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Onshore Geology Series

Technical Report WA/98/41

Geology of the central Pentland Hills

1:10 000 Sheet **NT16 SE** (Scald Law) and
1:10 560 Sheets **NT15 NW** (Baddinsgill)
and part of **NT15 NE** (Carlops)

Part of 1:50 000 Sheet 32W (Livingston), 32E (Edinburgh) and 24W (Biggar)

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Geographical index
Scotland, Midland Valley, Pentland Hills,
Bavelaw, Baddinsgill, Carlops

Subject index
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CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

This report describes the geology of 1:10 000 sheet NT16SE (Scald Law), and the 1:10 560 sheets NT15NW (Baddinsgill) and the area NW of the Pentland Fault on NT15NE (Carlops). These are included in 1:50 000 geological sheets 32W (Livingston), 32E (Edinburgh) and 24W (Biggar). Sheet boundaries are depicted on Figure 1.

The area resurveyed falls within the City of Edinburgh, Midlothian, Borders and West Lothian unitary authority areas (Figure 1). It straddles the central part of the south-west to north-east chain of the Pentland Hills, including the highest summits of Scald Law (579m), West Kip (551m), East Cairn Hill (567m) and West Cairn Hill (562m). The north-west side of the range is drained by the Water of Leith via the Harperrig, Threipmuir and Harlaw reservoirs. Cutting north-west to south-east between Black Hill and Scald Law is the major glacial meltwater channel of Green Cleugh. To the south the basins of the Baddinsgill and North Esk Reservoirs are drained by the Lyne Water and River North Esk respectively (Figure 2).

Most of the upland area is used for grazing sheep and to a lesser extent for hill cattle. Some grouse shooting takes place though this is in decline. Mixed farming predominates to the north-west of Threipmuir Reservoir and on the low ground immediately north-west of the Pentland Fault. The Pentlands are also extensively used for recreation, particularly walking and mountain-biking. Much of the resurveyed area on NT16SE and NT15NE is managed, in partnership with the owners, by the Pentland Hills Regional Park.

The Edinburgh to New Galloway road, the A702, follows the Pentland Fault in the south-east of the area (Figure 1).

The area was first geologically surveyed on the 1:10 560-scale by A Geikie and H H Howell in 1856–1866 and published on the 1:63 360-scale in 1859.

Sheet NT16SE was revised in 1902–1903 by B N Peach, J S Grant-Wilson and E H Cunningham Craig. A second revision was carried out during 1949–1952 by H E Wilson and W Mykura and the sheet was resurveyed by H F Barron and A D McAdam in 1993–1996.

Sheet NT15NE was revised by E H Cunningham Craig, L W Hinxman and B N Peach, and resurveyed by W Mykura, T Robertson and H E Wilson in 1938–1952. A second resurvey was carried out by H F Barron (north of the Pentland Fault) and A D McAdam (south of the Pentland Fault) in 1994–1996.

Sheet NT15NW was revised by B N Peach and partly published in 1907; W Q Kennedy, W Mykura and H H Read resurveyed the sheet in 1928–1952. A second resurvey was carried out by H F Barron in 1994–1996.

A new 1:63 360-scale edition (solid) of sheet 32 was published in 1967 and accompanying memoir published in 1962 (Mitchell and Mykura, 1962). The sheet was reprinted at 1:50 000-scale in 1977 without geological revision as Sheet 32W (Livingston) and 32E (Edinburgh).

All grid references used in this report refer to National Grid 100 km square NT.

This report is an interim statement and lithostratigraphical nomenclature may require revision as mapping proceeds in the contiguous areas.

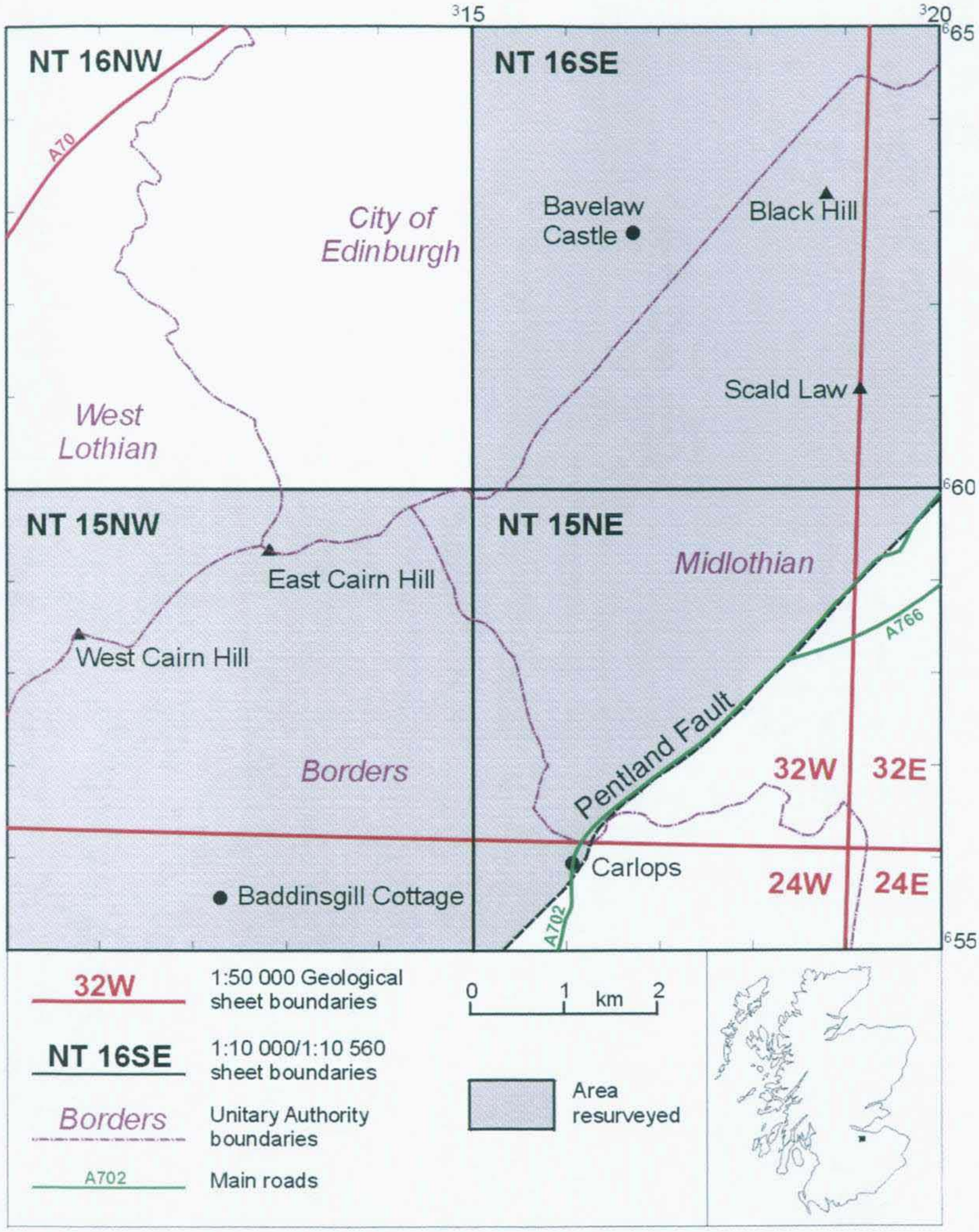

Figure 1 Area resurveyed and sheet boundaries

2 General Account

The area lies on the southern margin of the Midland Valley of Scotland close to the Southern Upland Fault. The Pentland Hills are composed of a core of steeply-dipping Silurian strata of the North Esk Group unconformably overlain by Siluro-Devonian sedimentary and volcanic rocks of the Lanark Group. They are bounded on the south-east by the Pentland Fault which brings Siluro-Devonian Lanark Group rocks in contact with the Carboniferous rocks of the Midlothian basin. Along the north-western margin, Carboniferous rocks of the Inverclyde Group rest unconformably on an eroded Siluro-Devonian land surface. A simplified map of the solid geology of the area is presented in Figure 2. During the Quaternary the area was subject to at least one episode of glaciation resulting in the deposition of a blanket covering of till on the lower ground and localised deposits of sand and gravel.

2.1 Geological Succession

The geological sequence occurring within the area is summarised in Table 1 above and on the generalised vertical section (Figure 3).

Quaternary		Peat Scree and Debris Cones Alluvium, River Terrace Deposits and Alluvial Fan Deposits Glaciofluvial Deposits Hummocky Glacial Deposits and Till				
System	**Series *(Stage)***	**Group**	**Formation**	**Member**	**Map Code**	**Approx. max thick. (m)**
Carboniferous	Tournaisian –Viséan *(Courceyan –Chadian)*	Inverclyde	Ballagan	'Upper Sandstone'	BGN sa"	140
				'Upper Shale'	BGN md"	400
				'Middle Sandstone'	BGN sa'	390
				'Lower Shale'	BGN md'	100
	Tournaisian *(Courceyan)*		Kinnesswood		KNW	300
Siluro-Devonian	*(Ludlow/ Pridoli/ Lochkovian)*	Lanark	Pentland Hills Volcanic	Carnethy Volcanic	CAHI	?200
				Woodhouselee Volcanic	WDH	100
				Caerketton Volcanic	CAE	50
				Allermuir Volcanic	ALMR	500
				Bell's Hill Volcanic	BHHB	300
				Bonaly Volcanic	BNY	70
			Swanshaw		SWAS	340
			Greywacke Conglomerate		GRWC	270
Silurian	Wenlock *(Sheinwoodian –Homerian)*	North Esk	Henshaw		HSW	725
	Wenlock *(Sheinwoodian)*		Wether Law Linn		WLN	total 265
				Baddinsgill Mudstone	BDD	155
				Lamb Rig Siltstone	LAR	55
				Grain Heads Siltstone	GHD	55
			Cock Rig		CKRI	100
	?		Deerhope		DHP	390 in N Esk Inlier
	Llandovery *(Telychian)*		Reservoir		RSVR	? 1100

Table 1 Geological Succession on 1:10 000 sheets NT16SE, NT15NE and NT15NW

The North Esk Group is of Telychian to ?Homerian age (Llandovery to Wenlock) and is exposed in the North Esk, Bavelaw Castle and Loganlee inliers (Figure 2). The strata represent a regressive sequence from shallow marine (Reservoir, Deerhope, Cock Rig and Wether Law Linn formations) to terrestrial red-beds with minor marine incursions (Henshaw Formation). A complete sequence from Reservoir to Henshaw formations is present in the North Esk Inlier; only the Reservoir and Deerhope formations are exposed in the Bavelaw Castle Inlier, and in the Loganlee Inlier only the Reservoir Formation is present.

Siluro-Devonian strata of the Lanark Group rest unconformably on North Esk Group rocks and the Black Hill microgranite. The alluvial fan deposits of the Greywacke Conglomerate and the Swanshaw formations are overlain by the lavas and volcaniclastic rocks of the Pentland Volcanic Formation. A radiometric age of 412.6 ± 5.7 Ma (Ludlow to Pragian) was obtained from a rhyodacite lava from the northern Pentland Hills (Thirwall, 1988).

Unconformable on the North Esk and Lanark groups are the fluviatile and marginal marine rocks of the Carboniferous Inverclyde Group.

Several large south-west to north-east faults cross the area. The Pentland Fault brings the Swanshaw and Pentland Volcanic formations of the Lanark Group in contact with the Carboniferous rocks of the Midlothian basin. The Loganlee Fault separates the Pentland Volcanic formation from the Reservoir Formation of the Loganlee Inlier in the north-east, and to the south-west, thick Lanark Group sequences to the south-east of the fault from relatively thin Greywacke Conglomerate Formation to the north-west. A continuation of the Loganlee fault to the south-west throws Kinnesswood Formation sandstones against rocks of the North Esk and Lanark groups.

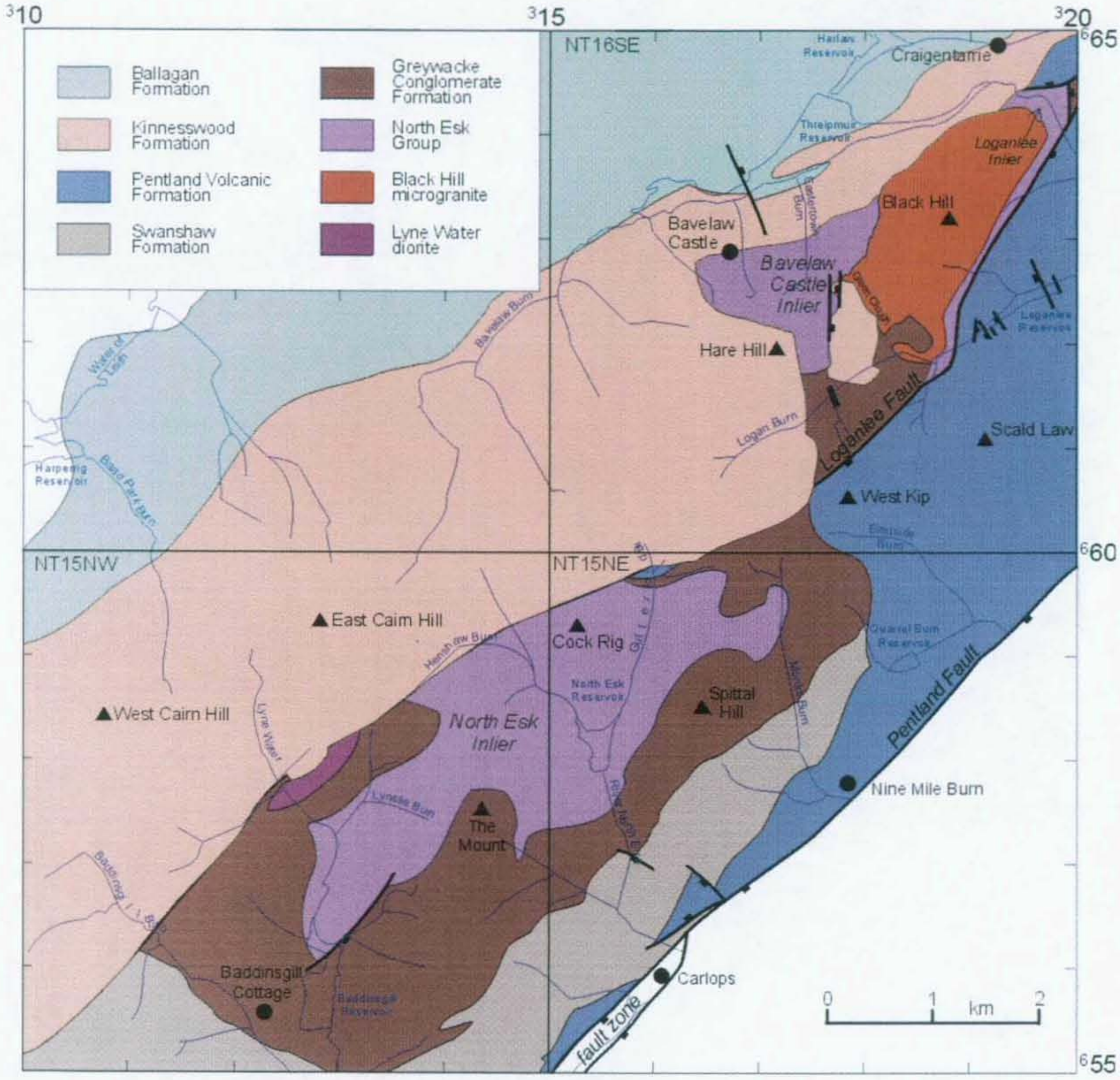

Figure 2 Simplified solid geological map of the central Pentland Hills

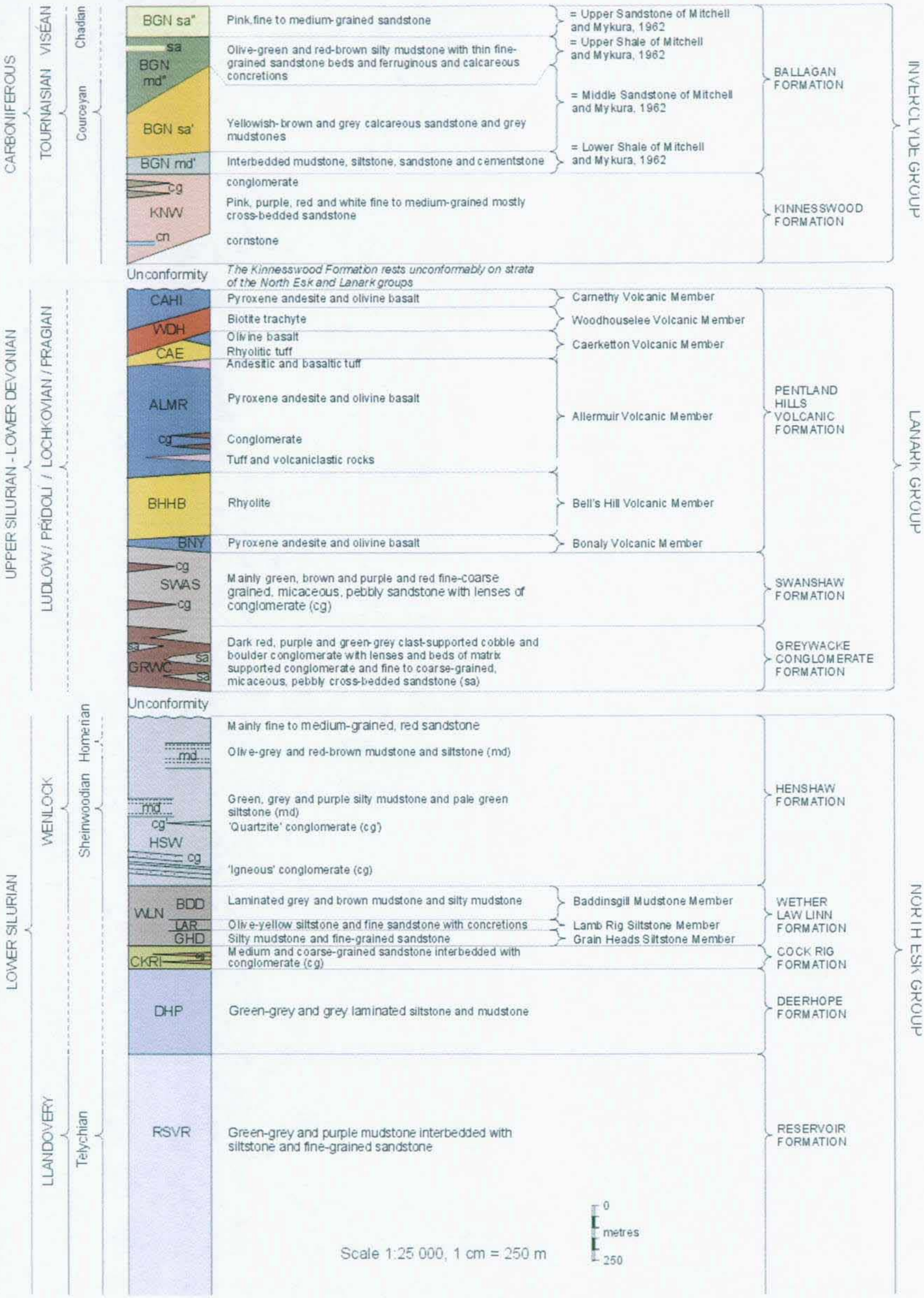

Figure 3 Generalised vertical section for sheets NT15NW, NT15NE and NT16SE

Figure 3

3 NORTH ESK GROUP (SILURIAN)

The Silurian rocks of the Pentland Hills have attracted geologists and palaeontologists since the early part of the nineteenth century. For a history of previous research see Bull and Loydell (1995), Robertson (1989), Bull (1987), Clarkson and Howells (1981), Clarkson et al. (1977) and Mykura and Smith (1962).

During the present resurvey 48 samples were collected for palynostratigraphical and palaeoenvironmental analysis. The locations of these samples are plotted on generalised sedimentary logs of the inliers (Figure 4).

3.1 North Esk inlier

The North Esk Inlier covers an area of 6.6 km^2 between Baddinsgill Reservoir and the headwaters of the Monks Burn (Figures 2 and 5). Exposure is reasonable, but largely confined to sections in burns. Tipper (1976) defined four formations for the North Esk Group: Reservoir, Deerhope, Wether Law Linn and Henshaw. Robertson (1989) redescribed Tipper's four formations and defined the Cock Rig Formation for the first time.

The beds strike north-east to north-north-east and are steeply dipping to overturned. Mykura and Smith, (1962, p13) noted that as a general rule the beds in the North Esk Inlier young to the west-north-west, but that there were considerable sections without good younging criteria where the presence of local isoclinal folds could not be ruled out. Robertson (1989) believed the entire North Esk Group younged to the north-west. In this study some evidence of south-east younging was found (see 3.1.1). The maximum thickness of the North Esk Group is probably around 2600 m.

3.1.1 Reservoir Formation

The Reservoir Formation (**RSVR**) crops out in the River North Esk [155 578 to 756 575]; the shores of the North Esk Reservoir, the Gutterford Burn [157 584 to 160 595], the Fairliehope Burn [147 571], and the headwaters of the Monks Burn [17 59]. The presence of at least some repeated strata and many small faults precludes a reliable estimate of the thickness of the Reservoir Formation. However, Robertson (1989) estimated the formation to be at least 1080 m thick and Bull (1995) gave a figure of 1100 m.

The formation is characterised by green-grey and purple mudstone and siltstone with interbeds of sandy siltstone and very fine-grained sandstone up to 1.2 m thick. The sandstone and siltstone beds have well defined upper and lower contacts and erosional structures such as flute and groove casts are commonly seen, particularly along the east shore of the North Esk Reservoir. Cross [1593 5931] and convolute [1583 5884] lamination is present in the siltstone beds and bioturbation is common in silty mudstone and mudstone beds. *Chondrites* burrows are common and meandering *Planolites* have been recorded (Bull, 1995). Bull (1995) also noted a few examples of swaley and hummocky cross stratification, small-scale sand volcanoes, possible subaerial mudcracks and mudflake conglomerates. A fold, probably resulting from syn-sedimentary slumping, can be seen at the mouth of the Gutterford burn [1556 5836] (Figure 6). Robertson (1989) stated that tool marks and ripple lamination indicated palaeocurrents from the east, but Bull (1995) found that palaeocurrent data were inconclusive. The beds appear to mostly young to the west-north-west. However, dewatering structures (dish and pillar) found in sandstone beds in the Gutterford Burn [1588 5904] indicate south-east younging and suggest that some local isoclinal folding is present and some strata are probably repeated.

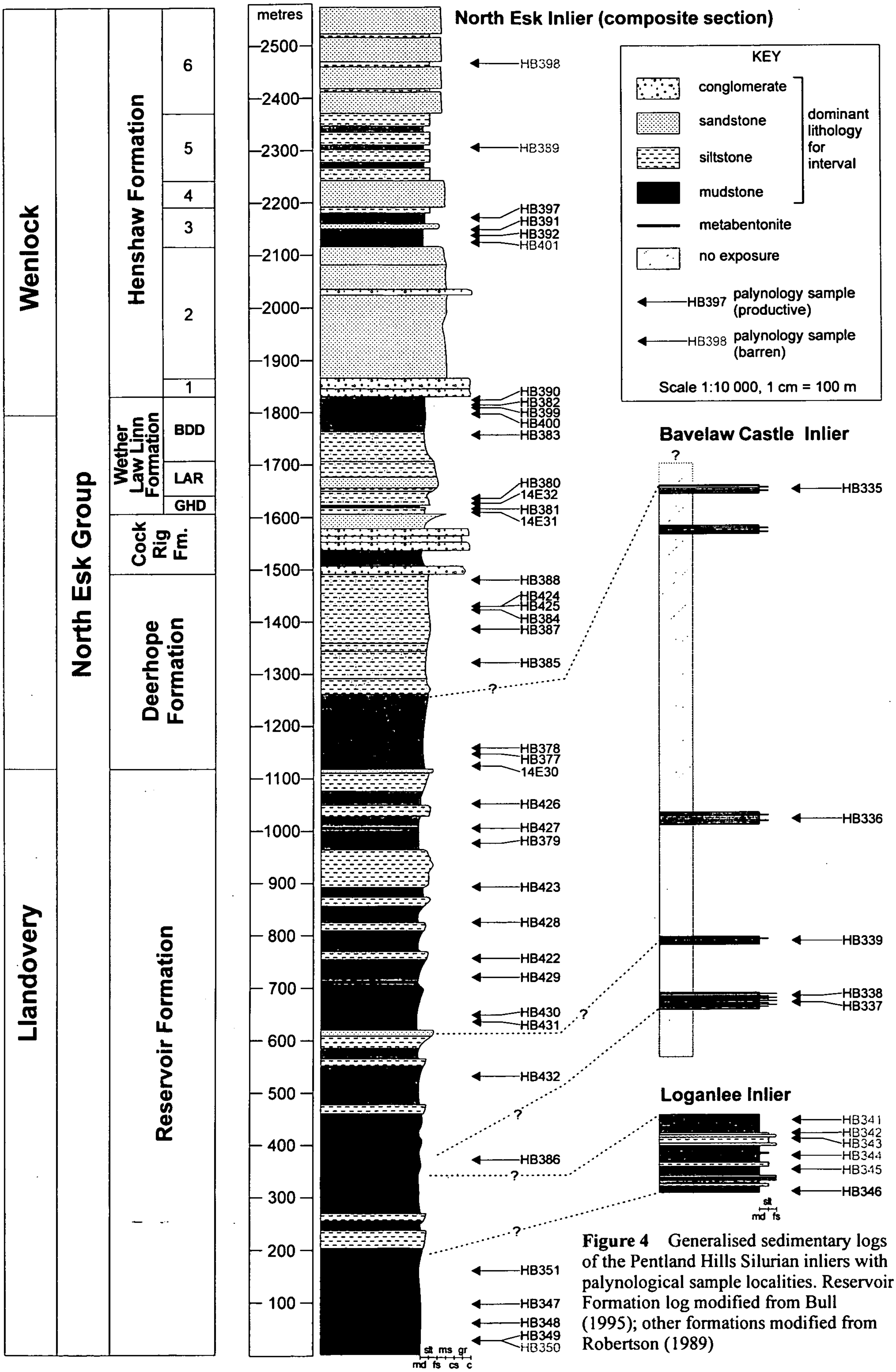

Figure 4 Generalised sedimentary logs of the Pentland Hills Silurian inliers with palynological sample localities. Reservoir Formation log modified from Bull (1995); other formations modified from Robertson (1989)

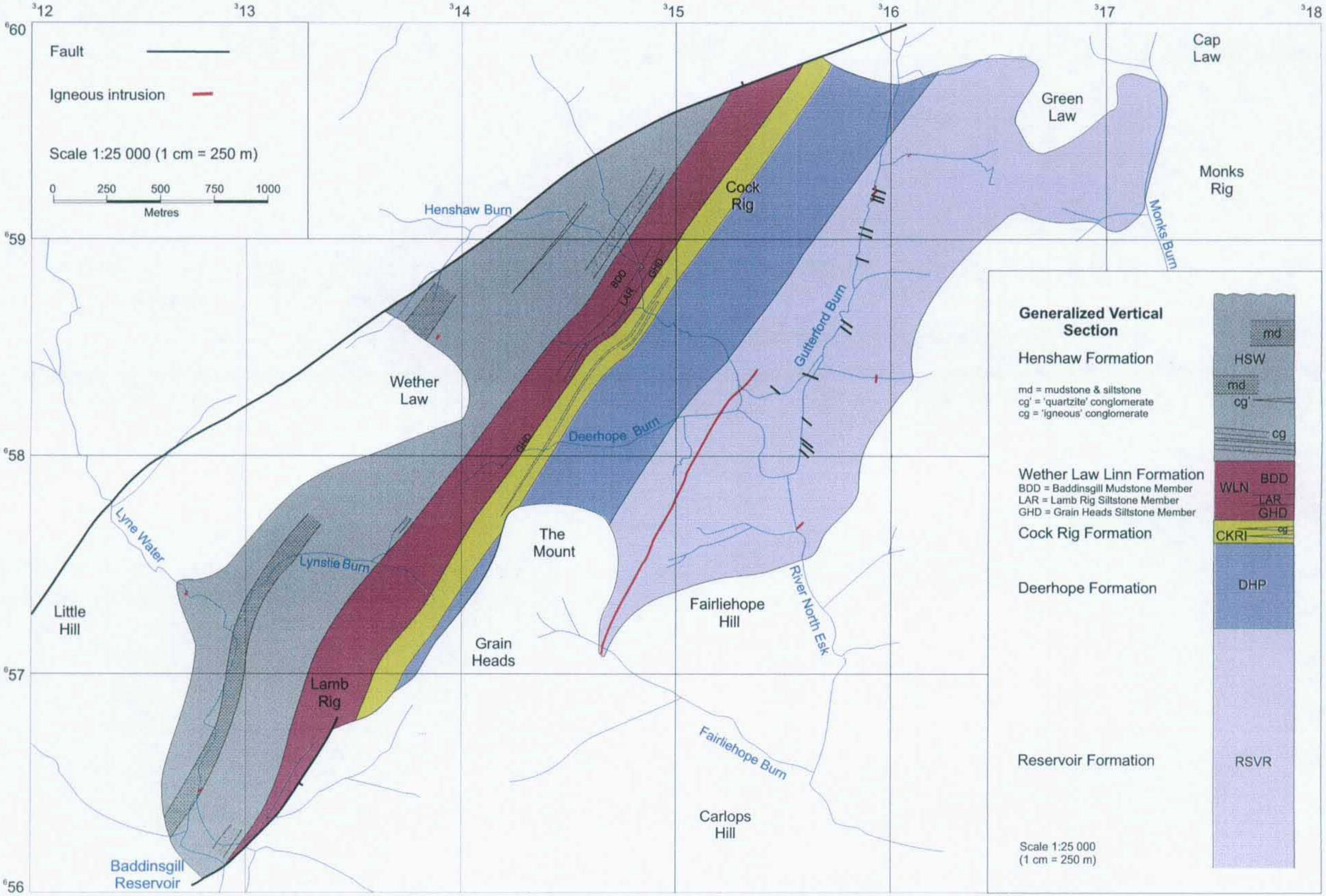

Figure 5 Simplified solid geological map of the North Esk Inlier

A thin-section (S98799) taken from a very fine-grained calcareous sandstone bed [1566 5795] at the south-east corner of the North Esk Reservoir revealed moderately-sorted, subangular quartz grains with abundant detrital muscovite and biotite, and minor feldspar and chlorite pseudomorphs. (Beddoe-Stephens, 1998) Lithic clasts included phyllite and felsitic and chloritised volcanic lithologies. The abundance of mica suggests a proximal depositional environment.

Robertson (1989) interpreted the Reservoir Formation as having been deposited in an offshore submarine fan setting, but based on sedimentology and graptolite faunas, Bull (1995) proposed rapid deposition by distal to intermediate storm sands on a low-energy, mud-dominated shelf, or by the infilling of a shallow marginal basin.

Other than the common *Dictyocaris*, macrofossils are rare in the Reservoir Formation, with only a few graptolites and brachiopods recorded. Exceptions to this are the nine fossiliferous beds, including the 'Gutterford Burn Limestone Bed' (Bull, 1995) and the well-known 'Eurypterid Bed' (Waterston, 1979). The former is a 0.25 m thick calcareous siltstone lag deposit containing abundant coral and bryozoan fragments, disarticulated brachiopods, as well as gastropods, trilobites, ostracods and crinoid ossicles.

Graptolite faunas indicate the Reservoir Formation can been assigned to the *spiralis* Biozone (Zalasiewicz and Tunnicliff, 1992; Bull, 1995; Bull and Loydell, 1995) of the Telychian Stage (upper Llandovery).

Sixteen samples collected for palynological analysis (Figure 4) reveal that a distinctive palynomorph assemblage occurs in the Reservoir Formation. The most commonly occurring forms are thick-walled sphaeromorph acritarchs and *Moyeria cabottii*, followed by species of *Tylotopalla* and *Visbysphaera* (Molyneux, 1996a,b; 1998). The palynomorphs are consistent with the latest Telychian age suggested on graptolite evidence (Bull and Loydell, 1995). There is no evidence to suggest any difference in age between the samples. If the appearance of *Visbysphaera connexa* in the *spiralis* Biozone of Gotland (Le Hérissé, 1989, p204) represents the true base of its range, the occurrence of *V. connexa*? in sample HB386 taken from south of the North Esk Reservoir [1557 5757] suggests that the middle part of the formation may not be older than the *spiralis* Biozone (Molyneux 1996b). Predominance of sphaeromorphs and *Moyeria cabottii* suggest a nearshore marine environment of deposition, supporting the conclusions of Bull (1995) and Bull and Loydell (1995).

3.1.2 Deerhope Formation

The Deerhope Formation (**DHP**) is exposed in the Deerhope Burn [1446 5806 to 1495 5810] and the River North Esk [1497 5864 to 1524 5845]. The formation consists of green-grey, grey and brown-grey mudstone and siltstone with a total thickness of approximately 390 m. Sedimentary structures include indistinct ripple lamination and parallel lamination and near the top of the formation in the River North Esk [1498 5862] tool marks and lineations can be seen on the bases of siltstone beds. These indicate palaeocurrents from the east or east-north-east. Also at this locality fossiliferous lags comprising bioclasts of brachiopods, bivalves, rugose corals, trilobites and pelmatozoans occur at the base of some siltstone beds (Robertson, 1989). The 'Deerhope Coral Bed' [1461 5800] is described by Clarkson and Taylor (1989). Mudstone beds are commonly bioturbated. The siltstones often have corrugated or striated surfaces which were thought to be tectonic in origin (Mykura and Smith, 1962, p15), but in thin-section (see below) a primary depositional fabric is indicated. According to Robertson (1989) they were probably produced by erosive currents on pre-existing weakly cohesive substrates.

Thin-sections (S99026A and B) of a siltstone from this locality [1498 5862] contained angular to subangular grains of quartz, feldspar, muscovite and biotite, the latter variably altered to chlorite. The fabric in this rock is defined by the alignment of mica flakes. Predominant is a pervasive, albeit weak set of slightly undulose but subparallel laminae or partings, typically 0.3 to 1mm apart. These parting are essentially defined by layers of mica one to a few flakes thick and presumably represent primary sedimentary lamination. In the domains between these pervasive partings, other discontinuous seams are defined by alignment of mica flakes, at moderate to high angle to the pervasive seams, or locally asymptotic. These show linear to curved habit and variable orientation so are unlikely to be cleavage related. More likely they represent primary features, possibly small-scale ripple-like sedimentary structures. This interpretation is born out by subtle grainsize variations in the sediment, with coarser lensoid to crudely trough-like domains (Beddoe-Stephens, 1998).

Graptolites faunas are rare but similar to those found in the Reservoir Formation (Robertson, 1985). Bull and Loydell (Fig. 3,1995) correlate the Deerhope Formation with the *grandis* Biozone of the late Telychian.

Nine samples collected for palynological analysis (Figure 4) reveal similar, though generally less diverse and abundant, acritarch, chitinozoa and sporomorph assemblages to those of the Reservoir Formation (Molyneux 1992; 1996a,b; 1998). The assemblages are consistent with the *grandis* Biozone assignment of Bull and Loydell (1995).

Bull (1995) interpreted the formation as overbank deposition from a fan in a nearshore setting. The interpretation is supported by the palynomorph assemblages.

3.1.3 Cock Rig Formation

The Cock Rig Formation (**CKRI**) crops out on the hillsides to the south-west [148 586] and north-east [149 588] of the River North Esk, the banks of the Deerhope Burn around [144 580], and at the headwaters of the Lynslie Burn [1387 5736]. The formation is characterised by olive-brown to pink and grey medium to coarse-grained sandstone, interbedded with conglomerate and thin mudstone partings. Conglomerates are clast-supported and show some evidence of normal and reverse grading. Cross-bedding [1488 5867] and basal load structures [1483 5863] can be seen at the River North Esk section. Robertson (1989) recognised at least 14 beds of conglomerate, mostly around 0.25 m thick with clast of up to 50 mm across. These beds appear to die out towards the south-west. The sandstone beds are 0.1 to 1.0 m thick and also display cross-bedding. Near the top of the formation in the Deerhope Burn [1432 5804] current ripples and trough cross-bedding can be seen.

A thin-section (S99025) from a coarse-grained sandstone with sporadic granules collected above the east bank of the River North Esk [1487 5866] showed moderately-sorted, subangular to angular grains of quartz, feldspar, lithic clasts, polycrystalline quartz and rare detrital muscovite. The abundant lithic clasts comprise felsitic and basic volcanic, and granite fragments (Beddoe-Stephens, 1998).

Transported fossil assemblages have been found, particularly near the top of the formation. They include brachiopods, pelmatozoans and bivalves (Robertson, 1989).

The Cock Rig Formation is interpreted as submarine fan feeder channel (Robertson, 1989) in a nearshore setting (Bull, 1995). No palynological samples were collected from the Cock Rig Formation.

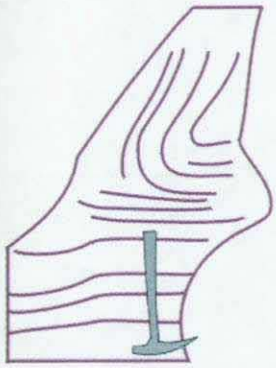

Figure 6

Probable syn-sedimentary slumping in the Reservoir Formation at the mouth of the Gutterford Burn [1556 5836] (hammer = 0.3 m)

Figure 7 Spheroidal weathering in calcareous concretions, Lamb Rig Siltstone Member, Wether Law Linn Formation, Wether Law Linn [1453 5843] (hammer = 0.3 m)

3.1.4 Wether Law Linn Formation

Robertson (1989) divided the Wether Law Linn Formation (**WLN**) into Lower, Middle and Upper members. These are here renamed Grain Heads Siltstone Member, Lamb Rig Siltstone Member and Baddinsgill Mudstone Member.

The Grain Heads Siltstone Member (**GHD**) crops out in the Wether Law Linn [1457 5852 to 1472 5862], the banks of the River North Esk [1481 5874], the banks of the Deerhope Burn [1430 5804] and the headwaters of the Lynslie Burn [1387 5737]. This member consists mainly of green-grey and olive, parallel laminated and bioturbated silty mudstone, sandy siltstone and fine-grained sandstone. It is richly fossiliferous, particularly at the top and base and palaeoecological analysis has been carried out by Robertson (1985). Molyneux (1996b) suggested that the presence of the brachiopod *Dicoelosia* cf. *verneuiliana* in this member indicates a lower Wenlock age, and that acritarchs, chitinozoa and spores recovered in four samples from this member (Figure 4) suggest a late Llandovery to Wenlock age.

A small exposure of pale cream to white clay up to 0.15 m thick occurs in a gully on the south-east bank of the Wether Law Linn [1469 5858]. Batchelor and Clarkson (1993) identified this as a metabentonite and the original volcanic ash was of rhyodacitic composition. The metabentonite horizon marks a dramatic change in marine faunas. Below the horizon the faunas are rich and diverse whereas directly above, the faunas are restricted. It would appear that the Volcanic ash fall killed off many invertebrate species.

The Lamb Rig Siltstone Member (**LAR**) is exposed in the Wether Law Linn [1453 5844 to 1457 5852], the banks of the River North Esk [1482 5876 to 1481 5883] and the banks of the Deerhope Burn [1418 5795]. This member is characterised by olive-yellow siltstones and fine-grained sandstones with well developed calcareous concretions (Figure 7). Fossils are rare, but brachiopod, orthocone and dendroid graptolite fragments have been found (Robertson, 1989). No palynological samples were collected from this member.

The Baddinsgill Mudstone Member (**BDD**) crops out in the banks of the River North Esk [1481 5883 to 1476 5900], the banks of the Henshaw Burn [1478 5888 to 1474 5892 and along the burn draining into the north-east corner of the Baddinsgill Reservoir [1303 5626 to 1326 5663]. This member consists mainly of grey, green-grey and yellow-brown, laminated and bioturbated mudstone and siltstone. At the top of the member, in the North Esk River [1476 5899] manganese dendrites and weathered pyrite cubes are found in olive-brown rusty siltstone and silty mudstone beds which pass upwards into poorly-lithified red mudstone (Robertson, 1989).

Well preserved fossils are common in this member; see Robertson (1989) for details. Five samples collected for palynological analysis (Figure 4) yielded variable assemblages of acritarchs, chitinozoa and spores that indicate a late Llandovery or early Wenlock age. (Molyneux 1996b)

3.1.5 Henshaw Formation:

The Henshaw Formation (**HSW**) crops out along the north shore of Baddinsgill Reservoir [1298 5624 to 1278 5635], Lyne Water [1282 5684 to 1268 5742], the North Esk River [1475 5906 to 1469 5909] and the Henshaw Burn [1467 5901 to 1437 5910 and 1386 5872 to 1388 5862]. The formation comprises red conglomerates and sandstone, and green-grey, olive and purple siltstone and mudstone, and has been informally subdivided into six units (Table 2). These correspond to beds 5 to 10 of Mykura and Smith (1962), though the 'Lynslie Burn Fish Bed' is taken to be same horizon as the 'Lyne Water Fish Bed' (Robertson, 1989).

Distinctive features of the formation are two conglomeratic horizons. The lower 'Igneous Conglomerate' (Unit 1), well exposed in the River North Esk [1475 5905] and on the north shore of Baddinsgill Reservoir [1294 5623 to 1288 5623]. The upper 'Quartzite Conglomerate' (in Unit 2) can be seen in the south-west bank of the Henshaw Burn [1450 5908].

A thin-section (S99024) taken from the 'Igneous Conglomerate' beside the east bank of the River North Esk [1476 5906] revealed a poorly-sorted, fine-grained breccia/conglomerate with angular, subangular and subrounded fragments up to pebble grade. The are dominated by a variety of igneous lithic clasts, including granite with granophyric texture, porphyritic microgranite and felsite showing spherulitic to variolitic texture. Other clast include fine-grained sandstone to siltstone and probable chert, plus traces of phylitic or pelitic metamorphic fragments. Crystal fragments include quartz, polycrystalline quartz, K-feldspar, minor plagioclase and minor detrital muscovite (Beddoe-Stephens, 1998).

A thin-section (S98800) taken from a light grey to green, fine-grained, sandstone cropping out on the east bank of the Lyne Water in Unit 3 (HFB11) [1284 5664] comprised well-sorted subrounded to subangular grains of quartz, plagioclase, K-feldspar, scattered detrital muscovite and biotite, rare garnet, common lithic fragments. Rock fragments include felsitic lithologies, showing spherulitic texture, chloritised basic-intermediate volcanic lithologies, phyllite, mudstone flakes, and rare psammitic schist (Beddoe-Stephens, 1998).

Macrofossils are only represented by rare, broken, disarticulated specimens in the Henshaw Formation, apart from the 'Lyne Water Fish Bed', where the fish *Ateleaspis tesselata, Birkenia elegans* and *Lasanius elegans,* and crinoid fragments are recorded (Robertson, 1989).

Wellman and Richardson (1993) described a sporomorph assemblage from the 'Lyne Water Fish Bed' at the Lynslie Burn locality [1317 5746] and assign the flora to the *chulus–nanus* Spore Assemblage Biozone which is earliest Sheinwoodian (early *centrifugus* Biozone) to Homerian (upper *lundgreni* Biozone), or possibly latest Sheinwoodian (*ellesae* Biozone) in age. Rare acanthomorph acritarchs in the assemblages suggest a transitory marine incursion in this largely terrestrial alluvial fan and playa lake environment.

Three out of six Henshaw Formation samples (Figure 4) collected for palynological analysis yielded sporomorphs and acritarchs. The age assessment of Wellman and Richardson (1993) and the marine influence was confirmed (Molyneux, 1996b).

Unit	Main Lithologies	Thickness (metres)
6	Red-brown **sandstone**, fine to medium-grained, micaceous, in beds up to 0.5 m thick, with minor **siltstone** and purple **mudstone**. Sandstone beds display trough cross-bedding and desiccation cracks [1278 5736].	?200
5	Green-grey and purple, thinly-laminated **mudstone** and micaceous **siltstone**	?130
4	Red **sandstone**, fine to medium-grained, with lenses of pebble **conglomerate**	50
3	Olive, green-grey, red-brown **mudstone, siltstone** and fine-grained **sandstone**. Sandstone beds are up to 0.1 m and display ripple lamination [1299 5713] indicating palaeocurrents flowed from the east-north-east. Desiccation cracks infilled with sandstone can be seen in some mudstone beds [1288 5672 and 1296 5705]. The 'Lyne Water Fish Bed' (Robertson, 1989) can be seen in the Lyne Water [1288 5672] and in the Lynslie Burn [1322 5754].	75
2	Red **sandstone**, fine to coarse-grained, micaceous forming flaggy beds, 0.1 to 0.5 m thick. Lenses of quartz-granule conglomerate, pebble stringers and mudclasts. Towards the top, a single conglomerate bed, ('Quartzite Conglomerate') 1.5 m thick, contains sub-rounded to rounded pebble and cobble-sized clasts of hematite-veined white quartzite and occasional clasts of igneous and fine-grained sedimentary rocks (Robertson, 1989).	250
1	Red **conglomerate** ('Igneous Conglomerate'), clast-supported, poorly-bedded, forming continuous beds up to 1.0 m thick. Clasts are mainly sub-rounded cobbles and boulders up to 0.3 m across, of granite, quartz-feldspar-porphyry, microgranite, rhyolite, trachyte, altered sub-basic lava, chert, quartzite and fine-grained sediments (Robertson, 1989; Mykura and Smith, 1962).	35

Table 2 Henshaw Formation lithologies

3.2 Bavelaw Castle Inlier

The Bavelaw Castle Inlier occupies a roughly triangular area of around 1.3 km^2 between Black Hill, Hare Hill and Bavelaw Castle (Figure 2), and comprises poorly-exposed strata of the Reservoir and Deerhope formations.

3.2.1 Reservoir Formation

The Reservoir Formation (**RSVR**) is best exposed in two large gullies [177 623 and 176 623] cut in the south bank of a large glacial meltwater channel. Here, strata of steeply-inclined interbedded green-grey mudstone, siltstone and very fine-grained sandstone are seen. Robertson (1985, p40) correlated the easterly gully [176 623] with outcrops of the Reservoir Formation below the North Esk Reservoir in the North Esk Inlier, and the westerly gully (177 623) with outcrops around the North Esk Reservoir at the mouth of the Gutterford Burn. Sedimentary structures seen include current ripples [1757 6230].

Robertson (1985, p.39) recorded *Dictyocaris* sp., *Lingula* sp., *Lissatrypa atheroides, Hyolithes* sp., *Acernaspis (Eskaspis) sufferta,* a Cephalopod and a Monograptid from localities in these gullies. Faunal lists from these localities were also published by Peach and Horne (1899, p605) and Lamont (1952, p27). The latter considered the fauna to indicate deposition in shallow water with periodic emergence.

Four samples from the Reservoir Formation (Figure 4) were collected for palynological analysis yielded acritarchs assemblages of variable diversity and abundance. The floras obtained can be correlated with those obtained from the middle to the upper part of the Reservoir Formation in the North Esk Inlier, which broadly supports the correlation of Robertson (1989). The presence of the acritarchs *Schismatosphaeridium perforatum, Tylotopalla astrifera*? and *Visbysphaera connexa*? in a sample from the Eastertown Burn [1744 6277] indicates a probable late Telychian age, though an early Wenlock age cannot be excluded (Molyneux 1996b). *V. connexa* is reported by Le Hérissé (1989) to appear within the uppermost Telychian on Gotland (*spiralis* Biozone) and to be well represented about the Llandovery–Wenlock boundary and in the lower part of the Wenlock. Predominance of thick-walled sphaeromorphs and *Moyeria cabottii* suggest deposition in a nearshore marine environment.

3.2.2 Deerhope Formation

The Deerhope Formation (**DHP**) is exposed in two small quarries [1680 6262 and 1681 6253] to the south of Bavelaw Castle, and consists of bioturbated olive-grey to green-grey mudstone with some silty laminae. They are placed in the Deerhope formation on account of their similarity with Deerhope Formation strata exposed in the North Esk River (Robertson 1985, p.40). Well preserved macrofossils are relatively common and include *Dictyocaris*, brachiopods, bivalves, trilobites and cephalopods (Robertson, 1989, Table 8). One palynological sample collected on the footpath [1675 6266] south of Bavelaw Castle yielded a sparse acritarch and sporomorph assemblage indicating a late Telychian or early Wenlock age.

3.3 Loganlee Inlier

The Silurian rocks of the Loganlee Inlier crop out in a narrow strip (0.4 km^2) extending from the Logan Burn to the north-eastern foot of Black Hill (Figure 2). The inlier is bounded on the west by the Black Hill Felsite and on the east is faulted against lavas of the Pentland Hills Volcanic Formation (Figure 8). The strata are highly inclined and strike approximately north-north-east.

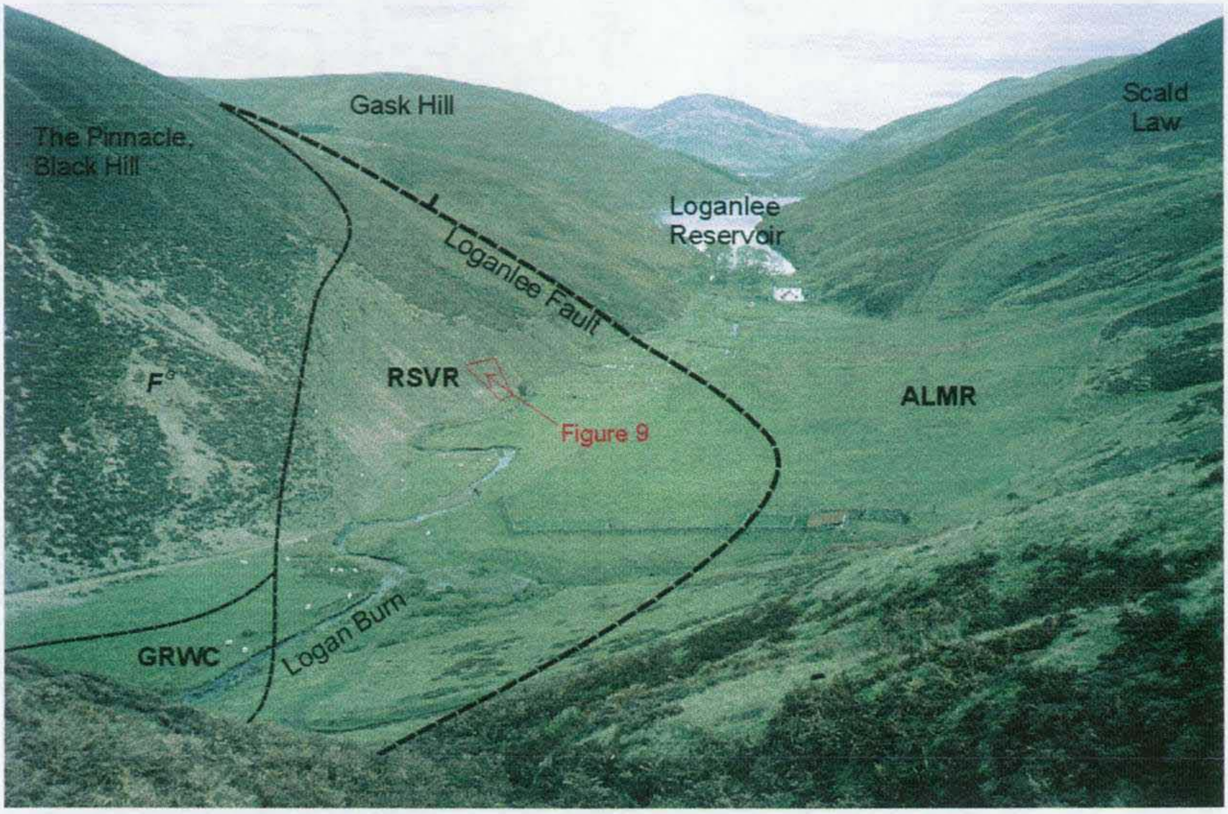

Figure 8 Part of the Bavelaw to Loganlee glacial meltwater channel from Lover's Loup [186 618]. F^G = Black Hill Felsite, RSVR = Reservoir Formation, Loganlee Inlier, GRWC = Greywacke Conglomerate Formation, ALMR = Allermuir Volcanic Member

Figure 9

Interbedded mudstone and siltstones, Reservoir Formation, Loganlee Inlier [1877 6194] (hammer = 0.3 m)

3.3.1 Reservoir Formation

The Reservoir Formation (**RSVR**) is best exposed on the south-east slope of Black Hill close to the footpath leading from Loganlee to Bavelaw [187 619] (Figures 8 and 9). The strata comprise vertical to steeply-dipping, green-grey and purple mudstones, buff to greenish-grey siltstone and occasional beds of very fine-grained sandstone up to 1.5 m thick. Load and flute casts on the bottom surface of the sandstone beds indicate they young to the west-north-west. Mykura and Smith (1962) stated that depositional currents varied from north-east to east-south-easterly flow. Robertson 1985, p.38) assigned the strata of the Loganlee Inlier to the Reservoir Formation on account of the sedimentary structures displayed in the coarser-grained beds. He suggested the Loganlee beds are stratigraphically lower than those exposed in the North Esk River and higher than those in the Monk's Burn in the North Esk Inlier.

Sparse, poorly preserved graptolites have been recorded from the Loganlee Inlier (Mykura and Smith, 1962).

Six samples were collected for palynological analysis from the north side of the Logan Burn [1867 6187 to 1886 6199] (Figure 4); five were barren but one [1886 6199] yielded a low diversity acritarch and spore assemblage similar to those found in the lower part of the Reservoir Formation in the North Esk Inlier.

4 LANARK GROUP (SILURO-DEVONIAN)

Siluro-Devonian strata of the Lanark Group (Lower Old Red Sandstone) crop out on NT16SE, NT15NW and NT15NE 1:10 000 sheets (Figure 2). The group comprises the Greywacke Conglomerate and Swanshaw formations overlain by lavas and volcaniclastic rocks of the Pentland Hills Volcanic Formation. The biostratigraphical age of the Lanark Group is difficult to determine due to the lack of fossil evidence. However, a radiometric age of 412.6 ± 5.7 Ma (upper Prídolí to Pragian) was obtained from a rhyodacite lava from the northern Pentland Hills [235 677] (Thirwall, 1988).

4.1 Greywacke Conglomerate Formation

The Greywacke Conglomerate Formation (**GRWC**) is exposed on all three sheets, though is of greatest extent and thickness on NT15NW and NT15NE. On NT16SE, the formation is best exposed near the waterfalls on Logan Burn [182 618 to 183 619] and in north-facing cliffs of Habbies Howe700 m to the west-south-west of Loganlee Reservoir [184 618 to 186 618]. On NT15NE the formation is exposed in Monks Burn [173 589 to 173 586] (Figure 10) and the River North Esk [156 575 to 158 571]. On NT15NW it crops out in Glenmade Burn [132 562 to 139 559], the burn to the south-west of Grain Heads [132 564 to 138 565], the burn to the south-west of Mount Maw [133 550 to 139 554] and Baddinsgill Burn [112 563 to 122 553].

The strata comprise green-grey and purple, massive to coarsely-bedded, clast-supported conglomerate with occasional sandstone interbeds, the latter more common in the upper part of the formation (best seen on NT15NW). The conglomerates are bimodal in grain-size distribution, with rounded to well-rounded clasts of pebble to boulder size in a poorly sorted lithic sandstone matrix. Clasts are predominantly greywacke sandstone with subordinate radiolarian chert and jasperised basic lavas. Occasionally, imbrication structure is seen (e.g. Glenmade Burn [1364 5598]. Syba (1989, fig. 3.5.1) noted current sources from the east-

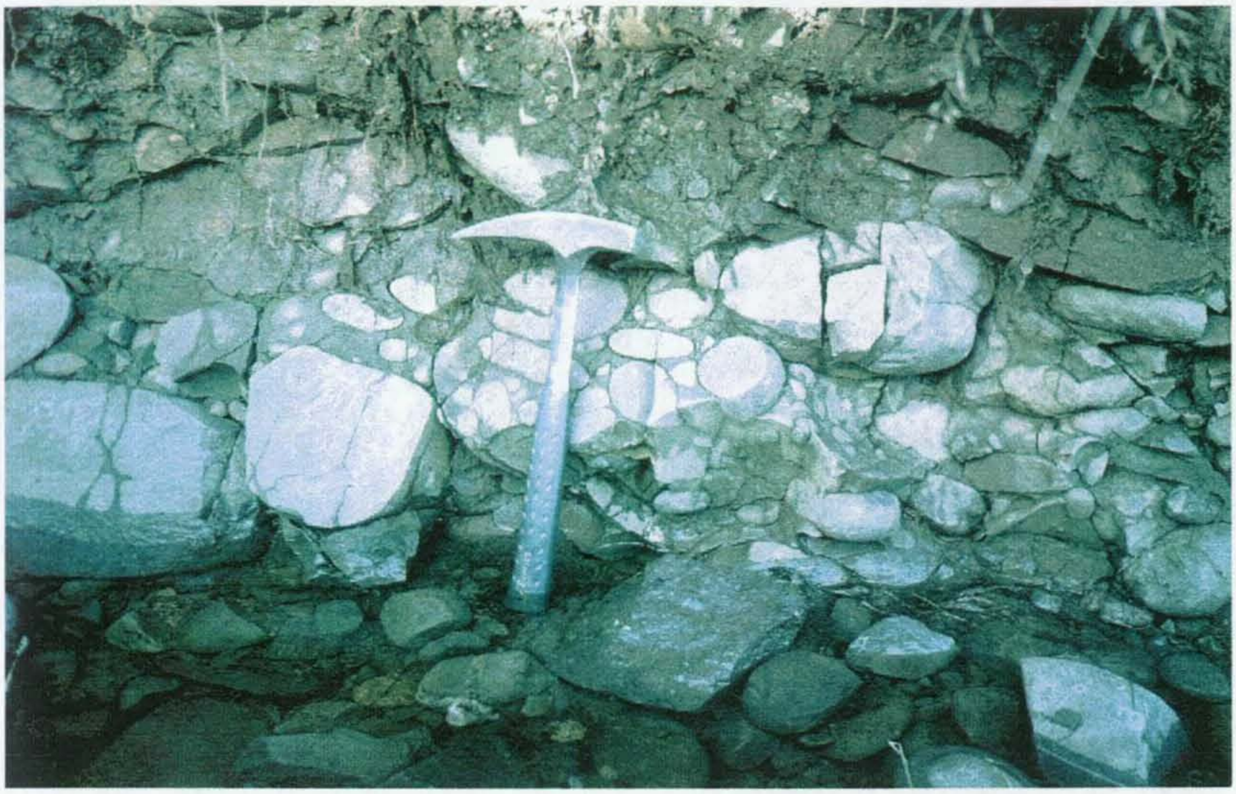

Figure 10 Fractured conglomerate, Greywacke Conglomerate Formation, Monks Burn [1717 5980] (hammer = 0.3 m)

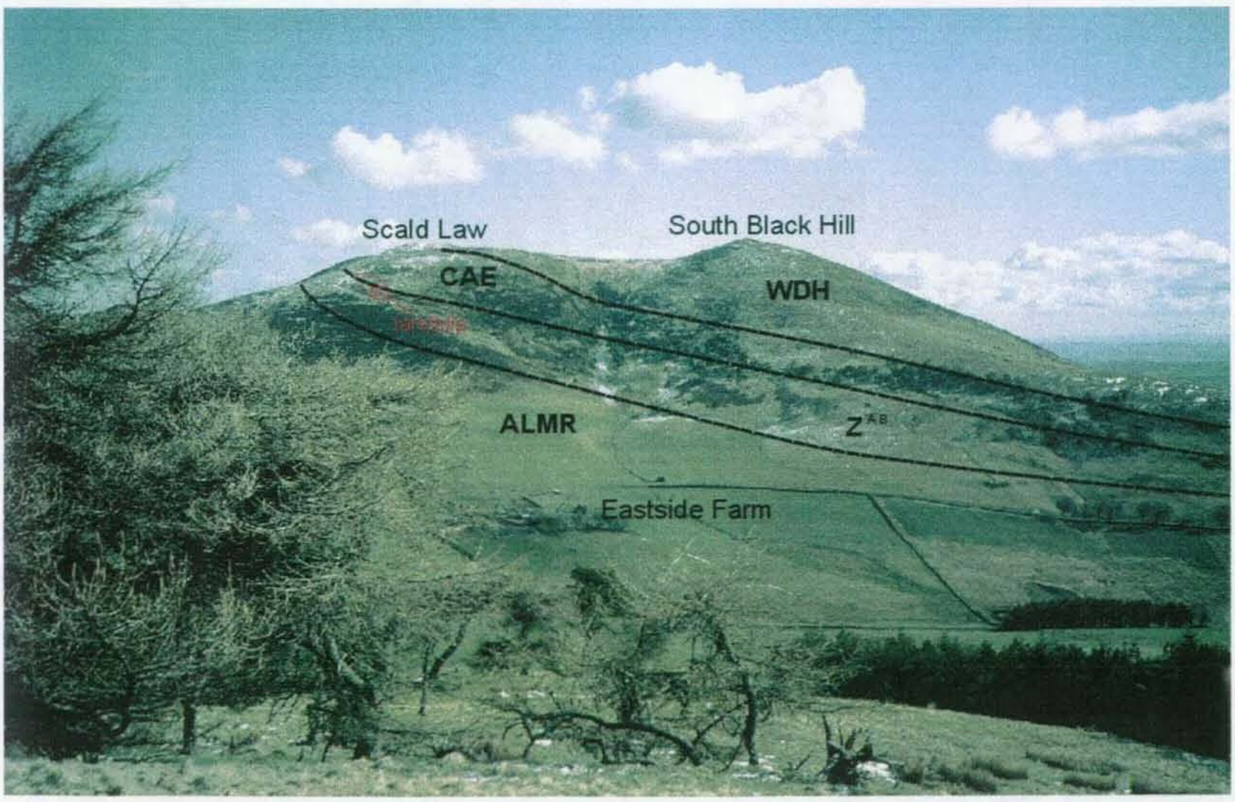

Figure 11 South Black Hill from Braid Law. ALMR = Allermuir Volcanic Member andesites and basalts, Z^{AB} = Allermuir Volcanic Member basaltic and andesitic tuff, CAE = rhyolitic tuff of Caerketton Volcanic Member, WDH = Woodhouselee Volcanic Member trachyte

north-east and east-south-east from imbrication in the Greywacke Conglomerate Formation of the North Esk Inlier area.

The sandstone interbeds are mostly composed of green-grey, purple and brown, fine to coarse-grained, poorly-sorted, micaceous, feldspathic and lithic sandstone. Trough cross-bedding can be seen in the Glenmade Burn [1333 5615] and near the Baddinsgill Burn [1158 5588], with current sources from north-east and south-east. Thin-sections of sandstones (S98804, S98805 and S99020) on NT15NW reveal fine to coarse grained, moderately-sorted sandstones with common detrital muscovite, biotite and feldspar. Lithic clasts are common to abundant and are predominantly phyllite, schist, psammite and polycrystalline quartz. Also present are intermediate (altered to Fe-oxide) and felsitic volcanic lithologies, and rare garnet (Beddoe-Stephens, 1998).

In the Logan Burn [1817 6187], the conglomerate forms indistinct beds of around two to four metres thick with a maximum clast size of 0.6 m. The clasts are well rounded and composed of:

greywacke (94%),
red chert (5%),
felsite (microgranite) (5%),
jasperised basic lava (5%),
quartz (2%),
pink granite (2%),
limestone with brachiopods and coral (2%).

A thin section (S98797) of a greywacke clast from this locality revealed a poorly sorted, coarse sandstone which is dominated by subangular clasts of quartz, many showing sub-grain texture, plagioclase, K-feldspar and lithic grains. Detrital garnet, polycrystalline quartz and white mica are also conspicuous constituents. The lithic component includes granite (with micrographic texture), felsitic rocks showing porphyritic and spherulitic texture, other chloritised, more basic volcanic fragments, psammite and phyllite. Clear irregular patches of chlorite are scattered throughout, possibly derived from a mafic phase. The rock is close-packed due to annealing of quartz with only a small amount of fine-grained chlorite-mica intergrain matrix (Beddoe-Stephens, 1998).

Also in the Logan Burn [1821 6183 to 6125 6185], blocks of Silurian limestone from the Greywacke Conglomerate Formation have yielded corals, trilobites, brachiopods and orthocones (Peach and Horne, 1899, p606). A thin-section (S98798) of a fine-grained calcareous sandstone from the Logan Burn [1830 6188] contained moderately-sorted, subangular grains dominated by quartz and lithic fragments. Common reddish K-feldspar, detrital muscovite, foliated polycrystalline quartz, chlorite pseudomorphs, minor opaque oxide, rare garnet and fresh plagioclase were observed. Common lithic fragments include cryptocrystalline felsite (some spherulitic), phyllite and fine-grained schist and chloritised basic/intermediate volcanic clasts. Cementation of this rock is by carbonate which replaces discrete grains and corrodes others, pressure solution annealing and patchy very fine chlorite-mica aggregate (Beddoe-Stephens, 1998).

Mykura (1962a) noted that near the base of the formation, local clasts (well-rounded quartzite, granite and acid lava) derived from the three Silurian conglomerate bands in the North Esk Inlier are common. He also noted that pebbles from the Pentland Hills Volcanic Formation do not normally occur in the lower part of the sequence except in the vicinity of Loganlee.

McGiven (1968) concluded that the Greywacke Conglomerate Formation was deposited as fans, mainly by the action of sheet floods in a terrestrial environment. More recently, Syba (1989) noted that the formation was formed by the vertical stacking of small proximal fans. These fans were dispersed mainly from the east and to a lesser extent, from the south with the geochemistry of the clasts suggesting that they probably came from a cryptic greywacke source within the Midland Valley (Syba, 1989).

The total thickness of the Greywacke Conglomerate Formation in the North Esk area is estimated to be around 270 m.

4.2 Swanshaw Formation

The Swanshaw Formation (**SWAS**) is best exposed on NT15NW where it crops out in the burn draining the north-east slopes of Byrehope Mount [1099 5542 to 1111 5590], the Byre Hope [1131 5527] and the Baddinsgill Burn [1230 5513 to 1236 5509]. On NT15NE good exposures occur in the River North Esk [1529 5674 to 1597 5623] and the Linn Burn [1506 5564 to 1559 5574]. Other exposures occur in the burn to the north of Spittal Farm [1687 5772 to 1694 5768] and at scattered localities on Scroggy Hill [176 584].

The formation consists predominantly of fine to coarse-grained, red-brown and green-grey lithic arenites with subordinate pebbly sandstones, conglomerates and argillaceous intercalations. The base of the formation is transitional with the underlying Greywacke Conglomerate Formation. Clasts in the conglomerates are predominantly greywacke with subordinate basic and intermediate lava, chert and quartzite, and reach a maximum size of 0.2 m. Rounded to well-rounded pebbles of pebbles of basic and intermediate lava up to 50 mm across are locally common in the sandstones. Red-brown silty mudstone galls are also sporadically seen.

In thin section, a sample taken from the burn draining the north-east slopes of Byrehope Mount (S98976)[1107 5568] revealed a medium-grained, moderately sorted sandstone comprising angular and subangular quartz with common feldspar and lithic fragments, together with detrital muscovite and chloritised biotite. Rarer grains of polycrystalline quartz and garnet are also present. Rock fragments include fairly common phyllitic clasts, mudstone/siltstone, felsic volcanic rocks and ?intermediate volcanic clasts altered to chlorite and Fe-oxide. Apatite and zircon are accessory detrital components. Feldspar appears to be dominantly K-feldspar (including microcline) and is variably altered to fine white mica. The minor matrix to this sandstone is a fine-grained intergranular chlorite plus mica aggregate, probably largely derived from degradation of lithic material (Beddoe-Stephens, 1998).

About 100 m downstream, a sample (S98803)[1108 5579] of a weakly laminated, moderately sorted, medium-grained sandstone comprised predominantly angular quartz with feldspar, detrital biotite and muscovite, relatively common garnet and opaque oxide, and altered rock fragments. Tourmaline and monazite/zircon are accessory phases. Heavy minerals are locally concentrated in laminae, Lithic clasts consist of common phyllite and schistose fragments, minor chloritised and felsitic volcanic rocks and polycrystalline quartz. Accessory heavy minerals are tourmaline zircon/monazite and rutile. Opaque oxides are relatively common and tend to be concentrated along sedimentary laminae with other heavy minerals. The intergranular matrix comprises Fe-stained mica/chlorite derived from degraded lithic material (Beddoe-Stephens, 1998).

Farther to the east on NT15NE, the sandstones tend to be less micaceous. A sample taken from the Linn Burn (S99021) [1502 5589] revealed a medium-grained, poorly sorted sandstone comprising subangular to angular grains of quartz, feldspar, lithic clasts, polycrystalline quartz, sparse garnet and only very rare small flakes of biotite or muscovite. Rock fragments comprise basic/intermediate fine-grained crystalline volcanic clasts, common rounded mudstone/siltstone (one example up to 3 mm), phyllite, psammite, chert and rare felsite. The minor intergranular matrix comprises fine-grained mica-chlorite and quartz (Beddoe-Stephens, 1998).

Tabular cross-bedding seen on Whauplie Rig [1110 5584] and in the Baddinsgill Burn [1235 5510] indicate palaeocurrent sources in the north-east. On Whauplie Rig, a conglomerate with imbricate texture [1599 5545] also indicates north-easterly derivation.

A sample taken from a siltstone intercalation in a grey-green, fine-grained micaceous sandstone [1624 5771] on Patie's Hill was examined for palynomorphs, but though it yielded organic material, it proved to be barren of palynomorphs.

The total thickness of the Swanshaw Formation in the North Esk area is estimated to be around 340 m.

4.3 Pentland Hills Volcanic Formation

The volcanic succession of Pentland Hills described in detail by Mykura (1960) is here termed the Pentland Hills Volcanic Formation (**PDH**). It is exposed on NT16SE, NT15NE and NT15NW, with the greatest extent on NT16SE and only minor exposures on NT15NW. The formation comprises basalts, andesites, trachytes and rhyolites conformably overlying the Greywacke Conglomerate and Swanshaw Formations and contains several distinct lava members together with interbedded pyroclastic rocks and some sedimentary beds. Six of Mykura's groups are recognised in the area and here formalised as members. The lithologies of the individual members is listed below.

Carnethy Volcanic Member	olivine-basalts and basic andesites
Woodhouselee Volcanic Member	trachytes, andesites and other silicified acid rocks
Caerketton Volcanic Member	Rhyolitic tuffs and basic andesite
Allermuir Volcanic Member	basic andesites and olivine basalts with intercalations of sandstone, basic tuffs and breccias; local rhyolite and rhyolitic tuff
Bell's Hill Volcanic Member	Rhyolites with lenses of conglomerate
Bonaly Volcanic Member	Feldsparphyric andesites and olivine basalts; local rhyolites

The base of the formation is seen west of Braid Law [NT 180 590] where rhyolite of the Bell's Hill Volcanic Member overlies the Swanshaw Formation.

The geochemistry of the Lanark Group volcanic formations has been examined by Thirlwall (1981) and is considered to be calc-alkaline in character, related to a subducting slab of oceanic plate descending to the west-north-west.

Thirlwall (1988) obtained a radiometric age of 412.6 ± 5.7 Ma (upper Prídolí to Pragian) for a rhyodacite lava from the Capelaw Volcanic Member in the northern Pentland Hills [235 677] (NT26SW). The position of the Capelaw Volcanic Member is between the Bell's Hill and Allermuir Volcanic members in the north.

4.3.1 Bonaly Volcanic Member

The Bonaly Volcanic Member(**BNY**) is represented by several small outcrops of decomposed basic lava on the north-west slopes of Bell's Hill [199 647]. It is assumed to be faulted against the Reservoir Formation of the Loganlee Inlier to the south.

4.3.2 Bell's Hill Volcanic Member

Rhyolites of the Bell's Hill Volcanic Member (**BHHB**) are exposed in White Cleuch [198 635] and on Braid Law [1847 5930]. The Braid Law rhyolite is flow-banded and locally vesicular; in thin-section it is sparsely porphyritic with phenocrysts of decomposed sanidine feldspar and a felsitic or microcrystalline matrix of quartzo-feldspathic aggregate (Mykura, 1960). The maximum thickness of this member on NT16SE area is estimated to be around 300 m.

4.3.3 Allermuir Volcanic Member

The andesite and basalt lavas of the Allermuir Volcanic Member(**ALMR**) crop out from the east ridge of Gask Hill [198 630] (Figure 8) to the south-west slopes of Mount Maw [149 550]. They overlie the rhyolites of the Bell's Hill Volcanic Member north of Gask Hill, are faulted against the Reservoir and Greywacke Conglomerate formations in the west (NT16SE), and overlie the Swanshaw formation in the south-west (NT15NE).

The lavas attain a maximum thickness of around 500 m on the northern slopes of Scald Law and thin rapidly to the south-west of West Kip. They are best exposed on the west-south-west ridge of West Kip [1765 6047 to 1783 6060] and the south ridge of East Kip [1829 6082 to 1831 6062]. On the latter ridge at least seven distinct flows of four to five metres thickness can be discerned in a series of small craggy outcrops. The flows are highly vesicular and have only thin, non-vesicular central portions (Mykura, 1960). Intercalated with the lavas are volcaniclastic sandstones and fine conglomerates; the former are well exposed on the north shore of Loganlee Reservoir [1942 6248 to 1966 6258] (Figure 12) and small outcrops of the latter can be seen on the north side of the track south-east of West Kip [1798 6034]. Basic tuff [1875 6104] and agglomerate [1875 6049] are locally present at the top of the member.

A mudstone parting from a volcaniclastic sandstone on the north shore of Loganlee Reservoir [1960 6256] was investigated palynologically, but proved to be barren of palynomorphs and organic matter.

4.3.4 Caerketton Volcanic Member

The rhyolitic tuffs of the Caerketton Volcanic Member (**CAE**) crop out in a narrow belt from Crooked Rig [200 619] to Walstone Burn [183 584]. A thin lenticular flow of basic andesite occurs partly interbedded with the tuff between Scald Law and Carnethy Hill; small outcrops of this can be seen to the south and west of the Grain Burn [198 614]. On the south side of South Black Hill [1902 5979] (Figure 11), the tuff is fragmented with blocks up to 0.25 m in size. The maximum thickness of this member on NT16SE is estimated to be around 130 m.

While mapping was in progress, a small pit [1938 6130] had been dug for footpath hardcore on the north-east shoulder of Scald Law. A sample (S98790) of rhyolitic tuff from this pit was thin-sectioned and revealed a laminated/bedded volcaniclastic rock almost entirely composed of angular to sporadically cuspate volcanic lithic clasts, up to 3 mm in diameter. These lithic clasts include devitrified glassy fragments, some showing perlitic cracks, flow-banded felsitic lithologies and ragged 'fiamme' aligned parallel to sedimentary lamination. Most of the volcanic fragments appear aphyric, a fact born out by the virtual absence of crystals clasts. Grain size within this sample varies from very fine ash to coarse ash grade. Over most of the

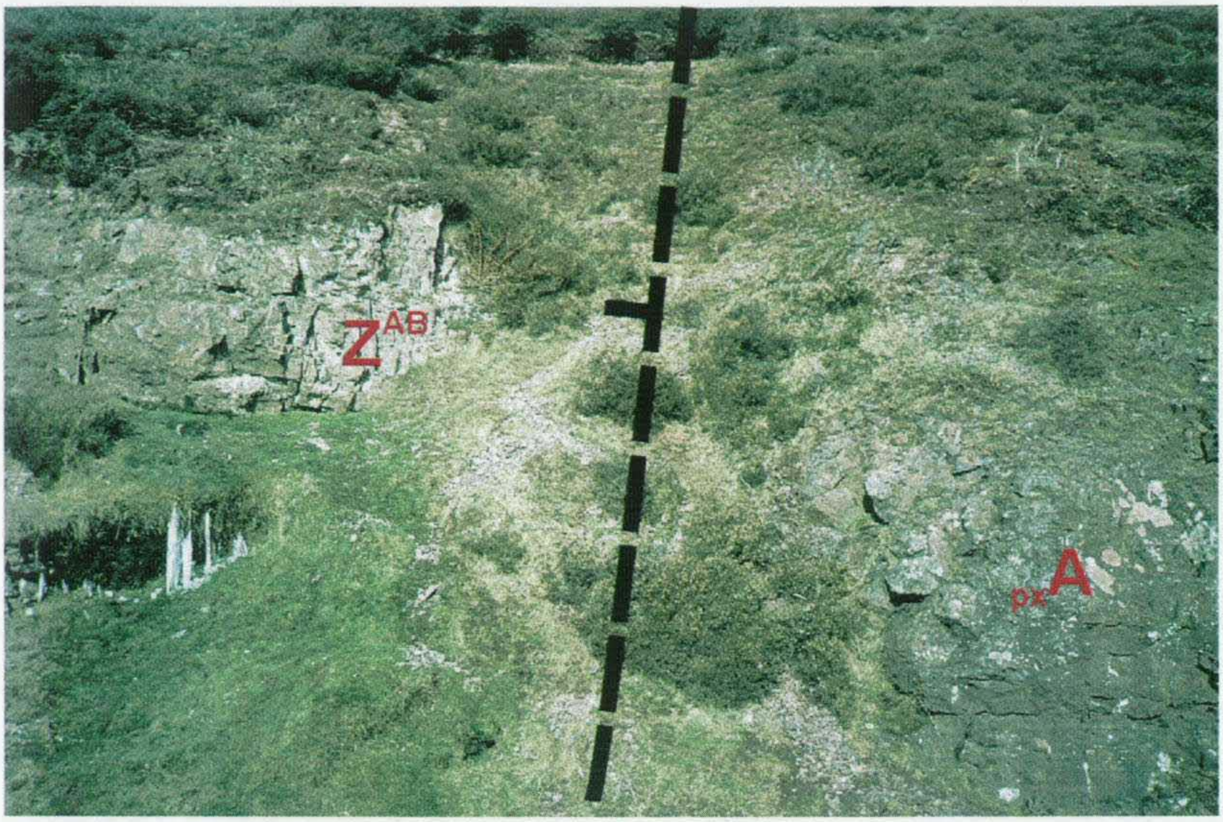

Figure 12 Fault in Allermuir Volcanic Member on north shore of Loganlee Reservoir [1969 6259]. Volcaniclastic sandstone and tuff (Z^{AB}) in Hanging wall, basic andesite($_{px}$A) in footwall. Vegetation for scale

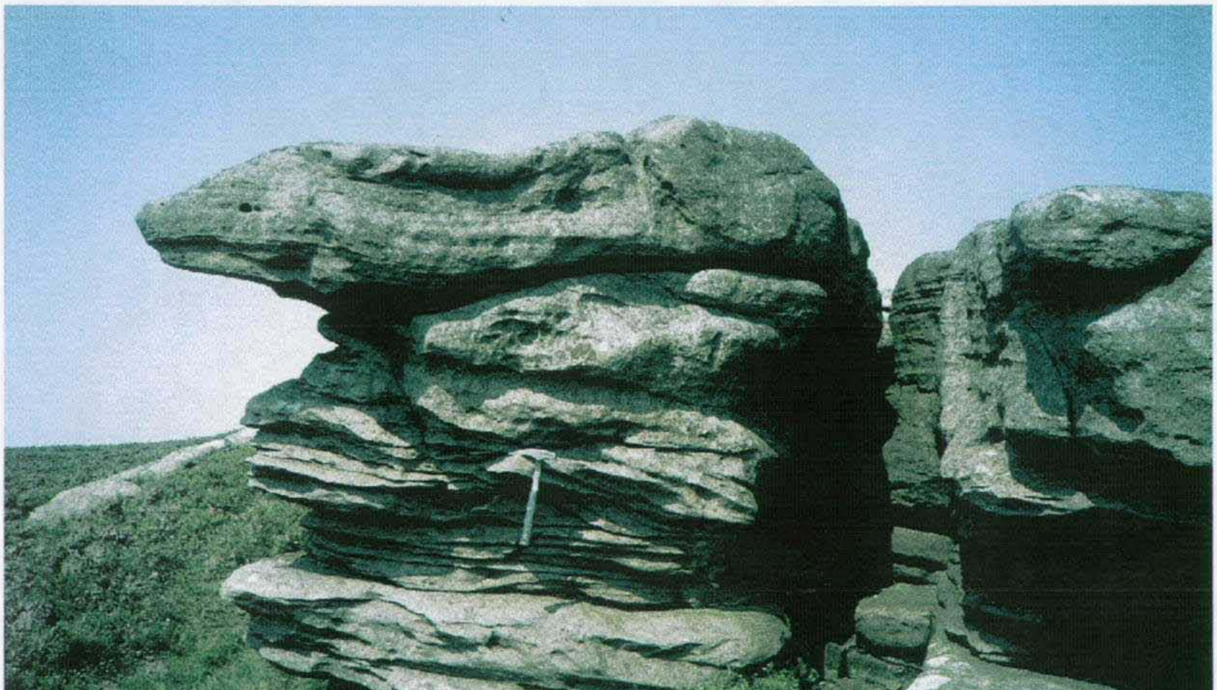

Figure 13 Tor of pink, fine-grained, cross-bedded sandstone, Kinnesswood Formation, Cloven Craig, West Cairn Hill [1053 5799] (hammer = 0.3 m)

thin section there is a high proportion of fine ash matrix, evident as homogeneous, cryptocrystalline material; however, a third of the section is composed of a coarse ash very poor in ash matrix, and with intergranular seams and patches of clear secondary quartz.

Alteration of the lithic clasts varies from cryptocrystalline devitrified glass to fine-grained felsitic recrystallisation texture. Some clasts show the development of clear quartz spots. Many of the fiamme in addition show overprinting by a fine stringy white mica aggregate. Flattening of the latter is attributed to diagenetic collapse rather than welding compaction

This rock is interpreted as a primary bedded ash, though whether emplaced by fall or surge-like flow cannot be ascertained from thin section. The mostly high proportion of fine ash matrix and angular glassy fragments, showing only minor evidence for vesiculation, suggests an origin by phreatomagmatic explosions. Localised winnowing of the deposit (by water/wind) with removal of fine matrix is also indicated (Beddoe-Stephens, 1998).

4.3.5 Woodhouselee Volcanic Member

Lavas of the Woodhouselee Volcanic Member (**WDH**) crop out from the east and south slopes of Scald Law and South Black Hill (Figure 11) to the south-east slopes of Pillar Knowe [185 587]. The rocks consist of highly kaolinised trachytes and andesites with phenocrysts of biotite and alkali-feldspars in a fluidal matrix of laths of sanidine with patches of hematite and secondary grains of quartz (Mykura, 1960).

4.3.6 Carnethy Volcanic Member

The basalts and andesites of the Carnethy Volcanic Member (**CAHI**) crop out in the south-east corner of NT16SE and the north-east corner of NT15NE. Heavily faulted and fractured basic andesite can be seen in the disused Silverburn Quarry [199 606].

5 INVERCLYDE GROUP (CARBONIFEROUS)

Carboniferous strata of the Inverclyde Group crops out on all three sheets, though are best developed on NT15NW and NT16SE. In this area the group comprises the Kinnesswood and Ballagan Formations which are Tournaisian in age ranging from Courceyan to early Chadian (Browne et al., 1996). The uppermost unit of the Ballagan Formation, the 'Upper Sandstone' may be equivalent to the Clyde Sandstone Formation.

5.1 Kinnesswood Formation

The Kinnesswood Formation (**KNW**) is best exposed on NT15NW and NT16SE where it forms a two to three-kilometre wide outcrop extending from Hare Hill [17 61] south-westwards to West Cairn Hill [10 58] (Figure 2). In the northern part of NT16SE, the formation forms a narrow strip on the south shore of Threipmuir Reservoir which extends to Craigentarrie (Figure 14). In the Cairn Hills area the formation is up to 300 m thick (Mykura, 1962b). It also crops out between the strands of the Pentland Fault south-west of Carlops (Figure 2).

It comprises pale pink to red-brown and white moderate to well-sorted, mostly medium-grained quartzose sandstone with subordinate interbeds of red-brown and pale green siltstone, mudstone, fine conglomerate and cornstone beds. Most sandstones are cross-bedded and arranged in upwards fining units (Figure 13).

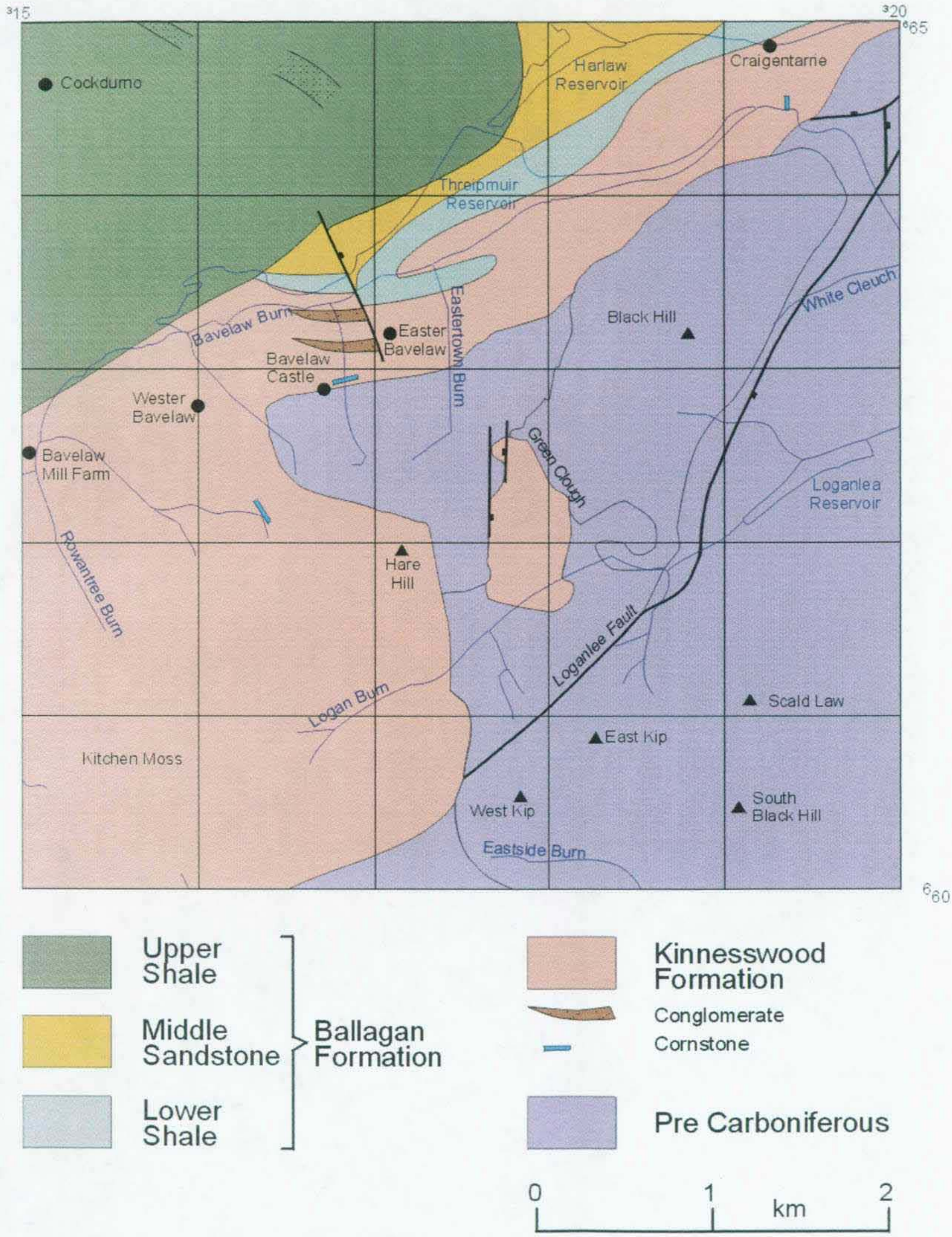

Figure 14 Carboniferous geology of NT16SE

Cornstone is generally developed near the base of the formation, a few metres above the unconformity with the Lanark and North Esk groups, and is considered to represent the development of caliche in a fossil soil horizon (Burgess, 1961). It is best developed in disused pits on the north-west slopes of Hare Hill [164 622], in the burn between Bavelaw Castle and Easter Bavelaw [1684 6289], in the Ravendean Burn [1191 5732], and between the strands of the Pentland Fault south-west of Carlops [154 553 and 157 557].

A thin basal conglomerate is developed at the northern end of the outcrop. It is exposed in the burn between Bavelaw Castle and Easter Bavelaw [1685 6314 to 1681 6330], the Eastertown Burn [1739 6353], the Logan Burn [1743 6123] between Hare Hill and West Kip, and between the strands of the Pentland Fault south-west of Carlops [1564 5560]. The conglomerate is generally matrix-supported and contains mostly subangular clasts up to 0.1 m across composed of lavas from the Pentland Hills Volcanic Formation, and also vein quartz, quartzite, jasper and chert. Red, medium to coarse-grained pebbly sandstone occurs in association with the conglomerate.

The bulk of the formation is composed of pink to red-brown moderate to well-sorted, medium-grained, generally tabular and trough cross-bedded quartzose sandstones arranged in upwards fining units. These are well exposed in the West and East Cairn Hills and the Hare Hill area (Figures 2 and 13). Subordinate interbeds of red, fine-grained sandstones and red-brown and pale green siltstones and mudstones also occur. Orientation of cross-bedding on Hare Hill [1710 6187], East Cairn Hill [1374 5941 and 1384 5942], Byrehope Mount [1021 5555] and White Craig Hill [1012 5672] suggests palaeocurrents flowed approximately from the south-east. On Cloven Craig [1052 5800] there is also evidence for flow from the north-west.

Two samples were collected from a small section to the west of Hare Hill (Figure 15) were examined in thin-section:

S98973 This is a fine-grained sandstone, moderately well-sorted with subrounded to subangular grains. It is dominantly composed of quartz with only minor fresh feldspar. Detrital flakes of muscovite are relatively common. Rutile (replacing opaque oxide) with accessory tourmaline and monazite are also present. Rock fragments are sparse, very fine-grained and largely indeterminate, although phyllitic, fine-grained micaceous fragments are visible. Cementation is by pressure solution but common interstitial pockets of clay occur, together with patchy ?illite/sericite derived from feldspar breakdown. Porosity appears minor (Beddoe-Stephens, 1998).

S98974 A medium-grained well-sorted sandstone composed of subrounded to subangular dominantly quartz grains. Very little fresh feldspar is apparent, most is totally altered to sericite or kaolinite. Minor detrital muscovite and polycrystalline quartz grains are present, together with biotite. Minor rock fragments comprise mudstone/siltstone, phyllite and mica schist. Tourmaline is an accessory phase. Cementation is by early quartz overgrowth and pressure solution annealing, followed by common kaolinite infill and tabular barite crystals. The latter are locally strained or bent, suggesting this was an early authigenic phase before total burial compaction. Intergranular Fe-oxide patches are disseminated throughout the rock, giving rise the purple mottling evident in hand specimen. These may derived from dissolution of siderite or ferroan calcite cement (Beddoe-Stephens, 1998).

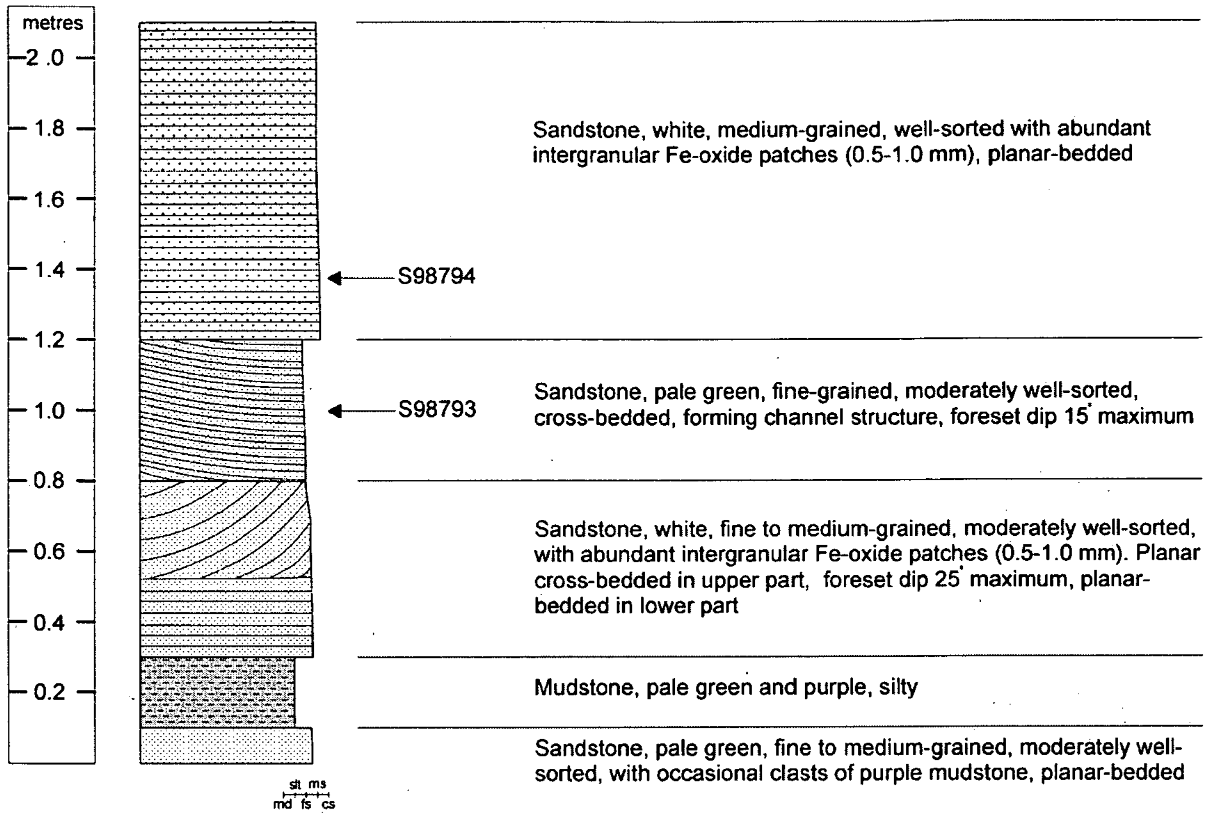

Figure 15 Sedimentary log of section in Kinnesswood Formation to the west of Hare Hill [1637 6217]

Browne et al. (1996) envisage that the cross-bedded sandstones were deposited in fluvial channels and the fine-grained sandstones and mudstones were deposited as overbank deposits on associated floodplains.

No biostratigraphical data are available for the Kinnesswood Formation in the area mapped. However, in the base of formation in the Gass Water, New Cumnock on BGS sheet 15W (New Cumnock), a sample yielded spores typical of zones LN–PC of Higgs et al. (1988), which corresponds to a latest Devonian to early Carboniferous (Tournaisian) age (Smith, 1998). This confirms the formation may straddle the Devonian–Carboniferous boundary, but most of it is of early Carboniferous age.

5.2 Ballagan Formation

The Ballagan Formation (**BGN**) crops out on the north-western side of the Pentland Hills and occurs on NT16SE and NT15NW (Figures 2 and 14). Mitchell and Mykura (1962, p38) divided the Ballagan Formation (previously Cementstone Group) into four informal units; Lower Shale, Middle Sandstone, Upper Shale and Upper Sandstone.

5.2.1 Lower Shale

The Lower Shale (**md'**) is exposed in the Eastertown Burn [1742 6341 to 1739 6352] and a neighbouring burn to the east [1764 6347 to 1760 6357]. Here it comprises purple, red and grey calcareous mudstones with calcareous concretions interbedded with nodular fine-grained calcareous sandstones, siltstones and thin ferroan dolomites (cementstones). Bed thickness ranges from 0.15 to 0.65 m and the maximum thickness is estimated to be 100 m. A sample from Eastertown Burn [1742 6341 to 1739 6342] yielded an impoverished spore assemblage indicating broad affinities with Tournaisian assemblages (Turner, 1995).

5.2.2 Middle Sandstone

The Middle Sandstone (**sa'**) is seen only in several small exposures on the eastern shore of Harlaw Reservoir [184 649] and comprises pale grey and ochre, fine to medium-grained calcareous cross-bedded sandstone associated with grey calcareous mudstone. A sample taken from the north bank of the burn draining into the eastern tip of the Reservoir [1846 6490] yielded an impoverished spore assemblage indicating broad affinities with Tournaisian assemblages (Turner, 1995). Other palynological samples collected from the Middle Sandstone in the Bavelaw and Kinleith Burns on NT16NE contained spore assemblages not older than latest Tournaisian CM Zone (Turner, 1995).

5.2.3 Upper Shale

The Upper Shale (**md"**) crops out in the north-west corner of NT16SE and in Baad Park [10 59] in the north-west corner of NT15NW. No exposures were seen in either of these areas, however, buff and red argillaceous and micaceous sandstones were recorded from trial pits dug during the previous survey. A water borehole (NT16SE/3) drilled at Cockdurno Farm [1514 6454] in 1968 proved 15 m of red calcareous mudstone above a 41 m interbedded sequence of red sandstones, siltstones and cementstone (Table 3). A 1.5 m thick dolerite was also recorded at 55.8 m below ground level.

Palynological samples collected from the Upper Shale on NT16SW and NT16NE yielded spore assemblages of PC–Pu (late Tournaisian to early Viséan) Zone age (Turner, 1995).

Borehole NT16SE/3 NT 1512 6455		
Lithology	**Thickness**	**Depth to base**
Soil	0.30	0.30
Till	1.98	2.29
Boulder	0.46	2.74
Red Calcareous mudstone	14.94	17.68
Red Sandstone	2.29	19.96
Red Calcareous mudstone	0.76	20.73
Red Sandstone	1.22	21.95
Silty Sandstone	2.59	24.54
Red Sandstone	1.37	25.91
Silty Sandstone	4.27	30.18
Red Sandstone	3.66	33.83
Cementstone	1.52	35.36
Calcareous siltstone	1.83	37.19
Cementstone	1.22	38.40
Calcareous siltstone	2.59	41.00
Silty Sandstone	5.79	46.79
Calcareous sandstone	7.62	54.41
Dolerite	1.52	55.93
Silty Sandstone	4.11	60.05
Red Sandstone	0.91	60.96

Table 3 Lithological log of Upper Shale unit from Cockdurno Farm water borehole (depths in metres below ground level)

5.2.4 Upper Sandstone

The Upper Sandstone(**sa**") occurs in the north-west corner of NT15NW where several small outcrops of pink, fine to medium-grained sandstone are exposed in the Cushie Syke [1024 5977 to 1023 5985]. Browne et al. (1996) suggest that the Upper Sandstone may belong to the Clyde Sandstone Formation, the uppermost formation of the Inverclyde Group.

6 INTRUSIVE IGNEOUS ROCKS

6.1 Lyne Water dioritic intrusion (*H*)

A small elongate intrusion of highly decomposed diorite occurs in the Lyne Water to the north-west of the North Esk Inlier (Figure 2). Small exposures of weathered diorite can be seen in the Lyne Water [1245 5765 and 1252 5758] and scattered diorite and microgranite debris is seen on the hillside to the north-east. The Greywacke Conglomerate Formation has been highly indurated in a belt extending from 90 to 120 m from the south-east margin of the intrusion, and is hornfelsed up to 55 m from the contact (Mykura, 1960).

Mykura (1960) described the intrusion in detail and suggested that it may well be the southern margin of a larger intrusion of granitic composition now covered by the Kinnesswood Formation.

6.2 Black Hill Felsite (F^G)

Black Hill is formed of pink to pale red microgranite covering an area of over two square kilometres (Figure 2). It is best exposed on the sides of Green Clough [1793 6226 to 1844 6194] and north of the Logan Burn [1866 6188] west of The Howe (Figure 8). Other exposures include the northern [195 643 and 1895 6405], western [1820 6294] and eastern [1887 6265 and 1896 6261] slopes of Black Hill.

Peach et al. (1910, p26) described the felsite as a laccolith intruded along the plane of the North Esk Group and Lanark Group unconformity, whereas Mykura (1960, p146) suggested that the felsite may well be an extrusive cumulo-dome.

6.3 Minor basic intrusions (*P*)

Minor intrusions are relatively common within the Silurian inliers and Greywacke Conglomerate and Swanshaw formations, but are absent from the Inverclyde Group. All are assumed to be latest Silurian to mid Devonian in age. They are hydrothermally altered and vary in composition from olivine-dolerites and basalts to acid andesites (Mykura, 1960). Cockburn (1952) described these intrusions in detail and additional intrusions were mapped during the previous survey (Mykura, 1960). The greatest concentration of minor intrusions seems to occur in a broad belt roughly parallel to the Pentland Fault from the Quarrel Burn [181 591] to the River North Esk [15 56].

A sample (S98802) from a small intrusion in the burn draining the north-east slopes of Byrehope Mount [1101 5547] revealed a fine-grained, sparsely microporphyritic, amygdaloidal dolerite. It is dominated by interlocking plagioclase laths with intergranular chlorite after probable pyroxene (but also possibly, in part, after glass or amphibole). Disseminated opaque oxides also occur showing equant anhedral to subhedral and bladed morphology; but there is also stringy/patchy secondary Fe-oxides throughout the rock. Plagioclase is probably albitised and has included flecks of white mica. Microphenocrysts comprise single or glomerophyric crystals of plagioclase up to 1mm. Rare possible microphenocrysts of pyroxene are represented by pseudomorphs of carbonate. There is only a trace of interstitial mesostasis in the form of quartz (+?K-feldspar), although this may be secondary. Amygdales range up to 2 mm and consist of polycrystalline dusty carbonate (Beddoe-Stephens, 1998).

Robertson (1989) described the 3.5 to 10.0 m thick Failiehope-Gutterford intrusion [1466 5712 to 1606 5938] as being folded by f1 and f2 folds in the Gutterford Burn [159 592] and thus of Silurian age. No evidence of this folding in this intrusion was observed. Bull (1995, p91) noted that Gutterford Burn locality is on a line of en-echelon folding in the Reservoir Formation and that the intrusion is not folded but bifurcates and follows weaknesses and flexures in the sedimentary layers, thus removing the need for this intrusion to be of early Silurian age.

7 QUATERNARY

Most of the landforms and Quaternary deposits in the Lothians date from the Late Devensian (Dimlington Stadial) glaciation during which ice from the south-west Highlands and Southern Uplands advanced into the area from the west and south-west depositing a basal till. During the wasting of this ice sheet, subglacial meltwater channels and localised deposits of glaciofluvial sand and gravel were formed in the Pentland Hills. In post-glacial (Flandrian) times local deposits of peat and alluvium accumulated on the glacial deposits and on rockhead.

7.1 Late Devensian

7.1.1 Glacial landforms

There are a number of south-west to north-east oriented ice-moulded rock ridges in the north-east of NT15NE, including north of Nine Mile Burn [177 578 to 181 582], Walstone [181 581 to 184 583], Pillar Knowe [184 587 to 191 593] and Camp Hill [190 595 to 192 596]. No glacial striae were recorded during this survey, but Peach et al. (1910, p327) noted one south-easterly trending striation in the pass between West Kip and Cap Law and a north-easterly trending striation near Walstone (Figure 16).

Glacial meltwater channels are common in this area, particularly to the north and south of Threipmuir Reservoir and from Carlops to the Quarrel Burn Reservoir (Figure 16). Those to the south-west of Carlops [152 550 to 164 565] are among the finest examples of sub-glacial meltwater channels in Scotland. They follow the line of the south-west to north-east trending Pentland Fault system and illustrate clearly the anastomosing pattern of subglacial meltwater flow, with the hydraulic gradient reflected in the 'up and down' channel profiles. They are described in detail by Sissons (1963) and Gordon and Sutherland (1993). Large meltwater channels also occur at Green Clough (Figures 8 and 16) and south-east of Craigentarrie (Figure 16). The meltwater channels to the north-west of Hare Hill are described by Mykura (1986, p165), and those to the north of Threipmuir Reservoir by Mykura and Earp (1962, p119).

7.1.2 Glacial deposits

The cover of glacial till is widespread on the lower ground and is patchy or absent above 400–500 m. It is most extensive to the north-west of the Pentlands Hills on NT16SE and reaches thicknesses of up to four metres to the north of Threipmuir Reservoir. Till cover is patchier on the south-eastern slopes of the Pentlands.

The till consists of a stiff, tough, dark grey sandy and silty clay with boulders, cobbles and pebbles from local rock types and also Highlands and Southern Upland lithologies.

On the northern part of NT15NW near the headwaters of the Lyne Water and River North Esk (Figure 16), the basal till is overlain by reddish-brown sandy till with a higher proportion of boulders. It locally attains a thickness of three metres and the junction with the basal till is usually a horizontal surface, though sections exposed in the headwaters of the Lyne Water near the Cauldstane Slap [11 58] show some interdigitation of the two lithologies with shear structures and thrust wedges along the junction (Mykura and Earp, 1962).

An area of hummocky morainic ground can be seen to the south-east of the Cauldstane Slap [119 577 to 128 582] (Figure 16).

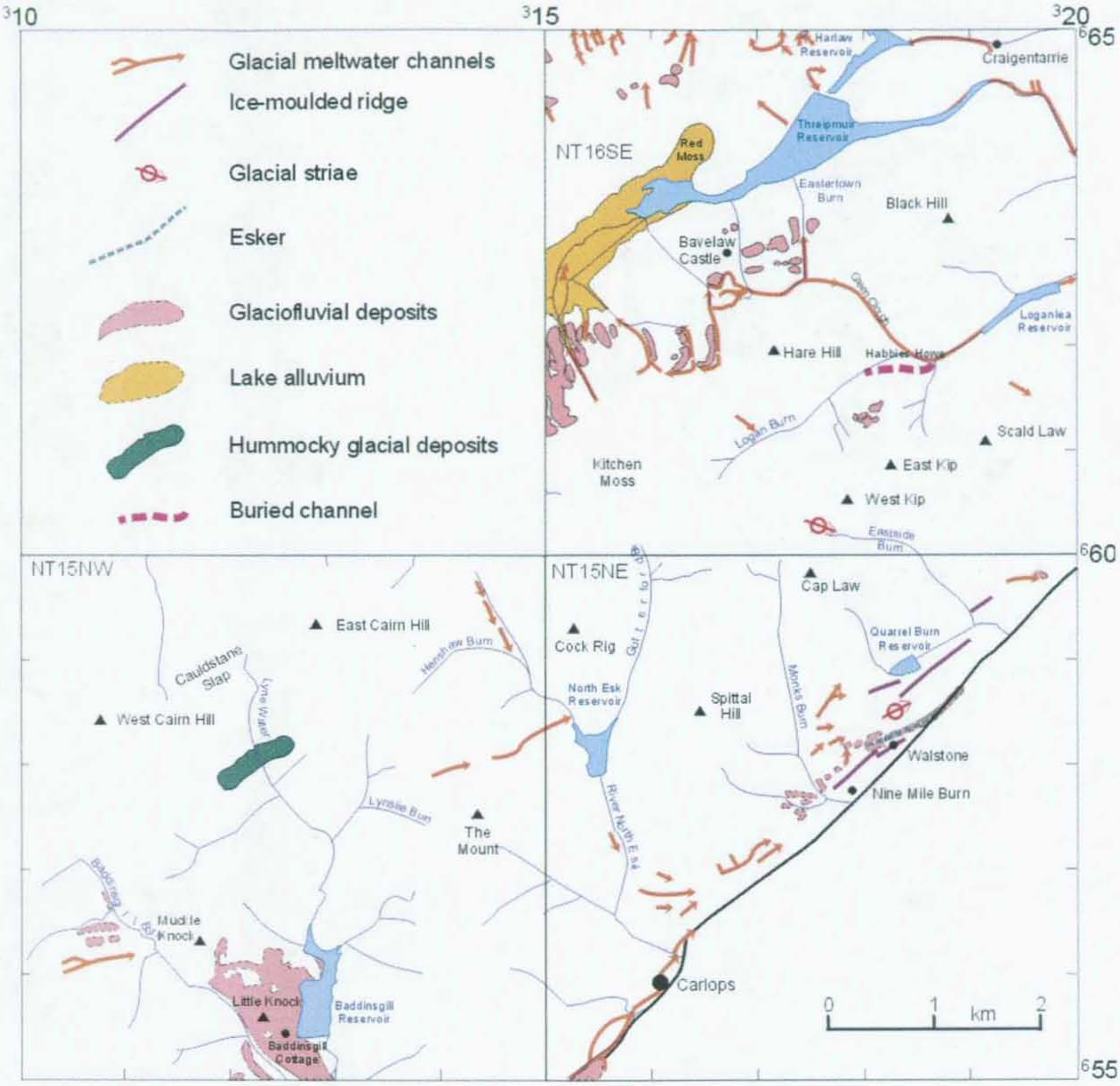

Figure 16 Simplified map of ice-retreat features and glaciofluvial deposits, central Pentland Hills

The pre-glacial channel of the Logan Burn to the south of Habbies Howe [181 617 to 186 618] is now drift-filled and the rock gorge to the north [182 618] is post-glacial.

7.1.3 Glacial meltwater deposits

Sand and gravel deposited from glacial meltwater at or near the edge of the ice sheet occur on all three sheets. On NT16SE extensive deposits of sand and gravel in the form of mounds 5 to 15 m high occur to the south-west east of Bavelaw Castle [15 61] (Figure 16). The deposits consist mainly of fine sand and silt with minor proportions of medium and coarse gravel and boulders up to 0.3 m (McAdam, 1978). Less extensive mounds and ridges occur to the south-south-west and east of Bavelaw Castle, the north-west slopes of East Kip and to the north-west of Threipmuir Reservoir (Figure 16).

On NT15NE, a well-defined esker occurs to the north-east of Nine Mile Burn [182 583 to 189 587], several mounds and ridges can be seen to the west of Nine Mile Burn [17 57], and moundy sand and gravel occurs to the south-west of Carlops [154 551].

On NT15NW, a sheet-like deposit of sand and gravel covers Little Knock to the west of Baddinsgill Reservoir and two esker-like ridges and several mounds of sand and gravel occur near the headwaters of the Baddinsgill Burn [10 56] (Figure 16).

The alluvial flat at the west end of Threipmuir Reservoir represents the probable site of an ice-dammed loch formed at a late stage in the retreat of the ice-sheet (Mykura, 1986).

7.2 Flandrian

7.2.1 Peat

Peat has been mapped where greater than one metre thick. Extensive deposits of hill peat (blanket bog) occur on Kitchen Moss [15 60] and around the headwaters of the Ravendean Burn [11 56, 11 57], both at an elevation of around 400 to 450 m. Some erosion has occurred and peat hags can be seen in both these areas. Patchy accumulations occur at higher elevations, such as on Scald Law (550 m)[189 608], Black Hill (500 m)[189 632], East Cairn Hill (500–550 m)[129 596], Grain Heads (500–530 m)[141 571], and Mount Maw (500–530 m)[142 555]. A lowland raised bog occurs on the north side of Threipmuir Reservoir [163 639]. This bog, known as the Red Moss, is an SSSI and listed in Lindsay and Immirzi (1996).

7.2.2 Scree

Well-developed scree deposits occur on the south-east slopes [193 609 and 197 606] and north-west slopes [191 612] of Scald Law and on the sides of Green Clough [179 626 to 187 619]

7.2.2 Landslips

A small landslip in rhyolitic tuff occurs on the west shoulder of Scald Law [1872 6077] (Figure 10).

7.2.3 Alluvium

On NT16SE, river alluvium and small alluvial fans occur in the drainage channel between Threipmuir and Glencorse reservoirs on the north-east side of Black Hill [19 64, 19 63], in the glacial meltwater channels south of Bavelaw Castle [16 62, 17 62] and at the western end of Loganlee Reservoir [188 619].

Extensive deposits of alluvium occur in the base of the large meltwater channels at Carlops [152 550 to 164 565] on NT15NE. River terraces and alluvium occur in the lower reaches of the Eastside Burn [18 59, 19 59] and on either side of the Quarrel Burn Reservoir [183 590].

On NT15NW, small deposits of alluvium occur in the Lyne Water [12 57], the River North Esk [14 59] and in the Baddinsgill Burn [110 563 to 125 550]. A large alluvial fan is developed in the East Burn at the foot of the large gully on the north-west slopes of West Cairn Hill [103 582].

7.2.4 Man-made deposits

The two main types of man-made deposits in this area are earthworks for dams and spoil heaps from small quarries. Earthwork dams are present on the Threipmuir, Loganlee, Quarrel Burn, North Esk, and Baddinsgill Reservoirs.

8 STRUCTURE

The central Pentland Hills area on sheets NT16SE, NT15NE and NT15NW lies close to the southern margin of the north-east-trending Midland Valley graben bounded to the south-east by the Southern Upland Fault. In general the rocks of the area form an asymmetric north-east-trending anticline with the North Esk Group rocks at the core, unconformably overlain by the Lanark Group, and the south-east limb truncated by the Pentland Fault. The Inverclyde Group rocks in the north-west form the south-east limb of a north-east-trending syncline (Figures 2 and 17).

8.1 Pre-latest Silurian structures

8.1.1 Folding

In the Silurian North Esk Inlier the rocks strike north-east to north-north-east and are steeply dipping to overturned. Large-scale open folds occur throughout the inlier and account for the variation in strike and dip. These can be seen at the Lyne Water [129 567], the Wether Law Linn [146 585] and on the east shore of the North Esk Reservoir [156 580]. Intense folding is limited to laterally impersistent antiform-synform fold pairs found only in the Reservoir Formation. These occur in the gorge cut by the old overflow channel from the North Esk Reservoir [1551 5765 to 1553 5765] and in the Gutterford Burn [1593 5927 and 1598 5944]. Robertson (1989) stated that there were two distinct episodes of folding, the isolated intense folding (f1) and the large-scale open folds (f2). However, Bull (1995) examined the structure of the Reservoir Formation in detail, suggesting that only one phase of deformation was involved with folding occurring around a single axial plane dipping 10–20^0 towards 225^0. Bull (1995) suggested that the exposures of more intense folding are chevron folds formed at the intersection of two conjugate kink bands. The alternation of mudstone and siltstone beds which characterise the Reservoir Formation leads to a high ratio of competent to incompetent layers, a condition well suited to the formation of kink bands. The upper formations of the North Esk Inlier are more uniform and less likely to form kink bands (Bull, 1995).

Smith (1995) proposed that sinistral transpression during post-Wenlock to pre-latest Silurian times turned the strata of the Pentland Hills inliers to a near vertical position. This deformation may be a result of relative movement to the south-west towards a restraining bend in the Wilsontown Fault.

8.1.2 Faulting

The Pentland and Loganlee faults are part of a group of Midland Valley Caledonoid strike-parallel faults which have had a long history of movement and reactivation. The Pentland Fault forms the southern boundary of the Pentland Hills (Figure 17) and continues offshore as the Firth of Forth Fault. It is a Lower Palaeozoic or older deep crustal lineament (Floyd, 1994; Smith, 1995), and has a considerable pre-Westphalian downthrow to the south-east (Floyd, 1994).

8.1.3 Thrusting

Robertson (1985) described a thrust at one locality in the Gutterford Burn [1576 5859], but no evidence of this was seen during the current resurvey. Small-scale, bedding-parallel thrusts with displacements of up to one metre were observed in the gorge cut by the old overflow channel from the North Esk Reservoir [1554 5765] and in the Loganlee Inlier [188 619]. Bull

(1995) suggested that the attitude of the thrusts indicated pressure from the south or south-east.

8.2 Mid- to late Devonian structures

8.2.1 Folding

Lanark Group strata are generally tilted 20–50^0 to the south-east, locally modified by gentle flexures. Folding of the Lanark Group in the southern Midland Valley occurred during mid- to late Devonian times, with the resulting folds having a more east-north-easterly trend than the major north-east-trending faults. Phillips et al. (1998) suggested that this was due to a component of sinistral transpression during displacement along the Southern Upland Fault.

8.2.2 Faulting and thrusting

The Pentland and Loganlee faults were probably reactivated during the mid-Devonian. There is a marked difference in thickness of the Greywacke Conglomerate Formation over the Loganlee Fault, with only thin remnants preserved to the north-west of the fault.

All of the Pentland Hills Silurian inliers and the Lanark Group are cut by many small north-north-west to west-north-west trending strike-slip faults. Locally, some of these faults have sub-horizontal slickensides or are infilled with calcite and quartz. Most of these faults have very small sinistral displacements. Faults with well-developed horizontal slickensides are exposed in the Logan Burn [1770 6153] (Mykura, 1960). The pressure was from the south-east and was applied after the emplacement of the minor basic intrusions in the inliers and the overlying Lanark Group (Mykura, 1960). On the south bank of the Logan Burn [1772 6147], a sub-basic sill intruded into conglomerate is cut by a compound thrust inclined towards 110^0, associated with east–west sub-horizontal slickensides (Mykura, 1960). Another small thrust can be seen in siltstones and mudstones in the Lyne Water south of the junction with the Lynslie Burn [1317 5751].

8.3 Carboniferous and post-Carboniferous structures

After the deposition of the Inverclyde Group the rocks of the Pentland Hills were folded to form an asymmetrical anticline. The Kinnesswood and Ballagan formation dipping from 5 to 40^0 to the west or north-west on the west flank of the Pentland Hills, while east of the Pentland Fault Carboniferous sediments dip steeply to the east-south-east (Mykura, 1960). The Pentland Fault has a small post Permian downthrow to the north-west (Floyd, 1994).

8.4 Metamorphism

Illite crystallinity (IC) measurements were made on 11 Llandovery and Wenlock mudstone samples from the North Esk Inlier. The results show a range of values (0.60-0.97 D°2q) indicative of the late diagenetic zone. The IC data suggest that the Silurian strata have been deeply buried beneath 4.5–6 km of overburden, but temperatures did not exceed 150 °C. (Merriman, 1998). Such an overburden is consistent with burial beneath the Lanark Group of the Midland Valley (Marshall et al., 1994). Colour alteration indices (CAI) of conodonts from the Silurian of the Pentland Hills have a value of 2.5, indicating temperatures of 100–150 °C (Oliver et al., 1984).

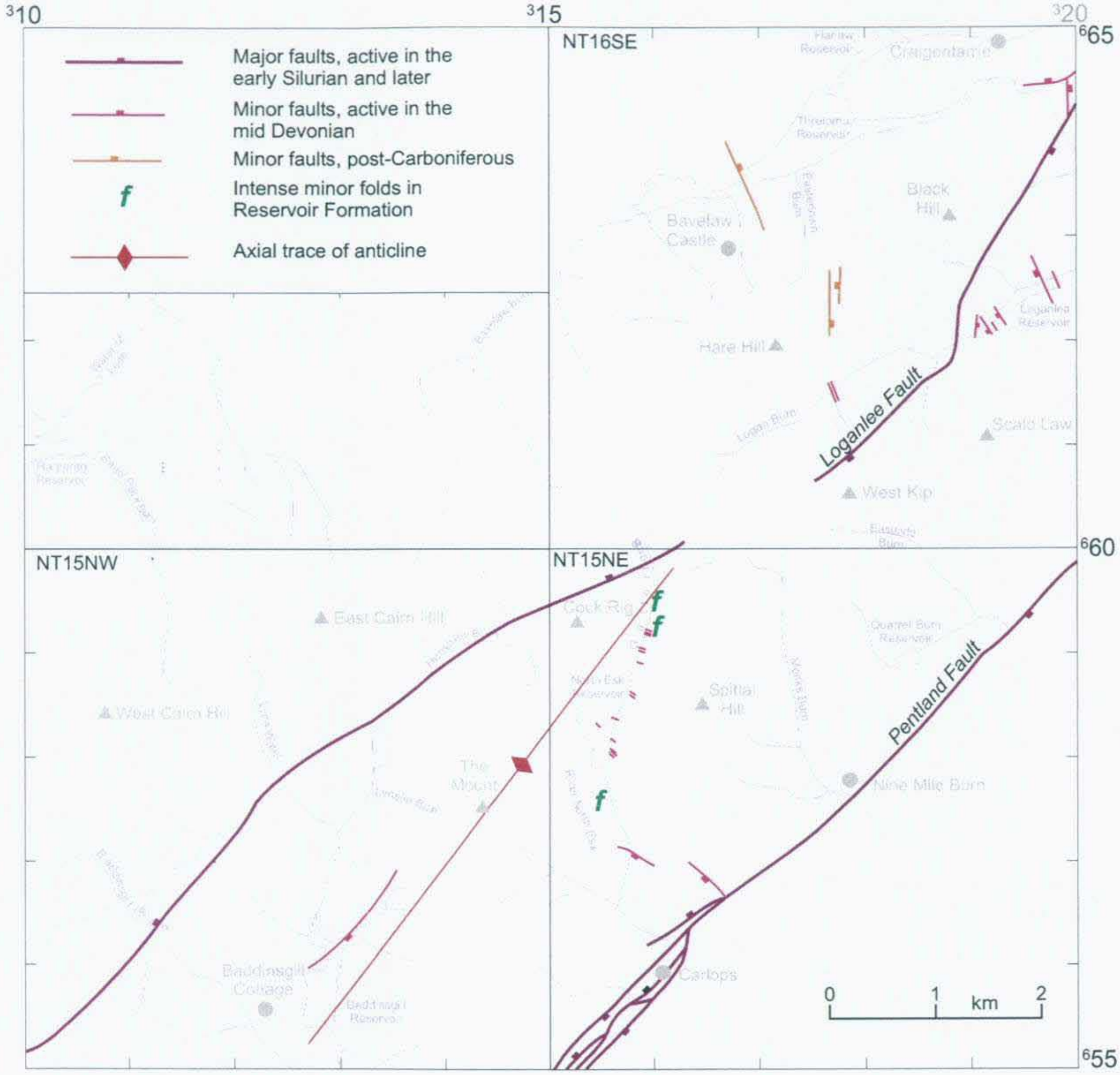

Figure 17 Structure of the central Pentland Hills

9 OTHER INFORMATION

9.1 Resources

9.1.1 Hard rock aggregate

Basic andesite from the quarry at Silverburn [199 606] was used for road metal between about 1900 and 1920 (MacGregor, 1945) and also in the 1960s. Small quarries and pits were formerly used locally for walling stone, track metal and possibly local building.

9.1.2 Limestone

The cornstone towards the base of the Kinnesswood Formation was used to provide a local source of lime. Small quarries can be seen near Muckle Knock [1135 5660] and west of Hare Hill [164 622]. At the latter site the remains of a lime kiln can be seen.

9.1.3 Peat

Extensive deposits of hill peat occur on Kitchen Moss [15 60] and around the headwaters of the Ravendean Burn [11 56, 11 57]. As both locations are relatively remote upland areas there are unlikely to be of commercial interest. The lowland raised bog at Red Moss (section 7.2.1) is an SSSI.

9.1.4 Water

Much of the central Pentlands Hills serve as the catchment area for several reservoirs situated within the three sheets. Loganlee Reservoir forms part of the Edinburgh water supply, while Baddinsgill Reservoir serves West Lothian. Threipmuir and Harlaw reservoirs are used as compensation reservoirs. North Esk Reservoir used to supply water for the paper mills at Penicuik but is now a wildlife refuge and breeding ground for gulls.

Groundwater boreholes are described in Chapter 10.

9.2 Environment

9.2.1 Sites of Special Scientific Interest (SSSIs)

There are three SSSIs within the central Pentland Hills:

1) North Esk Valley. This includes a c. 100–170 m wide strip along the River North Esk from Carlops Bridge [160 562] to the North Esk dam [154 579], the east and north shore of the North Esk Reservoir and the Gutterford Burn to just beyond the sheep shelter [1597 5944]. Also included is the Fairliehope Burn from the junction with the North Esk River to Fairliehope [1545 5662] and a section further upstream [1518 5682 to 1493 5693]. Selected for geological and botanical interest

2) Lynslie Burn. No details available.

3) Red Moss (see 7.2.1).

10 BOREHOLES

There are three water boreholes on NT16SE:

Borehole	NGR	Total Depth (metres bGL)	Date drilled	Comments
NT16SE/1	NT 1511 6452	60.96	1903	
NT16SE/2	NT 1534 6411	45.11	1968	No geological information
NT16SE/3	NT 1512 6455	60.96	1968	See Table 3, section 5.2.4

There are no records of boreholes on NT15NW and on NT15NE north-west of the Pentland Fault.

11 UNPUBLISHED SOURCES OF INFORMATION

11.1 Previous surveys

Unpublished maps from previous surveys were referred to during the compilation of the latest survey maps. The overlapping six-inch county sheets are listed for each National Grid sheet.

1:10 000 sheet	Six-inch County series maps from previous survey
NT16SE	Edinburgh 6SE, 7SW, 12NE, 12SE, 13NW, 13SW
NT 15NE	Edinburgh 12SE, 13SW, 18NE, 19NW, Peebles 2SW, 2SE, 5NW, 5NE
NT15NW	Edinburgh 12SW, 12SE, Peebles 1SE, 2SW, 4NE, 5NW

11.2 PhD theses

The following unpublished PhD theses were consulted during the current resurvey:

1. BULL, E. 1995. Palaeontology and Sedimentology of the North Esk Inlier, Pentland Hills, Near Edinburgh, Scotland. Unpublished PhD thesis, Open University.
2. MCGIVEN, A. 1968. Sedimentation and provenance of post-Valentian conglomerates up to and including the basal conglomerate of the Lower Old Red Sandstone in the southern part of the Midland Valley of Scotland. Unpublished PhD thesis, University of Glasgow.
3. ROBERTSON, G. 1985. Palaeoenvironmental interpretation of the Silurian rocks of the Pentland Hills. Unpublished PhD thesis, University of Edinburgh.
4. SYBA, E. 1989. Sedimentology and provenance of the Lower Old Red Sandstone Greywacke Conglomerate, Southern Midland Valley, Scotland. Unpublished PhD thesis, University of Glasgow.

11.3 Unpublished BGS Technical Reports

11.3.1 Biostratigraphy

1. MOLYNEUX, S G. 1992. A palynological report on three samples from the Silurian of the North Esk Inlier (Scottish 1:50 000 sheet 32). *British Geological Survey Technical Report, WH/92/238R.*
2. MOLYNEUX, S G. 1996a. A palynological assessment of priority samples from the North Esk, Loganlee and Bavelaw Castle inliers, Pentlands Hills. *British Geological Survey Technical Report, WH/96/51R.*
3. MOLYNEUX, S G. 1996b. Palynology of samples from the Silurian North Esk, Loganlee and Bavelaw Castle inliers, Pentlands Hills. *British Geological Survey Technical Report, WH/96/147R.*

4. MOLYNEUX, S G. 1998. Palynology of samples from the Reservoir and Deerhope Formations (upper Llandovery), North Esk Inlier, Pentlands Hills. *British Geological Survey Technical Report, WH/98/27R.*

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