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The geology of the A9 corridor between Luncarty and Ballinluig

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Open Report OR/19/022

BRITISH GEOLOGICAL SURVEY

GEOLOGY AND LANDSCAPE SCOTLAND PROGRAMME

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The geology of the A9 corridor between Luncarty and Ballinluig

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Tay valley north of Dunkeld. View to the north.

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Foreword

This report is an initial review of data from a resurvey of the superficial geology of the A9 corridor between Luncarty and Ballinluig. The resurvey was conducted to improve understanding of the superficial deposits and ground conditions along a vital transport route linking southern and northern Scotland.

During the resurvey, information from historic geological maps was supplemented by data from field surveys conducted in 2013 and analysis of borehole records from the BGS archive. Preliminary geological maps and cross-sections are included in this report. The production of new 1:10,000 scale digital geological maps based on these data is ongoing.

Note this report was originally released as an internal report in 2014, and reissued as an open report in 2019.

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Summary

Revision mapping and analysis of existing borehole data for a 30 km section along the A9 corridor between Luncarty and Ballinluig has been conducted in order to develop a consistent interpretation of the superficial deposits overlying bedrock. Data compiled from historic and current digital geological maps was combined with new information from geological field surveys carried out in 2013. Nine cross-sections along and perpendicular to the A9 route were also constructed from analysis of borehole records.

In the area between Luncarty and Murthly, the A9 crosses relatively low relief terrain underlain by glacial till with extensive tracts of glaciofluvial sand and gravel deposits. North of Murthly, the A9 follows the south-west side of Strath Tay. In this area, glaciofluvial, river terrace and alluvial depsoits, all comprising sand and gravel and silty sand occur along the valley floor. The sand and gravel is locally 30 – 40 m thick, particularly around the confluence of the River Braan with the River Tay near Dunkeld, but thins rapidly towards the edges of the valley where bedrock is exposed at the surface along much of the valley sides. Approximately 2.5 km north-west of Dunkeld, the A9 crosses the River Tay and follows the eastern side of Strath Tay. In this area, a wide alluvial floodplain is developed, which overlies 15 – 30 m of glaciofluvial sand and gravel deposits that line the valley floor and form narrow, steep terraces along the valley sides up to an elevation of c. 110 m above OD.

Most borehole records currently held by the BGS pre-date the construction of the A9 and therefore do not provide details of artificial ground associated with road embankments and cuttings. Comparison of the start height recorded in borehole logs and the modern ground surface elevation has been used to estimate the thickness of made ground associated with embankments along the A9.

1 Introduction

Revision mapping of the superficial deposits along the A9 corridor between Luncarty (3093, 7293) and Ballinluig (2970, 7548) was undertaken in 2013. Field surveys and analysis of borehole records were conducted to provide a basis for development of a consistent interpretation of the superficial geology and improved knowledge of ground conditions.

The A9 is a vital linking route between southern Scotland and the Highlands and the city of Inverness. Parts of the A9, including the section between Luncarty and Ballinluig, are currently being targeted for upgrade works including the construction of dual carriage way. Improved subsurface information and resources are intended to enhance understanding of the landscape and ground conditions to aid decision making and increase efficiency in construction and development works.

Future products of the revision survey will include new digital geological maps at 1:10,000 scale. This report provides a preliminary review of the new digital geological data and cross-sections constructed using historic borehole records held in the British Geological Survey (BGS) archives for an approximately 1 km wide corridor along the A9 between Luncarty and Ballinluig.

1.1 GEOLOGICAL BACKGROUND

1.1.1 Bedrock Geology

The bedrock geology of the study area is characterised by resistant metamorphic rocks to the north and un-metamorphosed sedimentary rocks to the south. These different strata are juxtaposed across the Highland Boundary Fault (HBF) which has a north-easterly trend and crosses the study area in the region near Birnam Wood (3046, 7397), 4 – 5 km south-east of Dunkeld (Figure 1).

To the north-west of the HBF the terrain is underlain by metamorphosed sandstone and mudstones (psammite and pelite) of the Southern Highlands Group. A belt of steeply dipping slate occurs just north of the HBF ('Birnam Slate'). Just to the south-east of the HBF the bedrock comprises an un-metamorphosed cobble and gravel conglomerate interbedded with andesitic lavas of the Devonian age Arbuthnott-Garvock Group. Approximately 3 km south-east of the HBF, another north-east fault brings the conglomerate in contact with sandstone of the Strathmore Group. In the vicinity of Luncarty the sandstone is conformably overlain by mudstone.

1.1.2 Quaternary History

The study area has been glaciated numerous times during the Quaternary period (past 2.6 Ma), most recently during the Late Devensian (~ 30 – 11.7 Ka) when a large ice sheet covered the whole of northern Britain. Deglaciation occurred between c. 17 ka and 11.7 Ka, with the retreat of the glaciers was punctuated by a redevelopment of glacial conditions between c. 12.9 and 11.7 Ka, during a period known as the Younger Dryas (Ballantyne, 2010).

During the main phase of the Late Devensian glaciation, the whole of the study area was under several kilometres of ice which flowed generally eastwards across the lowlands of Perthshire and the Firth of Tay in to the area now occupied by the North Sea. During the later stages of the Late Devensian, thinning of the ice sheet resulted in the formation of a mountain ice cap in the western Highlands. The retreat of glaciers up the Tay valley during deglaciation is likely to have occurred around 17 – 15 Ka. During the Younger Dryas, glaciers re-advanced to the vicinity of Loch Tay and Drumochter but are not thought to have extended further south or east.

Glacial erosion during the Late Devensian removed pre-existing superficial deposits left by earlier rivers and glaciers and consequently superficial deposits older than Late Devensian age are not thought to be present within the study area. The superficial deposits in the study area comprise sediments deposited beneath the Late Devensian ice or by meltwater streams draining the glaciers, and those formed by river and hillslope processes during the Holocene (11. 7 Ka to the present).

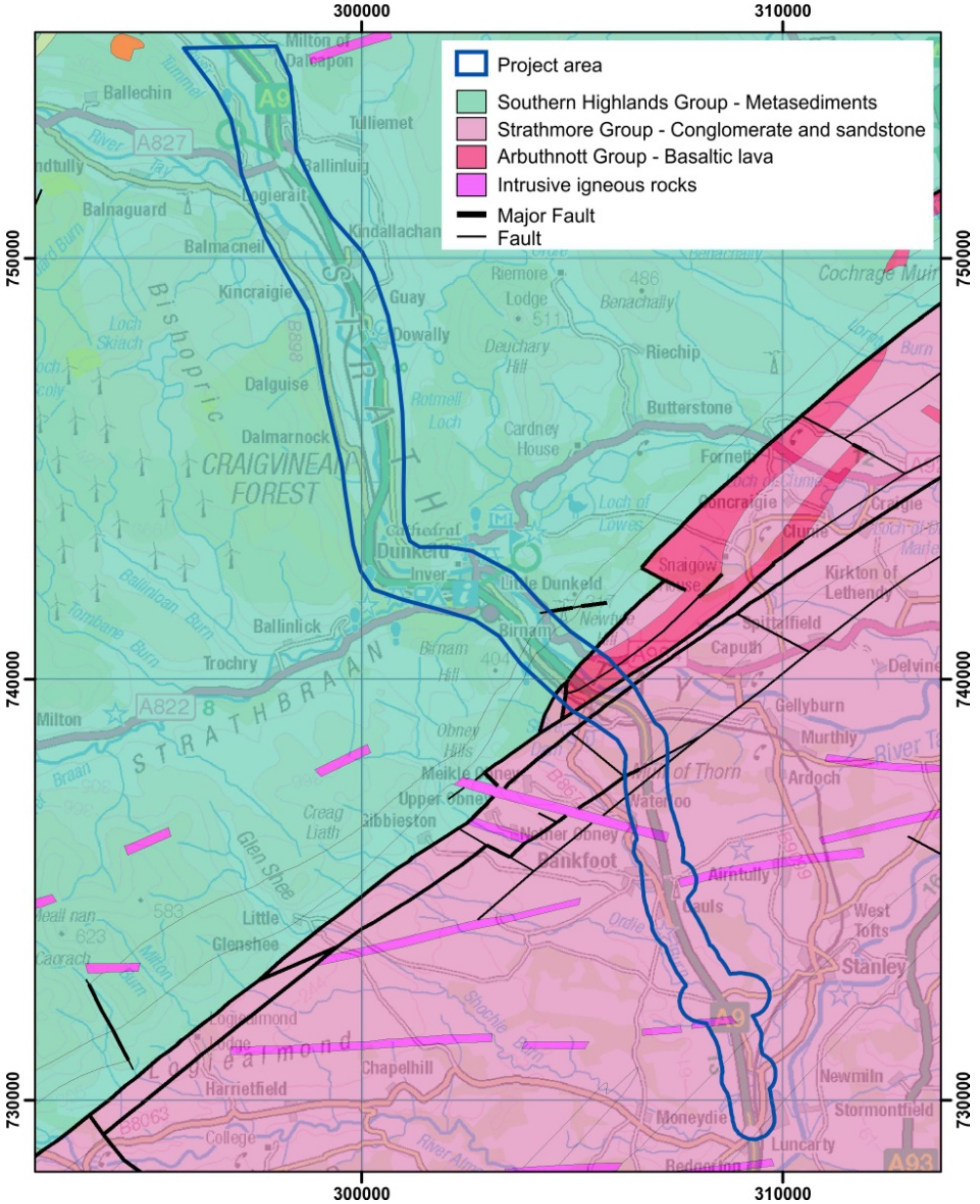

Figure 1 Bedrock geology map of the study area derived from BGS DigMap-50. The National Grid and other Ordnance Survey data © Crown Copyright and database rights 2014. Ordnance Survey Licence No. 100021290 EUL.

2 Methods

2.1 COMPILATION OF EXISTING GEOLOGICAL MAP DATA

During the revision mapping, existing geological data was revised on the basis of new information provided by field survey and assessment of borehole records. Digitised data from historic geological maps and recent digital field surveys have been compiled by BGS into a national digital geological map at 1:50,000 scale, DiGMapGB-50. This digital data provides the background information for the resurvey. The historical geological maps provide varying levels of detail of the superficial deposits of the area, and different levels of revision were required to provide a consistent geological interpretation.

The most detailed historic data coverage is for the area south and east of Dunkeld covered by the published 1:50,000 Sheet 48 W (Perth) (British Geological Survey, 1984). Standard maps (paper) at 1:10,000 scale were produced for the area south and east of Dunkeld following field surveys conducted between 1967 and 1974. These 1:10,000 scale maps were digitised prior to the 2013 field survey and minor revisions to the superficial geology mapping have been made.

The area to the west of Dunkeld which lies within 1:50,000 Sheet 47 E (Crieff) has the poorest historic data coverage in the study area; there are no pre-existing superficial deposits maps for this region at 1:10,000 scale or 1:50,000 scale. In the DiGMap-50 compilation only areas of alluvium and river terrace deposits which were marked on older county maps and fieldslips were included. Consequently the digital geological information for this area was limited and the superficial geology maps have been completely revised following the 2013 field survey.

The area north of the A9 Tay Bridge at Dunkeld (3004, 7439) lies within 1:50,000 scale Sheet 55 E (Pitlochry). Although there are no published superficial deposits maps for this area at 1:50,000 or 1:10,000 scale, DiGMap-50 provides reasonable detail of the superficial geology of the area derived from compilation of information from older county maps and fieldslips. Local revisions of the 1:50,000 scale data were made following the 2013 field survey.

2.2 GEOLOGICAL SURVEYING

A geological field survey focusing on superficial and artificial deposits was conducted by two geologists over 12 days in May and June 2013. Data was collected using the BGS SIGMA digital field data capture system.

In addition to the field survey, analysis of modern and historic Ordnance Survey (OS) topographic maps, 25 cm resolution digital aerial photograph imagery (© Getmapping: Licence Number UKP2006/01) and digital elevation data was conducted using ArcGIS.

2.3 BOREHOLE ANALYSIS AND CROSS-SECTION CONSTRUCTION

Borehole information held within the BGS Single Onshore Borehole Index and Borehole Geology Database was used to aid the interpretation of the superficial geology and artificial deposits, by providing information on the composition and thickness of the subsurface deposits. Borehole records for the area date from c. 1970s to recent, with most associated with A9 site investigations conducted prior to previous road construction works.

The borehole data forms the basis for development of a cross-section along the route of the A9 which was constructed using the BGS GSI3D geological modelling software. The down-hole lithological information for selected boreholes at 500 m to 1 km intervals along the A9 in the study area was coded into the BGS Borehole Geology database (Figure 2). Boreholes penetrating to rockhead, and therefore recording the full sequence of superficial deposits, were preferred where available. Boreholes with deep records but not proving rockhead, and those with detailed records for shallower depths, were selected where no other information was available. The ground surface was represented by the NextMap Digital Terrain Model (DTM) with 5 m horizontal and 1 m vertical resolution which was acquired from flown Interferometric Synthetic Apature Radar (IfSAR) collected between 2002 and 2003 (Intermap Technologies, 2004).

In addition to a main section, 8 shorter cross-sections, oriented perpendicular to the A9, were constructed (Figure 2). These valley-spanning cross-sections are only constrained by boreholes in the vicinity of the A9. Elsewhere the superficial geology has been interpreted from the mapped data.

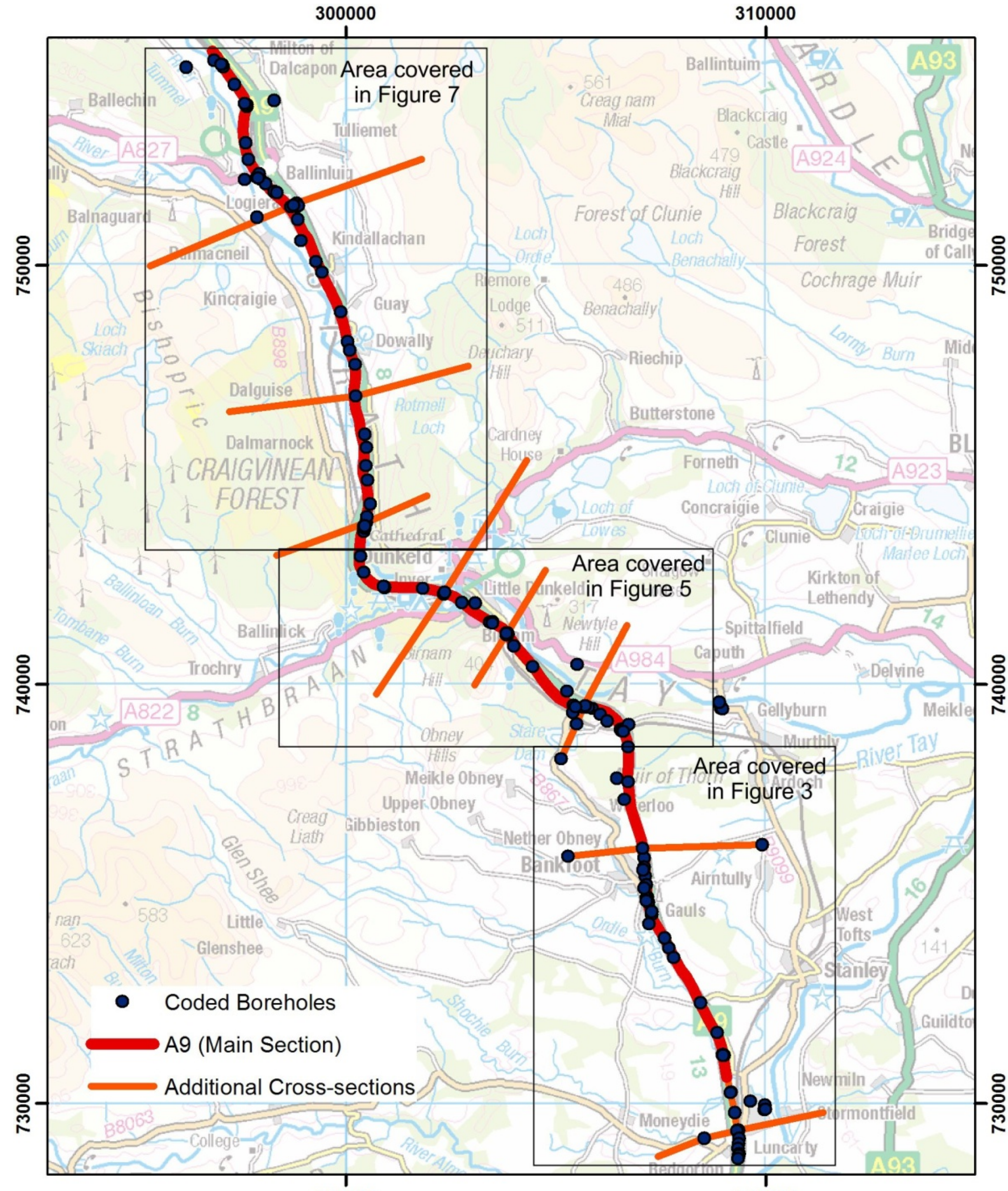

Figure 2 Locations of cross-sections and coded boreholes in the study area. The boxes highlight the segments of the route described separately in section 3. The National Grid and other Ordnance Survey data © Crown Copyright and database rights 2014. Ordnance Survey Licence No. 100021290 EUL.

Boreholes records were also used to assist in the interpretation of the thickness of artificial ground. The distribution of artificial ground was defined through the field survey, but composition and thickness of these deposits is poorly known. Most of the available borehole records are from site investigations drilled prior to the construction of the A9 and therefore do not include areas of made and worked ground associated with the road embankments and cuttings.

Comparison of the elevation of the ground surface recorded in the borehole log with the elevation of the present ground surface (i.e. the DTM elevation) gives an indication of the elevation change following the road construction. Comparison of the borehole start height and the DTM surface elevation at the borehole point can therefore give a preliminary estimate of the thickness of made ground. This method forms the basis of estimates of made ground thickness depicted in the cross-section.

3 Superficial Deposits

The superficial deposits overlying bedrock in the study area have been formed through the action of glaciers, rivers and slope processes during and after the most recent glaciation (Late Devensian to present). The main deposits encountered are briefly described in Table 1.

The area can be divided into three main segments characterised by different landforms and associations of deposits (Figure 2). Between Luncarty and Murthly, the A9 crosses generally low relief terrain characterised by a broad, shallow valley filled with wide spreads of glaciofluvial deposits. In the Dunkeld area, between Murthly and Inver Wood, the A9 follows Strath Tay and crosses glaciofluvial sheet deposits associated with the confluence of the rivers Tay and Braan. Between Inver Wood and Ballinluig, Strath Tay is characterised by a wide alluvial floodplain and lower valley slopes mantled by glaciofluvial ice contact deposits. An overview of the superficial geology for each of these areas is given below.

Age	Deposit	Description
Holocene	Peat	Organic deposits
	Head	Mass movement deposits comprising clay, silt, sand, gravel and cobbles.
	Lacustrine Deposits	Lake deposits of clay, silt, sand and organic material.
	Alluvial Deposits	River and floodplain deposits comprising sand, gravel and cobbles and/or clay, silt, sand and organic material.
	Alluvial Fan Deposits	Fan-shaped deposits containing silt, sand, gravel, cobbles and boulders formed at the outlets of tributary streams.
	River Terrace Deposits	Raised terraces of alluvial deposits containing sand, gravel, clay, silt and organic material.
Late Devensian	Glaciofluvial Sheet Deposits	Sand, gravel and cobbles with beds or lenses of silty sand deposited by glaciofluvial streams.
	Glaciofluvial Ice Contact Deposits	Silt, sand, gravel, cobbles and boulders with pockets or lenses of silty sand deposited by meltwater streams in the vicinity of a glacier
	Till	Consolidated silty, sandy clay with gravel, cobbles and boulders deposited beneath glaciers.

Table 1 Superficial deposits of the study area.

3.1 LUNCARTY TO MURTHLY

In the southern part of the study area the A9 crosses relatively low relief, undulating terrain which rises from lowlands around Luncarty (3094, 7296) at an elevation of c. 20 – 30 m above Ordnance Datum (OD) to the moorland south of Murthly (3065, 7390) at an elevation of c. 120 m AOD.

In the Luncarty area the uppermost superficial deposits are alluvial sediments deposited on floodplains of the Shochie Burn, Ordie Burn and the River Tay. The route of the A9 crosses the Shochie and Ordie Burns to the north of Luncarty and runs along the edge of alluvial deposits associated with the Ordie and Garry in the area between 0.5 – 1.5 km south of Bankfoot (30730, 73425). The alluvial deposits are variable in composition, containing clay, silt, sand and organic material, but in some areas comprise coarse gravel and sand.

Between Luncarty and Bankfoot, the A9 is underlain by extensive tracts of glaciofluvial deposits comprising two main forms; flat topped, raised terrace-like glaciofluvial sheet deposits, and moundy or irregular glaciofluvial ice contact deposits. Both types of glaciofluvial deposits consist largely of poorly consolidated gravel and cobbles in a matrix of silty sand (Figure 4A), but fine-grained laminated silt and sand with thin silty clay laminae (Figure 4B) is also present. At least 2 m of laminated silty and sand is exposed in a disused rail cutting in glaciofluvial sheet deposits north of Newmill (308435, 732570), and at least 5 m has been proved in boreholes in glaciofluvial ice contact deposits near Bankfoot (307196, 734978), and in glaciofluvial sheet deposits near Luncarty.

The glaciofluvial deposits line a network of glacial meltwater channels consisting of a series of narrow east-south-east trending valleys that intersect a broader south-east trending valley now occupied by the minor streams of the Ordie and Garry burns (Figure 3). This broad tract of glaciofluvial deposits is connected to deposits in Strath Tay in the area of the Pass of Birnam (30525, 73910). The thickness of the glaciofluvial deposits is highly variable (Figure 3) within the broad valley of the Ordie Burn it generally varies between 2 to 10 m, but in the vicinity of Bankfoot the thickness of the units may be over 20 m. The glaciofluvial deposits are interpreted to have been deposited by meltwater streams flowing beneath the Late Devensian ice, and later by pro-glacial streams draining the retreating ice margin.

The glaciofluvial deposits overlie glacial till, consisting of consolidated/dense sand, gravel, cobbles and boulders and a matrix of clay and silt (diamicton). Both the till thickness and composition (i.e. the proportion of matrix and clasts) are laterally variable. The till appears to be thickest in the south of the area with boreholes near Luncarty proving at least 6 – 10 m. However, even in this area the till is locally thin or absent, possibly having been locally eroded during the deposition of overlying glaciofluvial deposits. North-east of Luncarty the Shochie Burn has cut an 8 m high bank into 3 m of glaciofluvial sheet deposits overlying at least 5 m of till consisting of matrix supported diamicton with some angular gravel, cobbles and occasional large boulders in a silty clay matrix (Figure 4C). However, in the area of the Muir of Thorn, near Murthly (30673, 73887), the thickness of glacial till is poorly constrained but is thought to be generally less than 5 m and is locally overlain by peat. In this area, the till consists of a dense clast-supported diamicton with gravel and small cobbles in a matrix of sandy silt (Figure 4D).

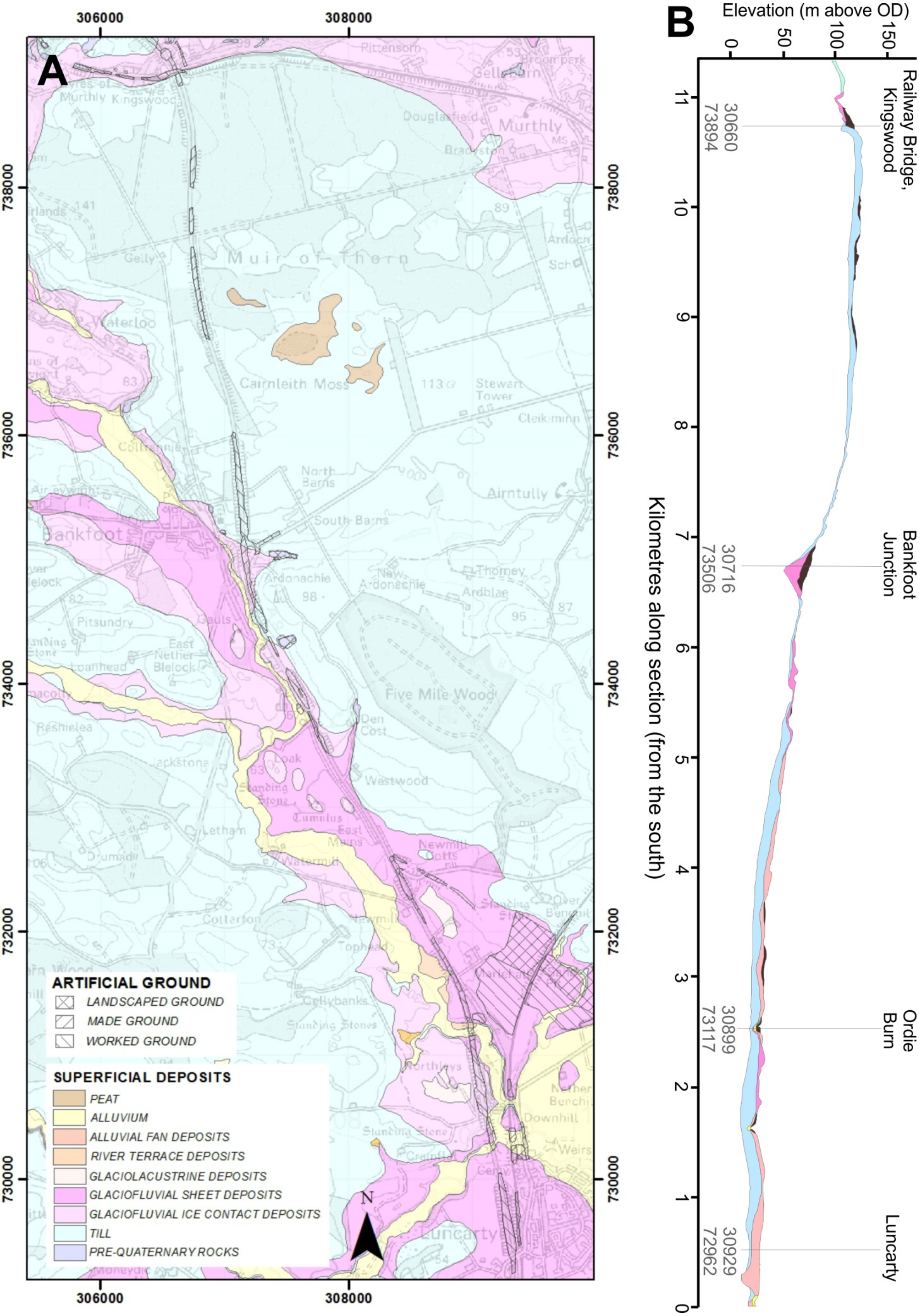

Figure 3 Map (A) and cross-section (B) along the route of the A9 between Luncarty and Murthly. Note: Made Ground is shown as dark brown on the cross-section. The National Grid and other Ordnance Survey data © Crown Copyright and database rights 2014. Ordnance Survey Licence No. 100021290 EUL.

A) Glaciofluvial ice contact deposits (sand, gravel and cobbles) in ditch near Bankfoot (307320, 734933).

B) Glaciofluvial sheet deposits (laminated silty sand) in disused rail cutting near Newmill (308435, 732570).

C) Glacial till (matrix-supported) in the bank of the Shochie Burn near Luncarty (30898, 73020).

D) Glacial till (clast-supported) in a ditch near Murthly (30673, 73887)

Figure 4 Field photographs of superficial deposits in the area between Luncarty and Murthly.

3.2 DUNKELD AREA: MURTHLY TO INVER WOOD

North of Murthly, the A9 descends into Strath Tay, passing the town of Dunkeld. North-west of the Highland Boundary Fault, which intersects the A9 between Murthly and Birnam, the bedrock consists of metamorphosed sediments of the Southern Highlands Group. These resistant rocks are associated with steeper, more rugged terrain through which the River Tay follows a deep, narrow valley. A relatively thick superficial deposits sequence is developed within Strath Tay, but on adjacent uplands there is extensive exposure of bedrock and only thin, patchy till.

Alluvium deposited by the River Tay and its tributary the River Braan, which joins the Tay near Dunkeld, forms the youngest superficial deposit within Strath Tay. The A9 crosses alluvium at the confluence of the Braan and Tay at Inver (30191, 74224), west of Dunkeld (Figure 5). Borehole and trial pit records from areas of the river floodplain near Inver indicate that the alluvium consists of 0.5 to 2.5 m of loose to dense fine to medium sand with some fine gravel overlying medium dense to dense coarse sand, gravel and boulders. The full thickness of the alluvium is difficult to determine from borehole records because these deposits overly glaciofluvial deposits of similar composition.

River terraces at an elevation of 50 – 60 m AOD, c. 7 – 10 m above the low-water level of the River Tay, occur in the vicinity of Birnam, Dunkeld and Inver. Similar to alluvium, these deposits consist of sand, gravel and cobbles, with some boulders, but may locally contain beds of sand and organic deposits including peat.

At Inver Wood (300260 743280), the A9 crosses part of a small alluvial fan that has formed at the outlet of a minor stream (Figure 5). There are no borehole records within this deposit, but it is thought likely to comprise gravel, cobbles, boulders in a matrix of silt, sand and clay.

Glaciofluvial ice contact deposits and glaciofluvial sheet deposits are exposed on the lower slopes of the valley sides throughout Strath Tay and underlie the alluvial, alluvial fan and river terrace deposits.

Glaciofluvial sheet deposits consisting of elevated, flat-topped terraces, locally bisected by relict drainage channels (paleochannels), flank the alluvial deposits along the rivers Braan and Tay in the vicinity of Dunkeld and the Hermitage (30115, 74209; Figure 6C). The highest terraces occur at a level of approximately 90 m AOD along the River Braan near its confluence with the Tay, with the terrace level descending gradually to the east to ~60 m AOD. These terraces appear to be a dissected fan system formed of sediment from a glacial meltwater stream in Strath Braan that choked Strath Tay during the latter stages of the Late Devensian deglaciation. Subsequent erosion by both the rivers Braan and Tay has now dissected this fan leaving east sloping terraces as remnants of the fan surface. Borehole records indicate that the glaciofluvial sheet deposits in this area comprise medium to very dense silty sand, gravel, cobbles and sparse boulders. The thickness of the glaciofluvial sheet deposits is greatest towards the head of the fan, with terraces in the Hermitage indicating a thickness of 20 – 30 m of sand and gravel, decreasing to 8 – 10 m at Little Dunkeld (30257, 74185). The glaciofluvial sheet deposits are underlain by glaciofluvial ice contact deposits in the central areas of Strath Tay, but may rest directly on bedrock at the valley edges.

Glaciofluvial ice contact deposits form irregular mounds within Strath Tay (Figure 6A) and small kame terraces dissected by drainage channels, and containing kettleholes, along the valley sides at elevations of 90 – 110 m AOD (Figure 5). These deposits consist largely of well-rounded gravel, cobbles and boulders in a matrix of fine to medium sand, but laminated silty sand is also found locally. In an exposure along a forestry track in Inver Wood (30009, 74298), contorted sand and sand and gravel deposits indicate that slumping of the glaciofluvial ice contact deposits may have occurred in places during or after deposition (Figure 6B).

The thickness of the glaciofluvial ice contact deposits is extremely variable; a 15 m high mound of sand and gravel is currently being quarried at Inver Wood (30019, 74302), but 300 m to the east bedrock is exposed in the bed of the River Tay indicating that there are no glaciofluvial sediments below the alluvium. At the confluence of the rivers Tay and Braan near Inver, at least 38 m of superficial deposits, comprising up to 10 m of alluvial and river terrace deposits overlying in excess of 28 m of glaciofluvial ice contact sand and gravel, is recorded in boreholes. The thick superficial deposits in this area may be the result of infilling of a deeply excavated valley where the River Braan joins the Tay.

Borehole records indicate that the glaciofluvial ice contact deposits rest directly on bedrock in much of the area, however, relatively few boreholes are drilled to rockhead, and it is likely that thin, patchy developments of till will be locally present beneath overlying sediments throughout the area.

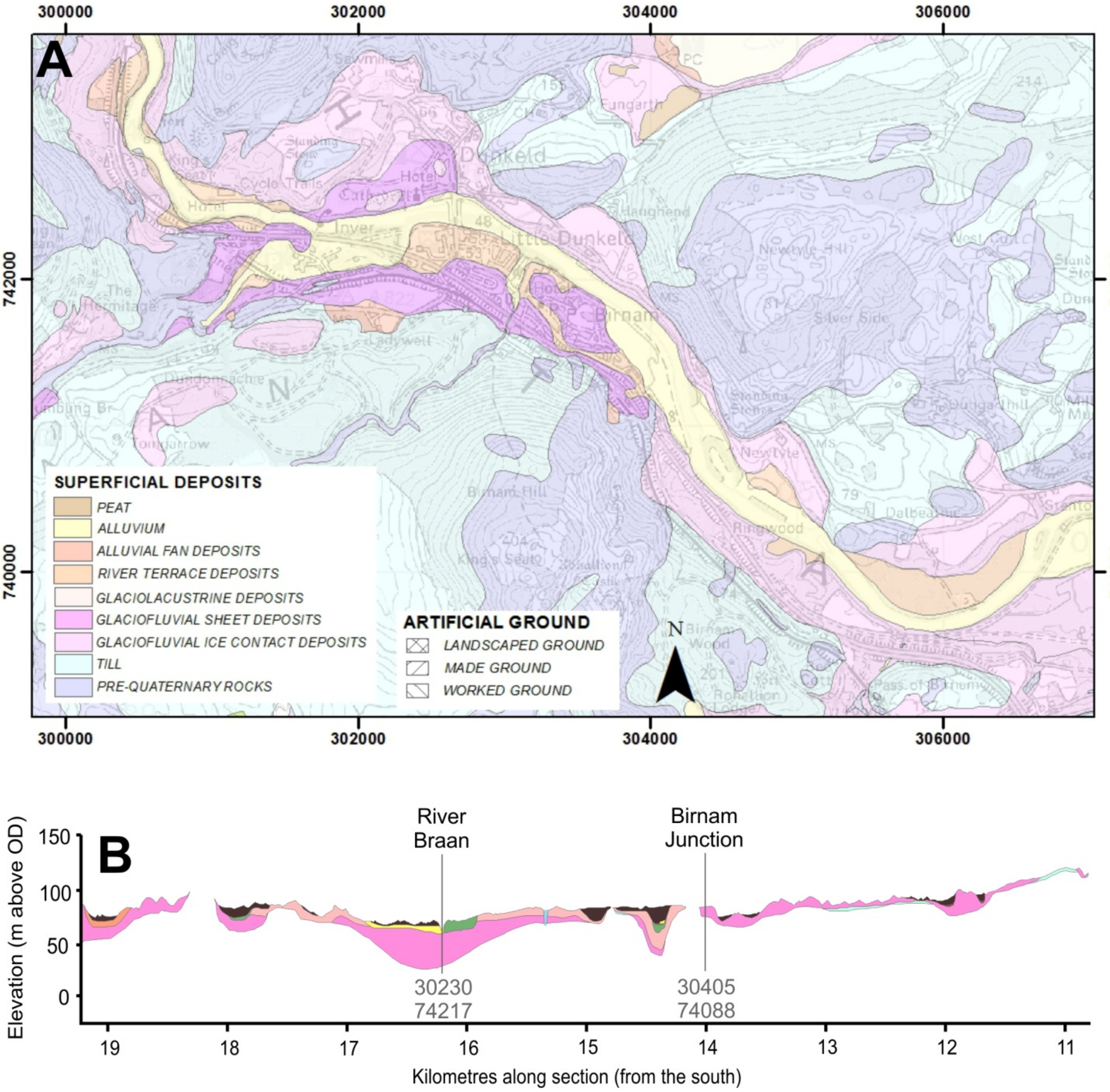

Figure 5 Map (A) and cross-section (B) of the A9 between Murthly and Inver Wood (Dunkeld). The National Grid and other Ordnance Survey data © Crown Copyright and database rights 2014. Ordnance Survey Licence No. 100021290 EUL.

A) Glaciofluvial Ice Contact sand and gravel in Quarry at Inver Wood (30019, 74302). Quarry face is c. 15 m high (note the orange rucksack just left of the centre of the image for scale).

B) Glaciofluvial Ice Contact contorted silty sand and sand and gravel in track section at Inver Wood (30009, 74298).

C) View of Glaciofluvial Sheet Deposit looking east from Bishops Hill, to the east of Dunkeld (30208, 74253). The terrace is c. 15 m above the level of the River Tay which is located behind the trees on the left of the image. The undulation in the field is a paleochannel descending in elevation (i.e. formerly flowing) towards the right. Note the car in the field in the centre of the image for scale.

Figure 6 Field photographs of superficial deposits in the area between Murthly and Inver Wood

3.3 INVER WOOD TO BALLINLUIG

North of Inver Wood, Strath Tay widens and an alluvial floodplain 500 m to 1 km wide is developed along the valley floor. The A9 crosses the River Tay less than 1 km north of Inver Wood, where the valley begins to widen, and continues northwards along the eastern side of the valley at the outer edge of the alluvial floodplain (Figure 7).

Borehole records indicate that the alluvial deposits of the floodplain are variable in composition, consisting of loose to dense sandy silt and silty sand, possibly containing organic matter, interbedded with dense sand and gravel. The similarity in composition between the alluvium and underlying glaciofluvial deposits means that the thickness of alluvial deposits is difficult to estimate, but the location of the A9 at the margin of the floodplain suggests that alluvium the underlying the road is likely to be thin (less than 3 m). Towards the centre of the valley, the alluvium may be considerably thicker; in a borehole near the bridge of the A827 over the Tay at Ballinluig, 'organic inclusions' interpreted to indicate alluvial deposits are recorded up to a depth of 22 m below the ground surface. However, 'organic inclusions' are not mentioned in the records of other nearby boreholes and therefore this thickness of alluvium cannot be confirmed.

Alluvial fans consisting of 2 to 10 m of gravel, cobbles and sand are locally developed adjacent to the main Tay floodplain at the outlets of minor streams, notably at Inchfield (30011, 74461), Dowally (30010, 74801), Guay (29990, 74915) and Kindallachan (29947, 75004).

North of Inver Wood, glaciofluvial ice contact deposits are present along the lower slopes of the steep valley sides and underlie the alluvium in the centre of the valley. These deposits form narrow, discontinuous kame terraces at elevations of 90 – 110 m AOD (Figure 8). An elongate mound of sand and gravel, that may be a partially buried esker, is also seen at Dalmarnock (29978, 74565).

The glaciofluvial ice contact deposits generally comprise dense rounded gravel, cobbles and boulders in a matrix of silty sand, but laminated silty sand and sandy silt with sparse gravel is locally seen in Inver Wood (30009, 74298) and near Dalmarnock (29955, 74580). Numerous beds of laminated silty sand 2 – 8 m thick within the glaciofluvial deposits are also recorded in boreholes at the A9 Tay Bridge at Dunkeld. These bores prove a minimum thickness of 42 m of sediment, of which the upper 5 m may be alluvium. A lack of boreholes drilled to rockhead north of the Tay Bridge means that the thickness of glaciofluvial sediment in Strath Tay (and therefore the depth to rockhead) is poorly constrained in many areas.

South of Dowally (30012, 74792), where the A9 is cut into glaciofluvial ice contact deposits along the valley side, boreholes drilled prior to the excavation of the road cuttings record at least 29 m of glaciofluvial ice contact deposits comprising sand and gravel with 2 – 15 m thick beds of silty sand or sandy silt which are commonly laminated. At Westhaugh of Tulliemet (29872, 75135) boreholes drilled in the hillslope above the A9 prove 12 – 15 m of glaciofluvial sand and gravel overlying rockhead. However, the glaciofluvial deposits are likely to be considerably thicker in the centre of the valley; 1 km to the north-west, near Ballinluig, 25 – 26 m of glaciofluvial deposits, overalain by alluvium, rest directly on rockhead. To the north of Ballinluig where the A9 follows the valley of the River Tummel, rockhead is encountered in boreholes at depths of 9 – 12 m suggesting that the thickness of the alluvial and glaciofluvial sediments in the Strath Tummel is less than that of Strath Tay.

All of the boreholes that prove rockhead in the area indicate that the glaciofluvial ice contact deposits rest directly on bedrock near the centre of Strath Tay. Thin glacial till is exposed on the higher parts of the valley sides and may locally underlie the glaciofluvial deposits along the valley margin.

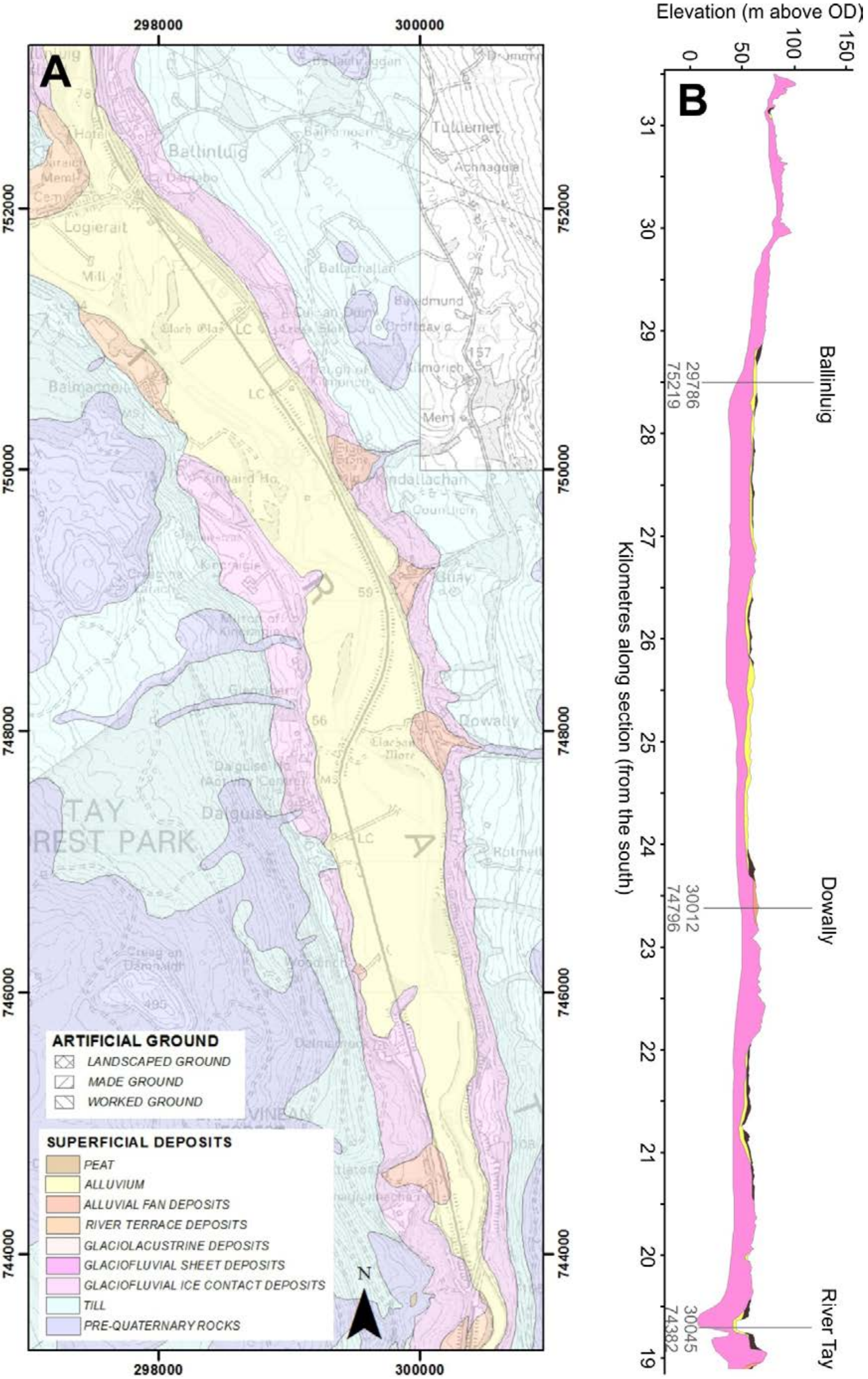

Figure 7 Map (A) and cross-section (B) along the route of the A9 between the A9 Tay Bridge (near Dunkeld) and Ballinluig. Note: Made Ground is shown as dark brown on the cross-section. Blue outline marks the limited of the resurveyed area. The National Grid and other Ordnance Survey data © Crown Copyright and database rights 2014. Ordnance Survey Licence No. 100021290 EUL.

Figure 8 View of glaciofluvial ice contact terraces (purple outline, pink shading) along Tay valley looking east-north-east from Inchfield (30006, 74473). The positions of the River Tay and A9 are highlighted. Aluvial fan deposits and alluvial deposits underlie the fields in the foreground and middle ground respectively.

4 Artificial Deposits

Substantial areas of made and worked ground were created during construction of the A9 in the 1970's and later road improvement works such the construction of the road junction at Ballinluig. Other areas of artificial ground within the A9 corridor include quarries and gravel pits, and embankments and cuttings associated with minor roads and railway lines (see maps 4, 6 and 8). The largest quarries and gravel pits in the area include a disused sand and gravel pit near Marlehall (30916, 73163), and Birnam Quarry (30376, 74045) which was formerly worked for slate. The Marlehall site has been partially landscaped and returned to agricultural land since extraction ceased in the mid 2000s. Narrow strips of made ground associated with levee embankments are found along the River Tay floodplain between the Tay Bridge and Ballinluig.

Deposits of made ground associated with the construction of residential properties and the installations of sub-surface services are likely to be present in the urbanised areas of Dunkeld, Luncarty and Bankfoot but have not been mapped. In addition, the materials comprising road surfaces have not been included in the consideration of artificial ground deposits associated with roads. Even in areas where no artificial ground is mapped or worked ground is shown along roads, ~1 m of artificial deposits consisting of asphalt and underlying aggregates may be expected.

The depth and composition of artificial deposits associated with made and landscaped ground is poorly known as there are few boreholes that intersect them. Along the A9, most of the available borehole records are from site investigations drilled between 1972 and 1976, prior to the construction of the road. Near Ballinluig, a number of boreholes drilled in 2005 – 2006 record up to 2.6 m of made ground consisting of gravelly sand and ash with cobbles and brick fragments. However, changes to the surface deposit thickness and composition in this area are likely to have occurred during construction of the new Ballinluig junction in the late 2000s.

4.1 THICKNESS OF MADE GROUND ALONG THE A9

Although few boreholes intersect the made ground, estimates of the thickness of made ground associated with embankments and worked ground in cuttings along the A9 can be inferred from the start heights of boreholes drilled prior to the construction of the road.

Digital elevation models (DEMs) of the ground surface, such as the NextMap DTM used in the cross-section construction, record the surface elevation at the time of data acquisition. In the case of the NextMap this occurred in the early 2000s (Intermap Technologies, 2004). However, the start height of boreholes drilled between 1970 and 1976 records the ground surface elevation prior to the construction of the A9.

Comparison of boreholes start heights with the DTM surface highlights substantial positive and negative offsets that are commonly related to areas of cuttings and embankments (Figure 9). When potential uncertainties associated with the DTM representation of the ground surface or the recorded borehole start height are accounted for, the offsets between the borehole start height and the DTM surface can be used to estimate the thickness of made or worked ground.

Uncertainty associated with the borehole start height may arise from the surveying methods used and as this information is not known, this uncertainty cannot be assessed in this study. Representation of the ground surface level in DEM models is affected by the presence of trees and buildings (in the case of digital surface models, DSMs), or by the algorithm used to strip these features from the elevation model (in the case of digital terrain models, DTMs).

The algorithms used to remove surface features from the NextMap DTM is known to result in some inaccuracies in the ground surface level in urban and forestry areas, and in areas marked by sharp breaks of slope which tend to be smoothed during the processing. The made ground depicted in the cross-sections in Figures 3, 5 and 7 has been interpreted from the borehole start heights relative to the NextMap DTM and the geometry shown should be considered as representative of the made ground present rather than an accurate delineation of its form.

5 Conclusions

The superficial deposits of the A9 corridor between Luncarty and Ballinluig predominantly comprise glaciofluvial sand and gravel deposits and glacial till deposited by glaciers and glacial meltwater streams during the Late Devensian glacial stage (between 26 – 15 ka). The resurvey has identified a dissected glaciofluvial fan system in the vicinity of the Hermitage and Dunkeld, originating at the mouth of Strath Braan which formerly choked Strath Tay and has been eroded and reworked by the rivers Tay and Braan during the Holocene.

The analysis of borehole records has provided new information on the thickness of superficial deposits in the study area. Within Strath Tay, there is considerable variation in the thickness of glaciofluvial ice contact sand and gravel deposits that overly bedrock in the base of the valley and flank the valley sides. This variation is thought to reflect the irregular bedrock valley floor, with thick sequences of glaciofluvial sediment developed where Strath Tay has been deeply scoured by ice at the confluence of the rivers Braan and Tay and in the narrow section at the A9 bridge near Inver Wood. However, few of the available boreholes intersect rockhead and its depth is therefore poorly constrained along much of the A9 route.

Construction of the A9 has resulted in the formation of numerous areas of made and worked ground associated with embankments and cuttings. Although the available boreholes pre-date the construction of these features, the thickness of the made ground can be estimated from comparison of the borehole start height, which records the original ground surface level, and the modern ground surface represented by DTMs. Further analysis to include different digital elevation models could be undertaken to develop more detailed representations of the made ground thickness.

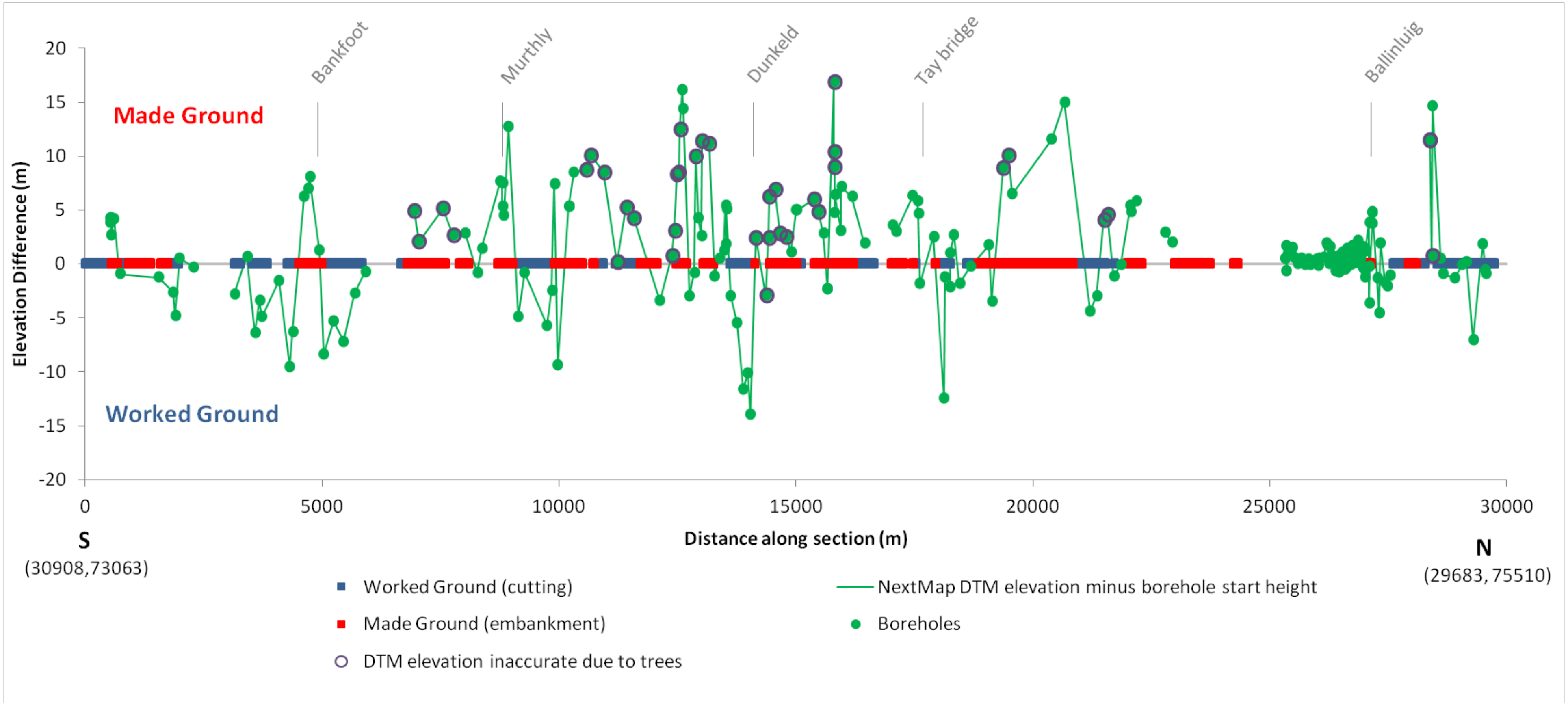

Figure 9 Plot of the difference between the NextMap DTM elevation versus borehole start heights along the A9 between Luncarty and Ballingluig. Boreholes located in areas where the DTM elevation is considered inaccurate due to tree cover are marked. The distribution of made and worked ground associated with cuttings and embankments are also shown. Positive differences are generally associated with areas of made ground, whereas negative differences are largely associated with areas of worked ground.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

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