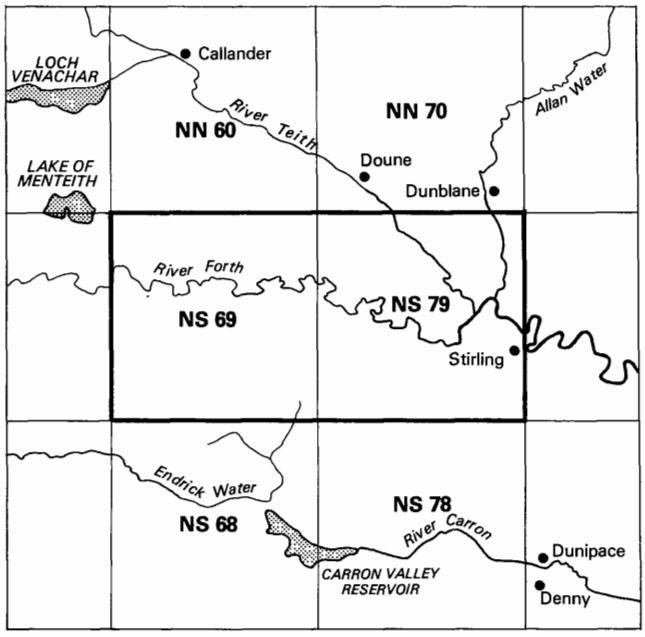
INSTITUTE OF GEOLOGICAL SCIENCES

Natural Environment Research Council

Mineral Assessment Report 131



The sand and gravel resources of the country west of Stirling, Central Region

Description of 1:25 000 sheet NS 69, 79

J. L. Laxton and D. L. Ross

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ISBN 0 11 887421 7*

Edinburgh Her Majesty's Stationery Office 1983

The first twelve reports on the assessment of British sand and gravel resources appeared in the Report series of the Institute of Geological Sciences as a subseries. Report 13 and subsequent reports appear as Mineral Assessment Reports of the Institute.

Details of published reports appear at the end of this report.

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PREFACE

National resources of many industrial minerals may seem so large that stock-taking appears unnecessary, but the demand for minerals and for land for all purposes is intensifying and it has become increasingly clear in recent years that regional assessments of the resources of these minerals should be undertaken. The publication of information about the quantity and quality of deposits over large areas is intended to provide a comprehensive factual background against which planning decisions can be made.

Sand and gravel, considered together as naturally occurring aggregate, was selected as the bulk mineral demanding most urgent attention, initially in the south-east of England, where about half the national output is won and very few sources of alternative aggregates are available. In 1968, following a short feasibility study initiated in 1966 by the Ministry of Land and Natural Resources, the Industrial Minerals Assessment Unit (formerly the Mineral Assessment Unit) began systematic surveys which have been extended progressively through central and northern England. Work in Scotland, which began in 1975 in the Darvel area of Strathclyde Region, is being financed by the Department of the Environment, acting through the Scottish Development Department and is being undertaken with the cooperation of the Sand and Gravel Association of Great Britain.

This report describes the resources of sand and gravel of 189.5km^2 of country west of Stirling, Central Region, and shown on the accompanying resource map. The survey was conducted by J. L. Laxton and D. L. Ross under the supervision of E. F. P. Nickless, Officer-in-Charge of the sub-unit in Edinburgh. The work is based principally on the revision geological survey at a scale of six-inches to one-mile of sheets 38E and 39W undertaken between 1950 and 1961 by I. H. Forsyth, E. H. Francis and W. A. Read of the North Lowlands Unit.

The section of the report on the geology of the area was prepared by M. Armstrong. Palaeontological analysis was carried out by D. K. Graham and D. M. Gregory.

J. D. Burnell, ISO, FRICS (Land Agent), has been responsible for negotiating access to land for drilling; the ready cooperation of land owners, tenants and sand and gravel operators is gratefully acknowledged.

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June 1982

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Plate 3 East from *[760 933]*, the flat Carse of Stirling stretches away towards quartz-dolerite scarps topped by Stirling Castle and the Wallace Monument; beyond the Wallace Monument the fault-margined Ochil Hills can be seen. In the foreground the post-Glacial clay has been cut into by a tributary stream of the River Forth (MNS 3310)

The sand and gravel resources of the country west of Stirling, Central Region

Description of 1:25 000 sheet NS 69, 79

J. L. Laxton and D. L. Ross

SUMMARY

The geological maps of the Institute of Geological Sciences, sixty-two boreholes and sixteen shallow pits sunk for the Industrial Minerals Assessment Unit, together with data from thirty-two other boreholes and the inspection of sand and gravel workings, form the basis of the assessment of sand and gravel resources in the area west of Stirling, Central Region.

All deposits in the area which might be potentially workable for sand and gravel have been investigated. The 1:25000 map is divided into three resource blocks, for one of which a simple statistical method is used to estimate the volume of potentially workable sand and gravel over an area of 12.4km^2. The reliability of this volume estimate is given at the symmetrical 95 per cent probability level. For the two other resource blocks inferred assessments are offered for 2.7 and 2.9km^2, respectively, of mineral.

The geology of the deposits is described and the mineral-bearing area, the mean thickness of overburden and mineral, and the mean grading are stated. Detailed borehole data are given. The geology, the outlines of the resource blocks and the position of boreholes and shallow pits used in the assessment are shown on the accompanying map.

Bibliographic reference
LAXTON, J.L. and ROSS, D.L. 1983. The sand and gravel resources of the country west of Stirling, Central Region. Description of 1:25000 resource sheet NS 69 and 79. *Miner.Assess.Rep.Inst.Geol.Sci.*, No.131.

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Note
National Grid references are given in square brackets. In this publication all lie within the 100-km square NS.

INTRODUCTION

The survey is concerned with the estimation of resources, which include deposits that are not currently exploitable but have a foreseeable use, rather than reserves, which can only be assessed in the light of current, locally prevailing, economic considerations. Clearly, both the economic and the social factors used to decide whether a deposit may be workable in the future cannot be predicted; they are likely to change with time. Deposits not currently economically workable may be exploited as demand increases, as higher grade or alternative materials become scarce, or as improved processing techniques are applied to them. The improved knowledge of the main physical properties of the resource and their variability which this survey seeks to provide will add significantly to the factual background against which planning policies can be decided (Archer, 1969; Thurrell, 1971, 1981; Harris and others, 1974).

The survey provides information at the 'indicated' level "for which tonnage and grade are computed partly from specific measurements, samples or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to permit the mineral bodies to be outlined completely or the grade established throughout" (Bureau of Mines and Geological Survey, 1948, p.15).

It follows that the whereabouts of reserves must still be established and their size and quality proved by the customary detailed exploration and evaluation undertaken by the industry. However, the information provided by this survey should assist in the selection of the best targets for such further work.

The following arbitrary physical criteria have been adopted:

a The deposit should average at least 1m in thickness.
b The ratio of overburden to sand and gravel should be no more than 3:1.
c The proportion of fines (particles passing the No.240 mesh BS sieve, about $\frac{1}{16}$mm) should not exceed 40 per cent.
d The deposit must lie within 25m of the surface, this being taken as the likely maximum working depth under most circumstances. It follows from the second criterion that boreholes are drilled no deeper than 18m if no sand and gravel has been proved.

A deposit of sand and gravel which broadly meets these criteria is regarded as 'potentially workable' and is described and assessed as 'mineral' in this report. As the assessment is at the indicated level, parts of such a deposit may not satisfy all the criteria.

For the particular needs of assessing sand and gravel resources, a grain-size classification based on the geometric scale $\frac{1}{16}$mm, $\frac{1}{4}$mm, 1mm, 4mm,

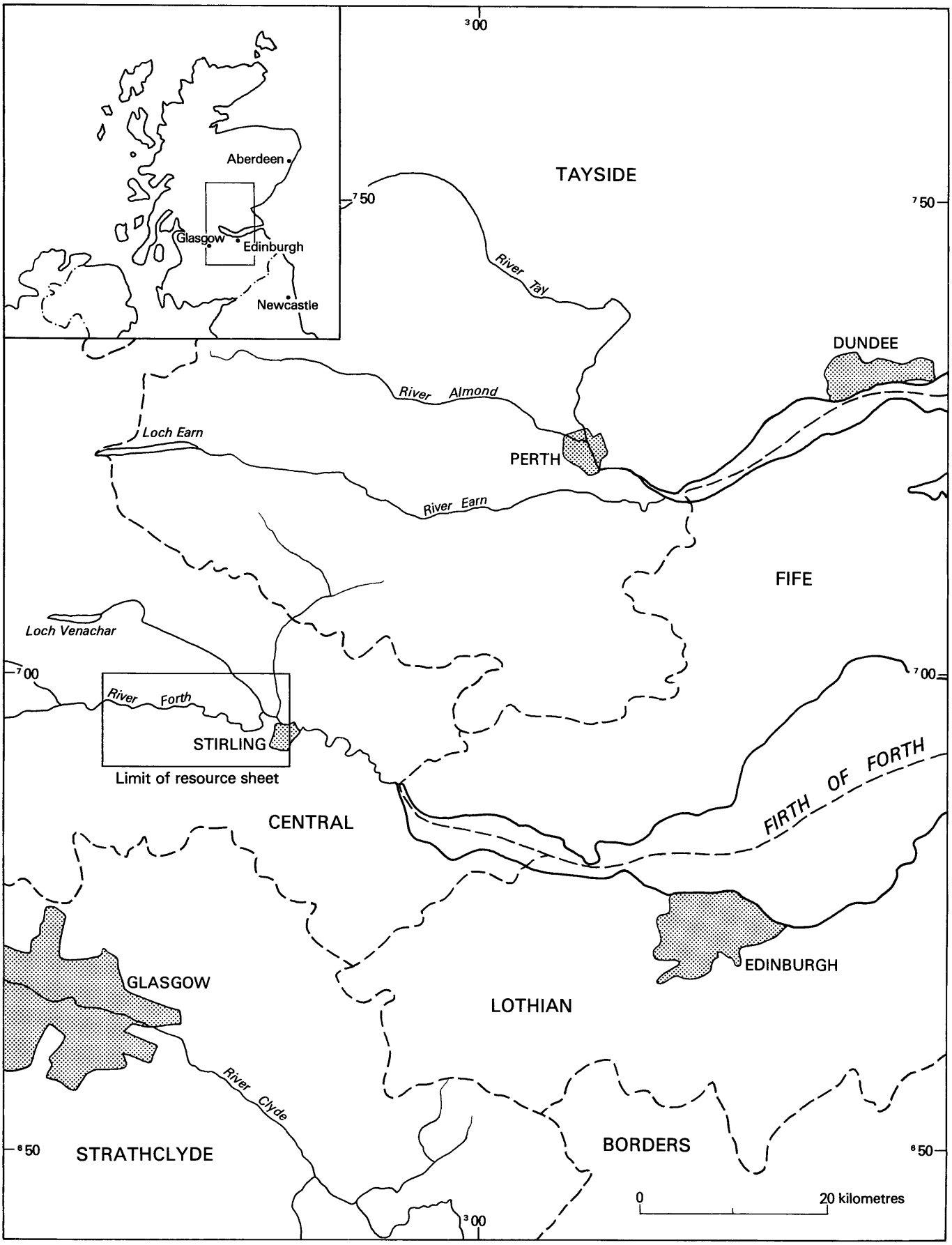

Figure 1 Sketch-map showing the location of the Stirling area

16mm has been adopted. The boundaries between fines (that is, the clay and silt fractions) and sand, and between sand and gravel material, are placed at $\frac{1}{16}$mm and 4mm respectively (see Appendix C).

The volume and other characteristics are assessed within resource blocks, each of which ideally, contains approximately 10km^2 of sand and gravel. No account is taken of any factors, for example, roads, villages and high agricultural or landscape value, which might stand in the way of sand and gravel being exploited, although towns are excluded. The estimated total volume therefore bears no simple relationship to the amount that could be extracted in practice.

It must be emphasised that the assessment applies to the resource block as a whole. Valid conclusions cannot be drawn about the mineral in parts of a block, except in the immediate vicinity of the actual sample points.

DESCRIPTION OF THE RESOURCE SHEET

GENERAL AND TOPOGRAPHY

The survey area, which lies to the west of Stirling (Figure 1), is topographically dominated by the flat Carse of Stirling which trends east to west across the central part of the resource sheet. Most of the Carse is underlain by post- and late-Glacial marine sediments which mask the earlier morphology to give a plain, generally 4km to 5km wide, sloping gently from about 14m above Ordnance Datum in the west to 8m in the east.

On both sides of the Carse, rock is generally at or near the surface. The ground rises to a maximum height of about 150m above Ordnance Datum in the extreme north-east and to over 465m above Ordnance Datum on the Gargunnock *[69 91]* hills in the south. In the west, two discrete areas, defined as sub-block C_2 on the resource map, rise to about 50m above Ordnance Datum and have topography, which although more moundy and less elevated, is generally similar to that found north of the Carse. Other than the higher parts of the uplands in the south, which are rough moorland only suitable for sheep grazing, the area is mainly given over to mixed farming: the Carse is particularly fertile with hay a major crop. Within historic times the greater part of the Carse was peat covered but it has been systematically cleared for agriculture and now only remnants of the peat remain, the largest being Flanders Moss *[63 99]* which covers an area of around 9km^2 in the north-west of the resource sheet.

The River Forth and its tributary the Goodie Water, both misfits, meander across the Carse. To the north-east of Hill of Drip *[7662 9560]* the Forth is joined by the larger River Teith and a little further downstream by the Allan Water. All these rivers are incised two to three metres into the post-Glacial clay and therefore alluvium is generally restricted to narrow and discontinuous strips, although more extensive spreads border the River Teith upstream of Greenocks *[7668 9649]* .

The urban areas of Stirling and Bridge of Allan lie in the east of the resource sheet area: the former contains the administrative offices for both Central Region and Stirling District Councils, as well as much light industry; Bridge of Allan is now principally a dormitory town for Stirling. In the west the villages of Thornhill *[665 000]* , Kippen *[651 948]* and Gargunnock *[705 944]* grew up to serve the local agricultural community, although now the last-named in particular houses many commuters from Stirling and farther afield.

The principal lines of communication from Glasgow to north-east Scotland lie in the east where both the M9 and the main line railway run north to south across the assessment area. The natural access-ways of the Carse and the Valley of the Teith are used by the trunk roads from Stirling to Erskine Bridge and north-west Scotland respectively.

GEOLOGY

For the most part the resource sheet area falls within the Stirling (39W) Sheet of the 1:50000 Geological Map of Scotland, but a narrow strip to the west is within the unpublished Aberfoyle (38E) Sheet. The ground was originally surveyed at a scale of six-inches to one mile by B.N. Peach and R.L. Jack and the results of this work were incorporated in the first editions of one-inch Sheets 38 and 39, published in 1901 and 1882 respectively. Following a six-inch resurvey between 1950 and 1961 by I.H. Forsyth, E.H. Francis and W.A. Read, a second edition of one-inch Sheet 39 in separate Solid and Drift

Table 1 Geological classification of deposits

DRIFT	
Recent and Pleistocene	Peat
	Alluvium
	Alluvial cone
	Raised beach and marine deposits, post-Glacial
	Fluvioglacial sand and gravel of the Loch Lomond Stadial
	Raised beach deposits, late-Glacial
	Marine deposits, late-Glacial
	Fluvioglacial sand and gravel
	Glacial sand and gravel
	Till
SOLID	
Permo-Carboniferous	Quartz-dolerite sills
Carboniferous	
Upper	Limestone Coal Group
Lower	Lower Limestone Group
	Calciferous Sandstone Measures (Upper Division including Clyde Plateau Lavas; Lower Division comprising Downies Loup Sandstone and Ballagan Beds)
	Cornstone Beds
Devonian	
Upper	Gargunnock Sandstone - mainly red Sandstone
Lower	Teith Formation - sandstone
	Cromlix Formation - mudstone
	Dunblane Formation - sandstone
	Buttergask Formation - sandstone and siltstone
	Sheriffmuir Formation - sandstone
	Ochil Volcanic Formation - mainly andesitic lava with interbedded volcanic conglomerate and tuff

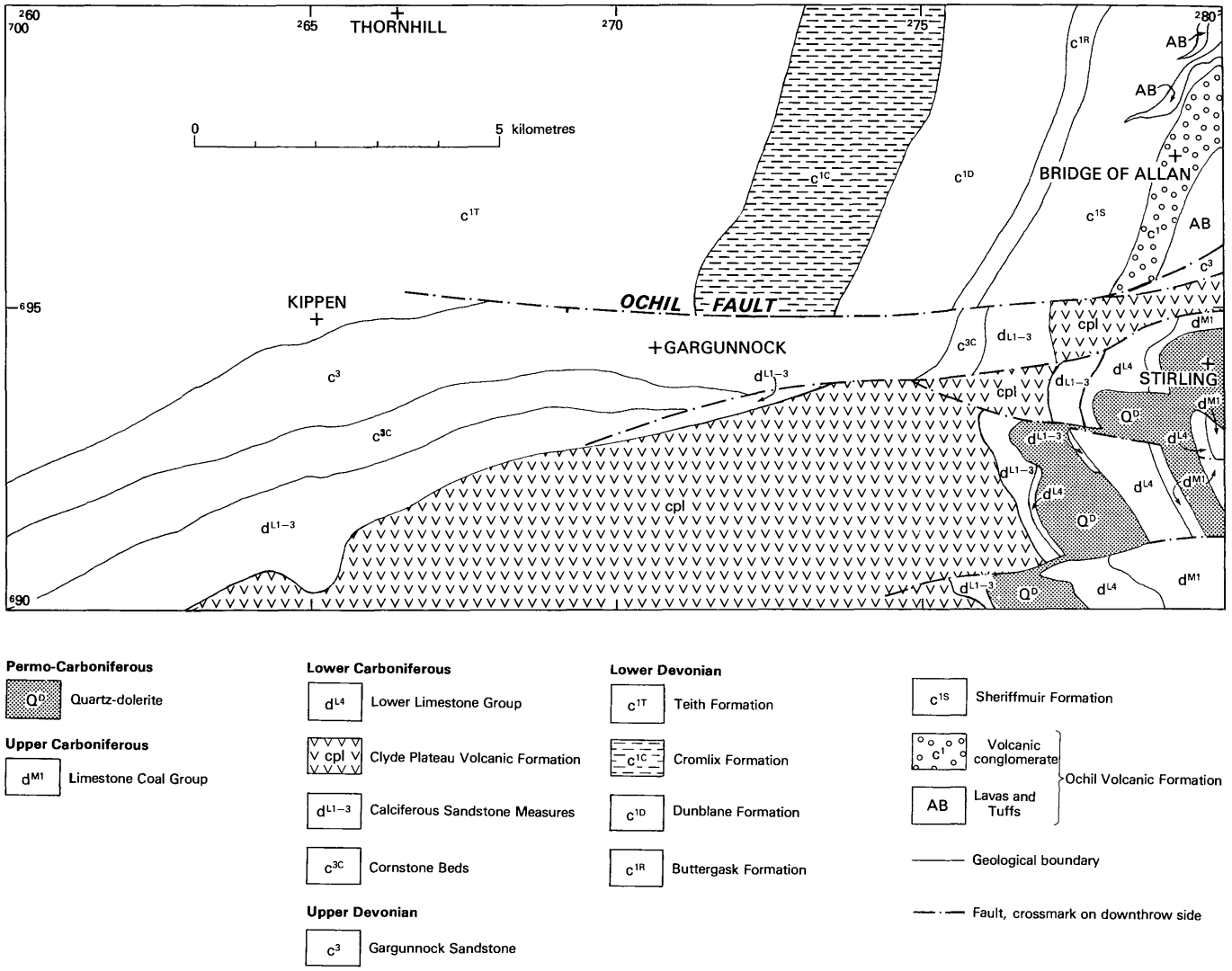

Figure 2 Sketch-map showing the solid geology

versions was published in 1969 and was accompanied by a descriptive memoir (Francis and others, 1970). The currently available 1:50000 Solid and Drift editions of sheet 39W (Stirling) were published in 1974 and are also based on the 1950 to 1961 resurvey.

Over the greater part of the assessment area the solid rocks, ranging in age from Lower Devonian to Permo-Carboniferous, are overlain by sediments of Quaternary age, comprising till, glacial sand and gravel, fluvioglacial sand and gravel, raised beach and marine deposits, alluvium and peat. The geological sequence, in general order of increasing age, is represented in Table 1.

Solid

The distribution of the solid rocks below the drift cover is shown in Figure 2. The oldest rocks exposed in the resource sheet area are of Lower Devonian age and crop out for the most part north of the Ochil Fault. They comprise mainly sandstone, siltstone and mudstone with some interbedded andesitic and basaltic lavas, and associated volcanic conglomerate and tuff near the base of the exposed sequence. These predominantly fluvial deposits were laid down in a subsiding trough parallel to and south of the Highland Boundary Fault, the sediments being derived from the erosion of Dalradian rocks to the north of the fault. During the Middle Devonian period, the Lower Devonian strata were folded, the principal structure formed at this time being the Strathmore Syncline, the north-east-trending axis of which crosses the resource sheet area west of Thornhill. Following uplift and considerable erosion, Upper Devonian strata (Gargunnock Sandstones) were laid down in a fluvial environment and rest unconformably on the Lower Devonian. The unconformity is at outcrop only south-west of Kippen *[651 948]* : further east the Ochil Fault throws Upper against Lower Devonian. The Cornstone Beds conformably overlie the Gargunnock Sandstones: they comprise a sequence of fluvial sandstones with thin concretionary limestones (cornstones), and mark the passage between the Devonian and Carboniferous systems. The Calciferous Sandstone Measures embrace a basal division of cementstones and mudstones, the Ballagan Beds, which were deposited under quasi-marine conditions. These beds pass up into the Downies Loup Sandstone, overlain in turn by the basaltic lavas and tuffs of the Clyde Plateau which occupy the prominent upland area of the Touch *[73 92]* and Gargunnock *[69 91]* hills. The volcanic episode was succeeded by the deposition of sandstones, mudstones, siltstones and marine limestones of the upper part of the Calciferous Sandstone Measures and of the younger Lower Limestone Group. The youngest Carboniferous rocks, cropping out south of Stirling, are referable to the Limestone Coal Group.

Post-Carboniferous earth movements in the area

are evidenced mostly by the prominent faults of east-west trend, most notably the Ochil and Abbey Craig faults. Such faults have in places been utilised by cross-cutting elements in the Permo-Carboniferous Stirling quartz-dolerite sill complex, the youngest rocks found in the assessment area.

Drift

Within the resource sheet area, as in the whole of central Scotland, the glacial deposits and features are probably all of late-Devensian age. The effects of the earlier Quaternary glaciations have not been distinguished nor have any inter-glacial deposits been identified. The Highland source of the ice is indicated by the wide distribution of clasts of Highland origin, either as individual erratics or as components of glacial deposits. The most characteristic of the erratics are of Dalradian schistose grit and of Lower Devonian conglomerate from the Highland Border.

The main late-Devensian ice-sheet reached its maximum extent about 18000 years ago (Penny and others, 1969) when most of Scotland was ice-covered. By about 13000 years ago the ice had largely disappeared and total deglaciation may have taken place by 12500 years ago (Sissons, 1974). Subsequently, during the Loch Lomond Stadial about 11000 to 10000 years ago, ice again accumulated, principally in the Western Highlands and extended into the western part of the assessment area.

Till, directly laid down from the ice, is the oldest drift deposit found in the resource sheet area and covers the solid rocks everywhere except over the higher parts of the Touch and Gargunnock hills. It is masked by younger deposits over the lower ground. A particularly close relationship between bedrock and till matrix has been observed south of the River Forth where it is presumed that the main late-Devensian ice moved north-eastwards parallel to the outcrop of the various solid formations. Thus the maxtrix of till overlying the brick-red Gargunnock Sandstone is generally brick-red and very sandy: over the Cornstone Beds it is brown, and on the outcrop of the Ballagan Beds a more clayey grey or greyish brown till has been observed (Read *in* Francis and others, 1970, p.268). Along the north side of the Carse of Stirling the till is generally sandy, with a reddish brown or purple-brown colour reflecting the nature of the underlying Lower Devonian rocks.

During the break-up of the main late-Devensian ice-sheet the higher ground emerged at an early stage leaving a glacier (hereafter referred to as the Forth Glacier) occupying the low ground. The recession of the Forth Glacier was probably interrupted when the ice-front stood for a time at Stirling where the quartz-dolerite sill-complex forms a constriction in the valley. At this time the land, although recovering rapidly from the isostatic lowering caused by the load imposed by the ice-sheet, was nevertheless still considerably depressed and, as in addition the return of glacial meltwaters to the oceans was causing a eustatic sea-level rise, the late-Glacial sea encroached over the low ground up to levels now in excess of 30m above Ordnance Datum. While the Forth Glacier stood at Stirling its meltwater deposited outwash fans which descend south-eastwards and merge with raised beach deposits (Sissons and Smith, 1965) with which they are laterally continuous: for this reason the outwash, glacial sand and gravel, on both the north and south sides of the valley of the River Forth in the vicinity of Stirling is shown as late-Glacial raised beach deposits on the resource map. West of Stirling differentiation between the glacial sand and gravel deposits and raised beach deposits is more marked, the sand and gravel deposits north of Touch Mollar *[7510 9167]* , having formed when glacier-ice still occupied the valley of the River Forth to the north. Subsequently, the clays and sands of the late-Glacial marine deposits in the ground south-east of Touch House *[7530 9277]* and in the neighbourhood of Arnhall Castle *[7638 9854]* on the north side of the valley, were laid down after the recession of the Forth Glacier from its still-stand position at Stirling, but before the late-Glacial sea had fallen below 30m above Ordnance Datum (Browne and others, 1981). Thus although a fall of sea-level probably took place while the Forth Glacier stood at Stirling (Dinham, 1927) the extent of the fall may not have been as great as the 18 to 20m suggested by Sissons and Smith (1965).

Further west, on both sides of the valley of the River Teith, north of the point where it joins the Carse of Stirling, a series of fluvioglacial sand and gravel terraces occur up to a level well above that of the Carse. It is possible that the highest of these terraces, shown by Smith and others (1978) to grade to a level of the order of 32m above Ordnance Datum, is related to a sea-level at about this altitude: such an interpretation is supported by the occurrence in borehole 79 NW 5 of possible marine clays below the fluvioglacial sand and gravel underlying the terrace near Blair Drummond.

Apart from the sediments already mentioned, within the resource sheet area the valley of the River Forth is noticably lacking in meltwater deposits related to the final stages in recession of the main late-Devensian ice. However, over considerable areas along the north side of the Carse of Stirling between Blair Drummond *[7322 9898]* and Thornhill *[665 000]* , and in places on the south side of the valley, terrace-like features occur and have been mapped as late-Glacial raised beach deposits. If correctly identified, these deposits imply that the late-Glacial sea remained at a level in excess of 20m above Ordnance Datum after the Forth Glacier retreated west of Thornhill.

Linton (1962), in discussing the effects of glacial erosion on topography, estimated that, over an area of 100km^2 on the Devonian outcrop in the valley of the River Forth, no less than 100m of rock was removed by ice during the Quaternary glaciations. A gravity survey and drilling programme (Read *in* Francis and others, 1970, p.265) have demonstrated that a glacially overdeepened rock basin descends to at least 109m below Ordnance Datum beneath the late-Glacial and post-Glacial fill in the southern part of the Carse of Stirling.

Many boreholes, for example IMAU bores 69 NW 12, 69 NE 7 and 18, and previous drilling by IGS, have found, at depth within these basins, marine deposits laid down after the retreat of the Forth Glacier. These beds correspond, in part at least, to the Clyde Beds of the west of Scotland and contain a related molluscan fauna (Peacock, 1974, p.65).

It is generally accepted that by the time of onset of the Loch Lomond Stadial about 11000 years ago, sea-level in the Stirling district had fallen considerably, possibly to below Ordnance Datum as glaciers reoccupied the Loch Lomond basin and the upper valley of the River Forth. Ice again advanced eastwards into the resource sheet area but only as far as Arnprior *[612 949]* , to the north of which an extensive moraine crosses the

valley of the River Forth. Although this very broad feature is composed largely of stiff, clayey till, hardly to be distinguished from that formed by the preceding ice-sheet, much of the western part of the moraine-complex lying mainly outside the resource sheet area, contains glacially transported sand and gravel and marine clays of Clyde Beds aspect originally laid down in or west of the Lake of Menteith basin. Sissons (1966) suggested that outwash deposits relating to the glacier at Menteith descend eastwards to a low level, passing below subsequent post-Glacial raised marine deposits which overlap against the moraine. However, such buried deposits were nowhere proved during the present survey, boreholes 69 NW 3, 5 and 69 SW 7, along with an auger hole at *[6043 9967]*, all showing post-Glacial sediments to lie either on bedrock or the lithologically varied deposits of the moraine complex and indicating that the buried outwash deposits may be of limited areal extent.

Fluvioglacial sand and gravel terraces related to a contemporaneous glacier in the Callander area, descend the valley of the River Teith and pass below post-Glacial marine deposits to the south and east of Blair Drummond where they form an extensive buried fan (Kemp, 1971, Smith and others, 1978) which overlies late-Glacial marine clays and silts, as proved in IMAU boreholes 79 NW 8, 13 and 69 NE 10 and by commercial drilling.

On the basis of detailed programmes of hand-boring, Sissons (1966) and Kemp (1971) have recognised a series of buried raised beaches below the post-Glacial Carse Clay. The highest (and oldest) of these, the High Buried Beach at 12m above Ordnance Datum, is not developed west of the Menteith moraine and therefore cannot postdate the final retreat of ice of the Loch Lomond Stadial from the moraine. The two lower buried features, the Main Buried Beach (at 10m above Ordnance Datum) and the Lower Buried Beach (at 7m above Ordnance Datum), have been dated at 9600 years ago and 8800 years ago respectively, on the age of the base of the Sub-Carse Peat which overlies them (Sissons and Brookes, 1971).

The post-Glacial sea, after falling below the levels of the Main and Low buried beaches reached its lowest altitude about 8500 years ago and was at this time confined to an estuary which, although at a lower topographic level, was situated approximately on the line of the present course of the River Forth. The Sub-Carse Peat, which had begun to grow on the abandoned surfaces of the raised beaches as they were successively abandoned by the sea, was buried during the main post-Glacial transgression by marine deposits known as the Carse Clay: the sea reached its highest level about 6000 years ago.

During the subsequent fall of sea-level peat mosses grew extensively on the surface of the Carse Clay in the western part of the Carse of Stirling. Peat growth had persisted in part of the Flanders Moss area *[63 99]* throughout the period of high sea-level and here there exists a continuous peat sequence representing the period from 8000 years ago to the present day.

During the fall of the sea towards its present level the rivers Forth and Teith became incised into the surface of the Carse. In the valley of the River Teith broad alluvial terraces, composed mainly of sand and gravel were developed at levels below that of the Carse surface.

COMPOSITION OF THE MINERAL DEPOSITS

Particle size distributions for the three potentially workable deposits investigated by more than two sample points are portrayed graphically in Figures 3 to 5: detailed grading data for all potentially workable deposits are given in Tables 6 to 8 and summarised in Table 5.

Composition analyses (pebble-counts) were carried out on four composite samples, derived as shown in Table 2: for composite samples 2 and 3 it was necessary to group material from neighbouring boreholes in order to provide sufficient 10- to 14- mm material for the composition analyses and the mechanical testing. Three of the samples were taken from the statistically assessed deposits of block A: the fourth, from the glacial sand and gravel in the vicinity of Cambusbarron *[777 925]*. The testing programme was conducted on the same samples used for the pebble-counts so that any relationship between the mechanical and physical properties of the material and its petrography might be examined.

The classification used for the composition

Table 2 Source and geological classification of composite samples

Composite sample number	Resource block	Geological classification of deposit and location	Boreholes from which samples were taken	Depth range (m)	Number of bulk samples*
1	A	Fluvioglacial terrace deposit	79 NW 6	0.4-7.4	7
2	A	Buried fluvioglacial and late-Glacial sand and gravel deposits south and east of Blairdrummond	79 NW 7 79 NW 8 79 NW 13 79 NW 15 79 NW 16	1.4-6.5 5.0-20.5 4.7-7.6 3.2-6.1 4.0-7.1	5 7 3 3 3 (21)
3	A	Alluvium, fluvioglacial, post- and late-Glacial sand and gravel south-east of Ochtertyre	79 NE 8 79 NE 12	0.3-18.3 2.0-5.4	10 3 (13)
4	C3	Glacial sand and gravel south-west of Stirling (Cambusbarron)	79 SE 33	5.5-25.0	17

* Totals in parenthesis

Table 3 Pebble-counts of composite samples 1 to 4 (10- to 14-mm size fraction)

Composite sample number (for location see table 2)		1	2	3	4
British Standard Petrological Group	Rock Type				
BASALT (2)*	Basalt and andesite	4.5 *4.6*	2.6 *2.4*	9.5 *9.7*	2.5 *2.2*
GABBRO (4)	Diorite and microdiorite	- -	- -	0.3 *0.4*	- -
GRITSTONE (6)	Sandstone	23.9 *20.8*	12.8 *10.7*	20.1 *17.9*	35.6 *36.2*
PORPHYRY (9)	Felsite and porphyry	7.3 *7.3*	1.6 *2.1*	3.9 *5.2*	2.8 *2.5*
QUARTZITE (10)	Quartzite and psammite	55.7 *59.7*	70.7 *74.7*	50.3 *52.6*	51.1 *53.1*
SCHIST (11)	Schist	0.3 *0.1*	5.3 *4.3*	2.6 *2.5*	- -
OTHERS	Vein quartz	6.2 *5.8*	6.3 *5.7*	8.2 *8.1*	6.3 *5.4*
	Siltstone and mudstone	2.1 *1.7*	0.7 *0.2*	4.9 *3.6*	1.6 *0.6*
Number of pebbles counted		289	304	304	317

Results are given in frequency per cent with corresponding weight per cent in italics

*The numbers in parenthesis correspond with those used in BS 812.1:1975

analyses is based on the British Standard petrological groups (trade groups) as outlined in BS 812.1:1975 with the addition of an 'others' group which comprises vein-quartz, siltstone and mudstone. The analyses are presented in Table 3 as per cent number of clasts and weight per cent. Approximately 300 pebbles are included in each analysis, and it is assumed that the 10- to 14- mm size fraction is also representative of other sizes.

In each of the four samples which were examined the quartzite group was the most abundant, ranging from 52.6 per cent to 74.7 per cent by weight, and reflecting the Highland origin of much of the material in these deposits. The gritstone group comprises the greater part of the remainder of the samples, ranging from 10.7 per cent by weight in sample 2 to 36.2 per cent in sample 4.

Glacial sand and gravel The deposit, which is restricted to the south-eastern part of the resource sheet area, was proved at depth in borehole 79 SE 33: surface deposits were investigated by pit 79 SE 29 and form thin discontinuous spreads south-east of Croftstony *[7456 9236]* (Table 8). Borehole 79 SE 33 proved 19.5m of the glacial sand and gravel which shows a rapid vertical variation in grading ranging from pebbly sand to ill-sorted gravel with 10 per cent cobbles: it is likely that an equally rapid lateral inhomogeneity occurs within the sand and gravel.

Petrographic analysis of composite sample 4 from borehole 79 SE 33 (Table 3) shows that although quartzite is the principal consitituent, as in all the gravels of the resource sheet area, sandstone, which comprises 36 per cent, is more abundant than elsewhere: the clasts range across the whole spectrum of angularity although generally sandstone is more angular than quartzite, in part due to having been transported for a shorter distance.

Fluvioglacial sand and gravel Fluvioglacial deposits formed prior to the Loch Lomond Stadial only occur beneath the highest terraces north of Blair Drummond *[7322 9898]*. These sediments were investigated by borehole 79 NW 5 which showed the potentially workable part of the deposit to comprise 3.7m of 'clayey' sand (Table 6). This analysis is thought to be typical of the sediments underlying the terrace within the resource sheet area but farther north, borehole 70 SW 12, on the Callander and Dunblane resource sheet, proved silt (Merritt and Laxton, 1982).

Fluvioglacial sand and gravel of the Loch Lomond Stadial In this account these deposits, which are found both as terraces and in a buried fan beneath post-Glacial clay, are described with the potentially workable post-Glacial deposits proved in borehole 79 NE 12 and the alluvial deposits of the River Teith, both of which are compositionally very similar to the fluvioglacial sediments (Table

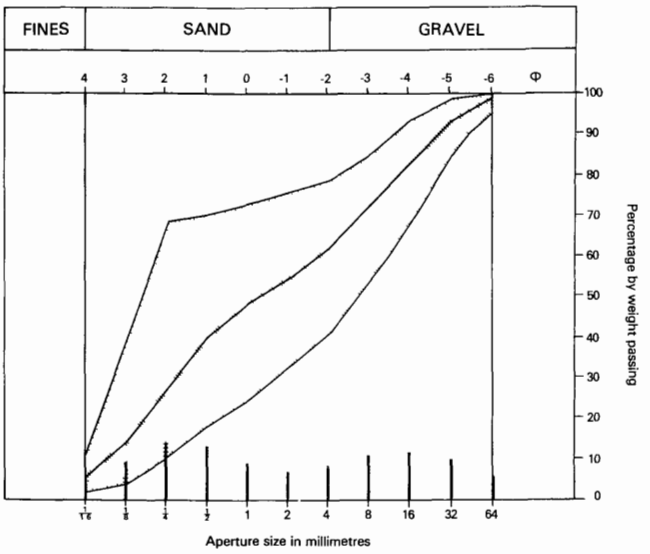

Figure 3 Grading characteristics of the deposits included in the statistical assessment of block A: the continuous line is the cumulative weighted mean; the broken lines denote the envelope containing the cumulative mean grading at individual sample points. The frequency distribution of the mean grading is represented by the bar graph, the abundance of +64mm material is not shown but can be determined from the line of the cumulative weighted mean

6 and Figure 3) and were laid down under similar sedimentological conditions. Figure 3 portrays the grading data for all the statistically assessed deposits of block A, that is, the fluvioglacial and associated deposits are included with the late-Glacial marine deposits proved in borehole 79 NW 16 which are compositionally analogous to the buried channel deposits described below. The principal effect on Figure 3 is to increase the width of the upper envelope, particularly in the fine sand grade.

The potentially workable fluvioglacial, post-Glacial and alluvial deposits grade predominantly as sandy gravel or gravel although pebbly sand was proved in boreholes 79 NW 17 and 79 NE 8: the 1.0m of alluvium proved in borehole 79 NE 12, and which grades as 'very clayey' sand, is not considered typical of this deposit. The sediments as a whole show no progressive vertical or lateral variation in grading other than in borehole 79 NE 8 where 3.9m of alluvial gravel overlies 2.0m of fluvioglacial sandy gravel on 5.6m of pebbly sand: the alluvium at this site was, with 76 per cent, the most gravelly of any of the fluvioglacial and associated deposits proved in boreholes. Taken as a whole these deposits, although relatively poorly sorted, have a distinct bimodality with peaks in the coarse gravel and fine to medium sand grades.

Composite samples 1 to 3, taken from different areas of the deposit (Table 2), show quartzite and psammite, of Highland origin, to be dominant with more locally-derived red sandstone comprising from 11 to 21 per cent by weight (Table 3). The greater abundance of material of Highland origin is due to its greater resistance to erosion, which also results in clasts of this material being generally more rounded than those of sandstone. Nevertheless it is not known why sample 2 has from 15 to 20 per cent by weight more psammite and quartzite than the other two samples.

Late-Glacial beach deposits Beach deposits, although widespread within the resource sheet area, were only shown to be potentially workable in the vicinity of Cambusbarron where borehole 79 SE 33 proved them to comprise 2.8m of sandy gravel overlying late-glacial marine deposits and glacial sand and gravel. The late-Glacial beach deposits in the resource sheet area are generally derived from the underlying sediments and it is the occurrence of glacial sand and gravel in this vicinity which has given rise to potentially workable beach deposits and explains why both are compositionally very similar.

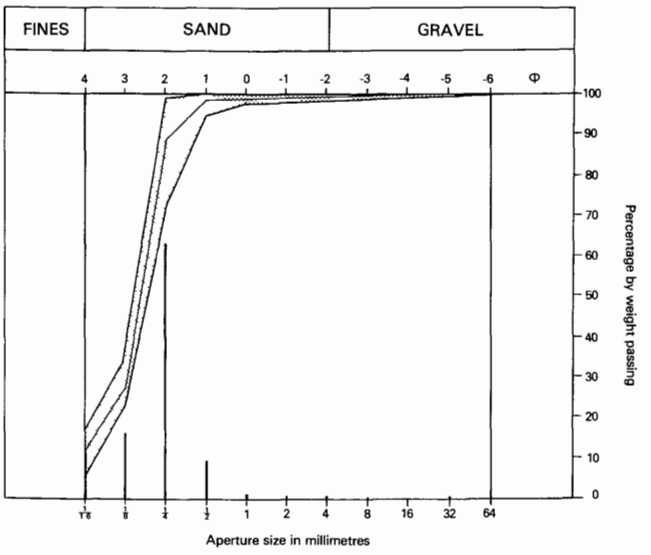

Figure 4 Grading characteristics of resources in the late- and post-Glacial buried channel deposits (for explanation see Figure 3)

Late- and post-Glacial buried channel deposits Five boreholes in Block B (Table 7) and one, 79 NW 16, in block A, prove these deposits to be mineral. The grading data for those sediments in block B are illustrated in Figure 4, which shows them to be strongly unimodal in the fine sand grade: although the deposits in borehole 79 NW 16 are not included in the diagram their particle size distribution is very similar. The buried channel deposits, which are of both late- and post-Glacial age, have been grouped together as they are considered to have formed under very similar, estuarine, conditions. The very narrow envelope about the mean grading of the sediments (Figure 4) is considered significant and not to be dependent on the relatively small number of sample points: it supports the contention that the sediments have a common origin.

Although predominantly of quartz the sand includes a little mica and, locally, shell fragments.

Post-Glacial buried raised beach deposits These sediments were shown to be potentially workable in three boreholes (Table 7) and their particle size distribution is illustrated in Figure 5. The mean grading of the buried beach deposits, like that of the channel deposits, is 'clayey' sand. In spite of being constructed on the basis of only three sample points the envelope about the mean of the buried beach deposits (Figure 5) is much wider

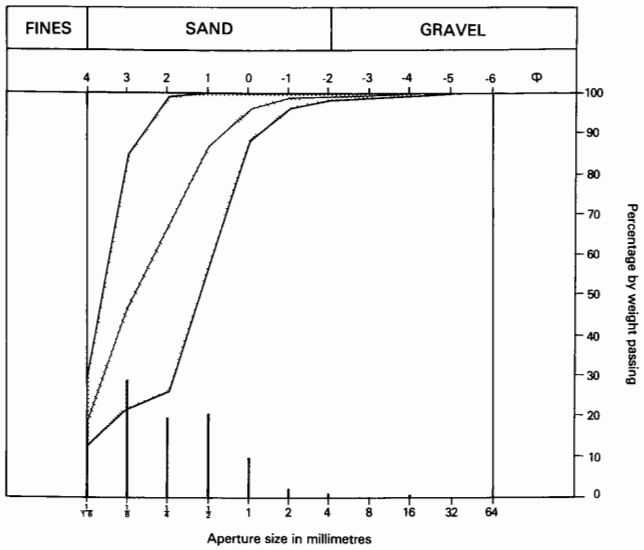

Figure 5 Grading characteristics of resources in the post-Glacial buried raised beach deposits (for explanation see Figure 3)

than that for the channel deposits (Figure 4): similarly the buried beach deposits are much more poorly sorted than the channel sediments, the dominant particle sizes being in the fine- to medium- sand grades. Together the grading envelope and poor sorting indicate a more variable and higher energy environment of deposition for the beach deposits, as would be expected.

Locally, mainly near the base of the sediments, gravel clasts are found and the sand, although predominantly of quartz, contains rock and some shell fragments.

Alluvial fan deposits These sediments proved to be potentially workable south of Watson House *[6925 9460]* and Gargunnock *[705 944]* where pit 69 SE 10 (Table 8) showed them to comprise pebbly sand. Both the sand and the gravel fractions of the deposit appear to have been largely derived from the underlying Upper Devonian sandstone, although the gravel also includes a little quartz and psammite: the sand is predominantly fine grade.

Alluvium Apart from the alluvium of the River Teith, which has been described above, the only potentially workable alluvial deposit is that of Bannock Burn. Pits 79 SE 31 and 35 show the deposit to comprise a very poorly sorted gravel with up to 31 per cent cobbles in pit 79 SE 31. Most of the clasts comprise basalt or dolerite, which crop out nearby, and this, along with the poor sorting, suggests the sediments have been transported only a very short distance.

MECHANICAL AND PHYSICAL PROPERTIES OF THE AGGREGATE

A programme of mechanical and physical testing, in accordance with BS 812:1975 was carried out on material from the four composite samples listed in Table 2. All the tests were conducted on the 10- to 14- mm fraction, obtained by resieving bulk samples after completion of particle size analysis. Around 17.5kg of material are required to determine aggregate impact value (AIV), aggregate crushing value (ACV), 10 per cent fines value, relative density (both oven-dried and surface-dried), apparent relative density and water absorption. In addition values of aggregate impact value residue (AIVR) and aggregate crushing value residue (ACVR), as defined by Ramsay (1965) and Ramsay, Dhir and Spence (1974) were calculated. The results of the compositional analysis (Table 3) were compared with those of the mechanical and physical testing (Table 4). Work by Ramsay (1965) and Ramsay, Dhir and Spence (1974) has shown that the principal petrographic factors affecting aggregate strength are: the strength of the intergranular cement in sedimentary rocks, and, in igneous rocks, the degree of crystal interlocking which decreases with increase in the surface area of crystals, therefore being inversely proportional to grain size. Additionally, in coarse grained igneous rocks the strength of individual crystals, a function of twinning, cleavage, and microfracture planes, becomes important. Weathering tends to reduce the strength of any rock.

Table 4 Results of mechanical and physical tests

Composite sample	Deposit type	AIV (%)	AIVR (%)	ACV (%)	ACVR (%)	10% fines value (kN)	Relative density (oven-dried basis)	Relative density (surface-dried basis)	Apparent relative density	Water absorption
1	Fluvioglacial terrace deposit	26	36	20	39	190	2.54	2.59	2.68	2.1
2	Buried fluvioglacial and late-Glacial deposits	23	34	20	40	200	2.58	2.62	2.68	1.4
3	Undifferentiated fluvial deposits	26	34	21	40	180	2.54	2.58	2.66	1.8
4	Glacial sand and gravel	26	37	21	42	180	2.42	2.50	2.62	3.1

The resistance of aggregate to impact is measured in the AIV test whereas the cataclasis produced by a slowly applied compressive load is measured in the ACV and 10 per cent fines value tests. In the AIV test the sample is subjected to fifteen blows of a standard magnitude: the weight of material passing a 2.36mm sieve is then compared to that of the original. The AIV test does not consider material which, although reduced in size, does not pass a 2.36mm sieve. However, in an aggregate it is frequently the ability of clasts to withstand impact relatively intact rather than to withstand a high level of comminution that is most important and for this reason Ramsay (1965) introduced the AIVR (aggregate impact value residue) which indicates the amount of +10mm material remaining after the AIV test. The 10 per cent fines value differs from the ACV in that it measures the load required to produce ten per cent fines in ten minutes as against measuring the degradation produced by applying a gradually increasing load attaining 400kN after ten minutes. In weaker aggregate the 10 per cent fines value is held to be a more sensitive indicator of strength than the ACV which, it is thought, becomes non-linear at values above about 30, further compaction being reduced by the infilling of spaces between particles with fine material (Cox, 1973). ACVR is defined in a similiar way to the AIVR.

The results of the AIV, ACV and 10 per cent fines tests (Table 4) appear to show composite sample 2 to be the strongest, although this may be misleading as the AIVR and ACVR indicate that this sample is no more able to withstand partial breakdown than the others. There is little variation between the results for the other three samples: sample 1 has slightly higher resistance to cataclasis, but again this is not reflected in the AIVR and ACVR. The samples appear to have the same relative strength both to impact and compression and to different levels of compression as reflected in the ACVR and 10 per cent fines tests. However, the present AIV results are all much higher than the average for worked gravels of 19 given in Edwards (1970).

It can be seen from the results of the pebble-counts (Table 3) that sample 2 contains a higher percentage of quartzite and psammite and a correspondingly lower proportion of sandstone than the other three samples, perhaps explaining its slightly better performance in the mechanical tests.

The water absorption value is a measure of the amount of water absorbed by the aggregate after 24 hours of immersion, expressed as a percentage of the oven-dried weight and is important because of its broad linear relationship with drying shrinkage, both of the aggregate itself and any concrete manufactured from it (Edwards, 1970). The drying shrinkage in turn is a key factor affecting the stress carrying and weathering ability of concrete. In very general terms quartz and flint give the lowest absorption, gritstone, mudstone and shale the highest, with acid igneous rocks having a lower absorption than more basic ones: weathering can increase the absorption of any rock.

The present study gives a range of water absorption values from 1.4 to 3.1 per cent which compare with the mean of 1.48 per cent given by Edwards (1970) for Scottish and English gravels. The values in Table 4 bear a close relationship to the petrogaphy, water absorption increasing in direct proportion to the presence of sandstone. Using the linear relationship between water absorption and concrete drying shrinkage given by Edwards (1970), samples 1 to 3 have inferred shrinkage values lying between 0.058 and 0.073 and would be suitable, with qualification, for most concreting applications. Sample 4, with the highest sandstone content, has an inferred shrinkage value in excess of 0.09 and such aggregate, if used in concrete manufacture, is likely to give rise to excessive drying shrinkage.

It must be emphasised that derived shrinkage values should be interpreted cautiously and that true values can only be obtained by laboratory testing of concrete blocks.

Values of relative density are quoted on both an oven-dried and a surface-dried basis, and again sample 4 is distinctive in having the lowest values.

THE MAP

The sand and gravel resource map is folded into the pocket at the end of this report. The base is the Ordnance Survey 1:25000 Outline Edition which together with the contours is printed in grey: the geological lines and symbols are in black. Mineral resource information, is presented in shades of red.

Geological data The geological boundary lines are taken from geological maps surveyed at the scale of 1:10000 or 1:10560; these offer the best interpretation of the available data but, due to the highly variable nature of the deposits, the accuracy of the map will be improved as new evidence from boreholes and excavations becomes available.

Borehole data, which include the stratigraphical relations and mean particle-size analysis of the sand and gravel samples collected during the assessment, are also shown on the map.

Mineral resource information The map is divided into resource blocks (see Appendix A) within which the extent of mineral-bearing ground is shown in red. The dark shade denotes where mineral is exposed, that is, the overburden averages less than 1.0m in thickness: a lighter tone is used to identify where it is present in relatively continuous spreads beneath overburden averaging more than 1.0m in thickness. Within these areas, however, there may be small patches where sand and gravel is absent or not potentially workable, as for example, around borehole 79 NE 10.

Areas where sand and gravel is deemed to be not potentially workable, where superficial deposits do not contain mineral, or where bedrock crops out, are shown uncoloured. Sand and gravel within built-up areas and patches too small to be assessed, but which may nevertheless be potentially workable, are indicated by red stipple.

For the most part the distribution of resource categories is based on mapped geological boundaries. Where transitions between categories cannot be related to the geological map, inferred boundaries have been inserted. Such boundaries, drawn primarily for the purpose of volume estimation, are shown by a distinctive zigzag symbol, which is intended to convey an approximate location within a likely zone of occurrence rather that to represent the breadth of the zone; its width is dictated by cartographic considerations. For the purpose of measuring areas the centre-line of the symbol is used.

THE ASSESSMENT

The resource sheet area, outwith the burghs of Stirling and Bridge of Allan, is divided into three resource blocks for assessment; the urban areas are not assessed. The block boundaries have been drawn both to provide sufficient sample points on which to base an assessment and to group together deposits of broadly similar origin and composition. As far as possible the block boundaries are determined by geological lines.

Fluvioglacial sand and gravel of the Loch Lomond Stadial is the most extensive potentially workable deposit within the resource sheet area and the boundaries of block A have been drawn, in the main, to delimit it. Block B includes all the remaining ground underlain by post-Glacial Carse Clay: the potentially workable deposits are buried channel and beach deposits of late- and post-Glacial age. Within the remaining, upland, ground sand and gravel is found in a diverse, but

Table 5 The sand and gravel resources: summary of statistical and inferred assessments

Resource block. Main mineral-bearing deposits	Number of sample points	Area		Mean thickness		Volume of sand and gravel			Mean grading percentage		
		Block	Mineral	Overburden	Mineral		Limits at the 95% probability level		Fines	Sand	Gravel
		km^2	km^2	m	m	$m^3 \times 10^6$	±%	$\pm m^3 \times 10^6$	$-\frac{1}{16}$ mm	$+\frac{1}{16}$ -4 mm	+4 mm
A											
Fluvioglacial sand and gravel of the Loch Lomond Stadial, alluvium, and late-Glacial marine deposits											
	38**		12.4	3.5	5.5	69	31	21	5	58	37
Fluvioglacial sand and gravel											
	2**		0.6	0.3*	4.9*	3*	-	-	11	89	0
Total		**14.4**	**13.0**								
B											
Post-Glacial buried raised beach deposits											
	3		2.7	4.6*	2.4*	6*	-	-	18	82	0
Post-Glacial buried channel deposits, north-west of Inch-of-Leckie [6792 9522]											
	4**		3.8	8.6*	8.4*	32*	-	-	12	88	0
Total		**67.8**	**6.6**								
C_1		19.4	0.0								
C_2		4.0	0.0								
C_3											
Late-Glacial beach deposits and glacial sand and gravel at Cambusbarron											
	2**		1.0	0.2*	15.7*	15*	-	-	4	50	46
Glacial sand and gravel between Touch House [7530 9277] and Chartershall [7926 9028]											
	1		1.2	0.3*	1.2*	1*	-	-	8	60	22
Alluvium of Bannock Burn											
	1**		0.3	0.6*	2.1*	1*	-	-	7	26	67
Alluvial fan deposits near Gargunnock											
	1		0.4	0.5*	1.5*	1*	-	-	7	81	12
Total C_3		**83.9**	**2.9**								
Total A to C	**52**	**189.5**	**22.5**	**4.0**	**5.7**	**128**	**-**	**-**	**8**	**66**	**26**

* Inferred assessment

** Includes non-IMAU borehole information. Many sample points in block A have a weighting of less than 1

Notes

1. Overall mean overburden and mineral thickness have been derived by weighting values from individual assessed deposits by the area of the deposits. Overall mean grading is determined by weighting individual values by the respective volumes

2. Figures may not sum to total shown because of rounding

areally restricted, range of deposits which are described in block C; this block is divided into three sub-blocks for geographical convenience. The mineral resources are described in the notes on the resource blocks and, following these, some conclusions are offered regarding the resources most likely to command attention in the short-to-medium term.

RESULTS

The results of the assessment of resources are summarised in Table 5 and more detailed grading and thickness data by block are given in Tables 6 to 8. At the borehole density adopted for the present survey only in block A are the potentially workable deposits sufficiently extensive for there to be enough sample points to make a statistical assessment, the procedure for which is outlined in Appendix B. All sand and gravel deposits in Block A are assessed together, with the exception of those underlying the high fluvioglacial terrace north of Blair Drummond *[7322 9898]* , for which a separate, inferred, assessment is provided. When calculating mean thickness for the statistical assessment of block A all boreholes within the area of potentially workable material shown on the map have been considered; a nil thickness is taken for those boreholes which, although not proving potentially workable material, lie within an area where mineral generally occurs.

For blocks B and C inferred assessments are provided for six areas which range from 0.3 km^2 to 3.8 km^2: isolated patches of sand and gravel of smaller area, and locally potentially workable till, have not been assessed.

Accuracy of results For block A the accuracy of the statistical assessment at the 95 per cent probability level is 31 per cent (that is, it is probable that on average nineteen out of every twenty sets of limits constructed in this way contain the true value for the volume of mineral). However, the real value is more likely to be near the median than the limits. Moreover, it is probable that roughly the same percentage limits would apply to the estimate of mineral volume within a very much smaller parcel of ground (for example, 100 hectares) containing similar sand and gravel deposits, if the results from sample points with the same cumulative weighting (13) were used in the calculation. Thus, if closer limits are needed for the quotation of reserves, data from more sample points would be required.

For each block the total volume present in the ground is given in millions of cubic metres. An impression of the quantities present over part of a block may be gained by careful examination of the thickness of mineral proved in boreholes lying within or close to a particular area of interest, but such data must be considered within the context of the mean thickness and range of values proved for the block as a whole. It cannot be over-emphasized that any attempt to use the data presented in this report to evaluate parts of a block must be approached most cautiously as data quoted for an individual borehole or pit refer strictly to that site.

The amount of recoverable resources will depend on many factors not least of which are working practice, the size and shape of the area for exploitation, planning and judicial constraints. Because there are so many variables, it is not possible to suggest what proportion of the in-situ resources either for a block as a whole, or for part of it, may prove to be recoverable.

NOTES ON THE RESOURCE BLOCKS

Block A

From Blair Drummond to the northern limit of the resource sheet the River Teith flows in a valley margined by fluvioglacial terraces which locally attain a height of 40.8m above Ordnance Datum (Smith and others, 1978); the block boundary follows the geological boundary of the outermost limit of the highest terrace. Further east the northern margin of the block boundary is drawn along the edge of the post-Glacial deposits whereas in the south, east, and west, it follows an inferred boundary (zigzag line) delimiting the extent of buried potentially workable fluvioglacial deposits.

The fluvioglacial terrace deposits formed during the retreat of the main late-Devensian ice are distinguished from the fluvioglacial terrace deposits of the Loch Lomond Stadial on the basis of height. The former were investigated by borehole 79 NW 5 which proved the feature to be underlain by 3.7m of 'clayey' sand (Table 6) on laminated clay of possible late-Glacial marine origin. Although a borehole on this terrace to the north of the resource sheet, sunk for an assessment of the sand and gravel resources of the Callander and Dunblane areas (Merritt and Laxton, 1982), showed it to be underlain by silt, commercial borehole 79 NW 1/6 situated near the northern margin of the Stirling resource sheet area indicated 6.1m of mineral beneath the terrace. On this basis it is considered that the entire fluvioglacial terrace south of northing 00 is underlain by mineral, for which an inferred assessment is 3 million m^3.

The fluvioglacial terrace on the western side of the valley of the River Teith is separated from the lower fluvioglacial terraces of the Loch Lomond Stadial by an area of till and late-Glacial raised beach deposits which are considered to be non-mineral by analogy with similar deposits to the west within block C_1. The lower terraces are worked in a quarry extending over the northern margin of the resource sheet area and were investigated by borehole 79 NW 6 which proved 7.0m of gravel on late-Glacial marine clay and till. Although not investigated by boreholes, field evidence suggests that on the eastern side of the valley of the River Teith the higher, fluvioglacial terrace deposits are predominantly coarse sand and gravel, and for assessment purposes they have been considered along with the lower terraces.

Apart from alluvial deposits of the River Teith, which are extensive south-east of Ochtertyre *[7505 9784]* , the remainder of the block is covered by post-Glacial clay with silt. The clay which formed in an estuarine environment is generally grey, laminated, moderately stiff, and homogeneous both laterally and vertically. Boreholes sited on the post-Glacial deposits show them to range up to 8.8m in thickness in borehole 79 NE 10 and generally to overlie potentially workable sand and gravel. Kemp (1971) and Smith and others (1978) consider this underlying deposit to be a buried fan both continuous and contemporaneous with the main Loch Lomond Stadial terrace deposits north of Blair Drummond. Boreholes sunk during the present survey and commercial records show the upper surface of the buried deposit to incline to the south and south-east from Blair Drummond (Figure 6 and section 2 on the map), the depth of burial ranging from 1.4m in borehole 79 NW 7 to 9.1m in borehole 79 NE 10. The fluvioglacial sand and gravel also generally thins in all directions away from Blair Drummond. It was proved to be 0.5m thick in

Table 6 Block A: Data from sample points and the assessment of resources

Sample point	Recorded thickness			Mean grading percentage							
Borehole	Total mineral	Depth of burial	Intervening waste	Fines	Fine sand	Medium sand	Coarse sand	Fine gravel	Coarse gravel	Cobbles and boulders	Descriptive category (see the diagram in Appendix C)
	m	m	m	$-\frac{1}{16}$ mm	$+\frac{1}{16}$ $-\frac{1}{4}$ mm	$+\frac{1}{4}$ -1 mm	+1 -4 mm	+4 -16 mm	+16 -64 mm	+64 mm	
FLUVIOGLACIAL SAND AND GRAVEL OF THE LOCH LOMOND STADIAL, ALLUVIUM, POST-GLACIAL DEPOSITS AND LATE-GLACIAL MARINE DEPOSITS											
79 NW 6	7.0	0.4	-	7	6	11	17	27	29	3	G
79 NW 7	5.1	1.4	-	4	6	17	19	33	21	0	G
79 NW 8	5.5	5.0	4.7	4	12	32	17	21	10	4	SG
79 NW 13	2.9	4.7	-	3	11	27	17	29	13	0	SG
79 NW 15	2.9	3.2	-	4	16	29	22	20	9	0	SG
79 NW 16	9.3	4.0	0.6	11	58	4	6	10	10	1	CPS
79 NW 17	5.3	4.5	-	2	11	42	21	18	6	0	PS
79 NE 8	11.5	0.3	-	3	25	28	9	17	17	1	SG
79 NE 10	0.0	-	-	-	-	-	-	-	-	-	-
79 NE 12	4.4	1.0	-	7	17	13	11	33	18	1	G
Mean	5.5	3.5	0.4	5	23	21	14	21	15	1	SG
FLUVIOGLACIAL SAND AND GRAVEL											
79 NW 5	3.7	0.3	-	11	69	20	0	0	0	0	CS

Statistical assessment of all deposits other than fluvioglacial sand and gravel

Area of mineral-bearing ground	12.4km^2
Mean thickness of overburden	3.5m
Mean thickness of mineral	5.5m
Estimated volume of mineral	**69 million m^3**

Statistical assessment of fluvioglacial sand and gravel

Area of mineral-bearing ground	0.6km^2
Mean thickness of overburden	0.3m
Mean thickness of mineral	4.9m
Estimated volume of mineral	**3 million m^3**

borehole 79 NW 4 but both here, and in boreholes 79 NW 10 and 11, all in block B, the deposit is not potentially workable because it fails to satisfy the criteria of thickness and overburden ratio adopted for the survey: the margin of block A limits the area of potentially workable fluvioglacial sand and gravel.

The fan deposits generally grade as gravel or sandy gravel (Table 6 and Figure 4); Kemp (1971) suggested there is a fining towards the margin of the fan but the evidence from the present survey does not substantiate this contention. However, in borehole 79 NE 8 there is fining with depth, 2.0m of sub-alluvium sandy gravel overlying 5.6m of pebbly sand. In borehole 79 NW 16 an upper gravel layer overlies 'clayey' sand but here the two deposits are separated by 0.6m of reddish brown laminated clay, considered to be of late-Glacial marine origin. The 'clayey' sand, therefore, predates the formation of the fluvioglacial fan and was probably deposited in early late-Glacial times, as an estuarine channel deposit associated with an early outflow from the valley of the River Teith.

Although the greater part of the fan probably formed during the Loch Lomond Stadial there is evidence that gravel deposition has continued to the present day. Kemp (1971) notes the presence of gravel lenses within the post-Glacial clay and borehole 79 NE 12 proved 3.4m of sub-alluvium gravel, indistinguishable from the fluvioglacial fan deposits but with abundant oyster shells near the base, indicating relatively warm water conditions at the time of deposition. Borehole 79 NE 8 was sited on the alluvial flat of the River Teith and proved an upper 3.9m layer of gravel with organic bands, (possibly old soil levels) on sandy gravel and pebbly sand. The gravel is considered to be typical of recent alluvial deposition by the River Teith. The underlying deposits have been classified as part of the fluvioglacial fan, but, as the alluvium is derived by reworking of fan deposits, the two are difficult to distinguish. At borehole 79 NE 12 the alluvium appears to be represented by only a metre of 'very clayey' sand and it is likely that the small patches of alluvium further downstream from this borehole are not potentially workable due to excessive fines.

In the area north of Greenocks *[7668 9649]*, between the River Teith and Bridge of Allan, there are numerous commercial boreholes which have been used to determine the thickness and extent of the fan deposits. These indicate that borehole 79 NE 10, sunk during the present survey, is atypical in proving the fluvioglacial deposits to have too great an overburden to be potentially workable. North-east of Moss Farm *[7750 9693]* records indicate a substantial thickening of the fluvioglacial deposits which Kemp (1971) suggested may infill a depression in the bedrock surface; the alignment of these thicker deposits towards the point at which the Allan Water flows out onto the post-glacial clay suggests the sediments may be the result of deposition by an early course of this river. To the north of Moss Farm commercial records and borehole 79 NE 11 delimit an area where sand and gravel is either absent or not potentially workable; Kemp (1971) suggested both non-deposition and subsequent erosion in

post-Glacial times as possible explanations. For assessment purposes all deposits, except the fluvioglacial sand and gravel formed during the main late-Devensian ice retreat, have been assessed together (Table 6 and Figure 3). The volume is assessed at 69 million m^3 ± 31per cent: the mean grading is 5 per cent fines, 58 per cent sand, 37 per cent gravel (sandy gravel).

The buried fluvioglacial deposits overlie late-Glacial marine sediments in all boreholes except 79 NW 15 and 17, where they rest directly on till. The marine deposits are not potentially workable, apart from the 'clayey' sand in borehole 79 NW 16, and comprise predominantly clays and silts. Boreholes 79 NW 8 and 79 NE 9 proved a basal sandy gravel layer and 79 NE 11 1.9m of 'very clayey' sand: this sand and gravel is not potentially workable due to excessive overburden. Where the base of the late-Glacial marine deposits was proved they rested on till except in borehole 79 NE 8 where they lie on rock. Where the full thickness of till was proved it ranged from 0.4m in borehole 79 NW 15 to 6.5m in borehole 79 NW 13 and, except in borehole 79 NW 17, overlay rock: nowhere is the till potentially workable. Borehole 79 NW 17 found 8.6m of laminated silt, which has been classified as glaciolacustrine mainly on the basis of its position beneath 3.3m of very stiff till. It is possible the soft sediments were overridden, rather than eroded, by the ice that deposited the till, due to their position in the lee of the bedrock knoll south of Nyadd *[7420 9742]* . The glaciolacustrine sediments are probably late-Devensian in age, the overlying till is thought to be the product of a temporary readvance during the main ice retreat. However, it is possible that the silts are much older and formed either during an interstadial or interglacial period: as no organic remains were identified in the silt this cannot be substantiated.

Block B

All of the flat Carse land west of the urban areas of Stirling and Bridge of Allan, other than that within block A, is included in block B. The Carse owes its distinctive topography to the drift geology. The extremely flat country seen today masks an over-deepened glacial valley which was progressively filled during late- and post-Glacial times by estuarine, outwash, and beach deposits. Post-Glacial deposits or peat are found at surface over the greater part of block B and the block boundary in the main follows the geological boundary of these deposits against till or rock which form the higher ground of block C. In the north-west, and locally in the west and east, the block extends to the margin of the resource sheet area: in the north-east it is limited by the inferred boundary marking the extent of the potentially workable fan deposits of block A, and in the east it abuts the unassessed urban areas of Stirling and Bridge of Allan.

Within historical times the greater part of the area was covered by peat, but this was largely stripped-off in the eighteenth and nineteenth centuries to expose the post-Glacial clay and thus bring the ground into cultivation. However, residual areas of peat remain throughout the area, by far the most extensive being Flanders Moss which ranges up to 7.5m in thickness (Francis and others, 1970). Small areas of clayey alluvium locally margin the River Forth: compositionally similar deposits downstream of Old Mills Farm *[7796 9576]* are inter-tidal and distinguished as reclaimed inter-tidal flats on the resource map. Along the southern margin of the block many of the small streams running off the high ground have produced alluvial fans which rest on the post-Glacial clay: field evidence suggests these are not potentially workable.

Apart from the exceptions already described and bedrock knolls which crop out at Hill of Drip *[7662 9560]* and Craigforth *[774 948]* , the surface deposit throughout the block is post-Glacial clay: known as the Carse Clay, it is generally stiff and grey with brown mottling near the surface. Along the line of the deepest part of the buried valley underlying the southern Carse (sections 1 and 2) it is thought there was continuous, essentially estuarine, deposition from when the area was deglaciated in late-Glacial times, subsequent to the main late-Devensian ice retreat, until the end of the sedimentation of Carse Clay. In order to distinguish the late-Glacial estuarine deposits proved in boreholes three criteria have been used: in the area south and south-east of Blair Drummond the buried fluvioglacial fan gravel, of Loch Lomond Stadial age, is considered to separate late- and post-Glacial estuarine deposits; for some boreholes palaeontological evidence has helped indicate the palaeo-environment which, considered within the broad stratigraphic framework, permits the age of the deposits to be inferred; and finally, lithological criteria locally distinguish late- from post-Glacial deposits, in particular, reddish tinged clay is thought to be late-Glacial. However, in certain boreholes there is little hard evidence and the distinction of late- from post-Glacial deposits is largely arbitrary. Nevertheless it is considered that generally the relative thickness of the deposits shown on the logs and in sections 1 and 2 is of the right order.

Locally, generally near the edge of the Carse, the post-Glacial deposits comprise only clay (for example, borehole 69 NE 12), but more usually clay overlies a varied sequence of post-Glacial sediments. Borehole 69 NW 11 shows the clay to be underlain by peat which rests in turn on silt and 'clayey' sand, thought to form a post-Glacial buried raised beach (Sissons, 1966), overlying late-Glacial deposits. A sequence similar to this is found beneath both the northern part of the Carse and the southern fringe. Local variations are common, however; for instance, peat is found either within the Carse Clay (for example boreholes, 79 NW 10 and 79 SE 30) or to be absent (for example, boreholes 69 NW 5 and 7). Similarly, post-Glacial beach deposits grading as mineral are only found in boreholes 69 NW 11, 14, 69 NE 8, 14 and 17, of which the deposits in the last two named are not potentially workable due to excessive overburden: more generally the buried post-Glacial raised beach deposits were found to comprise silt alone. On the basis of the borehole evidence it is considered that the post-Glacial beach deposits contain material grading as mineral beneath most of the area north-west of Powblack *[6696 9696]* . In the south-east these deposits become not potentially workable due to an excessive overburden of Carse Clay and non-mineral beach deposits, whereas to the north-west beneath Flanders Moss, the increased thickness of peat overburden renders the deposits non-mineral. Borehole and auger information, have been used to define a crescent-shaped area from *[638 977]* to *[620 998]* , which may be more or less extensive than indicated, where it is considered overburden is sufficiently thin for the post-Glacial beach deposits to be potentially workable. A volume of 6 million m^3 may be inferred: the mean grading is 18 per cent fines, 82 per cent sand ('clayey' sand) (Tables 5 and 7).

On the basis of boreholes sunk during the

Table 7 Block B: Data from sample points and the assessment of resources

Sample point	Recorded thickness			Mean grading percentage							
Borehole	Total mineral m	Depth of burial m	Intervening waste m	Fines $-\frac{1}{16}$ mm	Fine sand $+\frac{1}{16}$ $-\frac{1}{4}$mm	Medium sand $+\frac{1}{4}$ -1 mm	Coarse sand +1 -4 mm	Fine gravel +4 -16 mm	Coarse gravel +16 -64 mm	Cobbles and boulders +64 mm	Descriptive category (see the diagram in Appendix C)
POST-GLACIAL BEACH DEPOSITS											
69 NW 11	2.1	3.6	-	14	12	62	11	1	0	0	CS
69 NW 14	3.0	4.8	-	13	60	27	0	0	0	0	CS
69 NE 8	2.0	5.5	-	29	70	1	0	0	0	0	VCS
Mean	2.4	4.6	-	18	49	30	3	0	0	0	CS
POST-GLACIAL AND LATE-GLACIAL BURIED CHANNEL AND MARINE DEPOSITS											
69 NW 16	7.0	8.0	-	6	76	16	1	1	0	0	S
69 NE 9	15.7+	10.2	-	17	76	7	0	0	0	0	CS
69 NE 10	3.0	9.0	-	4	95	1	0	0	0	0	S
Mean of assessed channel deposits	8.4	8.6	-	12	79	9	0	0	0	0	CS
79 NW 12	10.0	12.0	-	8	85	6	1	0	0	0	S
79 SE 26	5.0	11.0	-	10	62	26	1	0	1	0	CS
Mean of all channel deposits	8.1	9.6	-	11	78	10	1	0	0	0	CS

Inferred assessment of Post-Glacial buried raised beach deposits

Area of mineral-bearing ground	2.7km^2
Mean thickness of overburden	4.6m
Mean thickness of mineral	2.4m
Estimated volume of mineral	**6 million m^3**

Inferred assessment of Post-Glacial buried channel deposits

Area of mineral-bearing ground	3.8km^2
Mean thickness of overburden	8.6m
Mean thickness of mineral	8.4m
Estimated volume of mineral	**32 million m^3**

present survey, records of older, deeper, boreholes (for example, 69 NE 2), and geophysical evidence presented by Francis and others (1970), the sub-Carse topography can be seen to be strongly asymmetric with a deep buried basin or valley beneath the southern part of the Carse (sections 1 and 2). The post-Glacial deposits within this area are distinct and generally comprise solely clay, as in boreholes 69 NW 10, 69 NE 19, 21, 26, 79 NW 14. However, assessment boreholes 69 NW 16, 69 NE 9, 10, 79 NW 12 and 79 NE 9, along with an older IGS borehole 69 NE 3, and a commercial bore not shown on the map, all proved deposits which grade from sand to 'very clayey' sand, and are up to more than 15.7m thick in borehole 69 NE 9: only in borehole 79 NE 9 are these deposits not potentially workable due to excessive overburden. Largely on the basis of palaeontological evidence from borehole 69 NE 10 and 79 NW 12, it is considered these sediments are post-Glacial, although the occurrence of the deposits in borehole 69 NE 9 to a depth in excess of 13.7m below Ordnance Datum may be indicative of an earlier age for the lower part of the deposit. Both the greater depth to the base of the sands relative to that of the post-Glacial clay, and their areal distribution suggest the former deposits were laid down in estuarine channels (sections 1 and 2). North-west of Inch-of-Leckie *[6792 9552]* borehole evidence has enabled boundaries to be drawn which approximately define the most extensive area of buried potentially workable channel deposits: an inferred assessment of these is 32 million m^3: the mean grading is 12 per cent fines and 88 per cent sand ('clayey' sand) (Tables 5 and 7). It is not possible on the basis of the available data to determine the much more limited areal extent of the potentially workable channel deposits proved in borehole 79 NW 12 and no assessment is offered.

Near the margins of the Carse, as well as in the vicinity and to the east of Hill of Drip, post-Glacial deposits rest directly on till or bedrock (for example, boreholes 69 NE 12, 22 and 79 NE 13): late-Glacial deposits are also absent beneath much of the buried raised beach north-west of Powblack *[6696 9696]* (for example, boreholes 69 NW 14 and 69 NE 14). In contrast, beneath the remainder of the Carse, post-Glacial deposits rest on late-Glacial sediments (sections 1 and 2), the latter deposits being predominantly silts and clays although boreholes 69 NE 26, 79 SW 13, 79 SE 26 and 30 prove material of presumed late-Glacial age which grades as potentially workable sand or 'clayey' sand. These sands are generally similar to the post-Glacial channel deposits and are thought to have formed in a similar environment. The late-Glacial sands are, however, generally thinner, and when the overburden ratio is

considered, only those in borehole 79 SE 26 are potentially workable (Table 7); they have not been assessed as there are insufficient data to determine their limited areal extent. Borehole 69 NE 2 indicates the existence of thick sand deposits within the lower part of the late-Glacial sequence which extends down to depths of around 100m below Ordnance Datum, but such deposits are considered to be too deeply buried to be potentially workable. Above the overdeepened southern part of the Carse, assessment boreholes were terminated within the late-Glacial sequence (for example, 69 NW 10, 69 NE 19 and 79 NE 9), but marginal to this, and beneath the northern Carse, boreholes show the late-Glacial, or post-Glacial where the former is absent, to rest on till or rock (sections 1 and 2). Although many boreholes (for example, 69 NW 12 and 79 NE 16) found the till to be sandy, nowhere was it sufficiently so to be potentially workable.

Block C

Those parts of the resource sheet area which are neither included in blocks A and B, nor are within the urban areas of Stirling and Bridge of Allan, are assigned to block C. This block comprises mainly upland ground, marginal to the flat Carse country and has been divided into three sub-blocks primarily on geographical grounds.

Sub-block C_1 Extending from Thornhill *[665 000]* to north of Bridge of Allan the sub-block includes all the country to the north of the Carse other than the terraces of the River Teith, which are assigned to block A and separate sub-block C_1 into two areas, to the east and west of the River Teith respectively.

The southern margin of the sub-block is generally marked by a cliff which delimits marine post-Glacial deposits, a feature that is particularly well developed where cut in rock as to the east of Craighead *[6886 9801]* . The topography rises to the north and north-east, the greater part of the ground being covered by till through which knolls of bedrock commonly crop out, indicating that the drift generally only forms a thin cover.

Field survey shows that generally the till, although locally sandy and silty, has the same predominantly clayey matrix as the till which underlies the post- and late-Glacial deposits of the Carse. However, two out of three boreholes sunk in connection with the construction of the M9 north of Knockhill *[7806 9784]* indicated the presence of sand and gravel beneath a till cover. In addition, pit 79 NE 14 showed the upper 1.6m of till hereabouts, although non-mineral, to have a very sandy, clay-bound, matrix. It is likely that at greater depth, near the junction with the underlying Lower Devonian bedrock, the sand content of the till matrix is sufficient for the deposit to be considered potentially workable. However, the available evidence indicates that mineral till is only developed locally and no assessment has been attempted.

An extensive area in the southern part of the sub-block between Thornhill *[665 000]* and the River Teith, and smaller patches of ground east of the river, are underlain by late-Glacial beach deposits. West of the River Teith these sediments were investigated by pits 69 NE 11, 16, 23 and 79 NW 9 which showed them to comprise a diverse sequence from 0.4m to 1.0m in total thickness, the grain size of individual beds ranging from a 0.2m band of silty clay in pit 69 NE 23 to 0.4m of sandy gravel in 79 NW 9: field evidence (Browne and others, 1981) indicates that the deposits in the vicinity of Arnhall Castle *[7638 9854]* , east of the River Teith, comprise predominantly clays and sands classified as late-Glacial marine deposits. The deposits in pit 69 NE 11 were poorly bedded and those in pits 69 NE 23 and 79 NW 9 exhibited imbrication of the platey sandstone clasts, suggestive of deposition in a high-energy environment such as a beach. Although locally the late-Glacial beach deposits grade as mineral (for example pits 69 NE 16, 23, and 79 NW 9) all data points show such material to be less than a metre in thickness and therefore not potentially workable in terms of the criteria adopted for this survey.

Small patches of alluvium fill hollows throughout the sub-block but these sediments are nowhere considered to be mineral.

Sub-block C_2 Lying in the north-west of the resource sheet area the sub-block comprises two discrete, relatively small, and generally till-covered areas. These are separated by the valley of the River Forth and margined by the post-Glacial Carse Clay. The topography is more hummocky but less high than that of sub-blocks C_1 and C_3 and is continuous with an area of moundy sand and gravel deposits lying just to the west of the resource sheet. The area as a whole is part of a feature which has a general north-south alignment across the valley and was identified as a terminal moraine of the Loch Lomond readvance by Simpson (1933) (in this report termed the Loch Lomond Stadial). In its western part, the moraine is formed largely of glacially transported marine clays and fluvioglacial deposits (Sissons, 1966). Farther east, within the resource sheet area, the deposit was investigated by borehole 69 NW 9 and pits 69 NW 1, 2, 4 and 6 which showed it, in the main, to be a clayey till indistinguishable from that deposited by the main late-Devensian ice-sheet. Bedrock crops out in the post-Glacial cliff south of Cardross *[6049 9765]* , in a small patch at *[6056 9823]* , and was proved at a depth of only 2.7m in borehole 69 NW 9, strongly suggesting that within the sub-block till is generally only a thin cover on rock.

It is likely that a rock ridge hereabouts acted as a barrier to the eastward progress of ice during the Loch Lomond Stadial: morainic deposits built up against this ridge although local over-riding occurred. Thus the thickest moraine occurs to the west of the ridge, outside the resource sheet area, and it is likely that within the sub-block much of the till was formed by the earlier main late-Devensian ice-sheet. Locally, however, as in pit 69 NW 4, the till includes highly contorted laminated clay and silt with questionable shell fragments. Such material is probably equivalent to the glacially transported deposits within the moraine from which Sissons (1967) obtained shells having a radio-carbon date of 11800 ± 170 years. This date places an upper limit on the age of these sediments and suggests that their incorporation in the moraine occurred during the Loch Lomond Stadial. Further to the east, evidence as to the age of the deposits is provided by a raised beach feature cut in the sandy till east of borehole 69 NW 9. This lies one to two metres higher than the peat of Flanders Moss, which abuts it to the east, and is therefore in the order of six metres above the post-Glacial Carse Clay. The feature, and the deposits into which it is cut, are therefore probably of late-Glacial age but pre-date the Loch Lomond Stadial when the sea was at a much lower level. Locally, particularly in the vicinity of Flanders Hill *[620 990]* thicker, sandy deposits occur which in

Table 8 Block C: Data from sample points and the assessment of resources

Sample point	Recorded thickness			Mean grading percentage							Descriptive category (see the diagram in Appendix C)
Borehole	Total mineral m	Depth of burial m	Intervening waste m	Fines $-\frac{1}{16}$ mm	Fine sand $+\frac{1}{16}$ $-\frac{1}{4}$mm	Medium sand $+\frac{1}{4}$ -1 mm	Coarse sand +1 -4 mm	Fine gravel +4 -16 mm	Coarse gravel +16 -64 mm	Cobbles and boulders +64 mm	
SUB-BLOCK C_2 TILL											
69 NW 6	1.4+	0.7	-	7	35	18	6	21	9	4	SG
SUB-BLOCK C_3 LATE-GLACIAL BEACH DEPOSITS AND GLACIAL SAND AND GRAVEL											
79 SE 29	1.2	0.3	-	8	43	17	10	11	11	0	PS
79 SE 33	22.3+	0.1	2.8	4	18	18	14	22	20	4	SG
79 SE 34	1.0	0.3	-	31	45	9	3	6	6	0	VCPS
ALLUVIAL FAN DEPOSITS											
69 SE 10	1.5+	0.5	-	7	68	11	2	5	7	0	PS
ALLUVIUM OF BANNOCK BURN											
79 SE 31	1.3+	0.3	-	6	4	9	12	19	19	31	G
79 SE 35	0.8+	0.8	-	9	7	11	9	23	29	12	G
Mean of alluvium			-	7	5	10	11	20	23	24	G

Inferred assessment of late-Glacial beach deposits and glacial sand and gravel at Cambusbarron

Area of mineral-bearing ground	1.0km^2
Mean thickness of overburden	0.2m
Mean thickness of mineral	15.7m
Estimated volume of mineral	**15 million m^3**

Inferred assessment of alluvium of Bannock Burn

Area of mineral-bearing ground	0.3km^2
Mean thickness of overburden	0.6m
Mean thickness of mineral	2.1m
Estimated volume of mineral	**1 million m^3**

Inferred assessment of glacial sand and gravel between Touch House and Chartershall

Area of mineral-bearing ground	1.2km^2
Mean depth below surface	0.3m
Mean thickness of mineral	1.2m
Estimated volume of mineral	**1 million m^3**

Inferred assessment of alluvial fan deposits near Gargunnock

Area of mineral-bearing ground	0.4km^2
Mean thickness of overburden	0.5m
Mean thickness of mineral	1.5m
Estimated volume of mineral	**1 million m^3**

the past have been worked on a small scale: it is possible these were formed in the Loch Lomond Stadial as fluvial ice-front deposits.

Pit 69 NW 6 proved more than 1.4m of potentially workable till, grading as sandy gravel, underlying 0.4m of clayey till (Table 8). Although the deposits at Flanders Hill may be of considerable thickness they, along with that proved in pit 69 NW 6, are considered to be of highly variable composition and limited areal extent: no assessment has been attempted.

In the vicinity of *[601 961]* a small area of post-Glacial deposits has been included within the sub-block for geographical convenience: it is likely that till of the moraine complex underlies a thin cover of Carse Clay.

Sub-block C_3 This, the largest of the sub-blocks, covers all the ground south of the Carse apart from that included within the urban area of Stirling. The sub-block has three topographic sub-divisions which reflect the underlying solid geology. Below and to the north-west of a pronounced scree-margined scarp, running from *[630 900]* to *[745 937]*, the ground is underlain by Upper Devonian and Lower Carboniferous sediments which give a terrain of low hills aligned generally to the east-north-easterly strike of the rocks. The drift cover is predominantly of till although there are many bedrock outcrops, and streams draining to the Carse have generally cut down to rock. The till cover is therefore considered to be thin and, where investigated by pit 69 SE 9 near the base of the scarp face, proved to be very stiff with abundant large clasts. Nowhere within the sub-block is till considered to be potentially workable.

The scarp is formed by a thick sequence of Carboniferous lavas which dip to the south-east and underlie all but the extreme south-east of the remainder of the sub-block. The lavas form the highest ground within the resource sheet area and are overlain in their western part by a thin cover of peat through which they frequently crop out. In the vicinity of Touch Muir *[72 91]* is an area

of till mounds but to the east of this there is little drift cover on the lavas. In the extreme east and south-east of the sub-block the topography is more subdued being underlain by Carboniferous sediments.

Mounds, ridges and spreads of glacial sand and gravel are aligned south-east from Croftstony *[7456 9236]* to the margin of the resource sheet area. The largest and most northerly of these areas lies south of Touch House *[7530 9277]* and was examined by pits 79 SE 28 and 29: the former proved till immediately below a sandy soil whereas the latter, central to the mapped area of sand and gravel, penetrated 1.2m of pebbly sand before reaching till. It is considered that pit 79 SE 28, very near the edge of the deposit, is anomalous. On the basis of field observation and the examination of pipeline trenches undertaken prior to the present assessment, it is thought that the thickness proved in pit 79 SE 29 is generally representative of the glacial sand and gravel found throughout this area: on this basis an inferred assessment is 1 million m^3 (Tables 5 and 8).

Late-Glacial beach deposits have been mapped in the vicinity of Cambusbarron *[777 925]* and were investigated by assessment borehole 79 SE 33 and site investigation bores 79 SE X1 and X2 (Table 8): these deposits extend beneath much of the southern part of the Stirling urban area where they were proved by pit 79 SE 34 and site investigation boreholes 79 SE X4 and X5. Boreholes 79 SE 33, X1, X2 and pit 79 SE 34 all showed an upper sand and gravel deposit to overlie laminated red clay of late-Glacial aspect, although in borehole 79 SE X1 the clay was only about 0.3m thick. In boreholes 79 SE 33, X1 and X2 the clay overlies lower sand and gravel deposits which in the last named borehole rested on till. The upper sand and gravel is thought to be a late-Glacial beach deposit and graded as sandy gravel in borehole 79 SE 33. The lower sand and gravel varies in grading from pebbly sand to gravel and has been classified as glacial sand and gravel: it is thought to have been formed in an ice-front environment during a still-stand of the main late-Devensian ice retreat (Francis and others, 1970). Based on boreholes 79 SE 33 and X2, an inferred assessment for the late-Glacial beach deposits and glacial sand and gravel, considered together, which lie outwith the Stirling urban area is 15 million m^3: the mean grading is 4 per cent fines, 50 per cent sand, 46 per cent gravel (sandy gravel). These are the thickest sediments within the resource sheet area having a gravel to sand ratio in excess of 3:1. Even outwith the Stirling urban area much of the deposit has been sterilised around Cambusbarron: within the urban area, for which no assessment is provided, boreholes 79 SE X4 and X5 indicate that several times the volume inferred for sub-block C_3 may be present.

South-west of Knowehead *[6445 9208]* there are two small, isolated mounds of glacial and fluvioglacial sand and gravel, and a similar mound occurs north-east of Craigend *[6166 9017]*. There are no data on the thickness of these deposits and no assessment has been attempted: the limited area over which they have been mapped indicates that only a very small volume of potentially workable material is likely to be present.

To the west of Boquhan Bridge *[6703 9455]*, along the northern margin of the sub-block, isolated late-Glacial raised beach features are found, which, unlike the late-Glacial raised beach in the vicinity of Cambusbarron, have been cut in rock or till. Field evidence indicates that these features, unlike the late-Glacial raised beaches to the north of the Carse, locally have a thin potentially workable cover of beach deposits; no assessment has been attempted.

South of both Watson House *[6925 9460]* and Gargunnock *[705 944]* alluvial fan deposits are found above the level of the Carse: they appear to be graded to a late-Glacial sea-level (Francis and others, 1970). Unlike the modern alluvial fans, which rest on the post-Glacial clay, both field evidence and pit 69 SE 10 show the late-Glacial fans to be potentially workable, the pit proving 1.5m of pebbly sand on presumed rock (Table 8). On the basis of pit 69 SE 10 which is considered to be representative, an inferred assessment of the volume of the fan deposits is 1 million m^3 (Tables 5 and 8).

Small patches of alluvium locally margin many of the streams in the sub-block but the most extensive, and the only one that is considered potentially workable, is that of Bannock Burn. This deposit extends almost continuously from *[7650 9070]* downstream to the margin of the resource sheet area; it was investigated by pits 79 SE 31 and 35 and site investigation borehole 79 SE X3. The borehole proved 2.1m of alluvium and the pits, which did not reach the base of the deposit, showed it to comprise a poorly sorted cobble gravel which has a mean grading of 7 per cent fines, 26 per cent sand, 67 per cent gravel (gravel) (Table 8): pit 79 SE 35 proved 0.6m silty clay overlying the gravel. On the basis of the thickness proved in borehole 79 SE X3 an inferred volume for the deposit is 1 million m^3 (Tables 5 and 8).

CONCLUSIONS

The sand and gravel resources of the survey area have been described systematically. As the individual deposits within the assessed area are the products of very different sedimentary processes they exhibit marked variation in both thickness and composition, and for this reason are generally considered separately, no volumetric assessments being provided for all the potentially workable material in any resource block (Table 5). However, within block A the fluvial deposits formed during, and subsequent to, the Loch Lomond Stadial, although sub-divided on the resource map and in the borehole logs on the basis of their age, are thought to have formed under generally similar depositional conditions resulting in a similarity of composition: these deposits are considered together and are the only sediments for which a statistical assessment has been possible.

Within the resource sheet area only four deposits have volumes estimated in excess of five million m^3 (Table 5), and lesser volumes, where they have been inferred, are considered to be of only local significance. Of the geological factors to be considered in evaluating the potential usefulness of these four deposits, composition, depth of burial and the position of the water-table are perhaps the most important. In block B, the post-Glacial buried raised beach deposits and the buried channel deposits are both potentially workable and grade as 'clayey' sand (Table 7). This composition, a mean depth of burial of 4.6m and 8.6m respectively, and the fact that all the material occurs below the water-table suggests that the deposits are unlikely to command attention until such time as more attractive deposits have been discounted.

The late-Glacial beach deposits and glacial sand and gravel in the vicinity of Cambusbarron, when considered together, comprise the thickest

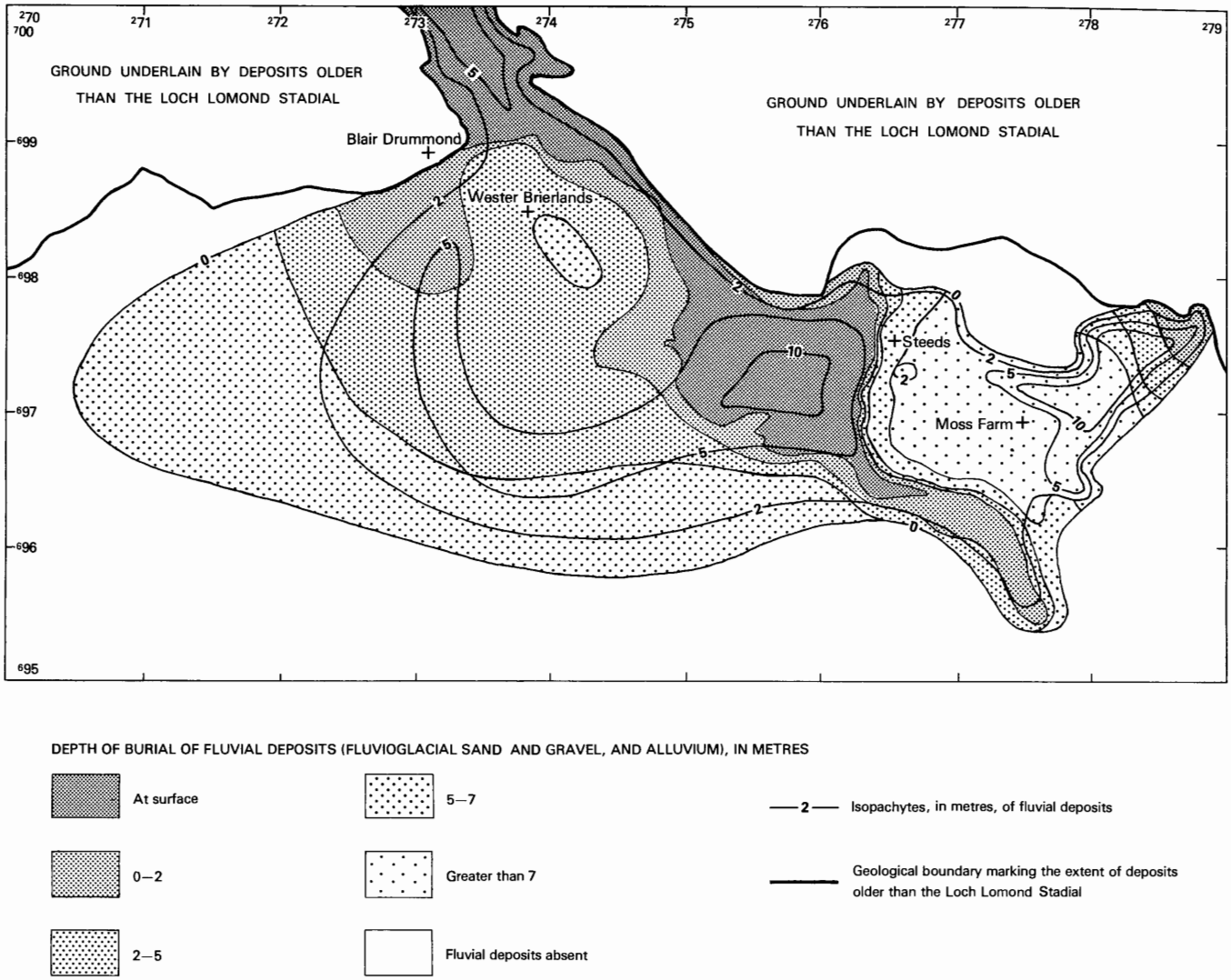

Figure 6 Depth of burial and thickness of fluvial sediments south and east of Blair Drummond deposited during and subsequent to the Loch Lomond Stadial (see text)

and most gravelly potentially workable material within the resource sheet area. Although borehole 79 SE 33 encountered water within these deposits at a depth of only 2.3m and physical testing shows the gravel fraction to have a relatively high water absorption, the volume, composition and thin overburden would suggest that the deposits might be worthy of further consideration now. However, Cambusbarron is built over part of the deposit and the presence of urban development may make the remainder unattractive.

The fluvial deposits of block A, that is the fluvioglacial and alluvial sediments as a whole, are the volumetrically most significant in the resource sheet area, and are relatively uniform in composition: the grading is sandy gravel (Tables 5 and 6). Their mechanical and physical test results which, although poorer than the average of Scottish natural aggregate, are similar to those from deposits which are extensively worked farther up the valley of the River Teith (Merritt and Laxton, 1982). The fluvial deposits only lie above the water-table beneath the relatively narrow terraces to the north of Blairdrummond Park, which in 1981 were being worked in part, and, in spite of their limited extent, are the most attractive resource within the assessed area. The greater part of the fluvial deposits are water-saturated and form a fan which underlies the Carse to the south and east of Blair Drummond (Figure 6). Because grading and composition are satisfactory throughout the fan deposits, the two most important factors determining the relative usefulness of the sediments in different places are thickness and depth of burial. Generally a fan will thin away from the point from which sediment is being supplied, in this case the valley of the River Teith at Blair Drummond. However, the surface upon which the fan lies is inclined generally to the south and this has caused the deposit to thicken in this direction. The result of these two countervailing factors is that the fluvioglacial fan deposits attain their greatest thickness beneath a crescent-shaped area running from south-west of Wester Brierlands *[7387 9847]* to near Steeds *[7650 9750]* (Figure 6). South-east from Blair Drummond the River Teith has reworked the fan deposits and, as a consequence, south-west of Steeds the alluvial (reworked fan deposits) and the fluvioglacial deposits themselves give a combined thickness in excess of 10m.

To the north-east of Moss Farm *[7750 9693]* fluvial sediments attain similar thicknesses (Figure 6) and it is thought these sediments are the product of a separate fan emanating from the valley of the Allan Water. Figure 6 shows that the depth of burial of the fluvial deposits increases to the south and east from the main Blair Drummond fan, and to the west from the

smaller Allan Water fan. This pattern is complicated by the potentially workable alluvium of the River Teith which is considered generally to overlie directly the fan deposits: beyond the eastern limit of the alluvium the overburden thickness increases steeply. As the source of supply of the Allan Water fan deposits is nearer, these sediments might be expected to be closer to the surface: this is not the case suggesting that the depth of burial of the fan deposits beneath the Carse of Lecropt is in part due to their infilling a pre-existing hollow.

Although the Allan Water fan deposits are of considerable thickness they only occur within 5m of the surface close to Bridge of Allan, where the proximity of urban development may reduce their potential. The most promising area for possible wet working is the ground underlain by alluvium south-east of Ochtertyre *[7505 9784]*, where modern river gravels at the surface directly overlie the thickest part of the Loch Lomond Stadial deposits of the Blair Drummond fan.

LIST OF WORKINGS

In January 1982 only one sand and gravel pit was being worked.

Location	*Grid Reference*	*Deposit worked*
North of Blair Drummond	*732 999*	Fluvioglacial sand and gravel of the Loch Lomond Stadial

Apart from the remains of very small, local workings, there are no disused pits within the area.

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APPENDIX A

FIELD AND LABORATORY PROCEDURE

Trial and error during initial studies of the complex and variable glacial deposits of East Anglia and Essex showed that an absolute minimum of five sample points evenly distributed across the sand and gravel are needed to provide a worthwhile statistical assessment, but that, where possible, there should not be less than ten. Sample points are any points for which adequate information exists about the nature and thickness of the deposit and may include boreholes other than those drilled during the survey and exposures. In particular, the cooperation of sand and gravel operators ensures that boreholes are not drilled where reliable information is already available; although this may be used in the calculations, it is held confidentially by the Institute and cannot be disclosed.

The mineral shown on each 1:25000 sheet is divided into resource blocks. The arbitrary size selected, 10 km^2, is a compromise to meet the aims of the survey by providing sufficient sample points in each block. As far as possible the block boundaries are determined by geological boundaries so that, for example, glacial and river terrace gravels are separated. Otherwise division is by arbitrary lines, which may bear no relationship to the geology. The blocks are drawn provisionally before drilling begins.

A reconnaissance of the ground is carried out to record any exposures and inquiries are made to ascertain what borehole information is available. Borehole sites are then selected to provide an even pattern of sample points at a density of approximately one per square kilometre. However, because broad trends are independently overlain by smaller scale characteristically random variations, it is unnecessary to adhere to a square grid pattern. Thus such factors as ease of access and the need to minimise disturbance to land and the public are taken into account in siting the holes; at the same time it is necessary to guard against the possibility that ease of access (that is, the positions of roads and farms) may reflect particular geological conditions, which may bias the drilling results.

The drilling machine employed should be capable of providing a continuous sample representative of all unconsolidated deposits, so that the in-situ grading can be determined, if necessary, to a depth of 30m at a diameter of about 200mm, beneath different types of overburden. It should be reliable, quiet, mobile and relatively small (so that it can be moved to sites of difficult access). Shell and auger rigs have proved to be almost ideal.

The rigs are modified to enable deposits above the water table to be drilled 'dry', instead of with water added to facilitate the drilling, to minimise the amount of material drawn in from outside the limits of the hole. The samples thus obtained are representative of the in-situ grading, and satisfy one of the most important aims of the survey. Below the water table the rigs are used conventionally, although this may result in the loss of some of the fines fraction and the pumping action of the bailer tends to draw unwanted material into the hole from the sides or the bottom.

A continuous series of bulk samples is taken throughout the sand and gravel. Ideally samples are composed exclusively of the whole of the material encountered in the borehole between stated depths. However, care is taken to discard, as far as possible, material which has caved or has been pumped from the bottom of the hole. A new sample is commenced whenever there is an appreciable lithological change within the sand and gravel, or at every 1m depth. The samples, each weighing between 25 and 45kg, are despatched in heavy duty polythene bags to a laboratory for grading. The grading procedure is based on British Standard 1377 (1975). Random checks on the accuracy of the grading are made in the laboratories of the Industrial Minerals Assessment Unit.

All data, including mean grading analysis figures calculated for the total thickness of the mineral, are entered on standard record sheets, abbreviated copies of which are reproduced in Appendix E.

Detailed records may be consulted at the appropriate offices of the Institute, upon application.

APPENDIX B

STATISTICAL PROCEDURE

Statistical assessment

1 A statistical assessment is made of an area of mineral greater than $2km^2$, if there is a minimum of five evenly spaced boreholes in the resource block (for smaller areas see paragraph 12 below).

2 The simple methods used in the calculations are consistent with the amount of data provided by the survey. Conventional symmetrical confidence limits are calculated for the 95 per cent probability level, that is, there is a 5 per cent or one in twenty chance of a result falling outside the stated limits.

3 The volume estimate (V) for the mineral in a given block is the product of the two variables, the sampled areas (A) and the mean thickness ($\bar{d}_m$) calculated from the individual thicknesses at the sample points. The standard deviations for these variables are related such that

$$S_V = \sqrt{(S_A^2 + S_{\bar{d}_m}^2)}. \qquad [1]$$

4 The above relationship may be transposed such that

$$S_V = S_{\bar{d}_m}\sqrt{(1 + S_A^2/S_{\bar{d}_m}^2)} \qquad [2]$$

From this it can be seen that as $S_A^2/S_{\bar{d}_m}^2$ tends to 0, S_V tends to $S_{\bar{d}_m}$.

If, therefore, the standard deviation for area is small with respect to that for mean thickness, the standard deviation for volume approximates to that for mean thickness.

5 Given that the number of approximately evenly spaced sample points in the sampled area is n, with mineral thickness measurements d_{m_1}, d_{m_2} ... d_{m_n}, the the best estimate of mean thickness, $\bar{d}_m$, is given by

$$\sum (d_{m_1} + d_{m_2} \ldots d_{m_n})/n.$$

For groups of closely spaced boreholes a discretionary weighting factor may be applied to avoid bias (see note on weighting below). The standard deviation for mean thickness $S_{\bar{d}_m}$ expressed as a proportion of the mean thickness, is given by

$$S_{\bar{d}_m} = (1/\bar{d}_m)\sqrt{[\sum(d_m - \bar{d}_m)^2/(n-1)]}$$

where d_m is any value in the series d_{m_1} to d_{m_n}.

6 The sampled area in each resource block is coloured pink on the map. Wherever possible, calculations relate to the mineral within mapped geological boundaries (which may not necessarily correspond to the limits of deposit). Where the area is not defined by a mapped boundary, that is, where the boundary is inferred, a distinctive symbol is used. Experience suggests that the errors in determining area are usually small relative to those in thickness. The relationship $S_A/S_{\bar{d}_m} \leq 1/3$ is assumed in all cases. It follows from equation [2] that $S_{\bar{d}_m} \leq S_v \leq 1.05S_{\bar{d}_m}$.

7 The limits on the estimate of mean thickness of mineral, $L_{\bar{d}_m}$, may be expressed in absolute units

$\pm(t/\sqrt{n})\times S_{\bar{d}_m}$ or as a percentage

$\pm(t/\sqrt{n})S_{\bar{d}_m}(100/\bar{d}_m)$ per cent, where t is Student's t at the 95 per cent probability level for (n-1) degrees of freedom, evaluated by reference to statistical tables. (In applying Student's t it is assumed that the measurements are distributed normally).

8 Values of t at the 95 per cent probability level for values of n up to 20 are as follows:

n	t	n	t
1	infinity	11	2.228
2	12.706	12	2.201
3	4.303	13	2.179
4	3.182	14	2.160
5	2.776	15	2.145
6	2.571	16	2.131
7	2.447	17	2.120
8	2.365	18	2.110
9	2.306	19	2.101
10	2.262	20	2.093

(from Table 12, Biometrika Tables for Statisticians, Volume 1, Second Edition, Cambridge University Press, 1962). When n is greater than 20, 1.96 is used (the value of t when n is infinity).

9 In calculating confidence limits for volume, L_V, the following inequality corresponding to equation [3] is applied: $L_{\bar{d}_m} \leq L_V \leq 1.05L_{\bar{d}_m}$.

10 In summary, for values of n between 5 and 20, L_V is calculated as

$[(1.05t)/\bar{d}_m]\times[\sqrt{\sum(d_m - \bar{d}_m)^2/n(n-1)}]\times 100$ per cent,

and when n is greater than 20, as

$[(1.05\times 1.96)/\bar{d}_m]\times[\sqrt{\sum(d_m - \bar{d}_m)^2/n(n-1)}]\times 100$ per cent (weighting factors may be included: see paragraph 15).

11 The application of this procedure to a fictitious area is illustrated.

Inferred assessment

12 If the sampled area of mineral in a resource block is between $0.3km^2$ and $2km^2$ an assessment is inferred, based on geological and topographical information usually supported by the data from one or two boreholes. The volume of mineral is calculated as the product of the area, measured from field data, and the estimated thickness. Confidence limits are not calculated.

13 In some cases a resource block may include an area left uncoloured on the map, within which mineral (as defined) is interpreted to be generally absent. If there is reason to believe that some mineral may be present, an inferred assessment may be made.

Block calculation

Scale: 1:25000
Block: Fictitious

Area
Block: 11.08km^2
Mineral: 8.32km^2

Mean thickness
Overburden: 2.5m
Mineral: 6.5m

Volume
Overburden: 21 million m^3
Mineral: 54 million m^3

Confidence limits of the estimate of mineral volume at the 95 per cent probability level: ±20 per cent. That is, the volume of mineral (with 95 per cent probability): 54 ± 11 million m^3

Thickness estimate (measurements in metres)
d_o = overburden thickness d_m = mineral thickness

Sample point	Weighting ω	Overburden d_m	Overburden ωd_o	Mineral d_m	Mineral ωd_m	Remarks
SE 14	1	1.5	1.5	9.4	9.4	IMAU boreholes
SE 18	1	3.3	3.3	5.8	5.8	
SE 20	1	nil	-	6.9	6.9	
SE 22	1	0.7	0.7	6.4	6.4	
SE 23	1	6.2	6.2	4.1	4.1	
SE 24	1	4.3	4.3	6.4	6.4	
SE 17	½	1.2	1.6	9.8	7.2	Hydrogeology Unit record
123/45	½	2.0		4.6		
1	¼	2.7	2.6	7.3	5.8	Close group of four boreholes (commercial)
2	¼	4.5		3.2		
3	¼	0.4		6.8		
4	¼	2.8		5.9		
Totals	$\Sigma\omega = 8$	$\Sigma\omega d_o = 20.2$		$\Sigma\omega d_m = 52.0$		
Means		$\overline{\omega d_o} = 2.5$		$\overline{\omega d_m} = 6.5$		

Calculation of confidence limits

ωd_m	$\lvert(\omega d_m - \overline{\omega d_m})\rvert$	$(\omega d_m - \overline{\omega d_m})^2$
9.4	2.9	8.41
5.8	0.7	0.49
6.9	0.4	0.16
6.4	0.1	0.01
4.1	2.4	5.76
6.4	0.1	0.01
7.2	0.7	0.49
5.8	0.7	0.49

$\Sigma(\omega d_m - \overline{\omega d_m})^2 = 15.82$

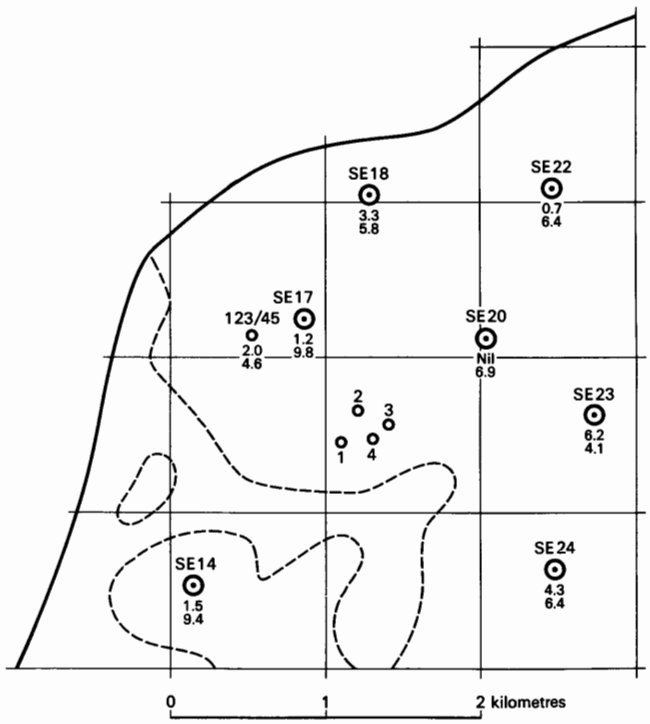
$n = 8$
$t = 2.365$
L_v is calculated as

$$1.05(t/\overline{\omega d_m})\sqrt{[\Sigma(\omega d_m - \overline{\omega d_m})^2/\, n(n-1)]} \times 100$$

$$= 1.05 \times (2.365/6.5)\sqrt{[15.82/(8\times7)]} \times 100$$

$$= 20.3$$

$$\simeq 20 \text{ per cent}$$



SE24 IMAU borehole

4.3 / 6.4 Overburden / Mineral — Thickness in metres

Other boreholes

Boundary of resource block

Boundary of sand and gravel deposit

Example of resource block assessment: map of fictitious block, calculation and results

14 No assessment is attempted for an isolated area of mineral less than 0.25km^2.

15 **Note on weighting** The thickness of a deposit at any point may be governed solely by the position of the point in relation to a broad trend. However, most sand and gravel deposits also exhibit a random pattern of local, and sometimes considerable, variation in thickness. Thus the distribution of sample points need be only approximately regular and in estimating the mean thickness only simple weighting is necessary. In practice, equal weighting can often be applied to thicknesses at all sample points. If, however, there is a distinctly unequal distribution of points, bias is avoided by dividing the sampled area into broad zones, to each of which a value roughly proportional to its area is assigned. This value is then shared between the data points within the zone as the weighting factor.

APPENDIX C

CLASSIFICATION AND DESCRIPTION OF SAND AND GRAVEL

For the purposes of assessing resources of sand and gravel a classification should take account of economically important characteristics of the deposits, in particular the absolute content of fines and the ratio of sand to gravel.

The terminology commonly used by geologists when describing sedimentary rocks (Wentworth, 1922) is not entirely satisfactory for this purpose. For example, Wentworth proposed that a deposit should be described as a 'gravelly sand' when it contains more sand than gravel and there is at least 10 per cent of gravel, provided that there is less than 10 per cent of material finer than sand (less than $\frac{1}{16}$mm) and coarser than pebbles (more than 64mm in diameter). Because deposits containing more than 10 per cent fines are not embraced by this system a modified binary classification based on Willman (1942) has been adopted.

When the fines content exceeds 40 per cent the material is not considered to be potentially workable and falls outside the definition of mineral. Deposits which contain 40 per cent fines or less are classified primarily on the ratio of sand to gravel but qualified in the light of the fines content, as follows: less than 10 per cent fines - no qualification; 10 per cent or more but less than 20 per cent fines - 'clayey'; 20 to 40 per cent fines - 'very clayey'.

The term 'clay' (as written, with single quote marks) is used to describe all material passing $\frac{1}{16}$ mm. Thus it has no mineralogical significance and includes particles falling within the size range of silt. The normal meaning applies to the term clay where it does not appear in single quotation marks.

The ratio of sand to gravel defines the boundaries between sand, pebbly sand, sandy gravel and gravel (at 19:1, 3:1 and 1:1).

Thus it is possible to classify the mineral into one of twelve descriptive categories (see the figure at the end of this Appendix). The procedure is as follows:

1 Classify according to ratio of sand to gravel
2 Describe fines

For example, a deposit grading 11 per cent gravel, 70 per cent sand and 19 per cent fines is classified as 'clayey' pebbly sand. This short description is included in the borehole log (see Note 11, Appendix D).

Many differing proposals exist for the classification of the grain size of sediments (Atterberg, 1905; Udden, 1914; Wentworth, 1922; Wentworth, 1935; Allen, 1936; Twenhofel, 1937; Lane and others, 1974). As Archer (1970a,b) has emphasised, there is a pressing need for a simple metric scale acceptable to both scientific and engineering interests, for which the class limit sizes correspond closely with certain marked changes in the natural properties of mineral particles. For example, there is an important change in the degree of cohesion between particles at about the $\frac{1}{16}$-mm size, which approximates to the generally accepted boundary between silt and sand. These and other requirements are met by a system based on Udden's geometric scale and a simplified form of Wentworth's terminology, which is used in this Report. It appears at the end of this Appendix.

The fairly wide intervals in the scale are consistent with the general level of accuracy of the qualitative assessments of the resource blocks. Three sizes of sand are recognised, fine ($+\frac{1}{16}$-$\frac{1}{4}$mm), medium ($+\frac{1}{4}$-1mm) and coarse (+1-4 mm). The boundary at 16mm distinguishes a range of finer gravel (+4-16 mm), often characterised by abundance of worn tough pebbles of vein quartz, from larger pebbles often of notably different materials. The boundary at 64mm distinguishes pebbles from cobbles. The term 'gravel' is used loosely to denote both pebble-sized and cobble-sized material.

The size distribution of borehole samples is determined by sieve analysis, which is presented by the laboratory as logarithmic cumulative curves (see, for example, British Standard 1377:1967). In this report the grading is tabulated on the borehole record sheets (Appendix E), the intercepts corresponding with the simple geometric scale $\frac{1}{16}$ mm, $\frac{1}{4}$ mm, 1 mm, 4 mm, 16 mm and so on as required. Original sample grading curves are available for reference at the appropriate office of the Institute.

Each bulk sample is described, subjectively, by a geologist at the borehole site. Being based on visual examination, the description of the grading is inexact, the accuracy depending on the experience of the observer. The descriptions recorded are modified, as necesssary, when the laboratory results become available.

The relative proportions of the rock types present in the gravel fraction are indicated by the use of the words 'and' or 'with'. For example, 'flint and quartz' indicates very approximate equal proportions with neither constituent accounting for less than about 25 per cent of the whole; 'flint with quartz' indicates that flint is dominant and quartz, the principal accessory rock type, comprises 5 to 25 per cent of the whole. Where the accessory material accounts for less than 5 per cent of the whole, but is still readily apparent, the phrase 'with some' has been used. Rare constituents are referred to as 'trace'.

The terms used in the field to describe the degree of rounding of particles, which is concerned with the sharpness of the edges and corners of a clastic fragment and not the shape (after Pettijohn, 1975), are as follows

Angular: showing little or no evidence of wear; sharp edges and corners.

Subangular: showing definite effects of wear. Fragments still have their original form but edges and corners begin to be rounded off.

Subrounded: showing considerable wear. The edges and corners are rounded off to smooth curves. Original grain shape is still distinct.

Rounded: original faces completely destroyed, but some comparatively flat surfaces may still remain. All original edges and corners have been smoothed off to rather broad curves. Original shape is still apparent.

Well-rounded: no original faces, edges or corners left. The entire surface consists of broad curves; flat areas are absent. The original shape is suggested by the present form of the grain.

Classification of gravel, sand and fines

Size limits	Grain-size description	Qualification	Primary classification
64 mm	Cobble		
16 mm	Pebble	Coarse	Gravel
4 mm		Fine	
1 mm		Coarse	
¼ mm	Sand	Medium	Sand
1/16 mm		Fine	
	Fines (silt and clay)		Fines

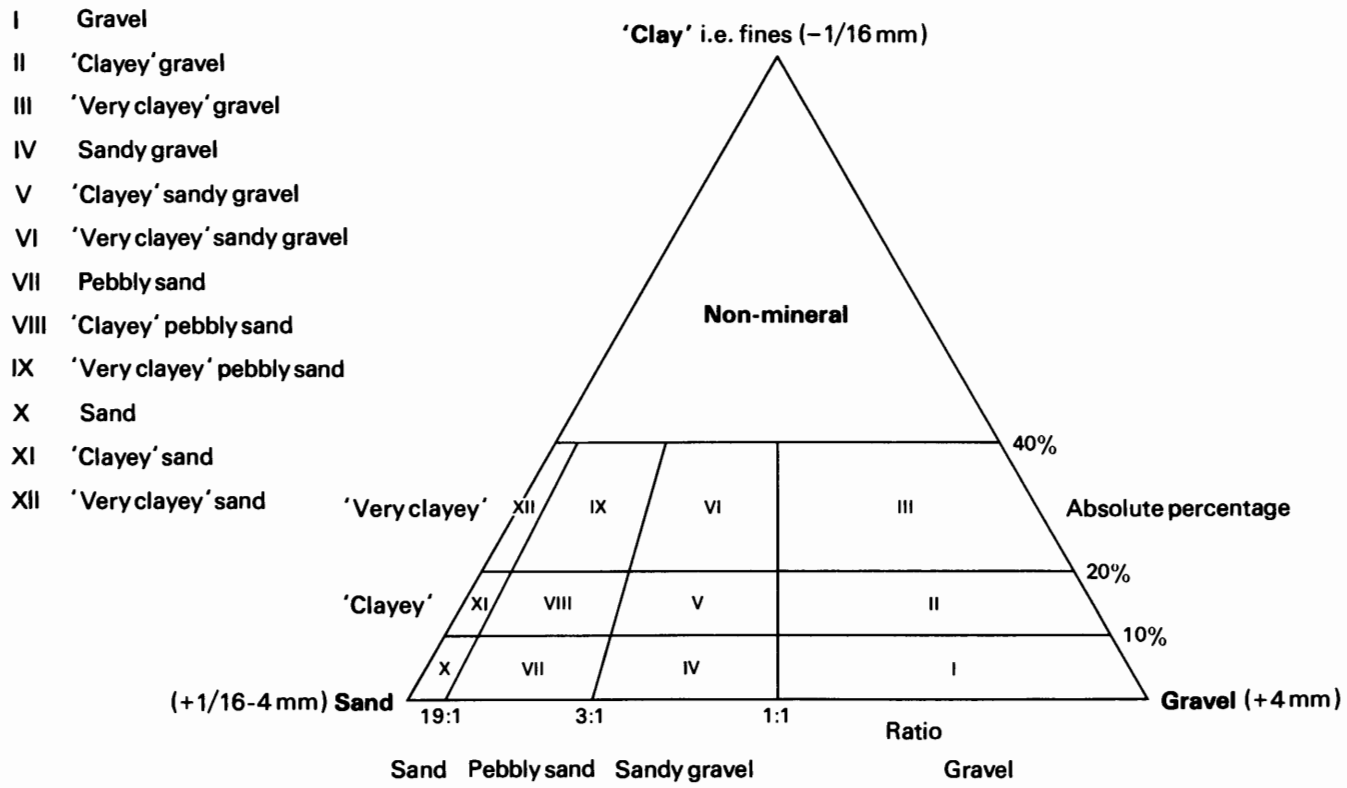


Diagram to show the descriptive categories used in the classification of sand and gravel

APPENDIX D

EXPLANATION OF THE ASSESSMENT RECORDS

Annotated example

NS 79 NE 8[1]	**7575 9734**[2]	**Ochtertyre, Kincardine**[3]	**Block A**

Surface level +9.0m (+30 ft)[4]
Water struck at +8.6m[5]
250mm and 200mm percussion[6]
October 1980

Overburden[7]	0.3m
Mineral	11.5m
Waste	6.5m
Bedrock	0.2m+[9]

LOG

Geological classification	Lithology	Thickness[8] m	Depth m
	Soil, clayey and silty with pebbles, dark brown	0.3	0.3
Alluvium[10]	a Gravel[11] Gravel: coarse and fine with rare cobbles up to 9cm in diameter, ill-sorted, subrounded to well rounded, sandstone, quartzite, psammite, schist, basalt, quartz, felsite Sand: coarse with medium and fine, ill-sorted, angular to well rounded, quartz and rock fragments Fines: silt, medium brown, disseminated, and in thin bands with organic remains, the latter probably old soil levels	3.9	4.2
Fluvioglacial sand and gravel	b Sandy gravel Gravel: fine with coarse and, above 5.2m some cobbles, angular to well rounded, composition as above Sand: medium with coarse and fine, angular to subangular, quartz and rock fragments. Brown above 5.2m, grey below this due to increasing abundance of quartz with depth Fines: silt, disseminated	2.0	6.2
	c Pebbly sand Gravel: fine and coarse, composition as above Sand: fine and medium, moderately well sorted angular to subrounded, quartz with a few rock fragments, grey. Carbonaceous fragments below 10.2m Fines: silt, disseminated	5.6	11.8
Late-Glacial marine deposits	Silt, grey, slightly sandy, with grey laminated clay bands and a few, mainly angular, red sandstone pebbles	5.1	16.9
	Sandy gravel Gravel: fine and coarse with rare cobbles, predominantly angular sandstone with some more rounded, rock types of Highland origin Sand: medium and fine with a little coarse purplish grey quartz and feldspar probably derived from the Old Red Sandstone. Some shell fragments Fines: silt, disseminated with rare, thin orange clay bands	1.4	18.3
Lower Devonian	Sandstone, medium grained, flaggy purplish grey	0.2+	18.5

NS79NE 8
GRADING

	Mean for deposit[15] percentages			Depth below surface (m)[12]	percentages[13]							
	Fines	Sand	Gravel		Fines	Sand			Gravel			
				from to	-$\frac{1}{16}$	+$\frac{1}{16}$-$\frac{1}{4}$	+$\frac{1}{4}$-1	+1-4	+4-16	+16-64	+64	mm
a	1	23	76	0.3-1.3	4	6	6	9	20	49	6	§[14]
				1.3-2.2	1	2	6	15	45	28	3	§
				2.2-3.4	0	2	5	16	45	32	0	§
				3.4-4.2	0	2	12	12	31	43	0	§
				Mean	**1**	**3**	**7**	**13**	**36**	**38**	**2**	
b	1	60	39	4.2-5.2	1	11	27	15	19	21	6	§
				5.2-6.2	1	11	39	17	25	7	0	§
				Mean	**1**	**11**	**33**	**16**	**22**	**14**	**3**	
c	5	90	5	6.2-7.4	1	28	55	7	6	3	0	§
				7.4-8.3	3	32	50	5	6	4	0	§
				8.3-9.3	4	50	37	2	1	6	0	§
				9.3-10.2	10	72	17	1	0	0	0	§
				10.2-11.8	6	49	42	2	1	0	0	§
				Mean	**5**	**46**	**41**	**3**	**3**	**2**	**0**	
b&c	4	82	14	**Mean**	**4**	**37**	**38**	**7**	**8**	**5**	**1**	
atoc	3	63	34	**Mean**	**3**	**25**	**29**	**9**	**17**	**16**	**1**	
	2	62	36	16.9-18.3	2	25	30	7	20	16	0	§*[16]

The numbered paragraphs below correspond with the annotations given on the specimen record above.

1 Borehole registration number
Each Industrial Minerals Assessment Unit (IMAU) borehole or shallow pit is identified by a registration number. This consists of two statements.

1 The number of the 1:25000 sheet on which the borehole lies, for example NS 79
2 The quarter of the 1:25000 sheet on which the borehole lies and its number in a series for that quarter for example NE 8

Thus the full registration number is NS 79 NE 8. Usually this is abbreviated to 79 NE 8 in the text.

2 The National Grid reference
All National Grid references in this publication lie within the 100-km square NS. Grid references are given to eight figures, accurate to within 10m for borehole locations. (In the text, six-figure grid references are used for more approximate locations, for example, for quarries.)

3 Location
The position of the borehole is referred to the nearest named locality on the 1:25000 base map, usually followed by the name of the parish. The resource block in which it lies is also stated.

4 Surface level
The surface level at the borehole site is given in metres and feet above Ordnance Datum. Measurements were made in metres: approximate conversions to feet are given in brackets.

5 Groundwater conditions
If groundwater was present the level at which it was either encountered or statically measured is normally given (in metres above Ordnance Datum).

6 Type of drill and date of drilling
Modified shell and auger rigs were used in this survey. The drilling method, the external diameter of the casing used, and the month and year of completion of the borehole are stated.

7 Overburden, mineral, waste and bedrock
Mineral is sand and gravel which, as part of a deposit, falls within the arbitrary definition of potentially workable material (see p. 1). Bedrock is the 'formation', 'country rock' or 'rock head' below which potentially workable sand and gravel will not be found. Waste is any material other than bedrock or mineral. Where waste occurs between the surface and mineral it is classified as overburden.

8 Thickness and depth
All measurements were made in metres.

9 The plus sign (+) indicates that the base of the deposits was not reached during drilling

10 Geological classification
The geological classification is given whenever possible. For economy of space the term post-Glacial raised beach and marine deposits is abbreviated in the logs to post-Glacial deposits.

11 Lithological description
When sand and gravel is recorded a general description based on the mean grading characteristics (for details see Appendix C) is followed by more detailed particulars. The description of other rocks is based on visual examination, in the field.

12 Sampling
A continuous series of bulk samples is taken through the thickness of sand and gravel. A new sample is commenced whenever there is an appreciable lithological change within the sand and gravel or at every 1m of depth.

13 Grading results
The results are expressed as per cent by weight retained on British Standard sieves whose aperture sizes are given in millimetres or fractions thereof.

14 Bailed samples
Fully representative sampling of sand and gravel is difficult to achieve, particularly where groundwater levels are high. Comparison between boreholes and adjacent exposures suggests that in borehole samples the proportion of sand may be higher and the proportion of fines and coarse gravel (+16mm) may be lower. Samples obtained by the bailing technique (that is, from deposits below the water table) are indicated thus §.

15 Mean grading
The grading of the full thickness of the mineral deposit identified in the log is the mean of the individual sample gradings weighted by the thicknesses represented. The classification used is shown in the Table in Appendix C. Where two or more distinct mineral units form continuous sequences the mean gradings of these are also given under each unit. Trace amounts are indicated this: **

16 Samples with less than 40 per cent by weight passing $\frac{1}{16}$mm, but not considered in the calculation of mean grading, are indicated this: *. These samples are considered either non-mineral owing to the amount of overburden or form small parts of sequences regarded as generally unworkable.

APPENDIX E

INDUSTRIAL MINERALS ASSESSMENT UNIT BOREHOLE AND SHALLOW PIT RECORDS

NS 69 NW 1 **6046 9887** **Blaircessnock, Port of Menteith** **Block C^2**

Surface level +46.0m (+151 ft)
Water not struck
Pit
April 1981

Waste 1.9m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, medium brown	0.2	0.2
Till	Clay with abundant silt and angular to subangular quartz sand. Clasts up to 17 cm in diameter, well rounded to angular and ill-sorted, of red sandstone with basalt, psammite and quartzite	1.7+	1.9

NS 69 NW 2 **6031 9769** **Cardross, Port of Menteith** **Block C_2**

Surface level +30.3 m (+99 ft)
Water struck at +29.5 m
Pit
April 1981

Waste 1.9m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty, medium brown	0.3	0.3
Till	Above 0.8m matrix of ill-sorted fine to coarse sand of angular to subangular rock fragments and quartz, with disseminated silt; below 0.8m matrix is a stiff clay with a poorly developed fabric. Reddish brown becoming greyish brown with depth. Ill-sorted angular to subrounded clasts of flaggy sandstone and siltstone with some quartz	1.6+	1.9

NS 69 NW 3 **6097 9731** **Cardross, Port of Mentieth** **Block B**

Surface level +12.4 m (+41 ft)
Water struck at +6.6m
250 mm percussion
June 1981

Waste 6.5m
Bedrock 0.1m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, very clayey, grey-brown	0.2	0.2
Post-Glacial deposits	Clay, stiff with light grey and brown mottling, grading down into softer, laminated, dark grey clay below 2.0 m	5.6	5.8
Till	Silty clay matrix, red-brown, with fine to coarse gravel grade clasts, angular to rounded, of red sandstone and siltstone with quartz and Dalradian grits	0.7	6.5
Lower Devonian	Sandstone, fine to medium grained, reddish grey. Only recovered as a sand	0.1+	6.6

NS 69 NW 4 **6029 9640** **Tod Knowe, Kippen** **Block C_2**

Surface level +17.0m (+56 ft)
Water not struck
Pit
April 1981

Waste 1.9m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.2	0.2
Till	Stiff, red-brown to brown clayey matrix with highly contorted laminations and ? shell fragments. Ill-sorted subangular to subrounded clasts up to 30 cm in diameter of sandstone and quartzite with various metamorphics	1.7+	1.9

NS 69 NW 5 **6099 9555** **Easter Garden, Kippen** **Block B**

Surface level +14.0m (+46 ft)
Water struck at +8.3m
250mm and 200mm percussion
April 1981

Waste 13.5m
Bedrock 0.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, greyish brown	0.3	0.3
Post-Glacial deposits	Clay, laminated, becomes increasingly stiff with depth. Grey below 1.5m, grey and brown mottled above this. Root remains below 1.5m	3.2	3.5
	Silt, quartz with a little mica, medium grey becoming reddish grey below 4.0m. Sand partings near the base. Trace shell fragments	3.0	6.5
Late-Glacial marine deposits	Clay. Above 8.0m, laminated, very stiff, dark grey abundant shell material and rare small clasts. Below 8.0m better laminated, reddish grey, with shell material and clasts absent. Palaeontological analysis of the fauna from 7.0m depth indicates a marine environment with temperatures appreciably lower than in present-day British waters	7.0	13.5
Lower Devonian	Sandstone, medium grained, reddish grey, with angular inclusions of reddish grey mudstone	0.2+	13.7

NS 69 NW 6 **6135 9885** **Ballangrew, Port of Menteith** **Block C_2**

Surface level +23.0m(+75 ft)
Water struck at +21.7m
Pit
April 1981

Overburden 0.7m
Mineral 1.4m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, reddish brown	0.3	0.3
Till	Clay, brown, becoming increasingly sandy with depth, with a few clasts up to 27 cm in diameter	0.4	0.7
	Sandy gravel Gravel: fine with some coarse and cobbles, subangular to subrounded, sandstone and various rock types of Highland origin Sand: fine with medium and some coarse Fines: disseminated	1.4+	2.1

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm	
7	59	34	0.7-2.1	7	35	18	6	21	9	4	*

NS 69 NW 7 **6145 9668** **Faraway, Port of Menteith** **Block B**

Surface level +13.0m (+43 ft)
Water not struck
250mm and 200mm percussion
April 1981

Waste 18.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey	0.2	0.2
Post-Glacial deposits	Clay, mottled grey and orange, locally reddish, silty faintly laminated, contains rootlets	1.2	1.4
	Silt, coarsely laminated, with bands of clayey silt, silty sand and rare, thin, clay. Medium grey to dark grey and foul smelling. At 3.7m and 4.6m 1cm thick bands of wood and other plant material	10.0	11.4
Late-Glacial marine deposits	Silt, soft, dark grey to blue-grey, very clayey, sand laminae at 14.0m. Palaeontological analysis indicate a cold water depositional environment	6.6+	18.0

NS 69 NW 8 **6167 9591** **Newburn, Kippen** **Block B**

Surface level +13.1m (+43 ft)
Water struck at +7.4m
250mm and 200mm percussion
April 1981

Waste 18.6m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty and clayey, grey-brown	0.3	0.3
Post-Glacial deposits	Clay, above 1.4m moderately stiff, poorly laminated, grey with brown mottling, with rootlet fragments. Below this depth, soft, silty, medium grey, with possible shell fragments	4.6	4.9
Peat	Peat, contains many well preserved wood fragments	0.7	5.6
Post-Glacial deposits	Silt, light grey above 6.2m becoming darker and more clayey with depth. From 8.0m to 9.0m clasts up to 10cm in diameter of basalt and red sandstone	3.4	9.0
Late-Glacial marine deposits	Silt, dark grey, more clayey than above, with some shells. Below 12.0m a few red sandstone clasts and interbedded grey clay, sandy below 15.0m	9.6+	18.6

NS 69 NW 9 **6220 9893** **Flanders Hill, Port of Menteith** **Block C_2**

Surface level +19.0m (+62 ft)
Water struck at +18.4m
250mm percussion
June 1981

Waste 2.7m
Bedrock 0.4m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, brown	0.3	0.3
Till	Matrix of reddish brown silty sand above 1.7m, becoming stiff clay below this. Silt laminae at 1.7m. Angular to subangular clasts of sandstone, siltstone and rock types of Highland origin, siltstone predominantly below 2.6m	2.4	2.7
Lower Devonian	Siltstone, reddish brown	0.4+	3.1

NS 69 NW 10 **6262 9675** **Poldar Bridge, Port of Menteith** **Block B**

Surface level +13.0m (+43 ft)
Water struck at +1.5m
250mm and 200mm percussion
May 1981

Waste 18.5m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.4	0.4
Post-Glacial deposits	Clay, laminated, soft, slightly silty, light grey with brown mottling above 1.5m, dark to medium grey below this	11.1	11.5
Late-Glacial marine deposits	Clay, soft, laminated, black above 13.0m, greyish brown below this, shell fragments above 14.0m, silt laminae from 13.0m to 14.0m, and, from 11.5m to 12.2m, sandy with angular to rounded clasts up to coarse gravel grade of red sandstone with rare quartz and seatearth	7.0+	18.5

NS 69 NW 11 **6377 9973** **Wards of Goodie, Port of Menteith** **Block B**

Surface level +15.0m (+49 ft)
Water struck at +11.8m
250mm percussion
May 1981

Overburden 3.6m
Mineral 2.1m
Waste 3.3m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty and clayey, dark brown	0.2	0.2
Post-Glacial deposits	Clay, moderately stiff, grey with, above 0.5m, brown mottling. Abundant plant remains	1.6	1.8
Peat	Peat, medium brown where fresh, to black	1.2	3.0
Post-Glacial deposits	Silt, light grey, sandy below 3.2m some rootlet remains in upper part	0.6	3.6
	'Clayey' sand Gravel: at the base of the deposit rare clasts up to 15cm in diameter of red sandstone and quartz Sand: medium with fine and coarse, angular to subangular, quartz and rock fragments, grey Fines: disseminated silt	2.1	5.7
Late-Glacial marine deposits	Clay, laminated, greyish brown	1.3	7.0
Till	Clay, greyish brown, soft and sandy above 8.0m, stiffer and less sandy below this. Subangular clasts up to 15cm in diameter of red sandstone with rare quartzite.	2.0+	9.0
	Borehole terminated due to slow progress		

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
			from to	−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64 mm
14	85	1	3.6-5.7	14	12	62	11	1	0	0 §

NS 69 NW 12 **6329 9582** **Drum, Kippen** **Block B**

Surface level +14.0m (+46 ft)
Water struck at +5.0m
250mm and 200mm percussion
April 1981

Waste 16.2m
Bedrock 0.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty and clayey, greyish brown	0.3	0.3
Post-Glacial deposits	Clay, poorly laminated, mottled light brown and grey above 2.0m, grey below this	3.5	3.8
Peat	Peat, brownish black, with many well preserved wood fragments up to 13cm in diameter	0.3	4.1
Post-Glacial deposits	Silt, medium grey, well laminated, including some black, possibly carbonaceous, laminae. Root remains in the upper part. A little disseminated shell material and, near the base, a few clasts up to 15cm in diameter of basalt and red sandstone	3.4	7.5
Late-Glacial marine deposits	Clay, well laminated, reddish grey above 12.4m, greyish brown below this, stiff, with partings of fine to medium sand above 9.0m, soft, slightly silty, and with rare red sandstone pebbles up to 3cm in diameter, below	8.0	15.5
Till	Clay, red, sandy, with fine to coarse gravel grade clasts of red sandstone, Dalradian grits, quartz and basalt	0.7	16.2
Lower Devonian	Sandstone, medium grained, reddish grey with inclusions of reddish brown mudstone	0.2+	16.4

NS 69 NW 13 **6451 9975** **Wards of Goodie, Port of Menteith** **Block B**

Surface level +14.0m (+46 ft)
Water struck at +9.3m
250mm percussion
May 1981

Waste	5.5m
Bedrock	0.4m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey and silty, grey-brown	0.2	0.2
Post-Glacial deposits	Clay, poorly laminated, stiff and light grey with brown mottling above 1.5m, soft and medium grey below this	4.0	4.2
	Silt, slightly brownish grey, with red sandstone clasts up to 10cm in diameter near the base	1.3	5.5
	Mudstone, fissile, red-brown. Above 5.8m weathered to a red and greenish grey mottled clay with mudstone inclusions	0.4+	5.9

NS 69 NW 14 **6490 9871** **East Moss-side, Kincardine** **Block B**

Surface level +15.0m (+49 ft)
Water struck at +10.2m
250mm percussion
May 1981

Overburden	4.8m
Mineral	3.0m
Waste	2.3m+

LOG

Geological classification	Lithology	Thickness m	Depth m
Peat	Peat, blackish brown	0.5	0.5
Post-Glacial deposits	Clay, soft, light grey with, above 1.5m, reddish brown bands	3.2	3.7
Peat	Peat, poorly decomposed grasses with some twigs of birch, black to medium brown	1.1	4.8
Post-Glacial deposits	'Clayey' sand Gravel: trace fine, light brown, mudstone, below 5.9m Sand: fine with medium, quartz with some rock and a few shell fragments, angular to subrounded, grey Fines: disseminated grey silt, most abundant above 5.9m	3.0	7.8
Till	Silt, red-brown, sandy, with ill-sorted angular to subangular clasts up to 16cm in diameter of red sandstone and siltstone with Dalradian grits. Pushing boulder below 9.8m	2.3+	10.1
	Borehole terminated due to lack of progress		

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm	
12	88	0	4.8-5.9	22	68	10	0	0	0	0	§
			5.9-6.8	8	59	33	0	0	0	0	§
			6.8-7.8	6	53	39	1	0	1	0	§
			Mean	**12**	**61**	**27**	**	**0**	**	**0**	

NS 69 NW 15 **6460 9733** **Easter Poldar, Port of Menteith** **Block B**

Surface level +12.8m (+42 ft) Waste 18.0m+
Water struck at +6.5m
250mm and 200mm percussion
May 1981

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.2	0.2
Post-Glacial deposits	Clay. Above 1.8m very stiff, orange-brown with grey mottling, with rootlets; below this depth, soft, medium to dark grey, with interlaminated grey silt and carbonaceous material. Reddish brown shelly clay partings at 4.8m and 2cm thick peat band at the base of the deposit	9.6	9.8
Late-Glacial marine deposits	Silt, locally laminated, medium grey with partings of reddish grey, rare comminuted shell material. Below 10.1m abundant angular to subrounded clasts of sandstone with basalt and rock types of Highland origin	3.7	13.5
	Clay, poorly laminated, very soft, silty, medium grey	4.5+	18.0

NS 69 NW 16 **6437 9700** **Easter Poldar, Port of Menteith** **Block B**

Surface level +13.0m (+43 ft)
Water struck at +6.0m
250mm and 200mm percussion
May 1981

Overburden	8.0m
Mineral	7.0m
Waste	7.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.2	0.2
Post-Glacial deposits	Clay, very stiff, orange-brown with grey mottling above 1.5m, grey below this	2.2	2.4
	Silt, laminated, soft, medium grey, clayey, thin peat bed with rootlets at 3.4m	2.7	5.1
Peat	Peat, compact, brown	0.2	5.3
Post-Glacial deposits	Clay, stiff, medium grey, with depth becomes interlaminated with silt and sand	2.7	8.0
	Sand Gravel: trace Sand: fine with medium, angular to subangular, quartz, feldspar, and rock fragments, with carbonaceous fragments, grey Fines: disseminated silt with rare clay partings, both becoming less abundant with depth	7.0	15.0
Late-Glacial marine deposits	Silt, soft, medium grey, sandy, with rare shells and shell fragments	7.0+	22.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	-1/16	+1/16-1/4	+1/4-1	+1-4	+4-16	+16-64	+64	mm
6	94	1	8.0- 9.0	10	88	2	0	0	0	0	§
			9.0-10.0	7	89	3	0	0	1	0	§
			10.0-11.0	6	89	5	0	0	0	0	§
			11.0-12.0	5	71	22	1	1	0	0	§
			12.0-13.0	6	41	50	2	1	0	0	§
			13.0-14.0	6	72	20	2	0	0	0	§
			14.0-15.0	4	87	8	1	0	0	0	§
			Mean	**6**	**77**	**16**	**1**	**	**	**0**	

NS 69 NW 17 **6459 9549** **Strewiebank, Kippen** **Block B**

Surface level +14.0m (+46 ft)
Water struck at +9.3m
250mm percussion
May 1981

Waste 7.3m
Bedrock 0.4m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Made ground	1.0	1.0
Post-Glacial deposits	Clay, laminated, soft, grey, slightly silty	3.7	4.7
Peat	Peat, medium to dark brown	0.1	4.8
Post-Glacial deposits	Silt, laminated, very clayey, slightly brownish grey, rootlet remains in upper part, at the base some platey clasts lying in the plane of the laminations. Micropalaeontological analysis suggests the sediments at the base may be late-Glacial	2.5	7.3
Lower Devonian	Sandstone, fine to medium grained with poor laminations, reddish grey	0.4+	7.7

NS 69 NE 7 **6558 9961** **East Moss-side, Kincardine** **Block B**

Surface level +13.0m (+43 ft)
Water struck at +1.8m
250mm and 200mm percussion
May 1981

Waste 13.6m
Bedrock 0.1m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.2	0.2
Post-Glacial deposits	Clay, above 1.5m very stiff, mottled brown and grey, below this depth silty, laminated, light grey to medium grey, locally dark bluish grey. Palaeontological analysis indicates a littoral marine environment	2.4	2.6
	Silt, interlaminated with silty sand, medium grey, rare black carbonaceous laminae and subangular to subrounded fine gravel grade clasts. Rootlets common at 4.0m	1.8	4.4
Late-Glacial marine deposits	Clay, laminated, very stiff, dark to medium grey, includes shells and gravel clasts. Palaeontological analysis indicates a littoral marine enviroment	0.9	5.3
	Silt, laminated, medium grey, with possible drop-stones. Palaeontological analysis indicates a cold-water marine environment	2.7	8.0
	Clay, silty, reddish brown to brown. Palaeontological analysis indicates a cold-water marine enviroment	3.2	11.2
Till	Sandy matrix with angular to subangular clasts, predominantly of indurated sandstone, with some igneous rocks and siltstone	2.4	13.6
Lower Devonian	Sandstone, fine grained, highly indurated, reddish brown	0.1+	13.7

NS 69 NE 8 **6553 9792** **Poldar Moss, Kincardine** **Block B**

Surface level +12.7m (+42 ft)
Water struck at +7.4m
250mm percussion
June 1981

Overburden	5.5m
Mineral	2.0m
Waste	2.1m
Bedrock	0.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, very clayey, grey-brown	0.1	0.1
Post-Glacial deposits	Clay, laminated, above 1.0m stiff and light grey with orange-brown mottling, below this softer with no mottling. Root remains above 1.5m, silty with some shell fragments below 3.4m	4.2	4.3
Peat	Peat	0.1	4.4
Post-Glacial deposits	Silt, laminated, slightly brownish grey, very clayey, a little shell material, sandy below 5.3m	1.1	5.5
	'Very clayey' sand Sand: fine, predominantly quartz, with some shell fragments Fines: disseminated grey silt	2.0	7.5
Till	Clay, very stiff, red-brown, sheared, slightly sandy, with ill-sorted clasts up to 13 cm in diameter of angular to subangular red sandstone with quartz and Dalradian grits	2.1	9.6
Lower Devonian	Siltstone, poorly laminated, highly indurated, reddish grey	0.2+	9.8

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm
29	71	0	5.5- 7.5	29	70	1	0	0	0	0 §

NS 69 NE 9 **6522 9673** **Little Kerse, Kippen** **Block B**

Surface level +12.2m (+40 ft)
Water struck at +4.6m
250mm and 200mm percussion
May 1981

Overburden 10.2m
Mineral 15.7m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, medium brown	0.5	0.5
Post-Glacial deposits	Clay, laminated, above 2.0m greyish brown and moderately stiff, below this softer and medium grey. Silt laminae below 4.0m and becoming darker grey below 6.0m	7.1	7.6
	Silt, medium grey, with bands of dark grey and greyish brown laminated clay, sandy and shelly above 9.5m, less abundant below this	2.6	10.2
	a Sand Gravel: rare fine quartz from 11.4m to 12.4m, and subangular to rounded clasts up to 4.5cm in diameter of red sandstone at the base. Bivalve shells throughout Sand: fine with medium, subrounded to rounded, quartz with rock fragments and rare mica, medium to dark grey Fines: silt, disseminated and in thin seams	3.9	14.1
	b 'Very clayey' sand Gravel: above 17.2m and below 22.0m trace white and red sandstones up to 18 cm in diameter Sand: fine, quartz with a little mica and rare carbonaceous material, the last named more abundant below 22.0m, rounded, medium grey becoming slightly reddish grey below 23.3m due to the presence of some feldspar, shell fragments below 22.0m Fines: disseminated medium grey silt and, from 21.1m to 22.0m, bands of light grey silt and brownish grey clay up to 1cm thick	11.8+	25.9

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages							
	Fines	Sand	Gravel		Fines	Sand			Gravel			
				from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm	
a	5	95	0	10.2-11.4	3	72	25	0	0	0	0	§
				11.4-12.4	4	59	36	0	1	0	0	§
				12.4-14.1	8	69	23	0	0	0	0	§
				Mean	**5**	**68**	**27**	**0**	**	**0**	**0**	
b	21	79	0	14.1-16.8	16	82	2	0	0	0	0	§
				16.8-17.7	21	78	1	0	0	0	0	§
				17.7-18.7	16	83	1	0	0	0	0	§
				18.7-19.7	13	86	1	0	0	0	0	§
				19.7-21.1	31	68	1	0	0	0	0	§
				21.1-22.0	22	77	1	0	0	0	0	§
				22.0-23.3	12	87	1	0	0	0	0	§
				23.3-25.9	28	71	0	1	0	0	0	§
				Mean	**21**	**78**	**1**	**	**0**	**0**	**0**	
a&b	17	83	0	Mean	17	76	7	**	**	0	0	

NS 69 NE 10 **6594 9570** **Crawfordston, Kippen** **Block B**

Surface level +12.9m (+42 ft)
Water struck at +3.9m
250mm and 200mm percussion
May 1981

Overburden 9.0m
Mineral 3.0m
Waste 10.1m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Made ground	1.3	1.3
Post-Glacial deposits	Clay, laminated, above 2.0m moderately stiff, light grey with brown mottling, below this depth softer, slightly silty, medium grey becoming dark grey with depth	7.7	9.0
	Sand Sand: fine, quartz with a little mica, brownish grey becoming grey with depth Fines: disseminated grey silt	3.0	12.0
Late-Glacial marine deposits	Clay, laminated, soft, slightly silty, with shell material, brownish grey above 12.5m, dark grey from 12.5m to 13.5m, and slightly brownish grey below this. From 12.0m to 12.5m and from 15.0m to 15.5m a few angular clasts of red sandstone and Dalradian grits. Palaeontological analysis indicates a cold-water environment	10.1+	22.1

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm	
4	96	0	9.0-10.3	5	94	1	0	0	0	0	§
			10.3-12.0	4	96	0	0	0	0	0	§
			Mean	**4**	**96**	**	**0**	**0**	**0**	**0**	

NS 69 NE 11 **6698 9949** **Norrieston, Kincardine** **Block C_1**

Surface level +23.9m (+79 ft)
Water not struck
Pit
April 1981

Waste 1.3m
Bedrock 0.1m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey and silty, medium brown	0.3	0.3
Late-Glacial beach deposits	Silt, clayey with some fine sand, angular clasts of fine grained flaggy red sandstone increasing in abundance with depth. Poorly developed banding	1.0	1.3
Lower Devonian	Sandstone, fine grained, red, slightly micaceous, interbedded with red micaceous siltstone	0.1+	1.4

NS 69 NE 12 **6697 9912** **Norrieston, Kincardine** **Block B**

Surface level +14.4m (+47 ft)
Water not struck
250mm percussion
May 1981

Waste 1.8m
Bedrock 0.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.4	0.4
Post-Glacial deposits	Clay, stiff, mottled grey and brown locally sandy, becomes silty and light to dark grey with depth. Rootlets	1.4	1.8
Lower Devonian	Sandstone, fine grained, flaggy, indurated, reddish brown	0.2+	2.0

NS 69 NE 13 **6609 9903** **Netherton, Kincardine** **Block B**

Surface level +13.9m (+46 ft)
Water struck at +4.2m
250mm percussion
May 1981

Waste 10.0m
Bedrock 1.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.2	0.2
Post-Glacial deposits	Clay, stiff, brown with grey mottling above 1.4m, below this soft, medium grey	2.3	2.5
	Silt, well laminated and sandy locally, medium grey with rare black carbonaceous laminae	3.7	6.2
Till	Matrix of reddish brown sandy silt with angular to subangular clasts up to 20cm in diameter of sandstone and Dalradian grits with basalts and, near the base, reddish brown siltstone	3.8	10.0
Lower Devonian	Siltstone, reddish brown, highly weathered	1.0+	11.0

NS 69 NE 14 **6651 9739** **Myme, Kincardine** **Block B**

Surface level +12.1m (+40 ft)
Water struck at +6.6m
250mm percussion
May 1981

Waste 8.5m
Bedrock 0.1m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.3	0.3
Post-Glacial deposits	Clay, stiff, mottled grey and orange	1.0	1.3
	Silt, interbedded with silty clay, the latter becoming less abundant with depth, soft, medium to dark grey, faintly laminated, rare shell fragments	2.7	4.0
Peat	Peat, contains wood fragments	0.1	4.1
Post-Glacial deposits	Silt, laminated, light to medium grey, rare shell fragments, fine silty sand laminae which increase in thickness and number with depth and have reddish tinge below 4.7m. Rootlets at top	1.6	5.7
	'Very clayey' sand Gravel: trace fine with coarse, angular with subangular and subrounded, dolerite and red and purple sandstones Sand: fine, subangular to subrounded, grey, quartz and feldspar with shell fragments Fines: disseminated silt and clay and silt laminae	1.6	7.3
Till	Clay, locally both sandy and laminated, very stiff, red, with clasts up to cobble size predominantly of dolerite and sandstone, the latter becoming dominant near the base	1.2	8.5
Lower Devonian	Sandstone, fine to medium grained, highly indurated purplish red	0.1+	8.6

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
23	77	0	5.7-7.3	23	72	3	2	0	0	0	§*

NS 69 NE 15 **6680 9527** **Boquhan Home Farm, Gargunnock** **Block B**

Surface level +13.4m (+44 ft)
Water struck at +5.4m
250mm percussion
May 1981

Waste 11.6m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, medium brown	0.2	0.2
Post-Glacial deposits	Clay, light grey with, in the upper part, brown mottling, interlaminated plant material	4.3	4.5
	Silt, laminated, clayey, light grey, slightly sandy and less clayey below 8.0m	4.2	8.7
Till	Clay, stiff above 9.3m becoming softer below this, sandy, red-brown, with ill-sorted angular to rounded clasts up to 13cm in diameter of red sandstone with Dalradian grits and basalt	2.9+	11.6
	Borehole terminated for technical reasons		

NS 69 NE 16 **6794 9875** **McOrriston, Kilmadock** **Block C_1**

Surface level +25.3m (+83 ft)
Water struck at +22.2m
Pit
December 1980

Waste 3.1m
Bedrock 0.1m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, above 0.3m clayey and silty, medium brown, below this orange-brown clay with mudstone and fine grained sandstone fragments	0.7	0.7
Late-Glacial beach deposits	Pebbly sand Gravel: fine, platey pebbles of laminated sandstone and mudstone, with some rock types of Highland origin Sand: medium and coarse with fine, angular to subangular, quartz with feldspar and rock fragments Fines: disseminated silt, medium brown	0.9	1.6
Till	Clay, reddish brown, with abundant ill-sorted angular clasts of reddish brown mudstone and fine grained reddish grey sandstone	1.5	3.1
Lower Devonian	Sandstone, fine grained, reddish grey	0.1+	3.2

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
			from to	-1/16	+1/16-1/4	+1/4-1	+1-4	+4-16	+16-64	+64 mm
3	73	24	0.7-1.6	3	16	28	29	22	2	0 *

NS 69 NE 17 **6749 9833** **Carse of McOrriston, Kilmadock** **Block B**

Surface level +13.3m (+44 ft)
Water struck at +8.3m
250mm percussion
May 1981

Waste 6.5m
Bedrock 0.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.2	0.2
Post-Glacial deposits	Clay, above 1.8m very stiff, mottled, brown, medium grey, and orange, below this depth softer, medium grey	1.8	2.0
	Silt, very soft, dark to medium grey, with carbonaceous laminae and shells, the latter indicating a shallow water environment with temperatures similar to those of today	3.0	5.0
	'Very clayey' sand Gravel: trace fine, subangular to subrounded, sandstone Sand: fine, quartz, feldspar and rock fragments, subangular, grey Fines: disseminated silt	1.5	6.5
Lower Devonian	Sandstone, medium to fine grained, platey, highly indurated, reddish brown	0.2+	6.7

GRADING

Mean for deposits percentages			Depth below surface (m)	percentage						
Fines	Sand	Gravel	from to	Fines -1/16	Sand +1/16-1/4	+1/4-1	+1-4	Gravel +4-16	+16-64	+64 mm
27	73	0	5.0-6.5	27	72	1	0	0	0	0 §*

NS 69 NE 18 **6739 9764** **North Mid Frew, Kincardine** **Block B**

Surface level +13.4m (+44 ft)
Water struck at +6.4m
250mm and 200mm percussion
May 1981

Waste 15.1m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.2	0.2
Post-Glacial deposits	Clay, above 1.7m stiff, brown with grey mottling, below this depth silty, grey	2.3	2.5
	Silt, laminated, medium to dark grey, clayey, rare shelly laminae, with platey clasts of sandstone from 7.5m to 8.5m, and a peaty band at 4.5m	6.0	8.5
Late-Glacial marine deposits	Clay, laminated, soft, silty, light to medium grey with locally, a slight reddish brown tinge	5.7	14.2
Till	Silt matrix, moderately stiff, sandy, reddish brown, with subangular to subrounded clasts of sandstone with Dalradian grits and basalt. Almost exclusively sandstone below 14.8m	0.9+	15.1
	Borehole terminated on possible bedrock		

NS 69 NE 19 **6747 9648** **Wester Culmore, Gargunnock** **Block B**

Surface level +12.0m (+39 ft)
Water struck at 0.0m
250mm and 200mm percussion
May 1981

Waste 18.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Made ground	0.5	0.5
Post-Glacial deposits	Clay, stiff and brown with grey mottling to 1.2m, softer and medium grey to 2.0m, dark grey below 2.0m. From 5.5m soft, poorly laminated, silty, evil smelling, with silt and sand laminae, the latter containing shell debris	12.0	12.5
Late-Glacial marine deposits	Silt, sandy and clayey, laminated, shelly, with sand bands up to 10cm thick	5.5+	18.0

NS 69 NE 20 **6849 9763** **Bridge of Goodie, Kincardine** **Block B**

Surface level +12.6m (+41 ft)
Water struck at +6.6m
250mm percussion
May 1981

Waste 10.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.1	0.1
Post-Glacial deposits	Clay, above 1.8m stiff and brown with grey mottling, below this depth soft, medium to dark grey with silt partings. Shelly sand parting at 4.8m and thin peat at 5.0m	4.9	5.0
	Silt, interlaminated with silty sand, soft, medium grey, with angular to subangular clasts up to 5cm in diameter of sandstone and dolerite	1.7	6.7
Late-Glacial marine deposits	Clay, laminated, moderately stiff, reddish grey, locally silty	1.2	7.9
Till	Sandy silt matrix, reddish brown becoming bright red below 9.0m, with angular to subrounded clasts up to 15cm in diameter of sandstone with lavas and Dalradian grits	2.1+	10.0
	Borehole terminated due to slow progress		

NS 69 NE 21 **6852 9600** **Culbeg, Gargunnock** **Block B**

Surface level +12.0m (+39 ft)
Water not struck
250mm percussion
May 1981

Waste 18.5m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, greyish brown	0.2	0.2
Post-Glacial deposits	Clay, laminated, above 2.0m moderately stiff and light grey with brown mottling. Below this depth softer, medium grey, with silt laminae. From 5.9m to 10.0m silt more abundant, both disseminated and in brownish grey bands up to 10cm thick. Below 10.0m includes red sand laminae, shell fragments and a 2cm peat band	10.3	10.5
Late-Glacial marine deposits	Clay, moderately stiff, dark grey, with silt laminae, and, below 13.5m, sand laminae	8.0+	18.5

NS 69 NE 22 **6854 9503** **Birkenwood, Gargunnock** **Block B**

Surface level +13.1m (+43 ft)
Water struck at +8.1m
250mm percussion
May 1981

Waste 8.5m
Bedrock 0.4m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, medium brown	0.2	0.2
Post-Glacial deposits	Clay, laminated, above 1.5m light grey with brown mottling, below this depth silty, softer, dark grey	3.6	3.8
Peat	Peat, dark brown	0.3	4.1
Post-Glacial deposits	Silt, laminated, soft, very clayey, medium brownish grey becoming medium to dark grey below 6.0m. Abundant fine sand below 8.1m	4.4	8.5
Upper Devonian	Sandstone, laminated, fine grained, red with greenish grey reduction spots, weathered	0.4+	8.9

NS 69 NE 23 **6972 9868** **Nether Spittalton, Kilmadock** **Block C_1**

Surface level +31.0m (+102ft)
Water struck at +28.0m
Pit
December 1980

Waste 3.0m
Bedrock 0.1m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.3	0.3
Late-Glacial beach deposits	Sand, silty, fine with medium, dark red-brown with fine platey pebbles of fine grained sandstone and siltstone. Locally imbricated	0.2	0.5
	Clay, silty, stiff, mottled light yellowish and bluish grey	0.2	0.7
	Sand, silty, well sorted, greyish maroon, rare pebbles	0.3	1.0
Till	Matrix clayey and silty, greyish maroon, becoming increasingly sandy with depth so that in the basal metre sand is predominant. Includes angular to subangular clasts up to boulder size of mudstone and sandstone	2.0	3.0
Lower Devonian	Sandstone, fine grained, dark grey, with some cross-laminations and mudstone partings	0.1+	3.1

NS 69 NE 24 **6960 9793** **Coldoch, Kincardine** **Block B**

Surface level +13.0m (+43 ft)
Water struck at +8.8m
250mm percussion
May 1981

Waste 5.8m
Bedrock 0.1m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, grey-brown	0.2	0.2
Post-Glacial deposits	Clay, laminated, above 1.8m stiff and light brownish grey with brown mottling, below this depth softer and light grey. Some shells	3.6	3.8
Peat	Peat, medium brown with pine needles and wood fragments up to 15cm in length	0.4	4.2
Post-Glacial deposits	Silt, poorly laminated, slightly brownish light grey	1.6	5.8
Lower Devonian	Siltstone, fissile, reddish brown, exhibits microfolding	0.1+	5.9

NS 69 NE 25 **6962 9703** **Easter Frew, Kincardine** **Block B**

Surface level +12.3m (+40 ft)
Water struck at +2.5m
250mm and 200mm percussion
June 1981

Waste 14.6m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Made ground	0.4	0.4
Post-Glacial deposits	Clay, above 1.5m stiff and brown mottled with grey, below this depth medium to dark grey and inter-bedded with silt bands some of which are shelly. Rare sandstone clasts around 7.2m	7.4	7.8
Late-Glacial marine deposits	Clay, laminated, very stiff medium to reddish grey, rare shells	2.0	9.8
	Silt, soft, reddish brown	1.3	11.2
Till	Matrix of moderately stiff sandy silt, reddish brown, with angular to subangular clasts up to 18cm in diameter of red sandstone with some lavas and Dalradian grits	3.4+	14.6
	Borehole terminated on probable bedrock		

NS 69 NE 26 **6971 9547** **Greenfoot, Gargunnock** **Block B**

Surface level +13.3m (+44 ft)
Water struck at -2.7m
250mm and 200mm percussion
May 1981

Waste 20.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Made ground	0.6	0.6
Post-Glacial deposits	Clay, above 1.8m very stiff, brown mottled with grey, below this depth soft, poorly laminated, medium grey to blue-grey locally silty, sand laminae below 13.5m	15.4	16.0
Late-Glacial marine deposits	Sand Sand: fine and medium, subangular to subrounded, quartz, feldspar and rock fragments with a little shell material, grey Fines: disseminated silt and rare thin clay bands	2.0	18.0
	Silt, soft, grey, sandy, with rare shells	2.0+	20.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel	from to	Fines -$\frac{1}{16}$	Sand +$\frac{1}{16}$-$\frac{1}{4}$	+$\frac{1}{4}$-1	+1-4	Gravel +4-16	+16-64	+64 mm	
7	93	0	16.0-17.0	8	49	41	2	0	0	0	§*
			17.0-18.0	6	41	52	1	0	0	0	§*
			Mean	**7**	**45**	**47**	**1**	**0**	**0**	**0**	

NS 69 SW 7 **6024 9479** **Middleton, Kippen** **Block B**

Surface level +15.9m (+52 ft)
Water struck at +14.4m
250mm percussion
April 1981

Waste 5.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown, with rare clasts	0.3	0.3
Post-Glacial deposits	Clay, firm, red with orange and grey mottling, silty in part, rare clasts up to 2cm in diameter of sandstone and lavas	0.3	0.6
Till	Matrix of stiff sandy clay, red to reddish brown, with subangular to subrounded clasts up to 25cm in diameter of sandstone with lavas and siltstone. Angularity of clasts increases below 4.7m	4.6+	5.2
	Borehole terminated due to slow progress		

NS 69 SE 9 **6536 9037** **Lees Hill, Gargunnock** **Block C_3**

Surface level +255.0m (+837ft)
Water not struck
Pit
April 1981

Waste 1.8m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, light to medium brown	0.4	0.4
Till	Matrix of very stiff greyish brown clay weathered above 1.1m to moderately stiff mottled yellow-brown and grey clay. Ill-sorted clasts up to 35cm in diameter of basalt with white, and a little red, sandstone	1.4+	1.8

NS 69 SE 10 **6938 9436** **Watson House, Gargunnock** **Block C_3**

Surface level +35.0m (+115ft)
Water struck at +33.0m
Pit
April 1981

Overburden 0.5m
Mineral 1.5m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, medium brown	0.5	0.5
Alluvial fan	Pebbly sand Gravel: principally near the base of the deposit fine and coarse with rare cobbles up to 25cm in diameter, angular with subangular and subrounded, red sandstone with some quartz and psammite Sand: fine with some medium, the latter increasing in abundance with depth, angular to subrounded, quartz, red Fines: disseminated red silt	1.5+	2.0
	Pit terminated on probable bedrock		

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm
7	81	12	0.5-2.0	7	68	11	2	5	7	0

NS 79 NW 4 **7064 9713** **Arnieve, Kincardine** **Block B**

Surface level +12.1m (+40 ft)
Water struck at +5.3m
250mm and 200mm percussion
October 1980

Waste 18.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.1	0.1
Post-Glacial deposits	Clay, above 1.5m silty, firm, mottled grey and orange, below this becomes increasingly silty with depth, soft, medium to bluish grey, evil smelling, some fine sand	4.9	5.0
	Silt and fine sand, soft, slightly micaceous, dark grey evil smelling	1.8	6.8
Fluvioglacial sand and gravel	Gravel, up to 20cm in diameter, angular, platey, sandstone with rare siltstone. Matrix of silt and fine sand	0.5	7.3
Late-Glacial marine deposits	Clay and silt, coarsely laminated, the former becoming increasingly abundant with depth, locally interbedded with silty sand, firm becoming soft below 8.5m, medium to dark grey above 8.5m, becoming light to medium grey with bands of reddish pale grey below this depth	10.7+	18.0

NS 79 NW 5 **7284 9922** **Blairdrummond Cottages, Kincardine** **Block A**

Surface level +32.0m (+105ft)
Water struck at +29.9m
250mm percussion
October 1980

Overburden 0.3m
Mineral 3.7m
Waste 7.8m
Bedrock 0.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, very sandy, light brown	0.3	0.3
Fluvioglacial sand and gravel	'Clayey' sand Gravel: trace Sand: fine with medium, angular to subangular, quartz with a few rock fragments Fines: disseminated silt, brownish grey becoming medium brown with depth	3.7	4.0
Late-Glacial marine deposits	Clay, brownish grey, grey and reddish grey laminations, silty from 5.0m to 7.5m	4.9	8.9
Till	Matrix of red sandy clay becoming stiffer and less sandy below 11.0m. Subangular clasts up to 12cm in diameter of red sandstone with rock types of Highland origin	2.9	11.8
Lower Devonian	Sandstone, fine grained, slightly micaceous, greyish red	0.2+	12.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm
11	89	0	0.3-1.3	4	74	21	0	1	0	0
			1.3-2.3	11	65	24	0	0	0	0
			2.3-3.3	7	66	27	0	0	0	0 §
			3.3-4.0	27	69	3	0	1	0	0 §
			Mean	**11**	**69**	**20**	**0**	**	**0**	**0**

NS 79 NW 6 7338 9979 **Blairdrummond Park, Kincardine** **Block A**

Surface level +15.0m (+49 ft)
Water struck at +9.9m
250mm percussion
October 1981

Overburden	0.4m
Mineral	7.0m
Waste	0.7m
Bedrock	0.5m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty and clayey, medium brown	0.4	0.4
Fluvioglacial sand and gravel	Gravel Gravel: fine and coarse with rare cobbles up to 13cm in diameter, angular to well rounded, psammite, quartzite, quartz, schist, basalt, and felsite, with a little sandstone. The last named increases in abundance below 5.1m and is the dominant rock type below 6.1m Sand: poorly sorted, coarse with medium and fine, angular to subrounded, quartz and rock fragments Fines: disseminated, medium brown, clay above 2.2m, silt below this	7.0	7.4
Late-Glacial marine deposits	Clay, stiff, laminated, reddish brown	0.5	7.9
Till	Matrix of sandy red clay with abundant angular to subangular clasts of red sandstone with some rock types of Highland origin	0.2	8.1
Lower Devonian	Sandstone, fine grained, purplish grey	0.5+	8.6

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm
7	35	58	0.4-1.2	14	9	11	12	21	33	0
			1.2-2.2	7	11	9	9	15	37	12
			2.2-3.2	11	6	11	14	24	34	0
			3.2-4.2	6	7	13	20	31	23	0
			4.2-5.1	8	7	11	15	31	28	0
			5.1-6.1	3	5	10	24	29	23	6 §
			6.1-7.4	2	3	11	22	36	26	0 §
			Mean	**7**	**7**	**11**	**17**	**27**	**28**	**3**

NS 79 NW 7 **7322 9813** **Wester Brierlands, Kincardine** **Block A**

Surface level +12.3m (+40 ft)
Water struck at +10.9m
250mm percussion
October 1980

Overburden	1.4m
Mineral	5.1m
Waste	5.3m
Bedrock	0.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, very stiff, dark grey	0.1	0.1
Post-Glacial deposits	Clay, very stiff, grey and greyish brown laminations	1.3	1.4
Fluvioglacial sand and gravel	Gravel Gravel: fine with coarse, subrounded to well rounded with some angular quartz, quartzite and psammite with basalt and sandstone Sand: coarse and medium with fine, angular to subrounded, rock fragments with quartz Fines: disseminated silt, more abundant and with clay below 5.6m	5.1	6.5
Late-Glacial marine deposits	Clay, moderately stiff, laminated greenish grey and reddish brown	3.6	10.1
Till	Matrix of red sandy clay, becoming very stiff with much less sand below 10.7m. Angular to subangular clasts up to 17cm in diameter of indurated dark reddish grey sandstone	1.7	11.8
Lower Devonian	Sandstone, red, fine grained	0.2+	12.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm	
4	42	54	1.4-2.6	3	4	17	18	30	28	0	§
			2.6-3.6	1	3	11	11	32	42	0	§
			3.6-4.6	1	3	12	23	45	16	0	§
			4.6-5.6	1	3	14	21	45	16	0	§
			5.6-6.5	14	20	33	21	11	1	0	§
			Mean	**4**	**6**	**17**	**19**	**33**	**21**	**0**	

NS 79 NW 8 **7355 9653** **Westwood Smithy, Kincardine** **Block A**

Surface level +10.9m (+36ft)
Water struck +5.9m
250mm and 200mm percussion
October 1980

Overburden	5.0m
Mineral	3.1m
Waste	4.7m
Mineral	2.4m
Waste	6.8m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Post-Glacial deposits	Clay, above 1.5m silty, firm, mottled pale grey and orange, below this depth very silty, soft, pale bluish grey	3.3	3.5
	Silt, soft, dark grey, evil smelling, some disseminated peaty material, clayey above 4.5m, sandy below this	1.5	5.0
Fluvioglacial sand and gravel	a Sandy gravel Gravel: fine with coarse and rare cobbles, subrounded to well rounded with the fine grade material containing subangular, red and grey sandstones, siltstone, psammite, quartz, quartzite Sand: medium with fine and coarse, angular to subangular with subrounded to well rounded, quartz with psammite and siltstone, medium grey, with comminuted shell material and rare whole mussel shells Fines: disseminated silt with silty clay bands	3.1	8.1
Late-Glacial marine deposits	Silt, soft, dark grey becoming coarsely interlaminated medium grey and reddish medium grey below 11.0m, sandy comminuted shell material above 9.0m	4.7	12.8
Fluvioglacial sand and gravel	b Sandy gravel Gravel: fine with medium and cobbles, angular to well rounded, red and grey sandstone, siltstone, with quartz and psammite. Some mussel shells Sand: Medium with fine and coarse, subrounded to well rounded psammite, siltstone, grey sandstone, and angular quartz. Abundant shell fragments with some carbonaceous material Fines: disseminated clayey silt	2.4	15.2
Late-Glacial marine deposits	Clay, soft, silty, pinkish medium grey	4.3	19.5
	Sandy gravel Gravel: fine and coarse, subangular to subrounded, red, brown, green, and grey sandstones with some quartz and psammite Sand: ill-sorted fine to coarse, angular to subangular, quartz and sandstone Fines: disseminated silty clay, reddish pale grey	1.0	20.5
Till	Clay, stiff, red-brown, silty and sandy, with sub-angular to well rounded clasts up to cobble grade mainly of sandstone	1.5+	22.0
	Borehole terminated due to slow progress		

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages							
	Fines	Sand	Gravel		Fines	Sand			Gravel			
				from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
a	4	52	44	5.0-6.0	4	7	23	19	33	9	5	§
				6.0-7.0	4	4	13	31	33	15	0	§
				7.0-8.1	4	13	32	14	24	13	0	§
				Mean	**4**	**8**	**23**	**21**	**30**	**12**	**2**	
b	5	70	25	12.8-13.8	5	17	51	14	10	3	0	§
				13.8-14.8	4	16	40	8	10	11	11	§
				14.8-15.2	6	13	31	16	16	6	12	§
				Mean	**5**	**16**	**42**	**12**	**11**	**7**	**7**	
	7	48	45	19.5-20.5	7	18	13	17	24	21	0	§*
a&b	4	60	36	**Mean**	**4**	**12**	**31**	**17**	**22**	**10**	**4**	

NS 79 NW 9 **7153 9855** **Burnbank Wood, Kincardine** **Block C_1**

Surface level +16.0m (+52ft)
Water not struck
Pit
December 1980

Waste 1.8m
Bedrock 0.1m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty, medium brown	0.5	0.5
Late-Glacial beach deposits	Sandy gravel, imbricated platey clasts of fine grained sandstone in a matrix of fine sand derived largely by weathering of the sandstone clasts	0.4	0.9
Till	Clay, moderately stiff, red, with rare mudstone clasts	0.9	1.8
Lower Devonian	Sandstone, fine grained, red, interbedded with mudstone	0.1+	1.9

NS 79 NW 10 **7195 9763** **Blairdrummond Moss, Kincardine** **Block B**

Surface level +12.1m (+40 ft)
Water struck at +7.9m
250mm and 200mm percussion
May 1981

Waste 13.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, greyish brown	0.2	0.2
Post-Glacial deposits	Clay, above 1.5m stiff, light grey with brown mottling, below this depth soft and light grey	3.4	3.6
Peat	Peat, black to medium brown, with wood fragments	0.1	3.7
Post-Glacial deposits	Clay, soft, light grey	0.3	4.0
	Silt, medium grey, micaceous, clayey above 4.5m, laminated with carbonaceous material near the base	1.8	5.8
Fluvioglacial sand and gravel	Pebbly sand Gravel: fine with a little coarse, angular to subrounded, red sandstone, siltstone, quartz, Dalradian grits Sand: medium and coarse with fine, angular to subrounded, quartz with rock fragments, mainly Dalradian grits. Some shell fragments Fines: disseminated silt	1.1	6.9
Late-Glacial marine deposits	Clay, laminated, stiff, reddish brown. Sandstone clasts up to 10cm in diameter rest on the surface of the clay	1.6	8.5
Till	Matrix of reddish brown sandy silt above 22.3m, becoming stiffer and clayey below this depth. Angular to subangular clasts up to 15cm in diameter of red sandstone with rare Dalradian and Old Red Sandstone conglomerate	4.5+	13.0
	Borehole terminated due to slow progress		

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
6	73	21	5.8-6.9	6	11	26	26	19	2	0	§*

NS 79 NW 11 **7165 9680** **Blairdrummond Moss, Kincardine** **Block B**

Surface level +12.0m (+39 ft)
Water struck at +7.0m
250mm and 200mm percussion
May 1981

Waste 18.7m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey and silty, medium brown	0.2	0.2
Post-Glacial deposits	Clay, poorly laminated, light grey, mottled brown in the upper part, becoming increasingly silty and sandy below 4.0m, shelly bands below 3.9m	6.3	6.5
Fluvioglacial sand and gravel	'Clayey' pebbly sand Gravel: coarse with fine, angular, mainly red sandstone and siltstone Sand: fine with some medium, quartz with rock and some shell fragments, angular to subangular, grey Fines: disseminated silt and clay, grey	1.1	7.6
Late-Glacial marine deposits	Clay, poorly laminated, reddish grey, very sandy and silty, the former both disseminated and in sand rich bands, shell fragments, with angular clasts up to 12cm in diameter throughout but most abundant near the top	11.1+	18.7

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm
14	77	9	6.5-7.6	14	63	12	2	3	6	0 §*

NS 79 NW 12 **7104 9583** **Offers, Kincardine** **Block B**

Surface level +11.2m (+37 ft)
Water struck at 0.0m
250mm and 200mm percussion
May 1981

Overburden 12.0m
Mineral 10.0m
Waste 3.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, medium brown	0.1	0.1
Post-Glacial deposits	Clay, moderately stiff, medium brown above 1.0m, blackish grey below this. Laminations throughout, become better developed below 4.0m where deposit is slightly silty. Shelly laminae below 11.0m. Palaeontological analysis indicates estuarine deposition in temperature conditions similar to those of today	11.9	12.0
		10.0	22.0
	Sand Gravel: rare clasts up to 10cm in diameter of siltstone and red, grey and yellow sandstones, angular to subrounded Sand: fine with a little medium, quartz with a few rock and shell fragments, angular to subrounded Fines: silt, disseminated, dark grey, with carbonaceous material and, at 19.5m, a 2cm thick grey clay band		
	Palaeontological analysis indicates estuarine deposition in temperature conditions similar to those of today		
Late-Glacial marine deposits	Clay, poorly laminated, dark grey becoming dark brownish grey below 23.2m, with silt and sand, the latter particularly abundant above 23.2m, rare shell fragments and carbonaceous material	3.2+	25.2

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm	
8	92	0	12.0-12.9	5	87	7	1	0	0	0	§
			12.9-13.8	3	83	13	1	0	0	0	§
			13.8-14.7	4	82	11	1	0	2	0	§
			14.7-16.0	6	81	11	1	0	1	0	§
			16.0-17.0	6	88	6	0	0	0	0	§
			17.0-17.9	7	89	4	0	0	0	0	§
			17.9-19.0	9	89	2	0	0	0	0	§
			19.0-19.9	9	90	1	0	0	0	0	§
			19.9-21.1	12	81	6	1	0	0	0	§
			21.1-22.0	14	85	1	0	0	0	0	§
			Mean	**8**	**85**	**6**	**1**	**0**	**	**0**	

NS 79 NW 13 **7254 9719** **Blairdrummond Moss, Kincardine** **Block A**

Surface level +12.0m (+39 ft)
Water struck at +7.3m
250mm and 200mm percussion
May 1981

Overburden	4.7m
Mineral	2.9m
Waste	10.4m
Bedrock	0.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil and fill, clayey, medium brown	0.3	0.3
Post-Glacial deposits	Clay, above 1.5m stiff and light brownish grey with brown mottling, soft and light grey below this	4.4	4.7
Fluvioglacial sand and gravel	Sandy gravel Gravel: less abundant from 5.7m to 6.7m, fine with coarse, angular to well rounded, quartz and Dalradian grits with red sandstone Sand: medium with coarse and fine, poorly sorted, quartz and rock fragments of the same composition as the gravel, angular to subrounded, a few shell fragments and a little black carbonaceous material, grey Fines: silt, disseminated	2.9	7.6
Late-Glacial marine deposits	Clay, laminated, soft, reddish brown, with, from 7.6m to 7.8m, a band of reddish grey laminated silt	3.9	11.5
Till	Above 13.5m matrix of red-brown sandy clay, below this depth a stiff sandy silt. With ill-sorted clasts up to 12cm in diameter of angular to subangular red and grey sandstones, with siltstone increasing in abundance with depth, and rare epidiorite and barytes	6.5	18.0
Lower Devonian	Siltstone, micaceous, red-brown	0.2+	18.2

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
3	55	42	4.7-5.7	2	7	27	13	32	19	0	§
			5.7-6.7	6	20	40	17	12	5	0	§
			6.7-7.6	2	5	12	21	46	14	0	§
			Mean	**3**	**11**	**27**	**17**	**29**	**13**	**0**	

NS 79 NW 14 **7234 9550** **Woodyett, Gargunnock** **Block B**

Surface level +11.1m (+36 ft)
Water struck at +3.1m
250mm and 200mm percussion
May 1981

Waste 18.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.2	0.2
Post-Glacial deposits	Clay, above 1.5m very stiff, mottled orange and grey, below this dark grey to blue grey, evil smelling, with rare thin peat bands. From 1.5m to 2.8m soft and silty, below 2.8m becoming increasingly stiff, with silt laminae	7.8	8.0
Late-Glacial marine deposits	Silt, laminated, soft, sandy, medium to light grey, locally shell fragments abundant	10.0+	18.0

NS 79 NW 15 **7398 9709** **Nyadd, Kincardine** **Block A**

Surface level +10.8m (+35 ft)
Water struck at +7.6m
250mm percussion
May 1981

Overburden 3.2m
Mineral 2.9m
Waste 0.4m
Bedrock 0.1m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, dark brown-grey, a few clasts	0.2	0.2
Post-Glacial deposits	Clay, laminated, above 1.5m stiff, light grey with brown mottling, below this depth moderately stiff, grey, with interlaminated plant material	3.0	3.2
Fluvioglacial sand and gravel	Sandy gravel Gravel: fine with coarse and rare cobbles up to 7cm in diameter, angular to well rounded, Dalradian grits and quartz with some andesite, conglomerate and red sandstone, the last named is predominant below 5.6m Sand: medium with coarse and fine, poorly sorted, angular to subangular quartz and rock fragments of the same composition as the gravel, grey Fines: silt, disseminated	2.9	6.1
Till	Matrix, of moderately stiff, red-brown, sandy clay with abundant ill-sorted angular clasts of red siltstone and sandstone	0.4	6.5
Lower Devonian	Sandstone, flaggy, slightly micaceous, red-brown	0.1+	6.6

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	-1/16	+1/16-1/4	+1/4-1	+1-4	+4-16	+16-64	+64	mm
4	67	29	3.2-4.4	2	8	31	18	24	17	0	§
			4.4-5.6	7	17	29	29	16	2	0	§
			5.6-6.1	3	33	21	15	21	7	0	§
			Mean	**4**	**16**	**29**	**22**	**20**	**9**	**0**	

NS 79 NW 16 **7436 9840** **Easter Brierlands, Kincardine** **Block A**

Surface level +14.4m (+47 ft)
Water struck at +10.4m
250mm and 200mm percussion
May 1981

Overburden	4.0m
Mineral	3.1m
Waste	0.6m
Mineral	6.2m
Waste	8.8m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, dark brown	0.2	0.2
Post-Glacial deposits	Clay, laminated, above 1.0m stiff, light grey with brown mottling, below this depth softer, medium grey and with much interlaminated plant material	3.8	4.0
Fluvioglacial sand and gravel	a Gravel Gravel: coarse and fine with rare cobbles up to 10cm in diameter, very poorly sorted, angular to well rounded, quartz and Dalradian grits with andesite, basalt and red sandstone. Many clasts have a brown, algal, coating Sand: coarse and medium with fine, angular to well rounded, rock fragments with quartz, grey above 5.1m, grey-brown below this depth Fines: silt, disseminated	3.1	7.1
Late-Glacial marine deposits	Clay, laminated, reddish brown, with partings of silt and fine, medium brown, sand	0.6	7.7
	b Clayey sand Sand: fine, quartz with a few rock and mica fragments and some black carbonaceous material, angular to subangular, greyish brown above 10.9m, grey below this depth. Rare shell fragments Fines: silt, disseminated, with bands of reddish brown and reddish grey laminated clay	6.2	13.9
	Silt, light grey, sandy and below 16.6m, clayey and slightly cohesive. Sand band from 16.2m to 16.6m	4.2	18.1
	Clay, laminated, moderately stiff, greyish brown, with 5cm thick bands of sand and sandy silt at 18.6m and from 20.2m to 20.7m	4.6+	22.7

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages							
	Fines	Sand	Gravel		Fines	Sand			Gravel			
				from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
a	2	33	65	4.0-5.1	3	4	12	16	29	31	5	§
				5.1-6.6	1	3	15	20	32	29	0	§
				6.6-7.1	2	8	5	11	29	38	7	§
				Mean	**2**	**4**	**12**	**17**	**30**	**32**	**3**	
b	15	85	0	7.7-8.6	19	80	1	0	0	0	0	§
				8.6-10.0	10	90	0	0	0	0	0	§
				10.0-10.9	9	91	0	0	0	0	0	§
				10.9-12.1	10	90	0	0	0	0	0	§
				12.1-13.9	23	76	1	0	0	0	0	§
				Mean	**15**	**85**	**	**0**	**0**	**0**	**0**	
a&b	11	68	21	**Mean**	**11**	**58**	**4**	**6**	**10**	**10**	**1**	

NS 79 NW 17 **7471 9697** **Carrat, Kincardine** **Block A**

Surface level +10.6m (+35 ft)
Water struck at +9.6m
250mm and 200mm percussion
May 1981

Overburden 4.5m
Mineral 5.3m
Waste 11.9m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, peaty, black	0.1	0.1
Post-Glacial deposits	Clay, above 1.5m stiff, light grey with brown mottling, below this depth softer and light grey. A few sand partings below 3.5m	4.4	4.5
Fluvioglacial sand and gravel	Pebbly sand Gravel: fine with coarse, and rare cobbles up to 13cm in diameter, angular to well rounded, quartz and Dalradian grits with some andesite, basalt and red sandstone, the last named more abundant below 8.2m Sand: medium with coarse and fine, angular to subrounded, quartz with rock fragments Fines: silt, disseminated, grey	5.3	9.8
Till	Matrix of very stiff red-brown, slightly sandy clay, with ill-sorted clasts up to 12 cm in diameter of red sandstone with quartz and Dalradian grits. At the base, lumps of the underlying silt appear to have been incorporated into the deposit	3.3	13.1
Glaciolacustrine deposits	Silt, laminated, soft, light grey, slightly sandy throughout but more abundant from 16.7m to 17.5m, from 19.0m to 19.9m and below 20.7m	8.6+	21.7

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm
2	74	24	4.5-6.2	2	12	28	19	29	10	0 §
			6.2-7.2	2	12	43	23	18	2	0 §
			7.2-8.2	2	11	61	20	6	0	0 §
			8.2-9.8	1	9	45	22	14	9	0 §
			Mean	**2**	**11**	**42**	**21**	**18**	**6**	**0**

NS 79 NW 18 **7431 9552** **Westwood Lane, Kincardine** **Block B**

Surface level +10.7m (+35 ft)
Water struck at +2.7m
250mm and 200mm percussion
May 1981

Waste 18.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, grey-brown	0.2	0.2
Post-Glacial deposits	Clay, above 1.5m very stiff, brown mottled with grey, below this depth softer, laminated, locally silty, medium grey with rare dark carbonaceous laminae. Rare shell fragments and rootlets. 1cm thick peat bands at 4.6m and 6.0m. Becomes sandier with depth	9.3	9.5
Late-Glacial marine deposits	Silt, moderately stiff at the top becoming soft with depth, red, sand laminae abundant, a 20cm diameter sandstone clast at 11.5m	8.5+	18.0

NS 79 NE 8 **7575 9734** **Ochtertyre, Kincardine** **Block A**

Surface level +9.0m (+30 ft)
Water struck at +8.6m
250mm and 200mm percussion
October 1980

Overburden	0.3m
Mineral	11.5m
Waste	6.5m
Bedrock	0.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey and silty with pebbles, dark brown	0.3	0.3
Alluvium	a Gravel Gravel: coarse and fine with rare cobbles up to 9cm in diameter, ill-sorted, subrounded to well rounded, sandstone, quartzite, psammite, schist, basalt, quartz, felsite Sand: coarse with medium and fine, ill-sorted, angular to well rounded, quartz and rock fragments Fines: silt, medium brown, disseminated, and in thin bands with organic remains, the latter probably old soil levels	3.9	4.2
Fluvioglacial sand and gravel	b Sandy gravel Gravel: fine with coarse and, above 5.2m some cobbles, angular to well rounded, composition as above Sand: medium with coarse and fine, angular to subangular, quartz and rock fragments. Brown above 5.2m, grey below this due to increasing abundance of quartz with depth Fines: silt, disseminated	2.0	6.2
	c Pebbly sand Gravel: fine and coarse, composition as above Sand: fine and medium, moderately well sorted angular to subrounded, quartz with a few rock fragments, grey. Carbonaceous fragments below 10.2m Fines: silt, disseminated	5.6	11.8
Late-Glacial marine deposits	Silt, grey, slightly sandy, with grey laminated clay bands and a few, mainly angular, red sandstone pebbles	5.1	16.9
	Sandy gravel Gravel: fine and coarse with rare cobbles, predominantly angular sandstone with some more rounded, rock types of Highland origin Sand: medium and fine with a little coarse purplish grey quartz and feldspar probably derived from the Old Red Sandstone. Some shell fragments Fines: silt, disseminated with rare, thin orange clay bands	1.4	18.3
Lower Devonian	Sandstone, medium grained, flaggy purplish grey	0.2+	18.5

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages							
	Fines	Sand	Gravel		Fines	Sand			Gravel			
				from to	-1/16	+1/16-1/4	+1/4-1	+1-4	+4-16	+16-64	+64	mm
a	1	23	76	0.3-1.3	4	6	6	9	20	49	6	§
				1.3-2.2	1	2	6	15	45	28	3	§
				2.2-3.4	0	2	5	16	45	32	0	§
				3.4-4.2	0	2	12	12	31	43	0	§
				Mean	**1**	**3**	**7**	**13**	**36**	**38**	**2**	
b	1	60	39	4.2-5.2	1	11	27	15	19	21	6	§
				5.2-6.2	1	11	39	17	25	7	0	§
				Mean	**1**	**11**	**33**	**16**	**22**	**14**	**3**	
c	5	90	5	6.2-7.4	1	28	55	7	6	3	0	§
				7.4-8.3	3	32	50	5	6	4	0	§
				8.3-9.3	4	50	37	2	1	6	0	§
				9.3-10.2	10	72	17	1	0	0	0	§
				10.2-11.8	6	49	42	2	1	0	0	§
				Mean	**5**	**46**	**41**	**3**	**3**	**2**	**0**	
b&c	4	82	14	**Mean**	**4**	**37**	**38**	**7**	**8**	**5**	**1**	
atoc	3	63	34	**Mean**	**3**	**25**	**29**	**9**	**17**	**16**	**1**	
	2	62	36	16.9-18.3	2	25	30	7	20	16	0	§*

NS 79 NE 9 **7545 9526** **West Drip, Kincardine** **Block B**

Surface level +10.0m (+33 ft)
Water struck at +3.5m
250mm and 200mm percussion
October 1980

Waste 18.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, very clayey, dark brown	0.4	0.4
Post-Glacial deposits	Clay, moderately stiff, poorly laminated, slightly silty, light brown becoming medium grey with depth	6.1	6.5
	Silt, medium grey	1.0	7.5
	'Clayey' sand Sand: fine, subangular to rounded, quartz with a few rock and rare coal fragments, grey Fines: silt, disseminated	1.1	8.4
Late-Glacial marine deposits	Clay, stiff, grey, silty above 9.7m. Psammite boulder resting on the surface of the deposit	9.6+	18.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
5	92	3	7.5-8.4	5	88	3	1	2	1	0	§*

NS 79 NE 10 **7752 9696** **Moss Farm, Dunblane** **Block A**

Surface level +9.9m (+33 ft)
Water struck at +0.8m
250mm and 200mm percussion
October 1980

Waste 18.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, very clayey, dark brown	0.3	0.3
Post-Glacial deposits	Clay, above 2.0m stiff, greyish brown, below this depth less stiff, medium grey	8.8	9.1
Fluvioglacial sand and gravel	Gravel Gravel: fine with coarse, subrounded to well rounded, quartz, quartzite, psammite, basalt, with a little sandstone Sand: coarse and medium with some fine, angular to subrounded, quartz and rock fragments with a few shell fragments Fines: silt, disseminated, with, at 9.8m, 10cm thick dark grey laminated clay bands	2.4	11.5
Late-Glacial marine deposits	Silt, medium grey, with some fine sand	6.5+	18.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
0	38	62	9.1-10.4	0	3	16	20	41	20	0	§*
			10.4-11.5	1	4	12	19	44	20	0	§*
			Mean	**0**	**4**	**14**	**20**	**42**	**20**	**0**	

NS 79 NE 11 **7707 9811** **Craigdownings, Dunblane** **Block A**

Surface level +10.6m (+35 ft)
Water struck at +8.6m
250mm percussion
May 1981

Waste	14.2m
Bedrock	0.3m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey brown	0.3	0.3
Post-Glacial deposits	Clay, above 2.0m very stiff, brown with grey mottling, abundant rootlets, below this depth, soft, medium grey, abundant carbonaceous laminae and some 1cm thick peat bands	4.5	4.8
Late-Glacial marine deposits	Silt, sandy clay and silty sand interbedded, range from soft to moderately stiff, red locally grey. Sand bands contain rare subangular to subrounded clasts	5.3	10.1
	'Very clayey' sand Sand: fine with some medium, subangular to subrounded, quartz and rock fragments, reddish brown Fines: silt, disseminated, and thin silty clay bands	1.9	12.0
	Clay, laminated, stiff, rare clasts	0.7	12.7
Till	Matrix of reddish brown sandy silt with abundant subangular to subrounded clasts of rock types of Highland origin with some sandstone	1.5	14.2
Lower Devonian	Sandstone, fine to medium grained, highly indurated, red-brown	0.3+	14.5

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
28	71	1	10.1-11.1	25	58	13	2	1	1	1	§*
			11.1-12.0	32	59	8	1	0	0	0	§*
			Mean	**28**	**58**	**11**	**2**	**1**	**0**	**0**	

NS 79 NE 12 **7631 9655** **Blackdub, Kincardine** **Block A**

Surface level +7.6m (+25 ft)
Water struck at +5.4m
250mm percussion
May 1981

Overburden	1.0m
Mineral	4.4m
Waste	4.8m
Bedrock	0.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil and fill, dark brown	1.0	1.0
Alluvium	a 'Very clayey' sand Sand: fine with a little medium, angular to subangular, quartz with feldspar and rock fragments Fines: silt and clay, disseminated, medium brown	1.0	2.0
Post-Glacial deposits	b Gravel Gravel: fine with coarse and rare cobbles up to 12cm in diameter, angular to well rounded, quartz and Dalradian grits with red sandstone, andesite and basalt Sand: coarse and medium with fine, angular to subrounded, quartz and rock fragments Fines: silt and clay, disseminated, dark brown with laminated grey silt and clay bands up to 3cm thick below 3.3m Above 2.5m interbedded peat with wood fragments up to 5cm in length. Below 4.2m abundant shells including Ostrea	3.4	5.4
Late-Glacial marine deposits	Clay, laminated, moderately stiff, grey-brown	4.2	9.6
Till	Matrix of moderately stiff, red-brown, sandy clay with angular to subrounded clasts up to 15cm in diameter of red-brown sandstone and siltstone with Dalradian grits, quartzite and epidiorite	0.6	10.2
Lower Devonian	Siltstone, poorly laminated, red-brown	0.2+	10.4

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages							
	Fines	Sand	Gravel		Fines	Sand			Gravel			
				from to	-1/16	+1/16-1/4	+1/4-1	+1-4	+4-16	+16-64	+64 mm	
a	24	74	2	1.0-2.0	24	56	14	4	2	0	0	
b	2	33	65	2.0-3.3	2	7	16	14	43	18	0	§
				3.3-4.2	1	4	11	14	44	26	0	§
				4.2-5.4	2	5	11	13	40	25	4	§
				Mean	**2**	**6**	**13**	**14**	**41**	**23**	**1**	
a&b	7	**41**	**52**	**Mean**	7	**17**	**13**	**11**	**34**	**17**	**1**	

NS 79 NE 13 **7625 9594** **Hill of Drip, Kincardine** **Block B**

Surface level +11.0m (+36 ft)
Water struck at +6.0m
250mm percussion
May 1981

Waste	5.4m
Bedrock	0.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, and fill, medium brown	0.4	0.4
Post-Glacial deposits	Clay, laminated, above 2.0m stiff, light greyish brown with darker mottling, below this depth softer, and light grey. Below 4.0m slightly silty with shells, mainly of Ostrea	5.0	5.4
Lower Devonian	Sandstone, flaggy, fine grained, micaceous, reddish grey	0.2+	5.6

NS 79 NE 14 **7789 9857** **Gallow Hill, Dunblane** **Block C_1**

Surface level +54.4m (+178 ft)
Water not struck
Pit
April 1981

Waste	1.6m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey and silty, medium brown	0.3	0.3
Till	Matrix, of clay bound sand, fine with medium and coarse, angular, quartz with rock fragments, with clasts up to 19cm in diameter of psammite, epidiorite and quartz, with red sandstone and basalt	1.3+	1.6

NS 79 NE 15 **7831 9527** **Kildean, St Ninians** **Block B**

Surface level +10.1m (+33 ft)
Water not struck
250mm percussion
May 1981

Waste 14.1m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.2	0.2
	Made ground	0.6	0.8
Post-Glacial deposits	Clay, above 2.2m very stiff, mottled brown and grey, below this depth softer and greyer	2.8	3.6
	Silt and silty clay, laminated, moderately stiff, dark grey to black, evil smelling. Shelly bands from 5.4m to 5.6m and from 9.7m to 9.8m	6.2	9.8
Till	Matrix of moderately stiff red silt or sandy silt with angular to subangular clasts up to 20cm in diameter of sandstone and basalt	4.3+	14.1
	Borehole terminated due to slow progress		

NS 79 NE 16 **7962 9600** **Greencarse, Logie** **Block B**

Surface level +9.5m (+31 ft)
Water struck at +7.4m
250mm percussion
May 1981

Waste 9.4m
Bedrock 0.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.2	0.2
Post-Glacial deposits	Clay, above 1.0m brown with grey mottling and abundant rootlets, below this depth medium grey and softer	1.9	2.1
	Silt, poorly laminated, soft, dark to medium grey, with, below 8.5m, sand laminae and rare shells	7.0	9.1
Till	Matrix of reddish brown silty sand with subangular to subrounded clasts up to 10cm in diameter of rock types of Highland origin with basalt and sandstone	0.3	9.4
Lower Devonian	Sandstone, reddish brown	0.2+	9.6

NS 79 SW 11 **7052 9496** **Fleuchams, Gargunnock** **Block B**

Surface level +12.8m (+42 ft)
Water struck at +2.0m
250mm and 200mm percussion
May 1981

Waste 18.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.3	0.3
Post-Glacial deposits	Clay, above 2.1m very stiff, brown, mottled, below this depth, moderately stiff, light to medium grey, with abundant silt laminae and rare shell fragments and carbonaceous bands	10.3	10.6
Peat	Peat, brown-black, very consolidated	0.2	10.8
Late-Glacial marine deposits	Silt and silty fine sand, laminated, soft, medium grey, 10cm thick gravel band at 11.4m and clasts from 17.5m to 18.0m	7.2+	18.0

NS 79 SW 12 **7211 9451** **Mains Farm, Gargunnock** **Block B**

Surface level +13.1m (+43 ft)
Water struck at +11.3m
250mm percussion
May 1981

Waste 7.2m
Bedrock 0.4m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, brown	0.2	0.2
Post-Glacial deposits	Clay, stiff, brown, mottled, with a 2cm thick peat band at the base	1.6	1.8
	Silt, silty sand, and clay, interlaminated, light to medium grey with darker laminae	5.4	7.2
Upper Devonian	Sandstone, medium grained, red, highly indurated	0.4+	7.6

NS 79 SW 13 **7329 9452** **West Carse, St Ninians** **Block B**

Surface level +10.8m (+35 ft)
Water struck at +6.2m
250mm percussion
May 1981

Waste 17.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Made ground	0.5	0.5
Post-Glacial deposits	Clay, above 1.5m, very stiff, brown with grey mottling, below this depth soft, medium grey, locally silty, interbedded with laminated silt and fine silty sand	9.0	9.5
Late-Glacial marine deposits	Silt, laminated, soft, medium grey fine silty sand laminae, rare shells and clasts at 10.5m	3.0	12.5
	Sand Gravel: fine, subrounded, sandstone and lavas Sand: fine with medium, subangular, quartz and rock and shell fragments, light to medium grey Fines: silt, disseminated, and silty clay bands	3.0	15.5
	Silt, dark grey to black, sandy, with thin clay bands	1.5+	17.0
	Borehole terminated due to technical reasons		

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
5	94	1	12.5-13.5	6	51	36	5	2	0	0	§*
			13.5-14.5	5	47	41	6	1	0	0	§*
			14.5-15.5	4	54	36	5	1	0	0	§*
			Mean	**5**	**51**	**38**	**5**	**1**	**0**	**0**	

NS 79 SW 14 **7493 9391** **Craigniven, St Ninians** **Block B**

Surface level +9.8m (+32 ft)
Water struck at +1.6m
250mm percussion
May 1981

Waste 18.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Made ground	0.7	0.7
Post-Glacial deposits	Clay, stiff, mottled brown and grey	1.6	2.3
	Silt, clay, and fine silty sand interlaminated, soft, medium to dark grey. 1cm thick peat layers at 8.2m	5.9	8.2
Late-Glacial marine deposits	Silt, soft, medium grey, rare sand partings	9.8+	18.0

NS 79 SE 26 **7554 9457** **West Cambusdrenny, Kincardine** **Block B**

Surface level +10.3m (+34 ft)
Water struck at +1.6m
250mm and 200mm percussion
May 1981

Overburden 11.0m
Mineral 5.0m
Waste 5.2m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil and fill, medium brown	0.5	0.5
Post-Glacial deposits	Clay, laminated, light grey with brown mottling becoming dark grey with depth, with silt laminae	8.2	8.7
Late-Glacial marine deposits	Clay, laminated, moderately stiff, greyish brown	2.3	11.0
	'Clayey' sand Gravel: coarse with fine below 15.4m Sand: fine with medium, angular to subrounded, quartz with feldspar, mafic minerals and rock fragments, reddish brown. Generally similar in colour and texture to the Lower Devonian sandstone Fines: silt, disseminated, reddish brown, with bands of reddish brown laminated silty clay	5.0	16.0
Till	Matrix of reddish brown clay, abundant fine and medium sand above 16.5m, below this depth less sandy and more cohesive and silty, with angular to rounded clasts up to 12 cm in diameter of red sandstone with some Dalradian grits and quartzite	5.2+	21.2
	Borehole terminated due to slow progress		

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
10	89	1	11.0-12.0	11	76	12	1	0	0	0	§
			12.0-13.1	11	65	23	1	0	0	0	§
			13.1-15.4	9	59	31	1	0	0	0	§
			15.4-16.0	14	47	31	2	1	5	0	§
			Mean	**10**	**63**	**25**	**1**	**	**1**	**0**	

NS 79 SE 27 **7573 9306** **Touch House, St Ninians** **Block B**

Surface level +13.1m (+43 ft)
Water not struck
250mm and 200mm percussion
May 1981

Waste 18.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Made ground	0.4	0.4
Post-Glacial deposits	Clay, above 1.6m very stiff, medium brown with grey mottling, below this depth, laminated, soft, silty medium grey, with black carbonaceous laminae and, near the base, 1cm thick peat bands	5.2	5.6
Late-Glacial marine deposits	Clayey silt and silty clay, poorly laminated, very soft, reddish brown to grey, rare sandstone clasts above 6.6m abundant silty sand laminae from 12.0m to 13.6m	12.4+	18.0

NS 79 SE 28 **7503 9246** **Touch House, St Ninians** **Block C_3**

Surface level +49.0m (+161ft)
Water not struck
Pit
April 1981

Waste 1.6m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, dark red-brown	0.3	0.3
Till	Matrix of sandy clay with clasts of lava, subrounded to rounded above 0.6m, more angular below this	1.3+	1.6

NS 79 SE 29 **7526 9182** **Touch Mollar, St Ninians** **Block C_3**

Surface level +73.0m (+240ft)
Water struck at +71.5m
Pit
April 1981

Overburden 0.3m
Mineral 1.2m
Waste 0.4m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy	0.3	0.3
Glacial sand and gravel	Pebbly sand Gravel: fine and coarse with rare cobbles up to 20cm in diameter, lavas and sandstone Sand: fine with some medium and coarse, subangular to subrounded, quartz and rock fragments Fines: silt and clay, disseminated	1.2	1.5
Till	Matrix of stiff, red-brown clay, with fine, and rare coarse grade, clasts of lava	0.4+	1.9

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm
8	70	22	0.3-1.5	8	43	17	10	11	11	0

NS 79 SE 30 **7625 9447** **Baad, Kincardine** **Block B**

Surface level +10.4m (+34 ft)
Water struck at +2.7m
250mm and 200mm percussion
June 1981

Waste 21.0m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Made ground	0.4	0.4
Post-Glacial deposits	Clay, mottled grey and brown becoming laminated and dark grey with depth, abundant shelly silt laminae, 2cm thick peat band at 5.6m	7.3	7.7
Late-Glacial marine deposits	Silt, soft, medium grey	1.1	8.6
	Sand Sand: fine angular to subangular, quartz, feldspar, rock and shell fragments, medium to dark grey Fines: silt, disseminated, grey, with rare thin silt bands	1.4	10.0
	Silt, soft, poorly laminated, grey, interbedded with silty sand, rare clasts at 11.5m. Palaeontological analysis suggests deposition in a shallow marine environment	9.5	19.5
Till	Matrix of reddish brown sandy silt with angular to subangular, with a few subrounded, clasts up to 10cm in diameter, sandstone with basalt and rock types of Highland origin	1.5+	21.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm	
7	93	0	8.6-10.0	7	88	5	0	0	0	0	§*

NS 79 SE 31 **7699 9083** **Wester Craigend, St Ninians** **Block C_3**

Surface level +73.9m (+242ft)
Water not struck
Pit
April 1981

Overburden 0.3m
Mineral 1.3m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, dark brown	0.3	0.3
Alluvium	Gravel Gravel: cobbles up to 25cm in diameter, with fine and coarse, ill-sorted, angular to well rounded, basalt with quartz and psammite Sand: coarse and medium with fine, angular to subangular, predominantly rock fragments of the same composition as the gravel fraction Fines: silt, disseminated	1.3+	1.6

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
6	25	69	0.3-1.6	6	4	9	12	19	19	31	§*

NS 79 SE 32 **7730 9381** **North Kersebonny, St Ninians** **Block B**

Surface level +10.9m (+36 ft)
Water struck at -0.7m
250mm percussion
May 1981

Waste 13.5m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Made ground	0.4	0.4
Post-Glacial deposits	Clay, very stiff, faintly laminated, brown mottled with grey	1.0	1.4
	Clayey silt, clay, and silty clay, interlaminated, very soft, medium to dark grey becoming blue-grey below 6.0m. Abundant laminae of black carbonaceous material and, below 6.0m, silty fine sand. Rare shell fragments at the base	10.2	11.6
	Matrix of very sandy clay with angular to subangular clasts of sandstone, lava, and rock types of Highland origin.	1.9+	13.5
	Borehole terminated on possible bedrock		

NS 79 SE 33 **7762 9820** **Hayford Mills, St Ninians** **Block C_3**

Surface level +17.4m (+57 ft)
Water struck at +15.1m
250mm and 200mm percussion
June 1981

Overburden	0.1m
Mineral	2.8m
Waste	2.6m
Mineral	19.5m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, with pebbles, medium brown	0.1	0.1
Late-Glacial beach deposits	a Sandy gravel Gravel: fine with coarse and rare cobbles up to 13cm in diameter, subangular to rounded. Dalradian grits, quartzite, red sandstone, with a little felsite Sand: fine to coarse, ill-sorted, angular to subangular with, in the coarse grade, rock fragments. Fines: silt, orange-brown, disseminated	2.8	2.9
Late-Glacial marine deposits	Clay, laminated, stiff above 3.6m yellow-brown with reddish brown silt laminae, below this depth reddish brown with rare silt and red sand laminae	2.6	5.5
Glacial sand and gravel	b Gravel Gravel: coarse and fine with cobbles up to 18cm in diameter, angular to well rounded, red sandstone with Dalradian grits and some siltstone, quartz, felsite, and basalt Sand: coarse with fine and medium, angular to rounded, rock fragments of the same composition as the gravel fraction with, in the fine and medium grade, quartz and feldspar Fines: silt, disseminated, reddish brown, with at 9.2m, a very silty sand band	8.4	13.9
	c Pebbly sand Gravel: fine, coarse, and cobbles, composition as above Sand: fine with medium and a little coarse, becomes finer with depth, angular to subrounded, quartz and feldspar with rock fragments, reddish brown Fines: silt, disseminated, reddish brown	3.5	17.4
	d Sandy gravel Gravel: becomes much less abundant below 23.2m, fine with coarse and rare cobbles up to 8cm in diameter, angular to well rounded, red sandstone with Dalradian grits, shale, quartz and red siltstone, Dalradian grits become predominant below 21.0m Sand: medium with fine and coarse, angular to subrounded, rock fragments of the same composition as the gravel, quartz, and feldspar, reddish brown Fines: silt, disseminated, reddish brown, with a 10cm thick band of reddish brown silty clay at 17.4m	7.6+	25.0

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages							
	Fines	Sand	Gravel		Fines	Sand			Gravel			
				from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64 mm	
a	9	55	36	0.1-1.2	9	14	23	21	25	8	0	
				1.2-2.9	9	17	13	22	26	13	0	
				Mean	**9**	**16**	**17**	**22**	**25**	**11**	**0**	
b	3	29	68	5.5-6.5	8	6	4	14	33	35	0	§
				6.5-7.5	3	4	4	16	31	22	20	§
				7.5-8.6	2	5	6	12	31	44	0	§
				8.6-9.7	3	11	14	26	29	17	0	§
				9.7-11.0	2	6	6	15	31	33	7	§
				11.0-11.9	2	4	4	9	23	58	0	§
				11.9-12.9	2	16	9	9	8	34	22	§
				12.9-13.9	3	9	8	13	14	19	34	§
				Mean	**3**	**8**	**7**	**14**	**25**	**33**	**10**	
c	5	86	9	13.9-15.0	4	26	35	15	6	6	8	§
				15.0-17.4	6	55	34	3	1	1	0	§
				Mean	**5**	**45**	**34**	**7**	**3**	**3**	**3**	
d	4	54	42	17.4-18.4	4	10	8	13	25	40	0	§
				18.4-19.7	3	9	11	24	36	17	0	§
				19.7-21.0	3	7	12	25	33	15	5	§
				21.0-22.3	2	13	23	14	28	20	0	§
				22.3-23.2	4	20	30	10	25	11	0	§
				23.2-24.3	5	30	37	5	10	13	0	§
				24.3-25.0	5	41	48	3	2	1	0	§
				Mean	**4**	**17**	**22**	**15**	**24**	**17**	**1**	
btod	4	49	47	**Mean**	**4**	**10**	**18**	**13**	**21**	**21**	**5**	
atod	4	50	46	**Mean**	**4**	**18**	**18**	**14**	**21**	**20**	**5**	

NS 79 SE 34 **7866 9183** **Torbrex, St Ninians** **Block C_3**

Surface level +42.8m (+140ft)
Water not struck
Pit
April 1981

Overburden 0.3m
Mineral 1.0m
Waste 0.6m+

LOG

Geological classification	Lithology	Thickness m	Depth m
Late-Glacial beach deposits	Soil, sandy, dark brown	0.3	0.3
	'Very clayey' pebbly sand Gravel: fine and coarse, angular to rounded, red sandstone with basalt and rock types of Highland origin Sand: fine, angular to rounded, quartz with feldspar Fines: silt and clay, disseminated, clay becomes more abundant with depth	1.0	1.3
Late-Glacial marine deposits	Clay, poorly laminated, red	0.6+	1.9

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
31	57	12	0.3-1.3	31	45	9	3	6	6	0	*

NS 79 SE 35 **7936 9023** **Chartershall, St Ninians** **Block C_3**

Surface level +46.3m (+152ft)
Water not struck
Pit
April 1981

Overburden 0.8m
Mineral 0.8m+

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty and clayey, dark brown	0.2	0.2
Alluvium	Clay, silty, medium brown	0.6	0.8
	Gravel Gravel: coarse and fine with cobbles up to 19cm in diameter, ill-sorted, rounded and well rounded with some subrounded to angular, red sandstone and basalt with some rock types of Highland origin Sand: ill-sorted fine to coarse, angular, rock fragments Fines: silt and clay, disseminated, brown	0.8+	1.6

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages							
Fines	Sand	Gravel		Fines	Sand			Gravel			
			from to	$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1-4	+4-16	+16-64	+64	mm
9	27	64	0.8-1.6	9	7	11	9	23	29	12	*

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Printed in the United Kingdom for Her Majesty's Stationery Office by
Bell & Bain Limited, Glasgow
Dd 714640/4336 C10 2/83

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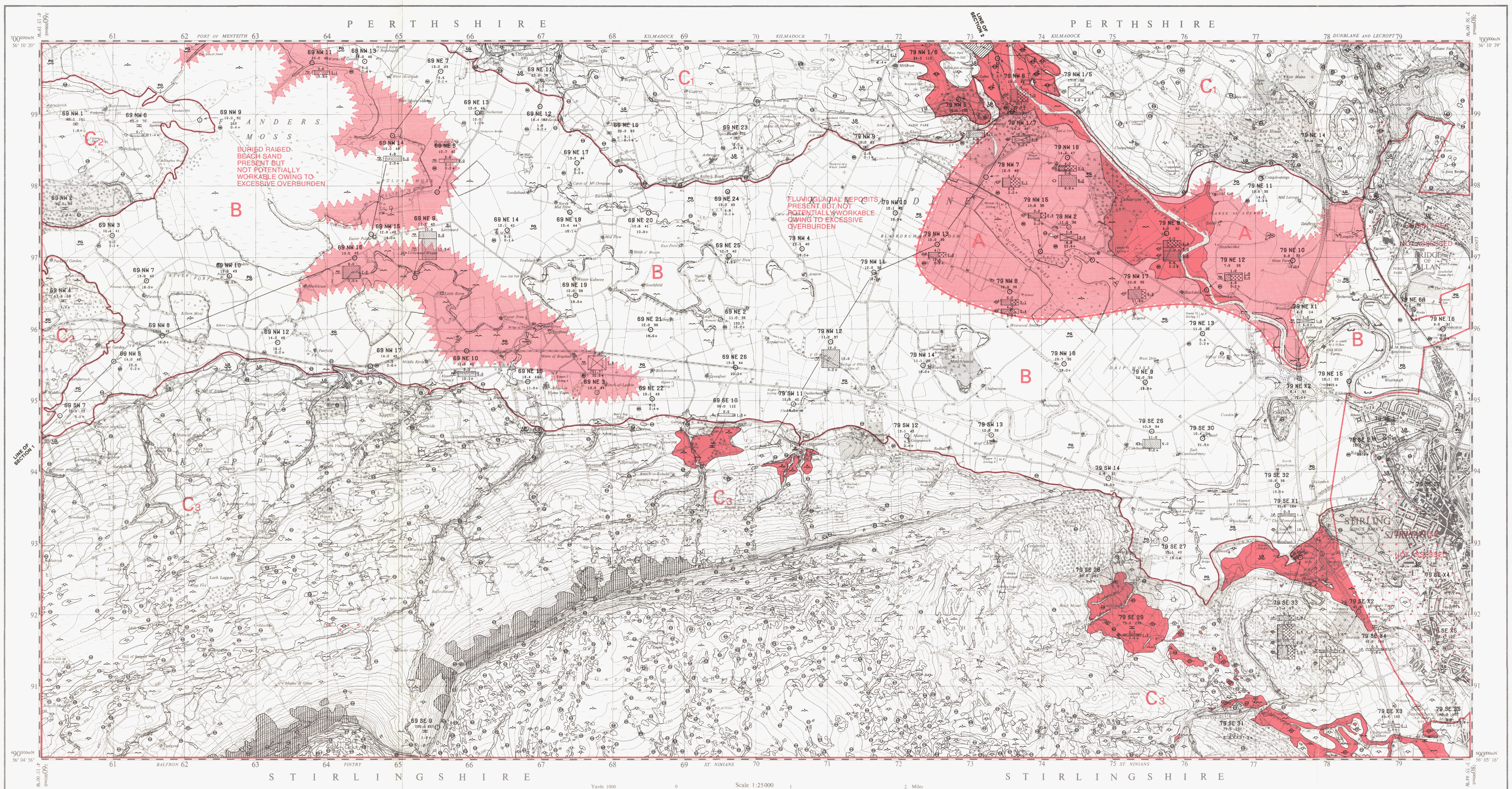
INSTITUTE OF GEOLOGICAL SCIENCES

INDUSTRIAL MINERALS ASSESSMENT UNIT

THE SAND AND GRAVEL RESOURCES OF THE COUNTRY WEST OF STIRLING, CENTRAL REGION

Scale 1:25 000 or about 2½ Inches to 1 Mile

ORDNANCE SURVEY
SHEETS NS 69 & NS 79
PROVISIONAL EDITION



The representation on this map of a Road, Track, or Footpath, is no evidence of the existence of a right of way.

Scale 1:25 000

Yards 1000 0 1 2 Miles

Metres 1000 0 1 2 3 Kilometres

The GRID lines on this sheet are at 1 Kilometre interval.
Heights are in feet above Mean Sea Level at Newlyn.

Contour values are in feet

1 square inch on this map represents 99·639 acres on the ground.

Data quoted for an individual sample point refer strictly to that site; reliable conclusions cannot be drawn about the thickness and grading elsewhere in the deposit particularly in material as variable as sand and gravel. However, estimates of volume and mean grading of the mineral as a whole in each Resource Block are given in the Report

Compiled from 6" sheets last fully revised 1898-1934
Other systematic revision 1946-54 has been incorporated
Major roads revised 1976

Made and published by the Director General of the Ordnance Survey, Southampton. Reprinted with minor corrections 1956.

Original geological survey on the six-inch scale by B.N. Peach and R.L. Jack in 1871.

Re-survey by I.H. Forsyth, E.H. Francis and W.A. Read between 1950 and 1961. T.R.M. Lawrie District Geologist

Sand and Gravel survey by J.L. Laxton and D.L. Ross in 1981, under the supervision of E.F.P. Nickless. R.G. Thurrell, Head, Industrial Minerals Assessment Unit.

1:25000 Sand and Gravel Resource Sheet published 1982. G.M. Brown, D.Sc., F.R.S., Director, Institute of Geological Sciences, incorporating the Geological Survey of Great Britain, the Museum of Practical Geology and Overseas Geological Surveys.

Borehole Graphics drawn by computer using programs written by J.L. McInnes, NERC Computing Service, IGS, Edinburgh

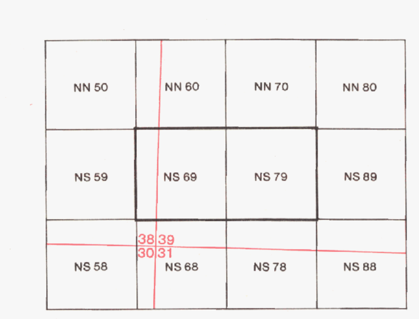
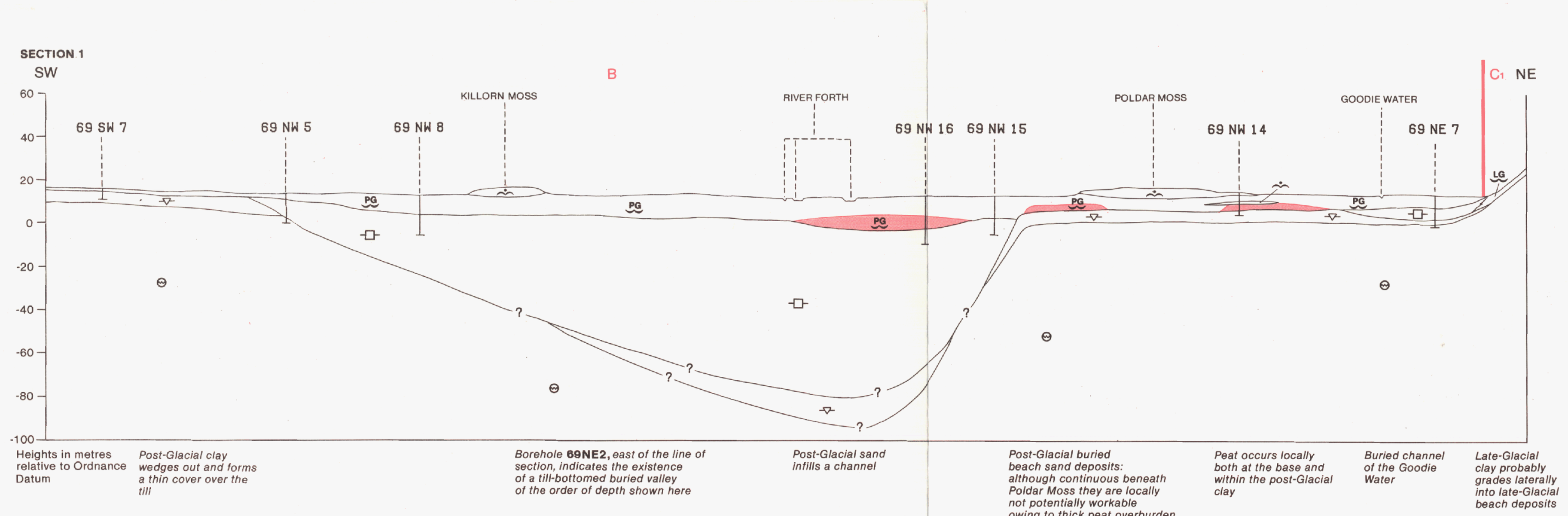


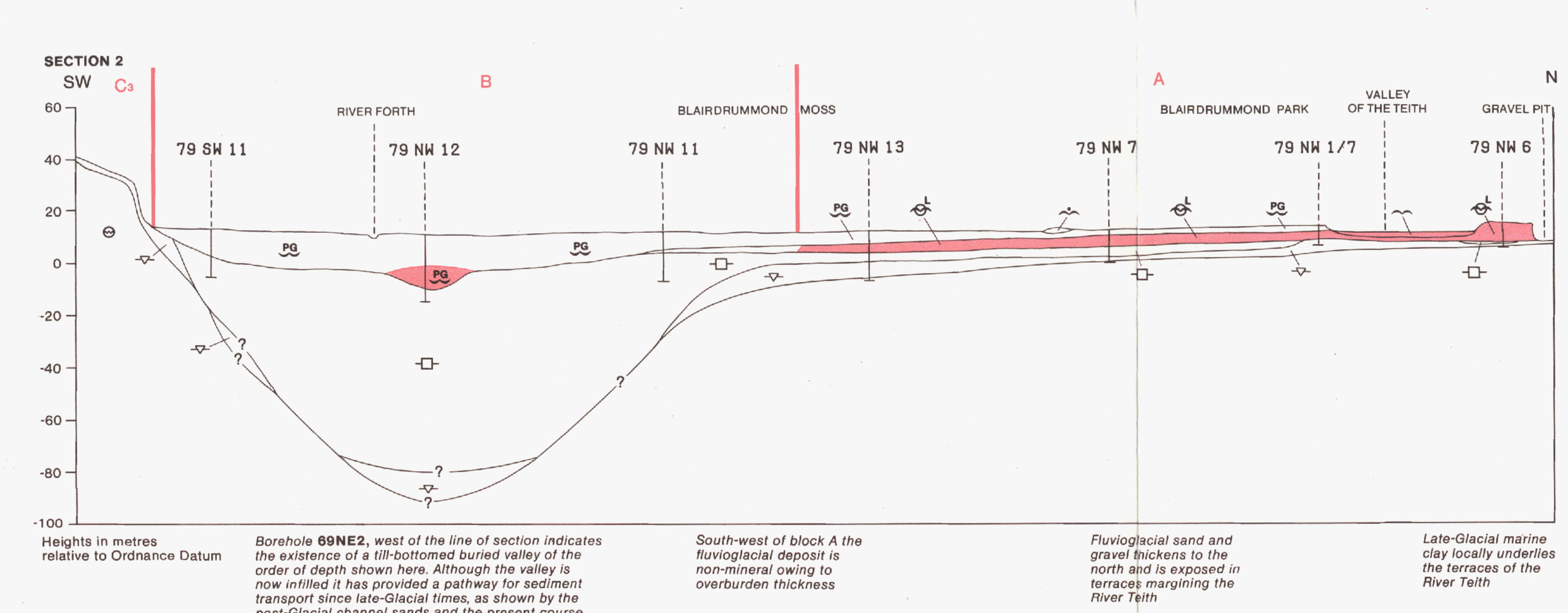
Diagram showing the relation of this sheet with the National Grid 10km squares and the One Inch New Series Geological Sheets 30, 31, 38, 39

Produced for the Institute of Geological Sciences by Carto-Graphics (Edinburgh) Limited
Printed by John Bartholomew & Son Ltd. Edinburgh 1982

GENERALISED HORIZONTAL SECTIONS SHOWING RELATIONSHIPS OF DRIFT DEPOSITS

HORIZONTAL SCALE 1:25 000 VERTICAL EXAGGERATION 12.5×





THE SAND AND GRAVEL RESOURCES OF THE COUNTRY WEST OF STIRLING, CENTRAL REGION

This map should be read in conjunction with the accompanying Report which contains details of the assessment of resources.

EXPLANATION OF SYMBOLS AND ABBREVIATIONS

Landslip L-1

DRIFT

Recent and Pleistocene

Peat P-1

Alluvium of flood plains (or undifferentiated)—gravel, sand, silt, or clay A-75

Alluvial cone—fan composed of alluvium AC-2

Head and scree (undifferentiated) H-54

Reclaimed intertidal flats RF-1

Raised beach deposits and associated estuarine alluvium, post-Glacial—estuarine grey clay, with beach deposits of sand and silt, and channel sand RS-9

Raised beach deposits, late-Glacial—silt, sand, clay and gravel RS-10

Raised marine deposits, late-Glacial—mainly red and grey clay, with channel sand RS-11

Fluvioglacial sand and gravel of the Loch Lomond Stadial—generally gravel or sandy gravel with subordinate sand FL-28

Fluvioglacial sand and gravel—mainly fine sand to the west of the River Teith, probably sand and gravel on the eastern side FL-29

Glacial sand and gravel—predominantly gravel and sandy gravel, with interbedded sand GS-83

Till—stiff stony clay of various colours, locally sandy TL-11

SOLID

Bedrock at or near surface (undifferentiated)—the Carse and ground to the north is underlain by Lower Devonian red sandstone. Bedrock in the western part of the area south of the Carse is Upper Devonian sandstone and Lower Carboniferous Calciferous Sandstone Measures rocks whereas the Touch and Gargunnock hills are underlain by volcanics of the Clyde Plateau Series. In the south-east of the area Lower and Upper Carboniferous sediments are intruded by a Permo-Carboniferous quartz-dolerite sill

Worked ground (sand and gravel) as at January 1982 WG-6

BOUNDARY LINES

Geological boundary

Inferred boundary between categories of deposit

Resource block boundary

Line marking back feature of terrace

BOREHOLE DATA

SITE LOCATIONS

Industrial Minerals Assessment Unit (IMAU) boreholes

Other boreholes

Shallow pits

IMAU BOREHOLES

Note:
(i) Figures underlined denote thicknesses used in the assessment of resources
(ii) The + sign indicates that the base of the deposit was not reached
(iii) The geological classification is given only for mineral and bedrock

Registration Number

Each IMAU borehole and pit is identified by a Registration Number, for example **79 NE 8.** The first numbers and letters refer to the quarter sheet and the final figures to the IGS serial numbers for that quarter. The unique designation for borehole **79 NE 8** is **NS 79 NE 8**

Grading Diagrams

Each grading diagram shows the mean particle size distribution of a deposit of mineral.

Sand ($+\frac{1}{16}$–4mm)
Fines ($-\frac{1}{16}$mm)
Gravel (+4mm)

The height of the diagram is proportional to the mineral thickness

The width of the divisions shows proportions of **Fines, Sand and Gravel**

Note:
When grading data are not sufficiently detailed or are absent the grading diagram is crossed through or shown without ornament

OTHER BOREHOLES

Site investigation boreholes which provide ancillary assessment data are located on the map. These boreholes are identified by serial numbers prefixed by the letter X, and indexed by the numbers and letters of the relevant standard quarter sheet, for example, **79 SE X1**

SHALLOW TRENCHES

The registration and layout of information for shallow trenches is the same as for IMAU sample points

CATEGORIES OF DEPOSITS

Exposed, potentially workable sand and gravel (mineral) CAT-E7

Continuous or almost continuous spreads of potentially workable sand and gravel beneath overburden CAT-C4

Sand and gravel not assessed CAT-NI

Sand and gravel absent or not potentially workable CAT-A4

RESOURCE BLOCKS

For the purpose of assessment, the mineral-bearing land is divided into Resource Blocks (see Report). Each is designated by a letter

KEY TO SECTIONS

Potentially workable sand and gravel (mineral), exposed or beneath overburden

Bedrock and waste, including overburden, are uncoloured

Geological boundary

Inferred boundary limiting the extent of potentially workable sand and gravel

Otherwise symbols and abbreviations as map legend

Detailed records may be consulted on application to the Officer-in-Charge, Industrial Minerals Assessment Unit, Institute of Geological Sciences, Murchison House, West Mains Road, Edinburgh EH9 3LA