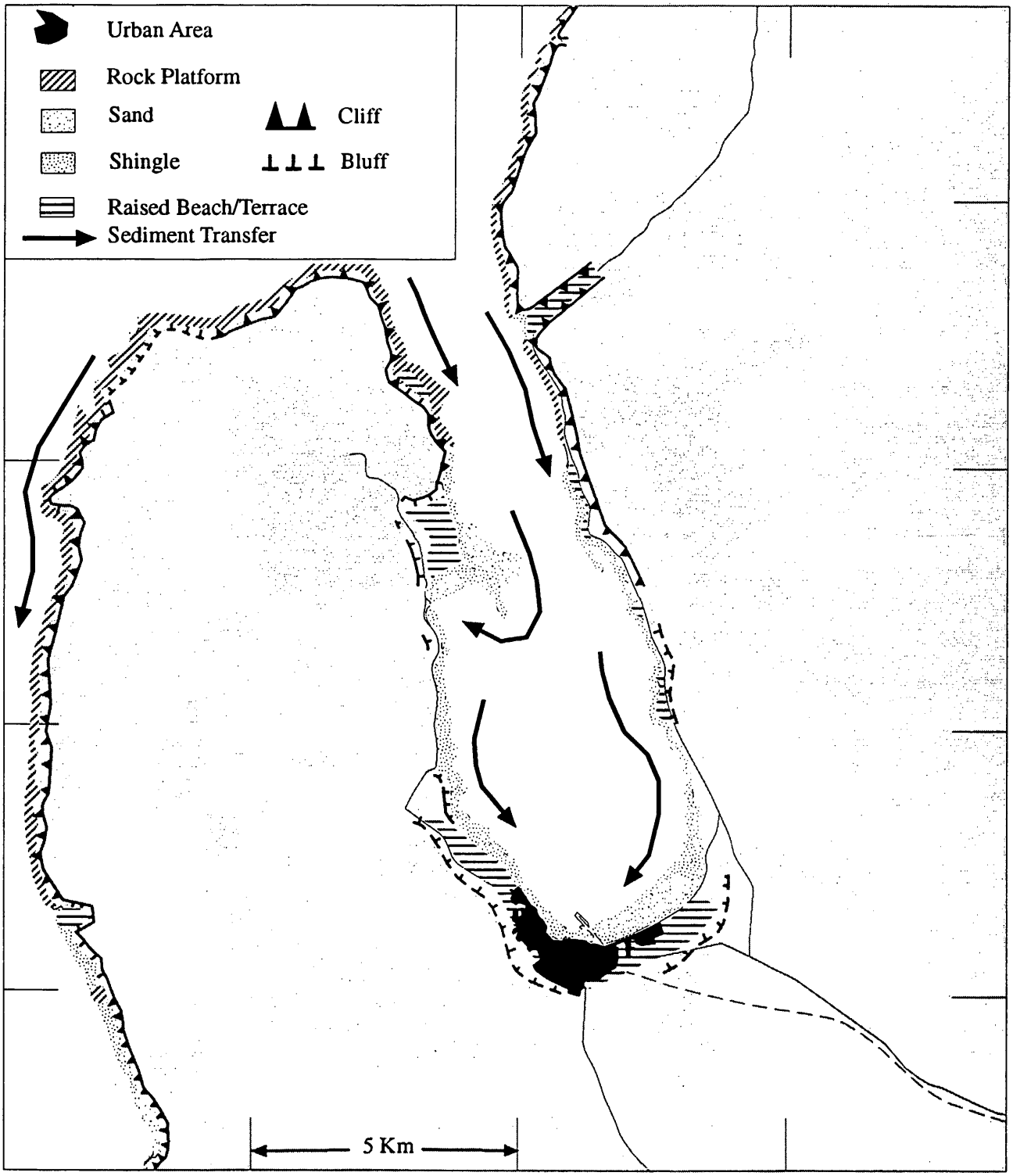


Fig. 4.2. Loch Ryan: Geomorphological features and processes

4.2.3 Coastal wetlands

Saltmarshes are rare in the Loch Ryan coastal cell (Fig. 4.2). Despite the apparent shelter within Loch Ryan itself, no extensive coastal wetlands are present. This may be a reflection of strong shoreline currents, indicated by numerous spits. Some areas of coastal wet grassland are present along the western coast of The Rhinns headland. At Moidoch Hole (NW973701), several creeks which penetrate into the grassland showed some minor erosion in January 1994. The surface of the grassland, even close to the shore, was composed of a peat with only a minor mineral component, suggesting that it is rarely, if ever, inundated and may be a largely relict raised feature.

4.3 Late Quaternary landforms and sedimentary environments

Raised and reoccupied marine features occur along much of the coastline. A pronounced fossil cliffline is present at Lady Bay in Loch Ryan and at Moidoch Hole. The base of this cliff rests at 5-10m OD which correlates closely with the altitude of the Main Postglacial Shoreline (Fig. 11.2; irth *et al.* 1993). The form of this cliffline becomes less acute near the head of Loch Ryan where the bedrock is less resistant.

Raised shingle ridges are present inland of the active shingle spit of Kirkcolm Point at Kirkland (NX038687).

Fine marine sediments are locally present above the present tidal limit. At Moidoch Hole, they rest on a rock platform just above mean high water springs and at Auchneel (NX041627) where several metres of fine mineral sediment are present. The town of Stranraer is largely built upon raised former marine surfaces and sediments.

4.4 Human impacts

Clearly, the main human impact in this coastal cell is associated with the harbour at Stranraer where sea walls and piers are present (Fig. 4.3). It is likely that the route into the harbour is regularly dredged, interrupting sediment transfer around the head of the loch. This may explain why, despite clear evidence of net sediment transfer along the east and west shorelines towards the loch head is present, no major accumulation of material, (e.g. in the form of beach ridges) is present there. A long breakwater is present at Cairnryan (NX064684) and a smaller harbour is present near High Claddy House (NX071675). There are several slipways in Loch Ryan, e.g. at Innermessan Bridge (NX082637) and a jetty serving a boat club is at Glenside (NX036664). These clearly will have some effect upon local sediment movement, though no major redistribution of material was noted in January 1994.

The harbour activities and ship movements potentially could be a source of pollution, though no evidence for this was observed. The local population (*pers. comm.)* has also suggested that increased coastal erosion has been produced by the bow-waves from recently introduced catamaran ferries. Although it is possible that repeated wave activity from such a source could have some impact on the shoreline, it must be set in the context of annual wave activity. In normal circumstances one winter storm associated with northern winds will probably have a far greater impact on the coast than years of bow-wave activity. It is thus highly likely that slightly larger waves are being produced by these new ferries but their impact on sediment movement is probably limited.

Animals are grazed on the coastal wet grasslands and may cause some limited local erosion, particularly of channel banks. The depth of most of these channels, and the steepness of their banks, at Moidoch Hole though makes it unlikely that animals would deliberately attempt to cross them. As a result, erosion by grazing animals is likely to be

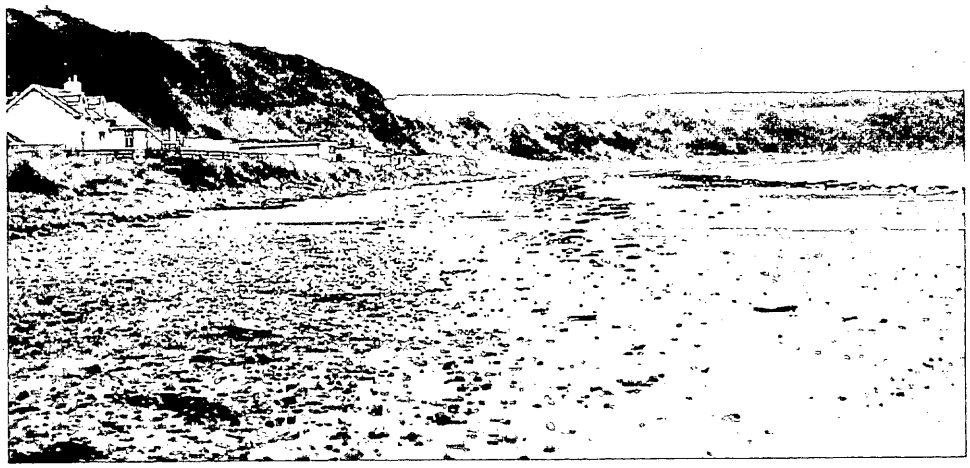


Plate 5: Narrow sand beach, Culzean Bay, Ayrshire Coast.



Plate 6: Wide sand beach and eroding dunes , Irvine Bay, Ayrshire Coast.

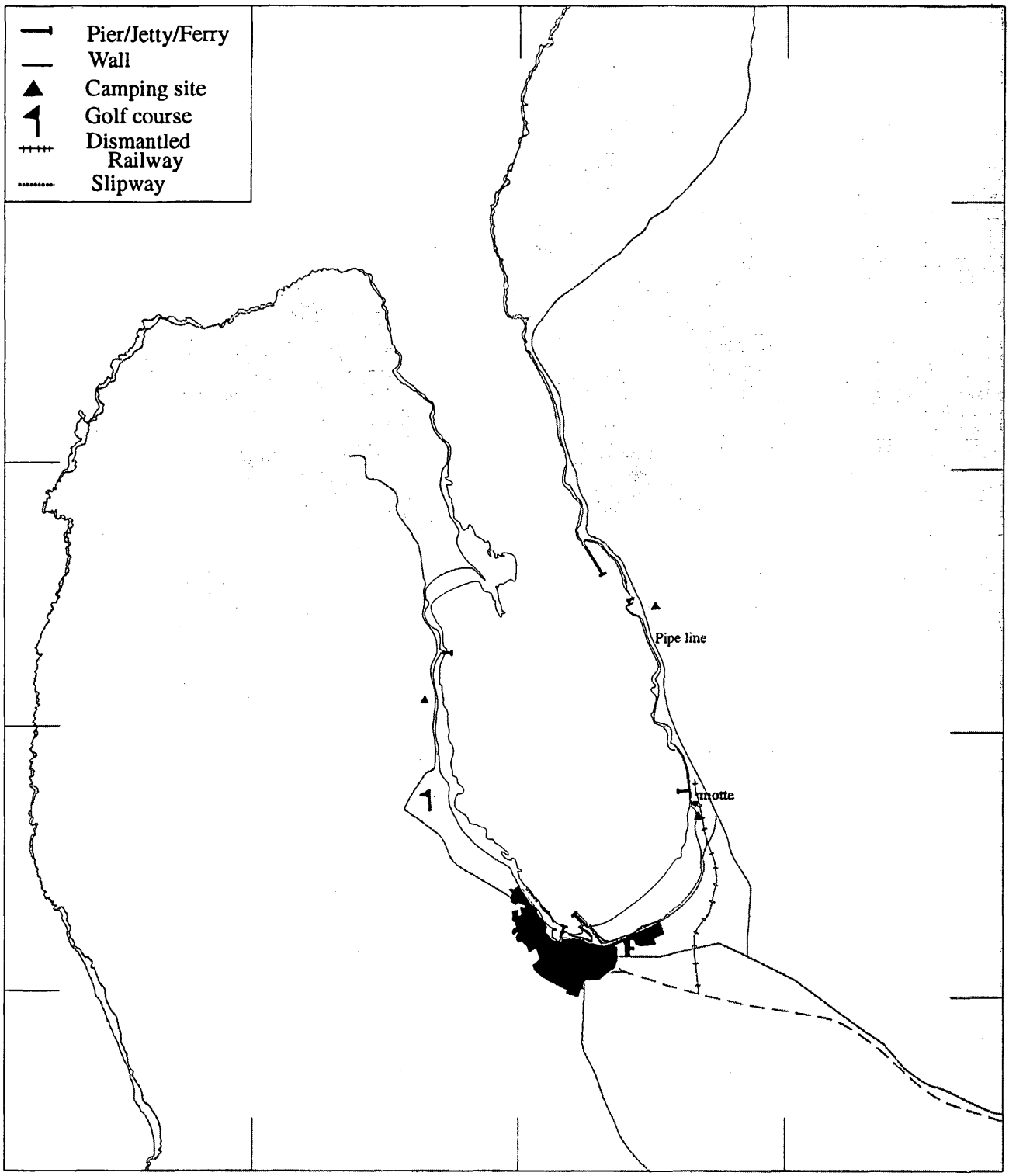


Fig. 4.3 Loch Ryan:Human impacts

5.0 THE COASTAL LANDFORMS: AYRSHIRE COAST

5.1 Introduction

The Ayrshire Coast, for the purposes of this report, consists of the shoreline that lies between Currarie Port (NX062773) in the south to Farland Head (NS177484) in the north and it also includes the islands of Ailsa Craig and Pladda (Fig. 5.1). The southernmost section of the coastline (Currarie Port to Heads of Ayr, NS284188) provides an almost straight shoreline, indented by small embayments, some 45 km long which is generally aligned in a SSW-NNE direction. The northern part of this area consists of the broad Irvine-Ayr embayment which is separated into the bays of Ayr/Prestwick and Irvine by the Troon promontory (Fig. 5.1) Much of the southern shoreline consists of rock platforms or shingle beaches backed by active or raised cliffs and dune systems, whilst in the north wide sand beaches and an active dune system have accumulated. The area contains 13 SSSIs, 8 with biological interest and 7 with geological and geomorphological interest (Fig. 1.5; Tables 1.1 & 1.2).

Geomorphological literature for this area is limited (Ting 1937; Mather 1979, Orford 1995; HR Wallingford 1996) and tends to concentrate on the depositional features in the area. As a result large sections of the coastline were visited this being aided by the road system which follows the shoreline in much of the area.

5.2 Contemporary landforms and sedimentary environments

5.2.1 Rock Platforms

Almost the whole of the Ayrshire coastline is underlain by rock platforms associated with the Main Rock Platform and backed by the cliffline associated with this feature. These features are however only intermittently exposed at the shoreline (Fig 5.2). In the south shoreline platforms with backing cliffs up to 40 m high occur in the vicinity of Downan Point (NX068806), Bennane Head (NX091867), Kennedy's Pass (NX149932) and Turnberry Lighthouse (NS196073). Farther north, short sections of platform are present between Dunure Point (NS246153) and Heads of Ayr (NS285188), at the headlands of Troon (NS310310), Saltcoats (NS245410) and Farland Head, although at these sites the backing cliff has been abandoned (part of the Main Rock Platform).

These erosional features will certainly have been modified by current coastal processes, which have probably operated in this zone for the last 1000 years. However, in most situations the platforms represent the frontal margin of the Main Rock Platform (Gray 1974, 1995, Dawson 1980) and thus are largely inherited features. Clear examples of this at Farland Head (Plate 1) and south of Ardwell Bay (Plate 2). At a number of locations the platform is partly overlain by shingle and boulders. The boulders may have fallen from nearby cliffs or they may have been winnowed from the former cover of till or fluvioglacial sediments.

5.2.2 Gravel Beaches

Extensive gravel beaches are rare along this section of the coast and are mainly confined to small shingle beaches south of Heads of Ayr (Fig. 5.2). These beaches are usually no more than 10-30 m wide with a storm ridge at the top and a steeply sloping seaward face. All of them are backed by dunes or Holocene raised beaches into which they are eroding. To the seaward the beaches are fronted by platforms and occasionally sand beaches, up to 300 m wide, these features being exposed at low tide. Classic examples of these shingle beaches occur at Culzean Bay (NS245128) (Plate 3) and Dunure (NS256163).

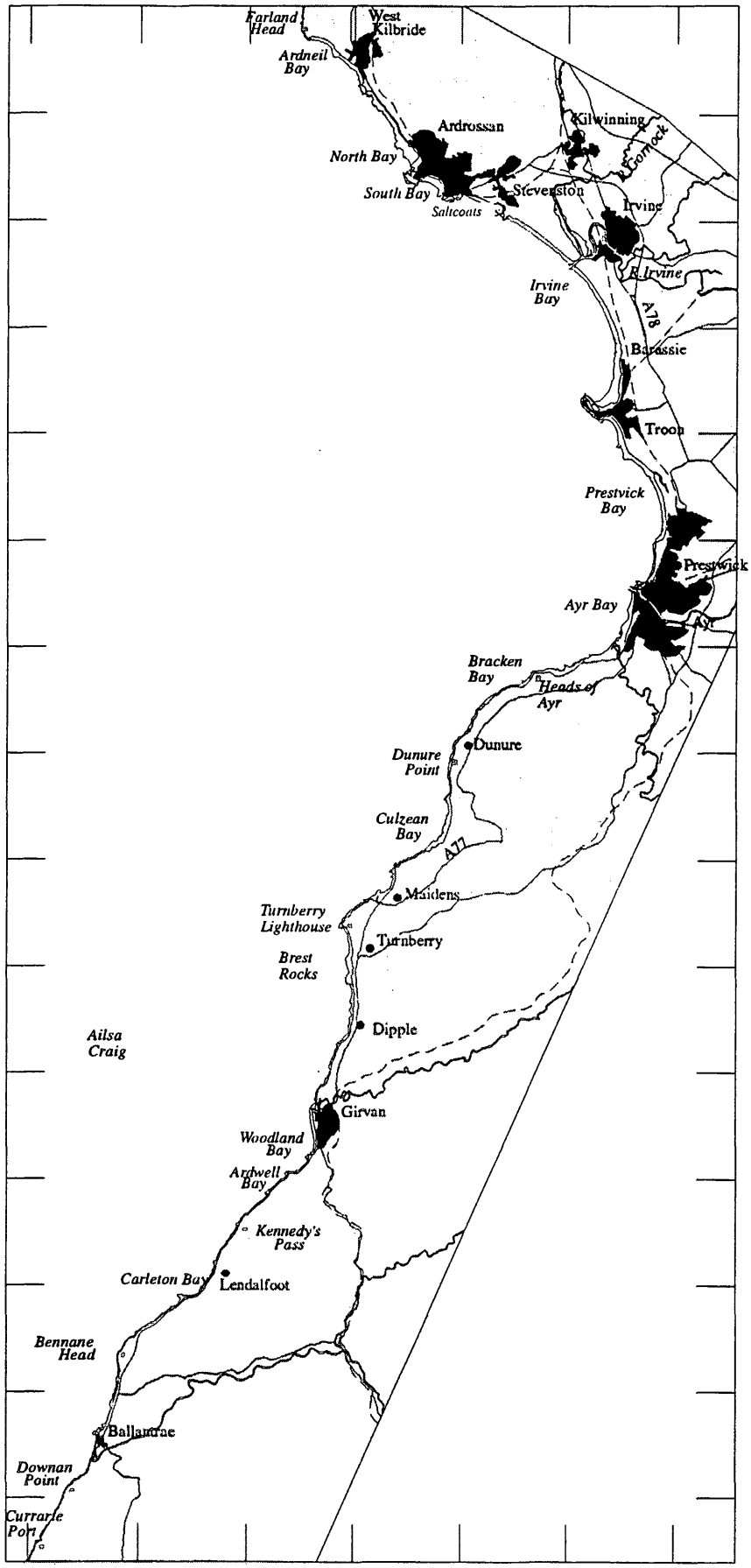


Fig.5.1. Ayrshire Coastline: Site Map

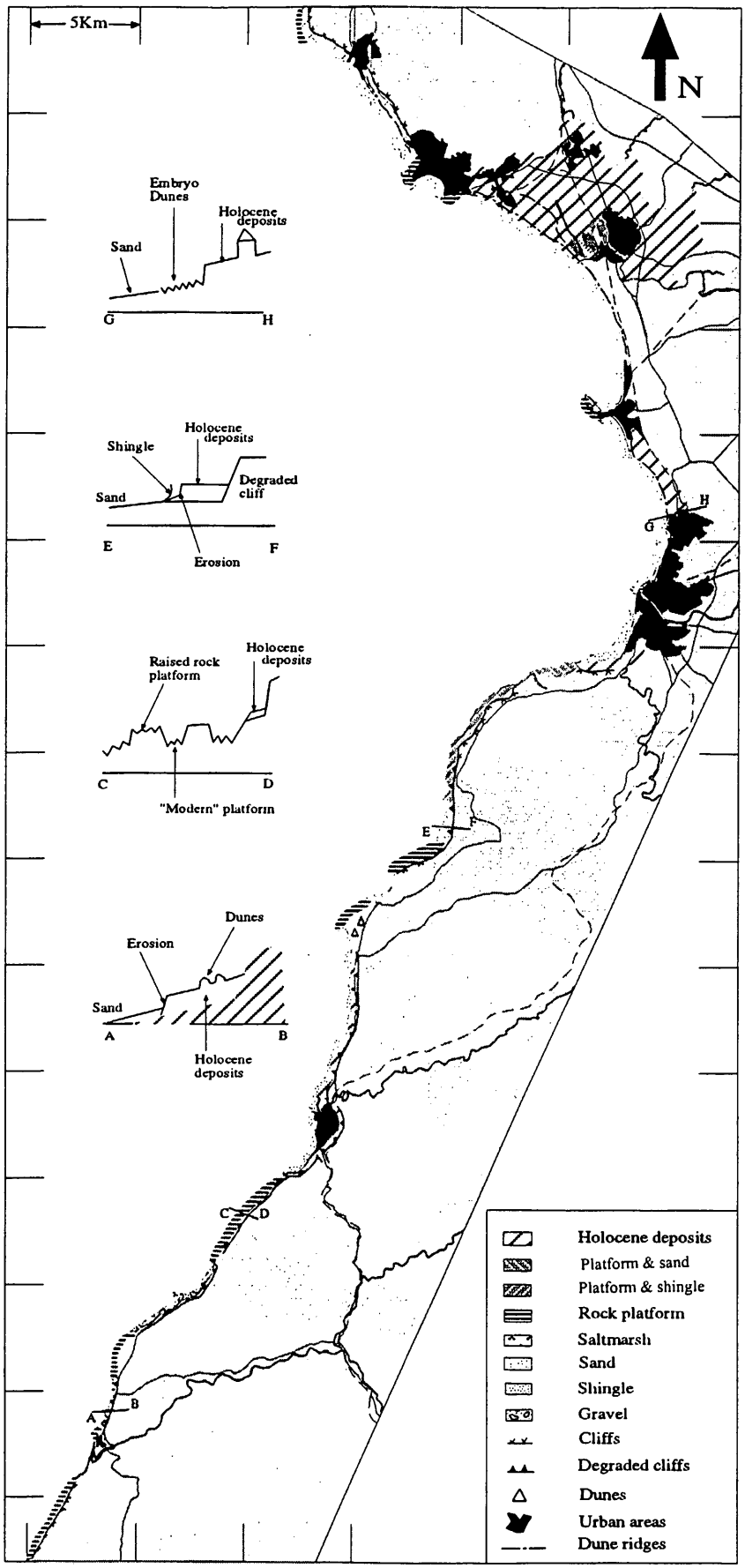


Fig 5.2 Ayrshire coastline: Geomorphological features and processes

A contrasting feature is the complex shingle bar at Ballantrae (Plate 4) which has been designated an SSSI on the basis of the biological habitats it provides. The bar consists of locally derived pebbles, mostly under 10cm in diameter which have been built into a ridge whose crest stands *circa* 2.5 m above mean high water mark (Mather 1979). The seaward side of this ridge is very steep, and during current fieldwork there was evidence of overwashing. Mather (1979) has suggested that the bar is supplied with sediment from the north and as a result the northern end of the feature is relatively stable. In contrast the central and southern end of the bar has experienced considerable change during the last 120 years as evidenced by the varied location of the River Stinchar's outlet. Ting (1937) reported that in the early nineteenth century the mouth of the Stinchar water was drawn as an estuary on old maps. By 1855 a well developed bar was present with a central outlet for the river, except the northern section of the bar partly overlapped the southern feature. Groome's map of 1884 shows river outlets at either end of the bar. In 1906 the northern outlet was closed and the southern outlet open, but within three years the converse was true (Ting 1937). By 1912 the Stinchar Water drained through a centrally located outlet and this position seems to have been maintained at least until 1937. However, by 1973 the outlet was located at the southern end of the bar (Mather, 1979) whilst during the current investigation it had returned to near the centre of the feature. Ting (1937) noted that a crescent shaped mound was present across the mouth of the outlet, exposed only at low tide. This feature was noted during the current field investigations and consists of a small shingle spit extending southward from the northern section of the bar. The dramatic changes in the location of the river outlet are noteworthy and may represent cyclic evolution of the feature. Material is brought into the area from the north which gradually extends the northern bar southwards, material passing via the outlet mound onto the southern bar. During periods of sediment shortage the barrier becomes breached in the centre or northern end and the remaining material joins the southern bar. Renewed growth from the north then starts the cycle once more. It is possible that some of the instability described by Ting was the result of interference by society with the coastal sediment supply, perhaps the construction of Ballantrae Pier, dramatically reduced sediment supply for a number of decades which lead to the bar becoming breached at both its northern and southern ends.

More recent gravel/cobble features are present at Stevenston where former mine waste is being reworked into cobble beaches and a small spit (NS269404). Erosion of the headland of dumped material is producing a north-south aligned spit of coarse material. The feature is noteworthy since it is composed almost entirely of bricks and building stone and provides a good site to study rates of pebble rounding.

5.2.3 Sand Beaches

Very extensive sand beaches are present along the Ayrshire coastline, these taking the form of narrow often linear/bay head beaches in the south and more extensive features in the north. All the evidence tends to suggest that there is a general drift of material northward along the coast although detailed measurements are lacking. To a large extent the sandy beaches rest on the frontal margins of the Main Rock Platform and as a result small sections of platform are often exposed within the sand at low tide. The rear of the beach is often marked by erosion although at some locations embryo dunes are starting to develop (e.g. Lendalfoot NX130900).

Classic examples of the narrow southerly beaches are present at Culzean Bay (NS245120) (Plate 5), Bracken Bay (NS281184) and Woodland Bay (NX173953). In each case the thin sand beach is underlain and flanked by rock platforms and often succeeded landward by a narrow steeply sloping shingle beach. The width of the beach is largely determined by the underlying rock platform and varies from 100m at Woodland Bay to 150m at Turnberry. At some locations the sand beach is succeeded landward by subdued dunes whilst in other areas there are Holocene raised marine deposits. In all cases the shoreline is being

eroded. Many of the features form narrow elongate beaches interspersed with platform fragments (e.g. beach north of Ballantrae NX090851, Carleton Bay NX121895, Girvan NX183985). Slightly wider beaches are present at Turnberry and Maidens where the fringing platform fragments provide greater protection to the foreshore. Within these narrow beaches, wave energy is dissipated on the frontal platform fragments but is still sufficient to produce slow erosion along the shoreline. At selected sites small streams drain onto the beach and in doing so they tend to produce small accumulations of coarse material on the beach (e.g. Dipple NX200024).

The larger sand beaches, form features 150-700 m wide which extend as broad crescents for many kilometres along the shore between intervening headlands. The principal beaches are located at Ayr (4km), Woodfield (2km), Prestwick (4.25km), Troon (2km), Irvine Bay (11.5km), South Bay (1km), North Bay (2.5km) and Ardneil Bay (1km) (Fig. 5.2). Many of these features are composed entirely of sand with low beach gradients. The beach surface often consists of a complex series of ridges and runnels (Mather 1979). In general these beaches are backed by large dune systems in the northern and central part of each bay and by small embryo dune systems in the south (Fig. 5.2). Within each bay erosion of the shoreline tends to dominate the northern and central sections whilst the southern ends of the bay are sites of accretion or are stable beach systems (Plate 6).

A detailed analysis of the evolution of Irvine Bay (Plate 7) has been carried out by HR Wallingford (1996) this being based upon analysis of historical shoreline locations illustrated on maps and detailed monitoring of 5 beach profiles over a 10 month period. The results indicate general landward retreat of the shoreline (Mean High Water) at 0.1m per year and of the Low Water mark (0.8m per year) during the last 100 years (HR Wallingford 1996). The intertidal beach has steepened which tends to suggest that there has been a net volumetric loss of intertidal beach material. The beach monitoring revealed that during the summer months sediment is moved landward whilst during the winter months there is a general draw down of material (HR Wallingford 1996). Modelling indicated that for Irvine bay sediment tends to drift towards Irvine Harbour from the north and south. This material is then either moved onshore by wind to be incorporated into the dunes or moved offshore by river and tidal flows. A small amount of material is probably recirculated onto the beach system.

Similar processes probably operate on the other large sandy beach systems. Mather (1979) suggested that in general littoral drift was to the south but it is highly likely that more complex drift patterns are present. It is clear that each of these beaches is experiencing erosion along much of the shoreline, in particular during major storms. Since little fresh material is being added to the area it would seem likely that this process is set to continue in the future, particularly if relative sea level rises.

5.2.4 Sand Dunes

The Ayrshire Coastline is characterised by extensive dune systems, some of which form major features within the landscape, whilst others are smaller and probably more sensitive to change (Fig. 5.2). The larger dune systems are located in the north of the area, being associated with the large sandy beaches whilst in the south smaller features tend to dominate. The dune systems are complex since they consist of both modern and Holocene features and it is often difficult to distinguish between them.

The smaller dune systems are associated with the smaller sandy beaches such as Carleton Bay, Culzean Bay and Lendalfoot. At these sites the south-westerly winds blow across the beach and drive the sand onshore. The dunes usually consist of a single low foredune ridge up to 8 m high with isolated pockets of embryo dunes fronting them (Mather 1979), although a thin cover of blown sand often extends further inland. Many of the dunes are

now being eroded along their seaward margin but their surfaces are largely stable and well vegetated. Along many other sections of the southern coast, although dune ridges are not present much of the coastal landscape is covered by a thin veneer of blown sand which rests upon Holocene raised marine sediments.

More extensive dune systems are present at Turnberry, Prestwick, Troon, Irvine Bay and Stevenston (Fig. 5.2). In each of these areas a large foredune is present which is succeeded landward by either further ridges or, more frequently, Holocene raised marine sediments with a veneer of blown sand. At a number of sites the frontal edge of the foredune is being actively eroded (e.g. Woodfield NS342244, Troon NS325304, Stevenston NS263410), whilst in other areas some accretion is taking place (e.g. Presswork NS343272, Barassie NS326330). At a number of locations the vegetation cover of the dunes has been disturbed and the features are becoming unstable (e.g. Stevenston NS263410).

The most degraded dune system occurs at Stevenston where a 6m high foredune is being actively eroded along the shoreline. Inland of this a series of dune mounds are present (Plate 7), with considerable areas of bare sand which are succeeded landward by a dune slack. It is suggested that much of the dune erosion has been aggravated by trampling.

Farther south within Irvine Bay a large foredune (up to 10m high) flanks the shoreline and inland of this larger (up to 20m high) dune ridges are present. This dune ridge tends to get lower towards the south to the extent that at Barassie it consists of little more than a veneer of sand (Plate 8) The foredune is being eroded by coastal processes (Plate 9) although in the vicinity of Irvine harbour dune accretion is taking place. The foredune and inner ridges are relatively well covered in vegetation but Richey *et al.* (1925) indicated that the inner ridges were certainly mobile in the middle of the last century. At selected locations the foredune is cut by small blowouts and contains mobile sections where trampling is a problem (Mather 1979). There is no evidence that sand is being supplied in significant quantities from the beach to the dune ridges (Mather 1979; HR Wallingford 1996).

Between Troon and Prestwick a foredune 5-6 m high follows the shoreline. Mather (1979) indicated that active dune accretion was occurring in this area. During the recent field investigations erosion was found to characterise the northern shoreline of this embayment with dune accretion in the form of small embryo dunes in the south (Fig. 5.2). At a number of locations the foredune system has been removed and greatly modified by society (e.g. Troon South Bay NS327298)

5.2.5 Coastal wetlands

The only major coastal wetlands in the area are located at the mouth of the Irvine and Garnock Rivers (Fig. 5.1). Immediately north of Irvine Harbour small areas of saltmarsh and mudflat are present (Bogside Flats; Plate 10). The most extensive area occurs at the confluence of the Irvine and Garnock Rivers, with smaller areas being located along the western side of the Garnock River. Since this represents the only area of saltmarsh along this coastline it has been designated as an SSSI, mainly for its biological and ornithological interest.

Small patches of saltmarsh are also present on some of the inner margins of the rock platforms. A good example is present at Troon, where marsh sediments 0.4-0.6m thick outcrop on the platform despite its somewhat exposed location. The presence of these deposits suggests that this platform is not active.

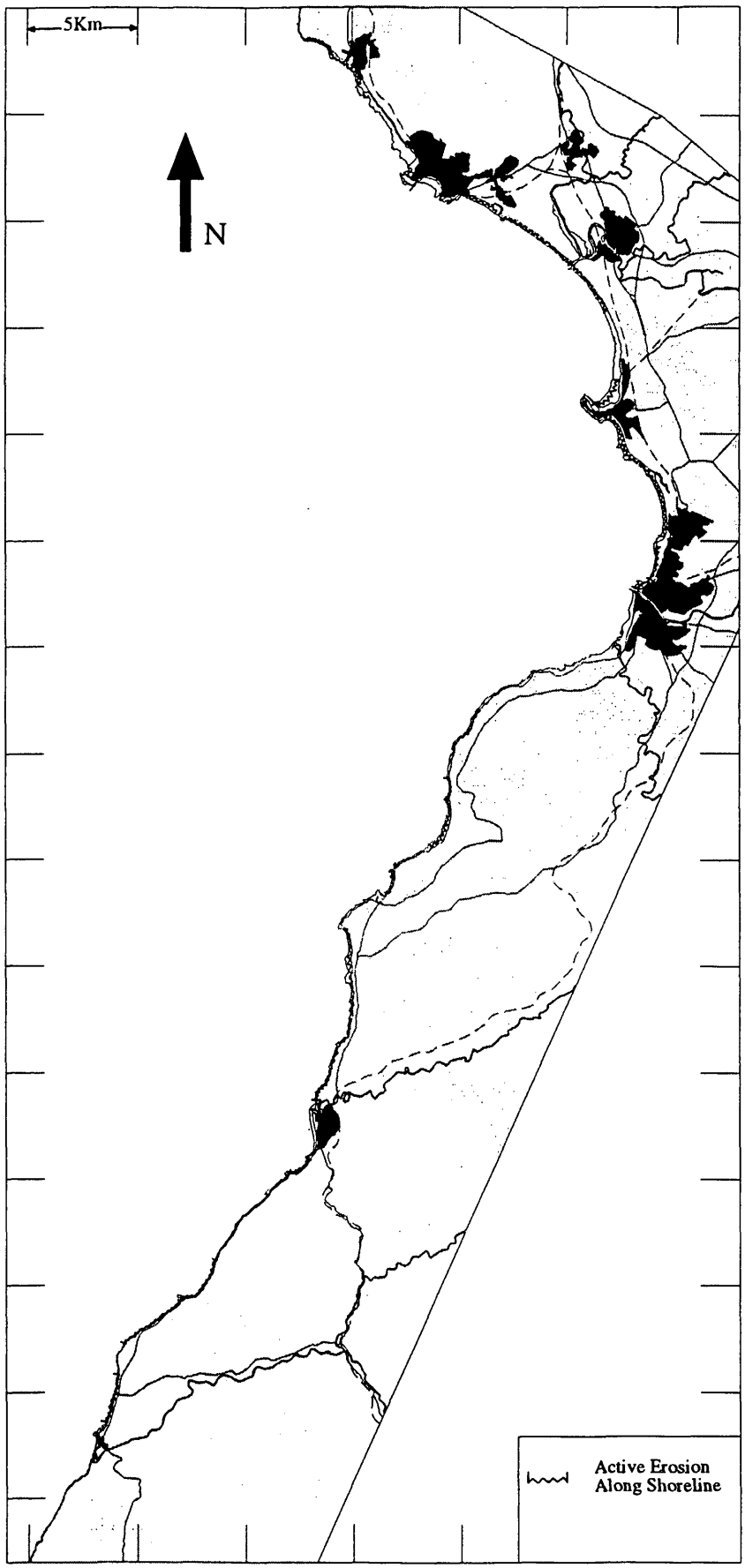


Fig. 5.3 Ayrshire Coastline: Sites of active erosion

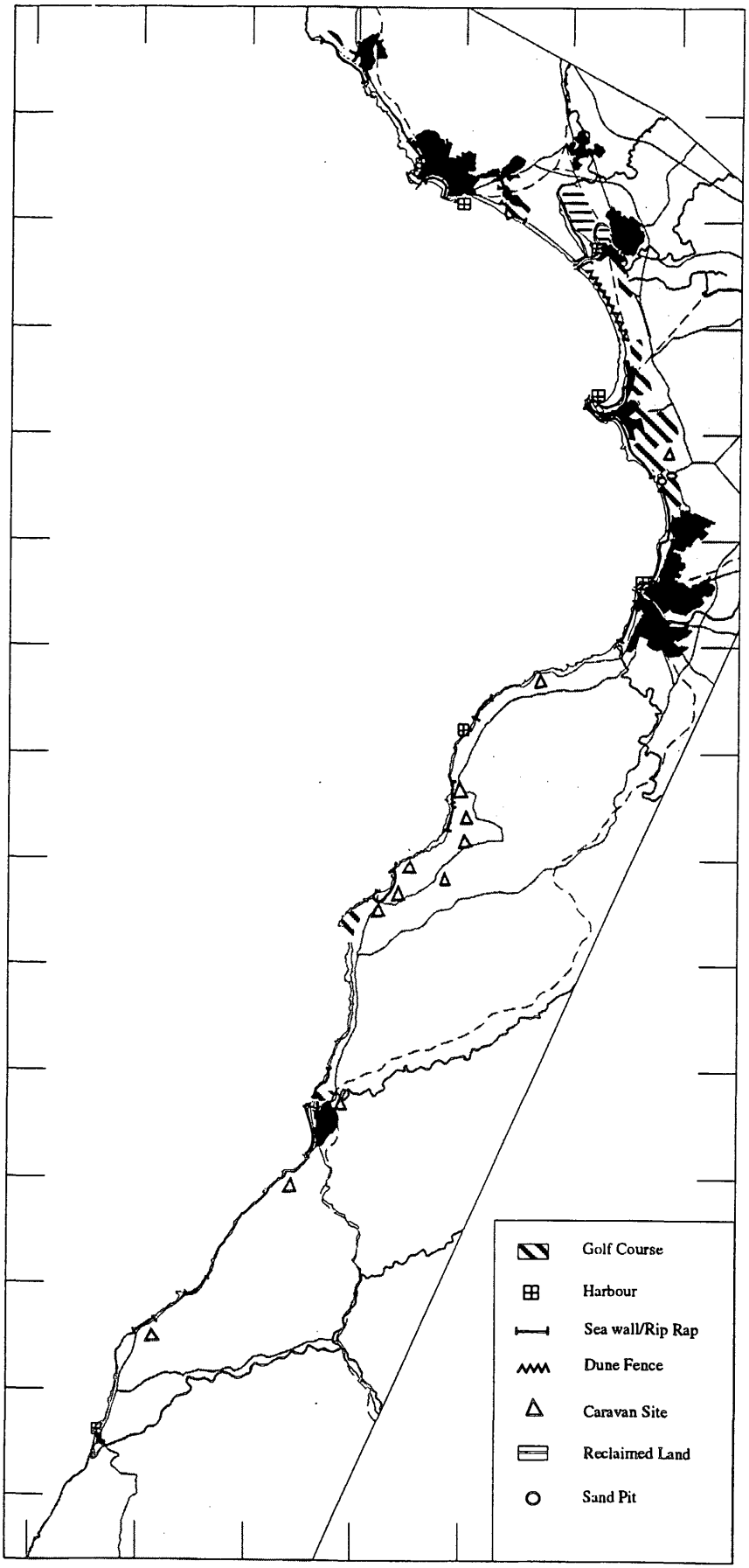


Fig.5.4. Ayrshire Coastline: Human Impacts

5.3 Late Quaternary Landforms and sedimentary environments

The present shoreline is fringed by raised Holocene marine deposits which formed at and subsequent to the culmination of the Main Postglacial Transgression at circa 6,000-4,000 yrs B.P., the former sedimentary environment being similar to the modern shoreline systems (Fig. 5.2). These deposits however rest upon the Main Rock Platform and its backing cliff which is well developed throughout the region. The sections of coast between Ardrossan and Farland Head (Plate 11) and just north of Ballantrae are good examples of these suites of landforms.

The early Holocene was characterised by rising sea levels which culminated between 6000 and 4000 yrs B.P. (Boulton *et al.* (1995) with the formation of the Main Postglacial Shoreline (Sissons 1976)). This feature has subsequently been uplifted and tilted towards the south as a result of glacio-isostatic movements. As a result the level of MHWST associated with the Main Postglacial Shoreline rises from about 5.5 m O.D. in the south to *circa* 10 m O.D. near West Kilbride.

No detailed maps are available of the Holocene coastal features along the Ayrshire coastline the map in the present report being based upon the field survey of the area and interpretation of 1:25,000 Ordnance Survey Maps. The Holocene features rarely exceed 300m in width, this again reflecting the width of the underlying platform. The Holocene deposits are wider in the vicinity of Irvine Bay and Prestwick, these areas representing the major zone of sediment accumulation during the period.

HR Wallingford (1996) suggested that many of the dune systems within the region are largely Holocene features, formed as relative sea level fell from the Main Postglacial maximum. It is proposed that as relative sea level fell it exposed large sand deposits which were subsequently reworked by the onshore wind systems to form the dune systems. There is no detailed evidence to support this view and there is clearly historical evidence which indicates that some of the inner dune ridges were active during the last 200 years. Such activity may however have been the result of society disturbing stabilised Holocene features.

5.4 Human Impacts

Large sections of the Ayrshire coastal zone have been affected by society, in particular between Ardrossan and Ayr (Fig. 5.4). The area is famous for its golf links (Troon, Turnberry) with a large number of smaller courses (West Kilbride, Gailes, Kilmarnock, Troon Municipal, Prestwick, Woodfield, Girvan). Each course has been constructed within the coastal dune systems and as a result the areas are highly managed. Shoreline erosion of the dune systems in these areas has lead to the construction of numerous sea defences (seawalls, gabion walls, dune fences; Plate 12) in particular sea walls constructed of rip rap derived from local quarry and building site debris (Plate 13). At West Kilbride lottery funds have been used to extend the shoreline some 5-10m seaward, whilst at Troon the dunes are fronted by a low sea wall. Similar defences have been constructed along other sections of the coast where active erosion of the dune system is taking place (e.g. Stevenston (Plate14) or at the very least dune fences have been erected to reduce trampling of these sensitive sites. At each site the defences appear to be only slowing the rate of shoreline retreat and many of the structures were in a poor state of repair when visited during this study.

The shoreline bordering each of the major settlements (West Kilbride, Ardrossan, Saltcoats, Irvine, Troon, Prestwick, Ayr, Girvan, Ballantrae) is protected by seawalls (Fig. 5.3), and in the main by vertical or curved sea walls constructed of concrete (Plate 15). Coastal defences are also common where roads boarder the shoreline, in particular north of

Ardrossan and south of Girvan (Fig. 5.3). The large sections of coast protected by structures is clear evidence of the progressive erosion occurring in this area and the general lack of accretion. It is noticeable that at a number of sites relatively new gabions have been constructed (e.g. Girvan) or the defences are in a poor state of repair and this perhaps implies that the erosional processes are becoming more pronounced. It is possible that the construction of sea walls has initiated beach scour and is thus accelerating erosion, however this view would need to be substantiated.

Few structures have been built in the nearshore zone (e.g. breakwaters) that influence patterns of longshore drift in this area. The notable structures include the breakwaters associated with ports/harbours at Ardrossan, Saltcoats, Irvine, Troon, Ayr, Dunure, Girvan and Ballantrae. In most cases the structures have been built on existing rock platforms and thus have produced a minimal impact on longshore drift.

Although rip rap/boulders have been dumped into the nearshore zone at a number of locations as a method of shoreline protection the only major input of clastic material is at Stevenston. It appears that mine waste was originally dumped into the nearshore zone but the site has been regraded and the dumping has now ceased. The dumped material has been reworked into active coastal features but the distribution of the material is limited. Similarly, relatively little coastal material is being extracted from the area via sand or gravel pits. The dune links certainly contain a valuable source of fine sand but their frequent use as golf links largely precludes their use by the extraction industry. During the field investigations local farmers were seen removing storm derived seaweed from the beach at Maidens (Plate 16). Since this is removing material that would naturally rot it is probably sustainable and no doubt has continued for some considerable time.

The largest impact by society on this section of coastline comes from tourism. As noted above the area is a major golfing locality and contains numerous caravan parks. In addition most of the towns have well developed promenades, hotels and tidal swimming pools. The fine sand beaches certainly attract large numbers of visitors from Glasgow in the summer months. The visitors, although only using the area for short periods of time, represent a major risk for many of the more accessible dune systems. Extensive trampling will make these fragile systems unstable and thus care must be exercised to ensure that the impacts are well managed.

6.0 ISLE OF ARRAN

6.1 Introduction

The Isle of Arran occurs between the Kilbrannan Sound and the main Firth of Clyde (Figs. 3.1, 6.1). The solid geology of the island is well known (Fig. 1.3). In the north, the main coastal outcrops of bedrock consist of schistose grit with less extensive outcrops of slates, Devonian, Carboniferous and Permian sandstone, Carboniferous Limestone and Coal Measures, and Triassic marls. The coast of the southern part of the island is dominated by Triassic marls, Permian sandstone and Tertiary intrusive dykes and sills. A particular characteristic of the extreme south of the island is the large number of dykes which extend out from the modern shore to the sub-tidal zone.

The island has been affected by Quaternary climatic and sea level variations (Fig. 1.4) and glacial sediments are extensive inland, though they are rare at the current coastline. Postglacial fluvial and marine deposits are also present, particularly in the lower gradient reaches of river valleys where they underlie terraces, for example near Brodick, Catacol Bay and Blackwaterfoot.

The human population of Arran is low, the main settlements being Brodick and Lamlash (Fig. 6.1).

Much of the description here is based upon a field visit made during January 1998 with comparison made to the earlier detailed beach survey reported in Ritchie (1975).

6.2 Contemporary Landforms and processes

6.2.1 Intertidal rock platforms

The intertidal zone around most of the Arran coast is characterised by outcrops of bedrock, though in many places this is covered by a thin veneer of sediment (Fig. 6.2). The outcrops generally form an irregular sloping surface towards the sea, sometimes with a lower gradient terrace at or near high tide. In some localities, the inland margin of this platform is marked by a steep bluff cut in bedrock (e.g. Newton Point near Lochranza, NR931516). Elsewhere, the platform forms a near continuous surface grading upward from the subtidal zone to well above modern high water.

It is likely that erosion in the recent geological past has contributed to the present appearance of these platforms, particularly where there is a supply of coarse sediment which could enhance attrition in exposed areas such as in Machrie Bay on the west coast (NR890350). In many areas, however, this platform occurs in relatively sheltered locations, for example in Loch Ranza. As a result, it is likely that the platform is largely a relic feature formed under different environmental conditions during one or more intervals in the past, rather than being an active abrasion surface as has been suggested previously (e.g. Ritchie, 1975).

Along the southern coast of Arran between Sliddery and Kildonan, the morphology of the coastal zone is modified by a large number of SSE (and occasionally SW) trending dykes which extend seawards from high tide level. To some extent, these dykes act as natural barriers to longshore transport of sediment and, as a result, cobbles and sand have accumulated in places, for example at Lagg (NR955207) and Bennan Head (NR998204).

Although the coastal zone of Arran typically has a steep gradient, there is little evidence for active cliff formation at present. The possible exceptions to this are the cliffs immediately east of Bennan Head, noted above, and at Dippin Head, where cliffs occur immediately

above the present intertidal rock outcrops. In places where cliffs do occur very close to the coast, they are normally fronted by a relic rock platform for example the northern coast between Lochranza and Sannox, or raised beach, as at Corriecravie (NR920233), Lagg (NR955208) and Auchenhew (NS010211).

6.2.2 Sand and Gravel Beaches

For much of its extent around Arran, the intertidal rock platform is obscured to a greater or lesser degree by a veneer of sediment (Fig. 6.2). In most places this appears to be unambiguously beach material (sand to cobble grade) that is being reworked by wave action, for example between Brodick Castle and Sannox Bay (NS018377 to NS017455), between Catacol and Lochranza (NR911497 to NR925510) and north and south of Pirnmill (NR444873). Elsewhere, large boulders are present on the platform, e.g. the northern shore of Loch Ranza (NR931514, which are probably glacial in origin.

The seaward ends of most of Arran's river valleys feature accumulations of cobbles which have largely been supplied by fluvial activity but now form linear beaches, often with distinct storm ridges. At Glen Catacol (NR909493), a shingle ridge was observed during the field survey which extended almost continuously across the mouth of Glen Catacol, a distance of approximately 600m. This ridge had largely impounded the flow of the main river channel at the south of the valley (the Abhainn Mor) and a smaller stream at the north of the valley (the Abhainn Bheag). This impounded water formed a number of small lagoons, the seawards margin of which was the cobble ridge, the inland margin being a low (<0.5m) bluff or slope formed of sand, gravel and cobbles of either beach or fluvial origin. A diagram and photograph in Ritchie (1975, Fig. 5.6.1, plate 5.6.2) show that the lagoons were not present in the mid 1970's but that the two channels were deflected slightly to the north by cobble bars, though Ritchie reported no evidence of significant spit formation at the time.

Similar features are present at Machrie Bay (NR892336), where the channel of the Machrie Water is deflected to the north though not blocked by beach deposits, and at Sannox Bay and North Sannox, where river channels are deflected to the south. At these sites, the January 1998 channel position appears very close to that reported by Ritchie (1975).

The best developed coarse-grained spit on Arran not directly associated with fluvial activity occurs in Loch Ranza (NR934507) where an active spit is attached to a relict spit on the south-western shore of the loch. A second, smaller spit may be beginning to form 300m seawards of the main spit. There is no mention of this second feature in Ritchie (1975), though whether it is a recently-formed feature or lay beyond the area mapped by Ritchie is not clear. The main spit provides a degree of shelter on its inland side and a small area of saltmarsh was reported by Ritchie (1975).

In several places, sand beaches are present. Many of these are small patches of sand which may be transitory features (e.g. near Auchenhew on the south coast, NS013209). Some larger sand dominated beaches are present, for example the southern end of Lamlash Bay (NS028303) and Brodick Bay (NS015365). At this latter site, the beach occurs on the seaward side of a sand bar or spit, the top of which is colonised by grasses (*Leymus arenarius* and *Ammophila arenaria*). It is difficult to determine the exact origin of this spit. Ritchie (1975) attributes it entirely to longshore drift. An horizon of peat exposed at approximately mean highwater springs level along the southern, Brodick end of the beach near to Cloy Bridge (NS015363) in January 1998, however, suggests that the present beach deposits may really be a veneer covering an older deposit. This may imply progressive retreat of the shoreline in Brodick Bay though further work is needed to clarify this.

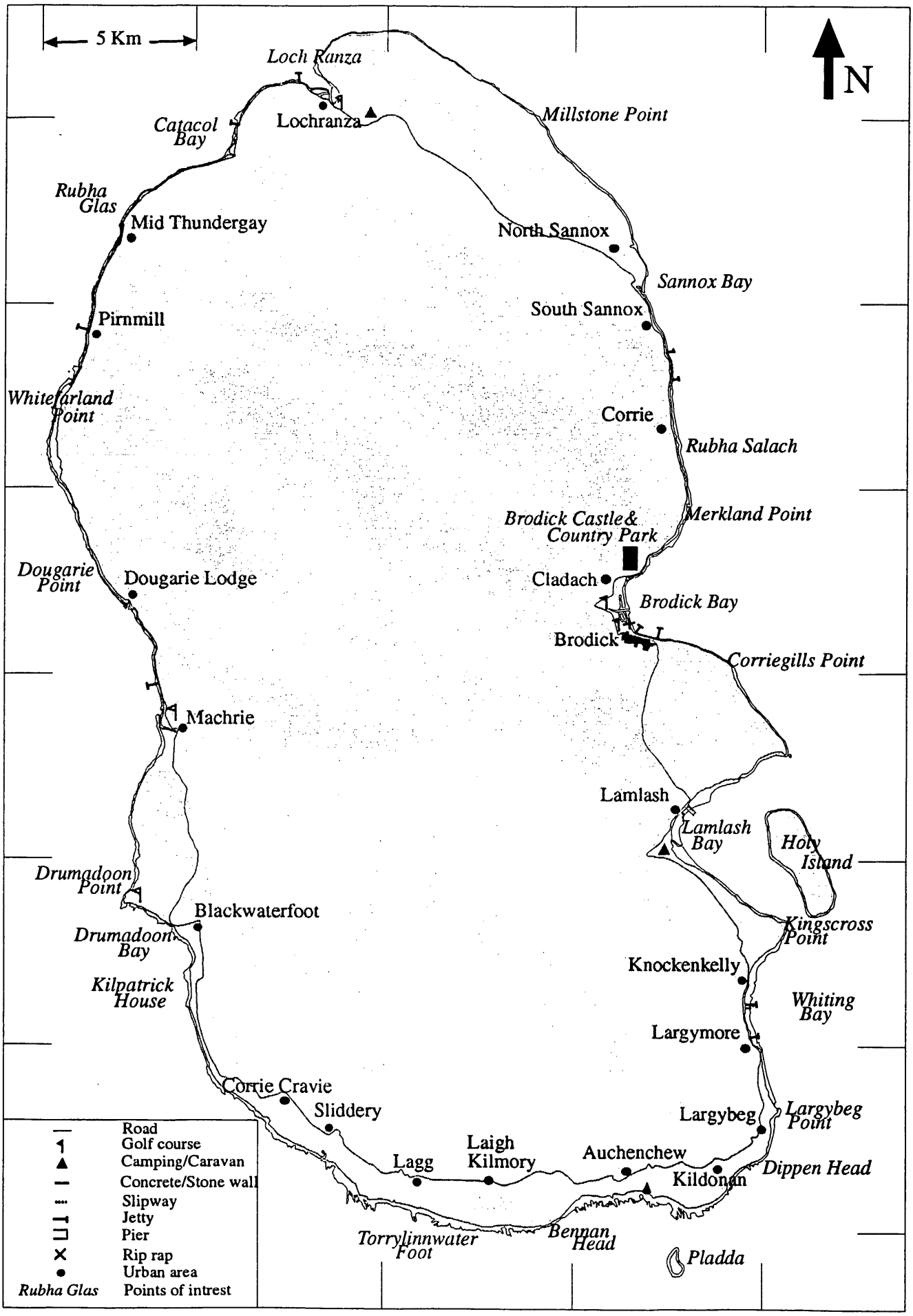


Fig.6.1 Isle of Arran: Site locations and human impacts

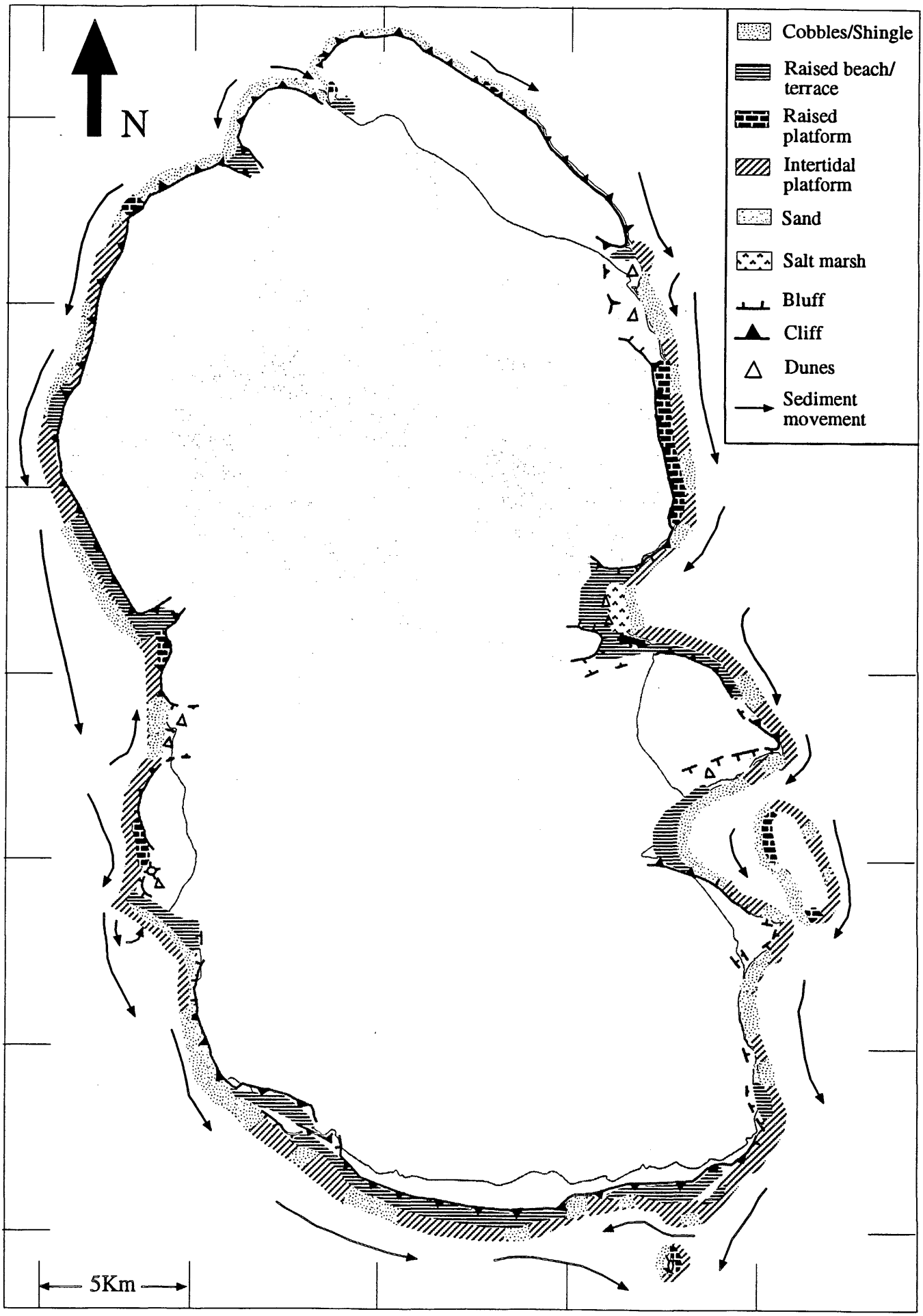


Fig. 6.2 Isle of Arran: Geomorphological features and processes

At Lagg (NR955207), the beach is mainly composed of sand, with coarser material present at Torrylinnwaterfoot, reflecting local fluvial sediment supply. A similar accumulation of gravel and cobbles is present at Slidderywaterfoot (NR934229). A shingle beach is present east of Bennan Head (NR998204), perhaps reflecting deposition in the lee of the Head. There may also be local sediment supply from the cliffs above the beach.

6.2.3 Dunes

Several small dune fields are present, mainly at the mouths of valleys on the western coast (Fig. 6.2), for example Machrie Bay (NR895338) and Drumadoon (NR285890) where they occur as linear features above high water. In these areas, older dune fields are also undergoing some reworking. Aeolian processes affect a number of places, for example the top of the beach ridge at Brodick (NR014370). The extent of the dunes around the island may, to some degree, reflect the limited local supply of suitable sediment. Their presence possibly reflects greater wind action on the western side of the island.

6.2.4 Coastal wetlands and mudflats

Saltmarshes and mudflats are not extensive on the Isle of Arran as the conditions required for their presence, principally low energy coastal conditions and a supply of fine sediment, are rare. In places, muddy veneers occur as a transient feature across both intertidal rock platforms and sand and cobble beaches. Some small areas of saltmarsh do occur in areas with some degree of protection, in particular behind beach ridges and along the tidal reaches of some of the streams, for example at Brodick and Lochranza (Fig. 6.2).

The largest saltmarsh on Arran is at Brodick (grid ref.) where a *Juncus maritimus* wetland has developed behind the modern beach ridge. The banks of the Glencloy Water and Glenrosa Water, which pass through this wetland, show some evidence of recent slumping. Comparison of the situation during the field visit in January 1988, however, with the detailed map of the site in the mid-1970s by Ritchie (1975, Fig. 5.15.2) and the sketch map by Ritchie (*op. cit.*) of conditions drawn from the 1:10560 map surveyed in 1864 and revised in 1914 suggests that there has been no major reduction in the extent of the saltmarsh. Indeed, it is possible that the area of tidal wetland vegetation has increased over time as fine sediment has accumulated.

At Lochranza, a small area of what is described as 'old salt marsh' was reported at the landward, inland margin of the Castle Spit (NR933506; Ritchie 1975, Fig. 5.15.1). This area of marsh was not noticed during a brief field visit in January 1998, though its apparent absence may have been the result of seasonal vegetation die-back rather than its disappearance. Fine sediment (sand, silt and clay) was present.

At Machrie, a thin band of saltmarsh was reported by Ritchie (NR892336;1975, Fig. 5.8.1) along the northern bank of the Machrie Water where it was protected by an intertidal sand spit.

At Catacol Bay (NR909493), narrow lagoons have formed between beach ridges. Although these are probably short-lived features - they are not present on Ritchie's map (1975, Fig. 5.6.1) - they provide temporary habitats for microphytes (benthic algae) and wildfowl, including eider ducks (observed January 1998).

6.3 Late Quaternary Landforms and sediments

6.3.1 Main Rock Platform and fossil cliff

A sloping platform cut into bedrock and generally backed by a steep relict cliff extends as an almost continuous feature around the island (Fig. 6.2). At its maximum, on the southern coast, the platform is up to 250 m wide. Where the coastline is broken by valleys, the rock platform merges into raised beach deposits. The cliffline around the northern part of the island features a number of relict sea caves, for example at Pirnmill (NR873444) and Auchengallon (NR891355). Originally, this type of raised platform was considered to be former abrasion platforms cut by wave action at a time of higher relative sea level. Recent research into erosional processes on marine and lake shorelines in periglacial regions has shown that, where ice seasonally develops, intense, freeze thaw related mechanical weathering can occur (Dawson *et al.* 1987). On Arran, the separated fragments would not have accumulated to form a protective veneer as long shore drift would have quickly removed them. The similarity between the raised platform and the current intertidal platform suggests that they formed as a result of similar processes. It is possible, therefore, that the platform currently in the intertidal zone is, in reality a reoccupied surface formed during one or more earlier cold stages.

6.3.2 Raised beaches

Numerous raised surfaces occur around the coastline of Arran which are underlain by a similar range of sediment types to the modern beaches, principally cobbles, gravel and sand. Several of these raised features are more extensive than their adjacent active equivalent and it is likely that they are composite features which include subtidal deposits and sediments formed over a period of time. In some places, their origin is ambiguous and some may be fragments of former river terraces rather than true raised beaches. Elsewhere, for example at Machrie, the original raised beach surface has been buried by subsequent deposits such as aeolian sand. At Machrie, Ritchie (1975) reports a raised shingle ridge.

The active spit at Lochranza is an extension of an older shingle feature extending out from the western side of the Loch. The upper surface of this relic feature is some 1-1.5m above the highest part of the active spit.

Relic dune fields are present locally, mainly occurring upon raised beach surfaces. At Machrie, a buried peaty soil provides evidence for occasional reactivation of the Holocene dunes (Ritchie 1975, plate 5.8.4).

Some of the smaller, steeper valleys feature alluvial fans where they reach the coast. These fans feed into both relict and active gravel beaches. At North Sannox (NS016466), the cobble, gravel and sand fan has been incised by river action and the seaward edge of the fan features a low bluff at the back of the active beach.

6.4 Human impacts

The permanent population is not high though significant numbers of people visit the island for recreational purposes. Modification of the coast has been limited and, while there may be local effects from these, it is unlikely that the human activity has caused significant deviation from natural conditions.

As much of the coastline is rocky, coastal protection works are mainly limited to near settlements and the small harbours. The road along the north coast of the island is constructed on the raised rock platform, above high tide level and generally requires no

protection. At Brodick, the seaward side of the A841 road between the ferry pier and the beach is protected by a low sea wall. The scoured surface of the intertidal platform cut across a glacial till deposit suggests that the road could be damaged without this protection. At the eastern end of the town is the ferry pier, together with fuel storage facilities, both of which are potential local sources of pollution.

A number of small stone jetties are present, for example at Corrie (NS026428). There are also some slipways, for example at Dougarie Lodge (NR883368) and Lochranza (NR926510), the latter serving a seasonal ferry service to Kintyre.

At Lochranza, the seaward side of the relict part of the Castle Spit has been covered by a sloping stone wall. This protection was probably solely intended to protect Lochranza Castle, a 16th Century building located near the tip of the spit, rather than preserve the landform itself. Access to the Castle is by a narrow metalled track and cars park on the grass. Despite this, there was little evidence of significant erosion of the spit's surface by vehicles.

Several golf courses are present, mainly occupying raised beach surfaces, for example at Brodick, Machrie and Blackwaterfoot (NR892283). At the latter, a car park near the course which has been extended onto the upper beach is protected by riprap covered by boulders.

Around much of the coast, gradients are too steep for agriculture, other than rough pasture. Where the Main Rock Platform is well developed, however, as in parts of the south of the island, improved pasture is present.

7.0 INNER CLYDE

7.1 Introduction

The Inner Clyde area is delimited, herein, by a line drawn between Barons Point (NS231811) and Farland Head (NS177484), including Gare Loch (*circa* NS250860) (Fig. 7.1). Two sub areas can be defined. The first is delimited by the limit of extensive fine intertidal sediments in the estuary of the River Clyde (approximately between Helensburgh on the north coast and Greenock on the south coast). The second sub-area includes the coastline near Kilcreggan on the north of the firth and from Greenock to Farland on the south.

7.2 Contemporary Landforms and processes

7.2.1 Intertidal rock platforms

Intertidal bedrock exposures are limited to the outer parts of the Inner Clyde coastal cell, for example west of Gare Loch near Barons Point, Kilcreggan (NS222810), at Farland Head, and Wemyss Point (NS188202) (Fig. 7.2). Compared to other parts of the Firth of Clyde, such as the Kintyre Peninsula, the bedrock outcrops are limited in extent. The exceptions to this are the platforms on the islands of Great Cumbrae and Little Cumbrae.

7.2.2 Sand and Gravel Beaches

Beaches of sand or shingle occur along much of the outer parts of the Inner Firth. In some places (e.g. near Cloch Point – NS205761) these occur as thin strips suggesting rapid sediment transportation along the coast. Wide sandy beaches are present near Hunterston Nuclear Power station (the Hunterston Sands and Southannan Sands, *circa* NS185525 and NS195535). This reflects a degree of protection afforded by the shallow embayment extending between Hunterston and Largs. The islands of Great Cumbrae and Little Cumbrae may also reduce wave energy. A small sand beach is present at Millport on Great Cumbrae (NS171555), while a sand and shingle beach is present on the sheltered northeastern side of the island between Clashfarland Point and Holm Bay (NS185563-NS183589). Further small sandy beaches are present south of Largs.

A narrow (50-100m) shingle beach extends around the shores of Gare Loch. At the northern end of the loch, the beach widens to 200-250m, suggesting net sediment transfer to the loch head at Garelochhead (NS236909). Near the mouth of the loch, Rhu Point (NS262836) and Limekiln Point (NS259835) appear to be sites of sediment accumulation, with the material burying a former morainic ridge.

Within the area of the River Clyde estuary, extensive sandflats occur. The most extensive of these occur north and south of Ardmore (*circa* NS320790), and north and south of the Clyde channel near Dumbarton (*circa* NS385745 and NS380738). Locally within these sand flats are areas of coarser sediment, for example at Cardross (NS344770). These may reflect locally higher energy conditions, or some may be the winnowed remains of glacial deposits.

Beaches are more extensive on the northern side of the Inner Clyde coastal cell west of Dumbarton, extending into Gare Loch (Fig. 7.2). Between Craigendoran and Dumbarton, the beaches are mainly composed of sand and are of a low gradient, passing seawards to sand and mudflats. On the southern side of the Ardmore peninsula (NS325786), the highest part of the beach includes cobbles, together with some dumped rubble. At Cardross (NS344771), cobbles are also present in the intertidal zone, perhaps associated with a local supply from the Geilston and Wallacetown Burns.

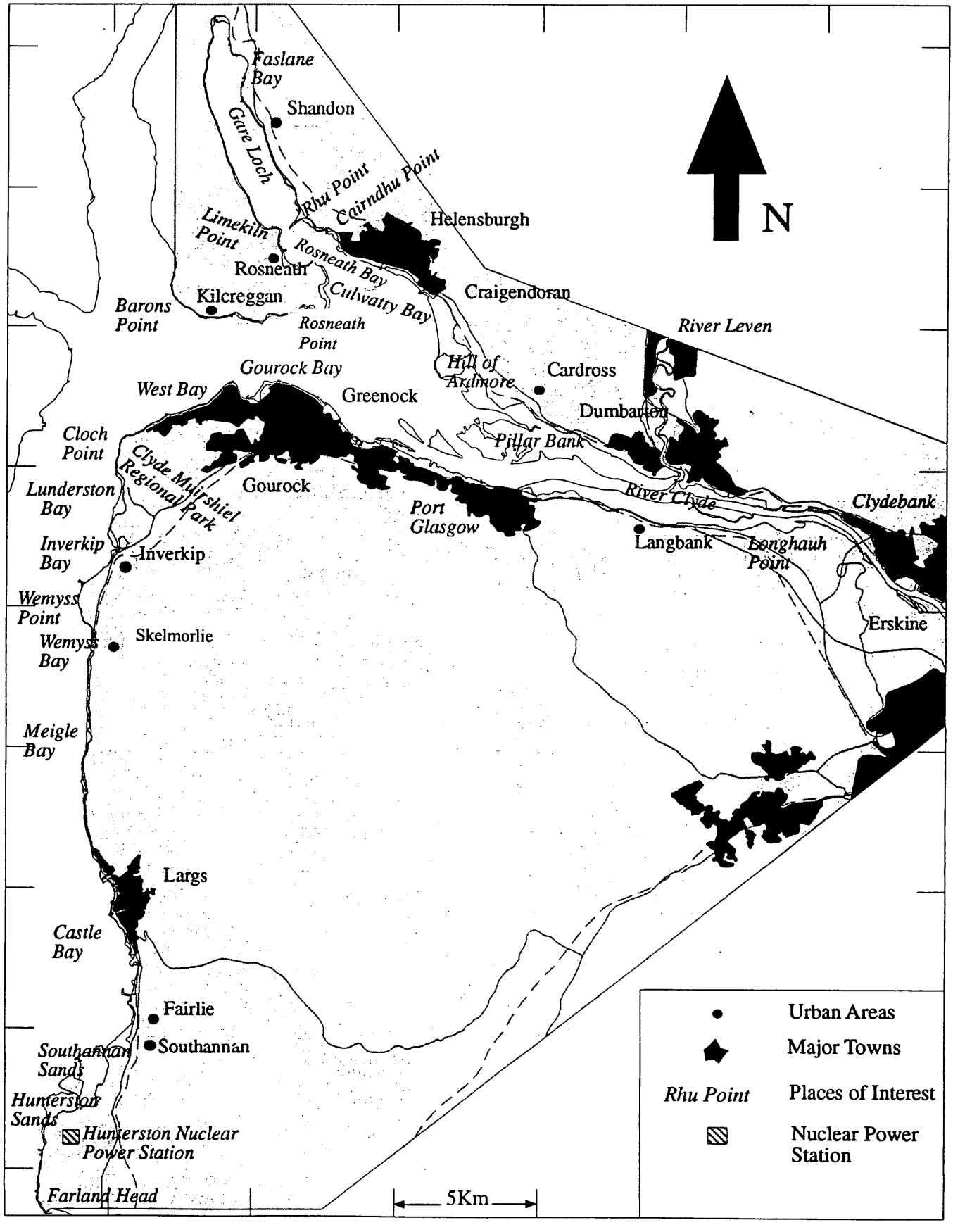


Fig.7.1 Inner Clyde:Location Map

Between Craigendoran and Rhu (NS215811-NS265838), the beach material includes sand, gravel, cobbles and some boulders. In places, for example at Cairndhu Point (NS279828), the beach is a thin veneer of cobbles and gravel resting directly upon a bedrock platform. A shingle spit, Rhu Point (*circa* NS262836) extends across the mouth of Gare Loch between Rhu and Rosneath, leaving a narrow entry channel into the loch.

7.2.3 Coastal wetlands and mudflats

A number of saltmarshes are present within the Inner Clyde, reflecting the low energy conditions and the supply of fine sediment which have produced extensive mudflats (Fig. 7.2). The saltmarshes do not have the same spatial extent as in other Scottish Firths (e.g. the Firth of Forth, Firth *et al.*, 1997) but they provide important habitats for a range of organisms.

At Ardmore, near Cardross (NS323788), a small area of saltmarsh is present above mudflats on the northern side of the ridge which joins Ardmore Point to the northern Clyde shore. The marsh here is largely composed of small hummocks capped by *Puccinellia maritima* turf. It is unclear whether these mounds are entirely erosional or depositional in form. Some slumping was observed in January 1998, although there was also some evidence of deposition, with fresh fine sediment present.

Erskine Harbour (NS464719) is now largely infilled by silty clays, the top of which has been colonised by tidal wetland vegetation. The front of the marsh consists of a bluff with some evidence of recent slumping, together with ramps of fine sediment which appeared to have been recently deposited.

Intertidal wetlands occur below the tidal limit of the River Level at Dumbarton. These appear to have been reduced in extent by land reclamation and dykes (e.g. Dumbarton Common, NS393764). Other areas of saltmarsh occur between Longhaugh Point and Erskine Park (*circa* NS444732) and between Newshot Island and Erskine (*circa* NS483702). In the latter, a former large tidal channel of the River Clyde has been infilled with sediment.

Mudflats occur across much of the River Clyde estuary. Some of the most extensive areas are at Pillar Bank (NS340760). Wide mudflats also occur near Langbank (*circa* NS395735). To the east of the Erskine Bridge (NS463724) intertidal mudflats are limited in extent. This probably reflects the higher energy environment associated with the river, and this is no doubt enhanced by the extensive sea walls in this area.

7.3 Late Quaternary Landforms and sediments

7.3.1 Main Rock Platform and fossil cliff

A sloping platform cut into bedrock and generally backed by a steep relict cliff extends as an almost continuous feature along the coastline of the Inner Clyde (Fig. 7.2). Typically the platform is narrow (up to 200 m across). The feature is best developed just north of Farland Head (Plate 1), between Wemyss Bay and Largs and around Great and Little Cumbrae Islands. At a number of locations raised caves are preserved in the backing cliff (e.g. Skelmorlie, NS193677). Originally, this type of raised platform was considered to be a former abrasion platform cut by wave action at a time of higher relative sea level. Recent research into erosional processes on marine and lake shorelines in periglacial regions has shown that, where ice seasonally develops, intense, freeze thaw related mechanical weathering can occur (Dawson *et al.* 1987) and produce rapid platform development. The feature is believed to have formed during the Loch Lomond Stadial, although periglacial processes operating at this time may have only retrimmed a pre-existing feature.

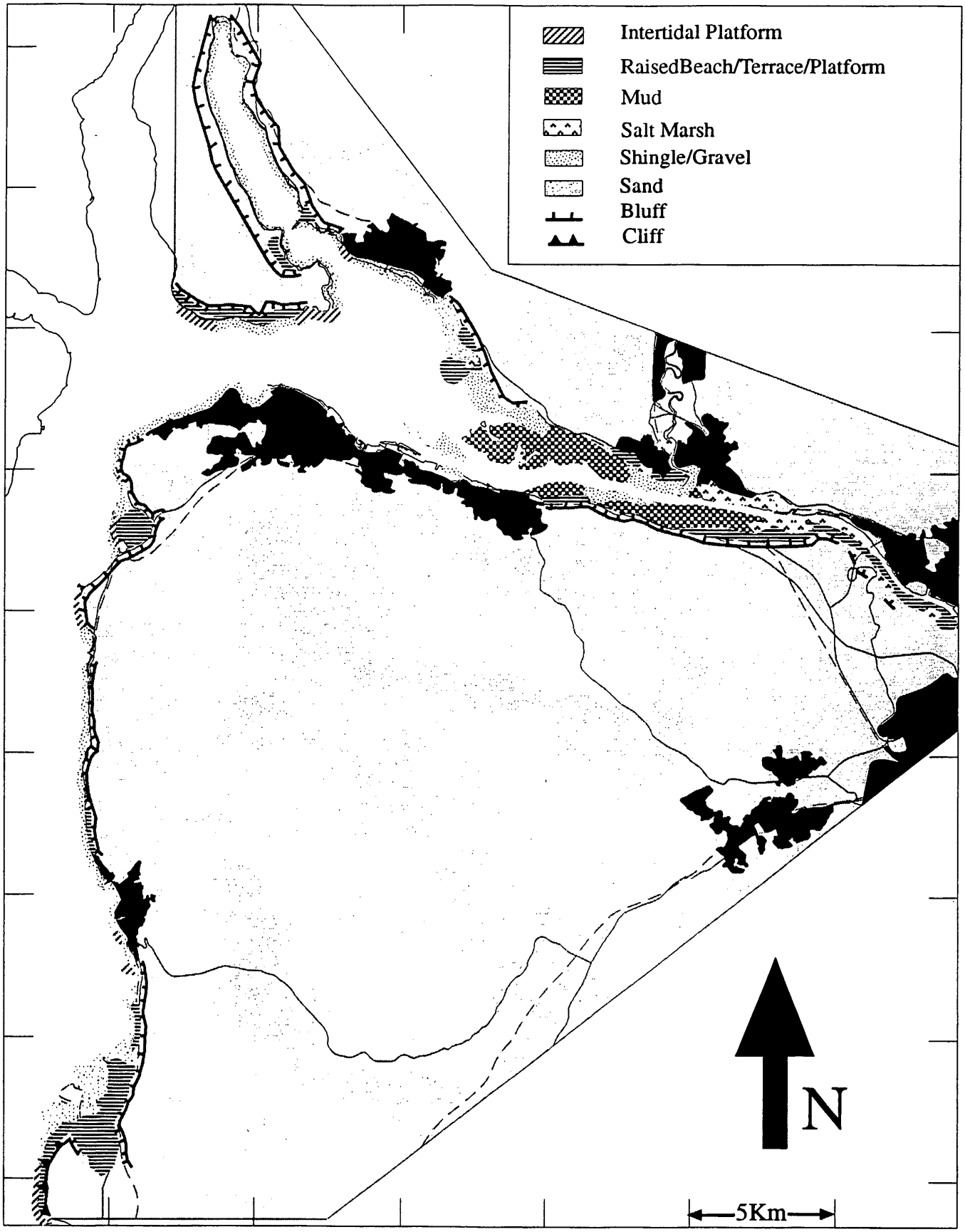


Fig.7.2 Inner Clyde: Geomorphological processes and landforms

7.3.2 Raised beaches

Wide areas of flat land are present on either side of the River Clyde estuary, typically backed by a low rounded bluff. These may in part reflect former marine features raised by continued isostatic uplift. However, the presence of dykes and walls (e.g. at Loughaugh Point, NS431730 and Clydebank, NS472713) suggests that many of these areas are reclaimed land. More extensive areas of raised mudflats lie beneath Glasgow.

7.4 Human Impacts

The coast of the Inner Clyde region has experienced intensive human activity which has resulted in a number of major modifications to the present shore (Fig. 7.3). The shores of the tidal River Clyde between the tidal limit and the Erskine Bridge (NS462724) are almost completely protected by sea walls and several large docks are present in Glasgow associated with ship building. Several road and rail bridges cross the Clyde in central Glasgow. Harbour developments with sea walls are also continuous on the southern shore of the Firth between Port Glasgow, Greenock and Gourock.

As noted above, dykes and walls are present in many areas and these are indicative of land reclamation. Construction of walls to protect property and to stabilise the river channels has an inevitable effect on the flow of the River Clyde, namely the river's power is increased and sediment accumulation reduced. Such processes are exacerbated by dredging activities.

At Erskine Bridge (NS461724) slipways which served the former Erskine Ferry are present, and these may be causing local turbulence which has lead to minor erosion along the eastern side of the southern slipway. Erskine Harbour (NS464718) has been abandoned and is now largely infilled by fine sediments, the sheltered conditions allowing a tidal wetland to develop within the former harbour (Plate 20).

An oil terminal and storage facilities, with associated sea walls and piers are present near Bowling (NS435736). Further major structures are present at Helensburgh (NS924821) (large quay protected by a boulder and riprap sea wall) and in Gare Loch where the extensive naval harbour at Faslane Port (NS247893) is present.

The most significant human impact on the outer coastline of the Inner Clyde occurs at Hunterston, where land reclamation, pier and jetty construction and major coastal defence works are associated with the nuclear power station, construction yard and ore terminal. It is likely that this activity has had an impact on local sediment budgets, in particular by blocking direct sediment movement between Hunterston and Southannan Sands. A minor amount of erosion at Southannan (NS207545) may reflect this. An evaluation of the direct impact of the construction of the Hunterston site on the Fairlie-Largs coastline is difficult to assess, since there are a large number of piers and jetties in that area as well as a new marina (NS208570).

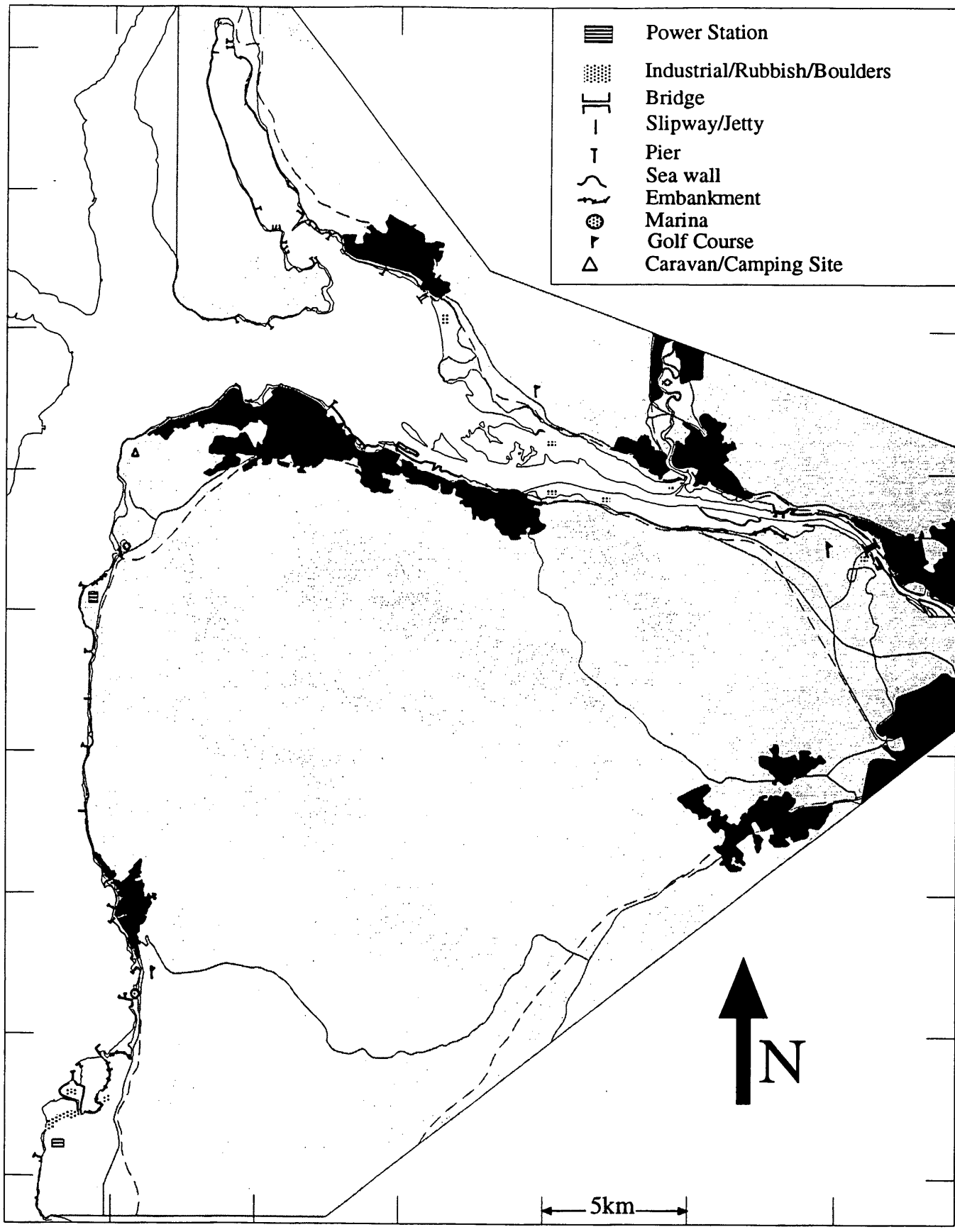


Fig.7.3 Inner Clyde: Human Impact

8.0 THE COWAL PENINSULA AND ISLE OF BUTE

8.1 Introduction

The Cowal Peninsula consists of the shoreline that lies between Barons Point (NS231811) in the east and Skipness Point (NR915582) in the west and it also includes the islands of Bute and Inchmarnock (Fig. 8.1). The area consists of a series of generally north-south aligned fjord lochs, namely, Loch Long, Loch Goil, Holy Loch, Loch Striven, Loch Riddon/Ruel, the Kyles of Bute and Loch Fyne (Fig. 8.1). The area is characterised by steeply sloping glaciated valleys which contain the limits of the Loch Lomond Stadial Advance glaciers. To some extent there the coastline within the ice limit is characterised by a lack of sediment whilst that outside the ice limit contains localised areas of coastal deposition. A notable feature throughout the area is the Main Rock Platform and backing cliff and in comparison Holocene and modern features are limited. The area contains 9 SSSIs and one National Nature Reserve, 4 for their biological interest and 6 for their geological and geomorphological interest (Fig. 1.5; Tables 1.1 & 1.2).

The whole coastal area was mapped by Sutherland (1981) who was principally interested in the Lateglacial and Holocene features in the area. Sutherland did note the location of some of the modern coastal feature but a more comprehensive inventory of the depositional features in the area has been provided by Ritchie (1975).

8.2 Contemporary landforms and sedimentary environments

8.2.1 Bedrock Shorelines & Rock Platforms

Much of the shoreline of the Cowal Peninsula and Isle of Bute consists of bedrock which is draped by a thin mantle of lag gravels and boulders. At many localities the shoreline consists of the frontal margin of the Quaternary Main Rock Platform in other areas this platform is absent and a more steeply sloping rock surface is present (Fig. 8.2). The Main Rock Platform and its associated cliff are best developed outside the Loch Lomond Stadial ice limits although extensive remnants of platform and cliff have been identified within the ice limit by Sutherland (Fig. 8.2). The best examples of the feature occur on Bute at Dunagoil (NS085534) and Scalpsie (NS065575) Bays (Plates 17 & 18). At the latter site the Main Rock Platform is 400m wide and its frontal margin now forms a rock platform along the shoreline. It is noteworthy that the platforms are well-developed in both sheltered and exposed locations, although they tend to be wider at the latter. Although these features are being modified by modern coastal processes they were formed largely during the Younger Dryas (Loch Lomond Stadial) and thus are inherited features. At many locations the platform is overlain by a thin veneer of sand, shingle or lag gravels.

At other sites, particularly inside the Loch Lomond Stadial ice limits, numerous bedrock shorelines are present. At these locations the bedrock is steeply sloping and no platforms have developed. At other sites the bedrock is mantled in a thin veneer of lag gravels and shingle. The majority of these sites lie well within the fjords and thus are relatively sheltered. As a consequence wave action is limited and has been restricted to removing the cover of Quaternary deposits to expose bedrock, but no bedrock erosion has occurred. In places the shoreline consists of glacially smoothed surfaces which have been exposed from beneath a cover of till by limited wave action. Classic examples of this type of shoreline are present on the eastern shore of Loch Long a few km south of Arrochar (NN272009) and in the vicinity of Strone Point (NN 112088) in Loch Fyne.

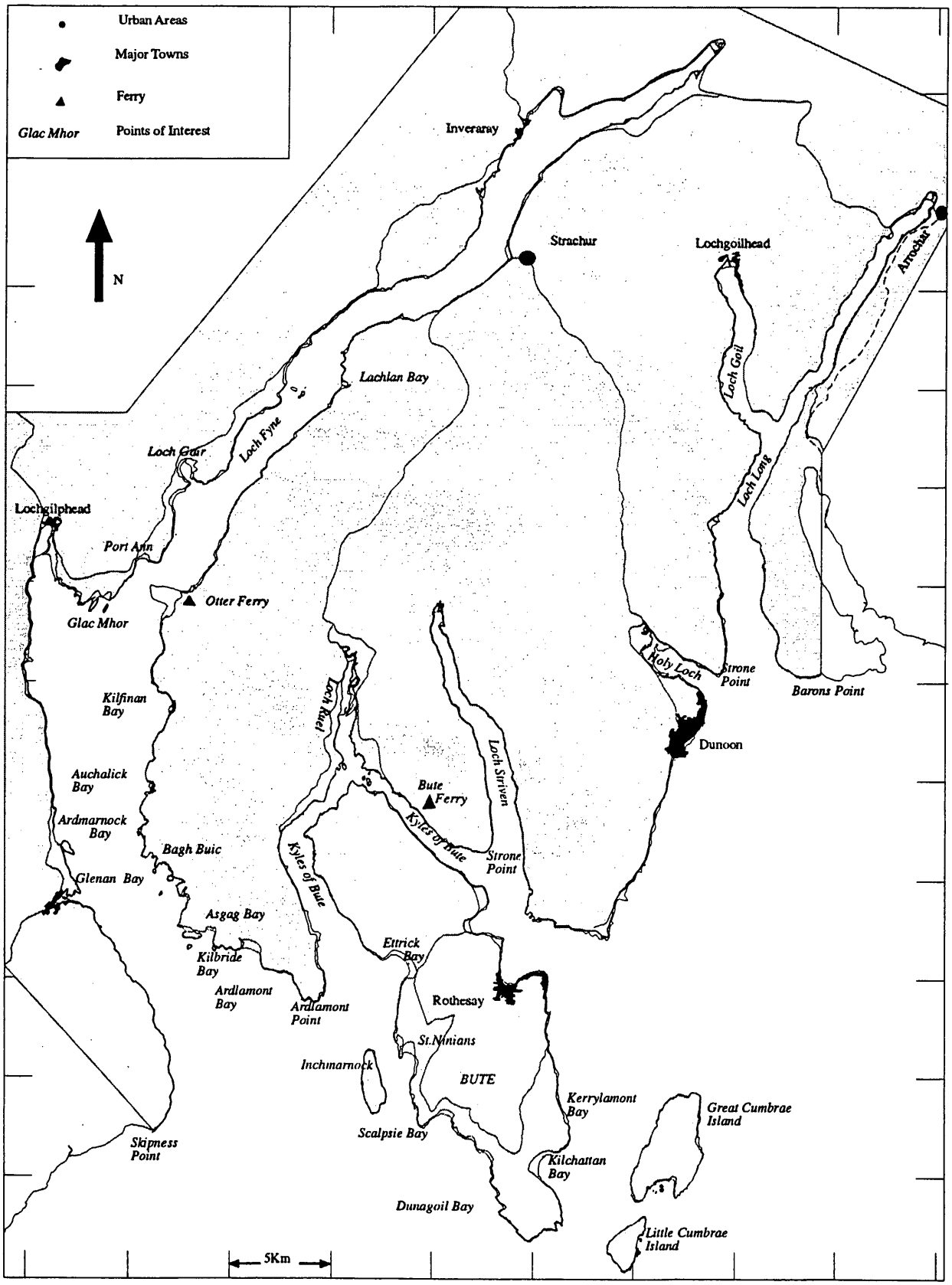


Fig. 8.1 Cowal Peninsula & Isle of Bute: Site Map

8.2.2 Gravel Beaches

Within the Cowal peninsula area gravel/shingle beaches occur in two general settings, along the shore of the lochs and in bay head beaches. Many of the deposits lie over the Main Rock Platform or represent a thin veneer of sediments over the wave washed bedrock (Fig. 8.2).

Long sections of the lochs are bordered by narrow (5-15m wide) steeply sloping gravel/shingle beaches. This type of shoreline feature is present throughout much of Loch Long, Loch Goil, Loch Striven and Loch Fyne. The beaches are often covered in cobbles and boulders which suggests that much of the material is a lag deposit formed by the erosion of the cover of Quaternary sediments. The beaches tend to get wider where streams drain to the sea, this perhaps indicating the input of coarse material to the coastline. Good examples are present in Loch Fyne, north and south of Strachur (NN095045 & NN080008) and along the shoreline of the eastern Kyles of Bute from the Bute Ferry (NS031745) to Strone Point (NS077714). Since much of the material associated with these features is a lag gravel and since wave action is often limited in the sheltered locations active sediment movement and erosion is limited. These features are thus stable and potential for further evolution is limited.

More mobile shingle features form the beaches in many of the small bays in the area. A series of these beaches is present along the eastern shore of Loch Fyne between Otter Ferry and Ardamount Point whilst a smaller number can be found in the vicinity of Lochgilphead. These features are usually located in embayments where the fetch is sufficient to develop significant wave action and the main examples occur at Ardlamont Bay, Asgog Bay, Portavadie, Glenan Bay, Bagh Buic, Ardmarnock Bay, Auchalick Bay, Kilfinan Bay, Otter Ferry, Glac Mhor, Port Ann, Lachlan Bay, Strachur Bay and Loch Gare (Fig. 8.2). Thin shingle beaches also tend to line the shoreline along many of the sandy beaches (see 8.2.3). Many of these beaches lie close to a former readvance margin of the Late Devensian ice sheet (Sutherland 1981) and this may explain their presence. The readvance was associated with high relative sea levels and the stable ice margin would have produced high volumes of sediment which were subsequently reworked into raised marine features or perhaps deposited as glacio-marine sediments. Such materials would have been easily reworked during the Holocene and by modern processes and this may explain the relative abundance of sediment in this area compared to the rest of the Cowal peninsula. Noteworthy features are the tombolos at the western end of Asgog Bay and at the eastern end of Glenan Bay and the shingle complexes of Auchalick Bay and Otter Ferry.

Asgog Bay consists of three small inlets which join together at low tide to form a southward facing bay. West of Asgog Bay a tombola connects Eilean Aoidhe with the mainland. The beaches in this bay are mainly composed of shingle, gravel and sub-angular cobbles (Ritchie 1975) with large shell fragments on the upper beach and sand banks exposed during low tide. Ritchie (1975) suggested that geomorphological activity was restricted to short term beach changes particularly during storm events.

Glenan Bay extends westwards for *circa* 1km from the tombolo that joins Eilean na Beithe with the mainland. Gravel and shingle line the shore and much of the material is sub-angular, probably having been derived from the erosion of glacial material. The angular nature of the material indicates limited wave action and coastal sediments are probably only moved during storm events.

Auchalick Bay is 600m wide and faces west and thus is associated with a limited fetch, although swell waves travelling north along Loch Fyne will be refracted onto the beach. The intertidal area is complex (Ritchie 1975) and consists of a curved deltaic beach in the south which extends into a spit and a curved deltaic beach in the north. There are also two minor

beach units associated with the tombolo that joins Eilean nan Gabhar to the mainland (Fig. 8.3). In general the beach sediments are of gravel and sub-angular shingle (Ritchie 1975). The complex pools behind the beach ridges are believed to reflect former channels of the River Auchalick (Ritchie 1975) and the spits are active and migrating landward. The south spit is longer and slightly recurved whilst the north spit is shorter and Ritchie considered it to be older and more stable. Older spits and associated recurves can be identified landward of the modern features. The spits clearly point to a dynamic evolution of the area, yet Ritchie (1975) reports that much of the lower beach is covered in seaweed which implies limited movement of material. It is thus proposed that the spits are largely storm features and are partly controlled by the evolution of the river channel. The two spit forms may reflect storm waves generated from different directions, the southerly spit being associated with southerly and southwesterly storms and the northern feature with westerly and north-westerly events.

At Otter Ferry the shoreline is fringed by a shingle beach and a large sand and shingle spit extends normal from the shore some 2km into the Loch. Deep water is located north of the spit and contrasts markedly with the shallow sediment covered banks to the south. Otter Ferry was the limit of a Late Devensian ice margin/readvance (Sutherland 1981) and it is possible that the spit marks the remnant materials of a terminal moraine complex that extended across the loch. The spit probably contains a thin veneer of marine sediments overlying a glacial feature and thus does not represent active longshore drift into the loch. This view is supported by the fact that steeply sloping gravel/cobble beaches fringe the shoreline in this area and a small spit is growing northward offshore of Ballimore (Fig. 8.3). This spit represents the main movement of material in the area. Along the remainder of the shoreline in this area erosion appears to be the dominant process (Ritchie 1975).

8.2.3 and Beaches

Sand beaches are rare in the Cowal Peninsula but a number are present on the Isle of Bute, particularly in the centre and southern parts of the island. These sandy bay-head beaches tend to face south or southwest and are often located along the more exposed sections of the coastline (Fig. 8.2). On the Cowal peninsula Kilbride bay forms the only major accumulation of sand, whilst on the Isle of Bute beaches are present at Ettrick Bay, St Ninian's Bay, Scalpsie Bay, Stravanan, Kilchattan Bay, and Kerrylamont Bay (Figs. 8.1 & 8.2).

Kilbride Bay is a southerly facing embayment near the southern tip of the Cowal peninsula. The bay is almost 600m wide and is filled by flat sand bars in the intertidal zone. Ritchie (1975) suggested that much of the material had been driven by waves from the offshore zone. The upper beach also consists of sand although at the margins of the bay the underlying shingle and gravel deposits are exposed. The current shoreline suggests that erosion is occurring.

The wide (100-400m) sandy bay-head beaches on the Isle of Bute are all very similar. The centre of the bay is dominated by a wide flat beach, with gravel coming to the surface at each end, this often merging landward with a narrow shingle storm beach. At St. Ninian's Bay the central shoreline is flanked by a shell beach, whilst at Ettrick (Plate 19), Scalpsie (Plate 20) and Kilchattan Bay the beach is succeeded landward by small dune systems. Much of the beach surface remains wet at low tide (Ritchie 1975) and thus aeolian transport of material is limited but many of the shorelines have embryo dunes developing. Much of the material in these bays has been derived from the erosion of glacial sediments, probably from the flanking headlands but the offshore zone is another possible source. The shoreline in these bays exhibited little evidence of erosion during the field visit which suggested that the features are stable.

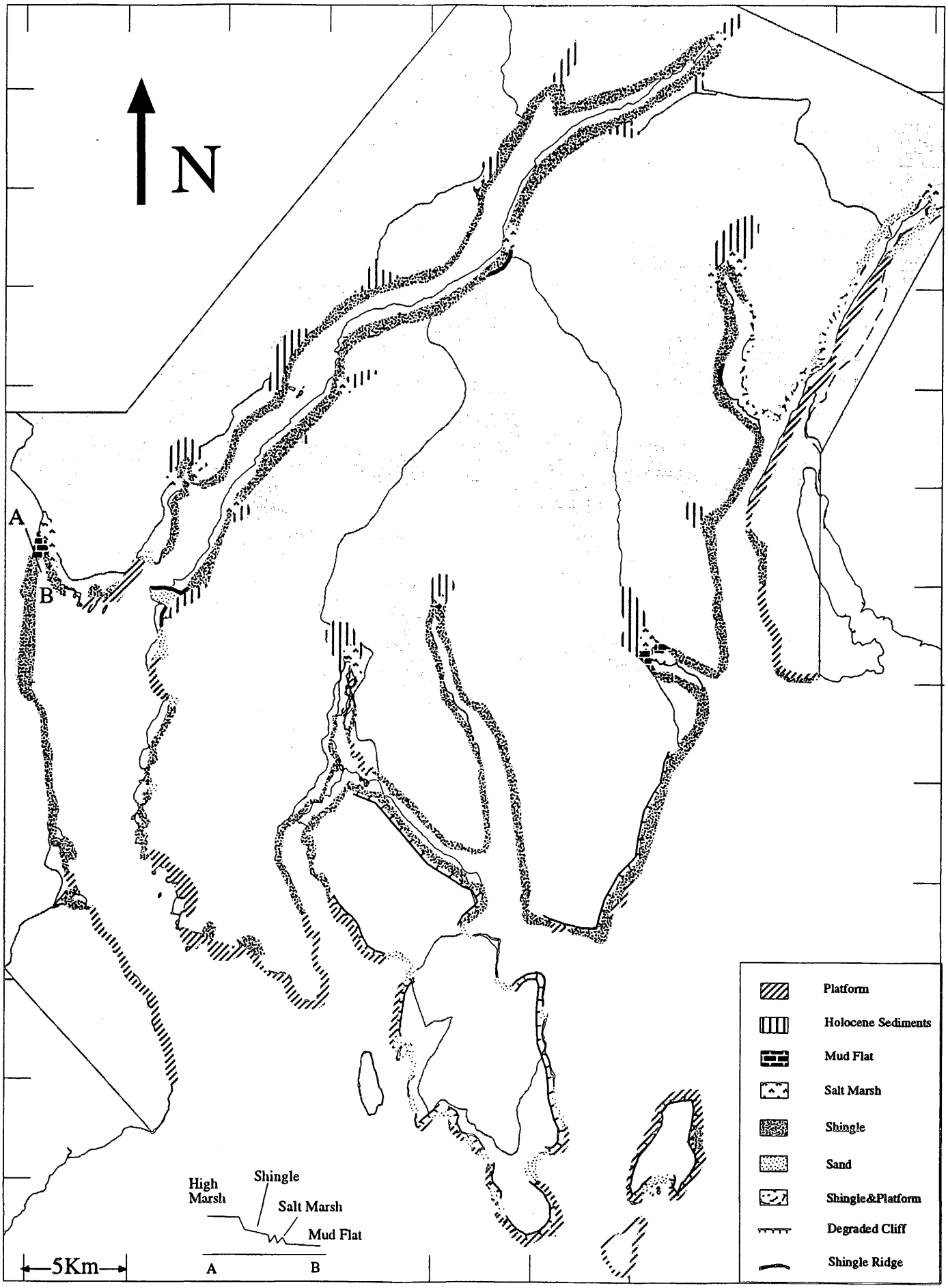


Fig. 8.2 Cowal Peninsula & Isle of Bute: Geomorphological features and processes

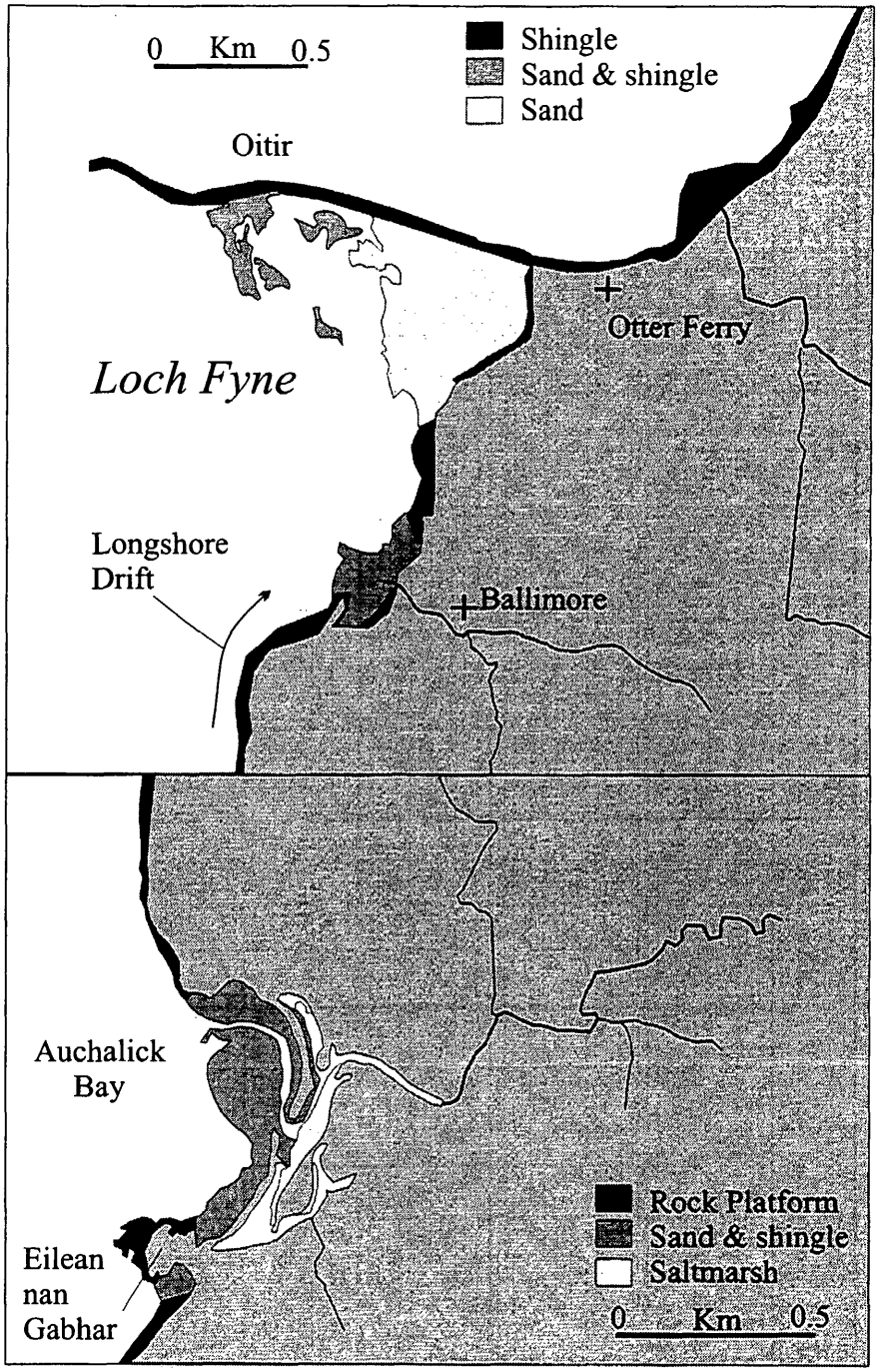


Figure 8.3 Geomorphic features of Auchalick Bay and Otter Ferry.

8.2.4 Sand Dunes

The Cowal Peninsula contains relatively few dune/machair systems and most of these are associated with the sandy beaches of the area (Fig. 8.2). Small dune systems are present at Kilchattan Bay, Scalpsie Bay, Ettrick Bay, Kilfinan Bay and Kilbride Bay. In most cases the dunes only consist of a low sand ridge (1-2m high) with marram grass (e.g. Plate 21). A more extensive area of dunes is present at Kilbride Bay where the low (6-8 m high) sand ridges/hills are actively forming and appear to be moving inland.

At other locations (e.g. Stravanan, Fig. 8.2) the beaches are succeeded landward by raised marine sediments mantled by wind blown material. Such areas are often referred to as machair. The aeolian sand is up to 1m thick and tends to form a gently undulating surface. The age of the machair sediments is unknown but is thought to have originated in the Holocene (Ritchie 1975). Similarly, the small dune systems are believed to be Holocene features that have been subsequently reactivated.

8.2.5 Coastal wetlands and mudflats

Coastal wetlands and mudflats only tend to occur at the heads of the sea lochs or within sheltered embayments. In each case the fine sediments only accumulate where a major river enters the sea, which suggests that fluvial material represents the main source of sediment. Major saltmarshes are present at the heads of Loch Fyne (Plate 22), Loch Gilp (Plate 23), Loch Ruel/Riddon, Loch Goil and Loch Long (Fig. 8.2). These marshes are generally very restricted in area and the frontal margin of the high marsh often ends in a cliff (Plate 24), with patches of low marsh vegetation on the shoreline. Extensive mudflats fronting these wetlands only occur in Loch Goil and Loch Ruel. Isolated patches of saltmarsh are also present behind the shingle spits at Auchalick Bay, and on some of the frontal margins of the Main Rock platform (e.g. west of St Ninian's Bay, east of Scalpsie Bay and near Inverneill; Plate 25).

The best developed area of coastal wetland occurs at the head of Loch Ruel/Riddon which forms the Ruel Estuary SSSI (Fig. 8.2). The area represents one of the few sites of intertidal mudflat in the region and is important for the wide range of invertebrates and small bird populations it supports (Plate 26). The site is however of national importance since the wetlands grade from coastal saltmarsh into freshwater marsh and then woodland. There are very few sites in the UK today where such changes can be seen at a single site. The marshes and mudflats have accumulated in this area because the valley is relatively shallow at its head, unlike most of the other lochs which rapidly descend into deeper water.

8.3 Late Quaternary Landforms and sedimentary environments

The present shoreline is fringed by raised Holocene marine deposits which formed at and subsequent to the culmination of the Main Postglacial Transgression at circa 6,000-4,000 yrs B.P., the former sedimentary environment being similar to the modern shoreline systems (Fig. 8.2). At many locations these deposits represent a thin veneer across the Main Rock Platform which is well developed throughout the region. Classic examples of the assemblage of features occur on the Isle of Bute between Ettrick Bay and Stravanan Bay and around most of the shore of Great Cumbrae Island. The feature is noteworthy since platforms up to 400m wide are present with degraded cliffs and former caves in often very sheltered locations where present day coastal erosion is very limited. The feature clearly formed in contrasting environmental conditions to those experienced today.

The early Holocene was characterised by rising sea levels which culminated between 6000 and 4000 yrs B.P. (Boulton *et al.* (1995)) with the formation of the Main Postglacial Shoreline (Sutherland, 1981). This feature has subsequently been uplifted and tilted

towards the south as a result of glacio-isostatic movements. As a result the level associated with the Main Postglacial Shoreline rises from about 10m O.D. on the Isle of Bute in the south to *circa* 14 m O.D. at the head of Loch Fyne.

Sutherland (1981) provided a detailed assessment of the Holocene marine features in the Cowal Peninsula. In general he noted that shoreline fragments occur at 6 distinct levels although no one site contains raised beaches from each level. The Holocene raised beaches are very much like those of the present day, somewhat fragmentary in nature. Along much of the coastline all that remains of the higher Holocene sea levels is a thin veneer of gravel on a steeply sloping terrace, similar to the steep gravel beaches of the current shoreline.

8.4 Human Impacts

The impact of society along much of this coastline is minimal and as a result much of the area is largely natural. Coastal defences in the form of sea walls and rip rap tend to front all of the coastal towns/villages (e.g. Millport, Kilchattan, Rothesay, Port Bannatyne, Innellan, Dunoon, Kilmun, Lochgilphead, Lochgoilhead, Arrochar and Inveraray) and where the road fringes the shoreline (e.g. Minard) (Fig. 8.4). Such structures have often been developed to provide a stable seafront, harbour or promenade rather than provide protection from coastal erosion. Such structures do not appear to have interfered with sediment transport systems in the area.

At a number of sites large industrial or military installations have been developed. At Ardyne Point and Portavadie the shoreline has been reconstructed for the oil rig fabrication yards. Whilst military installations are present in Holy Loch, Loch Goil and Loch Long (Naval fuel depot). Once again these major developments do not appear to have affected coastal sediment pathways within the region, nor have they significantly altered he delivery of sediment to the coastal zone.

The lack of sand and shingle deposits within the area probably explains the lack of extractive industries. A small sand pit is present within the machair of Scalpsie Bay (Fig. 8.4) and in the past the bare sand represented an erosion problem. The quarry is now no longer used and during the recent field visit no evidence of extensive bare sand was present.

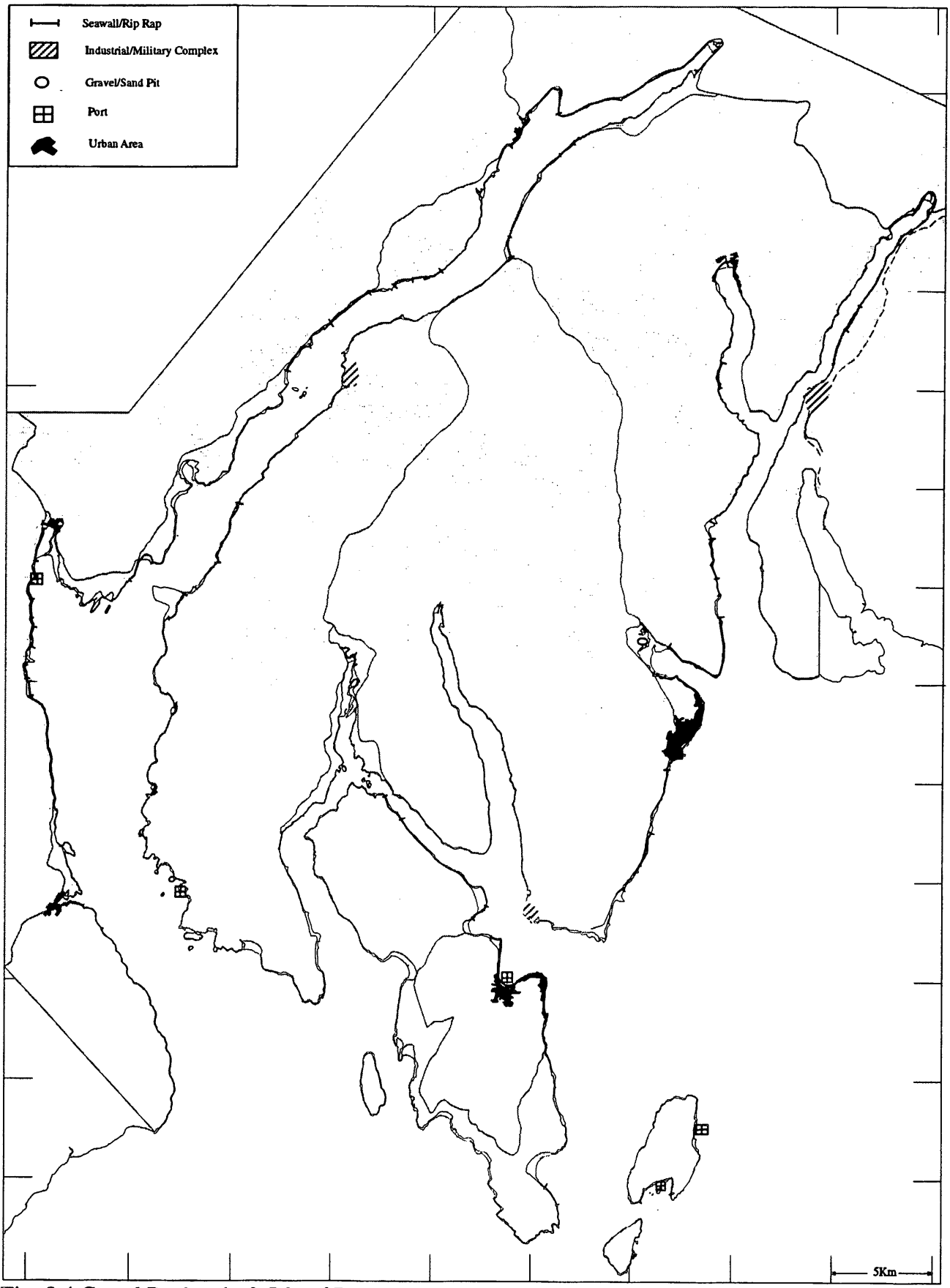


Fig. 8.4 Cowal Peninsula & Isle of Bute: Human impacts

9.0 KINTYRE COASTLINE

9.1 Introduction

This coastal cell forms the westernmost section of the Firth of Clyde region (Fig. 9.1) and extends from the Mull of Kintyre (NR586085) to Skipness Point (NR915974). The peninsula is separated from the Isle of Arran by the Kilbrannan Sound and its southern end is separated from Northern Ireland by the North Channel.

9.2 Contemporary Landforms and processes

9.2.1 Rock Platforms

Intertidal rock exposures extend along much of the east coast of Kintyre (Fig. 9.2). In some places these form a platform up to 250m across (e.g. at Smerby Rocks NR760232). Elsewhere, these outcrops are narrower and a true 'platform' may not be present, for example along the southern coast near the Mull (NR586084). The back of the platform is commonly marked by an abrupt increase in slope angle. South of Campbeltown Loch, the inland margin of the intertidal platform is frequently marked by steep cliffs. Further north, there is typically a gradual rise to the higher Main Rock Platform.

The age of the platform and southern cliffline is uncertain. Large boulders on the platform near 'The Bastard' (NR760116) suggest recent slope failures but the main form of these features may be inherited from earlier processes. In several places, the cliffline moves inland from the limit of the present intertidal zone (e.g. at Glenehervie, NR751107).

9.2.2 Sand and gravel beaches

The intertidal rock platform is buried by a veneer of sediment in many places, ranging in size from sand to boulders. In most places, this veneer occurs as a thin cobble beach or as localised accumulations of material infilling indentations, representing transitory bodies of sediment being moved along the coast by wave action.

More significant accumulations of beach sediment occur at the mouths of a number of rivers and streams, representing both local sediment supply and, in places, slightly more sheltered positions resulting from nearby promontories and islands or low offshore gradients. Cobble beaches are typical in the more exposed river mouths. At Skipness (NR902576), the beach is formed from a linear cobble bar which is currently breached in two places by streams. According to the local postmaster, originally there was only one breach, at the western end of Skipness village. The former course of the Skipness river behind the beach was observed in January 1998. The second breach, which forms the exit for the Skipness river at the eastern end of the village, is a relatively recent feature, though it was certainly present by the mid 1970s (Crofts and Ritchie 1973, Fig. 7.6.2). Crofts and Ritchie (1973) suggests that the newer breach may, in part at least, be due to dumping shingle to prevent westward migration of the single channel breach which could have threatened the road. The new channel breach has been progressively migrating westwards over at least the last ten years.

A large, composite cobble bar or tombolo, The Doirlinn, links Davaar Island to the mainland at the mouth of Campbeltown Loch (*circa* NR753203 to NR745195). This is distinctly asymmetrical in form, with a steep gradient into Campbeltown Loch and a much more shallow gradient to the east into Kildalloig Bay (NR752197). On the northern side of Campbeltown Loch, at Trench Point (NR735204) there is a shingle spit. These features suggest a degree of sediment movement into the mouth of the Loch.

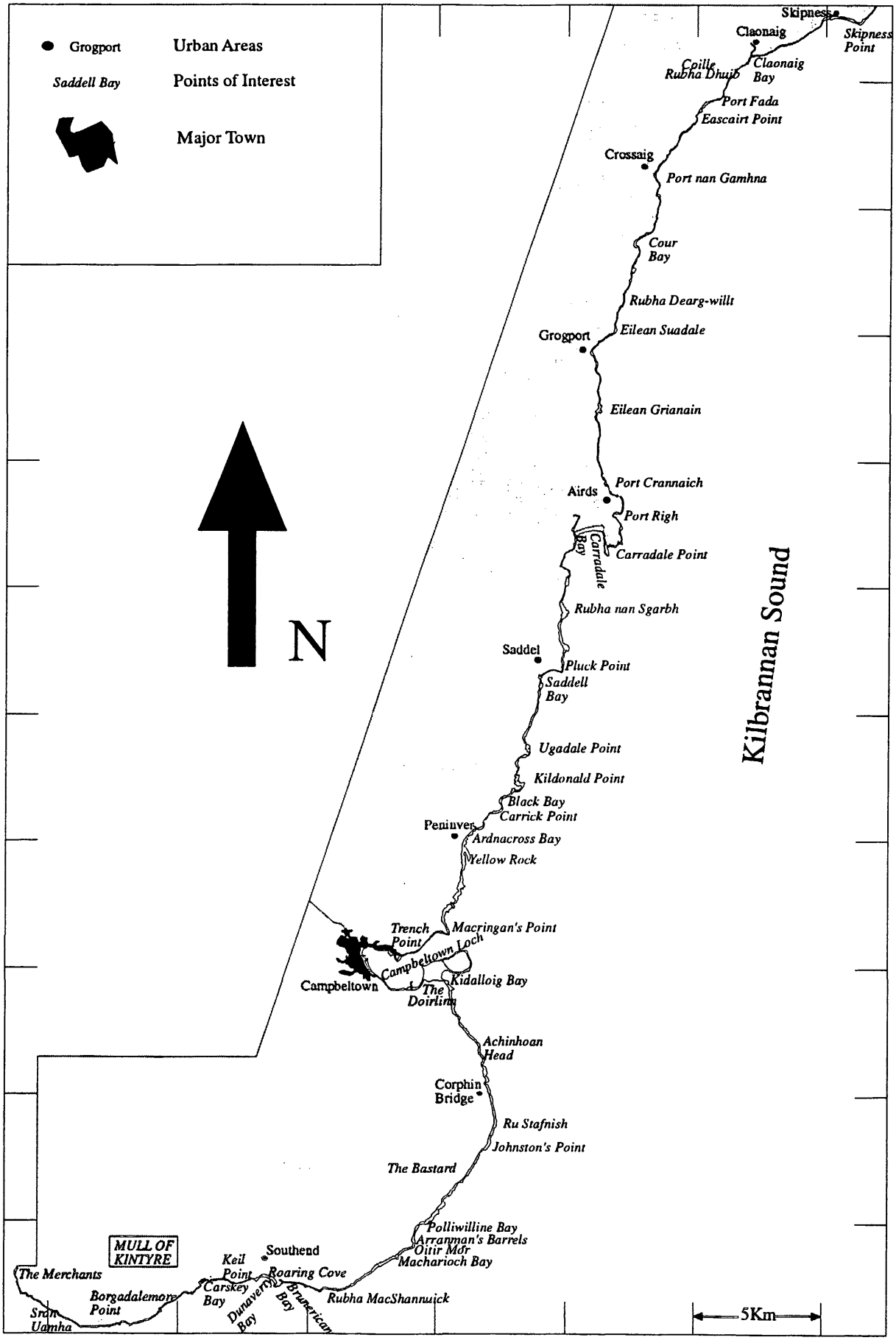


Fig. 9.1 Kintyre Coastline: Site locations

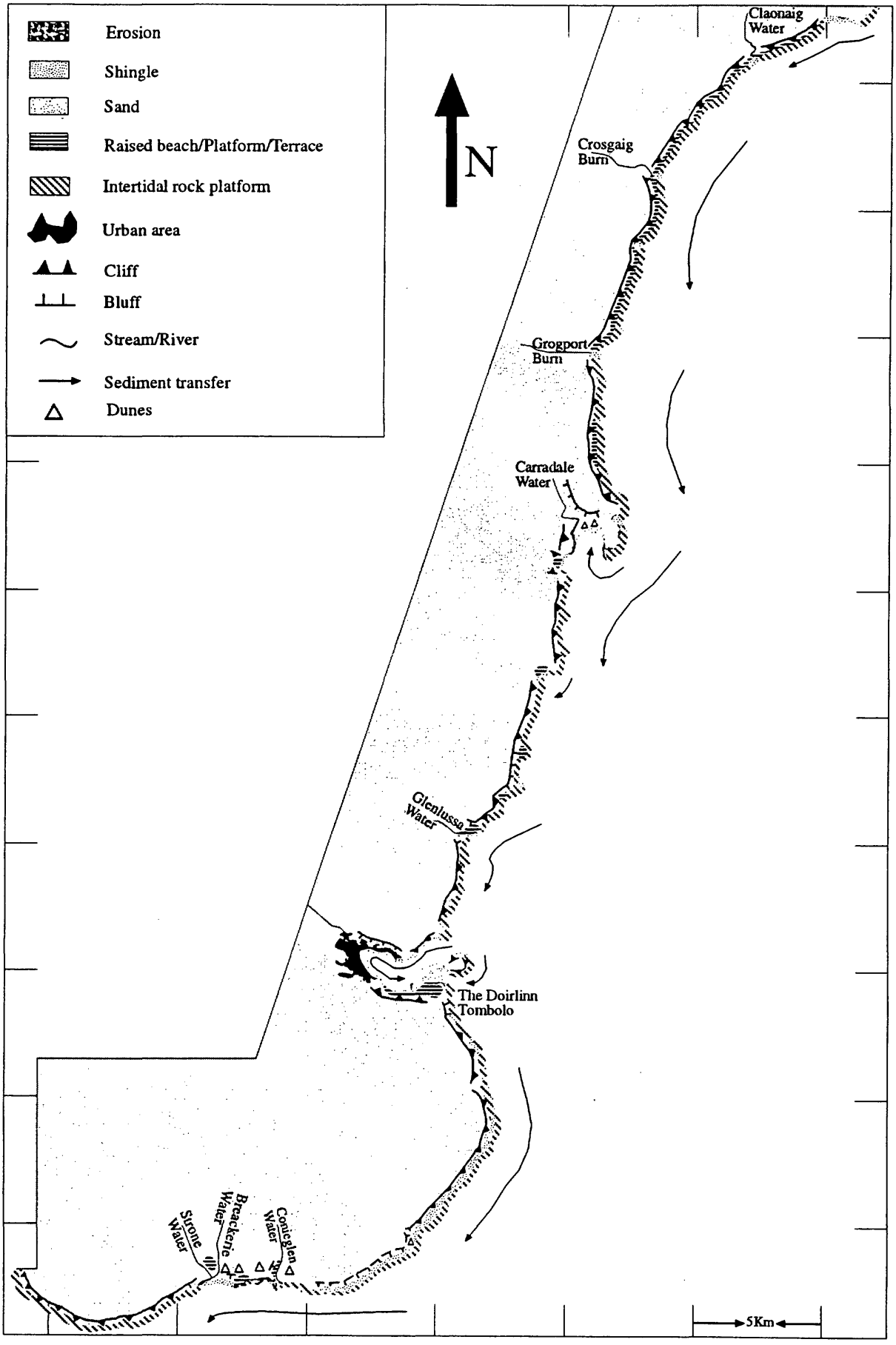


Fig.9.2 Kintyre Coastline: Geomorphological features and processes

Sand beaches are best developed at Carradale and around South End. At Carradale, the intertidal zone is up to 200m wide. The back of the beach merges into a storm ridge underlain by shingle and sand. The channel of the Carradale Water is deflected westward by this ridge. A similar situation occurs at Carskey Bay (NR660077) where the channels of the Breakerie Water and Strone Water are also deflected to the west.

9.2.3 Dunes – Carradale

The main areas of dunes in the area are, unsurprisingly, behind sandy beaches, principally, Carradale and near Southend. These dunes are generally colonised by marram (*Ammophila arenaria*). Some erosion of the dunes at the top of the beach at Carskey, near to Keil Point (NR 667077) and at Dunaverty Bay (NR684080) was observed in January 1998. A similar situation was observed in 1972 by Crofts and Ritchie (1973) who also noted that trampling by people and wind erosion may also be significant.

9.2.4 Coastal wetlands

The development of saltmarshes is very limited along the Kintyre east coast, reflecting limited supply of fine sediment and energy conditions that are generally too high for these sediments to be deposited. In a few rare localities, small pocket saltmarshes are present, for example south of Skipness. In this area, the surface of the intertidal rock platform is irregular, with a number of sheltered narrow embayments penetrating a short distance inland. Thin (<50cm) accumulations of sand, silt and clay have been deposited at Port an Leinibh (NR895570), Auchameanach Farm (NR885565) and Coille Rubha Dhuibh (NR863553). Although currently vegetated (*Juncus maritimus* and *Puccinellia maritima*), the permanence of these small wetlands is not known and they may be very vulnerable to high magnitude events.

9.3 Late Quaternary landforms and sediments

9.3.1 Rock Platforms

As with much of the Clyde region, a rock platform occurs above the present tidal limit along much of the Kintyre coast. Between Skipness and Claonaig, this is up to 150m wide and is largely covered by *Juncus* wetland. Typically, the raised platform is backed by a relict cliffline. At Coille Rubha Dhuibh (NR863553), 2 km southwest of Claonaig, this cliffline is cut by a waterfall.

9.3.2 River-formed features

A number of streams and channels are present along the Kintyre Peninsula coastline. Most of these are small. Locally, Holocene age fan deposits are present (e.g. Claonaig – NR873562). More extensive areas of fluvial deposits are present at Carradale (NR873562), Saddell (NR790323), Southend (NR693082) and Carskey (NR665082). The low elevation of these deposits makes it probable that they contain intertidal sediments.

9.3.3 Dunes

Dune fields occur at Carradale (NR807375), Southend (NR695077) and Carskey (NR668078). These are affected by modern processes, but their extent suggests that they were formed over a period of time during the Holocene.

9.4 Human impacts

The main centre for human activity on the east Kintyre coast is Campbeltown, largely as a result of its deep water and shelter (Fig. 9.3). The main coastal activities are the ferry to Northern Ireland, yachting, fishing and an oil pier, all of which have associated jetties and appear to have an impact on the local coastal environment. For example there appears to be some minor scouring on the north side of Campbeltown Old Quay (NR721205) while the New Quay (NR723203) may be blocking the transfer of sediment towards the head of Campbeltown Loch. The head of Campbeltown Loch has a continuous sloping sea wall and the waves it reflects may prevent the accumulation of beach material. Crofts and Ritchie (1973) note that circulation within the inner loch is poor and this makes it vulnerable to chemical and physical pollution.

Other developments in the area are mainly associated with tourism, with caravan and mobile home parks being common near the major sand beaches at Southend and Carradale. Mobile homes potentially lead to greater impact as they often require permanent mounting on concrete and may be occupied over greater periods of time. These parks introduce numbers of people to the coastal zone resulting in an increased potential of trampling and erosion of dunes in particular. At Dunaverty, Southend, a caravan park extends to the top of the dunes. The seaward side of these dunes is strewn with a variety of rubbish including concrete rubble which presumably has a local source.

At Port Righ (NR817378) boulders have been placed at the back of the beach, at the base of a glacial till cliff, in an attempt to slow erosion on the northern side of the beach. Comparison of photographs taken by Crofts and Ritchie (1973, Plate 7.6.6.2) with the situation in January 1998, indicates that a number of changes have occurred over the last 25 years. A number of new buildings are present along the cliff top on the northern side of Port Righ and much of the vegetation on the cliffline appears to have disappeared, leading to a bare till surface.

Much of the eastern Kintyre coastline is inaccessible to many people due to distance from roads and steep paths. As a result, many of the more interesting and potentially vulnerable features, such as the pocket saltmarshes noted above are probably protected from significant direct physical damage, though they could be affected by marine pollution.

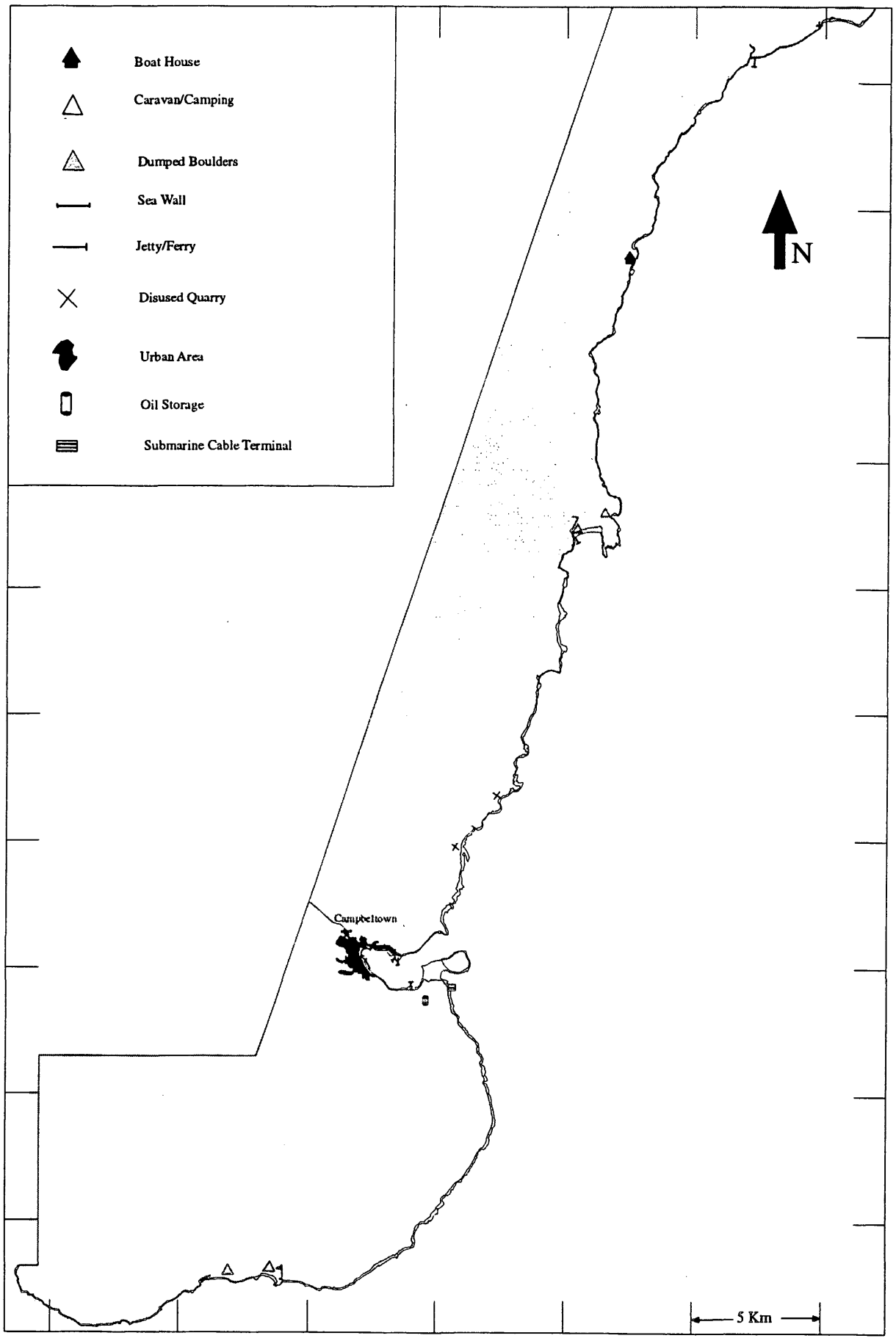


Fig. 9.3 Kintyre Coastline: Human Impacts

10.0 FIRTH OF CLYDE: HUMAN IMPACTS, UTILISATION AND IMPORTANCE

10.1 Introduction

The Firth of Clyde is a region of contrast in terms of its utilisation by society. Part of the region contains the largest industrial area in Scotland (Glasgow) and a high percentage of Scotland's population. As a consequence, these sections of the coast are extensively used by society for a wide range of activities. In contrast, other parts of the region are relatively undeveloped with low population densities and industrial centres largely absent. In utilising the estuary, society can have an impact on both the physical and ecological environment, the latter being particularly sensitive to pollution.

10.2 Utilisation of the Firth of Clyde

The coastal areas of the Firth of Clyde region are utilised in a wide variety of ways. The area is certainly an important recreational resource, illustrated by the large number of caravan sites that are located around the coastline. Along the Ayrshire coastline a large number of the dune systems represent important golfing links. In addition a number of the ports (Troon, Largs, Inverkip, Rhu) have become important marinas (Dunbar & Fowler, 1997). The beaches of the Ayrshire coast, eastern Bute and in the vicinity of Dunoon have always been recognised as important tourist centres, particularly for day-trippers from Glasgow. More recently the Kintyre Peninsula, Arran and the Cowal Peninsula have attracted tourists for their scenic beauty, although the number of visitors is much lower than that associated with the resort towns. As noted, in Section 1.3, sections of the coastline are also of scientific interest and much of it is of scenic value.

The Clyde region contains an important commercial fishery resource, with a series of major and minor ports and harbours located throughout the area (Fig. 9.1). The major ports (Ayr and Campbeltown) are small by Scottish standards and the fishing industry in the area is in decline, in particular since the decline of the herring industry in the 1980s (Murison & Robson 1997). The major types of marine life caught in the area are hake and the shellfish *Nephrops*.

The area contains four power stations, hydroelectric stations at Campbeltown, Lochgair and Arran and the large nuclear station at Hunterston, but their impact on the coastal zone appears to be minimal. In contrast the region contains major industrial complexes, in particular in the Inner Clyde and along the Ayrshire coastline, which have a major impact on the environment. Glasgow, Greenock, and Dumbarton are famous for ship building and for their metalworking industries. Glasgow contains the highest concentration of industry in Scotland, which includes printing, woollens, chemicals and electronics. Other major industrial sites include the chemical plants at Irvine and Stevenston, the ore terminal at Hunterston, the oil terminal at Bowling, oil rig construction yards at Ardyne Point and Portavadie (currently mothballed) and distilleries at Campbeltown, Dumbarton and Girvan. The area also contains a number of coastal quarries (Fig. 10.1), from which mainly igneous rocks are extracted; there are however 6 sand and gravel quarries, two of which are sites for silica sand extraction. More importantly, the northern coast of Arran and the region near Furnace have been identified as potential sites for superquarries although development appears to be unlikely.

Lastly the area is used for the disposal of effluent, both industrial and domestic sewage and for the disposal of spoil waste. The majority of domestic and industrial sewage outfalls are located in the inner Firth and along the Ayrshire coastline and many of these have no or very limited treatment. It is thus not surprising to discover that in 1994 73% of the beaches in the Strathclyde area were found to be polluted only and a very small percentage were of excellent quality (Crumpton & Goodwin, 1997). By far the biggest outfall is from the nuclear

power station at Hunterston which pumps 2,500,000 m3 of cooling water a day into the Clyde. This impact of this outfall on surrounding marine communities has not been assessed and there is no evidence to suggest that it contains radio-active waste.

In terms of dredging some 127,242 m3 of material is removed annually from the Clyde Ports and a further 21,771 m3 from Scotstoun Yard on the Clyde and 16,679 m3 from Ayr (Crumpton & Goodwin 1997b). This material is mainly deposited offshore of Ayr together with 1,603,000 tonnes of sewage sludge although the latter will cease in 1998 (Crumpton and Goodwin 1997).

10.3 Human Impacts

10.3.1 Physical Impacts

Society can have a direct impact on the shoreline through the development of physical structures. Many of these impacts have been outlined in the site surveys (Chapters 4-9) and thus only general patterns are described here.

Most of the coast in this region is exposed, rocky and undeveloped, with coastal erosion and flooding not being a significant problem in most areas. However, sea walls front most of the developed areas. Gabions have been installed to prevent erosion of the golf links at Troon and various other structures have been constructed to defend other courses. Sea walls front most of the main towns in the Inner Clyde, and between Gourock and Port Glasgow the coastline is entirely artificial. Similarly many of the Ayrshire towns and villages and most of the eastern and southern shore of Loch Ryan have seawalls constructed along their length. At other locations extensive rip rap has been used to try and halt coastal erosion.

Many of the dune systems along the Ayrshire coast are also protected by fencing, the aim being to keep people out of the dune fields. At other sites, active dune management is being undertaken, with boardwalks, notices and planned car-parks.

To a large extent the defensive features have a limited impact on the coastal zone and their impact on the biological habitats is also limited. The sea walls and breakwaters do not primarily effect coastal processes and their is no evidence to suggest that enhanced coastal erosion has occurred since these structures were developed.

10.3.2 Water Quality Impacts

The Firth of Clyde is reported to have water of a very poor quality, particularly within the Inner Clyde and the Ayrshire coastline (Crumpton & Goodwin 1997). The eastern beaches are noted for their litter, with plastics being common. Most of this material is derived very locally, but control of this issue is difficult to achieve.

10.4 National Importance of Clyde Coastal Landforms

The Clyde region contains a wide variety of coastal landforms which cover almost the full spectrum of features to be found around the shores of the United Kingdom. The importance of these features in national and international terms is difficult to assess since each coastal feature is unique. General comparisons can, however, be made in terms of the quality of each feature.

The coastal wetlands and mudflats at the head of the Inner Clyde are certainly the most extensive single feature in the area. They constitute a wide range of low energy coastal environments which support a wide range of biological habitats, however the close proximity

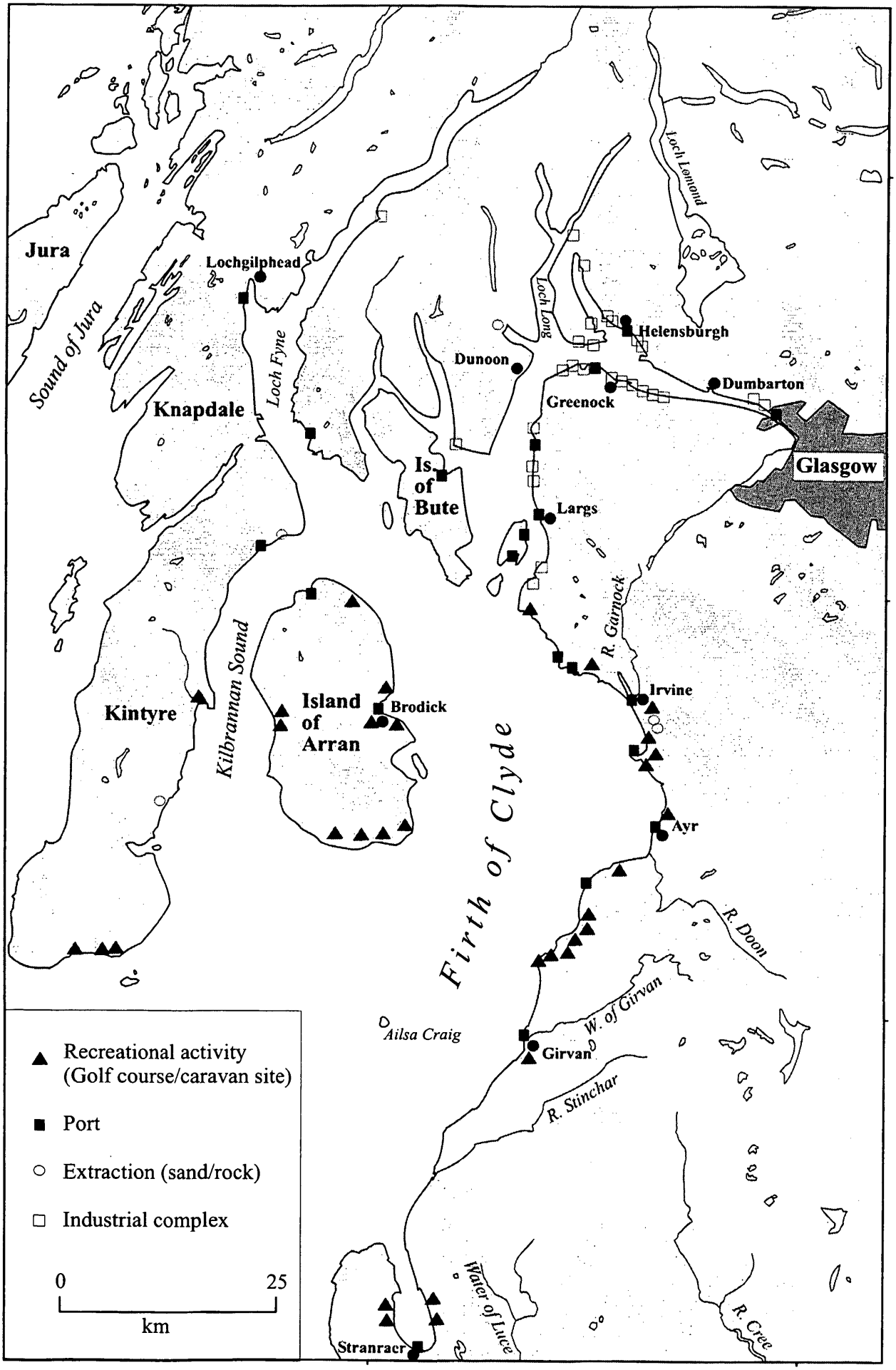


Fig.10.1 Society and the Firth of Clyde

of a major industrial centre limits the value of the area. The site does not represent a natural system and is thus of little value in terms of its morphology. In contrast, the much smaller wetlands and mudflats of Loch Ruel are of particular value since they represent one of the few sites at which the transition from coastal to freshwater wetlands is preserved naturally. As such the site is scientifically important, although it should be recognised that in terms of geomorphological features and development it is one of many sites around the United Kingdom.

The sandy beaches of the Ayrshire coastline together with their backing dune systems are internationally famous in terms of their golfing traditions, but in terms of coastal landforms they have limited potential since they are so highly managed. The dune systems are mainly being eroded at present and there is limited accretion. As such the systems are poor in comparison with those at Ynyslas (mid-Wales) or along the Ythan (north of Aberdeen). The smaller sandy beaches on the Isle of Bute are more representative of natural systems, but once again there are many features of this kind throughout western Scotland. The sites do however offer some opportunity to study the evolution of bay-head beaches.

The area does contain some interesting shingle beaches, in particular the ridges at Ballantrae and Auchalick Bay. These features are relatively small and are in no way comparable with the major shingle accumulations that characterise many areas of Scotland (e.g. Loch Fleet, Spey Bay) and England (Ordford Ness, Chesil Beach). They do however display complex patterns of evolution within an area of limited wave energy and thus offer some potential for further study.

The raised rock platforms and cliffs which shadow many sections of the coastline are certainly one of the best developed features in the area, with some platforms reaching widths of 400m. These coastal landforms are developed in exposed and sheltered locations and clearly have been re-occupied during the Holocene. Some of the platforms are certainly as well developed as those of other sections of western Scotland (e.g. Islay, Jura and the Firth of Lorne region) and in some cases they appear to illustrate the complex history of these features. The platforms on Arran, Greater Cumbrae, the Isle of Bute and at Portencross are outstanding and must be considered of national importance.

The shorelines that boarder the fjord lochs are in themselves not very impressive coastal features, but combined with the glacial features provide a classic example of a coastal glaciated landscape. Similar fjord lochs occur throughout western Scotland and it is difficult to assess which is the best example, but Loch Fyne must be rated highly on the list for its length, its closeness to the ice centre and for the variety of features it contains.

The spit at Otter Ferry is also noteworthy, since it probably represents one of only two moraine guided spits in the United Kingdom. The spit clearly bears little relation to modern coastal processes and thus provides an excellent example of the range of factors which control coastal development.

In conclusion, the most notable coastal features in the Firth of Clyde are not modern landforms, rather they are features which either formed in the past or as a result of glacial activity. The modern features, although diverse in nature, are insignificant in relation to other British or even Scottish examples but some of them are of regional importance and in some circumstances are certainly worthy of further investigation.

11.0 HOLOCENE COASTAL EVOLUTION OF THE FIRTH OF FORTH

11.1 Holocene Relative Sea-Level Changes

Holocene (last 10,000 years) sea level changes in the Firth of Clyde region have been complex due to the interaction of glacioisostatic changes in the level of the land, and eustatic (global) changes in sea level. In general, during this period the crust has been rising in response to the removal of the Late Devensian Scottish ice sheet. At the same time, world sea levels have seen a dramatic rise as the North American and Scandinavian ice sheets decayed. General patterns of relative sea level change in the Forth Valley were outlined by Sissons *et al.* (1966). It is important however to realise that the timing and magnitude of the changes vary along the coastline, reflecting contrasting rates of crustal uplift. Within the Clyde region no single site provides a detailed outline of Holocene sea level changes, rather a number of sites have been used to build up a general picture, with a generalised curve being produced for the inner Clyde region (Fig. 11.1) (Boulton *et al.*, 1993; Smith *et al.*, 1995).

During the early Holocene (10,000-8,500 years B.P.), the area is believed to have experienced a phase of falling relative sea levels. This view is only supported by one radio-carbon dated sample from Furnace where a buried peat layer lies above and below marine sediments. The peat layer indicates that the marine sediments were abandoned at 8,035±85 yrs B.P. and replaced by more terrestrial conditions (Sutherland,1981). During this period, glacio-isostatic uplift was outstripping the eustatic rise in sea level but the spatial variation in marine levels is poorly defined due to the lack of sites. The level to which relative sea level fell is unknown.

By 7,600 yrs B.P., relative sea-level was rising, this being referred to as the Main Postglacial Transgression (Sissons *et al.* 1966). This rise in sea level resulted from the final decay of the North American and Scandinavian Ice sheets when the delivery of meltwater into the world's oceans outstripped glacio-isostatic rebound in Scotland. The rise in water level was rapid (0.16 m/100 years near Rothesay) being more pronounced towards the mouth of the estuary (Fig. 11.1). During this rapid rise extensive deposits of estuarine clays (known locally as carse) were laid down within the inner Clyde and wide sand flats accumulated along the Ayrshire coastline. The sea also flooded into Loch Lomond at about 6,900 yrs B.P.

The rise in relative sea-level culminated with the formation of the highest Holocene raised marine features in the region, namely the Main Postglacial Shoreline (Sissons *et al.* 1966). The altitude of these features declines away from the centre of uplift, from 14.3 m O.D. at the head of Loch Fyne, to 10.4 m O.D. at Asgog Bay (Sutherland 1981) and then at lower altitudes further south (no detailed measurements have yet been undertaken). It has been proposed (Smith *et al.* 1985b) that the formation of the shoreline was diachronous (i.e. the culmination occurred earlier at sites near the centre of uplift), being attained at 6,500 yrs. B.P. at the head of the Clyde valley and at some later date near the mouth of the estuary.

During the later (6,000 yrs. B.P. - present), relative sea-level appears to have predominantly fallen in this region, although the available evidence is limited (Sutherland 1981; Smith *et al.* 1995). Sissons (1976) suggested that the fall may have been interrupted by stillstands or even minor rises in relative sea-level; there is, however, no firm biostratigraphical evidence to support these views. To what extent these changes have continued to the present is unknown and it is possible that the outer coastline at least has recently experienced a rise in water level, illustrated by the extensive erosion that appears to characterise the Ayr coastline.

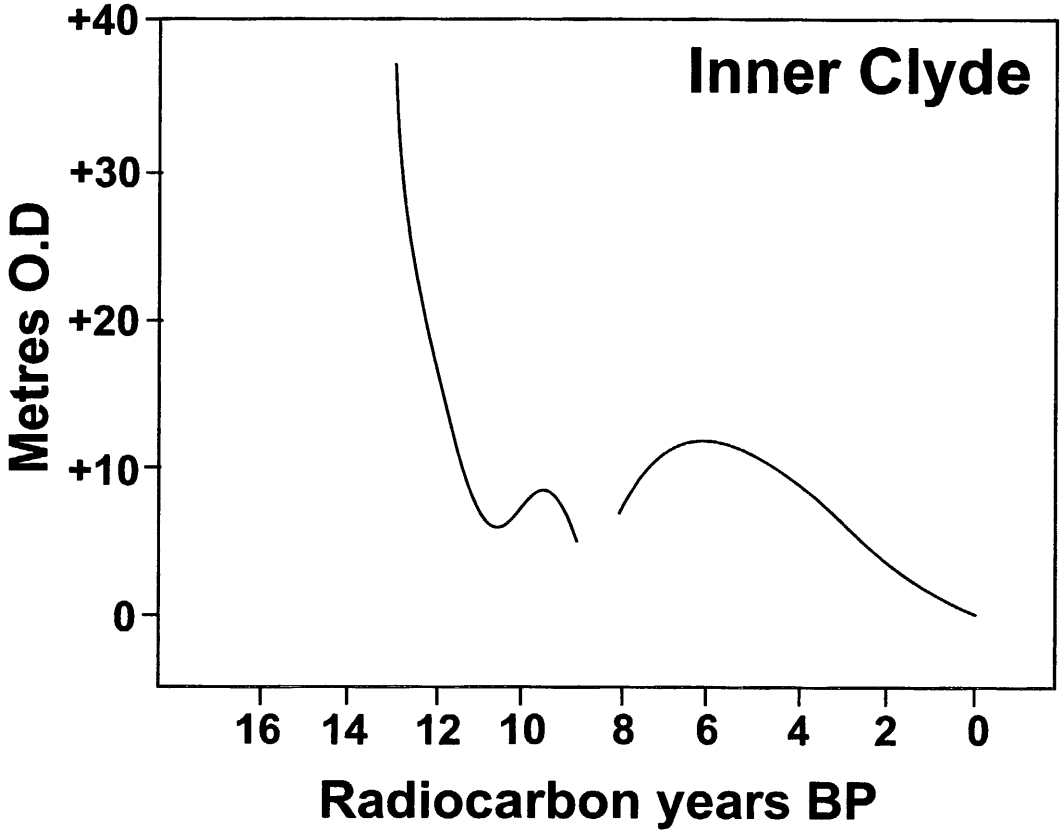


Fig.11.1: Late Quaternary relative sea-level curve for the inner Clyde region (after Boulton *et al.*, 1991)

The most recent period of falling relative sea level has had considerable implications for coastal development in the region. In the upper reaches of the Clyde, the estuary has narrowed and the coastal influence retreated from Loch Lomond to Dumbarton. Elsewhere the seaward relocation of the shoreline has generally been less marked. The fall in sea level has promoted the movement of offshore sediments towards the shoreline and thus assisted in the development of the wide sandy beaches, such as those at Prestwick and Irvine Bays.

11.2 Patterns and Rates of Holocene Crustal Uplift

The raised shorelines that border the Clyde allow the patterns of glacio-isostatic uplift to be evaluated, lines of equal uplift being referred to as isobases (Smith *et al.* 1969). Detailed analysis of the displacement of a number of glacio-isostatically tilted shorelines (e.g. Gray 1978, 1995; Sutherland 1981; Firth *et al.* 1993, Smith *et al.* 1995) indicate that at present isobases associated with the Main Postglacial Shoreline (Fig. 11.2) are the best representation of patterns of crustal movement in Scotland. It has been noted, however, that such isobases may mask local anomalies in the patterns of crustal movement.

On the basis of geological evidence (mainly sea level curves), it is possible to determine the Late Holocene rates of crustal uplift (e.g. Shennan 1989; Smith *et al.* 1993, 1995) in Scotland. The evidence from the Clyde region would suggest rates of crustal uplift of 2.35 mm/yr at the mouth of the fjord lochs. These rates of uplift are, however, maximum figures since they represent the mean rate of uplift during the last few thousand years.

Tide gauge records provide another method of determining rates of crustal movement and these have been adopted by Emery and Aubery (1985) and Shennan and Woodworth (1992). In the latter study, tide gauge records from Aberdeen and Dunbar were utilised and once recent eustatic changes in sea level (1.0-2.4 mm/yr, Trupin and Wahr, 1990) were removed it was concluded that the rate of uplift at Dunbar lies between 0.53-1.93 mm/yr and that at Aberdeen between 0.24-1.64 mm/yr. These variations are comparable with the uplift patterns illustrated by the isobases of the Main Postglacial Shoreline.

By combining the proposed rates of uplift with the patterns associated with the Main Postglacial Shoreline maps illustrating maximum and minimum rates of crustal movement in Scotland can be produced (Fig. 11.3). In terms of the Clyde region, the minimum rates of uplift (Fig. 11.3b) are estimated to range from 0.6-0.95 mm/yr, whilst the maximum rates lie between 2.0-2.3 mm/yr (Fig 11.3a). The lower estimates are probably a better approximation since they closely correlate with the uplift rates identified from the most recent geological evidence.

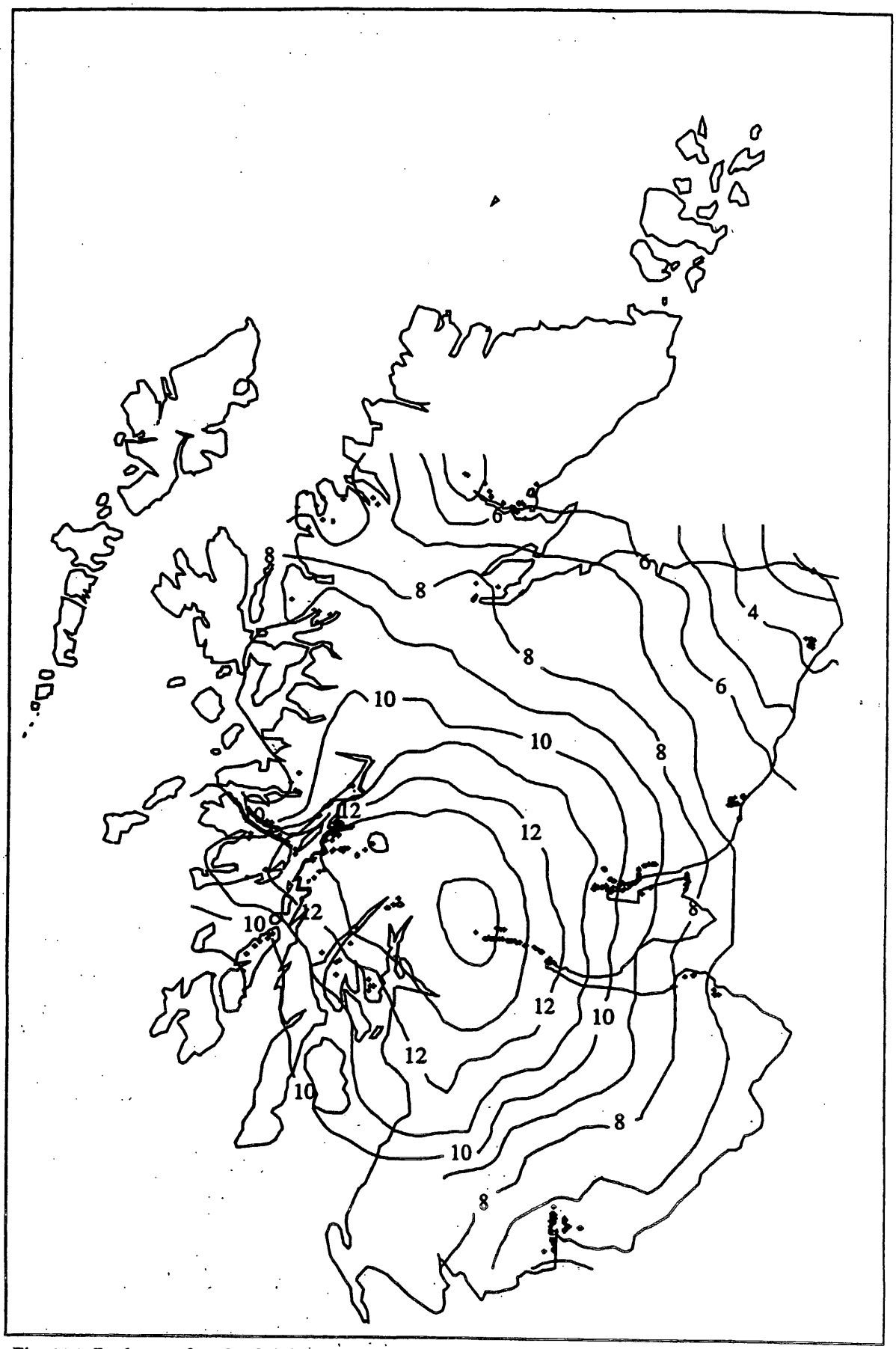


Fig. 11.2 Isobases for the Main Postglacial Shoreline

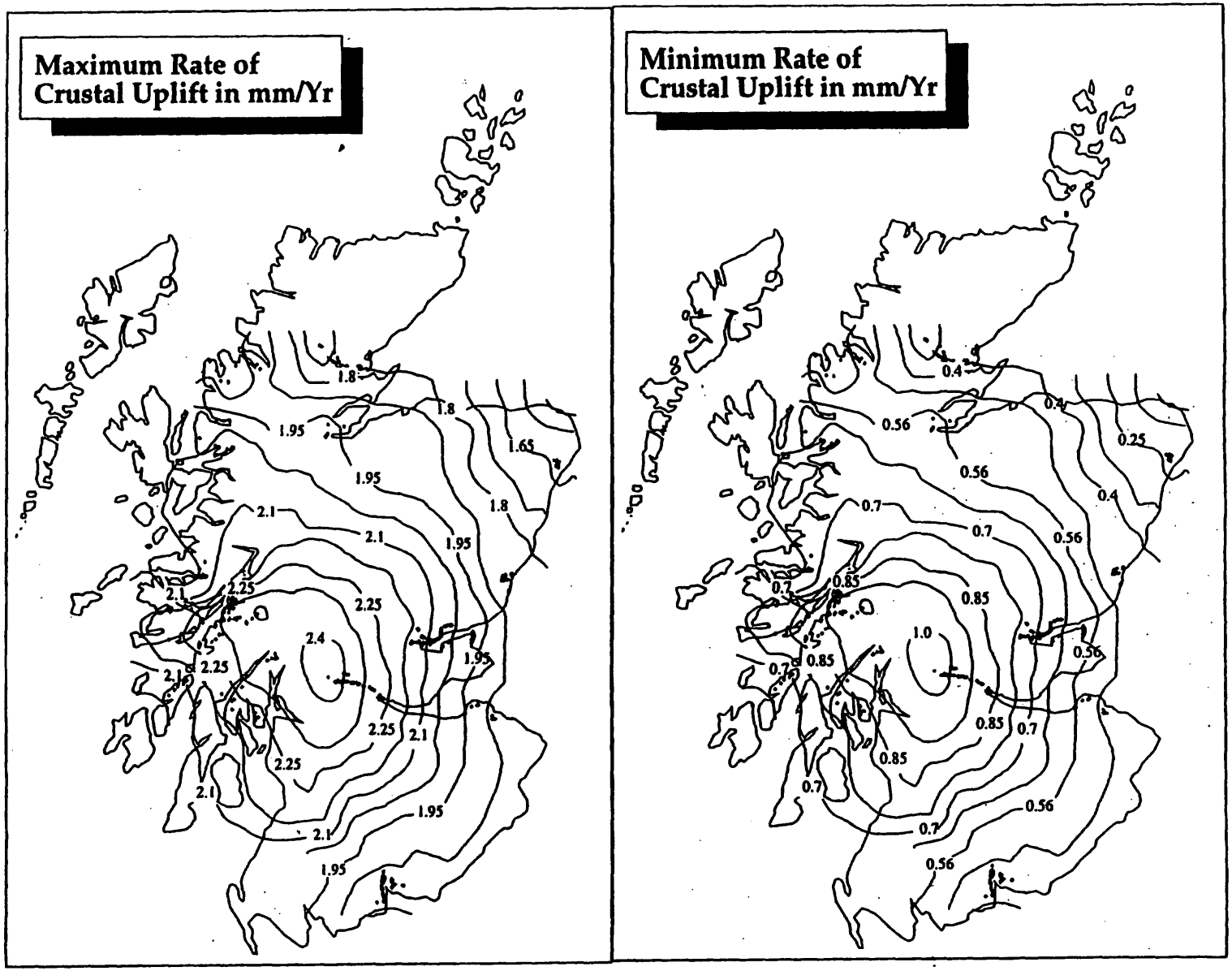


Fig. 11.3 Maximum and Minimum Rates of Crustal Uplift in Scotland

12.0 FUTURE ENVIRONMENTAL CHANGES AND IMPACTS

12.1 Sea Level Changes

Current research into future environmental changes predicts that global warming will result in a rise in global sea over the next 100 years (Warrick *et al.*, 1993). These estimates are based upon general circulation models which are recognised to have their limitations (Kukla 1990), upon uncertain estimates of future rates of energy use, and also upon a limited understanding of the possible feedback mechanisms. As a result, a wide variety of estimates are available (Table 12.1).

Table 12.1: Estimates of future global rise in sea level.

Authors	Best Estimate (cm)	Range (cm)	To Year
Raper *et al* ., 1990	21	5-44	2030
Oerlemans, 1989	20	0-40	2025
Van der Veen	-	28-66	2085
Warrick & Oerlemans, 1990	66	31-110	2100
Wigley & Rape, 1993	46	3-124	2100
Woodworth, 1993	61	-	2087

On the basis of the "best estimates" available the future rate of sea level rise probably lies between 4.2-6.3 mmyr-1 over the next 50 to 100 years. If the full range of values is adopted the rate of global sea level rise could vary between 0.3-11.3 mmyr-1. It must however be remembered that these figures relate to global sea levels and local variations will occur as a result of changes in the tidal patterns.

If these figures are accepted and then applied to the Scottish coastline, a wide range of outcomes are possible. If the rise in sea level is minimal, the Clyde region may continue to experience a fall in sea level because of the continuing isostatic recovery of the region. However, there is already limited evidence to suggest that in the recent past relative sea level has been rising and it thus seems more likely that, in the future, relative sea level will continue to rise along the Clyde coastline. In absolute terms, relative sea level is likely to rise between 0.33-0.54 m during the next 100 years at the head of the estuary and between 0.37-0.58m at the mouth

12.2 Wave Climate and Storm Surge Frequency

Future environmental changes may also affect the climate of the Clyde region and thus influence the wave conditions and possibly the frequency of storm events. Unfortunately considerable uncertainty exists over the nature and extent of climate change. The Department of the Environment (1991, 1997) assessment of climate change suggested that in the United Kingdom, summers will get moderately warmer and winters markedly warmer. The result of this could be a possible increase in anticyclonic weather during the summer, which could generate more easterly air flows but with lower air speeds. The result for winter months would be an increase in warm wet cyclonic activity which could lead to stronger south-westerly winds. There is also some evidence (Smith *et al.* 1993) which suggests that the warmer climates may increase the number of storm events although this still requires further verification.

The increased winter winds would have limited effect on wave activity in the inner Clyde and fjord lochs since the fetch is so limited in these areas. A greater impact may be seen in the outer Firth, particularly along the Ayrshire coastline. The increased south-westerly winds

would increase wave energy along the shoreline. On the Kintyre and eastern Arran shorelines and within Loch Ryan the climate changes would have minimal impacts since the majority of the winds would continue to blow predominantly offshore.

12.3 Impacts on Coastal Landforms and Habitats

Since climate and relative sea level changes are generally uncertain, it is difficult to predict how the Clyde coastline will respond. If it is accepted that sea level will rise and westerly winds and associated storms are going to intensify, then a varied response can be expected from the diverse range of coastal environments. Detailed responses can only be evaluated if the factors influencing current development are well understood and, at present, there are few areas in the region for which sufficient information is available.

The response of the saltmarshes and mudflats will largely be dependant upon the rate of sediment delivery. During the mid-Holocene the rate of sediment delivery was sufficient to largely keep pace with the rise in water level, although it seems likely that saltmarsh areas became more restricted as mudflats expanded. For large wetland areas (e.g. inner Clyde) it seems likely that the saltmarshes will continue to expand in the inner sections of the estuary whilst erosion of the marsh front and sand/mudflats will occur in the outer sections of the estuary. It is considered unlikely that these areas will be threatened by a rise in sea level. In contrast small coastal wetlands (Lochgilphead, Loch Riddon) may experience marked erosion along the marsh front with no substantial growth at the landward margin. The small coastal wetlands will thus probably get narrower and be more prone to destruction.

The wide sandy beaches of Irvine Bay, Ayr, Prestwick and Stranraer will probably experience increased erosion along the coastline. It is possible that where seawalls are present the fronting beach may start to degrade as a result of scour enhanced by the structure. At other sites the dune ridges may be progressively eroded and breached. However, the warmer temperatures (thus increased drying) and increased onshore winds may facilitate increased dune development with more material being moved onshore during low tide. The degrading dune systems may thus stabilise.

The gravel and narrow sandy beaches in the area (e.g. Ballantrae, Carradale Bay, Ettrick Bay, Kilbride Bay) are associated with limited sediment supplies and thus will either roll inland or degrade as they are eroded. In all cases the shoreline will probably migrate landward and thus start to rework former Holocene marine features which should provide ample sediments to maintain the features.

Along many sections of the fjord coastline the rise in water level will have minimal impact upon the steeply sloping gravel beaches. There may however be a tendency for the small patches of saltmarsh that often characterise the sheltered areas of these coastlines to be eroded. Similarly the potential environmental changes will have little impact along the rocky shorelines that characterise many of the coasts of Arran, Bute, Kintyre, south of Ayr and sections of the inner lochs.

13.0 POTENTIAL MANAGEMENT OPTIONS

13.1 Introduction

The Firth of Clyde is one of the most developed of the Scottish estuaries and as a result it is not just vulnerable to future environmental changes but also to proposed developments by society. Such changes include the proposed rise in relative sea level, the need for enhanced sea defences, land claim for development purposes and sand and gravel extraction.

13.2 Relative Sea-Level Changes

It has been suggested that for the last few decades, relative sea level has been rising along the Clyde coastline, since the rise in world sea level seems to have outstripped crustal movements. The future rises in global sea level which have been predicted will accelerate the rate of rise and could have a major impact upon the shoreline.

The Ayr and Loch Ryan coastlines are already experiencing progressive erosion and it is highly likely that the rate of erosion will accelerate. Similarly the bay head beaches that characterise the Isle of Bute will start to erode, the shoreline being pushed landward, whilst the volume of material held on the beach is reduced. The human response to such changes is normally to enhance or extend coastal defences, particularly where buildings and or lines of communication are involved. It needs to be recognised that such defences may enhance the loss of beach material and by reducing coastal erosion may influence the supply of sediment further along the coastal system. A better approach would be to allow the erosion to proceed, with relocation of structures, with exceptional cases being made for particular features (e.g. major settlements, major industrial plants, historical buildings.

The response of the more sheltered locations will depend upon the available sediment supply. Where the sediment supply is limited (e.g. the head of the fjord lochs) the rising water levels will tend to push the shoreline landward. The small wetlands will no doubt decrease in size, unless current agricultural land is lost and lines of communication relocated. In the initial stages loss of the frontal margin of the wetland can be sustained but in order to preserve such areas and thus the diversity of coastal environments it may be necessary to allow new areas of wetland to develop through flooding of existing floodplains. Such a strategy would be essential at the head of Loch Ruel and should be encouraged for the heads of Loch Fyne and Striven where development is limited.

Where sediment supply is sufficient (e.g. head of the Inner Clyde) the input of sediment may be able to keep pace with the rising water levels and the shoreline and coastal features will remain stable. No action needs to be taken in such areas, but it illustrates the need to be able to assess rates of sediment accumulation within the area.

Since much of the sheltered shoreline has a steep gradient the impact from rising sea levels will be minimal, since former Holocene marine sediments or washed bedrock that borders the fjord lochs will be reoccupied by the sea with minimal loss of land. Once again in such areas no action needs to be taken, except perhaps to relocate structures and lines of communication as they become threatened rather than try to halt erosion through the development of coastal defences.

13.3 Loch Ryan

13.3.1 Sea Defences

Large sections of this coastline are currently protected and the demand for additional defences may increase as relative sea level rises. Where seawalls front the shoreline, they may promote the loss of fronting beaches as sea level rises, since scour is likely to be enhanced by increasing water depths. At isolated sites it may be better to reposition road systems or allow individual buildings to collapse into the sea. Along the eastern and southern shore the sea defences are already in place and little further impact would be introduced by maintaining these features.

13.3.2 Land Claim and Managed Retreat

At present no claimed land has been identified in the Loch Ryan area. Although there is some scope for claiming land at the head of the Loch there are no plans to undertake such development. With rising sea levels the position of the coastline in this area will tend to remain static due to the steep shoreline or the current sea defences. The area also has limited potential for managed retreat, since natural processes could achieve the same result with no input from society. The recommendation is thus to allow as much as the coastline as possible to continue to evolve naturally in this area.

13.3.3 Sand and Gravel Extraction

No sand and gravel are extracted in this area although the extensive deposits in the vicinity of Stranraer represent a potential source of material. Such deposits could be developed away from the coast and so there is no reason why the coastal sediments should be exploited.

13.4 Isle of Arran and Outer Clyde Coastline

13.4.1 Sea Defences

Much of the Kintyre and Arran coastlines consist of rock cliffs and it is unlikely that coastal defences will be greatly extended in these regions. Localised sections of the coast are protected, mainly alongside villages, and as sea level rises it would seem likely that the current structures may need to be upgraded. None of these structures greatly effect longshore sediment transport or limit sediment supply to the coastal zone and as a result they are not seen as a major concern.

In contrast, the Ayrshire coastline is already heavily defended due to the extensive erosion that is taking place. It seems likely that as sea level rises so the sea defences will be extended, particularly along the golf links. Greater attention will be paid to stabilising the dunes and at some localities beach nourishment may be practised. It is unlikely that these defences will greatly alter the character of the coastal zone although the construction of sea walls may promote enhanced coastal erosion.

13.4.2 Land Claim and Managed Retreat

The only area of land claim lies near the mouth of the River Irvine where a limited area of land now lies protected behind embankments. New wetlands have developed in front of the embankments and these systems seem to have a high sediment supply. It is highly likely that the wetlands will keep pace with any future rise in sea level, but they will need space to migrate landward. Since the systems will be under pressure form rising sea levels further

land claim should be restricted since it may have a detrimental impact on the biological systems.

Within the Irvine Basin there is some opportunity for managed retreat of the shoreline. Current embankments could be removed thus allowing the saltmarshes to recolonise formerly claimed land. Such management strategies have to be carefully implemented to ensure that the biological system can cope with the newly flooded area. At present the need for such a scheme is minimal but the evolution of the current marsh needs to be carefully monitored to ensure that rising sea levels do not produce unexpected damage.

13.4.3 Sand and gravel extraction

Sections of the Ayrshire coastline and one site on Arran are already mined for their sand and gravel however the impact is limited. Since sand and gravel resources are limited in the area there is perhaps a tendency to increase use of the resources within the coastal zone, in particular the sediments held within the dune systems and within raised Holocene deposits. Such deposits are however of limited size and wherever possible such developments should be resisted since they could have major impacts on the stability of the current coastal zone.

The northern coast of Arran has been identified as a potential site for a superquarry. Such a development will greatly alter this highly scenic area and as a result it should be resisted.

13.5 The Inner Clyde and Cowal Peninsula

13.5.1 Coastal Defences

Current defences are restricted to the more developed coastlines of the Inner Clyde and around major settlements. It seems unlikely that rising sea levels will result in further defences being erected although many of those in place will require maintenance. Where vertical sea walls are present then the rising water levels may promote scour of fronting beaches and thus beach nourishment may be necessary, particularly at resorts.

The bay-head beaches on the Isle of Bute and within the Cowal Peninsula may start to see the construction of ad hoc sea defences as farmers try to protect their land. In many cases it will be better to allow these features to develop naturally since the loss of land will be minimal.

13.5.2 Land Claim and Managed Retreat

In contrast to many of the estuaries of Scotland the extent of land claim in the Clyde is limited and only the Inner Clyde contains any extensive areas of reclaimed land. There is some potential for further land claim to be made within the Inner Clyde although this should be resisted since it would have a major impact upon the biological habitat in this area.

In many coastal wetland areas scientists are proposing that the effects of sea level rise can be offset by managed retreat. Black *et al* (1994) indicate that such schemes in themselves present a risk since they are interfering with the natural development of the shoreline. Such schemes should only be attempted if a more detailed understanding of the physical processes and topographical variation of the sites involved has been produced. The scope for such work in the Inner Clyde is limited since many of the reclaimed areas are utilised by industry.

13.5.3 Sand and Gravel Extraction

At present there is only one working sand and gravel pit in the Cowal Peninsula, near the head of Loch Fyne and four bedrock quarries along the shores in the Inner Clyde. The lack of sand and gravel in the area makes further exploitation unlikely, particularly since many of the current coastal resources are relatively thin. Part of Loch Fyne has been designated as a potential superquarry, this building upon the active site at Furnace. Such activity will have minimal impact on the coastal zone but would certainly damage the scenic value of the area.

13.6 Options for Future Research

Within the Clyde region, relatively little coastal geomorphological research has been conducted and even less is being undertaken at the present. Most of the widely available information is related to Late Quaternary sea level changes and spit development. Detailed reports on the distribution and stability of beaches in the region were produced by staff at Aberdeen University for the Countryside Commission for Scotland (e.g. Crofts and Ritchie, 1973; Ritchie, 1975; Mather, 1979) but these are now becoming a little dated so there is some scope for a renewed survey to be undertaken. Additional research has been conducted on the sandy beach systems of the Ayrshire coast by HR Wallingford. Currently, research is being conducted by researchers in the Geography and Earth Science Department at Brunel University into the rate of sediment accumulation at wetland sites. These investigations include a detailed assessment of how the wetlands responded to rising sea levels and as such this research will have a direct bearing on future management of the extensive wetlands in the Firth.

Before a detailed management plan can be determined for a specific landform or suite of landforms, it is necessary to understand both the evolution of the landforms and the processes operating on them today. It is also important to have a detailed understanding of the sediment budget at each site. Such information is lacking from many sections of the Clyde coastline and is urgently required if detailed management plans are to be devised. The rate of sediment accumulation of wetlands and mudflats needs to be urgently assessed if the response of these areas to rising water levels is to be determined, in particular the areas at the head of the Ruel estuary and the inner Clyde since they provide a major ecological resource.

Further research should be concentrated on the bay-head beaches of the Isle of Bute, and the spits of Auchalick Bay and Ballantrae since very little is known about the evolution and current development of these sites. These sites have the advantage of being largely natural features and they may thus prove to be ideal sites to assess the impacts of sea level rise on coastal systems. A detailed assessment of the development and stability of the Ayrshire dune systems may also prove to be valuable, particularly since the area is of national importance in terms of its leisure activities.

The management of the coastline would also be greatly aided by the development of a Geographical Information System which could be used to update changes in landuse, conservation status of sites and landform development. As future climatic changes become known and pressures from society become more acute, it will be important for conservationists and managers to evaluate the changing situation rapidly. This will be best achieved by regular surveys of threatened coastlines being made available in an easily manageable format. The development of a geomorphologically based GIS may thus be seen as a major priority in the future.

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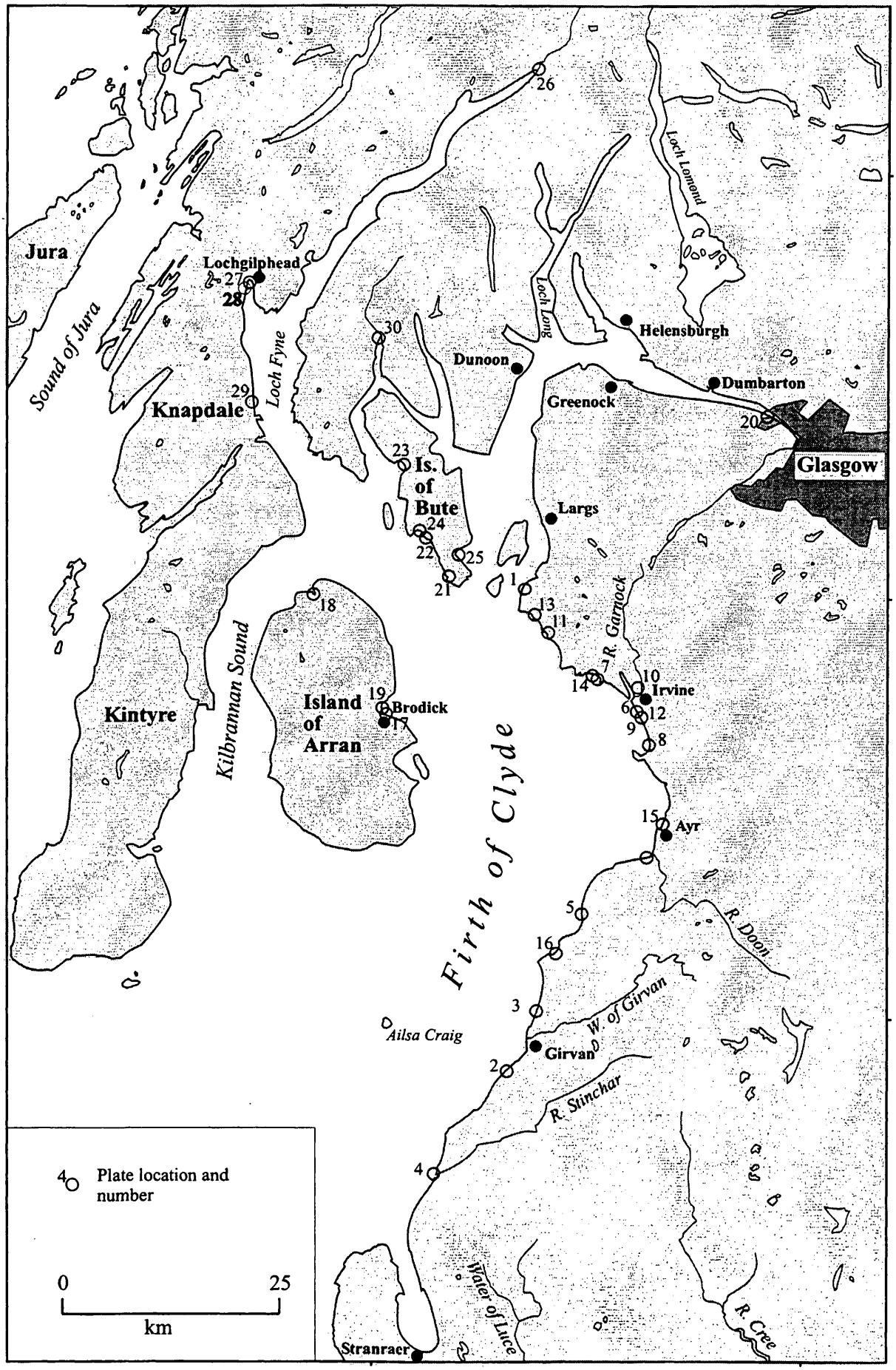
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Location of plates



Plate 1: The Main Rock Platform and fronting Holocene raised beaches at Farland Head, Ayrshire Coast.



Plate 2: The Main Rock Platform and fronting Holocene raised beaches at Ardwell Bay, Ayrshire Coast.



Plate 3: Shingle beach, Culzean Bay, Ayrshire Coast.



Plate 4: Shingle spit at Ballantrae, Ayrshire Coast.



Plate 5: Narrow sand beach, Culzean Bay, Ayrshire Coast.



Plate 6: Wide sand beach and eroding dunes , Irvine Bay, Ayrshire Coast.



Plate 7: Degrading dune system at Stevenston, Ayrshire Coast.



Plate 8: Dune plain at Barassie, Ayrshire Coast



Plate 9: Foredune erosion along Irvine Beach near Irvine Harbour, Ayrshire Coast



Plate 10: Bogside Flats saltmarsh, Irvine Harbour, Ayrshire Coast



Plate 11 Assemblage of Late Quaternary coastal landforms between Ardrossan and West Kilbride, Ayrshire Coast



Plate 12: Dune fences, Irvine Harbour, Ayrshire Coast



Plate 13: Rip-rap sea walls constructed of building material, West Kilbride, Ayrshire Coast



Plate 14: Sea wall at Stevenston protecting degrading dune system



Plate 15: Concrete sea wall fronting Ayr



Plate 16: Farmers collecting seaweed from Maidens Beach, Ayrshire Coast



Plate 17: Permo-Triassic conglomerate exposed on the foreshore, Brodick, Arran



Plate 18:View of the sea wall on the seaward side of Loch Ranza spit, Arran

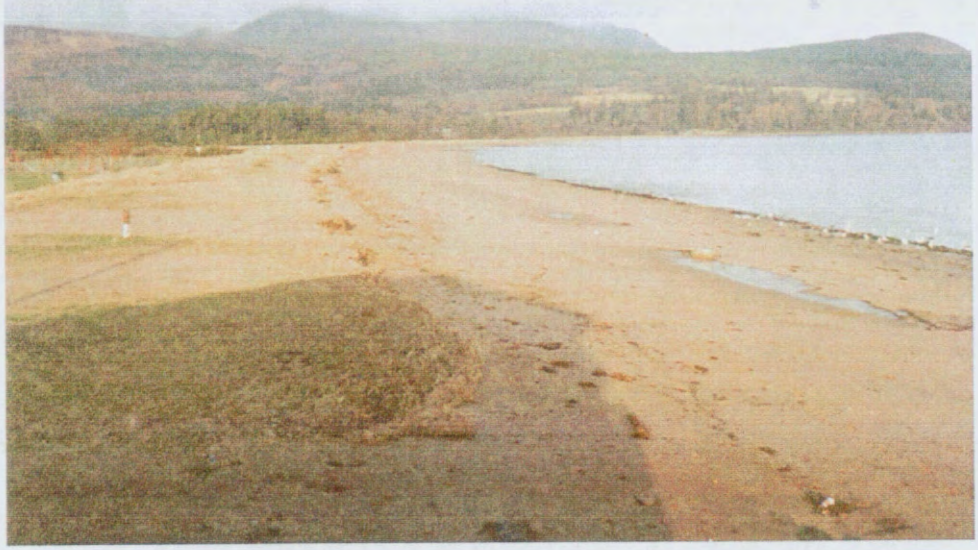


Plate 19: Sandy beach, Brodick, Arran



Plate 20: High marsh and mudflats, Old Erskine Harbour, Inner Clyde



Plate 21: Main Rock Platform and cliff, Dunagoil Bay, Isle of Bute



Plate 22: Main Rock Platform and cliff, Scalpsie Bay, Isle of Bute



Plate 23: Sandy bay-head beach, Ettrick Bay, Isle of Bute



Plate 24: Sandy bay-head beach, Scalpsie Bay, Isle of Bute



Plate 25: The low dune ridge, Kilfinan Bay, Isle of Bute

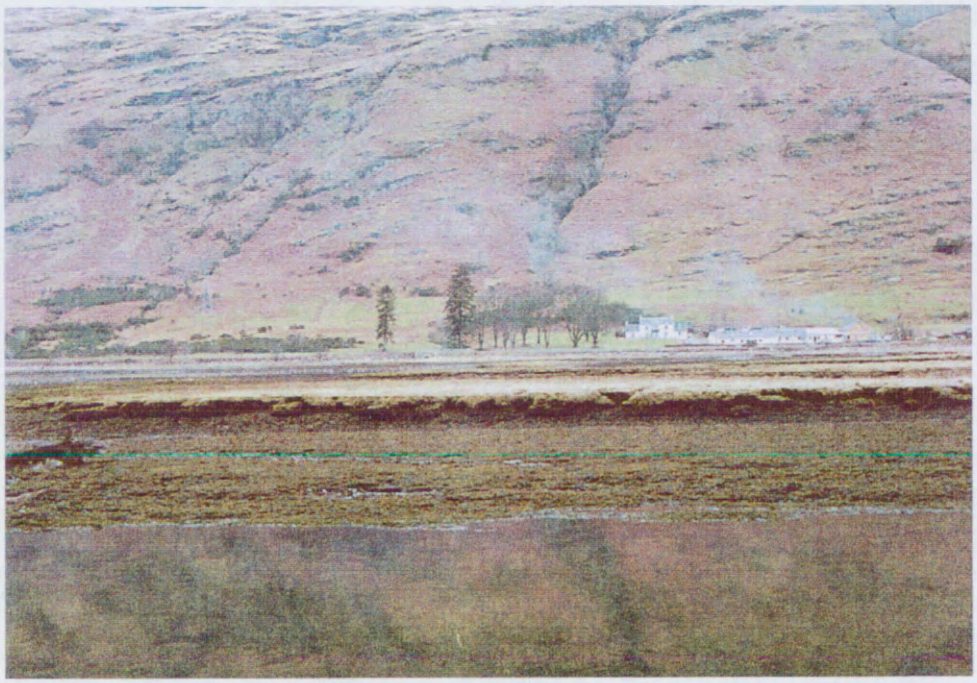


Plate 26: Saltmarsh at the head of Loch Fyne



Plate 27: Saltmarsh at the head of Loch Gilp



Plate 28: Frontal cliff of the saltmarsh at Lochgilphead



Plate 29: Saltmarsh sitting on the frontal margin of the Main Rock Platform, Inverneill



Plate 30: Loch Ruel coastal wetlands

Scottish Natural Heritage

Scottish Natural Heritage is an independent body established by Parliament in 1992, responsible to the Secretary of State for Scotland.

Our task is to secure the conservation and enhancement of Scotland's unique and precious natural heritage - the wildlife, the habitats, the landscapes and the seascapes - which has evolved through the long partnership between people and nature.

We advise on policies and promote projects that aim to improve the natural heritage and support its sustainable use.

Our aim is to help people to enjoy Scotland's natural heritage responsibly, understand it more fully and use it wisely so that it can be sustained for future generations.