8. GEOLOGY AND SEDIMENTS

8.1 Introduction

The sub-quaternary geology of the continental shelf west of Ireland is well documented now, with a combination of exploration well logs and a lot of seismic data. The quaternary geology is, however, not so well defined and some of the survey data for the proposed Corrib pipeline has allowed a much better understanding of this aspect of the marine geology of the area.

The geological succession of the Corrib area is known from well and seismic data to include a fairly complete succession from the Carboniferous (the likely source of the Corrib gas). This is shown in diagrammatical form in **Figure 8.1**. Rocks older than this have not been encountered in any exploration drilling, because there is no need to go beyond the source rocks, or indeed into the source rock. Overlying the Carboniferous are the Triassic rocks that form the Corrib gas reservoir.

The offshore quaternary geology is inferred on the basis of the better documented onshore succession.

Maps contained in this section cover the offshore section of the pipeline route. The onshore section of the route is discussed in Section 19.

8.2 Study Methods

Gardline Surveys carried out a detailed pipeline route survey for Enterprise. The primary objective of the survey was to define route(s) that would be topographically and geologically suitable for the installation of a pipeline and control umbilical from the Corrib Field to landfall in Broadhaven Bay. Osiris Projects carried out an inshore survey which overlapped the inshore extent of the Gardline survey and ran further inshore to 1.0 m below chart datum, or where the shoreline was steep, to the safe navigation limit of the survey vessel.

The offshore route was surveyed using a single-beam echo sounder, a multi-beam echo sounder, combined deep-tow sidescan sonar and sub-bottom profiler (pinger) with some additional boomer data was acquired near to shore. A magnetometer was also run along the proposed pipeline route with vibrocores and CPT's providing geotechnical information. The survey corridor along the proposed pipeline route ranged between 350 m and 550 m in width. Four to six survey lines were run at respective offsets of 75 m, 175 m and 275 m (where applicable) either side of a centreline. However, through the iceberg scour area, a detailed corridor 750 m wide was surveyed relative to a nominal median line, rather than orientating the survey along each leg of the proposed route. A survey line separation of 75 m was used within the corridor.

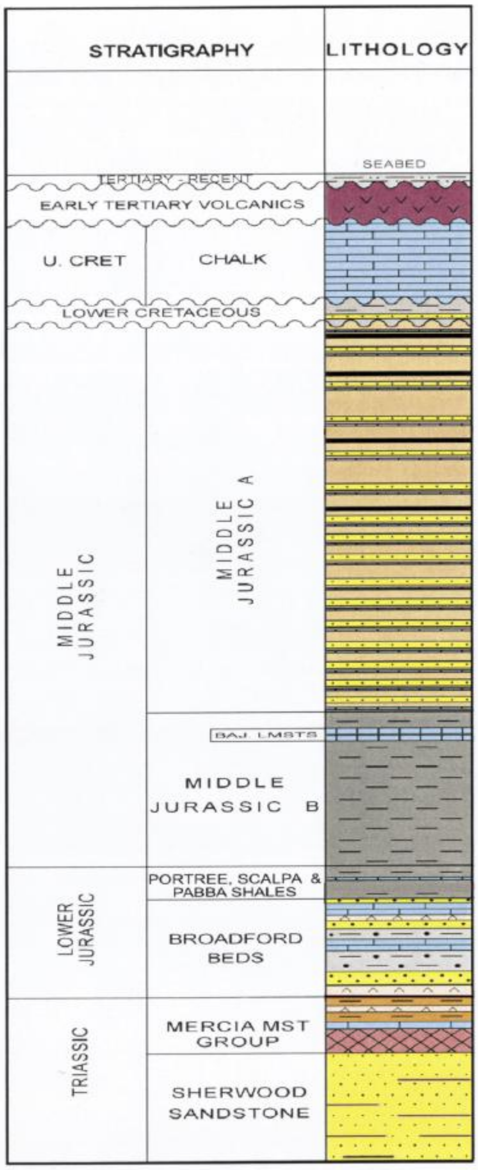

Figure 8.1: Stratigraphic column of the Corrib Field area

A less detailed seabed clearance and shallow soils survey to examine the feasibility of laybarge anchoring was undertaken along a 1.5 km minimum width corridor either side of the proposed Sealine Base Route from Corrib to IP2, the Sealine Northern Route and towards landfall. Swathe bathymetry, sidescan sonar and sub-bottom profiler equipment, was used along the survey lines, offset at approximately 250 m intervals. The width coverage was dependant upon water depth. For this survey, no seabed sediment samples were taken.

At the Corrib Field, infield flowline routes were surveyed between three existing wells and two possible locations for manifold structures. Bathymetry, seabed features and shallow soils were mapped along 500 m wide corridors.

Vibrocores and CPTs were acquired for the subsequent analysis and testing of soil properties at approximately 10 km and 5 km intervals along the sealine routes, respectively. The soil properties were analysed to assess the feasibility to trench/bury the pipeline and control umbilical.

Seabed sediment samples were collected along the route and in the vicinity of the Corrib Field, using a Day grab for environmental analysis. Stills camera and video footage taken was used to support the interpretation of the proposed pipeline.

The inshore survey, operating from an 8 m long vessel, used a hydrographic echo sounder, a surface towed sub bottom profiler (Boomer), a sidescan sonar and a magnetometer, to acquire marine geophysical data.

A three metre long vibrocore was used to obtain shallow sediment cores, in order to ground truth the geophysical data and provide a marine geological interpretation. A Van Veen grab was used to acquire surface sediment samples, for sidescan sonar data correlation.

8.3 Receiving Environment

8.3.1 Solid Geology

The shallowest deposits in the Corrib Field area are Recent – Late Tertiary (possibly Oligocene) clays and sandstones (about 40 m thick). These rest unconformably on between 53 m and 120 m of Early Tertiary basaltic lavas and tuffs. The volcanics pass unconformably down into Upper Cretaceous chalks with occasional interbedded stringers of limestone and calcareous claystone. In the field area, the Chalk Group ranges from 79 m to 392 m thick (average 246 m).

The underlying Early Cretaceous (Albian) Cromer Knoll Group is characterised by glauconitic, sandy claystones with occasional thin limestone stringers, which pass downwards into interbedded claystones and glauconitic sandstones. The Cromer Knoll Group ranges from 50 m to 96 m thick in the field area (average 77 m) and rests unconformably on the Upper to Middle Jurassic.

Where present, the Upper Jurassic consists of varicoloured, silty and locally pyritic claystones, interbedded with limestone stringers or sandstone beds, both of which are associated with traces to thin-beds of coal. Where identified, the Upper Jurassic ranges in thickness from 366 m – 506 m, but it is absent in 18/20-1 and 18/20-4 through erosion at the Base Cretaceous Unconformity.

The Middle Jurassic is a 1250 m – 1700 m thick section of interbedded claystones, sandstones, siltstones and limestones, with minor coals. An informal division of the interval into an uppermost Middle Jurassic A unit and deeper Middle Jurassic B unit is used in the Corrib Field area. These reflect a change from fluvio-estuarine claystones with interbedded siltstones, sandstones and coals in the Middle Jurassic A, to open marine carbonaceous claystones with interbedded limestones in the Middle Jurassic B. Close to the top of the Middle Jurassic B, an increased abundance of limestone stringers over a *c.* 40 m interval forms the regionally significant Bajocian Limestone Seismic Marker. These deposits lie on a regional unconformity above the Lower Jurassic.

The Lower Jurassic in the Corrib area has been assigned to the Portree Shales Formation (Early Toarcian), Scalpa Shale Formation (Pliensbachian), Pabba Shale Formation (Sinemurian – Pliensbachian) and the Broadford Beds Formation (Hettangian – Sinemurian).

The Portree Shale Formation to Pabba Shales Formation interval consists of grey and dark grey to black shales with variable silt and organic matter content, and with interbedded argillaceous limestone stringers. The interval is interpreted as open marine deposits. The Pabba Shales pass down conformably into interbedded shales, sandstones, limestones, anhydrites and dolomites of the lowermost Jurassic Broadford Beds Formation. Lower Jurassic thicknesses encountered in wells in the Corrib Field are highly variable due to faulting and local non-deposition/erosion, but maximum thickness encountered in the wells approaches 1100 m.

The Triassic Succession in the area consists of a mudstone dominated section (Mercia Mudstone Group), overlying a sandstone dominated section (Sherwood Sandstone Group). The Mercia Mudstone Group is generally an orange red, saliferous and anhydritic mudstone with a thick basal salt section, although halokinetic movement and faulting have resulted in significant thickness changes across the Field area.

The Sherwood Sandstone is characteristically a fine-medium grained, red brown, very hard, well cemented, arkosic sandstone, interbedded with subordinate thinly bedded red brown siltstones. Significant shale units are absent. These sands are interpreted as a barren fluvial red-bed sequence. A maximum thickness of 380 m of Sherwood Sandstone has been penetrated in the Corrib Field (well 18/20-4). The base of this unit has not been encountered.

The Sherwood Sandstone Formation forms the reservoir in the Corrib Field, whilst halites within the overlying Mercia Mudstone Formation provide an effective topseal. Corrib gas is assumed to have been sourced from postulated underlying Carboniferous strata (Namurian mudstones and/or Westphalian coals).

8.3.2 Regional /Tectonic Setting and Structural Evolution

The Corrib Field lies in the Slyne Basin. The Slyne Basin is a Mesozoic half-graben, orientated NNE-SSW and lying approximately 60 kms off the west coast of Ireland. It is part of a linked Mesozoic basin system which stretches from the West of Shetland basins in the north, to the Porcupine Basin in the south.

The Slyne Basin can be divided into three asymmetric half graben, of which Corrib lies in the Northern Slyne half graben. This sub-division is based on the presence of a number of complex transfer zones that show strike-slip movement and post-Miocene reactivation, and are often characterised by zones of poor quality seismic data. These graben reverse their dip directions (polarity) from east to west across the transfer zones; the Central Slyne Basin dips to the west, into the basin bounding fault and the Northern Slyne Basin dips to the east into the basin bounding fault.

The basin contains a thick sequence of Permo-Triassic and Jurassic sediments, which are unconformably overlain by a thin Cretaceous/Tertiary/ Quaternary section. The major rifting episode occurred during the Middle Jurassic, with up to 2.5 kms of Aalenian to Bathonian sediments being preserved in the hanging walls of the half graben. This rifting episode is interpreted to have been linked to the proto-North Atlantic rifting process, the episodes of rifting are related to the relative motion of the Rockall Plateau with respect to Eurasia.

Although the mega-scale basin geometry is controlled by the complex transfer zones, within each basin the tectonics are predominantly associated with extensional tectonics. The style of structures is controlled by the presence of halite layers, which act as detachment zones. In the Central Slyne Basin, this layer is the Zechstein, creating large faults which detach into the Zechstein. The Corrib feature is unique in the Slyne Basin, being a clearly defined anticline, with four way dip closure at Sherwood Sandstone level. The overburden is more complex, being a tilted fault block, with a rollover hanging wall anticline. Here, the faults detach on the Mercia halite, even though there is strong evidence that Corrib is underlain by Zechstein halite.

The proposed structural model for Corrib is illustrated in **Figure 8.2.** This shows the evolution of the structure in three stages, from the Lower Jurassic through to later Middle Jurassic. During the Lower Jurassic Broadford Beds deposition, there was simple flexure of the Corrib Field area, causing thinning and thickening of the Broadford Beds.

Later, during the Lower Jurassic, a major syn-sedimentary down to the west fault developed, allowing growth in the Portree/Scalpa/Pabba section to the west of this fault, and a thinning of this section on the footwall crest. This fault could have been enhanced by salt withdrawal in the hanging wall, perhaps flowing into the footwall area. An alternative to this could have been a relatively uniform deposition of the Portree/Scapla/Pabba sequence, with the fault developing at the end of the Lower Jurassic.

During the Middle Jurassic, this main fault became inactive, with uniform deposition across the area. After the deposition of the Bajocian Limestone, the main down to the east fault developed, which along with salt withdrawal, caused the collapse graben to form.

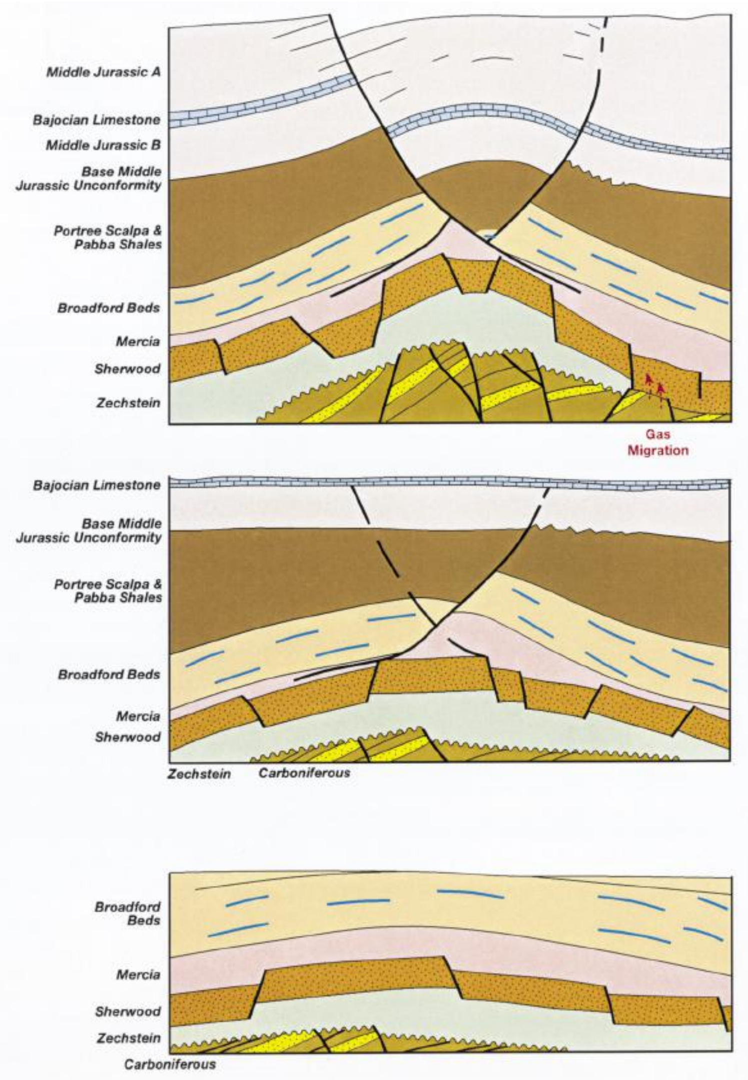

Figure 8.2: Figure showing the tectonic evolution of the Corrib Field area

Although the main down to the east fault shows movement during the Cretaceous and Tertiary, the main tectonic activity was during the Middle Jurassic. This is consistent with the evidence from the rest of the Slyne Basin, which shows Lower Jurassic growth faults and the significant Middle Jurassic growth faults which dominate the basin architecture. A description of the stratigraphy for the Corrib Field is given in **Table 8.1**.

Table 8.1 Description of the stratigraphy for Corrib Field

Period	Age (millions of years before present)	Comments
Quaternary	1.64 to present day	The youngest part of the geological sequence Represented by accumulations of glacial (Pleistocene) and post-glacial (Holocene) deposits.
Tertiary	65 to 1.64	Thin section (*c*.100 m) of volcanic rocks equivalent to the Antrim Lavas.
Cretaceous	145.6 to 65	A variable thickness section of hard chalk with interbedded flints overlying a thin section of interbedded mudstones and sandstones.

Period	Age (millions of years before present)	Comments
Jurassic	208 to 145.6	A thick succession of interbedded mudstones and sandstones with minor limestones.
Triassic	245 to 208	A variable thickness of mudstone and halite (salt) which acts as the seal for the underlying gas bearing thick succession of well cemented sandstones (at a depth of about 3400 m below sea level). This forms the reservoir for the Corrib gas.
Permian	290 to 245	Not penetrated in any of the Corrib wells. The upper part is assumed from other wells in area to comprise halite (salt) and evaporites (e.g. anhydrite).
Carboniferous	362.5 to 290	Not penetrated in any of the Corrib wells. The upper part is assumed from regional knowledge to consist of a succession of sandstones, mudstones and coals. Probable source of the Corrib gas.

8.3.3 Geology of Broadhaven Bay

In terms of the shore approach and landfall, the geology of Broadhaven Bay is expected to be similar to that found onshore, with the exception that it has undergone significant modification as a result of the marine transgression at the end of the last cold phase. The northern eastern half of the bay (north-east of a line from Brandy Point running north-west) comprises extensive rock out crop, which in terms of relief, resembles a wave cut platform.

South-west of the line from Brandy Point the seabed is predominantly sandy to within approximately 1 km from the coast, where rock reappears exposed on the seabed.

By interpolation from the Geology of North Mayo Sheet No.6 (Geological Survey of Ireland, 1992), the rocks exposed on the floor of the bay comprise the Broadhaven and Benmore Formations, belonging to the Erris Group of Late Precambrian (Dalradian) age. The rocks are known as psammitic schists, which means that they are sandstones which have been altered by metamorphic (heat and pressure) processes. They have also been extensively deformed by structural movements, whilst they were still ductile, during the metamorphic process.

The ‘Broadhaven Nappe’ is the name given to the structure that was developed during this deformation process and it comprises a series of slides where thick sequences of rock slid across each other. The quaternary succession in Broadhaven Bay can only be assessed from surveys carried out as part of the Corrib project and correlation of those surveys with the exposed geology onshore (Gardline, 2000; Osiris, 2000). Where rock is not exposed, the seabed immediately adjacent often comprises coarse granular deposits (gravel and cobbles) with occasional boulders. These deposits are likely to have been derived from the subtidal weathering processes acting upon the glacial deposits (tills), which are known further offshore to directly overlay the bedrock.

Moving still further from the areas of rock outcrop, the coarse granular deposits become buried by recent marine sands, commonly found in open bays. Occasionally, sand pockets appear to occur resting on the rocky platforms. Areas of boulders have also been found resting directly on the sand areas.

A peat layer 0.6 m thick was identified approximately 4 kms north-east of Brandy Point, buried beneath the recent marine sands.

8.3.4 Quaternary Geology and Superficial Sediments

The Quaternary geology of the area is not well understood due to the limited amount of regional study work. For the purposes of this impact assessment, reference is made to the onshore Quaternary which is much better understood and assumptions are made regarding the offshore sequences, supported by survey evidence.

The onshore Quaternary on the west of Ireland is considered by McCabe (1986, 1987) to comprise sediments of glaciogenic origin. In the cold phase known as the Late Midlandian (13-35k years BP), drumlins were deposited over much of Ireland. End moraine deposits at Ballycastle (Co. Mayo) and east of Malin Beg (Co. Donegal) suggest that ice advanced into Donegal Bay from the south and east. At this time the evidence suggests that Broadhaven Bay was unglaciated, however, in the earlier and much more extensive Munsterian cold phase, complete ice cover is thought to have existed over most of Ireland.

It is therefore assumed that the offshore sediments are also of a glaciogenic origin, comprising over consolidated sub-glacial lodgement/basal till. This sequence is likely to grade upwards into fluvioglacial or glaciomarine sands silts and clays, with ice rafted cobbles and boulders (Gardline 1999, 2000).

A summary of the results of the infield and pipeline route geological survey is presented on **Figure 8.3** (large fold-out map).

8.3.4.1 Corrib Field

The Quaternary geology in the Corrib Field comprises a sequence of buried iceberg scours, some of which are 5 m deep. Both the 1999 and 2000 Gardline reports relating to route surveys recorded pockmarks in the area of the Corrib Field.

Within the Corrib Field development area, bathymetry is irregular, characterised by numerous ridges and depressions. This is the result of intensive iceberg scouring, with depressions representing ploughmark troughs and ridges representing the ploughmark shoulders.

The composition of the seabed sediments, based upon shallow high resolution seismic, sidescan sonar and core/grab data, appears to be a thin veneer of sand overlying a soft sandy clay with the iceberg plough marks have an infill of very soft clay.

The seabed in the area shows evidence of having been trawled (scars visible on sidescan sonar traces), and the existence of natural seabed features is limited to the development of sand ripples due to tidal currents.

8.3.4.2 The 'Offshore Pipeline Base Route'

The 'Offshore Pipeline Base Route' represents the shortest and most direct course to shore, with little scope for deviation, due to the rugged nature of the seabed either side of the route.

The route passes within 2 km of Erris Head before turning to the south-east to enter Broadhaven Bay.

The longer, alternative, Offshore pipeline Northern Route approaches Broadhaven Bay from further offshore, avoiding much of the rocky area located across the north-west entrance to Broadhaven Bay. The two routes rejoin within Broadhaven Bay to make a common landfall at Dooncarton, 83.2 kilometres from the Corrib Field along the Offshore pipeline Base Route and 87.5 kilometres via the Offshore pipeline Northern Route.

The route is described in more detail below, the KP numbers refer to kilometre distance along the pipeline route from the Field.

KP0 – KP4.5

Within the Corrib Field development area, bathymetry is irregular, caused by numerous ridges and depressions. Although having a relatively gentle gradient, 2 m – 3 m localised changes in bathymetry occur. This is the result of intensive iceberg scouring, depressions representing ploughmark troughs and ridges the ploughmark shoulders. Though not well-defined, the bases of several iceberg scours are observable on the sub-bottom profiler records but there is little direct evidence of their presence on the sidescan sonar records. This would suggest they have been infilled over time. Where iceberg ploughmarks occur, they are infilled with very soft clay having a shear strength of less than 10kPa.

At the 18/20-2z well location, water depth is 346 m LAT (lowest astronomical tide), increasing slightly to 352 m by KP4.5. Seabed sediments comprise very soft silty sand less than 30 cm thick overlying very soft to soft sandy clay.

Across the Corrib Field and along the proposed route to circa KP2, numerous seabed scars are observed. These are probably related to previous drilling activity, and in particular, anchoring. Several minor depressions are also apparent on the sonar records along the proposed route, being interpreted as pockmarks formed by de-watering of the very soft upper sediments. Such features typically measure up to 10 m in diameter but are estimated to be less than 1 m deep.

Occasional exposures of the underlying clay are observed, with some coarse gravel and cobbles also being expected, the latter presumably represent ice-rafted debris.

KP4.5 – KP28.0

The water depth shallows from 352 m at KP4.5 to 185 m at KP28.0. The seabed is quite irregular, characterised by iceberg scouring, the ploughmarks having an orientation approximately north to south. Mound-like features up to 2.5 m in height are observed (as shown in **Figure 8.4**).

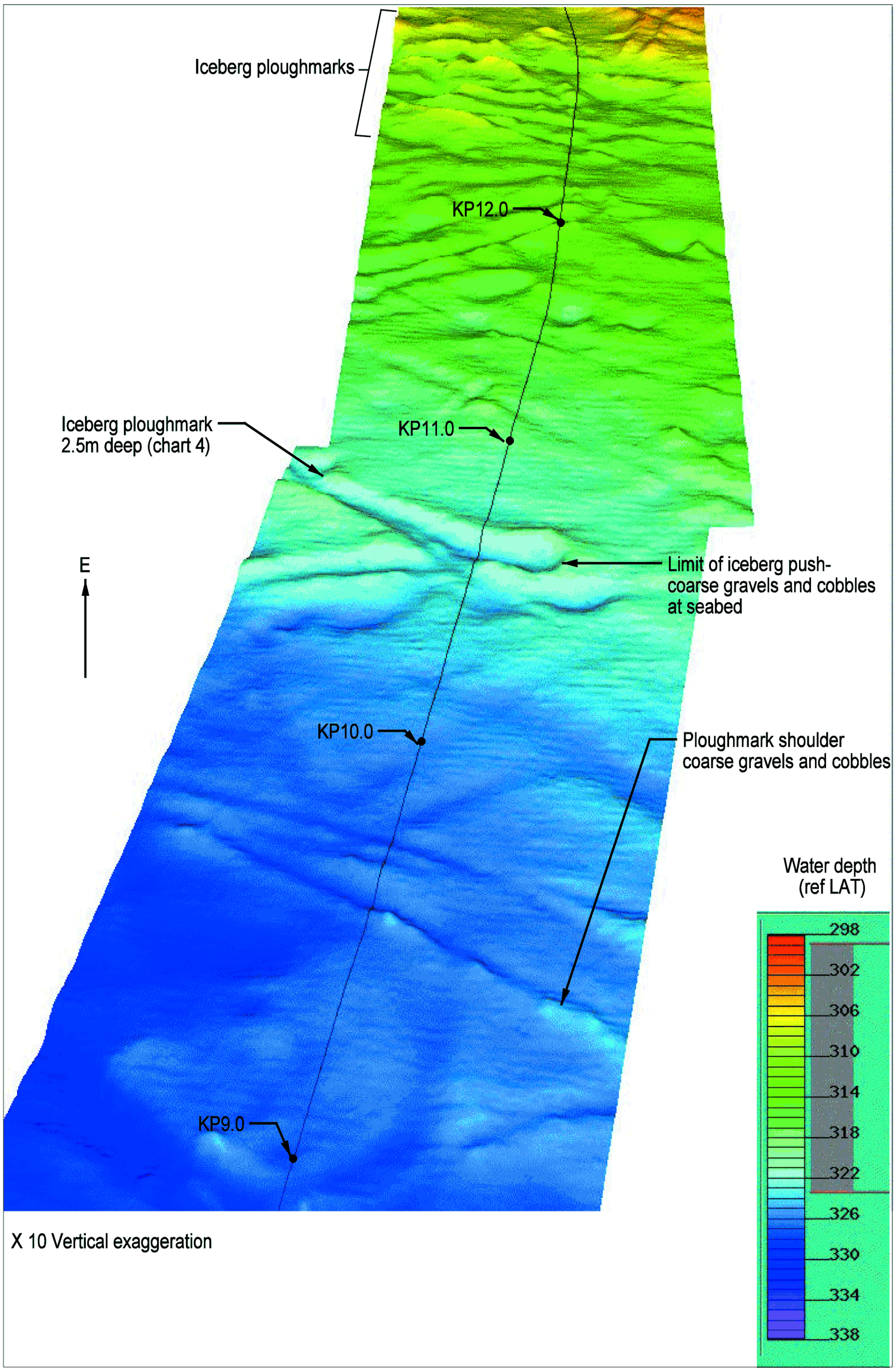

Figure 8.4: Iceberg plough marks between KP8 and KP13.5

Figure 8.4 shows a typical iceberg scour with associated ‘push-mound’, the mound representing the limit of scour for this particular iceberg.

Superficial sediments comprise a veneer of sand/silty sand less than 0.5 m thick with coarse gravels and cobbles mark the shoulders of ploughmarks. Between KP4.5 and KP20, numerous boulders are expected, typically less than 1 m high. Shoreward of KP20 (265 m water depth), boulders become considerably less frequent.

From KP17 to KP28 (water depth 290 m to 185 m), the seabed comprises predominantly coarse gravels and cobbles, covered only by a light veneer of megarippled sand, with wavelengths of 15 m, but less than 0.3 m high. Oceanographic data would indicate whether the megaripples are active but it is noted that in this area, towing the sonar fish along designated survey lines proved very difficult, indicating the presence of a relatively strong bottom current suggesting that the rippling is active. If this is the case, the thin cover of sand indicates a limited sediment input into the area.

The shallow soils comprise soft sandy, occasionally gravelly clay, becoming progressively stiffer as water depth decreases. This is thought to be due to iceberg loading effects. Core penetrometer (CPT) data suggests sediment shear strengths in excess of 150kPa may be expected, particularly over iceberg ploughmark shoulders although, where vibrocore data is available, shear strengths up to 80kPa were recorded.

Where ploughmarks are observed on sonar records crossing the proposed pipeline route, their base is not always seen on the sub-bottom profiler data. However, one clear example is shown in **Figure 8.5.**

Where ploughmarks occur, they are infilled by very soft to soft silty clay. Such infills are up to 5 m thick, for example, those at KP15.25 and KP17.15. This, therefore, shows that the upper 2 m of the shallow soils is likely to be highly variable, comprising extremes from soft clays to overconsolidated very stiff gravelly clays with numerous cobbles and small boulders.

KP28.0 – KP45.1

At KP28, the water depth is 185 m. To KP45.1, the seabed becomes more regular as it shoals, to a water depth of 129 m at KP45.1.

Iceberg ploughmarks are still expected to occur within the area up to the approximate shelf break, in a water depth of 137 m. Ploughmarks are broad and shallow rather than abrupt and deep, though the shoulders are still littered by coarse gravels and cobbles.

Between KP40.5 and KP45.1 the seabed is quite irregular with coarse gravel, cobbles and small boulders with only an occasional sandy veneer and thicker sand patches in places. Several larger boulders are also observed, greater than 0.5 m high.

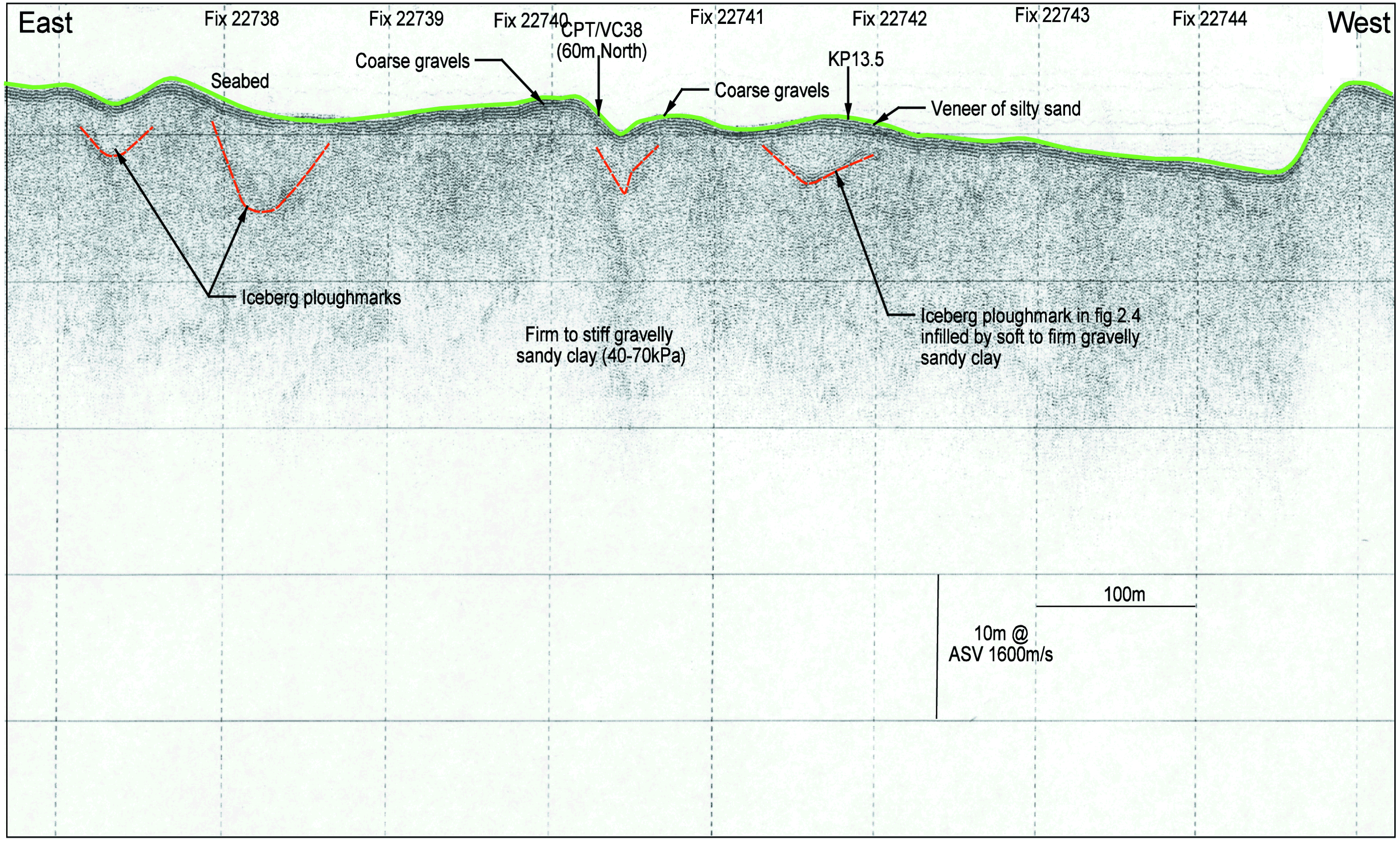

Figure 8.5: Soils section through ploughmark (KP13.5) (Line 2AS0075)

The shallow soils comprise firm to stiff gravelly sandy clay (>70kPa), possibly hard from around KP43, the geotechnical data indicates a general increase in shear strength as water depth decreases. The coarse gravels that are present at seabed, both on ploughmark shoulders and elsewhere, are interpreted as a winnowed top till sequence, fines being removed over time by wave and current action.

KP45.1 – KP50.45

The seabed is essentially flat and smooth, shoaling from 129 m at KP45.1 to 117 m by KP50.45. Superficial sediments comprise featureless dense sand, generally less than 1 m thick, overlying stiff to very stiff gravelly sandy silty clay topped by a layer of dense gravel. This is interpreted as a till sequence, possibly lodgement till.

KP50.45 – KP58.0

As sand cover becomes absent, the seabed becomes locally irregular, shoaling erratically but systematically from 118 m to 102.5 m. Superficial sediments comprise gravels, cobbles and small boulders, with an occasional sandy veneer and thicker sand patches. This irregular seabed is a characteristic of areas of exposed dense gravel while sands produce a smooth seabed.

The underlying sediments comprise stiff to very stiff, possibly hard, gravelly sandy clay (>150kPa), the coarse gravels/cobbles observed at seabed interpreted as winnowed top till sequence.

A number of larger boulders and clusters of boulders are observed on the sonar records, many within 50 m of the proposed route. Due to the reduced water depth and the lack of any evidence of iceberg activity, these boulders are thought to form part of the overall till sequence.

KP58.0 – KP65.35

The seabed shoals gently from 102.5 m at KP58.0 to 81 m at KP65.35. To KP60.4, superficial sediments predominantly comprise featureless sands with occasional exposures of the underlying gravel. Between KP60.4 and KP62.7, dense gravel, cobbles and small boulders occur on the seabed, covered by occasional sandy patches. A number of boulders up to 1.6 m high are present.

From KP62.7, seabed sediments comprise gravelly sand covered by a light rippled veneer of sand. Rippling indicates active sediment transport.

The shallow soils comprise a structureless till sequence, stiff to very stiff gravelly sandy clay, capped by a layer of dense gravel approximately 40 cm thick.

KP65.35 – KP66.7

This route section passes through the 'Cresswell Gap', a relatively narrow gap between a series of large rock outcrops, many of which are over 20 m high. The entrance to the passage is approximately 100 m wide, the designed nominal route passing within 30 m of rock to either side.

Swathe digital terrain mapping (DTM) examples in **Figure 8.6** show the nominal route through 'Cresswell Gap' and around other smaller but nonetheless, significant rock outcrops. From seabed video data, it would appear that the rock outcrops have near vertical sides.

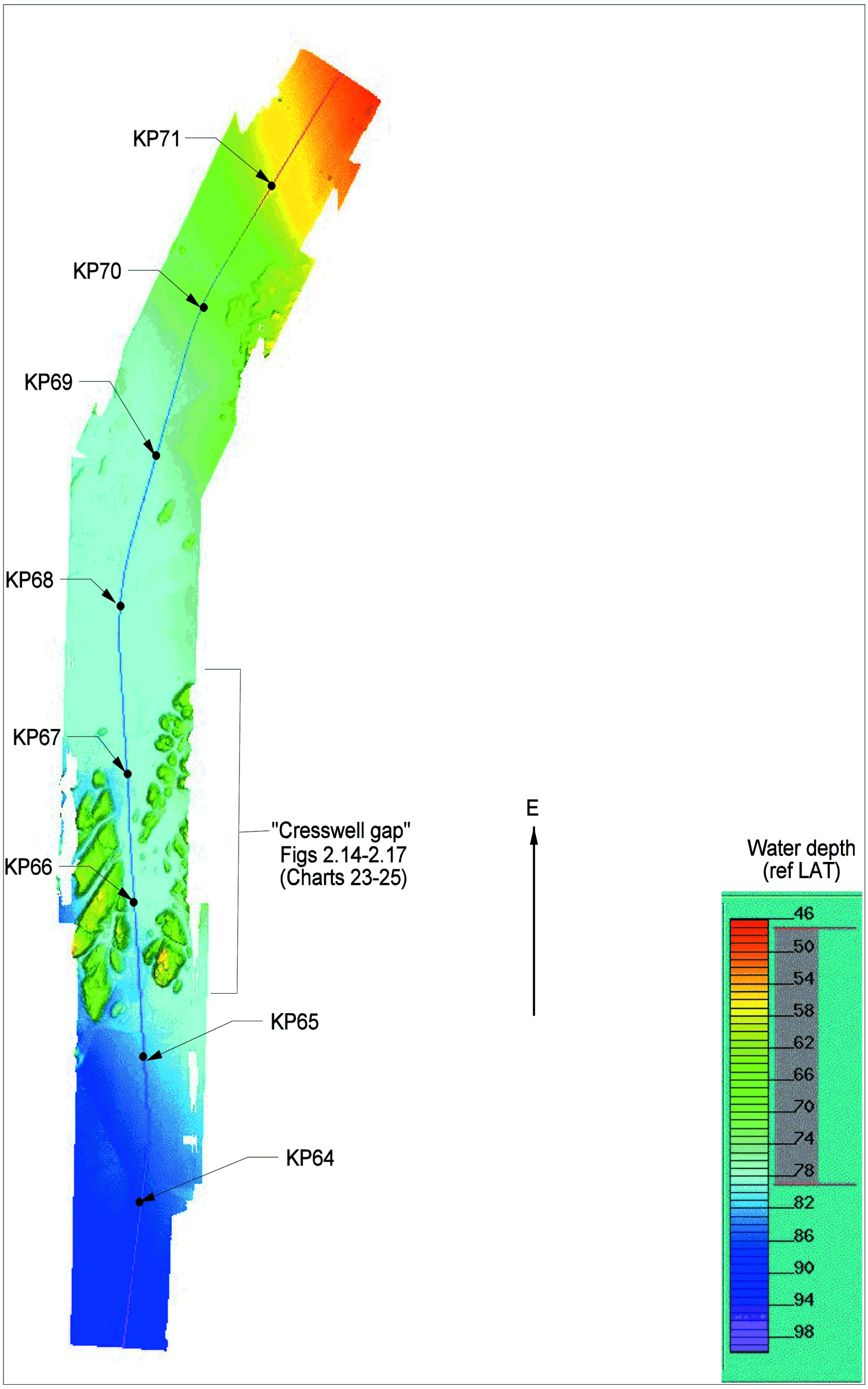

Figure 8.6: Route through "Cresswell Gap"

At KP65.35, water depth is 82 m, the seabed shoaling to a section minimum of 76.5 m at KP66.4. From the exit of 'Cresswell Gap', water depth increases to 79 m, at a gradient of 1:50. Photographs acquired during environmental sampling indicate very coarse seabed sediments, comprising cobbles and small boulders 15-30 cm in size.

A core sample (VC15) indicated shallow soils comprising overconsolidated gravelly sandy clay till, the coarse seabed sediments representing the winnowed top of the till layer. The thickness of these sediments is not known even though additional sub-bottom profiler lines were surveyed, using a more powerful boomer type system. This probably indicates rock head is close to seabed.

KP66.7 – KP70.55

From KP66.7, the seabed shoals from 80 m to 57 m by KP70.55. To KP68.5, superficial sediments comprise featureless sand less than 2 m thick with additional sand patches were observed around KP69.2 and between KP69.8 and KP70.15. These areas are quite noticeable on the seabed bathymetry contours, the sands representing areas of higher relief, resting upon the sediments beneath. Localised gradients of up to 1:10 are observed up and over the sands.

Elsewhere to KP70.15, sandy gravels occur at seabed, covered by a slight rippled sandy veneer, suggesting active sediment transport. From this, it is concluded that the patchy distribution of sand is a result of current and wave action and therefore the sands should not be expected to be static.

Shallow soils are expected to comprise dense to very dense shelly gravelly sand, overlying interpreted hard gravelly sandy clay till.

KP70.55 – KP77.0

From KP70.55, sand cover is quickly re-established, producing a smooth and featureless seabed, water depth decreasing from 57.5 m at KP70.55 to 35.8 m at KP77.0.

The shallow soils comprise dense shelly gravelly sand, becoming dense to very dense sand from KP72.5. Sub-cropping rock is observed between KP74.6 and KP74.95, the minimum depth to top rock being 6 m at KP74.85.

From KP75.0, the upper sands start to thin with a thickness of less than 2 m expected by KP77.0.

KP77.0 – KP83.20 Broadhaven Bay

The seabed shoals to landfall from 36.5 m to 1 m at KP82.57, the limit of the area surveyed. Gradients are typically slight, initially 1:200, increasing to 1:80 around KP81.5 and to shore.

Seabed sediments predominantly comprise featureless sand, though gravels occur at seabed intermittently to the limit of the surveyed area. Small isolated boulders less than 1 m were also identified.

The shallow soils comprise an upper layer of sand rarely exceeding 2 m thick. These sediments overlay presumed glacially derived sands and gravels, though between KP79.2 and KP80.1, very gravelly sandy clay till sequence is expected. Where the upper sands are absent, exposures of the underlying gravel occur.

Throughout this area, top rock does not appear to approach to within 5 m of sub-seabed.

8.3.4.3 Offshore Pipeline Northern Route

The Northern Route diverges from the Offshore pipeline Base Route at KP58.0, entering Broadhaven Bay further north. Although the route is more tortuous, it avoids many of the rocks that are present across the entrance to Broadhaven Bay, and in particular close to Erris Head at the north-west corner of the bay.

KP58.0 – KP63.5

At KP58.0, water depth is 102.5 m. To KP63.5, the seabed is essentially flat.

The upper sediments consist predominantly of slightly shelly sand. The thickness of this sand varies from absent to approximately 2.5 m.

Beneath the upper sand is a structureless till sequence, comprising stiff to very stiff sandy gravelly clay, capped by a layer of dense gravel up to 40 cm thick.

Where sands are absent, a slight increase in water depth occurs, leaving dense gravels at seabed. This occurs between KP58.9 and KP59.4 and around KP60.5 - in these areas, only a light rippled veneer of sand is observed, indicating active sediment transport.

KP63.5 – KP69.93

Between KP63.5 and KP69.93, the seabed shoals from 98 m to 88 m.

At KP63.5, sand cover quickly disappears leaving a ‘channel’ of dense gravel at seabed.

From KP63.7, sand cover gradually increases to a maximum thickness of 1.5 m at KP63.9, but stops rather abruptly at KP63.93. This body of sand is laterally extensive across the proposed route.

To KP69.93, the seabed is quite irregular, sediments comprising dense gravels, with cobbles and small boulders also expected. A sandy veneer and thicker sandy patches occasionally overlie this. Several isolated boulders (<1 m high) and clusters thereof are apparent within 50 m of the proposed pipeline route, with a 3 m high outcrop of bedrock being observed at KP66.25. A number of larger outcrops are also present further to the south.

The shallow soils comprise a structureless till sequence, capped by a layer of dense gravel up to 50 cm.

KP69.93 – KP75.1

From KP69.93, the seabed shoals from 87.6 m to 74.5 m at KP74.95, at a gentle gradient of 1:150.

Seabed sediments comprise featureless sand. The thickness of the sand varies from less than 1 m to greater than 4 m in places.

A number of large rock outcrops are present very close to the proposed centreline (as shown in **Figures 8.7, 8.8**).

At KP71.35 (**Figure 8.9**), rock occurs beneath the proposed Northern Route with two further minor rock outcrops occurring at KP73.0, though these outcrops are very small.

Beneath the superficial sands, the shallow soils initially comprise firm sandy gravelly clay with dense sands and gravelly sands further inshore. KP71.27 marks the eastern limit of interpreted clay till along the Offshore pipeline Northern Route. Into Broadhaven Bay, the remaining inshore sediments comprise sands with gravels to a greater or lesser extent.

At KP74.95, upper sand cover ceases, leading to a tongue of exposed gravelly sand/sandy gravel. This has a marked effect on the local bathymetry. Although seabed gradients into this feature are not steep, a gradient of 1:12 is observed once sand cover is quickly re-established. This feature is thought to result from localised bottom currents interacting with the general movement of water into the bay itself.

KP75.1 – KP81.3

From KP75.1, water depth gradually reduces, from 72.2 m to 36.5 m at KP81.3, the seabed shoaling at a uniform gradient of 1:180.

The upper soils consist of gravelly shelly sand. Initially, the upper sediments are 2 m thick, but quickly increase in thickness reaching a maximum of 10 m at KP77.7. The upper soils become less gravelly and shelly as water depth decreases

In and around KP78.5, rock is observed to sub-crop within 4 m of seabed (as shown in **Figure 8.10**). To KP81.3, the upper sands begin to thin, reaching 3 m at KP81.3. Underlying the mapped upper sands are presumed glacial sands and gravels.

At KP81.3, the Northern Route merges with the Offshore pipeline Base Route proceeding to landfall at KP87.49.

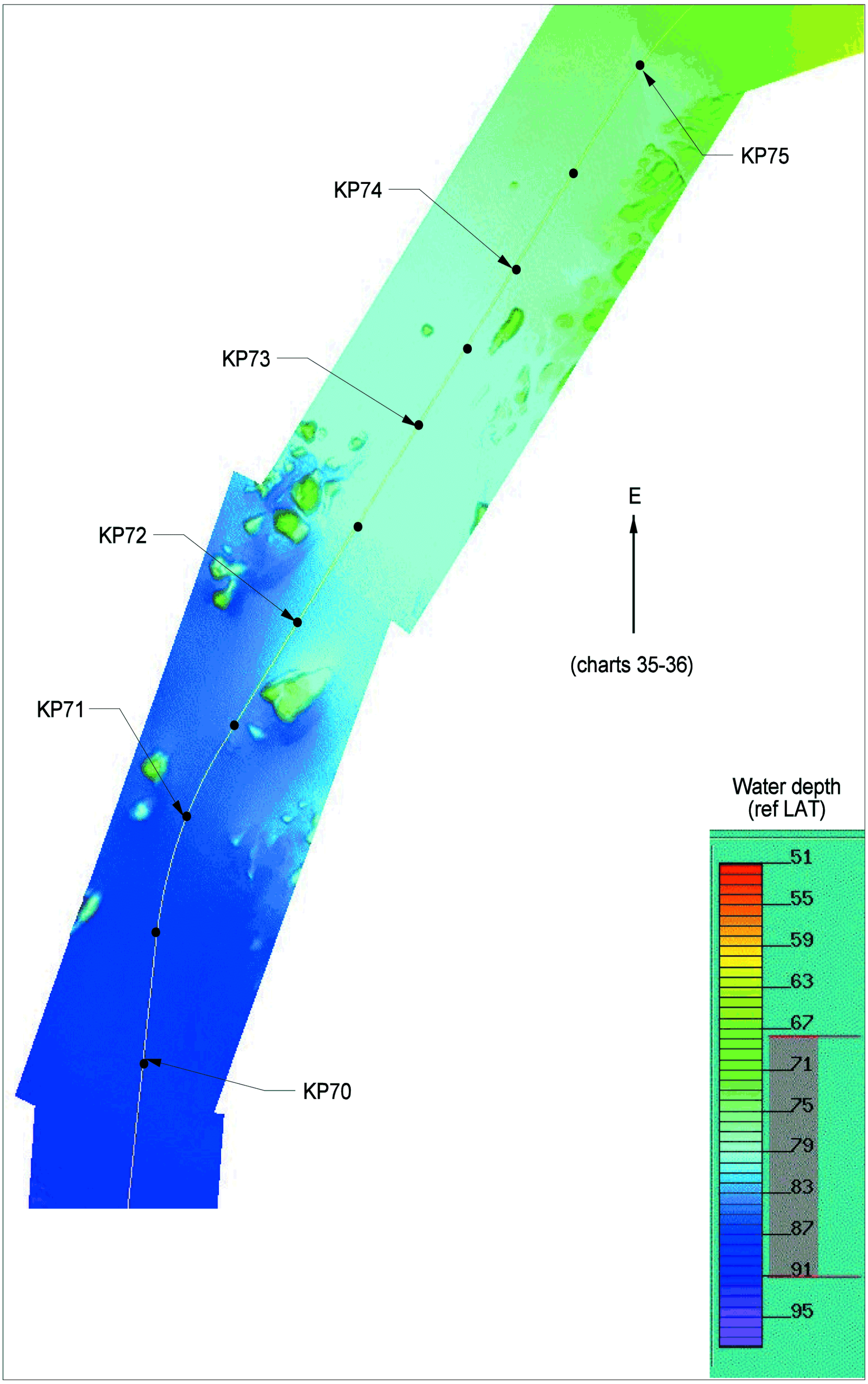

Figure 8.7: Plan view of proposed northern route (KP69 to KP76)

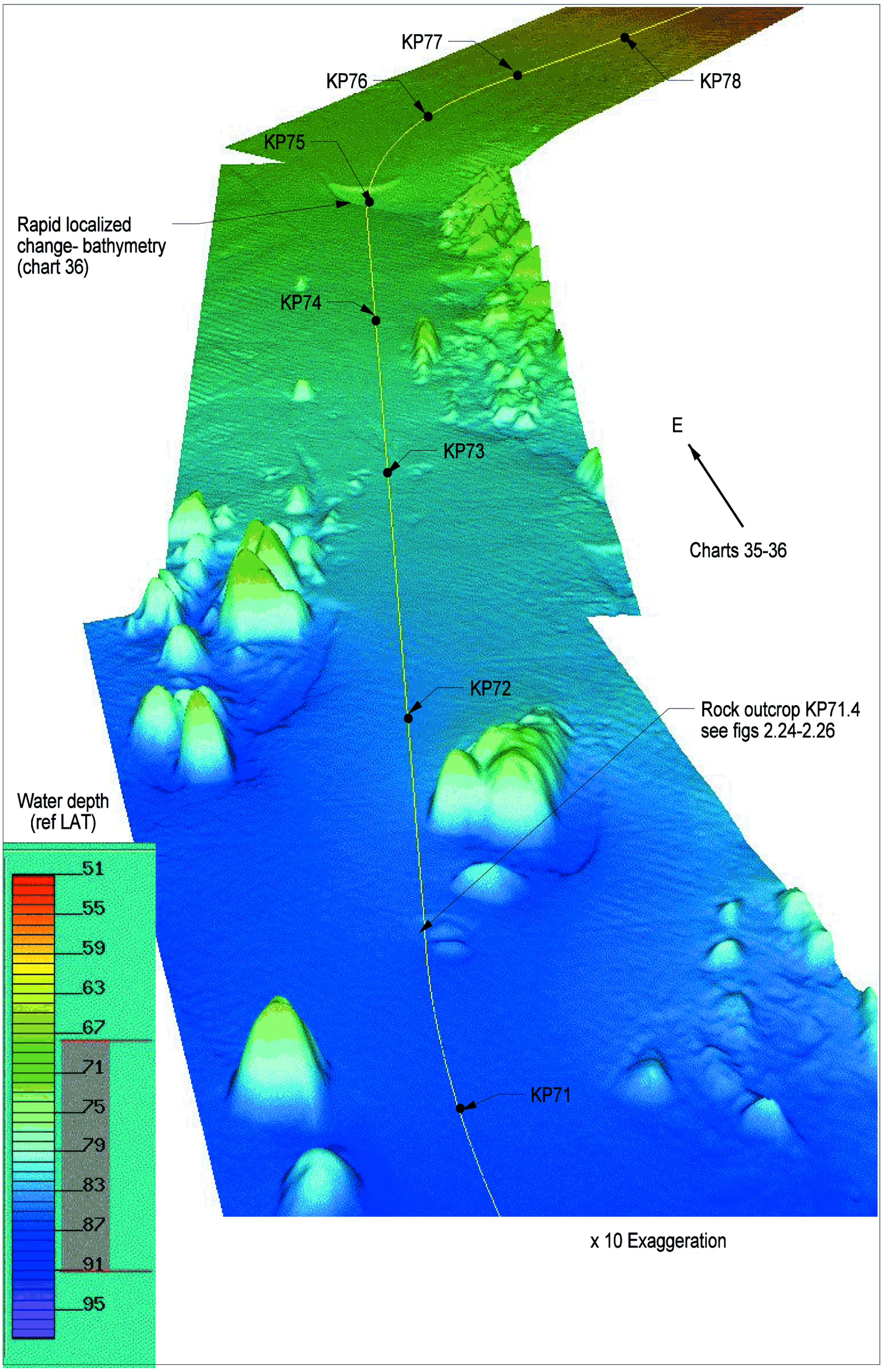

Figure 8.8: Rock outcrop along proposed northern route (KP71 – KP 78)

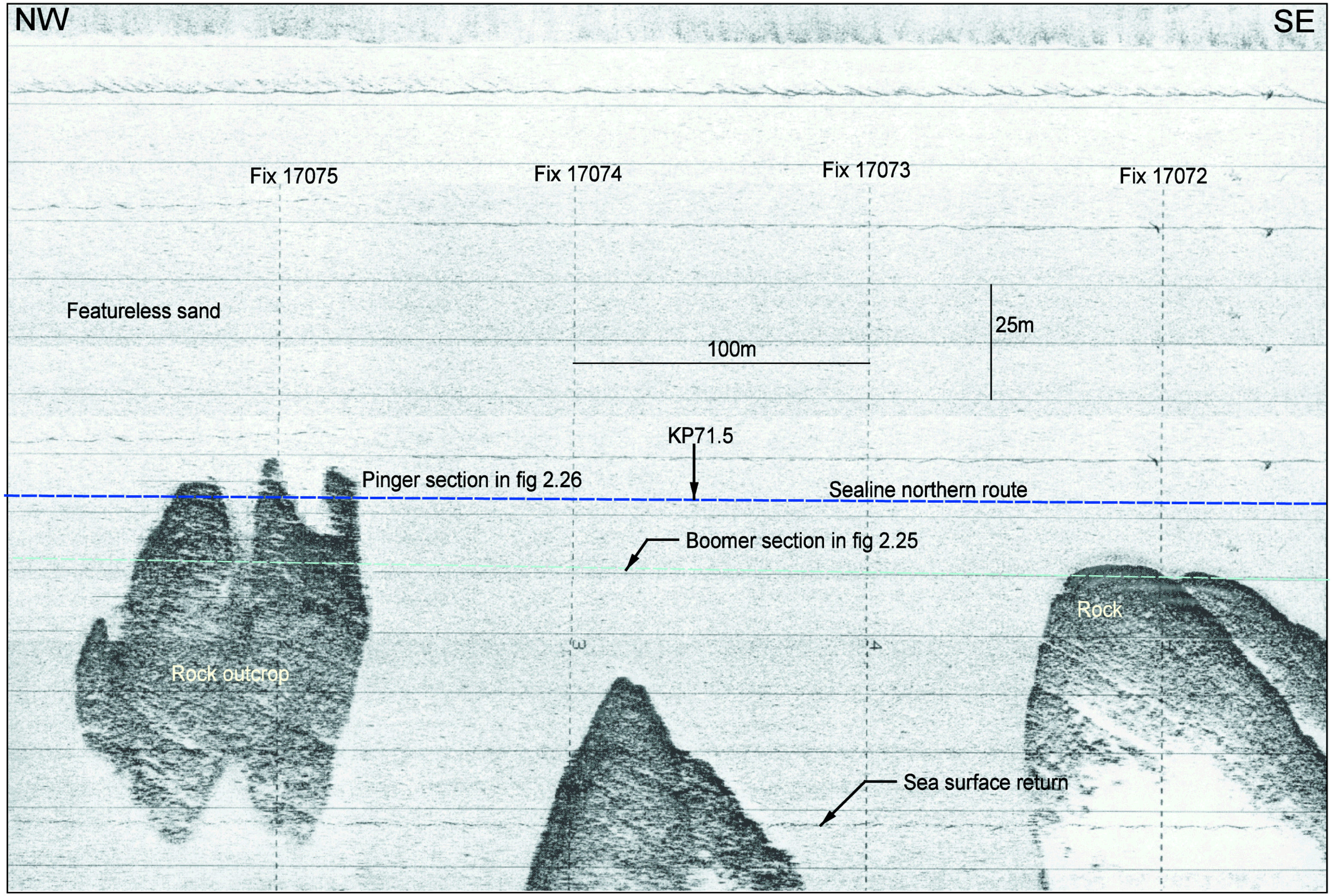

Figure 8.9: Rock outcrop along proposed route (KP71.5) (Line 11N0075)

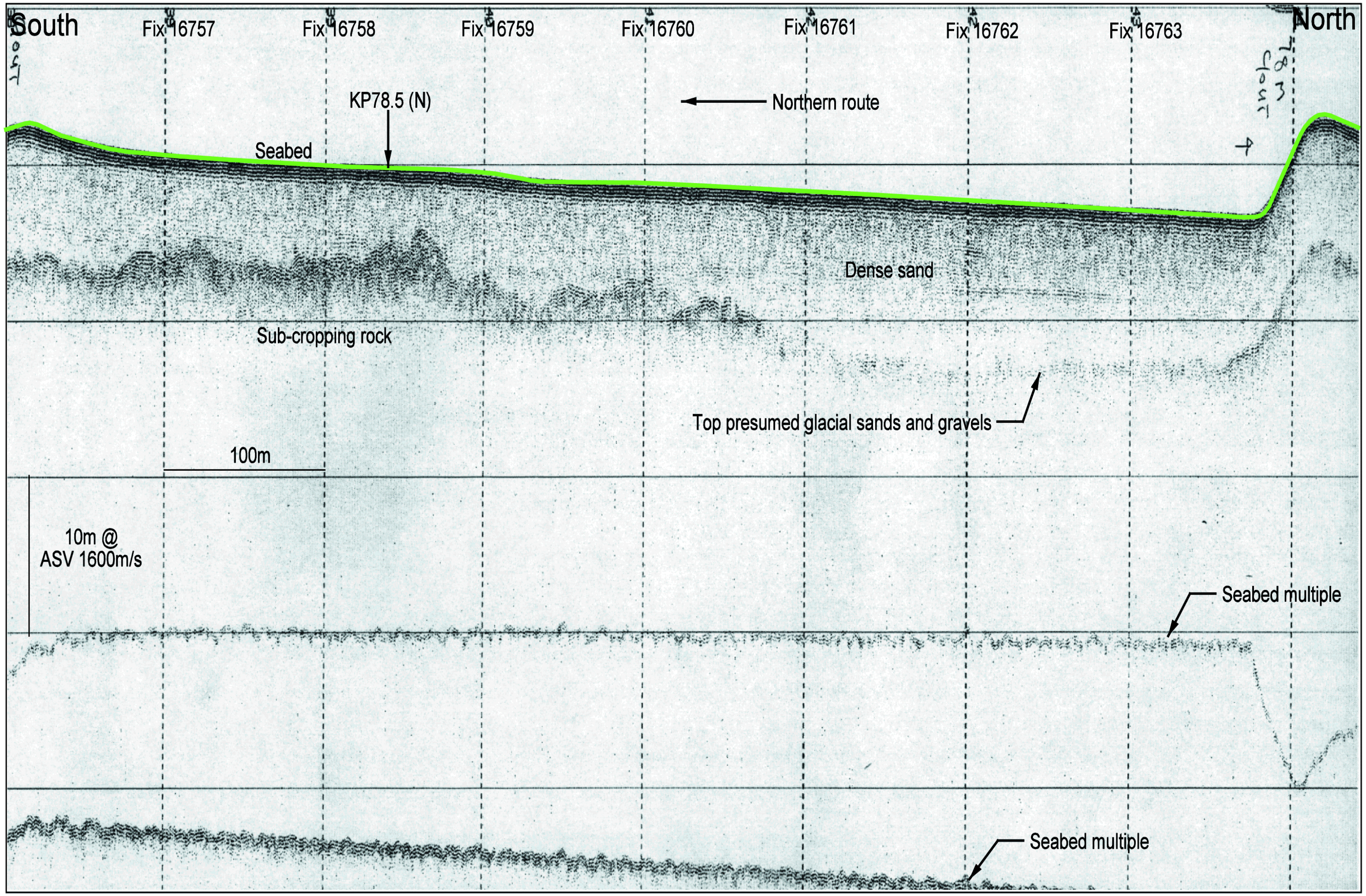

Figure 8.10: Subcropping rock along northern route (Line 1200)

8.3.4.4 Landfall Topography and Geology

The two landfall options were investigated with regard to superficial and solid geology. Sources consulted include:

- geology of North Mayo (1992) Regional Guide and accompanying 1:100,000 bedrock geology map;
- Corrib Onshore Pipeline Study. Additional Landfalls - Brandy Point (February 2000); and
- borehole information undertaken for the purposes of the Broadhaven to Galway pipeline.

Dooncarton Landfall

The Dooncarton Landfall comes ashore at Dooncarton (F 8154 3873). The geology encountered here consists of quartzites and psammitic schists of the undifferentiated Broadhaven/ Benmore Formations (Grampian Group). They comprise white to pale cream to very pale brown, yellow and green quartzite and psammitic schist.

Information obtained from Borehole 1 - 02, located approximately 50 metres from the coast, suggests that solid rock (quartzites and psammites) lies at 4.40 metres, overlain by approximately 1 metre of weathered rock, which is in turn overlain by approximately 3 metres of sands and gravels.

Information obtained from Trial Pit 1 - 01, located approximately 100 metres from the coast, suggests that solid rock lies at 3 metres. Sand and gravel overlies the solid rock, with approximately 10 cm of peaty material lying at 1 metre depth.

Schists are generally acknowledged to be weaker than quartzites, however as the coastline suggests structural discontinuities such as joints and fractures, cleavage and faulting appear to be more influential with regard to rock therefore, strength. Nevertheless, it will be the lithology and inherent strength of the rocks, as well as the density of discontinuities, that will be important for any drilled method of landfall construction.

The quartzite and schist dip at steep angles of 61° to the south-east.

Brandy Point Landfall Option

This option has not been used (see **section 4.0)**.

The Brandy Point option comes ashore at Brandy Point (F 7891 3752), where the Inver Schist Formation of the Appin Group forms a cliff (approximately 10 metres in height) at the coastline. This is the only geological formation encountered. A synclinal structure underlies the landfall site.

The Inver Schist Formation (Appin Group), underlying the landfall site comprises fault-bound blocks of grey flaggy mica schist with some more massive beds of micaceous quartzose gneiss. The rocks are generally foliated and crumpled, with foliation generally dipping SE at 60-70°, with frequent veins of quartz.

No trial pit, or borehole investigation, has taken place at the Brandy Point landfall location therefore no precise information concerning the superficial deposits is known. General information (Ove Arup, 2000b) on the superficial deposits suggest that the flat lying land, on the seaward side of the coast road, is underlain by glacial drift that has unknown thickness.

A thin layer of blanket bog overlies the drift on the higher ground immediately behind Brandy Point.

8.3.4.5 Exisiting Pollutant Levels

The drilling of exploration and development wells in the offshore environment produces a volume of ground up rock material that is recovered from the formations. The sediments in the vicinity of the well field show evidence of the discharge of drill cuttings during the exploration and appraisal phase of this project.

Drilling muds (a mixture of base fluids, muds and chemical additives) cannot be fully separated from the surface of these cuttings and are consequently discharged in small quantities along with the cuttings. This has generally led to an area of disturbed surface sediments within close proximity of each drill location, and in most cases, a localised layer of cuttings material.

Concentration increases can occur when the cuttings settle unevenly at the seabed and layers of higher concentration are initially covered by cleaner surface material.

Over time, the surface material disperses, allowing underlying chemicals to migrate to the sediment-water interface. This can significantly elevate the concentration in the surface sediments, whilst spatially, the area of impact slowly increases with physical or chemical dispersion away from the well. As an example for Corrib, the elevated bariteplume covered a circular area 500 metres wide, whilst the base-fluid only spread to about half of that size.

Since the drilling of the first exploratory well at 18/20-1 in 1996, a significant number of environmental surveys have been undertaken. For the most part, these were undertaken in the form of seabed sampling, utilising a remotely operated vehicle (ROV). These submersibles are fitted with a small bucket sampler, which is pushed into the seabed at a pre-determined distance and bearing from the well. The number of samples has varied between sites and years, ranging from 2 to 14 samples. In addition to this material, Gardline Surveys has undertaken a number of more comprehensive studies, utilising more sophisticated sampling equipment operated from a dedicated survey vessel. Whilst the number and quality of sediment samples is considerably better during these larger studies, access to the cuttings disposal locations, immediately surrounding the well location, has been restricted due to the presence of a semi-submersible drill rig in the area. Consequently a combination of the inner ROV samples and the outer vessel mounted surveys have given the best results.

With the exception of the study in 2000, all of the surveys previously undertaken within the Corrib Field were of sediment chemistry only. A summary of these surveys is given below in **Table 8.2**. Physical and chemical data from the 2000 survey are presented in **Appendix 8.1**.

Table 8.2 Summary of drilling activities and subsequent environmental sampling in the Corrib Field

Well number	Well location		Surveys		SBM Used
	LAT (N)	LONG (W)	Pre	Post	
18/20-1	54°20'47.554"	11°05'41.114"	ROV 1996	GS 1997, 98 & 2000	Mixed
18/20-2z	54°20'20.169"	11°03'26.819"	ROV 1998	ROV 98, GS 98 & 2000	Ester
18/25-1	54°19'09.119"	11°02'54.963"	None	ROV 1999 & GS 2000	Paraffin
18/20-3	54°20'51.419"	11°02'15.468"	ROV 2000	ROV 2000 & GS 2000	Paraffin
18/20-4	54°20'19.348"	11°03'26.173"	GS 2000	ROV 2000	Paraffin

GS = Gardline Surveys

18/20-1

This was the first well drilled at Corrib (in 1996). This site offers the greatest amount of survey data, having been sampled originally using an ROV and subsequently sampled by Gardline Surveys on three further occasions in 1997, 1998 and 2000. This well was drilled with mixed synthetic based mud (SBM) operating under the name "Ecosol". The base-fluid's primary component was paraffin, at 60%, but also had additional admixtures of poly alpha olefin (PAO) and linear alpha olefin (LAO) with 20% each. The initial ROV sampling in 1996 indicated that the majority of the base-fluid settlement was within 50 metres of the well location, with slight perturbation out to 100 m. The maximum concentration of base-fluid was recorded at 2,550 ppm. By 1997, this level had decreased at most sites to a maximum of 1,730 ppm, recorded 50 m south-east. The size of the accumulation had stabilised as an elongated patch spread approximately 100 metres north-west and south-east and showing a slight to moderate level of contamination. This decrease between years is relatively uncommon in sediments contaminated by synthetic fluids, which normally indicates little change, or even slight increases, due to uneven settlement and migration of the base-fluid within the surface layers (Gardline unpublished).

By 1998, further sampling at the 18/20-1 site indicated a continued decline in the sediment contamination. At this time, the maximum base-fluid concentration was recorded as 520 ppm, with the area of impact limited to a broad area extending 100 metres to north-east and south-east. This direction is expected to indicate an easterly residual movement of material at the seabed. The site was finally visited in 2000, where a single sample was recovered over the central location which indicated a base-fluid level of 52 ppm.

Overall, the survey history of this well indicates an initial settlement of only moderate contamination (0.25% oil-on-cuttings) and relatively localised dispersion. In subsequent years, the cuttings distribution on the seabed has remained relatively stable, within 100 metres of the well and the absolute level of base-fluid has shown a consistent fall in concentration. Maximum levels showed an increasing level of degradation year on year. In 1997, the overall level of base-fluid fell by 33%, in 1998 this rate had increased to 70% recording a 90% reduction in 2000. It is therefore reasonable to assume that the level of base-fluid will be virtually undetectable by 2001(approximately 5 years after drilling).

18/20-2z

The 18/20-2z well was drilled in 1998 using the ester based synthetic mud "Esterkleen". An ROV survey was carried out immediately on completion of drilling, with further sampling carried out by Gardline Surveys in 2000. The ester based drilling fluids, whilst generally included within the SBM systems, are accepted as demonstrating properties unique to the group. Both physical dispersion and rates of degradation on discharge are considerably greater than any of the other synthetic muds, as indicated in a study carried out by the Marine Laboratory at the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) in 1997. This was the "*Degradation of Synthetic Mud Base Fluids in a Solid-phase Test System*", and gave a comparative degradation of six different base-fluids in the laboratory. This showed that with the exception of esters, all of the base-fluids tested showed no enhanced degradation over traditional oil-based muds (OBM). The ester systems degraded more rapidly than any other system at all concentrations in all tests.

Immediately on completion of the 18/20-2z well, the ROV survey recorded a maximum base-fluid concentration of 88 ppm, within 100 metres of the central position. During the 2000 survey, this had fallen to an almost undetectable level of 0.5 ppm and trace concentrations within 250 metres of the well. This is indicative of significant degradation and dispersion throughout the survey area.

18/20-3

The 18/20-3 well was drilled in 2000. Prior to the commencement of drilling, two nearby well sites were sampled using an ROV, which were repeated on completion of the well. Additionally, Gardline carried out further sampling around this well location in 2000. The 18/20-3 well was drilled using a similar synthetic mud system to that employed at the 18/20-1 well in 1996. However, the mixed base-fluid had been reconstituted into an almost exclusively paraffin base-fluid. This revised mud system was called "Ecomul". A combination of both the ROV and Gardline samples showed that the level of contamination at the 18/20-3 was similar to that of the 18/20-1 well on completion of drilling. The maximum concentration was recorded as 3,800 ppm within 100 m of the well, with only slight contamination out to 250 m from the centre.

Allowing for the similarities between the two wells, the level of the chemical impact, spatial distribution and residence time for the organic contamination are all expected to be similar to that of the first well drilled in the field, although the lack of LAO in the mixture may be to the detriment of the degrading process. Therefore, the overall level of perturbation at 18/20-3 is expected to fall by about 25% in 2001, and approximately 50% the following year, with the rate of degradation should accelerate until the base-fluid should be virtually undetectable in c.2005 to 2006.

18/20-4

18/20-4 was also drilled in 2000, with Gardline Surveys conducting a pre drilling survey and ROV samples recovered on completion of the well. The location of the 18/20-4 well is within close proximity to that of the ester drilled well 18/20-2z, so the initial survey picked up low-level background contamination from this mud system. The post drill survey, undertaken by the ROV, indicated very low level contamination, with a maximum Ecomul concentration of 120 ppm over the central position. This is unlikely to constitute the largest concentration within the site and could be a function of the sampling technique used.

18/25-1

This well was drilled using Ecomul in 1999. The survey area was sampled directly after drilling using an ROV and again a year later by Gardline Surveys. The highest concentration recorded in the sediments immediately after drilling was 1,800 ppm within 100 m of the well. This had degraded to 710 ppm at a central position a year later, recording a recovery of almost 60% between survey years. It should, however, be noted that only a single sample was obtained in 2000, and so may not truly reflect *in situ* levels. The area of contamination would be expected to be within a 200m radius.

As with 18/20-3, the overall level of contamination initially recorded at this site was relatively low, and the rate of sediment recovery is expected to be similar to that already observed at the 18/20-1 site. Therefore, base-fluid contamination levels are expected to fall rapidly to approximately 100 ppm in 2002 and to be virtually undetectable by 2004.

18/25-3

This well was drilled in 2001 and post-dates the environmental surveys described above. The only mud and cuttings discharged from this well were those associated with the sections of the well drilled with WBM.. The cuttings produced during the use of the oil-based mud were stored on board the drilling rig and sent ashore for recycling or disposal (see **Section 15**).

8.4 Characteristics of the Proposed Development

8.4.1 Offshore

Past exploration activity undertaken in the vicinity of the Corrib Field includes two seismic surveys undertaken in 1994 and 1997 and three drilling programmes undertaken in 1996 and 1998-2001. In 1996 the exploration well 18/20-1 was drilled and subsequently abandoned. Between 1998 and 2001 five appraisal wells (18/20-2z, 18/25-1, 18/20-3, 18/20-4 and 18/25-3) have been drilled and suspended.

Future work includes the drilling of three additional development wells and re-entry and completion of the five existing appraisal wells (see **Section 3**). A 20" gas pipeline will then be constructed from the Corrib Field to the onshore Terminal and well operations will be controlled from the Terminal, by an integrated electro-hydraulic control umbilical, which will lie alongside the pipeline. The control / chemical injection umbilical serves as the interface between the Terminal and subsea control systems.

Each wellhead will consist of the casing heads, the tubing head and the valve assembly also known as christmas tree or production tree.

Structures will be installed to protect the christmas trees. These structures will be separate, with their own foundations, fully overtrawlable, snag resistant and protective against dropped objects. The structures, which will be placed on the seabed at the top of each well "wellhead facilities", will each cover a seabed area of approximately 225 m^2, they will be partially buried in the seabed, and the height remaining above the bed will be approximately 9 m.

In addition to the wellhead, there will be a number of structures on the seabed in the Corrib Field, including infield flowlines, the production manifold and the umbilicals (see **Section 2**).

8.4.2 Nearshore

The 20" gas pipeline will pass through the nearshore zone together with the control umbilical.

8.4.3 Landfall and Sruwaddacon Crossings

In addition to the above, a produced water discharge pipe will be laid in Broadhaven Bay from the terminal site. This will be installed at the same time, and in the same trench, as the gas pipeline and umbilical. It is likely that the discharge pipeline will be "piggy-backed" onto the larger gas pipe, in order to assist in the construction.

The gas pipeline and umbilical will landfall together. The umbilical will then be joined into the OTU, which will be positioned at the landfall and be completely buried.

At the crossings of the Sruwaddacon, the pipelines and umbilical will be trenched into the estuary bed to protect them from scouring.

8.5 Potential Impacts of the Proposed Development

8.5.1 Seismic Surveys

It is not expected that there will be any further wide area seismic surveys acquired as part of the Corrib Field development. The past surveys will not have had any impact on the geological environment, as they are a non-intrusive method of data collection. There are likely to be a short seismic test run from the drilling rig, following the drilling of a well, to confirm the stratigraphic profile. Vertical seismic profiling, as the process is known, is of short, intermittent duration (approximately 20 firings of the seismic source over 8 hours), using a low volume seismic source.

8.5.2 Drilling

The drilling of future wells will locally impact the solid geology in the removal of a core of rock during the drilling operation.

Locally adjacent to the well site there will be some impact on the seabed geology, in that it will be smothered by cuttings that arise from the well drilling operation. Again, in terms of impact, this is seen to be minor in terms of geological impact, as it is not an area that is known to be especially important in geological terms. Further, on well 18/25-3 and future wells those intervals drilled using oil-based mud will not be discharged, but will instead be transported to shore for specialist treatment and disposal.

The impact to seabed geology is expected to be limited to an approximate radius of 100 m.

In order to provide a pathway through areas of the source rock which have low permeability from the reservoir to the well, the process of hydraulic fracturing could be used. This basically involves a large volume (in the case of well 18/25-3, 170 tonnes) of a sand slurry being pumped into the reservoir in a restricted zone. The high pressures fracture the source rock, and the sand fills the fracture, keeping it open. A radioactive source is used to determine the areas of the reservoir which have been fractured. In the event that this operation is required in the Corrib Field, any radioactive material which is not retained in the well, will be returned, via the rig, to shore for disposal. Hydraulic fracturing has been used on one well to date in the Corrib Field (18/25-3).

8.5.3 Field Facilities

8.5.3.1 Installation

Locally adjacent to the well site there will be some impacts to the seabed geology during the construction process, in that the sediments will be disturbed and displaced by the installation of the infield flowlines, manifold and overtrawlable structures. It is anticipated that the seabed current regime in the area will return the sediment profiles over the umbilicals and pipelines to their natural levels in a matter of weeks.

8.5.3.2 Operation

There will be a minor impact during operation due to the physical presence of the facilities on the seabed. Any emissions will be aqueous and will not impact the geology of the seabed.

8.5.3.3 Decommissioning

During decommissioning the seabed will be disturbed, but it is anticipated that the natural profile of the sediment will return within a few weeks as a result of the near-bed currents.

8.5.4 Pipeline and Umbilical

8.5.4.1 Installation

Installation of the pipeline and umbilical will disturb the seabed and shallow sub-seabed geology temporarily during the construction phase. The umbilical will be buried and the seabed is expected to return to its present morphology within a matter of weeks after construction.

8.5.4.2 Operation

There will be no impact on the geological environment during operation, other than the presence of the pipeline.

8.5.4.3 Decommissioning

The impact on the geological environment will be negligible, if the pipeline has to be removed and if it is left in place, there will be no change from the operational condition.

8.5.5 Water Discharge Pipeline

8.5.5.1 Installation

Installation of the pipeline will disturb the seabed and shallow sub-seabed geology temporarily during the construction phase. As it is going to be laid concurrently with the gas pipeline, there will be no additional impact. In the long term, because the discharge pipeline will be buried, it will not impact upon the geology.

8.5.5.2 Operation

Waste water from the outfall will contain dissolved salts and low quantities of suspended solids. These are not expected to accumulate at the end of the pipeline, as they will be rapidly dispersed by the tidal current and wave action. If there were any small accumulations, the chemical constituents of the sediment immediately adjacent to the end of the pipeline may undergo very minor changes over the life of the project.

Since the minerals and salts discharged are naturally occurring, the impact, if any, is expected to be minor.

8.5.5.3 Decommissioning

If the waste water outfall is removed, there will be a disturbance to the seabed, similar to that during construction and installation. If it is left in place, then there will be no change.

8.6 Do-Nothing Scenario

If this development did not proceed, the geological environment would remain as it is, the main impact being the disturbance of the seabed sediment by fishing trawls.

8.7 Mitigation Measures

8.7.1 Seismic Surveys

Any vertical seismic profiling operations will be of short duration (approximately 8 hours per well), with intermittent firing of the seismic source.

8.7.2 Drilling

Minimising the volume of cuttings discharged and use of only water-based muds will reduce impacts to the geology in the area of the Corrib Field.

8.7.3 Field Facilities

The disturbance to the seabed created by the presence of the field facilities can only be minimised by ensuring that the footprint of the structures is reduced to the smallest size possible.

8.7.4 Pipeline and Umbilical

Disruption of the seabed will be minimised by only burying the pipeline in the shallow water areas.

8.7.5 Water Discharge Pipeline

In order to reduce the impact during construction and installation, this pipeline will be installed in the same trench as the gas pipeline.

During operation, the minimisation of the potential impact from this structure on the geology is achieved by the treatment of the produced water in the Terminal, prior to its discharge to the sea. The intention being that there will be no impacts on the marine environment from the operation of the outfall.

8.8 Predicted Impact of the Proposed Development

8.8.1 Seismic Surveys

It is not expected that there will be any impact on the geology due to seismic surveys.

8.8.2 Drilling

Some localised smothering of the seabed surface geology will occur due to the presence of water based mud on cuttings discharge.

8.8.3 Field Facilities

Some localised smothering of the seabed surface geology will occur due to the presence of the structures.

8.8.4 Pipeline and Umbilical

Some localised smothering of the seabed surface geology due to the presence of the structures.

8.8.5 Water Discharge Pipeline

Some localised smothering of the seabed surface geology due to the presence of the structures.

8.9 Monitoring

The entire subsea facility will be monitored for both scour and contamination during the life of the Field.

Chemical sampling of the seabed sediments will take place in the Corrib Field at a frequency to be determined in discussion with the Marine Institute. As there will be no further discharges of organic phase muds in the Field, the sampling is expected to record the decrease of SBM chemicals in the sediments.

The pipeline will be monitored annually for scours, due to currents passing over the pipeline and removing sediment beneath the line. If this occurs and goes unchecked, the scours can grow and eventually create spans that cause stresses in the pipe. In extreme cases this could lead to fractures.

The umbilical is designed to remain buried and hence, if scouring occurs which exposes the umbilical, it will be necessary to remediate the area.

8.10 Reinstatement and Residual Impacts

8.10.1 Pipeline Presence

There will be a residual impact related to the presence on the seabed of the pipeline. This impact is considered to be minor, in that the area of seabed taken by the pipeline is very small and does not exhibit any geological features that are unique and which would be lost or damaged.

8.10.2 Structures Removal

During decommissioning, some structures will be removed to below mudline and others will be removed at the mudline. In each case there will be some minor impact, which is dealt with in the decommissioning section. In terms of reinstatement and residual impact, there will be some reinstatement of the seabed probably by jetting and then the natural tidal current processes which operate will complete the reinstatement. There will be no structures or debris left above the seabed.

In respect of the pipeline, if it is to be removed at the end of field life, then there will be some temporary impact of a minor nature. The seabed should then revert to its equilibrium state, which is determined by the tidal current and wave actions that impact the area.