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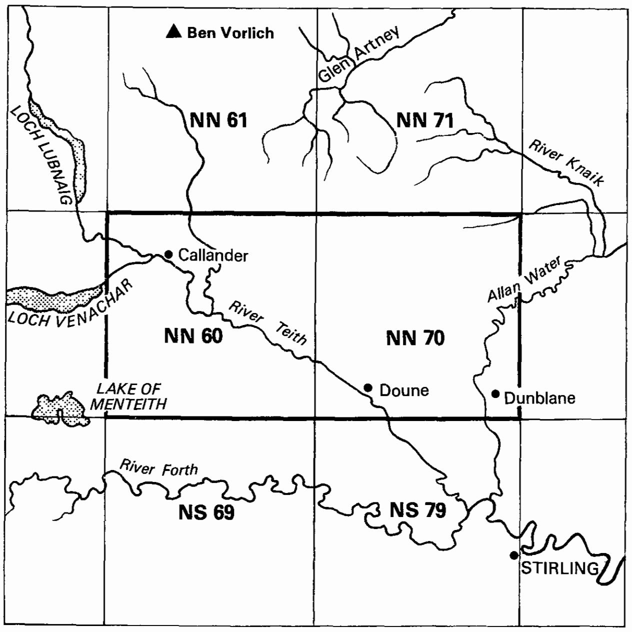

The sand and gravel resources of the country around Callander and Dunblane, Central Region

Description of 1:25 000 resource sheet NN 60 and 70

J. W. Merritt and J. L. Laxton

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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 200 km^2 of country around Callander and Dunblane, Central Region, shown on the accompanying resource map. The survey was conducted by J. W. Merritt and J. L. Laxton under the supervision of E. F. P. Nickless, Officer-in-Charge of the sub-unit in Edinburgh. The work is based principally on the geological survey, at a scale of six inches to one mile, of Sheet 39, undertaken between 1955 and 1960 by I. H. Forsyth of the North Lowlands Unit. The geological lines now presented at the 1:25000 scale include a partial re-appraisal of the drift geology by J. W. Merritt, based on a field survey in 1980. The section on the mechanical and physical properties of the aggregate was prepared by D. L. Ross.

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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SUMMARY

The geological maps of the Institute of Geological Sciences, fifty-one boreholes and twenty-three shallow pits sunk for the Industrial Minerals Assessment Unit, together with data from twelve other boreholes and the inspection of sand and gravel workings, form the basis of the assessment of sand and gravel resources in the area around Callander and Dunblane, Central Region.

All deposits in the area which might be potentially workable for sand and gravel have been investigated and a simple statistical method used to estimate the volume. The reliability of the volume estimates is given at the symmetrical 95 per cent probability level.

The 1:25 000 map is divided into four resource blocks, which contain between 2.6 and 9.6 km^2 of potentially workable sand and gravel as distinct from potentially workable morainic drift. The geology of the deposits is described and the mineral-bearing area, the mean thickness of overburden and mineral, and the mean grading of the various types of deposit are stated. Detailed borehole and section data are given. The geology and the outlines of the resource blocks, the position of the boreholes, shallow pits and sections used in the assessment are shown on the accompanying map.

Bibliographic reference

MERRITT, J. W. and LAXTON, J. L. 1982. The sand and gravel resources of the country around Callander and Dunblane, Central Region. Description of 1:25 000 resource sheet NN 60 and 70. *Miner. Assess. Rep. Inst. Geol. Sci.* No. 121.

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Note

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

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 geological 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 1 m 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 25 m 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 18 m 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

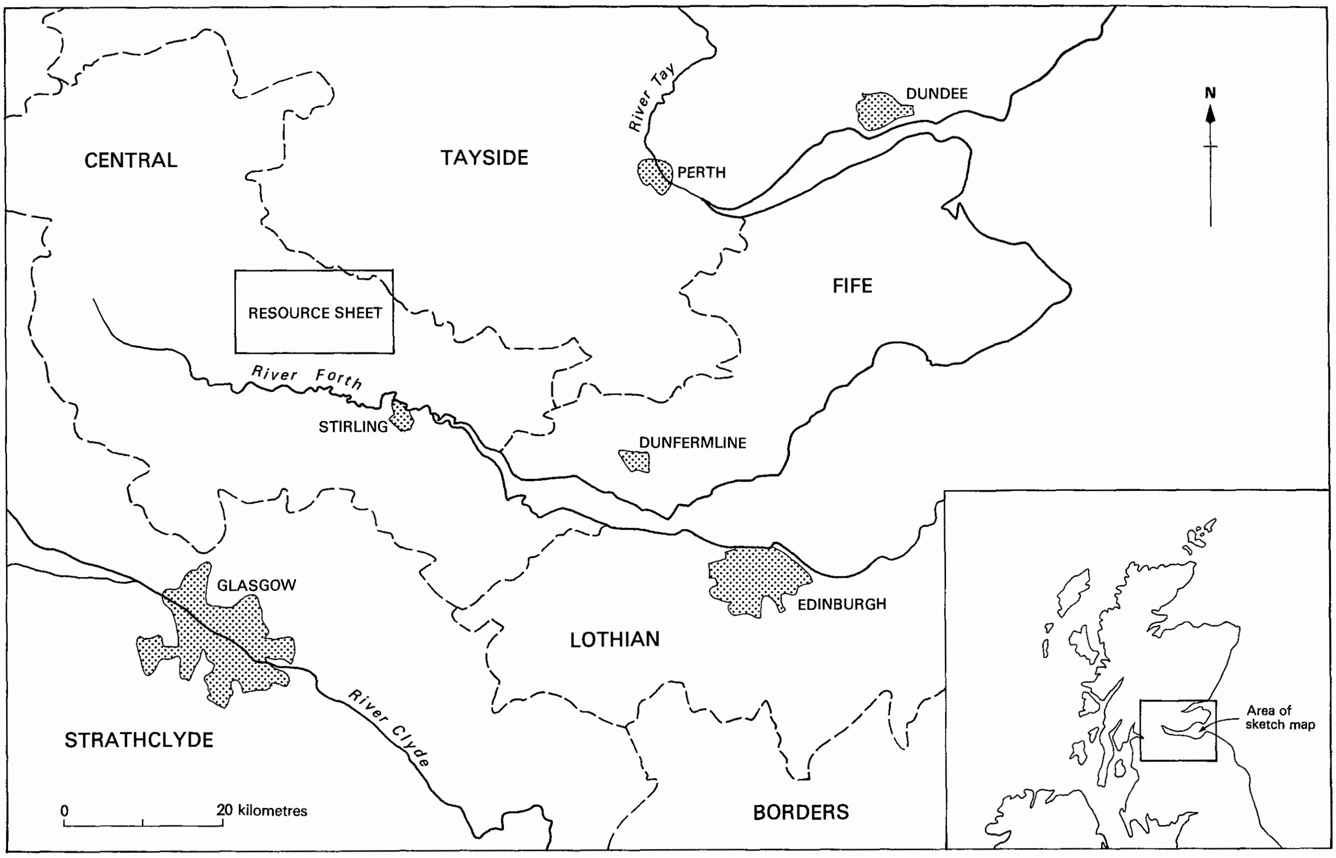

Figure 1 Sketch-map showing the location of the survey area

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

The volume and other characteristics are assessed within resource blocks, each of which, ideally, contains approximately 10 km^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 is situated about 7 km to the north-west of Stirling and borders the Central Highlands, which lie to the west and north (Figure 1). Four km beyond the north-western margin of the resource sheet area, Ben Ledi rises to 879 m above Ordnance Datum, but within the assessed area the topography is more subdued, reaching a maximum height of about 485 m above Ordnance Datum in the north (Figure 2), and rising in the south-west to 387 m above Ordnance Datum at Letter Hill [603 045] near Ben Gullipen. These two upland areas are separated by the south-east-trending valley of the River Teith, which forms the principal topographic feature of the survey area; the valley floor is generally about 1 km wide. In the east, the southerly-trending valley of the Allan Water is separated from the valley of the River Teith by an area of low hummocky ground between Doune [727 016] and Dunblane [782 013] through which the 'misfit' Ardoch Burn flows to join the River Teith at Doune. Part of the flat Carse of Stirling extends into the extreme south-west of the resource sheet area.

Most of the land higher than about 150 m above Ordnance Datum has till or rock at the surface and is either rough moorland or afforested; below this height, within the valleys, are extensive spreads of outwash sands and gravels which, together with a more sheltered situation, allow prosperous mixed farming. The population is concentrated in the valleys and is centred on Callander and Doune, situated beside the River Teith, and Dunblane on the Allan Water. Callander now depends principally on tourism for its prosperity and Dunblane has become a dormitory town for Stirling, Glasgow and Edinburgh; in contrast Doune, although it has a distillery, still principally depends on agriculture. The main lines of communication follow the valleys, that of the River Teith carrying the trunk road from Stirling to the West Highlands, and the Allan Water both the main road and railway lines from Glasgow to Inverness and Aberdeen.

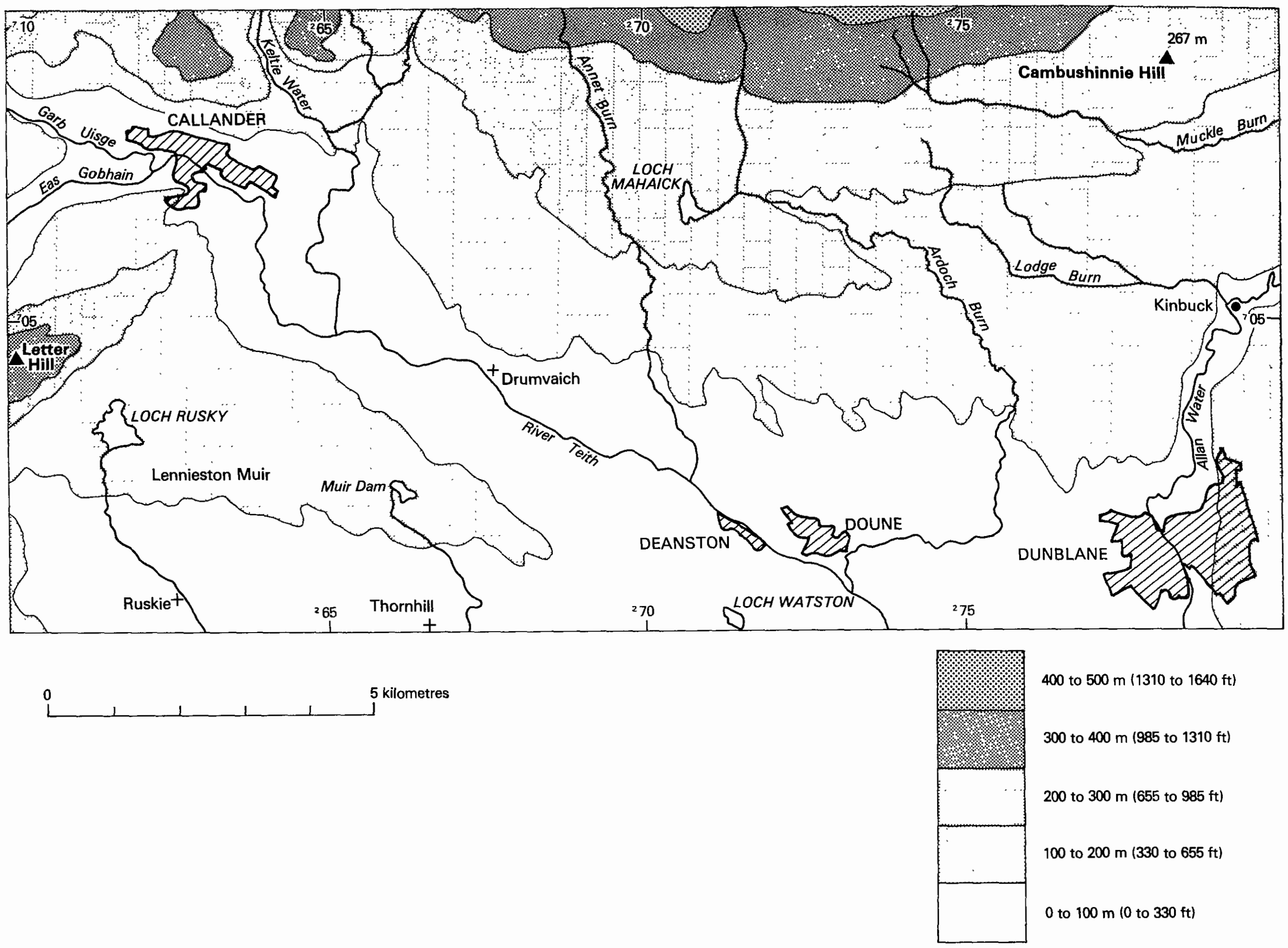

Figure 2 Generalised map showing topography and localities

The outwash sands and gravels have been extensively worked for aggregate: the extractive industry, agriculture, building, transport and recreation all compete for the limited land-area of the floor and lower sides of the valleys, making an improved understanding of the distribution of sand and gravel deposits of particular importance to the development of coherent land-use planning policies.

GEOLOGY

The resource sheet area, which is included in the Stirling (39 W) and Aberfoyle (38 E) sheets of the 1:50 000 Geological Map of Scotland, was first surveyed at a scale of six inches to one mile in the early 1870's by R. L. Jack, J. S. Grant Wilson and B. N. Peach; a small area to the north-west of the Highland Boundary Fault was surveyed by C. T. Clough in 1896. The results of this work were incorporated in the first editions of One-inch sheets 38 and 39, which were published in 1901 and 1882 respectively. The extreme south-east of the resource sheet area was re-examined in 1952 by E. H. Francis and most of the remainder was resurveyed between 1955 and 1960 by I. H. Forsyth. This revision survey at a scale of six inches to one mile was incorporated into the second edition of One-inch sheet 39, Solid and Drift versions of which were published in 1969 and accompanied by a descriptive memoir (Francis and others, 1970). The currently available 1:50 000 Solid and Drift editions of sheet 39 W (Stirling) were published in 1974 and are also based on the 1952 to 1960 resurvey. The drift was partially resurveyed in connexion with the present work by J. W. Merritt in 1980 and the results are incorporated on the resource map accompanying this report.

Over the greater part of the district the solid rocks, predominantly sandstone, are overlaid by sediments of Quaternary age, which comprise till, sand and gravel, silt and clay. The geological sequence is summarised in Table 1 where the deposits are listed as far as possible in order of increasing age.

A systematic but brief account of the principal known sand and gravel deposits and workings was given by Anderson (1946) and more recently, Browne (1977) summarised published and unpublished data for Central Region as a whole.

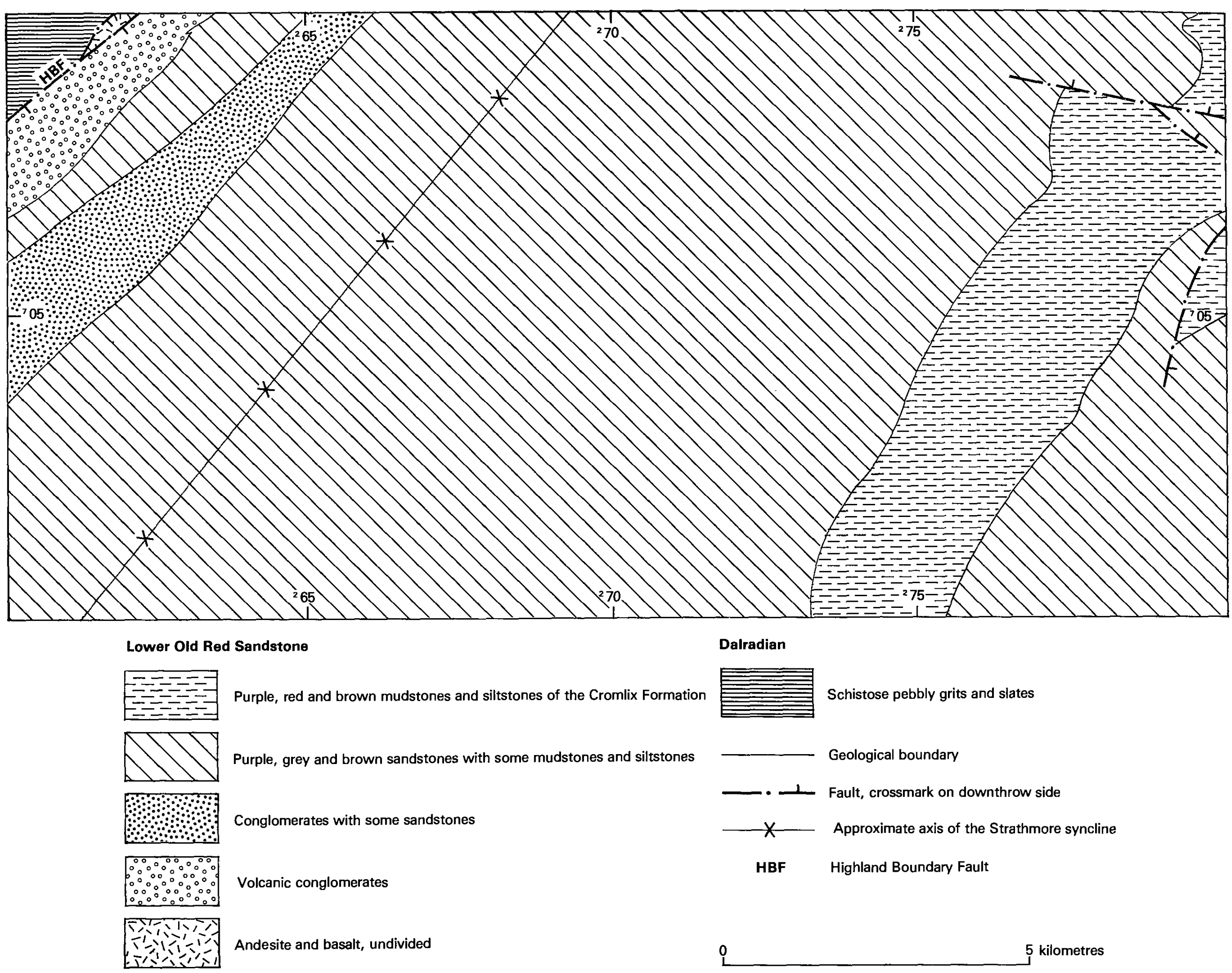

Figure 3 Sketch-map showing the solid geology

SOLID

The distribution of the solid rocks, which range from probably Cambrian to possibly Tertiary in age, is shown in Figure 3. The extreme north-west of the area is divided from the remainder by the north-east-trending Highland Boundary Fault, to the south of which rocks have been downthrown, probably by between 2500 m and 3000 m. Upper Dalradian rocks of probable Cambrian age crop out to the north-west of the fault and comprise, in the main, schistose grits and slates. These rocks were subjected to folding, low-grade metamorphism and the emplacement of minor intrusions during the Caledonian orogeny (mid-Ordovician to Lower Devonian times).

To the south-east of the outcrop of the Dalradian metasediments, a trough developed in late-Silurian to Lower Devonian times into which a thick sequence of lavas and fluvial sediments (the Lower Old Red Sandstone) was deposited under semi-arid climatic conditions. The lavas occur in the lower part of the Lower Old Red Sandstone and are only found within the resource sheet area as a small, fault-bounded slice of andesite and basalt bordering the Highland Boundary Fault. The disposition of the sedimentary rocks overlying the lavas is controlled by the north-east-trending Strathmore Syncline, the axis of which crosses the valley of the River Teith about 5 km south-east of Callander. The lowest exposed formation of the sedimentary sequence comprises volcanic conglomerates up to 900 m thick, which were formed by erosion of

Table 1 Geological classification of deposits

DRIFT	
Recent and Pleistocene	Peat
	Alluvium (undifferentiated)
	Raised beach deposits and associated marine and estuarine alluvium, post-Glacial
	Fluvioglacial sand and gravel, Loch Lomond Stadial
	Interstadial lacustrine deposits (borehole 60 NW 6 only)
	Raised beach deposits and associated marine and estuarine alluvium, late-Glacial
	Fluvioglacial sand and gravel, undifferentiated
	Glaciolacustrine deposits
	Glacial sand and gravel
	Flow-till
	Morainic drift
	Till
SOLID	
Permo-Carboniferous	Igneous dyke rocks
Lower Devonian	Lower Old Red Sandstone conglomerates, sandstones, siltstones and mudstones
	Andesite and basalt (undifferentiated)
Dalradian (?Lower Cambrian)	Schistose grits, slates and graphitic shale

previously erupted lavas. These rocks only crop-out in the north-west of the resource sheet area where they form part of the north-western limb of the Strathmore Syncline; on the south-eastern limb of the same structure they are exposed just to the south-east of the resource sheet area.

Overlying the volcanic conglomerates are over 2000 m of fluviatile sediments, predominantly sandstones, with subordinate siltstones, mudstones and conglomerates. The last-named are almost entirely confined to the narrow, steeply dipping, north-western limb of the syncline, that is, towards the Highlands from where most of the sediments forming the Lower Old Red Sandstone are thought to have been derived. The sediments fine to the south-east, for example, the central and north-western parts of the survey area are underlain by sandstones, often pebbly, with conglomerates and subsidiary mudstones and siltstones, whereas in the south-east about 760 m of mudstones and siltstones occur between two thinner formations, mainly comprising fine-grained sandstone.

During Middle Devonian times the area was subjected to earth movements: the Strathmore Syncline was formed and most of the dislocation along the Highland Boundary Fault is also thought to have occurred at this time. There is little evidence of the subsequent geological record within the area: a few west-trending quartz-dolerite dykes were intruded, probably in Permo-Carboniferous times, and an olivine-basalt dyke north-west of Callander may be of Tertiary age.

DRIFT

The survey area has almost certainly been subjected to repeated glaciation during the Quaternary. However, because erosion associated with each ice advance largely removes evidence of previous glaciations, only deposits associated with recent ice advances, the main late-Devensian and the Loch Lomond Stadial, are now observed within the area (see Table 2). The orientation of drumlins, the distribution of erratics and glacial striae on the valley sides of the River Teith and Allan Water all indicate that a major line of flow within the main late-Devensian ice-sheet extended south-eastwards down the valley of the River Teith, eastwards across the low interfluve between Doune and Dunblane, then north-eastwards up Strathallan and eventually towards the Firth of Tay at Perth (Francis and others, 1970).

Within the resource sheet area, till, deposited during the main late-Devensian glaciation, occurs extensively over much of the upland ground and within the valleys it was shown to be the lowest deposit in most boreholes that proved the full drift sequence. The deposit shows great lithological variation from highly consolidated clayey lodgement till (borehole 70 SW 17), to relatively uncompact clayey sand and gravel (borehole 60 NE 3). These differences in part reflect the bedrock lithology, for example, till proved in Strathallan at boreholes 70 NE 1 and 2 and 70 SE 7 is very clayey owing to the presence locally of mudstones, whereas till overlying sandstones in the valley of the River Teith is correspondingly sandier. However, not all the till deposits within the area are lodgement tills: some were formed sub-aerially as ablation or flow-tills (Thompson, 1972) and these generally comprise very ill-sorted and compact clayey sand and gravel. A convincing flow-till occurs at Auchenlaich [6480 0720] where the recent work (boreholes 60 NW 7, pits 60 NW 12 and 13) confirms Thompson's (1972) geomorphological interpretation of the locality. A speculative cross-section (A–A′) portraying the relationship of this deposit to others is given on the resource map. A hitherto unreported example of flow-till is also identified at borehole 60 NW 6, near Torrie Cottage [6425 0505], where the deposit lies above presumed interstadial lake deposits.

Tracts of hummocky ground underlain by morainic drift occur widely on the margins of the valley of the River Teith around Lennieston Muir [62 03], and on the upland between Easter Brackland [6640 0826] and Severie [7042 0801] (Plate 1). Although locally indistinguishable from lodgement till (for example, pit 60 NE 8) the deposit is generally lithologically distinctive, comprising very ill-sorted sandstone rubble with many angular cobbles and boulders set in a matrix of fine-grained, silty and clayey sand (Plate 2); it was proved to a maximum depth of 10.2 m in borehole 60 NE 5. Although the morainic drift extends north-westwards to within a few kilometres of the Highland Boundary Fault, it contains very few clasts of 'Highland' origin and must therefore be of extremely local derivation. In a section [661 040] near East Torrie, the deposit shows poorly developed bedding indicating some water sorting. However, it is likely that much of the morainic drift was formed as an ablation-till and flow-till complex during the retreat of the main late-Devensian ice-sheet.

Table 2 The late-Quaternary stratigraphy (after Mitchell and others, 1973; Gray and Lowe, 1977)

Epoch	*Stage*			*Climate*	*Possible dating years ago*
Holocene	Flandrian		post-Glacial	warm	present to 10 000
Pleistocene	Devensian				
	late-Devensian	Loch Lomond Stadial	late-Glacial	cold	10 000 to 11 000
		Lateglacial Interstadial*	late-Glacial	warm	11 000 to 13 000
		late-Devensian Stadial	Glacial	cold	13 000 to 26 000†
	middle-Devensian			mainly warm	26 000 to 50 000†
	early-Devensian			cold	before 50 000

*also known as the Windermere Interstadial
†dates highly speculative

Plate 1 View looking south-eastwards near Wester Coillechat [683 040]. Bracken-covered hummocks of morainic drift bordered by a kettled kame-terrace underlain by glacial sand and gravel. A peat-filled kettle-hole is seen in the centre right. (D86)

Plate 2 Morainic drift exposed in the sand and gravel pit near Cambusbeg [668 047]. Angular blocks of locally derived sandstone are scattered in a matrix of clayey fine-grained sand and sandy clay. (D3329)

It is debatable whether the late-Devensian ice-sheet began to thin during the glacial period as a result of snowfall becoming inadequate to sustain it (Sissons, 1981) or whether deglaciation only began following a general rise in mean annual temperature. However, it is clear that the higher ground in the resource sheet area was the first to become ice-free. In the valley of the River Teith the ice probably remained for a time as an active valley-glacier, whereas ice positioned in the lower part of Strathallan and in the 'misfit' valley linking Doune and Dunblane, became isolated and slowly melted away *in situ*. These differing histories of deglaciation account for the present contrast in topography. For example, much of the valley of the River Teith is characterised by terraced spreads of sand and gravel which were deposited by meltwaters at, or some distance from, the ice-front, whereas the lower reaches of Strathallan between Kinbuck and Dunblane exhibit 'dead ice' topography formed of moundy deposits of sand and gravel separated by 'flats' underlain by younger fine-grained glaciolacustrine deposits.

As the main late-Devensian ice-sheet underwent ablation, meltwaters collected into streams which flowed beneath, within, around and over the surface of the decaying ice, transporting and thereby sorting and abrading rock debris released from the ice and subsequently dumping it as sand and gravel. In places meltwaters became ponded, as for example in temporary ice-caverns and in supraglacial lakes, where sediment held in suspension settled out to form accumulations of silt and clay, often finely laminated (borehole 70 SW 4). As deglaciation progressed, the various meltwater deposits held within, or resting on, the ice-sheet were draped over a hummocky subglacial landscape of till and bedrock.

The subglacial meltwater system changed continually as old routes became choked and new routes were eroded. Streams, which were originally mainly aligned parallel with the general south-easterly direction of ice-movement, gradually migrated downslope at the base of the ice-sheet, eventually to occupy the present-day valleys. Evidence of the former presence of such streams is widespread but is best displayed along the northern flanks of the valley of the River Teith, between 90 and 150 m above Ordnance Datum, (see Francis and others, 1970), where there are many anastomosing channels and low gravel ridges (eskers). Some of the earlier channels (a few of which are portrayed on the 1:50 000 Drift map, but for cartographic reasons are omitted from the resource sheet) have 'up-and-down longitudinal profiles' and commonly cut obliquely across drumlins: much of the gravel forming the generally low, south-easterly-orientated eskers was deposited at the time these channels were cut. Many of the more extensive eskers, for example, the Argaty Esker, which extends from [7400 0402] near Lerrocks to Mill Cottage [7476 0166] are related to younger meltwater channels, which are not shown on the 1:50 000 map.

It is speculated here that the lower reaches of the valley of the River Teith downstream of Kirkton [704 030] became free of glacier ice before residual ice had disappeared in the valley separating Doune and Dunblane, and probably also in lower Strathallan. The snout of the glacier occupying the upper valley of the River Teith probably remained for a time in the vicinity of Kirkton and an extensive spread of outwash sand and gravel accumulated, extending downstream. The spread is now fragmented and is shown on the resource map as fluvioglacial terraces, which descend from about 45 m above Ordnance Datum, near Doune Lodge [7103 0330], to about 35 m above Ordnance Datum in the vicinity of Blair Drummond (Thompson, 1972, Figure 12:12). The most extensive terrace fragment lies between Doune and Doune Lodge and is referred to here as the Doune-Buchany Terrace. It ends abruptly at [731 017] near Doune, where Smith and others (1978) identified an ice-contact slope. Meltwaters passed to either side of High Daira [724 008] but the fluvioglacial deposits have been largely eroded away by the present river to the east of this hill.

Apart from the Doune-Buchany Terrace, which is predominantly underlain by gravel, other parts of the fluvioglacial spread, which remain to the south-east and south of Doune, were shown by drilling, pitting and hand-augering to comprise mainly silt and very fine-grained sand. These sediments were probably deposited in low-energy conditions, close to the late-Glacial sea. The silts and fine sands hereabouts commonly overlie silty clay of possible estuarine origin: glaciolacustrine silts were also proved in borehole 70 SW 11 and in several commercial boreholes beneath the fluvioglacial sand and gravel of the Doune-Buchany Terrace.

A belt of undulating glacial sand and gravel, generally about 500 m wide and with local terracing, occurs on the northern side of the River Teith from Kirkton upstream to the river's confluence with the Keltie Water. IMAU drilling and pitting data and several commercial records indicate that much of this ground is underlain by poorly sorted, very compact and locally clay-bound gravel. At borehole 60 SE 10 flow-till divides a deposit of such gravel: both deposits are likely to have formed in an ice-marginal environment during the retreat of ice which occupied the valley of the River Teith. Subglacial meltwaters leading to the snout of this glacier probably deposited the sand and gravel now forming a discontinuous esker and kame complex stretching from [657 050] near Ballochallan to near Drumvaich. These deposits are most extensive near Tynaspirit [644 047] where they have been largely dug away at Cambusbeg Pit.

Examination of pollen in the sediments of Loch Mahaick [707 068] (Donner, 1958) revealed continuous deposition since the main late-Devensian glaciation, suggesting that the survey area probably had become free of ice by 12 500 years ago. However, in the Loch Lomond and upper Forth area, Simpson (1933) recognised a late-Glacial event now termed the Loch Lomond Stadial, which is generally considered to have occurred between 10 000 and 11 000 years ago (Sissons, 1979); Simpson also suggested that some of the deposits in the upper reaches of the valley of the River Teith might relate to this episode. An arcuate, steep-sided, asymmetric, dissected ridge lies across the valley of the River Teith, stretching from near Drumdhu Wood [644 074], past the west of Cambusmore [6510 0623], to a little to the north-east of Braes of Greenock [6310 0537]. This feature has been identified by Thompson (1972) and Smith and others (1978) as the terminal moraine of a valley-glacier which existed during the Loch Lomond Stadial (Plate 3). An extensive series of fluvioglacial terraces occur upstream of the confluence of the River Teith and Keltie Water, and on the basis of

Plate 3 Large boulder of conglomerate [6422 0627] in fluvioglacial sand and gravel near Gart. The boulder is located about 300 m upstream of the terminal moraine of a valley-glacier which advanced from the Highlands during the Loch Lomond Stadial. (D3324)

Plate 4 View looking south-westwards from Drumvaich [675 043]. Moundy glacial sand and gravel occupies the foreground with morainic drift in the distance. A fluvioglacial terrace of the Loch Lomond Stadial with a well defined back-feature is seen in the middle distance. (D90).

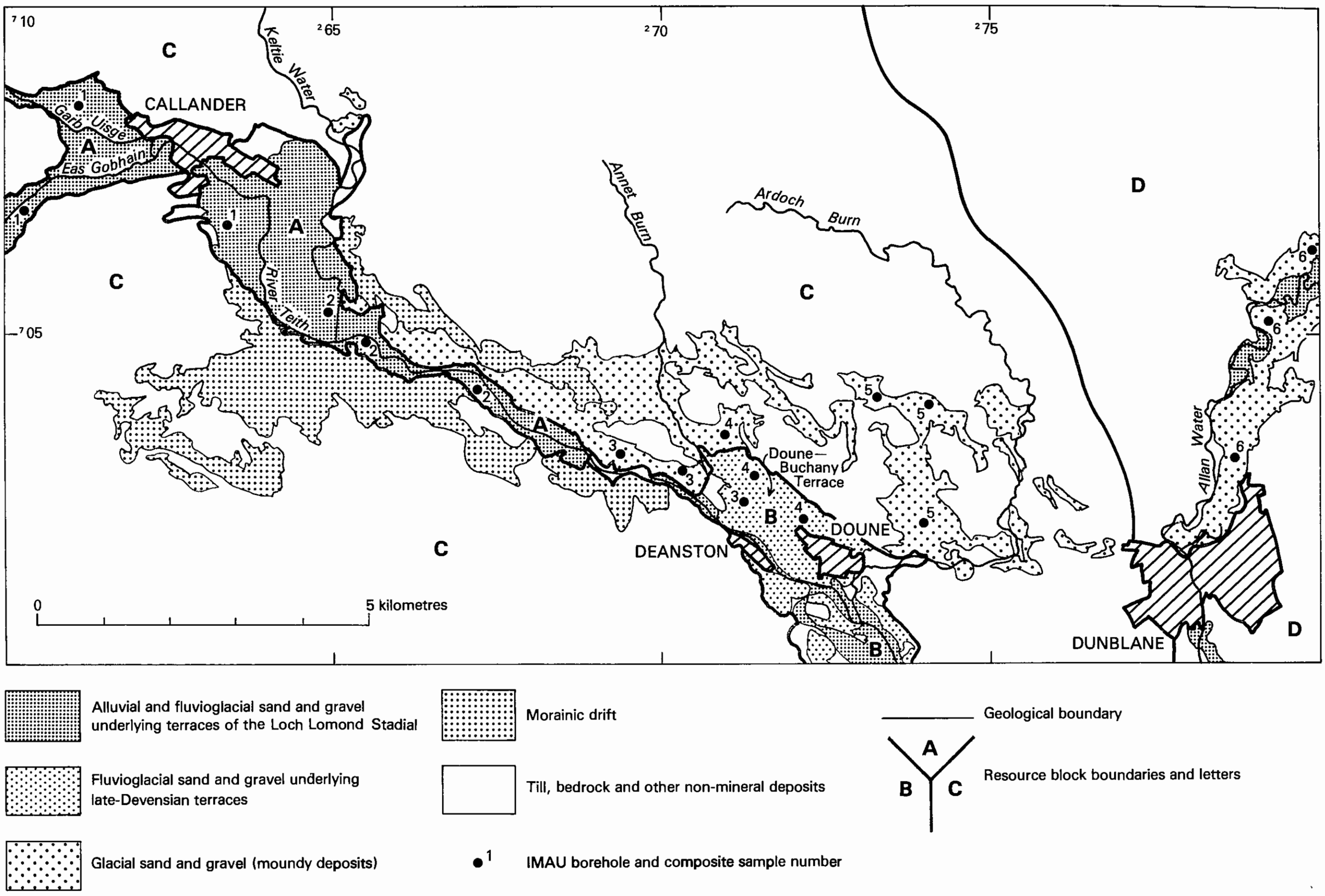

Figure 4 Generalised map of the more extensive mineral-bearing deposits and the sites of boreholes from which composite samples were selected

detailed levelling, Thompson (1972) has equated both these and some of the terraces occurring downstream as far as the valley of the Forth, with this event. Upstream of the terminal moraine the terraces are commonly kettled and some are associated with mounds and eskers; downstream they are generally flat (Plate 4).

During early post-Glacial times there was a substantial rise in sea-level, but although marine and estuarine deposits formed extensively in the valley of the River Forth at this time, they only occur in the extreme south of the present district, near Ruskie [626 007]. However, detailed levelling has shown that some alluvial terraces south of Doune are graded to this high sea-level (Smith and others, 1978). In recent times both the River Teith and Allan Water have deposited gravelly alluvium. In the valley of the River Teith this deposit is of restricted area but in that of the Allan Water quite extensive spreads have formed north and south of Kinbuck [791 051].

COMPOSITION OF THE MINERAL DEPOSITS

The sand and gravel deposits of the area can be separated into four groups (Figure 4); firstly, the fluvioglacial terrace and alluvial deposits of the valley of the River Teith; secondly, the alluvial deposits of the Allan Water; thirdly, glacial sand and gravel occurring widely at levels above those of the terrace deposits and lastly, the morainic drift. These groups are used as the basis for the description of the composition of the sand and gravel, although individual terraces and specific areas of glacial sand and gravel are described where sufficient data are available. Detailed particle-size distribution information is given in Tables 7 to 10 and, for the principal deposits, it is portrayed graphically in Figures 5 to 12, which show the cumulative mean grading for the deposit, as a whole, and the envelope within which the cumulative mean gradings of deposits from individual boreholes fall; the overall mean grading is also given as a frequency distribution.

Petrographical analyses (pebble counts) were carried out on six composite samples of 10- to 14-mm material, each derived from the combination of individual samples taken from the boreholes listed in Table 3 and located in Figure 4. In general, the composite samples represent geologically and geographically distinct deposits. However, because the samples were grouped at an early stage of the work, before the geological map was finalised, composite samples 3 and 4 now represent more than one deposit of sand and gravel. Nevertheless, as the boreholes from which the samples were taken are relatively close, and the composition of the mineral broadly similar, the composite samples are probably representative of the sand and gravel in the area.

Grouping of samples from three neighbouring boreholes was necessary to provide sufficient analytical material for each composite sample subjected to the mechanical and physical testing, described in detail below. The testing was carried out on the same samples as the petrographical analyses in order to determine whether any relationship exists between the mechanical and physical properties of the material, and its petrography.

Table 3 Source and geological classification of composite samples

Composite sample number	Geological classification of deposit and location	Boreholes from which samples were taken	Depth range (m)	Number of bulk samples
1	Fluvioglacial sand and gravel	60 NW 1	0.3–10.3	10
		60 NW 2	0.4–5.4	5
		60 NW 4	0.3–7.5	6
2	Fluvioglacial sand and gravel	60 NW 9	0.3–6.6	6
		60 SE 1	0.2–5.2	5
		60 SE 6	0.5–9.5	9
3	Glacial and fluvioglacial sand and gravel	60 SE 10	{0.4–3.4, 4.8–9.4}	7
		70 SW 5	{0.5–3.8, 4.4–11.0}	10
		70 SW 8	0.3–3.4	3
4	Fluvioglacial sand and gravel	70 SW 4	0.2–5.4	5
		70 SW 7	0.8–6.8	6
		70 SW 11	0.2–6.3	5
5	Glacial sand and gravel	70 SW 13	0.4–13.5	13
		70 SW 15	4.4–12.0	7
		70 SW 17	{1.5–6.5, 7.5–10.3}	7
6	Glacial sand and gravel	70 NE 3	1.0–9.1	8
		70 NE 5	1.0–13.0	12
		70 SE 9	1.0–14.0	12

The British Standard petrological (trade) groups defined in BS 812.1:1975 form the basis of the classification used for the pebble counts (Table 4), with the addition of an 'others' category which comprises quartz, siltstone and mudstone, and conglomerate, these rock types not being included in the British Standard scheme. In order to derive the maximum information from the pebble counts, the trade groups are subdivided into their component rock types and the results are expressed in terms of these as percentages by weight and frequency.

The solid rocks of the area are divided into two broad groups by the Highland Boundary Fault; metamorphic and igneous rocks crop out to the north-west of the fault whereas Lower Old Red Sandstone sediments occur to the south-east (Figure 3). The petrographical analyses generally reflect this division: rock types of 'Highland' origin, principally quartzite and psammite, but also including quartz and rocks of the gabbro, granite, porphyry and schist trade groups, become increasingly less common towards the south-east. Pebbles of the basalt trade group, and of tuff and volcanic breccia, have an anomalous distribution, however, in that they are most abundant in composite samples 3, 4 and 5 from the vicinity of Doune, possibly owing to the reworking of pebbly beds in the Lower Old Red Sandstone. The composition of sample 6, from the valley of the Allan Water, is distinctive in that it contains much locally-derived siltstone and mudstone.

Table 4 Petrographical analyses of composite samples*. Results are given in frequency per cent and weight per cent; for the origin of samples see Table 3

Composite sample number		1		2		3		4		5		6	
Number of pebbles counted		306		301		318		300		311		298	
British Standard Trade Group	Rock type	fr %	wt %	fr %	wt %	fr %	wt %	fr %	wt %	fr %	wt %	fr %	wt %
Basalt	Basalt and andesite	3.6	3.9	8.0	8.0	11.6	11.4	13.3	14.2	11.3	11.8	5.7	6.2
	Epidiorite	—	—	—	—	1.6	1.9	2.0	2.5	0.6	0.4	0.3	0.2
Gabbro	Amphibolite and hornblende schist	1.3	1.5	1.3	1.8	0.3	0.3	—	—	—	—	—	—
	Diorite and microdiorite	—	—	1.7	1.4	1.3	1.0	—	—	0.3	0.7	—	—
Granite	Granite and microgranite	0.3	0.5	1.0	0.8	0.6	0.6	0.3	0.4	—	—	—	—
	Gneiss	1.6	2.0	0.7	0.6	—	—	—	—	—	—	—	—
Gritstone	Sandstone	2.0	2.1	10.3	9.3	23.0	20.8	16.0	13.9	49.8	47.8	43.6	43.2
	Tuff and volcanic breccia	—	—	—	—	1.3	1.2	0.7	0.5	1.0	1.1	—	—
Porphyry	Felsite	2.0	2.1	1.3	1.0	2.8	3.0	2.0	2.5	1.0	1.6	1.0	1.0
Quartzite	Quartzite and psammite	60.1	60.5	57.1	61.9	44.0	46.0	47.3	48.5	26.7	27.8	15.8	17.0
Schist	Schist	6.2	5.5	3.0	2.5	—	—	0.7	0.5	0.3	0.6	0.3	0.2
	Slate	1.6	1.1	1.0	0.7	—	—	0.7	0.3	—	—	—	—
Others	Quartz	21.3	20.8	14.6	12.0	12.9	13.0	17.0	16.7	9.0	8.2	11.4	12.5
	Siltstone and mudstone	—	—	—	—	0.3	0.2	—	—	—	—	20.5	17.8
	Conglomerate	—	—	—	—	0.3	0.6	—	—	—	—	1.4	1.9

*10- to 14-mm size fraction

Fluvioglacial sand and gravel Within the valley of the River Teith there is little compositional distinction between fluvioglacial deposits and alluvium, and they are considered here together. Alluvial and fluvioglacial terraces are most extensive upstream of the confluence of the River Teith and the Keltie Water, and in the vicinity of Doune; the two areas are included respectively in resource blocks A and B. Taken as a whole, the sediments have a generally homogeneous composition, both laterally and vertically, grading generally as 'gravel' or 'sandy gravel' with abundant cobbles and boulders, especially near the surface, and exhibiting little sorting (Tables 7 and 8, Figures 5, 6 and 10). The narrower grading envelope (Figure 6) for the deposits underlying the Doune-Buchany Terrace in block B compared with that of all the sand and gravel deposits in block A (Figure 10) is probably a function of the smaller number of sample points for the former deposit.

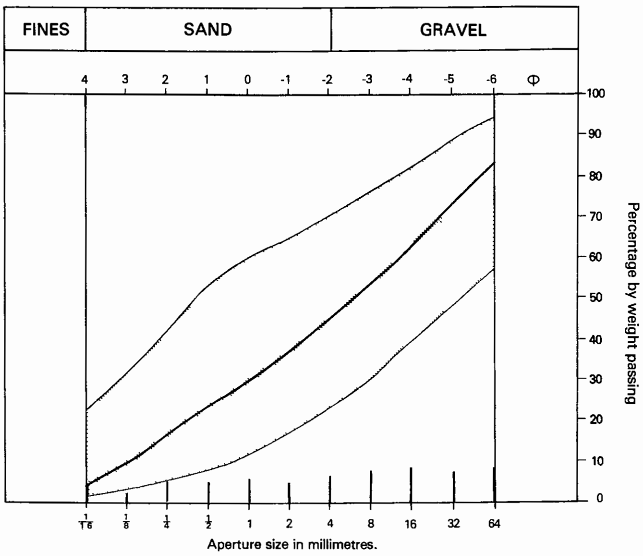

Figure 5 Grading characteristics of resources in the fluvioglacial sand and gravel (blocks A and B). The shaded area defines the envelope within which the cumulative mean gradings of the mineral proved at individual sample points fall; the centre line represents the cumulative mean; the frequency distribution of the mean grading ($\frac{1}{16}$ mm to 64 mm) is represented by the bar graph.

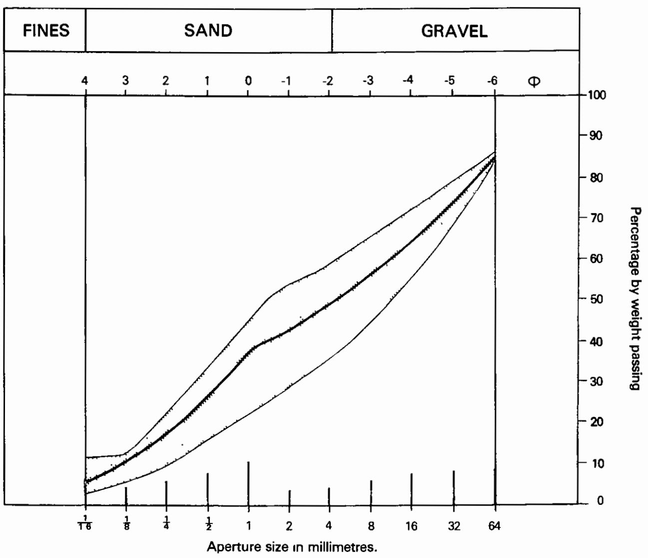

Figure 6 Grading characteristics of resources in the fluvioglacial sand and gravel underlying the Doune-Buchany Terrace (block B); for explanation see Figure 5.

In contrast to the deposits of the Doune-Buchany Terrace, which are predominantly gravelly, the deposits beneath the fragmentary late-Devensian fluvioglacial terraces to the south and east of Doune (see Figure 4) were shown by boreholes 79 NW 5 (sited on the adjoining resource sheet), 70 SW 9, 12 and pit 70 SW 18 to comprise predominantly 'clayey' sands and silts; exceptionally, borehole 70 SW 9 proved 1.1 m of 'clayey' sandy gravel overlying silt. These predominantly fine-grained deposits may have formed in a glacio-estuarine or glaciolacustrine environment. Grading data for the potentially workable part of these terrace deposits are given in Table 8 and illustrated in Figure 7; the wide grading envelope largely results from the inclusion of the 'clayey' sandy gravel deposit of borehole 70 SW 9. Fine-grained deposits were also found in borehole 70 SW 11, which was sited on the Doune-Buchany Terrace, and proved 6.1 m of gravel overlying 1.7 m of 'clayey' sand on 8.1 m of silt; the lower two deposits also may have formed in a glaciolacustrine environment.

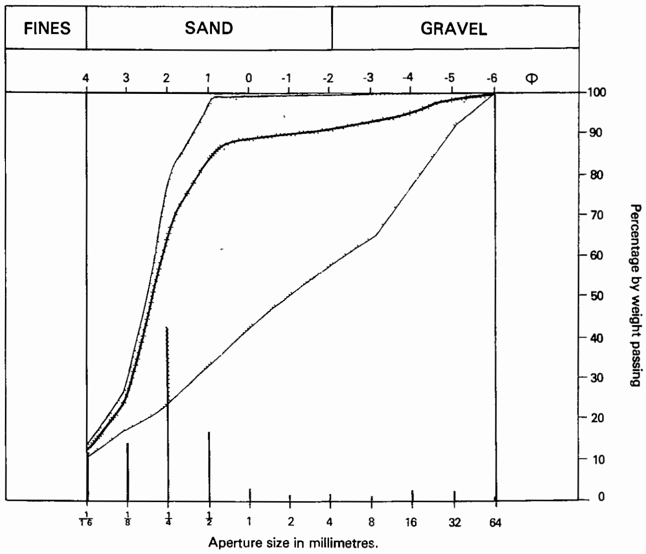

Figure 7 Grading characteristics of resources in the fluvioglacial sand and gravel of block B, excluding the Doune-Buchany Terrace; for explanation see Figure 5.

Glacial sand and gravel Glacial sand and gravel is extensive along the northern side of the valley of the River Teith, both sides of the valley of the Allan Water and in the misfit valley between them. It generally forms topography characterised by irregular-shaped mounds (kames) although, locally, sinuous esker ridges and flat-topped kame-terraces are found. The glacial sand and gravel is described in blocks C and D, the latter block encompassing deposits within the catchment area of the Allan Water; grading data are given in Tables 9 and 10. The glacial sand and gravel taken as a whole grades as 'gravel'; the particle-size distribution illustrated in Figure 8 reveals an extremely wide envelope and indicates the poor sorting and variability in grading of these deposits. However, if the mean gradings of resources in blocks C and D are considered separately (Figures 11 and 12), it can be seen that the deposits of block D are generally finer grained and better sorted than those of block C. The narrower grading envelope for block D is, however, mainly the result of fewer sample points.

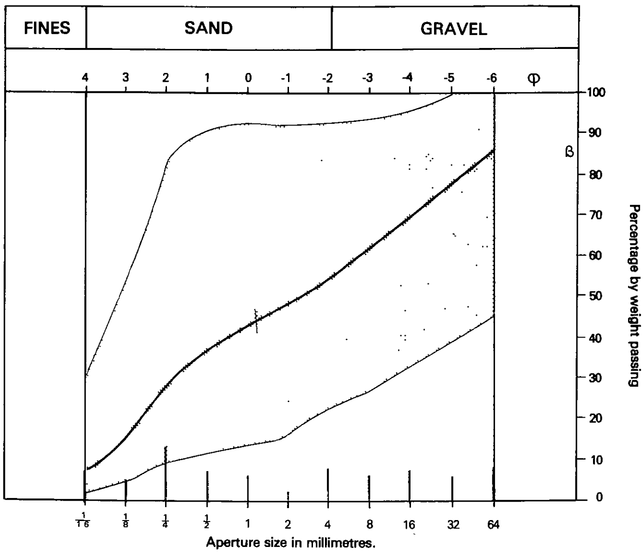

Figure 8 Grading characteristics of resources in the glacial sand and gravel (blocks C and D); for explanation see Figure 5.

Variation in grading is rapid both laterally and vertically. The point is demonstrated by borehole 70 NE 5, where 12 m of sand underlies some 13 m of gravel, seams of silt and clay being present throughout the sequence. Locally fining-downwards sequences are observed, which indicate a gradual change in the environment of deposition, as for example, at borehole 70NE 3, where there is a sequence of sandy gravel on 'clayey' sand on silt. However, more commonly the sediments appear to have been deposited in rapidly varying conditions, for example, at borehole 60 SE 4, where 7.9 m of sand lies between two beds of gravel. In borehole 70 SE 11 a reversed fining trend occurs and 8.0 m of 'clayey' sand, coarsening upwards, overlies 3.6 m of sandy gravel, fining upwards. Such rapid changes in grain-size are commonplace in deposits of an ice-marginal environment, which experienced widely varying sendimentary conditions ranging from meltwater torrents (débâcles) to ice-dammed, and seasonally frozen lakes. For example, glaciolacustrine deposits and glacial sand and gravel could have accumulated simultaneously and in close proximity. Although glaciolacustrine deposits predominantly comprise silt and clay, over 15.9 m thick in borehole 70 NE 4, 1.3 m of potentially workable 'very clayey' sand was proved in borehole 70 SW 4.

A discontinuous deposit of glacial sand and gravel occurs on the high ground in the vicinity of Middle Brackland [6628 0850] and although the grading is generally similar to the glacial sand and gravel elsewhere, it contains markedly more fines (Table 9).

The terminal moraine to the south and east of Gart [6405 0648] left by the glacier of the Loch Lomond Stadial, is classified as glacial sand and gravel. Two pits, 60 NW 11 and 14 were sited on this feature and proved sand and gravel comprised largely of cobbles and boulders set in a silty sand matrix; the mean grading is fines 11 per cent, sand 35 per cent and gravel 54 per cent ('clayey' gravel).

Flow-till The deposit is most extensive north-west of Auchenlaich [6480 0720] where it borders the terminal moraine left by the glacier of the Loch Lomond Stadial. Hereabouts, borehole 60 NW 7 proved 4.8 m of 'very clayey' sandy gravel. Flow till was also identified at boreholes 60 NW 6, 60 SE 10 and 70 SW 17, usually as the uppermost deposit. On the basis of grading from boreholes 60 NW 7 and 70 SW 17, the deposit has a mean grading of fines 25 per cent, sand 39 per cent and gravel 36 per cent ('very clayey' sandy gravel). However, in boreholes 60 NW 6 and 60 SE 10, the deposit is non-mineral owing to excessive fines.

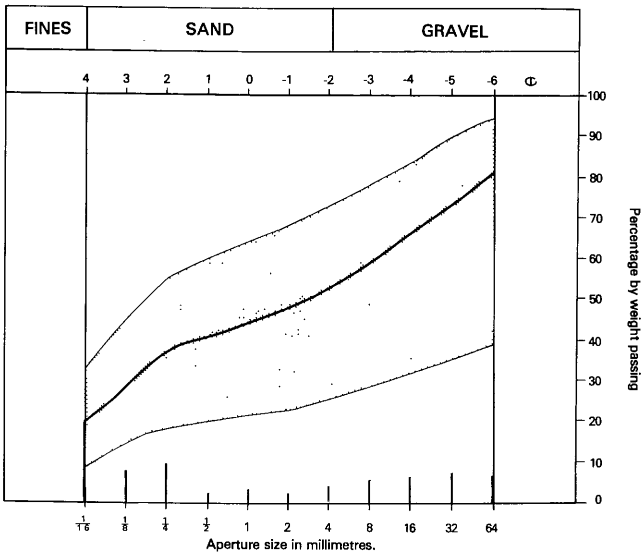

Figure 9 Grading characteristics of resources in the morainic drift (blocks A and C); for explanation see Figure 5.

Morainic drift Within the valley of the River Teith morainic drift occurs both at the surface and buried beneath sand and gravel. The philosophical basis of the assessment of this resource is discussed in the notes on block C and the chapter which describes the map explains the device used on the resource map to portray this deposit.

The potentially workable morainic drift has a mean grading of fines 20 per cent, sand 34 per cent and gravel 46 per cent: grading data are listed in Table 9 and illustrated by Figure 9. Although generally very poorly sorted, the particle-size distribution is weakly bimodal with peaks in the fine sand and in the coarse gravel grades. The deposit was derived almost entirely from local sandstone bedrock and comprises angular cobbles and boulders of sandstone set in a fine-grained, red to yellowish brown, silty sand matrix formed by the weathering and comminution of sandstone clasts.

The alluvial deposits of the Allan Water No fluvioglacial terraces are recognised in the valley of the Allan Water north of Dunblane, but at Kinbuck, and again to the south of Dunblane, alluvial flats and low-lying alluvial terraces border the river. These were investigated by boreholes 70 NE 4 and 70 SE 8, which proved pebbly sand and 'clayey' pebbly sand respectively (Table 10) although at the former site the mineral deposit underlay 1.7 m of clay. Fluvioglacial terraces occur downstream of Dunblane where site investigation boreholes proved sand and gravel but the mineral resource has been largely built over.

Table 5 Results of mechanical and physical testing*

Sample	AIV	AIVR	ACV	ACVR	10% fines (kN)	Relative Density (Oven Dried)	Relative Density (Surface Dried)	Apparent Relative Density	Water absorption %
1	24	37	19	44	200	2.55	2.59	2.65	1.6
2	27	37	19	44	160	2.44	2.51	2.60	2.6
3	19	44	16	45	220	2.57	2.62	2.69	1.7
4	27	33	18	44	150	2.50	2.58	2.67	2.6
5	26	34	18	43	200	2.47	2.53	2.63	2.6
6	25	38	16	46	190	2.25	2.42	2.68	7.1

*Conducted in accordance with BS 812; 2 and 3: 1975

MECHANICAL AND PHYSICAL PROPERTIES OF THE AGGREGATE

A programme of mechanical and physical testing, conducted in accordance with BS 812:1975, was carried out on +10–14 mm material from the six composite samples, listed in Table 3 and located in Figure 4, and comprised measurements of aggregate impact value (AIV), aggregate crushing value (ACV), 10 per cent fines, relative density (on both an oven-dried and surface-dried basis), 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 determined. The results of the pebble counts (Table 4) were compared with those of the mechanical testing (Table 5) to see if any correlation existed. It has been shown by Ramsay (1965) and Ramsay, Dhir and Spence (1974) that the principle petrographic factors affecting aggregate strength are, in igneous rocks, the degree of crystal interlocking, cleavage, the abundance of microfracture and twinning planes and, in sedimentary rocks, the strength of the intergranular cement.

The resistance of an aggregate to both sudden load and slowly-applied compressive load affects its potential use, particularly as a road-stone. AIV is an indicator of the former property and measures the relative amount of cataclastic material passing a 2.36 mm sieve, produced after a sample has been subjected to fifteen blows of standard magnitude. In considering the economic potential of an aggregate, however, it is usually the ability of clasts to withstand impact relatively intact, rather than to withstand a high level of comminution, that is most important. For this reason, Ramsay (1965) introduced the AIVR, which is calculated from the relative weight of +10–14 mm material remaining after the AIV test.

The 10 per cent fines value and the ACV are both measures of compressive strength, but for different levels and rates of loading. The 10 per cent fines value is the load required to produce 10 per cent by weight of fines in ten minutes and compares with the ACV in which the degree of compaction produced by applying a gradually increasing load attaining 400 kN after ten minutes is recorded. For the samples in the present study, the loads applied in the 10 per cent fines tests range from 150 to 220 kN, about half that applied in the ACV test: the 10 per cent fines value is thought to be a more accurate indicator for weaker aggregates (Cox, 1973). ACVR is defined in a similar way to the AIVR.

The results of the present survey (Table 5) show sample 3 to be the most resistant on the basis of the AIV, AIVR, ACV and 10 per cent fines tests. For the other five samples, however, although there is a possible inverse correlation between AIV and AIVR and between ACV and ACVR, there appears otherwise to be a random variation in the strength parameters with no evidence for any linear relationships between AIV and ACV, and AIVR and ACVR such as described by Dhir, Ramsay and Balfour (1971). The lack of correlation between the ACV and 10 per cent fines tests suggests that the relative strength of the samples varies for different levels of applied load.

The most distinctive variation seen within the pebble counts is the general increase of Old Red Sandstone sediments at the expense of 'Highland' material from sample 1 through to 6, which should be reflected by a concomitant decrease in strength. There is neither evidence of this nor any apparent petrographic explanation for the greater strength of sample 3: it is possible the deposit is less weathered than average owing to more rapid deposition or to a shorter distance of water transportation.

A prime factor determining the stress-carrying ability and weathering resistance of concrete is its susceptibility to drying shrinkage and wetting expansion (Building Research Establishment, 1968). This property is largely controlled by the shrinkage of the component aggregate, which is a function of the amount of water that can be absorbed by the rock matrix. Edwards (1970) has determined a very general, linear relationship between the water absorption of aggregate and the drying shrinkage of concrete made from it. The water absorption values measured in the present study (Table 5) are higher than the mean of 1.48 per cent quoted by Edwards (1970) for various Scottish and English gravels and appear to be directly controlled by petrography. For example, sample 1 with the lowest amount of sandstone, has the lowest water absorption whereas sample 6, with over 60 per cent sandstone, siltstone and mudstone has much the highest value. Using the graph showing the linear relationship between water absorption and concrete drying shrinkage given by Edwards (1970), samples 1 to 5 with inferred shrinkages ranging from 0.063 to 0.083 per cent are suitable as aggregates 'for most concreting applications'. Sample 6, however, with a high siltstone and mudstone content, is likely to give rise to excessive shrinkage unless these deleterious lithologies are removed, for example, by stockpiling and allowing them to weather away. Such inferred shrinkage values, however, should be treated cautiously as true values can be obtained only by the testing of concrete blocks.

The low relative density of sample 6 again reflects the high siltstone and mudstone content; there are only slight variations between the other samples, which have no apparent relationship to the petrography.

THE MAP

The sand and gravel resource map is folded into the pocket at the end of the report. The base is the Ordnance Survey 1:25 000 Outline Edition, which together with the contours is printed in grey. The geological lines and symbols are in black, potentially workable sand and gravel, notes and block boundaries in red, potentially workable morainic drift in lilac and areas of bedrock or barren ground in white.

Geological data The geological boundary lines are taken from geological maps surveyed at the scale of 1:10 560; these offer the latest interpretation of the available data but, because of the highly variable nature of the deposits, the accuracy of the map will be improved as new evidence from boreholes and excavations becomes available.

Mineral resource information Two types of potentially workable aggregate are recognised in the survey area, namely sand and gravel, and morainic drift (ablation till). Because the two materials pose different problems in terms of resource planning and exploitation they have been assessed separately. The resource map is in part a profile map, that is, it attempts to show the disposition and extent of the two potentially workable aggregates. A distinctive colour is used to identify each resource.

The extent of the potentially workable sand and gravel is shown in red. The dark shade denotes where mineral is exposed, that is, the overburden averages less than 1.0 m in thickness: a lighter tone is used to identify where it is present in relatively continuous spreads beneath overburden averaging more than 1.0 m in thickness. Within these areas, however, there may be small patches where sand and gravel is absent or not potentially workable, as for example, in the vicinity of pit 70 SW 18.

A further category which is shown on the resource map in the lightest tone of red, is recognised where potentially workable sand and gravel is considered discontinuous. The recognition of categories is subjective, depending on the proportion of boreholes which did not find potentially workable sand and gravel, and the distribution of these barren boreholes within a block. The mineral is described as 'almost continuous' if it is present in 75 per cent or more of the boreholes in a resource block, and as 'discontinuous' if present in more than 25 per cent but less than 75 per cent of the boreholes in a resource block.

The extent of morainic drift is shown in lilac, but for the reasons given in the notes on resource block C, the material is considered to be potentially workable only where is it exposed and where it directly underlies potentially workable sand and gravel: the matrix of the deposit must also be sandy and not strongly cohesive. It follows that unlike mineral sand and gravel for which three categories of resource are recognised and hence three shades of red used on the map, for the mineral morainic drift only a dark shade of lilac is used. In areas where potentially workable morainic drift underlies exposed potentially workable sand and gravel, the map is coloured predominantly red with narrow lilac bands.

Areas where sand and gravel or morainic drift are 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 categories of deposits is based on the mapped geological boundaries. Where there is a transition from one category to another, which cannot be related to the geological map and which could not be accurately delineated during this survey, inferred boundaries have been inserted. Such boundaries are shown by a distinctive symbol, which is intended to convey an approximate location within a likely zone of occurrence rather than 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.

Borehole data, which include the stratigraphical relations and mean particle-size analyses of the sand and gravel samples collected during the assessment survey, are also shown. Where boreholes prove sand and gravel, but no grading information is available, the grading box is crossed through and shown without ornament.

THE ASSESSMENT

The mineral-bearing ground is divided into four resource blocks for assessment. The positioning of the block boundaries is determined 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.

The principal resources of sand and gravel occur as fluvioglacial sand and gravel, glacial sand and gravel and alluvium (river gravel). The boundaries of blocks A and B delimit the main spreads of fluvioglacial material underlying terraces, whereas the moundy deposits of glacial sand and gravel are included in blocks C and D. The most widespread developments of gravelly alluvium occur in blocks A and D where they are associated respectively with the River Teith and the Allan Water. Morainic drift occurs principally in block C, although some underlies sand and gravel in block A.

The resources in each block are further subdivided in order that, as far as is practical and within the aims and limitations of the present survey, deposits of similar disposition and lithology are grouped together. For example, in block B the 'higher' terraces formed during the melting of the main late-Devensian ice-sheet are divided into two areas: the first includes the Doune-Buchany Terrace, which lies to the north-west of Doune and is underlain predominantly by gravelly deposits; the second takes in several fragmented terraces, which are to the south of the town, and are underlain predominantly by sand and silt. The 'lower' terraces of the Loch Lomond Stadial in block B are also considered separately.

The statistical procedure adopted for the volumetric assessment of the mineral resources is outlined in Appendix B. 'Statistical' assessments are given if there are sufficient sample points; otherwise 'inferred' assessments are offered based on the available data. A summary of the assessments is presented in Table 6.

The mineral resources of the sheet are described in the notes on the resource blocks. Data used in the assessment calculations, together with the results, are given in Tables 7 to 10: a summary of these data is

Table 6 The mineral resources; summary of statistical and inferred assessments

Resource block and principal mineral-bearing deposits	Area: Block km²	Area: Mineral km²	Mean thickness: Overburden m	Mean thickness: Mineral m	Volume of sand and gravel: $m^3 \times 10^6$	Limits at the 95% probability level: ±%	Limits at the 95% probability level: $\pm m^3 \times 10^6$	Mean grading percentage: Fines $-\frac{1}{16}$ mm	Sand $+\frac{1}{16}$ −4 mm	Gravel +4 mm
SUMMARY OF STATISTICAL ASSESSMENTS										
A Fluvioglacial sand and gravel (terraces of the Loch Lomond Stadial)	9.5	7.2	0.3	9.0	65	35	23	6	39	55
B Fluvioglacial sand and gravel (the Doune–Buchany Terrace)	5.3	1.5	0.5	5.9	9	40	4	7	42	51
B Fluvioglacial sand and gravel and glaciolacustrine or estuarine deposits underlying the 'higher' terrace south of Doune	5.3	0.9	0.4	2.4	2	80	2	12	79	9
C Glacial sand and gravel (isolated, generally moundy deposits)	144.9	7.8	1.0	6.2	49	29	14	8	48	44
C Morainic drift (hummocky ablation till)	144.9	10.4	0.6	4.0	42	37	15	20	34	46
D Glacial sand and gravel (moundy deposits in Strathallan)	40.3	2.5	0.5	13.5	34	41	14	9	62	29
Total*	200	19.9	0.7	7.5	149	20	30	8	49	43
SUMMARY OF INFERRED ASSESSMENTS										
A Morainic drift (mostly underlying fluvioglacial sand and gravel)	9.5	0.8	—	4.0	3	—	—	20	34	46
B Fluvioglacial sand and gravel (low-lying terraces correlated with Loch Lomond Stadial)	5.3	0.2	0.5	5.7	1	—	—	7	34	59
C Discontinous spreads of glacial sand and gravel at Brackland	144.9	1.8	0.2	1.4	1	—	—	18	40	42
D Alluvium and fluvioglacial sand and gravel in Strathallan	40.3	1.0	1.5	3.7	4	—	—	11	78	11
Total*	200.0	3.0	0.7	3.6	6	—	—	10	50	40
Combined total (sand and gravel)	200.0	22.9			155					
Combined total (morainic drift)	200.0	11.2			45					

*Sand and gravel only

presented in Table 6. Some conclusions are offered, following the block descriptions, 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 6. More detailed grading and thickness data by block are given in Tables 7 to 10 and presented graphically in Figures 10 to 12 which also show the envelopes within which the gradings fall.

Accuracy of results For the six resources assessed statistically, the accuracy of the results at the symmetrical 95 per cent probability level ranges from 29 to 80 per cent (that is, it is probable that on average nineteen out of twenty sets of limits constructed in this way contain the true value for the volume of mineral). However, the real values are more likely to be nearer the median than the limits. Moreover it is probable that roughly the same percentage limits would apply for 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 the same number of sample points (as provided by, say ten boreholes) were used in the calculation. Thus, if closer limits are needed for the quotation of reserves, data from more sample points would be required, even if the area is quite small. However, it must be emphasised that the quoted volumes of sand and gravel have no simple relationship with the amount that could be extracted in practice, as no allowance has been made in the calculations for any restraints (such as existing buildings and roads) on the use of land for mineral working.

NOTES ON THE RESOURCE BLOCKS

Block A

Block A includes gravelly fluvioglacial terrace deposits together with some moundy glacial sand and gravel, both formed during the Loch Lomond Stadial (Table 2), when a valley-glacier originating in the Highlands terminated two or three kilometres to the south of Callander. The glacier formed a terminal moraine, which remains as an almost continuous, asymmetric, arcuate ridge, stretching southwards from Drumdhu Wood [6430 0745] to [6340 0600] near Balvalachlan Farm. To the east of the River Teith the moraine appears to be largely constructed of sand and coarse gravel, as shown for example, by pits 60 NW 11 and 60 NW 14, which proved 2.6 m and 3.2 m of mineral respectively: to the west of the river the feature is probably mainly formed of till interbedded with very poorly sorted sand and gravel, as was found at pit 60 NW 10.

Upstream of the terminal moraine the glacier pushed aside or overrode glacial deposits laid down during the decay of the main late-Devensian ice-sheet. As the valley-glacier retreated, meltwaters deposited poorly sorted sand and gravel in the form of a descending series of fluvioglacial (kame) terraces, which also encompass isolated ridges and mounds of very poorly sorted and often very coarse sand and gravel (see Thompson, 1972, Figure 12:10). The most extensive ridge is the sinuous Roman Camp Esker (Francis and others, 1970), which extends south-eastwards from [6316 0748] near Callander to [6417 0641] near Gart.

Five boreholes were sited on the fluvioglacial terraces upstream of the terminal moraine. A sequence of terrace gravel on either till or bedrock was identified at 60 NW 1, 60 NW 2, 60 NW 3 and 60 NW 4, where 10.0 m, 5.0 m, 12.6 m and 7.2 m respectively of potentially workable sand and gravel was proved. In contrast, at borehole 60 NW 5, 1.7 m of till separates an upper mineral deposit of 3.0 m from a lower one, 6.2 m thick. At this site the lower deposit of sand and gravel may have been overriden by the valley-glacier during the Loch Lomond Stadial and could be significantly older than the upper deposit. An interpretation of the drift geology in this vicinity is presented on the resource map in cross-section A–A′ but it must be emphasised that with the limited amount of available data, the thickness and extent of mineral shown is largely speculative.

It is difficult to distinguish between fluvioglacial and alluvial terraces in the vicinity of Callander as many of the former do not include kettle-holes, features which are usually characteristic of terraces formed in a glacial environment. However, on the basis of detailed levelling, Thompson (1972) correlated certain terraces with inferred positions of the ice-front during its retreat. In the light of this work, the floodplain and lowest alluvial terrace shown on the published 1:50 000 geological map are considered to have formed during the last 10 000 years or so and are grouped together on the resource map where they are classified as alluvium.

Borehole 60 NW 3 proved 5.1 m of gravel underlying the wide floodplain formed to the west of Callander around the confluence of the Garb Uisge (River Teith) and Eas Gobhain: the material proved at this site is probably representative of the alluvium hereabouts.

Downstream of the terminal moraine, fluvioglacial terraces occur at several levels, the most extensive forming the Muir of Gart, which separates the River Teith and the Keltie Water and lies immediately upstream of their confluence [6500 0485]. Meltwaters almost certainly flowed across the Muir during the Loch Lomond Stadial but it remains unclear whether the terrace was entirely formed at this time or whether an older feature became modified. The thickness of the terrace gravels is variable because they overlie moundy morainic drift, which reaches the surface in places, for example, [6490 0570]. Borehole 60 NW 9 proved 6.3 m of shingly gravel on 0.5 m of clay-bound gravel, but it is unclear whether the lower deposit here is a basal till or the top of a lower unit of fluvioglacial material similar to the deposit of clayey and very poorly sorted gravel exposed at depth in Gart Pit, a kilometre to the north-west where section 60 NW 8 revealed 18.4 m of gravel. The height of this section is probably greater than the average thickness of the terrace deposits because it includes part of the esker which stood several metres above the general level of the terrace. However, in the overall calculation, this sample point partly compensates for the various moundy deposits in the resource block, such as the terminal moraine, where although a thicker-than-average sequence of sand and gravel may occur, the deposits proved impractical to drill and no thickness data are available. Consequently, the thinner deposits may be over-represented in the calculation of mean thickness.

Thompson (1972) and Smith and others (1977) identify terraces formed during the Loch Lomond Stadial along the length of the valley of the River Teith from the vicinity of Callander to Blair Drummond [7322 9898], where the features merge into a fan now largely buried by post-Glacial marine deposits. The terraces border the River Teith on one side or the other downstream as far as Lanrick Bridge [6896 0315] and were investigated by boreholes 60 SE 1 and 60 SE 6, which proved 7.3 m and 10.0 m of gravel respectively. Downstream of the bridge there is a stretch of about a kilometre in which they are absent, and although they reappear farther downstream, here they have been largely worked out: this part of the resource is included in block B and is described later. Geological cross-section B–B′ shows the relationship of the terraces with the drift deposits mantling the valley-sides.

Meltwaters flowing from the snout of the Loch Lomond Stadial valley-glacier largely eroded away any unconsolidated deposits from the valley-floor but on the flanks of the glacier such material survived. At Auchenlaich [6485 0723] borehole 60 NW 7 proved 3.8 m of very poorly sorted, clayey sand and gravel, identified as flow-till, overlying 7.2 m of fine-grained lacustrine deposits (see cross-section A–A′). On the other side of the valley (in block C), borehole 60 NW 6 near Torrie Cottage [6425 0505] proved 3.1 m of non-mineral flow-till overlying 3.1 m of fluvioglacial sand and gravel, which in turn rested on 3.8 m of lacustrine deposits containing organic material. The lacustrine deposits found at both sites probably pre-date the Loch Lomond Stadial.

A statistical assessment of the sand and gravel resources of block A is offered, based on ten sample points for which data are presented in Table 7 and Figure 10. The assessment (see Appendix B) is for all

Table 7 Block A: data from sample points and the assessment of resources

Sample point: Borehole, section or pit	Recorded thickness: Mineral m	Overburden m	Waste partings m	Mean grading percentage: Fines $-\frac{1}{16}$ mm	Fine sand $+\frac{1}{16}$ $-\frac{1}{4}$mm	Medium sand $+\frac{1}{4}$ -1mm	Coarse sand $+1$ -4mm	Fine gravel $+4$ -16mm	Coarse gravel $+16$ -64mm	Cobbles and boulders $+64$mm	Descriptive category (see Appendix C)
FLUVIOGLACIAL, GLACIAL AND ALLUVIAL SAND AND GRAVEL											
60 NW 1	10.0	0.3	—	5	14	21	14	19	20	7	SG
60 NW 2*	5.0	0.4	—	3	14	16	14	19	24	10	G
60 NW 3	12.6	0.4	—	9	37	16	10	12	11	5	SG
60 NW 4	7.2	0.3	—	3	5	10	17	18	32	15	G
60 NW 5	9.2	0.1	1.7	5	7	11	17	27	25	8	G
60 NW 7†	3.8	0.9	—	24	16	12	14	18	11	5	VCSG
60 NW 8	18.4+	0.2	—	6	2	7	11	15	18	41	G
60 NW 9‡	6.8	0.3	—	7	9	14	14	23	26	7	G
60 SE 1	7.3	0.2	—	5	6	7	15	23	31	12	G
60 SE 6	10.0	0.3	—	3	10	15	18	24	21	9	G
Mean	9.0	0.3	—	6	12	13	14	19	21	15	G

* Excludes 1.0 m of underlying mineral till
† Very poorly sorted sand and gravel, probably flow-till
‡ Basal 0.5 m possibly mineral till

Statistical assessment of the potentially workable sand and gravel

Area of exposed mineral	6.53 km^2
Area of continuous or almost continuous spreads of mineral beneath overburden	0.65 km^2
Total area of mineral-bearing ground	7.19 km^2
Mean thickness of overburden	0.3 m
Mean thickness of mineral	9.0 m
Estimated volume of mineral	**64.9 million m^3** ±35% or 22.6 million m^3

Inferred assessment of the potentially workable morainic drift (till)

Area of exposed mineral	0.09 km^2
Area of continuous or almost continuous spreads of mineral till beneath potentially workable sand and gravel	0.74 km^2
Total area of mineral-bearing ground	0.83 km^2
Estimated volume of mineral (based on a calculation explained in the text)	**3.3 million m^3**

Area of ground worked for sand and gravel 0.67 km^2

sand and gravel deposits together with the flow-till cropping out in the Auchenlaich area. An inferred assessment is offered for the potentially workable morainic drift, the mean thickness of the latter being determined from all the sample points proving this deposit irrespective of resource block.

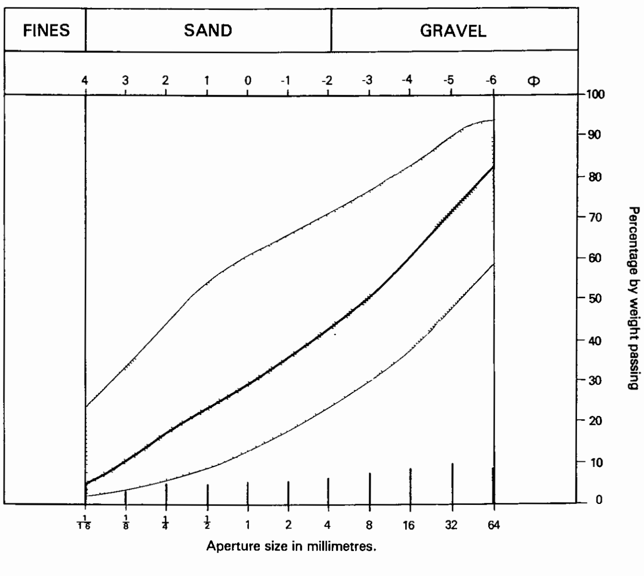

Figure 10 Grading characteristics of the sand and gravel resources of block A; for explanation see Figure 5.

Block B

The low-lying fluvioglacial terraces of the Loch Lomond Stadial that form the greater part of the mineral-bearing ground in block A continue downstream into block B but here constitute a lesser resource, being confined to the valley-floor. The deposits have been dug extensively at [714 019] near Clarkton, in the Valley of Coustry [731 001] and at Low Daira [733 002]: about 63 per cent of the potentially mineral-bearing ground has been worked out.

The major resource of sand and gravel underlies a wide, dissected fluvioglacial terrace, the Doune-Buchany Terrace, which stands some 12 to 16 m above the low-lying terraces of the Loch Lomond Stadial. The deposits were laid down during the decay of the main late-Devensian ice-sheet after the lower stretches of the valley of the River Teith had become free of ice. The snout of a glacier which occupied the valley of the River Teith at this time probably stood in the vicinity of Kirkton [7038 0304] and meltwaters formed an extensive spread of fluvioglacial sand and gravel, which thins and becomes finer-grained down-valley. To the south of Doune the deposits are generally fine-grained and have been deeply dissected by the River Teith, which once flowed to the west of High Daira [724 008] into the Valley of Coustry, and by the Ardoch Burn (see cross-section C–C′).

Statistical assessments are offered, both for the deposits of the Doune-Buchany Terrace and for the more fragmented, thinner and finer-grained terrace deposits occurring at a similar elevation downstream of

Table 8 Block B: data from sample points and the assessment of resources

Sample point	Recorded thickness			Mean grading percentage							Descriptive category (see Appendix C)
Borehole, section or pit	Mineral m	Overburden m	Waste partings m	Fines $-\frac{1}{16}$ mm	Fine sand $+\frac{1}{16}$ $-\frac{1}{4}$mm	Medium sand $+\frac{1}{4}$ −1mm	Coarse sand +1 −4mm	Fine gravel +4 −16mm	Coarse gravel +16 −64mm	Cobbles and boulders +64mm	
FLUVIOGLACIAL SAND AND GRAVEL (DOUNE–BUCHANY TERRACE)											
70 SW 7	6.0	0.8	—	4	7	13	13	20	29	14	G
70 SW 8	3.1	0.3	—	12	10	11	13	16	23	15	CG
70 SW 11	7.8	0.2	—	7	17	25	11	13	14	13	SG
Mean*	5.9	0.5	—	7	12	18	12	16	21	14	G
FLUVIOGLACIAL SAND AND GRAVEL AND GLACIOLACUSTRINE OR ESTUARINE DEPOSITS (THE 'HIGHER' TERRACES SOUTH OF DOUNE)											
70 SW 9	1.1	0.2	—	13	11	20	14	20	22	0	CSG
70 SW 18	0.6†	0.7	—	11	63	24	1	1	0	0	CS
79 NW 5‡	3.7	0.3	—	12	69	18	1	0	0	0	CS
Mean*	1.8	0.4	—	12	56	20	3	4	5	0	CS
FLUVIOGLACIAL SAND AND GRAVEL (THE 'LOWER' TERRACES OF THE LOCH LOMOND STADIAL)											
79 NW 6‡	7.0	0.4	—	7	6	11	17	27	29	3	G
Mean*											

* Commercial data have been used in the calculations.
† Non-mineral.
‡ Boreholes sited on area of adjoining resource map.

Statistical assessment of the potentially workable sand and gravel underlying the Doune–Buchany Terrace

Total area of mineral (all exposed)	1.49 km^2
Mean thickness of overburden	0.5 m
Mean thickness of mineral	5.9 m
Estimated volume of mineral	**8.8 million m^3** ±40% or 3.5 million m^3

Area of ground worked for sand and gravel 0.58 km^2

Inferred assessment of the potentially workable sand and gravel underlying the lower terraces

Total area of mineral (all exposed)	0.17 km^2
Mean thickness of overburden	0.5 m
Mean thickness of mineral	5.7 m
Estimated volume of mineral	**1.0 million m^3**

Area of ground worked for sand and gravel 0.29 km^2

Statistical assessment of the potentially workable sand and gravel underlying the 'higher' terraces south of Doune

Total area of mineral (all exposed)	0.90 km^2
Mean thickness of overburden	0.4 m
Mean thickness of mineral	2.4 m
Estimated volume of mineral	**2.1 million m^3** ±80% or 1.7 million m^3

Area of ground worked for sand and gravel 0.07 km^2

Doune. An inferred assessment is provided for the 'lower' terrace deposits of the Loch Lomond Stadial. As there are few IMAU sample points on which to base a volumetric assessment of resources, commercial data have been used in the calculations. In addition, boreholes 79 NW 5 and 79 NW 6, which are sited on the adjoining resource map for Stirling (Laxton and Ross, 1983), have also been used because the 'zones of influence' of both sample points fall partially into the area presently being assessed. Assessment data are presented in Table 8 and Figures 6 and 7.

The deposits for which statistical assessments are provided are described in more detail below.

Doune-Buchany Terrace Deposits underlying the terrace stretching from Buchany [712 028] to Doune are a prime sand and gravel resource and have been extensively dug, about 28 per cent of the potentially mineral-bearing ground (excluding built-up areas) being worked-out. The terrace deposits rest on a buried landscape formed of hummocky till and moraine and, consequently, vary considerably in thickness. For example, boreholes 70 SW 7 and 70 SW 11 proved 6.0 m and 7.8 m respectively of moderately well sorted, shingly gravel, whereas borehole 70 SW 8 proved 3.1 m of very poorly sorted and cohesive 'clayey' gravel, possibly the uppermost gravelly part of a largely buried drumlin of till which crops out nearby. At borehole 70 SW 11 the terrace gravels overlie 8.1 m of fine-grained glaciolacustrine deposits, which are probably quite widespread, as suggested in cross-section C–C′.

The 'higher' terraces south of Doune The fragmented, 'higher' terrace deposits south of Doune are generally much finer-grained than those of the Doune–Buchany Terrace and comprise, in the main, pale yellow, silty fine sand. The material was deposited in the distal part of the fluvioglacial spread (possibly in an estuarine environment) where any gravel would have been laid down in the form of sinuous, linear bodies by distributary streams. Immediately to the south of the resource sheet area, the terrace deposits pass laterally into late-Glacial raised beach deposits with associated estuarine and marine alluvium.

Sand and gravel has been worked at two localities to the north and east of Watston Farm [7154 0085] and on a very small scale at [7237 0000], 700 m south-south-east of Cobble Haugh; borehole data reveal little potentially workable material elsewhere. At borehole 70 SW 9, 1.1 m of silty sand and gravel overlay 0.8 m of laminated silt resting on morainic drift, whereas at 70 SW 12 the terrace deposits are wholly non-mineral, comprising laminated silt resting on till. On the eastern side of the valley, near Old Newton [7314 0122], pit 70 SW 18 revealed, somewhat unexpectedly, only 0.6 m of pebbly sand overlying till: only 100 m to the south of this site several metres of pebbly sand are exposed in a steep bank, suggesting that the terrace deposits thicken considerably towards the valley.

Block C

This block, which includes the higher ground on both sides of the valley of the River Teith together with the misfit valley between Doune and Dunblane, encompasses varied and scattered deposits of glacial sand and gravel, which collectively constitute a major mineral resource. Gravelly morainic drift is widespread and forms a marginal resource. Data from sample points and assessments of the two resources are offered in Table 9; mean grading data are presented in Figures 9 and 11.

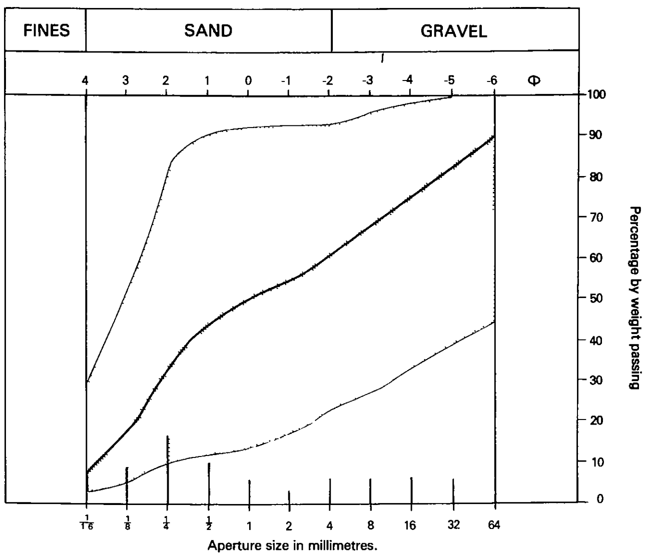

Figure 11 Grading characteristics of the sand and gravel resources of block C; for explanation see Figure 5.

Glacial sand and gravel In general, the sand and gravel within block C was deposited during the melting of the main late-Devensian ice-sheet. As deglaciation progressed, the various meltwater deposits held within, or resting on, the ice-sheet were draped over a hummocky sub-glacial landscape of till and bedrock. With sediments formed in such a depositional environment it is understandable that the thickness and grading of the sand and gravel bear no simple relationship to landform. For example, many knowes and hills which are gravelly at the surface, and at first sight may be interpreted as being wholly formed of sand and gravel, are found to be constructed of bedrock or till with a veneer of sand and gravel, as at boreholes 70 SW 6, 70 SE 5 and 70 SE 6, which proved only 0.6 m, 2.0 m and 0.9 m of gravel respectively.

Much of the potential workable sand and gravel shown on the resource map within block C is probably less than three metres in thickness and is patchy and remotely situated. Thicker deposits are mainly restricted to two linear complexes of eskers and kames, and to kame-terrace deposits flanking the larger valleys.

Esker and kame deposits In the valley of the River Teith a narrow belt of eskers and kames can be traced south-eastwards from a 10 metre-high section [6565 0514] in the pit near Ballachallan, through the pit [667 046] at Cambusbeg, and along the steep slopes of the valley above Drumvaich [674 043] until it peters out amongst hummocky morainic drift to the north of Wester Coillechat [6829 0400]. The ridges were highest in the vicinity of the pit at Cambusbeg prior to the extraction of sand and gravel which has occurred extensively in the last twenty years. Hereabouts, a 17.4 m-high section (60 SE 4) revealed 1.7 m of gravel on 7.9 m of sand overlying 7.8 m of cobble-boulder gravel, the lowest deposit forming the core of the esker. Boulder-gravel is also exposed in the degraded section at Ballachallan and the coarseness of material forming the ridges may preclude parts of the deposit from being worked. Sand and gravel generally thins rapidly to either side of the eskers in this district, as illustrated by borehole 60 SE 3, which proved only 1.1 m of gravel some 150 m from the main ridge.

A second belt of eskers and kames, the Argaty Esker described by Francis and others (1970), formerly extended southwards from [7400 0402] near Lerrocks towards Netherton [7405 0205], whereabouts it swung eastwards towards Argaty Mill Cottage [7476 0166]. The widest and highest parts of the complex occurred in the vicinity of Netherton, where it has been largely dug away. To either side of the old workings, now remodelled and landscaped, the ridge remains and is generally about 10 m high. On a spur from the main ridge, which has been preserved from extraction beneath the farm buildings at Netherton, borehole 70 SW 15 proved 11.6 m of sandy gravel overlying till. Towards the northern end of the esker, borehole 70 SW 17 proved 0.8 m of potentially workable flow-till overlying 8.8 m of gravel (including 1.0 m waste) resting on lodgement till.

Large spreads of mineral-bearing ground border the Argaty Esker on the south-western side, but the sand and gravel is probably generally thin and patchy, for example, borehole 70 SW 14 sited on a low kame near Argaty House [7370 0314] proved only 2.6 m of sandy gravel resting on lodgement till. The mineral hereabouts becomes increasingly fine-grained southwards and, between Netherton and the Ardoch Burn, generally comprises pale yellow silty fine sand.

Few of the other quite numerous, isolated eskers that occur within this block are sufficiently extensive to warrant description here: many are discontinuous, under 5 metres high and are composed of very coarse, poorly sorted material. Perhaps the most volumetrically significant of these deposits is an esker which extends for a kilometre or so in a north-westerly

Table 9 Block C: data from sample points and the assessment of resources

Sample point: Borehole, section or pit	Recorded thickness: Mineral m	Overburden m	Waste partings m	Mean grading percentage: Fines $-\frac{1}{16}$ mm	Fine sand $+\frac{1}{16}$ $-\frac{1}{4}$mm	Medium sand $+\frac{1}{4}$ -1mm	Coarse sand $+1$ -4mm	Fine gravel $+4$ -16mm	Coarse gravel $+16$ -64mm	Cobbles and boulders $+64$mm	Descriptive category (see Appendix C)
GLACIAL SAND AND GRAVEL (CONTINUOUS OR ALMOST CONTINUOUS SPREADS)											
60 SE 3	1.1	0.5	—	7	8	20	12	12	19	22	G
60 SE 4	17.4+	0.1	—	5	41	6	2	8	14	24	SG
60 SE 7	1.5*	1.1	—	29	55	8	1	1	1	5	VCPS
60 SE 10	7.6	0.4	1.4	14	24	18	10	14	14	6	CSG
60 SE 13	4.0+	0.0	—	7	3	4	11	28	24	23	G
60 SE 16	1.1+	0.8	—	5	5	7	7	10	11	55	G
60 SE 18	2.7	0.2	—	3	6	11	10	22	33	15	G
70 SW 1	5.4	13.4	—	No grading data available							
70 SW 3	1.9	0.3	—	5	7	11	15	19	30	13	G
70 SW 4	11.2†	0.2	—	15	39	16	5	7	12	4	CSG
70 SW 5	10.5	0.5	—	8	12	13	15	18	23	11	G
70 SW 13	13.1	0.4	—	5	9	13	18	22	22	11	G
70 SW 14	2.6	0.3	—	5	8	37	20	17	13	0	SG
70 SW 15	11.6	0.4	—	7	21	28	19	18	6	1	SG
70 SW 17	7.8	1.5§	1.0	7	12	16	17	17	18	12	G
70 SE 4	6.0	0.1	—	9	11	8	10	15	23	24	G
70 SE 5	2.0	0.2	—	9	16	24	14	21	16	0	SG
70 SE 6	0.9	0.1	—	12	38	26	8	12	4	0	CPS
Mean‡	6.24	0.97	—	8	22	15	11	15	17	12	SG
GLACIAL SAND AND GRAVEL (DISCONTINUOUS SPREADS AT MIDDLE BRACKLAND)											
60 NE 3	0.7	0.3	—	No grading data available							
60 NE 6	1.6	0.1	—	23	9	14	16	18	20	0	VCSG
60 NE 9	1.8	0.3	—	13	6	16	19	16	22	8	CG
Mean	1.37	0.23	—	18	7	15	18	17	21	4	CG
MORAINIC DRIFT											
60 SW 3	3.8+	0.5	—	12	15	7	9	14	19	24	CG
60 SW 4	5.3+	0.2	—	11	13	6	9	16	23	22	CG
60 NE 5	6.0	3.2	1.0	32	23	8	10	11	11	5	VCSG
60 NE 7	6.8	0.2	—	21	16	7	9	12	18	17	VCG
60 SE 3	4.0	—	1.2	27	20	5	6	9	14	18	VCG
60 SE 5	4.6	1.0	—	20	25	10	10	14	16	5	CSG
60 SE 7	2.0+	—	—	18	30	5	2	4	5	36	VCPS
60 SE 8	6.4+	0.1	—	18	24	8	10	17	17	6	CSG
60 SE 11	1.0	0.3	—	19	16	6	9	18	22	10	CG
60 SE 14	2.7+	0.3	—	9	10	3	4	6	6	62	G
60 SE 15	0.9	0.3	—	No grading data available							
Mean	3.95	0.6	—	20	19	7	8	13	16	17	VCG

* Sand and gravel overlying potentially workable morainic drift (till)
† Not including 1.3 m of potentially workable glaciolacustrine deposits
‡ Commercial data have been used in the calculations
§ Basal 0.8 m of overburden is potentially workable flow-till

Statistical assessment of the potentially workable glacial sand and gravel (continuous or almost continuous spreads)

Area of exposed mineral	7.49 km^2
Area of concealed mineral	0.29 km^2
Total area of mineral-bearing ground	7.79 km^2
Mean thickness of overburden	1.0 m
Mean thickness of mineral	6.2 m
Estimated volume of mineral	**48.6 million m^3** ±29% or 14.1 million m^3
Area of ground worked for sand and gravel	0.80 km^2

Inferred assessment of the potentially workable glacial sand and gravel (discontinuous spreads)

Total area of exposed, discontinuous spreads of mineral	1.78 km^2
Mean thickness of overburden	0.2 m
Mean thickness of mineral	1.4 m
Estimated volume of mineral	**0.6 million m^3**

Statistical assessment of the potentially workable morainic drift

Area of exposed mineral	8.75 km^2
Area of continuous or almost continuous spreads of mineral till beneath potentially workable sand and gravel	1.68 km^2
Total area of mineral-bearing ground	10.43 km^2
Mean thickness of overburden	0.6 m
Mean thickness of mineral	4.0 m
Estimated volume of mineral	**41.7 million m^3** ±37% or 15.4 million m^3
Area of ground worked for mineral till	0.01 km^2

direction from Burn of Cambus [7068 0300] and which has been worked on a small scale [7025 0330] near Kirkton. More typical, however, is the low esker near Corscaplie [7614 0234] upon which borehole 70 SE 4 was situated and proved 6.0 m of cobble-gravel resting on lodgement till.

Kame-terrace deposits Sand and gravel underlying kettled kame-terraces occurs at several localities, and is thought to have been deposited beside stagnant masses of ice, which occupied the central parts of valleys after higher ground had become predominantly ice-free. A broad belt of deposits, which were probably formed in this way, extend south-eastwards from Colvote [6870 0490] towards Doune Lodge [7104 0330] whereabouts there is a steep escarpment, probably an ice-contact slope, which is depicted in cross-section C–C′. Modern drainage has deeply dissected these deposits, which were worked in a large pit, now landscaped, to the south of Upper Coilentowie [6954 0445]. Although the material is probably thickest in the valley of the Annet Burn to the south of Milton of Cambus [7017 0436], borehole 70 SW 4, near Doune Lodge, proved 11.2 m of sand and gravel fining downwards into 4.4 m of fine-grained glaciolacustrine deposits (the lower 1.3 m of which is mineral) resting on till.

Less extensive kame-terrace deposits occur in the upper reaches of the valleys of the Buchany, Lundie, Argaty and Ardoch Burns, but the sediments vary greatly in thickness and grading, for example, in the valley of the Lundie Burn to the east of Mansfield [7229 0346], sand and gravel was dug for a couple of years but the material proved to be silty and sandy. In contrast, on a narrow terrace near East Lundie [7310 0425] in the valley of the Argaty Burn, borehole 70 SW 13 revealed 13.1 m of poorly sorted gravel resting on bedrock and here, as elsewhere, the kame-terrace deposits wedge out against the till and bedrock, which form the valley-sides: consequently the volume of sand and gravel present is probably much less than might be suggested by its aerial extent.

In the valley of the Ardoch Burn thick deposits of sand and gravel underlie a kame-terrace which extends south-eastwards from Horse Wood [7505 0400] towards Kilbryde Castle [7560 0367]. Borehole 70 SE 3 proved 2.8 m of sandy gravel on the 'feather-edge' of this deposit.

The deposits described above occur mainly in the upper reaches of the valleys of south-easterly flowing tributaries of the River Teith. However, kame-terraces also occur at lower levels, within the main valley, and were probably formed during the decay of the late-Devensian ice-sheet, when a valley-glacier stood for some time in the vicinity of Kirkton. Later, as the glacier retreated up the valley of the River Teith, gravelly kame-terrace deposits were laid down, mainly on the northern side of the valley, between Drumvaich and Burn of Cambus. Between Drumvaich and Easter Coillechat [6878 0378] the deposits have been extensively worked on both sides of the road. Hereabouts, the sand and gravel thins towards the valley-side, as demonstrated by borehole 60 SE 7, which proved only 1.5 m of silty pebbly sand on morainic drift. Field evidence suggests that thicker deposits may occur at higher levels between Drumvaich Wood, where sand and gravel was formerly dug [677 044], and Wester Coillechat; on the margin of this deposit, pit 60 SE 13 proved over 4.0 m of coarse gravel.

In the valley of the River Teith between Easter Coillechat and Burn of Cambus undulating kame-terrace deposits are bordered to the north by a ridge, possibly a lateral moraine, and to the south by knolls of morainic drift. Boreholes 60 SE 10 and 70 SW 5 sited on the terraces proved 7.6 m and 10.3 m respectively of predominantly very poorly sorted sand and gravel. At the former site, 1.4 m of non-mineral till, a flow-till, divided the mineral deposit. The sedimentary sequence here is suggestive of formation in close proximity to the ice-front. The thickness of sand and gravel underlying the kame-terraces is, however, very variable because the material accumulated over knolls of bedrock and moraine. For example, pit 60 SE 18, sited midway between boreholes 60 SE 10 and 70 SW 5, proved only 2.7 m of shingly gravel resting directly on bedrock.

The speculative lateral moraine, referred to above, is orientated in a west-north-westerly direction and is crossed by the road [6958 0326] near Kirkton Strips. To the north of the road it comprises a relatively narrow ridge composed of coarse gravel, whereas to the south it broadens, becomes much higher, and is capped, if not wholly formed, of till. At the eastern end of the feature a water bore at Kirkton Farm is reported to have penetrated 5.4 m of sand and gravel underlying 13.4 m of till, suggesting that a temporary readvance of the main late-Devensian valley glacier may have occurred in this vicinity.

Miscellaneous deposits Patchy deposits of sand and gravel lie within the broad 'misfit' valley linking Doune and Dunblane, where there have been several gravel workings in the vicinity of Auchinteck [7545 0190] and Stockbridge [7680 0180]. The mineral is generally sandy, often silty, and is commonly draped over drumlins of till, as illustrated for example, by boreholes 70 SE 5 and 70 SE 6. The most extensive deposits probably border the Ardoch Burn, where it abruptly changes course near Auchinteck; in this vicinity thick deposits of pebbly sand occur between Glenhead Cottage [7504 0142] and the small pit [7565 0142] described by Anderson (1946). Gravel probably underlies the floodplain of the Ardoch Burn upstream of the change in course.

To the north-east of Callander, fragmentary kame-terrace deposits occur within the valley of the Brackland Burn (Eas Fiadhaich), particularly along the western side of the valley in the vicinity of Wester Brackland [6510 0830]. Along the eastern side of the valley and around Middle Brackland, [6630 0850], thin and patchy deposits of sand and gravel rest on morainic drift, which hereabouts is predominantly a very stony, clayey till. Most of this area is remote, wild moorland and in view of this, individual patches of sand and gravel were not delineated. Consequently an area of 'discontinuous spreads of sand and gravel' is shown on the resource map where sand and gravel is thought most likely to occur. Discontinuous spreads of sand and gravel are also present to the south of Braes of Greenock [631 054], where the drift geology is complex. An undulating spread of very poorly sorted sand and gravel and gravelly till floors the valley of the Greenock Burn. The deposits probably formed during the Loch Lomond Stadial, when gravelly material on the valley-sides was moved downslope by solifluction. At borehole 60 NW 6, near Torrie Cottage [6425 0505], 3.1 m of 'clayey' pebbly sand underlies 3.1 m of flow-till. A statistical assessment is not offered and it is estimated that only 0.2 million m^3 of sand and gravel occur in this area.

Post-Glacial buried beach deposits A small part of the flat Carse of Stirling occurs south of Ruskie [624 008]. Although no boreholes were sited here, evidence from drilling to the south on the Stirling resource sheet (Laxton and Ross, 1983) suggests that discontinuous spreads of sand and gravel are buried beneath post-Glacial estuarine and marine deposits, the 'Carse Clay'. The mineral, which probably comprises two to three metres of silty fine- to medium-grained sand, is considered to be a beach deposit (Sissons, Smith and Cullingford, 1966) overlying non-mineral late-Glacial deposits and buried beneath three to four metres of Carse Clay. As only the feather-edge of the resource occurs within the present area no estimate of volume is attempted.

Morainic drift Heterogeneous accumulations of sandy, gravelly and roughly stratified ablation till, referred to here as morainic drift, are widespread in the resource sheet area. The deposit typically comprises a locally derived sandstone rubble in a matrix of silty fine-grained sand and has been used at two localities, [6404 0448 and 6613 0400], for covering domestic waste dumped in hollows. Elsewhere it has been crudely screened and used for constructing forest roads. The thickest potentially workable deposits probably occur at low altitudes within the valley of the River Teith, where they border and also underlie the various fluvioglacial and kame-terrace deposits of sand and gravel. The extremely hummocky and characteristic landscape formed by the morainic drift only occurs upstream of the vicinity of Lanrick [700 025] but the material has been identified as far downstream as borehole 70 SW 9, near the Bridge of Teith [7218 0125].

There appears to be a broad, positive correlation between the degree of sorting of the morainic drift and the altitude of the deposit. For example, on the higher ground between Wester Torrie [6500 0428] and Lennieston Muir the material generally comprises a continuous network of angular boulders of sandstone with a matrix of silty fine-grained sand, whereas along the lower slopes of the valley of the River Teith it comprises silty fine- to medium-grained sand with scattered blocks of sandstone.

In general, the deposits occurring on the high ground to the south of the valley of the River Teith are considered to be possibly workable, whereas those to the north are not. This judgement is arbitrary but is based on an assumption that the material only has a foreseeable use, for example as bulk-fill, if the matrix (sand, silt and clay) of the boulder gravel is non-cohesive, that is, it could be relatively easily worked. On such reasoning, the deposits occurring to the north of the River Teith, between the valley of the Brackland Burn and Severie [7042 0803], are non-mineral because the material was observed in many small stream sections and in pits 60 NE 10 and 60 NE 11 to comprise angular blocks of sandstone in a matrix of stiff, sandy silty clay. Although similar material was found at pit 60 SW 5, to the south of the River Teith, here the deposit was not considered to be typical for the area because a sandy matrix was observed in several small sections beside forest roads in the vicinity, and also in pits 60 SW 3 and 60 SW 4.

In judging the potential usefulness of the morainic drift some account has been taken of the disposition of the material. The deposit is regarded as potentially workable, and shown as such on the resource map, only if it is exposed and non-cohesive or is buried beneath potentially workable sand and gravel, with which it could possibly be worked. Consequently, those areas where morainic drift is covered by overburden, even if the overburden ratio is less than 3:1, are regarded as barren ground and are not otherwise distinguished on the resource map.

Although the morainic drift has rather limited applications, it nevertheless forms a low-grade resource and generally underlies ground of low agricultural quality. Clearly, however, the material cannot be regarded as sand and gravel in the generally accepted sense and consequently, where it has been considered to be potentially workable, it has been shown in lilac on the resource map in order to readily distinguish it from mineral sand and gravel, which is depicted in tones of red.

Data from sample points and the estimated volume of potentially workable morainic drift are given in Table 9; mean grading data are presented in Figure 9.

Block D

The boundary dividing resource blocks C and D roughly coincides with the watershed between the catchments of the River Teith and the Allan Water. Although close geographically, the drift geology of the two valleys is dissimiliar, probably because the valley of the River Teith supported a valley-glacier during the decay of the main late-Devensian ice-sheet and again during the Loch Lomond Stadial, whereas within the valley of the Allan Water the main late-Devensian ice-sheet became isolated and melted away *in situ* and the area was not subsequently overrun by ice. Consequently, the lower reaches of Strathallan remain largely choked with glacial meltwater deposits, which accumulated as a result of this ablation; distinct fluvioglacial terraces only occur downstream of Dunblane.

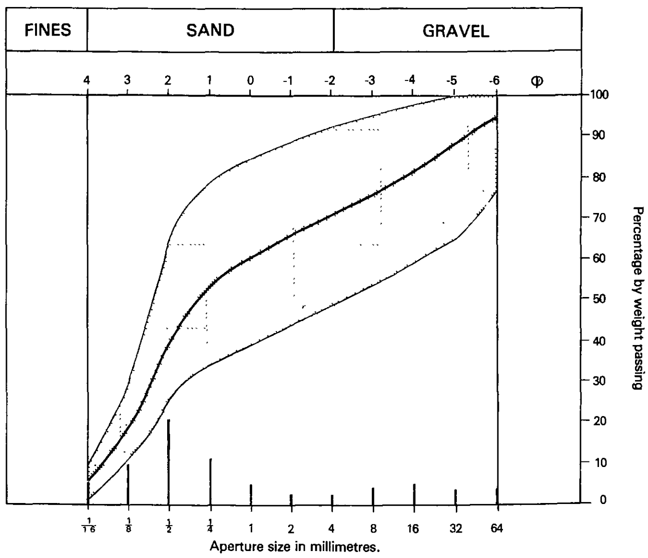

Figure 12 Grading characteristics of the sand and gravel resources of block D; for explanation see Figure 5.

Table 10 Block D: data from sample points and the assessment of resources

Sample point	Recorded thickness			Mean grading percentage							Descriptive category (see Appendix C)
Borehole, section or pit	Mineral m	Overburden m	Waste partings m	Fines $-\frac{1}{16}$ mm	Fine sand $+\frac{1}{16}$ $-\frac{1}{4}$mm	Medium sand $+\frac{1}{4}$ -1mm	Coarse sand $+1$ -4mm	Fine gravel $+4$ -16mm	Coarse gravel $+16$ -64mm	Cobbles and boulders $+64$mm	
GLACIAL SAND AND GRAVEL (MAIN OUTCROPS WITHIN THE VALLEY OF THE ALLAN WATER)											
70 NE 3	15.8	1.0	—	9	27	28	13	15	7	1	PS
70 NE 5	24.8+	0.2	—	7	39	22	8	13	10	1	SG
70 SE 1	15.6	0.5	—	No grading data available							
70 SE 9	13.0	1.0	—	12	17	12	12	18	21	8	CG
70 SE 10	12.9	0.2	—	5	25	15	5	11	19	19	PS
70 SE 11	11.6	0.2	—	11	56	19	7	6	1	0	CPS
70 SE X124	2.0	0.3	—	No grading data available							
Mean*	13.49	0.5	—	9	33	20	9	13	11	5	SG
ALLUVIUM AND FLUVIOGLACIAL SAND AND GRAVEL UNDERLYING TERRACES IN THE VALLEY OF THE ALLAN WATER											
70 NE 4	2.1	2.0	—	6	29	38	16	10	1	0	PS
70 SE 8	2.4	1.1	—	15	45	24	4	4	4	4	CPS
70 SE X3†	6.73	1.38		No grading data available							
Mean	3.74	1.49	—	11	37	31	10	7	2	2	CPS

* Commercial data has been used in the calculations
† Data from other boreholes have been used in the calculations

Statistical assessment of the potentially workable glacial sand and gravel (main outcrops)

Area of exposed mineral	2.31 km²
Area of continuous or almost continuous spreads of mineral beneath overburden	0.23 km²
Total area of mineral-bearing ground	2.53 km²
Mean thickness of overburden	0.5 m
Mean thickness of mineral	13.5 m
Estimated volume of mineral	**34.1 million m³** ±41% or 13.9 million m³
Area of ground worked for sand and gravel	0.24 km²

Inferred assessment of the potentially workable sand and gravel underlying the alluvium and fluvioglacial terraces of the Allan Water

Area of exposed mineral	0.44 km²
Area of continuous or almost continuous spreads of mineral beneath overburden	0.62 km²
Total area of mineral-bearing ground	1.06 km²
Mean thickness of overburden	1.5 m
Mean thickness of mineral	3.7 m
Estimated volume of mineral	**4.0 million m³**

Inferred assessment of the potentially workable patches of glacial sand and gravel in the Cromlix area

Total area of mineral-bearing ground	0.31 km²
Estimated mean thickness of mineral	2.0 m
Estimated mean thickness of overburden	0.5 m
Estimated volume of mineral	**0.6 million m³**

A statistical assessment is presented in Table 10 for the thick deposits of glacial sand and gravel in the valley of the Allan Water, stretching northwards from Dunblane towards Mid Cambushinnie [8000 0631]. Only a very tentative assessment is offered, however, for the numerous small and disparate patches of glacial sand and gravel lying to the north-west of Kinbuck [791 051]; these deposits might be attractive for local use but do not constitute a significant resource within a regional context. As only two boreholes were sited on the floodplain of the Allan Water, a separate volumetric assessment is not offered for the alluvial sand and gravel. Nevertheless, several site investigation boreholes were sited on fluvioglacial sand and gravel in, and to the south of, Dunblane and when these two deposits are considered together there are sufficient sample points for an inferred assessment to be offered: details are given in Table 10.

Glacial sand and gravel Sand and gravel has been worked for a long time at Barbush [786 026] and at [796 050], near Kinbuck. Sections in both pits have been described in some detail by Anderson (1946) and Browne (1976). From the disused station at Kinbuck southwards, gravel is principally restricted to a line of eskers, which extend as far as the pit at Barbush, where they are cored by very coarse, poorly sorted and partially clay-bound gravel. In general, more sandy and better sorted sand and gravel overlaps this core and also forms the kame and kame-terrace deposits that border the eskers on either side. Such sequences of fine on coarse deposits are identified at section 70 SE 10 and borehole 70 SE 9 where 12.9 m and 13.0 m respectively of sand and gravel was recorded; at borehole 70 SE 11, which was sited on a kame some 280 m to the east of the esker-complex, 8.0 m of silty fine-grained sand overlay 3.6 m sandy gravel. A broadly fining-upwards sequence is also reported in the record for borehole 70 SE 1, a water-bore drilled in 1926, which proved 15.6 m of sand and gravel.

In the area to the south of Kinbuck, the moundy glacial meltwater deposits include several deep kettle-holes and in the vicinity of Ashfield [784 038] these hollows have been filled with domestic and industrial waste as, for example, at the site of borehole 70 SE 1.

The kames are bordered to the east by flat, low-lying alluvial tracts which, like the kettle-holes, indicate the former sites of masses of residual ice, against which sand and gravel was deposited during deglaciation. The alluvium beneath these areas is probably chiefly fine-grained, as indicated, for example, by site investigation borehole 70 SE X1.

In the vicinity of Orwell Cottage [7928 0469] the eskers pass northwards into a crescent-shaped 'complex' of kames, which straddles the valley of the Allan Water and through which the river has cut a gorge at Kinbuck. Farther north the deposits take the form of a beaded esker standing some 18 m in height. In contrast to the esker and kame deposits between Kinbuck and Dunblane, where sandy deposits generally overlie coarse gravels, all the available evidence from boreholes and pit sections indicates that the glacial sand and gravel exhibits a broadly coarsening-upwards sequence in the area around, and to the north-east of, Kinbuck. A gravelly sequence overlies sandy deposits at borehole 70 NE 3, which, sited on top of the ridge near Mid Cambushinnie, proved 15.8 m of mineral resting on till. The phenomenon also occurs at borehole 70 NE 5, which was drilled on top of the kame north-west of Drumallan [7928 0522] and terminated in sand and gravel at 25 m.

Alluvium and fluvioglacial sand and gravel Upstream of Ashfield [786 039] the Allan Water crosses two alluvial flats separated by the 32 m-high kame at Drumallan [793 052] upon which borehole 70 NE 5 was drilled. Although bedrock is exposed in the bed of the river between these areas, borehole 70 SE 8 penetrated 2.4 m of 'clayey' pebbly sand (alluvium), resting on 14.8 m of fine-grained glaciolacustrine deposits, whereas borehole 70 NE 4 proved 2.1 m of pebbly sand (alluvium), overlying at least 15.9 m of glaciolacustrine deposits. The thickness of the drift at these two sites is surprising. Stagnant ice probably occupied the area of the present-day alluvial flats until after the sand and gravel forming the eskers and kames had been deposited, and, on melting, left a deeply hollowed drift surface, where fine-grained material accumulated in temporary lakes; the gravelly alluvium has been deposited by the modern river. Considering the thickness of drift proved by boreholes 70 SE 8 and 70 NE 4, sand and gravel may underlie the kame at Drumallan to a considerable depth.

Terraced fluvioglacial sand and gravel occurs within the valley of the Allan Water at Dunblane but the resource is largely sterilised by urban development. Several site-investigation boreholes drilled in connection with road improvement schemes revealed gravelly deposits, for example, 70 SE X3 proved 9.1 m of clayey sand and gravel resting on bedrock.

Miscellaneous deposits Scattered deposits of glacial sand and gravel occur immediately to the north-west of the 'beaded esker' at Mid Cambushinnie, and also around, and to the north-west of Cromlix House [7820 0608]. However, the material generally forms low mounds and ridges and is extremely variable in grading. The soils in this locality are locally very gravelly but these are mainly developed on a gravelly ablation till as, for example, at pit 70 NE 8. Locally the till may be potentially workable, as it is, for example, at borehole 70 NE 1, but here, as elsewhere, the material becomes increasingly clayey and consolidated with depth.

An inferred assessment of the isolated patches of glacial sand and gravel is offered in Table 10: the material is assumed to have an average thickness of 2.0 m. No volumetric assessment is given for resources in the ablation till, which, although widespread, generally has a clayey matrix and would be difficult to work. However, the till may be locally potentially workable as bulk fill.

CONCLUSIONS

The sand and gravel resources of the district, have been described systematically and the results of the assessment summarised in Table 6. It must be repeated that the survey concerns the estimation of *resources* rather than *reserves* and that the assessment of the deposits is judged solely in terms of the arbitrary physical criteria stated in the introduction to the report. No account is taken of prevailing environmental or economic considerations: the quoted volumetric estimates bear no simple relationship to the amount of sand and gravel that might be extracted in practice. The chief aim of the survey is to provide a factual, geologically based assessment of the sand and gravel, against which the economic, social and environmental costs in developing the resource can be weighed.

Bearing in mind that much more detailed exploration and evaluation of the deposits will be required to establish the whereabouts of reserves, it is possible nonetheless to indicate, with some degree of certainty, those resources which may first command attention. These are described block-by-block and a generalised map summarising this information is presented in Figure 13.

Block A The sand and gravel deposits of block A, which predominantly underlie fluvioglacial terraces, have a mean thickness of 9.0 m and a mean grading of fines 6 per cent, sand 39 per cent and gravel 55 per cent. The material is generally compact but is not often claybound; cobbles and boulders are common. On the basis of an examination of the +10–14 mm fraction of bulk samples of sand and gravel collected from boreholes, the aggregate is considered to comprise mainly durable rock-types, such as metaquartzite and vein-quartz, which together form over 80 per cent of the gravel-sized clasts. Noteworthy resources occur both upstream and downstream of Callander: downstream of the town, gravel has been worked extensively at pits near Gart and Ballochallan (see Table 11), but upstream little of the resource has been exploited.

An important factor governing the future development of the resource of this block is its position relative to the water-table. Although it is difficult to generalise, if the depth below the surface at which water was first struck in the assessment boreholes is considered, about 49 per cent of the resource in block A might be expected to lie below the water-table (the IMAU boreholes were drilled in a particularly wet period between August and October 1980). Generally the proportion of the resource lying above the water-table which could be worked dry depends upon the height of the terrace above river level. For example, the resource beneath the flood-plain and low-lying alluvial terraces of the River Teith, which is generally concealed beneath overburden, is wholly below the water-table and unless there is a change of current working practice, it will probably not command attention until the more immediately attractive deposits have been discounted.

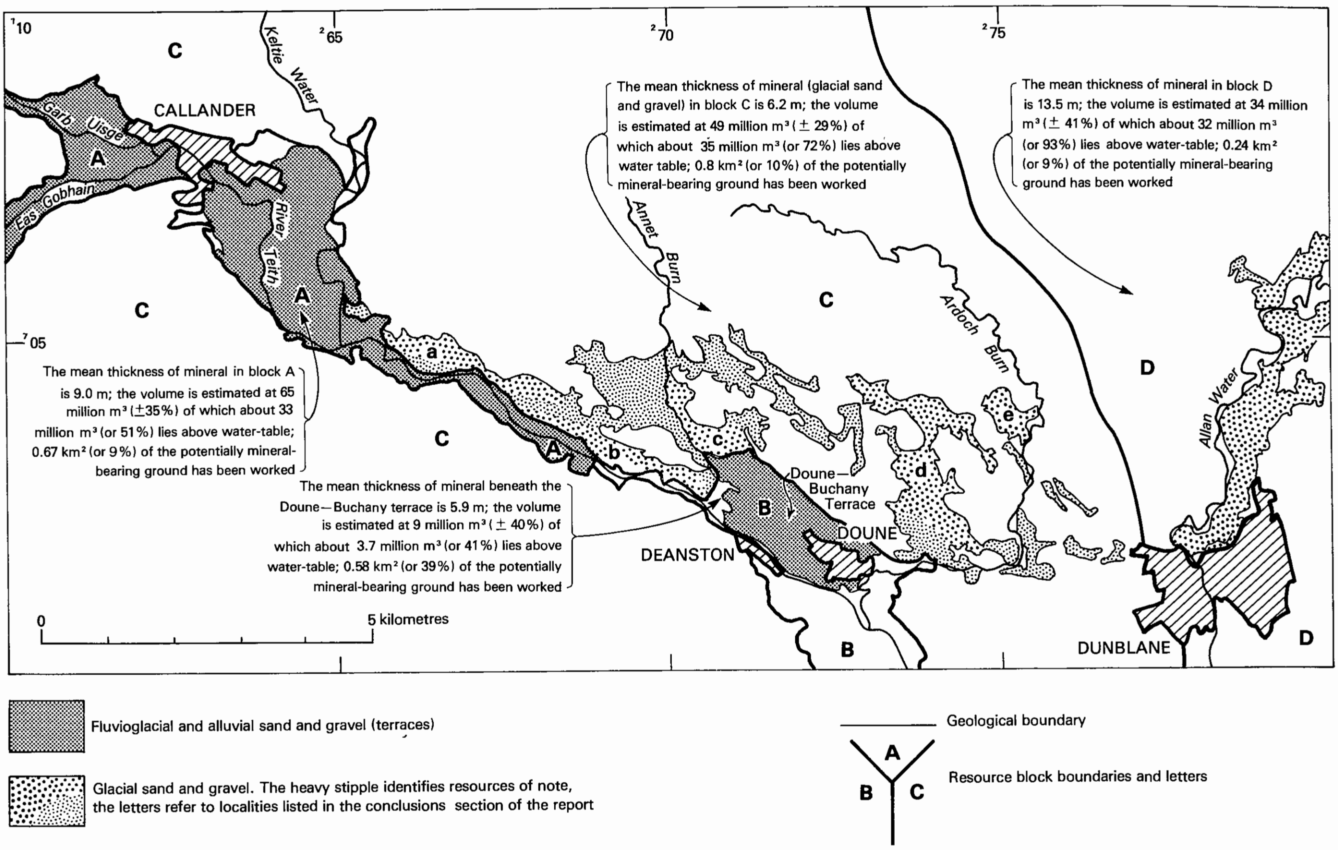

Figure 13 Generalised map showing resources which may be worthy of further investigation as potential reserves

On the other hand, the resource underlying higher terraces occurs largely above the water-table and could be worked dry.

Various practices have been followed in working the deposits underlying the higher terraces in block A. For example, at the old workings south of the road near Wester Coillechat [683 040], gravel was stripped to within a metre or so of the water-table, the area was then levelled, restored and returned successfully to farmland. However, much of the resource, hereabouts, may not have been removed because it lay beneath the water-table. In contrast, at the pit near Gart continuous pumping has allowed 'dry' methods of working to be used several metres below the water-table and the resource has been effectively worked-out. Dredging operations utilising pontoons, which are successful in winning low-lying terrace gravels of major English rivers such as the Thames and Trent, have not been tried in the present resource sheet area.

Block B The sand and gravel underlying the Doune-Buchany Terrace, (Figure 13), to the north-west of Doune, has a mean thickness of 5.9 m and a mean grading of fines 7 per cent, sand 42 per cent and gravel 51 per cent. On the whole the material is less coarse and more homogeneous than the sand and gravel in block A. On the basis of three IMAU boreholes, approximately 59 per cent of the resource is considered to occur below the water-table, that is, a slightly greater proportion than for block A. The composition of the material is essentially similar to that of the resource in block A although there is relatively more sandstone and basalt; the anticipated durability of the aggregate is also broadly similar. Although there are at present no operational pits on the Doune–Buchany Terrace, the sand and gravel underlying the feature is an important resource, since it is situated nearer to the present main centres of demand than the resources of block A.

Block C Rapid variation in thickness and grading is a feature of the glacial sand and gravel included in this block. The deposit ranges from well sorted (all fractions represented) sand to clay-bound boulder-gravel, has a mean thickness of 6.2 m and a mean grading of fines 8 per cent, sand 48 per cent and gravel 44 per cent.

In the past, failure to appreciate the composition and volume of the materials present has resulted in several operations being terminated more quickly than anticipated and, with the exception of the pit at Cambusbeg, this appears to have discouraged commercial interest in the resources of the block.

The resource, which comprises glacial sand and gravel, has the advantage that it can usually be worked dry as it is estimated that no more than 28 per cent lies below water-table. Also, many of the deposits underlie rough grazing land on the valley-sides, whereas the terrace deposits generally form good agricultural land over which there are commonly conflicts of land-use. Disadvantages, other than the rapid variations in thickness and grading, include the difficulties of access to many of the deposits and the common lack of a convenient supply of water for washing and screening.

Although it is more difficult than elsewhere to identify the more significant parts of the resource in this block, five areas have been selected which may repay further investigation. The localities, which are shown in Figure 13, occur (a) between Cambusbeg [661 052] and Wester Coillechat, (b) between Easter Coillechat

Table 11 List of active and disused workings

Location	Grid reference	Deposit worked	Area of worked ground at November 1980, in hectares
ACTIVE			
Gart (Cambusmore)	643 061	Fluvioglacial sand and gravel	33.2
Cambusbeg	667 047	Glacial " " "	14.3
Valley of Coustry	730 000	Fluvioglacial " " "	18.2
Barbush	785 026	Glacial " " "	14.5
Kinbuck	796 050	" " " "	7.1
East Torrie	661 040	Morainic drift	0.5
DISUSED			
Ballochallan (used for stockpiling)	653 052	Fluvioglacial " " "	23.0
Drumvaich	667 044	Glacial " " "	1.3
Wester Coillechat	678 038	Fluvioglacial " " "	5.6
" "	686 036	Glacial " " "	12.2
Lower Coilentowie	696 037	" " " "	22.6
Kirkton Knowe	698 044	" " " "	3.0
Clarkton	712 022	Fluvioglacial " " "	20.3
Wood of Doune (2 pits)	717 018	" " " "	14.7
Deanston	710 019	" " " "	0.7
Doune	725 020	" " " "	23.2
Watston (2 pits)	718 008	" " " "	7.1
Low Daira	732 004	" " " "	11.0
Mansfield	727 032	Glacial " " "	6.2
Westerton	734 022	" " " "	0.5
Netherton	742 022	" " " "	7.7
Auchinteck (3 pits)	756 017	" " " "	14.1
Stockbridge	766 017	" " " "	4.5
Cambushinnie	796 063	" " " "	2.2

[668 038] and the Annet Burn, south of Burn of Cambus [707 030], (c) to the north-west of Doune Lodge [710 033], (d) between East Lundie [731 042] and Argaty Mill Cottage [748 017], and (e) to the north-west of Kilbryde Castle [755 037].

Block D The thickest deposits of sand and gravel in the district occur within the valley of the Allan Water. Discounting the isolated patches of glacial sand and gravel that occur in the Cromlix area and the river gravels, neither of which form a resource of note, the sand and gravel in this block has a mean thickness of 13.5 m and a mean grading of fines 9 per cent, sand 62 per cent and gravel 29 per cent. Proportionately more of this resource could be worked dry than elsewhere as only 7 per cent is estimated to lie below the water-table. However, like the glacial sand and gravel in block C, the grading is variable. The thickest development of gravel probably occurs within the complex of esker ridges that lie between Kinbuck and Dunblane: elsewhere the material predominantly comprises sand.

Unlike the relatively durable aggregate forming the resources of the other blocks, the glacial sand and gravel of block D contains much locally derived mudstone, which swells and crumbles when exposed to the elements. However, this potentially deleterious constituent may be removed by allowing the gravel to weather in stockpiles before it is wet-screened.

It must be re-emphasised that the deposits highlighted above are considered to be resources of potentially workable sand and gravel which may first justify more detailed appraisal: in other words, they are the targets most likely to repay further investigation as prospective reserves. Nevertheless, there are deposits not specifically mentioned here which may be of interest, for example, the potentially workable morainic drift might satisfy a local need for large volumes of bulk-fill; likewise, should silty fine- or medium-grained sand be required, the glacial sand and gravel occurring in the valley linking Doune and Dunblane may deserve attention; so too, the high fluvioglacial terrace deposits situated south of Doune. Elsewhere, volumetrically small deposits of sand and gravel may provide useful local sources of aggregate, especially if little processing of this material should be necessary.

NOTES ON THE SAND AND GRAVEL WORKINGS OF THE AREA

The relatively large number of workings, both active and abandoned, in the resource sheet area reveals the interest that has been focused here by the industry for many years. A brief description of many of the older pits is given by Anderson (1946); more recent information is given by Browne (1977). A list of the larger active and disused workings is given in Table 11. Because many of the older pits have been successfully restored, the limits of the areas of worked ground shown on the resource map may encompass some small areas which, for one reason or another, were not dug. In total, 2.68 km^2 of ground has been worked for sand and gravel in the resource sheet area, that is, about 14 per cent of the total area of mineral-bearing ground identified in the conclusions as justifying more detailed appraisal.

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APPENDIX A

FIELD AND LABORATORY PROCEDURES

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 be not 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 1:25 000 sheet is divided into resource blocks. The arbitrary size selected, 10 km², 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. Exceptionally, other schemes for subdividing the resource sheet area (for example, the use of 'resource sub-blocks') may be used where these are considered to be more appropriate.

A reconnaissance of the ground is carried out to record and sample any exposures, and inquiries are made to ascertain what borehole information is available. In addition, shallow trenches may be cut to investigate the grading of deposits, particularly in very coarse material, and to test the geology prior to commencing the drilling programme. 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 30 m (100 ft) at a diameter of about 200 mm (8 in), 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 (sometimes referred to as 'percussion' 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 deposit, or, ideally, at every 1 m (3.3 ft) depth. The samples, each weighing between 25 and 45 kg (55 and 100 lb), 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 Institute's laboratories.

Other methods of drilling and sampling are occasionally employed, for example the Minuteman power auger rig, and downhole tests such as U4 and SPT may be carried out. The Minuteman, which is small and portable, is normally used when access to land with shell rigs would be difficult to arrange and when information is requested quickly.

The auger tool comprises a continuous-'flight' 76-mm (3-inch) spiral auger; the use of this equipment, as with all 'open-hole' drilling methods, inevitably leads to the mixing and contamination of the sampled material. Thus, data relating to depth and composition cannot always be accurately determined.

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 office of the Institute: the address is shown on page ii of this report, next to the preface.

APPENDIX B

STATISTICAL PROCEDURE

Statistical assessment

1 A statistical assessment is made of an area of mineral greater than 2 km², 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 (Hull, pp. 192–193 *in* Thurrell, 1981). 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 ($\bar{l}_m$) calculated from the individual thicknesses at the sample points. The standard deviations for these variables are related such that

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

4 The above relationship may be transposed such that

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

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

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 $l_{m_1}, l_{m_2}, \ldots l_{m_n}$, then the best estimate of mean thickness, $\bar{l}_m$, is given by

$$\Sigma(l_{m_1} + l_{m_2} \ldots l_{m_n})/n.$$

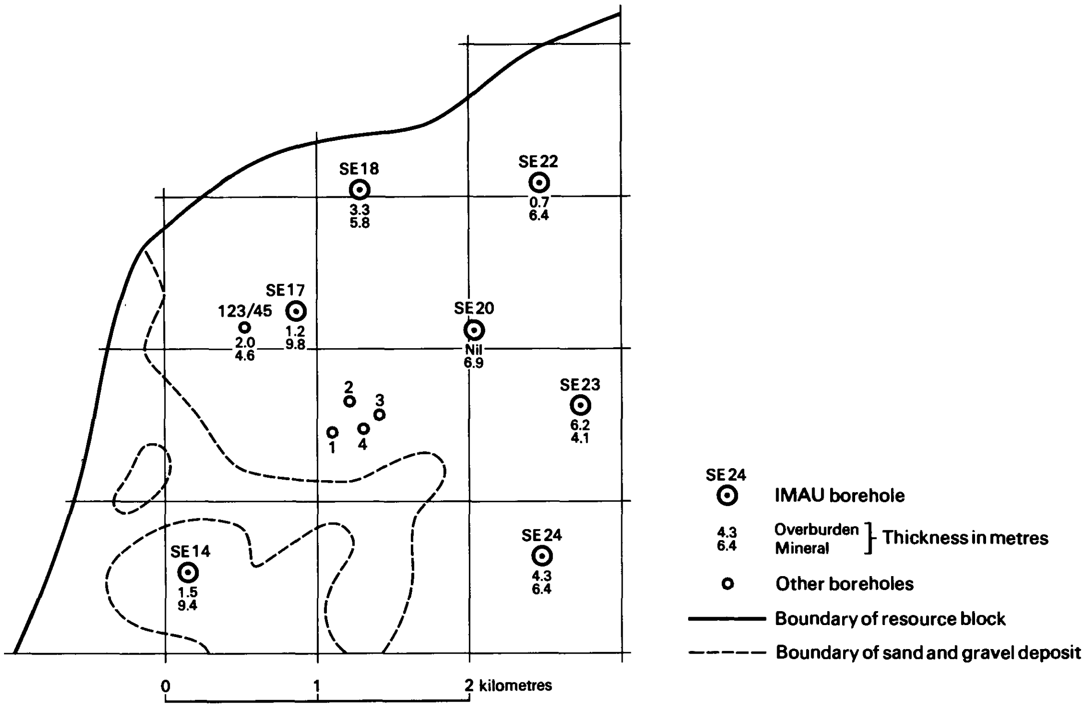
For groups of closely spaced boreholes a discretionary weighting factor may be applied to avoid bias (see note on weighting below). The standard deviation for mean thickness $S_{\bar{l}_m}$, expressed as a proportion of the mean thickness, is given by

$$S_{\bar{l}_m} = (1/\bar{l}_m)\sqrt{[\Sigma(l_m - \bar{l}_m)^2/(n-1)]}$$

where l_m is any value in the series l_{m_1} to l_{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

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



Block calculation 1:25 000 block: Fictitious

Area
Block: 11.08 km²
Mineral: 8.32 km²

Mean thickness
Overburden: 2.5 m
Mineral: 6.5 m

Volume
Overburden: 21 million m³
Mineral: 54 million m³

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 m³

Thickness estimate (measurements in metres)
l_o = overburden thickness l_m = mineral thickness

Sample point	Weighting w	Overburden l_o	Overburden wl_o	Mineral l_m	Mineral wl_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	$\Sigma w = 8$		$\Sigma wl_o = 20.2$		$\Sigma wl_m = 52.0$	
Means			$\overline{wl_o} = 2.5$		$\overline{wl_m} = 6.5$	

Calculation of confidence limits

wl_m	$\mid (wl_m - \overline{wl_m}) \mid$	$(wl_m - \overline{wl_m})^2$
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

$\Sigma(wl_m - \overline{wl_m})^2 = 15.82$
$n = 8$
$t = 2.365$

L_V is calculated as

$$1.05\,(t/\overline{wl_m})\sqrt{[\Sigma(wl_m - \overline{wl_m})^2/n(n-1)]} \times 100$$
$$= 1.05 \times (2.365/6.5)\sqrt{[15.82/(8 \times 7)]} \times 100$$
$$= 20.3$$
$$\simeq 20 \text{ per cent.}$$

c

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 $S_A / S_{\bar{l}_m} \leqslant \frac{1}{3}$ is assumed in all cases. It follows from equation [2] that

$$S_{\bar{l}_m} \leqslant S_l \leqslant 1.05\, S_{\bar{l}_m}. \quad [3]$$

7 The limits on the estimate of mean thickness of mineral, $L_{\bar{l}_m}$, may be expressed in absolute units $\pm (t/\sqrt{n}) \times S_{\bar{l}_m}$ or as a percentage $\pm (t/\sqrt{n}) \times S_{\bar{l}_m} \times (100/\bar{l}_m)$ 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_l, the following inequality corresponding to equation [3] is applied: $L_{\bar{l}_m} \leqslant L_l \leqslant 1.05\, L_{\bar{l}_m}$.

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

$$[(1.05 \times t)/\bar{l}_m] \times [\sqrt{\Sigma(l_m - \bar{l}_m)^2/n(n-1)}] \times 100$$

per cent, and when n is greater than 20, as

$$[(1.05 \times 1.96)/\bar{l}_m] \times [\sqrt{\Sigma(l_m - \bar{l}_m)^2/n(n-1)}] \times 100$$

per cent (weighting factors may be included: see paragraph 15).

11 The application of this procedure to a fictitious area is illustrated in the diagram which accompanies this Appendix.

Inferred assessment

12 If the sampled area of mineral in a resource block is between 0.25 km^2 and 2 km^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.

14 No assessment is attempted for an isolated area of mineral less than 0.25 km^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 deposit, 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 64 mm 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 (illustrated 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 the note on lithological description in 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, 1947). 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, and which appears in the table 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 ($+\frac{1}{4} - 1$ mm) and coarse ($+1 - 4$ mm). The boundary at 16 mm 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 64 mm 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: 1975). 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. Subsequently, the descriptive categories of the mineral for each borehole are modified according to the results obtained from the mean particle size analysis of the samples.

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 almost 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
	Cobble		
64 mm –			
		Coarse	Gravel
16 mm –	Pebble		
		Fine	
4 mm –			
		Coarse	
1 mm –			
	Sand	Medium	Sand
$\frac{1}{4}$ mm –			
		Fine	
$\frac{1}{16}$ mm –			
	Fines (silt and clay)		Fines

I Gravel
II 'Clayey' gravel
III 'Very clayey' gravel
IV Sandy gravel
V 'Clayey' sandy gravel
VI 'Very clayey' sandy gravel
VII Pebbly sand
VIII 'Clayey' pebbly sand
IX 'Very clayey' pebbly sand
X Sand
XI 'Clayey' sand
XII 'Very clayey' sand

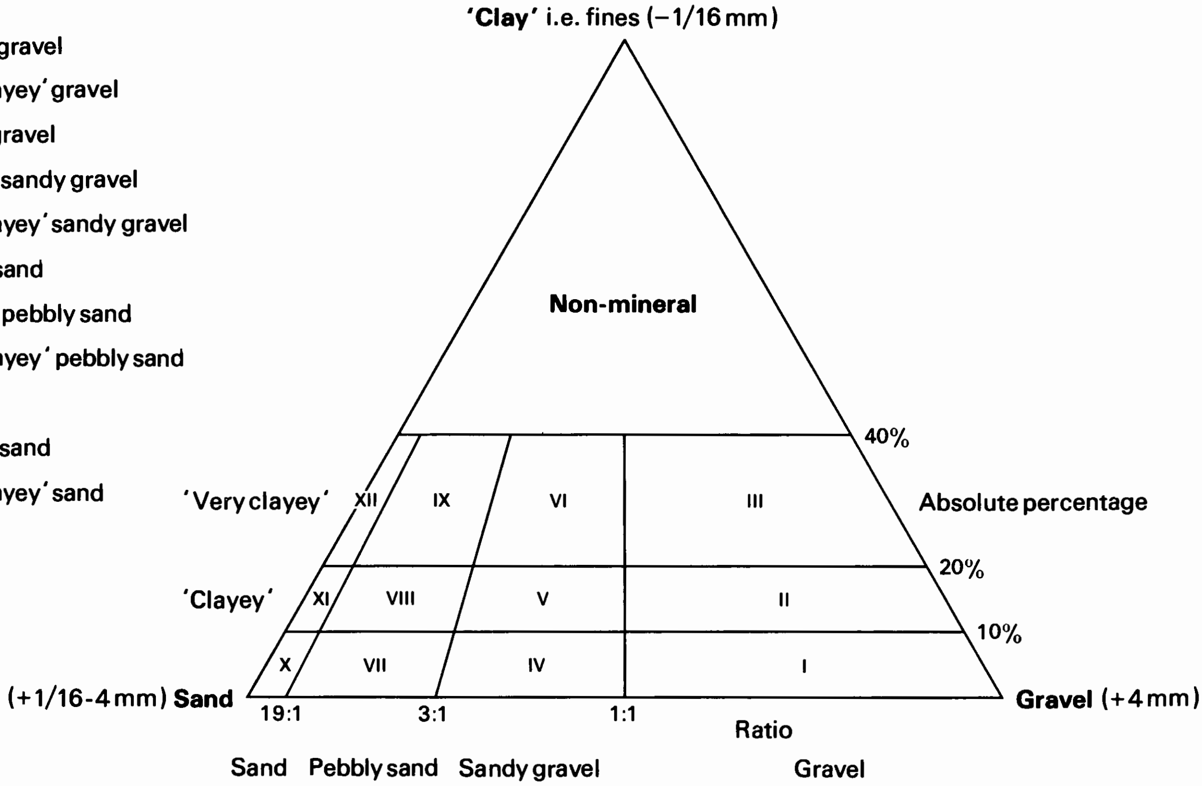


Diagram showing the descriptive categories used in the classification of sand and gravel

APPENDIX D

EXPLANATION OF THE BOREHOLE, SECTION AND SHALLOW PIT RECORDS

Annotated example

NN 60 NW 6[1]	6379 0509[2]	Torrie Cottage, Callander[3]	BLOCK C

Surface level + 75 mm (+ 246 ft)[4]
Groundwater level + 71.2 m[5]
250 mm percussion and shell[6]
September 1980

Overburden 3.3 m[7]
Mineral I 3.1 m
Waste 3.8 m
Mineral II 1.8 m +[9]

LOG

Geological classification[10]	Lithology[11]	Thickness[8] m	Depth m
	Soil	0.2	0.2
Flow-till	Clay, gravelly, sandy, silty, firm to soft, pale yellow-brown, chiefly subrounded to well rounded clasts of varied composition	3.1	3.3
Fluvioglacial sand and gravel	a 'Clayey' pebbly sand Gravel: fine with coarse but mainly restricted to basal metre, subangular to subrounded psammite, schistose grit and sandstone Sand: medium with fine and coarse, 'sharpish', rusty Fines: silt and clay, disseminated. Buff coloured seams of silt above 3.5 m	3.1	6.4
Interstadial lacustrine deposits	Clay, fine sandy, silty with scattered fine pebbles, fining downwards, soft to firm, medium grey	0.6	7.0
	Clay, very silty with fine sand, roughly laminated, medium grey with carbonaceous material, plant fibres and freshwater shell debris. Becoming finer grained downwards with less organic matter, laminae of fine sand and rare 'rotten' pebbles of schist	1.6	8.6
	Clay, silty, very soft, pale grey, finely laminated in parts, rare organic laminae	0.7	9.3
	Clay-bound gravel, angular to well rounded clasts of psammite and sandstone with vein-quartz, quartzite and schist set in a matrix of medium grey, soft to firm, very silty sandy clay	0.9	10.2
Morainic drift	b Gravel Gravel: fine and coarse, some cobbles, chiefly angular to subangular sandstone. Passing down into a sandstone 'rubble' Sand: coarse with some medium and fine, 'sharp', chiefly rock Fines: silt, disseminated, medium grey	1.8 +	12.0

Borehole terminated owing to slow progress, probably on bedrock

(Continued . . .)

GRADING

	Mean for deposit[15] percentages			Depth below[12] surface (m)	percentages[13]						
					Fines	Sand			Gravel		
	Fines	Sand	Gravel		−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64[14 16]
a	10	79	11	3.3−4.6	13	30	30	21	6	0	0†*
				4.6−5.6	7	31	39	20	3	0	0†*
				5.6−6.4	7	16	24	23	14	16	0†*
				Mean	10	27	31	21	7	4	0
b	8	40	52	10.2−11.2	7	6	10	15	20	22	20†*
				11.2−12.0	9	10	13	29	20	19	0†*
				Mean	8	8	11	21	20	21	11
a & b	9	65	26	Mean	9	20	24	21	12	10	4

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, section or shallow pit is identified by a registration number. This consists of two statements.
a The number of the 1:25 000 sheet on which the borehole lies, for example NN 60.
b The quarter of the 1:25 000 sheet on which the borehole lies and its number in a series for that quarter, for example NW 6.
Thus the full registration number is NN 60 NW 6. Usually this is abbreviated to 60 NW 6 in the text.

2 The National Grid reference
All National Grid references in this publication lie within the 100-km square NN. Grid references are given to eight figures, accurate to within 10 m 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 1:25 000 base map and the resource block in which it lies is 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 ground water 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 aggregate which, as part of a deposit, falls within the arbitrary definition of potentially workable material (see p. 1). Mineral I is potentially workable sand and gravel; Mineral II is potentially workable morainic drift or till. 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 deposit was not reached during drilling.

10 Geological classification
The geological classification is given whenever possible.

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 continous 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 1 m 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 proportions of fines and coarse gravel (+16 mm) 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 thickness represented. The classification used is shown in the Table in Appendix C. Where two or more units of mineral are distinguished, the mean grading for each unit is given in addition to the combined calculation for the log. For multiple mineral units, each is designated by a letter, for example, **a**, **b**, etc.

16 Grading data for samples of sand and gravel or till with less than 40 per cent by weight passing $\frac{1}{16}$ mm, but not considered in the calculation of mean grading, are indicated thus: *. These samples either are considered non-mineral owing to the amount of overburden or form small parts of sequences regarded as generally unworkable. The same symbol is sometimes used when there are grading data available for samples taken from sites at which the full thickness of mineral was not proved.

APPENDIX E

INDUSTRIAL MINERALS ASSESSMENT UNIT
BOREHOLE, SECTION AND SHALLOW PIT RECORDS

NN60 NW1 | 6027 0691 | Wester Gartchonzie, Callander | BLOCK A

Surface level + 84 m (+ 275.5 ft)
Groundwater level + 79.8 m
250 mm and 200 mm percussion and shell
August 1980

Overburden 0.3 m
Mineral I 10.0 m
Bedrock 0.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, brown, sandy with pebbles	0.3	0.3
Fluvioglacial sand and gravel	Sandy gravel Gravel: coarse and fine, cobbles common between 0.3 and 1.3 m and between 3.3 and 9.3 m. Above 3.3 m both coarse and cobble grade of rounded psammite, schist and quartzite whereas fine grade is subangular to rounded psammite, schist and quartzite with andesite, quartz, felsite and slate. Below 3.3 m cobbles up to 170 mm and all grades subangular to rounded psammite, quartzite and quartz with basalt, felsite, schist and microgranite. Sand: medium with coarse and fine, angular to subangular, more rounded between 1.3 and 3.3 m. Rock fragments with quartz and feldspar. Sand finer between 1.3 and 3.3 m and between 9.3 and 10.3 m Fines: silt, disseminated and between 1.3 and 2.3 m in bands up to 10 mm thick, pale brown.	10.0	10.3
Old Red Sandstone	Sandstone, medium- to coarse-grained, ill-sorted, quartz and rock fragments cemented by pink feldspar matrix. Basalt pebbles up to 30 mm in diameter	0.2 +	10.5

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
5	49	46	0.3−1.3	5	6	9	11	18	22	29
			1.3−2.3	6	30	41	7	8	8	0
			2.3−3.3	16	50	5	2	9	9	9
			3.3−4.2	8	11	10	16	32	18	5
			4.2−5.2	2	2	9	12	20	41	14†
			5.2−6.0	2	5	12	13	24	37	7†
			6.0−7.0	1	6	17	23	32	21	0†
			7.0−8.2	1	6	20	18	23	26	6†
			8.2−9.3	2	7	25	22	24	20	0†
			9.3−10.3	4	16	56	19	5	0	0†
			Mean	5	14	21	14	19	20	7

NN 60 NW 2 6113 0849 Kilmahog, Callander BLOCK A

Surface level + 80 m (+ 262.5 ft)
Water struck at + 76.2 m
250 mm percussion and shell
August 1980

Overburden 0.4 m
Mineral I 5.0 m
Mineral II 1.0 m
Waste 1.3 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, gravelly	0.4	0.4
Fluvioglacial sand and gravel	a Gravel Gravel: coarse with fine and some cobbles up to 200 mm, subangular to rounded schist, psammite, quartzite and vein-quartz with lavas, sandstone and conglomerate. Some clasts highly weathered Sand: medium with fine and coarse, subangular to rounded quartz and rock fragments Fines: disseminated silt and clay, deposit clay-bound between 2.4 and 3.4 m	5.0	5.4
Till	b Gravel Gravel: coarse and fine with numerous cobbles, more angular than above, composition as above Sand: medium, fine and coarse, angularity and composition as above Fines: clay	1.0	6.4
	Clay, very gravelly with sand, clasts up to cobble size	1.3 +	7.7

Borehole terminated at 7.7 m owing to slow progress

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	4	43	53	0.4–1.4	5	22	21	13	17	17	5
				1.4–2.4	4	14	16	10	20	36	0
				2.4–3.4	5	13	16	18	24	24	0
				3.4–4.2	3	21	16	10	16	21	13
				4.2–5.4	1	3	11	16	16	23	30†
				Mean	4	14	16	13	19	24	10
b	4	41	55	5.4–6.4	4	14	15	12	18	20	17† *
a & b	4	43	53	Mean	4	14	16	13	18	24	11

NN 60 NW 3 | 6138 0766 | Bochastle, Callander | BLOCK A

Surface level + 73 m (+ 239.5 ft)
Water struck at + 71.9 m
250 mm and 200 mm percussion and shell
October 1980

Overburden 0.4 m
Mineral I 12.6 m
Waste 0.6 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Alluvium	Silty fine sand, yellow-brown	0.2	0.4
	a Gravel Gravel: fine and coarse with cobbles up to 250 mm. Coarse gravel rounded to well rounded, fine gravel subangular to well rounded. Schistose psammite and grit, quartzite and vein-quartz with epidiorite, conglomerate, sandstone, schist, felsite and basalt. Platy siltstone and slate common in fine Sand: coarse with medium and fine, angular to well rounded, 'sharp' rock and quartz. Some platy siltstone and slate in coarse Fines: very silty above 1.4 m, clay matrix between 1.4 and 2.5 m, becoming cleaner downwards. Yellow-brown	5.1	5.5
Fluvioglacial sand and gravel	b 'Clayey' sand. Fining downwards Gravel: fine with some coarse, subangular to well rounded, composition as above Sand: chiefly fine, with medium and some coarse, well sorted, 'soft', quartzose, some subangular vein-quartz and rock in coarse Fines: silt, disseminated and as 100 to 200 mm seams below 8.0m. Pale yellow-brown	6.3	11.8
	c 'Clayey' sandy gravel. Poorly sorted Gravel: coarse and fine with some cobbles, angular to subrounded, composition as above Sand: chiefly fine with some coarse and medium, composition as above Fines: chiefly silt	1.2	13.0
Till	Clay, very sandy and silty with some fine and coarse gravel, firm becoming stiff downwards, pale yellow-brown	0.6	13.6
Old Red Sandstone	Siltstone, red, very hard with quartz veining	0.1 +	13.7

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	5	36	59	0.1−1.4	12	9	10	11	16	26	16
				1.4−2.5	4	7	9	14	24	28	14†
				2.5−3.5	4	10	18	21	21	26	0†
				3.5−4.5	2	5	9	17	32	23	12†
				4.5−5.5	4	12	8	19	27	11	19†
				Mean	5	9	11	16	24	23	12
b	10	86	4	5.5−7.0	7	55	33	2	2	1	0†
				7.0−8.0	4	31	40	12	11	2	0†
				8.0−9.8	12	59	20	7	2	0	0†
				9.8−10.8	10	80	8	1	1	0	0†
				10.8−11.8	17	78	4	0	1	0	0†
				Mean	10	60	22	4	3	1	0
c	17	51	32	11.8−13.0	17	36	6	9	12	16	4†
a to c	9	83	28	Mean	9	37	16	10	12	11	5

NN 60 NW 4 | 6335 0666 | Clash, Callander | BLOCK A

Surface level + 68 m (+ 223 ft)
Groundwater level + 66.1 m
250 mm percussion and shell
August 1980

Overburden 0.3 m
Mineral I 7.2 m
Waste 0.2 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, pebbly, brown	0.3	0.3
Fluvioglacial sand and gravel	a Gravel Gravel: coarse with fine and with numerous cobbles, subangular to well rounded schistose grit, psammite and andesite with sandstone, vein-quartz, epidiorite, hornblende-schist, quartzite and lavas. Schist often badly weathered Sand: coarse with medium and some fine, angular to subangular rock fragments, quartz and feldspar Fines: silt, disseminated, dark brown	5.0	5.3
	b Gravel Gravel: coarse with fine, some cobbles, clasts more angular than above, composition as above Sand: as above, but clasts more angular Fines: silty clay binding deposit, pale brown	2.2	7.5
Till	Clay, very silty with sand and gravel, soft becoming firm	0.2	7.7
Old Red Sandstone	Conglomerate, red, hard, coarse sandy matrix, feldspathic, with pebbles of vein-quartz, schist and lava	0.1 +	7.8

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
a	2	32	66	0.3–1.6	1	6	14	22	22	35	8
				1.6–2.6	4	7	13	19	21	25	11†
				2.6–3.6	1	3	8	12	16	32	28†
				3.6–5.3	1	3	8	15	15	24	34†
				Mean	2	4	11	17	18	29	19
b	5	32	63	5.3–6.3	5	4	7	13	20	45	6†
				6.3–7.5	5	6	13	21	15	35	5†
				Mean	5	5	10	17	17	40	6
a & b	3	32	65	Mean	3	5	10	17	18	32	15

NN 60 NW 5 | 6372 0619 | Balvalachlan, Callander | BLOCK A

Surface level + 65 m (213 ft)
Groundwater level + 62.2 m
250 mm percussion and shell
October 1980

Overburden 0.1 m
Mineral I 3.0 m
Waste 1.7 m
Mineral I 6.2 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, gravelly	0.1	0.1
Fluvioglacial sand and gravel	a 'Clayey' gravel Gravel: coarse with fine, some cobbles. Coarse gravel well rounded to rounded, fine gravel subangular to subrounded. Schistose grit, psammite, quartzite and vein-quartz with some andesite, epidiorite, sandstone and schist Sand: coarse, medium and fine, angular to well rounded rock, vein-quartz and quartz, poorly sorted Fines: silt, disseminated. Deposit bound by fine sandy silt and clay matrix below 2.2 m, pale brown	3.0	3.1
Till	Clay, silty, sandy and gravelly, clasts up to cobble size, firm to stiff, yellow-brown becoming pale grey	1.7	4.8
Fluvioglacial sand and gravel	b Gravel Gravel: fine and coarse with some cobbles up to 250 mm towards the base. Angularity and composition as above. Basal boulder bed Sand: coarse with medium and some fine, angularity and composition as above Fines: very little, medium grey to neutral	6.2	11.0
Old Red Sandstone	Sandstone, fine-grained, dark grey, micaceous with dark streaks	0.1+	11.1

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
a	12	35	53	0.1–1.1	8	9	9	10	17	29	18
				1.1–2.2	5	8	16	16	23	32	0†
				2.2–3.1	24	18	10	9	11	6	22†
				Mean	12	11	12	12	17	23	13
b	2	35	63	4.8–5.8	3	6	14	21	32	24	0†
				5.8–6.8	1	3	8	14	30	37	7†
				5.8–7.8	1	2	7	18	31	35	6†
				7.8–8.8	2	2	12	18	38	28	0†
				8.8–9.8	2	7	18	27	35	11	0†
				9.8–11.0	2	6	10	17	22	22	21†
				Mean	2	4	12	19	31	26	6
a & b	5	35	60	Mean	5	6	12	17	27	25	8

NN 60 NW 6 | 6379 0509 | Torrie Cottage, Callander | BLOCK C

Surface level + 75 mm (+ 246 ft)
Groundwater level 71.2 m
250 mm percussion and shell
September 1980

Overburden 3.3 m
Mineral I 3.1 m
Waste 3.8 m
Mineral II 1.8 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Flow-till	Clay, gravelly, sandy, silty, firm to soft, pale yellow-brown, chiefly subrounded to well rounded clasts of varied composition	3.1	3.3
Fluvioglacial sand and gravel	a 'Clayey' pebbly sand Gravel: fine with coarse but mainly restricted to basal metre, subangular to subrounded psammite, schistose grit and sandstone Sand: medium with fine and coarse, 'sharpish', rusty Fines: silt and clay, disseminated. Buff coloured seams of silt above 3.5 m	3.1	6.4
Interstadial lacustrine deposits	Clay, fine sandy, silty with scattered fine pebbles, fining downwards, soft to firm, medium grey	0.6	7.0
	Clay, very silty with fine sand, roughly laminated, medium grey with carbonaceous material, plant fibres and freshwater shell debris. Becoming finer grained downwards with less organic matter, laminae of fine sand and rare 'rotten' pebbles of schist	1.6	8.6
	Clay, silty, very soft, pale grey, finely laminated in parts, rare organic laminae	0.7	9.3
	Clay-bound gravel, angular to well rounded clasts of psammite and sandstone with vein-quartz, quartzite and schist set in a matrix of medium grey, soft to firm, very silty sandy clay	0.9	10.2
Morainic drift	b Gravel Gravel: fine and coarse, some cobbles, chiefly angular to subangular sandstone. Passing down into a sandstone 'rubble' Sand: coarse with some medium and fine, 'sharp', chiefly rock Fines: silt, disseminated, medium grey	1.8 +	12.0

Borehole terminated owing to slow progress, probably on bedrock

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
a	10	79	11	3.3–4.6	13	30	30	21	6	0	0†*
				4.6–5.6	7	31	39	20	3	0	0†*
				5.6–6.4	7	16	24	23	14	16	0†*
				Mean	10	27	31	21	7	4	0
b	8	40	52	10.2–11.2	7	6	10	15	20	22	20†*
				11.2–12.0	9	10	13	29	20	19	0†*
				Mean	8	8	11	21	20	21	11
a & b	9	65	26	Mean	9	20	24	21	12	10	4

NN 60 NW 7 | 6467 0734 | Auchenlaich, Callander | BLOCK A

Surface level + 82 m (+ 269 ft)
Groundwater level + 74.2 m
250 mm and 200 mm percussion and shell
September 1980

Overburden 0.9 m
Mineral I 3.8 m
Waste 7.2 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clasts up to 180 mm diameter	0.9	0.9
Flow Till	'Very clayey' sandy gravel (Basal 1.0 m non-mineral) Gravel: fine with coarse and some cobbles up to 180 mm, cobbles less common below 2.7 m. Subangular to well rounded psammite and quartzite with quartz, schist and volcanic breccia above 2.7 m, and psammite, quartzite, gabbro and diorite below 2.7 m and sandstone below 4.1 m Sand: fine and coarse with medium, angular to subangular quartz with rock fragments Fines: disseminated silt and clay, brown. Deposit is cohesive and very consolidated both above 2.7 m and below 4.7 m	4.8	5.7
Glaciolacustrine deposits	Silt with fine sand and clay. Clay as laminae up to 3 mm thick, brown. Silt, grey-brown becoming grey below 9 m. Fining downwards with rare clasts up to 60 mm diameter	6.2	11.9
Old Red Sandstone	Sandstone, flaggy, medium-grained, quartz with feldspar, red-grey, containing angular fragments of red-grey mudstone	0.1 +	12.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
24	42	34	0.9–1.7	17	9	12	14	19	17	12
			1.7–2.7	16	11	14	17	21	11	10
			2.7–3.7	28	19	13	16	18	6	0
			3.7–4.7	35	24	8	9	12	12	0
			Mean	24	16	12	14	18	11	5

NN 60 NW 8 | 6443 0624 | Gart, Callander | BLOCK A

Surface level + 72 m (+ 236 ft)
Groundwater level + 54.1 m, but pit being pumped
Section, sampled by hand and excavator
December 1980

Overburden 0.2 m
Mineral I 18.4 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Fluvioglacial sand and gravel	a Gravel Gravel: coarse with fine, numerous cobbles with some boulders, subrounded to well rounded with fine more angular than coarse, conglomerate, sandstone, schistose psammite, andesite, vein-quartz, felsite, metagabbro, schist, epidiorite (often 'rotten'), quartzite and slate. Schist and slate often platy Sand: coarse with medium and some fine, moderately sorted, angular to subangular, 'sharp' rock and quartz with some feldspar Fines: silty with clay below 9.7 m as a medium brown coating to clasts making deposit slightly cohesive	13.6	13.8
	b Gravel Gravel: coarse and fine with rare cobbles up to 250 mm, subangular to well rounded psammite, schist, vein-quartz, andesite and felsite with sandstone and conglomerate Sand: coarse with some medium and a little fine, angular to subrounded, mainly rock fragments, otherwise as above Fines: a little silt, disseminated	4.8 +	18.6

Base of deposit probably within 2 m, large fragments of sandstone bedrock dredged up from adjacent flooded part of working

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	6	14	80	0.2−5.5	9	1	7	8	10	15	50
				5.5−9.7	No grading data available						
				9.7−13.8	3	1	3	7	11	13	62
				Mean	6	1	5	8	11	14	55
b	3	39	58	13.8−18.6	3	4	13	22	28	30	0
a & b	6	20	74	Mean	6	2	7	11	15	18	41

NN 60 NW 9 | 6487 0522 | St Mary's Chapel, Callander | BLOCK A

Surface level + 62 m (+ 203.5 ft)
Water not struck
250 mm percussion
September 1980

Overburden 0.3 m
Mineral I 6.8 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.1	0.1
	Made ground: clayey sand and gravel	0.2	0.3
Fluvioglacial sand and gravel	a Gravel Gravel: coarse and fine, cobbles common and boulders up to 350 mm, sandstone, schistose grit, vein-quartz, conglomerate, epidiorite and diorite with quartzite, andesite, lavas, schist and 'rotten' siltstone Sand: coarse and medium with fine, 'sharpish', rock and quartz Fines: silt and clay binding deposit above 1.5 m, mostly silt below, becoming 'cleaner' downwards but deposit still lightly bound. Pale grey-brown	6.3	6.6
Till?	b 'Clayey' gravel Gravel: as above, a little more angular Sand: coarse with medium and fine, very 'sharp', rock fragments and quartz Fines: silty clay matrix	0.5 +	7.1

Terminated at 7.1 m owing to boulder obstruction

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a & b	8	37	55	0.3−1.3	6	8	16	14	32	24	0
				1.3−2.3	7	8	14	14	23	22	12
				2.3−3.3	7	11	16	14	24	28	0
				3.3−4.3	7	10	16	16	24	27	0
				4.3−5.3	8	7	11	13	19	26	16
				5.3−6.6	8	7	12	14	19	27	13
				6.6−7.1	11	11	14	16	19	20	9
				Mean	8	9	14	14	23	25	7

NN 60 NW 10	6374 0535	Braes of Greenock, Callander	BLOCK C

Surface level + 79 m (+ 259 ft)
Water struck at + 77.1 m
Pit
December 1980

Overburden 0.2 m
Mineral II 0.8 m
Waste 1.0 m
Mineral II 1.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty and clayey, dark brown	0.2	0.2
Morainic drift	Sandy gravel Gravel: ill-sorted, up to 300 mm, angular to subangular sandstone with some 'Highland' material Sand: fine, well sorted Fines: silt, disseminated, medium brown	0.8	1.0
	Clay, sandy, mottled grey-brown	1.0	2.0
	Pebbly sand Gravel: a few clasts of 'Highland' material above 3.0 m Sand: fine, well sorted, quartz, light brown	1.1 +	3.1

Pit terminated at 3.1 m. No grading data available

NN 60 NW 11	6444 0731	Drumdhu Wood, Callander	BLOCK A

Surface level + 81 m (+ 265.5 ft)
Water struck at + 79 m
Pit
December 1980

Overburden 0.4 m
Mineral I 2.6 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, peaty	0.4	0.4
Terminal moraine (Glacial sand and gravel)	Gravel Gravel: abundant cobbles with coarse and some fine, boulders up to 800 mm common, rarely up to 1 m. Coarse gravel subrounded to well rounded with some subangular blocks of sandstone; fine gravel subangular to well rounded sandstone, conglomerate, schistose psammite, epidiorite and metagabbro with vein-quartz, quartzite, andesite and slate. Non-sandstone clasts predominate Sand: coarse with medium and fine, poorly sorted, angular to well rounded rock with quartz and feldspar Fines: a little silt, disseminated. Becoming a little clayey and cohesive downwards, medium yellow-brown	2.6 +	3.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1−4	+4−16	+16−64	+64
2	13	85	0.4−3.0	2	3	4	6	10	17	58*

NN 60 NW 12	6460 0762	Auchenlaich, Callander	BLOCK A

Surface level + 86 m (+ 282 ft)
Water not struck
Pit
December 1980

Overburden 0.4 m
Mineral I 2.3 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty, sandy, stony, dark brown	0.4	0.4
Flow till	'Clayey' gravel Gravel: poorly sorted, clasts up to 300 mm, angular to well rounded sandstone with mudstone, basalt, quartzite, psammite and metagrabbro Sand: poorly sorted, fine to coarse, angular quartz and rock fragments Fines: silt and clay, disseminated, medium brown, binding deposit in upper part but becoming less abundant with depth	2.3 +	2.7

Pit terminated at 2.7 m. No grading data available

NN 60 NW 13	6477 0725	Auchenlaich, Callander	BLOCK A

Surface level + 82 m (+ 269 ft)
Water not struck
Pit
December 1980

Overburden 0.5 m
Mineral I 2.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Made-ground: old domestic dump	0.5	0.5
Fluvioglacial sand and gravel	Gravel Gravel: cobbles, coarse and fine, clasts up to 300 mm. Coarse gravel subrounded to well rounded, fine gravel angular to well rounded. Sandstone, mudstone, basalt, quartzite, psammite, metagabbro, conglomerate and epidiorite with vein-quartz andesite and slate. Boulders tend to be local sandstone, otherwise non-sandstone clasts predominate. Poorly sorted Sand: fine to coarse, poorly sorted, angular to well rounded, 'sharp', rock with quartz Fines: disseminated silt, some clay. Deposit consolidated but not clay-bound	2.2 +	2.7

Pit terminated at 2.7 m owing to slow progress in very coarse gravel. No grading data available

D

NN 60 NW 14	6409 0560	Gart, Callander	BLOCK A

Surface level + 70 m (+ 229.5 ft)
Water not struck
Pit
December 1980

Overburden 0.3 m
Mineral I 3.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, peaty	0.3	0.3
Terminal moraine (Glacial sand and gravel)	'Clayey' sandy gravel. Poorly sorted, very compact Gravel: fine with coarse, clasts up to 300 mm. Between 1.6 and 2.3 m deposit is composed mainly of angular blocks of sandstone up to boulder size, otherwise subangular to subrounded with some well rounded clasts of psammite, schist, quartzite, vein-quartz, andesite, felsite, conglomerate, epidiorite and metagabbro with some sandstone (increasing downwards) Sand: fine with coarse and medium, finer below 1.6 m, angular to well rounded rock and quartz with feldspar Fines: chiefly silt, mostly disseminated. Very silty between 1.6 and 2.3 m where deposit is very compact. Pale yellow-brown	3.2 +	3.5
	Large blocks of sandstone at base of pit		

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
18	53	29	0.3−1.6	22	21	15	13	17	12	0*
			1.6−2.3	No grading data available						
			2.3−3.5	13	22	13	22	18	12	0*
			Mean	18	22	14	17	17	12	0

NN 60 NE 3	6560 0827	Wester Bracklinn, Callander	BLOCK C

Surface level + 110 m (+ 361 ft)
Water struck at + 108.4 m
250 mm percussion and shell
September 1980

Waste 1.6 m
Bedrock 0.4 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.3	0.3
Glacial sand and gravel	Clayey sand and gravel Gravel: fine and coarse, some cobbles and small boulders, subangular to well rounded sandstone, siltstone, basalt and some schist Sand: medium with coarse and fine, subangular to subrounded though coarse chiefly well rounded, rock and quartz Fines: silt and silty clay slightly binding the deposit, pale orange-brown	0.7	1.0
Till	Clay with scattered clasts, stiff, pale yellow-grey	0.6	1.6
Old Red Sandstone	Sandstone, medium-grained with maroon-grey mudstone pellets. Rubbly to 2.0 m then hard	0.4 +	2.0

NN 60 NE 4	6542 0691	Dalvey, Kilmadock	BLOCK C

Surface level + 81 m (+ 267 ft)
Water struck at + 79.9 m
250 mm shell
September 1980

Waste 5.7 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty medium-brown	0.2	0.2
Alluvium	Gravel, fine to coarse, in orange-brown sandy silt matrix, with angular sandstone cobbles up to 150 mm below 0.7 m	0.6	0.8
Till	Clay, stiff, grey, becoming sandier and less stiff with depth. Subangular sandstone clasts up to 230 mm and some rounded basalt and quartz increasing in abundance below 4.0 m	4.9 +	5.7

NN 60 NE 5	6556 0591	Staid, Kilmadock	BLOCK C

Surface level + 75 m (+ 246 ft)
Water struck at + 71 m
250 mm percussion and shell
September 1980

Overburden 3.2 m
Mineral II 2.8 m
Waste 1.0 m
Mineral II 3.2 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, medium brown	0.3	0.3
Morainic drift	Clay, moderately stiff, red-brown, sandy with sandstone clasts up to 100 mm	2.9	3.2
	a 'Very clayey' gravel Gravel: coarse with fine and cobbles up to 160 mm, subangular to rounded, sandstone, basalt, andesite and rare pyroxenite Sand: fine with coarse and medium, angular to rounded, quartz with some rock fragments Fines: disseminated clay, increasing below 5.0 m, red-brown	2.8	6.0
	Clay, brown-grey, sandy, clasts up to 200 m	1.0	7.0
	b 'Very clayey' sandy gravel Gravel: fine with coarse, angular to subangular sandstone Sand: fine with medium and coarse, angular to subangular, quartz with rock fragments Fines: silt and clay, disseminated, grey-brown becoming grey below 8.1 m	3.2	10.2
Old Red Sandstone	Sandstone, medium-grained, quartz with feldspar, grey	0.1 +	10.3

(... continued)

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	29	32	39	3.2−4.0	32	12	7	11	13	17	8
				4.0−5.0	25	26	8	9	11	17	4†
				5.0−6.0	31	8	5	9	12	13	22†
				Mean	29	15	7	10	12	16	11
b	35	49	16	7.0−8.1	33	33	9	7	9	9	0†
				8.1−9.0	No grading data available						
				9.0−10.2	37	25	11	12	11	4	0†
				Mean	35	29	10	10	10	6	0
a & b	32	41	27	Mean	32	23	8	10	11	11	5

NN 60 NE 6   6662 0879   Middle Brackland, Callander   BLOCK C

Surface level + 181 m (+ 594 ft)
Water not struck
250 mm percussion
September 1980

Overburden 0.1 m
Mineral I 1.6 m
Waste 0.1 m
Bedrock 0.5 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, turf	0.1	0.1
Glacial sand and gravel	'Very clayey' sandy gravel Gravel: coarse and fine, rounded to well rounded, siltstone, sandstone, conglomerate, psammite and vein-quartz with some felsite and 'rotten' schist Sand: coarse and medium with fine, subangular rock and quartz Fines: silt, disseminated, red-brown. Becoming clayey downwards	1.6	1.7
Till	Silt and fine sand, 'soft', red-brown, overlying silty clay, stiff, yellow-brown	0.1	1.8
Old Red Sandstone	Sandstone with mudstone pellets, fine- to medium-grained, dark grey, very hard	0.5 +	2.3
	A second borehole 1 m away confirmed bedrock at 1.9 m		

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
23	39	38	0.1−1.7	23	9	14	16	18	20	0

NN 60 NE 7 | 6639 0513 | Cambusbeg, Kilmadock | BLOCK C

Surface level + 75 m (+ 246 ft)
Water struck at + 72 m
250 mm percussion and shell
September 1980

Overburden 0.2 m
Mineral II 6.8 m
Waste 1.1 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty, medium brown	0.2	0.2
Morainic drift	'Very clayey' gravel Gravel: coarse with fine, cobbles up to 150 mm, angular to subrounded sandstone with some well rounded dolerite, basalt and quartz Sand: fine with coarse and medium, angular to subrounded, coarse grains chiefly rock but otherwise quartz Fines: silt, medium brown, becoming grey below 4.1 m	6.8	7.0
	Silt, clayey with fine sand	1.1	8.1
Old Red Sandstone	Sandstone, fine- to medium-grained, green and grey	0.1 +	8.2

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand		Gravel			
				$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
21	32	47	0.2–1.4	12	8	6	11	15	40	8
			1.4–2.2	35	9	4	8	11	8	25
			2.2–3.0	No grading data available						
			3.0–4.1	14	17	8	5	3	2	51†
			4.1–5.1	31	27	9	7	14	12	0†
			5.1–6.0	31	21	8	7	9	6	18†
			6.0–7.0	12	14	7	13	20	34	0†
			Mean	21	16	7	9	12	18	17

NN 60 NE 8 | 6689 0958 | Tom Dubh, Callander | BLOCK C

Surface level + 281 m (+ 922 ft)
Water not struck
Pit
December 1980

Waste 0.8 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, peaty, black	0.3	0.3
Till	Clay, very stiff with sandstone clasts up to 450 mm, greyish-brown	0.5 +	0.8
	Pit abandoned because till was too hard to penetrate		

NN 60 NE 9 | 6602 0879 | Middle Brackland, Callander | BLOCK C

Surface level + 168 m (+ 551 ft)
Water not struck
Pit
December 1980

Overburden 0.3 m
Mineral I 1.8 m
Waste 1.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty, medium brown	0.3	0.3
Glacial sand and gravel	'Clayey' gravel Gravel: coarse with fine and some cobbles up to 80 mm. Finer below 1.5 m, angular to subrounded, basalt with psammite, quartzite and sandstone Sand: coarse with medium and some fine, very poorly sorted, angular quartz and rock fragments Fines: silt with clay more abundant downwards, disseminated, red-brown	1.8	2.1
	Silt, yellow-brown, laminated with partings of red-brown clay	0.5	2.6
Till	Clay with silt and angular sandstone clasts up to 350 mm, red-brown	0.7 +	3.3

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				-1/16	+1/16–1/4	+1/4–1	+1–4	+4–16	+16–64	+64
13	41	46	0.3–0.8	18	9	14	10	16	24	9
			0.8–1.5	13	3	5	6	19	39	15
			1.5–2.1	9	6	30	41	13	1	0
			Mean	13	6	16	19	16	22	8

NN 60 NE 10 | 6917 0863 | Sheills of Waterside, Kilmadock | BLOCK C

Surface level + 282 m (+925 ft)
Water not struck
Pit
December 1980

Waste 1.9 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Peat, black	0.3	0.3
Morainic drift	Clay, sandy with angular clasts of sandstone and volcanic breccia, grey-brown	1.6 +	1.9

NN 60 NE 11 | 6974 0847 | Sheills of Waterside | BLOCK C

Surface level + 272 m (+ 892 ft)
Water not struck
Pit
December 1980

Waste 2.8 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Peat, black, fibrous	0.6	0.6
Morainic drift	Very stony, sandy till with up to 70% angular to subangular gravel-sized clasts of sandstone, large boulders becoming more numerous downwards. Sand chiefly fine and medium. Fines chiefly silt but deposit becoming clayey below 2.0 m with matrix stiff and pale grey	2.2 +	2.8

NN 60 SW 3 | 6215 0332 | Lennieston Muir, Port of Menteith | BLOCK C

Surface level + 153 m (+ 502 ft)
Water struck at + 149.2 m
Pit
December 1980

Overburden 0.5 m
Mineral II 3.8 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, medium brown	0.5	0.5
Morainic drift	'Clayey' gravel. Very poorly sorted and compact Gravel: coarse and fine with numerous cobbles and boulders up to 300 mm, angular to subangular sandstone with some 'Highland' material in the finer grades (a little more rounded) Sand: fine with some coarse and medium, angular to subangular quartz with feldspar and rock fragments Fines: chiefly silt, disseminated, medium brown, becoming more clayey and light grey below 3.8 m where there is an iron-manganese pan	3.8 +	4.3

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
12	31	57	0.5–4.3	12	15	7	9	14	19	24

NN 60 SW 4	6401 0448	Wester Torrie, Kilmadock	BLOCK C

Surface level + 96 m (+ 312 ft)
Water struck at + 90.9 m
Section and pit
December 1980

Overburden 0.2 m
Mineral II 5.3 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Morainic drift	'Clayey' gravel. Very poorly sorted and compact Gravel: coarse with fine, cobbles and boulders common. Chiefly sandstone, typically as angular slabs up to 500 mm with some angular to subangular psammite, quartz, andesite and schist Sand: fine with coarse and some medium, some angular to well rounded rock in coarse, otherwise quartz Fines: silt with some clay, matrix more clayey in basal metre, pale yellow-brown	5.3 +	5.5

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
11	28	61	0.2−2.5	No grading data available						
			2.5−5.5	11	13	6	9	16	23	22

NN 60 SW 5	6452 0366	Wester Torrie, Kilmadock	BLOCK C

Surface level + 131 m (+ 430 ft)
Water not struck
Road section and pit
December 1980

Waste 4.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Morainic drift	Till, stony, sandy: continuous network gravel comprising blocks of sandstone up to 1m and rare rounded clasts of metagabbro, epidiorite, psammite and vein-quartz. Matrix of sandy silty clay, pale yellow-brown. (Deposit mineral in terms of stone content but matrix predominantly non-mineral)	3.9 +	4.1

Pit terminated at 4.1 m owing to the coarseness and hardness of the deposit

NN 60 SE 1 | 6548 0485 | East Torrie, Kilmadock | BLOCK A

Surface level + 51 m (+ 167 ft)
Water struck at + 49.8 m
250 mm percussion and shell
September 1980

Overburden 0.2 m
Mineral I 7.3 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Fluvioglacial sand and gravel	a Gravel Gravel: coarse with fine and some cobbles up to 200 mm, larger cobbles at base. Coarse subrounded to well rounded, fine angular to well rounded. Schistose psammite and grit, green schist and vein-quartz with sandstone and siltstone, porphyry, felsite, quartzite and epidiorite. Siltstone and schist commonly platy Sand: coarse with medium and fine, angular to well rounded schist, sandstone, siltstone and quartz, 'sharp'. Siltstone and schist commonly platy Fines: much silt. Clayey silty matrix between 1.2 and 2.2 m and below 3.2 m. Iron-pan and manganese staining above 2.2 m, yellow-brown	4.0	4.2
	b Gravel Gravel: as above but more angular with increased sandstone and siltstone. Sandstone boulders at base Sand: coarse with fine and medium, angular, coarse chiefly sandstone and siltstone Fines: silty fine sand matrix, pale yellow-brown	3.3	7.5
Old Red Sandstone	Sandstone, medium-grained, dark grey	0.1 +	7.6

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	4	23	73	0.2−1.2	5	2	10	12	20	25	26
				1.2−2.2	5	5	9	13	19	34	15†
				2.2−3.2	2	3	4	12	40	39	0†
				3.2−4.2	4	11	4	6	27	33	15†
				Mean	4	5	7	11	26	33	14
b	5	35	60	4.2−5.2	4	8	5	11	13	35	24†
				5.2−6.6	6	8	10	25	24	27	0†
				6.6−7.5	No grading data available						
				Mean	5	8	8	19	20	30	10
a & b	5	28	67	Mean	5	6	7	15	23	32	12

NN 60 SE 2 | 6533 0404 | Mid Torrie Farm, Kilmadock | BLOCK C

Surface level + 93 m (+ 28.5 ft)
Water not struck
250 mm percussion and shell
October 1980

Waste 6.5 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey and stony	0.3	0.3
Till	Clay becoming very sandy downwards, gravelly with clasts up to boulder size of sandstone, siltstone, lava, quartzite and psammite. Soft and yellow-brown above 0.5 m, crumbly and mottled pale orange-brown between 0.6 and 1.4 m, stiff and pale brown below 1.4 m	6.2 +	6.5
	Clay, sandy, silty with ill-sorted clasts up to boulder size, chiefly sandstone. Pale grey and extremely stiff		
	Borehole terminated at 6.5 m owing to slow progress		

NN 60 SE 3 | 6610 0484 | Tynaspirit, Kilmadock | BLOCK C

Surface level + 64 m (210 ft)
Water struck at + 58 m
250 mm percussion and shell
September 1980

Overburden 0.5 m
Mineral I 1.1 m
Mineral II 1.2 m
Waste 1.2 m
Mineral II 2.8 m
Waste 0.1 m +

LOG

Geological classification	Lithology	Thickness	Depth m
	Soil, silty with a few pebbles, medium brown	0.5	0.5
Glacial sand and gravel	a Gravel Gravel: coarse with fine, cobbles up to 130 mm common, subangular to well rounded psammite, gabbro, schist, rhyolite, andesite, basalt and conglomerate Sand: medium with coarse and some fine, quartz and rock fragments Fines: silt, disseminated	1.1	1.6
Morainic drift	b 'Very clayey' gravel. Very poorly sorted and compact Gravel: coarse with fine and cobbles up to 100 mm common, angular to well rounded sandstone with schist, quartzite, basalt and dolerite Sand: fine with some medium and coarse, angular to subrounded quartz with rock and feldspar Fines: silt, disseminated, light brown with a few thin laminated brown clay bands	1.2	2.8
	Silty sand and gravel, as above, but with more than 40 per cent fines	1.2	4.0
	c 'Very clayey' gravel. Very poorly sorted Gravel: coarse with fine and numerous cobbles up to 120 mm, angular to subangular sandstone with dolerite and quartz Sand: fine with some coarse and medium, angular to subrounded quartz with rock fragments and feldspar Fines: silt and clay, disseminated, medium brown	2.8	6.8
Till	Clay, very stiff, grey-red with clasts as above	0.1 +	6.9

(... continued)

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1⁄16	+1⁄16–1⁄4	+1⁄4–1	+1–4	+4–16	+16–64	+64
a	7	40	53	0.5–1.6	7	8	20	12	12	19	22
b	26	31	43	1.6–2.8	26	19	6	6	10	17	16
c	28	31	41	4.0–4.8	29	16	3	3	6	3	40
				4.8–6.1	27	21	6	6	10	16	15
				6.1–6.8	27	23	7	8	12	18	5†
				Mean	28	20	5	6	9	13	19
b & c	27	32	43	Mean	27	20	6	6	10	14	19
a to c	23	33	44	Mean	23	17	9	7	10	15	19

NN 60 SE 4 6690 0460 Laighlands, Kilmadock BLOCK C

Surface level + 63 m (+ 207 ft)
Water not struck
Section and pit
December 1980

Overburden 0.1 m
Mineral I 17.4 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.1	0.1
Glacial sand and gravel	a Gravel Gravel: numerous cobbles up to 250 mm, with some coarse and a little fine, subrounded to well rounded quartzite, psammite, schist, epidiorite basalt and andesite with sandstone and conglomerate. Many clasts are highly weathered and friable Sand: medium with fine and coarse, angular to subangular quartz with rock fragments in the coarse grade Fines: silt, disseminated, orange-brown	1.7	1.8
	b Sand Sand: fine, angular to subangular quartz, with a few rock and feldspar fragments. Generally flat fine lamination, but with some cross lamination and ripple-drift Fines: silt with some clay, disseminated, yellow-brown	7.9	9.7
	c Gravel Gravel: coarse with fine and numerous cobbles up to 1000 mm, subrounded to well rounded with angular to well rounded in finer grade, sandstone and conglomerate with some metagabbro, andesite, quartz and schist, the more slaty and schistose material in the finer grades Sand: medium, coarse and fine, angular to subangular rock fragments with quartz in the finer grades Fines: clay, disseminated and coating clasts, light brown	7.8+	17.5

(... continued)

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	3	15	82	0.1−1.8	3	4	7	4	8	13	61
b	7	93	0	1.8−9.7	7	86	7	0	0	0	0
c	3	12	85	9.7−17.5	3	3	5	4	15	29	41
a to c	5	49	46	Mean	5	41	6	2	8	14	24

NN 60 SE 5 — 6639 0404 — Tynaspirit, Kilmadock — BLOCK C

Surface level + 67 m (+ 220 ft)
Water not struck
250 mm percussion and shell
September 1980

Overburden 1.0 m
Mineral II 4.6 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil and boulders	1.0	1.0
Morainic drift	'Clayey' sandy gravel. Very poorly sorted and compact Gravel: boulders, cobbles, coarse and fine, chiefly angular blocks of sandstone with some siltstone and rare rounded to well rounded andesite, epidiorite, psammite, schist and vein-quartz. Much comminution of boulders Sand: fine with medium and coarse Fines: silt with some clay, pale yellow-brown	4.6 +	5.6

Borehole abandoned at 5.6 m obstruction, probably a large boulder

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
20	45	35	1.0−2.0	11	21	9	11	17	23	8
			2.0−3.0	33	32	8	8	15	4	0
			3.0−5.0	17	23	12	11	12	18	7†
			Mean	20	25	10	10	14	16	5

NN 60 SE 6 | 6711 0425 | Laighlands, Kilmadock | BLOCK A

Surface level + 50 m (+ 164 ft)
Water struck at + 42.5 m
250 mm percussion and shell
September 1980

Overburden 0.3 m
Mineral I 10.0 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, gravelly	0.3	0.3
	Boulders	0.2	0.5
Fluvioglacial sand and gravel	Gravel	9.8 +	10.3

Gravel: fine and coarse with cobbles and boulders, finer between 5.5 and 7.5 m. Coarse gravel subrounded to well rounded, fine gravel subangular to well rounded. Schistose psammite and grit, vein-quartz, quartzite and platy schist with some epidiorite, metagabbro, felsite and sandstone. Sandstone content increasing with depth

Sand: coarse and medium with fine, subangular to well rounded, 'sharpish' rock and quartz. Better sorted between 4.5 and 7.5 m

Fines: silt, disseminated at top but binding deposit below 8.5 m, pale yellow-brown

Borehole terminated on obstruction at 10.3 m possibly sandstone bedrock

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
3	43	54	0.5−1.5	2	5	13	13	23	28	16
			1.5−2.5	3	7	13	16	30	28	3
			2.5−3.5	5	11	9	12	19	19	25
			3.5−4.5	2	11	17	20	23	19	8
			4.5−5.5	2	13	17	22	24	16	6
			5.5−6.5	2	10	24	27	24	13	0
			6.5−7.5	2	10	21	22	27	18	0
			7.5−8.5	5	13	12	14	24	21	11†
			8.5−9.5	5	12	10	15	24	21	13†
			Mean	3	10	15	18	24	21	9

NN 60 SE 7 | 6779 0399 | Drumvaich, Kilmadock | BLOCK C

Surface level + 50 m (+ 164 ft)
Water not struck
250 mm percussion
September 1980

Overburden 0.8 m
Mineral I 1.5 m
Mineral II 2.0 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty brown	0.3	0.3
Glacial sand and gravel	Clay, medium brown with many clasts up to 220 mm	0.5	0.8
	a 'Very clayey' pebbly sand Gravel: fine with coarse and scattered cobbles above 1.5 m, subangular schist, psammite and sandstone Sand: chiefly fine with some medium and a trace of coarse, angular to sub-angular quartz with rock fragments, relatively more rock fragments and some feldspar below 1.5 m Fines: silt, disseminated, light brown, seams of silty sand above 1.5 m	1.5	2.3
Morainic drift	b 'Clayey' gravel. Very poorly sorted and compact Gravel: numerous cobbles up to 180 mm with a little coarse and fine gravel, angular sandstone with a little 'Highland' material Sand: chiefly fine with a little medium and coarse, quartz Fines: silt, disseminated, increasing with depth to form a matrix below 3.8 m, medium brown	2.0 +	4.3

Borehole terminated at 4.3 m owing to slow progress in compact till, material becoming non-mineral

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
a	29	64	7	0.8–1.5	30	46	9	1	1	2	11
				1.5–2.3	28	63	8	0	1	0	0
				Mean	29	55	8	1	1	1	5
b	10	17	73	2.3–3.3	11	12	2	3	5	6	61
				3.3–4.3	10	10	3	3	7	10	57
				Mean	10	11	3	3	6	8	59
a & b	18	37	45	Mean	18	30	5	2	4	5	36

NN 60 SE 8	6727 0335	Easter Loch of Daldorn, Kilmadock	BLOCK C

Surface level + 77 m (+ 253 ft)
Water not struck
250 mm percussion
September 1980

Overburden 0.1 m
Mineral II 6.4 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.1	0.1
Morainic drift	'Clayey' sandy gravel. Very poorly sorted and compact Gravel: boulders, cobbles, fine and coarse, chiefly angular sandstone and siltstone with rare subrounded to well rounded clasts of porphyry, andesite, epidiorite and psammite. Much commination of boulders Sand: fine with some coarse and medium, mainly rock in coarse, otherwise quartz Fines: silt with some clayey bands, especially towards the base	6.4 +	6.5

Borehole terminated at 6.5 m owing to an obstruction, probably not bedrock as borehole sited on a 10 m high mound

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
18	42	40	0.1−1.1	19	26	12	15	20	8	0
			1.1−2.1	18	27	8	9	17	17	4
			2.1−3.1	16	27	6	7	14	18	12
			3.1−4.1	17	24	7	9	19	24	0
			4.1−5.1	19	17	7	9	18	21	9
			5.1−6.1	20	21	7	10	16	13	13
			6.1−6.5	No grading data available						
			Mean	18	24	8	10	17	17	6

NN 60 SE 9 | 6950 0438 | Upper Coilentowie, Kilmadock | BLOCK C

Surface level + 97 m (+ 318 ft)
Water struck at + 95 m
250 mm percussion and shell
September 1980

Overburden 0.3 m
Mineral I 2.1 m
Waste 0.5 m
Bedrock 0.3 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.3	0.3
Glacial sand and gravel	Gravel Gravel: coarse with fine, cobbles common, subrounded to well rounded schistose grit, psammite, vein-quartz and sandstone Sand: coarse and medium with fine, 'sharpish' rock and quartz, angularity increasing downwards Fines: loamy silt matrix becoming clay-bound by 1.3 m, rusty orange-brown	2.1	2.4
Till	Clay, silty with fine sand, very stiff, scattered gravel of 'Highland' rocks and sandstone, dark yellow-brown	0.5	2.9
Old Red Sandstone	Sandstone, fine-grained, hard, red-grey and dark grey mottled	0.3 +	3.2

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1−4	+4−16	+16−64	+64
8	34	58	0.3−1.3	11	10	16	16	24	23	0
			1.3−2.4	5	6	10	10	14	23	32†*
			Mean	8	8	13	13	19	23	16

NN 60 SE 10 | 6930 0325 | Kirkton Wood, Kilmadock | BLOCK C

Surface level + 48 m (+ 157 ft)
Groundwater level + 41.2 m
250 mm and 200 mm percussion and shell
September 1980

Overburden 0.4 m
Mineral I 3.0 m
Waste 1.4 m
Mineral I 4.6 m
Waste 0.9 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Stony soil	0.4	0.4
Glacial sand and gravel	a 'Clayey' gravel Gravel: coarse with fine, some cobbles, coarse gravel subangular to well rounded, fine gravel angular to subangular. Sandstone, psammite, vein-quartz and basalt Sand: fine with coarse and medium, angular coarse grains, rock and quartz Fines: silt and clay, deposit becoming clay-bound downwards, brown-grey	3.0	3.4
Flow till	Clay-bound sand and gravel, quite stiff between 3.4 and 4.8 m	1.4	4.8
Glacial sand and gravel	b 'Clayey' gravel Gravel: fine with coarse, some cobbles. Subangular to well rounded schistose grit and psammite, conglomerate, sandstone, vein-quartz and schist Sand: fine, medium and coarse, 'sharpish' rock and quartz Fines: silt, disseminated, buff coloured	2.0	6.8
	c 'Clayey' pebbly sand Gravel: as above, but occurring in stringers Sand: fine with some medium and a little coarse, chiefly quartz Fines: as above, but also thin seams of pale yellow, fine sandy silt	2.6	9.4
Till	Silty clay with angular sandstone blocks, stiff, maroon-grey, becoming more stony downwnards	0.9 +	10.3

Borehole terminated at 10.3 m owing to technical difficulties

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	14	36	50	0.4−1.4	14	17	11	13	17	15	13
				1.4−2.4	14	15	11	10	18	28	4
				2.4−3.4	15	9	11	11	21	25	8
				Mean	14	14	11	11	19	23	8
b	12	42	46	4.8−5.8	10	11	9	13	25	17	15
				5.8−6.8	15	19	19	13	17	17	0
				Mean	12	15	14	13	21	17	8
c	14	77	9	6.8−7.8	10	38	27	8	4	5	8†
				7.8−9.4	16	45	28	7	3	1	0†
				Mean	14	42	28	7	3	3	3
a to c	14	52	34	Mean	14	24	18	10	14	14	6

NN 60 SE 11	6963 0271	Kirkton Wood, Kilmadock	BLOCK C

Surface level + 57 m (+ 187 ft)
Water struck at + 55.7 m
250 mm percussion and shell
October 1980

Overburden 0.3 m
Mineral II 1.0 m
Waste 2.9m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, medium brown, silty	0.3	0.3
Morainic drift	'Clayey' gravel. Very poorly sorted and compact Gravel: coarse with fine and some cobbles up to 130 mm, angular to sub-rounded sandstone with a little 'Highland' material Sand: fine with coarse and some medium, angular quartz with rock fragments Fines: silt and clay, disseminated, loosely binding deposit, medium brown	1.0	1.3
	Clay, silty with many cobbles up to 190 mm, medium brown, firm becoming stiffer with depth	2.9 +	4.2
	Borehole terminated at 4.2 m owing to slow progress		

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
19	31	50	0.3−1.3	19	16	6	9	18	22	10

NN 60 SE 12	6542 0020	Middleton of Boquhapple, Kincardine	BLOCK C

Surface level + 20 m (+ 66 ft)
Water not struck
Pit
December 1980

Waste 1.9 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey with crumbly texture, medium brown	1.0	1.0
Till	Clay, with ill-sorted clasts up to boulder size of flaggy sandstone and fine pebbles of mudstone, mottled purplish-brown to grey-brown	0.9	1.9
Old Red Sandstone	Sandstone, flaggy, red-grey	0.1 +	2.0

NN 60 SE 13 | 6770 0444 | Drumvaich, Kilmadock | BLOCK C

Surface level + 83 m (+ 272 ft)
Groundwater level + 79.2 m
Pit
December 1980

Mineral I 4.0 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
Glacial sand and gravel	Gravel Gravel: fine and coarse with cobbles up to 300 mm common, coarse gravel subrounded to well rounded, fine gravel subangular to well rounded. Sandstone, conglomerate, psammite, schist, metagabbro, epidiorite, andesite, vein-quartz and quartzite Sand: coarse with some medium and fine, angular to subrounded rock with some quartz and feldspar Fines: clay and silt, disseminated, yellowish medium grey-brown Large boulder at base of pit	4.0 +	4.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
7	18	75	0.0–1.0	No grading data available						
			1.0–4.0	7	3	4	11	28	24	23

NN 60 SE 14 | 6845 0430 | Wester Coillechat, Kilmadock | BLOCK C

Surface level + 95 m (+ 312 ft)
Water not struck
Pit
December 1980

Overburden 0.3 m
Mineral II 2.7 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Gravelly soil	0.3	0.3
Morainic drift	Gravel. Very poorly sorted and compact Gravel: numerous cobbles and boulders up to 300 mm with a little coarse and fine gravel, angular to subangular with some subrounded to well rounded (especially above 0.7 m), predominantly sandstone with rare 'Highland' material Sand: fine with some medium and coarse, 'soft', quartz with sandstone fragments Fines: chiefly silt, pale yellow-brown	2.7 +	3.0

(... continued)

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
9	17	74	0.3–0.7	No grading data available						
			0.7–3.0	9	10	3	4	6	6	62

NN 60 SE 15 — 6880 0439 — Easter Coillechat, Kilmadock — BLOCK C

Surface level + 100 m (+ 328 ft)
Water struck at + 98.4 m
Pit
December 1980

Waste 2.9 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, peaty	0.3	0.3
Head	Sand and gravel. Very poorly sorted, compact Gravel: coarse and fine, clasts up to 600 mm. Subangular to well rounded slabs of sandstone with subrounded to well rounded metagabbro and psammite Sand: fine and medium with coarse, poorly sorted, angular to well rounded rock with quartz and some feldspar Fines: silt, disseminated, yellow-brown	0.9	1.2
Till	Clay, very silty, fine sandy with scattered clasts up to boulder size, similar to above but buff and stiff	1.7 +	2.9

NN 60 SE 16 | 6951 0454 | Upper Coilentowie, Kilmadock | BLOCK C

Surface level + 115 m (+ 377 ft)
Water not struck
Pit
December 1980

Overburden 0.8 m
Mineral I 1.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, brown, sandy with bouldery subsoil	0.8	0.8
Glacial sand and gravel	Gravel Gravel: numerous cobbles with some coarse and fine gravel, boulders up to 500 mm, angular sandstone with angular to well rounded quartz, schist, psammite and epidiorite Sand: coarse, medium and fine, angular to subangular rock fragments and quartz Fines: clay and silt, disseminated, medium brown	1.1 +	1.9

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
5	19	76	0.8–1.9	5	5	7	7	10	11	55

NN 60 SE 17 | 6983 0317 | Kirkton Wood, Kilmadock | BLOCK C

Surface level + 55m (+ 180 ft)
Water not struck
Pit
December 1980

Waste 2.8 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, humus-rich, medium brown	0.2	0.2
Till	Clay, moderately stiff, red-brown with clasts up to 250 mm, angular to well rounded sandstone with schist, andesite, quartzite and psammite. Clast-free seams of yellow-brown silt between 1.8 and 2.5 m	2.6 +	2.8

NN 60 SE 18 69865 03005 Kirkton Wood, Kilmadock BLOCK C

Surface level + 44 m (+ 144 ft)
Water not struck
Pit
December 1980

Overburden 0.2 m
Mineral I 2.7 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, peaty	0.2	0.2
Glacial sand and gravel	Gravel. Moderately well sorted, unconsolidated Gravel: coarse with fine, scattered cobbles and boulders up to 500 mm (towards base). Coarse gravel subrounded to well rounded, fine gravel subangular to well rounded. Sandstone, psammite, metagabbro, epidiorite, vein-quartz, andesite and felsite Sand: medium and coarse with some fine. Coarse sand subangular to rounded rock, otherwise angular to subangular quartz and rock with some feldspar, 'sharp' Fines: silt, disseminated, yellow-brown	2.7	2.9
Old Red Sandstone	Sandstone, fine- to medium-grained, micaceous, hard, mottled medium grey and red-grey	0.1 +	3.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
3	27	70	0.2−1.2	3	7	12	8	19	36	15
			1.2−2.9	3	5	11	11	23	32	15
			Mean	3	6	11	10	21	34	15

NN 70 NE 1	7797 0559	Woodside Cottage, Dunblane	BLOCK D

Surface level + 121 m (+ 397 ft)
Water struck at + 115.1 m
250 mm percussion and shell
September 1980

Overburden 1.5 m
Mineral II 5.1 m
Waste 11.0 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty, medium brown	1.0	1.0
Till	Clay, very sandy and silty with pebbles, red	0.5	1.5
	'Clayey' gravel Gravel: fine and coarse, cobbles commonly up to 180 mm between 2.5 and 3.5 m and between 4.5 and 5.6 m. Angular to well rounded sandstone with basic volcanics and some mudstone and 'Highland' rocks Sand: coarse and fine with medium, quartz with rock fragments, variable sorting Fines: silt with clay, red-brown, disseminated. Clay content increasing with depth, deposit cohesive between 2.5 and 3.5 m	5.1	6.6
	Silt with fine sand and some gravel, red-brown	1.1	7.7
	Clay, sandy with sandstone clasts becoming siltier with depth, stiff, red-brown	9.9	17.6
Old Red Sandstone	Siltstone, purple, micaceous	0.1 +	17.7

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
14	40	46	1.5−2.5	9	21	24	17	18	11	0*
			2.5−3.5	12	8	7	14	19	14	26*
			3.5−4.5	18	13	10	14	21	24	0*
			4.5−5.6	13	16	7	9	15	22	18*
			5.6−6.6	17	12	11	18	24	18	0*
			Mean	14	14	12	14	19	18	9

NN 70 NE 2	7893 0628	Wester Cambushinnie, Dunblane	BLOCK D

Surface level + 131 m (+ 430 ft)
Water struck at + 130 m
250 mm shell
September 1980

Waste 8.5 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, red-brown	0.2	0.2
Till	Clay, silty and sandy with angular to subangular clasts up to 120 mm, chiefly of sandstone, red-brown. Matrix predominantly silt below 6.0 m	8.3	8.5
Old Red Sandstone	Siltstone, red, micaceous, fissile	0.1 +	8.6

NN 70 NE 3 | 7989 0635 | Ballendall, Ardoch | BLOCK D

Surface level + 128 m (+ 420 ft)
Water not struck
250 and 200 mm percussion and shell
September 1980

Overburden 1.0 m
Mineral I 15.8 m
Waste 0.3 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, loamy, gravelly	0.6	0.6
	Clay, sandy, gravelly, red-brown	0.4	1.0
Glacial sand and gravel	a Sandy gravel Gravel: fine with coarse and very rare cobbles, subangular to well rounded mudstone, siltstone and sandstone with basalt, andesite and some vein-quartz. Many 'rotten' clasts Sand: coarse and medium with fine, angular to subrounded mudstone, sandstone and quartz Fines: much silt slightly binding deposit, below 3.1 m deposit becomes cleaner with thin silt seams, red-brown	8.1	9.1
	b 'Clayey' sand Gravel: chiefly fine, in stringers, otherwise as above Sand: fine with medium and a little coarse, 'soft', chiefly quartz, loose between 12.1 and 14.5 m Fines: silt, disseminated, pale red-brown. Thin seams of silt below 1.1 m	7.7	16.8
	Silt, fine sandy, red-brown	0.1	16.9
Till	Clay, sandy, silty with subangular to well rounded clasts of vein-quartz and psammite and more angular sandstone blocks	0.2 +	17.1

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	9	52	39	1.0−2.0	15	14	22	17	21	11	0
				2.0−3.1	11	14	19	23	17	6	0
				3.1−4.1	6	8	27	25	23	11	0
				4.1−5.1	7	15	18	21	24	7	8
				5.1−6.1	10	18	21	20	22	9	0
				6.1−7.1	8	8	18	24	29	13	0
				7.1−8.1	10	8	11	22	35	14	0
				8.1−9.1	6	10	16	15	21	25	7
				Mean	9	12	19	21	25	12	2
b	10	86	4	9.1−10.1	10	45	25	13	7	0	0
				10.1−11.1	15	62	15	4	3	1	0
				11.1−12.1	12	42	19	10	12	5	0
				12.1−13.1	4	12	70	10	4	0	0
				13.1−14.1	6	29	64	1	0	0	0
				14.1−15.1	13	23	61	2	1	0	0
				15.1−16.8	8	69	21	1	1	0	0
				Mean	10	43	38	5	3	1	0
a & b	9	68	22	Mean	9	27	28	13	15	7	0

NN 70 NE 4 | 7976 0575 | Bridge Cottage, Dunblane | BLOCK D

Surface level + 97 m (+ 318 ft)
Water struck at + 95 m
250 mm and 200 mm shell
October 1980

Overburden 2.0 m
Mineral I 2.1 m
Waste 15.9 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, medium brown	0.3	0.3
Alluvium	Clay, silty with fine sand, medium brown	1.7	2.0
	Pebbly sand Gravel: fine, angular to subrounded, 'Highland' rock types and lavas Sand: medium with fine and some coarse, angular to subrounded quartz with rock fragments Fines: silt, disseminated, medium brown. A 100 mm band of stiff red-grey laminated clay near 3.8 m	2.1	4.1
Glaciolacustrine deposits	Silt becoming clayey with depth, partly laminated with clayey bands, medium brown becoming red-brown with depth, soft	15.9 +	20.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
6	83	11	2.0−3.0	8	34	38	14	6	0	0†
			3.0−4.1	4	25	38	18	14	1	0†
			Mean	6	29	38	16	10	1	0

NN 70 NE 5 | 7919 0527 | Kinbuck, Dunblane | BLOCK D

Surface level + 124 m (+ 407 ft)
Water not struck
250 and 200 mm percussion
September 1980

Overburden 0.2 m
Mineral I 24.8 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, dark brown	0.2	0.2
Glacial sand and gravel	a Gravel Gravel: fine and coarse with scattered cobbles up to 140 mm, angular to well rounded, less angular and better sorted below 6.0 m. Sandstone with siltstone, mudstone, quartz, quartzite, basalt, agglomerate, psammite and gabbro Sand: medium with fine and coarse, well sorted above 1 m, subangular to well rounded and quartzose. Angular to subangular below 1 m with rock fragments in the coarse grade and quartz in the finer. Better sorted below 12.0 m Fines: silt, disseminated, medium brown with seams of red silt up to 30 mm thick between 2.0 m and 3.0 m	12.8	13.0
	b Sand, fining downwards Gravel: trace above 13.8 m only Sand: fine with some medium and a trace of coarse above 15.0 m, angular to subangular quartz with some rock fragments in the medium grade and also in fine grade below 18.1 m, together with feldspar Fines: silt, disseminated, red-brown to light brown-grey with a 100 mm seam of pale grey-brown, laminated silt at 17.9 m and clay partings about 2 mm thick from 18.1 to 19.1 m	12.0 +	25.0

(... Continued)

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	6	47	47	0.2−1.0	8	56	24	7	2	3	0
				1.0−2.0	9	14	13	17	24	20	3
				2.0−3.0	9	13	18	19	15	16	10
				3.0−4.0	6	9	24	23	15	23	0
				4.0−5.1	7	15	33	17	11	11	6
				5.1−6.0	4	14	48	9	12	13	0
				6.0−7.0	4	11	29	12	25	19	0
				7.0−8.0	4	13	24	22	26	11	0
				8.0−9.0	4	6	8	17	51	14	0
				9.0−9.8	5	4	4	14	49	24	0
				9.8−11.1	3	3	3	5	38	39	9
				11.1−12.0	3	4	3	7	47	36	0
				12.0−13.0	8	26	25	4	11	26	0
				Mean	6	14	20	13	25	20	2
b	8	92	0	13.0−13.8	3	39	52	3	1	2	0
				13.8−15.0	3	29	51	17	0	0	0
				15.0−16.1	5	54	37	4	0	0	0
				16.1−17.0	4	60	32	4	0	0	0
				17.0−18.1	4	71	24	1	0	0	0
				18.1−19.1	7	73	19	1	0	0	0
				19.1−20.1	6	87	7	0	0	0	0
				20.1−21.1	4	75	21	0	0	0	0
				21.1−22.2	5	79	16	0	0	0	0
				22.2−23.0	7	79	13	1	0	0	0
				23.0−24.1	23	72	5	0	0	0	0
				24.1−25.0	17	81	2	0	0	0	0
				Mean	8	66	23	3	0	0	0
a & b	7	68	25	Mean	7	39	21	8	13	11	1

NN 70 NE 6 — 7677 0628 — Cullings, Dunblane — BLOCK D

Surface level + 157 m (+ 515 ft)
Water not struck
Pit
December 1980

Waste 2.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, gravelly, medium brown	0.3	0.3
Till	Clay, stony, stiff, red-brown with clasts up to 330 mm (larger blocks exposed nearby), chiefly angular to subrounded siltstone and sandstone, with rare, more rounded, 'Highland' rocks	1.9 +	2.2

NN 70 NE 7 | 7722 0552 | Cockstane, Dunblane | BLOCK D

Surface level + 133 m (+ 436 ft)
Water not struck
Pit
December 1980

Waste 2.4 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, peaty, dark brown	0.5	0.5
Till	Clay, moderately stiff, brown-red with angular to rounded clasts up to 130 mm of sandstone with some schist, quartzite and psammite	1.9 +	2.4

NN 70 NE 8 | 7927 0641 | Wester Cambushinnie, Dunblane | BLOCK D

Surface level + 131 m (+ 430 ft)
Water struck at 128.2 m
Pit
December 1980

Waste 2.8 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, medium brown	0.3	0.3
Till	Clay, sandy, very gravelly, red-brown, becoming stiffer with depth, chiefly angular clasts up to 260 mm of sandstone, siltstone and mudstone	2.5 +	2.8

NN 70 SW 3 7052 0453 Ternishee, Kilmadock BLOCK C

Surface level + 123 m (+ 403 ft)
Water not struck
250 mm percussion and shell
September 1980

Overburden 0.3 m
Mineral I 1.9 m
Waste 5.7 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Stony soil	0.3	0.3
Glacial sand and gravel	Gravel Gravel: coarse with fine, cobbles and small boulders common, angular to sub-angular sandstone boulders otherwise subrounded to well rounded sandstone with some andesite, schistose psammite and vein-quartz Sand: coarse with medium and fine, rock and quartz, poorly sorted Fines: silt and clay, disseminated. Deposit very compact and partially clay bound	1.9	2.2
Till	Clay with angular sandstone clasts, very stiff, dark maroon-grey	5.7	7.9
Old Red Sandstone	Sandstone, medium-grained, quartz with feldspar and mica, very hard, maroon-dark grey	0.1 +	8.0

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
5	33	62	0.3−1.3	4	7	9	10	14	31	25
			1.3−2.2	5	7	14	20	24	30	0
			Mean	5	7	11	15	19	30	13

NN 70 SW 4	7089 0345	Doune Lodge, Kilmadock	BLOCK C

Surface level + 89 m (+ 292 ft)
Water struck at + 75.5 m
250 and 200 mm percussion and shell
October 1980

Overburden 0.2 m
Mineral I 11.2 m
Waste 3.1 m
Mineral I 1.3 m
Waste 2.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, silty, pebbly	0.2	0.2
Glacial sand and gravel	a Gravel Gravel: coarse with fine, cobbles up to 150 mm, angular to well rounded sandstone, basalt, andesite, conglomerate, quartz, quartzite, schist and psammite Sand: fine with coarse and medium, angular to subangular quartz with rock fragments Fines: silt and clay, disseminated, medium brown. Pale brown seam of sandy silt between 2.1 and 2.3 m	5.2	5.4
	b 'Clayey' sand Gravel: very little Sand: fine with some medium, angular to subangular quartz with some rock fragments Fines: silt, disseminated, pale brown	3.9	9.3
	c 'Very clayey' sand Sand: fine, angular to subangular quartz Fines: silt, disseminated. Deposit poorly laminated between 9.7 and 10.4 m	2.1	11.4
Glaciolacustrine deposits	Silt laminated in part, medium to pale brown with some red clay laminae up to 0.5 mm thick above 12.5 m. Fine sandy, particularly between 12.0 and 12.5 m	3.1	14.5
	d 'Very clayey' sand Sand: fine, well sorted, quartzose Fines: silt, disseminated, grey-brown	1.3	15.8
	Silt, clayey with angular clasts up to 130 mm, medium brown	1.8	17.6
Till	Clay, silty with poorly sorted angular clasts, red-grey	0.4 +	18.0

Borehole terminated at 18.0 m owing to technical difficulties

(... Continued)

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	6	40	54	0.2−1.2	6	9	12	12	21	40	0
				1.2−2.1	6	7	19	15	16	25	12
				2.1−3.3	5	13	11	13	19	29	10
				3.3−4.3	4	5	8	12	19	35	17
				4.3−5.4	7	15	41	9	5	9	14
				Mean	6	10	18	12	16	27	11
b	12	85	3	5.4−6.4	10	48	39	2	0	1	0
				6.4−7.4	16	62	15	1	1	5	0
				7.4−8.4	10	62	24	1	2	1	0
				8.4−9.3	10	68	19	0	2	1	0
				Mean	12	60	24	1	1	2	0
c	20	80	0	9.3−10.4	24	69	6	0	0	1	0
				10.4−11.4	15	78	7	0	0	0	0
				Mean	20	73	7	0	0	0	0
d	36	63	1	14.5−15.8	36	62	1	0	1	0	0† *
a & c	14	84	2	Mean	14	65	18	1	1	1	0
a to d	13	63	24	Mean	13	42	16	5	7	12	5

NN 70 SW 5 | 7037 0282 | Kirkton, Kilmadock | BLOCK C

Surface level + 43 m (+ 141 ft)
Water struck at + 40.5 m
250 mm percussion and shell
September 1980

Overburden 0.5 m
Mineral I 10.5 m
Waste 0.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty and clayey with many cobbles up to 200 mm, medium brown	0.5	0.5
Glacial sand and gravel	a 'Clayey' gravel Gravel: coarse with fine, cobbles up to 180 mm common, particularly below 3.8 m, angular to well rounded sandstone with basalt, andesite, quartzite, quartz, psammite and schist Sand: fine with medium and coarse, angular quartz and rock fragments Fines: silt and clay, disseminated, brown	3.9	4.4
	b Gravel Gravel: coarse and fine with cobbles up to 200 mm, angular to well rounded quartzite, psammite, quartz and sandstone, with andesite, schist and pelite Sand: coarse with medium and fine, angular to rounded quartz and rock fragments Fines: clay and silt, some clay and silt-bound lumps retrieved, particularly below 8.3 m. Band of silty clay, laminated, red-brown, at about 8.3 m	6.6	11.0
Till	Clay, sandy, angular to well rounded clasts up to about 800 mm, stiff becoming stiffer with depth	0.2 +	11.2

Borehole terminated at 11.2 m owing to very slow progress

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	15	33	52	0.5−1.5	15	16	9	10	18	25	7
				1.5−2.5	13	16	8	7	12	10	34
				2.5−3.8	17	10	11	11	16	29	6†
				3.8−4.4	No grading data available						
				Mean	15	14	10	9	15	22	15
b	4	45	51	4.4−5.3	3	5	9	23	27	23	10†
				5.3−6.3	3	8	10	23	29	27	0†
				6.3−7.3	4	19	28	14	19	16	0†
				7.3−8.3	5	17	25	20	17	16	0†
				8.3−9.3	6	11	14	20	19	30	0†
				9.3−10.0	6	8	8	21	20	19	18†
				10.0−11.0	4	7	6	12	8	29	34†
				Mean	4	11	15	19	20	23	8
a & b	8	40	52	Mean	8	12	13	15	18	23	11

NN 70 SW 6 — 7153 0412 — East Brae, Kilmadock — BLOCK C

Surface level + 117 m (+ 384 ft)
Water struck at + 115.4 m
250 mm percussion and shell
September 1980

Waste 5.5 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty, orange-brown	0.3	0.3
Glacial sand and gravel	'Clayey' gravel Gravel: poorly sorted, clasts up to 130 mm, angular to well rounded sandstone with conglomerate, gabbro, schist and psammite Sand: poorly sorted, fine to coarse, quartz and rock fragments Fines: silt and clay, disseminated, medium brown	0.6	0.9
Till	Clay with clasts up to 150 mm, chiefly sandstone, moderately stiff becoming stiffer with depth, brown-red	4.6	5.5
Old Red Sandstone	Sandstone, fine- to medium-grained, flaggy, red-grey	0.1 +	5.6

NN 70 SW 7 — 7148 0278 — Carse at Cambus, Kilmadock — BLOCK B

Surface level + 43 m (+ 141 ft)
Groundwater level + 40.2 m
250 mm percussion and shell
September 1980

Overburden 0.8 m
Mineral I 6.0 m
Waste 2.9 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
	Pebbly silt with fine sand, dark grey-brown	0.6	0.8
Fluvioglacial sand and gravel	Gravel Gravel: coarse with fine, some cobbles particularly between 2.8 and 5.8 m along with boulders up to 250 mm. Coarse gravel rounded to well rounded, fine gravel subangular to well rounded. Schistose grit and psammite, quartzite, vein-quartz, schist, sandstone, epidiorite, andesite, felsite and conglomerate. Platy siltstone and schist in fine gravel Sand: medium and coarse with some fine, subangular to well rounded becoming more angular below 1.8 m. Rock and vein-quartz with some rounded, platy siltstone and schist Fines: silt, disseminated with clayey silt matrix between 1.8 and 2.8 m	6.0	6.8
Till	Clay, with much silt and fine sand and scattered clasts up to boulder size, chiefly of sandstone. Deposit more gravelly below 9.3 m. Firm, purple-brown, becoming very stiff and grey with depth	2.9 +	9.7

Borehole terminated owing to slow progress in very stiff, stony till

(... Continued)

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
4	33	63	0.8−1.8	7	15	20	12	29	17	0
			1,8−2.8	6	9	14	12	28	21	0
			2.8−3.8	1	3	9	10	20	22	35†
			3.8−4.8	2	3	9	13	16	38	19†
			4.8−5.8	4	3	8	11	12	31	31†
			5.8−6.8	3	9	19	20	16	33	0†
			Mean	4	7	13	13	20	29	14

NN 70 SW 8 | 7118 0243 | Clarkton, Kilmadock | BLOCK B

Surface level + 42 m (+ 138 ft)
Water not recorded
250 mm shell
September 1980

Overburden 0.3 m
Mineral I 3.1 m
Waste 7.5 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty, pebbly, medium brown	0.3	0.3
Fluvioglacial sand and gravel	'Clayey' gravel. Poorly sorted Gravel: coarse with fine with cobbles up to 200 mm, angular to well rounded sandstone, conglomerate, quartz and psammite Sand: coarse with medium and fine, angular to subangular rock fragments with quartz Fines: silt and clay, disseminated, medium brown	3.1	3.4
Till	Clay with subangular clasts up to 120 mm of sandstone and 'Highland' rocks. Stiff, red-grey becoming grey by 10.0 m	7.5 +	10.9
	Borehole terminated owing to slow progress		

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
12	34	54	0.3−1.3	15	13	14	16	20	22	0
			1.3−2.2	13	11	11	14	14	23	14
			2.2−3.4	9	6	9	10	13	25	28
			Mean	12	10	11	13	16	23	15

NN 70 SW 9 | 7182 0112 | Tullochanknowe Villa, Kilmadock | BLOCK B

Surface level + 38 m (+ 125 ft)
Water not struck
250 mm percussion
October 1980

Overburden 0.2 m
Mineral I 1.1 m
Waste 1.8 m
Mineral II 1.7 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, gravelly	0.2	0.2
Fluvioglacial sand and gravel	a 'Clayey' sandy gravel Gravel: coarse and fine, cobbles rare, subrounded to well rounded schistose psammite, vein-quartz and quartzite with sandstone, siltstone and andesite Sand: medium with coarse and fine, rounded to well rounded coarse sand of platy siltstone and schist, otherwise angular to well rounded quartz with rock Fines: silt, disseminated, orange-brown	1.1	1.3
	Silt, clayey, with scattered fine pebbles of psammite and quartz, roughly laminated, firm to crumbly, pale yellow-brown with green tint	0.8	2.1
Till (Morainic drift)	Clay, fine sandy with clasts often larger than 250 mm chiefly of sandstone and siltstone, pale red-grey	1.0	3.1
	b Very 'clayey' sandy gravel Gravel: fine and coarse with large sandstone boulders, angular to well rounded sandstone, siltstone and rare schistose psammite and quartz-dolerite Sand: medium with coarse and fine Fines: sandy clay matrix, pale yellow-grey. Rare seams of silty fine sand and of fissile clay	1.7 +	4.8
	Borehole abandoned at 4.8 m chiselling large sandstone boulders, possibly bedrock		

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
a	13	45	42	0.2–1.3	13	11	20	14	20	22	0
b	21	41	38	3.1–4.8	21	24	7	10	20	18	0*
a & b	18	42	40	Mean	18	19	12	11	20	20	0

NN 70 SW 10	7264 0333	Mansfield, Kilmadock	BLOCK C

Surface level + 77 m (+ 253 ft)
Groundwater level at 75.8 m
250 mm shell
September 1980

Waste 5.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, clayey, gravelly	0.3	0.3
Till	Clay, fine sandy with well rounded clasts of 'Highland' rocks and angular blocks of sandstone, yellow-brown	0.7	1.0
	Clay with sand, silt and angular to subrounded clasts of sandstone with 'Highland rocks', red-brown. Near the base, deposit mainly snadstone rubble with adhering clay	4.2 +	5.2

Borehole terminated at 5.2 m owing to slow progress, probably on bedrock

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NN 70 SW 11	7213 0205	Doune, Kilmadock	BLOCK B

Surface level + 38 m (+ 125 ft)
Water struck at + 36.0 m
250 mm percussion and shell
September 1980

Overburden 0.2 m
Mineral I 7.8 m
Waste 8.1 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy with pebbles, medium brown	0.2	0.2
Fluvioglacial sand and gravel	a Gravel Gravel: coarse and fine with cobbles up to 110 mm, angular to well rounded sandstone, conglomerate, quartzite, basalt, quartz, schist, psammite and felsite Sand: medium with coarse and some fine, angular to subangular quartz and rock fragments Fines: silt, disseminated, medium brown, with pale brown clay binding deposit between 2.3 and 3.4 m. Between 1.2 and 2.3 m gravel and sand coated with black material, possibly manganese oxide	6.1	6.3
	b 'Clayey' sand Sand: fine and medium with a little coarse, bands of coarser sand, angular to subangular quartz and rock fragments, fining downwards	1.7	8.0
Glaciolacustrine deposits	Silt with a little fine sand, partially laminated, pale grey clay seams below 9.0 m. At base 0.1 m band of stiff, laminated red-brown clay	8.1	16.1
Old Red Sandstone	Sandstone, fine-grained, indurated, grey-red	0.1 +	16.2

(... Continued)

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	6	43	51	0.2−1.3	10	18	14	12	19	18	9
				1.3−2.3	7	8	17	15	19	34	0†
				2.3−3.4	6	5	12	11	23	27	16†
				3.4−5.2	3	6	22	18	16	9	26†
				5.2−6.3	4	12	36	9	5	9	25†
				Mean	6	9	20	14	16	18	17
b	10	89	1	6.3−8.0	10	44	41	4	1	0	0†
a & b	7	53	40	Mean	7	17	25	11	13	14	13

NN 70 SW 12 | 7218 0022 | Cobble Haugh, Kincardine | BLOCK B

Surface level + 34 m (+ 112 ft)
Water struck at + 31.7 m
250 mm shell
October 1980

Waste 7.7 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty and clayey, grey-brown	0.2	0.2
Glaciolacustrine deposit	Silt, poorly laminated, pale grey-brown, some gravel below 1.6 m	2.1	2.3
Till	Clay, sandy, becoming more sandy and silty with depth with much gravel, chiefly sandstone below 7.4 m, soft, purple-grey	5.4 +	7.7
	Borehole terminated at 7.7 m on a boulder, probably close to bedrock		

NN 70 SW 13 | 7329 0410 | East Lundie, Kilmadock | BLOCK C

Surface level + 123m (+ 403 ft)
Water struck at + 113 m
250 mm percussion and shell
October 1980

Overburden 0.4 m
Mineral I 13.1 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty, dark-brown	0.4	0.4
Glacial sand and gravel	Gravel. Poorly sorted Gravel: fine and coarse with cobbles up to 160 mm, angular to subangular with some rounded clasts of sandstone with lavas, quartzite, psammite, quartz and conglomerate Sand: coarse with fine and medium, angular to subangular becoming more rounded towards base, quartz and rock fragments Fines: silt with clay above 10.5 m, disseminated, medium brown, relatively 'clean' below 10.5 m	13.1	13.5
Old Red Sandstone	Sandstone, fine- to medium-grained, flaggy, red-grey	0.1 +	13.6

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
5	40	55	0.4−1.4	6	7	9	12	21	23	22
			1.4−2.4	5	6	8	13	17	26	25
			2.4−3.5	2	8	14	15	21	29	11
			3.5−4.5	9	14	11	16	22	28	0
			4.5−5.5	6	12	9	16	22	14	21
			5.5−6.5	7	12	10	9	21	19	22
			6.5−7.5	6	10	7	7	18	27	25
			7.5−8.6	6	12	15	13	22	32	0
			8.6−9.5	6	10	17	25	27	15	0
			9.5−10.5	6	11	15	28	22	18	0
			10.5−11.2	3	8	23	39	21	6	0
			11.2−11.9	4	7	16	25	19	18	11†
			11.9−13.5	4	6	15	24	29	19	3†
			Mean	5	9	13	18	22	22	11

NN 70 SW 14 | 7398 0294 | Marl Loch, Kilmadock | BLOCK C

Surface level + 71 m (+ 233 ft)
Water not struck
250 mm percussion and shell
September 1980

Overburden 0.3 m
Mineral I 2.6 m
Waste 1.5 m
Bedrock 0.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.3	0.3
Glacial sand and gravel	Sandy gravel Gravel: fine and coarse, subangular sandstone, quartzite, quartz, schist and psammite Sand: medium with coarse and some fine, angular to subangular, quartz and rock fragments Fines: silt, disseminated, brown with a 100 mm thick, light brown seam of silt at 2.5 m	2.6	2.9
Till	Clay with angular sandstone clasts up to 180 mm, concentrated near the top, stiff, red	1.5	4.4
Old Red Sandstone	Sandstone, fine-grained, indurated, red-grey	0.2 +	4.6

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
5	65	30	0.3–1.3	5	6	18	22	26	23	0
			1.3–2.3	4	8	62	19	5	2	0
			2.3–2.9	9	10	26	19	21	15	0
			Mean	5	8	37	20	17	13	0

NN 70 SW 15 | 7399 0206 | Netherton, Kilmadock | BLOCK C

Surface level + 63 m (+ 206.5 ft)
Water struck at + 58.1 m
250 mm percussion and shell
September 1980

Overburden 0.4 m
Mineral I 11.6 m
Waste 3.0 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Turf, soil and made-ground	0.4	0.4
Glacial sand and gravel	a Pebbly sand Gravel: fine with some coarse and scattered cobbles, subrounded to well rounded, psammite vein-quartz and sandstone Sand: medium with fine and coarse, 'sharpish' rock fragments and quartz. Seams of predominantly coarse, 'clean' sand Fines: silt, disseminated and in 50 mm thick seams, yellow-brown	5.0	5.4
	b Gravel. Unconsolidated Gravel: fine with coarse and scattered cobbles, subangular to well rounded, sandstone, schistose grit, psammite, vein-quartz and quartzite Sand: coarse with medium and some fine, angular to well rounded, 'sharp', vein-quartz, sandstone and quartzite Fines: very little	4.0	9.4
	c 'Clayey' sand Gravel: very little, fine, otherwise as above Sand: fine with medium and some coarse Fines: much silt, disseminated, 10 mm thick seams of silty clay below 10.9 m, very soft, pale yellow-brown	2.6	12.0
Till	Clay with much fine sand and some gravel, firm to stiff, extremely stiff below 14.0 m maroon-grey with wisps of pale grey clay	3.0 +	15.0

Borehole terminated owing to slow progress and technical difficulties

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	9	76	15	0.4−1.4	14	19	42	15	9	0	1
				1.4−2.4	10	12	39	17	15	2	5
				2.4−3.4	6	16	54	17	7	0	0
				3.4−4.4	9	26	47	9	5	4	0
				4.4−5.4	6	18	22	27	18	9	0†
				Mean	9	18	41	17	11	3	1
b	2	47	51	5.4−6.4	3	5	8	31	42	8	3†
				6.4−7.4	1	3	17	25	39	15	0†
				7.4−8.4	2	4	26	27	28	13	0†
				8.4−9.4	2	6	12	24	42	14	0†
				Mean	2	4	16	27	38	12	1
c	11	85	4	9.4−11.0	10	43	28	14	5	0	0†
				11.0−12.0	13	64	20	2	1	0	0†
				Mean	11	51	25	9	4	0	0
a to c	7	68	25	Mean	7	21	28	19	18	6	1

NN 70 SW 16 | 7346 0084 | Inverardoch Mains, Kilmadock | BLOCK C

Surface level + 38 m (+ 125 ft)
Water struck at + 34.1 m
250 mm shell
October 1980

Waste 3.9 m
Bedrock 0.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty and clayey, dark brown	0.3	0.3
Till	Clay, sandy with scattered sandstone and siltstone clasts, cobbles below 3.4 m, crumbly, brown-red	3.6	3.9
Old Red Sandstone	Siltstone, red-brown, laminated	0.2 +	4.1

NN 70 SW 17 | 7407 0395 | Lerrocks, Kilmadock | BLOCK C

Surface level + 120 m (+ 394 ft)
Water struck at + 113.5 m
250 mm percussion and shell
September 1980

Overburden 0.7 m
Mineral II 0.8 m
Mineral I 5.0 m
Waste 1.0 m
Mineral I 2.8 m
Waste 3.2 m
Bedrock 0.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty, medium brown	0.7	0.7
Flow till	a 'Very clayey' gravel Gravel: coarse with fine, cobbles up to 80 mm common, angular to subangular with some more rounded clasts, sandstone with a little quartzite and basalt Sand: fine with coarse and medium, angular to subangular, predominantly quartz Fines: much silt and clay, disseminated, red-brown	0.8	1.5
Glacial sand and gravel	b Gravel Gravel: coarse and fine with sandstone cobbles up to 180 mm above 2.9 m, otherwise as above but with more 'Highland' material Sand: coarse and medium with fine, angular to subangular quartz and rock fragments, poorly sorted Fines: silt, disseminated, locally binding deposit. Thin seam of pale brown laminated silt near the top	5.0	6.5
	Very silty fine sand with rare pebbles, well sorted, quartzose, light brown	1.0	7.5
	c Gravel Gravel: coarse with fine, cobbles up to 120 mm, angular to well rounded sandstone with 'Highland' rocks Sand: fine, medium and coarse, poorly sorted, quartz and rock fragments Fines: silt, disseminated, brown	2.8	10.3
Till	Clay with clasts up to 120 mm, chiefly of sandstone, stiff, red-brown	3.2	13.5
Old Red Sandstone	Sandstone, fine-grained, indurated with quartz veins	0.2 +	13.7

(... Continued)

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	28	25	47	0.7−1.5	28	10	7	8	14	18	15
b	8	46	46	1.5−2.9	8	8	10	11	12	23	28
				2.9−4.1	8	14	30	20	11	5	12
				4.1−4.9	8	10	21	28	19	14	0
				4.9−6.5	8	8	12	20	22	22	8
				Mean	8	10	17	19	16	17	13
c	7	44	49	7.5−8.5	13	16	13	10	8	25	15†
				8.5−9.5	2	10	18	16	20	19	15†
				9.5−10.3	4	25	14	14	28	15	0†
				Mean	7	16	15	13	18	20	11
b & c	8	45	47	Mean	8	12	16	17	17	18	12
a to c	9	44	47	Mean	9	12	16	16	16	18	13

NN 70 SW 18 — 7317 0102 — Old Newton, Kilmadock — BLOCK B

Surface level + 39 m (+ 128 ft)
Water struck at + 36.1 m
Pit
December 1980

Waste 3.0 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, silty, medium brown	0.7	0.7
Glaciolacustrine deposit	Silty sand with rare fine pebbles, orange-brown. Sand coarsening downwards from fine to medium, subangular to subrounded, quartzose	0.6	1.3
Till	Clay, becoming sandier with depth, numerous sandstone clasts up to 300 mm, stiff, red-brown	1.7 +	3.0

NN 70 SE 3	7505 0407	Horse Wood, Dunblane	BLOCK C

Surface level + 115 m (+ 377 ft)
Groundwater level + 113 m
250 mm percussion and shell
October 1980

Overburden 0.2 m
Mineral I 2.8 m
Waste 2.3 m
Bedrock 0.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Gravelly soil	0.2	0.2
Glacial sand and gravel	Sandy gravel Gravel: coarse and fine with cobbles and boulders up to 250 mm, rounded to well rounded becoming more angular below 1.5 m. Siltstone, andesite and sandstone with some vein-quartz, psammite and quartz-dolerite. Bed of angular sandstone boulders between 2.5 and 3.0 m Sand: medium and coarse with fine, subangular to well rounded siltstone and quartz, poorly sorted and angular below 1.5 m Fines: silt above 1.5 m, disseminated, dark orange-brown. Silty clay matrix below 1.5 m, bright yellow-brown	2.8	3.0
Till	Clay, silty, pebbly, stiff becoming stiffer and more stony towards the base, clasts chiefly of siltstone and sandstone, purple-medium grey	2.3	5.3
Old Red Sandstone	Siltstone, hard, micaceous, purple-brown	0.2 +	5.5

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
8	48	44	0.2−1.5	6	9	14	14	21	26	10
			1.5−2.5	10	16	24	23	16	11	0†
			2.5−3.0	No grading data available						
			Mean	8	12	18	18	19	19	6

NN 70 SE 4	7580 0258	Corsaplie, Dunblane	BLOCK C

Surface level + 87 m (+ 285 ft)
Water not struck
250 mm percussion
October 1980

Overburden 0.1 m
Mineral I 6.0 m
Waste 0.2 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.1	0.1
Glacial sand and gravel	Gravel Gravel: cobbles and boulders up to and larger than 250 mm with coarse and some fine gravel. Chiefly subrounded to well rounded sandstone and siltstone with some schistose grit, psammite, vein-quartz, felsite, andesite and 'rotten' pebbles of sandstone and mudstone Sand: fine and coarse with medium, angular to well rounded sandstone and siltstone (often platy) with some vein-quartz and psammite. Coarsening and becoming more poorly sorted downwards Fines: much silt binding deposit, becoming cleaner and less compact below 3.1 m, red-brown, some grey sandy till mixed with deposit between 1.8 m and 2.1 m	6.0	6.1
Till	Clay, very silty with rare mudstone clasts, vivid red-brown	0.2	6.3
Old Red Sandstone	Mudstone, hard, slightly micaceous, deep-red-brown	0.1 +	6.4

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16–1/4	+1/4–1	+1–4	+4–16	+16–64	+64
9	29	62	0.1–1.1	10	10	8	12	16	29	15
			1.1–2.1	12	13	6	9	15	15	30
			2.1–3.1	9	10	7	9	12	17	36
			3.1–4.1	9	12	9	11	17	22	20
			4.1–5.1	9	10	9	10	15	31	16
			5.1–6.1	4	12	11	11	13	22	27
			Mean	9	11	8	10	15	23	24

NN 70 SE 5 | 7502 0168 | Argaty Cottage, Kilmadock | BLOCK C

Surface level + 71 m (+ 233 ft)
Water not struck
250 mm percussion and shell
September 1980

Overburden 0.2 m
Mineral I 2.0 m
Waste 10.0 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Loamy gravelly soil	0.2	0.2
Glacial sand and gravel	Sandy gravel Gravel: fine and coarse, rare cobbles, coarse gravel subrounded to well rounded, fine gravel subangular to well rounded. Schistose grit with some quartzite, vein-quartz and sandstone Sand: medium with fine and coarse, 'soft', subangular to well rounded rock and quartz Fines: silt, disseminated, pale brown	2.0	2.2
Till	Clay, gravelly, stiff becoming more clayey and stiff downwards, maroon-brown becoming brown-grey below 8.7 m, then red-brown below 10.8 m and maroon-grey below 11.5 m. Angular to subrounded clasts of grit, psammite, vein-quartz and sandstone with angular siltstone towards the base	10.0 +	12.0

Borehole terminated owing to slow progress, possibly on siltstone bedrock

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
9	54	37	0.2–1.2	10	20	28	14	18	10	0
			1.2–2.2	8	12	19	14	24	23	0
			Mean	9	16	24	14	21	16	0

NN 70 SE 6	7640 0181	Stockbridge, Dunblane	BLOCK C

Surface level + 80 m (+ 262 ft)
Water not struck
250 mm percussion and shell
October 1980

Waste 7.8 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, medium brown	0.1	0.1
Glacial sand and gravel	'Clayey' pebbly sand Gravel: fine with some coarse, subrounded to rounded sandstone with some 'Highland' rock types Sand: fine with medium and a little coarse, angular quartz with some rock fragments Fines: silt, disseminated and as thin seams, massive, red-brown	0.9	1.0
Till	Clay, sandy in parts with clasts up to 150 mm chiefly of sandstone, moderately stiff becoming very stiff with depth, red-brown	6.8 +	7.8

Borehole terminated at 7.8 m owing to slow progress

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
12	72	16	0.1−1.0	12	38	26	8	12	4	0

Deposit non-mineral as less than 1.0 m thick

NN 70 SE 7	7858 0472	Hutchison, Dunblane	BLOCK C

Surface level + 108 m (+ 354 ft)
Water struck at + 98.1 m
250 mm shell
September 1980

Waste 9.9 m
Bedrock 0.1 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Till	Clay with a little fine sand, becoming sandier below 9 m, stiff, red. Angular to subangular clasts up to 80 mm, chiefly sandstone and mudstone	9.7	9.9
Old Red Sandstone	Sandstone, fine-grained, red, highly micaceous	0.1 +	10.0

NN 70 SE 8	7882 0462	Craigton, Dunblane	BLOCK D

Surface level + 91 m (+ 298 ft)
Water struck at + 89.9 m
250 and 200 mm shell
September 1980

Overburden 1.1 m
Mineral I 2.4 m
Waste 14.8 m
Bedrock 0.3 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil, sandy, medium brown	1.1	1.1
Alluvium	'Clayey' pebbly sand Gravel: present only below 2.5 m, coarse and fine with cobbles up to 100 mm, subangular to subrounded sandstone with some mudstone, volcanic breccia, quartzite and quartz Sand: fine with some medium and a little coarse, angular to subrounded quartz and rock fragments Fines: silt, disseminated, very abundant above 1.5 m, medium brown	2.4	3.5
Glaciolacustrine deposits	Clay, laminated, red-brown with grey laminae becoming greyer with depth. Interbedded silty clay and clayey silt below 12.0 m with rare pebbles near the base	14.8	18.3
Old Red Sandstone	Sandstone, fine- to medium-grained, flaggy, slightly micaceous, red	0.3 +	18.6

GRADING

Mean for deposit percentages			Depth below surface (m)	percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
15	73	12	1.1−2.5	22	65	13	0	0	0	0†
			2.5−3.5	5	17	39	10	9	9	11†
			Mean	15	45	24	4	4	4	4

NN 70 SE 9 | 7869 0315 | Whinney Knowe, Dunblane | BLOCK D

Surface level + 101 m (+ 331 ft)
Water struck at + 89.8 m
250 mm and 200 mm percussion and shell
September 1980

Overburden 1.0 m
Mineral I 13.0 m
Waste 4.4 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
	Silty fine sand, possibly made-ground	0.8	1.0
Glacial sand and gravel	a 'Clayey' sandy gravel Gravel: fine with coarse and scattered cobbles, becoming coarser with numerous cobbles and small boulders below 5.0 m, subangular to well rounded sandstone and siltstone with vein-quartz, psammite, schistose grit and 'rotten' mudstone Sand: fine with medium and coarse, subrounded to well rounded coarse grains of sandstone and siltstone, otherwise quartz, 'soft', some mica Fines: very silty, red-brown. Deposit loosely bound above 5 m, becoming 'cleaner' downwards. Below 5 m, bands of silty clay matrix in association with coarse gravel	5.2	6.2
	b Gravel Gravel: coarse with fine and numerous cobbles and boulders up to 350 mm, subrounded to well rounded sandstone and siltstone with mudstone. Sand: coarse and fine with medium, coarse sand quite angular Fines: silty clay matrix binding deposit, medium to red-brown	7.8	14.0
Till	Clay, silty, gravelly becoming sandier downwards, very stiff, red-brown sandstone clasts up to 110 mm	4.4 +	18.4

Borehole terminated owing to slow progress in stiff till

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	16	51	33	1.0−2.0	30	36	18	6	7	3	0
				2.0−3.0	15	34	21	10	6	3	11
				3.0−4.0	20	42	18	7	11	2	0
				4.0−5.0	10	12	5	21	36	16	0
				5.0−6.2	7	7	11	10	20	26	19
				Mean	16	26	14	11	16	11	6
b	10	34	56	6.2−7.2	13	11	8	8	17	29	14
				7.2−8.2	13	11	6	6	17	47	0
				8.2−9.2	10	8	6	9	18	28	21
				9.2−10.2	14	11	9	13	21	27	5†
				10.2−11.2	12	9	7	11	15	27	19†
				11.2−12.2	8	14	12	12	24	30	0†
				12.2−14.0	4	15	15	20	25	17	4†
				Mean	10	12	10	12	20	28	8
a & b	12	41	47	Mean	12	17	12	12	18	21	8

NN 70 SE 10 | 7835 0216 | Barbush, Dunblane | BLOCK D

Surface level + 95 m (+ 311.5 ft)
Water not struck
Section and pit
December 1980

Overburden 0.2 m
Mineral I 12.9 m
Waste 1.3 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Glacial sand and gravel	a Pebbly sand Gravel: scattered fine and coarse, well rounded, composition as in lower deposit Sand: fine with some medium and a little coarse, subangular to well rounded quartz Fines: silt, disseminated, pale yellow-brown	6.0	6.2
	b Gravel. Poorly sorted and compact Gravel: coarse with fine, mainly boulders and cobbles up to 400 mm between 10.1 and 11.1 m. Coarse gravel subrounded to well rounded, fine gravel angular to well rounded. Sandstone commonly as boulders, with mudstone conglomerate, psammite, quartz, andesite, metagabbro, schist, quartzite and felsite Sand: coarse with medium and some fine, angular to well rounded becoming mainly angular below 10.1 m, rock fragments with quartz and some feldspar Fines: silt with clay, disseminated, red-brown becoming yellow-brown below 11.1 m	6.9	13.1
Till	Clay, stony, stiff becoming extremely stiff with depth, maroon-brown, chiefly sandstone clasts up to 450 mm	1.3 +	14.4

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					$-\frac{1}{16}$	$+\frac{1}{16}-\frac{1}{4}$	$+\frac{1}{4}-1$	+1–4	+4–16	+16–64	+64
a	7	81	12	0.2–6.2	7	51	28	2	7	5	0
b	3	15	82	6.2–10.1	2	1	3	7	11	35	41
				10.1–11.1	2	1	5	9	10	16	57
				11.1–13.1	7	7	6	9	25	31	15
				Mean	3	3	4	8	15	31	36
a & b	5	46	49	Mean	5	25	16	5	11	19	19

NN 70 SE 11 7932 0392 Cairnston, Dunblane BLOCK D

Surface level + 115 m (+ 377 ft)
Water struck at + 105.8 m
250 and 200 mm percussion and shell
September 1980

Overburden 0.2 m
Mineral 11.6 m
Waste 0.5 m
Bedrock 0.2 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Glacial sand and gravel	a 'Clayey' sand. Fining downwards Sand: fine with a little medium, some coarse below 8.0 m, quartz with mica above 6 m and rock below 6.2 m Fines: silt, disseminated and in bands, pale yellow-grey. 100 mm seam of silt at 1.6 m, 200 mm seam of laminated clayey silt at 6.0 m, both red-brown. Very silty between 4.2 and 6.0 m	8.0	8.2
	b Sandy gravel. Fining upwards Gravel: fine with some coarse, cobbles rare, coarse gravel subrounded to well rounded, fine gravel chiefly subangular to subrounded. Sandstone and siltstone with some 'rotten' mudstone, vein-quartz, psammite and epidiorite Sand: medium with fine and coarse, subangular to subrounded sandstone, psammite, siltstone and quartz with some platy schist, 'sharp' Fines: silt, disseminated. Iron-stained silty clay matrix between 8.8 and 9.2 m and silty 'pan' below 9.2 m, becoming 'cleaner' downwards	3.6	11.8
Till?	Boulder-bed with a red-brown, silty sandy clay matrix, possibly till	0.5	12.3
Old Red Sandstone	Sandstone, medium-grained, purple-brown and pale green-grey, banded with green-grey wisps of siltstone	0.2 +	12.5

GRADING

	Mean for deposit percentages			Depth below surface (m)	percentages						
	Fines	Sand	Gravel		Fines	Sand			Gravel		
					−1/16	+1/16−1/4	+1/4−1	+1−4	+4−16	+16−64	+64
a	13	87	0	0.2−1.2	8	78	14	0	0	0	0
				1.2−2.2	11	75	13	1	0	0	0
				2.2−3.2	7	84	9	0	0	0	0
				3.2−4.2	6	81	13	0	0	0	0
				4.2−5.2	19	80	1	0	0	0	0
				5.2−6.0	25	75	0	0	0	0	0
				6.0−7.0	18	64	18	0	0	0	0
				7.0−8.2	9	47	40	3	1	0	0
				Mean	13	72	14	1	0	0	0
b	8	69	23	8.2−9.2	7	22	36	23	11	1	0
				9.2−10.2	13	28	24	13	18	4	0†
				10.2−11.2	4	13	21	26	29	7	0†
				11.2−11.8	No grading data available						
				Mean	8	21	27	21	19	4	0
a & b	11	82	7	Mean	11	57	18	7	6	1	0

APPENDIX F

ANCILLARY BOREHOLE RECORDS

NN 60 NE 12	6999 0733	Coldhame, Kilmadock	BLOCK C

Surface level c + 218 m (c + 715 ft)
Water not recorded
Drilling method unknown
1963

Waste 7.5 m
Bedrock 2.4 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Peat	1.5	1.5
Till	Clay, sandy with clasts of decomposed sandstone and siltstone, firm, brown	6.0	7.5
Old Red Sandstone	Sandstone, firm	2.4 +	9.9

NN 60 SW 1	6117 0121	Blacklands Villa, Port of Menteith	BLOCK C

Surface level c + 43 m (c + 141 ft)
Water not recorded
Drilling method unknown
September 1926

Waste 5.9 m
Bedrock 14.5 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.5	0.5
Till	Clay, gravelly, yellow	4.5	5.0
	Sand, pebbly, grey	0.9	5.9
Old Red Sandstone	Sandstone, hard, grey	14.5 +	20.4

NN 60 SW 2	6226 0079	Calziemuck, Port of Menteith	BLOCK C

Surface level c + 39 m (c + 128 ft)
Water struck at c + 37.9 m
Drilling method unknown
1903

Overburden 0.5 m
Mineral I 1.3 m
Waste 11.0 m
Bedrock 27.0 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.5	0.5
Glacial sand and gravel	Sand and gravel	1.3	1.8
Till	Clay, stony with boulders up to 700 mm	11.0	12.8
Old Red Sandstone	Conglomerate, friable	2.5	15.3
	Sandstone, hard	24.5 +	39.8

NN 70 NW 1	7150 0726	Loch Mahaick, Kilmadock	BLOCK C

Surface level c + 217 m (c + 712 ft)
Water not recorded
Drilling method unknown
1963

Waste 4.7 m
Bedrock 7.8 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Peat	0.3	0.3
Till	Clay, sandy with some sandstone clasts up to boulder size, firm becoming stiffer downwards, brown	4.4	4.7
Old Red Sandstone	Sandstone, hard, with layers of clayey shale, brown	7.8 +	12.5

NN 70 NW 5 | 7132 0693 | Loch Mahaick, Kilmadock | BLOCK C

Surface level c + 205 m (c + 672 ft
Water not recorded
Drilling method unknown
1963

Overburden 0.4 m
Mineral I 8.6 m
Waste 0.8 m
Bedrock 13.4 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.4	0.4
Alluvium	Sand, clayey, brown	0.5	0.9
	Sand and gravel, coarsening downwards, chiefly boulders below 5.5 m, brown	8.1	9.0
Till	Clay, sandy with sandstone clasts, stiff, brown	0.8	9.8
Old Red Sandstone	Sandstone, firm with layers of clayey shale, brown	13.4 +	23.2

NN 70 NW 10 | 7067 0626 | Loch Mahaick, Kilmadock | BLOCK C

Surface level c + 215 m (c + 715 ft)
Water not recorded
Drilling method unknown
1963

Waste 4.8 m
Bedrock 3.9 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Peat	4.8	4.8
Old Red Sandstone	Sandstone, with a seam of clayey shale between 5 m and 6.2 m, brown, decomposed above 5 m	3.9 +	8.7

NN 70 SW 1 | 7033 0302 | Kirkton, Kilmadock | BLOCK C

Surface level c + 55 m (c + 180 ft)
Water struck at c + 53.2 m
Drilling method unknown
1901

Overburden 13.4 m
Mineral I 5.4 m
Bedrock 9.8 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.3	0.3
Till	Clay, stony, brown	13.1	13.4
Glacial sand and gravel	Gravel, extremely compact, sandy between 16.8 and 17.4 m	5.4	18.8
Old Red Sandstone	Sandstone, hard, with seams of shale	9.8 +	28.6

NN 70 SW 2 | 7321 0263 | Westerton, Kilmadock | BLOCK C

Surface level c + 83 m (c + 272 ft)
Water struck at c + 77.5 m
Drilling method unknown
1905

Overburden 33.3 m
Bedrock 5.3 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Till	Clay, with sandstone rafts up to 700 mm, clay becoming sandy at the base, extremely stiff	33.1	33.3
Old Red Sandstone	Sandstone, hard, red, with seams of shale	5.3 +	38.6

NN 70 SE 1 | 7885 0385 | Ashfield, Dunblane | BLOCK D

Surface level c + 98 m (c + 320 ft)
Water not recorded
Drilling method unknown
June 1926

Overburden 0.5 m
Mineral I 15.6 m
Bedrock 102.5 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.5	0.5
Glacial sand and gravel	Sand, with rounded gravel between 3.9 and 4.8 m and below 10.1 m, 'soft', silty, orange-gold	10.6	11.1
	Gravel, rounded	5.0	16.1
Old Red Sandstone	Sandstone with thin seams of shale, friable becoming harder with depth, red	102.5 +	118.6

NN 70 SE X1 | 7890 0285 | Duthieston House, Dunblane | BLOCK D

Surface level + 95 m (+ 312 ft)
Water struck at + 93.6 m
Drilling method unknown
June 1970

Overburden 3.6 m
Mineral I 3.0 m
Bedrock 0.9 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.2	0.2
Alluvium	Clay, very sandy, soft, brown	0.8	1.0
	Sand and gravel, clayey, fine- to medium-grained, loose, brown	0.4	1.4
Glaciolacustrine deposits	Clay, sandy, silty, laminated, soft, brown	1.4	2.8
	Sand, silty, clayey, fine-grained, brown	0.8	3.6
	Sand, silty, fine- to medium-grained with seams of soft silty clay	3.0	6.6
Old Red Sandstone	Sandstone, hard	0.9 +	7.5

NN 70 SE X2 | 7874 0243 | Cemetery, Dunblane | BLOCK D

Surface level + 94 m (+ 308 ft)
Water not struck
Drilling method unknown
June 1970

Overburden 0.3 m
Mineral I 2.0 m
Waste 3.7 m +

LOG

Geological classification	Lithology	Thickness m	Depth m
	Soil	0.3	0.3
Glacial sand and gravel	Sand, clayey, fine, compact, uniform brown	2.0	2.3
Till	Clay, sandy with some gravel, firm becoming very stiff below 4.5 m, red-brown	3.7 +	6.0

NN 70 SE X3 | 7810 0073 | Dunblane | BLOCK D

Surface level + 54 m (+ 177 ft)
Water struck at + 49.1 m
Drilling method unknown
May 1970

Overburden 0.5 m
Mineral I 9.1 m
Bedrock 0.9 m +

LOG

Geological classsification	Lithology	Thickness m	Depth m
	Soil	0.5	0.5
River terrace deposit	Sand and gravel, clayey with sandstone boulders and some layers of very sandy clay above 2.4 m, loose becoming compact below 2.4 m, brown	3.2	3.7
	Gravel, fine to coarse, compact	1.2	4.9
	Sand and gravel, clayey, fine to medium, compact, brown	4.7	9.6
Old Red Sandstone	Sandstone, friable	0.9 +	10.5

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THE SAND AND GRAVEL RESOURCES OF THE COUNTRY AROUND CALLANDER AND DUNBLANE, CENTRAL REGION

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

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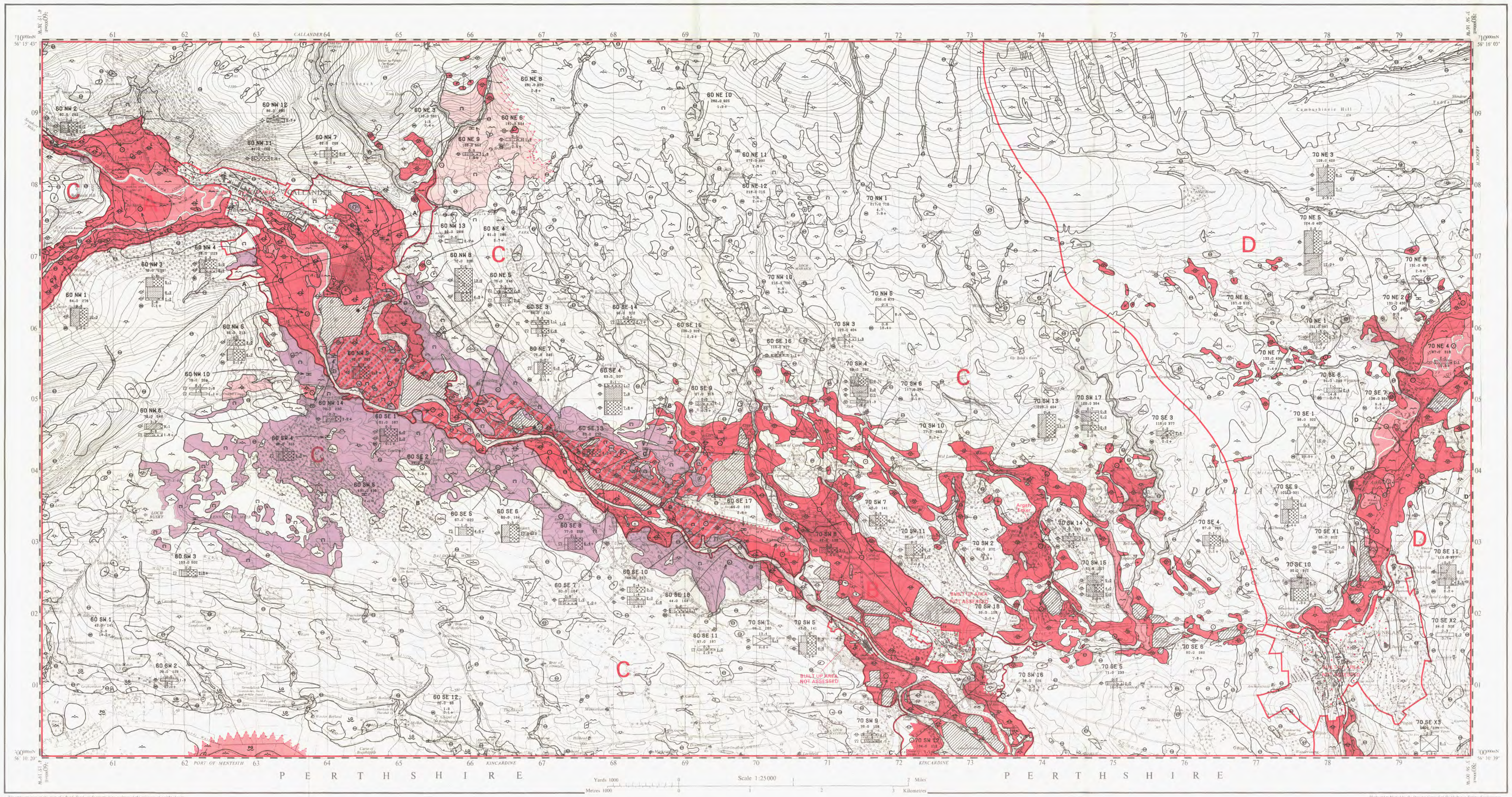

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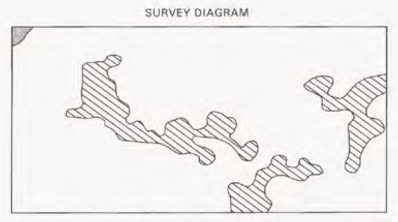
Revision survey by I. H. Forsyth and E. H. Francis, 1952 - 1960. J. Knox and J. R. Earp, District Geologists

Partial re-survey by J. W. Merritt, 1980. E. G. Poole, District Geologist

Sand and gravel survey by J. W. Merritt and J. L. Laxton in 1980 under the supervision of E. F. P. Nickless. R. G. Thurrell, Head, Industrial Minerals Assessment Unit

The 1:25 000 Sand and Gravel Resource Sheet published 1982.
G. M. Brown, D. Sc., F. R. S., Director, Institute of Geological Sciences

SURVEY DIAGRAM



- Original survey by C. T. Clough, 1896
- Revision survey by I. H. Forsyth and E. H. Francis, 1952-1960
- Partial re-survey by J. W. Merritt, 1980

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.

NN51	NN61	NN71	NN81
NN50 38	NN60	NN70 39	NN80
NS59	NS69	NS79	NS89

Diagram showing the relation of the National Grid squares to the One-Inch Geological sheets.

Borehole Graphics drawn by computer using programs written by J. L. McInnes, N E R C Computing Service, Edinburgh

Produced for the Institute of Geological Sciences by Clyde Surveys Scotland Ltd, Livingston, West Lothian. Printed by John Bartholomew & Son Ltd, Edinburgh 1982
Edinburgh 1982

THE SAND AND GRAVEL RESOURCES OF THE COUNTRY AROUND CALLANDER AND DUNBLANE, CENTRAL REGION

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

EXPLANATION OF SYMBOLS AND ABBREVIATIONS

- **Made ground** - waste and/or natural earth materials deposited on the original ground surface MG-3
- **Made ground** - waste and/or natural earth materials deposited in open-cast workings MG-8

DRIFT

Recent and Pleistocene

- **Peat** P-1
- **Alluvium of floodplains and undifferentiated alluvium** - floodplains and terraces are generally underlain by sand and gravel; otherwise chiefly silt and clay A-73
- **Alluvial cone** - fan composed of alluvium AC-2
- **Raised beach deposits and associated marine and estuarine alluvium, post-Glacial** - chiefly silty clay RS-7
- **Fluvioglacial sand and gravel of the Loch Lomond Stadial** - terraces chiefly underlain by gravel with sand, poorly sorted and dense FL-24
- **Raised beach deposits and associated marine and estuarine alluvium, late-Glacial** - chiefly fine-grained sand, clay and silt RS-8
- **Fluvioglacial sand and gravel (undifferentiated), generally pre-Loch Lomond Stadial** - terraces chiefly underlain by gravel with sand, poorly sorted and dense FL-25
- **Glaciolacustrine deposits** - very fine-grained sand, silt and clay, often laminated G-6
- **Glacial sand and gravel** - deposits vary from poorly sorted, dense, coarse gravels to well sorted, silty fine-grained sands GS-55
- **Flow-till** - very poorly sorted sand and gravel in a matrix of silty sandy clay FT-1
- **Morainic drift** - sandstone rubble in a matrix of silty sand or sandy clay MD-3
- **Till** - typically a stiff silty sandy clay containing gravel clasts up to boulder size TL-17

SOLID

- **Bedrock, undifferentiated** - Bedrock mainly comprises sandstone; conglomerate crops out towards the north-west of the resource sheet area and siltstone and mudstone in the south-east. These rocks form part of the Lower Old Red Sandstone and are separated from crystalline Dalradian rocks by the north-east trending Highland Boundary Fault which lies in the extreme north-west of the area. (See Figure 3 in Report).
- **Worked ground** - boundaries as at December 1980. In the survey area, usually the sand and gravel is worked only above water-table WG-2

BOUNDARY LINES

- Geological boundary
- Line marking back feature to a terrace
- Form-line identifying a major mound or ridge of sand and gravel
- Inferred boundary between categories of deposit
- Resource block boundary

BOREHOLE AND OTHER DATA

SITE LOCATIONS

- Industrial Minerals Assessment Unit (I M A U) borehole
- Other borehole
- Recorded exposure
- Shallow pit

I M A U BOREHOLES

Registration Number → 60 NW 5
65.0 219 ← Surface level in metres and feet above OD (Newlyn)
0.1 ← Overburden
3.0, 6.2 ← Mineral I
Waste → 1.7
Geological Classification →
Grading Diagram →
0.1+ ← Bedrock
Thickness in metres

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
(iv) Two types of mineral are recognised: mineral I is sand and gravel, mineral II is morainic drift. The designation is only used in Appendix F of the report

Registration Number

Each I M A U borehole is identified by a registration number, for example **60 NW 5**
The first numbers and letters refer to the quarter sheet and the final figures to the I G S serial numbers for that quarter. The unique designation for borehole **60 NW 5** is **NN 60 NW 5**

Grading Diagrams

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

Sand (+1/16–4mm)
Fines (−1/16mm) Gravel (+4mm)

The height of the diagram is proportional to the mineral thickness

The widths of the divisions show the proportions of **Fines, Sand** and **Gravel**

Note:

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

OTHER BOREHOLES

Site investigation boreholes and wells providing ancillary assessment data are located on the map where space permits. These boreholes are either registered in the same series as I M A U boreholes, for example, **70 SE 1**, or 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, **70 SE X3**

EXPOSURE RECORDS

Information from the inspection of exposures is shown in the same way as for I M A U boreholes but they are located by an asterisk, thus ✱. The exposures are registered in the same series as the boreholes, for example, **60 SE 4**

SHALLOW PITS

Where space permits the locations of shallow pits providing ancillary assessment data are shown by a distinctive symbol, thus ⌶. The pits are registered in the same series as the boreholes, for example, **60 SW 3**

CATEGORIES OF DEPOSITS

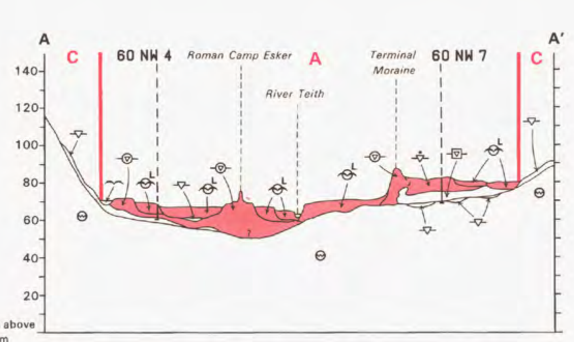
- **Exposed, potentially workable sand and gravel (mineral I)** CAT-E7
- **Continuous or almost continuous spreads of potentially workable sand and gravel beneath overburden** CAT-C4
- **Discontinuous spreads of potentially workable sand and gravel exposed or beneath overburden** CAT-D2
- **Sand and gravel not assessed** CAT-N1
- **Exposed, potentially workable morainic drift (mineral II)** CAT-E8
- **Exposed, potentially workable sand and gravel overlying continuous or almost continuous spreads of potentially workable morainic drift** CAT-E9
- **Potentially workable material absent** CAT-A5

RESOURCE BLOCKS

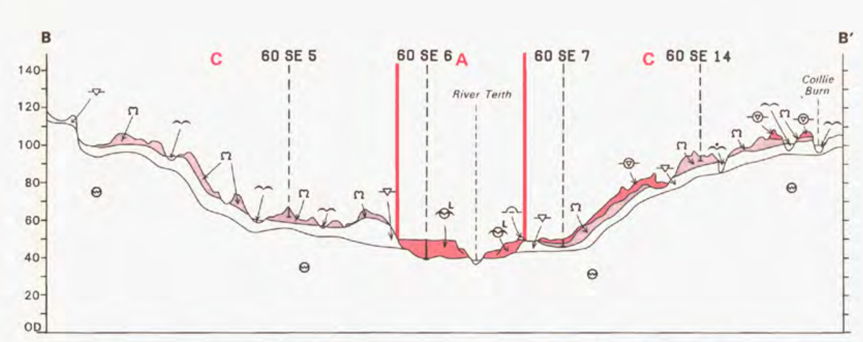
For the purpose of assessment, the mineral - bearing land is divided into Resource Blocks (see Report). Each is designated by a letter

GENERALISED HORIZONTAL SECTIONS SHOWING RELATIONSHIPS OF DRIFT DEPOSITS

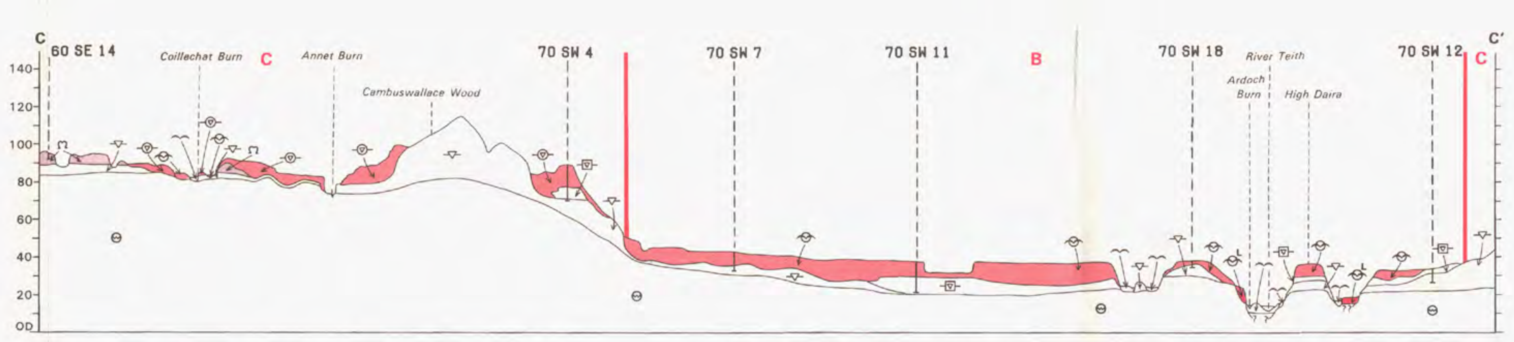
HORIZONTAL SCALE 1:25 000
VERTICAL EXAGGERATION 9·5x



The terraced fluvioglacial sand and gravel accumulated as outwash during the decay of the valley-glacier which advanced from the Highlands during the Loch Lomond Stadial (about 11,000 to 10,000 years ago) and terminated two or three kilometres to the south of Callander. In front of an arcuate terminal moraine formed by the glacier, flow-till locally obscures lacustrine deposits. The gravels forming the sinuous Roman Camp Esker were deposited by a subglacial meltwater stream which emerged at the snout of the glacier. Much of the glacial sand and gravel underlying the terraced fluvioglacial deposits may have been overidden by the ice.

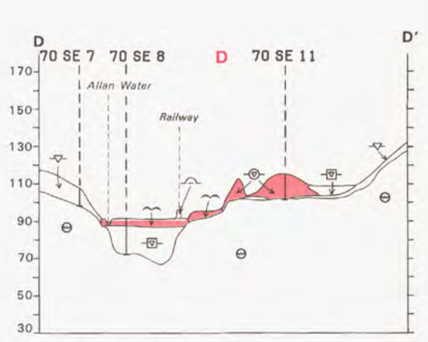


The terraced fluvioglacial sand and gravel in the centre of the valley of the River Teith (block A) was probably deposited by meltwaters during the Loch Lomond Stadial. The extremely hummocky topography on both sides of the valley is formed of morainic drift, a sandy, rubbly ablation till which generally overlies stiff clayey lodgement till. On the northern side of the valley glacial sand and gravel occurs as kames, kame-terraces and eskers and commonly overlies morainic drift: both deposits formed during the decay of the main late-Devensian ice-sheet.



Moundy morainic drift is commonly overlain by glacial sand and gravel which formed during the decay of the main late-Devensian ice-sheet. To either side of the ridge of clayey till at Cambuswallace Wood, sand and gravel underlies kettled kame-terraces which were formed laterally to ice occupying the central parts of the valleys and after the higher ground had become ice-free.

During the final stages of decay of the late-Devensian ice-sheet, the lower stretches of the valley of the River Teith became largely free of ice and, for a while, a glacier occupying the upper stretches of the valley probably terminated in the vicinity of Kirkton [704 030]. Meltwaters deposited a spread of fluvioglacial sand and gravel, mapped as terrace but now much dissected; the most extensive fragment, the 'Doune-Buchany Terrace', lies between Kirkton and Doune. The fluvioglacial sand and gravel thins and becomes much finer-grained downstream of Doune whereabouts the material commonly overlies silty clays formed in a glaciolacustrine or possibly a glacio-estuarine environment. The lower-lying fluvioglacial terraces were probably formed during the Loch Lomond Stadial when meltwaters passed to either side of High Daira.



During the decay of the main late-Devensian ice-sheet, residual ice probably occupied the central part of the valley of the Allan Water while glacial sand and gravel which forms eskers and kames was deposited by meltwaters. Fine-grained glaciolacustrine sediments accumulated in temporary lakes which occupied deep hollows left after these masses of ice had melted. The sandy alluvium is, in the main, the overbank deposit of the post-Glacial river system.

KEY TO SECTIONS

- Potentially workable sand and gravel, continuous or almost continuous deposits, exposed or beneath overburden
- Potentially workable morainic drift, continuous or almost continuous spreads, exposed or beneath potentially workable sand and gravel
- Bedrock and waste, including overburden, are uncoloured
- Geological boundary (broken line denotes uncertainty)
- Inferred boundary limiting the extent of potentially workable material
- 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