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Revised geological maps of Darlington based on new borehole information: explanation and description

A H COOPER & J.GORDON

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SUMMARY

The geology of the Darlington area has been revised based on the interpretation of new borehole information and a re-examination of archival data. The Permian Zechstein Group has been mapped through the district where it forms a series of easterly-dipping formations. These strata have been folded and an easterly-plunging syncline, faulted on its southern side, is mapped through the town of Darlington. This fold structure is partially modified by the dissolution of gypsum in the sequence resulting in the partial collapse and foundering of the strata. A series of maps is presented showing the revised geology, rockhead, drift thickness and the thickness of the gypsum sequence present at two horizons; the Hartlepool Anhydrite (present in the Edlington Formation) and the Billingham Anhydrite (present in the Roxby Formation). A series of five structure contour maps are presented illustrating the fold and fault structure of the area.

CONTENTS

(Maps at 1:100,000 Scale, Figures at 1:50,000 horizontal scale)

1 TERMS OF REFERENCE

As part of a study to investigate the effects of subsidence related to gypsum karst, Mr J. Gordon Darlington Borough Council has been collating borehole information for the area. The data has been input into the Council borehole recording package “Keyhole” and a copy of the dataset for holes that penetrated bedrock was made available to the British Geological Survey. The borehole information required geological assessment and the production of a revised geological map for the Darlington area. This map is required to help with the assessment of the hydrogeology of the area and subsidence problems affecting the eastern part of Darlington. Other information required from the borehole data included bedrock elevation, drift thickness and structure contour data.

2. INTRODUCTION

The eastern part of Darlington suffers from subsidence that is related to the presence of gypsum beneath the area. Gypsum is a readily soluble rock, which can have cavities and caves within it; funnelling of the overlying glacial material into these can cause subsidence. The natural or induced groundwater flow in the area can cause enhanced rates of gypsum dissolution, also resulting in subsidence. In addition to this, the lowering of the groundwater table may trigger the occurrence of subsidence.

In response to a report about subsidence at Darlington (Cooper 1994), Darlington Borough Council instigated the investigation of the geology and hydrogeology of the Parkside area. Four boreholes were initially drilled on two sites in the Parkside Estate. These holes were situated at the Parkside/Coleridge Gardens junction [NZ 2910 1320] and at the Shakespeare/Ruskin Road junction [NZ 2930 1296]. At each site, a deep cored borehole was drilled to investigate and monitor the Solid geology and its hydrogeology; in addition, a shallow shell and auger borehole was drilled to monitor the water levels in the Drift deposits. Because of the way the deep boreholes were finished, only one monitoring instrument can be installed in each hole, not the four originally planned. Two further holes were drilled to allow monitoring of water levels and allow samples to be taken from four levels in the sequence. These holes are South Park [NZ 2833 1339] situated to the west of Parkside, and Cleveland Bridge [NZ 2946 1321] situated to the east of Parkside. Details of the geology in these boreholes are presented by Cooper (1997).

After drilling these holes, Mr J.Gordon of Darlington Borough Council has collected extensive borehole information for Darlington and input them into the Council borehole database utilising “Keyhole” software. The logs include their full lithological descriptions and data fields that can be exported to spreadsheet packages. The numbers and grid references of all the holes that encountered solid rock were exported to Excel and additional columns of information input by Mr Gordon to identify rockhead and to classify the solid rocks in the area. This database was modified by A.H.Cooper for this study based on background knowledge of the geological sequence in the area.

The borehole data was examined initially using the MapInfo Geographic Information System (GIS) and subsequently ArcView GIS with bespoke British Geological Survey software that allowed a revised digital version of the geology to be constructed. The initial sweep through the data involved identifying the geology at rockhead and adding a column to the spreadsheet to show the formation, using the standard British Geological Survey lexicon codes for the formations. This was then plotted as a thematic layer coloured by formation to compare the newly interpreted geology with the existing geological maps. These were scanned and used as a backdrop to the borehole information. Numerous boreholes with interpretations that disagreed with the map were then immediately obvious.

The spreadsheet data also allowed the OD levels of the top contacts of the various formations to be compiled. This information was then plotted out for five key levels and printed alongside the coloured borehole data showing the formation at rockhead. The OD levels for the tops of the formations were then contoured by hand and the geology reinterpreted to produce structure contours for the area (Maps 6-10). These were projected up dip to rockhead and intersected with the rockhead contour information, also derived automatically from the GIS packages. Combining the formation at rockhead data from the boreholes, with the intersection data from the rockhead and structure contours, allowed the projected contacts of the formations to be constructed.

The structure contours were plotted for five levels in the area and a revised geological map (Map 1) produced using ArcView GIS utilising the British Geological Survey Geological Spatial Database (GSD) to capture the information. Plots at 1:100,000 scale were produced on A3 format and some larger plots at 1:50,000 were plotted using a Versatec plotter. The 1:100,000 scale plots form the basis of this report presented here.

2. GEOLOGY OF THE AREA

The geology of the area has two main classes, the solid and the drift. The drift geology extends from the surface down to rockhead and the contact with the underlying solid rock. The drift sequence is largely of glacial and post-glacial origin forming a thick covering, locally up to about 50m thick. The solid geology (Map 1) forms the bedrock with its associated gypsum and subsidence problems. The solid rocks were deposited around 250 million years ago and the drift sequence was deposited during approximately the last 100,000 years.

Rockhead

The rockhead geology of the area represents the former land surface or surfaces, prior to the deposition of the drift deposits that now conceal the bedrock. The rockhead surface may be of variable age depending on the presence or absence of cover materials. Presently, exposed rock areas are still being eroded while some alluvial and estuarine areas have been buried for a long time and are being buried by recent deposition. This would have been the situation in the past and it may be expected that variable deposits of variable ages will be present at the contact between the drift deposits and the underlying rock.

The contour plot of rockhead (Map 2) is taken only from borehole and exposure information derived from the borehole database and the published geological maps. The map has not been checked against the present land surface, consequently, it may include inaccuracies in the west where the drift deposits are thin. A future exercise will be to compare this structure contour model with the digital terrane model for the landscape surface and check that there are no inconsistencies. For most of the area, except along parts of the Tees, the drift deposits are thick and the rockhead contour map may be considered a reasonable interpretation.

The rockhead contour map shows the escarpment of the Raisby and Ford formations rising sharply to the north-west corner of the area and slightly to the south-west. This escarpment is cut through by the valley of the River Tees approximately along east-west grid line 514. East of the escarpment most of the area forms a buried undulating plane varying in elevation between about -10m and +10m. An area in the east of the map is suggested by the contouring package to be below -20m. This low area appears to be an artefact of the contouring package and parameters used since there are no boreholes actually in this sector. The rockhead contours also highlight several enclosed areas below OD. These include the area in the south of Darlington Town where boreholes for this study have proved the existence of gypsum deposits. The low areas in the bedrock here may be caused by the dissolution of the gypsum and the collapse of the ground.

Drift thickness

The map of drift thickness (Map 3) complements the rockhead contour map. Where the Raisby and Ford formations form the high ground in the north-west part of the are the drift is thin, generally less than 5m thick. In the low ground over the north-eastern quarter of the district extending into the area of Darlington itself, the drift is thick, ranging from 40 to 60 metres. The exception is at the location of one borehole near the north-east of the map, where the drift thickness is shown to be around 10m. This may be an artefact caused by an incorrectly interpreted borehole, or it might represent a buried hill of Carboniferous strata that penetrates though the Permian cover and is still upstanding beneath the drift. This latter explanation is suggested by the interpretation of the borehole by Dr D.B.Smith in 1987 when the Stockton geological map was published (British Geological Survey, 1987).

Drift geology

No attempt has been made to revise the drift geology of the area, reference should be made to the published 1:50,000 scale geological map (British Geological Survey, 1987). The boreholes that penetrated the solid strata generally agreed with the geological map for the drift geology of the area. However, if a study of all the shallow boreholes in the Darlington area is undertaken, changes in the detail of the drift geology may be expected. The thick drift over the district is mainly glacial till (formerly called boulder clay). Some thick glacial till is present to the west and north of Darlington, some of this is mapped as glacial moraine and other places such as High Beaumont Hill Farm [4298 5193] may also be morainic features. Laminated clay is present in the sequence forming an easterly widening a belt extending from Darlington along the Tees valley to Middlesbrough and Billingham. Throughout most of this area the laminated clay is both overlain and underlain by glacial till. Patchy glacial sand and gravel is also associated with the till. River terraces are present along the course of the River Tees and alluvial deposits are associated with both the rivers Skerne and Tees.

Solid geology

The generalised geological sequence of Permian and Triassic rocks that underlies the Darlington area is:

			Thickness
TRIASSIC		**Sherwood Sandstone Group** (formerly Bunter Sandstone), red-brown fine to medium-grained sandstone	c. 250m
PERMIAN	**Zechstein Group**	**Roxby Formation** (formerly Upper Marl): red-brown calcareous mudstone (marl) with subordinate gypsum beds and up to about **8m of gypsum or anhydrite** at its base	7 - 50m
		Seaham Formation (formerly Upper Magnesian Limestone): pale grey calcitic dolomite mainly in thin beds	14 - 20m
		Edlington Formation (formerly Middle Marl): red-brown calcareous mudstone (marl) with gypsum beds and up to about **30-40m of gypsum or anhydrite** at its base	6 - 53m
		Ford Formation (formerly Middle Magnesian Limestone): pale grey and yellow dolomitic limestone	8- 70m
		Raisby Formation (formerly Lower Magnesian Limestone): pale grey and yellow dolomitic limestone	10- 47m
		Marl Slate Formation, laminated calcareous bituminous mudstone	0 -c.2m
		Basal Permian Sands Formation, yellow fine to medium-grained sand of aeolian origin	0 - c.6m
CARBON-IFEROUS		**Carboniferous rocks, undivided,** sandstone, mudstone, siltstone and limestone (Thick folded sequence beneath the Permian strata)	

Sherwood Sandstone Group (Triassic)

The Triassic Sherwood Sandstone Group forms the bedrock over the south-eastern third of the district (Map 1). It comprises red-brown fine to medium-grained sandstones forming a sequence up to 250m thick. The sandstone is the main aquifer in the region, but it is heavily covered by superficial deposits. The exceptions are in the south of the district where it occurs as a slightly elevated buried ridge and crops out adjacent to the River Tees.

Zechstein Group (Permian)

The marine Permian sequence all belongs to the Zechstein Group. This is the terminology used in the North Sea, Holland and Germany. The group names that were proposed by Smith (1974) do not work well for the sequence, because they relate to cycles proved only in deep boreholes. Smith's groups have not been generally used outside of a few studies in northern England. The Zechstein Group includes all the formations between the Marl Slate Formation (or Raisby Formation if that is missing) and the base of the Sherwood Sandstone Group. The Basal Permian Sands Formation (or Yellow Sands Formation) belong to the largely terrestrial Rotliegede Group that underlies the Zechstein Group.

The distribution and development of the Zechstein Group in the Darlington area is partly constrained by the pre-Permian topography developed on the underlying Carboniferous strata. As a consequence of this topography, the Permian sequence laps against buried hills of Carboniferous rock both in the north of the district and to the south. Just south of the district (Map 1) most of the Permian sequence wedges out against a major bedrock high coincidental with the Middleton Tyas Anticline formed in the underlying Carboniferous rocks. To the north of Darlington, borehole information suggests that hills of Carboniferous strata perforate the Permian sequence.

Roxby Formation (including the Billingham Anhydrite Formation)

The Roxby Formation comprises a sequence of massive gypsum or anhydrite overlain by calcareous and gypsiferous mudstone. The gypsum/anhydrite is actually called the Billingham Anhydrite Formation, but for practical purposes this rock cannot be separated from the Roxby Formation at outcrop, so its description is included in that. The gypsum and anhydrite of the Billingham Formation occur at the base of the Roxby Formation forming a unit that ranges in thickness form 3 to 8m (Table 1), except where it has been dissolved and may be absent (Map 4). Gypsum ($CaSO_4.2H_2O$) or residues left after the dissolution of the gypsum are present in the outcrop area of the Roxby Formation, but down dip away from the outcrop the rock passes into anhydrite ($CaSO_4$ the anhydrous form of calcium sulphate). The boreholes suggest that the gypsum in the Roxby Formation is largely dissolved away where it comes to outcrop. However, in the area to the south-east of Darlington and where there is a cover of the Sherwood Sandstone Group, the gypsum is present, passing rapidly into anhydrite downdip to the east. The sequence overlying the Billingham Formation gypsum is composed of calcareous mudstone with some gypsum. Towards the top of this unit beds of sandstone are commonly present interbedded with the mudstone. The total thickness of the formation ranges up to 50m in the deep boreholes in the west of the district, but at the edge of the Sherwood Sandstone Group it is more likely to be around 25-30 m thick. However, the logs of borehole in fairly close proximity to the north-east of Darlington suggest an 11-49m range. This variation may be a function of the way the holes have been logged, or it may suggest thickening of the sequence due to foundering of strata caused by the dissolution of the underlying evaporites.

Seaham Formation

This formation is composed of dolomite and dolomitic limestone, typically in thin to medium beds. The beds are typified by the algal remains of the fossil *Calcinema permiana* that can commonly be identified in borehole cores and chippings. The formation varies in thickness, at and near outcrop, from about 15 to 20m (Table 1), but in the deep boreholes to the east it is much thinner reaching only 1.68m in the borehole at [435964 518562] (Darlington No 35189501). The formation may also be thickened where the strata have foundered due to the dissolution of the underlying evaporites. Some of the cores drilled into the Seaham Formation such as Skerne Park 2B (Darlington borehole No 29122902 [429294 512967]) show the complete brecciation of the strata due to this collapse.

Edlington Formation (including the Hartlepool Anhydrite Formation)

The Edlington Formation varies in thickness from about 6m, where all the evaporite deposits interbedded with it have dissolved, to a maximum of nearly 53m where the Hartlepool Anhydrite Formation is complete (Table 1). For practical reasons, the mapped Edlington Formation at outcrop also includes the gypsum and anhydrite of the Hartlepool Anhydrite Formation. This is because the Hartlepool Anhydrite Formation is partly dissolved towards the outcrop making it is very difficult to separate from the bulk of the Edlington Formation. Where no dissolution has occurred, the Hartlepool Anhydrite Formation includes up to 43m of anhydrite (borehole, Darlington No. 33112301 [433280 511390]). Elsewhere to the north, the formation is about 30m thick. When anhydrite is hydrated to gypsum by groundwater in the near-surface zone, it can expand by up to 63% (Mossop and Shearman, 1973) and it is possible that a greater thickness of gypsum could exist. However, the hydration can also involve the production of sulphate-rich fluids that can migrate or be deposited in adjacent formations (Shearman, et al., 1972) and thus remove gypsum from the originating formation. It is probable that the maximum thickness of gypsum present at outcrop was between 30 and 43m, but hydration may have produced an even greater thickness.

Little is known about the original thickness geometry of the anhydrite deposits. However, both Smith (1989, 1995) and Tucker (1991) show the Hartlepool Anhydrite Formation as a wedge-shaped deposit formed against the topography of the underlying and adjacent Ford Formation reef. Their model is for the Durham coastal area and further south the reef facies has not been recognised. There is a likelihood of original thickness variation being present in the Darlington area, but the evidence is not very good. It is possible that the 43m thickness proved to the east of Darlington is near to the maximum and that the wedge thins both to the west and east.

The actual thickness of the Hartlepool Anhydrite Formation present mainly as gypsum beneath Darlington is largely controlled by the way the rock has dissolved. Rapid thickness variations from 8.00m to 19.50m occur within short distances and the overlying rock is brecciated. These features suggest that the Hartlepool Anhydrite Formation as gypsum has partially dissolved and may still be dissolving beneath the area. The thickest deposits (18-19.50m) have been proved in the southern part of Darlington (for example Darlington boreholes No: 29129801, BGS Geneva Borehole [429900 512870] and No. 29131104, Skerne Park 1B [429108 513198]). However, between these two holes, the gypsum has dissolved leaving only about 13.00m of it and the overlying strata has collapsed and brecciated (Darlington borehole No 29122902, Skerne Park 2B [429294 512967]). These are on the flank of the Darlington Syncline (Map 1 and description below) adjacent to a major east-west fault. To the north of the syncline, a gypsum thickness of around 12m has been proved (Darlington borehole No. 31167801 [431741 516862]). There is no borehole information for the thickness of the gypsum in the core of the syncline; it may possibly be thicker than that proved on the flanks, it depends on the local groundwater flow and the amount of dissolution. Towards the west the gypsum has dissolved and the amount present in boreholes decreases rapidly. The South Parks borehole (Darlington borehole No. 28133301 [428331 513386]) proves only about 4m of gypsum. The Hospital Borehole (Darlington No 28152301 [428263 515328]) proves “15m of red marl with gypsum bands”. To illustrate the fact that this borehole still includes gypsum, a nominal thickness of 1.00m of gypsum is indicated for this site on Map 5.

Above the gypsum or anhydrite of the Hartlepool Anhydrite Formation, there is an irregular sequence of red-brown calcareous and gypsiferous mudstones and siltstones. These range in thickness from nothing (possibly washed out or collapsed) to about 15m or possibly 30m in the east; most typically they are 6-10m thick.

Ford and Raisby formations, undivided

For practical purposes, the Ford and Raisby formations are considered together. They are both dolomite formations and in the majority of boreholes, they cannot be separated. To the south of the district in Yorkshire, they are not separated, but mapped as the Cadeby Formation divided into two members. Only a few boreholes in the district penetrate the full thickness of the Ford and Raisby Formations. Five kilometres south of Darlington the two formations reach 84m thick, and about six kilometres north they reach 69m. Elsewhere, the upper part of the formation is truncated at the ground surface and the proven thickness varies from 5-82m. This variation is not consistent and probably reflects variations in the topography of the unconformity at the base of the Permian sequence, with or without variation in the thickness of the Basal Permian Sands Formation. Boreholes in close proximity show thickness variations of about 20m even thought the topography of the land is relatively even. Large variations in the level of the basal unconformity are indicated by the hills of Carboniferous strata that penetrate through parts of the Permian sequence in the north of the district. These hills crop out as inliers of Carboniferous rocks poking up through the Ford Formation and higher strata. In the core of the Darlington Syncline beneath the town of Darlington the combined thickness of the Ford and Raisby formations is probably between 70 and 80m if there are no major hills in the basal Permian unconformity.

Marl Slate Formation

The Marl Slate Formation is very thin and has not been differentiated on the geological map. It lies at the base of the Zechstein Group and comprises 0-about 2m of carbonaceous dolomitic mudstone commonly with a fish or plant fossil assemblage. To the east of the district it is well-developed and proved in boreholes. To the west, it laps onto and around both the buried land surface composed of weathered Carboniferous rocks and the Basal Permian Sands Formation.

Basal Permian Sands Formation

Only a very small area of Basal Permian Sands Formation is mapped on the Darlington area. It lies at the base of the Raisby Formation and probably only reaches a few metres in thickness. The Basal Permian Sands Formation represents the feather edge of the early Permian Rotliegede Group. It mainly comprises wind-blown sand preserved as lenticular sand dues that were subsequently buried beneath the Zechstein Group.

3 INTERPRETATION OF THE STRUCTURE

Revision of the published map

The examination and tabulation of the borehole information has permitted a complete revision of the geological map based on a new understanding of the structure of the area. The published geological map for Darlington (Stockton Sheet 33, British Geological Survey, 1987) has been changed, but the broad distribution of the sequence and outcrop shown on that map were approximately correct. The major changes mapped out concern the area immediately beneath Darlington and to the south of the town. Here the published map showed an outlier of PUM (Permian Upper Marl = Roxby Formation) that should actually have been labelled as an inlier of PMM (Permian Middle Marl = Edlington Formation) according to the large-scale maps of the area. This has been reinterpreted as a faulted syncline. The new geological map is shown in Map 1 with the east-west trending Darlington Syncline running beneath the town of Darlington. Map 1 shows the distribution of the boreholes that have constrained the construction of the outcrop pattern of the map. The other constraints have been derived from the study of the bedrock contours and their integration with structure contours derived for five levels in the stratigraphy.

Structure contour maps

Structure contours maps were constructed from the borehole and outcrop information, these are:
Map 6: Top of Roxby Formation/ base of Sherwood Sandstone Group
Map 7: Top of Seaham Formation/ base of Roxby Formation
Map 8: Top of Edlington Formation/ base of Seaham Formation
Map 9: Top of Ford Formation/ base of Edlington Formation
Map 10: Top of Carboniferous/ base of Permian Raisby Formation

In constructing the structure contour maps, the levels above and below the one being constructed helped to constrain the interpretation of the geology. Other datasets were also utilised to produce the maps. Unpublished work done by Dr D.B.Smith was used for the construction of the contours for map 10 showing the top of the Carboniferous/ base of the Permian Ford Formation. His structure contours for the area showed the western extension of the Darlington Syncline mapped on the adjacent Barnard Castle geological map (Sheet 32, British Geological Survey. 1969). The eastward extension of this syncline coincided with a westerly swing in the boundary between the Edlington Formation and the overlying Seaham Formation mapped on the original Stockton (Sheet 33, British Geological Survey, 1987). The intersections proved in the boreholes for the area suggested that the syncline continued eastwards affecting all the strata up to and including the Sherwood Sandstone Group. The boreholes and structure contours also suggested that the southern limb of the syncline abutted a normal fault throwing down to the south. Another change suggested by the structure contour information was the repositioning of the north-east trending fault that cuts the Sherwood Sandstone Group near Croft in the south of the district. This fault has been repositioned with the same trend, but a few hundred metres to the south-east from its position on the existing published map.

Cross-sections

The details of the structure are shown in three cross-sections derived from the structure contour information, borehole, outcrop and rockhead datasets, these are:
Figure 1. NNW-SSE section through Darlington.
Figure 2. N-S section through Darlington.
Figure 3. E-W section through Darlington.
All these sections were constructed with a horizontal scale of 1:50,000 and a 10-times vertical exaggeration (1:5,000 vertical scale). This vertical exaggeration has the effect of making faults look near-vertical and structural dips look much steeper than they actually are. This should be borne in mind when viewing the cross-sections.

NNW-SSE section through Darlington. Figure 1.

This cross-section shows the Darlington Syncline approximately beneath the centre of Darlington and the River Skerne. The dips on the limbs of the syncline are probably only a few degrees, the dip shown on the cross-section is increased by the vertical exaggeration factor. Here the Edlington Formation appears to be thick to the south of Darlington on the south limb of the Darlington Syncline and against the faulted graben formed by the east-west fault and the north-east trending fault through Croft. That the gypsum (Hartlepool Anhydrite Formation, Map 5) is fairly thick on the south side of Darlington as shown by the boreholes at Skerne Park and this is reflected in the thickness of the Edlington Formation here. To the north of Darlington, the cross-section suggests that the gypsum in the Edlington Formation is thinner. The Darlington Syncline preserves a core composed of the Seaham and Roxby formations. The borehole data suggest that the Billingham Anhydrite Formation mapped as part of the Roxby Formation is actually dissolved away. At the southern end o of the section the figure also indicates the thinning of the Permian sequence as it laps onto the buried topography of the underlying Carboniferous rock. The cross-section also shows the thick nature of the glacial deposits that cover the area of Darlington, and the way they thin southwards to the course of the River Tees. At the Tees the river has cut down exposing the bedrock in a few places. It is also where many of the springs emanate from the underlying sequence.

N-S section through Darlington, Figure 2.

The north-south section through Darlington shows similar features to Figure 1. The southern flank of the Darlington Syncline appears to have preserved the thickest Edlington Formation with the thickest gypsum (Hartlepool Anhydrite Formation) as shown by the boreholes on Map 5. The same graben structure shown in Figure 1 is intersected, but along this section the faults are further apart making the graben wider. Like section 1 the drift deposits are thin along the Tees valley and the Sherwood Sandstone Group is present at rockhead. The cross-section also shows very thick drift deposits towards the A1 road in the north of the district. These thick drift deposits may represent a morainic deposit of glacial till.

E-W section through Darlington, Figure 3.

The east-west cross-section through Darlington shows the easterly dip of the strata, which is also the plunge of the Darlington Syncline. Like the other sections, the vertical exaggeration makes the dip/plunge look quite strong, but in reality, it is probably only 1-2 degrees. The cross-section shows the westward thinning of both the Edlington Formation and the Roxby Formation as the gypsum of the Hartlepool and Billingham anhydrite formations has partially dissolved towards the outcrop. This has produced a slight monoclinal structure in the foundered Seaham Formation where it has collapsed across the dissolution front. A similar structure may also exist near the edge of the Sherwood Sandstone Group where it has collapsed over the dissolution front of the Billingham Anhydrite Formation. However, since the Billingham Anhydrite Formation only varies from about 4 to 8m in thickness, it is not very obvious on a cross-section presented at this scale. The other fact that the cross-section shows is the thickness of the drift deposits over most of the area, except where the River Tees runs across the Ford Formation west of Darlington. Coincidental with this intersection, the Darlington Syncline helps to delineate the Tees Valley, which has exploited the softer strata preserved in the syncline. This coincidence may also have important implications for the local hydrogeology of the Darlington area since the River Tees feeds water into the core of the syncline.

Dr Anthony H. Cooper C.Geol.
18th December 2000

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MAPS, CROSS-SECTIONS AND BOREHOLE TABLE

(Maps at 1:100,000 Scale, Figures at 1:50,000 horizontal scale)

Map 1. Revised geological map for the Darlington area with colour-coded borehole locations showing the formation intersected at rockhead

Map 2. Rockhead elevation derived from boreholes and exposure

Map 3. Thickness of the drift deposits

Map 4. Thickness of the Billingham Anhydrite Formation

Map 5. Thickness of the Hartlepool Anhydrite Formation

Map 6. Structure contours for top of Roxby Formation/ base of Sherwood Sandstone Group

Map 7. Structure contours for top of Seaham Formation/ base of Roxby Formation

Map 8. Structure contours for top of Edlington Formation/ base of Seaham Formation

Map 9. Structure contours for top of Ford Formation/ base of Edlington Formation

Map 10. Structure contours for top of Carboniferous/ base of Permian Ford Formation

Figure 1. NNW-SSE section through Darlington.

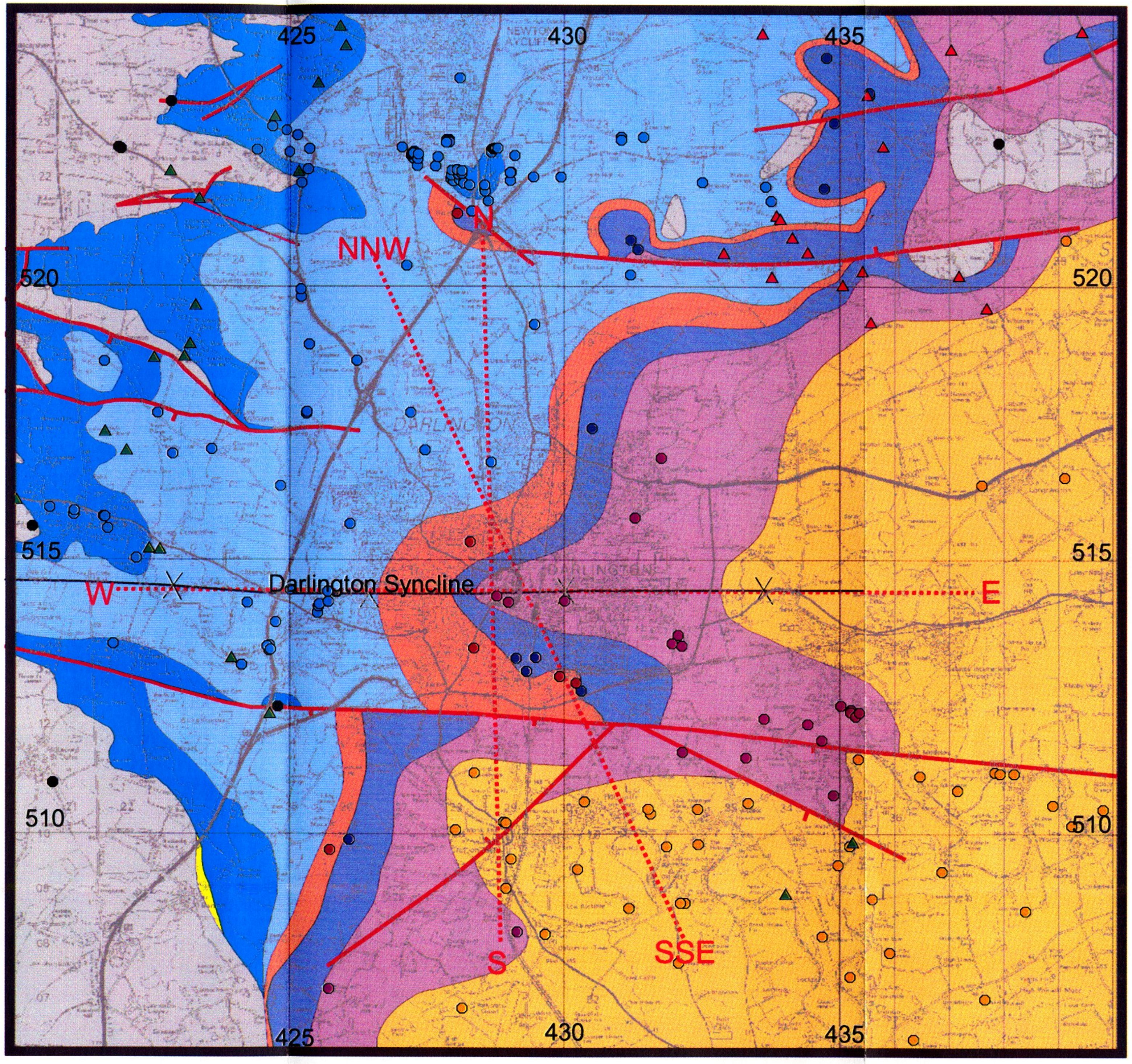
Figure 2. N-S section through Darlington.

Figure 3. E-W section through Darlington.

Table 1. Selected boreholes with information used to construct the structure contour maps and make the main geological interpretations. Boreholes that only penetrated the bedrock without proving geological boundaries have been omitted.

Darlington 1:100,000 scale
Solid Geology
Revised by A H Cooper December 2000
Based on boreholes collated by J Gordon

Map 1
Solid Geology



Sherwood Sandstone Group

Roxby Formation

Seaham Formation

Edlington Formation

Ford Formation

Raisby Formation

Basal Permian Sands Formation

Carboniferous Rocks [undifferentiated]

Unnamed Dyke, Tertiary

Faults

Syncline

Lines of sections

Boreholes and exposures

Sherwood Sandstone Group

Roxby Formation

Seaham Formation

Edlington Formation

Ford Formation

Raisby Formation

Carboniferous Rocks [undifferentiated]

Exposures of solid rock

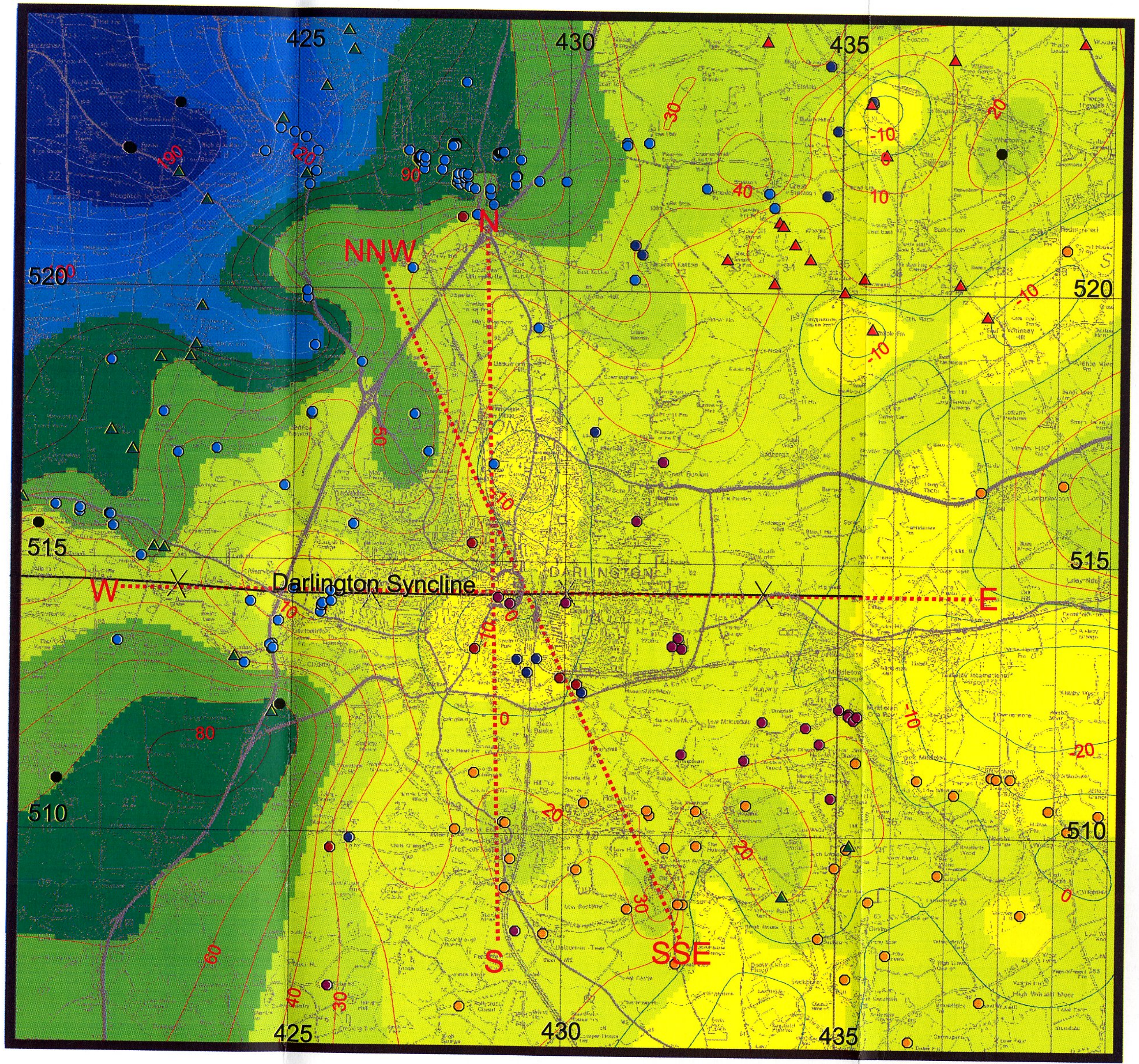
Rockhead proved in boreholes

Compiled by A.H.Cooper from borehole
information collated by J.Gordon

December 2000

Darlington 1:100,000 scale
Rockhead Contours at 10m Intervals
Revised by A H Cooper December 2000
Based on boreholes collated by J Gordon

Map 2
Rockhead Contours



Boreholes and exposures

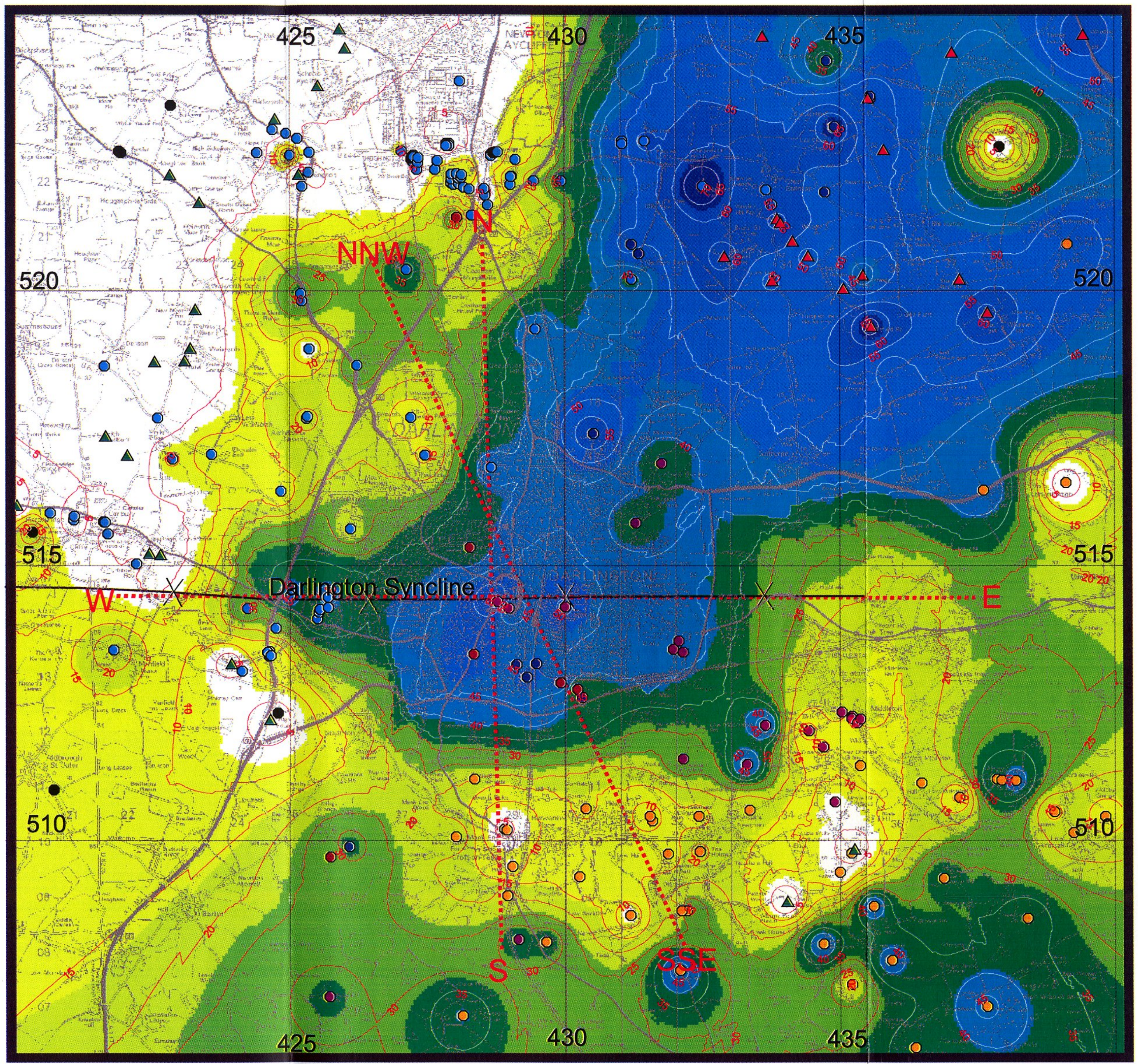
- Sherwood Sandstone Group
- Roxby Formation
- Seaham Formation
- Edlington Formation
- Ford Formation
- Raisby Formation
- Carboniferous Rocks [undifferentiated]
- Exposures of solid rock
- Rockhead proved in boreholes

Compiled by A.H.Cooper from borehole information collated by J.Gordon

December 2000

Darlington 1:100,000 scale
Drift thickness contours at 5m Intervals
Revised by A H Cooper December 2000
Based on boreholes collated by J Gordon

Map 3
Drift Thickness



Boreholes and exposures

- Sherwood Sandstone Group
- Roxby Formation
- Seaham Formation
- Edlington Formation
- Ford Formation
- Raisby Formation
- Carboniferous Rocks [undifferentiated]
- Exposures of solid rock
- Rockhead proved in boreholes

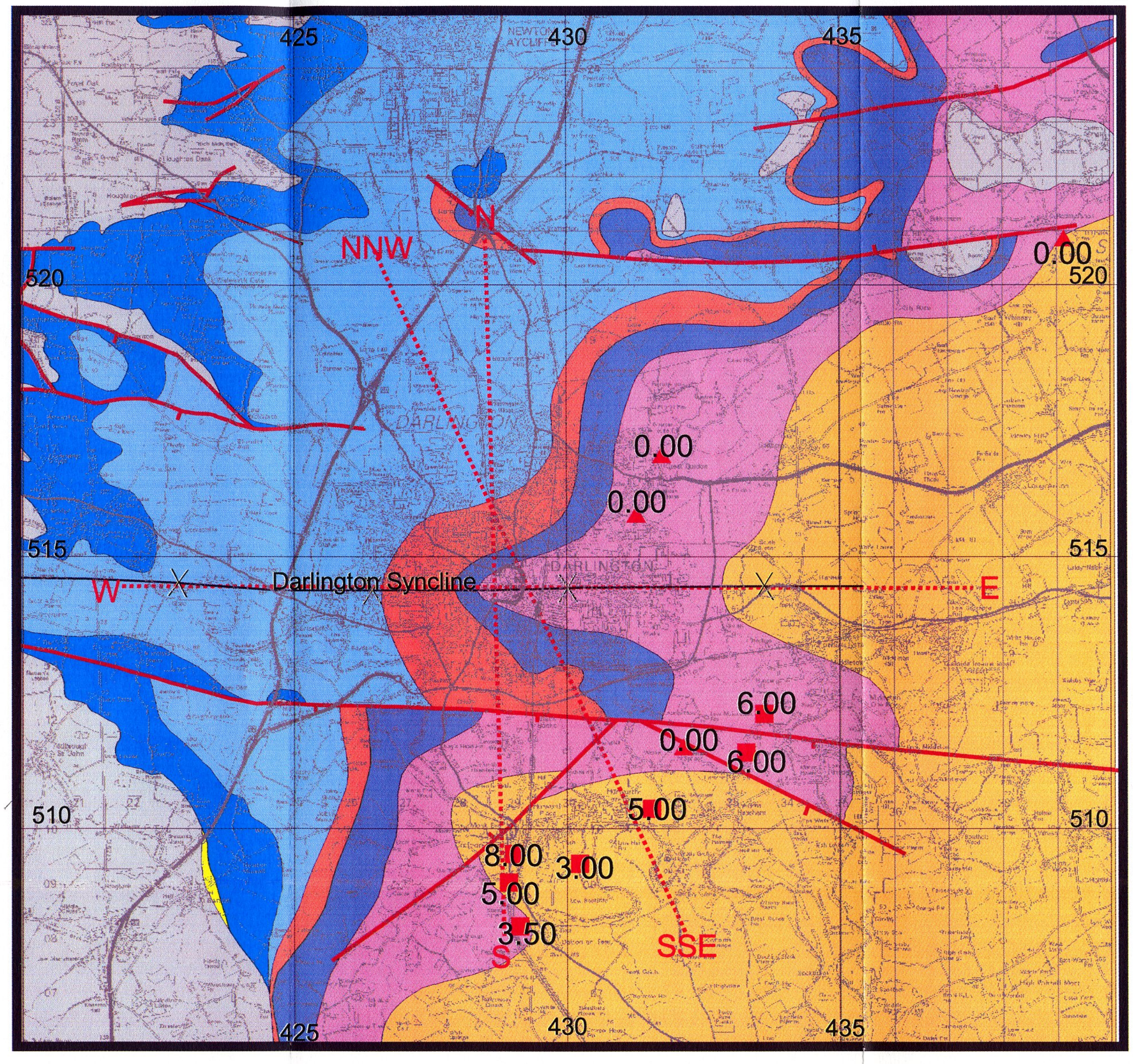
Compiled by A.H.Cooper from borehole information collated by J.Gordon

December 2000

Darlington 1:100,000 scale Bilingham Anhydrite
Squares - present with thickness
Triangles - dissolved
Revised by A H Cooper December 2000
Based on boreholes collated by J Gordon

Map 4
Billingham Anhydrite Fm.

- Sherwood Sandstone Group
- Roxby Formation
- Seaham Formation
- Edlington Formation
- Ford Formation
- Raisby Formation
- Basal Permian Sands Formation
- Carboniferous Rocks [undifferentiated]
- Unnamed Dyke, Tertiary
- Faults



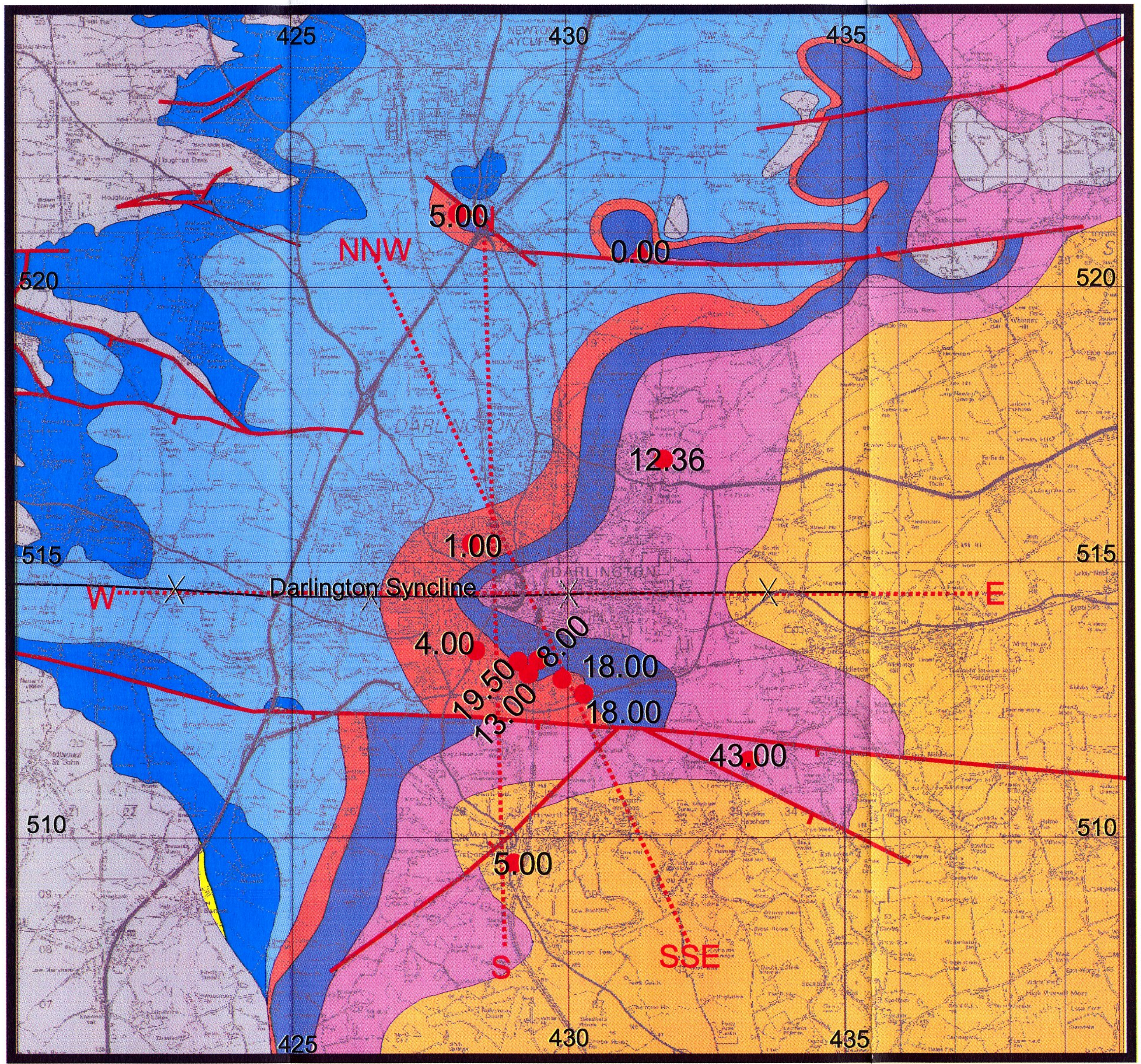
Compiled by A.H.Cooper from borehole information collated by J.Gordon

December 2000

Darlington 1:100,000 scale Hartlepool Anhydrite Fm.
Squares - present with thickness
Triangles - dissolved
Revised by A H Cooper December 2000
Based on boreholes collated by J Gordon

Map 5
Hartlepool Anhydrite Fr

- Sherwood Sandstone Group
- Roxby Formation
- Seaham Formation
- Edlington Formation
- Ford Formation
- Raisby Formation
- Basal Permian Sands Formation
- Carboniferous Rocks [undifferentiated]
- Unnamed Dyke, Tertiary
- Faults



Compiled by A.H.Cooper from borehole information collated by J.Gordon

December 2000

Darlington 1:100,000 scale
Structure Contours
Base Sherwood Sandstone Group/
Top Roxby Formation, 25m intervals
A H Cooper December 2000
Based on boreholes collated by J Gordon

Map 6 Structure Contours
Base Sherwood Sandstone Gro
top Roxby Formation

Structure contours on top of Roxby Formation/ base of Sherwood Sandstone Group

Sherwood Sandstone Group

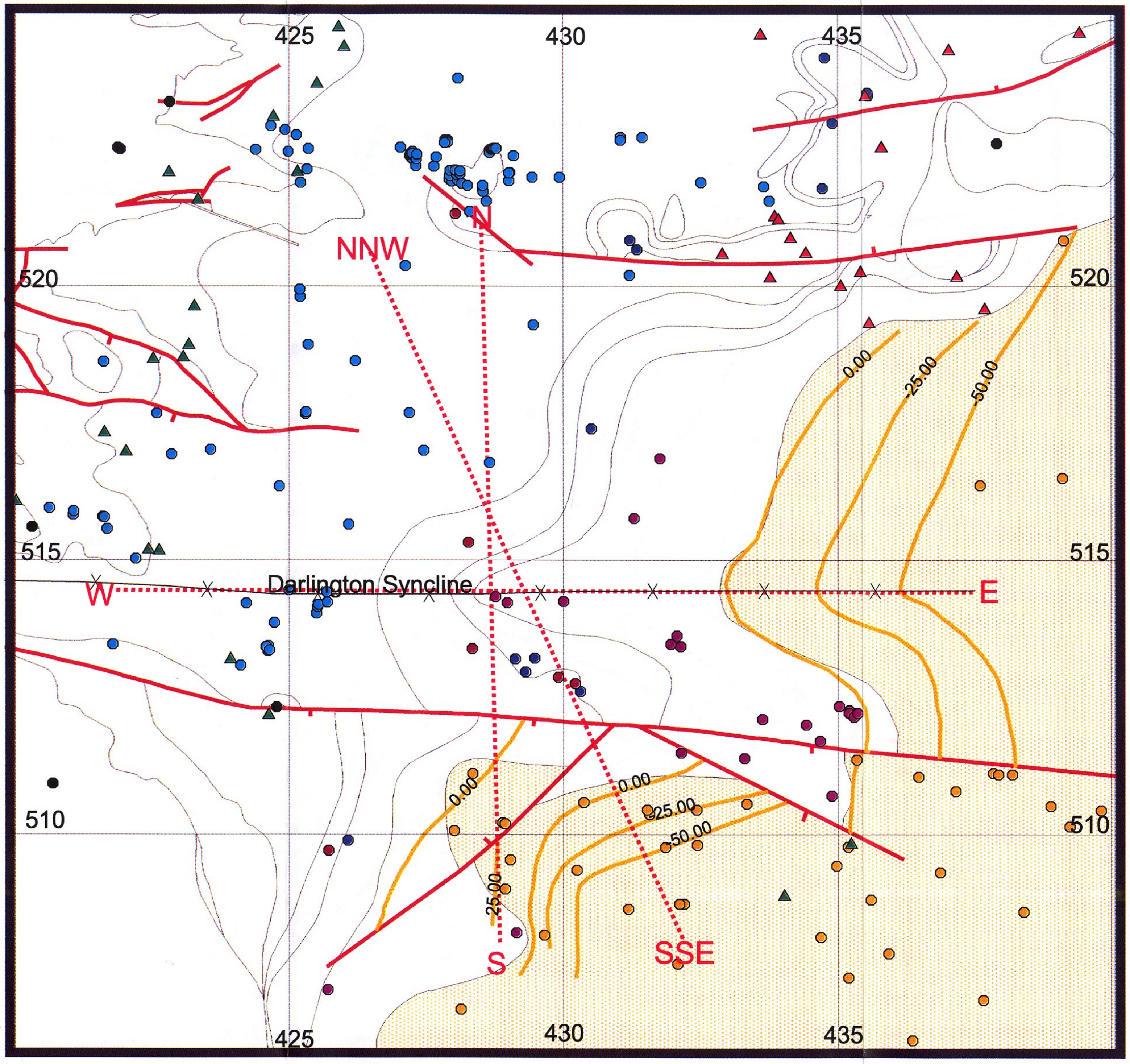
Faults

Syncline

Lines of sections

Boreholes and exposures

- Sherwood Sandstone Group
- Roxby Formation
- Seaham Formation
- Edlington Formation
- Ford Formation
- Raisby Formation
- Carboniferous Rocks [undifferentiated]
- Exposures of solid rock
- Rockhead proved in boreholes



Compiled by A.H.Cooper from borehole information collated by J.Gordon

December 2000

Darlington 1:100,000 scale
Structure Contours
Top Seaham Formation/
Base of Roxby Formation, 25m intervals
A H Cooper December 2000
Based on boreholes collated by J Gordon

Map 7 Structure Contours
Top Seaham Formation/
Base of Roxby Formation

Structure contours on top of Seaham Formation/ base of Roxby Formation

Seaham Formation

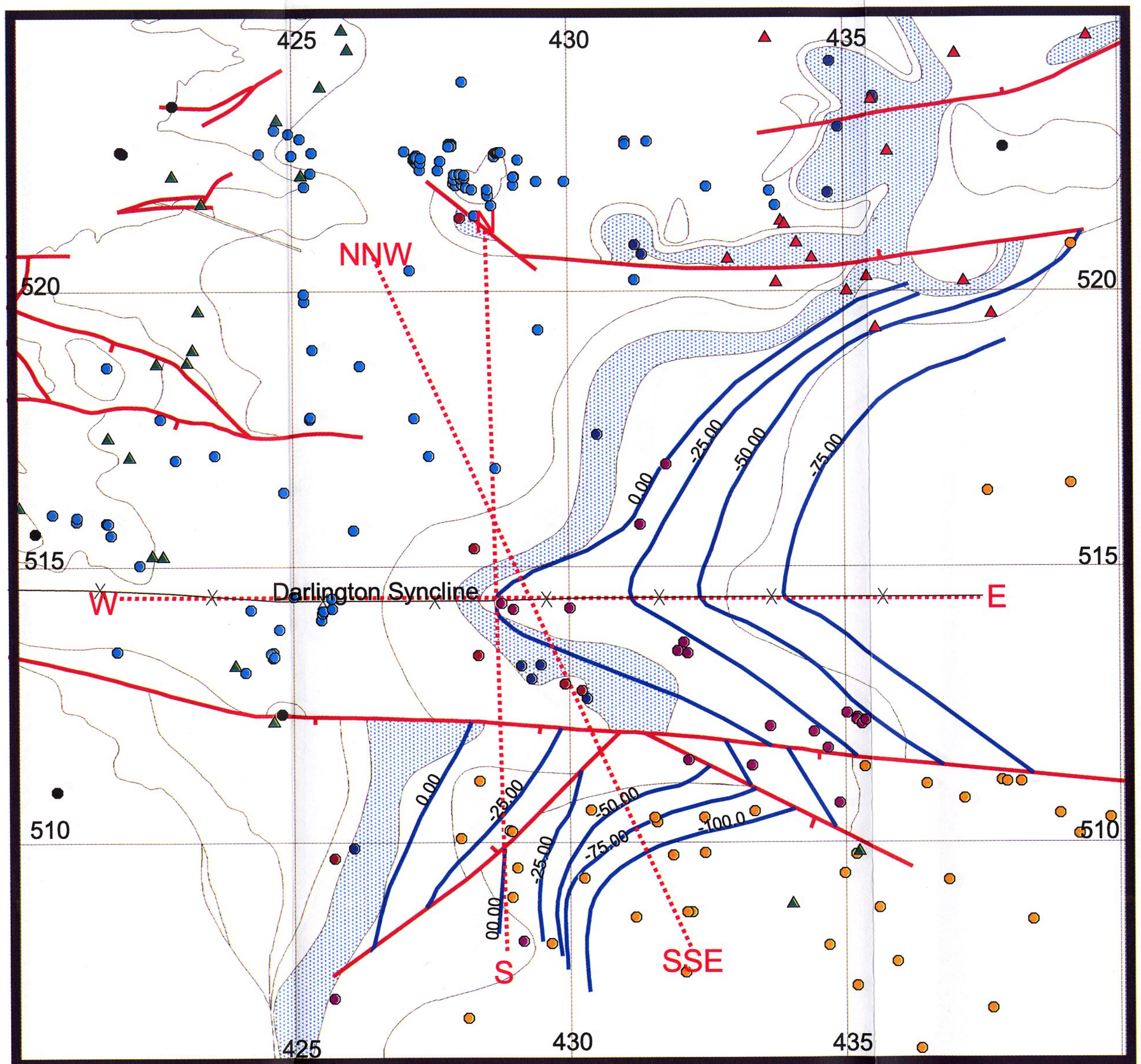
Faults

Syncline

Lines of sections

Boreholes and exposures

- Sherwood Sandstone Group
- Roxby Formation
- Seaham Formation
- Edlington Formation
- Ford Formation
- Raisby Formation
- Carboniferous Rocks [undifferentiated]
- Exposures of solid rock
- Rockhead proved in boreholes

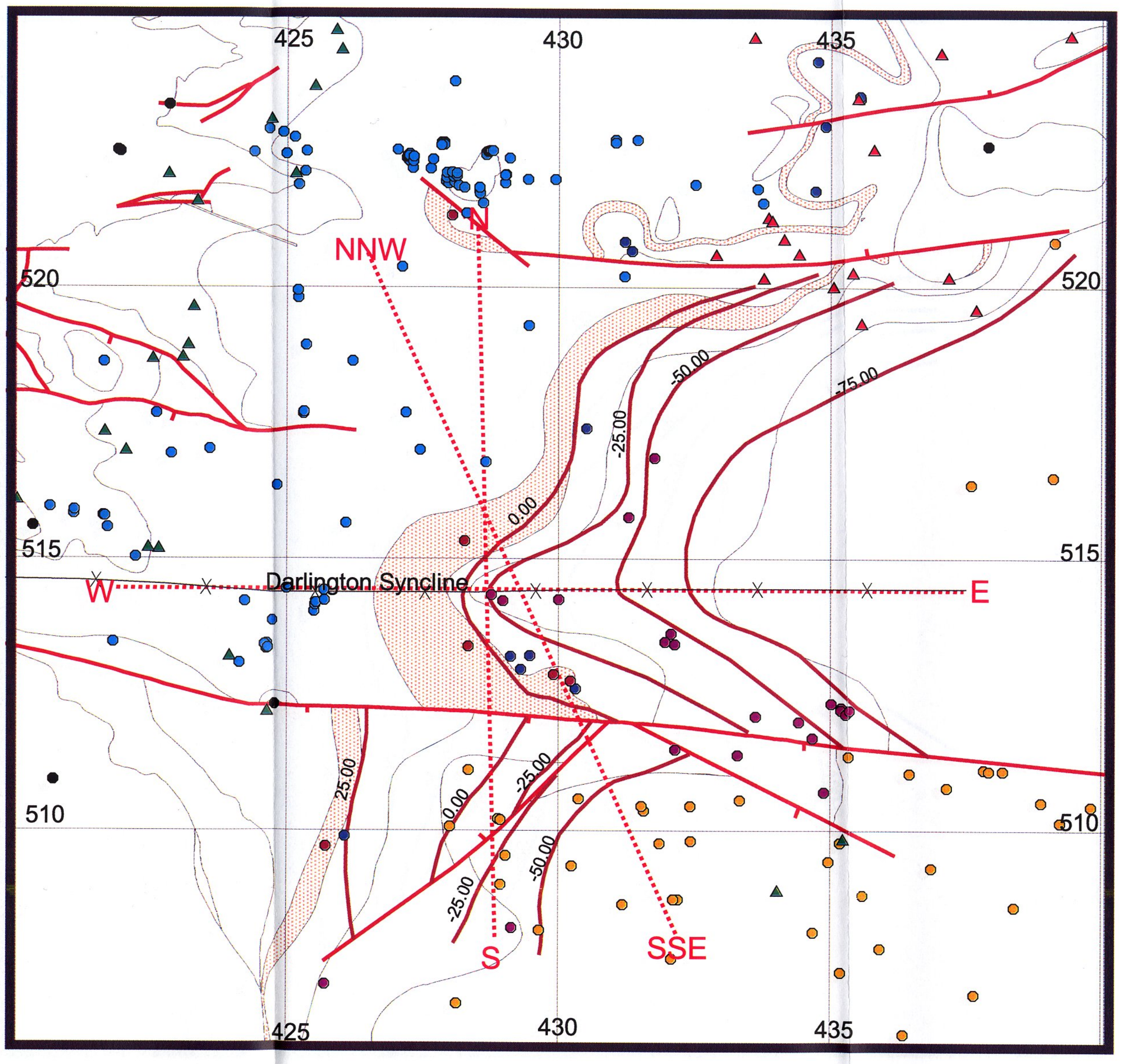


Compiled by A.H.Cooper from borehole information collated by J.Gordon

December 2000

Darlington 1:100,000 scale
Structure Contours
Top of Edlington Formation/
Base of Seaham Formation, 25m intervals
A H Cooper December 2000
Based on boreholes collated by J Gordon

Map 8 Structure Contours
Top Edlington Formation/
Base ofSeaham Formation



Structure contours on top of Edlington Formation/ base of Seaham Formation

Edlington Formation

Faults

Syncline

Lines of sections

Boreholes and exposures

- Sherwood Sandstone Group
- Roxby Formation
- Seaham Formation
- Edlington Formation
- Ford Formation
- Raisby Formation
- Carboniferous Rocks [undifferentiated]
- Exposures of solid rock
- Rockhead proved in boreholes

Compiled by A.H.Cooper from borehole
information collated by J.Gordon

December 2000

Darlington 1:100,000 scale
Structure Contours
Top of Ford Formation/
Base of Edlington Formation, 25m intervals
A H Cooper December 2000
Based on boreholes collated by J Gordon

Map 9 Structure Contours
Top Ford Formation/
Base of Edlington Formation

Structure contours on top of Ford Formation/ base of Edlington Formation

Ford Formation

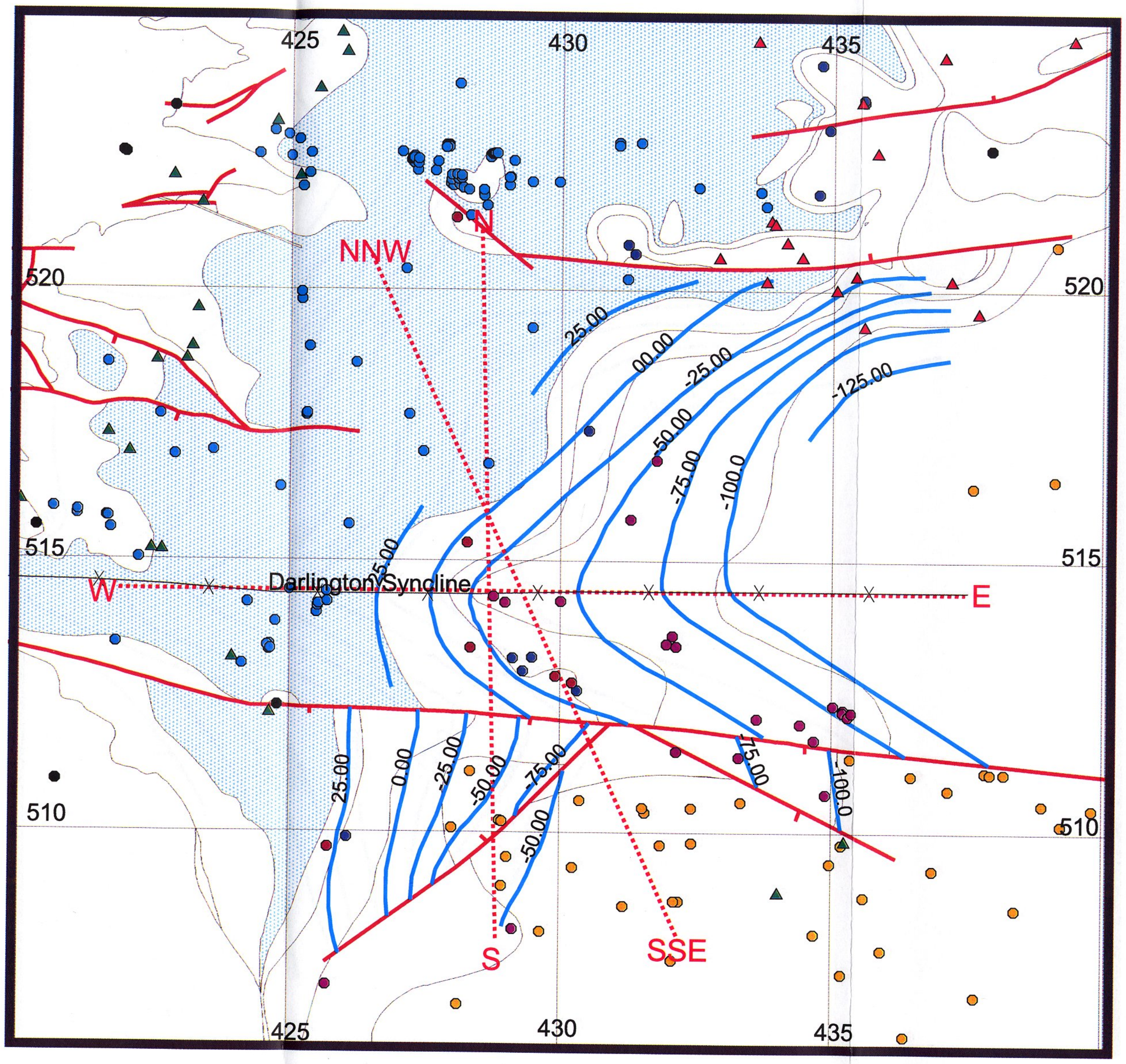
Faults

Syncline

Lines of sections

Boreholes and exposures

- Sherwood Sandstone Group
- Roxby Formation
- Seaham Formation
- Edlington Formation
- Ford Formation
- Raisby Formation
- Carboniferous Rocks [undifferentiated]
- Exposures of solid rock
- Rockhead proved in boreholes



Compiled by A.H.Cooper from borehole information collated by J.Gordon

December 2000

Darlington 1:100,000 scale
Structure Contours
Top of Carboniferous, undivided/
Base of Raisby Formation, 25m intervals
A H Cooper December 2000
Based on boreholes collated by J Gordon

Map 10 Structure Contours
Top of Carboniferous, un divided/
Base of Raisby Formation

Structure contours on top of Carboniferous/ base of Ford Formation

Carboniferous, undivided

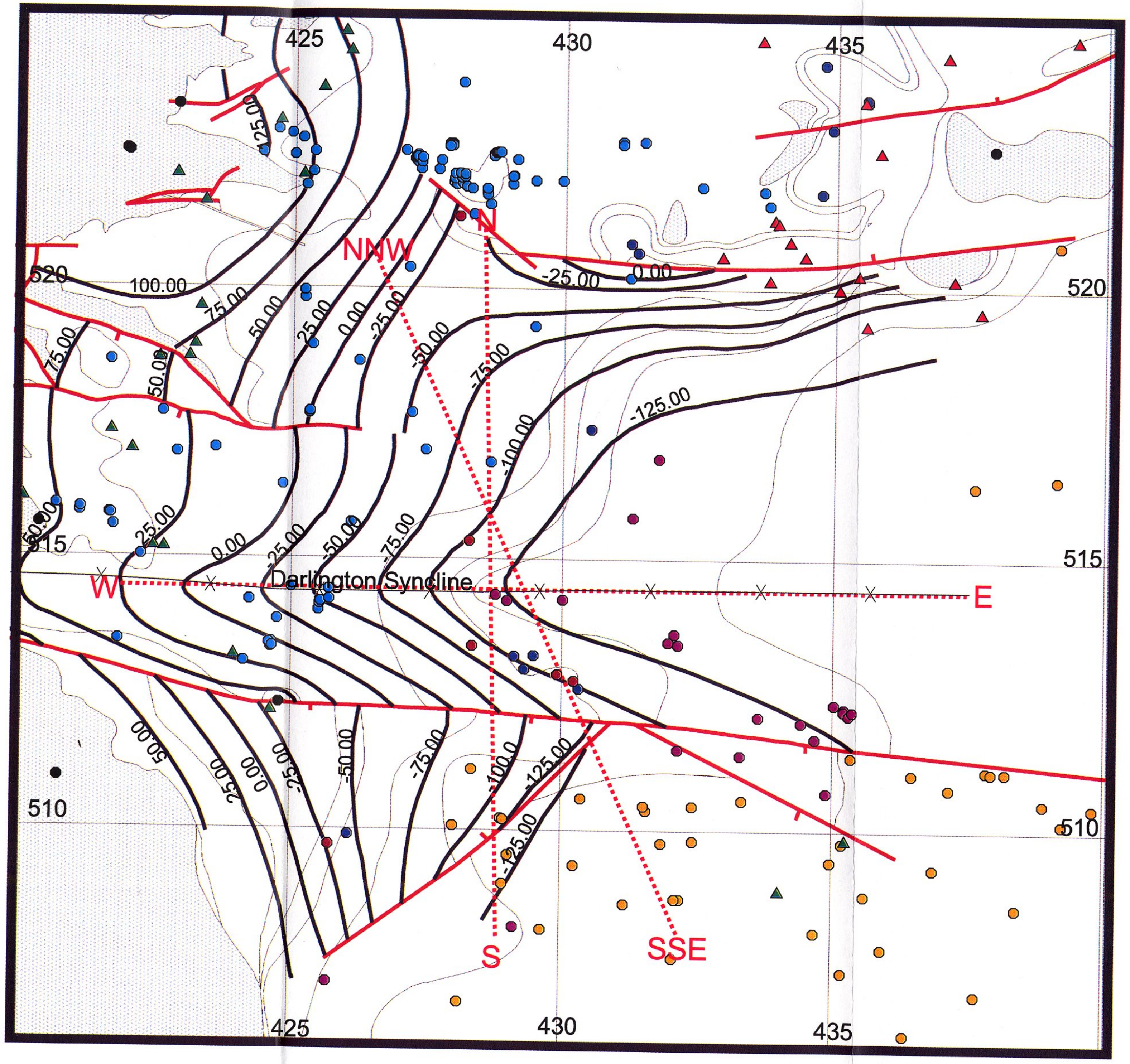
Faults

Syncline

Lines of sections

Boreholes and exposures

- Sherwood Sandstone Group
- Roxby Formation
- Seaham Formation
- Edlington Formation
- Ford Formation
- Raisby Formation
- Carboniferous Rocks [undifferentiated]
- Exposures of solid rock
- Rockhead proved in boreholes



Compiled by A.H.Cooper from borehole information collated by J.Gordon

December 2000

Figure 1. NNW-SSE section through Darlington

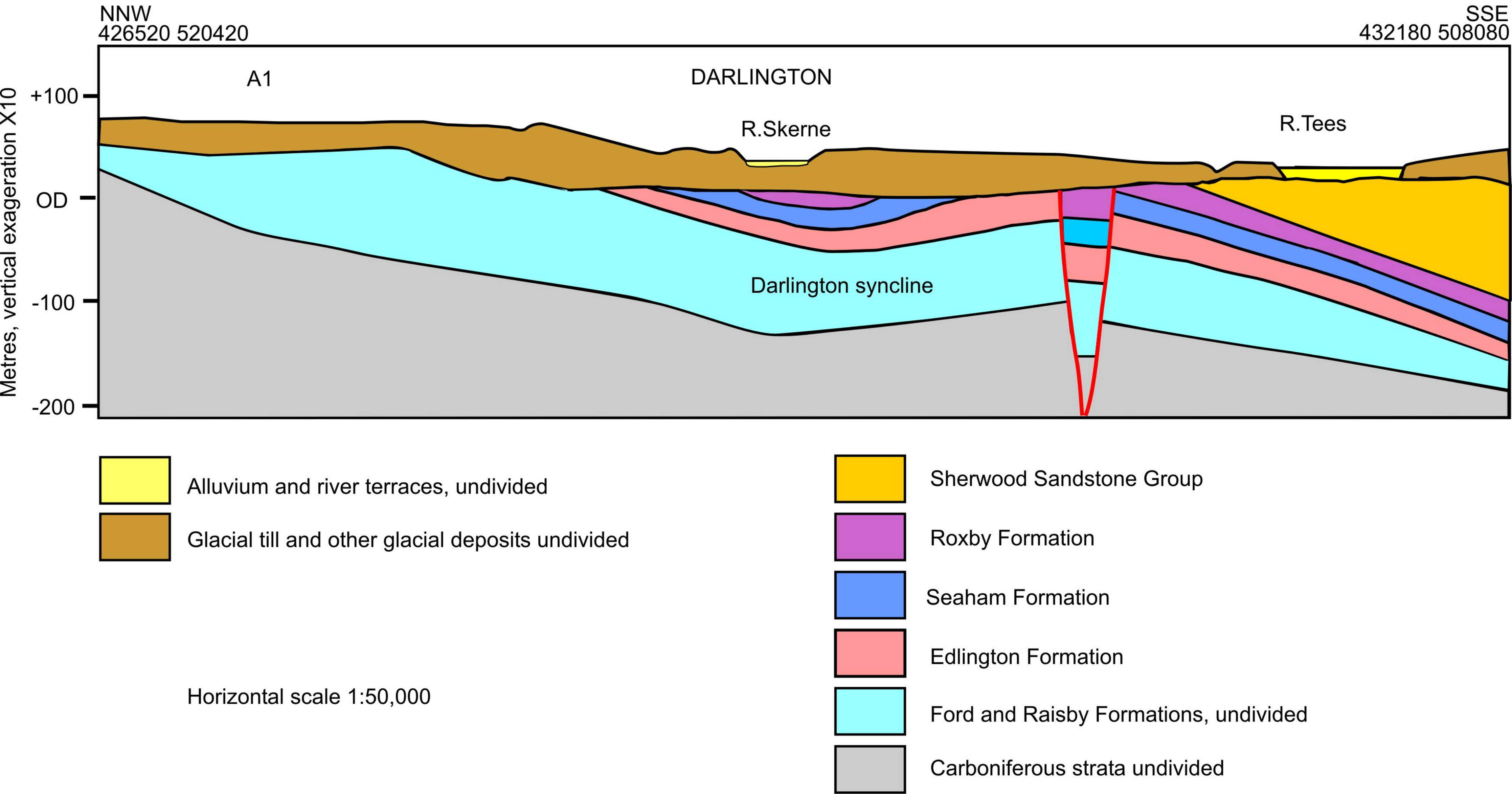


Figure 2. N-S section through Darlington

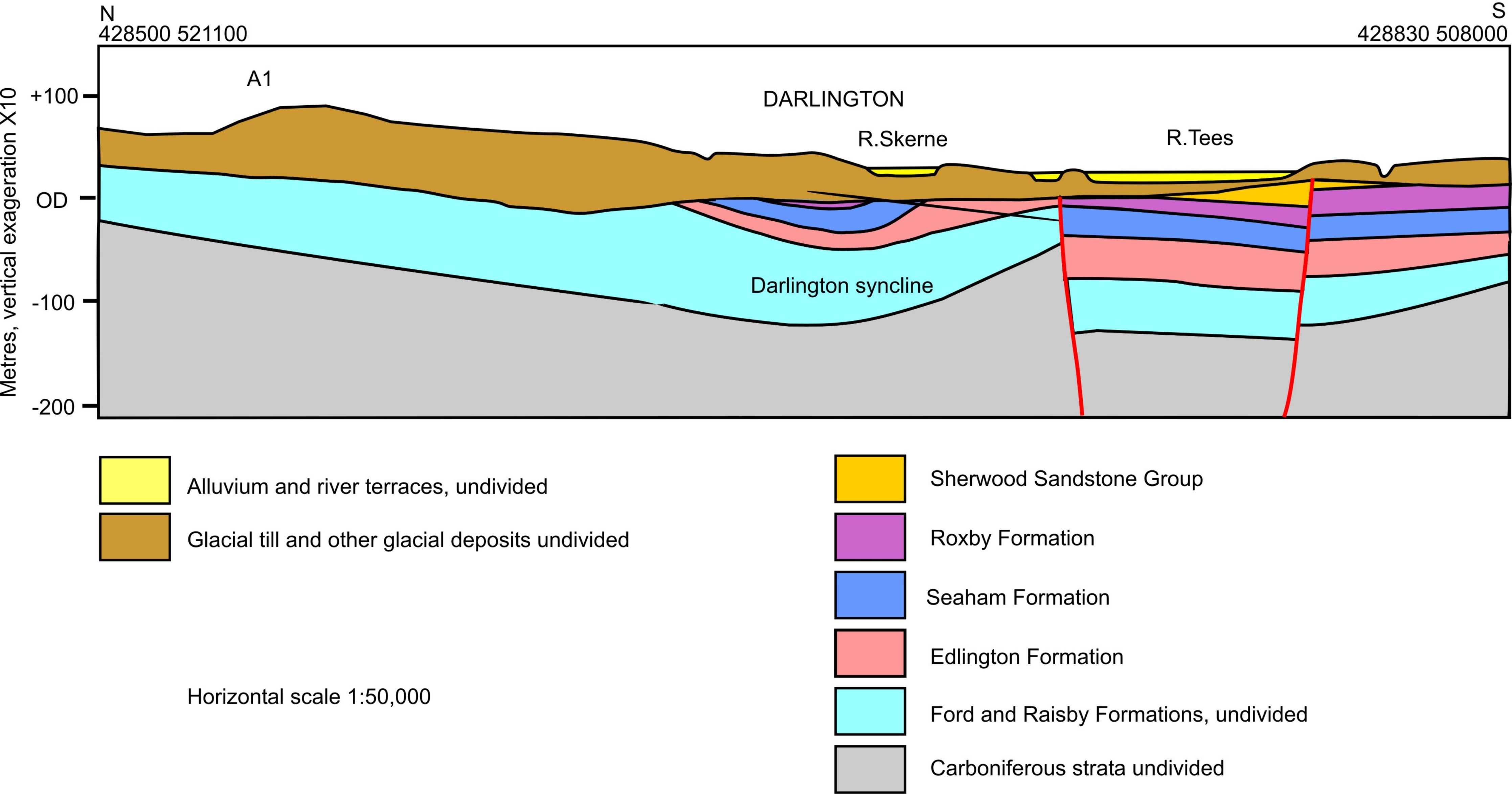
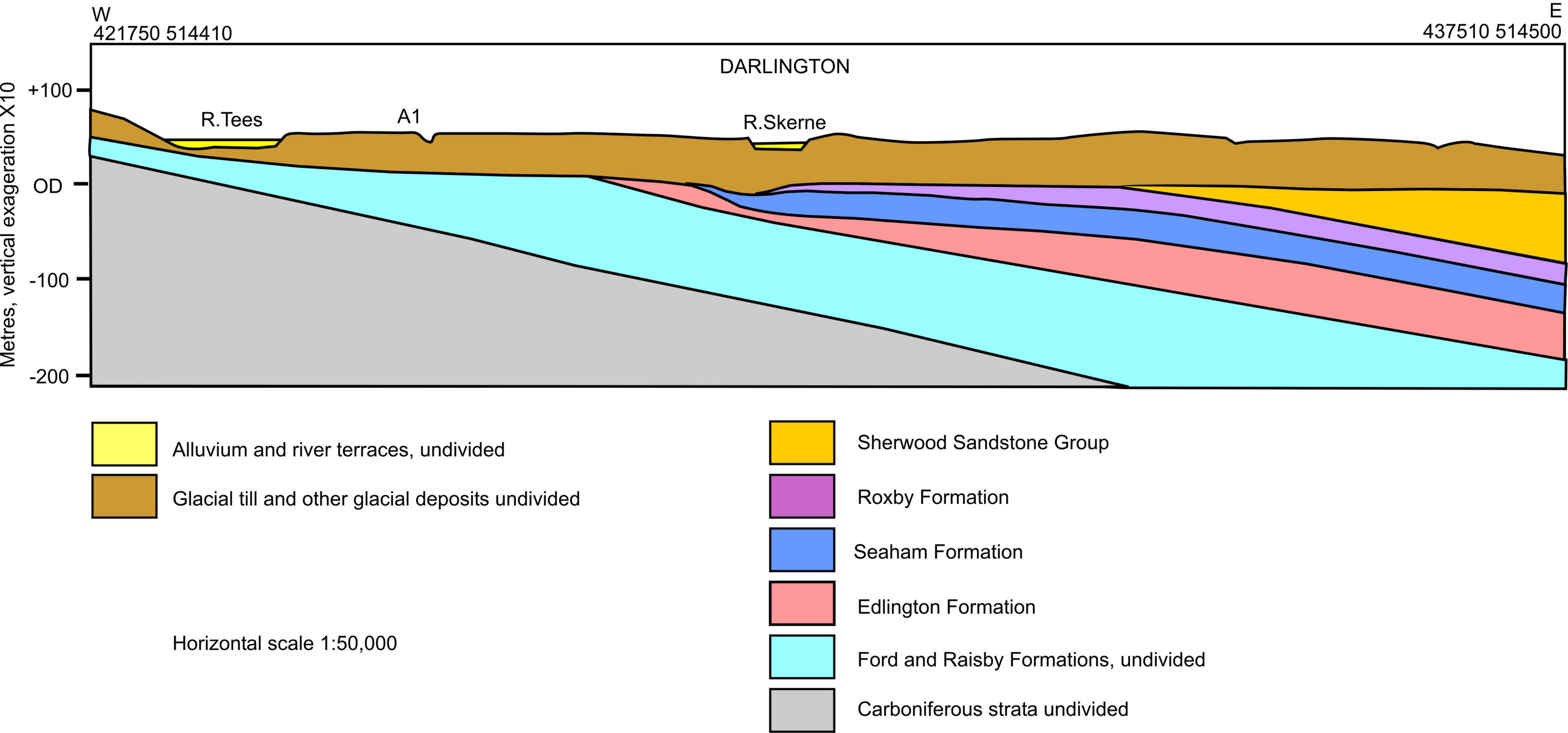


Figure 3. W-E section through Darlington



BH Reference	Easting	Northing	Ground Level	Depth	Drift Thick	Rock Head	Fm at RH	SSG OD	ROX THICK	BILL'H THICK	TOP ROX OD	SEH THICK	TOP SEH OD	EDT THICK	HART THICK	TOP EDT OD	FML THICK	TOP FML OD	RML THICK	TOP RML OD	RMFM THICK	TOP CARB OD	Remarks: tops of units may be truncated by drift
21137401	421760	513460	77.11	43.84	23.77	53.34	FML												10.67	53.34		42.67	
24168301	424801	516347	50.29	158.80	11.58	38.71	FML											38.71			30.84	7.87	
24223401	424380	522494	152.25	5.87	1.98	150.27	RML												3.13	150.27		147.14	
24229401	424980	522460	140.21	33.53	26.21	114.00	FML											114.00			5.18	108.82	
25076101	425690	507160	64.62	60.96	32.00	32.62	ROX		11.28		32.62		21.34										Not very reliable log bh to east proves sequence
25097701	425708	509706	57.91	40.23	25.30	32.61	EDT							5.18		32.61		27.43					Edlington Formation truncated by drift
26090801	426060	509890	51.82	51.21	33.12	18.70	SEH					12.30	18.70			6.40							
27201301	427120	520371	77.95	84.58	36.58	41.37	FML										8.07	41.37		33.30			Carboniferous below -6.63m
28099001	428925	509003	42.12	50.90	21.34	20.78	SSG	20.78	6.43	5.00	1.43		-5.00										Billingham 5m gysum/anhydrite
28147302	428756	514339	48.77	75.92	58.90	-10.13	ROX		3.17		-6.96	15.85	-10.13			-25.98							Some doubt about Edlington Formation depth
28149205	428963	514224	37.81	51.82	38.99	-1.18	ROX		3.38		-1.18		-4.56										Pure Ice borehole
28152301	428263	515328	51.81	86.50	36.00	15.81	EDT							17.00		15.81		-1.19					Memorial Hosp. Bh, Red marl with gypsum bands, Edlington Fm. truncated by drift
28166701	428650	516780	29.26	86.50	41.86	-12.60	FML											-12.60					
28210301	428032	521320	83.82	110.95	35.97	47.85	EDT							5.18	5.00	47.85	21.33	42.67	47.86	21.34	69.19	-26.52	Hartlepool 5m gypsum, Edlington Formation truncated
28212301	428298	521364	66.47	58.24	18.29	48.18	FML											48.18			39.55	8.63	North of fault
29081201	429130	508200	51.05	62.58	34.75	16.30	ROX		23.90	3.50	16.30		-7.60										Billingham 3.5m gypsum
29086101	429632	508158	51.51	76.20	33.53	17.98	SSG	17.98															Roxby Formation top below -24.67
29149201	429989	514247	47.50	74.98	50.60	-3.10	ROX		3.65		-3.10	15.85	-6.75			-22.60							Some doubt about sequence
30092301	430230	509350	32.99	129.08	13.11	19.88	SSG	19.88	26.39	3.00	-64.85		-91.24										Billingham 3m gypsum
30122607	430294	512604	38.42	73.80	34.00	4.42	SEH					11.90	4.42	24.53	18.00	-7.48		-32.01					Hartlepool 18m gypsum
30122702	430206	512753	40.18	47.30	36.30	3.88	EDT									3.88							
30175401	430500	517400	64.01	76.20	58.22	5.79	SEH					7.31	5.79			-1.52							?Seaham Formation or Edlington Formation
31105301	431550	510360	28.60	104.32	9.75	18.85	SSG	18.85	49.51	5.00	-24.40		-73.91										Billingham 5m gypsum/anhydrite
31139402	431942	513475	48.60	42.00	40.10	8.50	ROX				8.50												Sst, possibly foundered Sherwood Sandstone Group or gypsiferous mudst
31152703	431270	515770	45.42	54.17	37.17	8.25	ROX		10.99	0.00	8.25		-2.74										Billingham dissolved 0m was at 34162504 as well
31220701	431030	522720	92.53	91.74	49.38	43.15	FML										20.42	43.15	14.32	22.73	34.74	8.41	
32112401	432125	511490	35.66	44.68	28.96	6.70	ROX		12.62	0.00	6.70		-5.92										Billingham 0m dissolved
33126001	433610	512100	51.21	73.61	48.21	3.00	ROX		25.17	6.00	3.00		-22.17										Billingham 6m
34217701	434710	521790	64.27	109.74	51.21	13.06	SEH					40.54	13.06			-27.48						-41.81	Edlington Formation with evaporites unconformable on Carboniferous
35235401	435550	523490	38.25	73.00	51.00	-12.75	SEH					20.00	-12.75			-32.75							
35235501	435540	523530	39.22	74.00	51.00	-11.78	SEH					21.00	-11.78			-32.78							
27109001	427997	510070	33.50	54.40	23.47	10.03	SSG	10.03	8.95		-7.10		-16.05										
29090501	429020	509530	29.30	165.30	7.09	22.21	SSG	22.21	26.86	8.00	10.80	13.72	-16.06	7.17	5.00	-29.78	70.41	-36.95	13.59	-107.36	84.00	-120.95	Breccia -120.57below OD, Billingham 8-16m, Hartlepool 5m
29129801	429900	512870	42.00	68.82	49.00	-7.00	EDT								18.00	-7.00							Hartlepool 18m+ not bottomed
33112301	433280	511390	54.30	132.11	46.92	7.38	ROX		10.03	6.00	7.38	15.90	-2.65	52.75		-18.55		-71.30					Billingham 6m, Hartlepool 43m
34124001	434400	512000	11.00	135.76	7.54	3.46	ROX		27.97		3.46	16.76	-24.51	25.76		-41.27		-67.03					
39201801	439130	520840	44.81	100.51	53.00	-8.19	SSG		1.74	0.00	-49.11		-50.85										Billingham dissolved 0m
28133301	428331	513386	38.64	101.50	49.00	-10.36	EDT							5.00	4.00	-10.36		-15.36					Hartlepool 4m
29122902	429294	512967	43.61	105.00	49.15	-5.54	SEH					14.55	-5.54	18.10	13.00	-20.09		-38.19					Hartlepool 13m
29131104	429108	513198	40.09	93.00	44.70	-4.61	SEH					4.50	-4.61	24.40	19.50	-9.11		-33.51					Hartlepool 19.5m
29134201	429464	513214	41.48	108.00	47.50	-6.02	SEH					0.00	-6.02	40.50	8.00	-6.02		-46.52					Hartlepool 8m, Seaham Formation foundered
22168901	422832	516936	60.96	32.18	10.67	50.29	FML											50.29			82.07	-31.78	
24141201	424192	514219	51.82	78.94	31.09	20.73	FML											20.73			44.65	-23.92	
25172601	425288	517675	60.05	44.20	20.72	39.33	FML											39.33					Carb below 15.87
25173701	425301	517709	57.91	56.92	19.82	38.09	FML											38.09			29.76	8.33	
25183901	425340	518930	108.00	32.92	5.49	102.51	FML											102.51			19.20	83.31	Raisby and Ford formations undifferentiated
25191801	425199	519807	99.21	59.82	25.91	73.30	FML											73.30			33.91	39.39	
25191901	425186	519938	95.71	51.82	34.44	61.27	FML											61.27			17.07	44.20	
26150601	426080	515660	48.83	39.62	21.34	27.49	FML											27.49			16.93	10.56	?Carboniferous
29194301	429450	519300	56.10	61.26	41.76	14.34	FML											14.34					Carboniferous below -5.16
31167801	431741	516862	45.72	125.58	36.58	9.14	ROX		49.07	0.00	9.14	20.25	-39.93	12.36	12.36	-60.18		-72.54					Billingham dissolved
31203601	431330	520670	74.40	104.24	49.38	25.02	SEH					19.81	25.02	6.40		5.21		-1.19					Hartlepool 0m dissolved, Carboniferous below -29.54
31224701	431433	522720	89.61	78.33	57.00	32.61	FML										18.58	32.61		14.03			Carboniferous below 11.28
25145102	425523	514195	45.72	101.19	38.40	7.32	FML											7.32			57.69	-50.37	
31201201	431197	520202	72.88	76.20	37.64	35.24	FML										14.48	35.24	20.49	20.76	34.97	0.27	
31201801	431198	520841	83.82	126.80	52.12	31.70	SEH					11.58	31.70	8.69		20.12	31.24	11.43		-19.81			Carboniferous below -42.98
31220601	431029	522668	93.57	97.54	49.38	44.19	FML											44.19			42.67	1.52	
32214801	432495	521898	106.68	94.49	70.56	36.12	FML										9.30	36.12	9.45	26.82	18.75	17.37	
33217501	433744	521562	71.79	79.86	54.56	17.23	FML										11.91	17.23		5.32			Carboniferous below -8.07
34228901	434894	522982	69.10	74.98	66.45	2.65	SEH					11.58	19.42	5.19		7.84		2.65					Carboniferous below -5.88

Abbreviations:
SSG: Sherwood Sandstone Group; ROX: Roxby Formation; SEH: Seaham Formation; EDT: Edlington Formation; FML: Ford Formation; RML: Raisby Formation; RMFM:Raisby and Ford Formations, undivided; CARB: Carbonifeous, undivided