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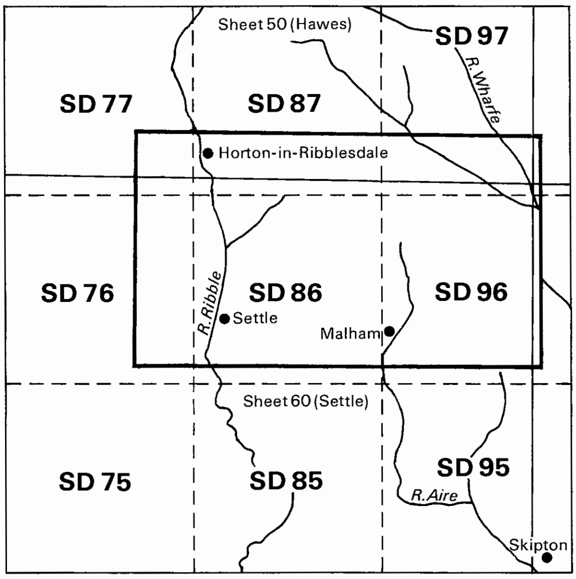

The limestone and dolomite resources of the country around Settle and Malham, North Yorkshire

With notes on the hard rock resources of the Horton-in-Ribblesdale area

Description of parts of 1:50 000 geological sheets 50 and 60

D. W. Murray

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The first twelve reports on the assessment of British sand and gravel resources appeared in the Report series of the Institute of Geological Sciences as a subseries. Report 13 and subsequent reports appear as Mineral Assessment Reports of the Institute.

Details of published reports appear at the end of this report.

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PREFACE

National resources of many industrial minerals may seem so large that stocktaking appears unnecessary, but the demand for minerals and for land for all purposes is intensifying and it has become increasingly clear in recent years that regional assessments of resources of these minerals should be undertaken. The publication of information about the quantity and quality of deposits over large areas is intended to provide a comprehensive factual background against which planning decisions can be made.

The interdepartmental Mineral Resources Consultative Committee recommended that limestone should be investigated, and following a feasibility study initiated in 1970 by the Institute and funded by the Department of Education and Science, the Industrial Minerals Assessment Unit (formerly the Mineral Assessment Unit) began systematic surveys in 1972. The work is now financed by the Department of the Environment and is being undertaken with the cooperation of the extractive industry.

This report describes the limestone resources and other important hard-rock resources of 247 km^2 of country around Settle and Malham, North Yorkshire, shown on the accompanying 1:50000 resource map. The assessment was conducted by D. W. Murray. D. McC. Bridge, D. J. Harrison, R. Thompson, H. Mathers, J. Dennis, Mrs S. P. Sobey, Mrs M. E. Hill and Miss H. Parkes provided additional support. The assessment is based on geological mapping at the 1:10 560 scale by R. S. Arthurton, E. W. Johnson, Mrs L. C. Jones and D. J. C. Mundy (Settle Sheet) and on a geological compilation by A. A. Wilson of published and unpublished work (Hawes Sheet). (For the dates of surveys see map in pocket.)

Gamma-ray logs of two boreholes were obtained with the support of the Institute's Applied Geophysics Unit.

Chemical analyses were carried out by A. E. Davis of the Analytical Chemistry Unit. K. S. Siddiqui of the Petrology Unit carried out X-ray diffraction analyses.

W. N. Pierce (Land Agent) was responsible for negotiating access to land for drilling. The ready cooperation of landowners, tenants and quarrying companies in this work is gratefully acknowledged.

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CONTENTS

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D. W. Murray

SUMMARY

Information obtained from 10 cored boreholes and from minor sections, together with information from the records and geological maps of the Institute of Geological Sciences form the basis of the assessment of limestone resources in the Settle and Malham area, North Yorkshire. The petrology, mineralogy, chemistry and mechanical properties of the limestones have been investigated and the limestones have been classified on the basis of their calcium carbonate content. The accompanying map shows the distribution of the recognised categories of limestone at surface. Horizontal sections constructed from borehole data and from knowledge of the regional geology, indicate categories likely to be encountered at depth. Limestone purity is stratigraphically controlled and most of the boundaries between categories coincide with geological boundaries. The geology, the carbonate resources and the chemical and mechanical characters of each division are described. Detailed information is presented within the outline borehole logs appended. A brief description of the hard-rock sandstone and gritstone resources of the Horton-in-Ribblesdale inlier is included.

Bibliographic reference

Murray, D. W. 1983. The limestone and dolomite resources of the country around Settle and Malham, North Yorkshire (with notes on hard-rock resources of the Horton-in-Ribblesdale area). Description of parts of geological sheets 50 and 60. *Miner. Assess. Rep. Inst. Geol. Sci.*, No. 126.

Note

National Grid references are cited in square brackets. In this report all lie within the 100-km square SD.

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INTRODUCTION

Limestone output in the United Kingdom has doubled over the past 20 years and, although it has fallen slightly in recent years, national production is currently totalling about 92 million tonnes annually (Institute of Geological Sciences, 1981). Most of this material is extracted from limestones of Carboniferous age which give rise to much of the impressive scenery associated with the Pennine uplands. If the amenity value of such areas is to be protected and at the same time they are to continue to supply much of the country's requirements for limestone, then more specific information on the nature of the deposits is needed to ensure that land-use and mineral planning is carried out with the benefit of the most up-to-date geological knowledge. The provision of such information, relating to the mechanical and chemical properties of the limestones of the area around Settle and Malham outlined on the resource map (hereafter called the Settle and Malham district) is the objective of the present study. The report also includes a description of the hard-rock sandstone and gritstone resources of the Horton-in-Ribblesdale inlier.

The survey has been carried out at a reconnaissance level and is based on techniques evaluated in an earlier feasibility study (Cox and others, 1977). Whilst detailed information is available for sample sites, the accompanying 1:50 000 map is more generalised. The survey has benefited from the ready cooperation of the minerals industry, which has made available numerous borehole logs, borehole core and chemical and aggregate test data.

DESCRIPTION OF THE DISTRICT

The district is situated in North Yorkshire and lies partly within the Yorkshire Dales National Park. It is predominantly rural but there are road and rail communications between the main commercial centre of Settle and the surrounding conurbations (Figure 1). The upland areas are sparsely populated, but many small villages lie in the valleys and along the foot of the limestone escarpment. The local economy is based largely on pastoral farming, tourism and mineral extraction, but there are also light manufacturing industries. Formerly, limestones were worked locally in small quarries for building, walling and lime-burning, but more recently, large quarries have been developed to produce raw materials for the construction and chemical industries. In addition, Lower Palaeozoic sandstones and siltstones are extensively quarried in the Ribble Valley near Horton-in-Ribblesdale, for crushed-rock aggregate.

TOPOGRAPHY

The district is largely underlain by the Carboniferous Limestone (Dinantian) which forms a plateau ranging in

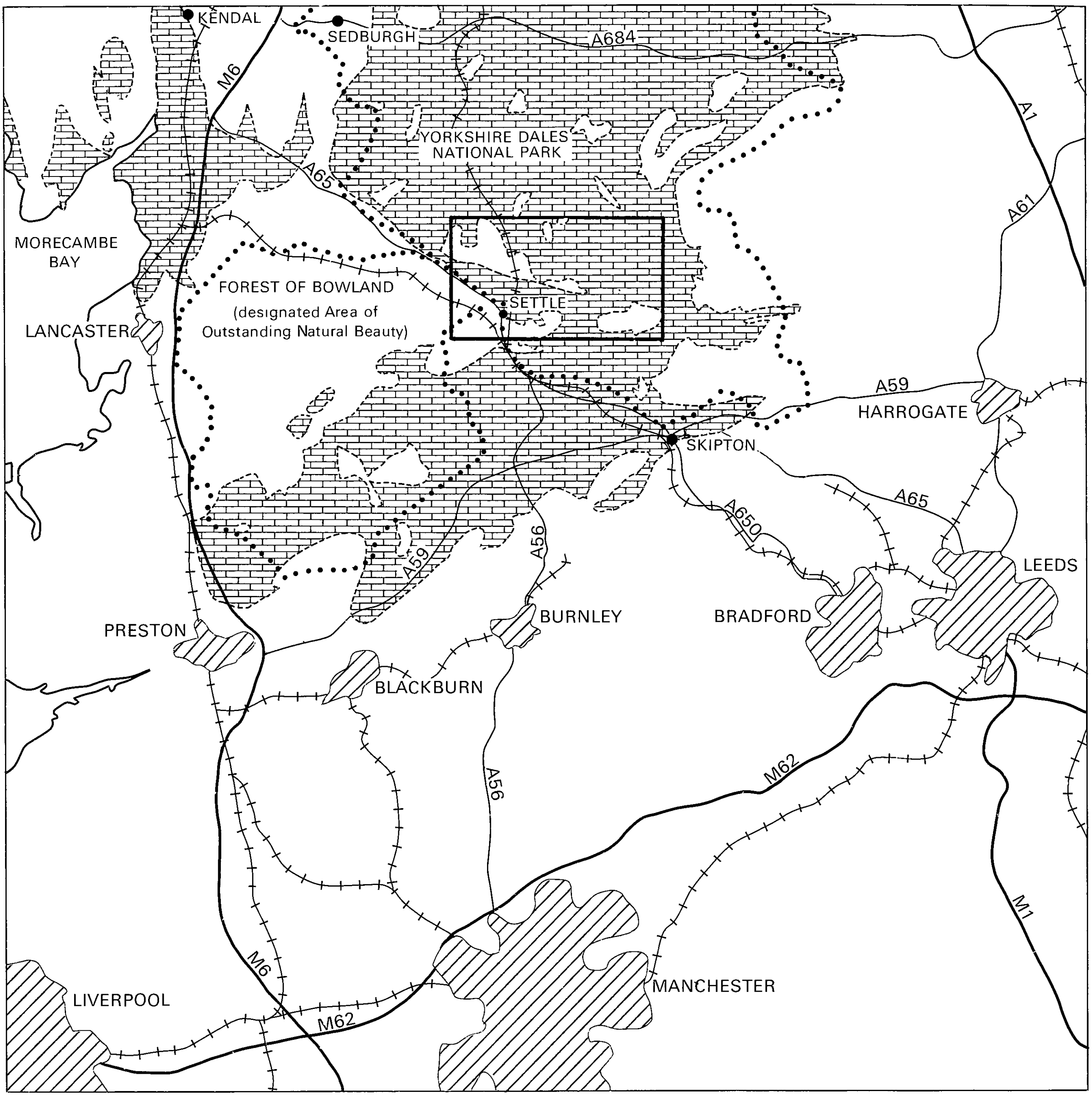


Figure 1 Sketch map showing the location of the district.

elevation from about 200 m to over 650 m at its highest point on Fountains Fell (see Figure 2). Karst features, treeless pastures and bleak moorland characterise much of the district. The plateau is deeply dissected by the north–south-trending valleys of the rivers Ribble and Wharfe, and also by their tributary valleys which trend approximately east–west. The steep-sided valleys, up to a mile wide, are floored by variable thicknesses of hummocky drift, and are the focus for the farming activity in the north of the district. Locally the quarrying of limestone, dolomite and pre-Carboniferous rocks has modified the scenery.

In the south of the district, the limestone escarpments of Giggleswick Scar and Gordale Scar mark the junction between the higher plateau limestone and the more subdued, drift-covered topography of the Craven Lowlands. The latter are underlain by sandstones, shales and limestones of Namurian and Dinantian age and compared with the plateau are more fertile and intensively farmed.

GENERAL GEOLOGY

The district is covered by part of geological Sheet 60 (Settle), and includes the southern margin of geological Sheet 50 (Hawes). This account is based on the geological investigations during 1976–80 by R. S.

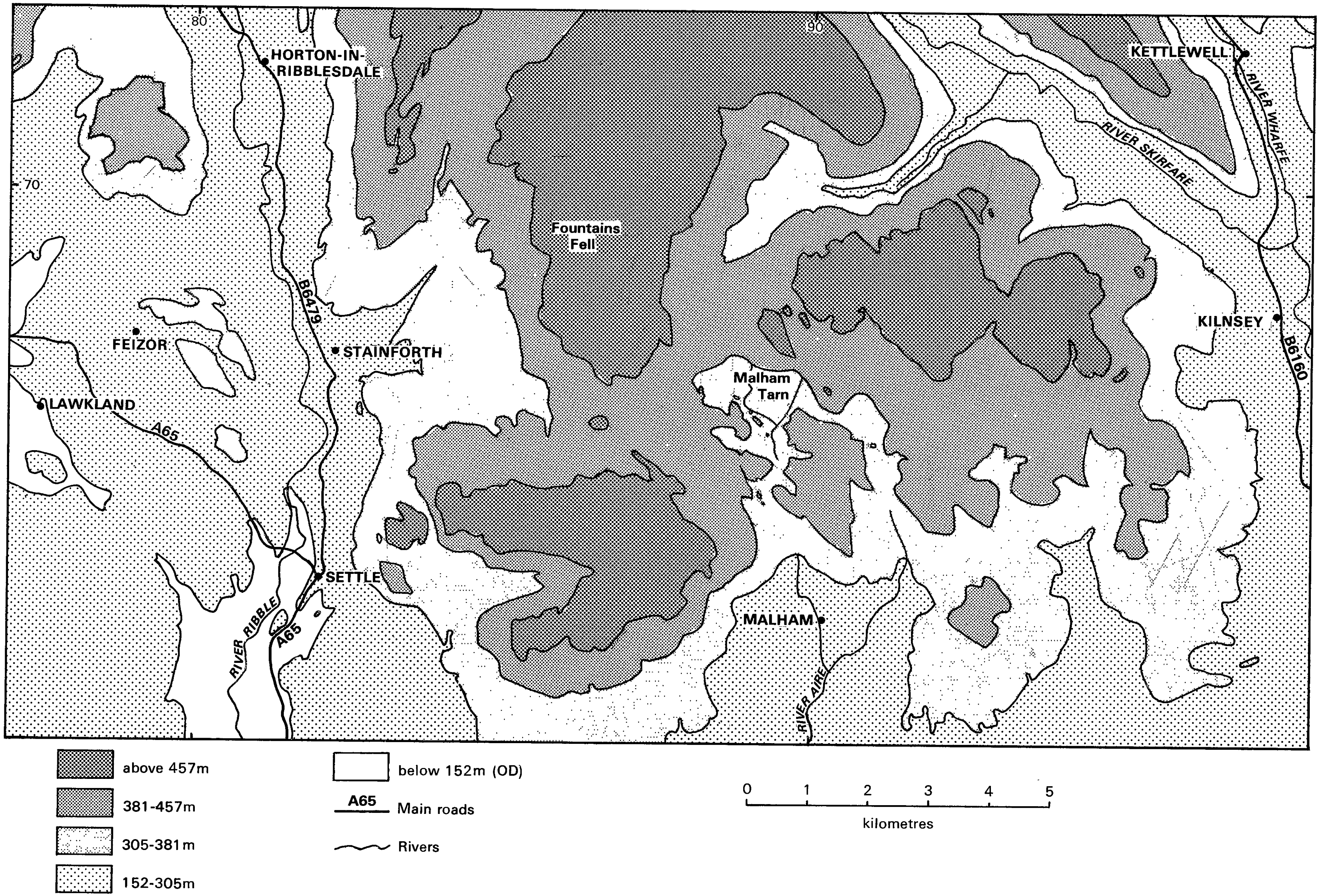


Figure 2 Topography of the district.

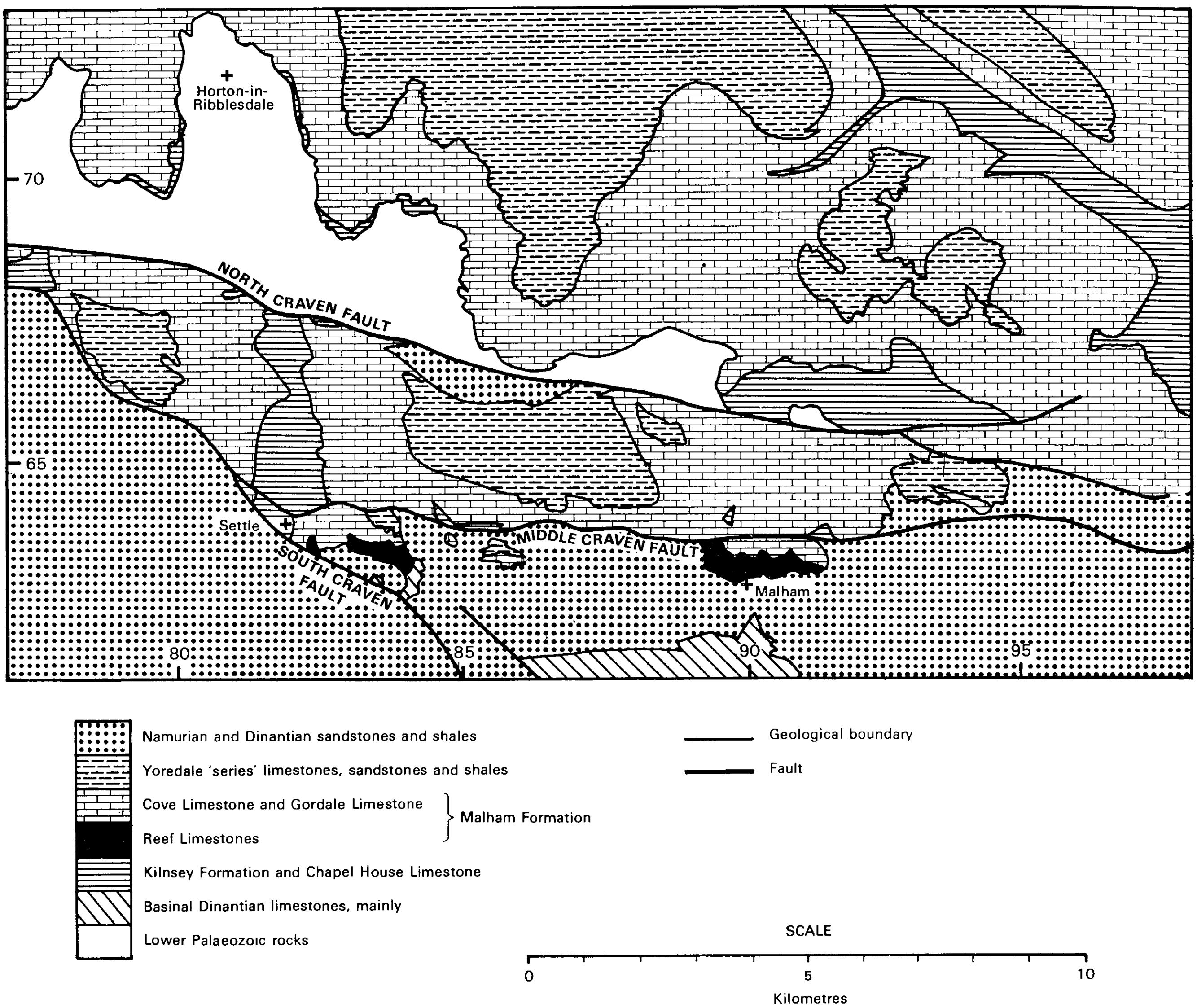


Figure 3 Simplified sketch map of the solid geology.

Arthurton, E. W. Johnson, L. C. Jones and D. J. C. Mundy of the Institute's Land Survey Divisions.

Most of the district is underlain by sedimentary rocks of Carboniferous age, but Lower Palaeozoic rocks crop out in Ribblesdale and Crummackdale (Figure 3). Evidence from gravity surveys (Whetton, 1956; Bott, 1967) and from boreholes suggests that these rocks underlie the Carboniferous rocks over most of the district. A brief account of the geology of the pre-Carboniferous rocks, including an evaluation of their use as hard rocks, is given in the latter part of this report.

During the Lower Carboniferous (Dinantian), shallow marine conditions were gradually established over the north and central parts of the district, which formed part of a sedimentary platform known as the Askrigg Block. To the south lay the deeper waters of the Craven Basin. As the seas gradually encroached onto the Block, conglomerates, dark limestones and muddy sediments were deposited (Chapel House Limestone and Kilnsey Formation, Table 1), however, as marine conditions became fully established, more uniform pale-coloured limestones (Malham Formation) were deposited on the Block, while at the Block/Basin margin, reefs of virtually pure lime sediment developed. Towards the end of the Dinantian, an alternating sequence of limestones, mudstones and sandstones (the Yoredale 'series') was deposited in response to the periodic deepening and shallowing of the Carboniferous sea. Sedimentation on the Block was broken in the late Dinantian following uplift of the south-eastern part of the Askrigg Block. Extensive erosion of the upper part of the sequence followed and continued into the Namurian when deltaic sands and grits were deposited unconformably on the Dinantian rocks.

The Dinantian rocks are mostly well exposed, and boulder clay and peat are present only in small pockets on the limestone plateau. In the main valleys and on the Lower Palaeozoic crop thicker deposits of boulder clay occur, though these rarely exceed 10 m in thickness.

South of the Middle and South Craven faults drift deposits obscure most of the Carboniferous rocks. The drift in these areas is of variable thickness, often exceeding 10 m. Boulder clay, which is the most extensive deposit, is moulded into drumlins in the Lawkland area, and in the Ribble valley.

Structure

The Askrigg Block is bounded to the south by the Craven Fault system comprising the North, Middle and South Craven faults. The North Craven Fault has the largest displacement and brings Lower Palaeozoic rocks to crop along its northern side. North of this fault, the

Table 1 Simplified stratigraphy for the Dinantian limestones of the district

	Stage	Coral/ brachiopod zone		Stratigraphy	
				Askrigg Block	Craven Basin
Silesian (Upper Carboniferous)	Pendleian	E1	Yoredale 'series'	Main Limestone	
Dinantian (Lower Carboniferous)	Brigantian	D2		Underset Limestone Middle Limestone Simonstone Limestone Hardraw Scar Limestone Upper Hawes Limestone Gayle Limestone Lower Hawes Limestone	
	Asbian	D1	Malham Formation (includes reef limestones)	Gordale Limestone	Pendleside Limestone
				Cove Limestone	Worston Shale Group
			Kilnsey Formation	Kilnsey Limestone Kilnsey Limestone with Mudstone	(Scalebar Quarry Limestone) (Scalebar Force Limestone)
	Arundian	C2 S1		Chapel House Limestone	
	?		Stockdale Farm Formation		

Lower Palaeozoic (Ordovician and Silurian) *For details see Table 14*

Lower Palaeozoic rocks appear to have acted as a rigid basement and only minor folding and NE–SW-trending faulting is seen in the overlying limestones. However, in the ground between the North and Middle Craven faults, where the sediments are draped over the margin of the Askrigg Block, the limestones are structurally complex with many minor faults trending NW–SE.

Mineralisation

The district lies on the periphery of the Northern Pennine Orefield which is centred, to the east of the district, at Greenhow, near Pateley Bridge. At various times after the end of the Carboniferous period certain faults, fractures and cavity systems, mainly confined to the Yoredale 'series', became the host for sulphide ores and associated calcite-baryte-fluorite gangue minerals. The district has a long history of metalliferous mining stretching back as far as Roman times; but production was at its peak in the eighteenth and nineteenth centuries with the mining of lead, copper and zinc from irregular, thin and pocketed veins.

Deposits of barytes ($BaSO_4$) and smithsonite (calamine) ($ZnCO_3$) were also locally present in economic quantities to be worked as minerals in their own right. The calamine mine north of Malham [876 640] is well documented (Raistrick, 1973) and was worked extensively at the beginning of the nineteenth century. By 1900 most of the mining in the district had ceased. The distribution of old workings is shown in Figure 4.

Dolomitisation and silicification

Secondary dolomite and silica have replaced limestones in the district. Their occurrence is common in the vicinity of the North and Middle Craven faults, particularly in the Malham Formation and the Lower Hawes Limestone. The replacement bodies are irregular to stratiform in type or may be restricted to faults or joints. The larger replacement bodies are shown on the resource map (see also Figure 4).

Laterally persistent beds of stratiform replacement dolomite are recorded at the Kilnsey Limestone/Cove Limestone boundary and at various horizons within the Kilnsey Limestone. Dolomites of a similar type are recorded in borehole core from the Chapel House Limestone. Dolomites related to faults and joints are common throughout the district but are laterally impersistent. However, extensive dolomitisation of this type occurs in the vicinity of Skythorne Quarry, near Threshfield [976 645].

Discrete dolomite bodies occur in the vicinity of High Hill [833 635] and Back Scar [860 650]. Extensive silica replacement has occurred near Rye Loaf Hill [860 633]. Other small dolomite bodies are present in the district but are restricted to the area south of the North Craven Fault.

ASSESSMENT OF LIMESTONE RESOURCES

The assessment is based on information from IGS maps and the forthcoming Settle Memoir, together with the results of a field survey which provided the rock samples for study in the laboratory and the data for interpretation. The procedures adopted are similar to those used in other limestone assessment reports (Cox and others, 1977).

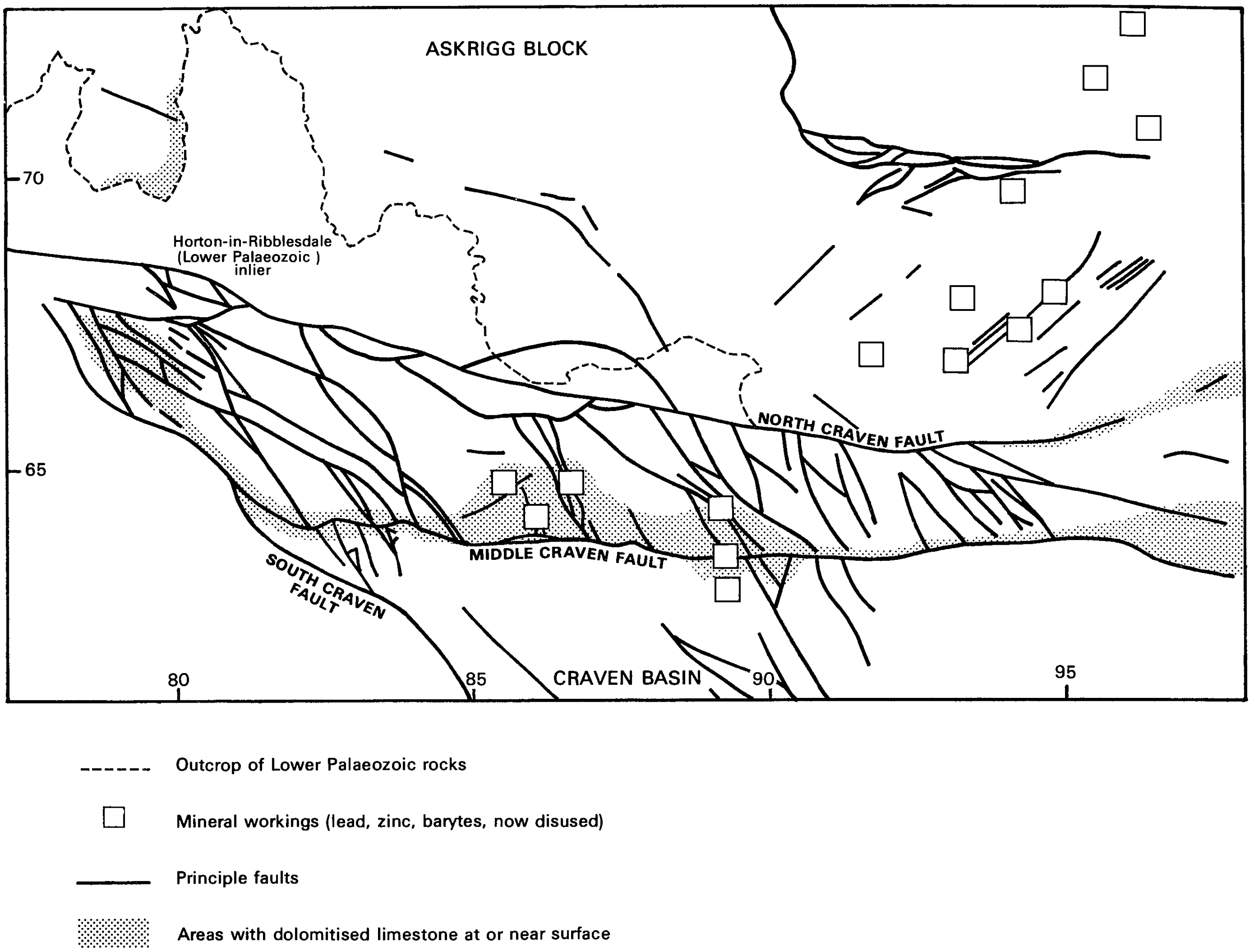


Figure 4 Map showing main structural components of the district, disused metalliferous mineral workings and areas of known dolomitisation.

PROCEDURES

Field survey

The boreholes required for the assessment of the limestones and dolomite resources in the district were sited with the aid of up-to-date 1:10 560 geological maps, and with reference to natural exposures and quarry sections. Five boreholes were drilled to depths ranging from 65 to 220 m and these provided continuous cores of at least 47 mm diameter. The boreholes were drilled by contractors using a lorry-mounted rig and water-flush techniques. In general the core recovery exceeded 95%, but some difficulties were encountered with sampling clays and shales. Two boreholes were logged by downhole geophysical techniques.

In addition to the five assessment boreholes, cores from five further boreholes were made available by Imperial Chemical Industries Limited, Eskett Quarries Limited/Steetley Minerals Limited and Cominco S. A. Spot samples were also collected from quarry and natural sections.

Laboratory programme

Lithological, petrological and mineralogical determinations were made using a combination of microscopical and staining techniques applied to sawn and etched rock surfaces. Additional mineralogical data were determined by X-ray diffraction analysis of selected rock powders.

A primary classification of the rocks, based on carbonate content (Cox and others, 1977), was made by measuring the amount of the acid insoluble residue of rock samples aggregated over 5-m lengths for all boreholes.

The insoluble residues of individual spot samples were also determined but no additional tests were carried out on the spot samples.

Chemical analyses for major and trace elements were performed by the Analytical Chemistry Unit of the Institute on aggregated samples from lengths of core of from 2 to 10 m from all borehole cores. Analyses were made using direct electron excitation X-ray spectrophotometry for Ca, Mg, Si, Al, Na, K, S, Sr, P, F and Fe; other elements were determined by atomic absorption spectrometry (AAS), and As by colorimetry (Roberts and Davis, 1977).

The colour of the rock powder is important if the limestone is to be used as a whitening agent or in applications where the colour of the manufactured product is important. A reflectance spectrophotometer was therefore used to determine the reflectivity, relative to a $MgCO_3$ standard, of powered samples (63 µm particle size) of the limestones. In more general descriptions of the rock colour of borehole core and hand specimens, terminology from the Geological Society of America's Rock-Color Chart has been applied. The common descriptive terms used in this report are shown in Table 2.

In order to provide guidance on the likely perfor-

Table 2 Rock colours as defined by the Rock-Color Chart (Geological Society of America, 1970)

Value (lightness)	Value (lightness)	Value (lightness)
9 White	6 Medium light grey	3 Dark grey
8 Very light grey	5 Medium grey	2 Greyish black
7 Light grey	4 Medium dark grey	1 Black

mance of the rocks as aggregates most of the samples were subjected to the Aggregate Impact Value (AIV) test (British Standard 812: 1975).

Classification
The two methods of classification chosen for use in this report are based on petrology and on calcium carbonate ($CaCO_3$) content. The first (Dunham, 1962) is used to describe the rocks in lithological terms, but the second is preferred for use in the description of resources (Table 3).

Table 3 Classification of limestones by purity with some possible industrial uses

Category	Percentage $CaCO_3$	Equivalent CaO	Possible industrial uses*
1 Very high purity	98.5	55.18	steel, glass, rubber, plastics, paint, whiting
2 High purity	97–98.5	54.34–55.18	iron, ceramics, general chemical use, Portland cement, sugar
3 Medium purity	93.5–97	52.38–54.34	paper, animal feeding stuffs, agriculture
4 Low purity	85–93.5	47.62–52.38	asphalt
5 Impure	85	47.62	natural cement, mineral wool

* $CaCO_3$ content is only one of several chemical specifications governing end use: silica, iron, sulphur and certain trace elements may be as important in some of these applications.

THE MAP

The resource map folded into the pocket at the end of this report is based on parts of New-Series geological Sheet 50 (Hawes) (published 1971) and a provisional edition of geological Sheet 60 (Settle), based on the mapping at 1:10 560 in 1976–80. The resurvey of Sheet 60 has necessitated the revision of some geological boundaries on the southern margin of Sheet 50.

Thick drift deposits (greater than 5 m) are largely restricted to drumlin-covered areas, which are indicated on the resource map by pecked feature lines; elsewhere the drift cover is unlikely to exceed 5 m. Structural information is shown on the map in red, and geological boundaries in black.

The limestone resources of the district are summarised on the resource map. They are indicated on the map by colours. Shades of blue indicate the expected purity of the limestones at the surface. Purity values were determined at sample points and this information combined with field observations indicates the composition of the limestone in a regional fashion. Areas of partial dolomitisation are indicated by black dots. Over most of the district limestone purity is related to the stratigraphy, so most of the category boundaries coincide with geological boundaries.

The site of each borehole is marked with its registration number. The purity, generalised lithology, colour and mechanical strength of the limestones at each site are indicated in the corresponding tablet below the map. The purity was averaged for each 5-metre increment of strata and this value determined the category of limestone according to a generalised version of the classification given in Table 3. The various limestone divisions are identified by stratigraphical symbols; an explanation of these symbols is shown in the generalised vertical section for the boreholes adjacent to the borehole tablets.

RESULTS

The results are here described by reference to the geological formations rather than under headings relating to chemical or mechanical properties such as were appropriate for other limestone assessment surveys in the southern Pennines (e.g. Cox and Harrison, 1980). The geological formations are described in stratigraphical order from the base upwards.

Limestones of the Askrigg block

Chapel House Limestone
The Chapel House Limestone is only exposed in the core of a small anticline in the Ribble valley, near Stainforth Bridge [818 672] (Plate 2). However it is within 10 m of the surface in other areas of Ribblesdale and Wharfedale, and has been encountered in boreholes both north and south of the North Craven Fault.

North of the North Craven Fault, the Chapel House Limestone rests on an irregular surface of Lower Palaeozoic rocks and shows considerable variation in thickness and lithology. The maximum proved thickness of 11.22 m was seen in borehole SD 87 SW 9 [8435 7143], but the Chapel House Limestone is absent in a borehole (SD 77 SE 1 [7955 7171]) only 5 km to the west. The basal beds north of the North Craven Fault are generally conglomeratic. In borehole SD 96 NE 1 [9726 6647] 2.6 m of conglomerate consisting of Lower Palaeozoic pebbles set in a carbonate matrix were recorded. The conglomerate is frequently pyritous and contained abundant corals in borehole SD 87 SW 9.

South of the North Craven Fault, Lower Palaeozoic rocks are not encountered beneath the Chapel House Limestone. A continuous sequence of limestone, mudstone and sandstone was recorded in borehole SD 86 SE 6 [8259 6670] within the Chapel House Limestone. Above the conglomerates, both north and south of the North Craven Fault, the limestones become sparry, dark grey to light grey grainstones and packstones. Algae, foraminifera and pellets are locally abundant in these rocks which also contain scattered lithoclasts. In the lower parts of these limestones, thin mudstones and dolomitic siltstones were present. Calcilutites with fenestral fabrics were also observed.

In two boreholes (SD 86 NW 4 and SD 96 NE 1) the Chapel House Limestone was extensively dolomitised; it is thought that this might be typical of the Chapel House Limestone at depth elsewhere in the district.

Data collected were restricted to samples prepared from borehole cores. *Reflectance values* obtained from powders prepared from the Chapel House Limestone (see Figure 7) were less than 70% for a wavelength of 600 nm. The highest values (see map for graphical borehole logs) were obtained from samples from borehole SD 86 SE 6.

Most *insoluble residue values* ranged between 1% and 10% with the residue mineralogy being predominantly silica, pyrite and clay minerals.

The non-dolomitised parts of the Chapel House Limestone produce aggregates which are of above average strength (see Figure 6), in contrast to the dolomites which are generally vuggy and pyritous, and which are substantially weaker (see map for graphical borehole logs).

The Chapel House Limestone is locally of *medium to high purity* (93% to 98.5% $CaCO_3$), but most samples are categorised as *low to medium purity* (85% to 97% $CaCO_3$).

The *chemical data* on the Chapel House Limestone are derived from the analyses of seven samples taken from boreholes SD 86 NW 4, SD 86 SE 6 and SD 87 SW 9, summarised in Table 4. The presence of lithoclasts, clay minerals and patchy dolomitisation results in variable silica, alumina, magnesia, potash and manganese values. Pyrite associated with the clay-rich limestones causes variation in iron values. Trace elements are present at low background levels, although local mineralisation was recorded.

Table 4 Chemistry of the Chapel House Limestone
Results obtained from the analysis of 7 samples from 3 boreholes

	Maximum value	Minimum value	Mean	Standard deviation
	weight per cent			
CaO	54.16	44.99	51.90	3.35
MgO	7.23	0.56	1.61	2.50
SiO_2	6.80	0.20	2.32	2.28
Al_2O_3	1.61	0.70	0.61	0.46
Na_2O	0.03	0.01	0.01	0.01
K_2O	0.43	0.08	0.17	0.11
SO_3	0.62	0.08	0.23	0.19
P_2O_5	0.03	0.0	0.01	0.01
Loss at 1050° C	43.40	39.48	42.33	1.45
F	0.05	0.0	0.01	0.02
SrO	0.07	0.02	0.04	0.02
Fe_2O_3	0.72	0.07	0.32	0.28
	parts per million			
MnO	470	160	275	110
Cu	0	0	0	0
Pb	10	0	1	4
Zn	30	10	23	10

Kilnsey Formation

The Kilnsey Formation crops out principally in Ribblesdale, Wharfedale, Littondale and adjacent to the North Craven Fault, ėast of Malham. It is dividėd lithologically into a lower argillaceous division and an upper division consisting of well-sorted sparry limestones. Their maximum proved thickness in borehole SD 86 SE 6 was 43.25 and 61.59 m respectively. The Kilnsey Formation thins northwards. The locality at Kilnsey Crag (Plate 3) [974 681] shows the whole of the upper division, the Kilnsey Limestone, and part of the lower, the Kilnsey Limestone with Mudstone.

Kilnsey Limestone with Mudstone The passage from the Chapel House Limestone to the Kilnsey Limestone with Mudstone is marked by the abrupt appearance of shales and argillaceous limestones. These argillaceous beds comprise a mixed and laterally variable sequence which is typically medium dark grey to dark grey in colour.

To the north of the North Craven Fault these beds are exposed in the main river valleys, but south of the North Craven Fault, the main exposure lies in the Ribble valley.

Mudstones and the more argillaceous limestones are poorly exposed, but boreholes prove that individual mudstones range in thickness between 10 cm and 2 m. The mudstones are commonly micaceous and pyritous. The limestones are generally argillaceous wackestones. Corals, crinoids, algae (especially encrusting forms), intraclasts and evidence of bioturbation are all locally common.

The results of the laboratory tests are from samples taken from boreholes SD 86 NW 4 [8259 6670], SD 86 SE 6 [8541 6378], SD 87 SW 9 [8435 7143] and SD 96 NE 1 [9726 6647], supplemented by data from 5 spot samples.

Reflectance values obtained from powders prepared from the Kilnsey Limestone with Mudstone (see Figure 7) were less than 60% for a wavelength of 660 nm. Values as low as 30% were obtained from more argillaceous limestones.

Insoluble residue values range between 5% and 15% and these beds are therefore classified as *low purity* limestone (85% to 93.5% $CaCO_3$) although the sequence is likely to contain beds which are *impure* (less than 85% $CaCO_3$) or of *medium purity* (93.5% to 97% $CaCO_3$).

Dolomitisation is common within the lower division, but is restricted to the less argillaceous limestones. Silicification and variable amounts of pyrite were noted in the argillaceous limestones.

An above average strength, relative to other formations tested, is suggested by *Aggregate Impact Values*

Table 5 Chemistry of the Kilnsey Limestone with Mudstone
Results obtained from 26 samples from 4 boreholes

	Maximum value	Minimum value	Mean	Standard deviation
	weight per cent			
CaO	53.58	42.72	49.23	2.83
MgO	6.02	0.68	1.98	1.69
SiO_2	11.31	1.15	5.38	2.56
Al_2O_3	2.78	0.41	1.35	0.57
Na_2O	0.08	0.01	0.03	0.01
K_2O	0.50	0.10	0.28	0.09
SO_3	1.42	0.21	0.74	0.31
P_2O_5	0.03	0.0	0.01	0.01
Loss at 1050° C	43.01	36.13	40.40	1.65
F	0.07	0.0	0.02	0.02
SrO	0.15	0.03	0.08	0.03
Fe_2O_3	1.26	0.32	0.75	0.24
	parts per million			
MnO	950	70	247	215
Cu	5	0	1	2
Pb	0	0	3	5
Zn	40	0	17	10

Plate 1 Cowside Beck, Yew Cogar Scar.

Dark Kilnsey Limestone at the base, grading upwards into pale limestones of the Malham Formation. The topographic profile is typical of this part of the sequence. L2375

Plate 2 River Ribble, Stainforth.

Grainstones in the Chapel House Limestone. L2687

Plate 3 Kilnsey Crag, Kilnsey.

Type section of the Kilnsey Limestone. The limestone becomes argillaceous at the base of the cliff. L2693

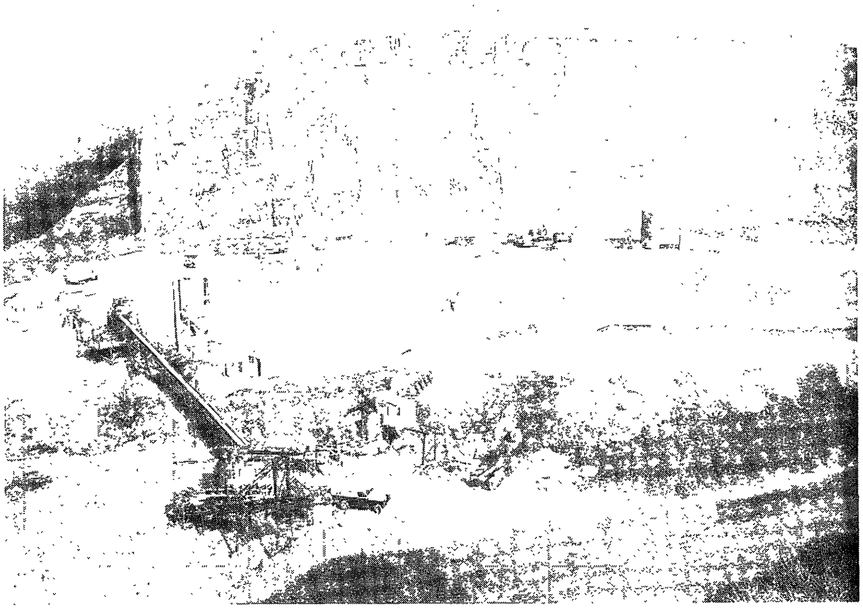


Plate 4 Giggleswick Quarry.

Cove Limestone. L2700

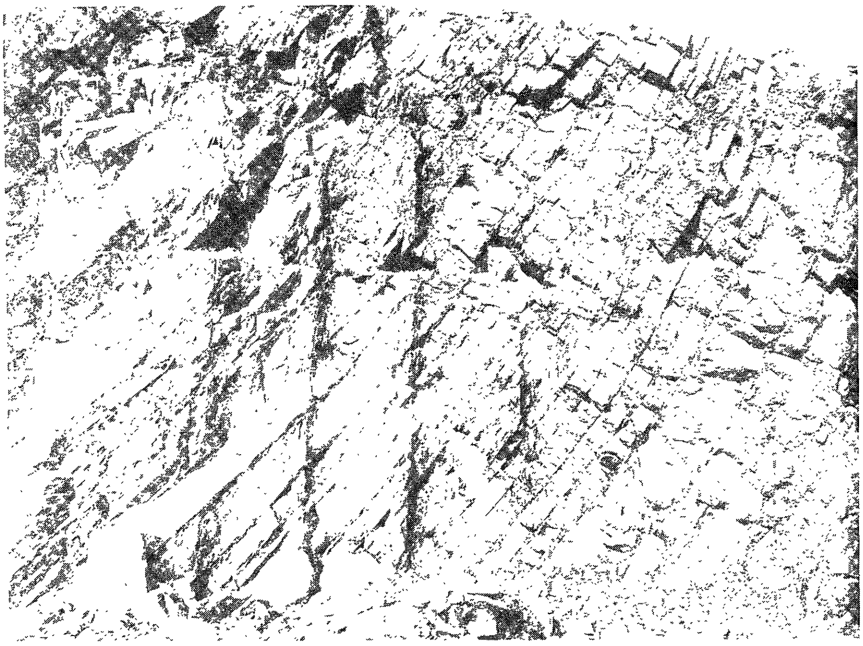


Plate 5 Arcow Quarry.

Austwick Formation: well-bedded arkosic sandstones are separated by siltstone partings and overlain by laminated siltstones on the left of the photograph. L2350

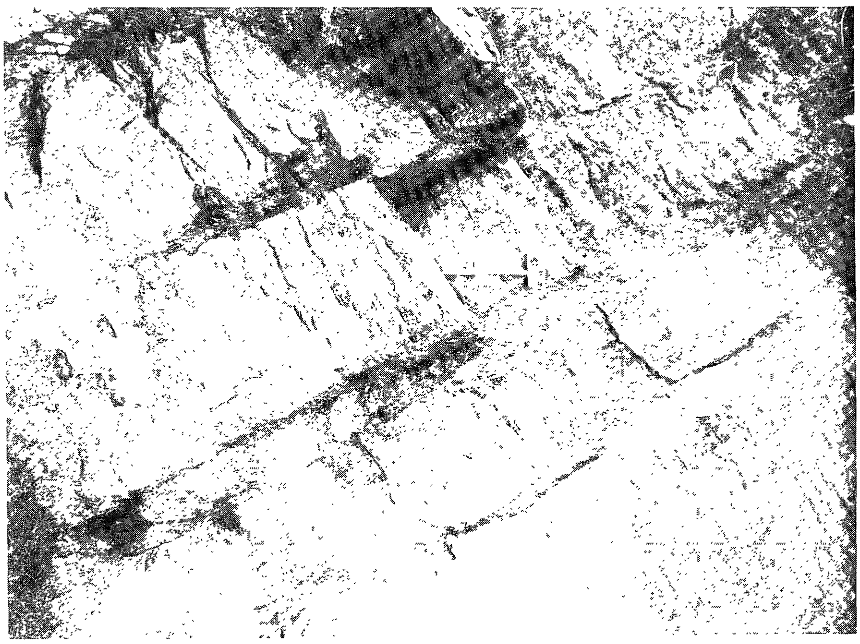


Plate 6 Wharfe [777 700].

Prominent cleavage, in Austwick Formation. L2352 obtained from Kilnsey Limestone with Mudstone material (Figure 6).

The *chemical data* on the Kilnsey Limestone with Mudstone which were obtained from 26 samples taken from boreholes SD 86 NW 4, SD 86 SE 6, SD 87 SW 9 and SD 96 NE 1, are summarised in Table 5. The mean values for CaO, Al_2O_3, and K_2O indicate the argillaceous nature of the limestones and the presence of potassium-rich clay minerals. Silica values are also high (mean SiO_2 value is 5.38%) in the argillaceous parts of the sequence because of bioclastic silicification. Patchy dolomitisation of parts of the rock is responsible for the variation in magnesia values. The dolomitic samples also contain high amounts of manganese. The common presence of pyrite and limonite, particularly in the argillaceous parts of the sequence, result in wide variation in iron values. Trace elements are present at low background levels although some observed mineralisation near the base of the limestone in borehole SD 96 NE 1 is associated with a variable degree of dolomitisation.

Kilnsey Limestone The argillaceous limestones pass upwards into well-sorted sparry limestones, the Kilnsey Limestone. These latter limestones are also dark grey to medium grey in colour, but this is caused by bituminous staining rather than by clay impurities. The limestones are commonly well-sorted packstones and grainstones, containing abundant pelletal debris with some algae, shells and corals. In borehole SD 77 SE 1 [7955 6722] lithoclasts are also present.

The Kilnsey Limestone is well exposed in Ribblesdale, Wharfedale, and in their tributary valleys. In Wharfedale, it forms a major scar (Plate 3) at Kilnsey Crag [974 681].

The limestones of the Kilnsey Limestone were proved in seven boreholes. Samples from these boreholes, supplemented by 17 spot samples from exposures, form the basis for the results detailed below.

Reflectance values obtained from powders prepared from the upper division (Figure 7) were less than 60% for a wavelength of 660 nm. Higher values were obtained from the top of the division where the colour change from Kilnsey Limestone to Cove Limestone was less abrupt.

Insoluble residue values were consistently low (less than 2%), and these limestones are therefore classified as *high to very high purity* (greater than 97% $CaCO_3$).

Aggregates produced from these beds are likely to be of average strength relative to the other formations (Figure 6).

The *chemical data* on the Kilnsey Limestone were obtained from 26 samples taken from boreholes SD 77 SE 1, SD 86 NW 4, SD 86 SE 6, SD 87 SW 9, SD 96 NE 1, SD 96 NE 2 and SD 96 NE 3, summarised in Table 6. The limestones which were not affected by dolomitisation typically gave high CaO values, which are at their highest in samples from borehole SD 77 SE 1, in which the Chapel House Limestone and the Kilnsey Limestone with Mudstone are not present. Lithoclasts of arenaceous material are common in the limestones from this borehole, and the silica and alumina values are therefore anomalous. Dolomitisation is responsible for the variable magnesia and manganese values. Trace elements are present at low background levels.

Table 6 Chemistry of the Kilnsey Limestone
Results obtained from 26 samples from 7 boreholes

	Maximum value	Minimum value	Mean	Standard deviation
	weight per cent			
CaO	55.78	44.43	52.96	3.40
MgO	9.26	0.37	2.31	2.76
SiO_2	1.90	0.0	0.24	0.37
Al_2O_3	0.48	0.09	0.15	0.09
Na_2O	0.03	0.0	0.01	0.01
K_2O	0.14	0.03	0.04	0.02
SO_3	0.25	0.03	0.10	0.06
P_2O_5	0.01	0.0	0.01	0.0
Loss at 1050° C	45.38	42.83	43.80	0.63
F	0.03	0.0	0.0	0.01
SrO	0.06	0.01	0.04	0.01
Fe_2O_3	0.51	0.02	0.12	0.15
	parts per million			
MnO	570	70	224	151
Cu	10	0	2	3
Pb	10	0	4	5
Zn	40	0	19	12

Malham Formation

The Malham Formation comprises a sequence of very high purity limestones (greater than 98.5% $CaCO_3$) which crop out extensively and form the most important limestone resource in the district. The limestones form the karst topography typical of many parts of the district, including the classic localities of Malham Cove [898 657], Gordale Scar [915 640] and Giggleswick Scar [802 657].

The Malham Formation reaches its maximum thickness of about 170 m in the outcrops between the North and Middle Craven faults. Two named members are recognised, the Cove Limestone and the Gordale Limestone. In the vicinity of the Middle Craven Fault, reef limestones are also present. These were developed at the same time as the Cove and Gordale Limestones and their description is included here.

Cove Limestone The boundary between the Kilnsey Limestone and the Cove Limestone is commonly marked by a change in colour from medium dark grey to light grey. The maximum thickness of about 100 m is present in the area between the North and Middle Craven faults, but north of the North Craven Fault the Cove Limestone is thinner, and a maximum thickness of 60 m is estimated.

The Cove Limestone comprises a monotonous sequence of massively bedded light grey wackestones and packstones (Plate 4). Some grainstones are also present, with sporadic lamination and cross-bedding. The limestones are commonly mottled or spotted (pseudobrecciated) by recrystallisation and they also typically show closely spaced jointing. Crinoids, brachiopods, algae (including *Koninckopora*) and foraminifera are common throughout the sequence.

In outcrops north of the North Craven Fault, a useful marker horizon, the Porcellanous Beds, is present two or more metres below the boundary between the Gordale Limestone and Cove Limestone. The Porcellanous Beds consist of 1 to 2 m of interbedded calcilutite (with fenestral fabric) and fine-grained laminated grainstones. Palaeokarstic surfaces are associated with the calcilutite. The Porcellanous Beds are not present south of the North Craven Fault.

Dolomitisation occurs mostly on a small scale, related to faults, joints and fractures, but the Cove Limestone of Skythorns Quarry, near Threshfield [978 642] is extensively dolomitised.

The limestones of the Cove Limestone were proved in seven boreholes. Samples from these boreholes, supplemented by 36 spot samples from exposures, form the basis for the results detailed below.

The limestones are typically uniform in chemical composition, strength and colour.

Reflectance values obtained from powders prepared from the Cove Limestone (Figure 7) were generally between 70% and 80% for a wavelength of 660 nm.

Insoluble residue values are generally less than 1%, although the Porcellanous Beds may contain up to 3% of non-carbonate minerals. The chief non-carbonate minerals are silica, pyrite and clay minerals, all of which occur in trace quantities. Some disseminated hematite was observed in the lower beds. Traces of galena and barytes occur sporadically in calcite veins and along joints. The Cove Limestone is consistently classified as *very high purity* limestone (greater than 98.5% $CaCO_3$).

An average to below average strength, relative to other formations tested, is suggested by *Aggregate Impact Values* obtained from the Cove Limestone material (Figure 6).

The *chemical data* on the Cove Limestone, which were obtained from 73 samples taken from boreholes SD 77 SE 1, SD 86 NW 4, SD 86 SE 6, SD 87 SW 9, SD 96 NE 2, SD 96 NE 3, SD 96 SW 1, are summarised in Table 7.

The Cove Limestone has a mean CaO value of 55.20%, although values as high as 56% are common. The limestones are chemically uniform, exhibiting only very local variations as indicated by the low standard-deviation values.

Trace elements are present at low background levels. Maximum values of lead and zinc were found in samples from the basal part of the sequence along the Middle Craven Fault and also from samples in the eastern part of the district, which lies on the edge of the Northern Pennine Orefield.

Table 7 Chemistry of the Cove Limestone
Results obtained from 73 samples from 7 boreholes

	Maximum value	Minimum value	Mean	Standard deviation
	weight per cent			
CaO	56.10	47.71	55.20	1.32
MgO	5.51	0.17	0.66	1.26
SiO_2	0.40	0.0	0.08	0.14
Al_2O_3	0.32	0.06	0.13	0.11
Na_2O	0.03	0.0	0.01	0.01
K_2O	0.09	0.02	0.04	0.01
SO_3	0.31	0.0	0.02	0.04
P_2O_5	0.02	0.0	0.01	0.0
Loss at 1050° C	44.68	42.88	43.40	0.33
F	0.03	0.0	0.0	0.0
SrO	0.04	0.0	0.01	0.01
Fe_2O_3	0.16	0.02	0.04	0.03
	parts per million			
MnO	480	50	126	86
Cu	5	0	1	2
Pb	20	0	1	4
Zn	40	0	9	7

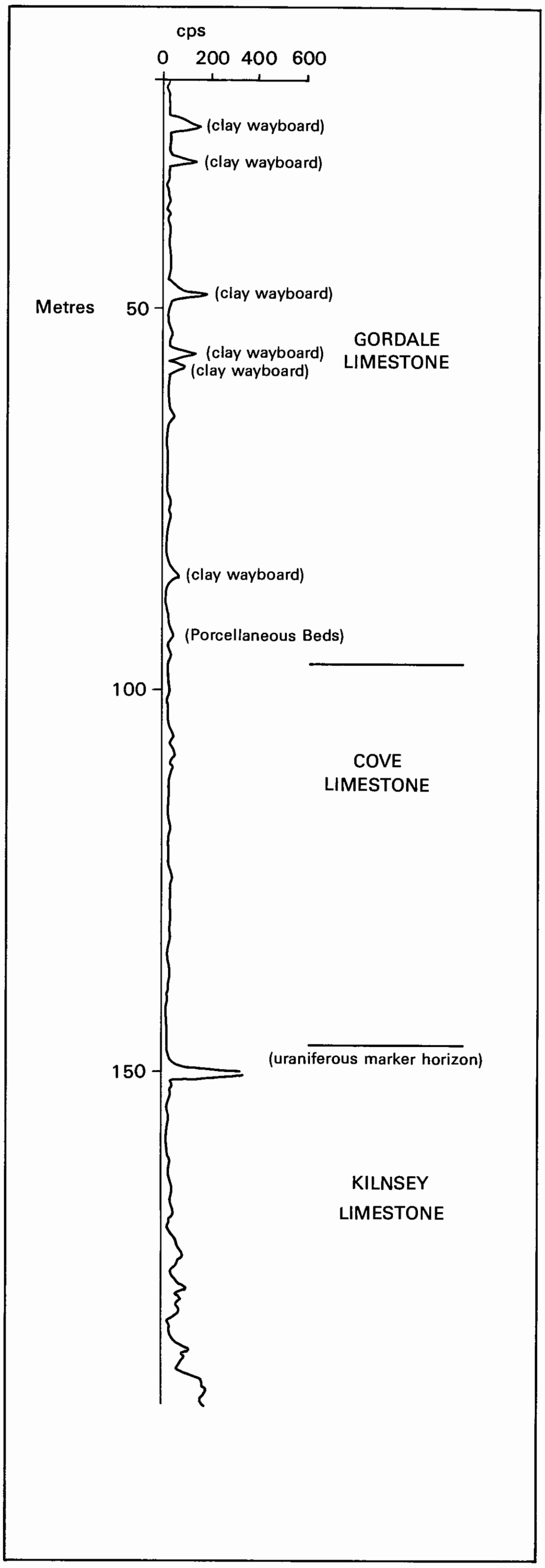


Figure 5 Part of gamma-ray log from borehole SD87SW9.

At approximately the same level as the boundary between the Cove Limestone and the Kilnsey Limestone, a marker horizon was observed on down-hole gamma logs from boreholes SD 86 NW 4 and SD 87 SW 9 (Figure 5). Three samples of core were analysed for uranium by delayed neutron counting. As expected, uranium was present in quantities up to 20 ppm, and is thought to come from phosphatic fossil debris concentrated at this horizon.

Gordale Limestone There is no lithological change at the boundary between the Cove Limestone and the Gordale Limestone. The maximum thickness of the Gordale Limestone measured in outcrops between the North and Middle Craven faults is approximately 70 m, but in the north of the district it thins to about 50 to 60 m.

The Gordale Limestone comprises a monotonous sequence of massively bedded limestones which typically form prominent topographic scars (Plate 1). The limestones are generally light or medium light grey wackestones and packstones: laminated grainstones are sporadically developed. The fauna includes crinoids, brachiopods, algae (including *Koninckopora*) and foraminifera, which all occur as biostromes. The limestones are commonly mottled, spotted or pseudobrecciated by recrystallisation. Minor dolomitisation was noted associated with joints, fractures and faults.

Prominent bedding planes occur throughout the Gordale Limestone north of the North Craven Fault, and thin clays are occasionally found along these bedding planes. South of the North Craven Fault the clays are very rare. Core recovery of these clays was poor, but their individual thicknesses, inferred from the collation and logging of the core, range from about 10 cm to 1 m. The downhole gamma log obtained from this borehole (Figure 5) shows the frequency with which clays occur in the Gordale Limestone. Evidence from potholes (Waltham, 1971) indicates that these clays can attain thicknesses of up to 2 m.

Palaeokarstic surfaces are developed in places and have been identified at outcrop and in boreholes both north and south of the North Craven Fault. Where bedding-plane clays are present, a palaeokarstic surface is generally present at the base of the clay.

X-ray diffractometry of the bedding-plane clays shows then to contain mixed-layer clay, chlorite, kaolinite, quartz and pyrite. They are similar to clays found in the Carboniferous Limestones of Derbyshire (Walkden, 1972) which are thought to be of volcanic origin.

The clays are blocky and pale brown when fresh, and show streaks of red, green and purple. They are commonly pyritous and the pyrite contaminates the limestone immediately adjacent to the clays. The presence of bedding-plane clays may lower the overall purity of the limestone, but as they can be removed during the quarrying and processing of the stone, they have been excluded from the purity calculations for this assessment.

The limestones of the Gordale Limestone were proved in 4 boreholes, and samples from these boreholes supplemented by 27 spot samples, form the basis for the results detailed below.

The Gordale Limestone is typically uniform in chemistry, strength and colour. *Reflectance values* obtained from powders prepared from the Gordale Limestone (Figure 7) were generally between 70% and 80% for a wavelength of 660 nm.

The limestones generally yield low *insoluble residue values* (less than 1%) and are of *very high purity* (greater than 98.5% $CaCO_3$). Local concentrations of pyrite adjacent to the bedding plane clays are deleterious impurities.

Aggregate Impact Values indicate that the Gordale Limestone is likely to be comparable with the Cove Limestone in its resistance to impact, and therefore of average to below average strength (Figure 6).

The *chemical data* on the Gordale Limestone were obtained from 4 samples taken from boreholes SD 87 SW 9, SD 77 SE 1, SD 86 SE 2 and SD 96 SW 1; they are summarised in Table 8. The Gordale Limestone has a mean CaO value of 55.54%, but is only locally more variable in purity than the Cove Limestone. Dolomitisation of the limestones is rare as indicated by the low maximum magnesia values. The maximum manganese values were recorded from borehole SD 86 SW 1 in which a thin zone of brecciation and minor dolomitisation was recorded from depths between 52.91 and 54.05 m. The relatively high maximum values of silica, alumina, potash, sulphur and iron are due to the presence of clay wayboards. The concentrations of trace elements are generally at very low background levels, but higher values, particularly of zinc, occur at the top of the sequence.

Table 8 Chemistry of the Gordale Limestone
Results obtained from 48 samples from 4 boreholes

	Maximum value	Minimum value	Mean	Standard deviation
	weight per cent			
CaO	56.10	51.97	55.54	0.74
MgO	0.81	0.18	0.26	0.11
SiO_2	2.96	0.0	0.26	0.52
Al_2O_3	2.14	0.07	0.23	0.37
Na_2O	0.03	0.0	0.0	0.01
K_2O	0.33	0.03	0.05	0.05
SO_3	0.59	0.01	0.06	0.12
P_2O_5	0.01	0.0	0.01	0.0
Loss at 1050° C	43.66	40.72	43.16	0.50
F	0.15	0.0	0.01	0.01
SrO	0.04	0.0	0.17	0.14
Fe_2O_3	0.56	0.02	0.08	0.12
	parts per million			
MnO	470	60	150	76
Cu	5	0	0	1
Pb	10	0	0	1
Zn	40	0	8	9

Reef limestones Reef limestones outcrop just south of the line of the Middle Craven Fault. They are best exposed at High Hill [832 636], near Settle and in the immediate vicinity of Malham.

The reefs are composed of light grey, sparsely bioclastic calcite mudstones interbedded with fossiliferous packstones and wackestones. The massive appearance of the limestones disguises their well-jointed and fractured nature; ferruginous staining is common. Replacement of the limestone by silica or dolomite or both is common on High Hill and High South Bank [832 636].

Results detailed below are based on the analysis of 11 spot samples taken from exposures.

Insoluble residue values obtained from spot samples of reef limestone ranged from 5% to less than 1% and impurities included silica and trace amounts of clay minerals. Samples of calcite mudstone were found to be marginally less pure than the bioclastic limestones. The reef limestones of the Craven reef belt are mostly of *very high purity* (greater than 98.5% $CaCO_3$), but replacement by silica and dolomite of some limestones locally downgrades the purity to the *high purity* category (97% to 98.5% $CaCO_3$).

Lower Hawes Limestone, Upper Hawes Limestone and Gayle Limestone

For the assessment of limestone resources, the Lower Hawes Limestone, Gayle Limestone and Upper Hawes Limestone are divided on gross lithology into two divisions: the limestones below the base of the Girvanella Beds (most of the Lower Hawes Limestone) and those above. This boundary represents a notable change in purity, which is shown on the resource map. The Girvanella Beds lie, stratigraphically, at the top of the Lower Hawes Limestone. Although the base of the Lower Hawes Limestone marks the base of the Yoredale 'series', there is no abrupt lithological change at the junction with the Malham Formation and the basal 5 to 10 m are of similar high purity to the Gordale Limestone.

These limestones crop out over much of the high ground of the district, notably south of Feizor [790 670], in the area around Langcliffe Scar [880 650], in the area north of Kilnsey Moor on High Mark [935 675] and in the areas skirting Fountains Fell [870 710]. They have a maximum recorded thickness of approximately thirty metres in the district.

Lower division (Lower Hawes Limestone, excluding the Girvanella Beds) The limestones below the Girvanella Beds are light grey to medium grey wackestones and packstones. There is a colour change from medium to dark grey at higher levels in the sequence, and the limestones are generally darker in colour than the Gordale Limestone. The limestones at the base are spotted and mottled like the Gordale Limestone, but this feature is absent higher in the sequence, which is darker and contains clay minerals. A fauna of brachiopods, algae, foraminifera and crinoids is present: crinoids are seen to be more common towards the top of the sequence.

Dolomitisation is present along joints and faults. In borehole SD 76 NE 9 intense dolomitisation of the limestone was observed, and parts of the lower division in the Feizor area [790 670] may be expected to be similarly dolomitised.

Mineralisation in veins and along joints is sporadic both north and south of the North Craven Fault.

The results of tests detailed below are based on samples from four boreholes, supplemented by the analysis of nine spot samples collected from outcrops in the district.

Reflectance values obtained from powders prepared from the lower division were generally greater than 70% at the base and decreased steadily up the sequence to less than 60% just below the Girvanella Beds for a wavelength of 660 nm.

Insoluble residue values of less than 2% were typical of these limestones which are mostly classified as *very high purity* (greater than 98.5% $CaCO_3$) in the lower part of the division but grade to *high purity* (97% to 98.5% $CaCO_3$) in the higher beds. The chief non-carbonate minerals identified were silica, clay minerals and, rarely, pyrite.

Aggregate Impact Values showed considerable variation and ranged between 18 and 22 (Figure 6).

The *chemical data* on the lower division were obtained from 13 samples taken from boreholes SD 87 SW 9, SD 86 SE 2, SD 96 SW 1 and SD 76 NE 9 and they are summarised in Table 9. The lower division has a mean CaO value of 54.30% and the CaO values gradually decrease at higher levels in the sequence. Fluctuations in magnesia, manganese, alumina and silica values are caused by local dolomitisation (for example, in borehole SD 76 NE 9), and also by the presence of clay minerals (for example, in borehole SD 87 SW 9). Trace elements are generally present at low background levels.

Table 9 Chemistry of the Lower Hawes Limestone excluding the Girvanella Beds
Results obtained from 13 samples from 4 boreholes

	Maximum value	Minimum value	Mean	Standard deviation
	weight per cent			
CaO	55.30	52.20	54.30	0.80
MgO	1.87	0.41	0.76	0.42
SiO_2	2.32	0.01	0.60	0.60
Al_2O_3	1.77	0.10	0.30	0.40
Na_2O	0.04	0.0	0.01	0.01
K_2O	0.21	0.04	0.06	0.05
SO_3	1.45	0.04	0.23	0.37
P_2O_5	0.06	0.01	0.02	0.01
Loss at 1050° C	43.83	39.83	43.17	1.02
F	0.04	0.0	0.01	0.01
SrO	0.07	0.01	0.04	0.02
Fe_2O_3	0.95	0.06	0.24	0.26
	parts per million			
MnO	830	140	320	220
Cu	10	0	2	3
Pb	20	0	3	6
Zn	90	10	45	20

Upper division These beds include the Girvanella Beds (part of the Lower Hawes Limestone), the Upper Hawes Limestone and the Gayle Limestone.

The upper division generally consists of dark grey to medium grey wackestones and packstones. They are commonly argillaceous and sparsely bioclastic; crinoids and shells predominate. The limestones contain mudstone partings, which increase in thickness towards the top of the division.

The beds at the base of the division contain algal nodules (predominantly *Girvanella*) and these have been called the Girvanella Beds (Garwood and Goodyear, 1922). Their thickest development occurs in the Langcliffe Scar [839 650] to Great Scar [862 642] area. The nodules can be easily identified: they are up to 15 mm across and commonly iron stained.

The results of the tests detailed below are based on sampling from two borehole cores, supplemented by the collection of seven spot samples from exposures in the district.

Reflectance values obtained from powders prepared from upper division limestones were less than 60% for a wavelength of 660 nm.

Insoluble residue values obtained from these limestones are relatively high (greater than 6.5%), and they are, therefore, classified as *low purity* limestones (85% to 93.5% $CaCO_3$), although beds of *medium purity* (93.5% to 97% $CaCO_3$) as well as *impure* (less than 85% $CaCO_3$) limestone are present. The chief non-carbonate minerals are silica (in the form of silicified fossil debris), disseminated pyrite and clay minerals.

Aggregate Impact Values obtained from these limestones range between 21 and 23 and indicate an average strength (Figure 6).

The *chemical data* on the upper division were obtained from seven samples taken from boreholes

Table 10 Chemistry of the Girvanella Beds, Upper Hawes Limestone and Gayle Limestone
Results obtained from 7 samples from 2 boreholes

	Maximum value	Minimum value	Mean	Standard deviation
	weight per cent			
CaO	54.15	49.05	50.40	4.20
MgO	3.12	0.70	2.60	3.70
SiO_2	5.79	0.95	2.70	1.94
Al_2O_3	1.67	0.40	0.80	0.50
Na_2O	0.02	0.01	0.01	0.0
K_2O	0.33	0.08	0.16	0.10
SO_3	0.95	0.07	0.38	0.27
P_2O_5	0.12	0.03	0.07	0.02
Loss at 1050° C	43.47	39.88	42.52	1.70
F	0.02	0.0	0.01	0.01
SrO	0.11	0.05	0.08	0.02
Fe_2O_3	0.86	0.05	0.45	0.32
	parts per million			
MnO	630	160	511	381
Cu	5	0	1	1
Pb	10	0	1	1
Zn	40	10	26	9

SD 86 SE 2 and SD 76 NE 9, and summarised in Table 10. The upper division has a mean CaO value of 50.40% and higher silica, magnesia and alumina mean values than those obtained from the lower division.

Pyrite is locally common producing the observed fluctuations in the iron values, but trace elements are present at low background levels. Manganese is found in quantities which suggest that it is not solely related to localised dolomitisation of the limestones.

Hardraw Scar Limestone

The Hardraw Scar Limestone has a maximum thickness of about 15 m in the district and has a similar outcrop pattern to that of the Hawes Limestone. The sequence was proved in two boreholes, SD 76 NE 9 and SD 86 SE 2, both sited between the North and Middle Craven faults.

The limestone generally consists of medium dark grey to dark grey argillaceous packstones and wackestones, locally interbedded with mudstones at different horizons. Chert nodules (10 to 20 cm across) also are locally present in the upper parts of the sequence. A feature typical of the limestone is the abundant presence of crinoids which locally comprise virtually the whole of the limestone.

Various amounts of silicification were noted in all samples, and pyrite was also present. Dolomitisation is restricted to joints and faults.

The results of standard tests carried out on the Hardraw Scar Limestone, detailed below, are based on samples from two boreholes, supplemented by eight spot samples taken from exposures.

Reflectance values obtained from powders prepared from the Hardraw Scar Limestone were very variable; the mean value was 64%, for a wavelength of 660 nm (Figure 7).

Silicification and high clay content are the main causes of the high *insoluble residue values* (greater than 10%) which were typically observed, although the abundant crinoid debris present in several parts of the sequence reduces some insoluble residue values to less than 3%.

Table 11 Chemistry of the Hardraw Scar Limestone
Results obtained from 7 samples from 2 boreholes

	Maximum value	Minimum value	Mean	Standard deviation
	weight per cent			
CaO	53.06	37.93	47.25	5.16
MgO	1.94	0.76	1.27	0.50
SiO_2	19.65	2.41	9.82	6.40
Al_2O_3	6.33	0.41	2.00	2.00
Na_2O	0.08	0.04	0.05	0.01
K_2O	1.08	0.08	0.35	0.34
SO_3	0.81	0.09	0.37	0.28
P_2O_5	0.10	0.05	0.06	0.02
Loss at 1050° C	42.43	32.25	38.46	3.50
F	0.12	0.0	0.03	0.04
SrO	0.22	0.06	0.14	0.05
Fe_2O_3	1.58	0.43	0.87	0.46
	parts per million			
MnO	880	360	490	176
Cu	5	0	3	3
Pb	10	0	1	4
Zn	40	10	23	14

The purity of the Hardraw Scar Limestone is therefore variable although it is mostly of *low purity* (85% to 93.5% $CaCO_3$).

Aggregate testing data on the Hardraw Scar Limestone are restricted to four Aggregate Impact Values which indicate a variable strength (Figure 6).

The *chemical data* on the Hardraw Scar Limestone, which were obtained from seven samples taken from boreholes SD 76 NE 9 and SD 86 SE 2, are summarised in Table 11. CaO values vary between 38% and 53% with a mean value of 47.25%. The highest CaO values were obtained from samples of highly crinoidal limestone. The variable mineralogy of these limestones is reflected in the variable values for silica, alumina, potash, iron, magnesia and manganese. Trace elements are present at background levels.

Yoredale 'series' limestones above the Hardraw Scar Limestone

Limestones above the Hardraw Scar Limestone occur within a mixed sequence including mudstones and sandstones. They crop out mainly in the north of the district on the high ground, on the slopes of Fountains Fell. They are mostly concealed beneath peat and other drift deposits.

Spot samples of the Simonstone Limestone (3 samples), the Middle Limestone (3 samples) and the Underset Limestone (2 samples) were examined. Although the overlying Main Limestone of the Namurian was not sampled, a single exposure was examined in the field; the limestone comprised a dark grey argillaceous wackestones. Dolomitisation along joint surfaces and silicification of bioclasts were observed.

With the exception of a single sample of Simonstone Limestone which contained abundant bioclasts and was classified as *medium purity* (93.5% to 97% $CaCO_3$), insoluble residue values showed all the limestone samples were of *low purity* (85% to 93.5% $CaCO_3$).

Basinal facies limestone

Scaleber Force and Scalebar Quarry limestones (Arundian/Holkerian), which are well exposed in Scaleber

Force [841 626] and in Scaleber Quarry [843 624], comprise over 40 metres of dark grey argillaceous limestones with mudstones. The limestones are of limited extent (0.04 km²) and partly drift covered.

Six spot samples of these limestones, collected from Scaleber Force and Scaleber Quarry, were examined. The limestones of Scaleber Force are argillaceous and contain a sparse fauna. Dolomitisation along joints and minor silicification, particularly of bioclasts, are also present. A limestone boulder bed is exposed at the main waterfall in Scaleber Force; it occurs above the top of the Scaleber Force Limestone and contains large fragments, predominantly of reef limestone, set in an argillaceous matrix.

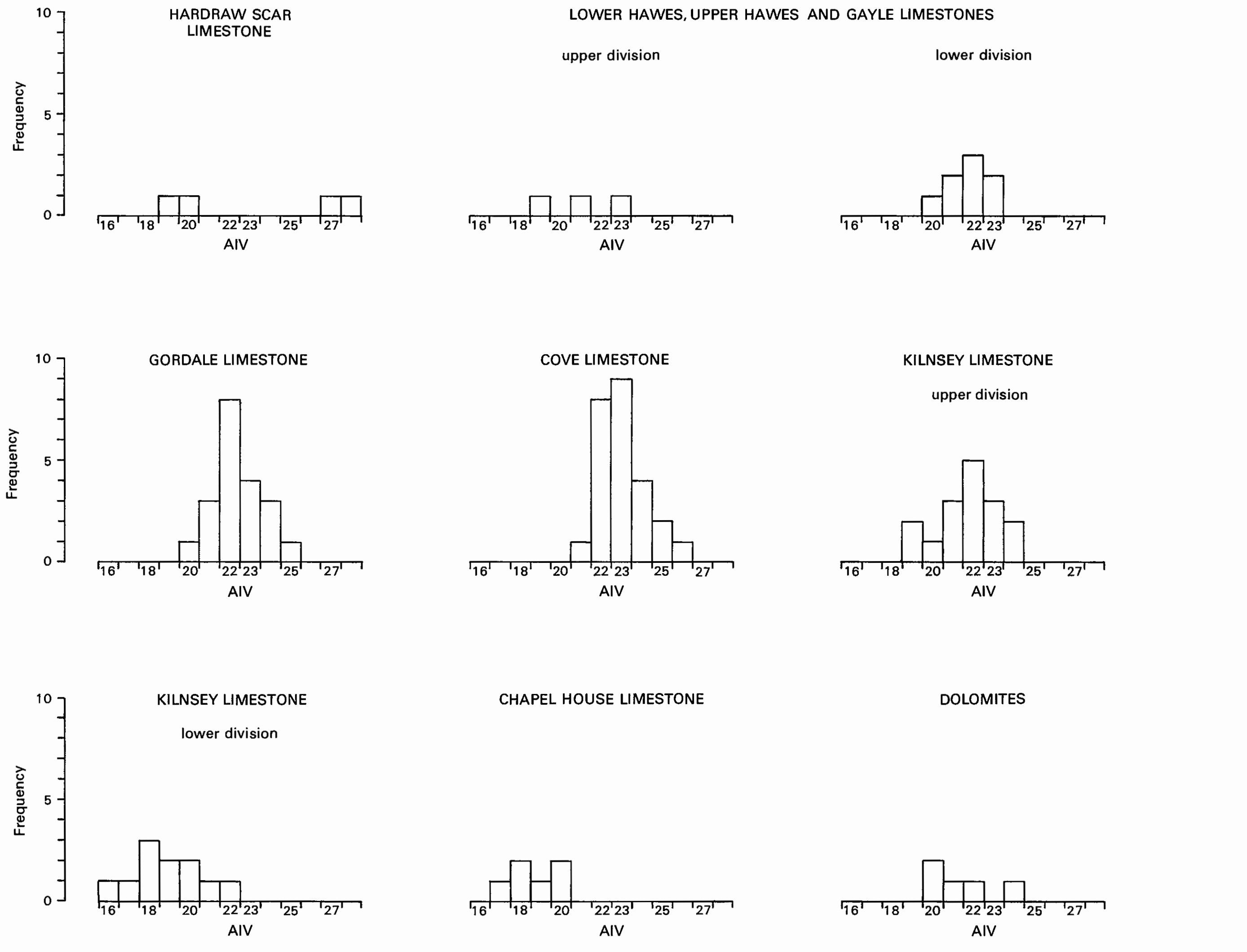
The limestones in Scaleber Quarry are dark grey, sparsely bioclastic argillaceous wackestone containing abundant nodules of chert.

Insoluble residue values obtained from the six spot samples indicate that these limestones are *impure* (less than 85% $CaCO_3$).

Limestones of the Craven Basin are exposed in the south of the district [870 610] in the area around Kirkby Malham. These limestones are largely drift covered and are of *low purity* or are *impure* (less than 93.5% $CaCO_3$). A report on the limestone and dolomite resources of the Craven Lowlands (Harrison, 1982) describes these limestones and gives an indication of their purity.

Dolomites

Dolomites and dolomitic limestones occur sporadically in the district. Discrete bodies were sampled from the High Hill area [833 635] and proved to be impure: silica and clay minerals were the dominant impurities. Other dolomites were sampled in boreholes SD 76 NE 9, SD 86 NW 4 and SD 96 NE 1, mainly from the Chapel House Limestone, the Kilnsey Limestone and the Lower Hawes Limestone. The results of the chemical analysis of 19 samples from these limestones in the above mentioned boreholes are summarised in Table 12. Silica is usually present in the dolomites (mean 2.19%); however silica was present in only trace amounts in two samples from borehole SD 96 NE 1. One sample proved to be a dolomite of commercial quality (21.53% MgO). Pure dolomite contains 21.85% MgO, and most commercial dolomites have between 20.75% and 21.70% MgO.



N.B. AIV data obtained during the assessment of limestone resources in the Southern Pennines, and in the Craven Lowlands indicate that AIV's of 22-23 are average for Carboniferous Limestone.

Figure 6 Histograms showing Aggregate Impact Value results for limestones. All data obtained during the assessment of limestones in the southern Pennines and the Craven Lowlands indicate that average AIVs for Carboniferous Limestone are 22–23.

Table 12 Chemistry of the dolomitised limestones
Results obtained from the analysis of 19 samples from 3 boreholes

	Maximum value	Minimum value	Mean	Standard deviation
	weight per cent			
CaO	48.23	30.38	37.36	5.40
MgO	21.53	7.34	14.85	4.69
SiO_2	14.28	0.0	2.19	3.98
Al_2O_3	0.69	0.11	0.37	0.21
Na_2O	0.08	0.0	0.02	0.02
K_2O	0.17	0.03	0.09	0.05
SO_3	0.97	0.0	0.20	0.29
P_2O_5	0.03	0.0	0.0	0.0
Loss at 1050° C	46.63	38.59	44.67	2.24
F	0.0	0.0	0.0	0.0
SrO	0.14	0.03	0.06	0.03
Fe_2O_3	1.66	0.13	0.75	0.45
	parts per million			
MnO	2930	300	950	728
Cu	5	0	2	2
Pb	10	0	0	0
Zn	90	0	15	20

SUMMARY OF LIMESTONE RESOURCES

The Settle and Malham district is partly underlain by Dinantian limestones which are currently quarried mainly for use in the construction industry, although much of the stone is of chemical grade. The working quarries are at Horton-in-Ribblesdale [798 723], Giggleswick [809 648], Kilnsey [966 673] and Threshfield [976 643].

The limestone assessment of the district is generalised owing to the wide distribution of sample points. Detailed limestone resource data quoted in this report are restricted to results obtained from boreholes and sampling from exposures.

The Malham Formation is the main limestone resource in the district. It comprises up to 170 m of very high purity limestone (greater than 98.5% $CaCO_3$) which are well exposed throughout the district. Deposits of similar purity are to be found in the Lower Hawes Limestone and also in the Kilnsey Limestone. However, more variation in chemistry, strength, colour and purity has been found in these deposits than in the Malham Formation.

The following figures and table summarise the basic data produced for the assessment of limestone resources.

Figure 6 gives an indication of the strength, measured by the AIV test, of the limestones. Samples from the Chapel House Limestone and from the Kilnsey Limestone with Mudstone gave the best resistance to impact results. Specific AIV results are shown on the graphical

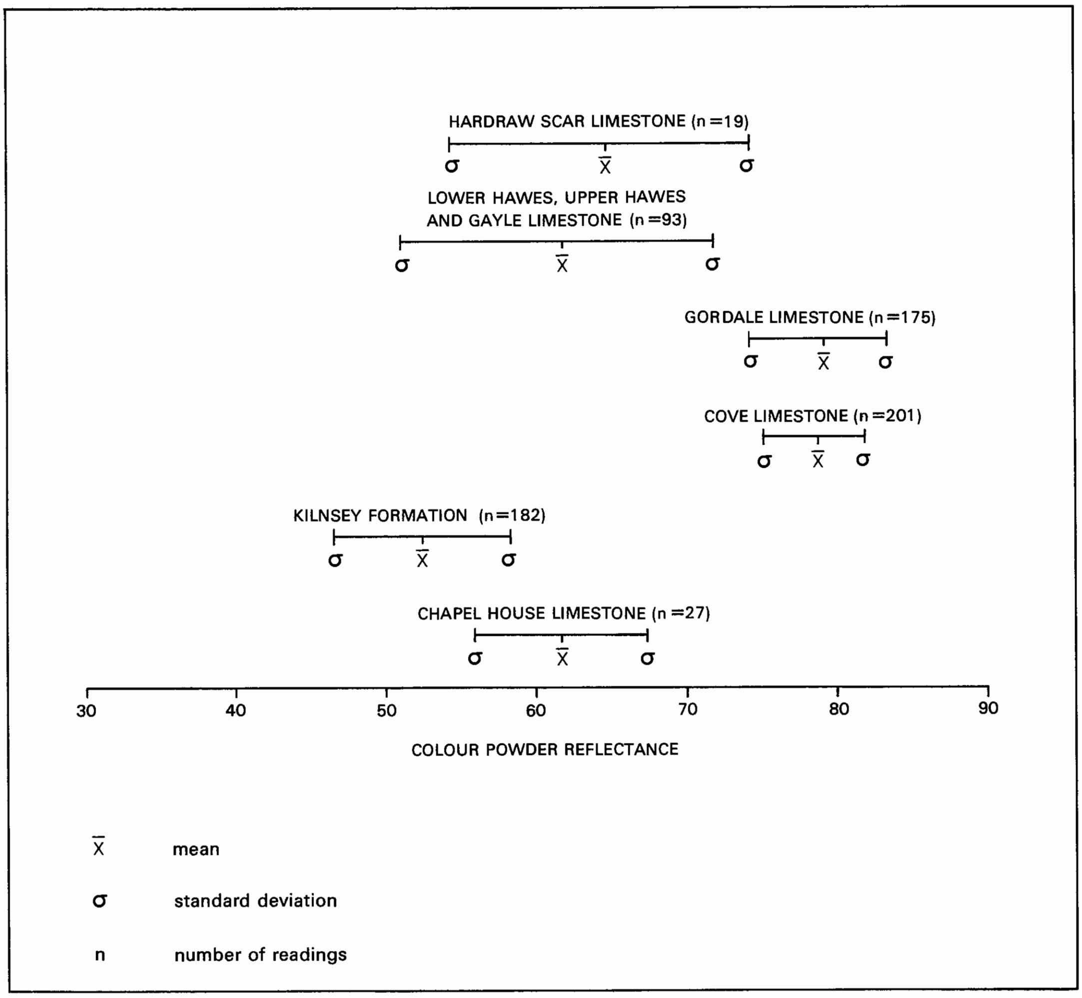


Figure 7 Means and standard deviations of colour powder reflectance values by formation. Grain size was less than 63 µm, and light of wavelength 660 µm was used.

Table 13 Summary of chemistry results and limestone purity classification

	Chapel House Limestone	Kilnsey Formation: Kilnsey Lst. with Mudstone	Kilnsey Formation: Kilnsey Limestone	Malham Formation: Cove Limestone	Malham Formation: Gordale Limestone	Hawes and Gayle Limestones: Lower division	Hawes and Gayle Limestones: Upper division	Hardraw Scar Limestone
	MEAN VALUES *weight percent*							
CaO	**51.90**	**49.23**	**52.96**	**55.20**	**55.54**	**54.30**	**50.40**	**47.25**
MgO	1.61	1.98	2.31	0.66	0.26	0.76	2.60	1.27
SiO_2	2.32	5.38	0.24	0.08	0.26	0.60	2.70	9.82
Al_2O_3	0.61	1.35	0.15	0.13	0.23	0.30	0.80	2.00
Na_2O	0.01	0.03	0.01	0.01	0.00	0.01	0.01	0.05
K_2O	0.17	0.28	0.04	0.04	0.05	0.06	0.16	0.35
SO_3	0.23	0.74	0.10	0.02	0.06	0.23	0.38	0.37
P_2O_5	0.01	0.01	0.01	0.01	0.01	0.02	0.07	0.06
Loss at 1050° C	42.33	40.40	43.80	43.40	43.16	43.17	42.52	38.46
F	0.01	0.02	0.00	0.00	0.01	0.01	0.01	0.03
SrO	0.04	0.08	0.04	0.01	0.17	0.04	0.08	0.14
Fe_2O_3	0.32	0.75	0.12	0.04	0.08	0.24	0.45	0.87
	parts per million							
MnO	275	247	224	126	150	320	511	490
Cu	0	1	2	1	0	2	1	3
Pb	1	3	4	1	0	3	1	1
Zn	23	17	19	9	8	45	26	23
PURITY CLASSIFICATION (*see Table 3*)								
Maximum purity	2	3	1	1	1	1	2	2
Minimum purity	5	5	4	2	3	4	5	5
Average purity	3	4	2	1	1	2	4	4

borehole logs on the resource map.

Figure 7 summarises the limestone powder reflectance values. The whitest powders, and the most consistently white powders were from the Gordale Limestone and the Cove Limestone. Specific data on the reflectance values are shown on the graphical borehole logs on the resource map.

Chemical analyses of 258 limestone samples are summarised by formation in Table 13. The mean values for èach element are quoted. Samples from the Gordale Limestone and the Cove Limestone have provided the highest carbonate values. Specific chemical data are presented by borehole at the beginning of Appendix C, and by formation in the Results section of this report. A summary of the purity classification (Table 3), based on insoluble residue data follows the chemical data in Table 13. Specific insoluble residue data are shown on the graphical borehole logs on the resource map.

HARD-ROCK RESOURCES OF THE HORTON-IN-RIBBLESDALE LOWER PALAEOZOIC INLIER

INTRODUCTION

Ordovician and Silurian (Lower Palaeozoic) rocks (Table 14) crop out as an inlier on the north side of the North Craven Fault and give rise to an area of generally subdued relief and hummocky rough pasture in Ribblesdale and Crummackdale. The drift cover is mostly less than 5 m thick, but boulder clay is locally moulded into drumlins on the eastern side of the River Ribble and there it may be more than 10 m thick.

The inlier is an important source of crushed-rock aggregate, with working quarries at Dry Rigg [805 693] and Arcow Wood [803 705]. Structurally the inlier is a complex fold system which consists of a south-easterly-plunging syncline with flanking anticlines. The Austwick and Horton formations (shown in pink and orange on the

Table 14 Generalized stratigraphy of the Horton-in-Ribblesdale inlier, with lithologies and thicknesses

Based on mapping by E. W. Johnson

CARBONIFEROUS ROCKS	
unconformity	
SILURIAN	
Ludlow Series	Neals Ing Sandstone *Greywacke sandstones* 250 m
	Horton Formation including Studfold Sandstone *Greywacke sandstones and siltstones* 700 m
Wenlock Series	Arcow Formation *Calcareous siltstones* 8 m
	Austwick Formation *Greywacke sandstones and siltstones* 300–600 m
Llandovery Series	Crummack Formation *Siltstones and mudstones* 0–20 m
ORDOVICIAN	
Ashgill Series	Sowerthwaite and Norber formations *Limestones, mudstones, siltstones, tuffs and conglomerates*
Arenig Series	Ingleton Group *Greywacke sandstones and feldspathic grits*

resource map), which are well exposed in the core of the syncline, are the source of the quarried stone. Lithologically the Silurian rocks consist of highly compacted gritstones, sandstones, siltstones and mudstones. The siltstones are flaggy and the sandstones are thickly bedded (Plate 5). Cleavage occurs in all formations (Plate 6).

The older rocks of the inlier (which are also hard rocks, whose aggregate potential has not been considered) are the poorly exposed greywacke sandstones of the Ingleton Group. Their outcrop is limited to an area of about 1 km² around Horton-in-Ribblesdale, but outside the district, to the north-west around Ingleton, a much larger outcrop exists and this is extensively quarried.

NOTES ON HARD ROCK RESOURCES

The Silurian rocks constitute the principal hard rock resource of the Horton-in-Ribblesdale inlier; they are shown in pink and orange on the resource map.

The recent geological mapping of the Settle sheet by E. W. Johnson of the Land Survey staff of the Institute has provided a better understanding of the resources. The Austwick and Horton formations are well compacted and cemented rocks which comprise mixed sequences of sandstones and siltstones. The coarser grained sandstones produce better aggregates than the finer grained siltstones, and mapping has shown that the proportion of sandstones in the sequence, especially of the Austwick Formation, thicken southwards across the syncline.

The crushed rock products are used mainly as high-quality surface dressings for roads although some of the finer aggregate is used in concrete manufacture. However, the presence of pyrite in the rock is a constraint on its use in concrete.

British Standard 812: 1975 specifies a number of tests which may be carried out to assess the suitability of a rock for use as an aggregate. These include the Aggregate Impact Value, the Aggregate Abrasion Value and the Polished Stone Value. High-quality aggregates, such as those used in surface dressings, are subject to strict specifications. Table 15 compares published aggregate data from the quarries in the inlier with the current requirements of the Department of the Environment for polish and abrasion resistance for aggregates which are used for road surfacing.

Data on the aggregate properties of the Silurian rocks have been compiled from records held by the Institute and from the testing of rock samples. Table 16 summarises the observed variations in aggregate properties between the sandstones and siltstones in the Austwick and Horton formations. The Neals Ing Sandstone (which consists of coarse-grained sandstones) was not sampled.

Table 15 Comparison of published aggregate test data from quarries in the Horton-in-Ribblesdale inlier with the DOE requirements for polish and abrasion resistance for road-surface aggregates

	AAV	PSV	
QUARRY			
Helwith Bridge[1]	12.5	58	
Dry Rigg[2]	9.8	65	
Arcow Wood[3]	12.0	62	(Harris, 1977)
DIFFICULT SITES	10 maximum	62 minimum	
AVERAGE SITES	12 maximum	59 minimum	(DOE, 1969)

Sources
1 Amey Roadstone Corporation Ltd
2 Redland Roadstone Ltd
3 Tarmac Roadstone Holdings Ltd

REFERENCES

Bott, M. H. P. 1967. Geophysical investigations of the northern Pennine basement rocks. *Proc. Yorkshire Geol. Soc.*, Vol. 36, 139–168.

British Standard 812: 1975. *Methods for sampling and testing of mineral aggregates, sands and fillers.* Parts 1 and 3. (London: British Standards Institution.)

Cox, F. C. and Bridge, D. McC. 1977. The limestone and dolomite resources of the country around Monyash, Derbyshire: description of 1:25 000 resource sheet SK 16. *Miner. Assess. Rep. Inst. Geol. Sci.*, No. 26

— and Hull, J. H. 1977. A procedure for the assessment of limestone resources. *Miner. Assess. Rep. Inst. Geol. Sci.*, No. 30

— and Harrison, D. J. 1980. The limestone and dolomite resources of the country around Wirksworth, Derbyshire: description of parts of sheets SK 25 and SK 35. *Miner. Assess. Rep. Inst. Geol. Sci.*, No. 47

Dunham, R. J. 1962. Classification of carbonate rocks according to depositional texture. *In* Ham, W. E. (editor), Classification of carbonate rocks, 108–121. *Mem. Am. Assoc. Pet. Geol.*, No. 1.

Garwood, E. J. and Goodyear, E. 1924. The Lower Carboniferous succession in the Settle district, and along the line of the Craven faults. *Q. J. Geol. Soc. London*, Vol. 80, 184–273.

Geological Society of America. 1970. *Rock-color chart.* (Boulder, Colorado: Geological Society of America.)

Harris, P. M. 1977. Sandstone. *Mineral Dossier No. 17. Inst. Geol. Sci.* (London, HMSO).

Harrison, D. J. 1982 The limestone resources of the Craven Lowlands: description of parts of 1:25 000 geological sheets 59, 60, 61, 67, 68 and 69. *Miner. Assess. Rep. Inst. Geol. Sci.*, No. 116.

Institute of Geological Sciences. 1981. *United Kingdom Mineral Statistics 1980.* (London: HMSO.)

McCabe, P. J. and Waugh, B. 1973. Wenlock and Ludlow sedimentation in the Austwick and Horton-in-Ribblesdale inlier, north-west Yorkshire. *Proc. Yorkshire Geol. Soc.*, Vol. 39, 445–470.

Ministry of Transport. 1969. *Specifications for road and bridge works.* (London: HMSO.)

Raistrick, A. 1973. *Lead mining in the Mid-Pennines.* (Truro, Cornwall: D. Bradford Barton Ltd.)

Roberts, J. L. and Davis, A. E. 1977. Analysis of limestone survey samples by electron excitation X-ray spectrometry. *Rep. Inst. Geol. Sci.*, No. 77/3.

Walkden, A. C. 1972. The mineralogy and origin of interbedded clay wayboards in the Lower Carboniferous of the Derbyshire Dome. *Geol. J.*, Vol. 8, 143–160.

Waltham, A. C. 1971. Shale units in the Great Scar Limestone of the southern Askrigg Block. *Proc. Yorkshire Geol. Soc.*, Vol. 38, 285–292.

Whetton, J. T., Myers, J. O. and Watson, I. J. 1956. A gravimeter survey in the Craven District of north-west Yorkshire. *Proc. Yorkshire Geol. Soc.*, Vol. 30, 259–287.

Table 16 Summary of aggregate test results from the Horton-in-Ribblesdale inlier

Test values quoted refer to single samples that are not necessarily representative of current commercial production

	Horton Formation 16 samples — 3 of coarse grained rocks, 13 of fine grained rocks			Austwick Formation 18 samples — 7 of coarse grained rocks, 11 of fine grained rocks		
	AIV	AAV	PSV	AIV	AAV	PSV
Mean (and standard deviation) of coarse-grained rocks	11 (5)	9.7 (1.9)	60 (5)	11 (4)	8.6 (2.2)	58 (3)
Mean (and standard deviation of fine-grained rocks	15 (1)	11.5 (1.8)	54 (2)	14 (2)	8.8 (2.7)	54 (2)
Maximum value	18	14.1	65	17	13	62
Minimum value	8	7.3	63	6	5.3	52

The higher the PSV, the greater the resistance to polishing.
The lower the AAV, the greater the resistance to abrasion.
The lower the AIV, the greater the resistance to impact.

APPENDIX A

LIMESTONE CLASSIFICATION AND GLOSSARY

Limestone classification

The petrographic classification of limestones by Dunham (1962) is used in this report. The classification is summarised in Table 17.

The classification describes the depositional texture of the limestones. The presence or absence of mud differentiates muddy carbonates from *grainstone*. The relative abundance of grains allows muddy carbonates to be subdivided into *mudstone*, *wackestone* and *packstone*, and the presence of signs of binding during deposition characterises *boundstone*. This last term was found not to be applicable to the limestones in the district. The degree of packing differentiates *packstone* from *wackestone*. Packstone is composed of grains in close contact with each other, whereas wackestone consists of a relatively small amount of grains 'floating' in a mud matrix.

In addition to purely textural parameters the classification used in this report recognises the basic grain types. These are bioclasts, peloids, oncolites and ooliths.

Table 17 Classification of carbonate rocks according to depositional texture (Dunham, 1962)

Depositional texture recognisable					Depositional texture not recognisable
Original components not bound together during deposition				Original components were bound together during deposition	
Contains mud (clay and fine silt)			Lacks mud and is grain-supported		
Mud supported		Grain supported			
Less than 10% grains	More than 10% grains				
Mudstone	Wackestone	Packstone	Grainstone	Boundstone	Crystalline carbonate

Glossary

Anticline An arch fold, the core of which contains the stratigraphically older rocks.
Argillaceous rocks Detrital sedimentary rocks that contain clay- or silt-grade material.
Arkosic rocks Detrital sedimentary rocks that contain sand-grade material, notable quantities of feldspar being present.
Authigenic Referring to those constituents that came into existence with or after the formation of the host rock.
Bioclasts Broken fragments of organic skeletal material.
Biostrome A bed or a layer consisting of, and built mainly by, sedentary organisms, such as shell beds or crinoid beds, and not swelling into mound-like or lens-like forms.
Bioturbation The churning and stirring of a sediment by organisms.
Calcarenite A limestone consisting predominantly (more than 50%) of detrital calcite particles of sand size (0.062 to 1 mm).
Calcilutite A limestone consisting predominantly (more than 50%) of detrital calcite particles of silt and/or clay size (less than 0.062 mm).
Calcirudite A limestone consisting predominantly (more than 50%) of detrital calcite particles larger than sand size (greater than 1 mm).
Diagenesis Those processes affecting a sediment while it is at or near the Earth's surface, i.e. low temperature and pressure.
Facies The sum characteristics of all the primary lithological and palaeontological characteristics exhibited by a sedimentary rock, from which its origin and environment of formation may be inferred.
Fenestral fabric Voids created during diagenesis, subsequently filled by calcite spar.
Gangue A mineral in a vein other than an ore mineral.
Grainstone A mud free grain-supported limestone.
Inlier A limited area of older rocks completely surrounded by younger rocks.
Intraclast Material created by penecontemporaneous erosion within a basin of deposition.
Lithoclast Externally derived material eroded from earlier lithified rock.
Microstylolite Thin undulating surfaces with clay/silt films.
Oncolite Algally coated grain.
Oolith Small, oval, accretionary bodies with concentric layering. Usually formed of calcium carbonate.
Packstone A grain supported limestone which contains some calcareous mud.
Palaeokarstic surface A surface containing evidence of aerial exposure.
Pellet An ovoid grain composed of clay size calcite particles. Many, but not all, pellets are of faecal origin.
Peloid A grain composed of clay size calcite particles. This term does not imply any particular mode of origin.
Plunge The inclination of a fold axis measured in the vertical plane.
Spar Transparent crystalline component of limestones consisting of calcite having diameters that exceed 10 μm.
Strike The direction of trend that a structural surface takes as it intersects the horizontal.
Stylolite An irregular suture-like boundary developed in some limestones.
Syncline A trough fold, the core of which contains stratigraphically younger rocks.
Unconformable Describes strata that are separated from underlying rocks by a surface that represents a significant break in sedimentation.
Wayboard An old mining term used commonly in Derbyshire to describe a discrete and deleterious thin rock bed usually of clay.

APPENDIX B

EXPLANATION OF FORMAT FOR WRITTEN BOREHOLE LOGS

The following list is arranged in the same order as data in the borehole records (see Appendix C).

1 Registration Number
This consists of two statements.
(i) The number of the 1:25 000 sheet on which the borehole lies, for example, SD 87.
(ii) The quarter of the 1:25 000 sheet on which the borehole lies and its number in a series for that quarter, for example, SW 9.
Thus, the full Registration Number is SD 87 SW 9.

2 Location
Borehole locations are referred to the nearest prominent named locality on the 1:25 000 maps.

3 The National Grid reference
All National Grid references in this report lie within the 100-km square SD unless otherwise stated. Grid references for borehole sites are given to eight figures (that is accurate to within 10 m). In the text, six-figure grid references are used for more approximate locations.

4 Surface level
The surface level at the borehole site is given in metres above Ordnance Datum.

5 Descriptive borehole log
The major rock types are listed, for example, limestone and dolomite. Each major rock type is described using the rock classification and nomenclature explained in Appendix A followed by a brief description.

6 Depth
The figures given relate to depths (in metres) to the base of the lithologies described in the log.

APPENDIX C

RECORDS OF BOREHOLES

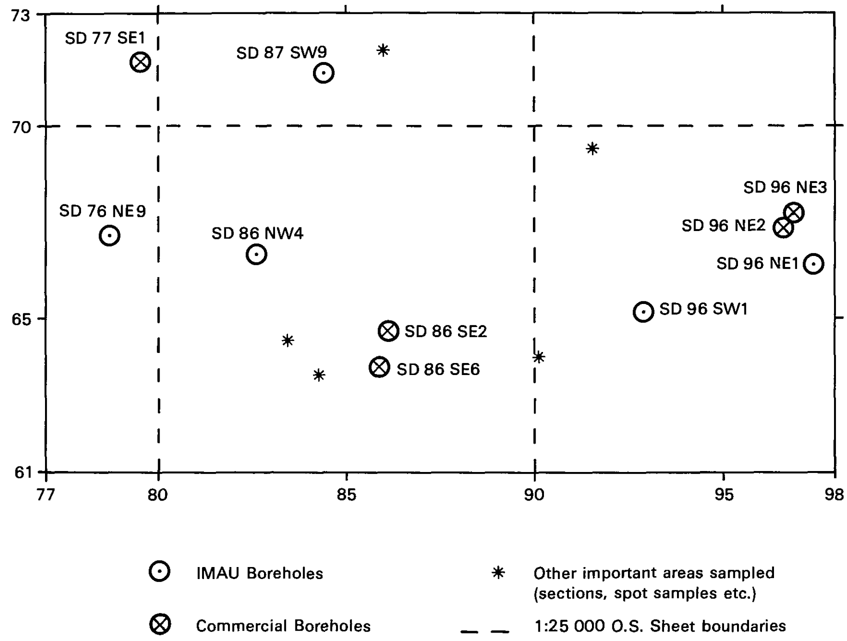


Figure 8 Distribution of data points.

Additional data which are not detailed in this report may be consulted at the Keyworth office of the Institute.

Chemical data
Where available, chemical data are shown in tabular form for each borehole.

Rapid instrumental and chemical methods of analysis were used. The table below shows estimated 95% confidence limits for results on the very high, high and medium purity (greater than 93.5% $CaCO_3$) limestones, together with the determination limits below which the accuracy is uncertain. The detection limits, which are also shown, are the concentrations of each element reproducibly measurable above the instrumental background signal. For impure limestones, the accuracy is uncertain because of inter-elemental interference effects. Some results may therefore lie outside the tolerances obtainable using standard or referee chemical methods of analysis.

	Estimated 95% confidence limits ±	Lower determination limit	Detection limit
CaO	0.8%	50%	—
SO_3	0.10%	0.10%	0.01%
Na_2O	0.02%	0.02%	0.02%
F	0.10%	0.05%	0.03%
SiO_2	0.10%	0.10%	0.02%
MgO	0.14%	0.10%	0.02%
Al_2O_3	0.10%	0.10%	0.01%
K_2O	0.02%	0.02%	0.01%
Fe_2O_3	0.12%	0.10%	0.05%
SrO	0.04%	0.20%	0.10%
P_2O_5	0.02%	0.05%	0.02%
Loss at 1050° C	0.15%	—	—
Cu	10 ppm	3 ppm	1 ppm
Pb	10 ppm	3 ppm	1 ppm
Zn	20 ppm	5 ppm	2 ppm
Acid-soluble MnO	20 ppm	10 ppm	3 ppm
Acid-soluble Fe_2O_3	20 ppm	10 ppm	3 ppm
As	2 ppm	2 ppm	1 ppm

CHEMICAL ANALYSES

	percentages												parts per million				
Depth (m)	CaO	MgO	SiO_2	Al_2O_3	Na_2O	SO_3	K_2O	SrO	P_2O_5	F	Fe_2O_3	loss at 1050°C	MnO	Cu	Pb	Zn	As
SD 76 NE 9	**7870 6722**		**Feizor**														
2	38.61	0.61	29.26	1.50	0.13	0.43	0.19	0.27	0.02	0.00	0.80	30.46	130	5	0	20	–
7	36.93	1.78	26.35	2.89	0.20	2.00	0.42	0.30	0.05	0.01	2.15	30.45	310	0	10	10	–
25	45.15	1.94	12.25	1.92	0.06	0.44	0.36	0.15	0.08	0.02	1.02	37.72	880	5	0	20	–
38	49.05	1.59	5.79	1.67	0.02	0.95	0.33	0.11	0.07	0.02	0.86	39.88	400	0	0	20	–
42	49.32	3.12	3.06	1.03	0.02	0.53	0.22	0.07	0.12	0.00	0.60	42.13	630	0	0	30	–
48	52.57	1.80	1.12	0.44	0.01	0.29	0.10	0.05	0.06	0.00	0.08	43.47	340	0	0	30	–
52	41.16	11.62	0.86	0.29	0.02	0.26	0.06	0.08	0.03	0.00	0.76	45.35	1400	0	0	10	–
58	53.92	1.14	0.45	0.30	0.01	0.24	0.07	0.06	0.03	0.00	0.06	43.32	210	0	0	30	6
62	53.49	1.87	0.06	0.13	0.00	0.09	0.04	0.04	0.01	0.00	0.10	43.51	280	0	0	10	–

	percentages												parts per million				
Depth (m)	CaO	MgO	SiO_2	Al_2O_3	Na_2O	SO_3	K_2O	SrO	P_2O_5	F	Fe_2O_3	loss at 1050°C	MnO	Cu	Pb	Zn	As
SD 77 SE 1	**7955 6722**		**Horton Quarry**														
5	55.43	0.20	0.05	0.15	0.00	0.03	0.04	0.00	0.00	0.00	0.05	43.08	80	0	0	0	–
9	55.54	0.21	0.14	0.20	0.00	0.02	0.05	0.02	0.01	0.00	0.06	43.20	60	0	0	10	–
13	55.56	0.20	0.01	0.12	0.01	0.02	0.04	0.00	0.00	0.00	0.04	43.14	90	0	0	0	–
17	55.16	0.20	0.19	0.20	0.00	0.01	0.06	0.01	0.00	0.15	0.06	43.13	100	0	0	0	–
21	54.21	0.81	0.37	0.32	0.00	0.07	0.09	0.02	0.01	0.00	0.11	43.53	180	0	0	10	–
25	55.65	0.21	0.00	0.08	0.00	0.01	0.03	0.00	0.00	0.01	0.03	43.19	90	0	0	0	–
29	55.41	0.17	0.00	0.07	0.00	0.01	0.03	0.00	0.00	0.00	0.03	43.07	80	0	0	0	–
33	55.80	0.18	0.00	0.07	0.00	0.01	0.03	0.02	0.00	0.00	0.03	43.16	100	0	0	10	–
37	56.03	0.20	0.00	0.07	0.00	0.02	0.03	0.01	0.00	0.00	0.03	43.16	90	0	0	10	–
41	55.83	0.18	0.00	0.07	0.00	0.01	0.02	0.00	0.00	0.01	0.03	43.26	100	0	0	0	–
45	55.49	0.19	0.00	0.08	0.00	0.01	0.03	0.00	0.00	0.00	0.03	43.31	110	0	0	10	–
49	54.95	0.23	0.04	0.09	0.06	0.03	0.05	0.04	0.01	0.00	0.03	43.18	90	0	0	10	–
53	55.57	0.23	0.01	0.11	0.00	0.02	0.03	0.00	0.00	0.01	0.03	43.20	90	0	10	10	–
57	55.23	0.25	0.21	0.22	0.00	0.03	0.06	0.00	0.00	0.01	0.05	43.55	90	0	0	10	–
61	56.01	0.27	0.16	0.20	0.01	0.03	0.07	0.01	0.01	0.00	0.06	43.44	100	0	0	20	–
65	55.38	0.30	0.06	0.15	0.00	0.03	0.05	0.01	0.01	0.00	0.06	43.68	100	0	0	10	–
69	54.65	0.48	0.23	0.20	0.01	0.13	0.06	0.05	0.01	0.00	0.07	43.75	90	0	0	30	–
73	53.14	1.09	1.90	0.48	0.03	0.19	0.14	0.06	0.01	0.01	0.36	42.83	180	0	0	20	–
SD 86 NW 4	**8259 6670**		**Lower Winskill**														
2	55.81	0.18	0.01	0.11	0.01	0.01	0.04	0.01	0.01	0.00	0.03	43.20	70	5	0	10	0
6	55.45	0.25	0.12	0.10	0.01	0.01	0.04	0.01	0.01	0.00	0.04	43.31	50	5	0	10	–
10	55.44	0.31	0.18	0.20	0.00	0.02	0.05	0.01	0.01	0.01	0.02	43.50	50	5	0	10	–
14	55.01	0.22	0.19	0.20	0.00	0.02	0.06	0.02	0.01	0.00	0.03	43.43	60	5	0	10	–
18	55.44	0.21	0.08	0.14	0.01	0.01	0.04	0.02	0.01	0.00	0.03	43.39	70	5	0	10	–
22	55.73	0.17	0.00	0.09	0.00	0.00	0.03	0.00	0.01	0.00	0.02	43.23	70	5	0	10	–
26	55.56	0.20	0.13	0.17	0.00	0.01	0.05	0.01	0.01	0.00	0.02	43.31	60	0	0	10	–
30	55.62	0.20	0.00	0.10	0.00	0.01	0.04	0.01	0.01	0.00	0.02	43.29	70	0	0	10	–
34	55.27	0.24	0.00	0.08	0.04	0.01	0.03	0.00	0.00	0.00	0.02	43.35	80	0	0	10	–
38	55.77	0.19	0.00	0.08	0.02	0.03	0.04	0.00	0.00	0.01	0.02	43.36	90	5	0	10	–
42	55.69	0.22	0.00	0.08	0.00	0.02	0.03	0.00	0.00	0.00	0.02	43.24	70	5	0	10	–
46	55.60	0.23	0.00	0.07	0.00	0.01	0.02	0.00	0.01	0.00	0.02	43.26	80	0	0	10	–
50	52.83	2.50	0.04	0.08	0.01	0.01	0.03	0.00	0.00	0.00	0.16	44.02	480	0	0	10	–
54	56.10	0.29	0.00	0.08	0.01	0.02	0.03	0.00	0.01	0.01	0.02	43.38	70	5	0	10	–
58	55.57	0.22	0.00	0.07	0.00	0.02	0.02	0.00	0.00	0.00	0.03	43.27	100	0	0	10	0
62	55.60	0.37	0.00	0.08	0.00	0.03	0.03	0.00	0.01	0.01	0.04	43.39	130	0	0	10	–
66	55.19	0.41	0.00	0.07	0.00	0.02	0.02	0.00	0.00	0.00	0.03	43.57	100	5	0	10	–
70	55.94	0.22	0.00	0.07	0.01	0.02	0.03	0.00	0.01	0.00	0.02	43.28	60	0	0	10	–
74	55.84	0.19	0.00	0.07	0.00	0.02	0.03	0.00	0.00	0.00	0.03	43.34	150	5	0	10	–
78	55.39	0.21	0.00	0.08	0.00	0.02	0.03	0.00	0.00	0.00	0.05	43.42	130	5	0	10	–
82	55.63	0.22	0.00	0.07	0.00	0.02	0.03	0.00	0.01	0.00	0.03	43.33	100	0	0	10	–
86	55.43	0.37	0.00	0.08	0.00	0.00	0.03	0.01	0.00	0.00	0.03	43.40	120	0	0	10	–
90	54.02	1.50	0.08	0.10	0.01	0.02	0.03	0.00	0.00	0.00	0.06	43.88	200	0	0	10	–
94	50.66	3.90	0.16	0.12	0.00	0.01	0.03	0.02	0.00	0.00	0.10	44.20	280	0	0	10	–
98	51.43	3.69	0.18	0.16	0.00	0.01	0.04	0.01	0.01	0.00	0.08	44.04	250	5	0	10	–
102	49.65	5.51	0.12	0.10	0.02	0.00	0.03	0.02	0.00	0.00	0.16	44.57	470	5	0	10	–
106	53.97	2.92	0.33	0.14	0.02	0.31	0.04	0.02	0.01	0.01	0.08	43.91	210	5	0	10	–
110	53.85	1.53	0.06	0.09	0.00	0.03	0.03	0.01	0.01	0.00	0.04	43.53	130	5	0	10	–
114	47.71	6.50	0.16	0.14	0.01	0.00	0.04	0.04	0.00	0.00	0.14	44.68	350	5	0	10	–
118	43.26	10.79	0.06	0.11	0.01	0.00	0.03	0.03	0.00	0.00	0.13	45.36	330	5	0	20	–
122	36.99	16.54	0.06	0.11	0.01	0.00	0.03	0.05	0.00	0.00	0.16	46.29	350	5	0	10	–
126	39.79	11.88	0.07	0.12	0.01	0.00	0.03	0.05	0.00	0.00	0.14	45.25	330	5	0	10	–
129	51.78	3.09	0.21	0.13	0.01	0.08	0.04	0.03	0.00	0.00	0.06	44.20	230	5	10	10	–
131	44.43	9.26	0.20	0.10	0.02	0.09	0.03	0.05	0.00	0.00	0.02	45.38	570	0	10	10	–
133	46.84	7.23	0.32	0.13	0.01	0.08	0.04	0.05	0.00	0.00	0.14	44.94	430	5	10	20	–
135	49.72	5.12	0.25	0.12	0.01	0.10	0.03	0.03	0.00	0.00	0.10	44.47	300	5	10	10	–
137	49.95	4.22	0.23	0.10	0.02	0.08	0.03	0.03	0.00	0.00	0.11	44.42	410	5	0	10	–
139	45.31	8.55	0.39	0.10	0.02	0.05	0.03	0.04	0.00	0.00	0.20	45.21	550	0	0	10	–
142	48.99	5.22	0.45	0.16	0.02	0.14	0.05	0.03	0.00	0.00	0.14	44.44	330	0	0	10	–
146	52.12	0.68	3.76	0.74	0.02	0.46	0.18	0.04	0.01	0.02	0.41	41.35	280	0	0	0	–
150	46.62	1.25	9.51	2.20	0.03	1.42	0.50	0.10	0.03	0.06	1.03	36.68	340	0	10	0	–
154	49.69	1.68	5.10	1.00	0.02	0.77	0.24	0.05	0.01	0.02	0.82	40.55	570	0	0	10	–
158	49.44	2.57	3.76	1.01	0.03	0.54	0.24	0.07	0.01	0.03	0.60	41.71	420	5	10	20	–
162	44.06	4.54	8.13	1.46	0.03	0.84	0.33	0.09	0.01	0.02	1.02	39.16	950	5	10	10	–
166	39.02	8.23	12.16	0.51	0.02	0.15	0.12	0.11	0.00	0.00	0.87	38.74	1450	5	0	10	–
170	32.90	12.46	14.28	0.63	0.08	0.21	0.16	0.14	0.00	0.00	1.63	38.59	2930	5	0	10	–
174	42.27	5.79	10.53	0.88	0.03	0.37	0.21	0.09	0.00	0.00	0.91	39.34	1570	5	0	10	–
178	44.89	6.02	6.06	0.61	0.03	0.27	0.16	0.07	0.00	0.00	0.49	41.55	710	5	0	10	–
182	32.93	18.66	2.02	0.55	0.03	0.12	0.14	0.07	0.00	0.00	0.70	45.76	1070	5	0	10	–
186	32.91	18.69	1.10	0.41	0.03	0.04	0.11	0.06	0.00	0.00	0.80	46.40	1190	0	0	90	–
190	44.99	7.23	2.92	0.52	0.01	0.08	0.14	0.04	0.00	0.00	0.30	43.40	320	0	0	10	–
194	32.79	17.77	2.74	0.69	0.03	0.06	0.17	0.07	0.00	0.00	0.51	45.18	530	0	0	20	–
198	30.38	21.32	1.34	0.46	0.03	0.04	0.11	0.07	0.00	0.00	0.58	46.63	580	0	0	0	–
202	35.79	16.60	1.22	0.58	0.02	0.07	0.12	0.06	0.00	0.00	0.57	45.79	710	0	0	0	–
206	37.18	15.12	1.09	0.42	0.03	0.12	0.10	0.05	0.00	0.00	0.91	45.55	1610	0	0	10	–
210	31.06	19.57	1.59	0.59	0.04	0.53	0.15	0.07	0.00	0.00	1.66	45.56	2310	0	0	0	–

	percentages												parts per million				
Depth (m)	CaO	MgO	SiO_2	Al_2O_3	Na_2O	SO_3	K_2O	SrO	P_2O_5	F	Fe_2O_3	loss at 1050°C	MnO	Cu	Pb	Zn	As
SD 86 SE 2	**8608 6470**		**Back Scar**														
3	45.66	0.86	15.83	0.97	0.05	0.11	0.20	0.17	0.05	–	0.60	36.00	470	–	–	–	–
7	53.06	0.79	2.41	0.41	0.04	0.09	0.08	0.06	0.05	–	0.43	42.43	400	–	–	–	–
12	51.25	0.76	5.64	0.81	0.04	0.16	0.16	0.10	0.05	–	0.60	40.98	360	–	–	–	–
17	46.48	1.64	8.71	2.57	0.05	0.68	0.45	0.16	0.07	–	1.40	38.55	420	–	–	–	–
21	37.93	1.77	19.65	6.33	0.08	0.81	1.08	0.22	0.10	–	1.58	32.25	460	–	–	–	–
25	51.20	1.12	4.31	1.04	0.05	0.31	0.18	0.09	0.07	–	0.52	41.32	440	–	–	–	–
29	51.04	0.97	4.93	1.33	0.02	0.45	0.26	0.10	0.10	–	0.61	40.89	340	–	–	–	–
33	52.12	0.81	3.79	1.04	0.01	0.14	0.20	0.09	0.09	–	0.55	41.87	430	–	–	–	–
37	54.15	0.65	1.38	0.42	0.01	0.07	0.08	0.06	0.06	–	0.13	43.19	390	–	–	–	–
42	54.13	0.70	0.95	0.40	0.01	0.35	0.09	0.07	0.05	–	0.05	43.41	160	–	–	–	–
47	54.55	0.59	0.59	0.27	0.01	0.25	0.06	0.07	0.06	–	0.08	43.51	160	–	–	–	–
52	54.10	1.12	0.56	0.24	0.02	0.12	0.06	0.06	0.02	–	0.24	43.67	540	–	–	–	–
57	54.66	0.77	0.40	0.18	0.02	0.11	0.05	0.06	0.03	–	0.08	43.83	230	–	–	–	6
62	55.08	0.60	0.24	0.12	0.00	0.03	0.04	0.04	0.01	–	0.09	43.70	230	–	–	–	–
67	55.32	0.32	0.50	0.34	0.01	0.03	0.07	0.03	0.01	–	0.10	43.49	250	–	–	–	–
72	55.59	0.31	0.19	0.20	0.00	0.02	0.05	0.04	0.01	–	0.04	43.34	100	–	–	–	–
77	55.92	0.19	0.09	0.08	0.01	0.02	0.03	0.02	0.01	–	0.04	43.15	110	–	–	–	–
82	55.63	0.25	0.09	0.13	0.00	0.01	0.04	0.02	0.01	–	0.04	43.23	120	–	–	–	–
87	55.35	0.29	0.28	0.09	0.00	0.01	0.03	0.02	0.01	–	0.07	43.27	200	–	–	–	–
92	55.75	0.26	0.37	0.13	0.00	0.01	0.04	0.02	0.01	–	0.06	43.13	200	–	–	–	–
97	55.63	0.27	0.29	0.09	0.00	0.02	0.03	0.02	0.00	–	0.05	43.07	160	–	–	–	0
102	55.44	0.28	0.44	0.09	0.00	0.01	0.03	0.03	0.00	–	0.09	43.06	200	–	–	–	–
107	55.65	0.21	0.56	0.17	0.00	0.01	0.04	0.03	0.01	–	0.06	42.82	130	–	–	–	–
SD 86 SE 6	**8541 6378**		**Stockdale Farm**														
17	54.27	0.47	0.65	0.17	0.00	0.05	0.05	0.05	0.03	–	0.06	43.34	150	–	–	–	–
22	54.59	0.51	0.32	0.17	0.01	0.08	0.04	0.04	0.01	–	0.04	43.50	110	–	–	–	–
27	54.38	0.47	0.31	0.14	0.01	0.05	0.04	0.04	0.05	–	0.03	43.42	130	–	–	–	–
32	54.55	0.50	0.30	0.14	0.01	0.10	0.04	0.05	0.03	–	0.03	43.53	100	–	–	–	0
37	54.37	0.53	0.21	0.14	0.01	0.07	0.04	0.05	0.01	–	0.04	43.57	100	–	–	–	–
42	54.24	0.63	0.35	0.19	0.01	0.15	0.05	0.05	0.01	–	0.03	43.43	110	–	–	–	–
47	54.31	0.63	0.16	0.14	0.01	0.12	0.04	0.05	0.01	–	0.02	43.52	80	–	–	–	–
52	54.66	0.54	0.21	0.14	0.01	0.09	0.04	0.04	0.01	–	0.04	43.75	120	–	–	–	–
57	53.90	0.70	0.77	0.39	0.01	0.22	0.09	0.05	0.01	–	0.08	43.26	110	–	–	–	2
62	48.19	0.91	8.06	1.94	0.05	0.76	0.36	0.11	0.02	–	0.79	38.80	190	–	–	–	–
67	45.16	1.23	11.31	2.78	0.08	1.59	0.48	0.15	0.03	–	1.26	36.13	220	–	–	–	–
72	50.27	1.02	4.47	1.49	0.04	0.92	0.28	0.10	0.02	–	0.74	40.65	140	–	–	–	–
77	48.83	0.87	7.81	1.57	0.06	0.87	0.27	0.11	0.02	–	0.69	38.57	120	–	–	–	–
82	49.31	1.13	5.76	1.84	0.04	0.79	0.33	0.08	0.02	–	0.80	39.95	130	–	–	–	–
87	48.81	1.07	6.79	1.95	0.05	0.90	0.35	0.10	0.02	–	0.81	39.34	120	–	–	–	–
92	51.79	1.14	2.69	0.92	0.02	0.47	0.18	0.08	0.01	–	0.48	42.13	70	–	–	–	–
97	51.62	1.03	2.90	1.02	0.02	0.54	0.21	0.10	0.01	–	0.49	42.05	90	–	–	–	–
102	49.87	1.08	4.82	1.77	0.03	0.93	0.34	0.13	0.02	–	0.76	40.64	90	–	–	–	–
107	50.49	0.97	4.23	1.55	0.03	0.85	0.32	0.11	0.01	–	0.76	41.09	120	–	–	–	–
112	51.74	0.98	2.99	0.97	0.03	0.54	0.22	0.08	0.01	–	0.48	42.01	140	–	–	–	–
117	53.58	0.70	1.15	0.41	0.01	0.21	0.10	0.03	0.01	–	0.32	43.01	150	–	–	–	–
122	54.16	0.56	0.90	0.30	0.01	0.11	0.08	0.02	0.03	–	0.08	43.24	160	–	–	–	–
127	53.93	0.57	0.92	0.32	0.01	0.09	0.09	0.03	0.01	–	0.32	43.18	320	–	–	–	2
132	53.67	0.58	1.19	0.36	0.01	0.15	0.10	0.05	0.00	–	0.08	42.89	180	–	–	–	–
137	53.93	0.63	1.20	0.46	0.01	0.24	0.13	0.05	0.01	–	0.07	42.87	190	–	–	–	–
142	44.68	1.43	12.51	2.64	0.28	0.57	0.54	0.13	0.02	–	1.19	35.01	290	–	–	–	–
147	24.54	5.43	35.38	6.83	0.48	1.38	1.44	0.31	0.02	–	2.76	22.49	480	–	–	–	–
152	39.06	2.82	17.45	4.22	0.22	0.89	0.97	0.18	0.02	–	1.74	32.51	440	–	–	–	–
SD 87 SW 9	**8435 7143**		**Silverdale**														
3	54.26	0.73	0.93	0.31	0.03	0.25	0.07	0.06	0.03	0.03	0.15	42.98	250	5	10	70	–
8	54.41	0.62	0.44	0.27	0.01	0.10	0.07	0.03	0.03	0.01	0.10	43.33	140	5	0	40	–
13	55.06	0.43	0.29	0.21	0.00	0.09	0.05	0.02	0.02	0.02	0.08	43.38	150	0	0	40	0
18	55.31	0.35	0.01	0.10	0.01	0.09	0.03	0.01	0.01	0.02	0.07	43.66	200	0	0	60	–
23	52.21	0.41	2.32	1.77	0.04	1.45	0.21	0.04	0.01	0.04	0.95	39.83	120	0	0	50	–
28	55.63	0.25	0.08	0.12	0.01	0.07	0.04	0.00	0.01	0.01	0.05	43.66	120	0	0	20	–
33	51.97	0.34	2.96	2.14	0.03	0.59	0.33	0.04	0.01	0.04	0.56	40.72	100	0	0	40	–
38	55.59	0.22	0.15	0.13	0.00	0.10	0.04	0.00	0.01	0.02	0.03	43.51	110	0	0	10	–
43	55.83	0.23	0.00	0.11	0.00	0.06	0.03	0.00	0.01	0.03	0.03	43.64	120	0	0	10	0
48	55.84	0.23	0.00	0.11	0.00	0.07	0.04	0.01	0.01	0.02	0.02	43.56	90	0	0	10	–
53	55.81	0.22	0.00	0.08	0.00	0.09	0.03	0.00	0.01	0.02	0.03	43.50	110	0	0	0	–
58	53.63	0.30	1.70	1.31	0.02	0.57	0.017	0.003	0.01	0.04	0.54	41.84	110	0	0	10	–
63	53.80	0.26	1.58	1.23	0.02	0.44	0.16	0.00	0.01	0.03	0.52	41.98	140	0	0	0	–
68	55.53	0.18	0.16	0.23	0.00	0.05	0.05	0.00	0.01	0.02	0.03	43.38	100	0	0	0	–
73	55.95	0.22	0.04	0.13	0.00	0.04	0.04	0.00	0.01	0.01	0.02	43.48	80	0	0	0	–
78	55.96	0.24	0.02	0.13	0.00	0.03	0.04	0.00	0.01	0.03	0.04	43.37	130	0	0	0	1
83	55.65	0.21	0.03	0.14	0.00	0.03	0.04	0.00	0.01	0.01	0.03	43.53	110	0	0	0	–
88	55.73	0.21	0.00	0.10	0.00	0.04	0.04	0.00	0.01	0.01	0.03	43.44	130	0	0	0	–
93	55.98	0.19	0.00	0.07	0.00	0.02	0.03	0.00	0.00	0.01	0.03	43.13	180	0	0	0	–
98	55.63	0.27	0.13	0.18	0.00	0.05	0.05	0.00	0.01	0.02	0.04	43.66	120	0	0	10	–

Depth (m)	CaO	MgO	SiO_2	Al_2O_3	Na_2O	SO_3	K_2O	SrO	P_2O_5	F	Fe_2O_3	loss at 1050°C	MnO	Cu	Pb	Zn	As
	percentages												parts per million				
SD 87 SW 9	**8435 7143**		**Silverdale**														
103	56.10	0.21	0.00	0.06	0.00	0.02	0.03	0.00	0.01	0.02	0.04	43.44	180	0	0	0	–
108	56.03	0.21	0.00	0.07	0.00	0.02	0.03	0.00	0.01	0.02	0.03	43.42	130	0	0	0	–
113	56.10	0.24	0.00	0.08	0.01	0.03	0.03	0.00	0.01	0.03	0.02	43.48	100	0	0	0	0
118	56.10	0.23	0.00	0.07	0.00	0.02	0.03	0.00	0.01	0.02	0.02	42.88	110	0	0	0	–
123	55.61	0.18	0.00	0.07	0.00	0.01	0.02	0.00	0.00	0.00	0.03	43.04	140	0	0	0	–
128	56.10	0.22	0.00	0.07	0.00	0.03	0.03	0.01	0.01	0.01	0.03	43.53	150	0	0	10	–
133	56.00	0.26	0.00	0.08	0.00	0.03	0.03	0.00	0.01	0.01	0.02	43.46	100	0	0	10	–
138	55.59	0.32	0.00	0.10	0.00	0.03	0.04	0.01	0.01	0.02	0.02	43.53	90	0	0	10	–
143	55.66	0.37	0.04	0.13	0.00	0.05	0.04	0.00	0.01	0.02	0.02	43.54	80	0	0	10	0
148	55.98	0.37	0.00	0.11	0.00	0.06	0.04	0.01	0.01	0.02	0.02	43.44	90	0	0	10	–
153	55.62	0.50	0.01	0.12	0.02	0.14	0.04	0.03	0.00	0.03	0.03	43.68	130	0	10	20	–
158	55.72	0.56	0.07	0.15	0.00	0.18	0.05	0.02	0.01	0.01	0.02	43.54	170	0	0	10	–
163	55.36	0.55	0.10	0.15	0.00	0.18	0.05	0.03	0.01	0.02	0.04	43.43	120	0	0	0	–
168	55.04	0.63	0.36	0.25	0.01	0.25	0.07	0.04	0.01	0.03	0.03	43.44	70	0	10	20	0
173	53.05	0.84	2.38	0.74	0.01	0.59	0.19	0.06	0.02	0.04	0.54	41.99	130	0	0	10	–
178	51.90	0.76	4.62	1.21	0.01	0.58	0.30	0.07	0.02	0.06	0.61	40.65	170	0	0	10	–
183	50.18	0.84	6.80	1.61	0.02	0.37	0.43	0.07	0.02	0.05	0.70	39.48	290	0	0	30	–
188	52.57	0.86	3.33	0.70	0.03	0.62	0.18	0.05	0.01	0.02	0.72	41.24	470	0	0	30	–
SD 96 NE 1	**9726 6647**		**Chapel House**														
3	50.00	5.64	0.14	0.13	0.00	0.02	0.04	0.04	0.01	0.00	0.51	43.46	510	0	0	10	–
8	52.44	3.42	0.01	0.11	0.01	0.05	0.04	0.03	0.01	0.00	0.49	43.36	280	5	0	20	–
13	54.63	1.80	0.01	0.11	0.02	0.05	0.04	0.03	0.01	0.00	0.45	43.06	250	5	0	20	0
18	48.43	7.23	0.04	0.12	0.01	0.02	0.04	0.04	0.01	0.00	0.53	44.01	410	5	0	20	–
23	43.80	11.33	0.00	0.11	0.00	0.00	0.03	0.04	0.00	0.00	0.64	44.56	550	0	0	10	–
28	40.22	15.11	0.22	0.23	0.00	0.06	0.06	0.06	0.00	0.00	0.54	45.15	300	0	10	20	–
32	48.80	3.35	4.00	1.47	0.02	0.80	0.08	0.08	0.01	0.00	0.96	41.06	220	0	10	30	–
48	49.96	1.92	5.66	1.68	0.04	1.08	0.09	0.09	0.02	0.00	1.29	39.44	320	0	10	10	–
53	50.05	2.28	4.94	1.03	0.03	0.61	0.05	0.05	0.01	0.00	0.79	40.53	200	0	0	20	–
58	46.06	7.34	1.96	0.61	0.00	0.32	0.06	0.06	0.01	0.00	0.65	43.43	300	0	0	30	–
63	50.97	1.77	5.40	1.65	0.02	0.88	0.09	0.09	0.01	0.00	0.91	40.35	110	0	0	20	–
68	46.56	5.91	3.04	1.16	0.02	0.76	0.08	0.08	0.01	0.00	0.83	42.13	270	0	10	40	–
73	31.87	21.53	0.28	0.20	0.02	0.97	0.07	0.07	0.00	0.00	1.32	45.72	890	0	0	0	9
78	33.39	20.48	0.59	0.29	0.03	0.90	0.07	0.07	0.00	0.00	1.27	45.44	820	0	0	10	–
SD 96 SW 1	**9279 6497**		**High Bank**														
2	54.56	0.47	0.87	0.17	0.01	0.04	0.04	0.06	0.02	0.00	0.39	43.24	550	5	0	40	–
5	54.31	0.90	0.32	0.22	0.00	0.04	0.06	0.05	0.02	0.01	0.48	43.58	830	0	0	30	–
8	55.07	0.48	0.18	0.20	0.01	0.15	0.05	0.05	0.01	0.00	0.41	43.46	520	0	0	40	6
11	54.83	0.43	0.87	0.56	0.00	0.12	0.13	0.04	0.01	0.01	0.09	43.12	140	5	0	20	–
14	55.77	0.31	0.11	0.16	0.00	0.03	0.05	0.04	0.01	0.00	0.13	43.46	260	5	0	10	–
17	55.78	0.24	0.09	0.12	0.00	0.02	0.04	0.02	0.01	0.00	0.08	43.47	200	0	0	10	–
20	56.10	0.29	0.15	0.16	0.00	0.03	0.04	0.03	0.01	0.00	0.06	43.38	150	0	0	10	–
23	55.85	0.29	0.09	0.14	0.00	0.02	0.04	0.03	0.01	0.00	0.05	43.34	130	0	0	10	–
26	55.85	0.26	0.20	0.20	0.00	0.02	0.05	0.03	0.01	0.00	0.05	43.10	130	0	0	10	–
29	55.58	0.20	0.12	0.10	0.00	0.01	0.03	0.03	0.01	0.00	0.09	43.21	240	0	0	10	–
32	56.10	0.21	0.02	0.10	0.00	0.02	0.03	0.01	0.01	0.00	0.06	43.19	160	0	0	10	–
35	55.20	0.23	0.11	0.14	0.00	0.01	0.04	0.01	0.01	0.02	0.06	43.18	150	0	0	0	1
38	56.10	0.24	0.12	0.17	0.00	0.02	0.05	0.04	0.01	0.00	0.06	43.14	160	0	0	10	–
41	56.05	0.18	0.03	0.10	0.00	0.01	0.03	0.02	0.01	0.00	0.04	43.01	110	0	0	10	–
44	56.10	0.19	0.00	0.09	0.00	0.01	0.03	0.02	0.01	0.00	0.04	43.08	100	0	0	0	–
47	56.03	0.25	0.16	0.21	0.00	0.01	0.06	0.02	0.00	0.00	0.05	43.01	90	0	0	10	–
50	56.08	0.19	0.00	0.11	0.00	0.01	0.04	0.02	0.00	0.00	0.03	42.89	80	0	0	0	–
53	56.10	0.23	0.00	0.10	0.00	0.02	0.03	0.02	0.00	0.00	0.15	43.29	370	0	0	0	–
56	56.08	0.23	0.00	0.08	0.02	0.02	0.05	0.03	0.01	0.00	0.18	43.47	470	0	0	0	–
59	56.10	0.23	0.01	0.11	0.00	0.02	0.04	0.03	0.00	0.00	0.05	43.06	120	0	0	0	–
62	55.37	0.24	0.07	0.13	0.00	0.02	0.04	0.00	0.00	0.02	0.06	43.11	140	0	0	0	–
65	56.10	0.22	0.12	0.17	0.00	0.02	0.05	0.03	0.00	0.00	0.05	42.96	110	0	0	10	–
68	56.10	0.21	0.05	0.14	0.01	0.02	0.04	0.03	0.01	0.00	0.07	43.22	190	0	0	0	0
71	55.97	0.21	0.01	0.12	0.00	0.01	0.04	0.00	0.01	0.00	0.04	43.22	110	5	0	0	–
74	55.45	0.20	0.07	0.13	0.00	0.01	0.04	0.00	0.00	0.02	0.03	43.17	100	0	0	0	–
77	55.92	0.24	0.38	0.35	0.00	0.04	0.08	0.04	0.00	0.00	0.03	43.35	80	0	0	0	–
80	55.57	0.25	0.40	0.34	0.00	0.02	0.08	0.03	0.01	0.00	0.04	43.19	70	0	0	0	–
83	55.95	0.22	0.14	0.19	0.03	0.02	0.06	0.02	0.01	0.00	0.03	43.17	90	0	0	0	–
86	56.10	0.20	0.01	0.12	0.00	0.01	0.04	0.02	0.01	0.00	0.03	43.17	100	0	0	10	–
89	55.54	0.24	0.18	0.22	0.00	0.01	0.06	0.03	0.01	0.00	0.04	43.28	80	0	0	10	–
92	56.01	0.22	0.04	0.13	0.02	0.02	0.05	0.03	0.01	0.00	0.03	43.24	80	0	0	0	–
95	55.15	0.25	0.35	0.28	0.01	0.03	0.08	0.03	0.01	0.00	0.03	43.40	90	0	0	10	–
98	56.10	0.20	0.00	0.09	0.00	0.01	0.03	0.02	0.01	0.00	0.03	43.33	130	0	0	10	–

SD 76 NE 9 Feizor SD 7870 6722
Surface level 232 m
Drilled for IGS

	Thickness m	Depth m
(Yoredale 'series' limestones)		
LIMESTONE Argillaceous, medium dark grey, fine calcarenite wackestone. Rare shells, corals and crinoids. Micaceous and pyritous.	8.41	8.41
MUDSTONE Dark grey, calcareous and pyritous. Rare shells and crinoids. Septarian nodules present. Micaceous along bedding planes.	4.21	12.62
LIMESTONE Medium dark grey, argillaceous, fine calcarenite wackestone. Sparsely bioclastic and pyritous in parts.	2.94	15.56
MUDSTONE Dark grey and calcareous. Some thin limestones. Crinoids present, occasionally silicified. Pyritous in parts.	4.34	19.90
Hardraw Scar Limestone		
LIMESTONE Medium to medium dark grey, fine calcarenite wackestone. Grades to rudite grainstone in parts. Occasional argillaceous partings. Crinoids are locally abundant, shells and corals are common. Bioclasts are often partly silicified. Chert nodules are common. Stylolites and calcite veining are common throughout.	11.87	31.77
MUDSTONE Dark to medium dark grey, pyritous and calcareous. Some crinoids present.	3.03	34.80
Lower Hawes Limestone, Upper Hawes Limestone and Gayle Limestone (undifferentiated)		
LIMESTONE Dark to medium grey, fine to medium calcarenite wackestone. Occasional thin mudstone partings. Argillaceous in parts. Crinoids, bryozoa and corals are present. Stylolites and pseudobrecciation are frequent. Rare calcite veins are partly silicified. Disseminated pyrite is common.	8.11	42.91
DOLOMITE Dolomitised crinoidal limestone	0.45	43.36
LIMESTONE Medium to medium light grey, fine to medium calcarenite packstone and wackestone. Argillaceous in parts. Shells and crinoids are abundant. Algae and bryozoa are also present. Stylolites, disseminated pyrite and calcite veins are present throughout. Some minor silicification at base.	6.38	49.74
LIMESTONE Dark grey, fine calcarenite wackestone and packstone. Crinoids, shells and algal nodules (*Girvanella* oncolites) are common. Frequent stylolites.	1.67	51.41
DOLOMITE Dolomitised shelly limestone.	2.89	54.30
LIMESTONE Medium dark to light grey, fine to medium calcarenite packstone. Crinoids, shells and oncolites are common. Foraminifera and pellets are common at base. Mottled at top. Disseminated dolomite and pyrite are present throughout. Minor calcite veining and carbonaceous material are locally present.	10.80	65.10

Borehole completed at 65.10 m.

SD 77 SE 1 Horton Quarry SD 7955 7171
Surface level 375 m
Drilled for Imperial Chemicals Industries Ltd.

	Thickness m	Depth m
No core recovery	3.00	3.00
Gordale Limestone		
LIMESTONE Medium light to light grey, medium to fine calcarenite packstone and grainstone. Crinoids, foraminifera, algae and shells are common, sporadic bryozoa and corals. Stylolitic and mottled. Trace amounts of dolomite.	16.50	19.50
Cove Limestone		
LIMESTONE (Porcellanous Beds) Medium light grey, calcilutite with fenestral fabric. Locally fine calcarenite packstone. Minor dolomitisation along sporadic stylolites.	2.10	21.60
LIMESTONE Medium light to medium grey, fine to medium calcarenite packstone and grainstone. Foraminifera and algae (including *Koninckopora*) are common. Corals, shells and crinoids are locally common. Lithoclasts of sand sized particles of siltstone become common to base. Mottling and trace amounts of dolomite occur throughout.	45.90	67.50
Kilnsey Limestone		
Medium dark to dark grey, fine to medium calcarenite packstone and grainstone. Argillaceous in parts. Algae, shells and crinoids are common. Lithoclasts of siltstones and fine arenite sandstones are common throughout.	9.61	77.11
Lower Palaeozoic rocks		
SILTSTONE Dark grey, pyritous, finely laminated and slightly calcareous. Graptolites on bedding planes. Dips at approximately 25°	11.07	88.18

Borehole completed at 88.18 m.

SD 86 NW 4 Lower Winskill SD 8259 6670
Surface level 297 m
Drilled for IGS

	Thickness m	Depth m
Cove Limestone		
LIMESTONE Light to medium light grey, fine to medium calcarenite packstone, locally grainstone. Stylolites and mottling increasingly common to base. Pellets and crinoids, rarely foraminifera, are common. Some minor calcite veining.	19.24	19.24

LIMESTONE Medium to medium light grey, locally medium dark grey, fine to medium calcarenite packstone and wackestone. Pellets, crinoids and foraminifera are common. Some palaeokarstic surfaces. Passage base.	12.71	31.95
LIMESTONE Light grey, fine to medium calcarenite packstone and wackestone. Crinoids, algae, foraminifera and shells are locally common. Dolomitisation of minor calcite veins present. Abundant foraminifera at base.	17.55	49.50
FAULT? Broken limestone fragments in dolomitised matrix. Complex anastomosing fractures and veins.	2.72	52.22
LIMESTONE Light to medium light grey, fine to medium calcarenite packstone. Moderately well sorted. Shells, algae, foraminifera and crinoids are common. Oncolites and intraclasts are present to base. Trace amounts of dolomite throughout. Grainstone at base.	35.38	87.60
LIMESTONE Light to medium grey, fine to medium calcarenite packstone and grainstone. Abundant algae and pelletal debris. Foraminifera and shells are locally common. Becomes increasingly dolomitised to base.	31.35	118.95
DOLOMITE Coarsely crystalline. Isolated patches of partly dolomitised limestone still present.	9.50	128.45

Kilnsey Formation

LIMESTONE Medium to dark grey, fine calcarenite packstone. Algae and corals are locally abundant. Crinoids and shells are common. Intraclasts become increasingly common to base. Trace amounts of dolomite are present throughout.	15.49	143.94
LIMESTONE Dark grey, fine calcarenite wackestone with argillaceous partings. Intraclasts are abundant. Corals and shells are present. Oncolites and algae are locally abundant. Frequent stylolites.	9.52	153.46
LIMESTONE Dark grey, fine to medium calcarenite wackestone. Argillaceous in parts. Intraclasts, pelletal debris and corals are locally common. Calcite veins and disseminated dolomite are present throughout.	10.27	163.73
DOLOMITIC LIMESTONE variable dolomitisation; coarsely crystalline dolomite to dark grey packstone and wackestone with disseminated dolomite. Corals, shells and crinoids are present. Much calcite veining at base.	16.93	180.66
DOLOMITE Coarsely crystalline dolomite with sand and gravel sized lithoclasts of bluish-grey and greenish-grey siltstones and sandstones. Pyrite present at base.	8.33	188.99

Chapel House Limestone

LIMESTONE Medium grey, medium calcarenite grainstone. Dolomitised in parts. Pelletal debris and lithoclasts are common. Disseminated pyrite present throughout.	4.31	193.30
DOLOMITE Coarsely crystalline dolomite with lithoclasts. Disseminated pyrite is common.	8.42	201.72
DOLOMITIC LIMESTONE Dolomitised, medium grey, fine to medium calcarenite. Some less dolomitised areas of grainstone and packstone. Intraclasts and pellets are present.	3.98	205.70
DOLOMITE Coarsely crystalline dolomite. Disseminated pyrite present throughout.	6.30	212.00
DOLOMITIC MUDSTONE Dark grey to buff grey, finely laminated and striped. Exhibits soft sediment deformation structures. Extremely pyritous.	7.50	219.50

Borehole completed at 219.50 m.

SD 86 SE 2 Back Scar SD 8606 6470

Surface level 427 m

Drilled for Cominco S. A.

	Thickness m	*Depth* m
OVERBURDEN Top soil and weathered limestone	1.50	1.50

Hardraw Scar Limestone

LIMESTONE Medium dark to medium light grey, medium to fine calcarenite grainstone and packstone. Slightly argillaceous with frequent stylolites and microstylolites. Abundant crinoid debris. Scattered shell and bryozoan fragments. Chert nodules at top. Minor silicification and dolomitisation is common throughout. Disseminated pyrite and ferruginous staining is present throughout.	13.34	14.84
LIMESTONE Argillaceous limestone with interbedded calcareous mudstones. Dark grey, fine to medium calcarenite wackestone, and locally packstone. Some minor silicification and dolomitisation. Traces of pyrite. Mudstones are finely laminated, micaceous and fossiliferous. Varied fauna includes crinoids, corals, brachiopods, bivalves and bryozoans.	13.59	28.43

Lower Hawes Limestone, Upper Hawes Limestone and Gayle Limestone (undifferentiated)

LIMESTONE Medium to dark grey, fine calcarenite to calcilutite packstone and wackestone. Slightly argillaceous and poorly sorted. Crinoids and shells are common. Oncolites and algae (including *Girvanella*) are locally common. Minor silicification and dolomitisation, and traces of pyrite are present throughout. Ferruginous staining and decalcification present on joints. Stylolites and microstylolites are frequent.	15.53	43.96

LIMESTONE Medium light to dark grey, fine to medium calcarenite packstone and wackestone. Crudely laminated at top. Shells and foraminifera are common. Stylolites are frequent. Minor silicification and dolomitisation present throughout. Ferruginous staining at base.	16.00	59.96
Gordale Limestone		
LIMESTONE Medium light to light grey, fine to medium calcarenite packstone and wackestone, and locally grainstone. Stylolites and pseudobrecciation are common, often associated with colour mottling. In the finer calcarenites, laminations and cross bedding are present. Shells, crinoids, foraminifera and algae (including *Koninckopora*) are locally common. Minor silicification and dolomitisation associated with stylolites, joints and calcite veining.	50.24	108.20
Borehole completed at 108.20 m		

SD 86 SE 6 Stockdale Farm SD 8541 6378

Surface level 381 m

Drilled for Cominco S. A.

	Thickness m	*Depth* m
No core recovery	15.24	15.24
Kilnsey Limestone		
LIMESTONE Light to medium grey, fine to medium calcarenite packstone and grainstone. Slightly argillaceous in parts. Shells, crinoids, foraminifera, algae (including *Koninckopora*) and bryozoa are common. Stylolites and pseudobrecciation are frequent. Trace amounts of dolomite and pyrite are present.	23.21	38.45
LIMESTONE Dark to medium grey, fine to medium calcarenite packstone and grainstone. Wackestone at base. Crinoids, algae and bryozoa are common. Thin mudstones are present at base. Stylolites and pseudobrecciation are common, often with adjacent disseminated dolomite.	20.04	58.49
Kilnsey Limestone with Mudstone		
LIMESTONE Dark to medium grey, fine to medium calcarenite wackestone, locally packstone. Argillaceous with frequent mudstone partings. Crinoids, shells, bryozoa, algae, foraminifera and pellets are locally common. Stylolites and pseudobrecciation are common, often with adjacent disseminated dolomite.	61.59	120.08
Chapel House Limestone		
LIMESTONE Medium dark to light grey, fine to medium calcarenite packstone. Crinoids and shells are locally common. Algae, foraminifera and pelletal debris are locally abundant. Slightly argillaceous at base. Stylolites are frequent. Disseminated dolomite and silica are present throughout. Rare calcite veins are often dolomitised. Trace amounts of pyrite present at base.	21.11	142.19
CONGLOMERATE Well rounded pebbles of bluish-grey and greenish-grey siltstones and limestone in a silty dolomitic matrix. Ooliths are common.	2.41	144.60
LIMESTONE Medium light grey, silty, fine calcarenite. Dolomitic and very silty in parts. Pellets, ooliths and fine grained lithoclasts are common. Stylolites, disseminated pyrite and bioturbation are present throughout.	15.10	159.70
MUDSTONE Dark grey, fissile, slightly calcareous with carbonaceous debris.	0.66+	160.36
End of detailed log: brief description of lower beds based on log by R. S. Arthurton and L. C. Jones		
LIMESTONE Predominantly limestone, medium to medium light grey, fine calcarenite. Interbedded with siltstones, sandstones and conglomerates. Some argillaceous partings.	9.64	170.00
Stockdale Farm Formation		
LIMESTONE predominantly limestone, medium grey, argillaceous, fine calcarenite and calcilutite. Dolomitised in parts. Interbedded mudstones. Shells and corals present in upper parts. Some Carbonaceous debris including plant fragments.	72.27	242.27
SANDSTONE Fine grained, occasionally silty with interbedded limestones, mudstones and siltstones. Plant debris locally common. Some shell debris.	67.13	309.40
Borehole completed at 309.40 m		

SD 87 SW 9 Silverdale SD 8435 7143

Surface level 427 m

Drilled for IGS

	Thickness m	*Depth* m
OVERBURDEN Topsoil	0.40	0.40
Lower Hawes Limestone, Upper Hawes and Gayle Limestone (undifferentiated)		
LIMESTONE Medium dark grey to medium grey, fine to medium calcarenite wackestone. Locally packstone. Shells, crinoids and algae (including *Girvanella*) are common. Pelletal to base. Some bioclastic silicification. Trace amounts of dolomite, pyrite and clay minerals present.	14.66	15.06
LIMESTONE Medium grey, fine to medium calcarenite packstone, locally wackestone. Shells, crinoids and pellets are common. Foraminifera common at base. Trace amounts of pyrite.	8.49	23.55

Gordale Limestone

	Thickness m	Depth m
Medium light to light grey, fine to medium calcarenite packstone and wackestone, locally grainstone. Stylolitic and often mottled. Biostromes of shells (e.g. *Davidsonia septosa*), foraminifera, algae and corals present. Interbedded, thin, light greenish-grey, fissile, often pyritous mudstones. A darkening of the limestone adjacent to the clays and the presence of pyrite is common. Trace amounts of dolomite, silica and hematite are present in some parts.	73.02	96.57

Cove Limestone

	Thickness m	Depth m
LIMESTONE (Porcellanous Beds) Medium light to light grey, fine calcarenite grainstones and calcilutite with fenestral fabric. Palaeokarstic surfaces present. Grainstones are laminated and frequently cross-bedded. Pellets are abundant. Algae, foraminifera, shells and bioturbation are also present.	5.39	101.96
LIMESTONE Medium light grey, fine to coarse calcarenite grainstone, locally packstone. Crudely bedded in parts. Pelletal debris, foraminifera, shells and crinoids are common. Algae are abundant at base. Intraclasts and bioturbation are present in parts. Dolomite and hematite is present in trace amounts.	9.35	111.31
LIMESTONE Medium light grey, calcilutite and fine calcarenite grainstone. Calcilutite (58 cm at top) exhibits fenestral fabric. Grainstone (to base) is pelletal and cross-bedded. Algae and foraminifera are locally abundant.	5.00	116.31
LIMESTONE Medium light to light grey, fine to coarse calcarenite packstone, locally grainstone. Mottled in parts. Shells and algae are common. Trace amounts of pyrite and dolomite present throughout.	30.21	146.52

Kilnsey Formation

	Thickness m	Depth m
LIMESTONE Medium to dark grey, fine to medium calcarenite wackestone, locally packstone. Grainstone at base. Shells and algae with rare corals are present. Stylolites with pseudobrecciation are common. Trace amounts of dolomite and silica are present throughout. Slightly pyritised at base.	25.44	171.96
LIMESTONE Medium dark grey, fine calcarenite wackestone, locally packstone. Calcilutite with silt at top. Crinoids and rare corals are present. Bioturbated, stylolitic and pseudobrecciated at base.	7.82	175.78
LIMESTONE Medium dark grey, fine to medium calcarenite wackestone, locally packstone and rarely grainstone. Shells and corals are common. Pellets, ooliths, algae and foraminifera are locally abundant. Frequent stylolites and pseudobrecciated at base.	4.00	179.78

Chapel House Limestone

	Thickness m	Depth m
LIMESTONE Medium dark to medium grey, calcilutite. Exhibits fenestral fabric. Interbedded with bluish-grey dolomitic silt. Disseminated pyrite and silica present throughout. Passage base.	5.52	185.30
LIMESTONE Medium dark grey, medium calcarenite grainstone. Pelletal grains and foraminifera are common. Some shells and corals are present. Trace amounts of silica.	1.45	186.75
LIMESTONE Medium dark grey, slightly argillaceous in part, fine calcarenite wackestone, locally packstone. Shells and crinoids are present. Trace amounts of silica.	2.50	189.25
LIMESTONE Medium dark to dark grey, fine to medium calcarenite grainstone. Abundant pellets and ooliths. Corals and shells are also common. Disseminated pyrite and silica throughout. Lithoclasts of well rounded, greenish-grey and bluish-grey siltstones and fine arenite sandstones increasingly common towards base. 15 cm of conglomerate at base.	1.75	191.00

Lower Palaeozoic rocks

	Thickness m	Depth m
SILTSTONES and MUDSTONES Greenish-grey, very fine arenite to lutite. Pyritous. Micaceous on cleavage planes. Steeply inclined bedding (dip approximately 30°).	9.77	200.77

Borehole completed at 200.77 m.

SD 96 NE 1 Chapel House (Outgang Laithe) **SD 9726 6647**

Surface level 263 m
Drilled for IGS

	Thickness m	*Depth* m
OVERBURDEN Broken rubbly limestone	1.33	1.33

Kilnsey Limestone

	Thickness m	Depth m
LIMESTONE Dark to medium grey, fine to medium calcarenite packstone and grainstone. Patchily dolomitised adjacent to joints, fractures and minor calcite veining. Pellets, algae, shells and crinoids are locally abundant. Rare corals and foraminifera.	16.63	17.96
DOLOMITE Partially to completely dolomitised limestone. Coarsely crystalline dolomite with isolated patches of pelletal packstone. Crinoids abundant at base.	11.13	29.09

Kilnsey Limestone with Mudstone

LIMESTONE Dark to medium grey, argillaceous, fine calcarenite wackestone. Frequently interbedded with thin mudstones. Shells, corals and crinoids are locally common. Evidence of bioturbation is

	Thickness m	Depth m
frequent. Dolomitisation, particularly of bioclasts, and disseminated pyrite are present throughout. Mudstones are dark grey, fissile and micaceous and often very fossiliferous.	22.11	51.20
LIMESTONE Dark to medium grey, slightly argillaceous, fine calcarenite wackestone. Passage base.	3.00	54.20
LIMESTONE Dark to medium grey, fine to medium calcarenite grainstone. Pellets, crinoids and shells are common. Disseminated pyrite is present throughout.	2.14	56.34
DOLOMITE Coarsely crystalline, pyritous.	1.59	57.93
LIMESTONE Dark grey, fine calcarenite wackestone and packstone. Slightly argillaceous. Occasional thin mudstone partings. Crinoids, shells and corals are locally abundant. Disseminated dolomite and pyrite present throughout. Bioturbated at base.	11.48	69.41
DOLOMITE Coarsely crystalline, very pyritous. Pyrite tends to be concentrated along joints and filling cavities.	11.75	81.16
Chapel House Limestone		
LIMESTONE Slightly dolomitic, well washed, medium dark grey, medium calcarenite grainstone. Ooliths and pellets are abundant. Very pyritous.	1.16	82.32
DOLOMITIC LIMESTONE Dark grey, fine arenite wackestones, interbedded with dolomitic mudstones. Bioturbated, sparsely fossiliferous. Quartz sand grains are often present. Extremely pyritous.	5.25	87.57
CONGLOMERATE Well rounded pebbles (up to 5 cm diameter) of sandstones, siltstones, limestones and coral fragments. Sand and gravel sized particles are also present. Interstitial carbonate matrix is pyritous.	2.55	90.12
Lower Palaeozoic rocks		
SANDSTONES and SILTSTONES Grey-green, fine laminated, fine arenite sandstones and interbedded siltstones.	17.00	107.12

Borehole completed at 107.12 m.

SD 96 NE 2 Kilnsey Quarry SD 9660 6738

Surface level 289 m

Drilled for Eskett Quarries/Streetley Minerals Ltd

	Thickness m	*Depth* m
No core recovery	*4.02*	*4.02*
Cove Limestone		
LIMESTONE Light to medium light grey, medium calcarenite grainstone, locally packstone. Bryozoa, algae (including *Koninckopora*), pellets, shells and spines are abundant. Some crinoids are present. Foraminifera increasingly common below 7 m. Ferruginous stained joints and minor calcite veins are frequent. Stylolites are also common.	14.98	19.00
LIMESTONE Medium light to medium grey, medium to fine calcarenite grainstone. Bioclasts present as above. Jointing and calcite veining is common.	8.44	27.44
Kilnsey Limestone		
LIMESTONE Medium grey to medium light grey, medium calcarenite grainstone. Grades to dark grey in parts. Algae, foraminifera, shells and pellets are abundant. Bryozoa, crinoids and spines are also present. Frequent stylolites with argillaceous residues. Some jointing and minor calcite veining.	11.36	38.80
LIMESTONE Dark grey, fine to medium calcarenite packstone and wackestone. Slightly argillaceous. Corals and shells are present. Rare oncolites.	1.20	40.00

Borehole complete at 40.00 m.

SD 96 NE 3 Kilnsey Quarry SD 9671 6780

Surface level 260 m

Drilled for Eskett Quarries/Steetley Minerals Ltd

	Thickness m	*Depth* m
OVERBURDEN Rubbly core	0.40	0.40
Cove Limestone		
LIMESTONE Light to medium light grey, medium to fine calcarenite grainstone. Some recrystallisation. Algae (including *Koninckopora*), foraminifera and shells are abundant. Crinoids, pellets and rarely corals are also present. Frequent stylolites, some dolomite along joints. Carbonaceous material present at top.	16.00	16.40
Kilnsey Limestone		
LIMESTONE Medium dark to medium grey, medium to fine calcarenite packstone. Moderately well sorted in parts. Shells, pellets and algae are common. Darker limestones are slightly argillaceous. Some dolomitisation at 28 m.	23.80	40.20
LIMESTONE Medium dark to dark grey, fine to medium calcarenite packstone. Algae, foraminifera, pellets and shells are common. Crinoids are abundant at base.	3.00	43.20

Borehole completed at 43.20 m.

SD 96 SW 1 High Bank SD 9279 6497

Surface level 384 m

Drilled for IGS

	Thickness m	*Depth* m
OVERBURDEN Rubbly limestone core	2.92	2.92
Lower Hawes Limestone		
LIMESTONE Medium to medium light grey, fine to medium calcarenite		

packstone and wackestone. Grainstone at base. Slightly argillaceous in parts. Crinoids, shells and foraminifera are common. Rare oncolites. Mottled in parts. Some jointing, minor calcite veining and associated disseminated dolomite present.	6.15	9.07
Gordale Limestone		
LIMESTONE Light to medium grey, fine to medium calcarenite wackestone and packstone, locally grainstone. Foraminifera and algae (including *Koninckopora*) are common. Shells and crinoids are locally abundant. Frequent stylolites and mottling. Jointing, fracturing and calcite veining, sometimes with barytes, are common.	43.84	52.91
FAULT? Broken and partially dolomitised limestone.	1.14	54.05
LIMESTONE Light to medium grey, fine to medium calcarenite wackestone and packstone. Rare corals and oncolites. Pelletal debris is common. Passes into fine calcarenite, laminated and cross-bedded at base.	7.35	62.40
Cove Limestone		
LIMESTONE Light to medium grey, fine to medium calcarenite wackestone and packstone. Foraminifera, algae, shells and crinoids are locally common. Stylolites and mottling are frequent. Minor calcite veins with mineralisation at top.	38.30	100.70

Borehole completed at 100.70 m.

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INSTITUTE OF GEOLOGICAL SCIENCES

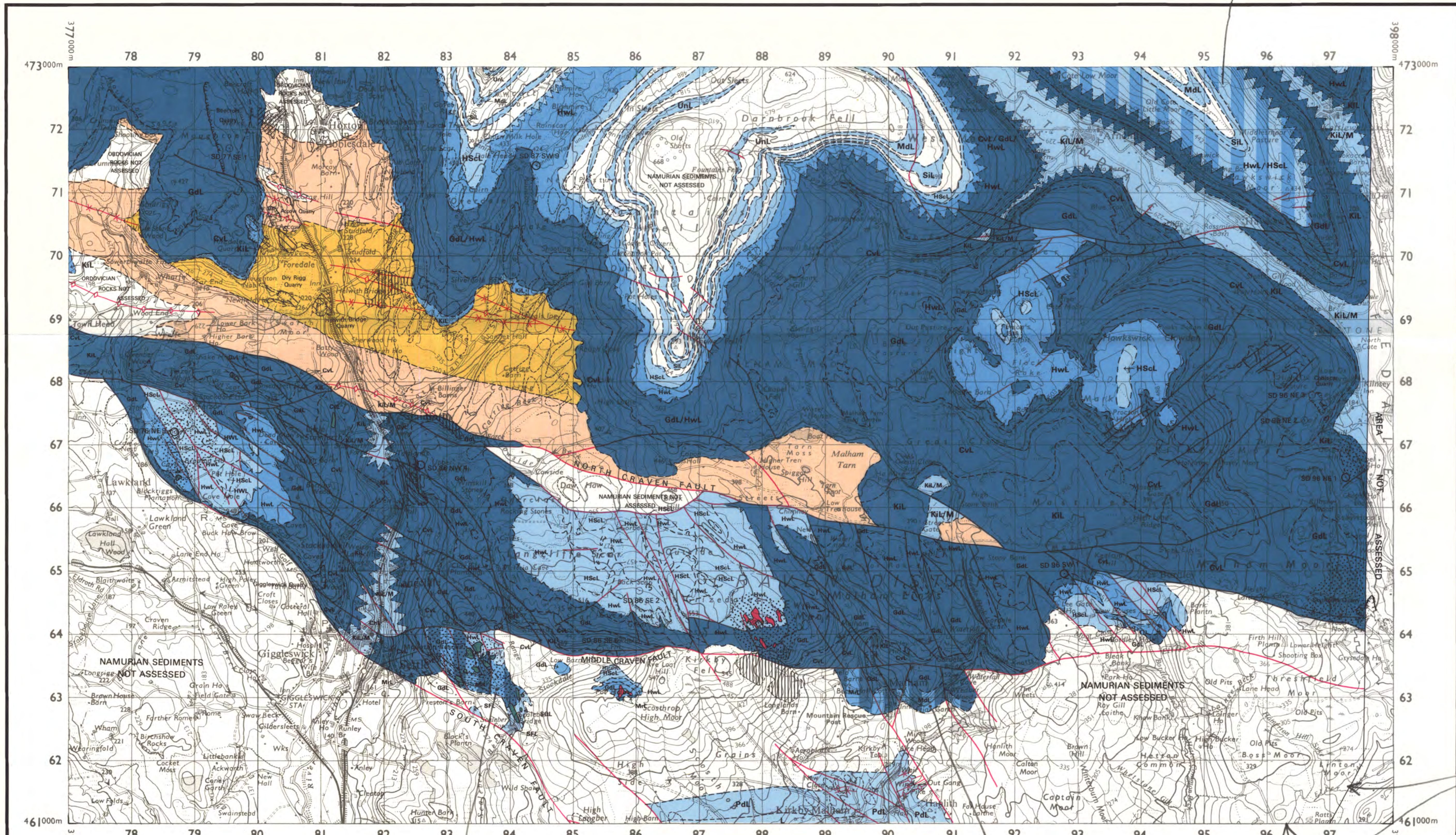
INDUSTRIAL MINERALS ASSESSMENT UNIT

THE LIMESTONE AND DOLOMITE RESOURCES OF THE COUNTRY AROUND SETTLE AND MALHAM, NORTH YORKSHIRE

THE LIMESTONE AND DOLOMITE RESOURCES OF THE COUNTRY AROUND SETTLE AND MALHAM, NORTH YORKSHIRE

126

This map should be read in conjunction with the accompanying Report which contains details of the assessment of the resources



Contour values are given to the nearest metre. The vertical interval is, however, 50 feet

Made and published by the Director General of the Ordnance Survey, Southampton.

Compiled from Ordnance Survey 1:50 000 1st series mapping, sheet 98.

Revised for major roads and significant changes 1974.

The representation on this map of a Road, Track, or Footpath, is no evidence of the existence of a right of way.

Assessment survey by D.W. Murray 1981. R.G. Thurrell, Head, Industrial Minerals Assessment Unit. Geological survey of Sheet 60 by R.S. Arthurton, E.W. Johnson, L.C. Jones and D.J.C. Mundy 1976-80, District Geologists, W.B. Evans, D.H. Land and J.G.O. Smart. Geological survey of Sheet 50 redrawn from the original geological survey by T.McK. Hughes, J.D. Dakyns, R.H. Tiddeman, C. Fox-Strangeways, W. Gunn, J.G. Goodchild and A. Strahan. Published on the one-inch scale with amendments based on work published and unpublished. Compilation 1:50 000 Limestone and Dolomite Resource sheet published 1983. G.M. Brown, D.Sc., F.R.S. Director, Institute of Geological Sciences. 1100/83

The resource map contains generalised geological information on the district and should not be used as a substitute for the 1:50 000 Geological sheets which contain more detailed geological information

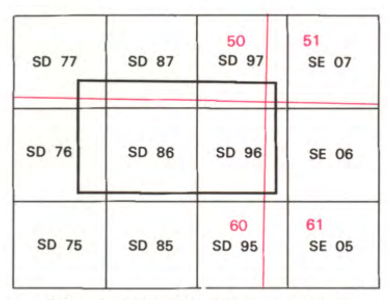


Diagram showing the relation of the Resource Sheet with the National Grid 1:25 000 sheets and 1:50 000 New Series Geological Sheets 50, 60, 51 and 61

Drawn by S.E.HURST I.G.S. Keyworth

EXPLANATION OF SYMBOLS AND ABBREVIATIONS

Landslip

DRIFT

Drift deposits (undifferentiated) moulded into drumlin features. Deposits exceeding approximately 5 metres in thickness are bounded by a pecked feature line

SOLID

DINANTIAN (Lower Carboniferous)

UnL	Underset Limestone
MdL	Middle Limestone
SiL	Simonstone Limestone
HScL	Hardraw Scar Limestone
HwL	Lower Hawes, Upper Hawes and Gayle Limestone
GdL	Gordale Limestone
CvL	Cove Limestone
MrL	Marginal reef Limestone
KiL	Kilnsey Limestone
KiL/M	Kilnsey Limestone with mudstone
ChL	Chapel House Limestone
PdL	Pendleside Limestone
L	Limestone in Worston shales
SQL	Scaleber Quarry Limestone
SFL	Scaleber Force Limestone

SILURIAN (Lower Palaeozoic)

Austwick Formation

Horton and Arcow Formations (and Neals Ing Sandstone)

Quarry extent at time of mapping

Made ground

Worked out area

BOUNDARY LINES

Geological boundary, Solid

Algal band (*Girvanella Beds*)

Inferred boundary between recognised categories of deposits

STRUCTURAL SYMBOLS

Fault

Anticline

Syncline

BOREHOLE DATA

SITE LOCATIONS

Industrial Minerals Assessment Unit (I.M.A.U.) Boreholes

Other Boreholes

Borehole Registration Number

Each borehole is identified by a Registration Number, eg SD 87. The letters refer to the quarter sheet and the figures to the I.G.S. serial number for that quarter. The unique designation for the borehole SW 9 is SD 87 SW 9.

CATEGORIES OF LIMESTONES

Very High Purity (greater than 98.5% calcium carbonate)

Medium Purity to High Purity (93.5% to 98.5% calcium carbonate)

Low Purity to Impure (less than 93.5% calcium carbonate)

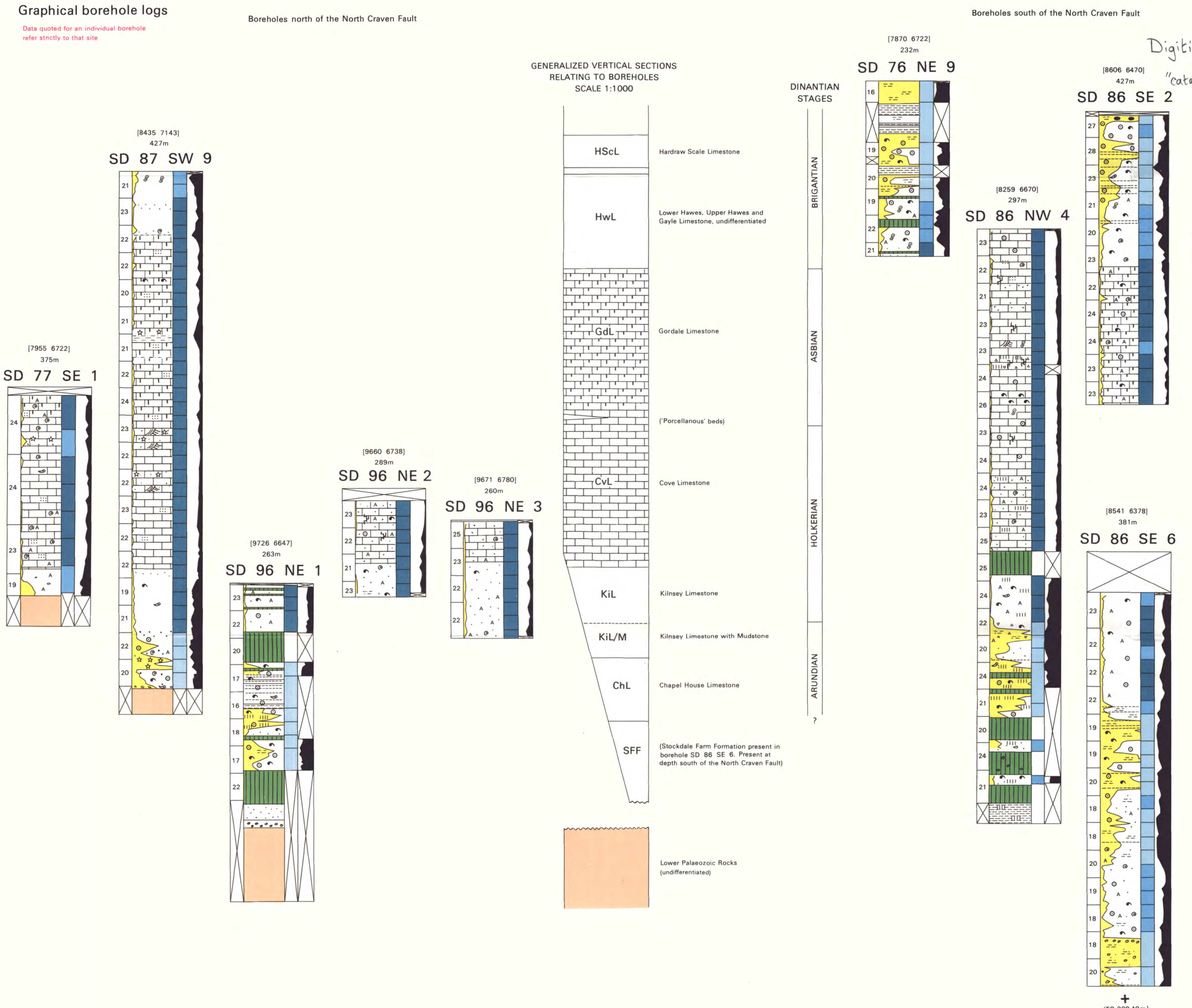
Limestone purity variable. Extensive zones of variable purity of rock. Colours indicate limestone categories involved

Dolomitised Limestones present at or near surface

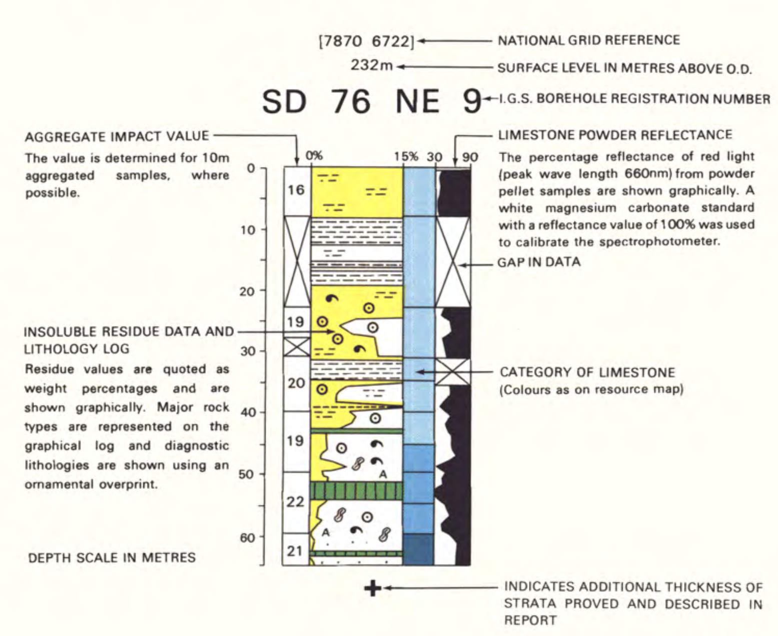
Silica (red) and dolomite (green) replacement bodies

Graphical borehole logs

Data quoted for an individual borehole refer strictly to that site



EXPLANATION OF GRAPHICAL BOREHOLE LOGS



Symbols on graphical logs

Limestone

Gordale Limestone

Cove Limestone

Mudstone

Thin mudstone

Replacement dolomite

Intraclasts

Lithoclasts

Brachiopods, bivalves and other undifferentiated shells

Crinoids and other undifferentiated echinoderms

Corals (undifferentiated)

Algae (encrusting forms including *Girvanella*)

Foraminifera

Algae (mainly Dasycladacae)

Pellets and ooliths

Chert nodules

limestone patchily dolomitised

mottled limestone

argillaceous limestone

extensive jointing

cross bedding present

clay wayboard

Birdseye structures

LOCATION OF BOREHOLES ON RESOURCE MAP