The geology of NY74SE, Nenthead, Cumbria

Geology and Landscape Northern Britain Programme

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Foreword

1:10 000-scale geological sheet NY74SE was surveyed by S. M. Clarke in 2006 and constitutes part of the resurvey of BGS 1:50 000-scale map of Alston (England and Wales Series sheet 25). This report summarises the geology of this sheet and includes a synopsis of field notes by the author, with palaeontological descriptions by M. T. Dean. This work is an output 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

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Contents

Summary

This field report provides a summary of geological information to accompany the recently resurveyed 1:10 000-scale sheet NY74SE, Nenthead, Cumbria. It should be consulted in conjunction with the published geological standard maps and fieldslips corresponding to this area.

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 intensely 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 sheet NY74SE, Nenthead, Cumbria, re-surveyed by S. M. Clarke in 2006. The area constitutes part of the re-survey of BGS 1:50 000 Sheet 25 (Alston).

1.1 GEOGRAPHY

The area covers 25 km^2 of upland terrain within the North Pennines Area of Outstanding Natural Beauty and includes the former mining town of Nenthead, close to the borders of Cumbria with Northumberland and Co. Durham (Figure 1). During the 18th and 19th centuries, the area was the site of extensive industrial mining activities for both coal and metaliferous ores. Today, the area is largely rural and the economy is driven by farming, and the tourism and leisure industries.

Much of the landscape is high, open moorland under the control of Weardale Estate and is managed for grouse and pheasant. Two major river valleys traverse the area, the upper reaches of the Nent valley in the north-east, and the South Tyne valley in the south-west. The valley of Ash Gill, a major tributary of the South Tyne, crosses the south of the area. Minor tributary streams of the Nent further dissect the moorland in the north-east of the area. 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.

1.2 PREVIOUS WORK

Most of the area (Figure 1) was surveyed on the 1:10 560 scale by K. Burns over the period 1869 to 1881, with additional notes from the minerals revision of 1919 by R. G. Curruthers, and is represented by first edition geological standard maps of the Cumberland County Series sheets 34 and 42. The eastern edge was surveyed by K. Burns from 1939-41 and is represented by the Durham Series sheets 15 and 42. All of these sheets depict the Visean limestones and major sandstones in acceptable detail, but do not subdivide the later 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.

The Nent valley and other major areas of mining 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 levels 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 their 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 BGS 1:50 000-scale England and Wales Series Sheet 25 (Alston) is derived from a map originally published at the 1 inch-to-the-mile scale and based on the County Series standard maps. The sheet shows little in the way of detail in the post-Visean strata, and superficial deposits are variably depicted.

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.

The aims of the present survey of northern England, 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 will be 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 sea-level from late Visean times onwards 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. Mine shafts, exploratory boreholes and extensive subsurface mining penetrate Visean age rocks beneath those seen at surface, but rocks older than Carboniferous age have not been proved within the area and no strata of Westphalian age or younger are preserved.

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 4). Several of these faults form localised horsts and graben and disrupt the regional dip tends of the Carboniferous strata. Most of the faults are mineralised with metaliferous ores (Section 5) and represent one of the richest parts of the Northern Pennine Orefield (Dunham, 1990).

Superficial deposits (Section 6) resulting from the last glaciation and subsequent Holocene processes are present throughout the area and intermittently blanket the bedrock. The presence and nature of superficial deposits, combined with the weathering characteristics of bedrock where not blanketed in superficial deposits, strongly control the present day landscape. The valleys of the Nent and the South Tyne 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 in 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, seatearth, and culminating in coal. This cyclic and predictable nature of the Carboniferous sedimentary rocks is most notable within the Visean strata where in this area seven major cyclothems crop out, each displaying most of constituent lithologies, although the coal is commonly absent. The cyclic nature is less evident in the post-Visean strata which consist predominantly of units of interbedded siltstone and sandstone with subordinate, 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 can make regional correlation between widely spaced outcrops of post-Visean strata problematic. However, the nature of the topography and the availability of subsurface data have facilitated the correlation of several post-Visean sandstone units locally within the area covered by this report.

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 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 rocks exposed or proved with the area, and the Great Limestone and underlying strata at the base of the Serpukhovian 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 and Stainmore troughs (Section 4), to the north and south of the present area respectively, the Alston and Stainmore formations, together with the underlying Tyne Limestone Formation form the Yoredale Group. On the Alston Block, 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 units 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 Tynebottom Limestone up to the top of the Great Limestone crop out within the south-west corner of the area described, along the lower slopes of the South Tyne and Ash Gill valleys. Within this stratigraphical interval, strata from the Four Fathom Limestone up to the top of the Great Limestone can be traced northwards into Nent valley.

These strata, and older Visean rocks, were proved in many of the mines of Nenthead, in the north-east of the area, although few lithological details exist. Similarly, numerous mine shafts throughout the area almost certainly penetrated Visean strata but no records exist. Eight shafts are known to have penetrated Visean strata:

Shaft / Bore	Easting	Northing	BGS BJ	Strata penetrated
Carr's Engine Shaft	7876	4300	31	(no details)
Engine Shaft	7896	4353	16	(no details)
Brewery Shaft	7830	4350	15	(no details)
Hayring Well	767	446	3	(no details)
Guddham Gill Mine #10*	-	-	11	Great Limestone to Quarry Hazle
Wellgill Shaft	7770	4434	19	Three to Five Yard limestones
Low Whimsey (Rampgill)	788	435	-	(no details)
Rampgill Underground Shaft	7975	4417	-	Great to Jew limestones

3.3.1 Strata below the Tynebottom Limestone

The Rampgill Underground Shaft recorded the Jew Limestone 227 m above OD (Dunham, 1990), thus proving strata belonging to one cyclothem below the oldest present day outcrop within the area. Similarly, workings of Ashgill Fields Mine [7584 4045], in the lower reaches of the Ash Gill valley, penetrate strata of the Jew Limestone cyclothem. In both cases no lithological details exist.

Approximately 3 m of measures are interpreted to crop out with the riverbed and banks of the South Tyne in the extreme south-west of the area. These beds are poorly exposed but small exposures between deposits of modern alluvium suggest a siltstone-dominated sequence. Their outcrop is limited to 150 m of riverbed in the footwall of the Crossgill – Potato-Garth Vein [7560 4010]. They represent the uppermost beds of the Jew Limestone cyclothem and are thus the oldest Visean strata that crop out within the area.

3.3.2 The Tynebottom Limestone cyclothem

The Tynebottom Limestone takes its name from exposures in the riverbed of the South Tyne between Tynehead and Alston. Part of this section crosses the south-western corner of the present area and the uppermost beds of the Tynebottom Limestone are exposed for 370 m of the riverbed [7540 4025] within the hanging-wall of the Crossgill – Potato-Garth Vein. Here they are extremely argillaceous, friable and difficult to distinguish from the overlying siltstone-dominated strata. However, they are considerably harder and their weathering characteristics attest to their calcareous nature.

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* Exact location unknown but believed to be within the south-west-facing slopes of the Nent valley, near the northern limit of the present area.

The Tynebottom Limestone is overlain by approximately 30 m of a siltstone-dominated succession within interbedded thin beds of fine-grained sandstone. The lowermost 10 m of this succession comprise exclusively dark siltstone in friable thin beds approximately 1 cm thick that are known locally as the Tynebottom 'Plate'. Although friable, the Tynebottom Plate is clearly well consolidated and able to maintain near-vertical banks to the lower reaches of Ash Gill [7550 4032], where the stream is heavily incised by at least 7 m. The uppermost 20 m of the succession consist of abrupt alternations of siltstone and thin beds of fine-grained sandstone, known locally as the 'Alternating Beds'. This sequence almost certainty represents a number of subordinate cyclothems within the Tynebottom cyclothem. Indeed, within other parts of the North Pennines, two limestones are recognised within this sequence: the Single Post and Cockleshell limestones. The Single Post Limestone comprises just one bed of greyish white limestone and the Cockleshell Limestone is characteristically full of giganteid productids. One of these limestones is recognised within Ash Gill [7577 4046] where it comprises two beds of arenaceous limestone atop a small waterfall. No giganteid productids have been recorded from this locality although it is likely that this limestone is the Cockleshell Limestone given its stratigraphical position within the Tynebottom Limestone cyclothem. The Single Post Limestone is not recognised but may well correlate with strata that overlie a strong sandstone that forms an additional small waterfall in the lower reaches of Ash Gill [7560 4036]. This unit forms a topographical feature in the hillside and its outcrop has been interpreted within the South Tyne valley of the present area.

The Alternating Beds culminate with a dark brown to grey, fine-grained sandstone consisting of one bed up to 1 m thick underlying the Scar Limestone (Section 3.3.3) within the base of Ashgill Force waterfall [7587 4047]. This bed contains abundant root structures and trace fossils. It varies in thickness dramatically over the extent of the exposure and may well pinch out just outwith the limits of the exposure. For this reason its outcrop has not been interpreted within the South Tyne valley.

The Tynebottom Limestone cyclothem was penetrated by the Rampgill Underground Shaft where 6.5 m of the Tynebottom Limestone and 48 m of Alternating Beds were recorded; no lithological details are available. The variation in thickness between Rampgill in the north-east and exposures at Ash Gill in the south-west suggests a possible southwards thinning of the Alternating Beds. This suggestion is supported by regional thickness measurements in a number of mine shafts within the North Pennines that indicate a broad southwardly and eastwardly thinning of the beds (Dunham, 1990).

3.3.3 The Scar Limestone cyclothem

Exposures of the Scar Limestone cyclothem are limited to the south-western corner of the present area, within the Ash Gill valley. Approximately 10 m of blue-grey limestone in planar beds averaging 30 cm thick are exposed beneath the bridge that carries the B6277 over Ash Gill [7590 4048]. Here they form the impressive waterfall of Ashgill Force. The unit contains thin siltstone partings between some of the upper beds and is highly fractured with near-vertical fracture planes spaced by 1 m in a rectilinear pattern. The partings and fractures have led to cambering and rock falls from the exposure. Chert nodules have been observed within the Scar Limestone in the Alston area (Dunham, 1990), but are not recorded within this exposure or within the Scar Limestone of the present area.

The exposure at Ashgill Force can be correlated with a strong and persistent feature on both sides of the South Tyne valley, and with conspicuous sinkholes in the south-west-facing slopes around Ashgillside House [752 408].

The remainder of the Scar Limestone cyclothem is extremely poorly exposed but evidence within Ash Gill suggests a siltstone-dominated sequence culminating in a sandstone unit. The whole succession is 12 to 15 m thick. The sandstone can be observed in a small exposure in the south-facing slope of Ash Gill [7594 4052] where a 20 cm bed of brown to grey, fine- to medium-grained sandstone is exposed immediately below beds of the Five Yard Limestone

(Section 3.3.4). This unit is well-documented in the Alston Moor area (Clarke, 2007a) where it is thinly bedded, micaceous and known locally as the ‘Slaty Hazle’.

Strata of the Scar Limestone cyclothem were penetrated by workings of Nentsberry Haggs Mine where the cyclothem was recorded as 18.3 m thick, of which the lowermost 9.1 m comprise the Scar Limestone and the uppermost 3.7 m comprise the Slaty Hazle. In Rampgill Underground Shaft the cyclothem is 29.9 m thick, of which the Scar Limestone comprises 13.1 m and the Slaty Hazle comprises 10.4 m. No lithological details are available for either locality.

3.3.4 The Five Yard Limestone cyclothem

Strata of the Five Yard Limestone cyclothem crop out along the South Tyne and Ash Gill valleys in the south-west of the present area. The Five Yard Limestone at the base of the cyclothem is so named for its thickness, although boreholes within the Alston area suggest an average thickness locally that is generally less than this (Dunham, 1990; Clarke, 2007a).

Exposures of the Five Yard Limestone are rare within the present area. Small exposures of the lowermost beds overlying the uppermost beds of the Slaty Hazle (of the Scar Limestone cyclothem) can be seen in the south-facing banks of Ash Gill, and limestone blocks indicating its presence can be found in the riverbed near Ashburnside Plantation [7636 4065]. However, the outcrop of the Five Yard Limestone along the south-west-facing slopes of the South Tyne and the south-facing slopes of the Ash Gill valleys is marked by a persistent and, in many places, strong feature. By contrast, outcrops on the north-east-facing slopes of the South Tyne and north-facing slopes of the Ash Gill valleys are interpreted from those on facing slopes and the regional dip as little evidence for their position exists.

The Five Yard Limestone is overlain by 12 to 16 m of siltstone-dominated measures that comprise the remainder of the cyclothem. In the Alston area (Clarke, 2007a), the uppermost 10 m of this sequence comprise a massive, fine- to medium-grained, siliceous sandstone known as the Six Fathom Hazle. In the present area, the measures of the cyclothem are poorly exposed and the outcrop of the Six Fathom Hazle has not been interpreted. However, small exposures of siliceous, rooty and sometimes cross-bedded sandstone within the Ash Gill [7654 4070], in both the footwall and hanging-wall of the Wellhope Knott Vein, may well correlate with the Six Fathom Hazle.

In Nentsberry Haggs Mine, 18.6 m of strata are assigned to the Five Yard Limestone cyclothem of which the lowermost 4.6 m comprise the Five Yard Limestone and the uppermost 11 m comprise the Six Fathom Hazle. Rampgill Underground Shaft penetrated 3.4 m of Five Yard Limestone and 6.4 m of the Six Fathom Hazle; the entire cyclothem is 17.1 m thick.

The best exposures of the top of the Five Yard Limestone cyclothem within the present area were reported from subsurface workings of Bentyfield Mine [755 426] (Dunham, 1990), where a thin coal (18 cm) overlies the Six Fathom Hazle and completes the cyclothem. Evidence of this coal has not been observed at surface but it may correlate with the Shillbottle Coal of Northumberland (Dunham, 1990). The following thicknesses for strata of the Five Yard Limestone cyclothem are reported from Bentyfield Mine:

	Thickness (m)
Coal (Shillbottle)	0.18
Sandstone (Six Fathom Hazle)	7.3
Siltstone with thin fine-grained sandstones	5.5
Limestone (Five Yard)	4.9

The cyclothem was also penetrated by the Wellgill Shaft and Rampgill Underground Shaft. In Wellgill Shaft 3.7 m of the Five Yard Limestone are overlain by 1.8 m of siltstone and 16.5 m of the Six Fathom Hazle. In the Rampgill Underground Shaft thicknesses of 3.4 m and 6.4 m are recorded for the Five Yard Limestone and Six Fathom Hazle respectively; the cyclothem is 17.1 m thick.

3.3.5 The Three Yard Limestone cyclothem

Strata of the Three Yard Limestone cyclothem crop out within the South Tyne and Ash Gill valleys in the south-west of the present area, and within the Nent valley to the north and north-east. In the South Tyne, Ash Gill and upper Nent valleys they are extremely poorly exposed and their interpretation and outcrop pattern are based largely on secondary evidence and subsurface data. In the middle Nent valley, at the northerly limit of the present area, exposures are good but limited to the uppermost few metres of the cyclothem.

The Three Yard Limestone, at the base of the cyclothem, is so named for its average thickness and crops out in the South Tyne and Ash Gill valleys, but is not exposed other than for approximately 40 m of the Ash Gill riverbed in the footwall of the Wellhope Knott Vein [7673 4076]. Here it is a blue-grey wackestone in medium-scale beds with slightly wavy bedding planes. These beds immediately overlie exposures of the top of the Six Fathom Hazle (of the Five Yard Limestone cyclothem) and the outcrop of the Three Yard Limestone may be traced through the south-facing slopes of the Ash Gill valley by virtue of the strong feature that it forms in conjunction with the Six Fathom Hazle. On the north-facing slopes of the Ash Gill valley and south-west-facing slopes of the South Tyne valley little evidence exists for the outcrop of the Three Yard Limestone and its position is based largely on subsurface data, secondary evidence and structural projection from facing slopes.

The Three Yard Limestone is overlain by approximately 25 m of measures comprising primarily siltstone that passes upwards into interbedded sandy siltstone and fine-grained sandstone. No exposures of the lower part of this succession are recorded at surface within the area but Johnson et al. (1962) recorded goniatites from this sequence within the North Pennines, indicating a marine origin for the siltstone.

The uppermost few metres of the succession are exposed in the Ash Gill valley [7687 4088] where they comprise fissile, planar laminated siltstone, interlaminated with fine-grained sandstone laminae and beds. Some sandstone beds reach 30 cm in thickness and are of fine to medium grain. The proportion of sandstone increases upwards and the succession culminates in a 30 cm thick, fine- to medium-grained sandstone unit with thin siltstone partings between some beds. Strong symmetrical ripple marks are recorded within this unit. This 30 cm sandstone is immediately overlain by the Four Fathom Limestone (Section 3.3.6) and therefore is mostly likely a lateral equivalent of the Nattrass Gill Hazle of the Alston area, although it is significantly thinner than the 6 m to 8 m of sandstone reported there (Clarke, 2007a). Alternatively, these beds may correlate with a thin sequence of measures containing a 46 cm thick coal seam that has been reported at the top of the cyclothem on Park Fell, in the Alston area, by C. L. Vye (Clarke, 2007a). No coal is recorded in the present exposure. A small adit in the top of the sequence, 100 m to the east, may have been a trial for coal, but is more likely to be access to workings on the Wellhope Knott Vein; the contents of the spoil heap are inconclusive.

In the middle reaches of the Nent valley, at the northern limit of the present area, sandstone representing the uppermost beds of the Three Yard Limestone cyclothem is exposed in the riverbed immediately under Nentsberry Bridge [7878 4491]. This sandstone correlates with the Nattrass Gill Hazle of the Nentsberry Haggs area, approximately 150 m north of the present area, where exposures indicate a maximum thickness for the unit of 6 m (Clarke, 2007a). Within the Nent River of the present area, the top of the Nattrass Gill Hazle is exposed and is immediately overlain by the Four Fathom Limestone under Nentsberry Bridge. The base of the unit is exposed approximately 90 m downstream, indicating a similar thickness to that recorded at Nentsberry Haggs. Approximately 350 m upstream of Nentsberry Bridge, medium-grained sandstone in 20 cm thick beds is underlain by interlaminated siltstone and fine-grained sandstone laminae and marks the base of the Nattrass Gill Hazle. Many of the sandstone beds show excellent ripple marks and some show intricate interference ripple patterns.

Based on recorded displacements on the Cowhill Cross-vein (Section 4), strata of the Three Yard Limestone cyclothem crop out along the banks of the River Nent between the vein [7730 4476] and Nenthead [783 436]. However, much of this section is obscured by large spoil heaps from previous mining activities at Nenthead and by modern engineering works to the river channel itself. Consequently only two exposures through strata of the Three Yard Limestone cyclothem are recorded in this area. At Greenends [7732 4473], in the footwall of the Cowhill Cross-vein, 5 m of channel-bound sandstone of the Nattrass Gill Hazle are exposed in the north bank of the River Nent, and at Gudham Gill [7765 4468] 3 m of yellow-brown, fine- to medium-grained sandstone in 50 cm beds are exposed in a small waterfall. Based on these exposures, the Nattrass Gill Hazle has been interpreted to crop out in the upper reaches of the Nent valley.

Strata of the Three Yard Limestone cyclothem were penetrated by Nentsberry Haggs Mine, Bentyfield Mine, Wellgill Shaft and Rampgill Underground Shaft. In all four, thicknesses of component strata were recorded but no lithological details are available. In Nentsberry Haggs Mine the Three Yard Limestone cyclothem is 28.3 m thick with the lowest 2.7 m attributed to the Three Yard Limestone and the uppermost 5 m attributed to the Nattrass Gill Hazle. In Bentyfield Mine, the Three Yard Limestone is 4.3 m thick and the Nattrass Gill Hazle is 10 m thick; the cyclothem is 36.3 m thick. In Rampgill Underground shaft, thicknesses of 2.4 m and 6.4 m are recorded for the Three Yard Limestone and the Nattrass Gill Hazle respectively, with the cyclothem attaining a thickness of 29 m. In Wellgill Shaft, the Three Yard Limestone is 1.4 m thick and overlain by 27.4 m of alluvium and siltstone. Consequently, subsurface data do not support a general thinning of the Nattrass Gill Hazle southwards indicated by surface exposures, although the thickness of this unit is clearly highly variable.

3.3.6 The Four Fathom Limestone cyclothem

The Four Fathom Limestone crops out in the Ash Gill valley, where it forms a prominent feature along south-facing slopes accompanied by a number of sinkholes, the south-west-facing slopes of the South Tyne valley, where again it forms a strong feature, and in the Nent valley where, along with the underlying Nattrass Gill Hazle, it forms a prominent feature and cliff section.

On the south-facing slopes of the Ash Gill, the lowermost beds of the Four Fathom Limestone are exposed in a small north-bank tributary stream [7687 4088]. They consist of 1 m of light grey, wackestone in medium (~40 cm) beds with slightly wavy bedding planes. 70 m to the east of this locality, the Four Fathom Limestone is again exposed in shallow surface workings on the Wellhope Knott Vein [7700 4092]. Here the bedding is disturbed and displays a strong 16° dip into the vein. The base of the Four Fathom Limestone can be traced for approximately 400 m upstream in the north bank of Ash Gill where it is thrown down by the Wellhope Knott Vein and a number of subparallel, small faults. In all exposures the bedding is highly disturbed and much cambering has taken place over the underlying measures of the Three Yard Limestone cyclothem. A number of large sinkholes have developed in the top of the bank at this point, although their size and position in relation to the exposed base of the Four Fathom Limestone suggests these have developed through the overlying measures and not directly into the limestone itself. The thickness of the Four Fathom Limestone here is interpreted to be 8 to 10 m based on the exposures and strong featuring.

The outcrop of the Four Fathom Limestone within the remainder of the south-facing slope of Ash Gill and the south-west-facing slopes of the South Tyne valleys is marked by a prominent feature. At least two small and largely overgrown quarries are present and a number of small sinkholes have developed in the outcrop.

In the north-facing slopes of the Ash Gill valley, the outcrop of the Four Fathom Limestone is largely obscured by extensive overburden resulting from heavy plantation and forestry activities. Its course is marked largely by secondary evidence including a number of sinkholes and a weak but persistent feature that crosses hillside. However, exposures of the base can be found in the banks of the Little Gill, a south-bank tributary of Ash Gill, within the present area [7756 4002]. Here, two 30 cm beds of grey wackestone are poorly exposed in the stream banks overlying siltstone interbedded with thin sandstone beds that are the measures of the top of the Three Yard

Limestone cyclothem. 200 m upstream, and 180 m south of the present area, the top of the Four Fathom Limestone is exposed in the streambed. These two exposures define the thickness of the Four Fathom Limestone as 8 m and provide the best control on the thickness in the south-west of the present area.

In the Nent valley the Four Fathom Limestone is well exposed in both banks under Nentsberry Bridge [7676 4491] where it rests on the Nattrass Gill Hazle in the streambed. It consists of 8 m of light grey wackestone in medium (~30 cm) beds with largely planar bedding surfaces. The bedding thickness is surprisingly consistent throughout the unit. The outcrop may be traced upstream for 500 m in the north bank by virtue of a number of similar exposures and a strong feature. The corresponding outcrop in the south bank is obscured by superficial deposits.

Downstream of Nentsberry Bridge, a feature in the north-facing slopes along which there has been much landsliding marks the course of the Four Fathom Limestone. Exposures are few although the limestone is exposed in two south-bank tributaries: Galligill Burn [7606 4490] and a small stream at Hayring [7650 4478]. In the latter, wackstone in 30 cm beds with smooth bedding surfaces is exposed in the base of the stream for approximately 10 m.

In the upper reaches of the Nent valley there are only two small exposures of the Four Fathom Limestone. The track along Gudham Gill exposes small patches accompanied by a spring line taken to mark the base [7761 4472], and a small exposure is present in the stream at Wellgill Cottages [7685 4440]. The remainder of the outcrop within the upper reaches of the Nent valley is an interpretation below man-made deposits based on these exposures and limited subsurface data.

Chert nodules have been reported within the Four Fathom Limestone (Dunham, 1990) and are noted at localities outwith the present area (Clarke, 2007b). With the exception of the Three Yard Limestone, 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.

Data from outwith the present area suggest 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 (Clarke, 2007a). There are no known exposures through this sequence within the present area. The measures pass upwards into approximately 6 m of white to brown, micaceous, medium-grained sandstone known as the Quarry Hazle. Exposures of the Quarry Hazle within the present area are rare but the unit can be seen in small quarries and workings just to the north of the present area along the south-facing slopes of the Nent valley, between Haggs Bank and Nether Nentsberry. Here it consists of a white to light brown, hard, thin- to medium-bedded, medium-grained sandstone. Many of the beds show thin laminae picked out by colour changes and sorting of the subangular to subrounded grains.

Within the Ash Gill valley the Quarry Hazle is largely unexposed. A small exposure of brown, rooty, fine- to medium-grained sandstone in a small adit on the south-facing slopes [7685 4100] is interpreted to be the Quarry Hazle. This exposure correlates with a prominent feature that can be traced along the south-facing slopes of the Ash Gill valley and the south-west-facing slopes of the South Tyne valley to correlate with further small exposures of sandstone. It is on the basis of these exposures and the strong featuring that the outcrop of the Quarry Hazle has been interpreted.

In the Nent valley, good quality exposures of the Quarry Hazle in Haggs Bank, just to the north of the present area, correlate with a strong feature that may be traced upstream and into the area. The outcrop of the Quarry Hazle within the upper reaches of the Nent valley is based on this feature and a strong spring line, both of which may be traced along the south-west-facing slopes as far as Nenthead. Here, the feature correlates with another small exposure of sandstone within Gillgill Burn [7827 4374], a north-bank tributary of the river Nent, under which an adit is driven.

In the north-east-facing slopes of the Nent valley, the Quarry Hazle is thrown down by the Cowhill Cross-vein (Section 4) and does not crop out other than in the far north of the area where it is obscured beneath superficial deposits; its outcrop is a construction from data in the opposing bank.

Strata of the Four Fathom Limestone cyclothem were penetrated in Rampgill Underground Shaft and several mining workings within the area. In all cases, thicknesses are given but no lithological details are available:

Strata (m)	Galligill Sike Mine [758 445]	N'berry Haggs Mine [766 450]	Dowgang Mine [775 430]	Rampgill Shaft [7975 4417]
Quarry Hazle sandstone	6.1	9.1	9.1	8.8
measures	8.9	12.3	12.3	11.9
Four Fathom Limestone	7.3	7.3	7.3	5.5

3.3.7 The Iron Post Limestone cyclothem

The Iron Post Limestone is rarely exposed within the Alston - Nenthead area. Exposures have been recorded in the West Allen riverbed, beneath the track to Barneycraig Farm, approximately 2 km north of the present area [8034 4676], and in Foreshield Burn [7525 4729], approximately 2.5 km north of the present area (Clarke, 2007a). An exposure has been noted previously in the headwaters of the River Nent at Nenthead [7847 4320] (B. Young, pers. comm.), although at the time of the present survey no such exposure was recorded as the River Nent was choked with modern alluvium.

In exposures close to, but outwith, the present area, the Iron Post Limestone is a single, thin bed of extremely hard limestone atop the Quarry Hazle. The name is derived from its hardness rather than any ferruginous content, and it is commonly 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. However, it has not been interpreted to crop out within the present area as no exposures have been recorded.

The remainder of the Iron Post cyclothem is approximately 7-10 m thick and comprises approximately 6 to 7 m of siltstone to dark mudstone overlain by 1 to 3 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 the Ash Gill valley, no exposures of the Tuft are noted. Here, the overlying Great Limestone (Section 3.3.8) forms near-vertical cliffs and the presence of a thin sandstone unit at the base would form an outcrop below the resolution of mapping. Consequently the Tuft is not interpreted to crop out in this valley.

In the South Tyne valley, the Tuft Sandstone is exposed in the riverbed of the Garrigill Burn, an east-bank tributary of the South Tyne River. It forms the riverbed for 150 m and is interpreted to crop out over the extent of this valley.

In the Nent valley, the uppermost 1.5 m of the Iron Post Limestone cyclothem are exposed in the north bank of the river Nent at Nenthead [7857 4308]. Here the section comprises approximately 1 m of dark grey siltstone and mudstone in laminae of 0.5 cm, overlain by 0.5 m of brown, fine- to medium-grained sandstone. The cyclothem culminates in approximately 1 m of seatearth overlain by 0.3 m of a dirty and very poorly developed coal.

Further exposures of this succession can be found in Gillgill Burn [7832 4375] where approximately 2 m of Tuft Sandstone overlie dark siltstone in the south-east bank. A small graben, formed by the Dowgang-Scaleburn and Rampgill-Brigal Burn veins, repeats the exposure of the Tuft in the bed of the River Nent at [7831 4376] where it is a brown, fine- to medium-grained sandstone that is reasonably well cemented and highly fractured. A similar exposure can be found in Dowgang Burn [7796 4338] exposed at the surface by displacement on the Cowhill Cross-vein. These exposures, combined with favourable relationships of geology to topography, have facilitated interpretation of the outcrop of the Tuft Sandstone over the extent of the Nent valley within the present area.

Strata of the Iron Post Limestone cyclothem were penetrated by the Nentsberry Haggs and Dowgang mine workings, and by the Rampgill Underground Shaft. In the two mines the Iron Post Limestone is 0.6 and 0.3 m thick respectively but it is not recorded within Rampgill Underground Shaft. In all three localities the Tuft sandstone is 2.7 m thick. No lithological details are available.

3.3.8 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 2 m 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 beds 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 10-11 m 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 dolomitisation, 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 beds are lenticular.

On the Alston Block, of which the present area is part (Section 4), 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 bistromes, are recognised regionally within the Great Limestone (Johnson, 1958). Within the Bench Posts (Fairbairn, 1978), or near the base of the Low Flat (Forester, 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 Frosterley Band is not a single biostrome but comprises a number of discontinuous macrofossil bands in different beds within the Fossil Posts (Fairbairn, 1978).

The Great Limestone is well exposed in the Ash Gill and South Tyne valleys, where its course across the hillsides between exposures is marked by a strong and persistent feature, and in the Nent valley where numerous outcrops allow correlation across the complicated structures.

The base and top of the Great Limestone are exposed within the streambed of Ash Gill [7802 4138] and the main beds form a near vertical cliff section in north-west-facing slopes. The base is not exposed within these slopes but several adits limit its position. The Tumbler Beds are not well exposed but form the topmost 3 to 4 m and small exposures of 30-50 cm beds of limestone with thin siltstone partings can be found in Stony Cleugh [7795 4096], a south-bank tributary to the Ash Gill. A proliferation of sinkholes, some of which are exceptionally large, in the area of Stony and Hunter's cleughs [778 406] attest to the presence of the Tumbler Beds, although the largest are almost certainly developed through overlying strata as well.

In the south-facing slopes of the Ash Gill valley, a surface working on the Wellhope Knott Vein exposes the main beds of the Great Limestone in vertical cliffs [7733 4105]. Here the Tumbler Beds are curiously absent and the Great Limestone is overlain immediately by a sandstone (Section 3.4.1) through which large sinkholes have developed. Small exposures of sandstone above the Great Limestone within Hunter's Cleugh [7786 4068] suggest a similar situation there.

* The term 'main posts' is commonly used in a somewhat ambiguous sense by other authors to refer to all of the Great Limestone with the exception of the Tumbler Beds. It is used in this report in the sense defined by Fairbairn (1978).

The course of the outcrop of the Great Limestone can be traced through the south-facing slopes of the Ash Gill valley and into the south-west-facing slopes of the South Tyne valley by way of a strong feature that connects several small quarries. The base of the Great Limestone within this feature is marked clearly at a number of places by prominent springs. Extensive areas of sinkholes, developed through overlying strata, are present.

In the South Tyne valley, the Great Limestone is exposed in Garrigill Burn, near to Bentyfield Mine. Here, 6-7 m of limestone are exposed in an abandoned quarry. The lowest 2 m are a single bed but the overlying 4-5 m are bedded on the 60 cm scale with undulating bedding surfaces. It is probable that this exposure represents the bottom 6-7 m of the Great Limestone in this area, including the Bench and Main posts (Fairbairn, 1978), as the base of the quarry correlates with exposures of the Tuft Sandstone locally, although no exposure is present in the base of the quarry itself.

In the Nent valley, the Great Limestone is best exposed in the upper reaches of the River Nent at Nenthead. Here, the base of the unit is exposed in the north bank overlying the Tuft Sandstone of the Iron Post Limestone cyclothem [7857 4308]. 5 to 7 m-high cliffs represent the Bench and Main posts of limestone in 30 cm to 1 m thick beds. The *Chaetetes* Band is extremely well developed in the lowest metre of the Bench Posts and the exposures here are designated a SSSI for this fossil. From this locality, M. T. Dean provided the following synopsis (full details of the fossil assemblages are given in Dean, 2007):

	Thickness (m)
Limestone, planar-bedded (Great)	
Limestone, wavy-bedded and comprising:	
Chaetetes band	0.2-0.5
Coral band	~0.2
Chaetetes band	0.3
Coral band	~0.15
Chaetetes band	0.15
Limestone, arenaceous and planar-bedded	1.05
Coal, very poor (‘smut’)	0.3
Seatearth, muddy and rooty	0.6
Sandstone	0.15
Seatearth, sandy and rooty	0.3
Sandstone (Tuft)	

The cliffs form a prominent waterfall in the River Nent and the Great Limestone forms the river bed for 50 m upstream. The top of the Great Limestone in the river is faulted against the overlying strata and the Tumbler Beds are not exposed. The cliff section in the south-west-facing slopes is immediately overlain by extensive man-made deposits from the mine workings at Nenthead that may obscure the Tumbler Beds but their presence at surface in this area cannot be conclusively determined.

Extensive faulting within the Nent valley significantly disrupts the outcrop of the Great Limestone and repeats various sections in the river. The lowermost beds are exposed in the River Nent resting immediately on the Tuft Sandstone in a small exposure [7824 4339] in a graben developed between the Brigal Burn-Rampgill and Dowgang-Scaleburn veins, and further small exposures of this outcrop may be found in the bank behind the Nenthead Mines Visitors’ Centre [7824 4345]. The topmost beds of the Tumbler Beds are exposed in streambed of Dowgang Burn [7782 4329], within the hanging-wall of the Cowhill Cross-vein, where they are heavily iron-stained and display a strong fracture pattern. Further exposures in this section are poor and it is not possible to ascertain the extent or thickness of the Tumbler Beds. The base of the Great Limestone and underlying Tuft Sandstone are also exposed in the same stream and give a thickness to the Great Limestone here of 17 m. In Gillgill Burn [7831 4377] the lowest beds are exposed overlying the Tuft Sandstone and form a prominent waterfall. The dip on these beds is up to 40° towards the north-east and represents extensive footwall drag into the Carr’s Cross-vein that truncates the limestone above the waterfall.

The outcrop of the Great Limestone within the south-west-facing slopes of the Nent valley between Gillgill Burn and the northern limit of the area is marked by a strong feature and distinctive contrast in vegetation. The outcrop here is in faulted contact with the overlying strata across the Carr’s Cross-vein and the flat, firm and well-drained foundation formed by the Great Limestone in the footwall has been exploited by a number of farms along its course.

The outcrop within the north-east-facing slopes is less well constrained as the strata here dip with a similar azimuth to the topography and the slopes are blanketed in superficial deposits. However, a persistent, if generally weak, feature connects small outcrops of limestone in Dowgang Burn, Galligill Burn [7583 4446] and other south-bank tributary streams of the Nent.

The Great Limestone was penetrated by Galligill Sike Mine, Nentsberry Mine (west), Bentyfield Mine, Dowgang Mine and Rampgill Mine (Rampgill, Capelcleugh, Cowhill, Carr’s and Smallcleugh levels) within the present area. In all but Rampgill Mine the reported thickness of the Great Limestone is 19.2 m. In Rampgill it is 18.9 m. In all cases, no lithological details are available. In the workings of Smallcleugh Level, all three flats (Forster, 1809) and the Tumbler Beds are exposed.

3.4 SERPUKHOVIAN TO BASHKIRIAN (NAMURIAN) ROCKS: STAINMORE FORMATION

Strata younger than the Great Limestone belong to the Stainmore Formation and crop out over most of the present area but dominate the hilltops of the north-east, south-east and those of Flinty Fell between the Nent and South Tyne valleys.

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 correlable cyclothems are recognised: the Little Limestone and Crag Limestone cyclothems. Younger strata are dominated by clastic rocks with few, poorly developed and laterally discontinuous limestone units making regional correlation problematic. Over the present area, one thin limestone is recognised within this succession that can be tentatively correlated regionally; the Lower Felltop Limestone. For the purposes of this description, strata younger than the Crag Limestone are subdivided at the Lower Felltop Limestone.

Strata of the Stainmore Formation were proved in many of the mines of Nenthead, in the north-east of the area, although few lithological details exist. Similarly, numerous mine shafts throughout the area almost certainly penetrated these strata but no records exist. Seven shafts of the area are known to have penetrated strata of the Stainmore Formation:

Shaft / Bore	Easting	Northing	BGS BJ	Strata penetrated
Brewery Shaft	7830	4350	28	(no details)
Longholehead Whimsey	7717	4226	-	(no details)
High Whimsey (Browngill)	7684	4232	-	(no details)
High Whimsey (B’gill Sun)	7667	4215	-	(no details)
Middle Whimsey (B’gill Sun)	6738	4210	-	(no details)
Low Whimsey (Rampgill)	788	435	-	Firestone Sandstone to Great Limestone
Gudham Gill Mine #10*	-	-	11	Firestone Sandstone to Great Limestone

* Exact location unknown but believed to be within the south-west-facing slopes of the Nent valley, near the northern limit of the present area.

3.4.1 Strata between the Great and Little Limestones

Strata overlying the Great Limestone and belonging to that cyclothem crop out in the Ash Gill, and South Tyne valleys, and within the north-east-facing slopes of the Nent valley. In the south-west-facing slopes of the Nent valley, these strata are faulted down below the present day landscape with the exception of two small fault-bounded outcrops at Nenthead and Gudham Gill.

These strata are dominantly siltstone and sandstone but considerable variation in detail occurs both regionally and over the extent of the present area (Dunham, 1990; Clarke, 2007a). At least one, and sometimes two, major coal seams are present also. These seams constitute the Little Limestone Coal and in the region of Alston Moor, to the north of the present area; they are, in places, of sufficient thickness and grade that they have worked extensively. Within the present area, there is some evidence of small-scale working of coals within this succession.

A typical 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 (Dunham, 1990). Over much of the Nent valley and Alston Moor, immediately north of the present area, this generalised sequence holds true to such an extent that the sandstone units have been given local names. These are the Low and High Coal sills, and the sandstone at the top of the succession (and the top of the Great Limestone cyclothem) is termed the White Hazle (Dunham, 1990).

Within the present area, much of the succession between the Great and Little limestones is poorly exposed but considerable variation is still apparent. As a consequence, the outcrops of individual sandstones within the succession have been mapped over short distances where exposure and surface evidence allows, but no attempt has been made to fully correlate these sandstones across the area.

The most complete section through the strata between the Great and Little limestones is exposed in the upper reaches of the River Nent at Nenthead between the Carr’s Cross-vein [7867 4296] and the Little Limestone [7884 4269]. The following is a summary from this section:

	Thickness (m)
Little Limestone	
Sandstone, strongly ganisteroid (White Hazle)	0.6
Siltstone	~5
Sandstone, ganisteroid and cross-bedded (?High Coal Sill)	1
Siltstone	4
Carr’s Cross-vein with Great Limestone in footwall	

The correlation of the sandstone exposed in this section with the High Coal Sill of Alston Moor is tentative and based on thickness measurements of the strata between the Great and Little limestones in Rampgill Mine. Here the section is 18 m thick implying that at surface in the Nent River approximately 8 m at the base of the succession are thrown down below the present day landscape on the Carr’s Cross-vein. Based on thickness measurements reported in the Alston Moor area (Dunham, 1990; Clarke, 2007a) this 8 m section should include the Low Coal Sill, but no lithological details are available from Rampgill Mine to confirm its presence here.

The uppermost 5 m of the river section are repeated further upstream in the Old Carr’s Burn, a tributary of the Nent that traverses the footwall of the Carr’s Cross-vein. The White Hazle at the top of the cyclothem and the overlying Little Limestone (Section 3.4.2) form a 2 m high waterfall [7877 4246].

In the Dowgang Burn much of the succession between the Great and Little Limestones is exposed intermittently along the banks and within the streambed between patches of modern alluvium. The following as a summary:

	Thickness (m)
Little Limestone in hanging-wall of Brigal Burn Vein	
Sandstone, ganisteroid with strong dip N (White Hazle)	1
Siltstone	~10
Coal	0.2
Sandstone, ganisteroid	1.5
Dowgang Vein with ~3m displacement	
Siltstone	~8
Carr's Cross-vein with Great Limestone in footwall	

The sandstone exposed here in the middle of the section is ganersteroid but interbedded with some orange, soft and poorly consolidated, fine-grained sandstone beds, and overlain by a thin coal seam that has been worked within the banks of the burn. It is unclear from this section if this sandstone unit can be correlated with the Low or High Coal Sill of Alston Moor. This outcrop is interpreted for a short distance from the burn but not over the remainder of the Nent valley.

In the north-east-facing slopes of the Nent valley, strata between the Great and Little Limestones are intermittently exposed in Galligill Burn [7575 4430]. Here the sequence comprises approximately 20-25 m of measures dominated by dark, fissile and organic siltstone, with a thin sandstone of the White Hazle at the top.

Despite the fact that the White Hazle at the top of the Great Limestone cyclothem is exposed in the Nent River, Dowgang Burn and Galligill Burn, its outcrop has not been interpreted over the extent of the Nent valley as it does not form a mappable unit.

In the South Tyne valley, strata between the Great and Little limestones are exposed in Garrigill Burn. Here, approximately 20 m of measures are exposed intermittently in the stream section. Two thin sandstones are recorded within this sequence and a further sandstone (the White Hazle) is recorded at the top, underlying the Little Limestone. The outcrop of none of these sandstones can be traced through the slopes of the Garrigill valley and consequently none is mapped. Evidence from workings in the north bank suggests a coal overlies the lower sandstone.

At the head of the Ash Gill valley, a succession similar to that of the Dowgang Burn may be summarised from isolated exposures in Ash Gill, Stony Cleugh and Hunter's Cleugh:

	Thickness (m)
Little Limestone	
Sandstone, sometimes ganisteroid (White Hazle)	1
Siltstone	~10
Sandstone, ganisteroid	4
Siltstone	5
Great Limestone	

The whole succession is of comparable thickness to that at Dowgang Burn and contains one major sandstone unit, the top of which is around the middle of the succession. However, this sandstone is considerably thicker than that at Dowgang Burn and exposures correlate with a strong feature that can be traced along both sides of the Ash Gill valley and the south-west-facing slopes of the South Tyne valley between other small natural exposures and quarries.

On Flinty Fell, within the south-facing slopes of the lower Ash Gill valley, the succession between Great and Little limestones is anomalous to that found elsewhere within the present area. The major sandstone in the middle of the succession is still present, but an additional sandstone unit is recorded at the base of the succession immediately overlying the Great Limestone. Such a sequence has not been reported from anywhere else within the Alston region (Clarke, 2007a). A thin coal is also present at the top of the succession. The strata can be summarised as follows:

	Thickness (m)
Little Limestone	
Siltstone with interbedded fine-grained sandstone (measures)	1
Coal	<0.5
Siltstone	~8
Sandstone, ganisteroid	4
Siltstone	4
Sandstone, flaggy	1.5
Great Limestone (?Main & Fossil posts)	

The best exposures though the lower part of this succession are to be found in a surface working on the Wellhope Knott Cross-vein [7738 4106]. Here, the Great Limestone is immediately overlain by 1 to 1.5 m of grey, flaggy, fine- to medium-grained sandstone. The top of the Great Limestone displays strong beds with few intervening siltstone partings, which suggests an absence of the Tumbler Beds with the sandstone resting directly on the posts. The presence of a strong sandstone unit on top of the Great Limestone has resulted in a wide flat bench feature into which a large number of deep sinkholes have developed. The presence of the sandstone seems to be conducive to sinkhole formation as these features are much more prevalent and more developed in the south-west-facing slopes of the Ash Gill valley than elsewhere within the area. Some of the larger sinkholes have developed through the overlying measures as well as the sandstone. In Hunter's Cleugh [7736 4068], a similar sandstone unit is evident immediately overlying the Great Limestone (although this does not appear to be the case in Ash Gill 500 m to the north) and large sinkholes are prolific in this area also.

Strata between the Great and Little limestones were penetrated by workings in Galligill Sike, Nentsberry (west), Gudham Gill, Bentyfield, Dowgang and Rampgill mines. In Galligill Sike Mine they attain a thickness of 21.3 m; 18.9 m were recorded from Rampgill Mine and 19.2 m were recorded from the remaining mines. In all cases no lithological details are available.

3.4.2 The Little Limestone cyclothem

The Little Limestone is the thinnest of the laterally continuous and regionally extensive limestones within the succession. It is also the youngest limestone within the Yoredale Group that can be correlated between exposures with a high degree of confidence. The Little Limestone crops out over the extent of the Ash Gill and South Tyne valleys, and the north-east-facing slopes of the Nent valley. It is cut out by displacement on the Carr's and Wellgill cross-veins (Section 4) over most of the south-west-facing slopes and occurs at surface only within isolated fault blocks.

The Little Limestone is typically a light grey, hard, fine-grained to crystalline 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 50-60 cm thick.

In the Ash Gill valley exposures of the Little Limestone are few. Small exposures of one or two 30-40 cm thick beds of light grey, fine-grained limestone overlying sandstone (White Hazle) in Black Ash Gill [7815 4134] and Stony Cleugh [7810 4092] demonstrate its presence. No further exposures are known within the Ash Gill valley and the outcrop of the Little Limestone has been interpreted from features and associated evidence, including workings on the underlying Little Limestone Coal on the south-west-facing slopes of Flinty Fell [7653 4120].

In Garrigill Burn, an east-bank tributary of the South Tyne River, approximately 2 m of limestone in three beds 60-70 cm thick are exposed forming a small waterfall [7584 4259]. Similar exposures are present in Souther Gill, a south-bank tributary of the Garrigill Burn, and in unnamed north-bank tributaries where the exposures are heavily iron coloured, possibly from their proximity to the Bentyfield veins. These exposures, coupled with the position of workings on the Little Limestone Coal [7838 4266] define the Little Limestone outcrop and correlate it across the Bentyfield veins.

On the north-east-facing slopes of the Nent valley, the Little Limestone is exposed in Dowgang and Galligill burns with secondary evidence for its presence in several other south-bank tributary streams of the Nent. In Dowgang Burn, small exposures of limestone can be seen in the north bank above coal workings on the Little Limestone Coal [7762 4316], and in Galligill Burn small exposures between the spoil and man-made structures of Galligill Sike Mine reveal two, 30-40 cm thick beds of light-grey limestone overlying sandstone [7570 4425]. Based on these exposures, a persistent, if weak, feature, and secondary evidence, the outcrop of the Little Limestone has been interpreted through the till-covered, north-east-facing slopes of the Nent valley.

In the upper reaches of the Nent valley, the Little Limestone is exposed in the river bed in two places as the Carr's Cross-vein repeats both it and the uppermost few metres of the Great Limestone cyclothem. In the northernmost exposure [7884 4268], 1.5 m of orange-brown weathered, fine-grained to crystalline limestone in thick (0.5 m) planar beds form a small waterfall. The limestone becomes arenaceous and softer upwards through the topmost 0.5 m. Many crinoid fragments and sporadic shells are present throughout. In the second, and most southerly, exposure [7876 4244], 1.6 m of brown weathered, fine-grained limestone in 50-70 cm-thick planar beds form, with the underlying White Hazle, a 2 m waterfall. In both these exposures, macrofossils of a large sponge-like body are conspicuous. This fossil is particularly indicative of the Little Limestone in the Alston region (Clarke, 2007a) and excellent examples may be seen within the exposures in the upper reaches of the West Allen valley, approximately 1.5 km north of the present area. Within the area, they have not been noted outwith the Nent valley.

In the south-west-facing slopes of the Nent valley the outcrop of the Little Limestone is largely cut out by displacement on the Carr's, Smallcleugh and Hansome Mea cross-veins (Section 4). In Rampgill Burn [7878 4341], a small exposure of approximately 3 m of dark-brown weathered limestone, in beds up to 1 m thick, demonstrates the presence of the Little Limestone at surface within the Smallcleugh – Mansome Mea horst (Section 4). These beds dip strongly by up to 30° into the Handsome Mea Cross-vein.

In Gudham Gill, the Little Limestone is again exposed at surface within the graben bounded by the Carr's and Wellgill cross-veins [7783 4487]. Here 2 to 2.5 m of brown weathered limestone in 30-70 cm-thick beds dip strongly towards the Wellgill Cross-vein. Macrofossils of large sponge-like bodies are conspicuous in this outcrop.

The Little Limestone is overlain by a siltstone-dominated succession up to 45 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 within the Nent valley of 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 upper reaches of the Nent valley, a sandstone unit 1.7 m thick forms a small waterfall over which the track to Flinty Fell Quarries passes [7888 4263]. It is a grey to white, hard, fine- to medium-grained sandstone in uneven beds 10-25 cm thick displaying a general reduction in bedding thickness upwards. In places it is quite ganisteroid, particularly towards the top but also displays weathering characteristics indicative of some calcareous content. This sandstone is approximately 7 m above the Little Limestone in the river section and most probably correlates with the 'Pattinson Sill' of the Nenthead Mines from which Dunham (1990) reports marine fossils and plant remains. Approximately 10 m of siltstone overlie the sandstone in the Nent river section, followed by another thin sandstone no more than 2 m thick that is exposed in Long Cleugh [7899 4261], Middlecleugh [7894 4252] and Old Carr's [7880 4250] burns; all tributaries of the Nent. It is probable that this sandstone correlates with the 'White Sill'* of Nenthead mines, where the uppermost beds are extremely fossiliferous (Dunham, 1990), and may well correlate with a similar sandstone recognised in the West Allen valley (Clarke, 2007a), although insufficient outcrop or subsurface data are available to demonstrate this conclusively. The remainder of the section overlying the White Sill is largely dark-grey, thickly laminated and commonly fissile siltstone.

In Dowgang Burn [7765 4302], one sandstone unit is recognised within the succession above the Little Limestone, although it is not possible to correlate this conclusively with either the Pattinson or White sills of the Nent section. Its outcrop has been interpreted over a short distance.

In the Ash Gill and South Tyne valleys, outcrop of the section overlying the Little Limestone is poor. The streambeds of Stony and Hunter's cleughs indicate a siltstone-dominated succession although with at least one thin sandstone unit that can be correlated over the short distance between the two streams, and with exposures in Black Ash Gill, 350 m north, on the basis of landscape features. In the south-west-facing slopes of the Ash Gill valley a reasonably strong feature at a similar stratigraphical position and secondary evidence suggests the outcrop of a laterally equivalent sandstone, although the evidence is too circumspect to correlate the two directly.

The Little Limestone and overlying strata were penetrated by workings of the Galligill Sike, Nentsberry (west), Bentyfield, Middlecleugh (Upper Level) and Rampgill mines. Measurements taken in these mines (Dunham, 1990) appear to show a thinning of both the Little Limestone and sandstone units within the overlying strata towards the south-west. The maximum thickness of the Little Limestone is 5.5 m in Rampgill with thickness of 3.7 m and 3.0 m recorded in Dowgang and Nentsberry (west) mines respectively. In Bentyfield and Middlecleugh mines the thickness is only 1.8 m and 1.5 m respectively (Dunham, 1990).

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 Alston Moor it is lithologically quite distinctive and, combined with the lithofacies immediately above and below, has been used as a correlation marker unit (Clarke, 2007a).

The Firestone Sandstone was mapped over the whole of the present area during the primary survey. It is a laterally extensive, channel sandstone, 10 to15 m thick, with varied characteristics reflecting the physical and temporal position of the exposures within a migrating and evolving channel. Within the present area it is largely poorly exposed with the exception of within the south-west-facing slopes of the Nent valley. The best exposure through the unit is at Firestone Bridge [7885 4353], approximately 500 m east of Nenthead, and 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 several centimetres. This is succeeded by an orange to brown, reasonably well cemented, very coarse-grained 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,

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

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. (Section 3.4.3) across the Patterdale Cross-veins.

In Gillgill Burn [7880 4390], 350 m north of Firestone Bridge, a similar section of cross-bedded, medium- to coarse-grained sandstone forms the steep river banks and a small waterfall. Above the waterfall, the unit, which forms the river bed, becomes more planar-bedded. Just below the waterfall the base of the sandstone is exposed in the south-east bank and demonstrates extensive down-cutting into the underlying siltstone and a thin coarse- to very-coarse-grained channel lag of rounded and poorly cemented quartz grains. This unit is again the Firestone Sandstone, exposed here in the footwall of Scaleburn Vein.

Two further exposures through parts of the Firestone Sandstone are recorded in the south-west-facing slopes of the Nent valley. Although these exposures do not provide extensive sections, they do allow correlation of the unit within the Nent valley and therefore permit correlation of much of the Namurian strata across the many faults of the area.

At Dykeheads [7801 4442] a deeply incised north-east-bank tributary of the Nent cuts down through a small gorge exposing brown to orange, medium- to coarse-grained sandstone in 5-10 cm thick beds. The beds become thicker downwards and display cross-bedding. A flecked appearance is evident on fresh surfaces. This section represents exposure of the middle and upper parts of the Firestone Sandstone, here thrown down in a graben formed by the Carr's and Wellgill cross-veins (Section 4).

In the north-west bank of Old Carr's Burn [7867 4229], at the head of the Nent valley small exposures of similar cross-bedded, medium- to coarse-grained sandstone can be found above an adit and large spoil heap. The adit probably gave access to workings of Middlecleugh Mine and marks the base of the Firestone Sandstone in the hanging-wall of the Cowhill Cross-vein.

To the north of the present area, exposures of the Firestone Sandstone with lithological characteristics similar to those seen in the Nent valley are aligned approximately north – south, whilst exposures to the east and west are not so uniquely characteristic and somewhat similar to younger Namurian sandstones. Clarke (2007a) tentatively suggested that this alignment indicates 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. The exposures of the Nent valley fit this hypothesis. However, it should be treated with caution as outcrop data are not sufficient to permit a regional palaeocurrent analysis to test it.

In the Ash Gill valley, exposures of the Firestone are few and limited to Black Ash Gill, Stony Cleugh and Hunter's Cleugh. In all cases the streams have cut down through extensive peat deposits to flow over the upper surface of a sandstone unit that is interpreted to be the Firestone Sandstone. Throughout the remainder of the valley, the outcrop of the Firestone is interpreted from a strong and persistent, flat-topped feature, commonly accompanied by blocks of medium- to coarse-grained sandstone at surface.

In the South Tyne valley, exposures of the Firestone are limited to Browngill Burn [7611 4238] and Garrigill Burn [7608 4265]. Both show medium-grained sandstone with similar lithological characteristics to exposures within the Nent valley, although those in Garrigill Burn also display ganisteroid textures towards the top of the unit and, at 2 m to 4 m thick, are considerably thinner that those in the Nent valley.

A thin sequence of measures containing a coal overlie the Firestone Sandstone in many parts of the Nent valley to complete the cyclothem. Formerly, this coal was worked at Nenthead where its thickness reaches 46 cm (Dunham, 1990) and the evidence of old workings can be seen at Gillgill Burn and the north-west-facing slopes of Allendale Common [7878 4398]. 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 18 km north of the present area. Outwith the present area, there is strong evidence in places for a coal underlying the Firestone Sandstone (Clarke, 2007a). No evidence for such a deposit has been recorded within the present area.

The Firestone Sandstone was penetrated by the workings of Galligill Sike, Nentsberry (west), Bentyfield, Middlecleugh (Upper Level) and Rampgill mines. Measurements of thickness taken in these mines show a south-westwards thinning of the unit commensurate with that observed in surface exposures and with that of the Little Limestone (Section 3.4.2). The Firestone Sandstone is at its thickest in Rampgill (11.6 m) and Nentsberry (west) (10.1 m) mines and thins to 1.8 m in Bentyfield Mine.

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 overlying the Firestone Sandstone. Consequently, the description of the remainder of the Stainmore Formation that is exposed within the present area 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 north-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 Rampgill Mine in the north-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 region (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 valley.

Within the present area, only one exposure of the Crag Limestone or its equivalent shell bed is known. In Gillgill Burn [7898 4395], in the Nent valley, a small waterfall 1.5 m high exposes 1.2 m of brown, fine- to medium-grained sandstone in beds 20 cm thick. The exposure becomes increasingly calcareous and ganisteroid towards the top, and it overlain by approximately 30 cm of arenaceous limestone containing many shells. This exposure probably represents the most westerly outcrop of the Crag Limestone on Alston Moor. Exposures of the same stratigraphical interval to the west tend to comprise shelly and sometimes calcareous sandstone (Clarke, 2007a).

In the Ash Gill and South Tyne valleys, the section overlying the Firestone Sandstone is extremely poorly exposed and no thin limestones or fossiliferous sandstones have been noted at this stratigraphical level.

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, and Ash Gill valleys attest to a measures-dominated sequence (siltstone interbedded with thin fine-

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

grained sandstone) in which up to six 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 sandstone units between valleys.

One of the most continuously exposed sections through the lower part of this succession can be found in Gillgill Burn [791 439], and through the upper part in Long Cleugh Burn [796 421]. The following is summarised from both:

	Thickness (m)
Limestone (Lower Felltop)	
Sandstone, soft	0.8
Siltstone	~8
Sandstone	7
Siltstone	5
Sandstone, fine to medium grained, cross-bedded	9
Siltstone, dark thin bedded and fissile	~25
Limestone (Crag Limestone)	0.3
Sandstone, brown fine to medium grained, calcareous	1.2
Coal	-
Measures (siltstone interbedded with fine-grained sandstone)	2
Sandstone (Firestone Sandstone)	

Approximately 25 m of dark, thinly bedded and fissile siltstone are exposed in the Gillgill Burn above the Crag Limestone. At Coalcleugh, approximately 2 km north of this locality and 1 km north of the present area, two thin beds of soft, fossiliferous sandstone have been noted within this sequence. These beds are prevalent throughout the North Pennines and are known as the Knucton Shell Beds (Carruthers, 1938). No such beds are recorded in Gillgill Burn, although the sequence was not examined in detail.

The two major sandstone units that lie above the Crag Limestone within this succession probably correlate with the Low and High 'Slate sills' recorded in the Rampgill workings where they are 10.7 and 9 m thick respectively, separated by 3 m of siltstone. In parts of the North Pennines a coal has been reported on top of either or both of the Low and High Slate sills and small-scale workings on the south-west-facing slopes of Black Hill [791 443], 400 m north of Gillgill, may have been for coal. These workings do not coincide with any known mineralised structure. A coal is also recorded at this stratigraphical level within the West Allen valley in Backstone Burn [7860 5549], and may possibly correlate with one around the same stratigraphical level at Rookhope.

At Rookhope, the High Slate Sill and coal are overlain by siltstones containing at least one, but commonly more, shelly and calcareous sandstone units known as the Rookhope Shell Beds. A section at or about the same stratigraphical level has been reported in Dowgang Hush by Dunham (1990):

	Thickness (m)
Sandstone, grey and flaggy	1.3
Siltstone, dark and sandy	0.3
Sandstone, grey with shells	0.2
Siltstone, grey and sandy	1.8
Sandstone, soft, brown and shelly	0.7
Siltstone, grey, with iron nodules	3.9
Sandstone, flaggy	1.5
Siltstone, dark	3
Sandstone, brown, hard and medium grained	1.5
Siltstone, dark	2.4
Sandstone, brown, some plant remains	1
Siltstone, sandy	6
Sandstone, brown medium to course grained and flaggy	2.7
Siltstone, inc. Knucton Shell beds (not seen)	~25
Sandstone (Firestone Sandstone)	

This section is overgrown now and is inaccessible. However, it is probable that the lowest two sandstone units correlate with one or both of the Slate Sills of Nenthead, although appreciably thinner, and the remainder of the succession represents the Rookhope Shell Beds.

The successions at Dowgang Hush and Long Cleugh Burn culminate in siltstone in which ironstone nodules have been reported, followed by a thin, soft sandstone that directly underlies the Lower Felltop Limestone.

On the west-facing slopes of Nag’s Head Hill, two sandstone units are recognised within the succession between the Crag and Lower Felltop Limestones. These units form strong, flat-topped benches which can be easily correlated across several major faults with the Low and High Slate sills at Rampgill. Small quarries are present in both units close to Perry’s Dam [788 415] although these are overgrown today and no exposure remains.

In the south-facing slopes of Ash Gill four principal sandstone units are recognised within the sequence with a fifth interpreted to crop out over a short distance. The last [763 413] represents the lowest sandstone in the succession between the Crag and Lower Felltop limestones in this valley and comprises an orange to white, well-cemented, medium- to coarse-grained sandstone in poorly defined and uneven beds approximately 50 cm thick. Some cross-bedding and small channels are evident and the upper beds are highly ganisteroid.

The third principal sandstone (and second below the Lower Felltop Limestone) is currently worked on the south-facing slopes of Flinty Fell at Flinty Fell Quarry [769 417]. The unit is planar-bedded in thick beds towards the base but becomes cross-bedded and flaggy upwards culminating in siltstone with a thin, planar-bedded sandstone unit. The base of the unit is seen in the floor of the quarry and is underlain by siltstone. The following section is taken from Flinty Fell Quarry:

	Thickness (m)
Peat	1.5
Till, stiff clay with matrix-supported boulders	1.5
Sandstone, thinly planar bedded in beds 5 cm thick	1.2
Siltstone, grey and sandy	10
Sandstone, strongly cross-bedded and flaggy	3
Sandstone with interbedded thin siltstones about 10 cm thick	1
Sandstone, two beds, cross-bedded with low angle foresets	1
Sandstone, thickly bedded up to 70 cm with thin (5 cm) siltstone partings	1.5
Sandstone, planar laminated with sporadic siltstone bed	1.5
Siltstone (underlying measures)	

In the South Tyne valley on the slopes of Middle Fell [753 432], the succession comprises siltstone interbedded with five thin but prominent sandstone units that form strong features within the hillside. These sandstones are rarely more than a few metres thick and poorly exposed. Small surface pits and excavations demonstrate their presence. A thin limestone within the lower part of the succession is also evident from surface workings and a limekiln. A limestone at this stratigraphical position is not noted elsewhere within the area, although it may be tentatively correlated with a thin unit of decalcified limestone, known locally as ‘famp’, observed by Dunham (1990) in Dowgang Hush.

Strata from the Crag to the Lower Felltop limestones were penetrated by Dowgang and Rampgill mines and are 73 m and 67 m thick in each respectively. No lithological details are available.

3.4.3.3 The Lower Felltop Limestone and overlying strata

The Lower Felltop Limestone is interpreted to crop out on the west-facing slopes of the Nent valley and the south-facing slopes of Middle Fell. Based on subsurface data it has been interpreted to crop out on Nunnery Hill.

In Long Cleugh Burn [7966 4213], on the west-facing slopes of the Nent valley, 1.3 m of grey, fine-grained limestone are exposed in the streambed overlying a soft sandstone and sandy siltstone. Both banks of the burn show extensive workings at this level, although these may be for ironstone known to occur in the underlying strata, rather than for limestone. No exposure in these workings remains today.

On Black Hill [793 443] in the Nent valley, quarry workings and a limekiln suggest the presence of reasonably well developed limestone, although there are now no surface exposures at this location.

Boreholes on Nunnery Hill proved ironstone in the underlying siltstone sequence, but the only evidence of the Lower Felltop Limestone appears to be 0.7 m of brown limestone reported by Dunham (1990) from two previous exposures on the north-east facing slopes. Both these sites are no longer exposed.

On the Summit of Middle Fell, the Lower Felltop Limestone is exposed in surface workings no more than 100 m from the western edge of the present area [749 440]. Here it comprises a grey, fine-grained limestone containing fossils of the alga *Girvanella* and associated brachiopods (Dunham, 1990).

A siltstone-dominated measures succession overlies the Lower Felltop Limestone and completes the Carboniferous stratigraphy exposed within the area. On the north-west-facing slopes of the Ash Gill valley and south-west-facing slopes of the Nent valley, four sandstone units are prominent these measures. The only near-complete section through this sequence is exposed in Long Cleugh Burn [796 422]:

	Thickness (m)
Summit of Nag’s Head	
Sandstone	2+
Siltstone	5
Sandstone, orange/white medium grained	3
Siltstone	~0.2
Coal	-
Siltstone	7
Sandstone	3
Siltstone	3
Sandstone	6
Siltstone	2
Limestone (Lower Felltop)	

Approximately 2 m of siltstone overlie the Lower Felltop Limestone, followed by a strong sandstone unit that has been worked in small quarries on Black Hill [7915 4458], although no exposure remains. The second sandstone in the succession has also been worked extensively on the summit Black Hill [7935 4446], near the county boundary of Cumbria with Northumberland. Here, small quarries expose a light-grey, medium- to coarse-grained sandstone in 6 cm to 20 cm thick beds. The bedding is very uneven and poorly defined, becoming more unevenly bedded and ganisteroid towards the top of the unit. There is some evidence of small-scale channels, although exposures are poor.

The overlying siltstone contains a coal that can be traced northwards from Long Cleugh Burn along the slopes of Killhope Moor by virtue of a prominent line of workings. The overlying sandstone is an orange to white, medium-grained sandstone bedded on the small (5 cm) to medium (15 cm) scale. The lowest beds are uneven and poorly defined; many show laminations on a 5 mm scale. The bedding thickness reduces upwards and the unit becomes flaggy towards the top. The remaining sandstone of the sequence that caps Nag’s Head Hill is unexposed and the evidence of its presence is a number of sandstone blocks on the summit.

On Nunnery Hill the Lower Felltop Limestone is overlain by approximately 15 m of measures in which two thin sandstones are prominent, the younger of the two forming the summit of the hill. A coal is also present in the siltstone sequence between the two sandstones.

4 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 – 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 30 m, cut the area in a generally rectilinear pattern and locally disturb the strata.

4.1 REGIONAL DIP AND FOLDING

The present area is dissected by major faults with displacements in the order of decametres and, as a result, the regional dip is somewhat difficult to separate from localised drag and rotation of fault blocks. However, a general trend to the strata can be elucidated from surface exposure and subsurface data. In general, strata of most of the south-western corner, including the Ash Gill and South Tyne valleys to the south-west of the Browngill Vein, dip gently by no more than 4° towards the north-east, levelling off to near-horizontal around Flinty Fell. To the north of the Browngill Vein, the strata of Nunnery Hill, Black Moss and Middle Fell are near-horizontal, becoming slightly north-eastwards dipping in the north-east-facing slopes of the Nent valley. The Nent valley, in the north-eastern corner of the area, is heavily dissected by major faults and stratal dips in this area are the result of displacement on these faults and generally localised. To the north-east of the Nent valley, on the slopes of Killhope Moor and Black Hill, strata dip gently towards the south-west by no more than 5°, levelling off towards the summits and the county boundary with Northumberland.

These regional dip trends define three main folds to the area. The Nent valley is centred on a low amplitude - long wavelength syncline, with an axis roughly parallel to the valley and defined clearly downstream to the north of the present area by regional dip trends (Clarke, 2007a; Dunham, 1990). Within the present area, the axis of this syncline is significantly disrupted by major faulting and overprinted by local fault-block drag. Strata to the north-east of the Nent valley syncline form a gentle anticlinal pericline centred on Wellhope Moor, approximately 1.5 km north of the present area (Clarke, 2007a), but the closure of this structure includes Black Hill in the far north-east of the area. A similar, gentle anticlinal pericline is centred on Middle

Fell, just off the western edge of the present area, and the closure of this structure defines stratal dips on Black Moss and Nunnery Hill.

4.2 FAULTING

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 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 5). The area around Nenthead is one of the richest parts of this orefield, and consequently numerous structures have been recorded and exploited. South-westwards, in the South Tyne and Ash Gill valleys, two areas of mineral-rich faults are known: the Bentyfield veins of Bentyfield Mine [7553 4256] in the South Tyne valley, and the Wellhope Knott and associated veins of Ash Gill Fields Mine [7584 4046], at the confluence of the Ash Gill with the South Tyne. A further structure, the Browngill veins, traverses Flinty Fell from the South Tyne valley to the Nent valley and links the centres of mining. This structure may have particular significance for the distribution of minerals within other structures of the area. (Section 5)

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).

4.2.1 Cross-veins

A number of north-west to south-east-trending cross-veins are recognised within the north-eastern half of 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 within the area occur in pairs with antithetic senses of displacement that result in intervening horst and graben structures.

4.2.1.1 THE NENTHEAD CROSS-VEINS

By far the most structurally complex part of the present area is the upper reaches of the Nent valley around Nenthead. A detailed cross-section of this area is presented with the geological standard map and reproduced here (Figure 4). This section is constructed principally from surface outcrop data but incorporates detailed measurements on the base of the Great Limestone from subsurface mining data (Dunham, 1990). Here, a number of cross-veins traverse the valley and form interlinked complex structures:

The Carr's – Wellgill Graben

Two major cross-veins, with antithetic senses of displacement and forming a graben are mapped in the lower reaches of the Nent valley (Clarke, 2007a), north of the present area. These structures penetrate onto the north-eastern corner of the present area and the resulting graben repeats the outcrop of the Firestone Sandstone in the south-west-facing slopes of the Nent valley around Dykeheads [780 455]. The effect of this structure on the strata of the area is best demonstrated in Gudham Gill [7782 4487] where the Little Limestone crops out in the stream bed within the graben and dips steeply to the north-east into the Wellgill Cross-vein. Exposures of the Great Limestone and the strong bench feature produced by this unit are clearly visible up the road to the west, within the footwall of the Carr's Cross-vein and topographically higher than the exposure of the Little Limestone.

A maximum throw on the Carr's Cross-vein of 77 m is recorded in Loveladyshield Level [7591 4614], north of the present area, and throw on this structure decreases south-eastwards, reaching 66 m at the northern edge of the area, and 25 m at Nenthead. It increases slightly to 30 m by Middlecleugh Burn [789 423] and then reduces to approximately 5 m at Nag's head [794 414]. The last of these measurements is based on surface interpretation of the cross-vein over the summit of Nag's Head, whilst the remainder were measured in subsurface workings (Dunham, 1990).

Throw on the Wellgill Cross-vein initially increases south-eastwards from the edge of the area, through Gudham Gill, to a maximum of 21 m between Whitehall [784 441] and Rampgill Mine [787 436]. From here, throw decreases south-eastwards to 12 m near Rampgill Burn [790 432] and the fault is interpreted to tip-out approximately 300 m south-east of the burn.

The variation in throw on these two structures locally affects the dip of strata within the graben. From the northern edge of the area, strata within the graben dip generally southwards towards a synclinal pericline against the Carr's Cross-vein in the vicinity of Gudham Gill. South-east of Gudham Gill, they dip generally east-north-eastwards into the same structural closure.

The Smallcleugh – Hansome Mea Horst

As displacement of the Wellgill Cross-vein decreases to the south-east of Gudham Gill, it is taken up by a similarly trending structure, the Hansome Mea Cross-vein, with an opposing dip orientation and sense of throw. This cross-vein and an associated structure, the Smallcleugh Cross-vein, are initially within the Carr's – Wellgill Graben and both disrupt the graben structure. The Smallcleugh Cross-vein has a south-westerly sense of throw and thus it generates a small horst with the Hansome Mea Cross-vein. The horst becomes more developed south-east of Nenthead.

The Smallcelugh and Hansome Mea cross-veins extend from Whitehall [784 441] south-eastwards to the eastern edge of the area at Nag's Head [794 414]. Throw on both structures increases towards the south-east, with a maximum throw of 15 m recorded on the Smallcleugh Cross-vein in the vicinity of Long Cleugh Burn [792 424] and 29 m on the Hansome Mea Cross-vein in the vicinity of Rampgill Burn [791 430]. Consequently, the strata of the horst dip gently to the north-west.

To the south-east of Smallcleugh Level [7875 4288] the strike of the Hansome Mea Cross-vein veers south-south-eastwards for a short time before returning to its former trend. This bend is the site of extensive flat mineralization within the horst (Section 5). As a consequence of strike variations in the Hansome Mea Cross-vein, the two faults converge and the width of the horst is no more than 100 m to the south-east of Long Cleugh Burn and over Nag's Head.

The Cowhill – Carr's Horst

Approximately 450 m to the south-west of the Carr's Cross-vein is a similarly trending fault known as the Cowhill Cross-vein. This structure extends from the Nentsberry Haggs Vein [7697 4530], approximately 300 m north of the present area, through the north-east-facing slopes of the Nent valley and over Nag's Head. The structure throws down towards the south-west and, with the Carr's Cross-vein, bounds a horst. Throw on the Cowhill Cross-vein is 14 m in Nentsberry Haggs Horse Level, at the northern edge of the present area. By Cowhill Level [7847 4316] it has decreased to between 6 and 9 m and by Longcleugh Vein [790 417] to 2.1 m. From here it increases to the south-east. Strata of the horst are near-horizontal to the north of Nenthead but dip towards the north-west in the area to the south of the settlement. The two faults converge to the south-east of Nenthead and the horst is no more than 250 m wide over Nag's Head.

Other cross-veins of Nenthead

A number of shorter cross-veins with significantly lower magnitudes of displacement cut the fault blocks of the Nenthead area.

The Rampgill Cross-vein, to the north-east of the Wellgill Cross-vein extends from the vicinity of Dykeheads [782 455] south-eastwards to west-facing slopes of Killhope Moor. Throw on this structure is at a maximum of 3 m between the Scaleburn and Rampgill veins [789 438] and decreases to both the north-west and south-east. The sense of throw is synthetic to the Wellgill Cross-vein (south-west) forming a fault block that ranges in width from 100 m in the north-west to 500 m in the south-east.

The Patterdale Cross-veins, a small number of short faults with throws of no more than 9 m, cut the fault block bounded by the Wellgill and Rampgill cross-veins in the vicinity of the Scaleburn and Ramgill veins [789 435]. They are significant for the effect they have on the outcrop of the Firestone Sandstone in this vicinity.

An unnamed cross-vein with a maximum throw of 16 m to the north-east, is known to cut the Smallcleugh – Hansome Mea Horst and the Carr's - Wellgill Graben where both structures are en-echelon near Whitehall [782 441]. This fault cuts the horst and graben blocks very obliquely and may represent an accommodation of stress where the two structures interact.

4.2.1.2 The Black Ashgill (and East) cross-veins and the Archer's Vein

The Black Ashgill Cross-vein extends from the vicinity of Blagill [740 470], approximately 2 km north-west of the present area, towards the south-east through to the north-west-facing slopes of the Ash Gill valley. The fault throws down to the south-west by increasing amounts south-westwards towards the Bentyfield veins [769 438], were it reaches approximately 18 m, and decreases thereafter to 12 m on Flinty Fell [789 420] and to zero within the north-west-facing slopes of the Ash Gill valley. From Flinty Fell towards the south-west, a subparallel-trending structure to the east, known as the Black Ashgill East Cross-vein, has an opposing sense of throw. The two faults bound a small horst that extends towards Nag's Head but by this point neither fault has a throw greater than a few metres.

On Flinty Fell, the east-west Browngill Vein, veers strongly towards the south-east and becomes the Archer's Vein. It approaches the Black Ashgill Cross-vein in the vicinity of the headwaters of the Ash Gill [781 416] and may even merge with this structure. On Flinty Fell, the throw on the Archer's Vein is 17 m to the north-east. Here, the Archer's Vein and Black Ashgill Cross-vein bound a significant graben.

4.2.1.3 OTHER CROSS-VEINS

The Jacob Teesdale Cross-vein is a westerly splay of the Black Ashgill Cross-vein that extends through the north-east-facing slopes of the Nent valley. Throw on this structure is towards the north-east and reaches a maximum of approximately 5 m near Galligill Burn [759 445], decreasing towards the south-east.

In the Tyne valley, the Old Groves Cross-vein is well known from subsurface workings of Bentyfield Mines where it throws down by no more than a few metres to the north-east. It crosses Garrigill Burn [751 425] with a north-west to south-east trend and links a number of veins in this area with the Browngill Vein.

4.2.2 Veins

North-east to south-west structures with generally small 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. Three clusters of veins can be recognised within the present area; Nenthead in the Nent valley, Bentyfield Mines in the South Tyne valley, and Ashgill Fields Mines in the Ash Gill valley.

The veins of Nenthead are clustered in two areas. At the head of the valley [790 420] a number of short structures with throws of no more than a few metres extend from both sides of the Nenthead cross-veins. In most cases, the veins are terminated by the cross-veins and are most prolific where the cross-veins die out.

Downstream, several short veins extend from either side of the cross-vein structures, but three major veins are known to cut the full stratigraphical interval that crops out with in the valley and interpreted to pass through the cross-veins, although with some offset. The most southerly of the three, the Rampgill Vein, extends from Killhope Head [800 442], on the eastern edge of the area, where it throws down by 9 m to the north-west and is marked by extensive surface workings, to Nenthead where it is known to cross the cross-veins. Between the Cowhill and Carr's cross-veins [783 434] the throw has increased to 18 m and the vein repeats the outcrop of the Great Limestone in the River Nent. To the south-west of the Nenthead cross-veins, the Ramgill Vein is known as the Brigal Burn Vein and it extends as far as Nunnery Hill [769 426], crossing the Black Ashgill Cross-vein where it is slightly offset to the south.

Approximately 500 m to the north-west of the Rampgill Vein, the Scaleburn Vein throws down to the south-east by no more than 1.3 m. It may cross the Nenthead cross-veins as a number of related minor faults to connect with the Dowgang Vein on the south-western side of Carr's Cross-vein, here with a throw of 3 m to the south-east [779 433].

Approximately 1 km to the north-west of the Scaleburn Vein, in the vicinity of Well Gill [780 444], the Gudhamgill Vein extends north-eastwards from the Wellgill Cross-vein and throws down by 2.7 m to the north-west. This structure may extend across the Carr's - Wellgill Graben to connect with the Greengill [777 443] and Bentyfield veins to the south-west, although the presence of a fault within the graben has never been proved.

In the Ash Gill valley, the Wellhope Knott Vein runs subparallel with the valley from the confluence of the Ash Gill with the South Tyne [756 401], crossing Ash Gill near Ashburnside Plantation [7668 4077] and again at the head of the valley. It has a small north-westerly throw of no more than 2 m, based on surface outcrop. The subsurface throw is not recorded. Surface workings on the vein mark its course across the lower slopes of Flinty Fell. A subparallel structure, the Potato Garth Vein is present 50 m to the south-east with a similar small north-westerly throw. This vein crosses the South Tyne to become the Crossgill Vein. Its course is clearly evident in the riverbed [7558 4012] where it juxtaposes the Tynebottom Limestone in the hanging-wall block against the underlying strata of the Jew Limestone cyclothem in the footwall block.

In the South Tyne valley, two parallel veins are known to extend from Garrigill Burn [756 425] north-eastwards across Black Moss. The Bentyfield Sun Vein, the southerly of the two, has a small north-westerly throw and extends no further than the summit of Black Moss [763 431], but the Taylor Sike Vein, the northerly of the two, extends north-eastwards, becoming first the Bentyfield Vein and then the Greengill Vein before reaching the Carr's Cross-vein at Well Gill. It may cross the Carr's - Wellgill Graben to become the Gudhamgill Vein. It has, in general, a north-westerly throw of a few metres. However, on the summit of Black Moss the Bentyfield Vein splays into two parallel branches for 750 m metres of its course, each with a north-westerly throw of up to 6 m.

4.2.3 Quarter-point structures

It is a matter of debate as to whether the Browgill Vein and its southerly splay, the Browngill Sun Vein can be classified as quarter-point structures in the same sense as those described in the Alston (Blagill) area (Clarke, 2007a). They may have more in common with cross-veins, particularly the amount of throw. Nevertheless, the Browngill veins do exhibit an east - west trend and are somewhat of a curiosity. There is good reason to regard them as one of the principal channels of mineralisation within the district (Dunham, 1990).

The Browngill Vein extends from the western edge of the present area [750 419], eastwards over Flinty Fell before veering significantly to the south-east and becoming the Archer's Vein. It throws down to the north by 13 m at the edge of the area, increasing to 18 m by the summit of Flinty Fell and reducing eastwards and south-eastwards thereafter. The Browngill Sun Vein splays from the main vein on the summit of Flinty Fell and continues westwards towards the South Tyne on a roughly parallel trend. The throw on the Sun Vein is no more than 4 m towards the north.

Extensive subsurface data from workings on the Browngill Vein indicate a significant amount of normal drag in both the hanging-wall and footwall that manifests itself in the outcrop pattern on the west-facing slopes of the South Tyne valley. Here, a third and unnamed fault, running subparallel to the veins and with the same sense of throw is interpreted based on the surface outcrop of the Great Limestone.

4.2.4 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.

In the north-east-facing slopes of the Nent valley, in the vicinity of Galligill Burn a number of faults are shown in the subsurface for which no surface positions are interpreted. These faults are known from the workings of Galligill Sike Mine [7573 4430] and Hudgill Mine, just of the northern edge of the present area. Similarly, in the vicinity of Overwater [778 436], the subsurface positions of a number of faults worked from the Nenthead Fields Levels [7787 4372 and 7772 4389] are shown with no surface position interpreted.

All of these faults have small throw and there is no evidence at the surface for their positions, if they penetrate to the surface at all. However, these structures have been of great economic importance as they carried some rich ore-shoots locally. For this reason they have been depicted in the subsurface on the current survey standard maps.

5 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, quartz, calcite and ankerite are common throughout the area. The principal economic metaliferous minerals are galena, sphalerite and iron sulphide minerals, found in association with gangue minerals of fluorite, 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 present area lies on the outer edge of the fluorite zone and within a rich zinc zone (Figure 5).

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 been depositied from mineral rich fluids circulating within 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 4) 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.

Cross-veins exhibit a similar relationship of dip to wall-rock competency (Section 4) but regionally they are rarely mineralised. Significant displacement on these structures entrains 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 mineralization 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 4).

Flat mineralisation represents metasomatic replacement of 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, mineralisation with veins and flats is extensive. The most productive flats have been within the Great and Four Fathom limestones but many veins carry mineralisation at higher stratigraphical levels as well. Notable examples include the Ramgill Vein [795 439], in which ancient workings can be found within higher strata, both in the subsurface and at surface on Killhope Moor, and the Middlecleugh veins [789 421] where the London Lead Company explored strata of the Stainmore Formation and on which there are more ancient surface workings in strata above the Firestone Sandstone.

Contrary to general observations of the North Pennine Orefield as a whole, the cross-veins of Nenthead, within present area, are significantly mineralised and have extensive flat deposits within the associated structures they bound. The scientific reasons behind this anomalous situation are poorly understood but may relate to the complex structure and loci of stress within the area, such as is demonstrated by the association between extensive flat mineralization within the Smallcleugh – Hansome Mea Horst and significant bends in the Hansome Mea Cross-vein, and possibly to the proximity of the Browngill structures which may have acted as one of the main migration pathways for mineralising fluids (Dunham, 1990). The area warrants further investigation in this respect as the mineralisation of the cross-veins makes it one of the richest parts of the North Pennine Orefield.

5.1 EXPOSED MINERALISATION

The present area contains two of the best exposed examples of mineralisation that can be seen at the surface within the Alston region.

Within the upper Nent valley, the Carr’s Cross-vein crosses the headwaters of the River Nent and truncates the outcrop of the Great Limestone. In the base of the waterfall [7859 4303] a large number of small fractures are evident, filled with galena deposits that can reach several centimetres in width. These mineral-filled fractures (or ‘stringers’) are associated with the main structure of the Carr’s Cross-vein approximately 70 m upstream.

At Firestone Bridge [7883 4353] the outcrop of the Firestone Sandstone is traversed by the Rampgill Vein. The weakness of the fault zone has been exploited by a small stream and at times of low water, particularly after high levels of run off, the narrow fault zone with mineralisation can be seen in the base of the stream.

5.2 SUBSURFACE AND SECONDARY EVIDENCE

Many of the main levels for the mines of Nenthead are still accessible and provide excellent opportunities to view mineralisation in situ within the subsurface. Smallcleugh Level [7875 4288] in particular provides access to the Great Limestone within the Smallcleugh – Hansome Mea horst where extensive flat mineralisation has been worked. Stoped-out areas in the high, middle and low flats of the Great Limestone display excellent crystalline examples of galena, sphalerite, quartz, ankerite, calcite, and other carbonate minerals within the wall rocks. Workings on the Hansome Mea Cross-vein also display excellent structural relationships within the subsurface that help to define the complex structure at surface.

The section of the river Nent, downstream of the Great Limestone [7860 4302] is usually choked with extensive tracts of cobble and boulder-grade alluvium containing many examples of mineralisation. Galena, sphalerite, quartz and calcite are abundant, along with many good examples of the iron sulphide minerals that are less common at other localities of within the Alston region.

Spoil heaps of the upper Nent valley provide excellent opportunities to observe many of the minerals worked from the subsurface. In addition to the main minerals of the Orefield, examples of the ‘drybone’ variety of smithsonite (zinc carbonate) can be found from the tips in Old Carr’s Burn [7875 4360].

Extensive tracts of waste rock, spoil and minerals can be found along the length of the Browngill Vein across Flinty Fell. Most of these deposits contain ankerite, sandstone and limestone, commonly displaying a dark red to brown colour from the oxidisation of iron minerals within them. Quartz and small specimens of galena are also present.

Early exploitation of minerals within veins and cross-veins within the present area was undertaken from the surface. Lengthy surface exposures of veins were worked to form wide, open-cuts within the landscape known as ‘hushes’. The hushes follow the course of the vein at surface and provide both good evidence of economic mineralization and geological evidence of the position of structures. The main hushes with in the area are described under Section 7.2.1 – Worked ground.

6 Superficial deposits

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

6.1 GLACIAL TILL

Late Devensian glacial till blankets much of the bedrock of the area and is up to 15 m 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, 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. 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 and implies at least some pre-existing expression of the present day topography prior to the last glaciation.

Within the area, till is present at surface on the north-east-facing slopes of the lower Nent valley and the South Tyne valley. Till may also be present on the north-east facing slopes of Flinty Fell, in the upper Nent valley but is obscured by extensive peat deposits. Exposures at Flinty Fell Quarry [769 417] indicate at least 1.5 m of till on these slopes. On the west-facings slopes of Nag’s Head Hill [788 412] extensive peat deposits are also present but exposures in stream sections show that these deposits are sitting directly on bedrock and no till is present.

The till is generally dark blue-grey, silty, sandy clay, with sporadic orange oxidisation speckles, possibly resulting from the weathering of sandstone gravel within it. It has a yellow to pale grey upper weathering profile, and is stiff to very stiff with matrix-supported, subrounded clasts of limestone and sandstone, presumably of local origin, and with a few lenses of sand gravel, and some clay-rich layers.

6.2 ALLUVIUM AND ALLUVIAL TERRACES

The valleys of the Ash Gill, Nent, and the South Tyne upstream of the Potato Garth Vein, all show modern day alluvial deposits, as do many of the minor streams draining the hillsides. 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 and in the lower reaches of the Ash Gill valley.

Holocene river terraces are best developed in the South Tyne valley and to a lesser degree in the Ash Gill valley. In general, terraces show normal grading from cobbles and boulders, overlain by sand and silt, the latter representing flood plain deposits. In the South Tyne valley, two levels of terraces can be identified. These have been mapped individually on fieldslips and correlated within the confines of the valley but are shown as undifferentiated alluvial terrace deposits on the standard map, with the back-scarp features of individual separate terraces depicted.

6.3 PEAT

Extensive areas of Holocene peat are present on many of the moorland hilltops 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 1 m thick were delimited and mapped using extensive augering. Areas of thinner peat cover were also indicated on fieldslips.

Extensive areas of peat are present on Killhope Head, Nag’s Head, Flinty Fell, Black Moss and Middle Fell. On Flinty Fell, quarry activities have exposed 1.5 m, and on the lower slopes of Nag’s Head [788 412], streams expose over 2 m of peat sitting directly on bedrock. On the summits of Nag’s Head, Knoutberry Hill and Black Moss extensive peat hags have developed as a result of wasting.

7 Mass-movement and Artificial deposits

7.1 LANDSLIDE

In contrast with much of the lower Nent valley, to the north of the present area, where landslides are prevalent, few landslides are recorded in the present area. This is probably a reflection of the immaturity of the streams combined with the lack of outcrop of highly permeable strata in the lower slopes of the valleys.

Only one area of sliding is of note. In the north-east-facing slopes of the Nent valley, at the northern limit of the area, two small slips have developed in superficial deposits, probably as a result of a spring line developed at the base of the permeable Four Fathom Limestone that crops out here. These slips represent the southern limit of an extensive area of slips developed in till over the same bedrock on NY74NE to the north.

7.2 ARTIFICIAL GROUND

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

7.2.1 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, no commercial-scale extraction of limestone has taken place but numerous small quarries are present. Most contain limekilns as the principal function of these quarries was to produce lime for fertiliser, as a flux for iron smelting, and as mortar. Examples can be seen on Black Hill in the Lower Felltop Limestone [7928 4440] and on the south-facing slopes of the Ash Gill valley [7610 4094] in the Great Limestone.

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. One large, commercial quarry, Flinty Fell Quarry [771 417], is currently operating in one of the sandstones between the Crag and Lower Felltop limestones, on the south-facing slopes of Flinty Fell. This quarry is operated by the Alston Stone Company based in Alston, and provides local stone for building and restoration. The extension and restoration of the old mine shop at YHA Ninebanks [7715 5138] in the Mohope valley, 6.5 km to the north of the present area, employed stone from this quarry.

Coal workings, most notably on the coal seam above the Lower Felltop Limestone, but also on seams of the Great and Little limestone cyclothems generally result in mappable areas of made ground (spoil and waste) rather than areas of worked ground. However, some worked areas are present, notably in the coal seam underlying the Crag Limestone to the north-east of Nenthead [7878 4398].

The surface working of minerals from mineralised faults was common practice in the early stages of exploitation. These workings have resulted in deep, and often wide, groves cut along the length of the fault known as 'hushes', many of which are of a scale that is mappable. Small-scale examples can be seen on Killhope Moor [7950 4394] where much of the surface course of the Rampgill Vein has been worked, and in the south-facing slopes of the Ash Gill valley where two short surface workings [7700 4091; 7736 4105] are present where the Wellhope Knott Vein crosses the outcrop of the Four Fathom and Great limestones. Within the area, three deep and extensive surface mineral workings are recorded. In the north-east-facing slopes of the Nent valley, near Nenthead, Dowgang Hush [775 430] is a 600 m long, 10 m to 15 m deep excavation on the Dowgang and Brigal Burn veins. On the north-east-facing slopes of Black Moss, Greengill Hush [768 436] is a 400 m long and 10 m deep working on both branches of the Bentyfield Vein. Further up the hill on the summit of a Black Moss [764 433] is a second 400 m long excavation on the same vein structure.

7.2.2 Made ground

Most made ground deposits within the area relate to mineral waste heaps from mining activities or coal spoil. With the exception of those within the Nent valley, most of these are small and associated with shafts, worked veins, or along the length of major coal outcrops, mainly that above the Lower Felltop Limestone but also seams of the Great and Little limestone cyclothems.

Within the Nent valley, extensive areas of made ground exist to the north, east and south of the town. To the north, on both sides of the river, extensive spoil heaps were landscaped and consolidated during the 1980s in an attempt to stabilise them and to improve the environment. The spoil heaps were smoothed off and covered in top-soil, grass and small trees. At the same time, the course of the river Nent through these deposits was engineered and lined with local stone to create a manmade channel and presumably to prevent the river undermining the spoil heaps. The lining stones are large blocks of limestone and sandstone. The prolific examples of the trace fossil *zoophycos* within these blocks suggest that their most likely origin is strata around the level of the Great Limestone (Tumbler Beds).

To the south of Nenthead, extensive areas of spoil are still present within the tourist attraction of Nenthead Mines and further upstream. These deposits are untreated and, in the main, poorly consolidated and not vegetated.

To the east of Nenthead, a further extensive area of spoil and tailings exists, generally spread evenly over the ground between the A689, the unclassified road over the Northumberland border to Coalcleugh, and Gillgill Burn [788 436]. Much of this area is now covered in coniferous woodland.

8 Economic geology

8.1 MINERALS

Substantial tonnages of lead ore were raised from the veins of the present area during the 18th and 19th centuries. There is little prospect for renewed economic extraction as remaining deposits are low grade and expensive extract compared to other reserves worldwide. However, there has been recent renewed interest in the zinc potential of the Nenthead area as potentially economic deposits may exist as vein and flat mineralization within limestones of the lower Visean strata below the Five Yard Limestone. These prospects were not tested or exploited by previous mining activities.

8.2 COAL

All former coal working within the present area was small scale and largely undertaken for subsistence purposes. The coal seam above the Lower Felltop Limestone appears the most extensively worked, particularly on Killhope Head [797 435] and Nunnery Hill [767 428]. There may be further reserves of this seam on the west-facing slopes of Nag’s Head [794 417] where the same stratigraphical level remains untested, although any reserves are not going to be commercially viable.

8.3 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 mineralisation within the limestones 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.

Flinty Fell Quarry has a licence to extend sandstone extraction to the east and west of the current quarry, securing reserves for a number of years to come. However, these reserves are ultimately limited by the Browngill and Archer’s veins and the dip on the strata will increase towards both. The east end of the present quarry already displays increased dips towards the Archer’s Vein.

8.4 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.

9 Environmental issues

9.1 LANDSLIDING

Although there is evidence of landsliding within the Nent valley at the northern limit of the present area, this is small-scale and involves only the superficial deposits. It is unlikely that landsliding poses a significant environmental threat.

9.2 COAL MINING

All of the former coal mining within the district was small scale. Most was extracted from thin seams below strong limestone or sandstone 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 because it has been supported by man-made structures that have decayed.

9.3 MINERAL MINING

The outcrop of many of the mineral veins and the sites of former mines are covered extensively in abandoned shafts, many of which have collapsed or are poorly backfilled. 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 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. Those on the Rampgill Vein [7950 4394] on the north-west-facing slopes of Killhope Head are good examples.

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 deposit cover exists and the adit entrance is supported by man-made structures that have decayed.

The large spoil heaps of the Nent valley have the potential to collapse, especially those of the upper valley where they can be undermined by the river during times of flood.

9.4 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, those of Nenthead are of note.

The former mining centre of Nenthead contains many large spoil heaps. Although the large heaps within and to the north of the town have been stabilised and vegetated, those of the upper valley regularly contribute waste to the river Nent. This is evidenced by the large number of mineral specimens within the alluvium. Spoil heaps to the east of the town, in the region of Firestone Bridge [788 436] are also heavily undermined by the Gillgill Burn and regularly contribute mineralised waste to the Nent via this tributary.

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 at Nenthead, particularly the Caplecleugh [7811 4349] and Rampgill [7815 4351] horse levels which are issuing water at the time of the present survey.

9.5 CONSERVATION AND TOURISM

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.

The tourist attraction of Nenthead Mines provides public interpretation of industrial mining heritage and underground tourist tours of the Carr’s Level workings [7851 4317]. The centre also undertakes archaeological investigations into many of the ruined mining structures of the valley. However, there remains significant potential for public interpretation of the geology of the upper Nent valley which is thus far under-exploited. The river section between Nenthead and Old Carr’s Burn provides excellent opportunities to view some classical sections through the stratigraphical intervals of most significance to the former mining activities, particularly the Great Limestone where examples of the *Chaetetes* Band and vein mineralisation can be found that are unsurpassed locally. Many exposures elsewhere within the site also offer good views of particular aspects of North Pennine geology.

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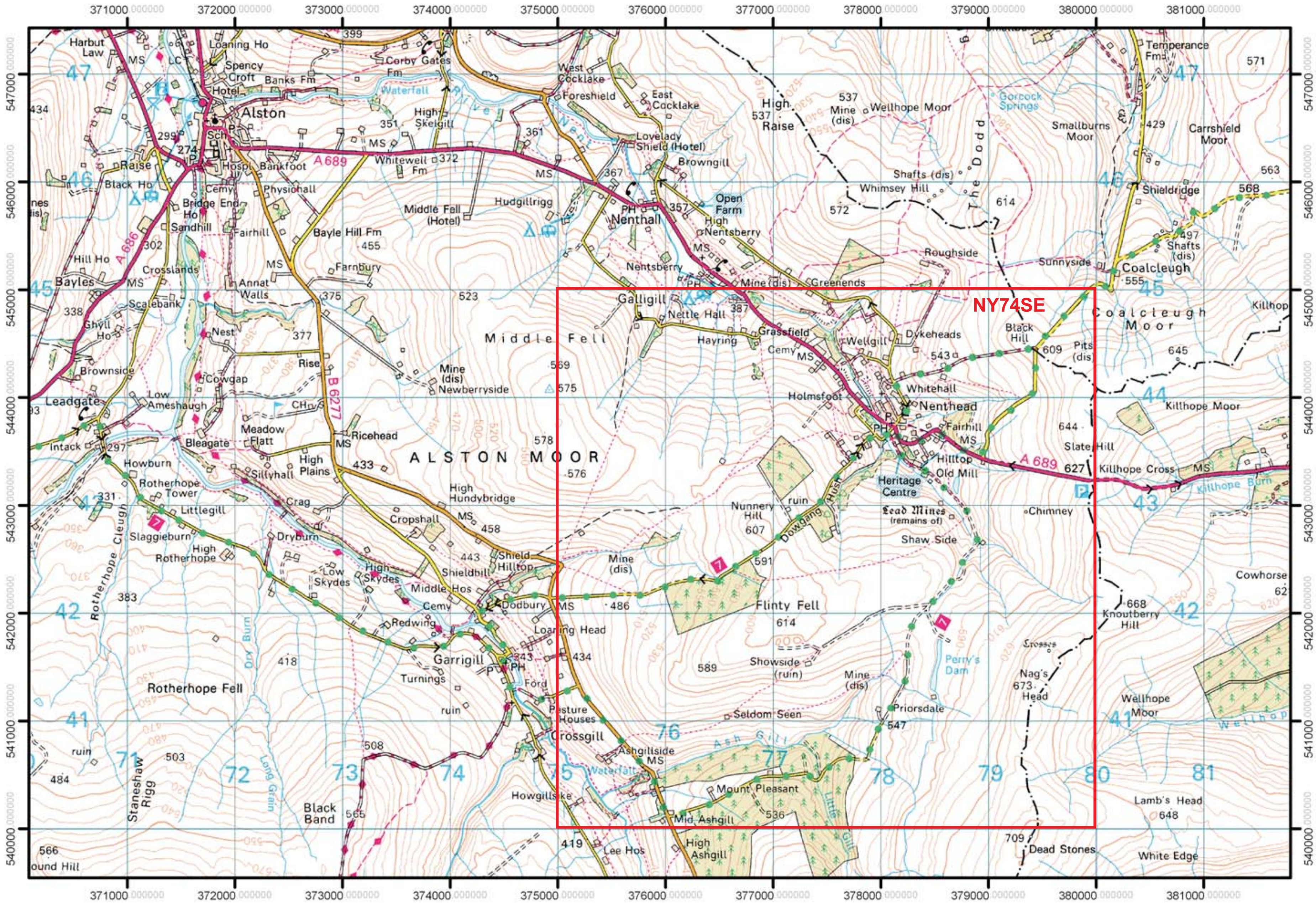

Figure 1. The geography of the area and the 1:10 000-scale sheet covered by this report

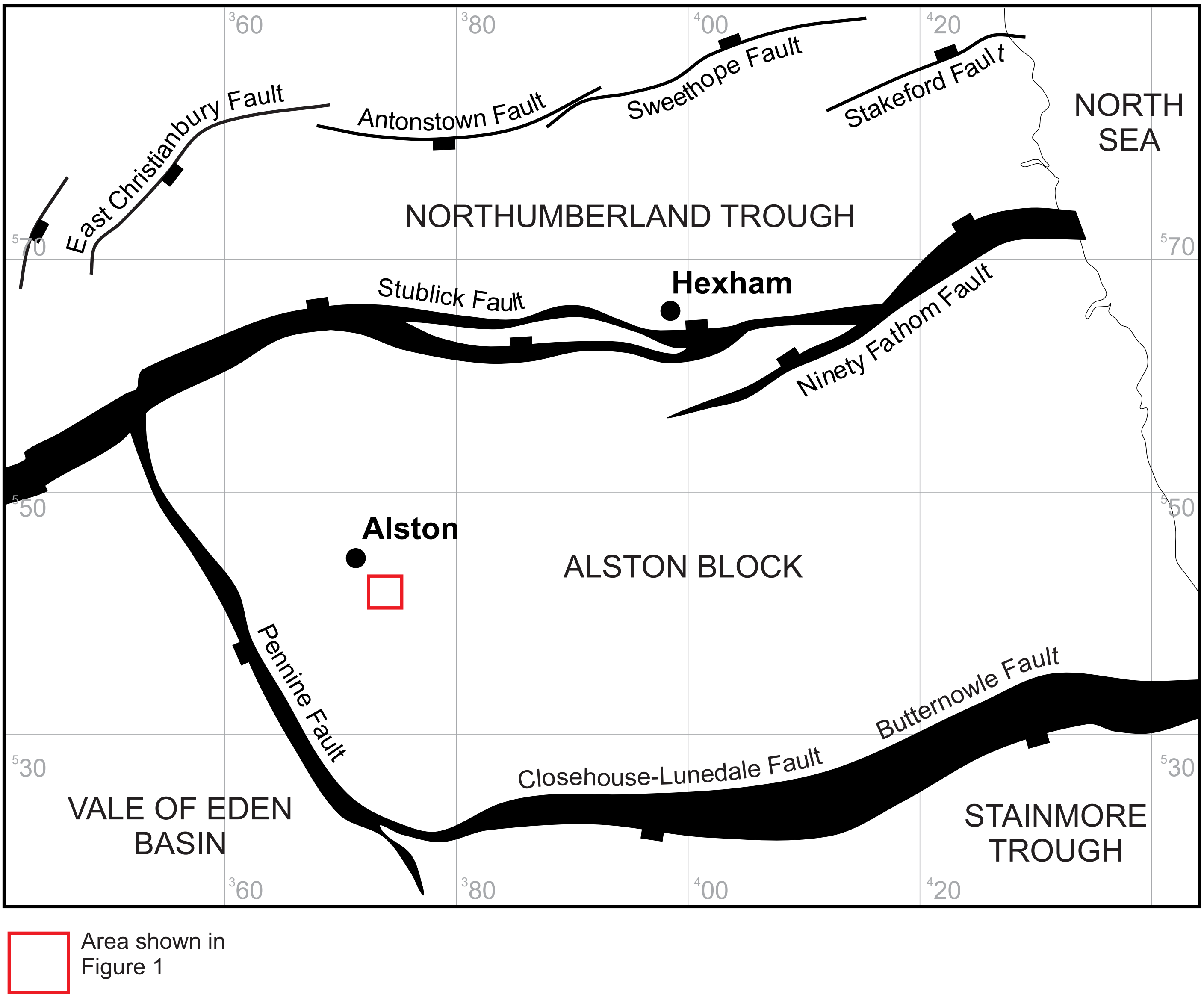

Figure 2. The regional structural geological setting of the study area

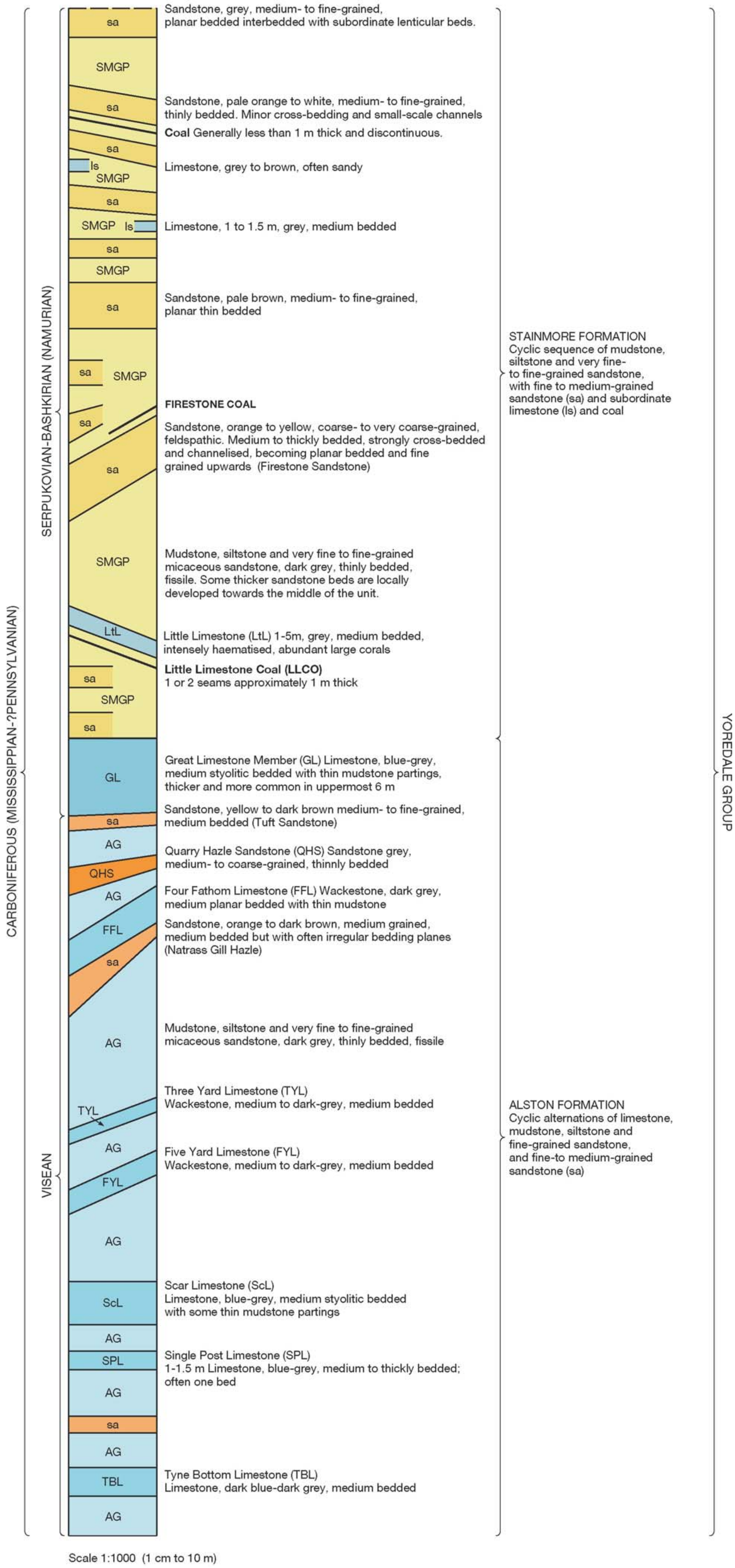

Figure 3. Representative generalised vertical section through NY74SE.

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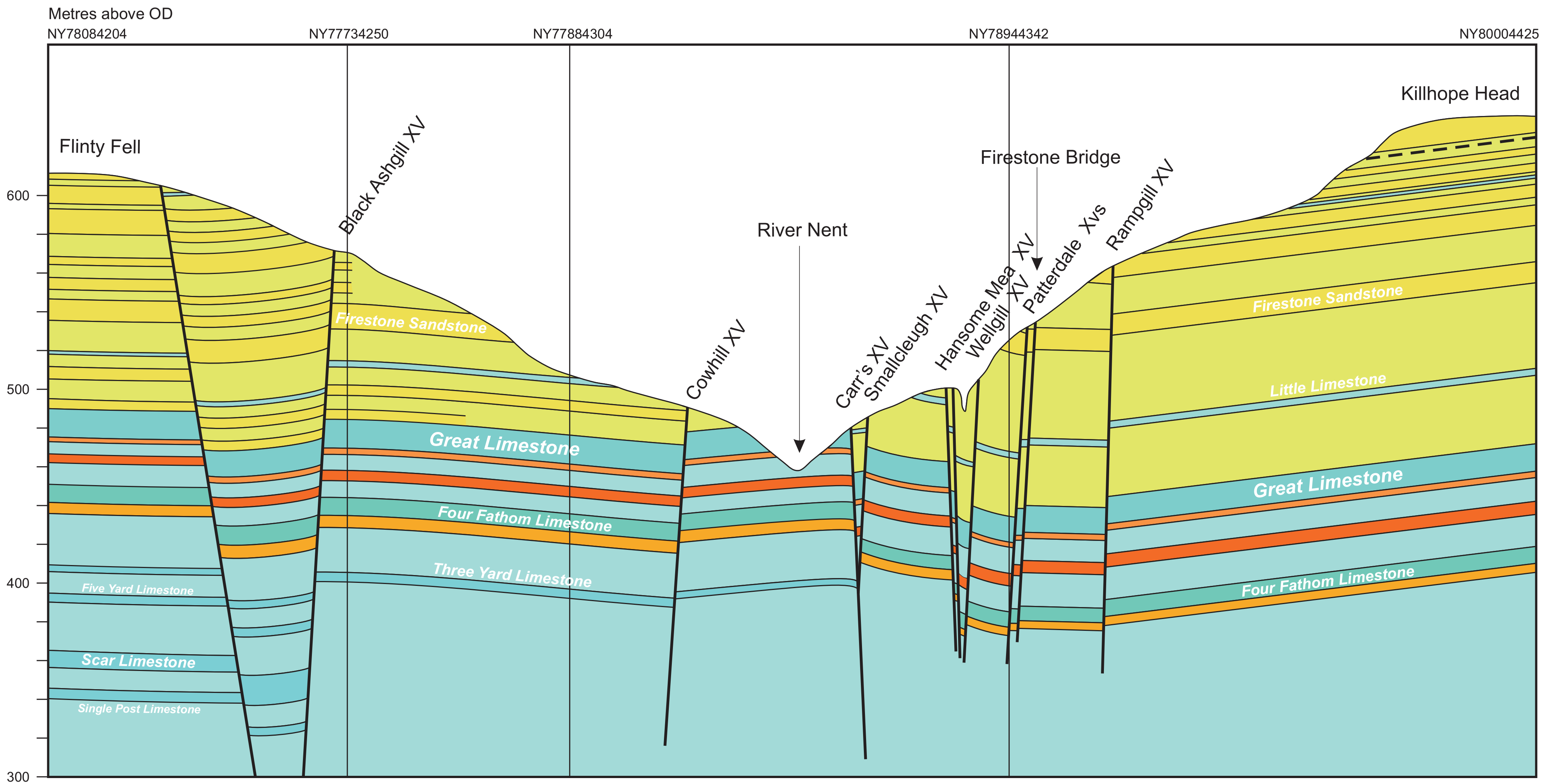

Figure 4. Generalised cross-section through the Nenthead area showing the complex horst and graben structure created by the cross-veins

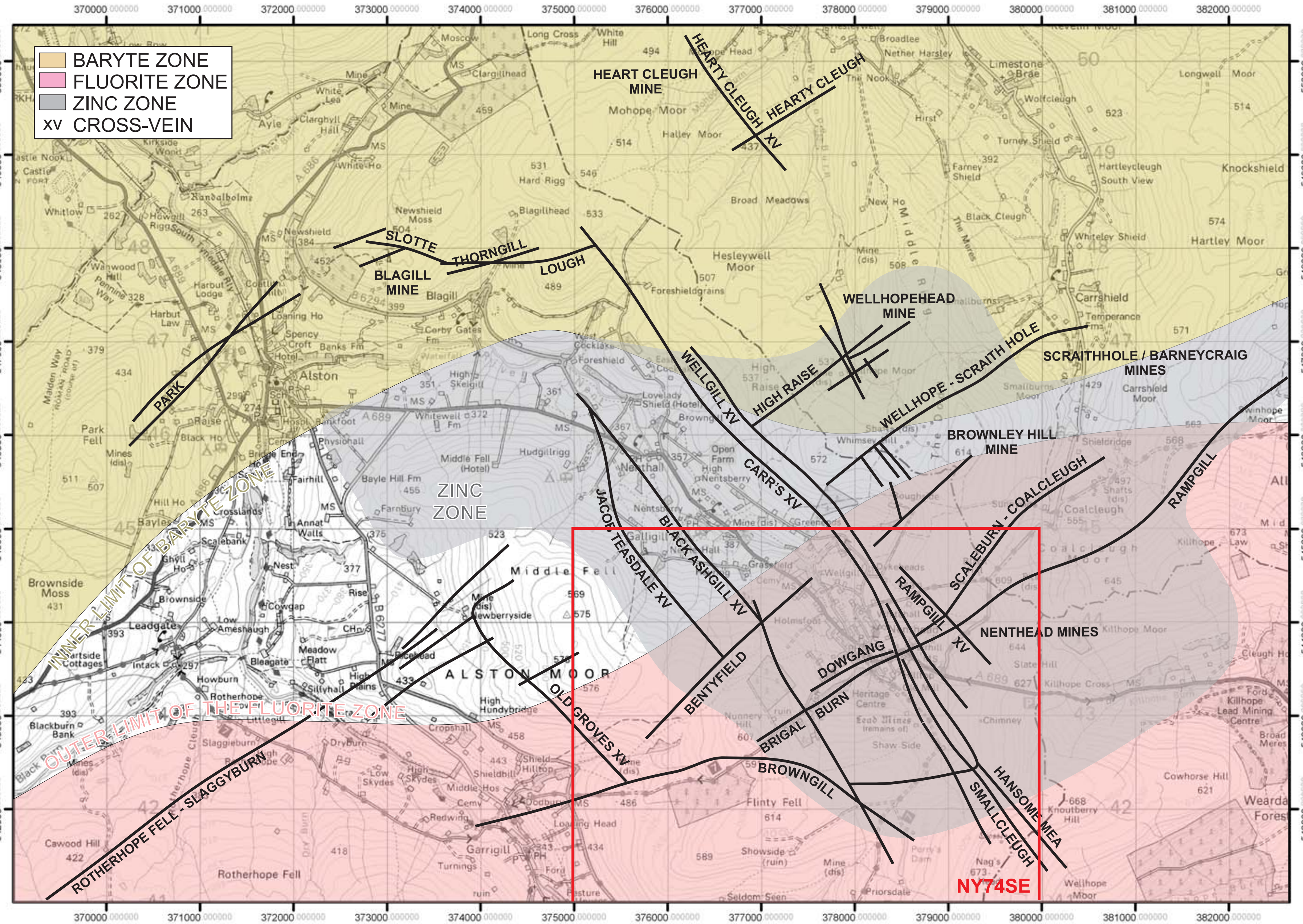

Figure 5. The limits of the fluorite and barium zones in the area between Alston and Nenthead with the position of the northern part of NY74SE shown. The positions of veins shown are for diagrammatic purposes only and should not be considered accurate at the scale of the basemap.