British Geological Survey
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Geology of NY74NE, NW and NY75NE, SW and SE, Alston, Cumbria

Geology and Landscape Northern Britain Programme

Open Report OR/07/032

BRITISH GEOLOGICAL SURVEY

GEOLOGY AND LANDSCAPE NORTHERN BRITAIN PROGRAMME

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Keywords

Geology, NY74NE, NY74NW, NY75, Northumberland, Cumbria.

National Grid Reference

SW corner 370000,545000
Centre point 375000,552500
NE corner 380000,560000

Map

Sheet 19, 1:50 000 scale, Hexham

Bibliographical reference

CLARKE, S. M. 2008. Geology of NY74NE, NW and NY75NE, SW and SE, Alston, Cumbria. *British Geological Survey Open Report*, OR/07/032. 51pp.

Keyworth, Nottingham British Geological Survey 2008

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Foreword

1:10 000-scale geological sheets NY74NW and NY75SW were surveyed by C. L. Vye over the period 2002 to 2003. Sheets NY74NE, NY75SE and NY75NE were surveyed by S. M. Clarke from 2002 to 2004. These areas constitute part of the resurvey of BGS 1:50 000-scale maps of Hexham and Alston (England and Wales Series sheets 19 and 25 respectively). This report covers all 5 1:10 000-scale sheets and includes a synopsis of field notes by S. M. Clarke and C. L. Vye, with palaeontological descriptions by M. T. Dean. This work was carried out as part of the Northern England – Alston Block Project (E2007S71).

Grid references

The area covered by this report lies within Ordnance Survey British National Grid square NY. References given to specific exposures and locations are quoted to six or eight figures as appropriate. References to named shafts and adits are derived from ground survey where these features can be positively identified on the ground, otherwise, they have been taken from Dunham (1990). In all cases, the prefix NY is omitted from the reference and should be assumed.

Acknowledgements

The author gratefully acknowledges the co-operation of all landowners within the area and with special thanks to the staff of Whitfield Estate who where extremely helpful throughout the survey of their land.

Contents

Summary

This field report provides a summary of geological information to accompany the recently resurveyed 1:10 000-scale sheets NY74NW and NE, and NY75 SW, SE and NE. It should be consulted in conjunction with the published geological standard maps and fieldslips corresponding to these areas.

The area comprises Carboniferous sedimentary rocks of the Alston Block, a regional high of the Carboniferous ‘block and basin’ structure of Northern England. These strata are generally flat-lying to gently dipping but are locally disturbed by late Carboniferous faults, many of which are highly mineralised with ores of lead, zinc, iron and barium, and associated gangue minerals. Superficial deposits originating for the late Devensian glaciation and subsequent Holocene processes intermittently blanket the bedrock and can be up to 15 m thick.

1 Introduction

This report describes the geology of Ordnance Survey 1:10 000-scale sheets NY74NE and NW, and NY75NE, SE and SW (Figure 1). The western half of this area (NY74NW and NY75SW) was re-surveyed by C. L. Vye in 2002 and 2003, with additions by D. Millward and K. Whitbread in 2006 and 2007. The eastern half (NY74NE, NY75SE and NY75NE) was re-surveyed by S. M. Clarke between 2002 and 2004. The area constitutes part of the re-survey of BGS 1:50 000 sheets 19 (Hexham) and 25 (Alston).

1.1 GEOGRAPHY

The area amounts to 125 km^2 of upland terrain within the North Pennines Area of Outstanding Natural Beauty (Figure 1) and includes the major market town of Alston [717 467], and the small hamlets of Ninebanks [782 533] and Whitfield (Bear's Bridge) [781 574]. During the 18^{th} and 19^{th} centuries, the area was the site of extensive industrial mining activities, for both coal and metaliferous ores, and the former major industrial lead-mining centre of Nenthead [782 438] lies just off the south-eastern corner. Today, the area is largely rural and the economy is driven by the tourism and leisure industries.

Much of the landscape is high, open moorland under the control of major estates, most notably the Blacket-Ord (Whitfield) Estate, and is managed for grouse and pheasant. Major river valleys dissect the moorland landscape, primarily those of the Nent in the south, the South Tyne (of which the Nent is a tributary) to the west, and the West Allen and Allen rivers to the east. Minor streams further dissect the moorland, most notably the Mohope, Whitewalls, Carr's, Coanwood, Snope, Clargill, and Blagill burns. Most of the lower valley slopes are cultivated or 'intake' land used primarily for sheep farming, small-scale forestry, and the production of hay for animal feed. Small hamlets or minor settlements exist in most valleys.

1.2 PREVIOUS WORK

The area (Figure 1) was surveyed on the 1:10 560-scale over the period 1869 to 1881 by D. Burns, W. Gunn and others, and is represented by first addition geological standards of the Northumberland and Cumberland County Series. Northumberland County Series Sheets 101, 102, 106, 107, 110 and 111 (published between 1881 and 1893) cover most of the area to the north of the county boundary with Cumbria, and Cumberland Sheets 33 and 34 cover the areas south of the county boundary, principally NY74NW and the south-western half of NY74NE. In addition, sheets 99, 104, 105, 106 and 110 of the Northumberland County New Series cover the area north of the Cumbria border. These maps were surveyed between 1924 and 1926 by K. Burns and S. E. Hollingworth with additional mapping and notes by T. Robertson over the period 1946-1949.

All of these sheets depict the Visean limestones and major sandstones in acceptable detail, but do not subdivide the post-Visean strata; only key limestones and one major sandstone unit are depicted. The detail of superficial deposits is variable; the limits of glacial till are defined and some alluvium and river terrace deposits are delimited, but with few peat deposits shown. Peat deposits that are shown are generalised and not depicted at a resolution commensurate with the scale of the mapping.

Much of the Nent valley and parts of the Mohope and West Allen valleys are covered by additional mapping at 1:10 560 scale by K. C. Dunham between 1939 and 1943. These maps show the extent and position of mineral veins and associated economic deposits, the outcrops of key strata that are known to host mineralisation, principally the Great Limestone, Four Fathom

Limestone and Firestone Sandstone, and the positions of adits, shafts and mine tunnels that provided access to economic deposits during 18th and 19th century mining activities. Few other details of the geology are shown and many of the marked positions of veins represent positions in key strata or mine tunnels within the subsurface. These maps represent a valuable source of subsurface data that can be integrated with ground survey to interpret the area structurally.

The area straddles the boundary between the BGS 1:50 000 England and Wales Series sheets 19 (Hexham) and 25 (Alston). These maps are derived from maps originally published at the 1 inch-to-one-mile scale and based on the County Series standard maps. On both these sheets little in the way of detail of the post-Visean strata is shown, and superficial deposits are variably depicted on Alston and not shown at all on Hexham.

Although many of the major limestones of the Visean strata have been named and correlated across the area by 18th and 19th century mine workers and geologists, the naming of intervening sandstones, and those of the post-Visean strata, has been somewhat localised and arbitrary with the result that several sandstones of the same name are different lithostratigraphical units in different valleys. Furthermore, there is marked inconsistency between the number of limestones identified and mapped on the recently revised 1:50 000-scale geological map of Brampton (Sheet 18) to the west and the succession shown on the Hexham and Alston sheets.

The aims of the present survey, of which the area covered by this report forms part, are primarily to revise and subdivide the post-Visean strata, and to survey the superficial deposits. The Visean strata and structure of the area were resurveyed on the 1:10 000 scale as part of the process.

2 Geological Summary

Structurally, the area lies entirely within the Aston Block (Figure 2), a major horst of the Carboniferous 'block and basin' structure of northern England (Chadwick et al., 1995). The Alston Block is bounded by the major graben of the Northumberland Trough and Solway Basin to the north, the Eden valley to the west, and the Stainmore Trough to the south. Although a structural high, the Alston Block was at or below seal-level from late Visean times and a generally flat-lying succession of marine, coastal and fluviatile sediments accumulated upon it.

The Carboniferous strata exposed at the surface today (Section 3) are of Visean to Bashkirian (Dinantian to mid-Namurian) age and comprise the Alston and Stainmore formations of the Yoredale Group (Section 3). Mine shafts and exploratory boreholes penetrate Visean age rocks beneath those seen at surface, but rocks older than Carboniferous age have not been proved within the area. The regional dip, although locally undulatory, is of low magnitude and generally orientated towards the north, thus progressively older Visean strata are exposed southwards towards Alston and Nenthead, and progressively younger Serpukhovian to lower Bashkirian strata are preserved on the hilltops towards the north. However, no strata younger than Bashkirian age are preserved within the area.

The Early Permian intrusive dolerite of the Whin Sill (Section 4) is not exposed within the area but has been proved locally by boreholes. Its presence in these boreholes, combined with surfaces exposures within a few kilometres to the south, east and west implies that the Whin Sill underlies the entire area within the Visean strata.

The area is crossed by a large number of late Carboniferous faults with displacements in the order of a few metres to tens of metres (Section 5). Several of these faults form localised graben and disrupt the regional northward dip of the Carboniferous strata. Most of the faults are mineralised with metaliferous ores (Section 6) and form part of the Northern Pennine Orefield (Dunham, 1990).

Superficial deposits resulting from the last glaciation and subsequent Holocene processes are present throughout the area and intermittently blanket the bedrock (Section 7). The presence and nature of superficial deposits, combined with the weathering characteristics of bedrock where not blanketed by superficial deposits, strongly control the present day landscape. All of the major (and most of the minor) valleys display asymmetrical profiles in which the south- to south-west-facing sides are strongly 'stepped' into extensive flat-topped benches with steep sides, but the north- to north-east-facing slopes are extremely smooth. The strongly featured slopes are the result of differential weathering of Carboniferous strata where not blanketed by superficial deposits, and the smooth slopes are the result of thick till cover. Feature mapping and structural projection are therefore the primary survey tools in this area.

3 Carboniferous bedrock

The Carboniferous strata throughout the area consist of interbedded units of limestone, sandstone and siltstone with subordinate coal seams. The stratigraphical order of these lithologies is predictable and represents repeated shallowing-upwards Yoredale cyclothems consisting of marine limestone and siltstone, coastal sandstone passing into fluvial sandstone and seatearth, and culminating in coal. This cyclic and predictable nature of the Carboniferous sediments is most notable within the Visean strata where in this area four major cyclothems crop out, each displaying most of constituent lithologies, although the coal is often absent. The cyclic nature is less evident in the post-Visean strata of the area which consist predominantly of interbedded units of siltstone and sandstone with subordinate, thin, poorly developed and laterally discontinuous limestones. Many of the sandstone units are fluviatile and the environment has less of a marine influence than that of the Visean stage. The fluvial nature of the sandstones and the impersistence of limestones make correlation between widely spaced outcrops of post-Visean strata problematic.

3.1 CYCLOTHEMS AND SEQUENCE STRATIGRAPHY

Modern sedimentological analysis favours the use of sequence stratigraphical principles to subdivide sedimentary successions. Divisions are drawn at major flooding surfaces within the sequence. This approach works well with other systems of the geology of Northern England, most notably the Permian System, and has been adopted in modern BGS publications. Within the Carboniferous succession of northern England, flooding surfaces representing parasequences or higher order sequences correlate with the coal horizons and therefore do not coincide with the traditional cyclothem division which is taken at the base of the limestone. However, a sequence stratigraphical approach to the subdivision and description of the Carboniferous strata of northern England has not been adopted in modern BGS publications (Stone et al., *in press*), partly because the cyclothemic approach is heavily entrenched in literature, but primarily because the limited and disparate nature of the exposure and the weathering characteristics of the constituent lithologies make a sequence stratigraphical approach unworkable as a means of subdividing the succession in the field. A cyclothemic approach to the subdivision of Carboniferous strata was therefore adopted during fieldwork and the lithostratigraphy is described, in so far as it is possible to do so, in terms of Yoredale cyclothems in this report. Each cyclothem begins with the limestone member and continues through the overlying strata to the base of the succeeding limestone. Each cyclothem is named after the limestone member at its base.

3.2 CARBONIFEROUS NOMENCLATURE

The lithostratigraphical nomenclature used in this report is that of the review of the Carboniferous lithostratigraphical nomenclature of northern Britain (Waters et al., 2006; Waters and Davies, 2006). All Visean age rocks exposed or proved with the area, and the Great Limestone and underlying strata at the base of Serpukovian Stage, are included within the Alston Formation (formerly the Alston Group). All Carboniferous strata exposed within the area that are younger than the Great Limestone are included within the Stainmore Formation (formerly the Stainmore Group). In the Northumberland Trough (Section 4), to the north of the present area, the Alston and Stainmore formations, together with the underlying Tyne Limestone Formation form the Yoredale Group. On the Alston Block of the present area, the Tyne Limestone Formation is not present and the Alston Formation at the base of the Yoredale Group rests conformably on the Great Scar Limestone Group.

Extensive exploitation of the area for minerals has left a legacy of long-established names for many of the limestones, sandstones and coal seams. Where possible, and where correlation between centres of mining proves that named beds are the same strata regionally, these names have been adopted.

The lithological succession and stratigraphical classification of the Carboniferous strata of the area are shown in Figure 3.

3.3 VISEAN (MISSISSIPPIAN) ROCKS: ALSTON FORMATION

Strata from the Scar Limestone up to the top of the Great Limestone crop out within the southern quarter of the described area, predominantly along the lower slopes of the Nent valley from Alston to Nenthead. Within this stratigraphical interval, strata from the Four Fathom Limestone up to the top of the Great Limestone can be traced northwards into the Mohope and West Allen valleys, and the Great Limestone can be traced further northwards along the West Allen valley to the southern edge of NY75NE where the northerly dip finally pushes it below the landscape.

These strata, and older Visean rocks, are proved in sixteen boreholes / shafts within the area:

Quarter Sheet	Shaft / Bore	Easting	Northing	BGS BJ	Strata penetrated
NY74NE	Wellhope Shaft	7787	4660	2	Great to Iron-Post limestones
	Nentsberry Haggs Shaft	7654	4503	26	3yrd to Single Post limestones
	Lovelady Shield Shaft	7568	4618	-	Cockleshell to 3yrd limestones
	Scaithe Hole (sic.) Shaft	7999	4682	1/5	Great Limestone
NY74NW	Jockeys Shaft	7222	4676	9	(no details)
	Gossip Gate Shaft	7253	4681	10	Scar Limestone
	High Nent Force Shaft	7333	4685	11	6fthm Hazle to Cockleshell Lmst
	Watergreens Shaft	7408	4688	12	3yrd to Cockleshell limestones
	Foreshield Shaft	7477	4677	13	3yrd to Cockleshell limestones
	Wanwood Hill Farm	7038	4755	8	3yrd to Single Post limestones
NY75SE	Longcleugh Mine #1	7685	5179	2	Great to Tynebottom limestones
	Longcleugh Mine #2	7672	5151	3	Little to Cockleshell limestones
	Longcleugh Mine #2a	7672	5151	4	Great to ?Jew limestones
	Longcleugh Mine #8	7703	5180	5	Iron Post to Tynebottom lmst
	Redheugh Cottage	7740	5507	8	Four-Fathom to ?5yrd limestones
NY75NW	Pampery Shaft	700	592	1	(no interpretation)

Gossip Gate, High Nent Force, Water Greens, Foreshield, Lovelady Shield and Nentsberry Haggs shafts are all ventilation shafts on the Nent Force Level; a major drainage and exploration level driven from Alston to Nenthead.

3.3.1 Proved but unexposed Visean strata

Visean strata representing two cyclothems below the oldest present-day outcrop within the area were penetrated by the Longcleugh Mine boreholes on NY75SE.

3.3.1.1 The Jew Limestone cyclothem and underlying strata

Approximately 6 m of dark grey, crinoidal limestone with brachiopods and corals, overlain by a similar thickness of hard-baked siltstone and 9 m of light-grey coloured and spotted, medium-grained sandstone with a rooty ganisteroid top were penetrated by Longcleugh Mine #2a boring (Johnson, et al., 1980). These strata are attributed to the Jew Limestone cyclothem although this interpretation is tentative as the presence of the Whin Sill (Section 4) at this level within the bore makes correlation of strata below the intrusion problematic.

If this interpretation is correct, beds below the Jew Limestone belong to the Lower Little Limestone cyclothem. Longcleugh Mine #2a boring penetrated the uppermost 5.5 m of this succession which consists primarily of sandstone with subordinate 30 cm-thick crinoidal limestone units and siltstone.

3.3.1.2 The Tynebottom Limestone cyclothem

Longcleugh Mine #1, #2a and underground boring #8 all encountered approximately 7 m of dark-grey/blue, crinodal limestone that is commonly sandier towards the base. *Gigantoproductus giganteus* was reported from #2a. This limestone is the Tynebottom Limestone and represents the oldest reliably proved strata within the area. It is well exposed in the South Tyne between Tynehead and Alston, just south of the present area, and it is from this locality that its name is derived.

Approximately 4 m of dark, fissile siltstone overlie the Tynebottom Limestone and are locally termed the Tynebottom 'Plate'. The remainder of the sequence consists of between 45 and 52 m of siltstone with interbedded thin sandstone beds. The repeating and alternating nature of lithologies within this sequence has earned it the name 'Alternating Beds' and the alternations almost certainly represent incomplete, subordinate cyclothems within the succession. Indeed, two thin limestones are commonly present within the Alternating Beds and both were encountered in the Longcleugh Borings and Nentberry Haggs Shaft. The lower, Single Post Limestone is up to 2 m thick in Longcleugh #1 and consists of a light-grey, finely crinoidal limestone that is nodular in part. In Nentberry Haggs Shaft it is 2m thick. In outcrops to the south of the present area, the Single Post Limestone is significantly thinner and often represented by only one or two beds (from which its name is derived). The upper, Cockleshell Limestone consists of up to 1m of dark-grey, hard and often shaly limestone in the Loncleugh borings, characterised by well-preserved *Gigantoproductus giganteus* fossils. In Nentsberry Haggs Shaft it is 1m thick. The Cockleshell Limestone was also encountered in the Lovelady Shield Shaft where it is 1m thick and in the Wanwood Hill borehole. Neither the Single Post nor the Cockleshell limestone is exposed in the present area, but rocks overlying the Cockleshell Limestone and representing the uppermost beds of the Tynebottom Limestone cyclothem are exposed.

3.3.2 The Scar Limestone cyclothem and underlying exposed strata

The oldest Visean strata exposed within the area are the Scar Limestone and the underlying siltstones and sandstones of the uppermost beds of the Tynebottom Limestone cyclothem. Exposures are limited to the south-western corner of the area, within the riverbed of the South Tyne and near the confluence of this river and the Nent at Alston [7206 4674]. This latter locality gives one of the best and most complete exposures through the Scar Limestone and underlying strata locally, where the Nent flows over the limestone's top surface for approximately 500 m before plunging approximately 9 m over a waterfall exposing its entire thickness. From this locality, C. L. Vye reported dark grey limestone in beds 20 cm to 60 cm thick with wavy bedding surfaces. The beds generally become thinner up through the exposure and contain many colonial corals and crinoid fragments towards the top.

On the east bank of the South Tyne, south of Alston, a prominent bench feature in places marks the outcrop of the Scar Limestone, but the equivalent outcrop on the western bank is concealed beneath superficial deposits, largely drumlinised till.

Siltstone with thin, fine-grained sandstone units overlie the Scar Limestone. These pass upwards into thinly bedded, micaceous and sometimes cross-bedded sandstone known locally as the 'Slaty Hazle'. The succession is approximately 10 to 15 m metres thick. Excellent exposure of the Slaty Hazle can be found in the Nent River approximately 1 km east of Alston [7333 4680], where this lithology and the overlying Five Yard Limestone form a small waterfall. From this locality, C. L. Vye reported pale grey, fine- to medium-grained sandstone in thin beds that are sometimes cross-bedded and chanellised, with some interbeds of siltstone.

Strata of the Scar Limestone cyclothem were penetrated by the Longcleugh Mine borings (NY75SE), where ironstone nodules were reported in siltstone overlying the Scar Limestone, and approximately 8m of black siltstone with a 7 cm-thick coal were reported above the Slaty Hazle (Longcleugh Mine #1 only). These characteristics have not been observed at outcrop. All of the ventilation shafts of the Nent Force Level penetrated the Scar Limestone cyclothem where the Scar Limestone was reported as 16 to 17 m thick, the overlying siltstone reported as 2 to 4 m thick, and the Slaty Hazle as 7 to 9 m thick (Dunham, 1990). 10 m of the Scar Limestone were also penetrated by the Wanwood Hill borehole. No lithological details are available from the Wanwood Hill or Nent Force Level shafts.

3.3.3 The Five Yard Limestone cyclothem

Strata of the Five Yard Limestone cyclothem crop out in the south-western corner of the area, most notably within the Nent valley approximately 1.5 km east of Alston. Here, the Nent, flowing from east to west, takes a marked dogleg through two bends, first to the south and then back to the west, and both bends are the sites of small waterfalls. The latter [7334 4682] marks the outcrop of the Five Yard Limestone, so named for its reported thickness, although the average thickness at outcrop and penetrated within shafts of the present area is generally less than 4.5 m (5 yrds).

Between 5 and 10 m of siltstone overlie the Five Yard Limestone followed by approximately 10 m of massive, siliceous, fine- to medium-grained sandstone that forms the impressive waterfall and first dogleg bend in the Nent [7336 4691] known locally as High Force (not to be confused with High Force in Teesdale). This sandstone is known as the Six Fathom 'Hazle'. The Six Fathom Hazle locally forms the top of the Five Yard cyclothem but in the west-facing slopes of the South Tyne valley and north-facing slopes of the Nent valley approximately 5 m of dark highly organic siltstone overlie it. In the Bentyfield Mine area [756 425], 4 km south of Nenthead and approximately 5 km south of the present area, an 8 cm coal is reported within this sequence that may possibly correlate with the Shillbottle Coal of Northumberland (Dunham, 1990).

The outcrop of the Five Yard Limestone and Six Fathom Hazle on the east bank of the South Tyne, to the north and south of Alston, is marked by strong bench-like features in a number of places. The corresponding outcrops on the west bank are largely concealed beneath superficial deposits, although the Six Fathom Hazle does form a feature in several places.

Strata of the Five Yard cyclothem were penetrated by the Longcleugh Mine borings with the exception of #2a where a fault cuts out most of the cyclothem. In all cases, no siltstone strata overlying the Six Fathom Hazle were recorded. All of the Nent Force Level shafts penetrated the cyclothem. In all, 4 m of Five Yard Limestone and between 9 and 11 m of Six Fathom Hazle were recorded, with the exception of Nentsberry Haggs Shaft which showed an anomalously thick 17 m sandstone representing the Six Fathom Hazle. 1 to 2 m of siltstone overlie the Six Fathom Hazle in Foreshield, Lovelady Shield and Nentsberry Haggs shafts. Strata that may be tentatively correlated with the Six Fathom Hazle based on interpolation from outcrop were penetrated by the Redheugh Cottage borehole. If this interpretation is taken to be correct, once again no siltstone strata overlie the Six Fathom Hazle. In the Wanwood Hill borehole 10.6 m of grey to yellow coloured sandstone correlate with the Six Fathom Hazle and are overlain here by 1 m of very dark siltstone forming the top of the cyclothem.

3.3.4 The Three Yard Limestone cyclothem

The Three Yard Limestone is generally less well exposed than other limestones within the Alston Formation due primarily to its thickness (from which the name is derived). It crops out only on sheet NY74NW and the westernmost edge of NY74NE and surface exposures are limited. However, its course along the valley sides of the Nent and South Tyne is well marked because of its proximity to the Six Fathom Hazle, which forms a pronounced feature. In some cases, the Three Yard Limestone forms a small feature in its own right, particularly where siltstone strata intervene at the top of the Five-Yard cyclothem. Exposures of the Three Yard Limestone can be found in the Nent between Fourshield Burn [7520 4660] and Lovelady Shield [7567 4617], in Clargill Burn [7130 4893], and in Blagill Burn [7394 4707].

At Lovelady Shield one to two beds of wackestone form a small bench and the river bed of the Nent in intermittent exposures between modern-day alluvium. The bedding is medium scale (~40 cm) with slightly wavy bedding planes.

At Blagill Burn, C. L. Vye reported approximately 1 m of dark-blue to grey limestone with numerous fossil fragments. Only three beds are exposed, ranging in thickness from 30 to 50 cm thick.

The Three-Yard Limestone is immediately overlain by dark grey, marine siltstone interbedded with thin (~5 cm) beds of very fine-grained sandstone. Exposures are present in the north bank of the Nent near Foreshield Burn. This passes upwards into sandy siltstone interbedded with sandstone, the entire sequence being 10 to 15 m thick. Within this sequence, two closely spaced sandstone units can be recognised locally to Alston. Due to their proximity they have been mapped by C. L. Vye as one sandstone unit over short distances, particularly around Clargill Burn [7140 4875] where they form a prominent feature.

The measures of the Three Yard Limestone cyclothem are overlain abruptly by the Nattrass Gill ‘Hazle’; approximately 6 to 8 m of sandstone that take their name from the east bank tributary to the South Tyne, 1.6 km south of Alston and just south of the present area. The outcrop of the Nattrass Gill Hazle is widespread over NY74NE and NW and much of its course can be traced because it forms a very strong feature with the overlying Four Fathom Limestone. This feature is particularly well pronounced along the north bank of the Nent, the north-east bank of the South Tyne north of Alston, the north-east bank of the West Allen at Broadlee Bank [788 506], and the Wellhope Burn at Appletree Shield [774 498].

Perhaps the best example of the impact of the Nattrass Gill Hazle on the present day landscape is seen in the north bank of the Nent immediately adjacent to the A689 from Haggs Bank to Nenthall. Here, the ground rises steeply from the road to a flat-topped bench formed by the overlying Four Fathom Limestone. The Nattrass Gill Hazle is exposed in many small quarries and diggings along this stretch and the contact between this unit and the Four Fathom Limestone is marked by a prominent line of springs. Exposures along this section show a dark pink to orange, medium-grained sandstone that is planar bedded on the medium scale (~40 cm) although with somewhat irregular bedding planes. The sandstone becomes more rooty and ganisteroid towards the top. Spoil heaps associated with workings on small veins in this area (Section 6) show dark-grey, friable siltstone and very fine-grained sandstone most probably derived from the underlying measures and therefore limiting the thickness of the Nattrass Gill Hazle to 6 m here.

North of Nenthall [462 759], the Nattrass Gill Hazle forms a strong feature that is distinct from that formed by the overlying Four Fathom Limestone. Good exposure of a reasonably sharp contact with the underlying measures can be found in a small north-east bank tributary of the Nent just south-west of Browngill Farm [7595 4618]. Here the Nattrass Gill Hazle forms a waterfall and extensive bench feature for 300 m to the north and west of Browngill Farm. Cross-bedding is present in stream exposures adjacent to the farm lane [7600 4622]; a sedimentary feature that is not evident in other exposures locally.

At Blagill the Nattrass Gill Hazel forms a prominent waterfall and cliffs where the bridge carries the old road into the settlement [7400 4732]. From 100 m downstream, C. L. Vye reported pale-brown, fine- to medium-grained sandstone in 20 to 30 cm beds. The beds appear not to be internally laminated and displayed ferruginous patches.

In the West Allen valley, the Nattrass Gill Hazle and Four Fathom Limestone form a strong feature akin to that of the Nent. However, exposures of the Nattrass Gill are rare and limited to a few minor streams. Exposures of orange, medium to thinly bedded, medium-grained sandstone in the lower reaches of Wolf Cleugh [7950 4954], near its confluence with the West Allen, are most probably the uppermost beds of the Quarry Hazle. A good exposure through approximately 2 m of dark grey organic siltstone with thin beds of very fine-grained sandstone at [7950 4952] belongs to the underlying measures and therefore limits this thickness of the Nattrass Gill Hazle here to a similar amount to that seen in the Nent valley.

The presence of the Four Fathom Limestone near Appletree Shield [7743 4965] (Section 3.3.5) implies that the Nattrass Gill Hazle should crop out in Mohope Burn in this area and approximately 200 m south of Blackpool Bridge. However, these outcrops are concealed below a large tract of modern-day alluvium.

On the north-facing slopes of the Nent valley, and the east-facing slopes of the South Tyne valley, the outcrop of the Nattrass Gill Hazle is largely concealed below superficial deposits. However, at intermittent points these deposits are thin enough for the bedrock to express a feature at the surface.

In the Nent valley at Nenthall there is little evidence for strata belonging to the Three Yard cyclothem overlying the Nattrass Gill Hazle. At Haggs Bank [7661 4505], approximately 30 cm of siltstone interbedded with thin fine-grained sandstone are exposed in the base of the waterfall immediately below the Four Fathom Limestone. Similarly, 70 cm of siltstone interbedded with subordinate sandstone are exposed in Wolf Cleugh immediately below the Four Fathom Limestone, from which this section is taken:

	Thickness (m)
Limestone (Four Fathom)	
Sandstone, orange / light-brown. Med.-grained	0.2
Siltstone, dark-grey and fissile	0.2
Sandstone	0.1
Siltstone	0.2+

These sedimentary rocks have not been separated from the Nattrass Gill Hazel in the current survey for much of the area as they do not form a sufficiently large outcrop at 1:10 000-scale. However, on Park Fell, west of Alston, up to 5 m of measures are interpreted to lie on top of the Nattrass Gill Hazle on the basis of landscape featuring and the existence of a well-worked 50 cm coal seam. Black carbonaceous siltstone has also been reported at this horizon in other areas regionally (Dunham, 1990).

Strata of the Three Yard cyclothem are penetrated by borings at Longcleugh Mine, Wanwood Hill Farm and Redheugh Cottage. The Longcleugh borings reported an average of 4.5 m of grey to dark-grey crinodal limestone (the Three Yard Limestone) overlain by 20 to 23 m of dark, commonly micaceous siltstone with crinoid fragments towards the bottom and shells towards the top. Between 8 and 12 m of the Nattrass Gill Hazle are reported with micaceous and carbonaceous siltstone partings towards the base, and with roots and plant fragments towards the top. Approximately 2.5 m of dark organic siltstone with interbedded fine-grained sandstone and a thin coal complete the cyclothem.

Approximately 2.4 m of intensely jointed limestone are attributed to the Three Yard Limestone in the Wanwood Hill bore, overlain by 9.5 m of interbedded grey siltstone and thin yellow/brown sandstone, and the lowermost 2.4 m of the Nattrass Gill Hazle immediately beneath superficial deposits.

Foreshield, Lovelady Shield and Nentsberry Haggs shafts all penetrated the lower part of the Three Yard cyclothem; in all, the Three Yard Limestone is 5-6 m thick; no lithological details are available.

A sequence of 3 m of limestone overlain by 7 m of interbedded siltstone, thin sandstones and very thin limestones, followed by 1 m of hard sandstone is attributed to the Three Yard Limestone cyclothem within the Redreugh Cottage bore, based on a tentative interpolation from surface outcrop. Whilst this interpolation appears sound, the reported thickness of the Nattrass Gill Hazle in this bore is somewhat small.

3.3.5 The Four Fathom Limestone cyclothem

The Four Fathom Limestone is the oldest limestone of the Alston Formation that crops out for a significant extent of the area. It is present in the Nent valley, where it forms, along with the underlying Nattrass Gill Hazle, a good feature along the south-facing slopes, the South Tyne valley where it forms a similar feature on the west-facing slopes, the West Allen valley and the Mohope valley, where the regional dip combined with faulting finally push the beds below the present-day landscape approximately 400 m south of Blackpool Bridge [782 519].

At Haggs Bank [7665 4507] the full thickness of the Four Fathom Limestone is exposed in a section cut by a small north-bank tributary of the Nent. It consists of 7.5 m of light grey, wackestone/packstone, in medium (~30 cm) beds with largely planar bedding surfaces. The bedding thickness is surprisingly consistent throughout the unit.

From Blagill Burn [7027 4501], C. L. Vye reported a 1 m high exposure of dark grey limestone in beds 15 to 20 cm thick. Bedding surfaces are largely planar but slightly wavy in places.

A large quarry [7167 4785] in the Four Fathom Limestone on the eastern bank of the South Tyne, approximately 1 km north of Alston, exposes very dark-grey to blue limestone in beds varying in thickness from 30 cm to 1 m. Most of the section is planar-bedded but wavy-bedded fossilliferous units are more prolific towards the bottom. The base of the Four Fathom Limestone is exposed here, resting on dark-grey siltstone.

From Ayle Burn, C. L. Vye reported 2.5 m of limestone exposed in the northern bank [7190 4930] attributed to the Four Fathom Limestone in the hanging-wall of a major north-south-trending fault. Here the bedding is on a 30-40 cm scale with slightly undulating bed surfaces.

In the West Allen valley at Wolf Cleugh [7954 4953], 5 m of dark-grey wackestone are visible forming a small waterfall. Bedding thickness ranges from 15 – 40 cm and bedding surfaces are generally planar although becoming slightly wavy on thinner beds.

In the Mohope valley at Shield Crag [7757 4932], the uppermost beds of the Four Fathom Limestone are exposed in the burn and consist of 3 m of dark grey, medium bedded (~60 cm) wackestone. Some beds contain 1.5 to 2 cm-long coral fossil fragments that weather proud and many bedding surfaces are mineralised with quartz and calcite.

Further downstream, the Four Fathom Limestone is exposed in the banks of the Mohope Burn at Appletree Shield Chapel [7742 5025] and forms the bed of the burn for much of its course northwards towards Blackpool Bridge. It is projected to dip below the landscape approximately 400 m south of the bridge although here it is concealed below extensive tracts of alluvium.

On the east-facing slopes of the South Tyne valley, west of Alston, the outcrop of the Four Fathom Limestone is marked in places by a well-developed feature, although exposures are rare. From a small tributary stream [7046 4565], C. L. Vye reported 5 to 6 m of dark-grey wackstone in beds up to 1 m thick.

The north-facing slopes of the Nent valley are blanketed in till and the concealed outcrop of the Four Fathom Limestone is largely a structural projection from good exposure on the opposite valley sides, combined with subsurface data and secondary surface evidence. On the western sides of Middle Fell a strong feature and several sinkholes denote its position and on the eastern side various locations display limestone blocks at surface or within stream sections.

Chert nodules have been reported within the Four Fathom Limestone (Dunham, 1990) and are noted at localities outwith the present area. Such nodules are rare in other limestones of the North Pennines and serve as a good control on stratigraphical position, although they have not been observed in any of the exposures within the area.

A reasonably thick succession of siltstone with interbedded thin laminae of sandstone overlies the Four Fathom Limestone. The lowest beds of this succession are commonly very calcareous and fossiliferous, and become sandier upwards. Good exposures of the lowermost beds can be observed at Haggs Bank [7665 4507] where approximately 1 m of thinly bedded, shaly siltstone is exposed, interlaminated with sandstone and highly organic streaks, adjacent to the track just above the waterfall. Interbedded sandstone and siltstone belonging to this succession are also exposed in Foreshield Burn and Blagill Burn. The measures pass upwards into approximately 6 m of white to brown, micaceous, medium-grained sandstone known locally as the Quarry Hazle.

Exposures of the Quarry Hazle can be seen in small quarries and workings along the south-facing slopes of the Nent valley, between Haggs Bank and Nether Nentsberry, where it comprises a hard, white to light brown, thin- to medium-bedded, medium-grained sandstone. Many of the beds show thin laminae picked out by colour changes and good sorting of the subangular to subrounded grains. Although most exposures are only 1 to 1.5 m high there is evidence in the shape of the landscape for the unit being approximately 6 to 9 m thick. Although further exposures are noted to the north in the Foreshield Burn, there are no exposures between these localities and little evidence in the landscape for the presence of the Quarry Hazle. However, its continued outcrop has been proved below a cover of 0.5 to 1 m of soil and regolith by auguring and, as a result, the outcrop on NY74NE is interpreted as continuous between these two localities.

Further northwards along the Nent valley, no clear sandstone exposure at this stratigraphical level has been reported by C. L. Vye in the Blagill Burn but the same sandstone was reported approximately 2.5 km to the north-west in Ayle Burn and again in a small north-bank tributary to the burn approximately 150 m south of the settlement of Ayle [7151 5926]. As a consequence of the disparate nature of these outcrops, the Quarry Hazle has not been interpreted as a continuous outcrop along the south-facing slopes of the Nent valley between Foreshield Burn and Alston.

In the West Allen valley, exposures of sandstone in Wolf Cleugh [7963 4960], Greenley Cleugh [7877 5098] and other small streams in the intervening ground, all of which correlate with a pronounced feature, confirm the outcrop of the Quarry Hazle in the south-west-facing slopes. A feature at the same stratigraphical level in the north-east-facing slopes is interpreted to mark the outcrop of the Quarry Hazle although no exposures are recorded until the confluence of the Mohope Burn and the West Allen. Here [7816 5165], recent landslides have exposed the full extent of the Four Fathom cyclothem. Approximately 7 to 8 m of dark grey, thinly bedded siltstone overlie the Four Fathom Limestone in the bed of the Mohope Burn. The siltstone is interbedded with some thin sandstone laminae and some thicker sandier siltstone beds, particularly towards the base of the section. 4 m of brown to pale orange, medium-bedded, medium-grained sandstone of the Quarry Hazle overlie the measures and correlate with a strong feature that can be traced southwards upstream in the eastern bank to further small exposures.

Further exposures of the Quarry Hazle are visible in the bed and banks of the West Allen under Blackpool Bridge and correlate with a strong feature that can be traced northwards along the west-facing slopes of the West Allen valley to correlate with other small exposures. The strata are interpreted to dip below present day landscape in the bed of the West Allen approximately 600 m north of Blackett Bridge [7820 5460]. The outcrop here is obscured by extensive alluvium.

The outcrop of the Quarry Hazle in the east-facing slopes of the West Allen and Mohope Burn, below extensive superficial deposits, mostly till, has been interpreted by structural projection from the west-facing banks combined with a pervasive, if weak, feature, and its proved existence in underground workings, most notably those of Longcleugh Mine.

All of the Longcleugh Mine borings penetrated the Four Fathom Limestone cyclothem where 8 to 9 m of grey crinoidal limestone of the Four Fathom Limestone are overlain by 9 to 12 m of dark grey siltstone, commonly limy and containing marine fossils towards the base. The Quarry Hazle is 7 to 12 m of white, medium-grained sandstone with roots and fossilised plant fragments towards the top. In bores #2 and #2a a 15 cm thick coal horizon and associated siltstone parting is reported approximately 3 m below the top of the Quarry Hazle; a feature not observed in surface exposures.

The Redheugh Cottage Borehole penetrated 8.5 m of the Four Fathom Limestone at rockhead, concealed below 2.8 m of till.

3.3.6 The Iron Post Limestone cyclothem

The Iron Post Limestone is rarely exposed within the present area. Small exposures are noted in Foreshield Burn [7525 4729], Ayle Burn [7270 4970] and in a small north-bank tributary of the South Tyne approximately 150 m south of Ayle [7153 4929]. Further exposures have been recorded in the West Allen riverbed, beneath the track to Barneycraig Farm, approximately 400m west of the present area [8034 4676], and in the headwaters of the River Nent at Nenthead [7847 4320]. The former of these two exposures is probably the best and most easily accessible locally as the later is periodically obscured by large amounts of alluvium deposited in the Nent by winter flood conditions.

In all of the exposures within the present area, the Iron Post Limestone is a single bed no more than 30 cm thick of extremely hard limestone atop the Quarry Hazle. The name is derived from its hardness rather than any ferruginous content, and it is often difficult to distinguish in weathered outcrop from the underlying sandstone.

Despite its thinness, the Iron Post Limestone (or a thin deposit of highly fossiliferous marine siltstone representing the same horizon), is believed to be present over much of the North Pennines as it is recognised in many underground workings. Indeed, it is likely to be continuous over the full extent of the present area as it is recognised in the Longcleugh Mine boreholes, where 30 to 40 cm of hard, dark coloured, compact, crinoidal limestone immediately overlie the Quarry Hazle, and in the Dodd cross-cut of Scraithole Mine where the Iron Post Limestone forms the crosscut sole. However, the outcrop has not been interpreted as continuous on the present survey due to the disparate nature of these provings across the area, combined with inconsistent and thin outcrop. The Iron Post Limestone is known to be obliterated by the Tuft Sandstone in the upper part of the cyclothem within the Weardale area (Dunham, 1990).

The remainder of the Iron Post Limestone cyclothem is approximately 10 to 15 m thick and comprises approximately 9.5 m of siltstone to dark mudstone overlain by 1 to 5 m of brown to pale-grey, thinly bedded to laminated, micaceous, fine- to medium-grained sandstone known as the Tuft or Water Sill Sandstone (Dunham, 1990). In many places, particularly along the Nent valley, this sandstone is soft and somewhat poorly cemented with thin laminae of carbonaceous material. Good exposures through the upper beds can be found at High Nentsberry [7637 4547] where approximately 1.5 m of brown, thinly bedded and poorly cemented sandstone are exposed immediately below the lower beds of the Great Limestone in a spring.

In Clargill Burn, a west-bank tributary of Ayle Burn, the Tuft Sandstone is better cemented, medium- to coarse-grained and micaceous. Here it comprises several 20 to 30 cm beds exposed in the base of the stream, some with thin laminae of carbonaceous material. A number of large (~20 cm) specimens of fossilised wood have been found within the uppermost beds.

In the Mohope valley, the Tuft Sandstone is exposed in the west bank of the burn at Yew Crags [7778 4837]. Here it is considerably more cemented than in the Nent valley, is deposited in beds up to 30 cm thick and resembles the exposures at Clargill. 2 to 3 beds are exposed in the bottom of a cliff section underlying the Great Limestone.

In Hearty Cleugh [7717 4912], a small west bank valley of the Mohope valley, the former workings of Hearty Cleugh Mine have exposed a 5 m cliff section primarily in the Great Limestone but exposing approximately 70 cm of the Tuft Sandstone in the base where it forms cemented beds up to 30 cm thick of light brown, medium-grained sandstone.

Despite the ubiquitous existence of the Tuft Sandstone over the extent of the present area, it has not been delimited from the measures of the cyclothem in the current survey other than in the west of NY74NW. The resistant nature of the sandstone is somewhat similar to the overlying Great Limestone and for much of the area the two lithologies form the same feature with a near vertical front face. As a result the map-face thickness of the Tuft is generally below the resolution of 1:10 000-scale mapping. Exceptions are the south-facing slopes of Ayle Burn, where the thickness and weathering characteristics of the Tuft allow it to be depicted, and the east-facing slopes of the South Tyne valley, south of the Alston, where a favourable relationship between the dip of the strata and that of the landscape result in a resolvable map-face thickness to the unit.

A few centimetres of marine siltstone and sometimes a thin coal have been reported overlying the Tuft sandstone regionally (Dunham, 1990), but no such strata have been observed in exposures of the present area.

The Tuft Sandstone is penetrated by the Longcleugh #2 and #2a borings where it consists of 3.6 m of soft brown to yellow sandstone. In Longcleugh #1 bore only 15 cm of soft yellow sandstone representing the Tuft are penetrated, underlain by mudstone. Longcleugh #8 underground boring begins at the level of the Iron Post Limestone; the base of the Tuft Sandstone and underlying mudstones are exposed in the walls and roof of the drilling chamber and north crosscut.

3.3.7 The Great Limestone

In the lithostatigraphical classification scheme adopted in the current survey and within this report (Waters et al., 2006; Waters and Davies, 2006), the top of the Great Limestone is taken as the top of the Alston Formation. For this reason, the Great Limestone is described separately from the remainder of the Great Limestone cyclothem in this account, with the overlying beds described as components of the Stainmore Formation.

The Great Limestone, first named by Forster (1809), is the thickest limestone that crops out within the North Pennines. It is similar in character to the other limestones of the Alston Formation being a grey-blue, fine-grained packstone / wackestone and breaking easily into beds, known locally as ‘posts’, varying from a few tens of centimetres to approximately 2m thick (Dunham, 1990). The posts are composed of skeletal debris in a fine-grained limy mud matrix (Fairbairn, 1978). However, unlike the other limestones of the Alston Formation, the internal bedding distribution of the Great Limestone and the presence of shaly partings are surprisingly consistent throughout the North Pennines (Fairbairn, 1978).

The uppermost 4 to 5 m of the Great Limestone contain a number of shaly siltstone partings ranging in thickness from a few centimetres to 0.5 m thick. These siltstone beds with their interbedded limestone posts have been termed the Tumbler Beds (Forster, 1809). The thickness and frequency of siltstone partings within this sequence increases upwards and the thickness of limestone posts decreases such that the Tumbler Beds are effectively transitional into the overlying strata.

Forster (1809) recognised two further thin siltstone partings within the remainder of the Great Limestone. The lowest beds of the Great Limestone are separated from the remainder of the unit by a thin shaly siltstone horizon approximately 4.5 m above the base. Similarly, a second shaly siltstone horizon is present 10 to 11m above the base. The presence of these two siltstone partings divides the section below the Tumbler Beds into three segments known from the base upwards as the low-, middle-, and high-flats (Forster, 1809; Dunham, 1990).

Fairbairn (1978, 2001) recognised further consistency to the internal stratigraphy of the Great Limestone throughout the North Pennines. Based on the variation in macrofossils, colour and degree of dolimitisation he recognised five divisions as follows (from the base upwards):

- The **Bench Posts** comprising four posts of planar-bedded, dark-grey limestone that is commonly impure and dolomitic. These posts are so named as they were commonly left unworked by quarrymen and formed a base or ‘bench’ to large quarries in the Great Limestone.
- The **Main Posts** characterised by wavy-bedded, paler grey limestone in which macrofossils are scarce.
- The **Fossil Posts** characterised by a proliferation of fossil horizons. The fossil posts are generally planar-bedded but some of the thicker beds display wavy bedding surfaces.
- The **Top Posts** are planar-bedded with a number of thin but persistent siltstone partings. Macrofossils are scarce and the posts mark a transition from the fossil posts to the overlying Famp Posts.
- The **Famp Posts** (or Tumbler Beds) comprising dark-grey limestone with few macrofossils separated by dark grey siltstone and mudstone units that become thicker upwards. Some of the posts are lenticular.

On the Alston Block, of which the present area is part (Section 5), the top of the Great Limestone is diachronous, with the Fossil Posts progressively passing northwards into the Famp Posts and then into fossiliferous shaly siltstone (Fairbairn, 1978; 2001).

Three fossiliferous horizons, or biostromes, are recognised regionally within the Great Limestone (Johnson, 1958). Within the Bench Posts (Fairbairn, 1978), or near the base of the Low Flat (Forster, 1809), approximately 1 to 1.5 m above the base of the Great Limestone, is a biostrome rich in colonial corals and *Chaetetes*. Approximately 5 m above the base of the unit is the Brunton Band, rich in microscopic algae, and within the Fossil Posts (Fairbairn, 1978), or near the bottom of the High Flat (Forster, 1809), approximately 6 to 7 m below the top of the unit, is a horizon rich in solitary corals and brachiopods known as the Frosterley Band. The Frosterly Band is not a single biostrome but comprises a number of discontinuous macrofossil bands in different beds within the Fossil Posts (Fairbairn, 1978).

The best and most complete exposure through the Great Limestone local to the present area is at Barneycraig Quarry [803 466], approximately 300 m east of the eastern edge. Here, the Bench Posts are well exposed as several beds of limestone forming the base of the quarry at its southern edge and exposing excellent examples of the *Chaetetes* Band (Dean, 2007). The Main and Fossil posts form the back face of the quarry although neither the Brunton nor Frosterley bands are recorded. The Famp Posts or Tumbler Beds form the uppermost 5 to 6 m and are largely obscured by vegetation.

The Great Limestone is well exposed within the area and has a profound influence on the landscape in the Nent, West Allen, South Tyne and Mohope valleys. It ranges in thickness from approximately 20 m in the Nent valley, reducing northwards to approximately 12 m in the Mohope and West Allen valleys. Along the south-facing slopes of the Nent valley, the Great Limestone forms a very conspicuous bench feature in the hillside that can be traced clearly and easily from the southern margin of the present area, at Haggs Bank, to Alston. To the west of Blagill [742 476] the outcrop of the Great Limestone is marked by a strong bench feature along which the course of the B6294 runs to its intersection with the A686 north-east of Alston. The benches formed by the Great Limestone, the underlying Four Fathom Limestone and, to a lesser extent, the overlying Little Limestone of the Stainmore Formation, along this section of the Nent valley, are some of the most spectacular and 'textbook' examples of the influence of differential bedrock weathering on landscape to be found anywhere in northern England. However, despite its influence on the landscape in the Nent valley, exposures are generally small and there are no worthy complete sections through the unit.

At Haggs Bank [768 452] beds of the Bench Posts (although not the base of the Great Limestone) are exposed intermittently within and along the edges of the track, and the uppermost beds of the Main and Fossil posts, along with some of the Tumbler Beds, are exposed in a major surface working on Nentsberry Haggs Vein (Section 6) for approximately 200 m south-west of the unclassified road from Nenthall to Nenthead. Here, the dip on the Great Limestone is approximately 4° towards the south-west and the gently south-west-sloping topography at this point is largely a dip-slope that remains entirely within these beds, extending the outcrop of the Great Limestone for 350 m north-east of Haggs Bank, across the aforementioned unclassified road and into the fields on the north-east side, where it is finally terminated by the Carr's Cross-vein (Section 6) accompanied by an abrupt change in slope angle.

At High Nentsberry [7637 4547] the base of the Great Limestone is visible in the washout from a large spring where the lowermost beds can be seen resting abruptly on the underlying Tuft Sandstone. A prominent spring line marks this boundary to the south-east. The same contact can be inferred some 400 m to the north-north-east [7646 4580], where spoil consisting of soft sandstone and shaly siltstone implies that the accompanying open adit is driven into the Tuft and underlying measures of the Iron Post Limestone cyclothem; no clear exposure can be seen in the first few metres of the adit entrance. The Great Limestone does not crop out on the south-west-facing slopes of the Nent valley for approximately 1 km north-west of High Nentsberry; it is cut out by the interaction between landscape and the Carr's Cross-vein.

At East Cocklake Farm [7580 4660], approximately 1 km north-west of High Nentsberry, the upper half of the unit, including poorly developed Tumbler Beds, is again exposed in small disused quarries. From here, north-westward along the Nent valley, the Great Limestone crops out largely continuously to the western limit of the present area.

In Foreshield Burn [7530 4738] a near continuous section from the base of the Great Limestone through to the Main Posts is exposed in a waterfall. No fossiliferous bands are visible in this section, although access to the burn and the exposure is extremely hampered by coniferous woodland. The burn and a small east-bank tributary stream flow across the bench feature formed by the Great Limestone for 100 to 150 m south-west of the farm track to Blagill. Small exposures of limestone, consisting of one or two 20-50 cm thick beds with extremely wavy bedding surfaces, exist along the lengths of the channels with some of the best exposure under the bridge that carries the track over Forshield Burn [7533 4743]. Here, five beds, ranging in thickness from 20-50 cm are exposed in the base of the stream. The nature of this succession (i.e. the absence of siltstone partings) suggests that it is not within the Tumbler Beds. This, combined with the presence of exposures through the overlying measures to the north-east of the track, suggests that the Tumbler sequence is poorly developed and locally thin, although a line of conspicuous and well-developed sink holes, beginning 200 m to the south-west [7500 4725] and continuing to Blagill, do imply at least some presence.

From Blagill [7421 4763] C. L. Vye reported 7 to 8 m of wackestone with many crinoidal fragments weathering proud. Neither the *Chaetetes* Band or the Tumbler Beds were reported and this exposure most probably corresponds to the Main Posts of Fairbairn (1978).

Approximately 1 km to the north-north-west of the confluence of the Nent and the South Tyne, two large quarries, Coatleyhill and Newshield, are workings in the Great Limestone. At Newshield up to 10 m of blue/grey wackestone are exposed, bedded on 10-30 cm scale and containing numerous crinoid fragments. Siltstone partings are evident and increase in frequency upwards. The exposure represents a section through the Main and Fossil posts, and Tumbler Beds, from which C. L. Vye reports the following:

	Thickness (m)
Limestone, bleu/grey, 10-30 cm beds with wavy surfaces	1.5+
Siltstone	0.2
Limestone, single bed	0.6
Siltstone	0.1
Limestone, 3 beds with wavy surfaces	1
Siltstone	0.1
Limestone, 3 beds with wavy surfaces	0.8
Siltstone	0.1
Limestone 4 beds, 5-30 cm with wavy surfaces	1
Siltstone	0.1
Limestone, highly wavy bedding surfaces	4+

In Clargill burn [7293 4972], one of the most complete sections through the Great Limestone is well exposed. The base is marked by a small (~0.7 m high) waterfall formed by the lowermost beds. At just under 1 m from the base of the unit the *Chaetetes* Band is beautifully exposed as 20 to 30 cm of algae underlain by very fossiliferous limestone beds packed full of solitary and colonial corals. M. T. Dean reported the following section (full details of the fossil assemblages are given in Dean, 2007):

	Thickness (m)
Limestone, planar-bedded with foraminifera, stick bryozoan? Orthotetoid, productoid, *Rugosochonetes celticus*, crinoid material	-
Limestone, wavy-bedded, variably developed as Chaetetes band and a coral band	0.8(variable)
Chaetetes Band	0.35(variable)
Bioclastic limestone	0.3
Coral band	0.15
Limestone, planar bedded	0.8
Seatearth, rooty	0.3
Sandstone	

The Main Posts are exposed as near vertical cliffs in both banks of the stream forming a small gorge and 3 m waterfall over which the Clargill Burn falls. Much of the higher part of this section is inaccessible but does show fantastic modern karstic features as fractures within the limestone have been opened up by ground waters from the surrounding hillsides. Above the waterfall, and to the south-east of the track, [7313 5967] the Tumbler Beds are exposed in the burn as five or six grey/brown, very hard limestone beds ranging in thickness up to 60 cm and interbedded with dark grey, shaly siltstone units up to 40cm in thickness. The highly fractured nature of the limestones has resulted in significant collapse of this section. Prolific *zoophycos* are evident on many of the limestone bedding surfaces.

Along the north-east-facing slopes of the Nent valley, near the southern limit of the present area, the outcrop of the Great Limestone is concealed below extensive superficial deposits. A small number of limestone blocks at surface and extremely subtle features are the only clues to its presence. Consequently, the outcrop pattern on NY74NE is largely a structural construction based on outcrop in the south-west-facing bank. Further downstream, on Middle Fell, a number of small quarries (e.g. [7485 4545]), a major quarry at Bayle Hill [728 456], and sinkholes attest to its presence.

On the east-facing slopes of the South Tyne valley, the outcrop of the Great Limestone is marked by a strong bench feature and, in many places, by well developed sink holes. A number of quarries and surface workings on two mineralised faults that cross Park Fell [7023 4572] expose 1 to 4 m of blue to grey wackestone in beds 10 to 40 cm thick with wavy bedding surfaces and interbedded with siltstone. The siltstone units become more prevalent towards the top of the exposures.

In the upper reaches of the Mohope valley (NY74NE), the outcrop of the Great Limestone is largely concealed beneath superficial deposits; its position is indicated by weak bench features and, in many places, by well-developed sink holes. However, despite the presence of significant superficial cover, two major exposures exist. At Yew Crags, the Mohope Burn has cut down through the full extent of the Great Limestone creating a spectacular narrow gorge. The thickness of the unit here is 12 to 15 m with the base and underlying Tuft Sandstone exposed at the mouth of the gorge [7752 4832] and the overlying measures of the Stainmore Formation exposed at the entrance [7792 4786], with the uppermost limestone beds of the Tumbler sequence forming the riverbed. The walls of the gorge expose a near complete section through the Great Limestone. Thin siltstone partings mark the three flat divisions of Forster (1809) but no fossiliferous bands have been noted at this locality. The Tumbler Beds, although poorly exposed, are approximately 2-4 m thick and form the steeply sloping ground that immediately bounds the gorge. Large sink holes on either side of the gorge, with small exposures of interbedded limestone and siltstone within them, attest to their presence.

At the site of the former Hearty Cleugh Mines [7715 4914], workings have exposed some 4 m of the lowermost beds of the Great Limestone, and underlying Tuft Sandstone, in a cliff section on the northern side of the valley. Again the *Chaetetes* Band is not noted at this locality. The outcrop of the base of the Great Limestone both up and down the valley from this point is marked by a conspicuous line of springs.

The lower reaches of the Mohope valley are blanketed in superficial deposits that are significantly thinner than those at the head of the valley to the south. Although exposures of the Great Limestone are rare, its outcrop along both sides of the valley is marked clearly by a significant feature and often a conspicuous change is vegetation. On the west-facing slopes conspicuous lines of deep sink holes mark the approximate course of the Tumbler beds. Particularly good examples are to be found around Hesleywell Farm [7770 5040], although many of the best developed and deepest ones expose measures of the Stainmore Formation suggesting that they are developed through the overlying strata.

On the east-facing slopes of the lower Mohope valley, the outcrop of the Great Limestone is faulted down to the south by approximately 20 m on the Kirsleywell Row East Cross-vein (Section 6) that traverses the valley side at an oblique angle. A conspicuous feature and vegetation change is only developed in the footwall of this fault, most notably around Kirsleywell Row [7715 5130], along which the unclassified road runs and on which a number of cottages to the east of the road stand. Small and poor quality exposures were present in surface workings on the Kirsleywell Row East and West veins, just east of the unclassified road, approximately 150 m north of the youth hostel, although these have been largely obscured by recent building works. The outcrop of the top of the Great Limestone in this area is interpreted to coincide with the topographical break in slope that runs along the western edge of the road, based on the presence of poorly developed sink holes in fields to the north [7732 5166] and the thickness of the unit projected from subsurface data. This interpretation was confirmed recently by building work at YHA Ninebanks which exposed the overlying measures of the Stainmore Formation to the west of the unclassified road and on which the Youth Hostel stands.

In the West Allen valley, the Great Limestone crops out on both the east- and west-facing slopes forming a conspicuous feature. On the west-facing slopes this feature is peppered for much of its length by well-developed sinkholes although exposures are rare. In Wolf Cleugh, waterfalls and the road cuttings expose various sections through the unit. Access is somewhat difficult and the exposure poor but both the base and the top of the unit are seen clearly in the river section giving a thickness to the great limestone at this point of approximately 18 m. Further north, in the vicinity of Blackpool Bridge, the West Allen Great Cross-vein (Section 6) crosses the valley at an attitude that is no more than 20° from that of the strike of the bedding, and with a throw of approximately 20 m down to the west. As a consequence, the Great Limestone in this area is repeated and major bench features mark its outcrop in both fault blocks. Although exposure is very limited in this area, as a result of well-developed soils and the presence of cultivated hay meadows, superficial cover is generally thin and the truncation and repetition of bedrock features by the fault are extremely clear when viewed from the opposing hillside. The Great Limestone in the hanging-wall block is exposed in a large quarry just south of the village of Ninebanks. Here, 8 to 10 m of cliff face expose a medium grey wackestone in beds of 15 to 60 cm thick often with wavy surfaces. Some quartz veining as also present on fracture surfaces.

On the east-facing slopes of the Allen valley, the outcrop of the Great Limestone is almost entirely concealed below superficial deposits but a subtle, yet laterally continuous, feature marks its course. The only exposure is at Ouston [7755 5300] where quarries and surface mineral workings on the Ouston Vein expose thin (20 cm) limestone beds with wavy bedding surfaces interbedded with very thin shaly siltstone partings. The proportion and thickness of limestone beds increases down section to a strong break of slope. These exposures represent the Tumbler Beds with the flats forming the bench feature below the break of slope; they represent beautifully the relationships between the geology of the Great Limestone and the topography it forms on weathering.

The Great Limestone is penetrated by the Longcleugh boreholes, Wellhope Shaft and Scraith Hole Shaft. Longcleugh #1, #2 and #2a penetrated between 12 and 16 m of grey, crinodal limestone that is highly mineralised on joint surfaces and within veinlets. #1 borehole, in which the lowest thickness of limestone is recorded, entered the Great Limestone immediately below 30 m of superficial deposits. It does not encounter any strata attributable to the Tumbler Beds and the thickness of limestone measured (12 m) may correlate with the main beds only. In all cases, the *Chaetetes* band is present within 1 m of the base. In Wellhope Shaft, 19.2 m of the Great Limestone are recorded of which 5.4 m comprise the Tumbler Beds, and in Scraith Hole Shaft 20 m are recorded. In both cases no lithological details are available.

3.4 SERPUKHOVIAN TO BASHKIRIAN (NAMURIAN) ROCKS: STAINMORE FORMATION

Strata younger than the Great Limestone crop out over most of the present area but dominate in the northern two-thirds, where a gentle, northerly orientated, regional dip results in the preservation and exposure of progressively younger strata northwards.

In addition to the strata between the Great and Little limestones, which belong to the Great Limestone cyclothem but fall within the Stainmore Formation, two, well developed and regionally correlatable cyclothems are recognised: the Little Limestone and Crag Limestone cyclothems. Younger strata are dominated by clastic deposits with few, poorly developed and laterally discontinuous limestones making regional correlation problematic. Over the present area, one thin limestone, the Lower Felltop Limestone, is recognised within this succession that can be tentatively correlated regionally. For the purposes of this description, strata younger than the Crag Limestone are subdivided at the Lower Felltop Limestone.

Strata of the Stainmore Formation are penetrated by the following boreholes:

Quarter Sheet	Shaft / Bore	Easting	Northing	BGS BJ	Strata penetrated
NY74NE	Wellhope Shaft	7787	4660	2	'Fiddler's' Sdst to Great Lmst
	Scaithe Hole (sic.) Shaft	7999	4682	1/5	Firestone Sandstone to Great Lmst
NY75SE	Longcleugh Mine #2	7672	5151	3	Little to Great limestones

3.4.1 Strata between Great and Little limestones

Strata overlying the Great Limestone and belonging to that cyclothem crop out in the Nent, South Tyne and Mohope valleys, and within the West Allen valley to approximately 1km north of Whitfield, where they faulted down below the present day landscape by two major faults that throw down to the north-east with a cumulative throw of approximately 12m.

These strata are dominantly siltstone and sandstone but considerable variation in detail occurs over the extent of the present area. At least one, and sometimes two, major coal seams are present also. These seams constitute the Little Limestone Coal and are at times of sufficient thickness and rank that they have worked extensively over much of Alston Moor. A generalised succession (from the base upwards) consists of siltstone, sandstone, coal, siltstone, sandstone, coal, siltstone and sandstone, and almost certainly represents at least two and possibly three subordinate and incomplete cyclothems within the Great Limestone cyclothem.

Over much of the Nent valley and Alston Moor this generalised sequence holds true to such an extent that the sandstones have been given local names. Dunham (1990) provided the following typical section from an underground section on the High Raise Vein [770 459] within the present area:

	Thickness (m)
Little Limestone	
Sandstone (White Hazle)	2.1
Siltstone	1.6
Coal (Little Limestone Coal)	0.25
Sandstone (High Coal Sill)	3.7
Siltstone	2.5
Coal (Little Limestone Coal)	0.1
Sandstone (Low Coal Sill)	3.0
Siltstone	5.5
Great Limestone	

Despite a general consistency in the succession noted in many of the mines of Alston Moor that has warranted the naming of individual sandstones, even within the Nent valley of the present area considerable variation has been noted in surface exposures. As a consequence, individual sandstones within this succession have not been delimited in the current survey.

In the Nent valley, a west-bank tributary stream to the Foreshield Burn [7528 4752] exposes some 5 m of very dark grey, thinly bedded and fissile siltstone interbedded with thin laminae of orange/brown, fine-grained sandstone that forms the top of this succession. The top 0.75 m shows an increase in frequency, grain-size and thickness of sandstone beds and culminates in a thin (10 cm) coal directly overlain by the Little Limestone (Section 3.4.2). The White Hazle Sandstone is not present. No major sandstone or additional coals at lower levels within the succession are noted at this exposure. However, substantial workings locally suggest that two seams may be present only 200 m to the east.

Between Foreshield Burn and Alston, the course of two coal seams along the south-facing slopes of the Nent valley is clear from the numerous surface workings.

Over the remainder of the area the strata between the Great and Little limestones are poorly exposed and their nature is largely interpreted from secondary evidence.

In the Mohope valley approximately 1.5 m of dark-grey, thickly laminated, shaly siltstone are exposed directly overlying the Great Limestone at the top of Yew Crags [7792 4786]. Evidence of coal workings 200 m to the south indicates that at least one coal seam is present with the succession on this side of the valley. The associated spoil heaps are composed entirely of siltstone with no clear evidence of sandstone. 300m to the north, exposures in Peatfell Sike [7806 4894] and quarry workings expose sandstone and suggest that the succession culminates with a White Hazle sandstone at least 2 m thick. Further coal workings 200m upstream from Hearty Cleugh Mine [7693 4900] and at Hesleywell Farm [7780 4983] indicate the presence of at least one coal seam but there is no exposure of the sequence at either of these sites.

On the east-facing slopes of the lower Mohope valley a small but deeply incised stream [7696 5042] exposes approximately 5 m of grey thickly laminated, fissile and shaly siltstone overlain by a 1 m of sandstone that are attributed to the uppermost strata including the White Hazle of the Great Limestone cyclothem.

In the West Allen valley exposures of strata attributable to the Great Limestone cyclothem are equally scarce. A number of east-bank tributary streams consistently expose a few metres of siltstone overlain by limestone (The Little Limestone 3.4.2) but the west bank is devoid of exposure until the river reaches the southern limits of Whitfield village [7827 5580]. Here cliffs in both the east and west bank expose sections of up to 5 m of siltstone with at least two interbedded, fine-grained, thin sandstones and overlain by a medium-grained sandstone of the White Hazle. The full succession is at least 20 m thick but exposed only intermittently.

Strata between the Great and Little Limestones are penetrated by the Longlcleugh #2 borehole and the Wellhope and Scraith Hole shafts. In Longcleugh #2, 10m of siltstone overlie the Great Limestone, overlain by a 1.5 m-thick seatearth and sandstone topped by 30 cm of the Little Limestone Coal. 10 m of thick sandstone with siltstone partings complete the succession. In Wellhope Shaft 6.7 m of siltstone overlie the Great Limestone, followed by a 1 m sandstone of the Low Coal Sill and 15 cm coal. The remaining 11.5 m of the succession comprises 2.8 m of measures, in which a second thin sandstone (the High Coal Sill) and associated coal can be found, overlain by 5.7 m of the White Hazle. Scraith Hole penetrated a similar succession but with a thinner (1 m) White Sill.

3.4.2 The Little Limestone cyclothem

The Little Limestone is the thinnest of the laterally continuous and regionally extensive limestones with the succession. It is also the youngest limestone within the Yordale Group that can be correlated between exposures with a high degree of confidence. The Little Limestone crops out over the extent of the Nent, South Tyne, Mohope valleys as well as the West Allen valley, where it can be traced as far northwards as Cupola Bridge [7995 5913].

The Little Limestone is typically a hard, light grey, crystalline, fine-grained limestone that varies in thickness from approximately 1 to 6 m. The maximum thickness on the Alston Block is recorded from Harehope Gill Mine, near Frosterley, Weardale, where 6.4 m are exposed (Dunham, 1990), but the average thickness is less than 3 m. Over the extent of the present area the Little Limestone is approximately 2 m thick or less and comprises two to three beds 50 to 60 cm thick.

Within the Nent and South Tyne valleys the best exposures of the Little Limestone are on the south- and south-west-facing slopes at Foreshield Burn and its western tributary [7530 4755] and in the Clargill and Ayle burns approximately 3 km north-north-east of Alston, [7335 4955] and [7315 5020] respectively. At Foreshield Burn approximately 1.5 m of light grey, hard wackestone in two major beds of equal thickness immediately overlie the dark grey siltstone and thin coal of the top of the Great Limestone cyclothem, and form a conspicuous bench feature. Scattered macrofossils of a large sponge-like body can be found in this exposure and are a characteristic of the Little Limestone. In Clargill Burn, a similar thickness of limestone, overlying some 10 m of siltstone is inferred from the presence of highly weathered blocks up to 1 m in lateral dimensions and 60 cm thick that rest on a strong bench feature. In Ayle Burn, C. L. Vye reported 1 to 1.5 m of dark-grey wackstone, with numerous small quartz and calcite veins, that are attributed to the Little Limestone.

The previous survey of NY74NW interpreted the Little Limestone to be continuous along the south-facing slopes of the Nent valley between the exposures in Clargill and Foreshield burns. However, exposures in this area indicate that the siltstone and coals of the upper part of the Great Limestone cyclothem are immediately overlain by up to 3 m of fine- to medium-grained sandstone, commonly in cross-bedded sets of approximately 50 cm thick, which form a strong bench feature approximately coincident with that formed by the Little Limestone at Clargill and Foreshield. There is no evidence of limestone and as a consequence the previous surveyors interpreted this sandstone to be the White Hazel and inferred the outcrop of the Little Limestone to run through the steeper slopes at the back of this bench feature; significantly thickening the Great Limestone cyclothem over this section. The present survey by C. L. Vye makes no attempt to interpret an outcrop of the Little Limestone over this distance. The nature of the exposed sandstone and its stratigraphical relationships to the underlying sequence (particularly the coals) suggest that it may not be the White Hazel but may represent an erosive body that has removed the Little Limestone. Unfortunately, the key outcrops that would confirm this hypothesis are obscured by coal workings and superficial cover in the ground 100 m to the west of Foreshield Burn and the exact relationships between this sandstone and the Little Limestone remain equivocal.

South-east of Foreshield Burn, and on the north-facing slopes of the Nent valley, the Little Limestone is interpreted to crop out in short sections within the footwall and hanging-wall blocks of the Carr’s Cross-vein (Section 6), but these interpretations are based largely on secondary evidence including the presence of coal seams in the underlying strata, the composition of mining waste and copious limestone blocks on the surface.

In the Mohope and West Allen valleys the Little Limestone is poorly exposed but can be found with surprising consistency at the correct stratigraphical position in almost all of the minor tributary streams that feed the Mohope Burn and West Allen River. It is also ubiquitously recorded in mine workings that underlie Wellhope Moor, Ouston Fell and the west-facing slopes of the West Allen valley. For these reasons, the outcrop of the Little Limestone in these areas has been interpreted as continuous and positioned largely from secondary evidence, principally the presence of coal workings in the underlying strata, limestone blocks on the surface and, in places, a very weak feature.

Further north along the West Allen valley good exposure of the Little Limestone can be found under the bridge at Whitfield Old Toll House [7745 5540] where 2 m of wackestone in 30 cm-thick beds are exposed containing abundant crinoid and shell fossils, and at Clinty Wood [7875 5790] where a large north-trending and east down-throwing fault crosses the river and displaces the Little Limestone by 10 m down to the river. 3 m of highly crinoidal limestone that become sandy towards the top are exposed in the east bank over- and underlain by siltstone. 100 m downstream, a further fault also throwing down to the east by a similar amount displaces the Little Limestone below the presence day landscape.

The interaction between the gently northwards dip of the strata and the topography in the region of the confluence between the West and East Allen rivers results in exposure of the Little Limestone in the bed of the Allen River under Cupola Bridge and as it enters the Allen gorge. Here, almost the entire bed of the river is highly fractured limestone with fracture trends of 340° and 070° forming a rectilinear pattern. The exposure is finally terminated 300 m downstream of Cupola Bridge where a small fault mineralised with galena displaces the Little Limestone below the landscape once more.

The Little Limestone is overlain by a siltstone-dominated section up to 50 m thick. Within this sequence, a sandstone, 3 to 10 m above the Little Limestone, has been recognised over much of the Alston block and the present area. It has been the practice to call this first sandstone above the Little Limestone the ‘Pattinson Sill’ (Dunham, 1990), although comparison of different sections strongly suggests that the name has been applied to several different sandstone bodies that are almost certainly chanellised or lenticular. In the Nent valley, C. L. Vye reported approximately 5 m of hard, fine- to medium-grained sandstone lying 10 m above the Little Limestone that can be traced along much of the south-facing slope and may represent the ‘Pattinson Sill’ of the Nenthead Mines. In the head-waters of the West Allen valley, just of the eastern edge of the present area [8012 4555], some 5 to 8 m of hard, light-grey, fine- to medium-grained sandstone in medium beds form a prominent waterfall. This unit becomes rotted towards the top and contains within it a thin (30 cm) highly arenaceous limestone some 50 cm from the top. The whole unit is named locally as the White Sill* but may correlate with a similar sandstone in Jeffries Shaft [9602 4781] called the ‘Pattinson Sill’ (Dunham, 1990). It is extremely unlikely that this outcrop is equivalent to the sandstone outcrops of the Nent valley that have been attributed to the Pattinson Sill. Nor is it likely that this outcrop is the equivalent of the White Sill of the Nent valley (Clarke, 2007) which shares many more characteristics with a higher sandstone in the West Allen section. Furthermore, the term ‘White Sill’ is applied to clearly younger Namurian sandstones in some mine workings within the present area and cannot be used reliably as a stratigraphical indicator.

In the present survey, a number of thin and laterally discontinuous sandstone bodies have been mapped in the Nent valley at the approximate stratigraphical level of the Pattinson Sill. No attempt has been made to correlate these outcrops or to force interpretation further than the field evidence allows as it is unlikely that these outcrops represent the same continuous sandstone body. In the upper reaches of the Nent valley, the Carr’s Cross-vein, throwing down to the north-east, displaces much of the sequence overlying the Little Limestone below the landscape and no sand bodies crop out at this stratigraphical level. Similarly, a lack of exposure does not allow the recognition of sandstones at this stratigraphical level in the Mohope and West Allen valleys over the extent of the present area.

The remainder of the section is largely dark grey, thickly laminated and commonly fissile siltstone, but some 15 to 20 m below the top a thin, dark-brown and commonly soft sandstone is present. This unit usually consists of only one or two beds approximately 15 to 20 cm thick that are dominated by shell fossils and shelly fragments. From localities in the West Allen valley [8010 4530], just off the eastern edge of the present area, M.T. Dean and P. Brand (pers. comm.) report the following fossil assemblage consisting largely of spiny productoid brachiopods:

Avonia sp.
Buxtonia sp.
Eomarginifera longispina
Overtonia fimbriata?
Productus concinnus
Promarginifera sp.

together with other brachiopods including: *Brochocarina* sp., ?*Phrycodothyris* sp., and a rhynchonellid, and *Rugosochonetes celticus*.

The unit may form a useful stratigraphical marker and has been recognised within the present area on the south-west-facing slopes of the Nent valley [7655 4646] and in Blaeberry Burn [762 557], localities separated by some 10 km, and just off the eastern edge of the present area in the headwaters of the West Allen River [8002 4537]. It may well correlate with the White Sill of the Nenthead area (Clarke, 2007) which has been shown in mine sections to be topped by a shelly sandstone (Dunham, 1990) although this argument is somewhat speculative as continuous outcrop cannot be traced between the two sections.

* Not to be confused with the White Hazel which lies below the Little Limestone

Longcleugh #2 borehole recorded 30 cm of ochreous 'famp' (decalcified limestone) with decalcified sandstone at the base that represent the Little Limestone. These strata are overlain by 17 m of dark siltstone with sandstone laminae towards the top, preserved below 22.8 m of superficial deposits. Wellhope Shaft penetrated 2.4 m of the Little Limestone overlain by 34 m of a siltstone-dominated sequence in which 8 separate sandstones no more that 1m thick are recorded. A thicker sandstone (2 m) is also recorded, 5 m above the Little Limestone, that is named the Pattinson Sill. In Scraith Hole Shaft approximately 30 m of siltstone-dominated succession overlie 4 m of Little Limestone. 3 sandstones between 2 and 5 m thick are recorded interbedded with the siltstone. Again, the lowermost sandstone, occurring approximately 7 m above the top of the Limestone, is named the Pattinson Sill.

3.4.2.1 THE FIRESTONE SANDSTONE AND ASSOCIATED COALS

Overlying the measures, and forming the top of the Little Limestone cyclothem is the Firestone Sandstone. This unit deserves special mention because, over much of the area, it is lithologically quite distinctive and, combined with the lithofacies immediately above and below, can be used as a correlation marker unit.

The Firestone Sandstone was mapped over the whole of the present area during the primary survey. It is a laterally extensive, channel sandstone, 10 to 15 m thick, with varied characteristics reflecting the physical and temporal position of the exposures with an evolving channel. The best exposure through the unit is just off the south-eastern edge of the present area, at Firestone Bridge [7885 4353] after which the unit is named. Here, the exposure consists of 12 m of sandstone with an erosional base which cuts down into the underlying siltstone on both the small and the outcrop-scale. The base of the sandstone consists of a coarse- to very coarse-grained, poorly cemented channel lag up to 30 cm thick of rounded to subrounded quartz grains, accompanied by intraformational rip-up clasts of siltstone ranging in size from a few millimetres up to a few centimetres. This is succeeded by an orange to brown, very coarse-grained, reasonably well cemented, massive unit up to 1 m thick comprising largely rounded to sub-rounded quartz grains. Organic steaks and pieces of fossilised wood up to 15 cm long are common. The breakdown of minerals on weathering within this section gives it a characteristic 'flecked' orange-dark brown appearance on fresh surfaces. The massive bed is overlain by 10 m of orange to brown, coarse- to very coarse-grained sandstone, strongly cross-bedded with foresets up to 2 cm thick. Finally, 1 m of brown to light brown, medium-grained sandstone that becomes increasingly finer grained and more planar bedded upwards with 5 cm thick beds completes the succession; the top of the exposure is in faulted contact with the overlying strata of the Crag Limestone cyclothem. A similar sequence is exposed in Gillgill Burn [7880 4390] just outwith the present area, and within the headwaters of the West Allen River at Coalcleugh [7992 4525].

Within the area, the Firestone Sandstone crops out in the Nent, South Tyne, Mohope and West Allen valleys. Exposures similar to those seen at Firestone Bridge are to be found in the Blaeberry Burn [7595 5556], Hareshaw Cleugh [7570 5145] and, to a lesser extent, within the Allen gorge [7975 5957], but elsewhere exposures are not so uniquely characteristic and somewhat similar to younger Namurian sandstones. The general north-south alignment of exposures that resemble that at Firestone Bridge tentatively suggests a north-south trend to the river system, with less characteristic exposures to the east and west representing channel system edges and over-bank deposits. However, this hypothesis should be treated with caution as outcrop data are not sufficient to permit a regional palaeocurrent analysis to test it.

In the Nent valley the Firestone crops out along most of the south-west-facing slopes between Nenthead and Alston. In Brown Gill, 600 m east of Nenthall Bridge [7662 4585] a small waterfall exposes cross-bedded, coarse-grained sandstone similar in characteristics to that at Firestone Bridge and allows correlation of the Firestone across the Carr's and Wellgill cross-veins (Section 6). An exposure of sandstone in Foreshield Burn is also interpreted to be the

Firestone based on its lithological characteristics, although here it is underlain by a thin (20 cm) hard limestone bed. Although this lithofacies has not been reported elsewhere, and this exposure is faulted down within the graben formed by the Carr's and Wellgill cross-veins (Section 6), there can be little doubt that it is the Firestone Sandstone as the displacement on both faults is extremely well constrained in the subsurface by mining data. The Firestone Sandstone is further exposed in surface workings at Blagill, from where C. L. Vye reported a light brown to pink, planar-laminated and cross-bedded, medium- to coarse-grained sandstone, and correlates with a strong feature between here and Alston where numerous small natural exposures are present in the hillside and in stream sections. On the north-facing slopes of the Nent valley the outcrop of the Firestone Sandstone is marked by a prominent feature and many small disused sandstone quarries.

On the west-facing slopes of the South Tyne valley, a sandstone at the stratigraphical level of the Firestone Sandstone is exposed in the Clargill and Ayle burns. Here, it has lithological characteristics somewhat similar to those of the overlying younger Namurian sandstones and this, combined with faulting, make a definitive correlation difficult. The sandstone is medium-grained and intensely trough-cross-bedded in places but with a bioturbated top. These characteristics, combined with its lithofacies associations (see below), tentatively suggests that this is the Firestone Sandstone.

In the Mohope valley there is little in the way of exposure of the Firestone Sandstone and its position and lateral continuation is inferred from strong featuring and secondary evidence. At Wellhopehead Mine [7840 4650] approximately 2 m of brown-orange, coarse-grained sandstone with flecky brown weathering forms a small waterfall in the burn. The sandstone is in 30 to 50 cm beds and is cross-bedded with evidence of small-scale channels. An exposure with the same characteristics is also present on Hessleywell Moor [7692 4794]. These represent the only direct control on the outcrop of the Firestone Sandstone within the Mohope valley.

On the west-facing slopes of the West Allen valley, the outcrop of the Firestone Sandstone is marked by a prominent bench in the hillside that is punctuated at regular intervals by abandoned quarries. Exposure is limited but where available indicates an orange to brown, medium- to coarse-grained sandstone, often cross-bedded and weathering to give a deep-brown flecky appearance. It is not until Dryburn Cleugh [7947 5300] that good exposures can be found. Here, orange-brown, coarse-grained sandstone may be seen in beds ranging from 30 to 50 cm. Most of the beds are cross-bedded with foreset laminations/beds ranging from 5 mm to 5 cm. The exposure weathers in the characteristic orange-brown flecky manner.

In the east-facing slopes of the West Allen valley, the outcrop of the Firestone Sandstone is poorly exposed and is interpreted between Braeberry Burn, Hareshaw Cleugh and the Allen gouge largely on the basis of strong featuring and secondary evidence, particularly extensive slippage of the overlying superficial deposits that is inferred to be the result of a well-developed spring line at the base of the Firestone Sandstone for much of its outcrop.

In places, quite extensive workings of the measures just below the Firestone Sandstone suggest the presence of an underlying coal. These occurrences tend to be located outside of the inferred principal channel area (where the coal is presumable cut out), for example at Gatehouse Burn [7870 4572] where a conspicuous line of workings exist in strata immediately below the Firestone in the north side of the stream and highly organic siltstones are exposed underlying the Firestone in the streambed.

A thin coal overlies the Firestone Sandstone in many parts of the present area to complete the cyclothem. This coal was formerly worked at Coalcleugh [7987 4535], and at Nenthead, to the south of the present area, where its thickness reaches 46 cm. The seam has been correlated with the Oakwood Coal of the Tyne area (Smith, 1923), the closest exposures of which can be found within the Allen gorge, in the hanging-wall of the Stublick Fault, approximately 3 km north of the present area.

Scraith Hole Shaft penetrated approximately 9 m of the Firestone Sandstone overlain by a thin coal directly beneath superficial deposits. The Wellhope Shaft encountered 8.5 m of Firestone Sandstone overlain by a coal 1.2 m thick. In both cases no lithological details are available.

3.4.3 The Crag Limestone cyclothem and younger strata

A thin and poorly developed limestone overlies the Firestone Sandstone and associated coal and marks the beginning of the next cyclothem in the Namurian sequence. However, marine influence is significantly reduced by Namurian times and mappable limestones of any quality and lateral persistence are rare* within the remainder of the Namurian succession of the present area. One appreciable limestone, the Lower Felltop Limestone, can be observed in places but there is little evidence that this unit is laterally continuous between exposures. Nevertheless, it does provide some stratigraphical control on the correlation of strata between the Firestone Sandstone and the lithologically distinctive pebbly sandstones that cap many of the hill tops. Consequently, the description the remainder of the Stainmore Formation is given based on a division at the Lower Felltop Limestone.

3.4.3.1 The Crag (Oakwood) Limestone

In Barneycraig Mine, just off the eastern edge of the present area, a number of faults are mineralised at the stratigraphical level of the Firestone Sandstone. Here, a thin limestone known locally as the Crag Limestone is reported overlying a thin sequence of organic-rich siltstone atop the Firestone Sandstone. The Firestone sandstone may be followed south-westward through continuous workings into the Rampgill Mine of the Nenthead area (Clarke, 2007), some 2km south-east of the present area, but here it is overlain by a ferruginous limy sandstone with shells which takes the place of the Crag Limestone in the Alston Moor area (Dunham, 1990). The Crag Limestone therefore forms a valuable stratigraphical marker within the present area and can be correlated regionally with the Oakwood Limestone of the Tyne area.

Within the present area, few exposures of the Crag Limestone or its equivalent shell bed are known. In Ayle Burn [7344 5070], C. L. Vye reported 2 m of extremely calcareous and rooty sandstone, the uppermost 1 m of which is extremely fossiliferous with abundant shells. This exposure may correlate with the Crag Limestone and therefore support the tentative correlation of the underlying Firestone Sandstone in this area with that of the Nent valley, although an anomalously thick sequence of at least 4 m of siltstone and mudstone strata separate the two, and no coal is reported.

In the West Allen valley, exposures in Dryburn Cleugh [7945 5305], of light brown, limy and highly fossiliferous sandstone directly overlie the Firestone and are probably the shelly equivalent of the Crag Limestone. No Further exposures in the West Allen valley within the present area have been recorded.

In the Mohope valley, the section overlying the Firestone Sandstone is extremely poorly exposed and no thin limestones or fossiliferous sandstones have been noted at this stratigraphical level.

The Wellhope Shaft penetrated approximately 1m of strata attributed to the Crag Limestone; no lithological details are available.

* Borehole data suggest that thin marine units are abundant within the succession but contain few distinctive taxa to make clear and unambiguous correlations.

3.4.3.2 Strata between the Crag and Lower Felltop limestones

The Namurian succession between the Crag and Lower Felltop limestones is poorly exposed throughout the area. However, strong featuring and small abandoned quarries in the Nent, Mohope and West Allen valleys attest to a measures-dominated sequence (siltstone interbedded with thin fine-grained sandstone units) in which up to five thicker sandstone units can be recognised. Although locally continuous and traceable in outcrop over several hundred metres by the strong features they create, all share similar lithological characteristics and many, if not all, of these units are probably chanellised or lenticular. Furthermore, their thickness and frequency, combined with the low and locally variable angle of dip do not facilitate correlation between isolated exposures with any degree of certainty. As a consequence, it is extremely difficult to correlate these sandstones between valleys. One of the most continuous exposures through the succession is to be found in Backstone Burn [7860 5549], an east Bank tributary of the West Allen River north of Ninebanks village. From here the following succession is taken:

	Thickness (m)
Limestone (Lower Felltop)	
Sandstone	5
Siltstone	17
Sandstone, dark-grey, med. beds and strongly cross-bedded	4
Siltstone	15
Sandstone, orange/white, thickly bedded, calcareous and rooty, crinoids	4
Siltstone	1
Coal	0.1
Siltstone	12
Sandstone, brow, med. to fine grained, cross-bedded	1.5-2
Siltstone	10
Sandstone, brown thinly bedded and chanellised	8
Siltstone	5
Sandstone (Firestone Sandstone)	

The coal noted within this section may possibly correlate with one around the same stratigraphical level at Rookhope where it is overlain by a series of siltstones with at least one shelly and calcareous sandstone known as the Rookhope Shell Beds (Carruthers, 1938). The same section can be observed in Dowgang Hush, Nenthead, just south of the present area (Clarke, 2007).

In the upper reaches of the Nent valley, three mappable sandstone units are recognised within this succession before the summit of High Raise Hill. Although somewhat similar lithologically to each other, the oldest of these three can be tentatively named based on local mining data as the ‘Fiddler’s Sandstone’. It is a pale-brown, planar bedded, fine- to medium-grained sandstone approximately 5 m thick that crops out 10 m above the top of the Firestone Sandstone. Beds are up to 50 cm thick and some of the lower ones are cross-bedded. On the south-west-facing slopes of the Nent valley it forms a prominent and easily traceable feature which may be tentatively correlated with a similar feature in the same stratigraphical position and associated with small exposures of a lithologically similar sandstone in the Mohope valley. It should be noted that the name ‘Fiddler’s’ has been applied to clearly different sandstones within the Namurian strata in the records of different mines and therefore the name should not be applied formally to this unit.

In the west-facing slopes of the South Tyne valley, at least three, and sometimes four, sandstone units can be mapped between the Crag and Lower Felltop limestones. The oldest of these, which occurs approximately 10 m above the Firestone Sandstone and correlates with a strong feature, is described from a locality in Ayle Burn [7345 5073] by C. L. Vye as 6 to 8 m of pale-grey, fine-grained sandstone in planar beds averaging 10-20 cm think but ranging up to 50 cm thick. There is evidence of some cross-bedding in the lower, thicker beds. This unit may correlate with that referred to as the Fiddler’s Sandstone of Nenthead, although faulting and a lack of exposure between the two outcrops do not allow this assertion to be made with any degree of certainty.

In the Mohope valley, up to five sandstone units can be mapped based largely on featuring and secondary evidence. Only the lowermost of these is well exposed and is lithologically similar to the Fiddler's Sandstone of the Nent valley.

In the West Allen valley up to five sandstone units are mappable from strong featuring and small poor quality exposures. On Dodd Hill, that forms the western slopes of the upper reaches of the West Allen River, six sandstone units are mapped between the Firestone Sandstone and the summit of the hill, although it is likely that not all of these lie stratigraphically below the level of the Lower Felltop Limestone. Although there is no direct evidence for the limestone, two coals and a number of small limestone blocks on spoil heaps may suggest that the overlying sandstone unit that forms the summit of the hill is younger.

The succession between the Crag and Lower Felltop limestones culminates in varied strata. In the Mohope valley, much of the Nent valley and east-facing slopes of the lower West Allen valley, the exposures suggest that the Lower Felltop Limestone is directly underlain by a siltstone sequence. Indeed, in Whitewall's Burn [7430 5110], a west-bank tributary of the West Allen, a thin coal is present directly below the limestone. However, at Ayle [7260 5070], the Lower Felltop Limestone is directly underlain by sandstone. C. L. Vye reported a yellow to pale orange, well silicified, medium- to coarse-grained sandstone in beds of variable thickness from 5 cm up to 30 cm. Thicker beds are cross-bedded, but thinner beds are planar and flaggy. Small circular depressions in the top surface of the unit may be a weathering feature or they may represent burrows or root structures.

A sandstone lying directly below the Lower Felltop Limestone is also evident at Cudd's House Quarry, Keenleyside [7898 5514], Monk Hills [7864 5587], and Shieldfield Hill [7905 5674], all on the west-facing slopes of the West Allen valley. Exposures reveal a soft, pale orange/brown to white, highly calcareous and in places micaceous, fine- to medium-grained sandstone in thin beds from 1 to 15 cm thick. The contact with the overlying limestone is not exposed.

A good section through the uppermost strata of the succession underlying the Lower Felltop Limestone has been reported from a small quarry on Keenleyside Hill [7901 5015] by the previous survey. This quarry is now backfilled and the following is taken from these survey notes:

	Thickness (m)
Massive crinoidal limestone (Lower Felltop)	
Soft, cross-bedded sandstone with clay pellets	1.2
Dark, micaceous siltstone	0.75
Soft, flaggy sandstone	0.22
Micaceous shaly siltstone	0.3
Soft, flaggy sandstone	0.15
Micaceous shaly siltstone	0.22
Soft, flaggy sandstone	0.1
Micaceous shaly siltstone	1
Hard, flaggy sandstone	0.75+

The Wellhope Shaft penetrated 20 m of strata that overlie the Crag Limestone. Within this siltstone-dominated succession two sandstones are recognised; one 10 m above the Crag Limestone and 3 m thick that probably correlates with the Fiddler's Sandstone of Nenthead, and one no more that 60 cm thick at the very top of the bedrock section of the shaft, below 10 m of superficial deposits.

3.4.3.3 THE LOWER FELLTOP LIMESTONE AND OVERLYING STRATA

Within the present area, the Lower Felltop Limestone crops out on the south-west-facing slopes of the South Tyne valley, the west-facing slopes of the West Allen valley (Whitfield Moor) and the east-facing slope of the West Allen valley on Keenly Fell where some of the best exposures are to be found. It is a fine-grained limestone varying in thickness from 0.3 m to 2.5 m thick.

In the upper reaches of Quonister Cleugh [7432 5305] C. L. Vye reported large blocks of limestone containing shelly fragments, bivalves and brachiopods. This description correlates with that from the summit of Middle Fell, south of Alston, where Dunham (1990) reported brachiopods and the alga *Girvanella* within the Lower Felltop Limestone.

On Keenley Fell, the outcrop of the Lower Felltop Limestone is repeated by the large north-south-trending Keenley Fault that throws down towards the west. Several quarries in the limestone exist including a large working within the footwall of the Keenley Fault that exposes the limestone's entire thickness of 2.5 m, overlain by thin siltstone deposits and underlain by sandstone in the base of the quarry. The limestone is a light-grey, wackestone with many easily visible shell fragments and crinoids. Beds are approximately 50 cm thick but with poorly developed and with wavy bedding surfaces.

The strata overlying the Lower Felltop Limestone are somewhat variable in thickness and character across the area due to the presence of pebbly coarse-grained sandstones with highly erosive bases that have cut down through varying amounts of the section (Section 3.4.3.4).

On the northern and western slopes of Whitfield Moor, north of Alston, the Lower Felltop Limestone is immediately overlain by approximately 25 m of siltstone with at least one and possibly two coals in the uppermost 10 m [7145 5210]. This is followed by up to 50 m of a measures-dominated succession, in which at least one, and up to three, strong sandstones are locally mapable, before the base of the pebbly sandstone unit is reached. On the southern slopes of Whitfield Moor, the Lower Felltop Limestone is overlain by no more that 15 m of measures before the base of the pebbly sandstone unit, the latter having removed the overlying section.

On Keenley Fell, 8 to 10 m of siltstone immediately overlie the Lower Felltop Limestone and contain one coal that has been much worked here and for 1.5 km to the south along Middle Edge. Two lines of workings are evident in the hillside but both are on the same coal, the outcrop of which has been repeated by displacement on the Keenley Fault. The coal is overlain by 2 to 3 m of siltstone and a thin sandstone approximately 1.5 m thick.

At Keenleywell West Farm [7950 5578] this sandstone is followed by approximately 3 m of siltstone and then 1.2 m of hard, grey, highly calcareous, medium-grained sandstone (or arenaceous limestone) that may represent the Upper Felltop Limestone. The section exposed in the former quarry here is particularly remarkable as it shows this unit to be highly fractured with extremely smooth-edged and widening-upwards crags that are filled with loose sand. This is directly overlain by approximately 1 m of light-brown to light-grey, flaggy, medium-grained sandstone with irregular 'wavy' beds approximately 3 cm thick, some of which are cross-bedded. The whole section suggests subaerial exposure and weathering of the Upper Felltop Limestone prior to infilling of the weathered cracks by loose sand and deposition of the overlying sandstone.

3.4.3.4 Pebbly Sandstone Unit

Much of the summit of Whitfield Moor, north of Alston, is capped by a large sandstone unit that is lithologically distinctive. Over much of the high flat moorland of Pike Rigg and Tarn Rigg, C. L. Vye reported exposures of pale-grey, very coarse-grained to pebble-grade, quartzitic sandstone with angular to subrounded grains up to 1.2 cm in diameter. The exposures are bedded on a 5 cm to 1 m scale and commonly poorly sorted. They are strongly cross-bedded in places with foresets up to 5 cm thick and show evidence of local channels and down-cutting. Many of the beds show rooty tops and at least one is overlain by a bed containing large brachiopod shells. Small abandoned quarries in this unit are commonly accompanied by the remains of millstones indicating that the lithological properties of the unit made it particularly sought-after for making these.

Exposures through the lower parts of the unit on Tarn Rigg show a buff-yellow to orange, slightly micaceous sandstone that is of slightly finer grain to that exposed on the summit. The sandstone is also moderate- to well-sorted with planar or, in places, trough-cross-bedding in sets from 5 to 25 cm thick.

The differences in character between exposures on the summit and those lower down may suggest that two separate sandstone units are present. However, landscape featuring, particularly in the area of Whitfield Lough, suggest that little, if any, measures intervene between these units and consequently the whole section has been mapped as one ‘pebbly sandstone’ during the present survey.

From its lithological characteristics, and those of the intervening section below the pebbly sandstone down to the Lower Felltop Limestone across the area, the pebbly sandstone unit has been interpreted as highly erosional and to cut down significantly into the underlying strata.

The pebbly sandstone unit does not crop out over the remainder of the area, principally because the summits of the hills that border the Nent, Mohope and West Allen valleys are lower than those of Whitfield Moor and strata that cap these summits are sandstones that are in the stratigraphical interval around the Lower Fell Top Limestone.

4 Intrusive igneous rocks

No igneous rocks are known to crop out within the area. However, the Early Permian (Stone et al., *in press*) Great Whin Sill was proved within the Visean strata in the Longcleugh #1, #2a and #8 boreholes on NY75SE. These occurrences, coupled with surface exposures in the Tynehead valley [759 373], at Cowshill [NY851 408], and in the South Tyne valley imply that the Sill underlies all of the present area within the Carboniferous strata.

In the Longcleugh #1 borehole, the Great Whin Sill is encountered 237.5 m below the surface within the Jew Limestone cyclothem of the Visean strata and Alston Formation. It is a medium-grained quartz-dolerite with pegmatitic bands containing large crystals of pyroxene. The pegmatite becomes coarser downwards but towards the base the dolerite becomes finer-grained and is associated with granophyric bands. The whole section is approximately 80 m thick but there is strong evidence of faulting within the upper part and consequently this measurement may not represent the true thickness. However, this section does represent the greatest thickness of a single leaf of the Whin Sill thus far proved within northern England (Johnson et al., 1980).

In Longcleugh #2a borehole, the Great Whin Sill was encountered 281 m below the surface, again within the Jew Limestone cyclothem. It is a medium-grained quartz-dolerite with small calcite veins in the upper third. Towards the centre several pegmatite zones are recorded. In the lower third the Sill is well jointed and broken with no mineralisation.

In Longcleugh #8 borehole, the Great Whin Sill was encountered 199 m below the surface, again within strata probably attributable to the Jew Limestone cyclothem. 3 m of fine-grained quartz-dolerite were proved before the bottom of the borehole.

5 Structure

The area covered by this report lies within the bounds of the Carboniferous Alston Block (Figure 2), a regional high underpinned by the North Pennine Batholith and bounded to the north by the Stublick – Ninety-Fathom Fault System and the Northumberland Trough, to the East by the Pennine Fault System and the Vale of Eden Basin, and to the south by the Lunedale – Closehouse – Butterknowe Fault System and the Stainmore Trough.

Late Visean and Namurian sedimentation on the Alston Block represents the post-rift thermal subsidence phase of basin evolution and therefore is generally horizontal to gently dipping with little disruption from major, basin-controlling faults. Post-depositional, late Carboniferous faults, with displacements ranging from less than 1 m to 80 m, cut the area in a generally rectilinear pattern and locally disturb the strata.

5.1 REGIONAL DIP AND FOLDING

Over the extent of the present area, Carboniferous strata are inclined gently towards the north by 2-5°. Consequently, progressively older Visean strata are exposed in the valleys to the south and progressively younger Carboniferous strata are preserved on the hilltops northwards. Dips greater than approximately 5°, or orientated counter to this trend, and open to tight folds are generally localised and can be attributed to normal drag in the hanging-wall (and, less commonly, the footwall) of late Carboniferous faults. However, there are two notable exceptions.

On Wellhope Moor, in the south of NY74NE, dip-trends indicate a low-amplitude, large-wavelength, gentle anticline. This feature has an elongate periclinal form with a long axis trending approximately north-west – south-east and is centred on Whimsy Hill [779 459] where natural exposures of sandstone, and those seen within the top metre of an open shaft [7821 4564], are near horizontal. Consequently, strata of the south-west-facing slopes of the upper Nent valley dip gently towards the south-west, whilst those of the Mohope valley, Dodd Hill [792 458], Carrier’s Hill [788 474] and Quarry Hill [784 485] dip towards the north and north-east. The periclinal nature is best demonstrated by exposures in the south- and west-facing slopes of Newshield Moss [734 483], north of Alston, where the Great Limestone tends to dip gently towards the south-west.

In contrast to the generally south-western dip of the strata of the south-west-facing slopes of the Nent valley, strata of the north- and north-east-facing slopes dip towards the north once more and define a gentle syncline with an axis centred approximately on, and parallel to, the valley itself. This feature is more pronounced southwards towards the limit of the present area, and is a gentle to open fold with a near-vertical axial plane in the region of Nenthead. Some inclination of the limbs of this feature is likely to be attributable to normal drag on the Carr’s and Black Ashgill cross veins that bound the axial portion, particularly as it becomes tighter around Nenthead, although regional dip data suggest that a board gentle fold does exist and controls stratal dips outwith the influence of these faults.

5.2 FAULTING

The whole of the area is cut by an extremely well-documented rectilinear pattern of late Carboniferous faults with displacements in the order of metres to decametres. Much of this fault system is highly mineralised and consequently a wealth of subsurface data exists. Three strong trends were recognised and named by 18th and 19th century mine workers. These names are heavily entrenched in the literature and are used in their historic sense here:

1) A generally north-west to south-east system of comparatively widely spaced and lengthy faults, with displacements usually in the order of decametres, crosses the area. These structures are termed *cross-veins* although in many cases they do not host significant amounts of ore minerals and therefore cannot be classed as ‘veins’ in the normal sense.

2) A generally north-east to south-west system of comparatively closely spaced faults, with displacements in the order of decimetres to metres, are highly mineralised *veins*.

3) A number of intensely mineralised faults with a generally east-west orientation commonly exhibit en-echelon relationships. These faults are termed *quarter-point structures*.

All three fault orientations comprise part of the North Pennine Orefield, a rich, lead, zinc, barium and fluorite province exploited principally in the 18th and 19th centuries (Section 6). The southern half of the present area borders some of the richest parts of this orefield and consequently numerous structures have been recorded and exploited, particularly within the Nent valley. Northwards, into the Mohope valley, veins (in the sense described above) become fewer in number and frequency and generally less rich in ore. This is accompanied by a gradual northwards re-orientation of the cross-vein fault systems. North of Whitfield, cross-veins continue on a northerly trend but no veins (or ore-bearing structures of any orientation) are recorded, with the exception of two or three structures on Agarshill [785 585].

The faults are summarised here and with attention given to features of the brittle structure that have been derived from the present survey. A detailed description of each fault is given by Dunham (1990).

5.2.1 Cross-veins

A number of north-west-trending cross-veins are recognised within the area. These faults generally have throws ranging up to several tens of metres and locally cause significant disruption to the strata and therefore to the outcrop patterns observed at surface.

Subsurface data show that these faults have a generally ‘stepped’ vertical profile with shallower dips in the more ductile measures and steeper to near vertical dips through competent beds of limestone and sandstone. Consequently, the fault zone (Peacock et al., 2000) is wider where the wall rocks comprise competent lithologies. Significant displacement on these structures has entrained large volumes of crushed rock and clay-rich gouge within the fault zones.

Striations on fault-block surfaces and preserved within clay gouges are near-horizontal to slightly dipping and therefore tend to indicate strike-slip to highly oblique-slip deformation. However, if these vectors are to be believed, a considerable component of strike-slip movement, in the order of hundreds of metres to kilometres would be required on each fault to achieve the observed throws along these vectors. Whilst no major structures are recorded within the faulted blocks, the offsets of which would confirm or refute this argument, such a large strike-slip component would seem wholly unreasonable given the length of many of the structures and the observed offset on some veins that pass through them. It is therefore likely that the cross-veins are in general dip-slip to slightly oblique-slip in nature. The striations recorded in the subsurface may represent minor late-stage movements that may post-date mineralisation (Dunham, 1990) rather than the principal deformation phase.

In most cases, cross-veins with the area occur in pairs with antithetic senses of displacement that result in an intervening graben.

5.2.1.1 THE CARR’S AND WELLGILL CROSS-VEINS

The Carr’s and Wellgill cross-veins traverse the south-west-facing slopes of the upper Nent valley from the southern limit of the area. Both faults are en-echelon with major structures in the Nenthead area and therefore the amount of throw increases on both faults towards the north-west. In Nentberry Haggs Horse Level [7662 4502], near the southern limit of the area, 61 m of throw are recorded on the Carr’s Cross-vein with the fault dipping at 55° towards the north-east. By Loveladyshield Level [7591 4614] the throw increases to 77 m. On the Wellgill Cross-vein, 9.8 m of throw are recorded in Brownley Hill Mine, at the southern limit of the area, increasing to 12.8 m in Loveladyshield Level. Together the two faults form a graben and throw down most of the Great and Little limestone cyclothems, juxtaposing the Great Limestone against the Firestone Sandstone at surface across the Carr’s Cross-vein, and strata of the Little Limestone cyclothem against the Firestone Sandstone at surface across the Wellgill Cross-vein.

The Wellgill Cross-vein does not extend more than 4 km from the southern limit of the area and is interpreted to tip out within the measures between the stratigraphical level of the Crag and Lower Felltop limestones, in the vicinity of Hard Rigg [7520 4880].

Within the vicinity of East Cocklake Farm [7580 4675], the Carr's Cross-vein splays into three subparallel structures known, from west to east, as the Blagill Moss Cross-vein, North Grain Cross-vein and the main Carr's Cross-vein. The last continues until at least Clargill where it is believed to terminate coal workings in Clargill Colliery, whist the former two have relatively small throws and do not persist past Blagill.

5.2.1.2 The West Allen Great Cross-vein and the Keenley Fault

A pair of faults with a north-west trend and bounding a small graben cross the West Allen valley from its headwaters on the eastern limit of the current area. In the upper reaches of the West Allen valley, just of the eastern edge of the area, these faults are known as the Coalcleugh East and Coalcleugh West cross-veins. As they enter the present area, the Coalcleugh West Cross-vein splays into a number of smaller structures with distributed displacements that are interpreted to extend no more than 500 m from the eastern edge of the area. They are recognised and well recorded [7980 4670] in Scraithhole Low Level. The Coalcleugh East Cross-vein continues north-eastwards as the West Allen Great Cross-vein through the east-facing slopes of the West Allen valley, across the valley floor at Greenley Cleugh [7854 5100] and into the west-facing slopes. It traverses the west-facing slopes with a strike approximately coincident with that of the strata and a throw of approximately 30 m to the west. As a consequence, the outcrop pattern of the Great Limestone is repeated in the footwall and hanging-wall of the fault. The West Allen Great Cross-vein finally tips out at the village of Ninebanks [7830 5305].

As the West Allen Great Cross-vein tips out, displacement is taken up on the Keenley Fault, 1.5 km to the east. The Keenley Fault extends from the eastern edge of the present area, north-westwards to northwards through the west-facing slopes of Keenley Fell and throws down by up to 10 m to the west, repeating the outcrop of the Lower Felltop Limestone and associated strata in the hillside. It breaks up in the vicinity of Shieldfield Hill [790 570] into a number of small faults with displacements in the syn- and antithetic sense, two of which cross the lower reaches of the West Allen River and terminate the outcrop of the Little Limestone.

The en-echelon relationship of the Keenley Fault to the West Allen Great Cross-vein and their common sense of throw create a north-dipping relay ramp structure between them that is evidenced by increased dip magnitudes and widened outcrop patterns (particularly of the Firestone Sandstone) in the region of Dryburn Cleugh.

5.2.1.3 Other Cross-veins

A number of smaller cross-vein systems are well known from subsurface mining data.

In the vicinity of Keirsleywell Row [7715 5130], extensive mining operations at Longcleugh and Keirsleywell mines have identified the Keirsleywell Row East and West cross-veins. These structures trend north-north-west across the east-facing slopes of the Mohope valley. The West Cross-vein is no more than 1km in length with a throw varying up to 3.4 m, down to the east. It is associated with a further, unnamed structure approximately 100m to the west that throws 10 m down to the west. Thus the two faults set up a small horst and repeat the outcrop of the Firestone Sandstone in the hillside. The East Cross-vein runs for approximately 3 km from the A686 at Crooked Bridge [7670 5225] southwards to intersect with vein systems at Hearty Cleugh Mine. It throws down the strata by up to 9m to the west and, with the East Cross-vein, sets up a small graben, 50-150 m wide, for part of its course.

On Hessleywell Moor, mining operations at Hearty Cleugh Mine [7715 4908] confirm the presence of the Heart Cleugh Cross-vein. At its northern end this fault splays into three branches known, from west to east, as the West, Main and East cross-veins. Little is known about the displacement on these faults.

In the upper reaches of the Nent valley, the Black Ashgill Cross-vein and its westerly splay the Jacob Teasdale Cross-vein, extend from the southern limit of the present area, north-westwards for approximately 1 km before merging into one structure, continuing north-westwards to finally tip out in the vicinity of the Nent River. Both faults are major structures in the Nenthead region (Clarke, 2007) but displacement on both decreases north-westwards such that within the present area the Black Ashgill Cross-vein throws down by 3 to 5 m to the south-west, and the Jacob Teasdale Cross-vein throws down by a similar amount but to the north-east.

On the south-west-facing slopes of Smallburns Moor [780 455] a number of comparatively short faults have been recognised in the workings of Brownley Hill Mine. Whilst these faults have the same trend as the cross-veins they cannot be considered true cross-veins as all have comparatively low displacements. Of particular note are the Brownley Hill High, West and Moss cross-veins, and the Nentsberry Cross-vein; a north-easterly splay of the Wellgill Cross-vein that connects with it some 300 m south of the southern limit of the present area.

On Barhaugh Common [712 521] two faults are interpreted on a trend similar to that of the cross-vein systems and with comparable throw. Each structure is no more than 2 km long and each throws down to the north-east by up to 10 m.

5.2.2 Veins

North-east-trending structures with generally low magnitudes of throw are prevalent throughout the area. Subsurface data indicate that these faults have a similar stepped vertical profile and variation in fault-zone width to those of the cross-veins, but their low magnitude of throw has resulted in little entrainment of fault-zone material. Many of these faults are terminated or displaced by the major cross-vein systems, and related vein structures on either side major cross-veins often have different names as a result of being exploited by different centres of mining. Consequently, the cross-veins tend to naturally divide the veins into informal ‘provinces’.

In the Nent valley and on Middle and Park fells, south-west of the Carr’s – Wellgill Cross-vein system, a large number of small veins with throws no greater than 2 m, and generally less than 1 m, cluster in four areas. In the Haggs Bank area [767 452] a number of subparallel veins no more than 500 m in length and spaced by approximately 150 m, cut the outcrop of the Great Limestone and older strata. In the Blagill area [740 475] one major vein, Fista’s Rake has a north-east trend. On the east-facing slopes of Park Fell [704 460] the Park Veins throw down to the north-west by up to 10 m, and on the south-west-facing slopes of Middle Fell several small veins cut the outcrop of strata from the Four Fathom Limestone to Little Limestone.

In the Mohope valley, between the Carr’s – Wellgill and West Allen Great – Keenley systems, three clusters of veins can be recognised. At the southern margin of the area a number of closely spaced faults with low displacements are the Brownley Hill veins of Brownley Hill Mine. Two are of note, the Brownley Hill and Brownley Hill North veins, which merge northwards to form the Wellhopehead Vein that throws down by approximately 30 cm to the south-east. This structure is comparatively long and extends across Wellhope Moor to become the Scraithhole Vein of Scraithhole Mine, just off the eastern edge of the present area in the upper reaches of the West Allen valley.

Further north, the Hearty Cleugh Vein traverses the Mohope valley. In the west-facing slopes, its course is marked by surface workings (Hesleywell Hush) but in the east facing slopes there is little surface evidence for the vein. Displacement on it is low but the sense is unknown. Two hundred metres north on the west-facing slopes is a subparallel and associated fault at least 400 m long and throwing down to the north by up to 10 m.

In the vicinity of Keirsleywell Row and Longcleugh mines, seven veins are recognised, four of which make a significant impact on the landscape. The Longcleugh Middle and South veins have anomalously high displacements up to 13.5 m and 12.5 m respectively. Consequently, they severely disrupt the outcrop pattern of the Great Limestone in the flat valley bottom. Both faults are known to traverse the valley and connect with the West Allen Great Cross-vein 200 m south-west of Blackpool Bridge, where displacement on the South Vein has reduced to 4.9 m.

The course of the Keirsleywell Row North and Sun veins is marked clearly in the east-facing slopes of the Mohope valley by two strong trenches. These two faults have similar magnitudes of throw (2.7 m) but opposing senses and therefore form a small graben. It is likely that the North Vein traverses the valley floor to become the Stag Rake Vein of the west-facing slopes but this has never been proved in the subsurface and its surface course is obscured by superficial deposits.

To the east of the West Allen Great Cross-vein, one major cluster of veins can be identified. Between Blackpool Bridge and Greenley Cleugh a large number of subparallel veins are given off from the north-east side of the West Allen Cross-vein. Some have displacements of up to 10 m and severely disrupt the outcrop pattern of the Great Limestone and surrounding strata. Most are interpreted on the basis of strong featuring to die out towards the north-east, but one, the Sparty Well Fault, is known to connect with the Keenley Fault. The previous survey interpreted this relationship as one where by the Sparty Well Fault cut and displaced the Keenley Fault. This relationship, whilst possible, seems unlikely since the West Allen Great Cross-vein and the Keenely Fault form an en-echelon system with a connecting relay-ramp structure, evidenced by the increased dips of outcrop. The present survey shows the Sparty Well Fault connecting with a continuous Keenley Fault and thus forming a breaching fault to the relay ramp; a more plausible interpretation of the available evidence.

5.2.3 Quarter-point structures

Within the present area a number of quarter-point structures with generally en-echelon relationships are evident. Subsurface data show that the vertical profile of these structures is similar to those of the cross-veins and veins, but the fault zone is significantly wider at points coincident with variations in strike and where en-echelon structures coalesce, implying some component of trans-tensional deformation on faults within this system.

Three main veins are recognised in the present area at Blagill [741 475] and named (from west to east): the Lough, Thorngill and Slotte veins. The Lough and Thorngill veins throw down by up to 9 m at Blagill but the Slotte Vein has little appreciable throw. All three faults have a down to the north sense of displacement. At its western end, the Slotte Vein has an associated subparallel structure known as the Coatley Hill Vein and a north-west splay known as Copperbole Head Vein. Whilst the Thorngill and Lough veins can be considered to interconnect, there is no such direct connection with the Slotte Vein and consequently the western end of the Thorngill Vein splays a number of west-north-west-trending faults from its south side, of which the Shieldwell Vein is one. To the east of Blagill, the Lough Vein, and therefore the en-echelon quarter-point system, is terminated by the Carr’s Cross-vein.

5.2.4 Other surface faults

A number of other faults and related fault systems are interpreted within the present area that can not be readily classified as cross-veins, veins or quarter-point structures.

In the South Tyne valley, a major fault is interpreted to trend northwards from the town of Alston, across the west-facing slopes of the South Tyne valley, traversing the Alye Burn and into the south-facing slopes of Alye Common. Displacement increases northwards reaching a maximum throw of approximately 15 m to the west at outcrop near Newshield [7183 4815]. Here it juxtaposes the Four Fathom Limestone in the footwall against the Great Limestone in the hanging-wall and repeats the outcrop of both limestones and intervening strata in the hillside. From this point, throw decreases northwards to approximately 10 m at Ayle Burn where the fault splays into two branches with the main westerly branch finally dying out within the pebbly sandstones on the top of Ayle Common. This fault is currently unnamed.

On Keenley Fell a number of faults with an east-north-east trend extend from the eastern side of the Keenley Fault. Whilst these structures have a trend close to that of the veins, they have displacements in the order of 5 to 10 m, are not mineralised, and appear to have nothing else in common with the veins to the south. The strong sandstone units that form distinctive benches on the top of Keenley Fell are faulted up and down by these faults.

On Fellhouse Fell [755 595] in the north-west of NY75NE, a fault trending north-east is interpreted to cross the corner of the area and displace the strata by approximately 5 m. Three, perhaps four, faults splay from the south-eastern side of this structure and trend approximately northwards. At least two of these faults are intensely mineralised and have been worked extensively from the surface in the Agarshill Fell area [755 585]. There are no known records of these workings or the displacement vectors on the faults and those shown on the map are interpreted entirely from surface outcrop.

In the north-eastern corner of the present area, a small fault is exposed in the river bed of the Allen as it enters the Allen gorge. This fault, orientated east - west and with displacement probably in the order of 10 m, throws down to the north and displaces the Little Limestone from the riverbed. The fault is mineralised with stringers of galena and exhibits excellent hanging-wall normal drag in the riverbank.

5.2.5 Subsurface structures

On the geological standard maps that accompany this report, the subsurface positions of faults are shown where they are known. Most faults that are known in the subsurface have an expression at surface and can be positioned with a reasonable degree of accuracy.

On NY74NE a rectilinear pattern of east-north-east and west-north-west trending faults with displacements of 5 m or less is depicted in the subsurface [780 646] for which no surface equivalents have been interpreted. These structures are shown in strata of the Four Fathom cyclothem, some distance below the surface. There are many recorded examples within the North Pennines of small faults in Visean strata that do not penetrate far into the post-Visean strata but die out vertically into the increased thickness of measures (Dunham, 1990). It is unlikely that these structures would penetrate to the surface and any attempt to depict them at surface would be misleading, especially given the extensive superficial deposits on Wellhope Moor. However, these structures have been of great economic importance as they carried some of the richest oreshoots locally. For this reason they have been depicted in the subsurface on the current map.

6 Mineralisation

The area covered by this report (Figure 1) lies within one of the richest parts of the North Pennine Orefield. The minerals galena, sphalerite, chalcopyrite, pyrite, fluorite, barite, witherite, barytocalcite, quartz, calcite and ankerite are common throughout the area but in greater concentrations towards the south. The principal economic metaliferous minerals are galena, sphalerite and iron sulphide minerals, found in association with gangue minerals of fluorite, baryte (and other barium minerals), quartz and calcite. Dunham (1990) gave a detailed account of the mineral contents of each vein.

The distribution of these minerals throughout the North Pennine Orefield is not random but ranges from concentrations in which fluorite is the dominant mineral, through deposits with workable quantities of lead, zinc and iron ores to deposits in which barium minerals dominate. Smythe (1922) first recognised a zonation to the North Pennine deposits in which fluorite is the dominant mineral in a central zone. The fluorite zone is surrounded by a narrow belt in which there are a few deposits carrying both fluorite and baryte but in which most of the deposits contain neither of these minerals. An outer barium-rich zone surrounds this in which fluorite minerals are rare and baryte, barytocalcite and witherite dominate. Specific areas rich in zinc ores in addition to lead ore can also be recognised. The zonation of mineral deposits within the North Pennine Orefield is of particular relevance to the present area as the outer limit of the fluorite rich zone and the inner limit of the barium-rich zone pass through the south of the area between Alston and Nenthead (Figure 4). Much of the south-eastern corner of the area is also within a zinc-rich zone.

The mineral deposits of the present area may be classified into two types:

Vein mineralisation formed as zoned layers of different minerals roughly parallel to the walls of faults that have resulted from mineral rich fluids circulating with the fault zone. The spatial variation in the concentration of mineral deposits within a fault bears a close relationship to the loci of strain (and therefore the fault geometry) and is related to the regions of faults that exhibit the greatest dilation. In veins (in the sense of the word used in Section 5) these areas are where the fault surface has the greatest dip; i.e. within those areas bounded by competent wall rocks of limestone and sandstone. Under extensional stresses, these areas dilate whilst areas of low dip, bounded by incompetent measures, tend to remain tight. The low magnitudes of throw on most veins do not entrain the incompetent material into the fault zone and those areas of the fault bounded by competent lithologies tend to focus mineralising fluids. Furthermore, the contrasting competencies of lithologies of the Alston Formation favour this scenario much more than those of the Stainmore Formation where sandstone units are less competent, limestone units are less pure and thinner, and the intervening measures sequences are thicker. Consequently, the greatest concentrations of minerals within veins are to be found coincident with wall rocks of thick limestone and sandstone of the Alston Formation, notably the Great Limestone. Within the present area, few concentrations are found above this level and none above that of the Firestone Sandstone.

Cross-veins exhibit a similar relationship of dip to wall-rock competency (Section 5) but within the present area they are rarely mineralised. Significant displacement on these structures has entrained much crushed rock and clay gouge into the fault zones that greatly reduce the permeability of the fault to mineralising fluids, even in those areas bounded by competent wall rocks.

Quarter-point structures do show a similar relationship between concentrations of mineralisation and wall-rock competency, but also display a stronger relationship to strike variations, with greater concentrations at loci of strain such as fault bends and splay points (Section 5)

Flat mineralisation represents metasomatic replacement deposits within the limestone wall rocks of faults. Nine limestones of the Carboniferous succession of the North Pennines are known to carry flat deposits, with the Great Limestone exhibiting the most extensive flats. The reasons behind flat formation are not fully understood but a number of geological factors appear to control their formation. Firstly, they appear to form only where the associated fault is accompanied by numerous small fissures in the wall rocks, secondly, there is some evidence that flats form within limestones when the upwards movement of fluids within the fault is inhibited by geological factors, and thirdly, some flats are shown to occupy topographical highs in limestone units.

Within the present area there are few surface exposures that show vein or flat minerals in situ. Examples of galena in small fissures in the Little Limestone in the footwall of a major fault can be seen in the river bed of the Allen River at Allen gorge [7990 5943]. Further examples can be seen at Blagill where the Lough and Thorngill veins have been worked in large open cuts and expose limonite, sphalerite and some galena in vein deposits around the stratigraphical level of the Great Limestone up to the Firestone Sandstone.

Despite the lack of surface exposures of mineralisation in situ, there is a wealth of secondary evidence for the presence of mineralisation across the whole of the area.

In the south-east of the area, on Wellhope Moor, the transition from the inner fluorite zone of the North Pennine Orefield to the outer barium-rich zone is evidenced by the contents of waste dumps on mineralised veins. Whilst the limits of each zone cannot be considered as abrupt demarcation lines across the hillside, there is a clear difference between the contents of dumps associated with the Coalcleugh and Nenthead vein systems and those of Wellhopehead [783 463]. Dumps on the veins of the Nenthead district, including the Coalcleugh and Gudham Gill veins that traverse the extreme south-east corner, exhibit abundant fluorite. The dumps at Barneycraig Mine, in the upper reaches of the West Allen River just off the eastern edge of the present area, also exhibit abundant fluorite. Most of these dumps are believed to have originated from the Coalcleugh Veins. By contrast, dumps on the Wellhophead Vein, particularly those around the open shaft at [7820 4564] and at Wellhophead Mine High Level [7795 4795] show abundant concentrations of baryte, barytocalite and witherite, the latter being a carbonate of barium that is common within the area but rare worldwide.

The veins of Brownley Hill Mine [780 452] are the type locality for the rare dimorph of barium calcium carbonate known as alstonite. Excellent specimens have been recovered from the subsurface but no recorded examples have been found on the surface.

Fista's Rake Vein and its associated spoil heaps at Blagill Mine [740 475] exhibit excellent specimens of barytocalcite and significant deposits of this mineral remain in situ within the vein. The area occupied by the spoil heaps [7420 4757] has been designated an SSSI for this mineral.

Spoil heaps adjoining the adit entrances to Wellhope Mine [779 479] and Hearty Cleugh Mine [772 492] contain good specimens of galena with abundant quartz. Those of Wellhope mine also contain abundant iron sulphide minerals.

No major spoil heaps are associated with Longcleugh Mine or workings on the viens of the west-facing slopes of the West Allen valley. A major elongate spoil heap [7760 5147] marks the entrance to Keirsleywell Mine but this is well consolidated and overgrown; small exposures along side the Mohope Burn show nothing but friable siltstone derived from workings in measures below the Great Limestone.

7 Superficial deposits

Over the extent of the area covered by this report, a four-fold division of the glacial and post-glacial superficial deposits was adopted during field survey.

7.1 GLACIAL TILL

Late Devensian glacial till blankets much of the bedrock of the area and is up to 15m thick in places. The till cover is not continuous nor randomly deposited but follows a well-recognised pattern. In general, the north- to north-east-facing slopes of major valleys, such as the Nent, West Allen and South Tyne, are blanketed in thick deposits of till whilst the south- to south-west-facing slopes are devoid of it or contain small thin patches in localised hollows. Smaller valleys follow a similar pattern. Valleys that trend generally northwards, such as the upper reaches of the Mohope valley, have till cover on the lower slopes of both valley sides but deposits on the west-facing slopes are generally thinner than those on the east-facing slopes and the expression of the bedrock tends to be reflected (albeit in a subdued manner) in the overlying till. This characteristic pattern of till cover results in asymmetrical valley profiles with steeper, stepped slopes on the south- to south-west-facing sides and shallower angle, smooth slopes on the north- to north-east-facing slopes. This regular arrangement of till deposits is believed to result from the passage of ice from a generally south-westerly direction across the North Pennines towards the north-east and implies at least some pre-existing expression of the present day topography prior to the last glaciation.

Within the present area, the till is generally dark blue/grey, silty, sandy clay, occasionally with orange oxidisation speckles, possibly resulting from the weathering of sandstone gravel within it. It has a pale-grey to yellow upper weathering profile, and is stiff to very stiff with subrounded to angular clasts of limestone and sandstone, presumably of local origin, and with a few lenses of sand and gravel, and some clay-rich layers. By contrast, in the extreme north, and particularly the northern part of NY75NW, off the northern edge of the present area, the till is red-brown in colour. Further north, more exotic clasts have been identified in this till with origins in the Southern Uplands and the Lake District. It is unclear at this level of field investigation without knowledge of tills further a field if the till can be subdivided based on these characteristics.

Most of till deposits are extremely smooth with little geomorphology. However, in the South Tyne valley [708 478], north of Alston, a number of strong mounds are present. Augering of these forms reveals a stiff, silty, sandy clay with the same properties as the surrounding till. These mounds can be attributed to drumlinised till with drumlin long axes orientated approximately parallel to the South Tyne River.

Although erratic boulders from the Lake District were identified during the primary survey of the Brampton Sheet to the west of the present area, no evidence of such was seen during this survey. Similarly, notes of such erratics are recorded on the west-facing slopes of Asholme Common, to the north of the present area. Although none has been recorded in the present survey, although their presence in exposures of till close by should be considered within a model of the late Devensian glaciation for the present area.

7.2 GLACIOFLUVIAL DEPOSITS

Deposits of sand and gravel of glaciofluvial origin are rare within the present area but they are known to increase in abundance and size northwards towards the Tyne valley. A number of small mounds of sand, gravel, cobbles and boulders are recorded within the West Allen valley, particularly on east-facing slopes, that are attributed to a glaciofluvial origin. All of these deposits show a long-axis orientated very approximately south-west to north-east. They rarely cover more that 300 m^2 with two notable exceptions.

Whitfield Hall [7780 5640] and the surrounding grounds stand upon a low mound of sand and gravel that covers approximately 1400 m^2. The surface of the mound is somewhat dissected by small and short-lived channels, presumably of glacial outwash origin, that generate many small undulatory features within the local landscape. Much of the mound now supports extensive grassland and woods but evidence of sand and gravel can be seen within the roots and rabbit holes under lone trees, particularly within the south grounds of the hall.

Larger and more extensive deposits of glaciofluvial sand and gravel can be found in the fields to the west of Old Town Farm [7880 5870]. These deposits have been worked on a subsistence scale and old quarries within them expose largely sand and gravel with rounded cobbles and boulders of sandstone and limestone.

7.3 ALLUVIUM AND ALLUVIAL TERRACES

All of the major valleys and most of the minor ones show modern day alluvial deposits. Much of this is of cobble or boulder grade and reflects the extensive high-energy nature of these rivers during times of high volume spring run off. Sand and silt-grade alluvial deposits are also common in areas of lower energy, particularly the inside of meander beds in the lower reaches of major valleys.

Holocene river terraces are present in the Nent, South Tyne, Mohope and West Allen valleys. Minor river terraces are also present between meander beds of most small tributary streams to these rivers. In general, terraces show normal grading from cobbles and boulders, overlain by sand and silt, and represent flood plain deposits. In most valleys a number of different terraces of progressively higher level and older age can be identified with distance from the river. These have been mapped individually on fieldslips and correlated within the confines of a single valley. However, without extensive study, terrace heights cannot be correlated between river valleys and, consequently, alluvial terrace deposits are shown on the standard maps as undifferentiated deposits but with the back-scarp features of individual separate terraces depicted.

7.4 PEAT

Extensive areas of Holocene peat are present on many of the moorland hilltops, in topographical lows, and on some bench features formed by differential weathering of bedrock. General areas of peat on hilltops were mapped during the primary survey but these broad indications were somewhat subjective, generalised and discontinuous. They were not recorded on published maps derived from that survey. During the present survey, areas of peat greater than 1m in thickness were delimited and mapped using extensive augering. Areas of thinner peat cover were also indicated on fieldslips.

Extensive areas of peat are present on Wellhope Moor [780 460], Hesleywell Moor [765 475], Newshield Moss [735 485], Ouston Fell [755 500] and the south-east-facing slopes of Whitfield Moor [755 525], and, with patchy cover, on the outcrops of the pebbly sandstone unit on Pike Rigg [725 540] and Tarn Rigg [725 515] on the summit of Whitfield Moor. In some places, these deposits reach several metres thick and are heavily ‘hagged’ due to wasting. Excellent examples can be found on the summit of The Dodd [751 459], where peat hags reach over two metres in depth.

7.5 EROSIONAL FEATURES AND MELTWATER CHANNELS

The general profile to most valleys (Section 7.1) can be attributed in part to the deposition of glacial till on one side and differential bedrock erosion, possibly accentuated by glacial scouring, on the other. In addition to this general valley form, a number of areas can be identified in which glacial meltwaters have eroded and deposited characteristic geomorphologies.

7.5.1 Drumlinoid forms

The narrow valley of the South Tyne just to the north and south of Alston shows several areas occupied by drumlinoid forms. The south-western drumlinoid area [708 460] constitutes a series of closely related mounds. These small oval mounds vary slightly from the large smooth drumlins noted slightly further north. Attempted augering of these drumlins revealed a sandy, gritty top under very thin topsoil. It was very difficult to get more than 20 cm into the deposit. From the stiffness of the material, the lack of any clay material and the geometry of these mounds it is inferred that they are erosional rather than depositional forms. These forms are likely to mark erosion through the top of surface of a fairly thick sandstone unit associated with the Alternating Beds of the Tynebottom Limestone cyclothem. Therefore, the separations between the mounds mark meltwater drainage courses. Thin peat, up to a maximum of 45 cm thick, has developed in the low ground between these mounds.

On the opposite side of the valley [717 457], very large elongate mounds are orientated parallel to the valley. These are covered with numerous angular sandstone boulders and are interpreted as lateral moraines. The meltwater channels cut on the upslope side of these mounds are suggested to be classic examples of a peripheral ice form as they are orientated extremely obliquely to the current valley slope and therefore are probably formed by meltwater cutting along the edge of the glacier.

7.5.2 Meltwater Channels

A number of flat-bottomed channels, 10 to 15 m deep, generally no more than 100 m wide, and with steep sides are present across the area. Many have small, modern streams in parts of them but clearly cannot be attributed to modern erosion by the streams they contain. Some also traverse the modern-day watershed. These features are interpreted as glacial meltwater channels eroded into superficial deposits and, in many cases, through bedrock.

An excellent example can be seen of the A686 on the county boundary north of Alston [742 510]. Here, the upper reaches of the Whitewalls Burn flow in a wide, flat-bottomed channel that traverses the watershed. The channel has been sculpted by glacial meltwater into bedrock around the stratigraphical level of the Lower Felltop Limestone.

8 Mass-movement and Artificial deposits

8.1 LANDSLIDE

Most of the minor valleys within the area are quite deeply incised with the result that small landslides are common. In most cases, these slips represent movement of the superficial deposits and overburden as the result of prolific spring lines developed at the bases of particularly permeable underlying bedrock strata, most notably many of the limestones and the Firestone Sandstone. Four major landslides require additional comment.

In the Nent valley, landslides and landslide deposits up to 300 m^2 are present along much of the length of north-facing slopes of the upper reaches. These slides are developed at the boundary between the glacial till that blankets the north-facing slopes and the flood plain alluvium deposits. They represent movement of the till as a consequence of over-steepening of the valley sides by river erosion, combined with ground water outflow from permeable limestone and sandstone units of the Four Fathom and Great Limestone cyclothems. Excellent examples that are still active can be found at Nenthall [7570 4574].

On the upper west-facing slopes of the West Allen valley [795 511], a major area approximately 500 m^2 of thin superficial deposits and overburden has slipped over the bedrock exposing sandstone and coal in the back-scarp. A strong spring line is conspicuous at the base of the sandstone in the back-scarp and the slip deposit is heavily waterlogged. It is likely that this slip is the result of the spring line but workings on the coal cannot be ruled out as a contributing factor. The coal is well-developed and heavily worked to the north of this site and, although poorly developed and uneconomic here, preliminary excavations on it may have contributed to the slip.

On the east-facing slopes of the Mohope valley, 500 m south of Keirsleywell Row [770 506], a large area of ground contains a number of strong but short-lived features. A strong sandstone unit caps a 10 m cliff behind this ground and contains several quarries. When viewed from the opposing valley side it is clear that the area of short-lived features is a significant landslide deposit that may involve some of the bedrock as well as the abundant superficial deposits. The slip is quite old and probably largely stable; an old farm building built on the deposit and in the shelter of the back-scarp attests to this. The cause of this slip is equivocal. A number of major faults, including the Keirsleywell Row East and West cross-veins, traverse the area and may have contributed to its instability. The workings within the back-scarp may be later as the slip is effectively below the workings and it is difficult to see how these could have contributed to it.

On the north-facing slopes of Whitewalls Burn [764 516] one of the largest and most impressive landslide deposits in the local area can be seen. Best observed for the A686 in evening light, this landslide, with its deposit covering some 2700 m^2, involves mass-movement of both superficial deposits, mostly glacial till, and the underlying bedrock. A large 10 m back-scarp is present that exposes a number of springs and the Firestone Sandstone. The origins of this slip are not clear, it is likely that major ground-water outflow from the base of the highly permeable Firestone Sandstone has contributed, but over-steepening of the valley side by the deeply incised Whitewalls Burn may has contributed. More than one stage of slippage appears likely, given the tight bend in the back-scarp, and the present deposit may represent a number of smaller slips that have coalesced. Further recent slippage of superficial deposits has occurred in the immediate riverbank, probably the result of over-steepening of the valley side by the river and the presence of a spring line at the base of the Little Limestone.

8.2 ARTIFICIAL GROUND

A long legacy of mining and quarrying within the area has resulted in significant areas of both worked and made ground.

8.2.1 Worked ground

Mapped areas of worked ground can be attributed to quarrying activities in outcrops of limestone and sandstone, small-scale surface workings of coal, or surface workings on mineralised faults.

Within the area, previous commercial extraction has been largely confined to the Great and Four Fathom limestones. A number of disused large- and medium-sized quarries exist, most notably, Newshield [719 481] and Coatleyhill [720 478] quarries in the Great Limestone outcrop of the west-facing slopes of Newshield Moss, Coppice Wood Quarry [717 478] in the Four Fathom Limestone outcrop of the same area, medium-scale workings in the Great Limestone at Bayle Hill [729 457] on the west-facing slopes of Middle Fell, and Ninebanks Quarry [782 531] in the Great Limestone outcrop at Ninebanks. No major commercial workings in sandstone are known within the area.

Small-scale workings are present in many of the limestones. Many contain limekilns as the principle function of these quarries was to provide limestone for the production of lime, for use as a flux for iron smelting, and for fertiliser. Excellent examples can be found Kudd’s House on Keenleyside Fell [7890 5520], and Ouston [7755 5285], where the limekilns have been restored magnificently. A large number of small sandstone quarries exist in the Firestone Sandstone and younger sandstone strata that provided stone for the maintenance of local farm buildings and for wall-building.

Coal workings, most notably on the Little Limestone Coal but also on coals higher up in the succession, generally result in mappable areas of made ground (spoil and waste) rather than areas of worked ground. However, some worked areas are present, notably at Hearty Cleugh Mines [770 490], Hessleywell Farm [776 498] and on Middle Fell [731 455]

The surface working of minerals from mineralised faults was common practice in the early stages of exploitation. These working have resulted in deep, and often wide, groves cut along the length of the fault, many of which are of a scale that is mappable. Notable examples include, Nentsberry Haggs Vein [7680 4515], Fista’s Rake, Thorngill and Lough Vein at Blagill [740 474], Park Veins on Park Fell [7725 4585], Hesleywell Hush [7775 4935] on the Hearty Cleugh Vein in the Mohope valley, Kiersleywell Row veins [7730 5150], Bates Hill Vein [7865 5163] on the west-facing slopes of the West Allen valley, and veins on Agarshill Fell [755 586].

8.2.2 Made ground

With the exception of the built environment, made ground deposits within the area relate to mineral waste heaps from mining activities or coal spoil. Most of these are small and associated with the major areas of mining, with worked veins, or along the length of major coals, mainly the Little Limestone Coal. The only other area of made ground of significance is the extensive grounds of Whitfield Hall [778 564], which represent built and landscaped deposits on the top of a low mound of glaciofluvial sand and gravel.

9 Economic Geology

9.1 MINERALS

Substantial tonnages of lead ore, fluorite and barium ore were raised from the veins of the present area during the 18th and 19th centuries. There is little prospect for renewed economic extraction of lead ore and fluorite as remaining deposits are low grade and expensive to extract compared with other reserves worldwide. However, there has been recent renewed interest in the zinc potential of the Nenthead district, just off the southeastern corner of the present area, as potential economic deposits may exist as vein and flat mineralisation within limestones of the Visean strata below the Five Yard Limestone. These prospects were not tested or exploited by previous mining activities. The north-westernmost corner of the prospective area extends onto the present survey incorporating the Coalcleugh veins (Scaleburn of Nenthead) and parts of Brownley Hill Mine.

Significant deposits of the barium ore barytocalcite remain within the Fista’s Rake vein of Blagill Mine at the level of the Four Fathom Limestone, and further deposits may exist at depth. These deposits could represent future economic prospects if any market should be found for an ore containing as little as 50 % barium oxide.

9.2 COAL

All former coal working within the present area was small scale and largely undertaken for subsistence purposes, with two notable exceptions. Clargill and Ayle Collieries [729 498], between the Alye and Clargill burns have worked the Little Limestone Coal commercially for many years. Alye Colliery is now abandoned but Clargill Colliery remains active. This operation is small scale and remains economic largely because it is a family run business and the coal extracted is of particularly high rank. However, the workings are quickly approaching the Carr’s Cross-vein (Section 5) in the footwall and depth of deposits in the hanging-wall is likely to render any extraction uneconomic and seal the fate of this enterprise.

9.3 LIMESTONE AND SANDSTONE

Limestone is used extensively in the aggregate and cement industries but the limestone outcrops of the present area do not offer much economic potential for these industries. Outcrops are not that large and do not offer great potential for mechanised extraction, especially as significant deposits of larger size exist locally within the North Pennines. The prolific faulting and vein and flat mineralization within the limestone of the present area probably renders them too impure to be of value in cement production.

The former extraction of limestone was principally for use as a fertiliser or for mortar. There is little call for limestone-based versions of these products today, although the sites of old quarries may offer commercial opportunities for the production of traditional lime mortar to support the growing restoration industry.

Most of the exposed sandstones in the area do not offer the properties sought after by modern building industries; many are too thinly bedded to provide decent building stone. However, many of the former quarries that exist in outcrops of sandstone provided building stone locally for farm buildings, small settlements, walls, stone floors and roofing flags. As these building are restored and developed, there is an increasing demand for local stone to match existing building work and to offer visual characteristics in keeping with the surrounding man-made structures. If the source of stone used in existing buildings can be identified to have come from a particular quarry or strata, there is economic potential in many of these former quarries. Indeed, the Alston Stone Company currently exploits reserves on Flinty Fell, near Nenthead and just south of the present area, to provide matched building stone for renovations and additions in the local area, and for stone flagging on floors and roofs. Stone from this quarry has been used recently in additions to Ninebanks Youth Hostel [7715 5133], to match the original stone of the Kiersleywell Mine shop that now constitutes part of the youth hostel.

9.4 SAND AND GRAVEL

The small deposits of glaciofluvial sand and gravel on NY75NE have not been worked commercially and there is little prospect for future exploitation. The deposits are, in general, small and insignificant. They have been worked in one or two places on a subsidence scale to provide aggregate for local farms and for the construction of tracks onto high moorland. Only two deposits of size exist and these fall within the lands of Whitfield Estate, one forming the landscaped grounds of the hall.

9.5 PEAT

There is no evidence within the present area of peat extraction either for use as a fuel or as a soil improver. Commercial interest is unlikely given that much of the peat moorland lies within the boundaries of major estates, where it provides important breading habitat for game birds, and all lies within the North Pennies AONB and is of high conservation value.

10 Environmental Issues

10.1 LANDSLIDING

Although there is evidence of landslides all over the present area, most is small scale and involves only the superficial deposits. It is unlikely that landslide poses a significant environmental threat. However, the presence of landslides, both ancient and modern, along the incised valleys of many rivers do demonstrate the potential for these areas to slip and deposit significant amounts of material into the river, which could lead to localised flooding.

10.2 COAL MINING

All of the coal mining within the district was small scale. Most was extracted from thin seams below strong limestone units and the potential for surface subsidence as a result is limited. A number of crown holes above coal adits have been recorded across the area and these indicate a potential small and localised hazard where coal was extracted in this way. Most of these crown holes form close to the adit mouth in areas where superficial deposits are significantly thick and where the adit roof is unstable or has been supported by man-made structures that have decayed.

10.3 MINERAL MINING

The outcrop of many of the mineral veins and the sites of former mines are covered in abandoned shafts, many of which have collapsed or are poorly backfilled and some of which are still open. These sites represent a potential hazard to landowners and the public alike, and the potential could only have increased following the Countryside and Rights of Way Act 2000. There is no official record of the position of shafts across the area. Where recognised during fieldwork, shafts have been recorded on the fieldslips of the current survey but this should not be regarded as a definitive inventory.

Within the present area, collapse of mine workings themselves is rare. A number of old surface workings pose a potential hazard as they may contain loose and unstable material in the bottom that is obscuring holes and shafts. A number of adits have associated crown holes that represent surface subsidence over the adit. Most crown holes are within a few hundred metres of the adit entrance and are prevalent where significant superficial cover exists and the adit entrance is supported by manmade structures that have decayed.

Discharged waters from mine adits, rich in metaliferous minerals, present a potential environmental hazard. This is particularly true of the major horse and drainage levels of the main sites of mining such as the Nentsberry Haggs Horse Level on the southern edge of the area [7662 4502] and horse levels at Blagill.

10.4 METALIFEROUS CONTAMINATION

Although many of the spoil heaps within the area are small, localised and contain such small amounts of ore material that they do not pose a great environmental issue, several major areas are of note.

The large former mining centre of Nenthead lies just of the south-eastern corner of the present area. This area contains many large spoil heaps that regularly contribute waste to the river Nent and that is carried onto the area. Remedial works over the past decade at Nenthead have largely stabilised this area and fortified the river channel, but there is still potential for significant metal contamination of the river waters in the lower reaches of the Nent.

Spoil and waste heaps associated with the Brownley Hill Mine veins and the Wellhopehead Vein on Smallburns and Wellhope moors contain a significant proportion of barium based, finely powdered minerals from localised crushing activities. The potential for these deposits to contaminate the surrounding soil is demonstrated by a new coniferous plantation that straddles the Wellhopehead Vein and associated veins on the south-west-facing slopes of Wellhope Moor [778 453]. Here, the conifers are significantly stunted in the vicinity of the vein.

At Blagill, significant quantities of barium minerals still exist in many of the waste dumps and on ground surrounding the burn and River Nent. These have the potential to pollute the Nent and to prove injurious to livestock, particularly poultry and small birds.

10.5 CONSERVATION

The whole of the area lies within the North Pennines AONB and International Geopark. Conservation, management and interpretation of the geological features within the Geopark are addressed within a comprehensive Geodiveristy Audit and Action Plan (North Pennines AONB Partnership, 2004) and the area offers great potential for geologically related historical conservation and geo-tourism.

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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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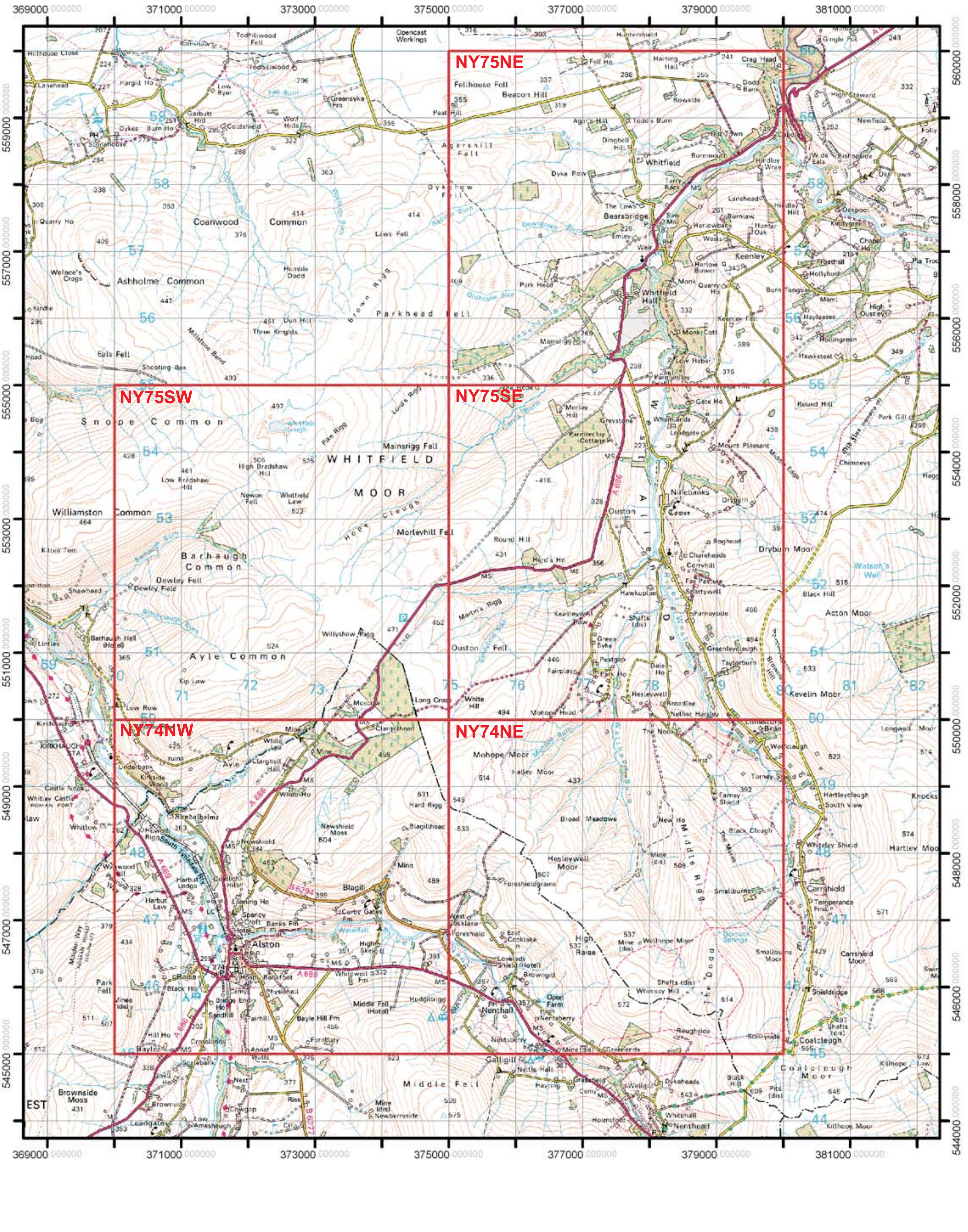


Figure 1. The geography of the area and the 1:10 000-scale sheets covered by this report

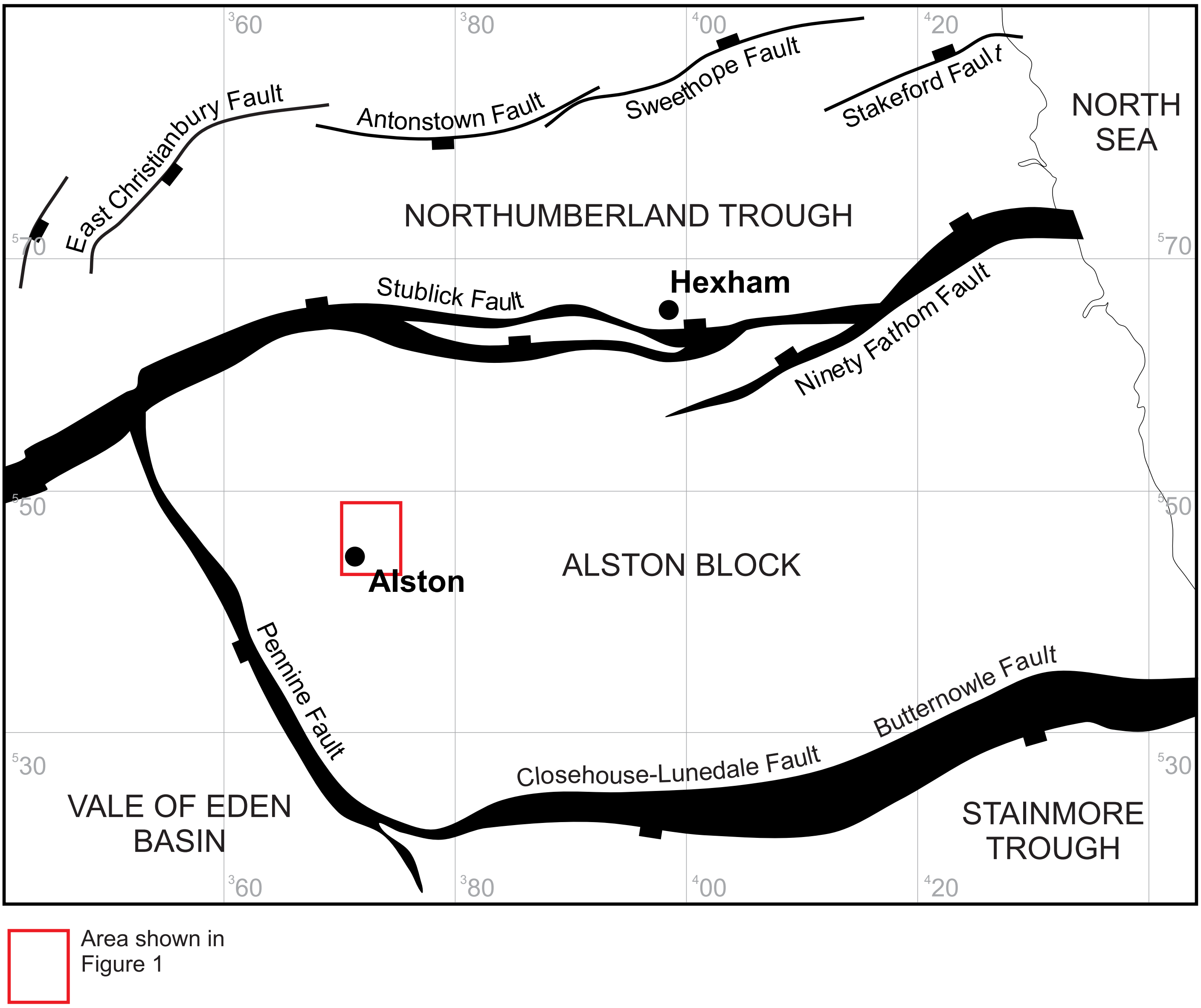
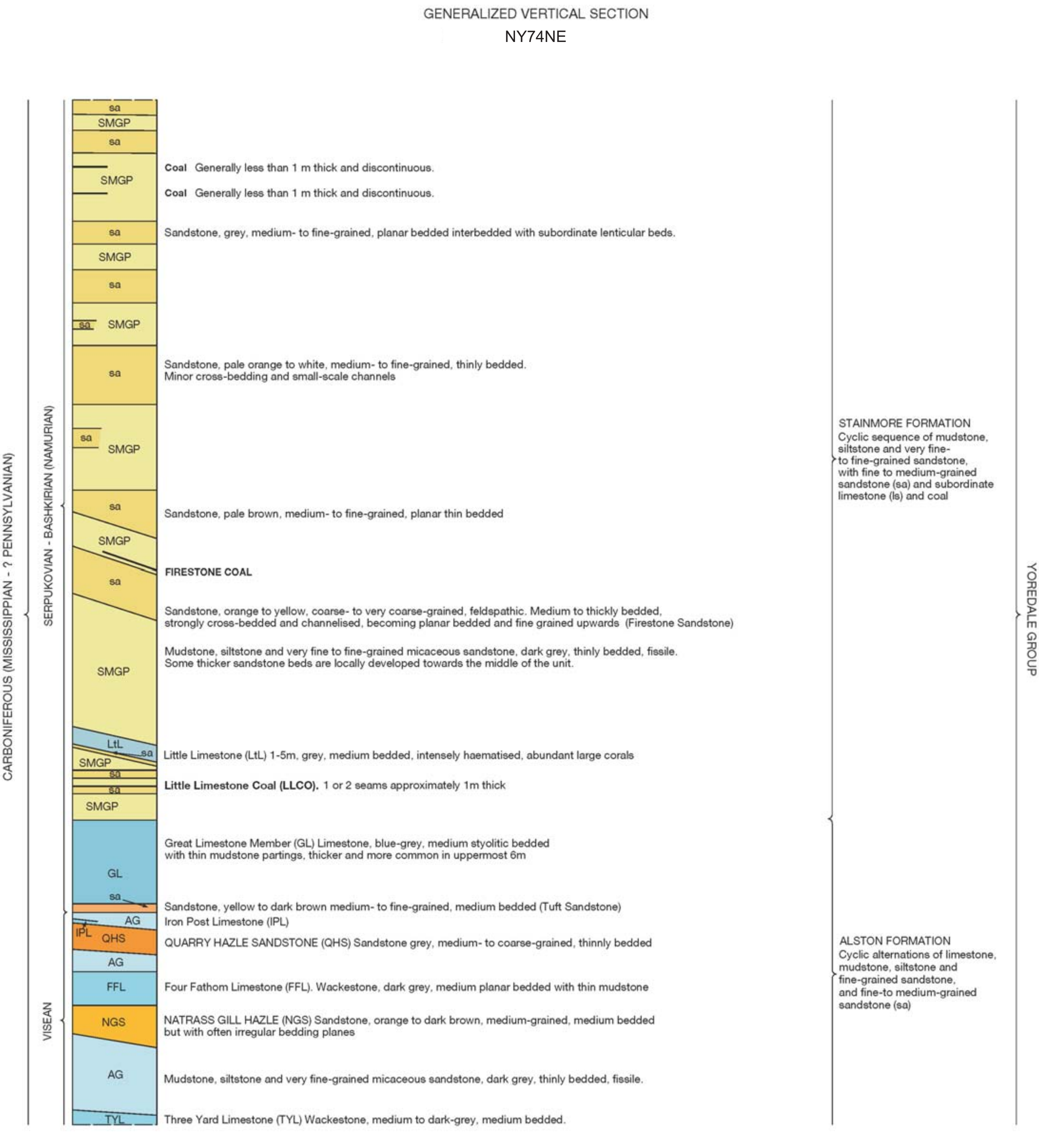
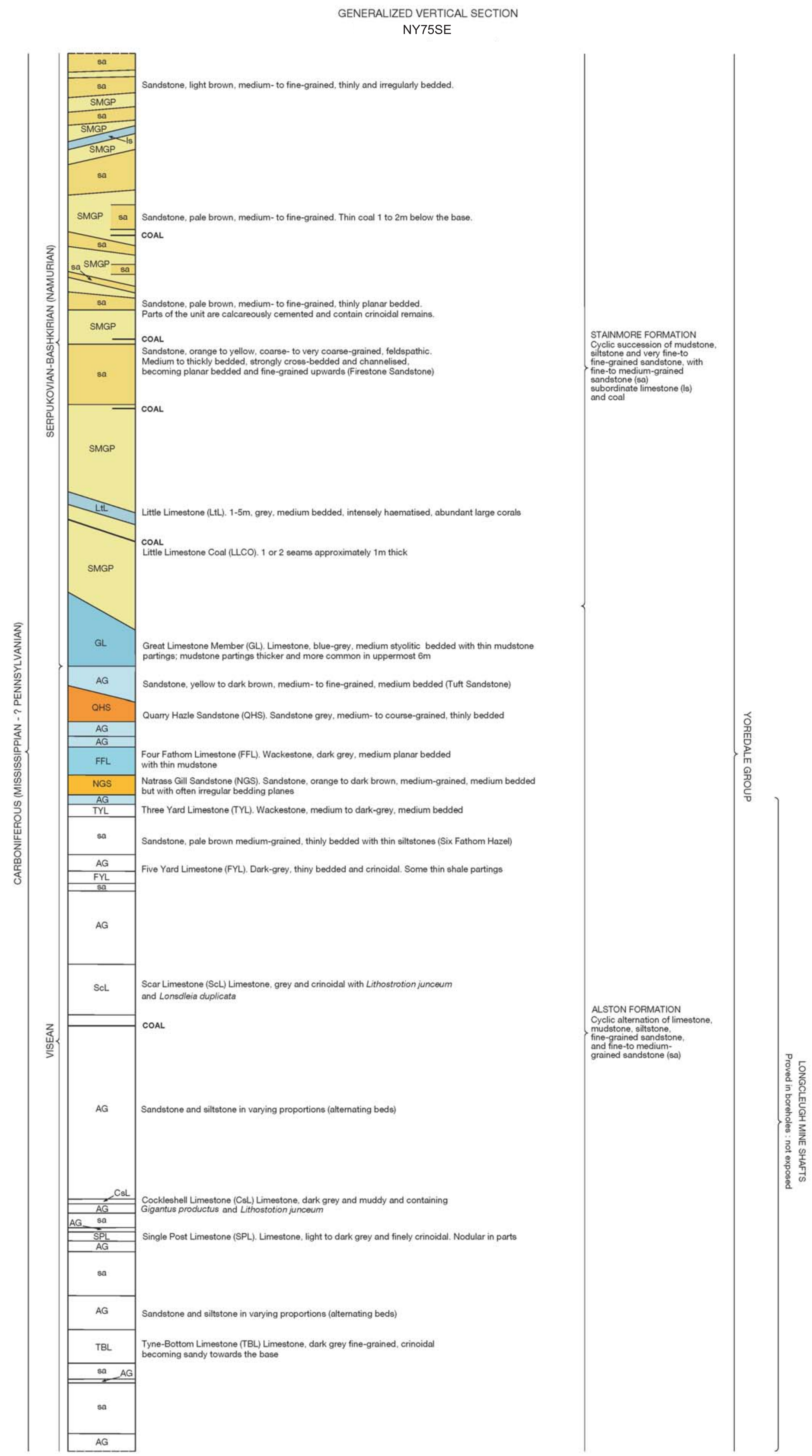


Figure 2. The regional structural geological setting of the study area



Scale: 1cm = 15m

Figure 3a. Representative generalised vertical section through NY74NE showing the stratigraphy and lithostratigraphical nomenclature used on the standard maps and within this report (Waters et al., 2007; Waters and Davies, 2007).



Scale: 1cm = 15m

Figure 3b. Representative generalised vertical section through NY75SE showing the stratigraphy and lithostratigraphical nomenclature used on the standard maps and within this report (Waters et al., 2007; Waters and Davies, 2007).

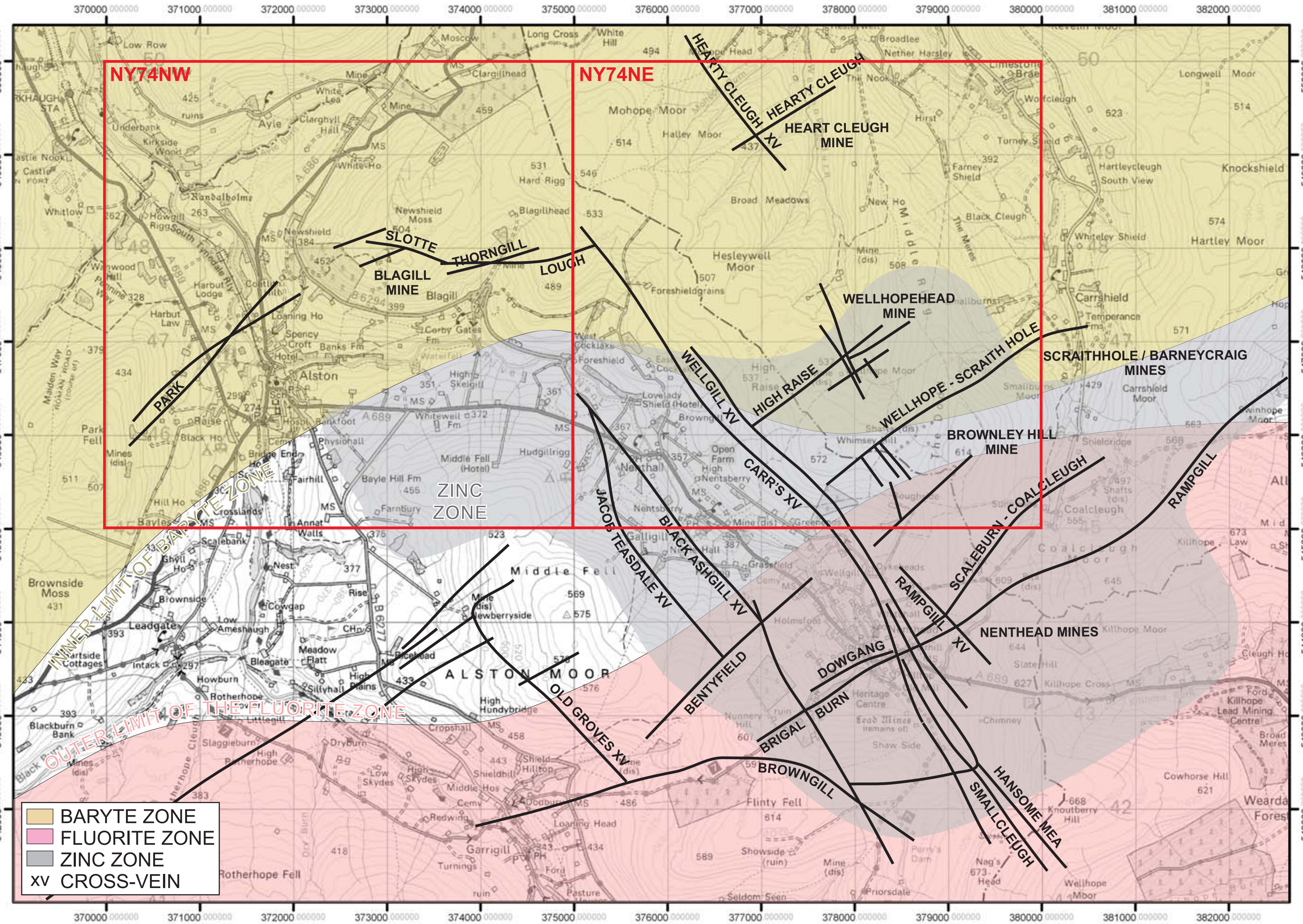


Figure 4. The limits of the fluorite and barium zones in the area between Alston and Nenthead with the positions of the southernmost two sheets, NY74NE and NW, covered by this report shown. The positions of veins shown is for diagrammatic purposes only and should not be considered accurate at the scale of the basemap.