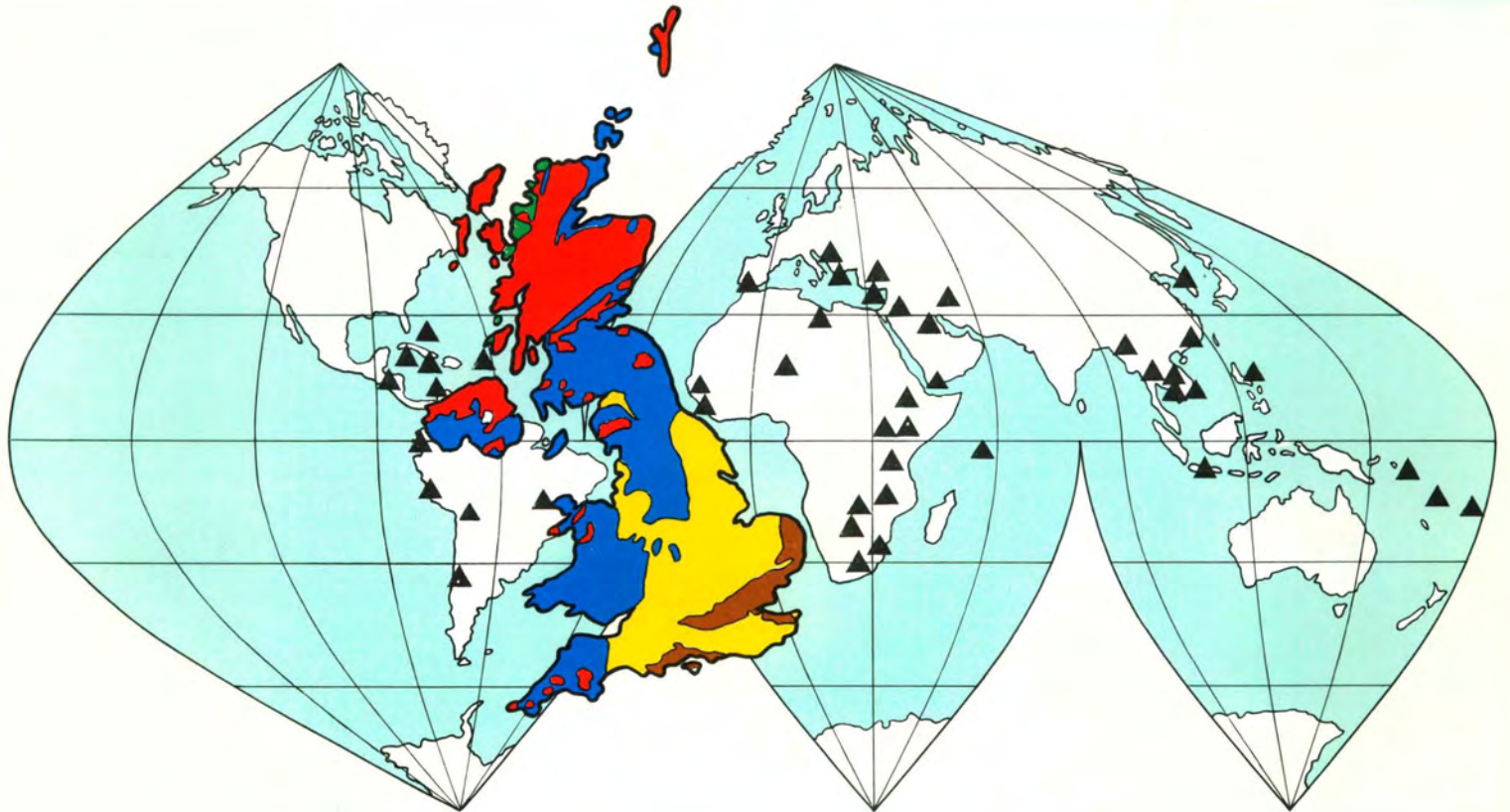


NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE OF GEOLOGICAL SCIENCES

Sand and gravel resources of the Central Region, Scotland

REPORT No. 77/9



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M.A.E. Browne

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Preface

The following account of the sand and gravel resources of the Central Region of Scotland has been compiled by the Institute of Geological Sciences, Edinburgh, at the request of the Scottish Development Department. It is essentially a summary of the published and unpublished records of the Institute together with other published data mentioned in the selected bibliography at the end of the report. The information has been augmented by visits to selected areas where time has permitted. The coverage is not comprehensive, but further detailed information is available for many localities and can be consulted at the Institute's Edinburgh office, Murchison House, West Mains Road, Edinburgh EH9 3LA.

The following constraints have been adopted in compiling this report:

1. The ratio of sand and gravel to overburden is 1:1 or more.
2. The thickness of deposit is 2 m or more.
3. The deposits are classified as resources rather than reserves and may include silt, clay, till and other unsuitable materials. Tonnages, where given, are at best inferred, being based on experience rather than detailed records of boreholes and sections. The conversion factor of one cubic metre equals two tonnes has been used throughout.
4. Deposits above and below the water-table have been considered separately.
5. Such considerations as possible markets and accessibility have been ignored.
6. Land use, conservation, and amenity considerations have been given only passing mention. There are many National Nature Reserves and Sites of Special Scientific Interest in the Region: information on these can be obtained from the Nature Conservancy Council, Hope Terrace, Edinburgh.
7. Resources underlying built-up areas are included. Estimated quantities of sand and gravel are given in Appendix 3. A list of working sand and gravel quarries and their localities is given in Appendix 1.

A. W. Woodland
Director

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1 November 1976

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Sand and gravel resources of the Central Region, Scotland

M. A. E. BROWNE

Introduction

GENERAL GEOLOGY

The Central Region of Scotland is crossed by a very important fracture zone known as the Highland Boundary Fault which trends in a generally north-easterly direction along a line passing approximately through Balmaha, Aberfoyle and Callander (Fig. 1). North of the fault, Dalradian rocks occur extensively and are the oldest rocks exposed in the Region. They consist chiefly of metamorphosed sedimentary rocks which include quartzite, impure quartzite, grit, schistose grit, schist with subordinate phyllite, slate and limestone. These rocks are commonly heavily veined by quartz. Minor quantities of metamorphosed igneous rock also occur. Easterly-trending basic dykes extend for several kilometres in places and smaller acid igneous dykes also occur. North of the Highland Boundary Fault, near Balmaha, a narrow outcrop of Upper Old Red Sandstone sediments is preserved. These rocks rest with marked unconformity on the Dalradian rocks beneath. South of the fault the geological succession comprises a thick sequence of strata of Lower Old Red Sandstone age which is overlain unconformably by Upper Old Red Sandstone sediments. These beds in turn appear to pass up conformably into rocks of Carboniferous age.

The Lower Old Red Sandstone rocks consist chiefly of brown, reddish-brown, purplish or green conglomerates (some of which may be rich in Highland or volcanic rock types), sandstones and siltstones or silty mudstones. Interbedded lava flows (mainly andesite and basaltic andesite) are present and may exceed 2500 m in thickness in the Ochil Hills. Similarly the sediments of the Upper Old Red Sandstone are reddish-brown, purplish, greenish, pink or white in colour and vary in grain-size from conglomerate to silty mudstone. Concretionary limestone beds and nodular bands commonly occur near the top of the sequence. The sedimentary rocks of both the Lower and Upper Old Red Sandstone seem to have been deposited in a mainly fluvial environment.

The Carboniferous strata consist chiefly of white or brown sandstones, grey siltstones and mudstones with subordinate conglomerates, limestones, ironstones and coals. These beds were deposited chiefly in deltaic and marine environments. Interbedded volcanic sediments and basaltic lavas also occur, particularly in the Campsie Hills. Intrusive igneous rocks including basalts, dolerites, diorites, felsites and fragmental rocks such as tuffs and agglomerates are also present and may be of Lower Old Red Sandstone or Carboniferous age.

NATURE OF THE DEPOSITS

Morainic drift

The term 'morainic drift' is used on IGS maps to describe the heterogeneous deposit which is left in the form of hummocks and undulating valley-bottom spreads by wasting ice-sheets during the melt phases of an Ice Age. This deposit may comprise stiff clayey to

light sandy boulder clay, ill-sorted mounds of sand and boulders or well-bedded, well-sorted sand and gravel. From an economic standpoint the lateral impersistence of well-sorted materials clearly renders morainic drift much inferior to fluvioglacial sand and gravel. The morainic deposits can provide good material locally, however, and may in some areas, with suitable processing, provide substantial quantities of high quality aggregate.

Fluvioglacial sand and gravel

Stratified fluvioglacial deposits constitute the major part of the sand and gravel resources of the Central Region. These water-laid materials were deposited by meltwater streams flowing in tunnels and caves within the ice and also by streams issuing from the margins of the ice-sheet or glacier. They are commonly rather poorly-sorted when compared with alluvial and beach deposits. Two types of fluvioglacial sand and gravel deposits are distinguished in this report, largely on the basis of present-day landforms. The first type is characterised by an irregular topography and commonly contains steep-sided mounds and ridges (eskers) which may be separated by low-lying, often marshy, areas. Such steep-sided landforms usually indicate deposition in close proximity to ice (ice-contact slopes), the deposits marking the sites of tunnels and caves in the ice and also river channels and lakes which formerly existed on the margins of the ice (kame-terraces). Closed depressions, often filled with peat or fine-grained lake sediments, are known as kettle-holes; these features commonly mark the sites of former ice-masses which have subsequently melted away.

The second type of deposit consists of flat-topped outwash spreads of sand and gravel, often of great lateral extent and in some cases pitted by kettle-holes. They were probably laid down by streams which issued from the ice-margin. Behind the ice-margin they may pass into mounded sand and gravel. Farther downstream, beyond the ice-margin they may pass into river terrace or deltaic deposits (in places lacustrine or marine). A common feature of these deposits is the development of a series of terraces due to the removal by erosion and subsequent redistribution of the older deposits either in response to changes of relative mean sea-level or by shifting glacial streams. Mounded sand and gravel can commonly be distinguished from outwash deposits by the considerable variations in grain-size both laterally and vertically within the former and by the lower degree of sorting of the fragments as compared with the latter type.

Alluvial deposits

Alluvial deposits are commonly represented by the floodplain (overbank) and channel sediments of rivers or, more rarely, by the sediments of alluvial cones where streams emerge from scarps and steep valleys onto lower ground. Some alluvial deposits may also be lacustrine in origin. Alluvial deposits may be terraced in a similar

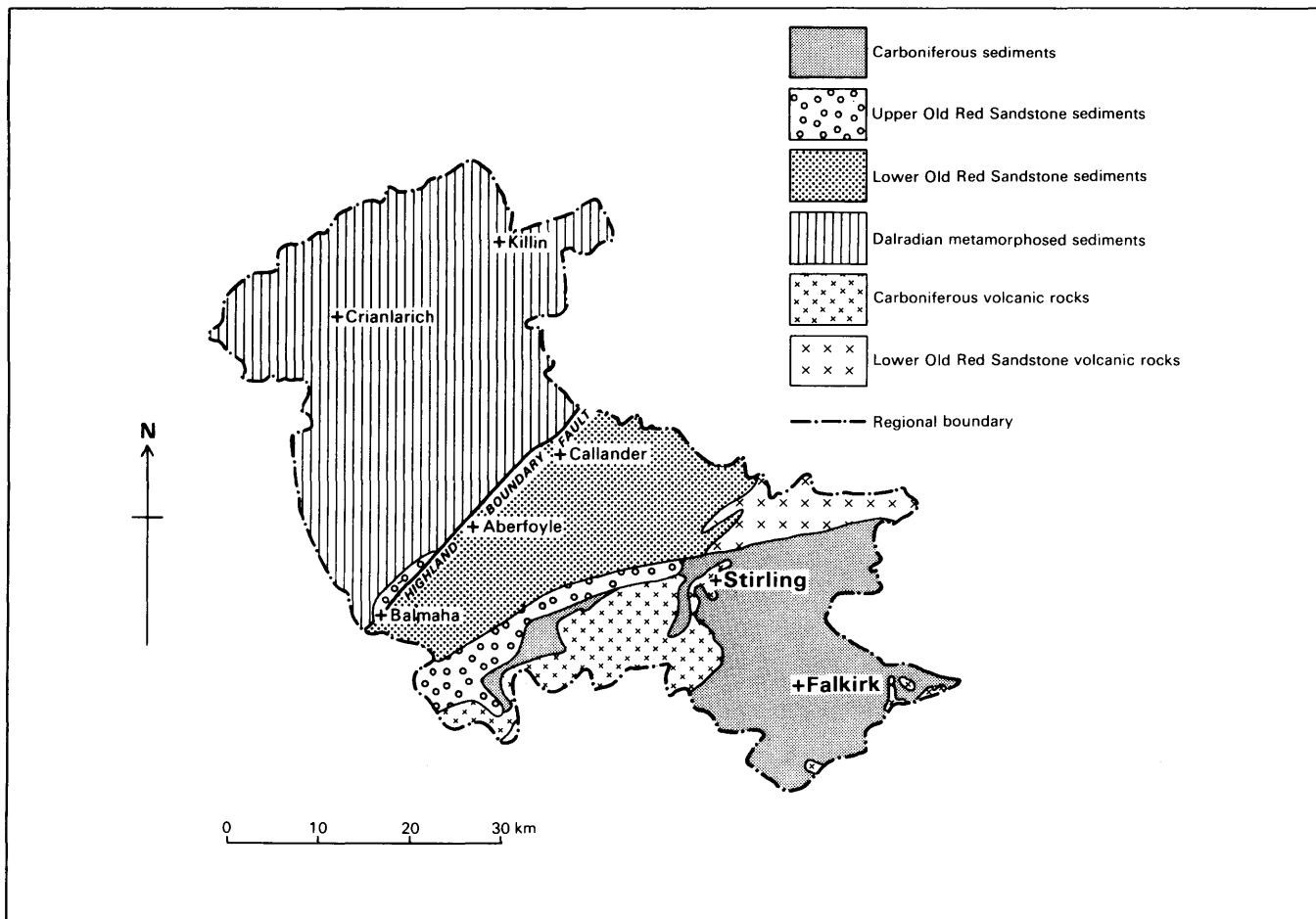


Fig. 1 The simplified solid geology of the Central Region

fashion to outwash fluvioglacial sand and gravel. They may also conceal older mounded and terraced fluvioglacial sand and gravel or else occur in channels cut in these older deposits. Alluvial deposits generally are well-sorted and range in grain-size from coarse gravel to silt and clay commonly fining upwards. In many instances the top surface of the modern alluvium may only be 1 m or 2 m above the river level so that the bulk of the resource occurs below the local water-table.

Raised-beach deposits

Raised-beach deposits are most commonly represented in volumetric terms by thick sequences of deltaic sand and gravel as, for example, the Carron Delta at Falkirk. Less commonly, thin deposits of beach sand and gravel may occur and cover fairly extensive areas.

During Late-Glacial times, as the last major ice-sheet in the Central Region decayed, the mean sea-level was at least 33 m higher than it is at present. The beaches associated with this sea-level are now raised and in places consist of sand and gravel. In some areas, however, where the former beach was developed on boulder clay or older marine clays these deposits may be reworked or merely benched. Such areas have not everywhere been recognised on existing maps of the Geological Survey. Furthermore, in some cases deposits of sand and gravel have not been distinguished from boulder clay or fluvioglacial gravel as they were not associated with a distinct feature and occur only as drapes. Locally, where beach or deltaic deposits

accumulated in association with remnant masses of stagnant ice, kettle-holes may be found in their surfaces.

In Post-Glacial times, after the final deglaciation of Scotland, sea-level for a time stood from 6 m to 10 m higher than present and extensive raised beaches were laid down which consist largely of estuarine silt and clay with laminae or thin bands of sand or gravel. Locally on exposed shores, where sorting has been a factor, better deposits of sand and gravel may occur. In an estuary such as the Forth, which was dominated by a high tidal range and a high influx of sediment during the early Post-Glacial period, an offshore channel facies containing sand and some gravel may be present. A similar distribution of sediments is present along the modern coastline and estuary of the Forth. These materials do not appear to form a significant resource of sand and gravel and are not described.

LITHOLOGY OF THE DEPOSITS

In the Central Region the bedrock geology is commonly reflected in the pebble content of the overlying sand and gravel. For example, in the morainic drift deposits, which are mainly confined to the Highlands, commonly up to 95 per cent of the pebbles are of the major local rock type with minor amounts of locally-derived vein quartz, acid or basic igneous, amphibolitic and epidioritic pebble types. Similarly in the Teith Valley in the Lowlands, the morainic drift deposits consist almost entirely of locally-derived brown sandstone. The mounded and

terrace-like fluvioglacial deposits are water-sorted and have been deposited by the action of meltwater within and around the former ice-sheet. Some of the materials of which the deposits are constituted may have been transported many miles before being mixed with locally-derived rock debris. Commonly, and especially where the local rocks are lava types, up to 50 per cent or more of the drift pebbles may be of local origin. Alluvial gravels (including terraced alluvium) resemble the fluvioglacial deposits in composition but may be more uniformly sorted in grain-size. The raised-beach deposits are commonly derived almost entirely from local materials except where they are deltaic in origin, in which case they may contain materials derived from distant sources.

Clearly the quality of the gravel aggregate will vary greatly depending upon the relative proportions of rock types present. Factors such as flakiness, shrinkage, expandability, resistance to weathering, grain shape and hardness influence the quality. The presence of a high proportion of quartzite, impure quartzite, grit, and to a lesser extent of schistose grit is desirable since these rocks are hard, weather-resistant and do not fracture easily. The presence of sandstone, siltstone and, to a lesser extent, of conglomerate is much less desirable because of the generally friable nature of these types. However, the hard component pebbles of conglomerate may be extractable from a soft matrix by crushing. The presence of coal and shale debris in the sand and gravel in any quantity is undesirable, as is the presence of limestone or shell debris for certain purposes. Excessive quantities of mudstone debris may cause problems relating to shrinkage or expansion but re-washing commonly removes most of this material which also may physically break down during a short period on the stockpile. Flaky materials such as schist, phyllite and slate are generally to be avoided where strength and hardness matter. Such materials as basalt, andesite or dolerite make an average aggregate suitable for many ordinary purposes but some of these rocks may be prone to shrinkage or expansion and to destruction by frost action which may open up their natural joints. A variable proportion of the lava debris may also be highly weathered or altered even when freshly quarried and will subsequently crumble readily.

DISTRIBUTION OF THE DEPOSITS

Within the Central Region (Fig. 2) there are four major areas of deposits. All the major valleys in the Highlands in the Stirling District have extensive spreads of morainic drift deposits and alluvium (including terraced alluvium) which represent a major resource of sand and gravel. The most extensive morainic deposits in the Highlands are present in Glen Dochart, the Braes of Balquhider and Strathfillan. In the lowland part of the Region the bulk of the economically important deposits are to be found in three major areas: (i) along the River Teith and Strathallan from Callander to Dunblane and Kinbuck in the Stirling District, (ii) along the Forth from Linlithgow to Falkirk (the Polmont area), and (iii) in the Carron and Kelvin valleys from Falkirk to Dunipace and Kelvinhead in the Falkirk District. Most of these deposits include mounded and outwash fluvioglacial sand and gravel in association with Late-Glacial deltaic and alluvial sediments. Smaller areas of mainly mounded deposits occur around Drymen, Buchlyvie and Lake of Menteith and of Late-Glacial raised-beach and deltaic deposits between Stirling and Pleau on the south side of the

Forth. Extensive mounded fluvioglacial deposits are also present in the River Devon from east of Alva in the Clackmannan District to the boundary of the Region at Powmill.

Clackmannan District

The Clackmannan District is the least well-endowed with sand and gravel deposits of the three districts of the Central Region. However, it possesses an area with considerable potential which extends from Pool of Muckart [NO 001 008] eastwards to Naemoor [NO 023 006]. In this lowland area the bulk of the sands and gravels are to be found in the valley of the River Devon (Fig. 2). Outside the Devon Valley small deposits of sand and gravel occur at Tullibody [NS 860 945] and Clackmannan but these will be described only briefly since they are probably rather thin. The sands and gravels in this District occur mainly as mounded fluvioglacial deposits but small amounts of Late-Glacial raised-beach, modern alluvial and alluvial-cone deposits are also present. The alluvial-cone deposits were formed where streams debouch from the Ochil Hills and underlie the towns of Dollar, Alva and Tillicoultry.

AREA C1: DEVON VALLEY

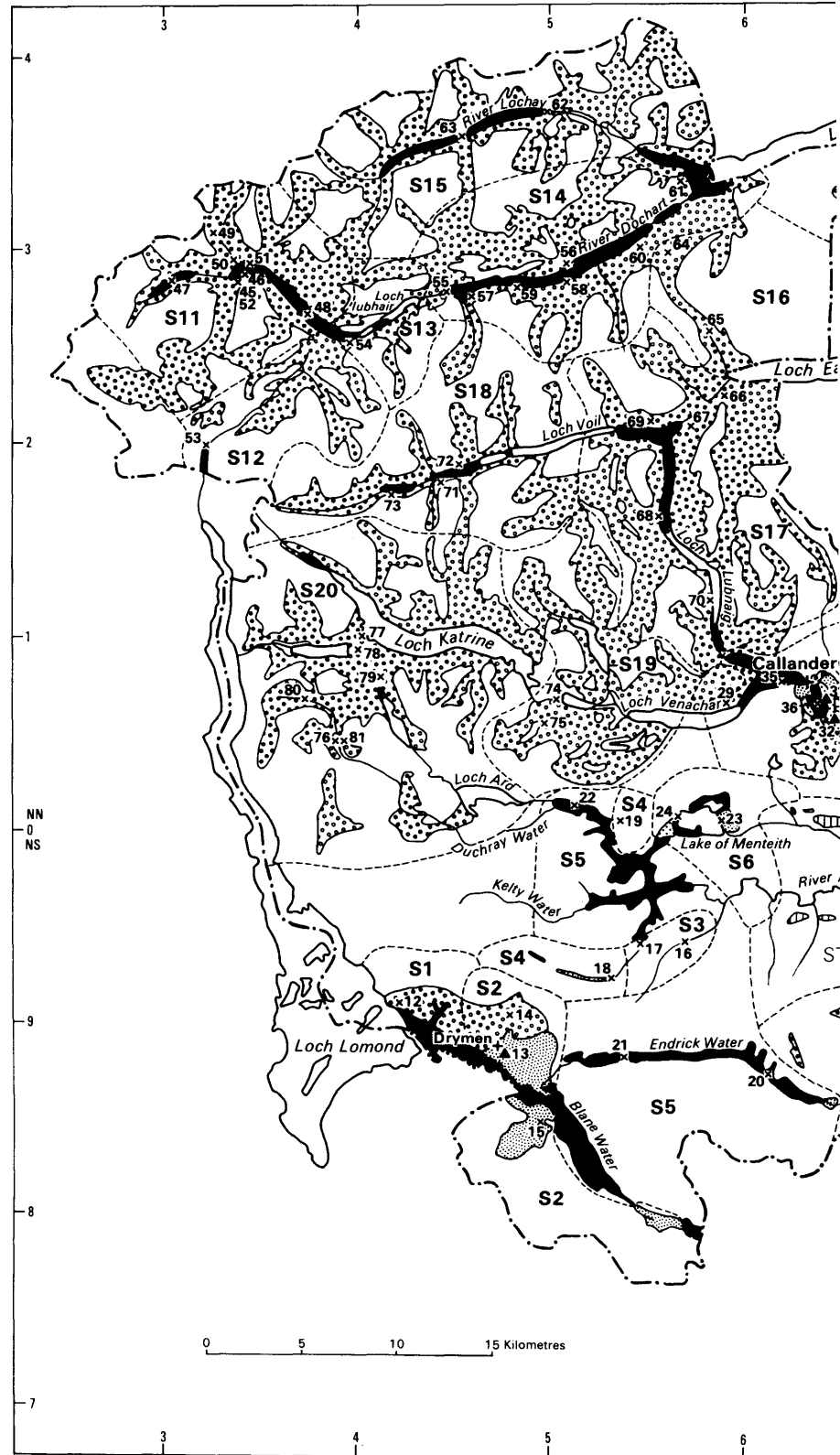
Deposits above the water-table

The mounded fluvioglacial deposits in the Devon Valley form an almost continuous spread from the eastern boundary of the Region to Dollar and discontinuously thereafter to Tillicoultry, where a mounded spread almost blocks the valley (Fig. 3). The Cunninghar Sandpit [NS 925 975] at Tillicoultry formerly worked this deposit but is now being built over. A small face up to 6 m in height showed very fine to coarse-grained sand with a bed up to 60 cm thick of medium to very coarse gravel (Appendix 2, No. 1). These deposits were cross-bedded, flat-bedded and ripple-laminated. The thickness of material was proved in boreholes to exceed 18 m just south of the main road. The pebble content of the gravel seen was rather varied and included deleterious elements such as coal and shale.

From Dollar eastwards a considerable spread of mounded fluvioglacial sand and gravel is developed, which was formerly worked in the Arndean Sandpit at Blairhill [NT 002 990]. The Blairhill locality, which is well above water-level beside the River Devon, is situated on an arm of the main spread in the Pool of Muckart area. The section showed mainly fine to coarse-grained sand with pebbly sand and gravelly bands (Appendix 2, No. 2). The deposit, which is cross-bedded and sometimes ripple-laminated, is estimated to exceed 20 m in thickness but has the disadvantage of being situated on steep ground overlooking the gorge of the River Devon, but the resources should extend to the west. The pebble content of the gravel at this locality is mixed with small amounts of poor-quality material such as coal and shale.

The main spread of fluvioglacial sand and gravel around Pool of Muckart [NO 000 004] is very poorly exposed but constitutes an important resource. The gravel, however, contains coal and shale in small quantities. Mounds up to 12 m high are present locally but the deposit appears to be only about 4 m thick in the area east of Dollar where it has been penetrated by boreholes. West of Pool of Muckart at Naemoor there is an extensive area with conspicuous mounds up to 7.5 m

Fig. 2 Sand and gravel deposits of the Central Region



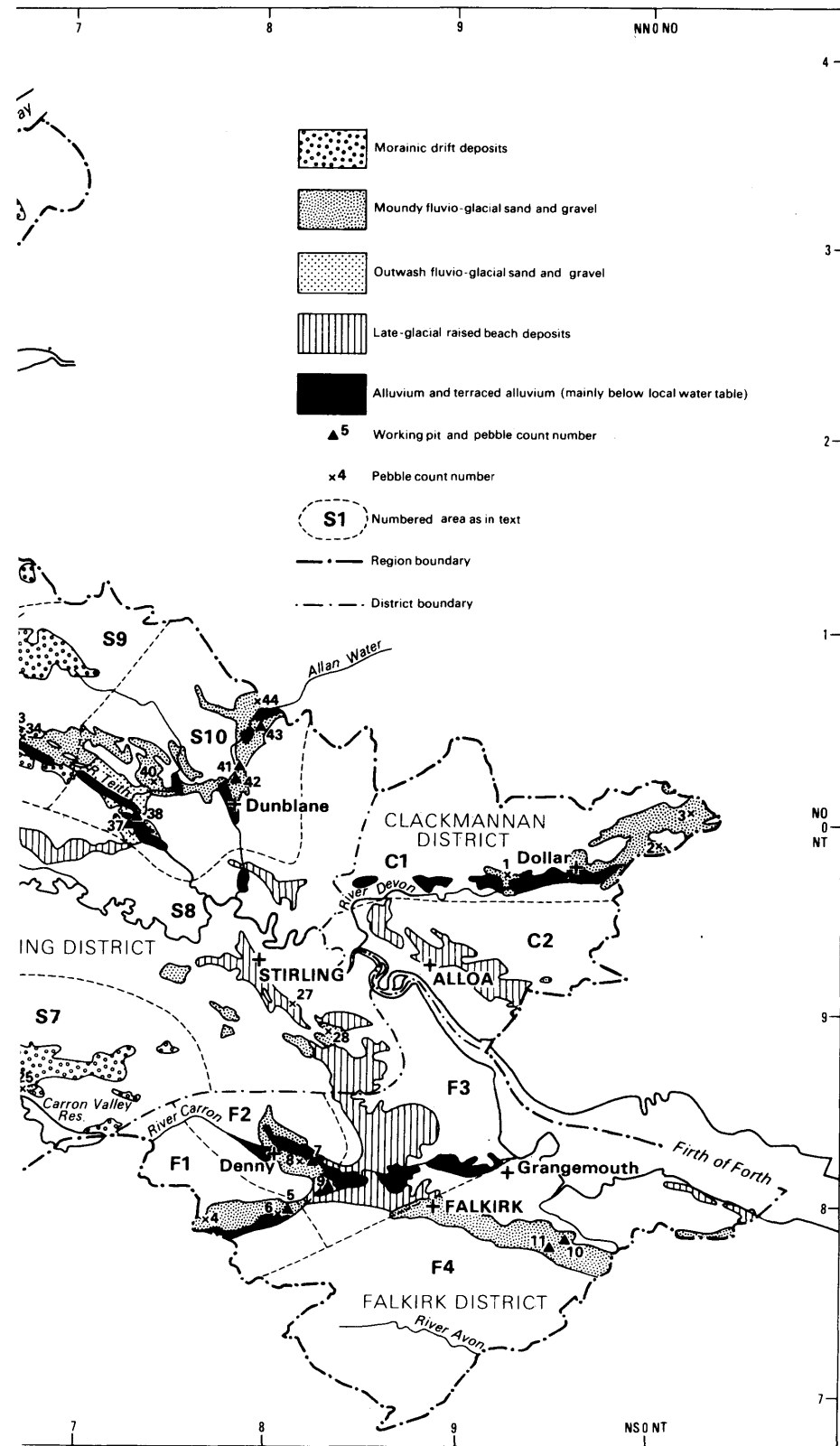
in height. An exposure in such a mound [NO 017 007] showed coarse gravel (from 4 cm to 15 cm) with a sandy matrix. The gravel was subrounded to rounded and of varied pebble content (Appendix 2, No. 3) which included shale but no coal. This unproved area of sand and gravel around Pool of Muckart is estimated to have some 50 million tonnes of resource.

There is little information regarding the quality and thickness of the other deposits of sand and gravel in the area. The towns of Alva, Menstrie, Tillicoultry and Dollar are situated on alluvial-cone deposits which could contain considerable quantities of sand and gravel but there is little field information and no

borehole data available.

Deposits mainly below the water-table

These include modern alluvium and terrace deposits. Terrace deposits are particularly well developed east of Dollar along the River Devon at Arndean [NS 990 985] and Muckart Mill [NJ 995 985]. They are, however, either too thin or of too limited lateral extent to be important. The raised-beach deposits of the Devon delta include a small proportion of sand and gravel. The bulk of the Late-Glacial sediments, however, occur in the buried channel of the River Devon (Francis and



others, 1970) and are known to exceed 90 m in thickness but consist mainly of silt and clay with some fine sand.

AREA C2: FORTH VALLEY

Although the raised-beach deposits are of considerable lateral extent in the Tullibody District and around Alloa and Clackmannan (Fig. 2) they do not represent a very important sand and gravel resource. These deposits include a considerable amount of clay which has been worked at Alloa for bricks. In temporary sections along the new Clackmannan Bypass up to 1.5 m of sand with some gravel and a little shell-debris rested on either brown clay or boulder clay. These

materials may be of use locally where the sands exceed 2 m in thickness.

A small fluvio-glacial mound occurs at Gartfinnan [NS 945 920] and may yield limited amounts of sand and gravel for local consumption.

Falkirk District

Within the Falkirk District (Fig. 2) there are extensive deposits of sand and gravel which have been classified broadly as moundy and outwash fluvio-glacial, raised-

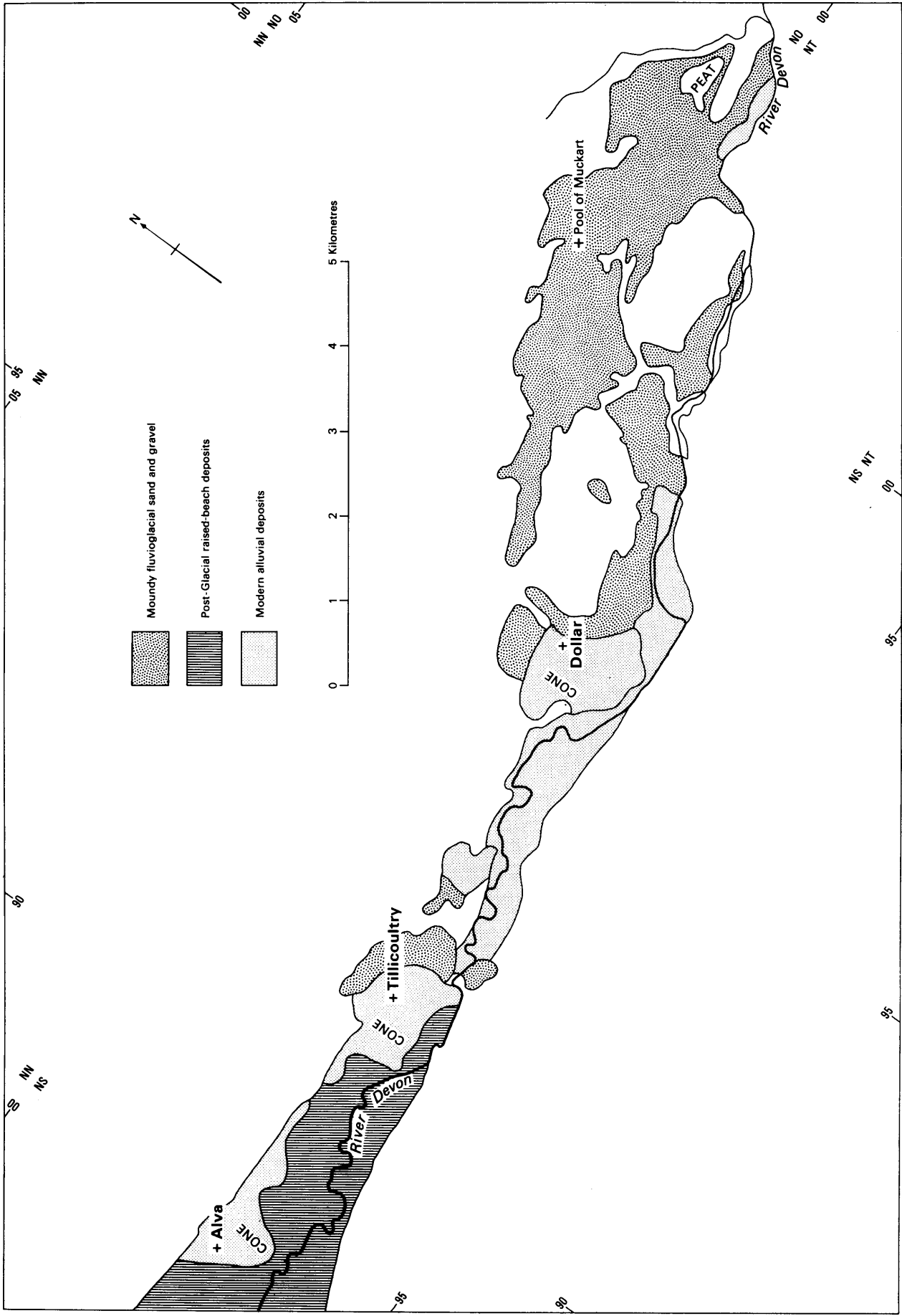


Fig. 3 Sand and gravel deposits of the Devon Valley

beach, and modern alluvium in origin. The resources of this District have been worked extensively and much of the remainder is currently sterilised by urban development. No modern geological maps are available for this area.

AREA F1: KELVINHEAD TO BONNYBRIDGE

Deposits above the water-table

An extensive area of mounded fluvio-glacial sand and gravel in the Kelvinhead to Bonnybridge area (Fig. 4) has been exploited extensively in the past. In general, the better-quality sand and gravel has been found to lie in the area between the main Bonnybridge to Kilsyth road and the Bonny Water (Fig. 4) where it is currently being worked at Bonnyfield Pit [NS 816 803] by Scottish Aggregates Ltd.

At present this pit produces about equal volumes of gravel and sand from a face 8 m high. These materials are used for building and concrete sand, for cement and plaster and also as washed sand and gravel. Recorded thicknesses of the deposit reach about 15 m but boreholes farther west near Easter Seamores [NS 815 797] have recorded some 30 m. Sections in the pit consist of fine to coarse (up to 15 cm) subangular to subrounded gravel interbedded with fine to coarse-grained sand. Pebbly sand is quite common and there are also some silty beds. The sediments are commonly cross-bedded and contain ripple-lamination in their basal part which is seen on the south side of the pit above the Bonny Water to rest on 1.5 m of grey boulder clay. In some small sections on the north-west side of the pit up to 50 cm of fine to medium gravel overlies 70 cm of very clayey fine gravel which in turn overlies 2 m or more of coarse gravel. The pebble content of the gravel is mixed and shale and coal debris is commonly present (Appendix 2, No. 4). West of Bonnyfield these deposits have been extensively worked in three old pits at Easter and Wester Seamores where small exposures of coarse gravel may still be seen. Wester Seamores includes the old Knowehead Pit and the material formerly worked here consisted of subrounded coarse gravel (Appendix 2, No. 6) with a very mixed pebble content. As a result of exploitation in the past, the remaining resource in the area is small.

It is clear from the many borehole records in the former coalfield area which lies to the north of the main Bonnybridge-Kilsyth road that the sand and gravel deposits in the general area of Banknock, Longcroft and Dennyloanhead are admixed with much clayey material of a till-like nature. As a result, they have been little worked in the past. The borehole records suggest that a maximum thickness of about 32 m is present but it is difficult to find any of them that indicates that more than 20 per cent of this thickness consists of good sand and gravel. Indeed many boreholes suggest that virtually all the material present is boulder clay. A section at Banknock [NS 773 791] showed 6 m of coarse and very coarse subangular gravel containing boulders up to 1 m in a plentiful stiff sandy matrix. The deposit showed bedding in places and contained a few thin, fine to coarse-grained gravel bands. The pebble content (Appendix 2, No. 4) was essentially a mixture of lava types, various sandstones and Highland rocks with minor amounts of shale and coal debris. The properties of these sand and gravel deposits taken as a whole are inferior and they are unlikely to be worked until better materials have been exhausted.

At Banknock, housing development is now well advanced on a prominent mound [NS 785 785] which

lies to the south of the main road but sections show that the mound mainly consists of boulder clay with only a veneer of gravel some 0.5 m to 2.0 m thick. Some gravel may also be obtained between here and Kelvinhead from the slopes to the south of the main road, but again boulder clay may be encountered at no great depth. It is apparent that in the open ground of the Bonnybridge-Kelvinhead area the best material has already been worked out and that areas which have not been exploited are either built on or contain rather low-quality material. However, some 30 million tonnes or more of sand and gravel may still be available, mainly situated to the north of the main Glasgow-Falkirk road.

AREA F2: DENNY AND DUNIPACE

Deposits above the water-table

Mounded fluvio-glacial deposits have been worked extensively from Denny westwards to Dunipace House (Fig. 4) and are now almost exhausted. In 1975 only the Headswood House Pit [NS 828 823], which is owned by Scottish Aggregates Ltd, still operated. The mounded deposits pass eastwards into deltaic deposits of the Falkirk and Larbert area. To the east and west of Dunipace there are two separate areas of mounded sand and gravel which are rather poorly exposed, but evidence from the River Carron indicated that in both areas the deposits may be about 8 m thick. A substantial area of sand and gravel beneath the town of Denny and a poorly-known elongate tract of open ground to the south of the old railway line constitute the major part of any potential reserves in the area.

In the Headswood House Pit up to 12 m of well-bedded very fine to coarse sand with pebbly sand beds and some fine to coarse gravel bands are present. These sediments are commonly flat and ripple-laminated, and less commonly, in the coarser materials, cross-bedded. Coarse gravel and boulders (up to 15 cm) are more common in the north-east face of the pit. The gravel is subangular in shape with a pebble content consisting chiefly of sandstones and lavas but in some beds fragments of coal and shale occur (Appendix 2, No. 7). Exposures in a disused pit [NS 818 824] at Denny show about 3 to 4 m of generally coarse subrounded gravel interbedded with medium to coarse-grained sand which is commonly cross-bedded (Appendix 2, No. 8). Beds with abundant coal and shale debris occur in this disused pit also. Farther south-west, Denny Cemetery is situated on a remnant of the mounded fluvio-glacial deposits. South-west of the cemetery, the gravels were formerly worked at the Leslie Park Quarry [NS 825 820]. All the exposures in this disused pit show cross-bedded sand and gravel, and also laminated, very fine sand which forms a drape over 'cores' of thick coarse-grained gravel. Whereas the bulk of the material exposed in the Headswood House Pit is sand (about 75 per cent), at Leslie Park Quarry sand and gravel appear to be present in equal amounts. The thickness of the deposit at Headswood House is of the order of 12 to 15 m though less may be present elsewhere. Approximately 30 million tonnes of sand and gravel may still remain in this area as a conservative estimate.

AREA F3: FALKIRK AND LARBERT

Deposits above the water-table

Extensive deposits of sand and gravel in this area are essentially continuous with the deposits farther west in the Bonny Water and the Carron River (Fig. 4). In the past they have been classified as raised-beach deposits

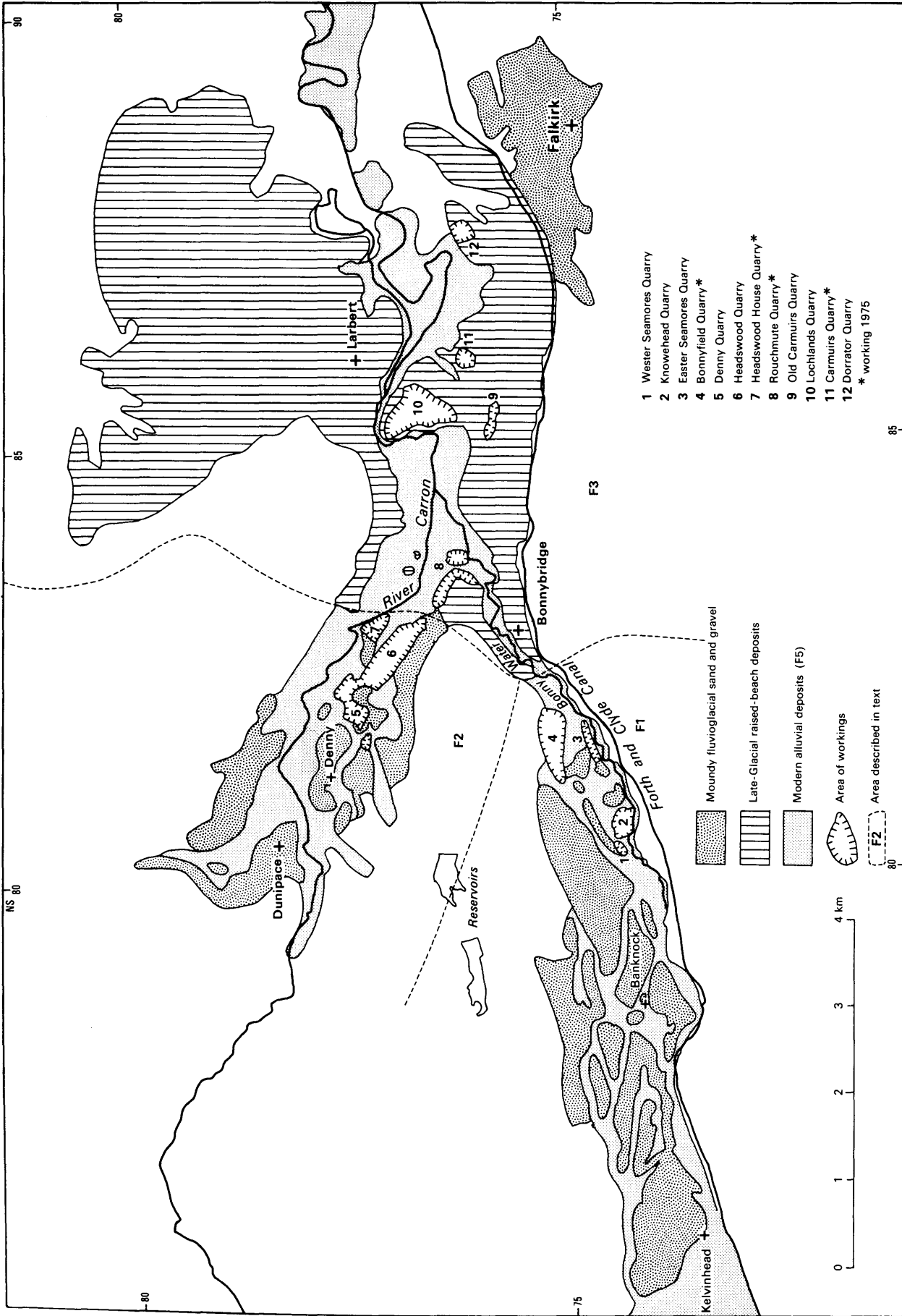


Fig. 4 Sand and gravel deposits of the Kelvinhead-Bonnybridge, Denny-Dunipace and Falkirk areas

and as fluvio-glacial outwash deposits but it is probable that they accumulated in a Late-Glacial marine delta. The deposits have been extensively worked around Falkirk and much of the resource is now exhausted or sterilised by the growth of Falkirk and the surrounding smaller townships. Currently there are only two working pits, at Rouchmute and at Carmuir. The Rouchmute Pit [NS 835 812] is an extension of an abandoned pit which has been reopened solely for the purpose of providing bedding material for local oil and gas pipeline trenches. The pit, with faces 10 to 12 m high, shows mainly very fine to coarse-grained sand with some pebbly sands and with fine to coarse gravel beds up to 2 m thick (Appendix 2, No. 9). The deposits are commonly flat-laminated or ripple-laminated but the coarser materials may be cross-bedded. Some lenses are rich in shale and coal debris. In places near the base of the pit up to 1.5 m of laminated silty clay and silt is present but some fine sand and silt occurs beneath. Reddish-brown clay laminae and thin bands may be present throughout the sequence. Further extension of this pit is limited by the golf course to the north-west.

Like Rouchmute, the Carmuir Pit [NS 863 813] has been reopened to supply material for the gas and oil pipeline trenches. The pit sections show very fine to coarse-grained sand showing flat-lamination, ripple-lamination and some cross-bedding. Graded-bedding is commonly present. Laminae and bands of brown clay are common in the basal 1 m. In the upper part of the sequence, cross-bedded fine gravel and pebbly sand occurs. Lenticles rich in coal and shale debris are also common. In the north-eastern face the finer materials are sharply overlain by fine to medium gravel with beds of coarse sand up to 1.5 m thick, which in places channel down into the lower beds. The Carmuir deposit is about 12 m thick in the pit faces and rests on laminated clays. Other disused pits in this general area, for example at Dorrator, show deposits up to 10 m thick composed predominantly of sand rather than gravel. Existing resources in this neighbourhood lie mainly beneath the golf course to the north since the rest of the Carmuir area is built over. An extensive abandoned pit at Lochlands [NS 855 818] is now used by the local burgh for refuse disposal. Sand with subordinate gravel was also worked in two old pits at Stenhousemuir [NS 868 827]. About 48 million tonnes, mainly of sand, remain in this area, and clay which is perhaps suitable for use in making bricks is present beneath.

AREA F4: POLMONT

Deposits above the water-table

This very extensive area of mounded fluvio-glacial sand and gravel, which extends from Falkirk through Polmont and Linlithgow to Bo'ness (Fig. 5), has been extensively worked around Polmont for the last decade or more. Between Falkirk and Polmont the area is effectively sterilised by early urban development and present growth and redevelopment. At present there are two active pits in this area, at Avon Glen and Nicolton. The materials from the latter pit are taken by lorry to be washed, graded and crushed at the old Kinneil Mill Pit [NS 975 783] nearer Linlithgow. In the Avon Glen Pit [NS 956 283] over 21 m of very fine to coarse-grained sand with many thick beds (4 m) of fine (1 cm) to very coarse gravel (39 cm) is exposed. The ratio of sand to gravel is estimated to be about 60:40. Beds of silt and fine sand up to 4.5 m thick also occur. Cross-bedding is common in the coarser sand and some of the finer gravel. The fine sand is usually flat-laminated or

ripple-laminated. Beds and lenticles rich in shale and coal debris are a common feature. The south face of the pit, the height of which exceeds 30 m in places, terminates against the smooth surfaces of a buried boulder-clay drumlin. The pebbles in the gravel at this locality average 5 cm to 8 cm and are subrounded, consisting mainly of sandstones and lavas (Appendix 2, No. 10). The uppermost part of the sequence seen in the working-faces is almost invariably very coarse gravel from 2 to 3 m thick.

The Nicolton Pit [NS 949 778] lies just to the south-west of the Avon Glen Pit. Some 12 to 15 m of sand and gravel is exposed with very fine to coarse sand just predominating over fine (2 cm) to very coarse gravel and boulders (25 cm). The finer materials are flat-laminated or ripple-laminated and the coarser are cross-bedded or thickly-bedded. Lenticles and beds up to 33 cm thick and rich in shale and coal are quite common. The beds of gravel reach about 2.6 m in thickness. At this locality the pebbles in the gravel average 2 cm to 8 cm in diameter and are subrounded to rounded in shape; they consist chiefly of sandstone and lava but a relatively large quantity of shale is also present (Appendix 2, No. 11). The areas which have been extensively worked at Polmont are shown in Fig. 5.

A deposit more than 9 m thick in places, which was worked in the past on the east bank of the River Avon at Linlithgow, lies mainly outside the Central Region but a small area south-west of Blackness falls within its limits. However, borehole records suggest that in this area the deposit is a thin veneer only and of little economic importance. The maximum recorded thickness is 3 m and commonly the thickness is less than 2 m.

In the ground to the east of Avon Glen and south of the old Kinneil Mill Pit borehole records suggest thicknesses of gravel up to 10 m (minimum recorded 6 m) and exceptionally 17 m on the banks of the River Avon. This ground is almost unworked but it is an area in which boulder clay drumlins may be concealed beneath the gravels. Valuable deposits of fireclay are also located hereabouts which could be worked by opencast mining. Over 90 million tonnes of sand and gravel are available in the Polmont area.

AREA F5: RIVER CARRON, RIVER AVON AND BONNY WATER

Alluvial deposits

Considerable areas of alluvial deposits are present in the Falkirk District in the floodplains of the River Carron, River Avon (west bank) and the Bonny Water but the deposits lie mainly below the water-table (Fig. 4). In the neighbourhood of their confluence [NS 844 815] the deposits of the channel and floodplain of the rivers Carron and Bonny Water consist of generally fine to coarse-grained, well-rounded gravel. These deposits appear to extend upstream from the confluence and downstream they persist as far as Carron [NS 880 824]. Beyond this place the river is tidal and the channel banks expose estuarine silt and clay. Areas of raised alluvium occur beside the River Avon and in small areas alongside the River Carron and Bonny Water as far west as Stenhousemuir. The thickness of both the modern and terrace alluvial deposits is not known in any detail although boreholes in the valley of the Bonny Water 1 km east of Kelvinhead show 23 m of sand. Boreholes on the line of the M80 Motorway bridge at Banknock show gravel

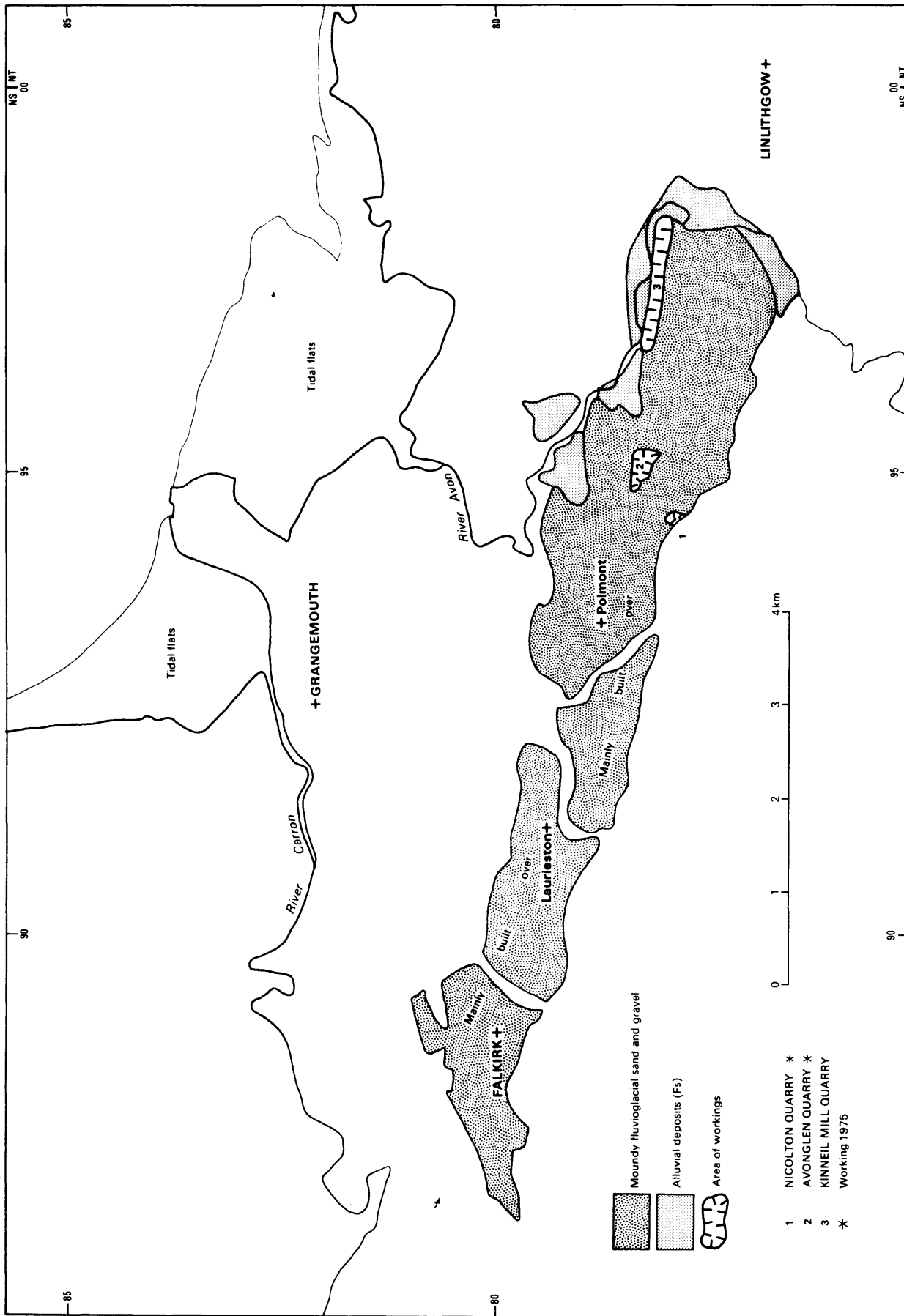


Fig. 5 Sand and gravel deposits of the Polmont area

which is generally about 6 m thick but which may reach 13 m in places. In the Carron west of Denny only 6 m of sand and gravel were proved but in the Headswood area to the east from 6 to 13 m were recorded. None of these records excludes the possibility of the presence of deep gravel-filled buried channels beneath the modern floodplains, particularly of the Bonny Water or the Carron. Indeed one borehole, at West Carron [NS 880 822] shows over 60 m of superficial deposits, part of which is alluvial gravel overlying Late-Glacial marine sediments. Other boreholes hereabouts have also proved more than 60 m of Post-Glacial or Late-Glacial deposits. These sequences consisted mainly of silt and clay.

Stirling District

The Stirling District is traversed by the north-easterly-trending Highland Boundary Fault. On the southern side of the fault the country is generally low-lying, while on the northern side it is mountainous and deeply dissected by major valley systems. The majority of the important sand and gravel resources lie in the lowland area and consists largely of outwash and mounded fluvio-glacial spreads. Considerable amounts of material are also contained in alluvial and raised-beach deposits. Modern geological maps are available for much of the area and as a result the nature and distribution of the sand and gravel deposits is generally well known.

More than half of the Stirling District lies in the area to the north of the Highland Boundary Fault. Much of this area was mapped in the early years of this century and information on the superficial deposits is less detailed. Sand and gravel occurs in two main types of deposit, the most widespread being morainic drift which occurs on the valley floors and on the lower hill slopes. The deposits are commonly less than 6 m thick on average but in Strathfillan, north of Criannlarich, and on the Braes of Balquhider, west of Inverlochrig, there are large mounds from 12 to 20 m high which contain significant amounts of sand and gravel. Resources of sand and gravel occur also in the alluvial spreads which form the floodplains of the major Highland rivers. There are in addition a number of small deposits of mounded fluvio-glacial sand and gravel. For convenience, these have been described with the morainic drift deposits.

AREA S1: BALMAHA

Deposits above the water-table

In the neighbourhood of Balmaha and Milton of Buchanan there occur a number of small mounds and local patches of mounded sand and gravel (Fig. 2). These mounds rise to a maximum height of about 7.5 m. A small exposure in a mound at Balmaha [NS 423 910] consisted chiefly of bedded medium to coarse-grained sand with some subangular to subrounded gravel. The pebbles (Appendix 2, No. 12) were chiefly of impure quartzitic rocks. Scattered exposures of a reddish-brown very sandy boulder clay were also seen. Though described in an earlier account (Anderson, 1946) as 'being too remote to be of economic interest' at least one company has sought planning permission to extract them in the past.

Deposits below the water-table

Deposits of modern alluvium occur in the area adjacent

to Loch Lomond at the mouth of the River Endrick and the Burn of Mar. These materials consist mainly of sand but some gravel is present on Gartincaber Farm in the Burn of Mar. A higher terrace showing sand and gravel at surface, may be a possible representative of the Post-Glacial raised-beach of Loch Lomond.

AREA S2: DRYMEN AND FINNICH GLEN

Deposits above the water-table

In the neighbourhood of Drymen (Figs. 2 and 6) there is an extensive area of mounded fluvio-glacial sand and gravel, currently being exploited at the Drumbeig Pit, Drymen [NS 484 882] by P. Caulfield and Co. Ltd. The general geological distribution of these materials is shown in Fig. 6. In the Drumbeig Pit an upwards-coarsening sequence of glacial sediments is well exposed. On the lower bench of the eastern working-face of the pit, up to 12 m of thinly-bedded, fine sand and silt is exposed showing flat and ripple-lamination. The upper bench shows up to 12 m of fine to coarse-grained cross-bedded sands with lenticular and erosive channel-beds of fine to coarse gravel and pebbly sand bands. The gravel is subrounded to rounded in shape and consists chiefly of pebbles of Lower Old Red Sandstone sediments and impure quartzitic Highland rocks (Appendix 2, No. 13). Most (80 per cent) of the material produced at this pit, however, is of various grades of sand.

The form of the deposit at Drumbeig is that of a series of ridges orientated north and south. To the north-west of Drymen, mounds of gravel between 6 m and 9 m high occur. Some of these mounds in the Garadhbhan Forest have been worked for making forestry roads. A section [NS 481 904] in one mound shows 5 m of angular to subrounded bedded fine to coarse gravel with beds of coarse to medium-grained sand. Unbedded, rather clayey gravel with a till-like aspect is also interbedded. The gravels consist chiefly of Lower Old Red Sandstone sediments with some quartzitic Highland rocks (Appendix 2, No. 14).

South of the River Endrick in Finnich Glen there is an area not yet exploited in which isolated mounds up to 12 m high occur. These appear to be made up chiefly of sand rather than gravel. An exposure [NS 482 837] in the river bank about 2 km southwards from the main road, however, shows 12 m of coarse gravel with a sandy matrix. The occurrence in the Glen of boulder clay and rock well above stream level makes an estimate of the volume of this resource difficult but it is likely that there is rather less gravel than previously believed (Anderson, 1946). A small exposure in close proximity to rock at the north end of the Glen [NS 497 850] shows fine to coarse subrounded gravel in a sandy matrix. The gravel consists chiefly of Lower Old Red Sandstone sediments and Highland rocks (Appendix 2, No. 15), similar to the deposit at Drumbeig. In the Drymen and Finnich area about 40 million tonnes, mainly of sand, may be available.

Miscellaneous deposits

In addition to superficial deposits of sand and gravel, consolidated sediments are also worked for aggregate and industrial sands in the Strathblane area at Muirhouse [NS 565 780]. These are interbedded sandstones and conglomerates which immediately overlie the Carboniferous lavas of the Kilpatrick Hills. The deposit ranges in thickness from 15 m to 20 m, averaging 18 m over the area. The proportion of pebbles, which consist almost entirely of quartz, is very

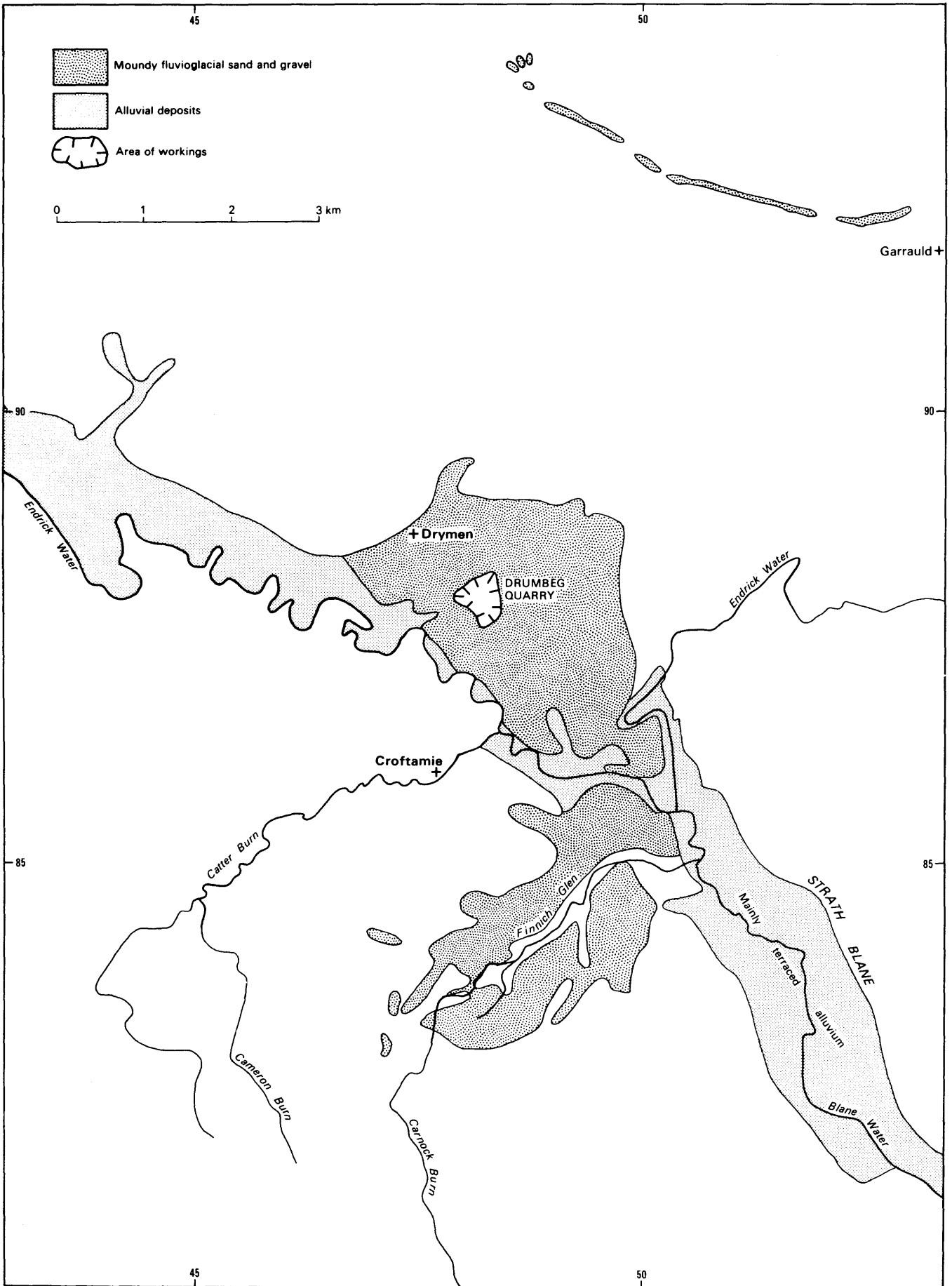


Fig. 6 Sand and gravel deposits of the Drymen area

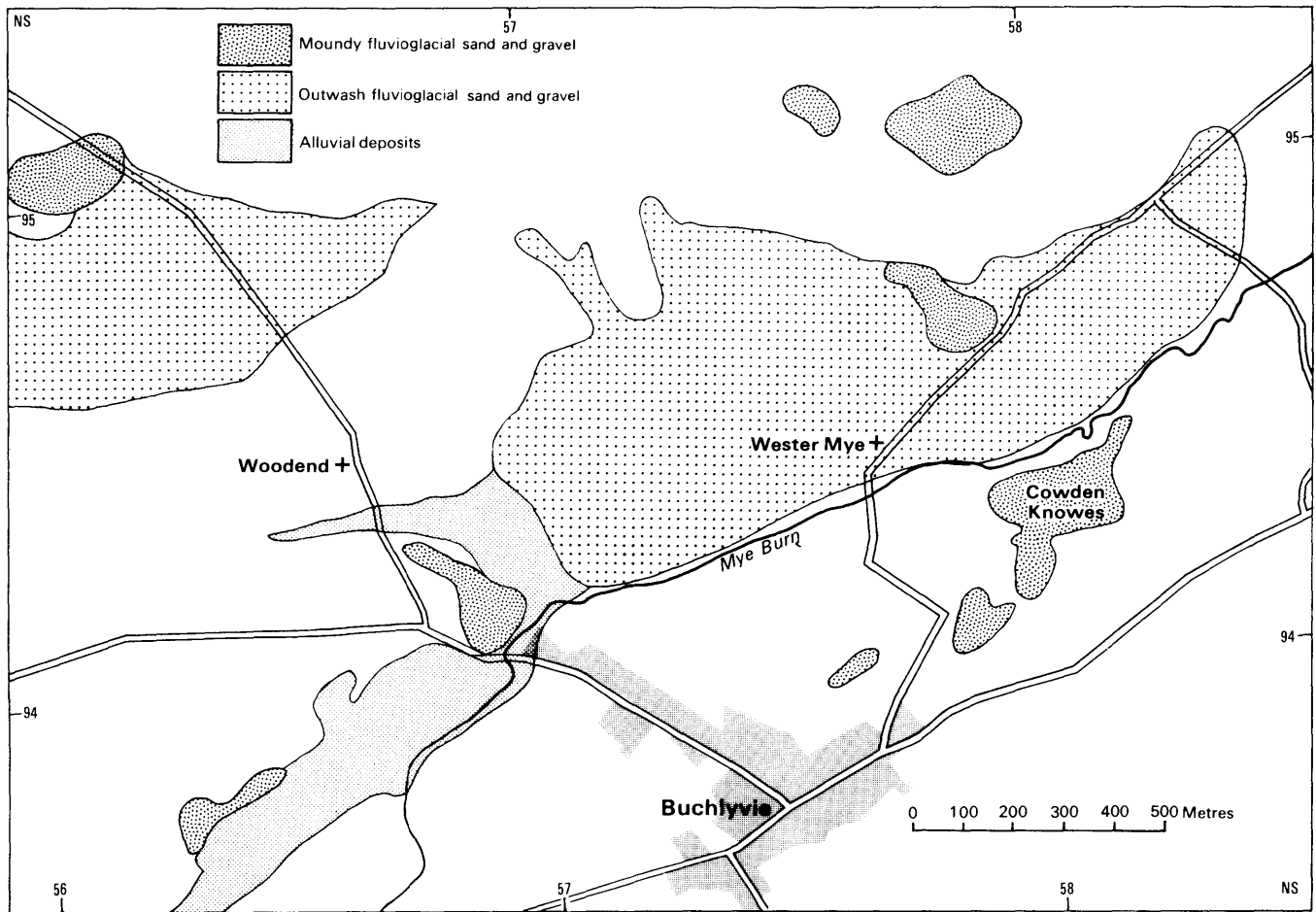


Fig. 7 Sand and gravel deposits of the Buchlyvie area

variable but averages about 40 per cent. It requires blasting before extraction and crushing before washing and grading, but produces a high-grade aggregate with very low shrinkage properties and silica sand suitable for foundry and other uses.

The deposit is known to extend under sandstone to the east but the ratio of coarse aggregate to sand decreases in this direction so that about 35 million tonnes of this deposit may be identified as resources.

AREA S3: BUCHLYVIE

Deposits above the water-table

North-east and north-west of the village of Buchlyvie (Figs. 2 and 7) scattered hummocks of moundy fluvioglacial sand and gravel are to be found. The mounds vary in height from about 4 m to 9 m and the most conspicuous of these is known locally as Cowden Knowe. In a disused sand and gravel pit [NS 568 942], dug into a mound 9 m high, an exposure showed about 2 m of subrounded, fine to coarse gravel in a sandy matrix. The pebble content (Appendix 2, No. 16) at this locality strongly resembled that at Drumbeg and Finnich Glen.

Deposits below the water-table

In addition to the conspicuous moundy deposits of gravel, the alluvial deposits of this area appear to contain gravelly materials. To the east of the village, alluvial and terrace deposits were formerly worked on a small scale [NS 585 945]. Extensive deposits of alluvial and terrace gravel of unknown thickness are present and continue outside the area shown on the map to

Kepdownrie Farm [NS 555 945]. To the south of Kepdownrie, at a road bridge [NS 548 938] near Auchentroig Farm, a temporary section revealed over 2 m of subangular to subrounded fine to coarse gravel some 4 m above the level of the modern alluvium. No gravel had been previously recorded at this locality and the extent of this material is not known. It is clear that the Buchlyvie area includes several patches of gravel of some interest but further work would be needed to define the amount of the resources present and therefore no quantitative assessment has been made.

AREA S4: GARRAULD AND ABERFOYLE

Deposits above the water-table

At Garrauld Farm about 5 km west-south-west of Buchlyvie (Figs. 2 and 6) an almost continuous ridge of moundy fluvioglacial gravel about 30 m across and from 3 to 10 m high can be traced in a generally west-north-westerly direction for almost 5 km. This esker is very poorly exposed, but the surface is strewn with large blocks of Highland rocks which commonly exceed 1 m across. At a small exposure [NS 532 921] near Garrauld Farm, angular to subangular fine to very coarse pebbles were set in a clayey sand matrix. The pebble content (Appendix 2, No. 18) was a fairly evenly proportioned mix of Old Red Sandstone rocks and siliceous Highland rocks. It is clear that this deposit is closely related in type to the morainic drift deposits in the Highlands.

At Braeval [NN 536 001] about 1.3 km south-west of Aberfoyle an elongate high ridge of glacial gravel about $\frac{2}{3}$ km long has been mapped. A large gravel pit in this

ridge, worked intermittently by the Forestry Commission, exposes up to 4 m of bedded medium to coarse subangular to subrounded gravel, often with very little matrix and with beds of medium to very coarse-grained sand. These materials may pass laterally into unbedded clayey gravel. The greater part of the original deposit has already been worked out and the smaller mounds to the south and also near Windygate [NS 533 990] now constitute the remaining sand and gravel resource in this area.

AREA S5: RIVER ENDRICK, RIVER FORTH, STRATHBLANE AND KELTY WATER

Considerable resources of sand and gravel lie in the alluvial deposits of the rivers Endrick and Forth and the Blane and Kelty Waters (Figs. 2 and 6). Exceptionally, most of the alluvial deposits of the Blane Water lie above the water-table.

The River Endrick rises in the Fintry Hills near Ling Hill [NS 673 894] and falls rapidly to the Gonachan Bridge 2 km west of Fintry. In this part of its course the river bed consists of fine to very coarse gravel and boulders chiefly of Carboniferous lavas. The small patches of associated floodplain deposits consist of sand and gravel. From the Gonachan Bridge to a point 3 km west of Balfron the river channel contains fine to coarse gravel and is flanked by a floodplain up to 0.5 km wide. The channel deposits at Fintry [NS 615 868], at East Gerchew [NS 580 885] and the Endrick Bridge [NS 540 882] consist of subrounded fine to very coarse gravel and cobbles which average between 5 cm and 15 cm and consist mainly of lavas at Fintry (Appendix 2, No. 20) but with a significant proportion of sedimentary rock types at the Endrick Bridge (Appendix 2, No. 21). The alluvial deposits of the Endrick from Balfron to Gonachan probably exceed 3 m in thickness and form a considerable resource hereabouts but they are likely to be of low quality. Between the point where the Endrick enters the fluvioglacial gravel deposits at Drymen [NS 519 877] and the confluence with the Blane Water at Killearn, there is only scanty river alluvium. From Killearn westwards to its mouth, however, the channel of the Endrick meanders through an ever-widening floodplain. Examination of sections of the overbank deposits in this part show mainly sand-grade material but with appreciable quantities of gravel in places. The river channel in this belt appears to carry sand with some gravel. The thickness of this deposit is unknown but 5 m would appear to be a very conservative estimate. As the floodplain deposits rarely stand more than 2 m above the river level, the water-table would be encountered in workings.

The low ground in Strathblane consists of alluvial deposits chiefly of sand. Very little modern alluvium is present, however, and most of the possible resource lies in a higher terrace some 4 m to 6 m above the level of the Blane. These materials were examined in temporary sections at Quinloch [NS 525 822] where about 0.5 m of clay overburden was seen to overlie 1 m of fine to medium-grained sand with very small pebbles. In the Moss Bridge area sections in the banks of the Blane showed up to 3 m of pinkish coloured fine and medium-grained sand with some silt. It would appear on the basis of the above information that in Strathblane there occurs a considerable volume of sand up to 6 m thick which is known (from borehole data) to overlie a thick deposit of clay. About 12 million tonnes, consisting mainly of sand, may be present here (Appendix 3, S5).

The deposits of the Kelty Water (Fig. 2) consist of fine to coarse gravel at the road bridge on the A81 [NS 535 963] but farther to the west, in the ground between Gartrenich Moss and Flanders Moss, the overbank material consists mainly of sand. These latter deposits occupy a restricted area only.

The alluvial deposits of the River Forth cover an extensive area south of Aberfoyle. They consist of fine to coarse gravel in the river channel and various grades of sand with some gravel in the overbank. The top surface of the floodplain deposit is between 1 m and 2 m above river level. The thickness of the deposits is not known although west of Aberfoyle they appear to be thin since solid exposures of rock are seen in the river bed. A notional thickness of 3 m is suggested but it is possible that the deposits are considerably thicker. At Aberfoyle [NN 513 014] the alluvial deposits were found to consist of subangular gravel made up chiefly of metamorphic quartzitic rocks with some slate pebbles (Appendix 2, No. 22). A similar lithology and composition occurs at Windygate Bridge [NS 533 985]. The River Forth carries gravel in its channel at least into the Flanders Moss area and sand through to Stirling.

AREA S6: LAKE OF MENTEITH

An extensive area of mounded fluvioglacial and alluvial sands and gravels occurs in the ground around the Lake of Menteith and southwards towards Arnprior (Fig. 8).

Deposits above the water-table

The glacial deposits were laid down by the last readvance of glacier-ice—termed the Loch Lomond Readvance—into this area between 10 250 and 10 800 years ago. These materials represent the terminal moraine deposited by the ice-lobe in the Forth Valley. The deposits chiefly take the form of a series of mounds or ridges up to 30 m high, which cross the Forth Valley from Port of Menteith to Arnprior in a north-to-south direction. A considerable portion of the materials making up the mounds may consist of boulder clay but sand and gravel occurs in a substantial area around Inchie Farm [NN 588 003] at the east end of the Lake of Menteith (Fig. 10). This generally hummocky ground consists of gravel and sand with some clay. A section at Inchie, beside the lake, showed 4.5 m of fine to very coarse subrounded gravel with a clayey sand matrix. The pebble content consisted mainly of Old Red Sandstone sediments and, to a lesser extent, of Highland grits etc. (Appendix 2, No. 23). The deposits appear to exceed 12 m in thickness and rest on a shelly brownish-grey boulder clay. Three small mounds 4 m high occur on Inchmahone island and scattered mounds or short ridges of glacial gravel occur at various places elsewhere around the lake (Fig. 10). One of these is at Malling [NN 567 004] where there is a ridge some 9 m high composed of subrounded gravel with pebbles predominantly of Highland origin (Appendix 2, No. 24). A series of mounds to the west of Malling links this area with the Braeval deposits near Aberfoyle. At least 4 million tonnes of sand and gravel is present in this general area. Other areas of mounded deposits occur at Keir Hill [NS 595 958] and at Easter Garten [NS 607 957] and in the intervening ground at Cardross Bridge.

Remnants of raised-beach and terrace alluvium are present on the north side of the Forth at Rednock [NN 600 001] and Flanders Hill [NS 607 991]. On the south side of the river, raised-beach deposits occur between Arnprior and Laraben Farm. These deposits, which

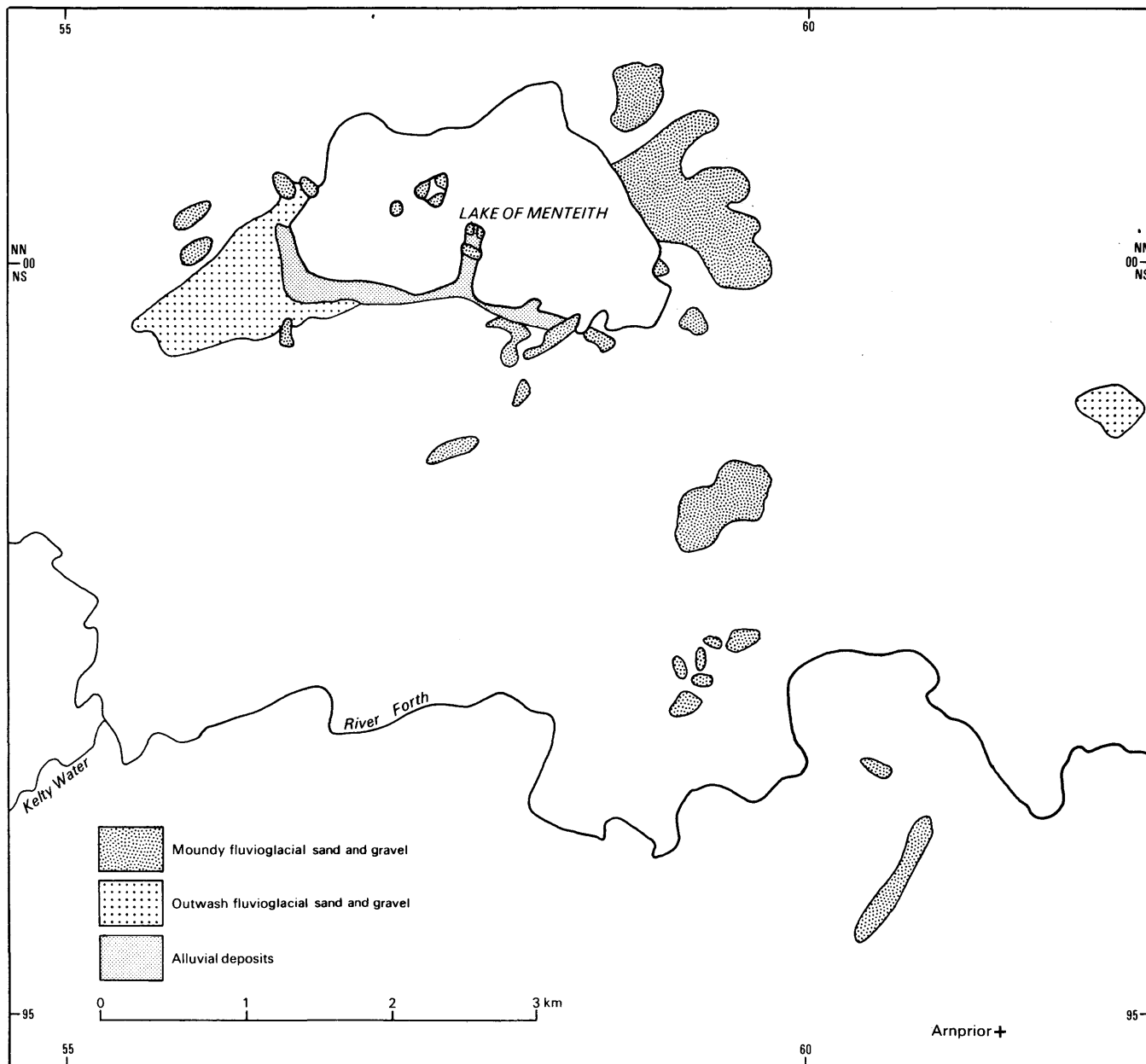


Fig. 8 Sand and gravel deposits of the Menteith area

consist of sand and gravel in varying proportions, in some cases resting on laminated marine silt and clay, are generally of unknown thickness. From a detailed investigation of the area to the east of Menteith it is clear that one of these terraces, composed of outwash sand and gravel, descends eastwards and passes beneath marine (Carse clays of Post-Glacial age. Borehole records show that between Menteith and Stirling Late-Glacial and Post-Glacial sand and gravel up to 30 m thick occurs beneath the Carse clays and overlies marine silt and clay.

Deposits below the water-table

On the south and west shores of the Lake of Menteith there is an alluvial terrace, or former beach, some 2 m above the level of the water which is made up of gravel and sand. To the west of this terrace there is a gravelly area which persists as far as Loch Macanrie [NS 562 994].

AREA S7: FINTRY HILLS

Deposits above the water-table

An extensive development of sand and gravel which has been classified as morainic drift deposits occurs in the Fintry Hills (Fig. 2) and is particularly well developed around Loch Walton and the headwaters of the River Endrick. Exposures showed 1 m of fine to coarse (2 cm to 8 cm) subangular to subrounded gravel overlying up to 6 m of unbedded, very sandy gravel near the Carron Reservoir [NS 675 858] (Appendix 2, No. 25) and resting on 9 m of fine to coarse cross-bedded sand at Loch Walton [NS 665 865] (Appendix 2, No. 26). These two exposures indicate that the deposits are of a very variable nature. The mounds and ridges of this area may reach from 9 m to 12 m in height. A considerable amount of sand and gravel could be present but since there is a very high proportion of lava and friable sedimentary rock types in the pebble content it is probable that the resource is of rather low quality.

AREA S8: STIRLING AND PLEAN

Deposits above the water-table

In the Stirling, Bridge of Allan, Thornhill, Cowie and Plean areas (Fig. 2) there are fairly extensive areas of Late-Glacial raised-beach and deltaic deposits. Smaller areas occur near Kippen at Touch Hill, and in the Allan Water near Bridge of Allan. With one or two exceptions these deposits are thin and consist of bedded fine to coarse-grained sand and some gravel which overlies a variable thickness of silty marine clay. The marine clay may also form much of the surface deposit of these beaches with little or no sand and gravel being present. At Cambusbarron, near Stirling, the deposits appear to be of deltaic rather than littoral origin, and were formerly worked on a large scale at several localities where they are up to 9 m thick and consist of fine to coarse-grained sand with some gravel. Most of this area is now built up.

In the Bannockburn area a small (1.5 m) exposure [NS 815 903] in the Late-Glacial raised-beach sediment shows subangular to subrounded, fine to coarse gravel which consists predominantly of sandstone together with subordinate Highland rocks and some Carboniferous mudstone (Appendix 2, No. 27). This deposit, however, and similar occurrences at Cowie are unlikely to represent a major resource; but at Plean [NS 840 870] the sand and gravel of deltaic and beach origin may be up to 12 m in thickness.

Moundy and outwash fluvioglacial deposits occur in a series of small spreads at Touch Hill near Cambusbarron which extends south-eastwards to Cowie where until recently a gravel pit was still working. The gravels are up to 12 m thick at Cowie but are somewhat thinner elsewhere and only 3 to 4.5 m thick near Bannockburn. Small exposures indicate that both sand and gravel are present but the Berry Hills Pit at Cowie [NS 836 894] shows only 2 or 3 m of bedded sand with some fine to coarse subangular gravel (Appendix 2, No. 28) in the only visible face. These deposits may contain as much as 50 million tonnes although large areas have been worked or sterilised by buildings.

AREA S9: CALLANDER TO DOUNE

Deposits above the water-table

Extensive areas of moundy and outwash fluvioglacial sand and gravel occur in the Teith Valley around Callander and Doune (Figs. 2, 9 and 10). Terraced outwash deposits are prominent for 3 or 4 km south-east of Callander and also from Burn of Cambus [NS 705 030] to Doune. In between these two areas mainly moundy and kettle-holed deposits occur. At several localities mounds of gravel occur in otherwise terraced areas. In 1975 there were two working pits, one at Cambusmore and the other at Cambusbeg. The pits in the vicinity of Doune, which have been described in detail by Forsyth (*in* Francis and others, 1970), are now all defunct.

Remnants of outwash fluvioglacial terraces, and limited areas of moundy deposits occur north and west of Callander as fringing deposits to the recent and terraced alluvial deposits. Similar deposits also occur on the northern shore of Loch Venachar at Portnellan [NN 589 063] and on the southern shore of the loch about 1.5 km west of Easter Dullater [NN 590 054]. A section at a small-scale working near Portnellan shows 4.5 m of fine to coarse subrounded gravel and beds of coarse sand. The pebble content (Appendix 2, No. 29) consists chiefly of impure quartzite rocks of Highland

origin.

In the neighbourhood of Callander, moundy and outwash terrace deposits are present but are mainly confined to the east bank of the River Teith where they were seen in temporary sections alongside the main road between Callander and the Keltie Water bridge. They are best seen, however, in a series of exposures in the Cambusmore Sand and Gravel Pit (Springbank Sand and Gravel Co. Ltd). In the more easterly exposures in the pit at Ballochallan [NN 655 053] moundy and outwash fluvioglacial sand and gravel as well as terrace and alluvial deposits have been worked. Exposures in the moundy deposits show up to 4 m of coarse (7 cm to 15 cm) and very coarse angular to subangular gravel and cobbles in a clayey sand matrix. A pavement of coarse (1 m plus) boulders is present in this sequence. Traces of bedding are seen in the upper part of the section. In a section farther east [NN 653 062], 3 m of this material rests on 30 cm of bedded, coarse to medium-grained sand (Appendix 2, No. 30). Exposures of the outwash fluvioglacial, terrace and alluvial deposits worked here are rather poor but consist generally of medium to coarse gravel (2 cm to 7 cm). At present the Springbank Sand and Gravel Co. is working some distance away from the original pit at Ballochallan. The new pits are situated near Gart House [NN 643 064] on the west bank of the Keltie Water. Exposures in the Gart pits show moundy and outwash fluvioglacial sand and gravel and terrace alluvial deposits. One exposure [NN 643 064] on the side of a mound shows up to 3 m of coarse subrounded to rounded, crudely-bedded gravel and boulders (over 1 m), with thin beds of fine gravel and sand. A block of volcanic conglomerate measuring 3 × 2.5 × 3 m was seen in this face. In the main working-face [NN 645 060], predominantly coarse (up to 15 cm but averaging between 5 and 10 cm) subrounded to rounded gravel and boulders was seen with, near the top, a bed of very clayey gravel up to 1 m in thickness. Bedding is usually inconspicuous except in the west face where thin beds of fine gravel and sand are seen. Rather more gravel than sand is present at this pit. The thickness of the deposits may exceed 6 m, the water-table lying about 4.5 m below the surface. The distribution of the present workings suggests that future development lies eastwards in the direction of St Mary's Well Wood and northwards along the west bank of the Keltie reaching as far as the A84 trunk road. To the north of the road, the moundy and outwash fluvioglacial deposits of the Keltie Water may also be thick enough in places to be workable, although rock is exposed in the stream bed from Wester Bracklinn northwards.

To the south-east of Cambusmore the deposits are chiefly in elongate mounds with intervening deep hollows. The deposits here are much more variable in lithology than at Cambusmore and range from very coarse gravel to silt and clay. They are currently being exploited at Cambusbeg by Callander Sand and Gravel Co. Ltd, producing sand and gravel in the ratio of approximately 7 to 3. In the northern corner of the pit a layer up to 2.5 m thick of boulders (15 cm to more than 1 m long) overlies a thin bed (0 to 1.3 m) of laminated silt and sand which in turn rests on a thin bed (up to 1.3 m) of fine and medium gravel. This gravel overlies a bed (maximum thickness 3 m) of grey till or moraine with large angular blocks set in a clayey matrix. It seems likely that to the west of this section up to 24 m of deposits have been removed in the old workings which have been back-filled to a depth of some 12 m.

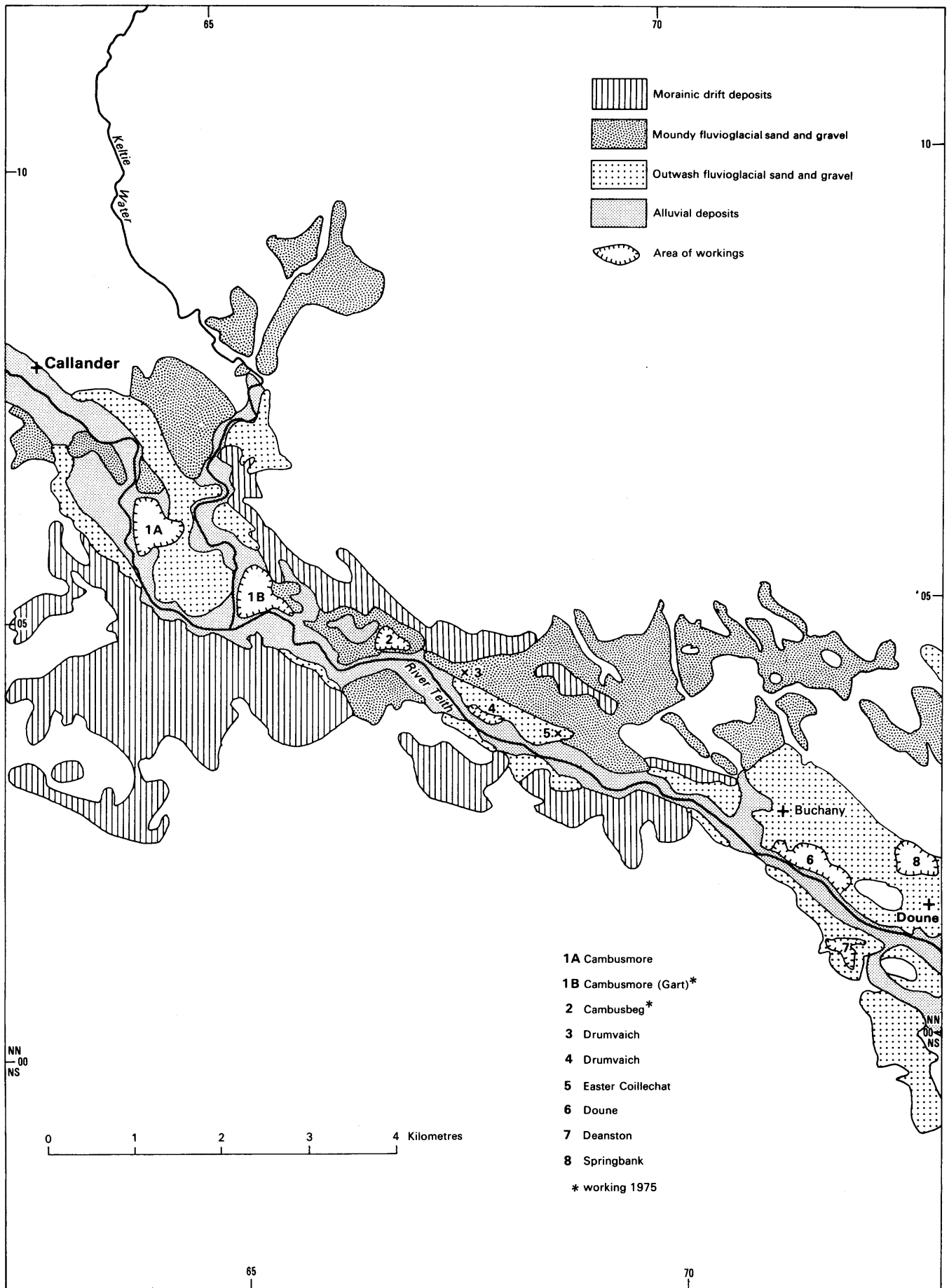


Fig. 9 Sand and gravel deposits of the Callander area

Exposures in the western part of the pit show up to 3 m of bedded coarse gravel and cobbles (from 2 cm to 12 cm) resting on a deposit which ranges from silty clay (rare), through fine silt and fine sand to coarse-grained sand, pebbly sand and fine gravel. These deposits may be flat-bedded, ripple-laminated, or cross-bedded. In places the lower silt and sand layer is overlain by wedges of boulder clay up to 1.5 m thick. In the southern side of the pit, coarser sediments are generally present and pebbly sand is very common [NN 667 046]. Cementation of the sand by calcite into a hardpan is common. In all, some 3 m of coarse gravel is seen to overlie 9 to 12 m of sand and silt. It is recorded that these beds rest upon some 12 m of coarse gravel in the back-filled parts of this pit. Because of the size of the mound at Cambusbeg the areal extent of the workings has changed little over twenty years since the Institute of Geological Sciences mapped the Callander district, and mounds in the near vicinity clearly would permit further developments. The gravel at Cambusbeg contains pebbles which are in general subrounded and consist principally of Highland rocks with some local Lower Old Red Sandstone sediments (Appendix 2, No. 33).

South of Cambusbeg many attempts have been made to open up pits in the Drumvaich area, in the mounded fluvio-glacial and terrace alluvial deposits which extend as far east as Lower Coilentowie [NN 695 033], but none have survived for long. The main problems appear to have been that the mounded deposits contain a high proportion of cobbles and boulders and that the better-quality terrace and alluvial gravels are too limited in area. At Drumvaich [NN 675 045] a poor exposure in an old pit shows coarse and very coarse subrounded gravel with boulders in a sandy matrix, the pebbles consisting chiefly of Highland rocks (Appendix 2, No. 34). A small area of terrace deposits has been worked to the south of the main road at Western Coillechat [NN 680 037]. These deposits consist of well-bedded subrounded gravel which averages from 2 cm to 8 cm in diameter. It is clear from this survey that a considerable volume of sand and gravel is present, and when the more attractive parts are exhausted interest will revive in these deposits.

At Buchany, on the east bank of the Burn of Cambus, an extensive outwash fluvio-glacial terrace is present which persists south-eastwards along the banks of the Teith to Blair Drummond. These deposits have been extensively worked in the neighbourhood of Doune and Deanston but at the moment there are no active pits. In the poor sections currently available fine to very coarse subrounded gravel interbedded with sand is present. The area of apparently worked-out ground is shown in Figures 9 and 10. The most obvious area for future development is in the ground west of the original Springbank Pit, that is north from Doune Railway Station, towards Buchany. The thickness of the deposit is known to reach 12 m with an average thickness of the order of 5 m in the old workings. One problem previously encountered in this area is the presence of buried drumlins which can substantially reduce the volume of material available. Limited areas may still be workable on the southern side of the river as far as Blair Drummond but are restricted to the area just south of Doune on the northern bank. The major unknown factor in these areas is the thickness of the deposit except near Deanston where they have been proved to a depth of 4 to 6 m.

West of Callander there are several terrace and alluvial areas which comprise fine and coarse gravels.

Near Callander Cottage in the Eas Gobhain area [NN 620 075] the gravel is subrounded to rounded and consists largely of Highland quartzitic rocks (Appendix 2, No. 35). A similar high-quality material probably forms the raised terraces of the Teith between Callander and Kilmahog. Extensive areas of terrace and modern alluvium exist south-east of Callander and more than 2 m of these deposits have been worked recently at Gart [NN 640 063]. They consist of subrounded fine to coarse gravel with boulders (maximum size 10 cm) which contains abundant pebbles of Highland rocks and smaller amounts of Lower Old Red Sandstone sediments. It is possible that these deposits reach 6 m in thickness. South-east of Gart many small patches of terrace and modern alluvium occur but, with the exception of the gravel seen in the Cambusmore Pit, they apparently have not been worked on anything but a very minor scale.

South of Doune on the Blair Drummond Estate the terrace deposits are being extensively worked by the Springbank Sand and Gravel Co. Ltd at the Valley of Coustry [NN 729 000] and Low Daira [NN 735 002] pits. In the first of these, from 2 m to 4 m of bedded subrounded to rounded gravel and boulders (5 cm to 24 cm diameter) is being exploited (Appendix 2, No. 37). Beds of fine to medium gravel, pebbly sand and bedded sand are also present. The water-table is generally about 4.5 m below surface level but, in trial holes at the northern end of the pit, very coarse angular gravel was found which has led to the abandonment of the deeper workings below water-table. At Low Daira the conditions are essentially similar with up to 3.5 m of the gravel (Appendix 2, No. 38) being worked. Reddish-brown boulder clay occurs in the floor of the eastern side of this pit. There is scope for further operations in this general area but the presence of boulder clay drumlins at surface and the possibility of the existence of buried ones indicates that its potential may be restricted. The Blair Drummond terrace deposits descend beneath the Post-Glacial Carse Clay in the neighbourhood of Blair Drummond House [NS 735 989] as shown by a trench section at Nyadd [NS 747 972]. It is clear from the geological history of this neighbourhood that a very large gravel fan formed at the mouth of the Teith during the final retreat of the ice-sheet about 10 000 years ago. This fan may extend as far east as Stirling and its thickness could reach from 3 to 5 m in places. It is overlain by some 2 to 3 m of Carse Clay. In all it is estimated that about 130 million tonnes of sand and gravel may be present in the Callander-Doune area.

Deposits below the water-table

A terrace near Callander Cottage in the Eas Gobhain [NN 620 775] consists of fine to coarse gravel which consists mostly of impure Highland quartzitic rocks. It is thought that the modern alluvium of this general area, which extends from Loch Venachar and Kilmahog to Callander, is also of this nature and varies from fine to coarse grade. Similar modern alluvium occurs south-east of Callander into the Gart area.

Miscellaneous deposits

Extensive morainic drift deposits are present in three distinct areas: (i) in the Torrie Forest at Lenniaston Muir [NN 645 045], (ii) in the Teith Valley as far downstream as Lanrick [NN 700 025] and (iii) to the north-east of Middle Brackland [NN 680 000]. Many of the exposures near Middle Brackland and on

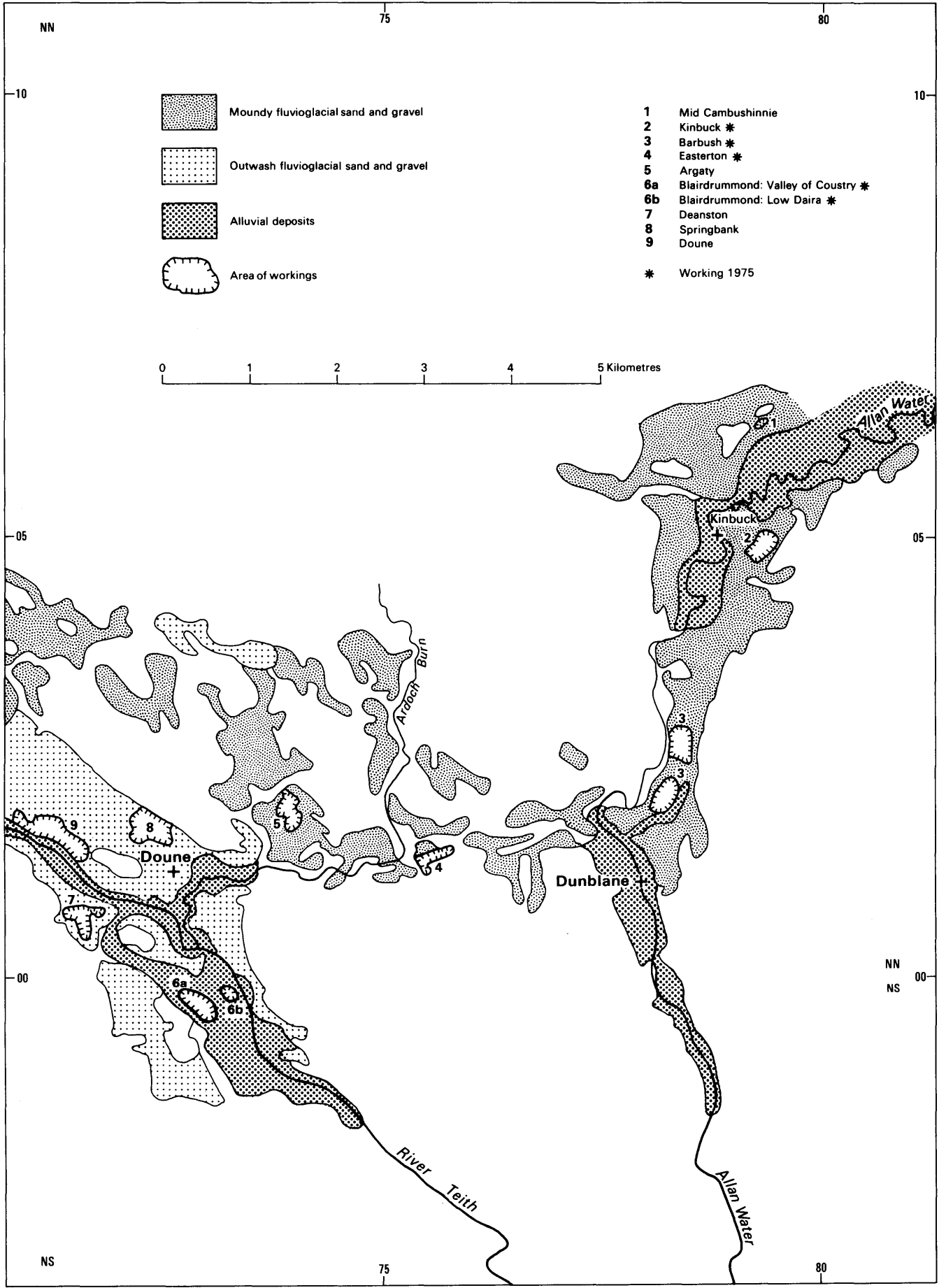


Fig. 10 Sand and gravel deposits of the Doune and Dunblane areas

Lenniaston Muir show angular gravel mostly composed of locally-derived sandstone, in a clayey matrix. A temporary section in these deposits at Cambusmore [NN 653 062] showed coarse angular sandstone debris in a generally stiff sandy and silty matrix (Appendix 2, No. 39). Although trial pits dug near Mid Torrie Farm by a commercial company were said to be discouraging, these deposits could provide low-quality materials in some quantity.

AREA S10: DOUNE TO MID CAMBUSHINNIE

Deposits above the water-table

The principal resources of this area consist of mounded fluvio-glacial sand and gravel deposits which occupy Strathallan between Mid Cambushinnie and Dunblane (Figs. 2 and 10). Smaller spreads of similar type occur in the area to the north and north-west of Doune and in the col which links the Teith Valley with Strathallan.

At present, there are two working pits in the area, at Barbush and Kinbuck which lie to the north of Dunblane. At the first of these, sand and gravel up to 15 m thick is worked by Andrew Fleming and Sons at two separate sites. A working face [NN 786 026] at the more northerly of these shows 12 m of coarse and very coarse subangular to subrounded gravel with boulders up to 30 cm across. The deposit is laterally variable and at one point coarse gravel gives way in a distance of less than 30 m to flat and ripple-laminated silt and fine sand with subordinate layers of pebbly sand and clay. These deposits are overlain by a variable thickness of medium-grained gravel with pebbles from 2 to 5 cm in diameter. In the 9-m high working face seen in the more southerly pit [NN 785 023] there is a greater thickness of gravel at the top of the sequence. Units of graded bedding up to 1 m thick are quite common but otherwise the deposits in the two pits are essentially similar. In this area there are considerable reserves northwards to Ashfield Farm and beyond. The pebble content of the gravels consist chiefly of Lower Old Red Sandstone sediments and includes 2 to 9 per cent of Cromlix Mudstone (Appendix 2, Nos. 41 and 42). It is not therefore a particularly high quality gravel but a second washing of the aggregate after allowing stockpiles to weather would remove most of the mudstone.

Farther north in Strathallan, the mounded fluvio-glacial deposits are being worked at Kinbuck [NN 796 050] by P. S. Nelson and Sons. The deposit probably reaches 30 m in thickness in places and consists of mainly thinly-bedded, flat or ripple-laminated sand and silt with some subrounded gravel of various sizes and types (Appendix 2, No. 43). At least 75 per cent of the material produced is of sand size. In general the Kinbuck Pit demonstrates an overall upward coarsening and the deposit also appears to become coarser towards the east. The coarser units are commonly cross-bedded and exhibit channel-like forms. The mounded deposits were formerly worked 2 km farther north, at a disused pit at Mid Cambushinnie [NN 796 062] which shows 2 to 3 m of bedded subrounded fine to coarse gravel (2 cm to 5 cm) and boulders (up to 23 cm), with beds of sand up to some 30 cm thick. The pebble content (Appendix 2, No. 44) was similar to Barbush.

The fluvio-glacial deposits in the neighbourhood of Doune have been less extensively exploited in the past. There are disused workings, however, near Argaty House [NN 737 031], to the south-east of Mansfield [NN 723 024] and near Netherton [NN 740 020]. At these localities, although the deposits may reach 12 m in

thickness, two of these pits had short lives, possibly due to the high proportion of silt and very fine-grained sand. The current programme of pipeline construction created a demand for soft fill and an abandoned pit near Easterton [NN 756 015] was re-opened for a time during 1975 to work fine-grained sand and silt. At the disused Argaty Pit near Netherton, where the ground is being reinstated, only small exposures remain, showing mainly fine to coarse-grained sand with subordinate gravel.

It is apparent that the Dunblane area contains very important resources of sand and gravel which are estimated at some 60 million tonnes. It is to be expected that commercial interest in this area will soon become more active.

Deposits below the water-table

The alluvial deposits of Strathallan appear to be mainly of sand-grade material but only a relatively small area of the main part of the alluvial spread falls within the Central Region. These materials are of unknown thickness, perhaps reaching as much as 4 to 5 m or even more.

AREA S11: STRATHFILLAN, TYNDRUM AND CRIANLARICH

This Highland valley (Fig. 2), some 11.2 km long, is floored with gravelly deposits. Most of this material has been classified as morainic drift but there are considerable spreads of modern alluvium in the floodplain of the River Fillan and its tributary, the River Cononish. Locally, beside the River Cononish, terrace gravels are also present. At least 160 million tonnes of sand and gravel of various kinds are available in this area.

Deposits below the water-table

A small area of modern alluvium composed of fine to very coarse-grained (average 15 cm) subrounded gravel of unknown thickness occurs in the neighbourhood of Tyndrum. Farther south, in the valley of the River Cononish near Dalrigh, about 2 m above the level of the modern alluvial floodplain a remnant of terrace is preserved [NN 387 286]. A section in this material showed about 2 m of fine to very coarse, subangular to subrounded gravel (Appendix 2, No. 46) in a coarse sandy matrix. This deposit rests on generally flat or ripple-laminated silt and fine sand which may be of morainic origin. Beds up to 15 cm thick of coarse sand are interbedded in the gravel. The modern alluvium in this general area appears to range from fine to very coarse subangular to subrounded gravel, as seen in the river channel, to sand seen in a section [NN 342 288] exposed by erosion in the river bank. It is difficult to assess the ratio of sand to gravel in the alluvium which may exceed 3 m in thickness. The pebble content (Appendix 2, No. 46) of these deposits consists chiefly of metamorphic grits, schistose grits and impure quartzite. Alluvial deposits also occur near Cononish Farm farther west in the River Cononish valley and in the river bed range from very fine to coarse subangular gravel (Appendix 2, No. 47). This deposit rests on or is eroded into the sands, silts, and subordinate gravels of the overbank deposits. Alluvial gravel of this type has been worked about 0.6 km east of the farm to provide aggregate for forestry roads.

A belt of alluvial deposits 0.5 km wide forms the floodplain of the River Fillan from Dalrigh to Crianlarich. Beside the bridge at Inverhaggernie Farm

[NN 373 266] the material in the river bed was found to consist of fine to very coarse, subrounded gravel chiefly of schists, schistose grits and impure quartzites (Appendix 2, No. 48). The floodplain which at this point is about 1 m above the general level of the river appears to contain both sand and gravel. A thickness of at least 3 m seems probable and the deposits may be much thicker. Until about 1965, alluvial gravel, said to be of a very high quality, was worked in this neighbourhood by P. Caulfield Ltd during the construction of various hydroelectricity works. In the neighbourhood of the high-level railway bridge at Crianlarich and for about 1 km westwards, the floodplain deposits of the River Fillan appear to be made up almost entirely of sand of varying grain-sizes.

Miscellaneous deposits

North-west of Clifton [NN 324 306], at the northern end of Strathfillan, morainic mounds up to 9 m in height appear to be composed of material ranging from clay or silt to very coarse-grained angular gravel consisting chiefly of metamorphic grits, schistose grits and impure quartzites (Appendix 2, No. 49). On the hillsides to the west of Tyndrum Lower Station [NN 326 303], smaller morainic mounds up to 4.5 m in height occur; in these mounds the proportion of clayey matrix is greater. About 1.6 km south of Tyndrum at Dalrigh Farm [NN 337 290], the morainic mounds on the west side of the main road in some cases exceed 15 m in height but are commonly about 10 m high. Exposures in this area were few in number but showed fine to very coarse, subangular gravel (Appendix 2, No. 50) with a generally sandy matrix [NN 337 290]. On the eastern side of the main road, a quarry, opened in a hummock 6 m high [NN 345 290], shows coarse and very coarse angular gravel with a mainly unstratified, clayey sand matrix with some rare silt or sand bands up to 0.15 cm thick (Appendix 2, No. 51). On the southern bank of the River Cononish [NN 336 285], but generally to the north of the Crianlarich to Fort William railway line, a fragment of a kame-terrace is preserved, the top surface being at about the same general level as the top of the morainic hummocks. It is likely that this deposit is about 30 m thick. The pebble content of all these deposits is uniform consisting chiefly of metamorphic grits, schistose grits and impure quartzites (Appendix 2, No. 52).

To the west of the railway line, the high morainic hummocks appear to persist as far as the west end of Coille Coire Chuilc Wood after which the hummocks are subdued and rarely exceed 4 or 5 m. Small exposures in this area indicate the presence of laminated silt and sand as well as angular fine to coarse gravel. Less subdued hummocky ground, but with a relief of no more than 6 m, is present also in the neighbourhood and to the west of Cononish Farm [NN 300 282]. South-eastwards from Dalrigh the morainic drift deposits persist as far as Crianlarich in a belt several kilometres wide on the valley sides. Sections beside the main road indicate the presence of bedded sand and silt as well as sandy, fine to very coarse gravel.

AREA S12: GLEN FALLOCH, CRIANLARICH TO INVERARNON

The Glen Falloch area (Fig. 2), some 11 km in length, is in part covered by sand and gravel. Much of this material is classified as morainic drift deposits but at the north end of Loch Lomond a spread of modern alluvium is also present.

Deposits below the water-table

South of Glen Falloch Farm to Inverarnon the River Falloch has deposited a considerable area of alluvium at the head of Loch Lomond. The river channel [NN 322 197] contains fine to very coarse subrounded gravel consisting chiefly of schistose grits, grits and impure quartzite (Appendix 2, No. 53). The floodplain deposits seem to contain both sand and gravel. The thickness probably exceeds 3 m but the proportion of sand to gravel is not known.

Miscellaneous deposits

The morainic drift spread of Strathfillan continues in a south-westerly direction into Glen Falloch where the mounds commonly reach 6 m in height. Sporadic poor exposures on the roadside from Crianlarich Upper Station [NN 385 250] to Keilator Farm [NN 372 242] show fine to coarse-grained angular gravel in a sandy matrix. Laminated sands and silts are also present at some localities. From Keilator Farm to Glen Falloch Farm [NN 320 195], the morainic hummocks are generally low and rather more sporadic in distribution. Most of the tributary valleys of the River Falloch contain some morainic material.

AREA S13: CRIANLARICH TO LOCH IUBHAIR

Much of the low ground from Crianlarich to the eastern end of Loch Iubhair, a distance of about 6 km, is covered by modern alluvium or morainic drift deposits.

Deposits below the water-table

Since the last Ice Age, the Benmore Burn has deposited an alluvial fan which divides Loch Dochart from Loch Iubhair. The thickness and the nature of these low-lying deposits is not known but a considerable quantity of sand and gravel could be present.

Sections in the floodplain deposits of the River Fillan east of Crianlarich show fine to coarse-grained sand with some gravel. The river channel in this area is deep and appears to be floored mainly by sand rather than gravel. It is difficult to assess the thickness of the modern alluvial deposits but a minimum of 3 m appears to be present and the possibility of sands and gravels occurring in a buried channel beneath these deposits cannot be ruled out. At the east end of Loch Iubhair the river alluvium consists of medium to coarse-grained sand but where the river flows under the road bridge to Loch Dochart House the sediments change rapidly to fine to coarse-grained gravel in the rock gorge.

Miscellaneous deposits

The morainic drift deposits, which are continuous with those in Strathfillan, persist eastwards to the western end of Loch Dochart (Fig. 2). Farther east these deposits are poorly developed or very sporadic in occurrence, as for example the isolated mounds on the southern side of the road east of Portnellan Farm [NN 415 259]. The height of the hummocks on the southern side of the valley exceeds 15 m in places but elsewhere they are no more than 5 m high. Unfortunately the thicker morainic deposits occupy only a narrow strip of ground immediately to the south of the main road from Crianlarich to Loch Dochart. Deposits at Inverardran [NN 395 249] were seen to consist of up to 2 m of bedded medium and fine-grained yellowish-brown sand with some gravel (Appendix 2, No. 54). In places these deposits are overlain by unbedded fine to very coarse angular to subrounded gravel in a slightly clayey sand

matrix. East of Portnellan [NN 415 259], where the road crosses the old railway track, up to 3 m of very sandy, fine to very coarse unbedded gravel is exposed in a morainic mound.

AREA S14: GLEN DOCHART, AUCHESSAN TO KILLIN

The Auchessan to Killin area (Fig. 2), which is about 16 km long and 2 km wide, is covered by gravelly material virtually throughout. The bulk of this material has been classified as morainic drift but there is also a considerable spread of modern alluvium and some terraces beside the River Dochart. At Allt Coire Chaorach there is a mounded fluvio-glacial gravel deposit in the form of three small kame-terrace fragments. At least 160 million tonnes of sand and gravel is present in this area.

Deposits below the water-table

The floodplain deposits of the River Dochart eastwards from Auchessan to just west of the Falls of Dochart at Killin were examined at Auchessan [NN 447 267] and Auchlyne [NN 505 286]. At Auchessan fine to very coarse gravel is present in the river bed. This material was subangular to subrounded in shape and consists chiefly of pebbles of impure quartzite (Appendix 2, No. 55). At Auchlyne, fine to medium-grained subrounded gravel containing similar rock types (Appendix 2, No. 56) is present in the river channel, but the overbank floodplain deposits consist of 1.3 m of bedded sand. It was not possible to assess the proportions of sand to gravel nor to estimate the thickness of the deposit which, however, may exceed 3 m. East of the Falls of Dochart at Killin, the rivers Dochart and Lochay have deposited an extensive delta at the western end of Loch Tay. Although the rivers carry coarse gravel in the vicinity of the falls, the channel deposits generally seem to be of medium to fine gravel and sand. The overbank floodplain deposits, which stand up to 1.5 m above water level, are made up of medium sand with some fine gravel in places. The eastern edge of the delta has been reworked by wave action depositing well-sorted beach sand. South of the river on the lands of Kinnell Farm, a fragment of a terrace some 5 to 6 m above the river level is preserved. This deposit was formerly worked in a pit [NN 577 328] near the farm but it is not now exposed. The deposit, however, seems to be composed of subrounded fine to coarse gravel possibly as much as 5 m thick. The eastern limit of the terrace is marked by the Achmore Burn.

Miscellaneous deposits

Morainic drift deposits cover much of the surface of the Auchessan-Killin area (Fig. 2). They therefore represent the major potential source of sand and gravel in this area. Near the confluence of the Allt Coire Chaorach and the River Dochart, however, there are three small kame-terrace fragments. A sample of gravel from the kame-terraces consisted of subrounded fine to very coarse-grained gravel made up chiefly of grits, schistose grits and impure quartzite (Appendix 2, No. 57). From the distribution of associated exposures of solid rock the gravel-rock interface is probably very steep.

In the neighbourhood of Auchessan, on the north bank of the River Dochart, there are numerous mounds of morainic drift. Exposures were poor but at least one showed laminated silt and sand as well as obscurely bedded gravel and there may be potentially useful

deposits in this area. A series of relatively high morainic hummocks, which extends eastwards from Allt Coire Chaorach [NN 455 275], also contained sandy gravel as shown by scattered exposures. At Innishewan [NN 481 280], close to the road junction leading into the Glen Dochart Caravan Park, 3 m of generally coarse gravel was exposed in a mound which has been partly removed, apparently for use as roadstone. The gravel is subrounded to rounded in shape and consists chiefly of metamorphosed impure quartzitic sediments (Appendix 2, No. 58). The average size of the pebbles in the gravel was from 5 to 7 cm but the largest boulder was about 2.5 m long and boulders up to 60 cm were not uncommon. Opposite Ledcharrie Farm [NN 506 282] a morainic mound up to 5 m in height has been worked for local use. This exposure shows fine to very coarse gravel in a somewhat stiff silty or clayey sand matrix. Bands of coarse and medium sand are common and traces of bedding were noted in the gravel. The gravel consists chiefly of metamorphic impure quartzitic rocks (Appendix 2, No. 59). Beside the main Callander to Tyndrum road near Wester Lix [NN 542 298] a poor exposure showed fine to very coarse gravel in a rather stiff sandy matrix. The gravel is angular to subrounded and consists chiefly of metamorphic impure quartzitic rocks with some schists (Appendix 2, No. 60). At Killin [NN 565 323] a small exposure up to 3 m high showed gravel of similar composition (Appendix 2, No. 61). In the Killin area, morainic drift deposits have been worked in the past for gravel at Achmore [NN 591 328]. The quantity of morainic drift in the Auchessan-Killin area is very great, but the quality of the material can rarely be determined.

AREA S15: GLEN LOCHAY, KILLIN TO FOREST OF MAMLORN

The Glen Lochay area (Fig. 2), some 20 km long and up to 2 km wide, is covered by gravelly material over a considerable part of its length. This material has been classified mainly as morainic drift and modern alluvium, with small terrace areas where the River Lochay joins the Dochart at Killin.

Deposits below the water-table

The alluvial deposits of the River Lochay occur in several isolated patches separated by rock-floored river channels. At Low Batourne [NN 498 369] these materials consist of coarse gravel, generally subrounded in shape, made up chiefly of metamorphic impure quartzitic rocks (Appendix 2, No. 62). At this locality small amounts of gravel have been removed for local use. The overbank floodplain deposits consist of fine to coarse sand with some fine gravel beds. At Lubchurran [NN 453 357] a higher proportion of schist fragments (Appendix 2, No. 63) is present, the pebbles being mostly subangular. At Killin, on the Lochay delta, there is coarse to fine gravel and sand in the channel as far as the confluence with the River Dochart but the overbank sections are mainly in sand of varying grain-size. Remnants of a higher terrace, which is 2 m above the floodplain, are preserved in places but have not been mapped separately. These remnants consist of yellowish-brown, bedded, medium to coarse, sometimes fine-grained sand with a few gravelly layers in places. A terrace-remnant forms most of the surface of one of the islands at the mouth of the rivers [NN 583 333]. It is likely that in places upwards of 6 m of sand with gravel is present and therefore these alluvial deposits of the Lochay may be a very important

resource.

Miscellaneous deposits

Although isolated hummocks of morainic drift exceed 6 m in height, most of these deposits in Glen Lochay have rather subdued topography. Only in the less accessible western parts—around Kenknock, Badour and Batavaime—do the hummocks generally reach 6 m in height. Sporadic exposures show angular, fine to very coarse gravel in a plentiful stiff silty or sandy matrix.

AREA S16: GLEN OGLE, WESTER LIX TO LOCHEARNHEAD

Glen Ogle, some 8 km in length, contains some gravelly deposits mainly in the form of subdued morainic hummocks with a few larger ones up to 6 m in height. A little alluvial gravel is present also.

Miscellaneous deposits

The morainic drift deposits at Heather Cottage [NN 557 294] are an integral part of the Glen Dochart morainic spread (Area S14) and at this locality are up to 4 m thick; they consist of angular, fine to very coarse gravel set in a stiff clayey sand matrix (Appendix 2, No. 64). In Glen Ogle [NN 579 256], at an old gravel pit, up to 2 m of coarse and very coarse gravel is exposed. In this exposure there are thin beds of fine gravel and clayey laminated silts and sands. The gravel is subangular to subrounded and as at the previous locality consists chiefly of metamorphic impure quartzitic rocks (Appendix 2, No. 65).

AREA S17: LOCH LUBNAIG, LOCHEARNHEAD TO PASS OF LENY

This Highland valley area (Fig. 2), some 18 km in length and 2 km in breadth, extends from Loch Earn via Loch Lubnaig to the Pass of Leny west of Callander. It is convenient to include here Glen Ample and the southern side of Loch Earn to the boundary of the Central Region. Gravelly materials, which have been classified as modern alluvium and to a lesser extent as morainic drift deposits, cover much of the surface. Beside Loch Lubnaig a little mounded fluvio-glacial gravel is also present.

Deposits below the water-table

Several metres of sand with some gravel has accumulated at the head of Loch Earn where the Kendrum Burn and River Ogle enter the loch. A similar gravelly delta has also been built out where the Burn of Ample enters the loch at Edinample. Extensive alluvial deposits occur west and south of Kingshouse [NN 565 204] where the River Balvag carries the waters of Loch Voil into Loch Lubnaig. The channel of the Balvag carries fine to very coarse gravel at Balquhidder village where it unites with the Carlair Burn and gravel is visible in the channel as far east as Kingshouse and Stroneslaney. The overbank floodplain deposits are mainly of sand of varying grain-sizes though gravel is present west of Stroneslaney in thin beds in the sections examined. From Stroneslaney to the northern end of Loch Lubnaig the alluvium is composed of sand-sized particles with some clayey material in places. Small areas of alluvium also fringe the shore of Loch Lubnaig in places and a gravelly fan has been formed where the Burn of Ample discharges into the loch at Ardchullaire More [NN 584 136]. The River Teith issues from the south end of the loch and generally carries sand in the

channel but fine to coarse gravel occurs in the stretch by the road bridge [NN 587 093] above the Falls of Leny. The overbank floodplain deposits in this general area consist of some gravel and variably coarse grades of sand. The alluvial deposits of this sub-area probably exceed 3 m in thickness and may in places be much thicker.

Miscellaneous deposits

The morainic drift deposits generally have a rather subdued topography but areas in which hummocks of 6 m or more in height are common include the ground between Loch Earn, Kingshouse and Balquhidder, Glen Ample and Glen Buckie. In Glen Buckie the terrain between Immeroin [NN 537 173] and Ballinluig [NN 537 197] contains mounds which may reach 12 m in height. A series of exposures at Lochearnhead [NN 585 225] shows angular fine to very coarse gravel (Appendix 2, No. 66) with an abundant matrix that is often of stiff clayey sand, and, less commonly, of laminated silt or sand. Farther south at Helensfield [NN 568 207] a hummock of morainic material has been worked for local uses. About 2 m of laminated silt and fine to coarse-grained sand with subangular to subrounded variably coarse gravel is exposed (Appendix 2, No. 67). At Bailefuill [NN 558 193], a mound 9 m high consists entirely of angular to subrounded gravel in a stiff, rather silty and sandy matrix. This material has also been worked for local uses. Similar morainic drift deposits were examined (Appendix 2, No. 68) at Kipp [NN 556 158]. These deposits extend along the valley side from Strathyre to Laggan and sporadically beyond to Stank. At Auchtoo [NN 549 206] between Kingshouse and Balquhidder, a worked section shows 2 m of angular fine to very coarse gravel in a sandy matrix (Appendix 2, No. 69). On both banks of Loch Lubnaig, there are small areas in which bedded fine to coarse rounded gravel is preserved. This material, which has been classified as mounded fluvio-glacial gravel, has been worked at Stank [NN 583 118] where almost 3 m of bedded gravel overlies up to 5 m of cross-bedded fine to coarse-grained pebbly sand (Appendix 2, No. 70). About 1.5 m of similar pebbly sand is seen in another exposure farther north [NN 576 134] and at two places on the eastern bank of the Loch [NN 588 115], and [NN 586 106] where up to 3 m of bedded gravel are present.

AREA S18: LOCH VOIL TO BRAES OF BALQUHIDDER

This Highland valley area some 18 km long by 1.5 to 2 km in breadth (Fig. 2), may be divided into two distinct parts, firstly an area around Loch Voil where gravelly material, chiefly in the form of subdued morainic drift deposits and isolated hummocks, is present on the valley sides and secondly, an area extending from Monachyle Glen westwards to the head of the Braes where there are extensive deposits of morainic drift and alluvium, which contain at least 48 million tonnes of sand and gravel.

Deposits below the water-table

The alluvial deposits west of Inverlochraig consist of fine to very coarse subangular to subrounded gravel with some overbank floodplain deposits of coarse or medium-grained sand. At Blairreich the extensive alluvial deposits to the west of Loch Doine [NN 444 183] consist of subrounded to rounded, mainly coarse and very coarse gravel in the river bed (Appendix 2,

No. 71). The overbank alluvium is formed of medium sand with some gravel beds. Downstream the gravel becomes finer and the overbank deposits include clayey silt. A thickness of more than 3 m seems likely for these deposits and the top of the floodplain is nowhere more than 1.5 to 2 m above the local water-table. An area consisting of variable coarse gravel and sand forms an alluvial cone at the mouth of the Monachyle Burn. The deposition of this cone is responsible for separating Loch Doine from Loch Voil and the deposits may be very thick.

Miscellaneous deposits

From Monachyle Farm to Inverlocharig Farm morainic mounds up to 6 m in height are common on the valley slopes above the alluvial flats. The tributary valleys such as the Monachyle Glen all contain similar extensive morainic drift materials (Fig. 2). A series of exposures near Ardcarnaig Farm [NN 453 186] show up to 3 m of subangular fine to very coarse gravel in a sandy or stiff silty matrix (Appendix 2, No. 72). Traces of bedding are seen in the finer sediments. A similar poorly-exposed section in an old pit was also noted near Inverlocharig [NN 446 185].

Immediately west of Inverlocharig Steading, the morainic deposits rise to about 20 m above the general level of the valley to the east. This area of thick morainic drift persists westwards, interrupted only where low-lying alluvial deposits occur, at least as far as the Allt a Chroin Burn [NN 400 170] but the hummocks are more widely spaced in the Ishag Burn area. No rock is exposed in the bed of this river so that the thickness of these materials hereabouts probably exceeds 20 m. There are also small exposures in the neighbourhood of Inverlocharig which show angular to subrounded gravel with an abundant sandy matrix. Mounds up to 12 m in height occur east of the Ishag Burn and exposures show considerable quantities of bedded sand and silt (Appendix 2, No. 73). Like the Cononish River (sub-area 11), this area would appear to merit further study.

AREA S19: LOCH VENACHAR, LOCH ACHRAY AND THE DUKE'S PASS

Deposits below the water-table

Small areas of alluvium, chiefly of fine to coarse gravel, occur at the western end of Loch Achray [NN 505 065] (Appendix 2, No. 74) between Loch Achray and Loch Venachar and also where the Finglas Burn enters Loch Venachar. These deposits probably exceed 3 m in thickness and include an unknown quantity of sand particularly in the floodplain deposits. They may also overlie sand and gravel in buried channels although no evidence is available.

Miscellaneous deposits

Westwards from Milton, on the shores of Loch Venachar, sporadic hummocks of morainic drift occur as far as Brig o' Turk but between this locality and Loch Achray little morainic drift is seen owing to the extensive cover of forest. Southwards from Loch Achray beside the road over the Duke's Pass morainic mounds up to 6 or 7 m in height are present. Much of this area lies within Achray Forest but quite extensive exposures in morainic drift are seen at Lon Mor [NN 496 052] where the Forestry Commission have worked these materials in a series of pits for aggregate. In these workings over 5 m of subangular to subrounded, fine to very coarse gravel with a sandy or stiff clayey or silty

matrix are exposed (Appendix 2, No. 75). Cross-bedded layers of medium to coarse-grained sand up to 0.3 m thick are present as well as flat-laminated silt and sand. Much of the upper 1.5 m exposed is a stiff sandy clay with stones. There is a tendency for the gravel to be better rounded in the better-bedded deposits. Other small exposures in the neighbourhood of Loch Drunkie and Aberfoyle generally show a stiff silty matrix with fine to very coarse angular stones. It is difficult to envisage these latter deposits being of any value except for minor local uses.

AREA S20: LOCH KATRINE, LOCH ARKLET, LOCH CHON AND LOCH ARD

Much of the low ground throughout this sub-area (Fig. 2) is covered by morainic drift deposits and to a lesser extent by modern alluvium containing some 104 million tonnes of sand and gravel.

Deposits below the water-table

Alluvial sand and gravel occurs at the head of Loch Katrine in Glen Gyle. The surface material in the floodplain adjacent to the loch consists of silt and peat. A considerable area of alluvium is now drowned by the waters of the Loch Arklet Reservoir. Small areas of gravelly alluvium are to be found in Glean Gaoithe [NN 385 060] and farther westwards. More extensive alluvium occurs in Gleann Dubh at Comer [NN 389 043] where subangular to subrounded, usually very coarse gravel (Appendix 2, No. 76) is present in the river bed. Downstream the floodplain deposits are made up almost entirely of sand and silt with a peaty uppermost surface. Other small areas of alluvium occur at the head of Loch Chon and Loch Ard and at their outflows.

Miscellaneous deposits

Exposures in morainic hummocks are commonly found on the southern side of Loch Katrine (Fig. 2) along the water's edge between [NN 467 088] and [NN 480 086]. These hummocks are up to 6 m in height and consist of angular fine to very coarse gravel with a stiff clayey or silty matrix. Similar mounds are exposed west of Brenachoile Lodge on the northern bank. Further exposures situated to the west of Glasahoile continue as far as Stronachlachar and confirm this general lithology. At Stronachlachar [NN 403 100] 3 m of fine to very coarse angular and subangular gravel (Appendix 2, No. 77) with a stiff silty matrix contains layers of sand 1 cm thick and up to 2 m in length. The same general characteristics may be noted at small exposures on the northern bank of Loch Arklet Reservoir and at Inversnaid Cottage [NN 347 095]. On the southern shore of the reservoir there is an extensive morainic spread of low mounds which is continuous with the moraine on the southern bank of Loch Katrine and alongside Loch Chon. Exposures at the eastern end of Loch Arklet [NN 400 092] and in the Loch Ard Forest [NN 413 076] show a silty matrix with fine to very coarse angular pebbles (Appendix 2, Nos. 78, 79). This morainic spread continues over the col at Lochan Mhaim nan Curn into Gleann Gaoithe, and Gleann Dubh and in the Caorunn Achaidh Burn. There are numerous exposures in Gleann Gaoithe [NN 375 067] which consist of angular fine to very coarse gravel in a clayey silt matrix (Appendix 2, No. 80). More rarely [NN 377 065] exposures show well-bedded silt, and fine to coarse-grained sand. In general these hummocks rarely exceed 6 m in height, except in the vicinity of Stuc a Bhuic [NN 393 043], at Comer Farm [NN 386 040]

and in the Caorunn Achaidh Burn where they may exceed 9 m. The exposure at Stuc a Bhuic is on the side of a mound 9 m high and consists of angular, fine to coarse gravel with a matrix of sand (Appendix 2, No. 81). North-west of Loch Dubh, most of the morainic hummocks have bedrock cores with thin veneers and patches of bedded sand and fine gravel. Morainic deposits occur within the rest of the area around Loch Chon, Loch Ard and along the Duchray Water but, whilst they may develop a hummocky topography in places, they mostly occur only as a low-relief spread.

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Appendix 1: List of quarries and operators

- Avon Glen Pit [NS 956 783]
Geological Sheet 31; Six-inch Sheet NS 97 NE
Owner: Alexander Russel Ltd, Glasgow C3 (Telephone Polmont 3617).
- Barbush Pit [NN 786 026]
Geological Sheet 39; Six-inch Sheet NN 70 SE
Owner: Andrew Fleming and Sons, Barbush Farm, Dunblane (Telephone Dunblane 2221).
- Blair Drummond Pits: Low Daira [NN 735 002], Valley of Coustry [NN 729 000]
Geological Sheet 39; Six-inch Sheet NN 70 SW
Owner: Springbank Sand and Gravel Co. Ltd, Doune.
- Bonnyfield Pit [NS 816 803]
Geological Sheet 31; Six-inch Sheet NS 88 NW
Owner: Scottish Aggregates Ltd, Bonnyfield Farm, Bonnybridge (Telephone Bonnybridge 2217).
- Cambusbeg Pit [NN 667 046]
Geological Sheet 39; Six-inch Sheet NN 60 SE
Owner: Callander Sand and Gravel Co. Ltd, Doune Road, Callander.
- Cambusmore Pit [NN 645 060]
Geological Sheet 39; Six-inch Sheet NN 60 NW
Owner: Springbank Sand and Gravel Co. Ltd, 6 Union Street, Bridge of Allan, Stirling (Telephone Bridge of Allan 2555).
- Carmuir's Pit [NS 863 813]
Geological Sheet 31; Six-inch Sheet NS 88 SE
Owner: Springbank Sand and Gravel Co. Ltd, 6 Union Street, Bridge of Allan, Stirling.
- Drumbeg Pit [NS 484 882]
Geological Sheet 38; Six-inch Sheet NS 48 NE
Owner: P. Caulfield and Co. Ltd, Dalmonach Works, Bonhill, G83 9HN (Telephone Alexandria 2010).
- Headwood House Pit [NS 828 823]
Geological Sheet 31; Six-inch Sheet NS 88 SW
Owner: Scottish Aggregates Ltd, Bonnyfield Farm, Bonnybridge.
- Kinbuck Pit [NN 796 050]
Geological Sheet 39; Six-inch Sheet NN 70 NE
Owner: P. S. Nelson and Sons, Well Place, Dunblane (Telephone Dunblane 3228).
- Lon Mor Pit [NN 496 052]
Geological Sheet 38; Six-inch Sheet NN 40 NE
Owner: Forestry Commission, Aberdeen.
- Muirhouse Quarry [NS 565 780]
Geological Sheet 30; Six-inch Sheet NS 57 NE
Owner: British Industrial Sand, Wray Common, Reigate, Surrey.
- Nicolton Pit [NS 949 778]
Geological Sheet 31; Six-inch Sheet NS 97 NW
Owner: Scottish Aggregates Ltd, Nicolton Road, Polmont.

Appendix 2: Pebble counts

Key:

	A	SA	SR	R	Quartzite and vein quartz	Impure quartz etc.	Schists and phyllite	Slates	Sand- stones	Lavas	Mud- stone	Acid igneous	Epidior- ites	Dol- erite	Coal	Round- ness
CLACKMANNAN DISTRICT																
1					6.1	21.1	2.0		41.5	23.1	1.4	2.7			2.0	SR-R
2					8.2	8.2	0.6		34.7	39.4	5.9	1.8		0.6	0.6	SR-R
3					7.1	15.8			31.2	36.2	5.0	2.1		2.8		SR-R
FALKIRK DISTRICT																
4					15.0	10.8			38.3	29.2	3.3			0.8	1.7	SA
5					19.0	16.8			35.0	19.0	4.4	1.5		4.4		SA-SR
6					15.2	28.2			24.8	25.6	2.4			3.2		SR
7					6.5	7.3			50.0	32.2	4.0					SA
8					14.5	12.2			24.4	43.5	3.1	0.8		1.5		SR
9					20.0	19.3			31.0	21.4	4.8	1.4		2.1		SR
10					9.0	13.3			29.5	36.7	7.2	1.8		1.8	0.6	SR-R
11					6.1	8.5			31.7	42.7	10.4	0.6				SR-R
STIRLING DISTRICT																
12					9.3	67.7		5.6	17.4							SA-SR
13					12.5	26.7	3.4		55.8	0.8	0.8					SR-R
14					4.1	11.1		1.8	74.9		8.2					A-SR
15					5.3	28.1	1.8		60.0	4.4						SR-R
16					13.5	27.0			58.9	0.5						SR
17					2.6	24.5	1.0		68.2		3.1	0.5				SA-SR
18					12.6	27.4	4.0		56.0							A-SA
19					16.7	72.0	6.1	1.5	3.8							SA-SR
20					1.9	3.2			0.6	94.2						SR
21					10.9	10.9			39.8	38.3						SR
22					18.8	63.8		17.4								SA
23					12.0	24.0	2.7		60.0	0.9		0.4				SR
24					13.6	68.9	7.7		9.8							SR
25					1.3	3.2			7.1	87.7		0.6				SA-SR
26					8.7	7.2			24.6	52.9		5.8	0.7			SA-SR
27					8.8	28.9			57.2	0.6	4.4					SA-SR
28					17.1	17.1			56.4	9.4						SA
29					14.4	76.5		2.1	5.3			1.1	0.5			SR-R
30					22.8	30.7	18.1		15.0	3.1		3.1	7.1			SR-R
31					19.4	47.0	13.4		15.7	4.5						SR-R
32					9.4	54.3	2.4	0.8	27.6	3.9		1.6				SR-R
33					38.7	23.4	12.0		19.8	5.4		0.9	0.9			SR
34					17.0	61.9	8.2		5.4	4.1		2.0	1.4			SR-R
35					18.2	68.6		3.1	5.7			1.3	3.1			SR-R
36					19.3	50.9	11.4		10.5	2.6		2.7	2.6			SR-R
37					15.9	51.4	6.6		8.7		6.5	5.1	5.8			SR
38					22.2	48.6	10.4		11.1	2.1		2.1	1.4	2.1		SR-R
39					1.8	3.6			93.7	0.9						A-SA
40					4.6	31.3			37.4	20.6	1.5	4.6				SR
41					8.8	5.1			70.1	5.1	8.8	2.2				SA-SR
42					6.3	17.1			70.3	3.6	1.8	0.9				SA-SR
43					6.2	15.4			60.8	8.5	6.2			3.1		SR
44					8.5	12.0			57.7	11.3	9.8	0.7				SR
45					6.3	85.4	4.4						0.6		3.2	SA-SR
46					4.7	75.9	18.2								1.2	SR-A
47					10.8	48.3	33.5					5.1			2.3	SA
48					11.6	22.1	66.3									SR
49					6.3	87.9	5.2								0.6	A
50					9.3	85.4									5.3	A
51					8.9	76.9	5.9								8.3	A
52					5.9	79.9	11.2								3.0	SA
53					11.2	68.7	13.4					1.1			5.6	SR
54					12.8	80.1									7.1	A-SR
55					5.9	79.1	11.2								3.7	SA-SR
56					9.5	72.6	13.1								4.8	SR
57					10.9	76.6	9.4								3.1	SR
58					6.3	89.6	3.6						0.5			SR-R
59					9.1	64.4	7.6					9.1			9.8	A
60					17.4	51.7	16.3					6.4	0.6		7.6	A-SR
61					10.6	64.3	19.1					0.5			5.5	A-SA
62					24.1	68.1	3.1					2.1			2.6	SR
63					9.0	62.2	23.1					1.3			4.5	SA-SR
64					15.2	66.7	7.3					3.4			8.5	A
65					7.7	76.2	7.7					3.0			5.4	SA-SR
66					13.1	65.4	5.5					4.1	0.7		11.0	A
67					24.9	64.6	1.6					2.6			6.3	SA-SR
68					9.0	71.8	9.0					4.0			6.2	A
69					13.6	72.8	5.9					3.0			4.7	A
70					14.6	78.0						1.5			5.9	SR-R
71					19.0	72.5	7.0					1.0		0.5		SR-R
72					14.5	72.8	4.0					4.6	1.2	1.7	1.2	SA
73					17.9	76.6	2.5					1.0	0.5		1.5	A-SR
74					10.4	69.5	20.1									SR
75					13.3	74.0		3.5				8.7	0.6			SA-SR
76					20.5	67.7	11.2					0.6				SA-SR
77					11.0	22.5	55.5					11.0				A-SA
78					19.7	16.2	59.6					4.0	0.5			A-SA
79					11.1		88.9									A
80					19.4	72.2	8.3									A
81					20.6	69.7	5.1					2.9	1.7			A

Appendix 3: Estimated resources of sand and gravel in the Central Region of Scotland

Area	Area	Thickness		Quantity	Remarks
		Av.	Max.		
	ha	m	m	Million tonnes	
C1 Pool of Muckart	500	5	20	50	Unexploited area
F1 Kelvinhead	300	5	32	30	North of A803
F2 Denny	300	5	15	30	Built over
F3 Falkirk	400	6	12	48	Built over
F4 Polmont	900	5	30	90	Built over west of Polmont
S2 Drymen and Finnich	400	5	12	40	Mainly sand
S2 Muirhouse	116	15	20	35	Quartz conglomerate
S5 Strathblane	300	2	5	12	Mainly sand and brick clay
S6 Menteith	100	2	5	4	
S8 Stirling	500	5	12	50	Built over
S9 Callander	1300	5	30	130	
S10 Dunblane	600	5	15	60	
S11 Strathfillan	4000	2	30	160	Mainly morainic drift deposits
S14 Glen Dochart	4000	2	20	160	Mainly morainic drift deposits
S18 Braes of Balquhidder	600	4	30	48	Mainly morainic drift deposits
S20 Loch Katrine	2600	2	15	104	Mainly morainic drift deposits

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