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CARBONIFEROUS BASEMENT ROCKS OF NORTHERN BRITAIN

by

ROGER NEIL KIMBER, BSc.

A Thesis Presented for the Degree of Doctor of Philosophy in the University of Durham.

Department of Geological Sciences,
University of Durham.

March, 1987



-6 JUL 1987

FRONTISPIECE



View looking towards Shap Fells, from Crosby Ravensworth Fell, with Shap Summit (right) and Shap Wells Hotel (left) both being seen in the Middle distance.

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ABSTRACT

The study of Carboniferous basement rocks of northern Britain has concentrated on the dominantly clastic rock succession which unconformably overlies the Lower Palaeozoic basement and occurs beneath the lowermost Carboniferous limestones in areas surrounding the Vale of Eden. The clastic rocks exposed at Shap, the Mell Fells (Ullswater), Sedbergh and Cross Fell, mainly reflect fluvial deposition over an Upper Palaeozoic landscape which locally had considerable topographic relief.

Within each clastic rock succession, which throughout the region varies in thickness from ca 4m to over 250m, overall largescale fining upward sequences document the evolution from gravel-dominated braided fluvial to sand-dominated braided fluvial deposits. This evolution is shown to be representative of the downstream transition from localised alluvial fans into a more extensive fluvial braidplain system, the latter also containing marked proximal to distal variations. Palaeocurrents are consistently toward the north and north-east throughout the region, demonstrating the existence of a broad northerly palaeoslope during clastic deposition.

Proximal to distal relationships and clast provenance data for each area are used to predict facies variations across the Vale of Eden region and to reconstruct the Palaeogeography. Areas of high ground are shown to be underlain by deep-seated Caledonide granite plutons, evolution of the fluvial braidplain demonstrating that with time denudation of high ground developed fining upward sequences by the superposition of progressively finer grained sediment on coarse. The development of the braidplain system is related to post-intrusive uplift of the granites underlying the highest ground with deposition mainly taking place prior to marine limestones associated with the basal Carboniferous marine transgression. A comparison with the Upper Old Red Sandstone clastic succession of the Northumberland Border Basin is assessed.

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DECLARATION

The content of this thesis is the original work of the author (other people's work is acknowledged by reference). It has not been submitted previously for a degree at this or any other University.

R.N. KIMBER

Durham, MARCH, 1987

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CHAPTER 1 INTRODUCTION

1.1 AIMS AND OBJECTIVES

The main aims and objectives of the study of the Carboniferous Basement Rocks of Northern Britain are set out below:

1. To assess the nature of the Upper Palaeozoic landscape prior to the deposition of the Basal Carboniferous by studying the unconformity surface between the Basal Carboniferous and the topmost Lower Palaeozoics.

2. To analyse the clastic rocks in each of the principal study areas using routine sedimentological techniques, mainly description of lithology, texture and the contained sedimentary structures, including measurement of palaeocurrents from the latter. These data will provide the basis for a detailed facies analysis which is used to develop a depositional model for each area.

3. To integrate facies data with clast composition data (from maximum clast size analysis and sandstone petrography) to develop a regional depositional model and reconstruction of the palaeogeography during the deposition of the 'Basal Carboniferous Clastics'.

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1.2 REGIONAL SETTING OF THE STUDY AREA

During the early Carboniferous, clastic deposition occurred beneath the lowermost Carboniferous Limestone and above the Lower Palaeozoics around the Vale of Eden, Northern Britain. The principal areas (Figure 1.1) studied reflect the present day outcrop distribution of these clastic rocks, namely Shap, the Mell Fells bordering Ullswater, Sedbergh, the Cross Fell escarpment and Ravenstonedale. The clastic rocks are generally regarded to be Tournaisian in age (George et al., 1976), with the Pinskey Gill Beds of Ravenstonedale the oldest datable Carboniferous in the region (mid-Courceyan).

The Vale of Eden formed a basinal area separating the Lake District Massif to the West from the Alston and Askrigg Blocks in the east and southeast respectively. These massif and block areas acted as areas of positive topographic 'highs' around which clastic deposition occurred. In fact the base of the Carboniferous system is marked by a major south to north marine transgression, reflecting the gradual invasion of the mature Old Red Sandstone land surface by the Devonian Sea which initially lay to the south and southwest of the British Isles (Johnson, 1967). Further north, away from the transgressing Carboniferous sea, much of Britain was an area of uplands and inter-montane basins, this topographically varied landscape persisting throughout much of the Carboniferous. Around the Vale of Eden, the initial marine transgression occurred through the east-west trending Ravenstonedale Trough, this apparently being flanked by the south by the Howgill Fells and to the north by the Ullswater - Skiddaw anticlinal belt, the

latter forming the divide from the Northumberland Trough (Capewell, 1956; George, 1958; Johnson, 1967; Johnson and Marshall, 1971).

1.3 THESIS ORGANISATION

Chapter 1 provides the general introduction to the area, presenting the main aims and objectives, regional setting, previous history of research, sedimentological analyses used in the study area and a brief review of the Lower Palaeozoic Geology and regional structure, useful when considering clast provenance data (Chapter 7).

Chapter 2 analyses the Basal Carboniferous Unconformity throughout the region and adjacent areas and assesses the nature of the Upper Palaeozoic landscape during Basal Carboniferous times.

Chapters 3, 4, 5, 6 and 8 provide the main area descriptions and facies interpretations, developing depositional models for each area concerned.

Chapter 7 presents the results of the clast provenance study while Chapter 9 integrates the facies data from each area with the clast provenance data to reconstruct the palaeogeography and develop a regional depositional model. It also assesses the regional structural context and makes a comparison with clastic successions in adjacent areas.

1.4 HISTORY OF RESEARCH

Bird (1871-1877?) provides a useful introduction to the study area describing a 'great thickness of red and yellow sandstones and Conglomerates, to which the name of Old Red Sandstone has been given'. He attributes the deposition of these beds to the contraction of the Silurian Sea.

Garwood (1907, 1912, 1916) provides a very detailed correlative account of the Lower Carboniferous succession in his north west Province. Biostratigraphical zones erected from assemblages in the Shap and Ravenstonedale type districts are used as stratigraphical correlatives for sections in the Furness, Grange, Westmoreland Pennines, Kendal, Teesdale, Kirkby Lonsdale and Arnside districts. A basement bed series characterised by red conglomerates and found in the type section at Shap Abbey usually forms the base of the succession in each area resting unconformably on the Lower Palaeozoic floor. Although unfossiliferous, Garwood assigned these conglomerates to the lower part of the lowest zone, Athyris glabristria. Sections in the Arnside, Kendal, Kirkby Lonsdale and Grange districts prove dun-coloured dolomitic limestones in close unfaulted contact with Silurian rocks, the basement beds being either absent or obscured by drift. Fossils within these denote an age from the Seminula gregaria sub-zone. Along the Cross Fell escarpment of the Westmoreland Pennines and in particular the Roman Fell area to the south, Garwood (op.cit. p. 535) distinguishes a lower conglomerate below the basement beds. These are the Roman Fell Beds which probably represent Up. Devonian-Lr. Carboniferous deposits

laid down by torrents and which correlate with the Polygenetic Conglomerates found near Sedbergh and Ullswater. Of special interest are the Pinskey Gill Beds which form the base of the succession in Ravenstonedale. These are considered the oldest Carboniferous deposits in the north west Province and underlie the basement bed conglomerate. They contain a unique fauna characterised by the brachiopod Spirifer pinskeyensis and consist of a sequence of sandstones, shales and vuggy dolomitic limestones. Correlation with the south west Province of Vaughan (1905) shows submergence of the land surface in the north west Province was later, the earliest marine limestones belonging to the equivalent of the Up. Zaphrentis zone. Garwood (op.cit.)shows that the doming of the Lake District probably happened post-depositionally and that the Carboniferous rocks were deposited over '...an even surface of Palaeozoic rocks over the whole site now occupied by the Lake District...', but more recent work throws doubt on this (Kimber & Johnson, 1986).

1.4.1 Ravenstonedale

As shown by Garwood (1912, p. 496) the lowest beds in his type area for the north west Province are the Pinskey Gill Beds which are well exposed in Pinskey Gill close to Ravenstonedale village.

Turner (1959) following on from his earlier work (1950) described sections of the Pinskey Gill Beds exposed in Lunedale and demonstrated the unfaulted and unconformable contact with the lower Palaeozoic rocks. He showed that they are overlain by Garwood's (1912) Shap Conglomerate.

Capewell in his earlier paper (1955) included the Pinskey Gill Beds in the regional study between Ullswater and Ravenstonedale. He believed the Pinskey Gill Beds to be the lateral equivalent of his Lower Conglomerates exposed at Shap; representing lagoonal beds adjacent to coarse clastic deposits laid down by alluvial fans. Pointing out that no representation of his Red Sandstones were present he concluded the conglomerate overlying the Pinskey Gill Beds to be equivalent to his Upper Conglomerate.

Johnson and Marshall (1971) give a recent account of the Pinskey Gill Beds. In the type section of Pinskey Gill, samples collected for miospore study confirm a Tournaisian age for the deposits. They refer to Garwood's Shap Conglomerate and underline the presence of pink orthoclase lithoclasts similar to the phenocrysts of the Shap granite.

Ramsbottom (1973) included the Pinskey Gill Beds in his major cycle 1 (figure 2, p. 573).

Varker and Higgins (1979) and Higgins and Varker (1982) used conodonts to date the Pinskey Gill Beds accurately. From various samples collected at outcrop and from a shallow borehole put down at Pinskey Gill (Holliday et al., 1979), the deposits are shown to be late K or early Z zone (Vaughan, 1905), i.e. mid-Courceyan (George et al., 1976).

Holliday et al., (1979) record the drilling of six shallow boreholes in the Ravenstonedale area. The boreholes drilled through

three formations including the Pinskey Gill Beds proving the latter to be unconformable on the Lower Palaeozoic, here the Bannisdale Slates. Thickness of the Pinskey Gill Beds varies from 45m-50m, the overlying conglomerate being in the order of 40m thick.

Welsh (1980) and Welsh and Owens (1983) established a Tournaisian age for the Pinskey Gill Beds based on miospore assemblages.

1.4.2 Shap

Mapping by Butterfield (1920, 1921) provides the first main account of the basal red beds in the Shap area. He concluded a natural passage between red sandstones and Carboniferous limestones above with the red sandstones unconformably overlying Silurian rocks.

Butterfield and Gilligan (1932, p. 330-1) described a 'green monogenetic conglomerate' occurring within the red beds and interpreted this as an alluvial fan deposit.

Capewell (1955) records the most complete account of the basal red beds. He recognised three divisions and divided a middle group of red sandstones from a lower 'local subaqueous fan conglomerate', with local unconformity, and an upper yellow conglomerate. He defined these as being conformable with the overlying limestones. On the origin of the basal beds he argued an alluvial fan of local origin to explain the Lower Conglomerate which rested on a leached and deeply weathered land surface whose relief was fairly pronounced. The Red Sandstones were flood plain deposits which infilled a north east - south west

palaeovalley. The yellow conglomerate represented littoral deposits as the Carboniferous lagoon transgressed rapidly over the area.

Cullen (1983) carried out a seismic refraction survey of part of the basal beds with a view to define the sub-surface geometry of the unconformity. He concluded a general dip of the unconformity falling gently from the west and deepening to the north. Local topographic variations along the unconformity are apparent and explain variations in the thicknesses encountered.

1.4.3 Mell Fell Conglomerate

In an early account, Oldham (1900, p. 564) described the conglomerates outcropping around the Mell Fells, at Ullswater, as a torrential deposit formed on dry land infront of a range of hills and consisting of a thickness of subangular and angular boulders. Red coloured finer 'gravelly material' represented actions of feebler streams after the floods.

Green (1918, p.24) regarded the conglomerate as the 'truncated remnant of a cone of detritus in which the layers had an original dip outwards from the mouth of a torrent'. He assigned an Old Red Sandstone age to the deposit.

A study by Capewell (1955) shows a cone arrangement consisting of three conglomerate lithologies; basal breccia and lower group, middle group and upper group (1955, p.25). The coarser and more angular basal breccia and lower group conglomerates represent deposition as a bajada

'laid down in a coalescing flat along the foot of a mountain tract which rose southwards'. These rest unconformably on Skiddaw Slates and the Borrowdale Volcanic Group of which no trace of the contact is seen. His middle and upper groups, characterised by cobble and bedded pebble conglomerates with flaggy sandstones, represent floodplain deposits laid down in quieter conditions. He regarded the conglomerates as Lower Old Red Sandstone in age, largely based on the recognition of an unconformity separating the middle and upper groups which he considered to be basal Carboniferous in age. Capewell argued a thickness of 5000 feet for the Mell Fell Conglomerate, the thickest development of conglomerate underlying the Carboniferous Limestone in North West England. Wadge (1978) provides a synthesis of the main clast source directions, mainly derived from the Coniston Grits, Eycott and Borrowdale volcanics.

More recently a publication by the Cumberland Geological Society (1982) describes major outcrops of the Mell Fell Conglomerate.

1.4.4. Cross Fell

Phillips in his Geology of Yorkshire (1835), first pointed out an alternating limestone and red sandstone series outcropping to the east of the Vale of Eden.

One of the earliest accounts of the 'basement bed conglomerates' is De Rance (1873). In a study mostly covering northern outcrops he demonstrated conglomerates and 'old red sandstones' that were

unconformable on Skiddaw Slates. He considered these to be up to 400 feet in thickness.

Goodchild (1874) described all the beds below the Melmerby Scar Limestone and called them the 'Roman Fell Beds' after the deposits outcropping around Roman Fell to the south. To the north and above the Swindale Beck Fault, the Roman Fell beds rested unconformably on the Silurian where no patches of Old Red Sandstone are in the way.

Garwood (1912, p.535) first questioned the Roman Fell Beds and recognised a faulted contact between these and a fossiliferous basement series above. He correlated the Roman Fell Beds with the Polygenetic Conglomerates of Sedbergh and Ullswater.

Turner (1927) agreed with Garwood (1912). His basement beds were up to 300 feet thick and overlie the Roman Fell Beds which he considered to be Devonian in age. The upper part of the basement series above represented the Ashfell sandstone of the Shap and Ravenstonedale district.

Shotton (1935) in a comprehensive mapping survey of the Cross Fell Inlier, but concentrating on the Roman Fell area, demonstrated the change in a north-west direction to coarser lithologies coupled with an increase in basement bed thickness from 300 feet in Scordale to 1000 feet below Melmerby Low Scar. Shotton was able to date the basement bed conglomerates and sandstones above the Swindale Beck Fault as Carboniferous thanks to the discovery of large scales of the

Carboniferous fish Rhizodus hibberti in Swindale Beck, Hilton. Shotton (op.cit.) re-examined the Polygenetic Conglomerate which was first referred to by Goodchild (1889) and Marr (1899). This occurs in pockets below the basement bed conglomerates and the Roman Fell beds reaching 250 feet in thickness at Grey Mares Tail. The conglomerate contains a variety of clast types from striking weathered granites to felsites and Ordovician sedimentary rock types. On the origin of the Polygenetic Conglomerate, he compares it with similar coarse conglomerates described by Green (1918) for the Mell Fell Conglomerate and by Dakyns (1891) for the Sedbergh conglomerates. These were deposited on dry land by fast moving torrents in front of mountain tracts and fault scarps. Stratigraphical relationships in the Roman Fell area show that the Roman Fell Beds lie above the Polygenetic Conglomerate with an unconformable contact, the latter deposited against an Ordovician fault scarp (Shotton, 1935, p. 644-645). He further suggests, contrary to Turner (1927), that the Roman Fell Beds are similar to the Basement beds at the north end of the Cross Fell Inlier with respect to the lack of shale, quartz content and red colouration and this further suggests that the Roman Fell Beds may in fact be Carboniferous in age (Shotton, 1935, p. 645).

Short (1954) studied a section of the Cross Fell Inlier from Ardale Beck to Craglinwater and included in his account the Polygenetic Conglomerate which is overlain by the 'Carboniferous Basement Group' in which he recognised four units. His current bedded red sandstones above the lower red conglomerate have a north-west derivation.

Capewell (1956) studied most of the major sections and came to a number of conclusions. He divided his 'Cross Fell Basement Series' into a Lower Conglomerate group and an Upper Sandstone group. Pebbles within the conglomerates are largely composed of quartz, with grains in the sandstones composed of slate lithologies. He correlated a colour change from purple to grey towards the south-east with increasing marine conditions. He argued that the Roman Fell Beds are equivalent to the Red Sandstones of the Shap district and thus represent a thrust slice emplaced from that region.

Burgess and Harrison (1967) studied the Roman Fell Beds and recognised a tripartite division. The Roman Fell Sandstones pass up from the Roman Fell Shales which overlie the Lower Conglomerate. Comtemporaneous movement along the Swindale Beck Fault accounted for a northern thinning of the Roman Fell Beds to the north of the fault. They consider the Roman Fell Beds to be equivalent to the Carboniferous basement beds at the north end of the inlier and not part of the Polygenetic Conglomerate as originally thought.

Arthurton and Wadge (1981) studied the sedimentology of the 'Basement Beds' in the northern part of the inlier above Crowdundle Beck. Their conclusions demonstrate a west-south-west Provenance indicating palaeoflow was towards the east-north-east. Fining up cycles correspond to a fluvial fan model (1981, p.27-28). The Polygenetic Conglomerate represents remnants of coalesced alluvial fans which built out from an east facing scarp.

Barraclough (1983) as part of a regional study of the Dinantian limestones, included the Roman Fell Beds and interpreted the Lower Conglomerates as representing proximal alluvial fan deposits and local valley infill. The Roman Fell Sandstones were deposited by ephemeral braided rivers flowing from west to east and deriving some clastic material from Lake District rocks. He considered the intervening Roman Fell Shales as representing low energy tidal flat sediments equivalent to the Pinskey Gill Beds of the Ravenstonedale district and indicating a marine incursion from the Stainmore trough. This model thus necessitates a non-sequence at the top of the Pinskey Gill Beds (?in the Shap-Ravenstonedale area), the Roman Fell Sandstones being deposited in a return to continental deposition during clastic shoreline progradation.

1.4.5 Sedbergh

The basal Carboniferous clastic rocks exposed principally along the River Rawthey and adjacent tributaries have been previously studied by Tiddeman (1891), Garwood (1912), Butterfield (1920 and 1921), Butterfield and Gilligan (1932), Foster, (1981) and Burgess (1986, and Pers. Comm.). Garwood (op.cit.) correlates the Sedbergh Conglomerates with the Polygenetic Conglomerate to the Cross fell area, and notes that locally the Conglomerates are 'crowded with blocks of Keisley Limestone' (see Section 1.6), a point supported by Burgess (op. cit.) and Butterfield and Gilligan (1932). Butterfield (1921) provided a detailed map showing the distribution of basal Carboniferous lithologies and the position of the main localities. He also noted the important

observation that little red sandstone is present in Sedbergh compared with the greater development in the Shap region (Tebay area).

1.5 SEDIMENTOLOGICAL ANALYSIS

1.5.1 Facies and Facies Relationships

In the present study, an effort has been made to describe and interpret the rocks as facies and to develop ideas as to the depositional environment with reference to facies associations. Reading (1978) states: 'A facies should ideally be a distinctive rock that forms under certain conditions of sedimentation, reflecting a particular process or environment...'.

Confusion as to the exact usage of facies has arisen over a large part of the century with wide applications of the term. Significantly, the original concept of facies, as introduced by Gressly in 1838 (cited in Teichert, 1958), still holds true. The 'roots' of environmental analysis still rely on the ability to subdivide on the basis of lateral and vertical changes in sedimentary units throughout any rock succession. Gressly (1838, from Teichert, 1958) defined five laws of facies in which he stressed facies should be erected on the basis that each rock unit should possess very distinct lithological or palaeontological characteristics. In particular, he paid special attention to describe changes in the rock unit both in the vertical and horizontal direction.

Walther's (1893 from Blatt, Middleton and Murray, 1972) contribution is invaluable in defining facies as the 'sum of all primary characteristics of a sedimentary rock'. In this respect, the common usage of 'lithofacies' is very near to the ideal concept of facies in describing the lithological characteristics of a certain rock.

Walther's Law of Succession of Facies (1893, from Blatt, Middleton and Murray, 1972) goes one step further in the analysis of facies and facies relationships. He realised the important concept that the special deposition of a set of facies, as in the modern environment, is reflected in the ancient record as a vertical sequence of facies within a conformable sequence. Indeed, for this to hold true there must be no major breaks in the sequence studied.

The modern analysis of a rock succession relies on grouping facies as facies associations. A single facies association, as a 'package', groups together all facies which can be considered as being genetically or environmentally related. This reduces the need for using a wide range of facies types to define a succession; striking a 'reasonable compromise between facies "lumpers" and "splitters"' (Leeder,1982b p.120). In addition, a set of facies, belonging to a certain facies association, may relate to a facies sequence which may comprise or be repeated within that association. These are defined by reference to the nature of the basal and top contacts and may therefore fine or coarsen up.

Differentiating facies and determining the relationships between facies, forms the basis for erecting environmental facies models (Anderton, 1985). Here, an environmental facies is 'the whole set of attributes possessed by the deposited sediment laid down in a particular environment', (Leeder, 1982b p.119). Miall (1977, 1978, 1982) using lithofacies and sub-facies based on the contained sedimentary structures, has developed six idealised models (see Figure 9.1) which attempt to trace proximal to distal relationships for braided rivers. It can be seen, therefore, that the term facies can be applied as a 'hierarchy' of various levels which interelate to define exactly the depositing conditions and processes acting on a particular succession of rocks in space and time.

Critical to any development of a facies model is the preservation potential of that particular environment, and this might vary. Relationships between facies will aid analysis when trying to determine the extent of variability between the ancient rock record and an analogous modern environment. Miall (1983) provides a discussion on the importance of determining both vertical and lateral facies variation to determine a depositional model. Interpretation may be of two types (Leeder, 1982): straightforward comparison may be employed to deduce variations in facies; secondly, in the case of a wealth of data, a statistical approach can deduce the most common relationship between facies and degree of repetitiveness. This is called Markov Chain Analysis and has been reviewed by Miall (1973). Cant and Walker (1976) used a Markov approach to observe facies relationships for the Devonian Battery Point Sandstone, Quèbec.

Objective use of facies is largely dependent on accurate field observations and a widest possible data base. In this study, this has been achieved where possible and in places a lack of good rock exposure has been aided by a study of relevant borehole material. The use of the term facies to deduce environmental facies models for the Carboniferous basement rocks has mostly followed the approach of Miall (1977 Figure 1.5) with lithofacies subdivided into subfacies on the contained sedimentary structures. The legend for the sedimentary structures used in the measured sections is presented in Figure 1.6.

1.5.2 Clast Size Measurement and Palaeocurrent analysis

Measurement of the clast size within the conglomerates was carried out on as many units as possible (cf. Bluck, 1967; Tucker, 1982) but principally the largest 20 clasts present within any one unit and this fraction is used as the maximum particle size fraction. From this fraction, an average maximum clast size was derived (see Appendix 1).

Palaeocurrent analysis was carried out whenever possible, principally on cross-bedded sandstones (by measurement of dip and dip direction) but also on conglomerate clast imbrication (measurement of the dip of the AB axial plane, direct B axis direction and measurement of the trend of the longest A axis). In fluvial deposits, the longest A axis is normally orientated 90° to current direction (cf. Rust, 1972b). Vector means were calculated for groups of data from the same sedimentary structures through any one sequence, using the method

outlined by Curray (1956), Miall (1974) and Tucker (1982) where tan $\bar{\sigma}$ (Vector mean) = $\frac{\Sigma n \sin \sigma}{\Sigma n \cos \sigma}$ where σ = azimuth of each reading from 0° to 360°, and n= number of readings within each Vector group (10° intervals). It is stressed that readings have not been corrected for tectonic dip as this is generally less (normally less than 5°) than the 25° (and 5° for planar-cross-bedding) value cited by Collinson and Thompson (1982). In fact, tectonic dip in the field could not in most places be measured accurately enough to warrant reorientation of the data, which in itself is, in some places, also difficult to obtain at 100% accuracy. Palaeocurrents, measured from a variety of bedforms are used to derive local and regional Palaeoflow (cf. Miall, 1974).

1.5.3 Petrographic Analysis

Petrographic analysis was used primarily to obtain data for clast provenance study (Appendix 2), samples, taken for thin section being stained (ARS/PF) for carbonate mineral cements and point-counted using 250 counts. The point-count data are presented in Appendix 3.

1.6 LOWER PALAEOZOIC GEOLOGY

1.6.1 Stratigraphy

The lower Palaeozoic succession below the basal Carboniferous rocks is exposed in sections studied in the Lake District, North Wales, the Isle of Man and the Cross Fell Inlier. The stratigraphy is well documented in an extensive literature and in particular 'Geology of the Lake District' (ed. F. Moseley, 1978).

Otley (1820) and Sedgwick (1832) completed the pioneering work on the geological survey of the Lake District and established the general succession. Much revision on the stratigraphy by many workers has been proposed, but the current 'state of the art' established two major unconformities and subdivides the succession into three (see Figures 1.2, 1.3). This, as Soper and Moseley (1978) point out 'reflects uplift and erosion associated with three important periods of Caledonian deformation'.

The Skiddaw Group (lower Ordovician) forms the oldest known strata in the Lake District and lies largely in the north of the region extending from Cockermouth to Ullswater. Jackson (1978) divides the group into four formations based on the type Skiddaw area. Four graptolite zones are covered up to the top of the Llanvirn (Didymograptus murchisoni). Jackson's (op. cit.) basal formation is the Hope Beck Slates which comprises 80m of bluish-black-grey coloured striped silty mudstones and reflect deposition in quiet water. The Hope Beck Slates coarsen up into the Loweswater Flags which were first named by Dixon in 1925 (in Jackson, op.cit.) to define an alternating sequence of grey flaggy sandstones and laminated mudstones. This typical 'flysch' facies, similar to the Aberystwyth Grits, contains over 900m of sediments with characteristic 'Bouma turbidite' structures indicating derivation from northward facing slopes. The Watch Hill lavas form a 10m unit comprising microcrystalline felsite lavas and provides evidence for contemporaneous volcanicity. The Loweswater Flags grade into the Kirk Stile Slates which in some areas form the top of the Skiddaw Group. Up to 1000m of black-grey coloured silty mudstones are present. The

topmost graptolite zone in the Cockermouth area comprises the Latterbarrow Sandstone consisting of 50m of flaggy quartzitic sandstones which are devoid of interbedded shales. The Skiddaw Group is equivalent to the Murton Formation of the Cross Fell Inlier.

Wadge (1978) inserts the Eycott Group above the Skiddaw Group for the Binsey and Eycott Hill areas. In these areas, the Eycott Group is laterally equivalent to the Kirk Stile Slates and Latterbarrow Sandstones of the type Skiddaw area, mudstones from the Tarn Moor Tunnel containing fossils belonging to Didymograptus murchisoni zone. The Eycott group is divided into a lower Binsey formation which is succeeded by an upper High Ireby Formation, and is transitional from the Skiddaw Group with the junction placed at the first mappable volcanic bed. They comprise mostly microporphyritic and non-porphyritic basaltic and andesitic lavas. Pyroclastic rocks take up 25% of the total succession and rhyolites have been recorded up to 100m total thickness. Three main 'lavas' are recognised (Eycott lavas) and these interbed with tuffs, agglomerates and mudstones. The Group totals 2500m in thickness. The Kirkland Formation is the equivalent in the Cross Fell Inlier succession and contains thicker mudstone interbeds suggesting deposition off slope and away from the main outcrops around Caldbeck, Ullswater and Brampton which were probably deposited close to an active volcano.

An unconformity separates the Skiddaw Group and Eycott Group from the Borrowdale Volcanic Group (see discussion by Wadge, 1978). The Borrowdale Volcanic Group overlies Arenig age Skiddaw Group sediments in the West and Llanvirn Eycott Group sediments and volcanics in the east.

Despite previous theories of faulted and thrusted contacts, (Goodchild, 1885; Ward, 1916 these cited in Wadge, 1978) and a conformable relationship (Sedgwick, 1832; Aveline, 1869; Green, 1920 these cited in Wadge, 1978), Wadge (1978) demonstrates an irregular erosive base marked by a variable thickness of conglomerates and sandstones. The group consists of a common association of lithologies and not a particular rock type. Flow brecciated lavas of basic, intermediate and acidic compositions predominate. Ignimbites are abundant and show good 'fiamme' structures. Ashfall tuffs form the largest part of the succession. The age is probably Llandeilo to lower Caradoc. Small Borrowdale Volcanic faulted block sections occur in the Cross Fell Inlier.

The second major break occurs in the upper Ordovician and the Ashgill Series is transgressive over the emergent landscape comprising Borrowdale and Skiddaw rocks. Strong overstep is present in the southern part of the region. The Cautley Mudstone formation, up to 600m thick, is of Ashgill-Caradoc age and outcrops in the Howgill Fells. Calcareous mudstones are overlain high up by shelly facies with a rich brachiopod and trilobite fauna. The Cautley Volcanic Formation comprises rhyolitic lavas and is transitional from below. The overlying Cystoid Limestone may mark an unconformity between the Cautley Volcanic Formation and the Ashgill Shale Formation above. This equates with the top Ashgill in North Wales.

In the main part of the Lake District the Coniston Limestone Group outcrops as a linear strip from the Duddon estuary to Shap and

correlates with the Cautleyan stage of the Ashgill Series in the Howgill Fells (Ingham et al., 1978). Facies were penecontemporaneously controlled by a horst block structure which affected sedimentation up to the lower Silurian. It separates the main part of the Lake District east to west of a line from Cross Fell to the Howgill Fells. The base is marked by a clastic sequence and this gives way to the Applethwaite formation which varies considerably in thickness. It comprises blue-grey coloured calcareous mudstones which become more nodular and silty towards the south-west. In the east the Applethwaite Formation is underlain by the Yarlside Rhyolite and the Stile End Formation. The latter comprises a rich brachiopod, coral, bryozoan and mulluscan fauna which has been thermally metamorphosed by the rhyolite above. Overlying the Applethwaite Formation are the phillipsinella beds, up to 7m thick, which contain abundant trilobites at some localities. Uplift and erosion in the topmost part separates the Coniston Limestone Group from the Ashgill Shale Formation, marked by the White Limestone along the base. The Ashgill Shale Formation in this part of the Lake District is thinner (28m compared with 90m on the Howgill Fells) and more sandy in lithology.

In the northern part of the Lake District, the north-south transgression is represented by the Drygill Shales, mid. Caradoc in age, which consist of ashes and calcareous mudstones. They correlate with the Corona-Melmerby beds of the Cross Fell Inlier and are succeeded by the Dufton Shale Formation. The latter represents the Ashgill Series in Cross Fell. Higher up in this part of the succession, the succeeding Swindale Limestone and Keisley Limestone may correlate with an age

higher in the Ashgill. The Keisley Limestone is a typical 'reef' facies comprising massively-bedded bioclastic limestone.

The Silurian crops out today in the southern part of the Lake District. The Llandovery is represented by the Stockdale Shales which are subdivided into the lower Skelgill beds and upper Browgill beds (Ingham et al., 1978). A transition is seen from thicker mudstones into coarser grained horizons and equate with the Aberystwyth Grits in central Wales. The Llandovery marks the onset of deepening conditions following on from the Ordovician shallow water limestone and mudstone facies. Differential subsidence across the still active Ordovician horst in the Howgill Fells deposited pyritic shales in the west and limestone in the east. The horst was submerged in the Atavas zone and mudstones were deposited throughout. Towards the top of the Llandovery and occurring throughout the area red and green mudstones were deposited.

The Wenlock comprises a thick sequence of mudstones, grits and siltstones and begins with the Brathay flags. Totalling 400m, these comprise hard blue-grey coloured laminated mudstones with calcareous nodules. The overlying middle Coldwell beds consist of grey mudstones with a rich trilobite and brachiopod fauna and indicate widespread conditions from Cross Fell to Horton-in-Ribblesdale. The lower Coldwell beds form a localised deposit of proximal turbidites near Ambleside and were evidently derived from the north-west and thin eastwards.

The Ludlow commences with the upper Coldwell beds and reverts back to typical Brathay Flags lithologies. The overlying Coniston Grits total over 50m and are characteristic fine sand grade turbidite deposits (greywackes) with occasional coarser grained horizons. Derivation was from a north-west direction. Several mudstones in the upper part are transitional to the Bannisdale Slates which comprise 600m of mudstones and siltstones with sandstone interbeds. Uppermost in the Silurian are the Kirkby Moor Flags which are mainly thinly bedded siltstones and are transitional to the topmost Scouthill Flags which contain red-bed sequences.

The change throughout the Silurian to a progressively coarser grain size lithology is associated with the closing of the Proto-Atlantic ocean. This is reflected in the upper Silurian by the north-west derived turbidites.

Figure 1.4 summarises some of the main clast compositions expected from the Lower Palaeozoic basement, while Chapter 7 discusses provenance and clast compositions in greater detail.

1.6.2 Structure

The Lower Palaeozoic basement conforms to a 'paratectonic' type of deformation. This is in contrast to the earlier 'orthotectonic' type of deformation of the Moinian , Celtic and Gramptian which display more intense folding and higher grades of metamorphism (Anderton et al., 1979). The paratectonic Caledonides of Johnson et al., (1979) show typical slate belt cleavage with upright folds and a low grade of

metamorphism. These structures are typical in the north-west of England.

A strong pre-Borrowdale cleavage trends north to north-north-east in the Skiddaw Group. Major folds trend east-west and represent 'primary compressional buckles' (e.g. Scafell/Place Fell syncline and Haweswater syncline). The regional 'Lake District anticline' is probably a composite structure with end Silurian structures superimposed (Johnson et al., op. cit.).

The main deformational episode occurred at the end of the Silurian and was probably associated with continental collision with the Southern Uplands. This is supported by northerly derived turbidite sequences in the Wenlock. The main structural element is an arcuate cleavage trending north-north-east and east-south-east. This period of cleavage formation is short and apparently post dates the youngest Silurian rocks and may thus conform to a lower Devonian age, i.e. immediately after the emplacement of the Granites (Johnson et al., op.cit.). Varying fold styles and cleavage intensity is reflected in the competence of rock lithologies. In the Silurian greywackes two major folds are recognised: the Bannisdale syncline and Felside anticline (Figures 1.2-1.3). Silurian fold traces are on average 5°-10° oblique to the cleavage, the congruous cleavage deliminating earlier fold structures. Anderton et al (1979) classify the deformational history in terms of four stages of deformation.

1.6.3 Deep Structure

The Shap, Eskdale and Skiddaw granites coincide with centres of low Bouger anomalies and suggest they form part of a 'large, composite acid batholith underlying the central and northern Lake District' (Bott, 1967, 1974; Bott et al., 1984). Radiometric dating supports a Devonian age and indicates that they post-date earlier bodies intruded into older strata. The latter include the Carrock Fell complex, the Ennerdale granophyre and the Threlkeld microgranite. These have intruded the Skiddaw Group and the Borrowdale Volcanic Group and the reader is referred to Firman (1978) for detailed descriptions.

Studies by Bott (op.cit.) have shown that despite the dense cover of Lower Palaeozoic rocks, the Lake District is associated with a belt of low Bouger anomalies which corresponds to a large granitic body to which the 'later vertical tectonic history of the region can be related' (Bott, 1978).

The Eskdale granite is essentially a granodiorite, being perthitic at the outer margins. Muscovite occurs as characteristic spherulitic aggregates.

The Skiddaw granite forms a large homogeneous ovoid body with the shape of the aureole suggesting a buried cupola north of the Carrock Fell complex. The granite thermally metamorphosed the Skiddaw slates in three distinct zones. The granite itself consists mainly of biotite with quartz interstitial blebs and orthoclase - perthite crystals. Varying stages of greisenization have taken place forming two-thirds

quartz and one-third muscovite. K:Ar dates this process at 385 Ma (Shepherd et al., in Firman, 1978).

The Shap granite crops out over an area of 8km^2. It classifies as an adamellite containing 30% orthoclase crystals up to 5cm across in a moderately coarsely crystalline groundmass of quartz, orthoclase and oligoclase in equal proportions. Biotite plus sphene, apatite, magnetite and pyrite are also common accessory minerals. The granite has formed an aureole by intruding chloritised andesites, from the Borrowdale Volcanic Group, and Silurian greywackes, producing biotite hornfels with quartz and plagioclase.

Minor intrusions occurring in the Silurian greywackes are probably Devonian in age (Firman, 1978) and extend from Sedbergh to the Cross Fell Inlier. Near Shap they trend south-south-east from the Shap granite and extend 3-4km north of the outcrop. Biotite forms large characteristic phenocrysts with feldspar, the intrusions classifying as minettes, kersantites and lamprophyres (Bonny and Houghton, 1878).

Granites tend to not vary greatly in their chemistry. Further, Dunham et al. (1961, 1965) have shown that the Weardale granite underlying the Alston block is analogous to the Skiddaw granite and Bott (1974) proposes a connection with the Lake District granites underneath the Vale of Eden. Figure 1.2 shows the extent of the batholith in the Lake District and the proposed ridge under the Vale of Eden. The batholith lies normally less than 2-3km deep and consists of ridges, especially in the northern part (Figures 1.2-1.3). Bott (op.cit.)

suggests the 'granite mass deficiency could be approximately compensating the present elevation of the Lake District above a datum of 80m, taking into account that the axis of the granite clearly lies under the highest elevations reached in the Lake District'. This further suggests that the granites may be responsible both for the present elevation and for the past tendency for the region to be uplifted in relation to its surroundings (Bott, op.cit.).

FIGURE 1.1 LOCATION OF STUDY

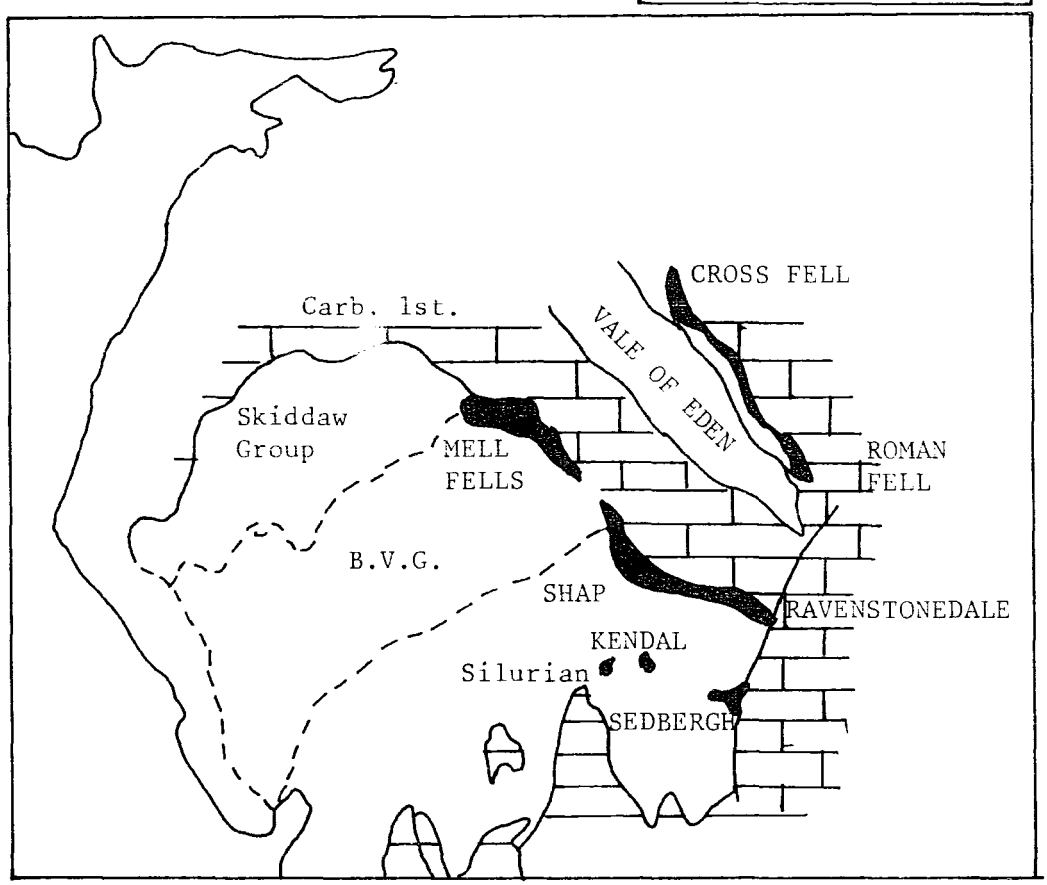


FIGURE 1.2

Map Showing the main structural elements of the Lake District Massif (from Johnson et al., 1978)

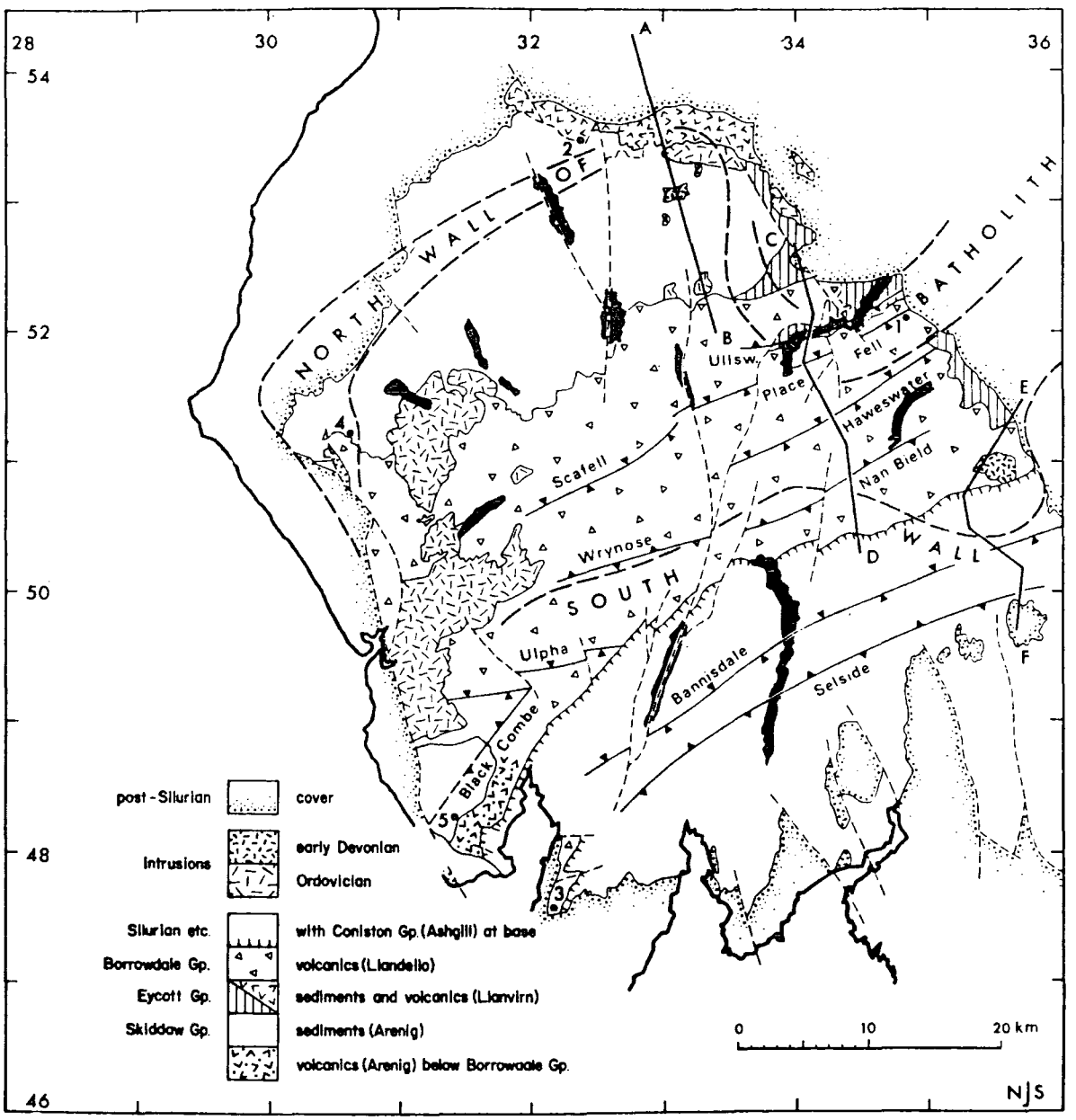

28
30
32
34
36
54
52
50
48
46
A
B
C
D
E
F
1
2
3
5
NORTH WALL
OF
SOUTH
D WALL
BATHOLITH
Ullsw.
Place
Fell
Haweswater
Nan Bield
Scafell
Wrynose
Ulpha
Bannisdale
Selside
Black Combe
post-Silurian
cover
Intrusions
early Devonian
Ordovician
Silurian etc.
with Coniston Gp.(Ashgill) at base
Borrowdale Gp.
volcanics (Llandeilo)
Eycott Gp.
sediments and volcanics (Llanvirn)
Skiddaw Gp.
sediments (Arenig)
volcanics (Arenig) below Borrowdale Gp.
0
10
20 km
NJS

FIGURE 1.3

Selected cross sections across the Lake District Massif (from Johnson et al., 1978)

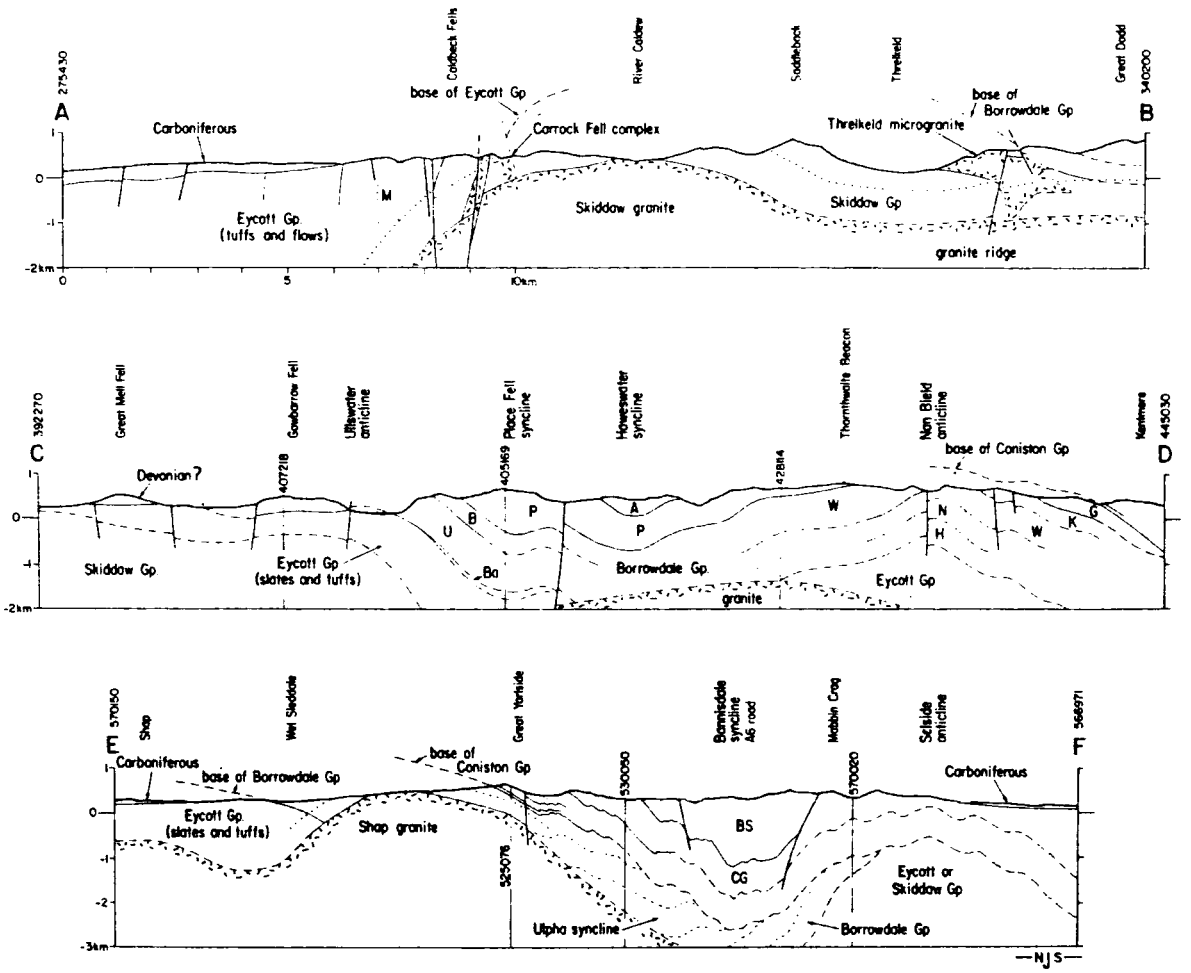

A
B
C
D
E
F
Carboniferous
base of Eycott Gp
Carrock Fell complex
Coldbeck Fells
River Caldew
Saddleback
Threlkeld
Great Dodd
Threlkeld microgranite
base of Borrowdale Gp
Eycott Gp (tuffs and flows)
Skiddaw granite
Skiddaw Gp
granite ridge
Devonian?
Great Mell Fell
Gowbarrow Fell
Ullswater anticline
Place Fell syncline
Howeswater syncline
Thornthwaite Beacon
Nan Bield anticline
Kentmere
base of Coniston Gp
Skiddaw Gp
Eycott Gp (slates and tuffs)
Borrowdale Gp
granite
Eycott Gp
Shap
Wet Sleddale
Great Yorkside
Bannisdale syncline A6 road
Mabbin Crag
Scandale anticline
Carboniferous
base of Borrowdale Gp
base of Coniston Gp
Eycott Gp (slates and tuffs)
Shap granite
Ulpha syncline
Borrowdale Gp
Eycott or Skiddaw Gp
BS
CG
NJS

FIGURE 1.4.

SIMPLIFIED TABLE SHOWING MAIN DERIVATION OF CLASTS.

AGE	FORMATION /GROUP	COMMON CLASTS
INTRUSIONS	SHAP GRANITE MINETTES ACID PORPHYRIES	Orthoclase phenocrysts are present in the Shap Red Beds. clasts from minor minette or acid porph. dykes are locally abundant in Mell Fell/Cross F
SILURIAN	BANNISDALE SLATES CONISTON GRITS BRATHAY FLAGS	These provide the main low grade Greywackes which form the main clast composition in most areas. Brathay Flags mudstone are present in the Shap Red Beds.
LATE ORDOVICIAN	CONISTON LST. GROUP KEISLEY LST.	Fragments of Coniston Lst. occur mainly in the Mell Fell Conglomerate.Clasts of Keisle y Lst. present in Sedbergh Cg
EARLY ORDOVICIAN	BORROWDALE VOLCANIC GROUP EYCOTT GROUP SKIDDAW GROUP (MANX SLATES)	Clasts of B.V.G. common in Shap Red Beds and locally in Mell Fell Cg.Maybe present in Cross Fell clastics. Some porph. clasts probably from Eycott lavas occur in Mell Fell Cg. Skiddaw Slates give Vein Qz. seen in Cross Fell clastics. Plus Hornfels.I.O.M. clastics From Manx Sls.grws.+quarzites

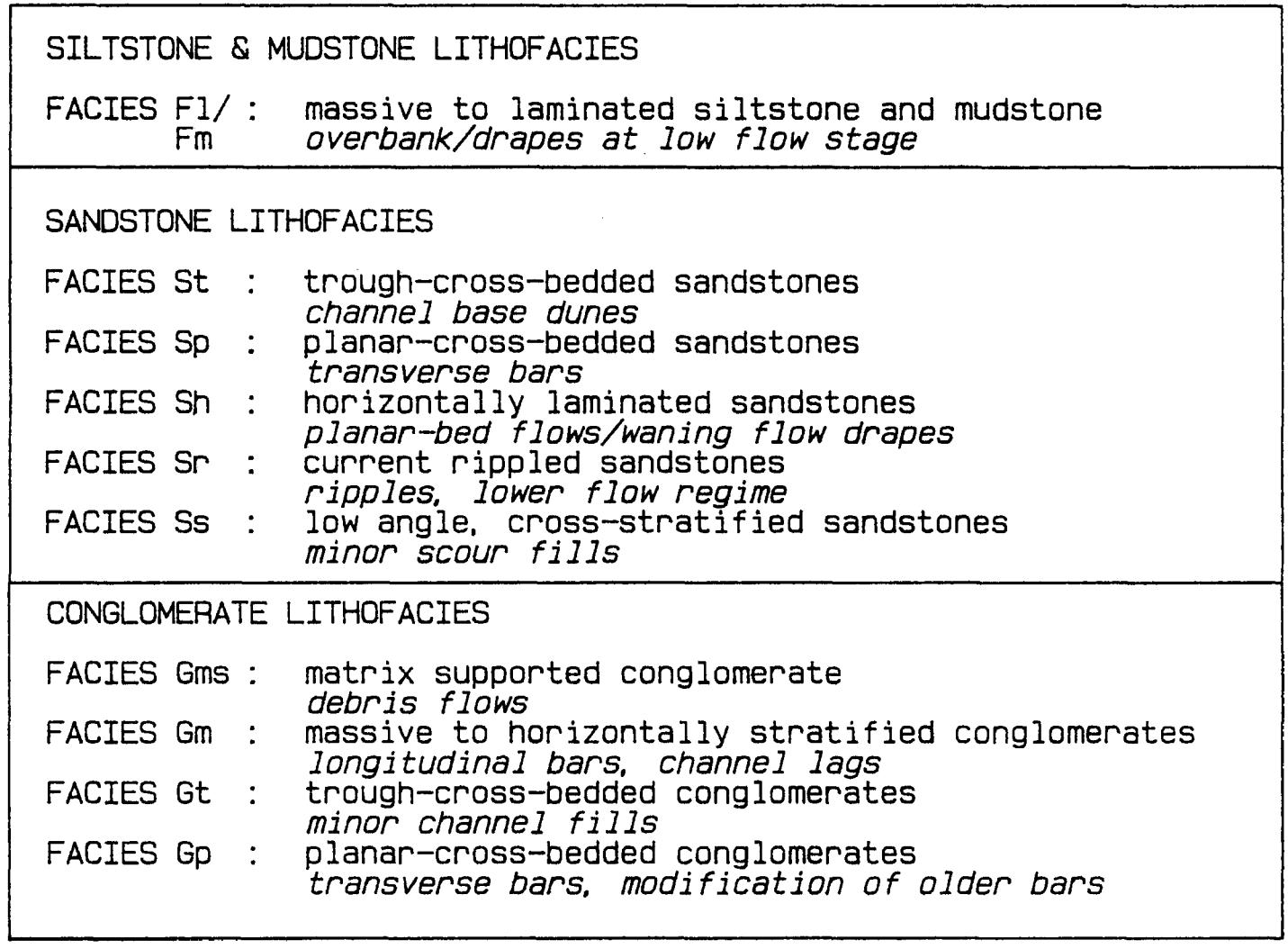
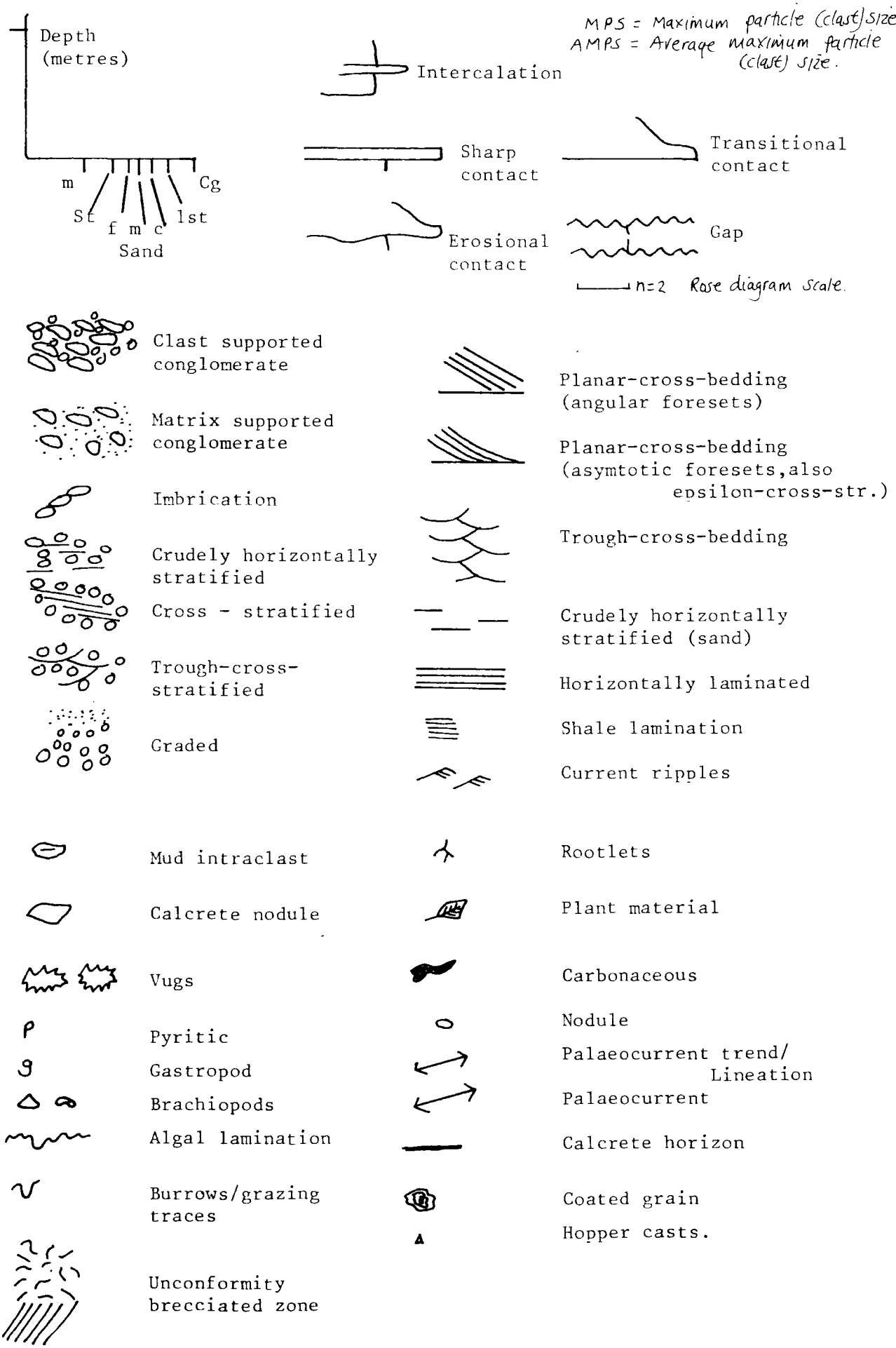


FIGURE 1.5 FACIES SCHEME FORMING A BASIS FOR ENVIRONMENTAL INTERPRETATION (after Miall, 1977)

FIGURE 1.6. MEASURED SECTION LEGEND



CHAPTER 2 THE UNCONFORMITY

The unconformity between the Carboniferous basement rocks and the Lower Palaeozoic succession is exposed in a number of places in the area of present study. Localities in this chapter are described for the Ravenstonedale, Shap, Sedbergh, Cross Fell areas and localities in the south Lake District, North Wales, Yorkshire, Cockermouth and southern Scotland districts.

2.1 RAVENSTONEDALE (Figure 2.1)

In the area adjacent to Ravenstonedale village the unconformity trends east-west along the foot of the northern slope of the Howgill Fells. The western part of the area contains the Pinskey Gill beds. East of Ravenstonedale the Dent faults cuts out the unconformity and lowermost Carboniferous near to Kirkby Stephen. Exposures are restricted to stream sections and are seen at four main localities, these being discussed in the sections below.

2.1.1 Artlegarth (NGR NY 726022)

The unconformity is poorly exposed at river level about 200m north of Artlegarth farm. Nearly vertical red-green coloured striped greywacke siltstones, typical of the Bannisdale slates, are overlain by approximately 2m-3m of buff-orange brown coloured calcarenites. Samples taken from the topmost part of the Silurian show in thin section a mosaic of fine dolomite veined with coarser dolomite crystals. Calcite maybe also present as shown by X-Ray Diffraction (XRD) of bulk sample.

Silt sized greywacke sedimentary rock fragments are present in some samples surrounded by a rim, 200μm thick, of fibrous dolomite. The distinctive green-purple colouration in hand specimen is almost certainly due to the chlorite and illite clay content as proved by XRD, present day weathering of the samples resulting in the degradation of illite to mixed-layer clays.

2.1.2 Pinskey Gill (NGR NY 697039)

The stream of Pinskey Gill lends its name to the Pinskey Gill beds and is thus considered the type section for these deposits. The Pinskey Gill stream section is discussed in detail in Chapter 8 (Figure 8.2) but the basal part of the section is most relevant to this chapter. The unconformity zone is marked by silty, micaceous sandstones overlying the steeply dipping, purple coloured Bannisdale Slates. As seen at Artlegarth, the top of the Silurian is marked by a green-yellow coloured mottled horizon 0.51m thick. XRD of bulk matrix from this zone comprises quartz, dolomite and minor calcite with degraded clays, probably chlorite and illite also being present. In thin section the matrix is a mosaic of finely crystalline dolomite cut by larger veins, 100μm-200μm wide, of coarser dolomite. Nodules of dense dolomite are present throughout, boundaries with the matrix varying from sharp to diffuse. Scattered within the matrix are silt grade detrital quartz grains.

2.1.3 Scar Sikes (NGR NY 683041 Figure 8.4)

The unconformity is well exposed in a stream section mid-way between Weasdale and Bowderdale and approximately 50m north of Scar

Sikes farm. Here, hard red-green coloured striped greywackes of the Bannisdale slates become increasingly veined and 'altered' by yellow-green coloured weathering dolomite 1m-1.5m below the base of the Pinskey Gill beds. Cracks, joints and fissures, relating to bedding and cleavage, are filled with carbonate and form a massive brecciated zone to the top of the Silurian. In thin section the bulk of the rock is chloritised greywacke forming clasts up to 3mm across. Margins are marked by prismatic to fibrous dolomite which form a discontinuous rim. This dolomite grades into finely crystalline dolomite, forming the matrix, and this is crossed by coarser dolomite veins, 6.5mm long and 200μm wide (in the area of the thin section slide). Over the area of outcrop, (4m-5m), relief of the unconformity surface is 0.5m.

2.1.4 Flakebridge (NGR 666047 Figure 8.3)

The unconformity is exposed at the level of the farm track immediately above Flakebridge farm. A 1.5m section through the Bannisdale slates again proves the brecciated zone at the top of the Silurian to be present. Thin sections of this zone show areas of finely crystalline dolomite matrix to enclose 'clasts' of the original host greywacke rock. The matrix again contains dolomite nodules which have mainly diffuse boundaries with the finer grained matrix, and some are veined internally (?crystallaria veins, cf. Wright, 1982) with coarser dolomite (100μm).

2.1.5 Wyegarth Gill (NGR NY 715030; 716032; 716032; Figures 2.3, 8.5; Plate 2.2)

Boreholes, recorded by Holliday et al., (1979) were put down in

Wyegarth Gill between 1975 and 1978 to investigate the Pinskey Gill Beds. Surface exposure is minimal but Bannisdale slates crop out further upstream (south of G.R. 715029). Wyegarth Gill borehole No.5 (Figure 2.3) cored the unconformity 10.5m below ground surface. The base of the Pinskey Gill beds is marked by light green-grey coloured silty micaceous sandstones which are underlain by 15cm of broken core. The latter has a distinctive green colour and consists of slate-like 'chips', up to 2cm across embedded in a mudstone matrix. Between 10.5m and 12m below ground surface, the core consists of host greywacke matrix intricately veined with buff-brown coloured dolomite, and larger areas of dolomite crystals (Plate 2.2). Downwards the colour becomes more purple coloured and the veining more intense. Below 12m and down to 13.3m below ground surface, cores become more like the typical Bannisdale Slates lithology observed at outcrop.

Thin sections of the intensely veined purple horizon (Sample C2/31d in Figure 2.3) are largely composed of greywacke siltstone with a high clay content. The purple colouration is probably associated with Fe rich dolomite (?ankerite) as proved by XRD. Adjacent to the host rock, fibrous dolomite forms isopachous rims 400μm wide, and gives way to 'rosettes' of dolomite crystals (600μm across) forming the matrix of the thin sections.

2.2 SHAP (Figure 2.1)

The region extends from 5km east of Tebay to the Lowther Valley, north-west of Shap village. Most localities are exposed along Birk Beck

and various tributaries in a 3-4km section from Greenholme to Shap Wells (Figure 2.1). The Lower Palaeozoic basement includes the Bannisdale Slates at Tebay but older strata are present progressively further north, such that the Coniston Limestone Group (C.L.G) is exposed north of Shap Wells and the Borrowdale Volcanic Group (B.V.G.) is seen at Shap Summit (Figure 2.1). The Eycott Group forms the basement in the Lowther Valley. The clastic succession in the region has been named the Shap Red Beds by the author (Chapter 3).

2.2.1 Ellergill Beck (NGR NY 639047 Figure 3.8)

Exposures of the Bannisdale slates, which dip steeply to the south-south-east, outcrop approximately 250m east of Gill Hole. Approximately 50m downstream 1.5m-2m of cobble conglomerate mark the current base of the Shap Red Beds.

2.2.2 Greenholme to Scoutgreen (NGR NY 599062-594076)

The unconformity is exposed at river level in the left hand bend of Birk Beck 400m north of Greenholme. Vertical green-grey coloured striped greywacke siltstones belonging to the Bannisdale Slates, are unconformably overlain by 1.5m of boulder-cobble conglomerate exposed as a bluff above the river. The plane of the unconformity is virtually horizontal with no evidence for topographic relief. Furthermore no evidence for a massive brecciated zone is seen (see discussion in Chapter 9).

At Ewelockbank (formerly Owletbank; NGR NY 590074) the unconformity can be placed within 5m in a gully above the farm track (Figure 3.2a).

Light grey coloured greywacke siltstones belonging to the Bannisdale Slates occupy the top part of the gully and crop out close to weathered green coloured pebble-cobble conglomerates belonging to the Shap Red Beds.

At the top of Hollin Gill (NGR NY 588074) the unconformity is poorly exposed at stream bed level for about 4-5m. At the back of the stream gully, the Bannisdale Slates crop out as a ridge which rises very steeply (70°-80°) above the Shap Red Beds and forms a waterfall 3.5m in height. Cobble conglomerates overlie the unconformity. Again there is no evidence for a massive brecciated zone at the top of the Silurian basement.

In Stakeley Beck, the upper Coniston Grits outcrop as a steep waterfall section below Gill farmhouse (NGR 588077). A short horizontal gap of 10m-20m separates the Coniston Grits from a small bluff section exposing cobble conglomerates faulted against fine grained red coloured sandstones, both belonging to the Shap Red Beds. No sign of a faulted contact is evident and an unconformable contact is suggested. Two lines of argument strengthen this point:

1. The steep slope, at least 15-20m high forming the waterfall forms a mappable feature between Stakeley Beck and Wasdale Beck, the unconformity being exposed at the base of the ridge at the latter (see below).

2. The unconformity seen in Hollin Gill is topographically above

Stakeley Beck, falling 25m within 0.5km, and suggests considerable relief of the Carboniferous landscape, both streams probably eroding back an exhumed rock wall. Leeder (1972, 1973) describes a similar feature for the upper Old Red Sandstone in the Northumberland/Scottish borders area.

Approximately 50m north of the waterfall a 2m wide lamprophyre dyke intrudes the Silurian basement and formed a probable Palaeo-ridge, the Shap Red Beds outcropping on both sides. The dyke resembles the minettes of Bonny and Houghton (1878) noted in Section 1.6.

With the author's assistance Cullen (1983) undertook a seismic refraction survey between Greenholme and Scoutgreen so that the level of the unconformity could be modelled over a total area of approximately 2.5km^2. Cullen's results are well recorded, but only the main conclusions are relevant here (Figures 2.4-2.7).

The survey determined a four-layered velocity structure. Soil and drift layers are recognised by the lowest seismic velocities, and are restricted to the two uppermost layers. Reversed profiles determined the two deeper layers (Shap Red Beds underlain by Bannisdale Slates) to have significantly higher seismic velocities. The Shap Red Beds, in this region consisting of mainly cobble conglomerates with interbedded cross-bedded sandstones, have velocities which vary between 2400 and 3400 m/s. The Bannisdale Slates vary from 4400-5200 m/s and show a northwards increasing trend in velocity which Cullen (op. cit.) interprets as 'a variation in lithofacies which could be a metamorphic

effect related to the nearby intrusion of the Shap granite'. The sharp break in velocity between the Shap Red Beds and the Silurian represents the unconformity. In all, 11 lines were shot to provide as close a spread of data base as possible. The main objective of the study was to shed some light on thickness variations of the Shap Red Beds and determine amounts of topographic relief on the unconformity surface.

From the seismic lines 'M01', 'T03' and 'K01', topographic differentiation along the unconformity was determinable (Figures 2.4-2.7). Along line K01, for example, thickness of the Shap Red Beds varies between 10m and 15m reflecting a larger scale topographic relief of the unconformity to be between 5m and 7m. Larger scale relief along lines M01 and T03 is seen to be between 10m and 11m over a horizontal distance of 300m-378m. Thickness of the Shap Red Beds might vary outside the study area, but the general thickness obtained from Line B01 (30m-35m) compares favourably with a maximum 55m obtained from logging and mapping of surface exposures along Birk Beck. The average slope of the unconformity within this region does not exceed 3% (Figure 2.5) and shows an unconformity of moderate relief which falls gently from the west and deepens to the north of Scoutgreen (Cullen op. cit.). The gradient of the unconformity is correlated with the interpreted palaeoslope towards the north to north-north-east as determined from surface mapping and palaeocurrent measurement (Figures 3.2a to 3.2e).

Between Shepherds Bridge and Wasdale Beck, the unconformity is not exposed but is easily identified from mapping as forming the ridge between these localities. In Stony Gill Beck (NGR NY 583087) the

Brathay Flags outcrop on the sides of a steep gully, the unconformity can be inferred within 5m-6m. Like the features seen at Hollin Gill and Stakeley Beck, the juxtaposition of steep 'ridges' of Silurian basement close to sub-horizontal Shap Red Beds with no signs of a faulted contact suggests that these ridges probably reflect an exhumed topography.

2.2.3 Wasdale Beck (NGR NY 578096 Figure 3.4; Plate 2.1)

The classic locality in Wasdale Beck, close to the Shap Wells Hotel, exposes 7.5m of pebble-cobble conglomerate unconformably overlying steeply dipping and cleaved siltstones belonging to the Brathay Flags. The unconformity surface is represented by an arcuate shaped ridge, 8m-10m high, which curves round in the direction of Blea Beck. The unconformity, which outcrops by a waterfall, has a steeply dipping surface of 20° and rises to a ridge, 2m-3m high, formed by the more resistant Brathay Flags. The Shap Red Beds lie sub-horizontally along Wasdale Beck but steepen up slightly parallel with the unconformity surface at the waterfall. Again a brecciated zone, 1m-1.5m thick, is present at the top of the Silurian (Plate 2.1), this being similar to those described for the localities at Ravenstonedale. Dolomite intensely veins joints and fissures in this zone producing a hard massive horizon breaking up the Lower Palaeozoic basement forming a breccia. The distinctive green colour of the basal Carboniferous and the topmost Silurian is most probably associated with the high chlorite content of the Silurian basement.

2.2.4 Blea Beck (NGR NY 577098)

The Shap Red Beds are present in the top part of the beck 'banked'

against a steep ridge, 7m-8m high, composed of rhyolitic tuffs which seem to belong to the interbedded tuffs, lavas and sediments of the Coniston Limestone Group (G.A.L. Johnson, Pers. comm.). This feature is an extension of the arcuate ridge described for Wasdale Beck and emphasises the distinct topographic differentiation of the unconformity noted for the southern part of the region. The Shap Red Beds, here cross-bedded fine grained sandstones, exhibit radiating dips (towards 059°-132°) away from the ridge varying from 38° against the ridge to 12° a few metres away.

Mapping in this part of the region proves the existence of rhyolites which crop out along the main railway cutting 350m towards the north-east (NGR NY 581100). These are similar to the tuffs described for Blea Beck. To test the existence of a possible palaeo-ridge connecting the two outcrops, Cullen (1983) ran three seismic refraction profiles across this area (Figure 2.7) from north-west to south-east. The results suggest that most of the area covered by drift is in fact underlain by the Borrowdale Volcanic Group, which again crops out near to Shap Summit just to the north. The area proposed as a buried ridge can be modelled as an asymmetric fault block with a faulted northern limb and a more gentle southern limb (Figure 2.7). Line SS2 records lower velocities, 3100 m/s, on the faulted side which were not detected by the other two lines. These undoubtedly belong to the Shap Red Beds, while line SS1 and SS3, in recording higher velocities of 5000 m/s, suggest the rhyolite (Coniston Limestone Group) ridge covers a larger area than previously thought.

2.2.5 Shap Summit (NGR NY 574107 Figure 3.13)

A situation similar to that above exists at Shap Summit where the footbridge crosses the main railway line. Dark andesitic lavas of the Borrowdale Volcanic Group crop out as a probable faulted block for approximately 400m, while the Shap Red Beds are exposed on the northern side in a short 12.5m section (Chapters 3 and 8). The line of contact is not directly exposed and the exact relationship is hard to determine. Harkness (1863, p130), however, observed that an irregular contact about the level of the present railway track was present and noted the presence of 'Silurian shales' which are not seen today.

2.2.6 Lowther Valley

North of Shap Summit the Shap Red Beds are nowhere exposed until Shap Abbey is reached (NGR NY 547153). Here, 6m-7m of stratified pebble-cobble conglomerates are exposed above purple stained slates probably belonging to the Eycott Group (Wadge, 1978). Harkness (1863) suggests that the purple colouration has been derived from the overlying 'Carboniferous series'. Again, the unconformity appears 'clean' with no evidence for a massive, brecciated zone seen in the Ravenstonedale localities and at Wasdale Beck. However, it must be said, the exact contact is not exposed.

In Rosgill Hall Wood (NGR NY 543158) the unconformity can be placed within 2m-3m vertical distance. Basement Carboniferous here consists of dolomitised sandstones, up to 2m thick which are succeeded by Limestones of Chadian age.

2.3 DISCUSSION

The textures described from the unconformity brecciated zone are similar to textures described in the literature for pedogenic calcretes. Goudie (from Watts, 1980) writes: 'Pedogenic Calcretes are terrestrial materials composed dominantly, but not exclusively of $CaCO_3$, which occur in states ranging from nodular and powdery to highly indurated and result mainly from the displacive and/or replacive introduction of vadose carbonate into greater or lesser quantities of soil rock or sediment within a soil profile'. They represent periods of subaerial exposure. Calcretes mainly form within flood plain sediment associated with fluvial systems (e.g. Allen, 1974a,b, 1981; Leeder, 1975; Steel, 1974b) but are well known in marine settings above palaeokarstic sufaces (e.g. Walkden 1974, Wright, 1982a,b,) and carbonate build-ups (Adams 1980). Calcrete profiles exhibit a range of textures which are commonly arranged in a set stratigraphic order. Allen et al., (1981) have shown that a transition exists from scattered calcrete nodules within red coloured sandstones into more mature horizons characterised by vertical pipes of coalesced nodules (glaebules) from the Old Red Sandstone of Pembrokshire. Steel (1974b) defined five main types of calcrete ('Cornstone', Figure 2.8) based on profiles for the New Red Sandstone, Western Scotland. Type one calcrete consists of small nodules taking up less than 10% of the host rock. These grade into type two and type three calcretes characterised by an increase in nodules and vertical pipes or sheets respectively with a corresponding decrease in host rock content. Type four calcretes contain rare amounts of clastic material being composed instead of carbonate matrix containing carbonate nodules

and veins (Crystallaria). Type five calcretes are the most mature type and exhibit laminar, brecciated or pisolitic textures. These profiles are built up by the downward percolation of calcium carbonate rich solutions, within the vadose zone of the soil profile.

As mentioned, calcretes are normally described from soil profiles, originating within a host sediment and not host bedrock, as apparent in this study. Steel (1974b), however, has described 'unconformity type cornstone' formed by normal cornstone forming processes but occurring within or above the New Red Sandstone to Pre-Cambrian unconformity Zone in Western Scotland. The carbonate occurs as a massive 'blanket' which veins the host rock via cracks and joints. The essential difference between this type and the other types of calcrete is the nature of the host rock, the bedrock being relatively impermeable not allowing normal calcrete (cornstone) profiles to be built up. In his analysis (Steel op. cit. table 3), he records a maximum zone depth of 3m for this 'carbonate blanket', normally being between 1m and 3m. Unconformities not consisting of a 'massive' blanket zone are defined as 'clean' unconformities.

Mann and Horwitz (1979) describe non-pedogenic 'groundwater calcretes' from Western Australia. These can be thick up to 10m in thickness, and form a hard calcrete pan within alluvial sediments deposited in drainage channels, but close to bedrock. Infact a transition zone is present comprising a gradation through veined carbonate into 'deformed an decapsulated' bedrock. Calcium carbonate is precipitated in the phreatic zone, beneath the water table, groundwaters being enriched in

calcium by percolating rainwater and by chemical reaction of groundwater with rock and soil. As precipitation of calcite proceeds, calcrete is 'pushed up' towards the surface in the form of pods and domes. Due to intense evaporation, dolomitisation of calcite takes place above the water table (Vadose Zone). In fact, according to Mann and Horwitz (op.cit. p.300), where 'salinites and magnesium ion concentrations are much higher, dolomite is abundant both above and below the water table. In such locations magnesium may enter the primary carbonate species and the formation of calcite may be supressed'.

The abundance of dolomite within the unconformity zone calcretes of the present study and the nature of these 'bedrock' calcretes being of similar texture to the 'groundwater' calcretes described above, suggest the process of formation was probably similar. Whether dolomite has replaced original calcite or whether it occurred in a primary form is unclear. However, it seems apparent that the formation of the unconformity zone calcretes was very much dependent an local variations in the Mg:Ca ratio.

The interpretation of calcrete type processes along the unconformity is significant in terms of climatic indicators and sediment input into the area. Calcrete forms in areas of low rainfall under arid or semi-arid climatic conditions. Further, mature calcrete takes up to 10,000 years to form (Leeder, 1975) and that during calcrete formation, the area is effectively starved of sediment input for considerable lengths of time. The presence of calcretes within the unconformity zone therefore suggests formation under arid or semi-arid conditions and low

rainfall and sediment starvation for up to 10,000 years. Further the presence of dolomite, if primary, implies intense surface evaporation and high Mg:Ca ratio.

Study of the unconformity in the Shap region indicates that the basal Carboniferous rocks were deposited over a distinctly uneven and undulating lower Palaeozoic landscape. Local variation in relief of the unconformity was as much as 10m-11m within 300m, and locally the Carboniferous may have been 'banked' up against ridges and rock walls, at least 8m high. How much the 'rock wall' topography between Shepherds Bridge and Wasdale Beck acted as a principal 'basin divide' is in doubt, although west of here the ground does rise very steeply towards the main part of the Lake District. As suggested by the 'flat lying' unconformity surface at Greenholme, however, the Carboniferous probably did extend certainly south of the Shap area, clasts derived from the Shap Granite (Section 7.1) indicating that the Carboniferous may also have been deposited further westwards towards the present day outcrop of the Shap Granite. In this case, the present day outcrop pattern of the basal Carboniferous is probably more appropriately related to the sharp 'hardness' contrast between the basal Carboniferous and the Silurian, and thus the implication of steep rock walls may mostly be due to this contrast. Capewell (1955) does however suggest that the Shap Red Beds represent the infill of a deep valley centred around Scoutgreen and 'pinching out both northwards and eastwards'.

2.4 SEDBERGH (Figure 5.1)

As far as the author is aware the only exposure of the basal Carboniferous unconformity at Sedbergh is along Hebblethwaite Hall Gill (approx. NGR SD 693932), described by Foster (1981). The author could not find this exposure but according to Burgess (pers. Comm.) the 'horizontally lying conglomerates are banked against a ridge of Silurian'.

2.5 CROSS FELL ESCARPMENT (Figure 2.2)

Outcrops are restricted to stream and crag exposures along a 24km stretch of the escarpment between Gamblesby in the north and Roman Fell in the south. The unconformity is nowhere exposed but in a number of cases can be placed within 10m horizontal distance. The Cross Fell clastic rocks for the purposes of the present study, have been divided into four lithological groups, as indicated on Figure 2.2. The groups, Polygenetic Conglomerate, Quartz Conglomerates, Red Sandstones and Green Sandstones, reflect the transition from coarse grained sediment into progressively finer grained sandstones and are organised into an overall fining upward sequence. These groups are discussed in detail in Chapter 6.

2.5.1 Melmerby Fell Track (NGR NY 627371)

Highly weathered slates belonging to the Murton Formation are poorly exposed at the side of the Fell Track approximately 450m east of the junction with the Gale Hall farm track. The level of the

unconformity is taken at a point where the distinct yellow-red colour of drift becomes much more red in colour. This position is about 25m horizontal distance from first exposures of the Polygenetic Conglomerate.

Short (1954) describes another unconformity exposure in the nearby Melmerby Beck. He notes visible outcrops of Ordovician slates are overlain by 70 feet of the Polygenetic Conglomerate. Upstream from the junction of Melmerby Beck with the Fell Track the Polygenetic Conglomerate thins to only 5 feet (Short op.cit.) due to 3 quartz porphyry dykes raising the Ordovician floor. However, today these outcrops are obscured by dense vegetation and forest.

2.5.2 Rake Beck (NGR NY 631369)

The basal 1.5m-2m of the Rake Beck section can possibly be assigned to the Polygenetic Conglomerate. The unconformity with slates of the Murton Formation can be inferred within 3.5m vertical distance.

2.5.3 Tributaries north of Rake Beck

The Gate Castle Fault upthrows the Murton Formation at the top of Rake Beck and slates outcrop along the Fell Track north-north-west of Meikle Awfell. In one stream (NGR NY 636370) draining Melmerby Scar a 6m-7m sequence through the Quartz Conglomerates (Chapter 6; Figure 6.9) lies about 10m above the slates.

In Dry Sike (NGR NY 639375) 1.5m of the Quartz Conglomerate are exposed within 10m-15m horizontal distance of Murton Formation Slates

although the actual junction may be faulted. Arthurton and Wadge (1981) note the unconformity exposed in Hungrigg Sike (NGR NY 636371) although again the junction may be faulted.

2.5.4 Dale Beck to Windy Gap

Directly south of Cuns Fell the basal Quartz Conglomerates in Dale Beck 1 Section (Figure 6.4) are cut by the Ladslack Fault although the junction in Dale Beck 2 Section (Figure 6.4) may be unfaulted.

Crag exposures on the north-west side of Musca Hill through the Quartz Conglomerates must lie very close to the unconformity, mapping by the British Geological Survey indicating a non-faulted contact.

At Windy Gap Col (NGR NY 647355) the Quartz Conglomerates dip steeply eastwards and are faulted against Murton Formation Slates by the Windy Gap Fault.

2.5.5 Ardale Beck to Kirkland Beck

At the foot of Ardale Beck, the Ladslack Fault up faults volcanic rocks of the Kirkland Formation (Eycott Group) which outcrop nearby. The basal part of Ardale Beck section (Figure 6.7) consists of at least 2m of the Polygenetic Conglomerate.

The Quartz Conglomerates are exposed at Cocklock Scar (NGR NY 655338, Figure 6.8) 500m further south. The base of the section can not be more than a few metres above the unconformity as andesitic lavas of the Kirkland Formation crop out in a disused quarry only 50m away. The

plane of the unconformity is unfortunately obscured by scree from the Cocklock Scar Section. In Kirkland Beck (NGR NY 660336) 2m of the Quartz Conglomerates must again lie very close to the unconformity.

2.5.6 Crowdundle Beck and Eller Gill Beck

According to the Geological Survey tuffs belonging to the Kirkland Formation crop out on nearby Grumply Hill. Quartz Conglomerates exposed in Crowdundle Beck appear to be close to the unconformity but no evidence of the Lower Palaeozoic was observed. Similar Quartz Conglomerates exposed in Eller Gill Beck (NGR NY 689313) are faulted against the Dufton Pike Fault. Arthurton and Wadge (1981) consider that Grumply Hill formed a palaeo-high, and that the Carboniferous Conglomerates thicken to the south-east.

2.5.7 Sink Beck, Knock

The unconformity can be placed within 3m-5m from the Quartz Conglomerates (NGR NY 696289). The basement here consists of purple coloured slates belonging to the Murton Formation.

2.5.8 South Cross Fell Escarpment and Roman Fell

South of Sink Beck, Knock towards the direction of Murton, exposures of the Cross Fell Clastic rocks are rare and possibly absent altogether. The unconformity is nowhere exposed. However, Burgess and Wadge (1974) do describe the unconformity at a locality in Murton Beck (NGR NY 755214) but this was not seen when visited by the author.

Poorly exposed Quartz Conglomerates are seen at the confluence of Swindale Beck, Hilton and Scordale Beck (NGR NY 751213) and which according to Burgess and Wadge (1974) lie close to the unconformity.

In the Roman Fell area, work in the present study has been mainly limited to the facies analysis of the Roman Fell Sandstones. Burgess and Harrison (1967) in a survey of this region, however, record exposures of the unconformity which is often marked by spring lines. One of their localities shows the basal conglomerates banked against a buried hill formed by rhyolitic tuffs. The reader is referred to their paper for more detail.

2.6 DISCUSSION

Results from the northern part of the Escarpment compare favourably with the results of Arthurton and Wadge (1981) and Burgess and Wadge (1974). The reader is referred to these papers for extra detail.

The Cross Fell 'clastics' infill a palaeo-depression, 17km wide, centred around Dale Beck and Musca Hill (up to a maximum estimated thickness of 122m). The unconformity here lies at a much lower level than further north in Rake Beck and because of the faulting at the base might be even deeper. Northwards the clastics thin to 52m at Grey Mares Tail although the Polygenetic Conglomerate is much thicker here than anywhere else and does of course suggest that a further depression was located here prior to the deposition of the Quartz Conglomerates and the Red Sandstones. The unconformity rises gradually south of Ardale Beck

and suggests that thicker clastic deposition in the northern part perhaps was the result of differential subsidence north of high ground underlain by the postulated central Vale of Eden granite ridge (see Chapter 9).

Arthurton and Wadge (1981) suggest that minor variations are superimposed on the general trend. South of Rake Beck for example, the unconformity rises but then falls rapidly to a much lower level north of Dale Beck. They also record a thinning of the Quartz Conglomerates south of Kirkland Beck around Wythwaite Tops.

The thickness of the Red Sandstones seems to be more constant than that of the Quartz Conglomerates. This can be explained by the fact that because the Quartz Conglomerates represent deposition in a more proximal setting original variations in land topography would have a more pronounced effect on changes in thickness (see Chapter 9).

South of Sink Beck, Knock the unconformity rises steeply such that the Quartz Conglomerates are absent and the Red Sandstones become thinner and overstep onto the Murton Formation. Arthurton and Wadge (1981) record a maximum thickness of 20m for the Red Sandstones at High Cup. The area from High Cup to Roman Fell sees a rapid increase in clastic thickness especially south of the Swindale Beck Fault (Burgess and Harrison 1967) with the unconformity dropping 160m in height below the 'high' underlying High Cup. Penecontemporaneous movement along the Swindale Beck Fault has been suggested by Barraclough (1983) to account for the rapid increase in the clastic thickness.

2.7 NORTH WALES, INGLEBOROUGH, COCKERMOUTH, ISLE OF MAN AND KIRKUDBRIGHTSHIRE

For comparative purposes these areas have been visited by the author during the course of the present study. Most importantly, however, they support the findings within the main areas of the study of an unconformity surface which locally shows significant topographical relief. Nowhere is this fact more evident than in the superb exposure of the unconformity at the 'Arches' near Castletown in the Isle of Man (basal Carboniferous clastics being well documented by Clague, 1887; Dawkins, 1889; Lamplugh, 1903 and Lewis, 1930), the plane of the unconformity containing scour-shaped depressions up to 2m across superimposed on a broad undulating planar surface, dipping at 19°. Local topographic relief along the unconformity is also demonstrated at the sections at Nant-y-Croen-Llwm (NGR SJ 005 709) and White Port (NGR NX 723433), North Wales (Basal Carboniferous studied by Morton, 1878; Neaverson, 1930; Strahan and Walker, 1879 and Jones, 1982) and Kirkudbrightshire (well documented by Craig and Nairn, 1956 and Deegan, 1970, 1973) respectively. In the former, boulder Conglomerates are 'banked' against a 'step-like' unconformity surface, sloping at 20°, the basement consisting of greywacke sandstones belonging to the Silurian Elwy Group (correlates with the Brathay flags of the Lake District). In the Kirkudbrightshire locality, the very basal conglomerates to the Carboniferous overlying the unconformity contain no vein quartz clasts, comparable to the Polygenetic Conglomerate at Cross Fell (see Chapter 6). The unconformity exposures around Ingleborough and Horton in Ribblesdale (well documented by Phillips, 1835; Sedgewick, 1852; Hughes,

1907; Strahan, 1910; Garwood, 1922; Dunham et al., 1953 and Scott, 1984) demonstrate broad topographic relief to the Upper Palaeozoic land surface, which was transgressed relatively late in Lower Carboniferous times (Holkerian), the basal Carboniferous in this area comprising mainly carbonate rocks with no clastic deposition occurring (see Chapter 9). Finally, Stabbins (1969) used borehole data in the Cockermouth to Egremont region (see Edmonds, 1922) to reconstruct the topographic relief of the unconformity; the area around Cockermouth demonstrating the lowest elevation, the Carboniferous limestones which overlap onto the Lower Palaeozoics further south, consisting here of the basement beds (Redmain/Tommy Gill Members, Welsh, 1980) which are succeeded by the Cockermouth lavas. In this north-western part of the Lake District, the Carboniferous succession contains a dominantly limestone succession which apparently progressively onlaps on to the Lake District Massif (Mitchell et al., 1978, Wadge, pers. comm.).

FIGURE 2.1

Diagram illustrating the unconformity between Shap and Ravenstonedale and the main rock types comprising the Lower Palaeozoic basement.

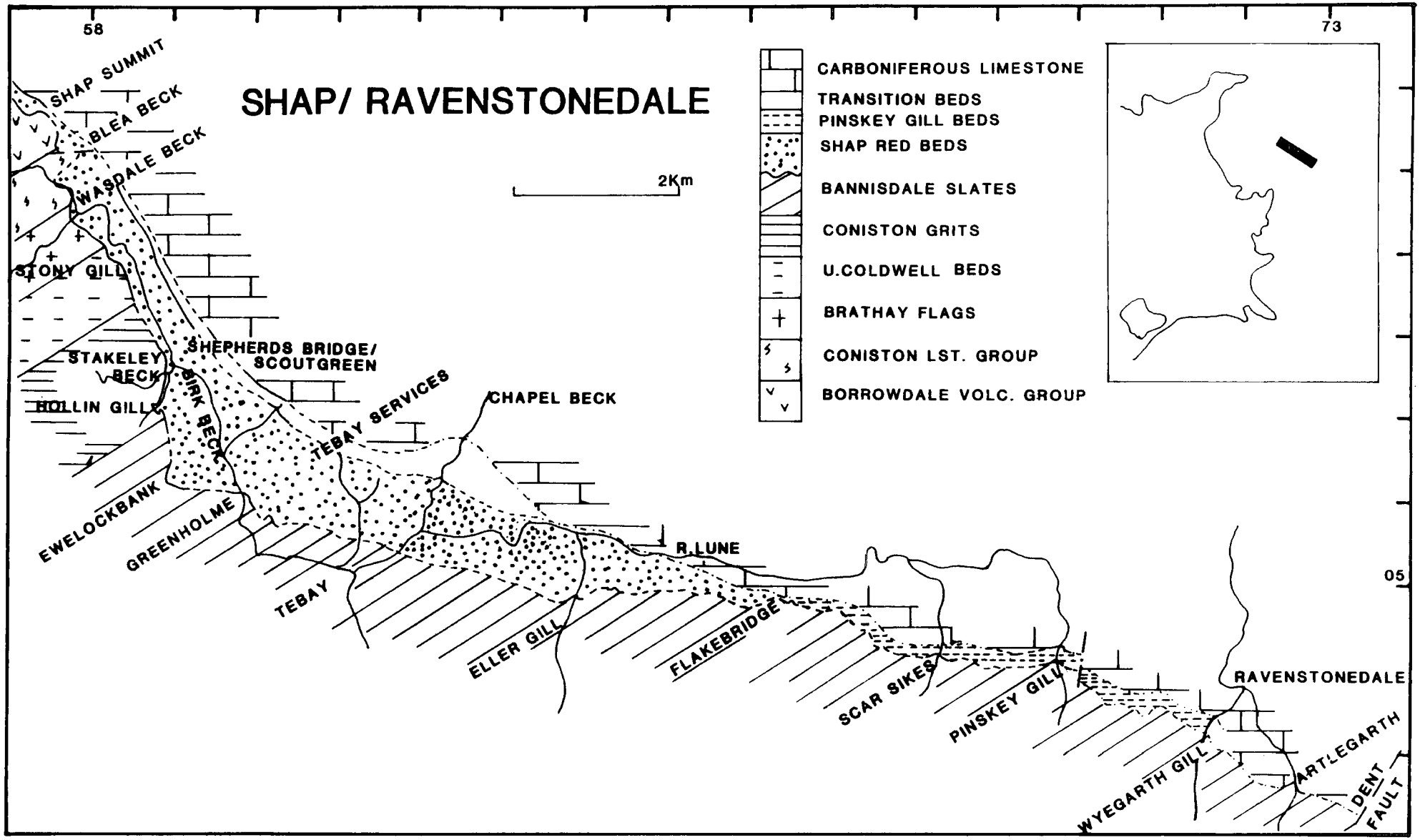

58
73
SHAP/ RAVENSTONEDALE
2Km
CARBONIFEROUS LIMESTONE
TRANSITION BEDS
PINSKEY GILL BEDS
SHAP RED BEDS
BANNISDALE SLATES
CONISTON GRITS
U.COLDWELL BEDS
BRATHAY FLAGS
CONISTON LST. GROUP
BORROWDALE VOLC. GROUP
SHAP SUMMIT
BLEA BECK
WASDALE BECK
STONY GILL
STAKELEY BECK
HOLLIN GILL
SHEPHERDS BRIDGE/ SCOUTGREEN
BIRK BECK
TEBAY SERVICES
CHAPEL BECK
EWELOCKBANK
GREENHOLME
TEBAY
R.LUNE
ELLER GILL
FLAKEBRIDGE
SCAR SIKES
PINSKEY GILL
RAVENSTONEDALE
WYEGARTH GILL
ARTLEGARTH
DENT FAULT
05

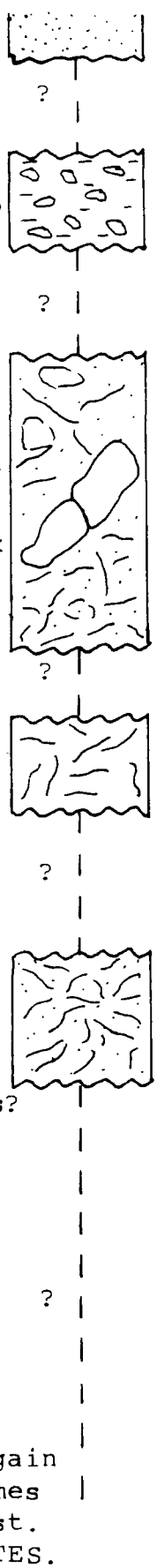
FIGURE 2.2

Cross-section showing the unconformity along the Cross Fell escarpment and the main rock groups comprising the Lower Palaeozoic basement.

UNCONFORMITY ZONE - WYEGARTH BOREHOLE NO. 5. FIGURE 2.3.

LITHOLOGY

XRD ANALYSIS



PINSKEY GILL BEDS gr.-green silty mic. sst. ?sharp break to:

?

Green-grey clr. shale chips up to 2cm in clay size matrix.

?

10.5m (35')

green-grey clr. becoming more purple with depth

nodular texture in f-m sst matrix increasingly veined with yll. mineral. ?carbonate clast 6cm+.

?

broken core similar purple/ yll.veined nod. texture.

?

continues as broken nodular texture with red -gn. silty clasts?

?

12m (40')

Up to 13m (44')again broken core becomes hard red-gn.siltst. ? BANNISDALE SLATES.

C2/31b. Sedimented sple. shows degraded illite + chlorite to be dominant. Bulk- quartz, dolom. - NO calcite. ? kaolinite.

C2/31c. similar to b. ? some calcite.

C2/31d. Bulk sple. shows Quartz + dolomite are dominant. Red colouration maybe due to Fe in dolomite (?ankerite). Some feldspar-?orthoclase. Some calcite. Clays- Chlorite and illite.

C2/31e. Very similar. Qz. and dolomite(yll. vein mineral).? orthoclase. No calcite. Clays- chlorite /illite.

C2/31f. Qz. and dolomite are main bulk constituents. Some orthoclase. Clays- dominated by chlorite /illite + some kaolinite.

FIGURE 2.4.

ELEVATION OF UNCONFORMITY ABOVE O.D. (AFTER CULLEN 1983)

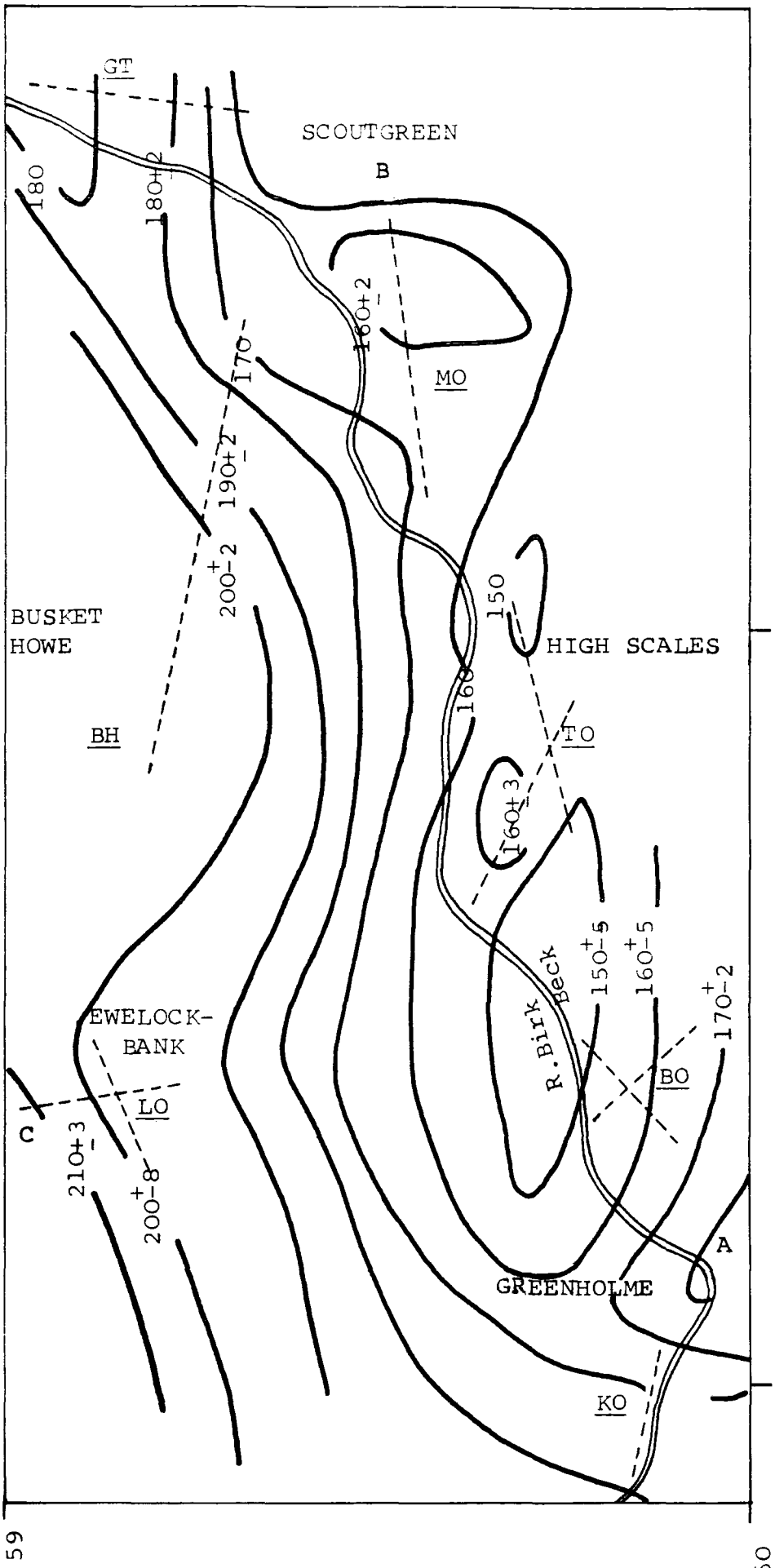


FIGURE 2.5.

SLOPE AND VARIATION IN RELIEF ALONG THE UNCONFORMITY (BASED ON CULLEN 1983).

LINE	LINE LENGTH (Ms)	TOTAL DEPTH TO U.C.-MACRO RELIEF (Ms) /SLOPE%	MICRO RELIEF
KO1	170	15.1-8.6 3.9%	3.6m over 10m Slope = 37% /3.6 over 30m Slope= 12%
BO1	170	41.9-21.5 12%	
BO2	170	32.5-17.9 8.6%	
TO1	300	44.5-42.4 .7%	
TO2	140	40.5-32 ?6%	
TO3	300	30.4-29.4 ?.33%	8.8m over 45m Slope= 19.6%/7.9 over 120m slope= 6.6%
GT1	285	42.9-19.1 8.3%	
MO1	378	35.5-25 2.7%	6.6m over 72m Slope= 9% /5.1m over 18m slope= 28.5%
LO1	198	27.7-24.7 1.5%	
LO2	198	27.7-23.9 1.9%	
BH1	198	11.7-6 2.8%	

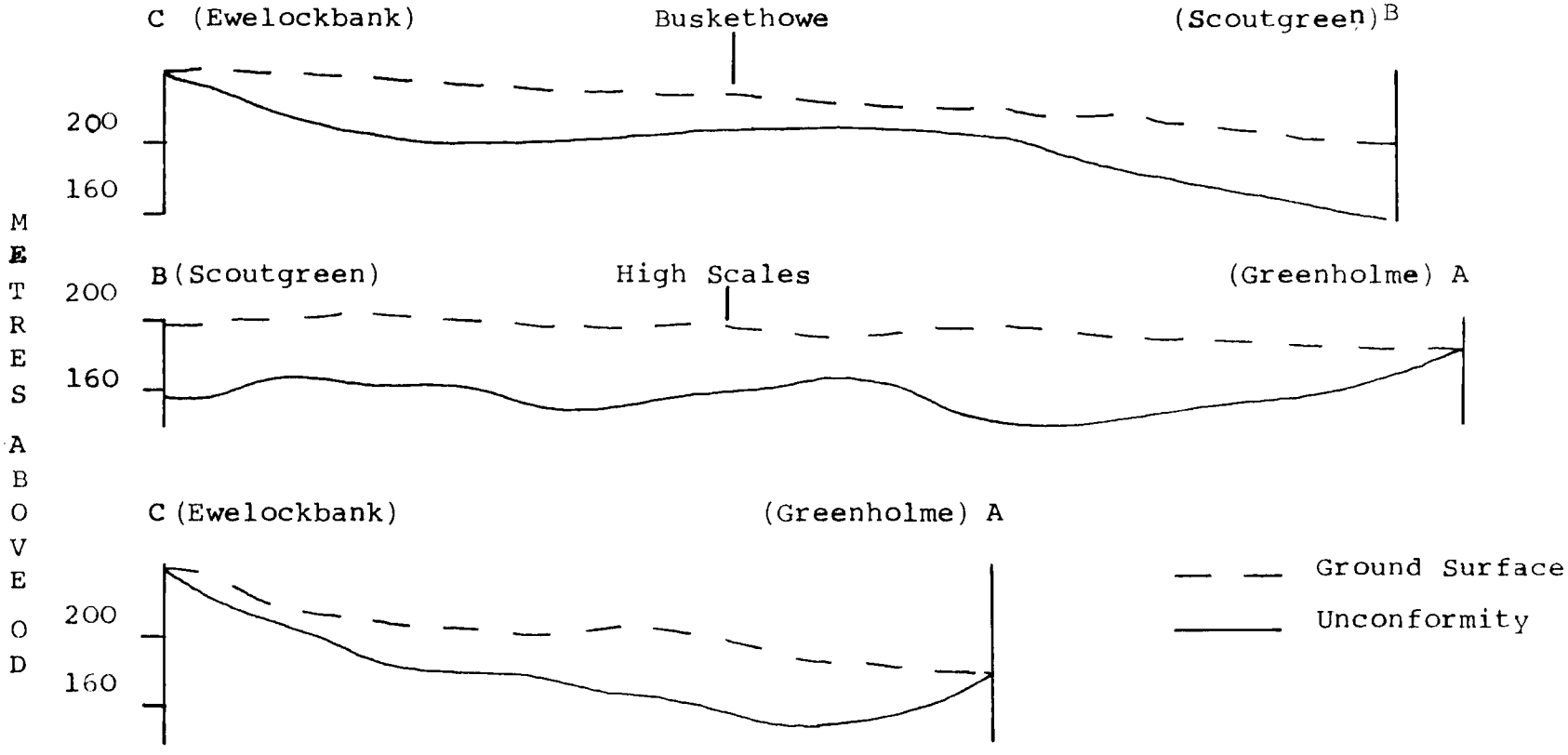
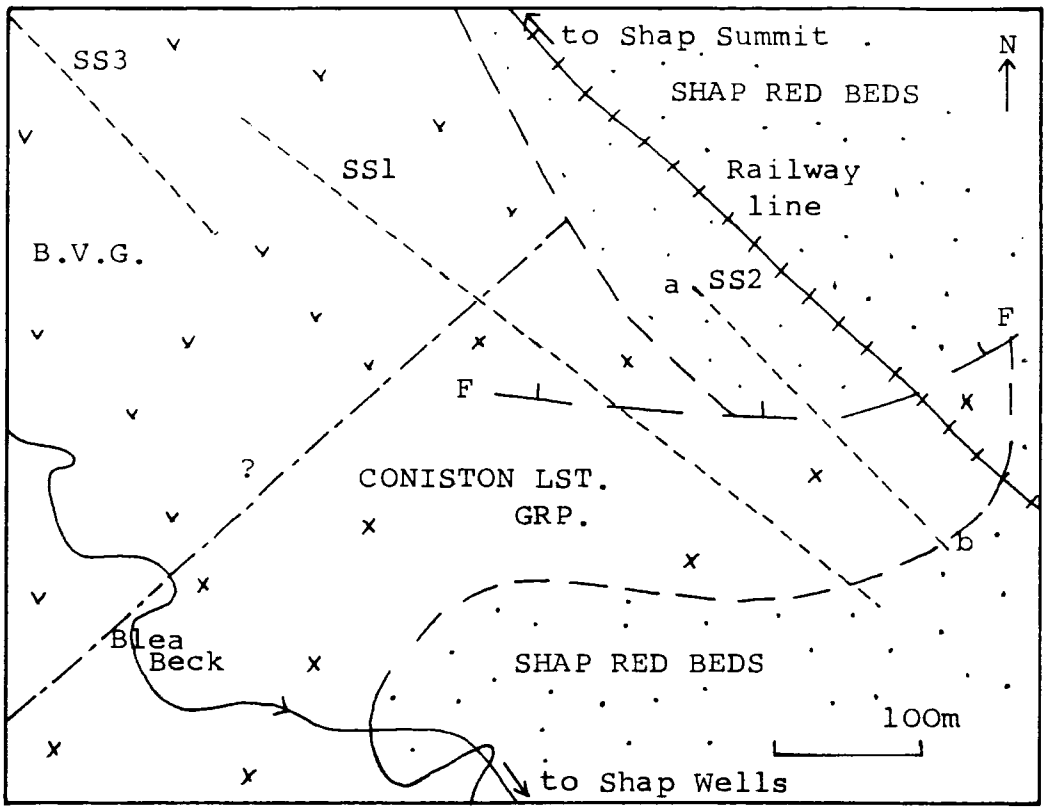


FIGURE 2.6.

SECTIONS (A-B-C) ALONG THE UNCONFORMITY BASED ON CULLEN 1983

SEISMIC SURVEY NEAR SHAP SUMMIT (AFTER CULLEN, 1983).



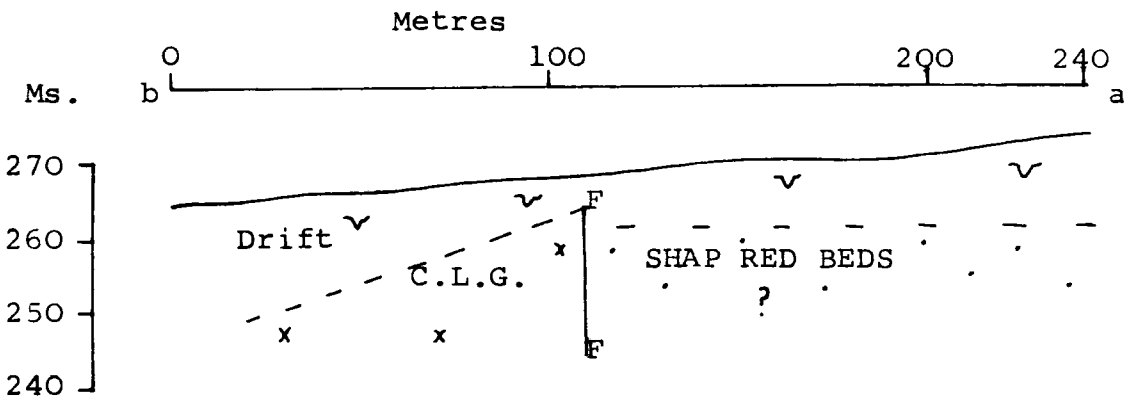


FIGURE 2.7.

SKETCH SECTION ALONG SS2 (b-a) (AFTER CULLEN, 1983).

FIGURE 2.8.

CORNSTONE (CALCRETE) TYPES OF STEEL 1974b

TYPE 4a

LAMINAR, BRECCIATED OR PISOLITIC CARBONATE FORMS A CAPPING TO TYPE 4

TYPE 4

CARBONATE BEDS WITH RARE PATCHES OF CLASTIC SEDIMENT

|

|

TYPE 3

CARBONATE APPEARS AS NODULES, VERTICAL PIPES OR HORIZONTAL SHEETS

MAKES UP GREATER THAN 50% HOST ROCK

CAN STILL MAKE OUT HOST CLASTIC SEDIMENT

|

|

TYPE 2

CARBONATE NODULES UP TO 10cm

MAY FORM VERTICAL PIPES UP TO 15cm

TAKE UP LESS THAN 50% OF HOST ROCK

|

|

TYPE 1

IRREGULAR NODULES UP TO 6cm, CROSSED BY VEINS OF HOST CLASTIC SEDIMENT

COMPRISE LESS THAN 10% HOST ROCK

|

HOST ROCK

PLATE 2.1

Plate shows close up view of unconformity at Wasdale Beck, Shap (N.G.R. NY 578095). Well cleaved and 'brecciated' chlorite rich siltstones belonging to the Brathay Flags are overlain by basal Carboniferous mudstone and stratified pebble conglomerate. Hammer (35cm) for scale along plane of unconformity (top of brecciated zone).

PLATE 2.2

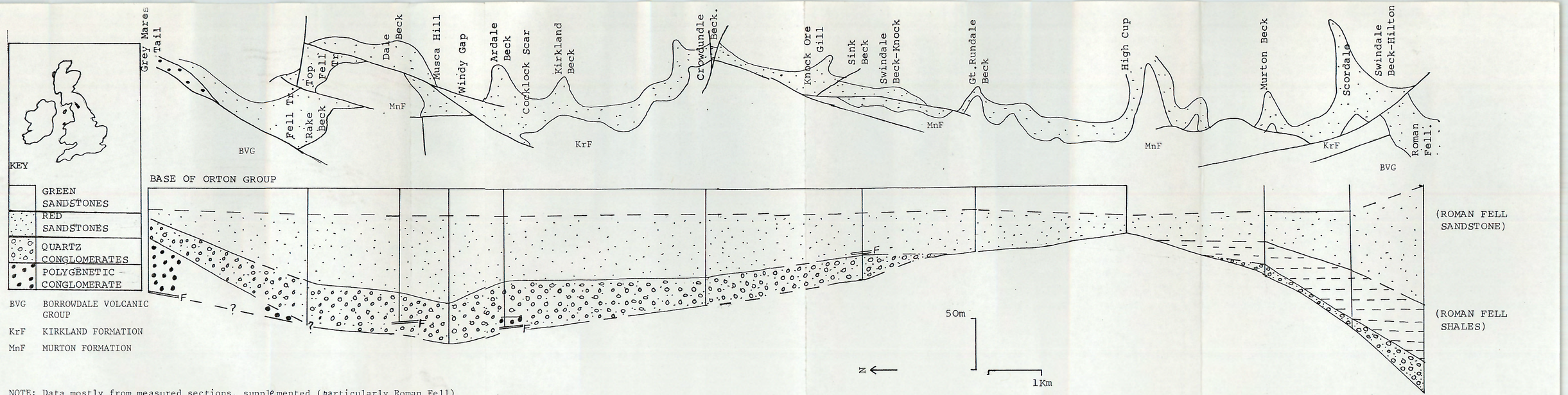
Plate showing close up view of unconformity brecciated zone within Bannisdale slates from Wyegath Gill Borehole No.5 Core. Note distinct nodular texture, highly chloritised fine to medium grained sandstone and dolomite veins (buff-yellow mineral). This cored interval (10.5m) corresponds to that illustrated in Figure 2.3 and samples C2/31b and C2/31c.

PLATE 2.1.



PLATE 2.2.





NOTE: Data mostly from measured sections, supplemented (particularly Roman Fell) from data in Burgess and Wadge (1974) and Arthurton and Wadge (1981).

CHAPTER 3 - SHAP (SHAP RED BEDS)

3.1 INTRODUCTION

The author has termed the Carboniferous basement rocks which outcrop near to the village of Shap, the Shap Red Beds. These deposits are mainly exposed along one stream section, the river Birk Beck, and its adjacent tributaries (Figure 3.1). Previous history of research in the Shap area has already been outlined in Section 1.4, but the work of Capewell (1955) provides the most detailed account of these deposits in recent years. In this chapter, the Shap Red Beds have been assigned to three main lithofacies, conglomerate (lithofacies G), sandstone (lithofacies S) and siltstone/mudstone (lithofacies F) and subdivided into facies, based on the contained sedimentary structures and related to the classification of Miall (1977, 1978 and Figure 1.5). Facies present in the Shap Red Beds are described and discussed in detail in the following sections with facies data summarised in tables 1 to 9 (Appendix 1). The main outcrops are summarised in figures 3.2a to 3.2e, vertical sections presented in figures 3.3 to 3.8 and 3.13 with summary of the facies distribution and facies relationships presented in figures 3.9 to 3.11.

3.2 CONGLOMERATE LITHOFACIES

Conglomerate forms a volumetrically (locally greater than 90%) significant part of the Shap Red Beds, and is dominantly exposed in the southern part of the Birk Beck section. The facies present under this

lithofacies include, massive and horizontally stratified conglomerate (facies Gm), trough-cross-bedded conglomerate (facies Gt) and planar-cross-bedded conglomerate (facies Gp). The summary of the data for these facies are presented in tables 1 to 3.

3.2.1 Facies Gm

Cobble and boulder conglomerates, forming units up to 2m in thickness, are exposed in the south of the Shap area, along Birk Beck and adjacent tributaries in the area especially south and west of Shepherds Bridge (Figures 3.1, 3.2a-d) and also along Wasdale Beck near to Shap Wells (Figure 3.2e, 3.4). Facies Gm is also exposed in the extreme eastern part of the Shap area along Ellergill Beck near to Tebay (Figures 3.1, 3.8).

Facies Gm forms the basal unit members of fining upward sequences and is commonly sharply overlain by facies Gt and facies St (trough-cross-bedded Sandstone). Facies Sh (horizontally laminated sandstones) and facies Fl/Fm (mudstone) are present as drapes and wedge-shaped units in between some conglomerate units (e.g. Stakeley Beck section, Figure 3.3). Conglomerate units are massive, locally imbricated (Plates 3.3, 3.4) and horizontally stratified, with maximum clast size commonly fining upward within a single unit (e.g. Greenholme, unit 1, table 1). Imbrication along the B axis of elongate clasts is commonly developed (e.g. Stakely Beck, unit 5, Table 1, Plate 3.3; Greenholme, Table 1) and shows that palaeoflow in some units was orientated between 315° and 044°. Because of poor exposure, imbrication in facies Gm is difficult to determine conclusively and thus may not be

a reliable indicator of palaeoflow. However, the recognition of imbrication in facies Gm is important in determining the likely depositional environment and sedimentary processes. Rust (1984, p. 679) discusses variance in the development of imbrication in conglomerates. He suggests that the maintenance of steady, high-velocity flow may be an important factor in forming an organised imbricate bed, in his case, the Malbaie conglomerates of Middle Devonian age from Gaspé, Canada. Also the type and shape of clasts is important. As far as the Shap Red Beds are concerned, the abundance of greywacke clasts (see chapter 7) is thought to be conducive to the formation of elongate 'discoidal' clast shapes developing imbrication along the AB plane.

Conglomerates are clast-supported and have a 'closed matrix' with spaces between clasts infilled with silt, sand and occasionally granules (cf. Doeglas, 1962; Ore, 1964), the grain size of the matrix possibly related to flow stage (cf. Eynon and Walker, 1974). According to Walker (in Rust, 1984, p.679), gravel sized material up to 0.07m can be transported and deposited simultaneously with coarse sand carried in suspension. This does not hold true for larger clasts and the presence of a matrix within clast supported conglomerates indicates later infiltration of sand. The clast supported framework and abundance of matrix between clasts is largely related to the process of deposition. Thus matrix-supported conglomerates are deposited by mass flow or debris flows in which the mud matrix is transported and deposited as a primary constituent of the deposit (Bluck, 1967; Rust, 1984). In contrast, clast-supported conglomerates are indicative of 'energetic aqueous transport that deposits gravel on the bed while sand is still carried in

suspension...' (Rust, op.cit). The author believes that the absence of matrix-supported conglomerate (Facies Gms of Miall, 1977), but abundance of clast-supported conglomerate points to deposition as bed-load sediment under high-velocity flow conditions.

The likely environments of deposition for clast supported conglomerates include stream flows on alluvial fans plus a variety of bars, lags and conglomerate sheets largely deposited by rivers over a sediment surface (Bluck, 1967) plus gravels deposited in a marine environment, including beach and submarine fan settings.

Bluck (op. cit.) has shown that on alluvial fans, a direct correlation exists between the amount of sediment discharge and flow competency and this relationship is expressed as the ratio between bed thickness and maximum particle size. In a downslope direction and away from sediment source, bed thickness diminishes and thus maximum particle size becomes finer. In this way, an increase in the rate of fluvial activity and dispersion over a less inclined surface is likely to increase the amount of erosion within the system and this would reduce the effective correlation between discharge and flow competency, conglomerate units not being the product of single flow events but forming composite sequences, deposited by multiple flood episodes. Streamflow deposits are intermixed with debris flows on alluvial fans and show the best correlation between maximum clasts size and bed thickness. Streamflow deposits are deposited by channelised or non-channelised flow, carrying sediment in suspension, saltation and traction, with conglomeratic channel-fills being the most coarse grained

and poorly sorted (Nilsen, 1982). Morphologically, these channel fills are difficult to distinguish from conglomerate channel-fills deposited in shallow braided river channels flowing further down-slope (cf. Ori and Penney, 1982), although it seems one difference is the positive correlation between bed thickness and maximum clast size for streamflow deposits (Bluck, 1967).

Conglomerates along Birk Beck are generally well exposed but only in plan view, vertical sections being rare and (e.g. Stakeley Beck, Figure 3.3) accurate thicknesses of individual units therefore being very difficult to determine accurately. Consequently, maximum clasts size and bed thickness cross-plots were thought to provide unreliable data and therefore have not been attempted. However, it is believed that the association with facies Gt and facies St (trough-cross-bedded sandstones) in the southern part of Birk Beck, indicates that facies Gm was deposited within fluvial channels. Further, the clast size grading, present within these conglomerate units, imbrication of clasts and locally well developed horizontal stratification resemble the deposits of conglomerates which accumulated as gravel bars within braided fluvial channels. Deposition as marine gravels are discounted due largely to the absence of marine fauna contained within interbedded deposits.

Gravel bars divide rivers up into two or more channels and represent deposition within areas of principal sediment dispersion, within main active channels (Williams and Rust, 1969; Mcdonald and Banergee, 1971, Boothroyd and Ashley, 1975; Miall, 1977). Within the channels, gravel is deposited initially as a coarse lag and immediately

down-current of 'pools' (cf. Ferguson and Werritty, 1983; Forbes, 1983). Pools occur at the intersection of two or more channels of equal or unequal strength and are sites of erosion and gravel transport (Hein and Walker, 1977 p. 564). Flow velocities are high here due to the 'funnelling' of water through the narrow openings to the pools. Hein and Walker (op.cit.) indicate that for the Kicking Horse River in British Columbia, gradients over the pools are high, depths averaging 1.0m to 1.3m, and widths up to 1.5m. As a consequence of this, flow velocities are high (0.75 to 1.0 m/s), which, after high flow stage has receeded, ensures that gravel is deposited as a lag.

Hein and Walker's (1977) observations in the Kicking Horse River support earlier observations by Williams and Rust (1969) for the Donjek River, Yukon. At high flow discharge, transport of sediment is too great for deposition and as a result continuous migration of channels and bars occur. Boothroyd and Ashley (1975, p.219) propose from work carried out in the Scott and Yana braided outwash fans, Alaska, that stream power is greater in deeper channels than over adjacent gravel bar surfaces and therefore larger clasts are transported in the channels as opposed to over the adjacent bar surface. Deposition occurs on falling stage of flow when water shallows over the bar, clasts accreting onto the bar surface as a result of the reduction in flow competency (Miall, 1977).

Gravel is first deposited as a 'short, submerged, central bar' (Miall, 1977) forming a rifle. Leopold and Wolman (in Smith, 1974, p.217) consider the first gravel deposits to be the largest in transport

with successive deposits progressively finer in grain size. Ore (1964) p.17) records the formation of the initial bar and subsequent growth as observed by Leopold and Wolman, ... 'At any time, the stream is carrying coarser fractions along the channel centre than at the margins, and due to some hydraulic conditions, part of the coarser fraction is deposited. Finer material is, in part, trapped by coarser particles, indicating a central ridge in the channel. Progressive additions to the top and downstream end of the incipient bar build the surface toward water level. As progressively more water is forced into lateral channels beside the growing bar, the channels become unstable and widen. The bar may then emerge as an island due to downcutting in lateral channels and eventually may become stabilised by vegetation. New bars may then form by the same process in lateral channels...' The developing gravel bar assumes a form depending on flow variables, bank stability and channel geometry (Smith, 1974), the initial bar forming a 'coarse lag' maybe no more than a few pebbles in height (Hein and Walker, 1977). Hein and Walker (op.cit.) call such low relief lags or incipient bars 'diffuse gravel sheets', with observations from the Kicking Horse River showing that these sheets are submerged and will only move during highest flow stage. Despite being of low relief, these diffuse gravel sheets extend for much of the channel width.

Bars develop by vertical aggradation from accumulation of clasts moved as coarse bed load. Smith (1974) distinguishes 'unit bars' from 'braid bars', the latter representing modification by dissection on waning flow and erosion during highest flow stages of the initial bar form. The braid bars develop thus as a result of local variables within

the channel at a certain time. Smith (op. cit.) considers braid bars to be formed by flow diversion, the bars then causing diversion of flow themselves and will subsequently have a complex morphology reflecting multiple depositional and erosional episodes.

A classification of initial bar form types or 'unit bars' in the terminology of Smith (1974) is presented in Figure 3.12. This summarises the main morphology and structure of gravel bars present in braided fluvial channels as described by a number of authors (Williams and Rust, 1969; Rust, 1972; Smith, 1974; Boothroyd and Ashley, 1975; Hein and Walker, 1977; Miall, 1977). Smith (1978) considers it important to separate bars with simple depositional histories (unit bars) from those with complex depositional/erosional events. There does not appear to be much difference in terms of stratification between longitudal and diagonal bars, and infact Miall (1977) considers the term 'longitudinal bar' to be the main bar form finding it extremely difficult to separate these two bars in the ancient record. Longitudinal bars are thus characterised by massive or crude, horizontal stratification and upwards fining clast sizes developed from aggradation of diffuse gravel sheets under high flow stage. Fining upwards clast size also reflects decrease in clast size from the upstream part to downstream part of the gravel bar. Bluck (1971, 1976, 1979, 1980) describes the morphology and evolution of gravel bars within both present day Scottish rivers of low sinuosity, and ancient bar deposits (Old Red Sandstone) and distinguishes between the upstream 'bar head' to downstream 'bar tail' regions of mid-channel 'medial' (longitudal) and 'lateral' (diagonal) bank attached bars. Low flow stage modification of

the bar tail region deposits a variety of small deltas and a combination of sand and gravel sheets which infill cross-cutting 'transverse' channels on the bar surface. Careful palaeocurrent analysis of these sand sheets under conditions of good three-dimensional exposure will differentiate bank attached lateral bars (with an inner 'slough' channel) from medial, longitudinal bars in which sand sheets are deposited by currents converging from both of the bar margins. The reader is referred to Bluck's papers (op. cit.) for a detailed account of the formation and evolution of these gravel bars.

Unfortunately, a lack of good three-dimensional exposure inhibited an accurate determination of the exact in-channel position of the gravel bars within the Shap Red Beds. However, the predominance of massive conglomerates and also horizontal stratification in some units combined with prominent upward fining clast size strongly suggest that facies Gm reflects the accumulation of gravel as longitudinal bars. The association of facies Gm with facies Gp, Gm, St and Sh indicate that the gravel bars were modified by a variety of low flow stage processes depositing sand and gravel as sheets and channel-fill deposits in the finer downstream part of the bar (bar tail) and on the bar surface. These 'channel-bar-complexes' are examined more closely in Section 3.5, this term being used extensively throughout the present study.

3.2.2 Facies Gt

Facies Gt is characterised by trough-cross-bedded pebble and granule conglomerate forming units up to 60cm in thickness (Plate 3.5). Throughout each unit, clast size may fine up from rare boulders at the

base to granules at the top (facies Gt - tables 1,2). At Shepherd's Bridge, facies Gt contains abundant mud intraclasts up to 8cm, bulk sample X-Ray diffraction analysis of these demonstrating that the dominant clay mineral present is illite. Facies Gt commonly consists of two or more crudely defined trough-cross-bedded sets, between 15 and 20cm thick and grouped as a coset, overlying a massive conglomerate (facies Gm) basal unit (Figure 3.5a). Palaeocurrent vector means for facies Gt (Figures 3.2d, 3.5a) demonstrate palaeoflow varies from 353° to 050°. These palaeocurrents differ from those obtained from facies St where these facies are in juxtaposition, for example at Shepherds Bridge. The variation may be explained by deposition under different flow stages as flow wanes accompanied by decreasing water depth, palaeocurrents showing greater divergence.

Facies Gt is interpreted as gravel channel-fills, the close association with facies Gm, suggesting either infill of a main side channel or more appropriately (thin development of Shap; see Chapter 4) minor channels cross-cutting the gravel bar surface. The fact that facies Gt forms relatively thin cross-bedded cosets, suggests that it infills minor channels cross-cutting the gravel bar surfaces, probably resembling the cross-cutting channels infilled by trough-cross-bedded gravel described by Williams and Rust (1969) from the modern-day Donjek River, Yukon. Steel and Thompson (1983) describe the infill (facies Gt) of scour channels, cut at high flow stage on the bar surface and infilled during waning flow. Similar features have also been described by Coleman (1969, p.190) from the Brahmaputra River. Facies Gt has been recorded from the base of main channels, in the Knik River, Alaska and

in the North Saskatchewan Rivers by Fahnestock and Bradley and also Galay and Neil respectively (both in Rust and Koster, 1984). A similar interpretation was reached by Bryant (1983) in late Pleistocene river deposits, southern Britain, in which facies Gt reflects migration of dunes in 'first order' channels. In the present study, gravel bars accreted within shallow channels by the aggradation of diffuse gravel sheets during high flow stage. The relative thin development of facies Gt overlying facies Gm suggests that cross-cutting channels were only floored by migrating gravel dunes during waning flow stage. Further, the presence of mud intraclasts in facies Gt suggests erosion of nearby mud drapes deposited on the bar surface during previous lowest flow stage and protected in depressions from erosion during subsequent higher flow stage.

3.2.3 Facies Gp

Planar cross-bedded conglomerate is apparently rare in the Shap Red Beds, only being identified with confidence in the Wasdale Beck Section (Figure 3.4; Table 2). In this section, facies Gp forms a unit at the top of the section, containing crudely defined planar foresets in pebble conglomerate (average maximum clast size is 3cm), with foresets inclined towards 054°. It overlies horizontally stratified conglomerate (facies Gm) being separated from facies Gm by a thin (Table 9), discontinuous mudstone (facies Fm) drape.

The close association of facies Gp with facies Gm in this section suggests that these facies are genetically related, being probably deposited under similar conditions and within the same channel system.

In present day braided rivers, planar-cross-stratified gravel accumulates as transverse bars, the planar foresets accreted by avalanching down the bar slipface. For example, Hein and Walker (1977) identify gravel transverse bars from the Kicking Horse River and conclude that bars with prominent slip-facies can form within the same channel as longitudinal and diagonal bars. The main control on their development according to the these authors is the rate of sediment discharge (see Figure 3.12); in areas of lower sediment discharge, gravel aggrades at a faster rate vertically than aggradation in a downstream direction. As such greater bar relief is formed, and clasts will avalanch from the higher bar top, down the created slipface. Steel and Thompson (1983) describe planar-cross-stratified conglomerates (their 'lithofacies B conglomerate') from the Triassic Bunter pebble beds. These conglomerates have finer clasts-sizes than horizontally stratified conglomerate (facies Gm; their facies 'A' conglomerate) as also noted by Smith (1974) and Rust (1984), although other textural characteristics remain similar. Facies Gp within the Bunter pebble beds, is interpreted by Steel and Thompson (op. cit.) as representing lateral accretion of the subaqueous 'bar-platform' of a medial or longitudinal bar across the rifle into the channel pool (cf. Bluck, e.g. 1971, 1976).

Although facies Gp in the present study shows similar characteristics to the conglomerates described above, a lack of three-dimensional exposure inhibits accurate determination of lateral facies relationships, especially with facies Gm. However, it is suggested that facies Gp represents the modification of the margins of a

longitudinal gravel bar by the divergence of currents away from the bar axis on falling stage of flow (see Figure 10 of Rust, 1984), as proposed by a number of authors (Costello and Walker, 1972: Rust, 1984; Ramos and Sopena, 1983).

3.3 SANDSTONE LITHOFACIES

In a northerly direction, sandstones predominate over conglomerates and form the dominant part of fining upward sequences north of Shepherds Bridge, conglomerate being restricted to a single 'lag' unit near Docker Force (Figure 3.5b). Four main facies have been recognised in the present study, trough-cross-bedded (facies St), planar-cross-bedded (facies Sp), horizontally laminated (facies Sh) and ripple-cross-laminated sandstones (facies Sr), following the scheme of Miall (1977) and as shown in Figure 1.5. Facies data within this lithofacies are summarised in tables 4-8.

3.3.1 Facies St

This facies comprises trough-cross-bedded fine to medium grained sandstones. These form the main part of fining upward sequences north of Shepherds Bridge (Figures 3.5a,b) but are restricted to relatively minor cosets interbedded with facies Gm and facies Gt in the southern part of the area. Typical thin sections (see Appendix 3) of these sandstones show moderately well sorted texture with sub-rounded to rounded grains. Monocrystalline and polycrystalline quartz grains are the dominant grain types (e.g. 60% to 86%) with subordinate feldspars and rock fragments (greywacke and rare felsite grains up to 8.5%).

Compactional effects are shown by the squeezing of mud intraclasts (not as abundant as those contained within facies Gt) to form pseudomatrix. Quartz is the main authigenic mineral cement occurring as syntaxial overgrowths on quartz grains, outside 'clear' haematite dust rims. Small dolomite needle crystals were observed cementing some intergranular pores from samples from the Tebay Services section.

Trough-cross-bedded sandstones commonly occur as grouped sets (Plates 3.1, 3.2) or festoon cosets (cf. Miall, 1977) often up to 2-5m and 3m and probably over 5m in thickness, e.g. between Docker Force and Salterwath (Figure 3.5b). Individual cross-bedded sets are on average 20-25cm thick with some sets up to 35cm thick. Importantly, as demonstrated by the Docker force section, there is apparently little variation in set thickness throughout the coset. In excellent, 'plan-view' exposures of facies St, trough axes are seen to extend for more than 3m in a down 'palaeocurrent' direction with trough widths reaching 1.5m across (e.g. Shepherd's Bridge, Table 5, Plate 3.1). In such exposures (e.g. Tebay Services; Shepherd's Bridge to Salterwath), foreset angle of dip decreased from 26° at the back of the trough to sub-horizontal along the axis. Palaeocurrent readings, where possible, were taken along the trough axis, parallel with the direction of decreasing dip. Palaeocurrents (Figures 3.2d-e; 3.5b) show a marked unimodal distribution and a dominant palaeoflow direction towards the north and north-north-east.

Facies St is associated with other sandstone facies in the central and northern part of Birk Beck and with conglomerate facies in the

southern part of Birk Beck (Figures 3.2a-c). At the Tebay Services section (Figure 3.7, Plate 3.2), facies St occurs in two distinct set sizes (see Section 3.5) interbedded and laterally equivalent (along section strike) with facies Sp. In fining upward sequences along Birk Beck, facies St is overlain by facies Sh and Sr. South of Shepherd's Bridge, facies St occurs in relatively thinner (up to 2-2.5m) cosets, compared with sequences developed further north, overlying facies Gt and facies Gm with a 'scooped basal contact' and overlain by facies Sh.

Facies St is interpreted as the deposits of migrating dunes active under lower flow regime conditions, and forming festoon trough-cross-bedded sets which reflect the infill of both minor and more major channels (Ore, 1964, Eynon and Walker, 1974, Miall, 1977, Turner, 1982). The infill of minor channels generates relatively thinner festoon cosets, up to 2m to 2.5m thick, associated with a conglomerate unit (facies Gm) which records the deposition of gravel as longitudinal bars, sequences interpreted as 'channel-bar complexes'. Thicker festoon cosets, at least 5m in thickness (Docker Force to Salterwath) are considered to reflect the infill of larger scale channels these not apparently being associated with a basal 'longitudinal conglomerate' bar unit. The size of the coset is not generally a reflection of the size or depth of the original channel (B. Turner, 1984 pers. comm.), the factor, however that is considered significant in determining the scale of the 'palaeo-channel' is the presence or absence of longitudinal bar gravels (facies Gm). The presence of facies Gm indicates that deposition of gravel occurred in the main channel under high stage of

flow, and that sand accumulated in minor channels cross-cutting the bar surface on waning flow stage.

In meandering streams, the depth of water in the channel can be derived from sand member thickness of fining upward cycles (Turner, 1980), but the lack of fining upward sequence in braided river deposits involves a different method based on the mean height of cross-beds. The reader is referred to Turner (op. cit.) for a detailed discussion and evaluation of the palaeohydraulics of Upper Triassic braided stream deposits in the Karoo Basin of South Africa. In the present study, because of the limited amount of three dimensional data at outcrop, it is felt that a detailed hydrological study in the form of Turner (op. cit.) is unrealistic. However, using the equations for determining mean channel depth and width (Turner, op. cit), the minimum dimensions of some palaeo-channels as calculated from average thicknesses of trough-cross-bedded sets are presented below.

1. The mean height of large-scale ripples (dunes) is proportional to mean water depth (H) by the following relationship:

   H = 0.086 dm 1.19, where dm = mean cross-bed thickness

   Substituting: 1) SHEPHERD'S BRIDGE TXB COSET - dm = 25cm

   H = 2.15m

   2) DOCKER FORCE TO SALTERWATH TXB COSET - dm = 20cm

   H = 1.72m

   3) Large-scale TXB AT TEBAY SERVICES, dm = 33cm

   H = 2.84m

2. Width of channels is estimated from the width to depth ratio (F) given by the equation:

$F = 255/M - 1.08$, where M is the 'sediment load parameter', or the percentage of silt and clay in the channel margins (Turner, 1980, Richards, 1982). Thus channels with silty banks are narrow and deep while sandy channels are wide and shallow. Following Turner (1980), a typical value for M is 5%, which is based on coarse sand bed load channel deposition within channels containing less than 10% gravel. Substituting this value, the width to depth ratio is 45.

This then gives an estimated width of the channels (1-3) as follows:

1) Depth = 2.15m, Width = 96.75m
2) Depth = 1.72m, Width = 77.4m
3) Depth = 2.84m, Width = 127.8m

The data above, therefore suggest that facies St records the infill of shallow and wide river channels, the channel dimensions comparing to a certain extent with channels from the south Saskatchewan River, Canada, in which channels average 3 to 5m in depth (Cant and Walker, 1976, Cant, 1978, 1982, Walker and Cant, 1984) and 150m wide.

3.3.2 Facies Sp

Facies Sp comprises planar-cross-bedded fine to medium grained sandstone, occurring mostly in isolated sets, 50cm to probably at least 2m in thickness and interbedded with facies St. In the Tebay services Section (Figure 3.7), medium grained planar-cross-bedded sandstones, occur in sets up to 80cm thick, forming a coset, 2m in thickness. Planar foresets have a high (12° to 27°) angle of dip with foresets base varying from angular to tangential (asymtotic). Facies Sp is mainly present along Birk Beck, especially between Shepherds Bridge and Docker Force (Figures 3.2d-e, Tables 5-7) and also at Shap summit (Table 8) and Tebay Services (Table 8, Figure 3.7). In thin section, facies Sp (Salterwath section) shows medium grained sandstone with a moderately sorted texture with monocrystalline and polycrystalline quartz the dominant (up to 78%) grain types. Greywacke rock fragments up to 3mm across are also present. Quartz grains are well cemented by syntaxial quartz overgrowths outside 'clear' haematite dust rims, which show that quartz grains are commonly well rounded. Dolomite is present (minor amounts) as a replacive and displacive intergranular cement, as is kaolinite which infills some intergranular pore spaces.

Palaeocurrent readings from facies Sp are shown in the facies tables (5-8) and against appropriate measured sections (Figures 3.5a,b, 3.7). Commonly, vector mean determinations differ markedly from those obtained from facies St, clearly evident at the Tebay services section (Figure 3.7). Here, facies Sp has a mean dip direction towards 317°, compared with 012° measured from facies St. Generally, however, the mean dip direction of planar foresets shows a general north-west to

north-east orientation. Facies Sp is most commonly associated with facies St, but also with facies Sh, seen at Tebay Services, where horizontally laminated silty fine grained sandstones form a drape unit inbetween two planar cross-bedded sets. Also, at Salterwath (Figure 3.5b; Plate 3.7), facies Sp is seen to be interbedded with sheet-like units of facies Sh.

Facies Sp is interpreted as the deposits of sandy transverse bars, produced by the avalanching of sand grains down a slipface at the downstream margin of the bar. Collinson (1970) describes transverse (linguoid bars) bars from the Tana River, Norway. The bars are sharply convex in the downstream direction with well-defined downstream margins. Barsides become parallel to the flow direction, and develop slipfaces from 50cm up to 2m high. Cant and Walker (1976), Walker and Cant (1984), and Cant (1978, 1982) describe transverse bars of 'various sizes' developed at different topographic levels within the braided South Saskatchewan River, Canada, and which generate planar-cross-bedded sets, less than 1m to up to 3m in thickness depending on the scale of the transverse bar. In the Platte River, Colorado (Smith, 1970), tabular, transverse bars are the dominant bedform, developed under flow conditions of relatively less steady discharge and little topographic expression in the channel. In contrast, in conditions of more steady discharges and higher degrees of in-channel, topographic expression e.g. in the South Saskatchewan River, channels are floored by sinuous crested dunes, and contain cross-channel bars and 'sand flats' developed on the emergent bar tops. The abundance of trough-cross-bedding as opposed to planar-cross-bedding in the Shap Red Beds is thus thought to be due to

deposition in shallow and wide channels which had topographic expression and probably had steady discharges. It may also be due to the constant shifting of shallow and wide channels, which largely removed any transverse bars that may have developed (cf. Turner, 1982).

Also included within facies Sp is a planar-cross-bedded lenticular sandbody up to 1.35m thick and exposed mid-way between Shepherds Bridge and Docker Force (Plate 3.8; Figure 3.5a; Table 6). Foresets are sigmoidal in shape, have an asymptotic base and dip at 10° towards 120° 'pinching-out' in the opposite direction. The southerly extent of the sandbody (at least 40m long), is masked by slumped material, but red, silty fine grained sandstones (facies Fl/Sr) which have fallen from the sandbody at its southerly point contain syneresis cracks (Plate 3.6) which are characterised by delicate 'eye-shaped' features which radiate from a single point and resemble a 'birds-foot' (compare Plate 3.6 with Figure 2 of Donovan and Foster, 1972). These syneresis cracks are a form of subaqueous shrinkage crack formed by the expulsion of pore water at or near the sediment/water interface (Donovan and Foster, 1972) which caused the clayey sediment infilling the cracks to suffer a volume decrease (Leeder, 1982a). Compaction of this sediment, causes crenulation normal to the depositional surface. Clemmey (1978) records syneresis cracks from the Precambrian Kitwe Formation, Zambian Copper Belt and suggests that they are characteristic of sheltered shallow water lacustrine environments. This fine grained facies apparently overlies shallow sets (10-15cm thick) of trough-cross-bedded fine grained sandstone (facies St, Table 6) which has a palaeoflow trend of 032°-212°.

The association of the sigmoidal planar cross-bed foresets and the highly lenticular shape of the sandbody with the palaeoflow orientations obtained from this facies and facies St, suggests that facies Sp resembles the epsilon-cross-statification of Allen (1963). The sandbody probably represents deposition on a point-bar surface within a laterally accreted meandering channel, in which the direction of lateral accretion was perpendicular to palaeoflow within the channel as shown by facies St in this section. In this context, the structures present resemble the deposits of classical point-bar meandering streams described by a number of authors (e.g. Allen, 1963, Leeder, 1975, Collinson, 1978, 1986). The fact that the sandbody is interbedded with fine grained, silty and cross-laminated sandstones (facies Sr) adds further support to this interpretation, as cohesive sediment adds stability to channel banks promoting lower width:depth ratios and the migration of meandering stream courses (Ore, 1964; Cant, 1982).

Facies Sp is directly overlain by a carbonate horizon, 15cm, thick, which, in thin section, shows textures attributed to nodular pedogenic calcrete development (see Chapter 2). Displaced silt-sized detrital quartz grains are surrounded by a microcrystalline mosaic of dolomite and calcite veins which resemble the crystallaria veins described by Wright (1982). In terms of the classification of Steel (1974b; Figure 2.8), as discussed in Chapter 2.2, this nodular calcrete horizon may be equivalent to stage 1 and 2, not containing features characteristic of a 'mature' profile (cf. Hubert, 1977; Allen and Williams 1979; Allen et al., 1981). The significance of calcrete above the channel is discussed in section 3.5.3 but indicates that climate was most probably semi-arid

with seasonal precipitation between 100mm and 500mm (Reeves, in Hubert, 1977). In fact Gile and Hawley (in Leeder, 1982a) have shown by radiocarbon dating that thick, mature calcretes take up to 10^4 years to develop, and although it is not thought that this thin horizon resembles a mature profile, clearly the position above facies Sp in this section implies abandonment of the area containing the channel through sediment starvation and probably for a considerable length of time.

3.3.3 Facies Sh

This lithofacies is mostly exposed along Birk Beck and forms good outcrop especially between Shepherd's Bridge and Docker Force (Tables 5-7; Figures 3.2d-e, 3.5a,b) and also at Salterwath (Table 7. ; Figure 3.5b; Plate 3.7). At the Salterwath section, facies Sh forms distinct sharply based and well-bedded units up to 94cm in thickness with a sheet-like geometry. These, mainly fine to medium grained sandstones are horizontally laminated, containing laminae about 0.5cm thick and some contain a primary current lineation, exposed on bedding plane surfaces. Palaeocurrent trends from these lineations predominantly give north to south trends (e.g. 164°-344° - Salterwath; 179°-359° - Shepherd's Bridge to Docker force; 178°-358°-Beckside to Scoutgreen).

Facies Sh also occurs as silty, horizontally laminated units, similar to those described above but which lack a primary current lineation. Such units, e.g. Salterwath (table 7, Figure 3.5b) fine upward into silty, fine grained sandstones containing current ripples (facies Sr). Extremely finely horizontally laminated, very fine grained sandstones also form thin, 10-15cm thick, wedge drapes in between

planar-cross-bedded sandstone sets (facies Sp - Tebay Services, Figure 3.7; Table 9) and also occur as units which separate massive conglomerate (facies Gm) beds (e.g. Stakeley Beck, Figure 3.3).

Horizontally laminated sandstones form under two hydrological conditions: under shallow water depths and high flow stage (Miall, 1977). Tunbridge (1981) describes braided fluvial sequences characterised by horizontally laminated sandstones in the Brownstones (Lower Old Red Sandstone) of South Wales, these being deposited by sheetfloods, under high flow stage. Fluvial experiments by Harms and Fahnestock (1965) have shown that horizontally laminated sandstones with primary current lineation are deposited under upper flow regime conditions in relatively shallow water depths. In such conditions grains move over the bed surface which becomes a 'traction carpet' (Miall, 1977). In the Malbaie sandstones, of Middle Devonian age, Rust (1984) describes horizontally laminated sandstones transitional to low angle (less than 10°) planar-cross-bedded sandstone, these being infilled ellipisoidal scours deposited under shallow, high velocity flow, the shape of the scours being determined from primary current lineation trends. Turner (1982) considers similar horizontally laminated sandstones to those of the present study, which overlie trough-cross-bedded sandstones and contain a primary current lineation, to be formed during falling stage from the transition between lower and upper flow regime plane beds on the shallowing channel floor. The lack of detailed three-dimensional exposure inhibits an interpretation similar to Rust's (1984) but the position above trough-cross-bedded sandstones suggests an interpretation similar to that of Turner (1982)

is appropriate. Furthermore, the palaeocurrent trends determined from the primary current lineation within some facies Sh units, being similar to palaeocurrents obtained from St suggests a close association between these two facies, deposition occurring within the same channel complex.

Where facies Sh forms thin beds (50cm thick) above facies St and facies Gm in the southern part of Birk Beck (e.g. Beckside to Scoutgreen, Table 5; Figures 3.2a-c), these resemble the 'Sand Wedge Units' of Rust (1972), described from the River Donjek, Yukon, and deposited during falling stage on the longitudinal gravel bar surface. Alternatively, these horizontally laminated sandstones may have been deposited as 'digitate sand sheets' interfingering with gravel deposited on the distal 'bar tail' region of gravel bars (cf. Bluck 1976, 1980). The position above facies St, however, which has been interpreted as the infill of minor channels cross-cutting the bar surface (see sections 3.3.1; 3.5.2; 3.6), suggests that facies Sh was deposited as sheet-like units during falling stage and over the shallowing channel floor.

Horizontally laminated silty sandstones lacking current lineation and occurring as thin (10-50cm) 'wedge drapes' interbedded with facies Gm (e.g. Stakeley Beck, Figure 3.3; Table 4) and facies Sp (e.g. Tebay Services, Figure 3.7) are thought to reflect deposition from plane beds within the lower flow regime and during lower flow stage (cf. Kirk, 1983). At Salterwath (Table 7; Figure 3.5b), the transition from current lineated sandstones to sandstones lacking current lineation and overlain by current ripples (facies Sr) adds support to this interpretation and indicates that these sequences were most probably a

result of waning flow sedimentation during flood 'pulses' (cf. Turner, 1982; Kirk, 1983; Tunbridge, 1981, 1984).

3.3.4 Facies Sr

This facies occurs near the top part of fining upward sequences overlying facies Sh and St but underlying siltstones and mudstones (facies Fl/Fm). Facies Sr comprises very fine, fine and locally medium grained current rippled-cross-laminated sandstones forming cosets up to 1.8m in thickness (Shepherd's Bridge to Docker Force, Unit 6, Table 6). Current ripples can be defined as 'periodic bedforms, of an asymmetrical longitudinal profile and arranged transversely to the current and whose height does not exceed 5cm' (Allen, 1966, p.156). Cross laminated sandstones occurring between Shepherd's Bridge and Docker Force, lateral to the laterally accreted channel unit (Table 6; Figure 3.5a; section 3.3.2) with set heights up to 10cm thick can probably be defined as 'megaripples', as indicated by Allen (op.cit.).

The association of facies Sr with facies Gm, as thin drape units (e.g. Hollin Gill, Figures 3.2c; Table 4) and above facies St and Sh, reflects deposition under lower flow regime and during low flow stage conditions.

3.4 SILTSTONE AND MUDSTONE LITHOLOGIES (LITHOFACIES F)

Siltstones and mudstones occur at the top of fining upward sequences. In the field, these deposits are largely associated with pools of deep water along Birk Beck, only seen exposed at a few

localities (e.g. Shepherd's Bridge to Docker Force, Units 1,2; Table 9). Lithofacies F is subdivided into two subfacies, laminated siltstones and mudstones (facies Fl) and thin drape units (facies Fm).

3.4.1 Facies Fl

Silty mudstones, normally associated with deeper pools of water as mentioned above, are seen at outcrop at Scoutgreen (Table 9) interbedded with thin pebbly sandstone units (50cm thick), and containing possible syneresis cracks and calcareous nodules (less than 0.5cm across). These nodules may be incipient calcrete nodules, equivalent to stage I of Steel (1974b; Figure 2.8). Red silty mudstones are also exposed at the top of the Stakeley Beck Section (Table 9; Figure 3.3) and again these contain probable calcrete nodules.

In the cliff section (Table 9; Figures 3.5a, Plate 3.4), just north of Shepherds Bridge, laminated silty mudstones, interbedded with thin fine grained sandstones, (facies Sh) overlie and underlie a pebbly conglomerate unit, (facies Gm), interpreted as the deposit of a longitudinal gravel bar. The position of facies Fl immediately above facies Gm, indicates accretion of a bar and subsequent abandonment as bed-load sediment was diverted elsewhere. Facies Fl also 'plugs' the laterally accreted channel sandbody (facies Sp, Section 3.3.2) outcropping between Shepherds Bridge and Docker Force (Figure 3.5a; Plate 7.8). As described before (Section 3.3.2), these deposits contain syneresis cracks (Plate 3.6).

This facies accumulated from suspension in overbank (inter-channel) areas during lowest flow stage as flood waters receded. Thicker sequences containing pebbly sandstone units record deposition from over-bank flood events, sourced from the main active channels. The presence of syneresis cracks indicate that temporary ponded waters may have existed after flood events which later dried out. The fact that calcrete nodules appear in some sections indicates that areas of the floodplain were kept free of sediment input for considerable lengths of time (see Section 3.3.2).

3.4.2 Facies Fm

Thin wedge-shaped mudstone units reflect deposition from suspension during lowest flow stages occurring mainly as 'drapes' on gravel bar surfaces (e.g. Wasdale Beck, Table 9).

3.5 ENVIRONMENTAL INTERPRETATION

The distribution of the three main lithofacies along Birk Beck and the adjacent tributary streams is shown in Figure 3.9. From this diagram, it can be seen that five facies associations can be recognised which correspond to five 'facies zones'. Tectonic dip in the area is estimated at 5° towards an easterly direction and suggests that the Shap Red Beds 'young' in this direction, as supported by palaeocurrent measurements, which indicate consistent palaeoflow towards a north to north-north-east direction. In this way, it is thought that facies Zone 4 is perhaps stratigraphically the highest facies zone and overlies

previous zones. The stratigraphic position of zone 5 is tentatively considered to be laterally equivalent to zones 2 and 3.

Due to the lack of vertical sections, the exact thickness of the Shap Red Beds along Birk Beck is therefore extremely difficult to determine but it is thought that the thickness might lie in the order of 55m to 60m although it seems that thickness in the Tebay region may be in the order of ca.130m. This value is in direct contrast to Capewell (1955) who believed the thickness to be about 900 feet (approximately 300m). The reason for this discrepancy may be that Capewell (op.cit.) did not take into account lateral facies relationships, as shown to exist in previous sections which demonstrate that, for example, conglomerates are genetically related to sandstone, the two lithofacies forming parts of channel-bar complexes. Instead, Capewell considered his three 'lithological groups' (Lower Conglomerate Group, Red Sandstone Group and Upper Conglomerate Group) to be distinct lithological 'units' which succeed each other vertically (Capewell's Upper Conglomerate Group is discussed in Chapter 8). In considering the Shap Red Beds in terms of lithofacies, it is believed they can be interpreted as a 'package' of clastic sediment deposited by a variety of channels and bars and accumulating fine grained deposits in overbank areas.

3.5.1 Birk Beck Section (Figure 3.9)

As outlined above, this section comprises facies Zones which are generally associated with fining upward sequences. Each zone is discussed in environmental terms in the following sections.

3.5.1.1 Zone 1 (Figures 3.2a-c)

Zone 1 is dominated by massive cobble and boulder conglomerates (facies Gm) with subordinate interbedded cross-bedded conglomerates (facies Gt) and sandstones (facies St). The Zone occupies the most southerly outcrops of Birk Beck and is overlain by Zone 2 at Beckside and Zone 5 east of High Steps Farmhouse. The dominance of facies Gm indicates that Zone 1 was an area in which gravel accumulated on longitudinal bars by the probable vertical aggradation of diffuse gravel sheets (cf. Hein and Walker, 1977; Bryant, 1983, Ramos and Sopena, 1983). The apparent absence of planar-cross-bedded gravel (facies Gp) suggests that foreset margins to the bars did not develop (cf. Eynon and Walker, 1974) and that sediment discharge must have been relatively high (cf. Hein and Walder, 1977) with maintainance of high flow stage (cf. Ore, 1964).

Near to Greenholme, trough-cross-bedded (facies St) sandstones are associated with facies Gm. These sandstones probably reflect the migation of dunes during waning flow within a minor channel, cross-cutting the surface of a gravel bar. Similar deposits have been described by Bluck (1976), Vos and Tankard (1981), and Ramos and Sopena (1983), the latter authors describing channel-bar complexes from Permian and Triassic rocks, central Spain. Over the area between Greenholme and Beckside towards Hollin Gill and Ewelockbank, the slope of the unconformity dips gently away from the West and South (section 2.2). The slope of the unconformity and the fact that similar gravel deposits are exposed at Ewelock Bank and Hollin Gill suggests that sedimentation throughout Zone 1 remained quite consistent. Outcrops in these two sections are very poor and measured sections are not presented.

However, facies Gm apparently comprises stacked boulder and conglomerate units deposited as longitudinal gravel bars. Only minor development of interbedded sandstones reflects local deposition at lower flow stage within minor channels and in the lee or 'bar tail' region of the bars (cf. Bluck, 1976).

Facies Gt, forms a unit at least 60cms thick, overlying facies Gm at Beckside and is interpreted as the infill of a channel, probably cut at high-flow stage and infilled during the initial stages of waning flow when the flow was still competent enough to transport pebble and granule sized clasts but prior to infill by sand (?not exposed).

At Beckside Bridge, poorly exposed gravel (facies Gm) and cross-bedded sandstone (facies St) the latter containing mud intraclasts are interbedded forming two fining upward sequences up to 85cms thick. A similar sequence near to High Scales is capped by horizontally laminated sandstone (facies Sh). These sequences are interpreted as representing the infilling of minor channels or shallow depressions in the lee of a gravel bar. They resemble the sequences described by Rust (1978b, 1981, 1984) for the upper member of the Cannes de Roche Formation, of Carboniferous age, Gaspe Canada, and the channel bar complexes of Vos and Tankard (1981). Vos and Tankard (op.cit.) attribute pebbly cross-bedded sandstone above conglomerate units to reflect the lateral and vertical infilling of channels and scours during waning flood stages and low water stages (sand-filled chute channels, sand wedge slipface and bar top sheet sand facies relationships). The reader is referred to fig. 12 of their paper (1981) for a reconstruction

of a 'longitudinal bar complex' from the Piekenier formation (Lower Palaeozoic), Cape Basin, South Africa. The deposits may also resemble facies relationships deposited in the bar tails of gravel 'medial bars', described by Bluck (1971, 1976) for Scottish present day braided streams.

3.5.1.2 Zone 2 (Figure 3.2b)

This facies zone forms an extension of facies 1 and generally shows similar facies relationships. However, siltstones and mudstones (facies Fl) are present at the top of the zone, exposed at Scoutgreen and forming the top of the overall fining upward sequence comprising facies Zone 2. Facies St comprises a festoon coset 2.5m thick, overlying thin development of facies Gt and facies Gm (at least 50cms thick) at the base of the zone. Facies Gt contains crudely defined shallow (10-15cms) trough-cross-bed sets with mud intraclasts and possibly forms a basal lag unit to the trough-cross-bedded sandstones above. The presence of mud intraclasts suggests erosion of mud, deposited as drape deposits during the low flow stage of previous flood events. These facies relationships are interpreted as reflecting the infill of a minor channel (facies Gt, St) cross-cutting a longitudinal bar surface (facies Gm). Dunes occupied the channel on falling stage of flow (Cf. Boothroyd and Ashley, 1975, p.203) when, on bar emergence flow was diverted from the main channel into minor channels dissecting the bar surface. The presence of facies Gt underlying facies St suggests infill of the channel in a position closer to the gravel bar with deposition probably under high stage of flow (as suggested in Zone 1 for similar deposits at Beckside). Facies St is overlain by thin (up to 50cms thick) pebble and

granule conglomerate interbedded with horizontally laminated sandstones (facies Sh) and isolated sets of facies St. This part of facies Zone 2 is extremely poorly exposed but the facies present resemble those facies relationships present at the top of Zone 1, near to Beckside and High Scales.

Facies Fl/Fm at the top of the sequence records the abandonment of the channel bar complex network when the whole active channel system had migrated away from the area, leaving inactive areas accumulating fine grained sediments deposited from suspension (cf. Rust, 1972, 1978b, 1981, 1984, Miall, 1970, 1977, 1978; Figure 3.10). Similar fining upward sequences have been described by Rust (op.cit.) for the Upper Member of the Cannes de Roche Formation, Gaspe, which he compares with the 'mid-reaches' of the River Donjek, Yukon. The presence of incipient calcrete nodules within facies Fl, seen at Scoutgreen supports the interpretation for abandonment; calcrete only forming in areas of very low or zero sediment input. However, as noted in section 3.4. interbedded pebble conglomerate units in the Scoutgreen section, record the deposition from flood events which did input sediment into the overbank area, inhibiting the development of a mature calcrete profile.

3.5.1.3 Zone 3 (Figure 3.2d)

This zone extends from Shepherd's Bridge to mid-way to Docker Force, the top of the zone taken at the top of the silty mudstone interval above the laterally accreted channel sandbody shown in Plate 3.8. Zone 3 (Figure 3.5a) consists of a composite fining upward sequence (at least 11m-12m thick) comprising stacked longitudinal gravel

bar-channel complexes (at the base) overlain by a stacked sequence of channel-fill sandstones (facies St/Sh) and capped by silty sandstones/mudstones, the latter recording the abandonment of the active channel tract.

The section along Stakeley Beck (Figure 3.3) occurs in the Southern part and, stratigraphically the base of facies Zone 3. It consists of stacked massive, imbricated boulder and cobble conglomerate (facies Gm) reflecting deposition on longitudinal bars under high flow stage within the main active channel. They are thus considered to be very similar to the interpretation of facies Gm in zones 1 and 2. The occurrence of facies Gp in this section suggests that, in part at least, downstream margins of some gravel bars were modified during falling stage of flow and possibly under relatively lower sediment discharge when bar relief had reached a certain height in relation to the depth of water for slipface formation to commence (cf. Rust, 1972, 1984; Hein and Walker, 1977; Ramos and Sopena, 1983). Horizontally laminated silty sandstones (facies Sh) were deposited as sand wedge drapes under lower flow regime plane bed conditions during lower flow stage (cf. Rust, 1972; Miall, 1977), these being preserved at a probable topographically higher level (see Section 3.6) on the bar surface due to protection from erosion from subsequent higher flood stage.

Facies Gm in the top part of the Stakeley Beck section has a well developed imbrication with B axes of some clasts imbricated towards 315° (Plate 3.3) and is overlain by trough-cross-bedded granule conglomerate (facies Gt) which contain abundant pebble-sized mud intraclasts. At

Shepherd's Bridge, approximately 200m to the east, similar facies relationships are present. Here, facies Gt (Plate 3.5) is overlain by facies St which forms a festoon coset, 2.5m thick, the palaeocurrents varying from 333° to 005°. These facies relationships are interpreted as the infilling of minor cross-cutting channels, marginal to longitudinal gravel bars (cf. Vos and Tankard, 1981, p. 181, 183) similar to those present in facies Zone 2. It is considered that facies St records the infill of minor channels flowing across the gravel bar surface (presence of facies Gm at the base). While facies Gt records the initial infilling of a minor channel in a more proximal part of the 'bar tail' region. Most likely the change from gravel to sand reflects deposition under higher stage of flow (cf. Bryant, 1983) than sands occurring in more distal parts. The difference in stage of flow is reflected in the palaeocurrent variance between facies Gt (350°, 003°) and facies St (333°, 005°), the wider distribution in facies St expected as, under lower flow velocities, water depth would be reduced and greater variance in current direction would result.

Facies St is overlain by a sequence, probably between 2m and 3m in thickness, comprising horizontally laminated sandstones (facies Sh) probably transitional to facies Fl (silty mudstones) above. This sequence records migration of the active channel tract away from the area leaving the 'old' channel-bar complex accumulating fine grained deposition from overbank flooding. The author notes, however, that alternatively the facies Fl may record the infilling of a slough channel on the 'bank' side of a laterally attached bar, as described by Bluck (e.g. 1976). However, whilst this remains a possibility, the relatively

poor exposure does not allow accurate enough palaeocurrent measurement to delineate the main channel from infilling of a 'slough' channel.

The abandonment sequence above the channel-bar complex, contains a stratified pebble conglomerate unit showing fining upward clasts size and is overlain by facies Fl. The sequence has been discussed in section 3.4.1 and is interpreted as the abandonment of longitudinal bar (Plate 3.4).

Between this point, approximately 200m north of Shepherds Bridge, and the top of Zone 3, facies St is the dominant facies present, with subordinate development of facies Sh. Palaeocurrent measurements for this part of the section derive vector means of 017° and 026° for facies St with a primary current lineation trend of 359°-179° for facies Sh. Facies Sh might be interpreted as the deposits of high velocity sheetfloods as described by Tunbridge (1984) for the Devonian Trentishoe Formation of North Devon. However, considering the thickness of facies St (at least 2-3m in thickness) it is thought that facies Sh, rather than reflecting deposition by single event sheetfloods, represents deposition of sand from upper flow regime plane bed under shallower water depth in the channel during waning flow stage (cf. Turner, 1982). It is thought that the apparent absence of interbedded facies Gm units in this part of facies Zone 3 reflects the gradual dominance of sand deposition in the main channel tract compared with gravel in facies Zones 1 and 2 and at the base of Zone 3.

The cliff section, 6m - 7m high, at the top of zone 3 (Plate 3.8) has been discussed in previous sections (3.3.2 and 3.4.1). It comprises mainly fine grained silty and current rippled sandstones (facies Sr) and contains a laterally accreted sandbody (facies Sp) near the top, 'plugged' by facies Fl which contains syneresis cracks. The channel sand is capped by a thin (15cm thick) nodular calcrete horizon. The channel was oriented 032° to 212°, thus showing a marked divergence from facies St deposited in the main channel below (oriented towards 354°). Using the method of Leeder, 1973b, an estimate of bankfull depth of the palaeo-channel (height of last recognisable lateral accretion surface) is 1.3m-1.5m, while two-thirds bankfull width would be at least 10m-11m. The significance of the section shows in detail the processes acting within an 'inactive' part of the channel system (see Figure 3.11). Sediment accumulated from waning overbank flooding (cf. Miall, 1970, 1977) as the flow in main channel was diverted elsewhere. Calcrete horizons point to the temporary starvation of the area from sediment input, but the return to fine grained sediment deposition immediately above indicates that the overbank area must have been a permanent site of overbank deposition for a long period of time. The establishment of a migrating high sinuosity channel shows that semi-permanent flow was able to develop at certain times within 'overbank' or channel margin areas. The presence of silty sediment gives a high degree of cohesiveness to channel banks promoting a highly sinuous channel pattern (Miall, 1970, 1977). The channel was eventually 'plugged' by silty mudstones, accumulated through gradual deposition from suspension, the presence of syneresis cracks providing an

indication that temporary 'ponds' must have developed at certain times on the floodplain surface.

Significantly, therefore, the top of Zone 3 records the abandonment of a channel 'system', by the lateral migration of the active channel leaving an 'inactive channel' area which accumulated fine grained sediment.

3.5.1.4 Zone 4 (Figures 3.2d-3; 3.5b)

Zone 4 extends mid-way between Shepherd's Bridge and Docker Force to Wasdale Beck, adjacent to Shap wells. Thickness of clastic sediment between Docker Force and Salterwath is at least 10m. The base of facies Zone 4 is marked by a laterally continuous cross-bedded unit (facies Sp), up to 2m thick, containing planar foresets dipping towards 359°. It is poorly exposed at the side of Birk Beck for approximately 250m and forms the base of the waterfall at Docker Force. Overlying facies Sp, is a thick festoon coset, at least 5m in thickness, of trough-cross-bedded fine to medium grained sandstones (facies St) which outcrops along the bed of Birk Beck up to Salterwath. Palaeocurrent vector means of facies St show a marked consistent, unimodal northerly distribution (003°-355°). Interbedded with facies St are planar-cross-bedded sandstones (facies Sp), approximately half-way through the sequence and these give palaeocurrent reading of 068° and 098°, clearly highly oblique to the considered main channel trend, observed from facies St.

This sequence is interpreted as the aggradation of sandy bed load channels, considering the absence of facies Gm. Channels were floored

by migrating dunes (facies St) in which sandy transverse bars (facies Sp, up to 60cms thick) were locally established. The thick development of facies Sp at the base is not clearly understood. The palaeocurrent pattern by being very similar to facies St, the main channel trend, is not consistent with oblique 'building' of transverse bars against the channel trend (cf. Collinson, 1970, Miall, 1977) such as those clearly shown by facies Sp higher up within the sequence. It may be that facies Sp at the base resembles the larger scale 'cross-channel' bars of Cant (e.g.1978), developed at channel junctions in the South Saskatchewan River. These slip-faced bounded bars form larger scale units up to 3m thick. The fact that the palaeocurent orientation is very similar to facies St, may probably be due to aggradation at similar stage of flow. Significantly, however, the presence of two distinct facies Sp units, distinguished on size, suggests that smaller units accreted at higher topographic levels, as in the South Saskatcehewan River (Cant, 1978, 1982, Cant and Walker, 1976).

At Salterwath, (Plate 3.7) more evidence that topographic differentiation existed is seen in the dominantly horizontally laminated sandstone (facies Sh) sequence, 4m thick, interbedded with facies Sr and facies Sp. Facies Sh overlies facies St and at the base contains a primary current lineation trend of 164°-344°. Approximately 1.8m above the base of the sequence (Figure 3.5b), current rippled fine grained sandstone (facies Sr) fines up from horizontally laminated silty sandstone.

The sequence is compatible with deposition from waning flood pulses. Facies Sh with prominent primary current lineation reflects deposition under upper flow regime planar bedflow over the shallowing channel floor during waning flow conditions. Further waning of flow produced bedforms representing transition from upper flow regime plane beds to lower flow regime plane beds (silty, horizontally laminated sandstones) and overlain by current ripples deposited under lower flow regime conditions (cf. Miall, 1977; Turner, 1982; Kirk, 1983; Tunbridge, 1984). Small, sandy transverse bars or probable sand waves developed at low flow stage possibly within minor channels at higher topographic levels (facies Sp). Facies Sh above, records the flow of upper flow regime plane beds over the smoothed top to the small bars (shown by the sharp top contact to facies Sp). This sequence strongly resembles the sand-flat sequence described by Cant (1978, 1982) and Walker and Cant (1984) for the South Saskatchewan River and the Battery Point Formation of Devonian age by Cant and Walker (1976). Sandflats form over the top of cross-channel bars on emergence and thus occur at topographically higher levels within the channel system. Flood deposits accrete a variety of bedforms over the top, including transverse bars, sand waves, current ripples and horizontal lamination, in response to waning flow. Although insufficient three-dimensional exposure has not allowed detailed enough study of the facies relationships, it is suggested that the section does compare favourably with the facies developed in sandy braided streams, especially those in the South Saskatchewan River.

North of Salterwath, facies St is poorly exposed but predominates over other facies, and, it is thought, reflects infill of similar

channels through this area. At Shap Wells, facies St overlies the stratified and cross-bedded conglomerate units (facies Gm, Gp; Figure 3.4) exposed along the classic section at Wasdale Beck. These conglomerate units are interpreted as the aggradation of longitudinal gravel bars, with slip-face margins developing planar-cross-bedded conglomerate units at lower flow stage and lower sediment discharge (cf. Ramos and Sopena, 1983; Bryant, 1983). Individual bar units are delineated by sand wedge units (facies Sp) and mudstone drapes (facies Fm).

3.5.1.5 Zone 5

This facies Zone is represented by the section outcropping along Micklegill Beck (Figure 3.6) in the southern part of the area. Stratigraphically, its position is unclear although it may equate with Zones 2 or 3. The sequence is dominated by sandstone lithofacies reflecting the infill of sandy braided channels. Turner (1982) explains the lack of planar-cross-bedding (facies Sp) in braided streams as a result of erosion, the removal of these bars being caused by constant lateral shifting of channels. Facies Sr present in some parts of the section reflects deposition under lower flow regime during low flow stage conditions. The top of the section does show a fining upward trend, overlain by more massive and silty fine grained sandstones these overlain by green coloured calcarenites (see Chapter 8).

3.5.2 Blea Beck Section

The section along Blea Beck, north of Shap Wells (Figure 3.2e) is very poorly exposed and the accurate determination of facies relationships

has not been possible. Nevertheless, isolated outcrops show that a pebble conglomerate (facies Gm) forms a basal unit underlying possible trough-cross-bedded fine grained sandstones (facies St). Underlying facies Gm, current rippled sandstone (facies Sr) gradationally overlies silty horizontally laminated sandstones (facies Sh) which are banked up against a ridge of acidic volcanic rocks belonging to the Ordovician Coniston Limestone Group (sections 1.6; 2.2). The observed facies resemble the relationships described along Birk Beck and interpreted as the deposits of channel-bar-complexes.

3.5.3 Shap Summit Section

The top part of the section (Figure 3.13; Plate 8.2) is discussed in environmental terms in Chapter 8. The base of the section consists of crudely horizontally stratified pebble to cobble conglomerate (facies Gm) unconformably adjacent to a palaeo-ridge of Borrowdale Volcanics, described in section 2.2. The Shap Red Beds are ca 11m thick, overlain by deposits equivalent to the Pinskey Gill Beds (Chapter 8). Above facies Gm, planar-cross-bedded fine grained sandstones (facies Sp) form a coset, 2m thick comprising sets, 20-25cms thick. These facies relationships are thought to reflect the infill of a channel, by a sandy transverse bar, cross-cutting a gravel bar surface. The sand unit resembles the sand wedges of Rust (1972).

3.5.4 Ellergill Beck Section

This section (Figure 3.8) exposes similar facies relationships to those interpreted as channel-bar-complexes along Birk Beck (facies Zones 1 to 3). Cobble to boulder conglomerates (facies Gm-table 3) are

crudely horizontally stratified forming a unit, at least 80cm thick, with clast supported framework and coarse sand infilling matrix. Facies Gm represents accumulation of gravel deposited during high flow stage across the bar surface.

Above the basal conglomerate, facies Gm is overlain by cobble conglomerates exposed in a small cliff, at least 2m high. In the basal part, conglomerates form crudely defined trough-cross-bedded sets up to 15cm deep (facies Gt) in which larger clasts are concentrated at the base of each trough set. The position of facies Gt above facies Gm is thought to represent infill of scours or minor channels on a longitudinal bar surface, deposited from relatively high stages of flow.

At the top of the section, facies St is developed above facies Gm (at least 50cm thick) and resembles the channel-bar-complexes present along Birk Beck. Above here, facies Sh and Sr reflect deposition under low flow stage conditions.

3.5.5 Tebay Services Section

This section outcrops on the east bank of the Northbound carriageway of the M6, immediately north of the exit from Tebay service station. The section is drawn to scale in Figure 3.7 and demonstrates the lateral facies relationships between large and small sets of facies St with sets of facies Sp. These relationships are thought to resemble those developed by a sandy braided river system, especially the South Saskatchewan (Cant, 1978, 1982, Cant and Walker, 1976; Walker and Cant,

1984) and also compare favourably with the Devonian Battery Point Formation, described by Cant (1978).

Trough-cross-bedded sandstones (facies St), with individual sets averaging 33cm thick form a coset at least 1.5m thick (at outcrop), the estimated channel dimensions showing a minimum width value of 127.8m and depth of 2.84m (Section 3.3.1). It is suggested that these sets reflect infill of the relatively major channels, showing a palaeocurrent vector mean towards 012°, and resemble the deposits of main channels of sandy braided rivers as described by Cant (1978). Further, the apparent absence of facies Sp interbedded with the larger-scale sets tends to support this interpretation (see discussion in Chapter 6 - Roman Fell Sandstones).

Smaller-scale trough-cross-bed sets, up to 20-25cm, are restricted to interbedded sandstones within cosets of facies Sp (planar-cross-bedded sandstones). These smaller scale sets are interpreted as the probably infill of small-scale channels developed on the surfaces of in-channel bars (facies Sp).

Planar-cross-bedded sandstones (facies Sp) are interpreted as the deposits of transverse or Linguoid bars as described by Smith (1970) in the Platte Rivers, Colorado, Collinson (1970) for the Tana River, Norway and e.g. Cant (1978) for the South Saskatchewan River, Canada. The presence of silty horizontally laminated sandstone (facies Sh) occurring as a drape over a planar-cross-bedded set suggests lower flow stage deposition and may resemble some of the 'reactivation' features

developed on falling stage, as described by Collinson (1970) in the Tana River. Significantly, cf. Jones (1977), the presence of low flow stage deposits associated with these bar deposits implies relatively slow decline in flow stage and discharge.

3.6 Discussion of the Depositional Model (Figures 3.10, 3.11)

The facies relationships discussed in the preceeding sections were deposited as channels and channel-bar complexes within, it is thought, a braided-fluvial system. A braided-fluvial origin for the channels is considered more appropriate than a meandering origin for the reasons outlined below:-

1. Identification of clast-supported conglomerates deposited on longitudinal gravel bars as in structures observed in present-day braided rivers. Rust (1978b, p. 619) states the presence of framework gravel is regarded as evidence that the system was braided (here, the Carboniferous Cannes de Roche Formation, Upper Member).

2. Major and minor channel-fill deposits associated with the absence and presence of gravel bars respectively and reflecting a channel system in which topographic differentiation was a key element. The hierarchy of channels and bars is compared with deposits and bedforms within present day braided gravelly and sandy rivers.

3. Identification of planar-cross-bedded sandstone thought to have been deposited by the accretion of sandy transverse bars. Cant (1982) emphasises the presence of 'planar-tabular' cross bed sets within the Devonian Battery Point Formation (Cant and Walker, 1976) gives evidence of the 'braided nature' of the sandbodies.

4. The presence of a variety of bedforms formed in response to flow stage and discharge fluctuations (cf. Jones, 1977) associated with gravel bar, sandy bar and base channel floor sedimentation.

Rivers can be classified into braided, meandering and straight as originally proposed by Leopold and Wolman (In, Friend, 1978), whereas Allen (1965) constructed four hypothetical alluvial facies models, piedmont formed of alluvial fans, braided stream, low sinuosity stream and strongly meandering stream. Rust (1978a) proposed a classification based on channel morphology, defined by two parameters, sinuosity and braiding parameter. Sinuosity is defined as the ratio of thalweg length to valley length, the thalweg being the line of the deepest channel, and valley length being the straight line distance down that part of the valley over which the thalweg is measured. Rivers can thus be divided into high sinuosity ([1.5) and low sinuosity (]1.5).

The braiding parameter measures the number of bars or islands in the channel and can be defined as the number of bars or islands per meander wavelength. Single channel rivers have a braiding parameter of less than 1, while multiple channel rivers are those with a braiding parameter of greater than 1.

Schumm (1968 and in Miall, 1977; Friend, 1978) classified rivers into bedload, mixed-load and suspended-load rivers. Meandering and anastomosed rivers are largely of mixed and suspended load type whereas braided rivers are generally bed-load rivers, being generally coarser grained than rivers of the other two types and dominated by sand or gravel. However there are exceptions to this (Miall, 1981) and as considered by Richards (1982), who states it is illogical to distinguish meandering from straight streams at an arbitrary sinuosity or indeed classify streams by sinuosity. Indeed there exists a continuum between river morphologies which is often dependent on flow stage (cf. Blodgett and Stanley, 1980), for example straight channels with mid-channel gravel bars appear braided at low flow stage and meandering streams in upland environments often have unvegetated point bars across which chutes are formed to create 'pseudo-braided' patterns at high flow stages (Richards op-cit). The Amite River (Louisiana) and Colorado River (Texas) as described by Mcgowen and Garner (1970) are examples of coarse grained meandering streams but which contain features characteristic of braided streams (see Chapter 6).

At least ten variables combine to determine channel morphology, these being discharge (amount and variability), sediment load, width, depth, velocity, slope, bed roughness and bank vegetation density (Miall, 1982). Collinson (1978) shows that the nature and abundance of sediment load in a river is dependent on 'The abundance of different types of bedrock in the source area, the overall climate which influences the relative abundance of suspended load and the magnitude of

sediment discharge which is influenced by relief, vegetation and run-off pattern, all of these variables being interrelated'.

Doeglas (1962) discusses the essential differences between braided and meandering rivers from observations in the Durance and Ardeche Rivers of Southern France and concludes that the main difference depends on discharge and slope. Meandering rivers have normally a more regular and continuous run-off pattern than braided rivers with one main channel which is generally in equilibrium with the discharge. In contrast, braided rivers show large fluctuations in discharge, the main controls on discharge being climate, relief, steep slopes and lack of vegetation in the source area which promotes rapid run-off (Doeglas, op.cit., Schumm, 1968; Miall, 1977; Richards, 1982). Leopold and Wolman (in Ore, 1964) found that channel division during braiding results in an increase in both slope and width and a decrease in mean depth. Consequently meandering rivers have low width:depth ratios and braided rivers high width:depth ratios. Leopold and Wolman (op.cit.) also established an empirical relationship between slope and discharge, braiding occurring at a higher discharge than meandering rivers. Meandering rivers are generally more laterally stable than braided rivers because of thicker, cohesive floodplain sediment forming channel banks, these being difficult to erode and thus inhibit the lateral migration of the river (Collinson, 1978; Cant, 1982). The lateral migration of meandering rivers occurs mainly by avulsion (Collinson, op.cit.) and channel-fill deposits tend to build elongated and ribbon-like sandbodies with a lenticular geometry. In contrast, braided rivers move easily across the 'floodplain' due to the less cohesive nature of the channel banks. The

easier lateral migration of the channels, combined with the extremely unstable position of the main current develops sheet-like sandbodies with high lateral connection (Campbell, 1976).

Channel migration and the effect of flow stage on channel and bar morphology has been well documented by Coleman (1969) for the Brahmaputra River and the following are some of the significant points from Coleman's studies. Bed configuration changes drastically under differing flow regimes with deposition of sediment at one locality causing erosion at another. Thus the position of the thalweg tends to wander from one point to another, characterised by two types of movement, gradual and 'continuous transverse' movement and a sudden shifting movement. Within the Brahmaputra River, shifting of the thalweg is related to flow stage, at high flood stage, the flow being concentrated in straight channels. As the flood waters subside, the excess of sediment carried by the river is rapidly deposited as flow velocities decrease and flow is diverted out of the main channel into many new channels across bar surfaces. At falling stages, therefore, the thalweg is in a state of constant movement. These new channels remain active during falling stages of flow but aggradation at this time is high and at low flow stage, flow diminishes and channels are abandoned. The effect of channel aggradation causes 'the main current to seek better gradients, new alignments and paths of least resistance. In this manner, the channel is in a state of constant migration, eroding and redepositing sediment of its own making as well as older deposits of previous channels' (Coleman, op.cit. p.180).

Bluck (1979) has also documented variations in channel and bar morphology and shows it is the characteristics of the flood cycle and the amount of sand and gravel which determines how the structures combine to form various bars. In fact the variability of climate, rate of erosion and other variables is subordinate to the effects of grain size on the structure of the sediment. Development of bar sequences and structures are generated on falling stage of flow, at high stage of flow, gravelly braided streams for example, are characterised by fairly featureless sheets of gravel. The complex arrangement of sedimentary structures within bar forms combined with stacking of bars within the channel builds up a fining upward sequence, overlain by floodplain deposits, the whole sequence reflecting the lateral migration of a channel system. In this way, upward fining sequences, although generally present in both meandering and braided streams, are normally much more complex in braided systems.

The recognition and characteristic sedimentary structures observed in braided streams is presented in Ore (1964) and the reader is referred to his paper for a more detailed account. He concludes that no single criterion can identify a braided regime, but rather the 'relative abundances of features seems to be means by which deposits of braided streams can be differentiated from those of other environments' (Ore, op.cit. p.14). Internal features also aid in the delineation of external forms, e.g. wedge-shaped deposits help in the identification of transverse bars. Rust (1978b, 1984) considers that the presence of clast supported conglomerate is the main distinguishing criterion for gravelly braided alluvium, deposited mainly as longitudinal gravel bars.

Cant (1982) considers the presence of planar-tabular cross-bedding, e.g. within the Devonian Battery Point Formation, provides evidence of braiding. Moody-Stuart (1966) provides models to illustrate the diagnostic features of high and low sinuosity streams with examples from the Devonian Wood Bay Formation, Spitsbergen. He concludes that high-sinuosity streams are characterised by low width:depth ratios, less pronounced scour, levees developed across the top of the sandbody, variable palaeocurrent pattern and especially the presence of epsilon-cross-stratification. Low sinuosity streams, however, are characterised by high width: depth ratio, more pronounced scour, levees only developed at the side of the sandbody, palaeocurrent pattern sub-parallel to the elongation of the sand-body and no epsilon-cross-stratification present.

In the Shap Red Beds, a braided-fluvial origin is considered more likely than a meandering one mainly for the reasons stated at the beginning of this section. The presence of bar forms, major and minor channel-fill deposits and a variety of bedforms developed as a response to flow stage fluctuation compare favourably with criteria established from published work and as discussed above. The gravel dominated facies in the southern part of the Birk Beck area were deposited in a gravelly braided river which, it is thought, probably resembled the gravel reaches of the present-day Donjek River, Yukon. This river is surrounded and fed by areas of high relief, actively undergoing degradation. Within the river, as described by Williams and Rust (1969) and Rust (1972), four topographic levels can be recognised (see Figure 3.10) which formed as a result of the progressive downcutting of



the river during its evolution. These levels were distinguished by Williams and Rust (op-cit P. 650) 'on the grounds of elevation, the amount of vegetation and the type and intensity of fluvial activity in progress'. Level 1 shows the greatest fluvial activity, highest discharge, highest flow regimes and the greatest number of active channels. With increasing elevation all these factors are reduced such that in level 4 channels are abandoned and sediment colonised by vegetation.

The facies relationships within the gravel dominated facies Zones 1, 2 and 3 are illustrated in Figure 3.10 which relates these with the topographic levels present in the modern day River Donjek. Gravel accumulated at high flow stage in the main network of active channels on longitudinal bars which were orientated parallel with the main flow direction. Downstream margins occasionally developed slip-faces on falling stage of flow, generating planar-cross-bedded gravel sets. During falling stage as discharge and velocities decreased, gravel was rapidly deposited and as bars emerged, flow was diverted from the main channel into a number of cross-cutting minor channels. At low flow stage, these filled with sand and were subsequently abandoned. Slightly higher topographic levels comprise abandoned channel-bar complexes as the main channel tract shifted course. At the highest topographic levels, mudstones and siltstones accumulated from suspension during overbank flood episodes.

The sand-dominated facies relationships present in the upper parts of Zone 3 and in Zones 4 and 5 and those seen at the Tebay services section

are thought to reflect deposition within a more sandy braided river system. The South Saskatchewan River from the Southern Prairies of Western Canada is a sandy braided River in which topographic differentiation is well developed with large complex depositional braid bars ('sand flats') and well developed floodplain areas (Cant, 1978, 1982; Cant and Walker, 1976; Walker and Cant, 1984). Major channels average 150m wide and 3m deep, echo sounding of channel bars showing that dunes are present within the channels at all river stages and generating trough-cross-bed sets up to 1m thick. Minor channels are also present and occur at topographically higher levels being floored by smaller sized dunes, giving rise to trough-cross-bedded sets less than 30cm thick. Large slip-face bounded cross-channel bars form at channel junctions where flow expands and velocity diminishes, extending across major channels having heights up to 3m and lengths of several hundred metres. Sand flats form from the emergent tops of the cross-channel bars, larger sand flats developing from the repeated erosion and accretion of smaller areas. These sand dominated areas accrete downstream, laterally across the channel and during lower flow stage bars develop on the surface causing vertical aggradation of planar-cross-bedded sets. On falling stage of flow, the sand flats are covered by 'small dunes, sand waves, and ripples which deposit a veneer of small cross bed sets and ripple lamination' (Cant, 1978). At highest topographic levels, islands and floodplains are covered by as much as 1m of vertically accreted mudstone.

Figure 3.11 shows the relationship between the active channel environment and the potentially preserved facies sequences. Relatively

larger trough-cross-bedded sandstone sets, forming festoon cosets up to 5m thick, reflect deposition from migrating dunes in the main active channels, with planar-cross-bedded sandstone sets representing the deposits of slip-face cross-channel bars also within the main channel. It is thought that sandstones present above facies St, e.g. at Salterwath, reflect the shallowing of the channel floor possibly on the margins of 'sand flat' areas which were covered at low flow stages by a variety of lower flow regime bed forms. The section at the top of Zone 3 (Plate 3.8) demonstrates a floodplain sequence accreted at low flow stage and containing a laterally accreted channel sandbody. This latter feature reflects flow in a semi-permanent channel sourced from overbank flooding and compares to highest topographic 'level 3' in the modern-day Donjek River (Williams and Rust, 1969, p. 651, 676).

The vertical fining upward sequences developed within the Shap Red Beds combined with the stratigraphic relationships between facies Zones are thought to reflect the migration of the active channel tract and abandonment of a 'segment' of the channel system superimposed on a progressive downstream change from a gravel dominated regime to a sandy dominated fluvial system.

Two types of fining upward sequences can be recognised. Smaller scale 'cycles', in the order of 4m to 5m thick, record the fill of channel-bar-complexes, for example those seen in facies Zones, 1 and 2. These result from the infill of minor channels at low floor stage cross-cutting gravel bar surfaces. As discussed above from the observations of Coleman (1969), the effect of channel aggradation causes

'the main current to seek better gradients, new alignments and paths of least resistance'. Larger scale fining upward sequences, up to 11-12m record the migration of the active tract through channel switching (cf. Turner, 1982) leaving inactive areas accumulating fine grained deposits. This mechanism compares with the model developed by Rust (1972) for sequences generated within the Donjek River. What is signficant in the Shap Red Beds is the recognition of topographic differentiation allowing fine grained deposits to accumulate by channel abandonment. It is generally considered that fine grained deposits are only present in minor amounts in braided rivers and commonly absent, being very abundant in meandering stream deposits (cf. Allen, 1970, Collinson, 1978). However, as considered here, fine grained deposits can be preserved in a braided-fluvial system in which floodplains are protected from high-velocity flows (cf. Miall, 1977; Cant, 1982). Where topographic differentiation is lacking or absent, for example in the Platte River system, Colorado (Smith, 1970), floodplains are inundated at high-flood stages and fine grained deposits, although preserved in a few areas are normally eroded and 'ripped' up being incorporated into intraformational mudclast conglomerates.

The northward change from gravel dominated to sand dominated facies relationships in the Shap Red Beds has been shown to compare with the deposits of both gravelly and sandy braided rivers. It is suggested that the northward 'depositional trend' may reflect the progressive downstream change from a gravel 'reach' to a sandy reach within the same fluvial system in which the downstream decrease in grain size is combined with the observed increase in transverse bar (Planar-cross-

stratification) sandstones as opposed to longitudinal bar conglomerates. The belief that the facies Zones form a vertical stratigraphic framework in which facies Zones 4 is thought to overlie previous Zones, supports this idea. Rust (1972) has also demonstrated in the Donjek River that in a downstream direction, grain size decreases combined with the increase in the amount of transverse relative to longitudinal bars. A similar downstream transition has been shown to exist in the Platte River by Smith (1970), in which longitudinal bars decrease in abundance downstream accompanied by a decrease in grain size, an increase in the ratio of planar-cross-stratification to horizontal stratification and a decrease in 'cross-channel topographic relief'. Again Boothroyd and Ashley (1975) have recorded similar downstream changes in the Scott and Yana braided outwash fans, Alaska, demonstrating the change from an upper gravel-dominated fan to a lower fan dominated by sand. The rate of change varies depending on the stream power (Miall, 1977) for example in the relatively small outwash fans described by Boothroyd and Ashley (1975), gravel extends between 7.5km and 16km from the glacier terminus, while gravel bars in the Platte River remain abundant up to 250km from the Mountain front (Miall, 1977, p.49). In a downstream direction, channel form over the long profile dimension, adjusts so that streamflow can maintain sediment transport (Richards, 1982 p. 229). There also exists a direct relationship between slope and particle grain size carried as bed load, such that as the channel gradient decreases downstream, 'coarser particles are deposited where they cannot be transported over the lower gradient' (Richards op.cit.).

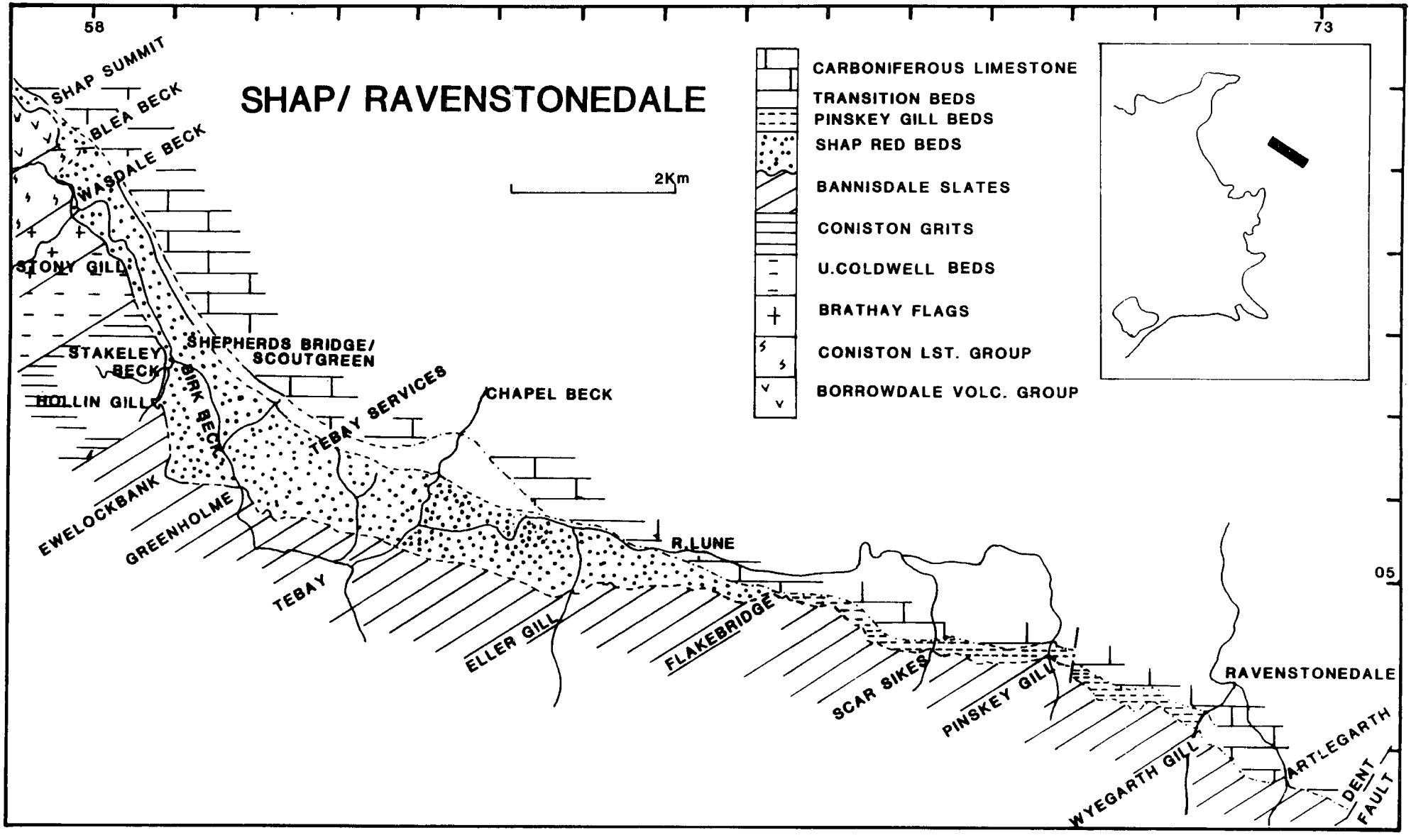
Miall (1977, 1978, 1982) and Rust (1978b) developed facies models to demonstrate the proximal to distal variations that would be expected in a downstream direction from gravel dominated to sand dominated braided rivers. The models are based on modern day rivers; in the context of the present study, the northward progression into a sand dominated regime reflects a change from the 'Donjek Type' to the 'South Saskatchewan' type of Miall (op.cit.). Rust (op. cit.) considers distal sandy braided rivers to be transitional to deposits of meandering systems with a significant primary mud content. These models, introduced here, are discussed more extensively in the succeeding chapters and especially in Chapter 9.

As discussed more fully in Chapter 8 and 9, the overall change from a gravelly braided system into a sand dominated one, together with a strong, consistent north-north-east to north palaeoflow correlates with other sections studied in the Vale of Eden region (Figure 9.4). Accounts by Capewell (1955) and others (e.g. Johnson and Marshall, 1971) have considered that the Shap Red Beds are laterally equivalent to the Pinskey Gill Beds of Ravenstonedale (Chapter 8). Deposits taken to be very similar to the latter overlie the Shap Red Beds at Shap Summit, at the top of the Micklegill Beck Section and near Scoutgreen, these being transitional to the Carboniferous Limestone above. The Pinskey Gill Beds are thought to be lagoonal tidal flat deposits associated with the marine transgression. To imply that the Shap Red Beds are laterally equivalent (cf. Capewell, op.cit) would mean that the Shap Red Beds Form part of a fluvial system which drained into the South Vale of Eden, and more importantly towards a more general easterly direction

(transgression accepted as coming from the east; Johnson and Marshall, op. cit.) into lagoonal tidal flats. That this is not so is shown by the consistent northerly palaeoslope, which as noted above is correlatable throughout the whole study region. Of course, the palaeocurrents could diverge to the east north of the Shap area (unexposed), although changing palaeocurrents should be traceable in the exposed sections, i.e. as the system evolved into a more sandy setting. That this is not so has been clearly demonstrated. The implication is, that the Pinskey Gill Beds do in fact stratigraphically overlie the Shap Red Beds and are not laterally equivalent, although it is tentatively suggested that establishment of lagoonal tidal flats in the region could have caused palaeoslope divergence (see Chapter 9) within an evolved distal braidplain setting (?evidence of finer grained sandstones near the top of Micklegill) when channels would radiate across the alluvial plain to aggrade it as evenly as possible (cf. Galloway, 1981).

FIGURE 3.1

Map showing the main localities in the Shap region.


58
73
SHAP/ RAVENSTONEDALE
2Km
CARBONIFEROUS LIMESTONE
TRANSITION BEDS
PINSKEY GILL BEDS
SHAP RED BEDS
BANNISDALE SLATES
CONISTON GRITS
U.COLDWELL BEDS
BRATHAY FLAGS
CONISTON LST. GROUP
BORROWDALE VOLC. GROUP
SHAP SUMMIT
BLEA BECK
WASDALE BECK
STONY GILL
STAKELEY BECK
HOLLIN GILL
SHEPHERDS BRIDGE/ SCOUTGREEN
BIRK BECK
TEBAY SERVICES
CHAPEL BECK
EWELOCKBANK
GREENHOLME
TEBAY
ELLER GILL
R.LUNE
FLAKEBRIDGE
SCAR SIKES
PINSKEY GILL
RAVENSTONEDALE
WYEGARTH GILL
ARTLEGARTH
DENT FAULT
05

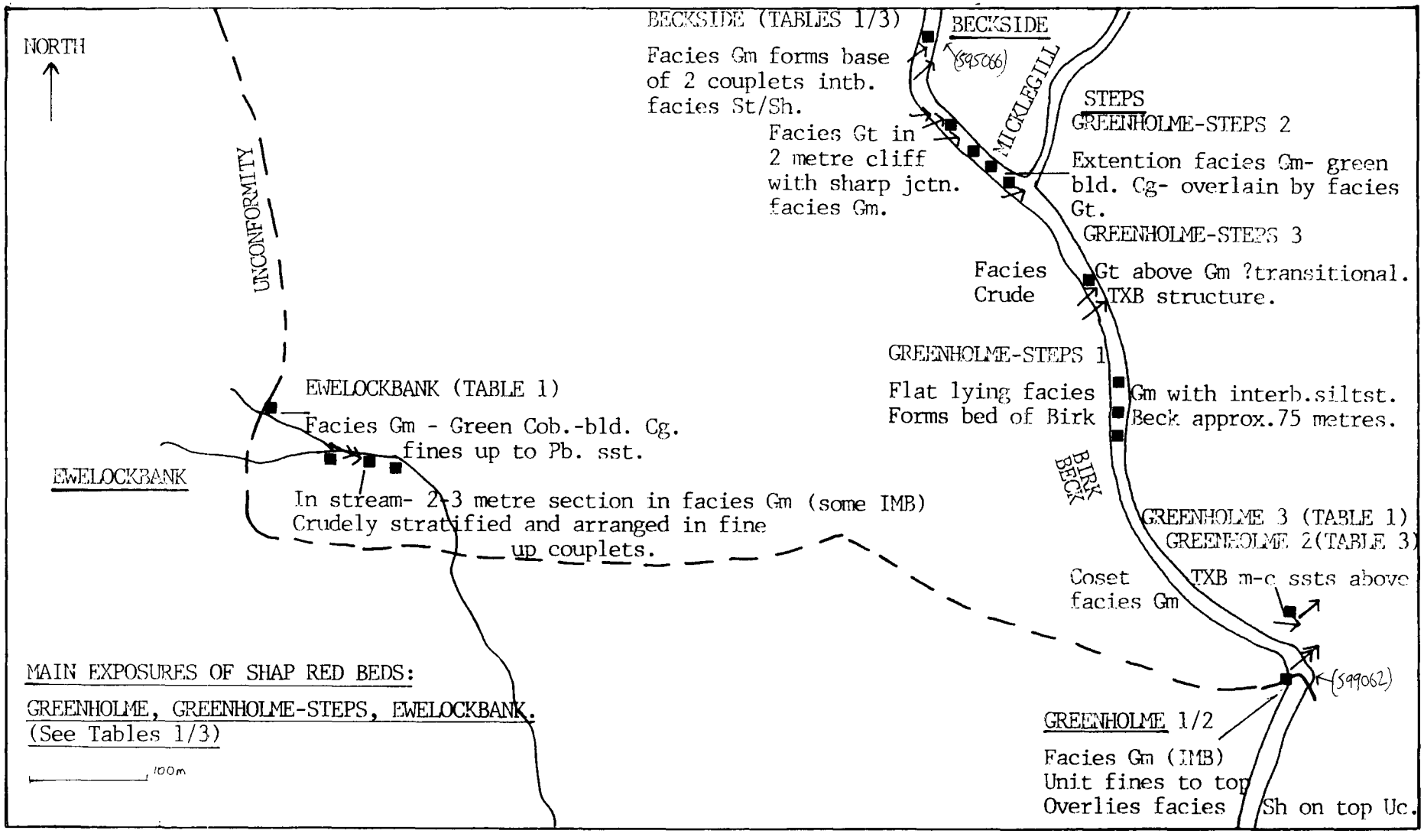

NORTH
UNCONFORMITY
BECKSIDE (TABLES 1/3)
Facies Gm forms base of 2 couplets intb. facies St/Sh.
Facies Gt in 2 metre cliff with sharp jctn. facies Gm.
BECKSIDE
(S95066)
MICKLEGILL
STEPS
GREENHOLME-STEPS 2
Extention facies Gm- green bld. Cg- overlain by facies Gt.
GREENHOLME-STEPS 3
Facies Crude
Gt above Gm ?transitional. TXB structure.
GREENHOLME-STEPS 1
Flat lying facies Gm with interb.siltst. Forms bed of Birk Beck approx.75 metres.
BIRK BECK
EWELOCKBANK (TABLE 1)
Facies Gm - Green Cob.-bld. Cg. fines up to Pb. sst.
EWELOCKBANK
In stream- 2-3 metre section in facies Gm (some IMB) Crudely stratified and arranged in fine up couplets.
GREENHOLME 3 (TABLE 1)
GREENHOLME 2(TABLE 3)
Coset facies Gm
TXB m-c ssts above
(S99062)
MAIN EXPOSURES OF SHAP RED BEDS:
GREENHOLME, GREENHOLME-STEPS, EWELOCKBANK.
(See Tables 1/3)
100m
GREENHOLME 1/2
Facies Gm (IMB)
Unit fines to top
Overlies facies Sh on top Uc.

FIGURE 3.2a.

FIGURE 3.2b.

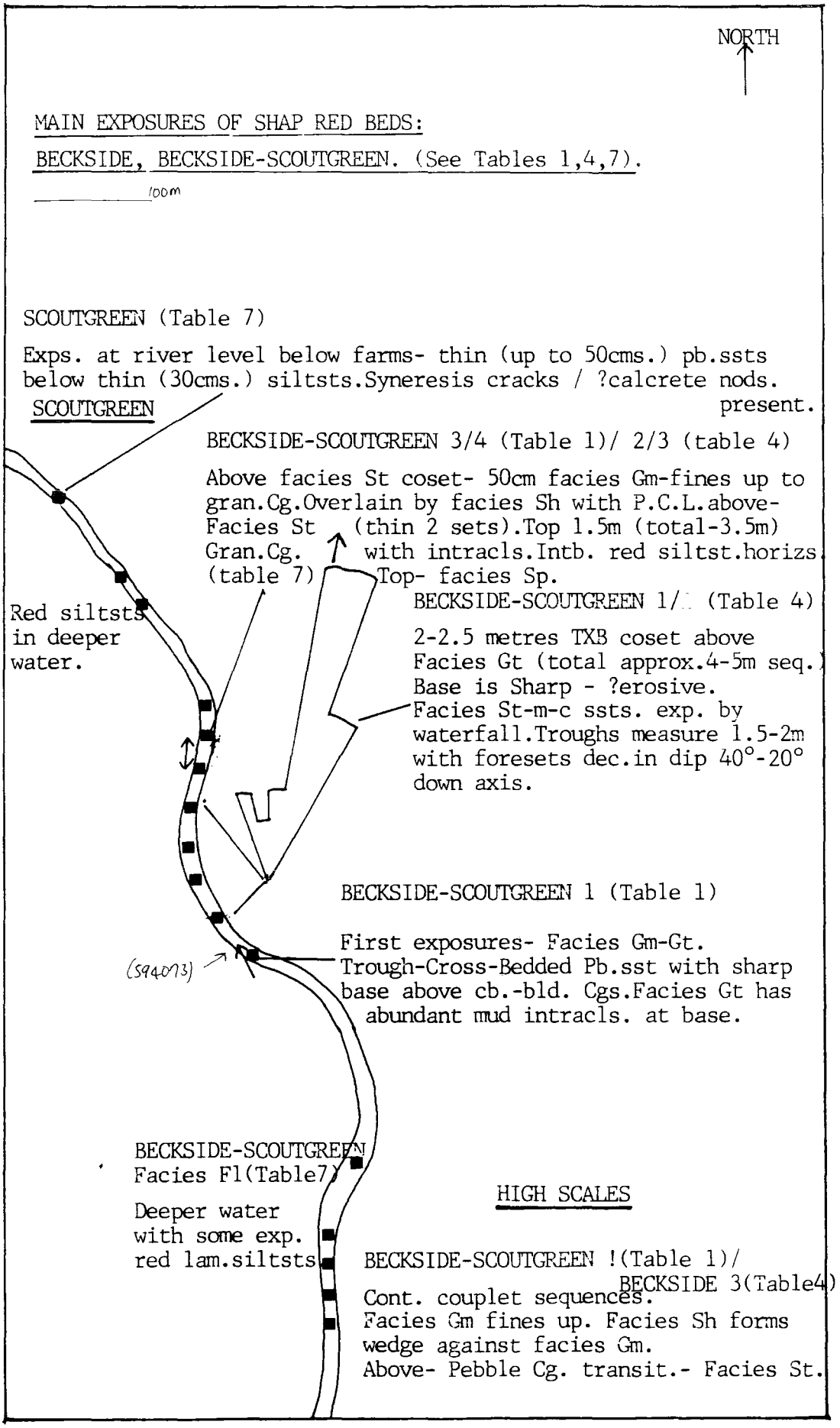

NORTH
MAIN EXPOSURES OF SHAP RED BEDS:
BECKSIDE, BECKSIDE-SCOUTGREEN. (See Tables 1,4,7).
100m
SCOUTGREEN (Table 7)
Exps. at river level below farms- thin (up to 50cms.) pb.ssts below thin (30cms.) siltsts.Syneresis cracks / ?calcrete nods. present.
SCOUTGREEN
BECKSIDE-SCOUTGREEN 3/4 (Table 1)/ 2/3 (table 4)
Above facies St coset- 50cm facies Gm-fines up to gran.Cg.Overlain by facies Sh with P.C.L.above- (thin 2 sets).Top 1.5m (total-3.5m) with intracls.Intb. red siltst.horizs.
Facies St Gran.Cg. (table 7)
Top- facies Sp.
BECKSIDE-SCOUTGREEN 1/ (Table 4)
2-2.5 metres TXB coset above Facies Gt (total approx.4-5m seq.) Base is Sharp - ?erosive. Facies St-m-c ssts. exp. by waterfall.Troughs measure 1.5-2m with foresets dec.in dip 40°-20° down axis.
Red siltsts in deeper water.
BECKSIDE-SCOUTGREEN 1 (Table 1)
First exposures- Facies Gm-Gt. Trough-Cross-Bedded Pb.sst with sharp base above cb.-bld. Cgs.Facies Gt has abundant mud intracls. at base.
(S94013)
BECKSIDE-SCOUTGREEN Facies Fl(Table7)
Deeper water with some exp. red lam.siltsts
HIGH SCALES
BECKSIDE-SCOUTGREEN !(Table 1)/ BECKSIDE 3(Table4)
Cont. couplet sequences.
Facies Gm fines up. Facies Sh forms wedge against facies Gm.
Above- Pebble Cg. transit.- Facies St.

FIGURE 3.2c.

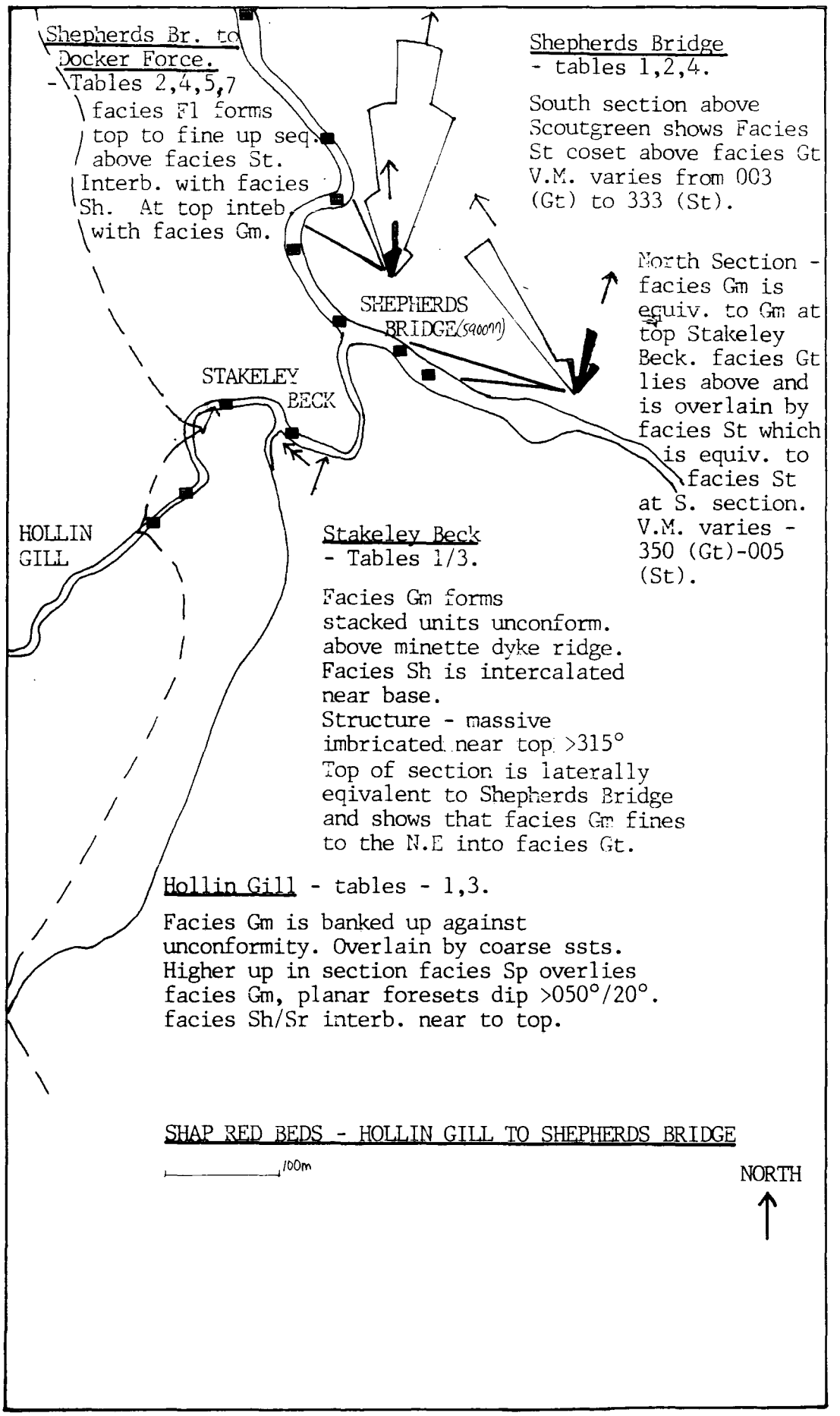
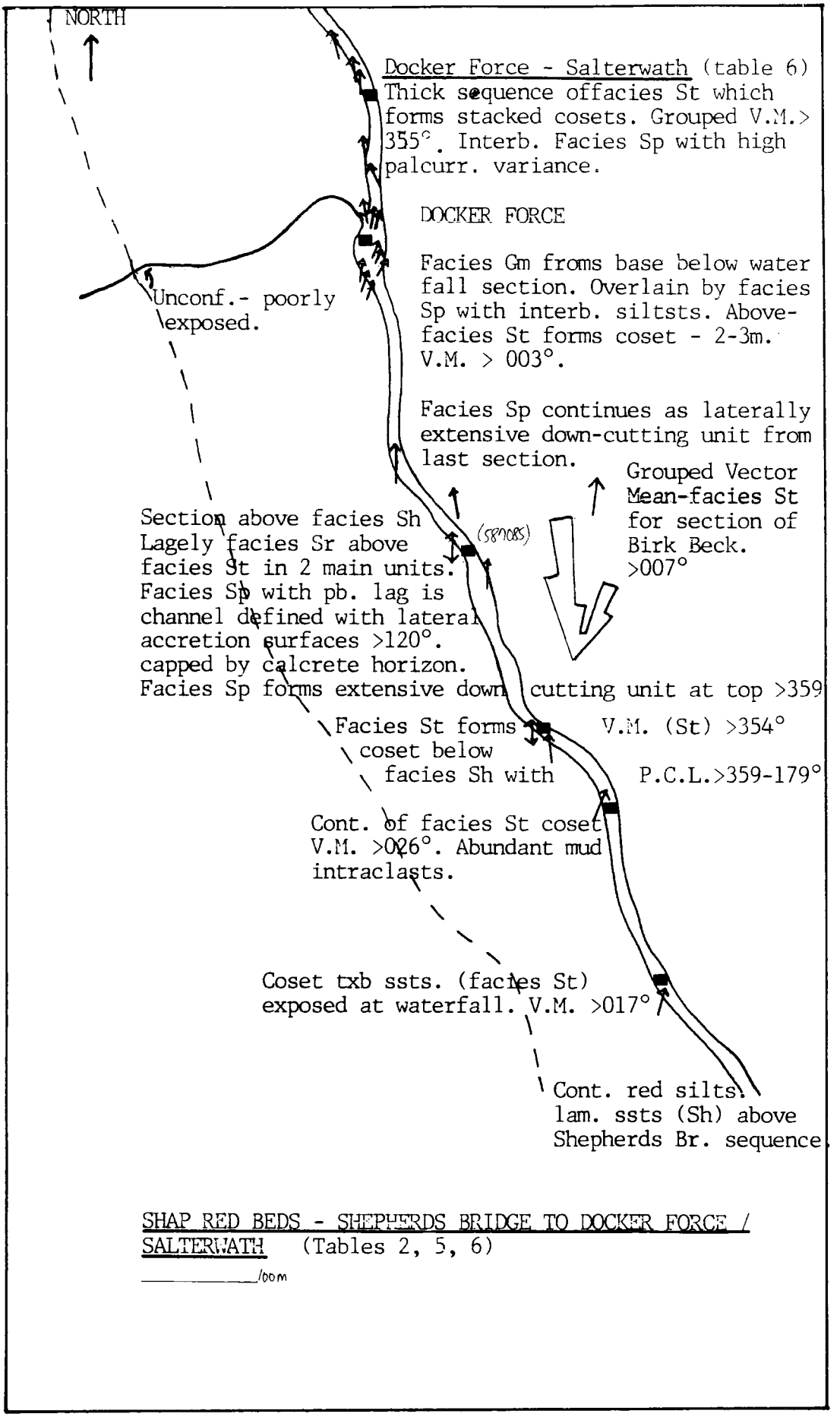

Shepherds Br. to Docker Force.
- Tables 2,4,5,7
facies Fl forms top to fine up seq. above facies St. Interb. with facies Sh. At top inteb with facies Gm.
Shepherds Bridge - tables 1,2,4.
South section above Scoutgreen shows Facies St coset above facies Gt V.M. varies from 003 (Gt) to 333 (St).
North Section - facies Gm is equiv. to Gm at top Stakeley Beck. facies Gt lies above and is overlain by facies St which is equiv. to facies St at S. section. V.M. varies - 350 (Gt)-005 (St).
SHEPHERDS BRIDGE(SBOOM)
STAKELEY BECK
HOLLIN GILL
Stakeley Beck - Tables 1/3.
Facies Gm forms stacked units unconform. above minette dyke ridge. Facies Sh is intercalated near base.
Structure - massive imbricated near top >315°
Top of section is laterally eqivalent to Shepherds Bridge and shows that facies Gm fines to the N.E into facies Gt.
Hollin Gill - tables - 1,3.
Facies Gm is banked up against unconformity. Overlain by coarse ssts. Higher up in section facies Sp overlies facies Gm, planar foresets dip >050°/20°. facies Sh/Sr interb. near to top.
SHAP RED BEDS - HOLLIN GILL TO SHEPHERDS BRIDGE
100m
NORTH

FIGURE 3.2d.



SHAP RED BEDS - SHEPHERDS BRIDGE TO DOCKER FORCE / SALTERWATH (Tables 2, 5, 6)

/oom

FIGURE 3.2e.

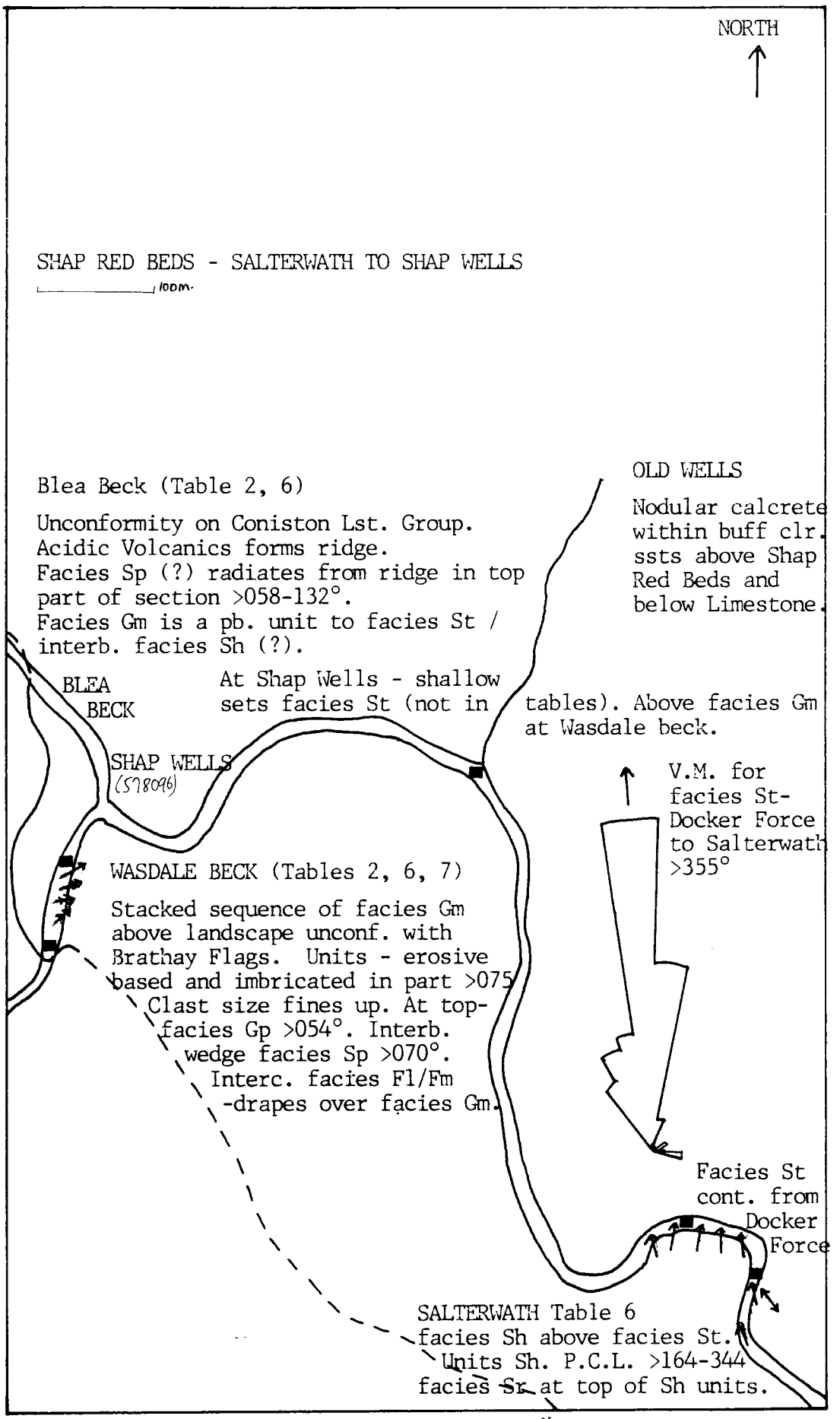
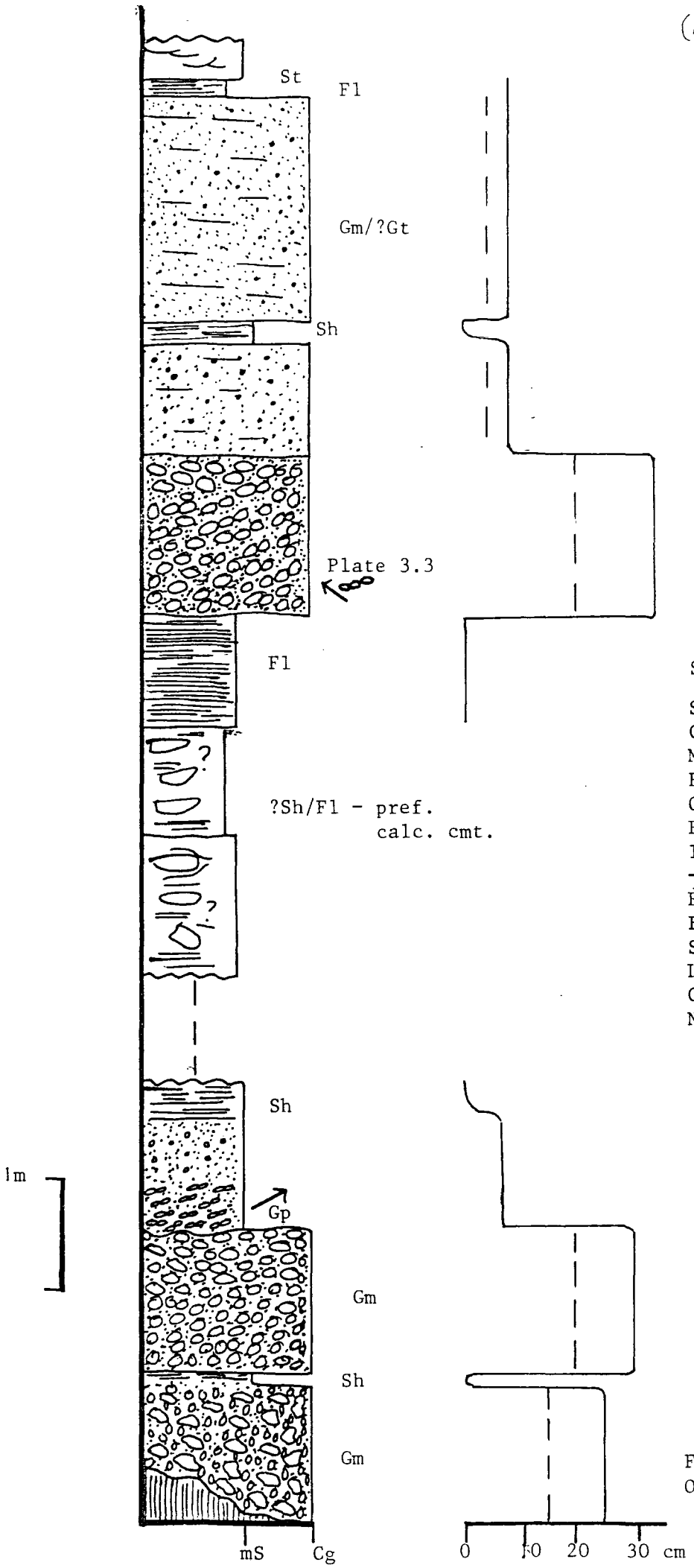

NORTH
SHAP RED BEDS - SALTERWATH TO SHAP WELLS
100m.
Blea Beck (Table 2, 6)
Unconformity on Coniston Lst. Group.
Acidic Volcanics forms ridge.
Facies Sp (?) radiates from ridge in top part of section >058-132°.
Facies Gm is a pb. unit to facies St / interb. facies Sh (?).
OLD WELLS
Nodular calcrete within buff clr. ssts above Shap Red Beds and below Limestone.
BLEA BECK
At Shap Wells - shallow
sets facies St (not in
tables). Above facies Gm
at Wasdale beck.
SHAP WELLS
(578096)
V.M. for facies St- Docker Force to Salterwath >355°
WASDALE BECK (Tables 2, 6, 7)
Stacked sequence of facies Gm above landscape unconf. with Brathay Flags. Units - erosive based and imbricated in part >075
Clast size fines up. At top- facies Gp >054°. Interb. wedge facies Sp >070°.
Interc. facies Fl/Fm -drapes over facies Gm.
Facies St cont. from Docker Force
SALTERWATH Table 6
facies Sh above facies St.
Units Sh. P.C.L. >164-344
facies Sr at top of Sh units.

FIGURE 3.3. MEASURED SECTION - STAKELEY BECK

(N.G.R. NY 589076)



SHAP RED BEDS

STACKED LONGIT. BAR CONGLOMERATES (Gm) WITH MINOR PXB CONGLOMERATE REFLECTING MODIFICATION ON FALLING FLOW STAGE. FACIES Gt AT TOP - INFILL OF BAR TOP CHANNE - LATERALLY EQUIV. TO FACIES Gt AT SHEPHERDS BRIDGE. FACIES Sh -MINOR SAND DRAPE;FACIES Fl - LOW FLOW STAGE MUDS, MAY CONTAIN INCIPIENT CALCR. NODULES.

MPS

AMPS

FACIES Gm AT BASE -UNCON OVERLYING MINETTE RIDGE

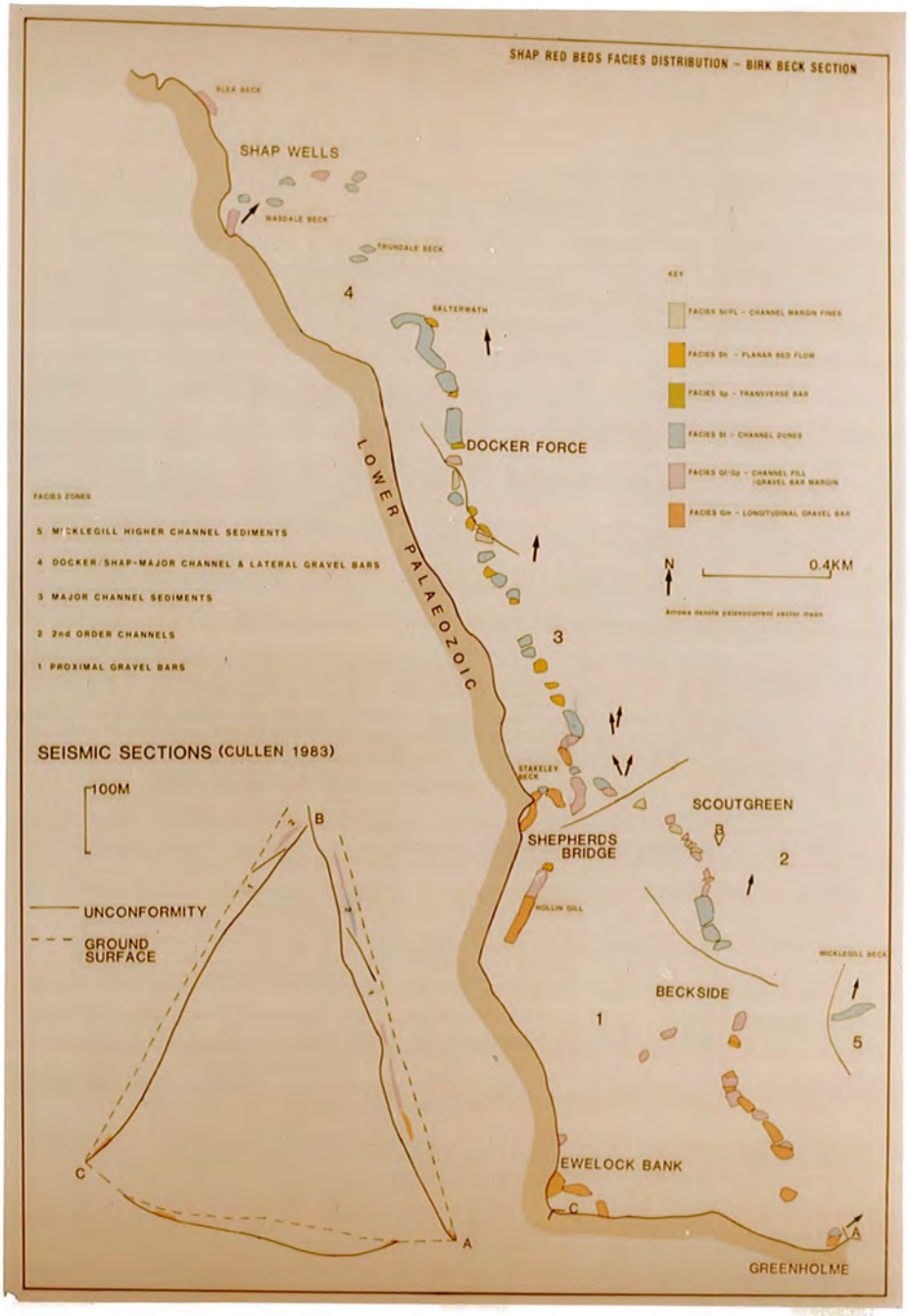

SHAP RED BEDS FACIES DISTRIBUTION – BIRK BECK SECTION
SHAP WELLS
HASDALE BECK
TRUNDALE BECK
SALTERWATH
DOCKER FORCE
LOWER PALAEOZOIC
STAKELEY BECK
SHEPHERDS BRIDGE
SCOUTGREEN
HOLLIN GILL
BECKSIDE
MICKLEGILL BECK
EWELOCK BANK
GREENHOLME
KEY
FACIES Sr/FL – CHANNEL MARGIN FINES
FACIES Sh – PLANAR BED FLOW
FACIES Sp – TRANSVERSE BAR
FACIES St – CHANNEL DUNES
FACIES Gt/Sp – CHANNEL FILL /GRAVEL BAR MARGIN
FACIES Gh – LONGITUDINAL GRAVEL BAR
N
0.4KM
Arrows denote palaeocurrent vector mean
FACIES ZONES
5 MICKLEGILL HIGHER CHANNEL SEDIMENTS
4 DOCKER/SHAP-MAJOR CHANNEL & LATERAL GRAVEL BARS
3 MAJOR CHANNEL SEDIMENTS
2 2nd ORDER CHANNELS
1 PROXIMAL GRAVEL BARS
SEISMIC SECTIONS (CULLEN 1983)
100M
UNCONFORMITY
GROUND SURFACE
A
B
C

FIGURE 3.4. MEASURED SECTION - WASDALE BECK

(N.G.R. NY 518095).

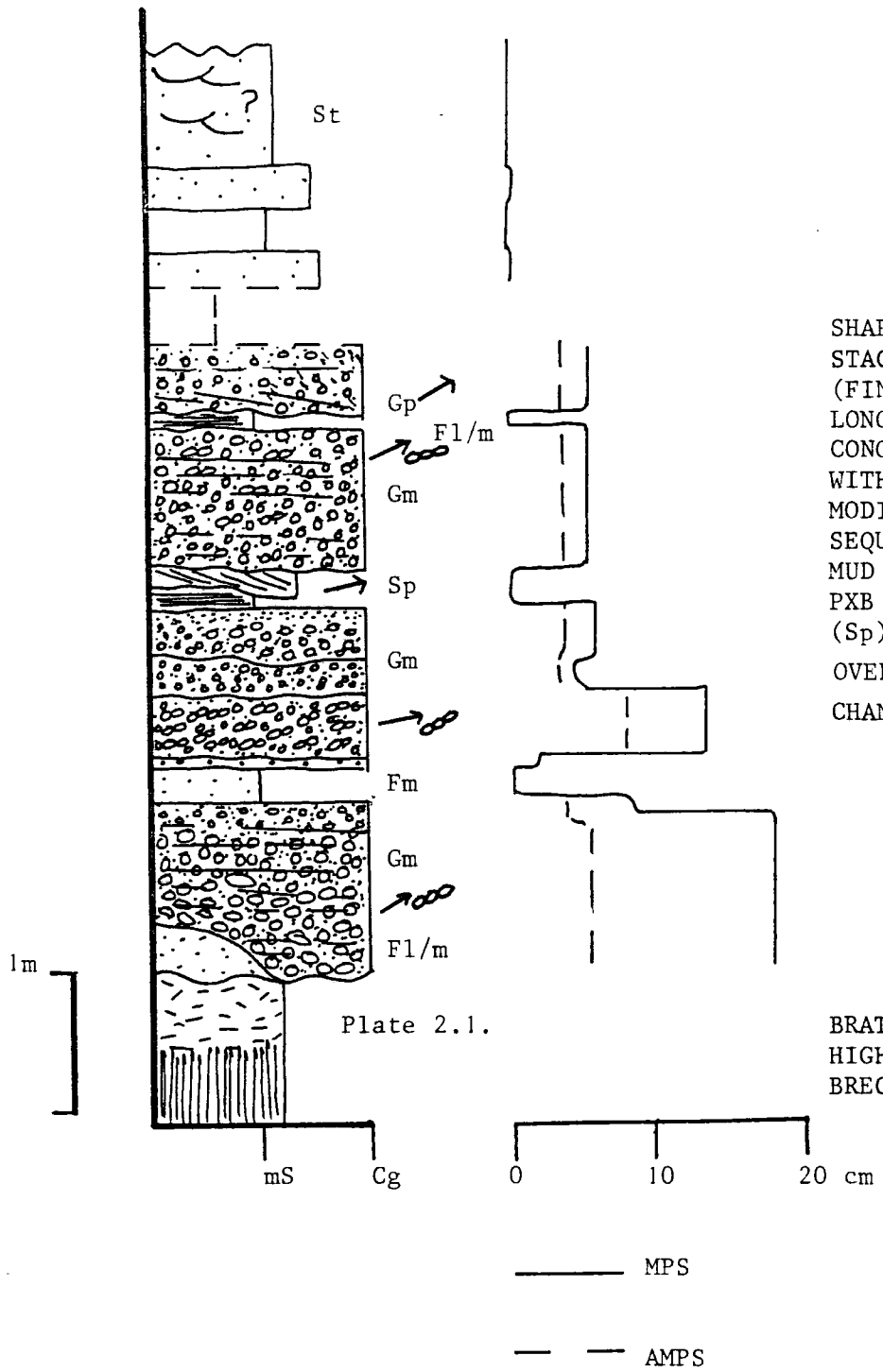
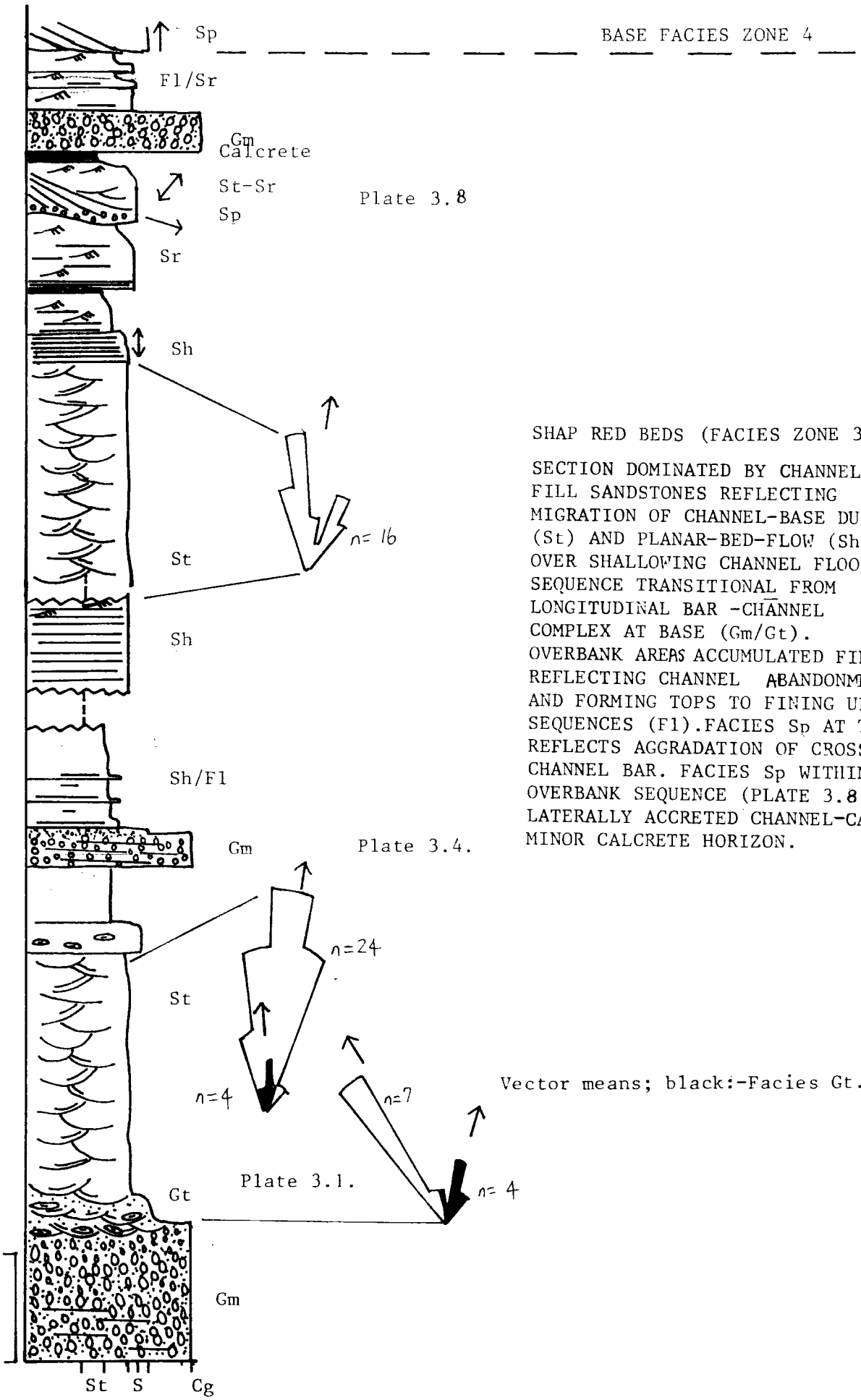


FIGURE 3.5a. MEASURED SECTION - SHEPHERD'S BRIDGE TO MIDWAY TO DOCKER FORCE (N.G.R. 590 077 - 587 085)



SHAP RED BEDS (FACIES ZONE 3)

SECTION DOMINATED BY CHANNEL-FILL SANDSTONES REFLECTING MIGRATION OF CHANNEL-BASE DUNES (St) AND PLANAR-BED-FLOW (Sh) OVER SHALLOWING CHANNEL FLOOR. SEQUENCE TRANSITIONAL FROM LONGITUDINAL BAR -CHANNEL COMPLEX AT BASE (Gm/Gt). OVERBANK AREAS ACCUMULATED FINES REFLECTING CHANNEL ABANDONMENT AND FORMING TOPS TO FINING UP SEQUENCES (Fl). FACIES Sp AT TOP REFLECTS AGGRADATION OF CROSS-CHANNEL BAR. FACIES Sp WITHIN OVERBANK SEQUENCE (PLATE 3.8.) - LATERALLY ACCRETED CHANNEL-CAPPED-MINOR CALCRETE HORIZON.

FIGURE 3.5b. MEASURED SECTION - DOCKER FORCE TO SALTERWATH
(N.G.R. NY 587085 - 584092)

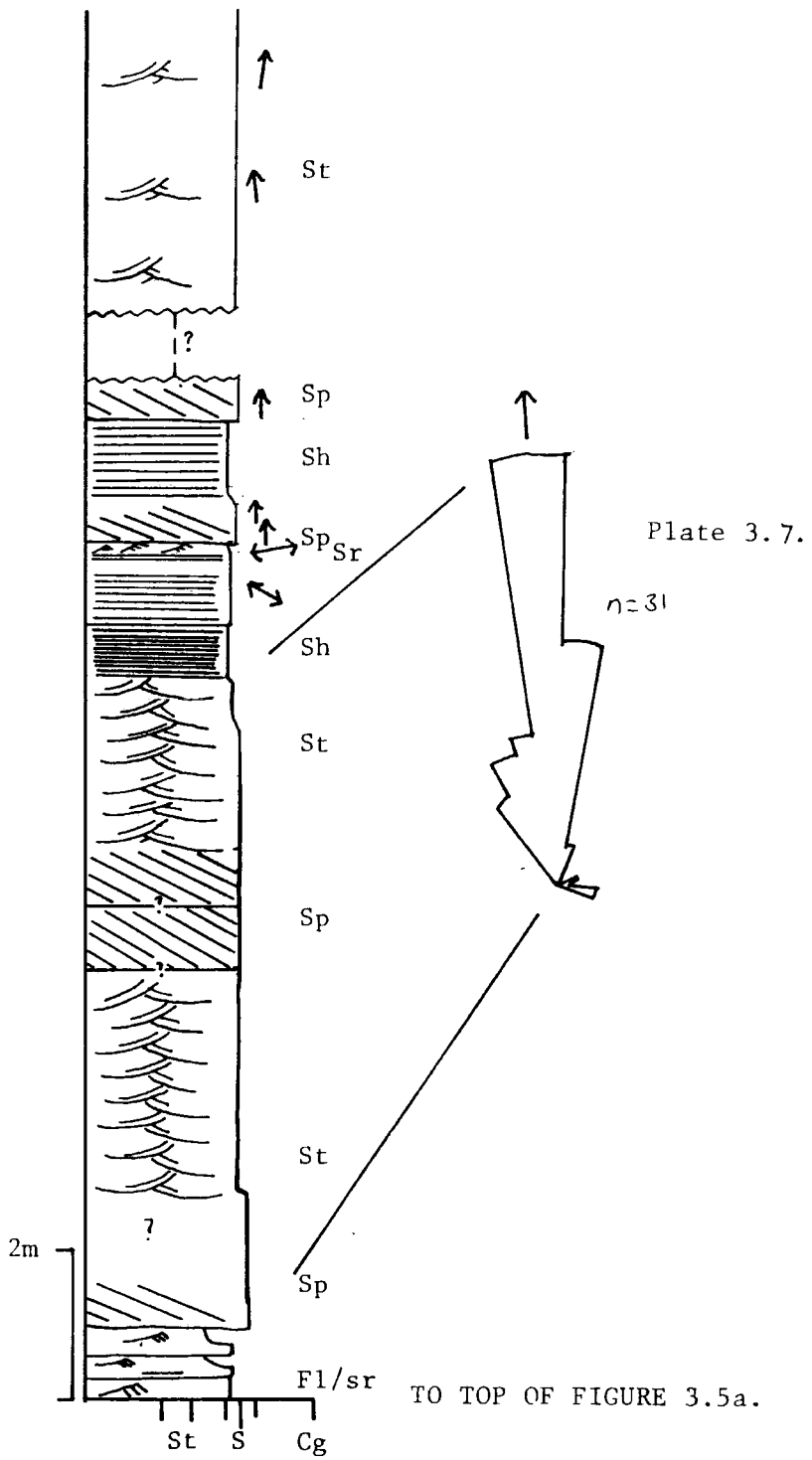


Plate 3.7.

SHAP RED BEDS

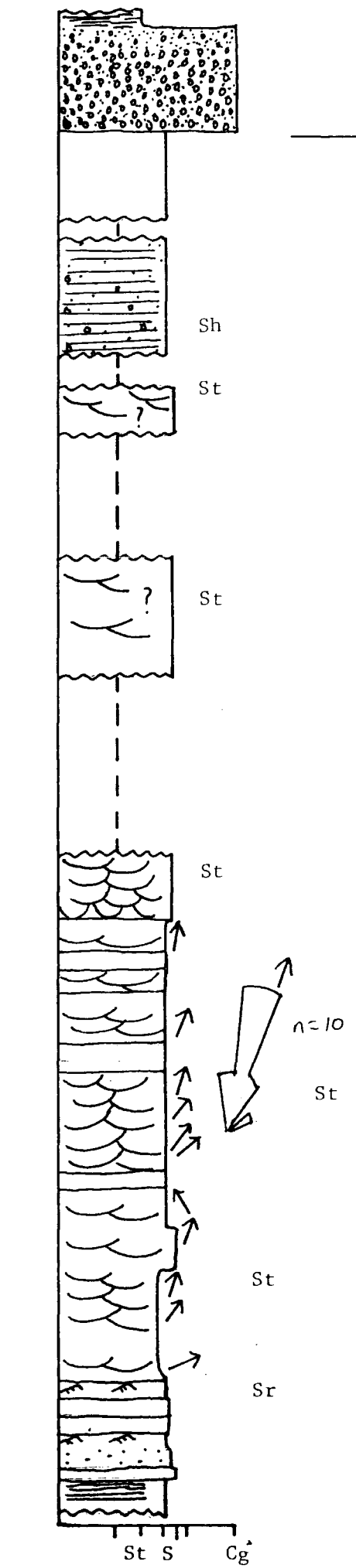
CONTINUATION OF CHANNEL-FILL SEQUENCE CONTAINING THICK FESTOON COSETS OF TXB SANDST. (St) WITH BOTH MAJOR (AT BASE) AND MINOR TRANSVERSE BAR SANDSTONES (Sp). FACIES Sh REFLECTS AGGRADATION OF SAND FLAT SEQUENCE AT TOPOGR. HIGHER CHANNEL LEVEL.

SECTION REPRESENTATIVE OF MOST OF FACIES ZONE 4.

TO TOP OF FIGURE 3.5a.

FIGURE 3.6. MEASURED SECTION - MICKLEGILL BECK

(Base NGR. Y 598068)



PINSKEY GILL BEDS (SHAP)

VERY SIMILAR CALCARENITE/CONGLOM. LITHOLOGY TO THE DEPOSITS AT THE SCOUTGREEN CROSSING SECTION. TYPICAL GRN—GREY CLR. DEPOSITED BY POSSIBLE WASH-OVER FAN.

SHAP RED BEDS (FACIES ZONE 5)

DONINATED BY TROUGH-CROSS-BEDDED SANDSTONES (St) REFLECTING STACKED CHANNEL-FILL DEPOSITS (MIGRATING DUNES), WITH MINOR LOW FLOW STAGE CURRENT RIPPLED (Sr) AND LAMINATED SANDSTONES (Sh). SECTION BELOW THE PINSKEY GILL BEDS (SHAP) CONTAINS FINER GRAINED AND MORE SILTY SANDSTONES SUGGESTING THAT THE SHAP RED BEDS FINES UP TO BENEATH THE PINSKEY GILL BEDS AT THIS SECTION.

FIGURE 3.7. MEASURED SECTION - TEBAY SERVICES
(N.G.R. NY 604066)

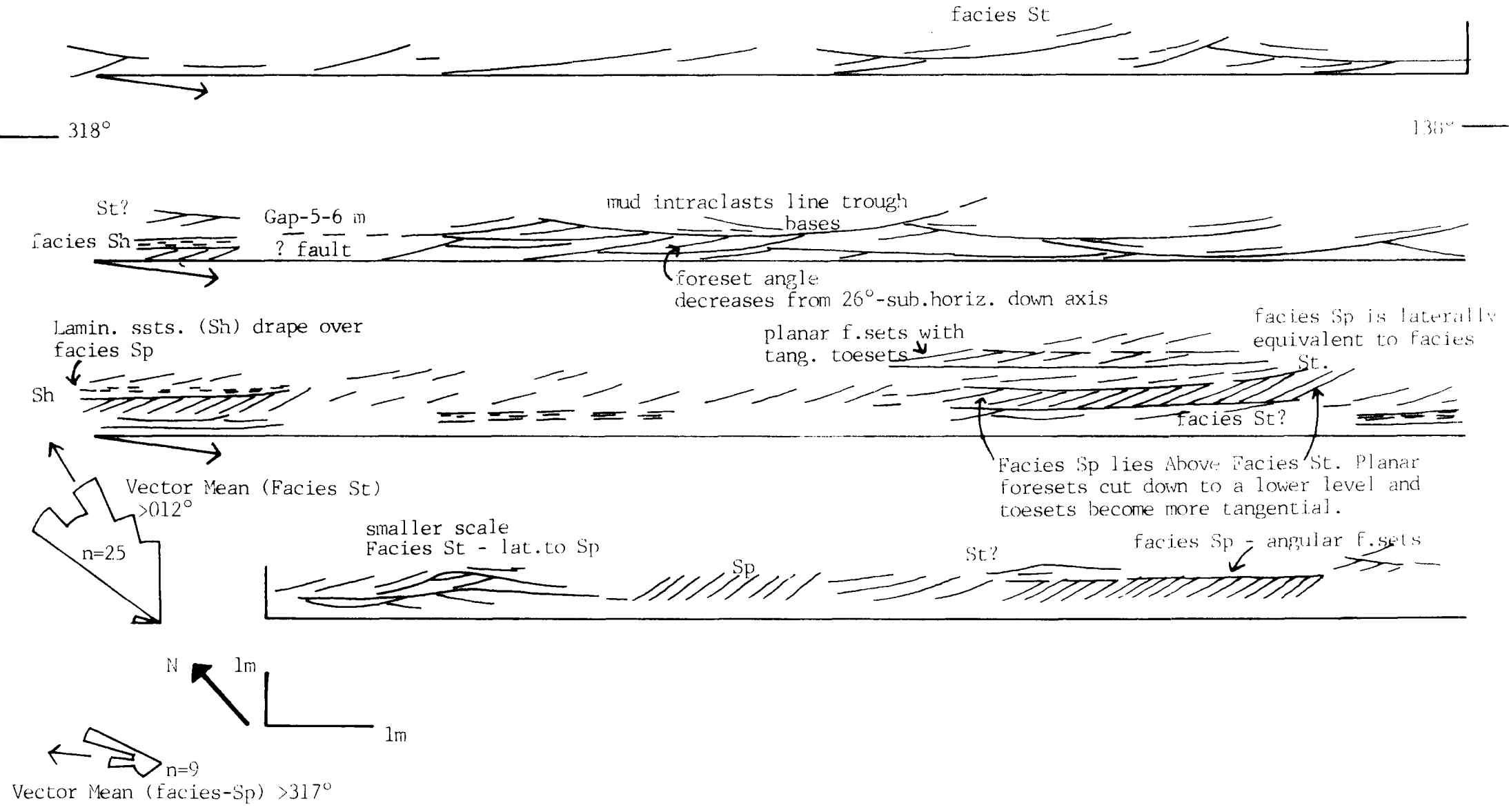
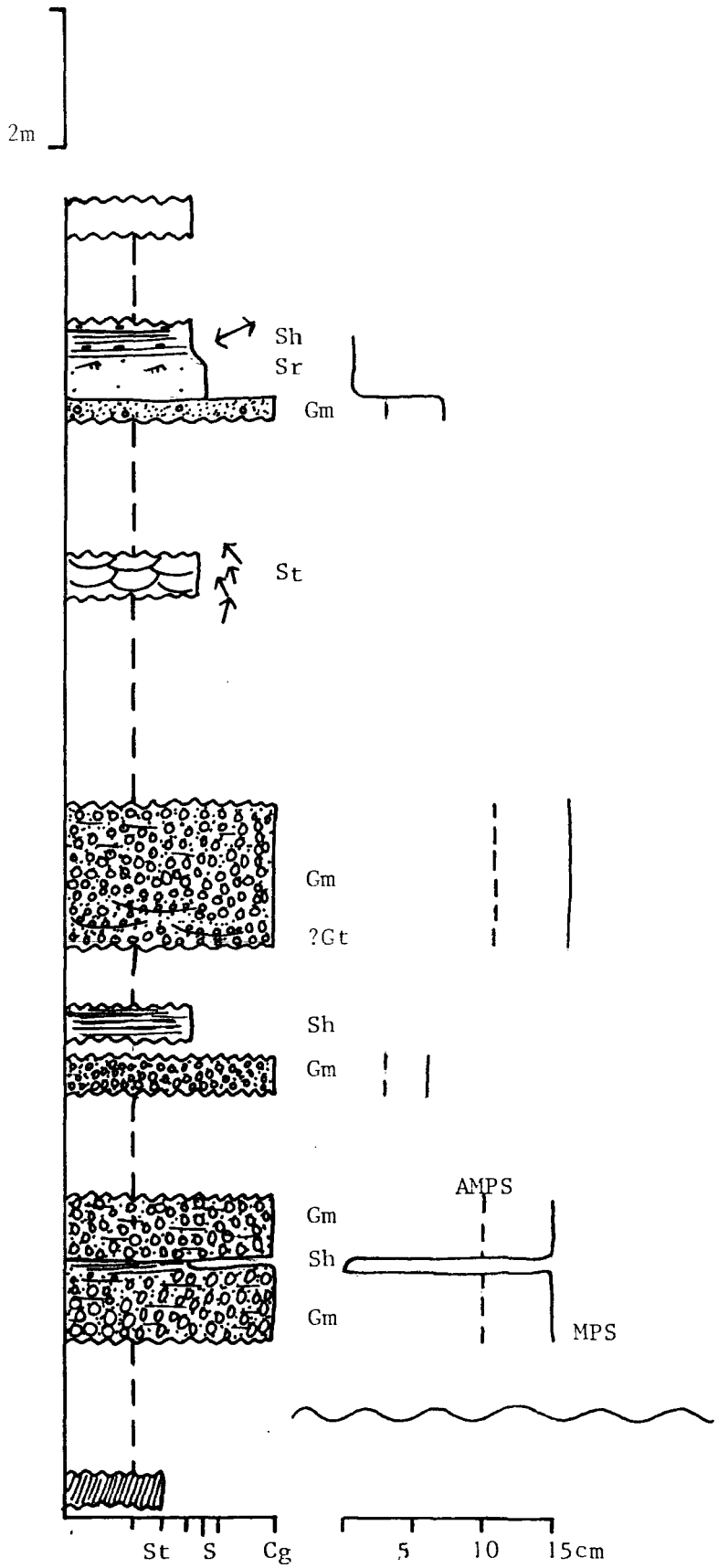


FIGURE 3.8. MEASURED SECTION - ELLERGILL BECK
(N.G.R. NY 640050)



SHAP RED BEDS

BASE OF SECTION CONTAINS LONGITUDINAL BAR CONGLOMERATES (Gm) WITH MINOR SANDWEDGE DRAPES DEPOSITED DURING LOW FLOW STAGE. POSSIBLE MINOR MINOR CHANNEL-TXB CONGLOM. FILL ABOVE. TOP PART OF THE SECTION CONTAINS CHANNEL-FILL SANDSTONES (St , PERHAPS ACCUMULATING WITHIN A CHANNEL-BAR-COMPLEX SETTING.

BANNISDALE SLATES

FIGURE 3.9

Shap Red Beds Facies Distribution - Birk Beck Section.

FIGURE 3.10. DIAGRAMATIC RECONSTRUCTION OF CHANNEL-BAR COMPLEXES, SHAP RED BEDS

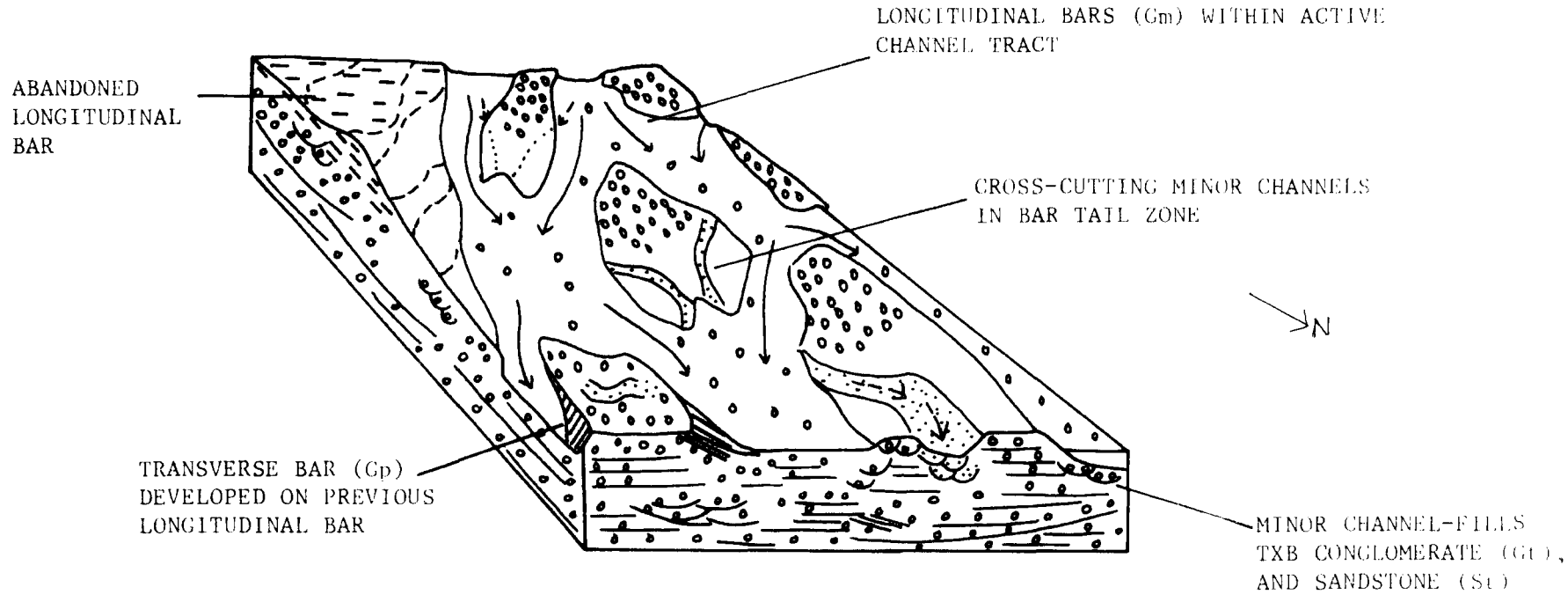


FIGURE 3.11. DIAGRAMATIC RECONSTRUCTION OF 'SANDY' CHANNELS, SHAP RED BEDS

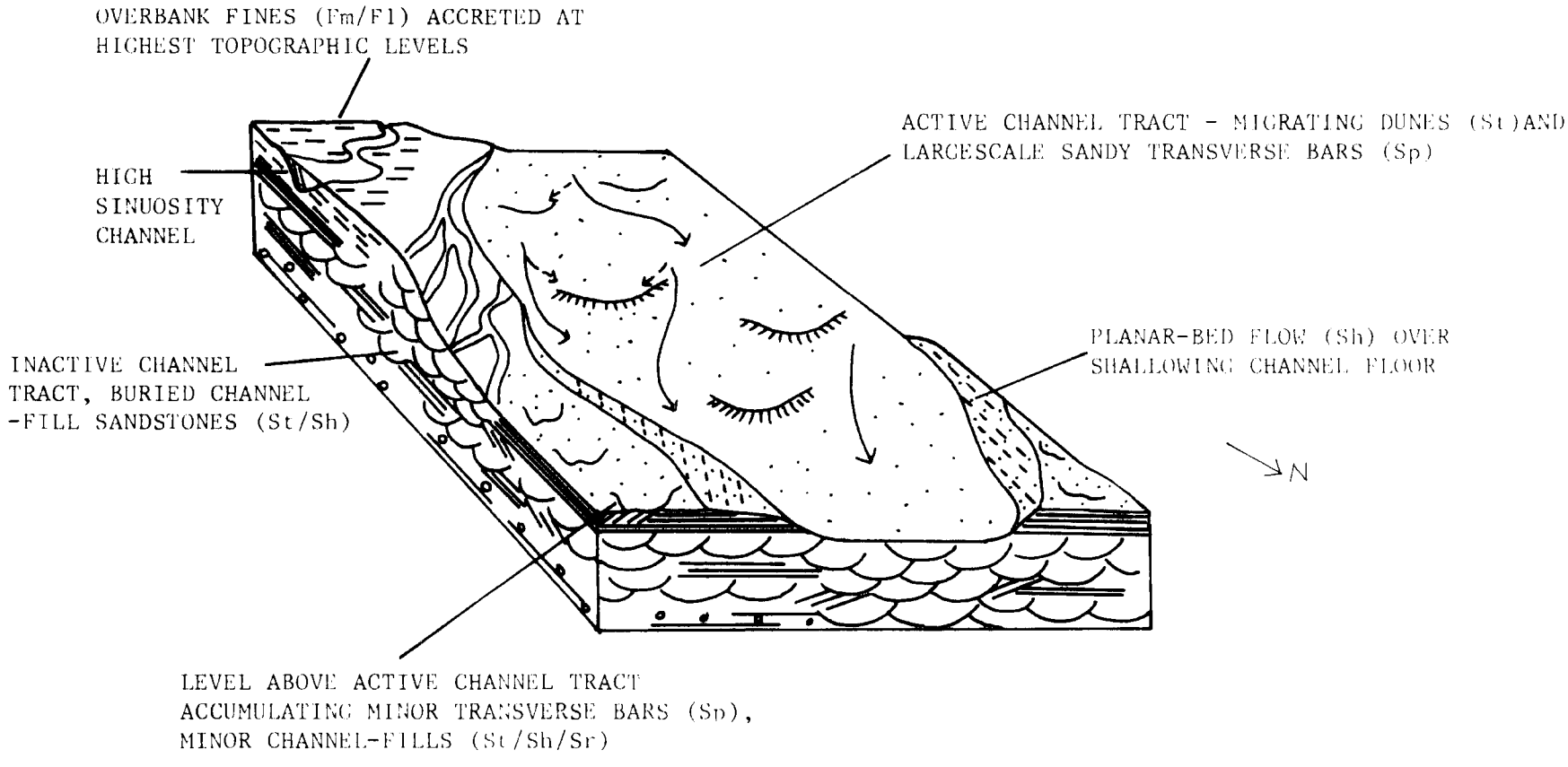


FIGURE 3.12: SUMMARY OF THE PRINCIPAL TYPES OF GRAVEL BAR (Williams + Rust, 1969; Rust, 1972; Smith, 1974; Boothroyd + Ashley, 1975; Hein Walker, 1977; Miall, 1977)

BAR TYPE	MORPHOLOGY	STRUCTURE
LONGITUDINAL	Diamond to lozenge shaped in plan: elongated downstream. Higher central ridge, parallel with flow. Little or no slipface development on downstream margins. Laterally extensive, Scott/Yana bars up to 100m. Undirectional, bank-parallel flow. Characterised by erosional edges + commonly bordered by incised channels. May develop slipfaces with growth: Bar relief becomes higher (up to 1m) + shows clast fining. May occur as LATERAL BARS along channel sides or as CENTRAL or MEDIAL bars in mid-channel.	Initial stratification develops from thin sheets of coarse, poorly sorted, well-imbricated gravel (diffuse gravel sheets). With continued bar growth, develops horizontal stratification through vertical aggradation under very high flow energy and sediment discharge. Develops downstream and upward fining clast sizes due to clast size decrease from channel to bar top.
DIAGONAL	Characterised by flows of unequal strength and net fluid/sediment transport DIAGONALLY across bar. Often sited in channel junctions, channel bends and in lee of older, 'complex' gravel accumulations (braid bars, eroded bar remnants).	No real difference in structure between Diagonal and longitudinal bars - only in the orientation of flow. Morphologies are gradational - caused by small (upstream) changes in flow strength.
TRANSVERSE	Relatively broad flat surfaces bounded by slipfaces at downstream margins. Occurs where flow diverges due to channel widening. Typically formed in deep channels between narrow banks.	Transverse bars develop foresets (facies Gp). Foresets developed by avalanching down gravel bar slip face. Formed in areas of lower sediment discharge - allowing greater vertical clast aggradation. Can form in same channels as longitudinal/diagonal bars.
POINT	Form in gently curved channels seperated from inner convex bank by a smaller channel. Low slopes towards outer bank/foreset margins toward inner.	Planar tangential cross-beds (facies Gp). Fine, imbricate gravel.

FIGURE 3.13. MEASURED SECTION - SHAP SUMMIT (N.G.R. NY 572108).

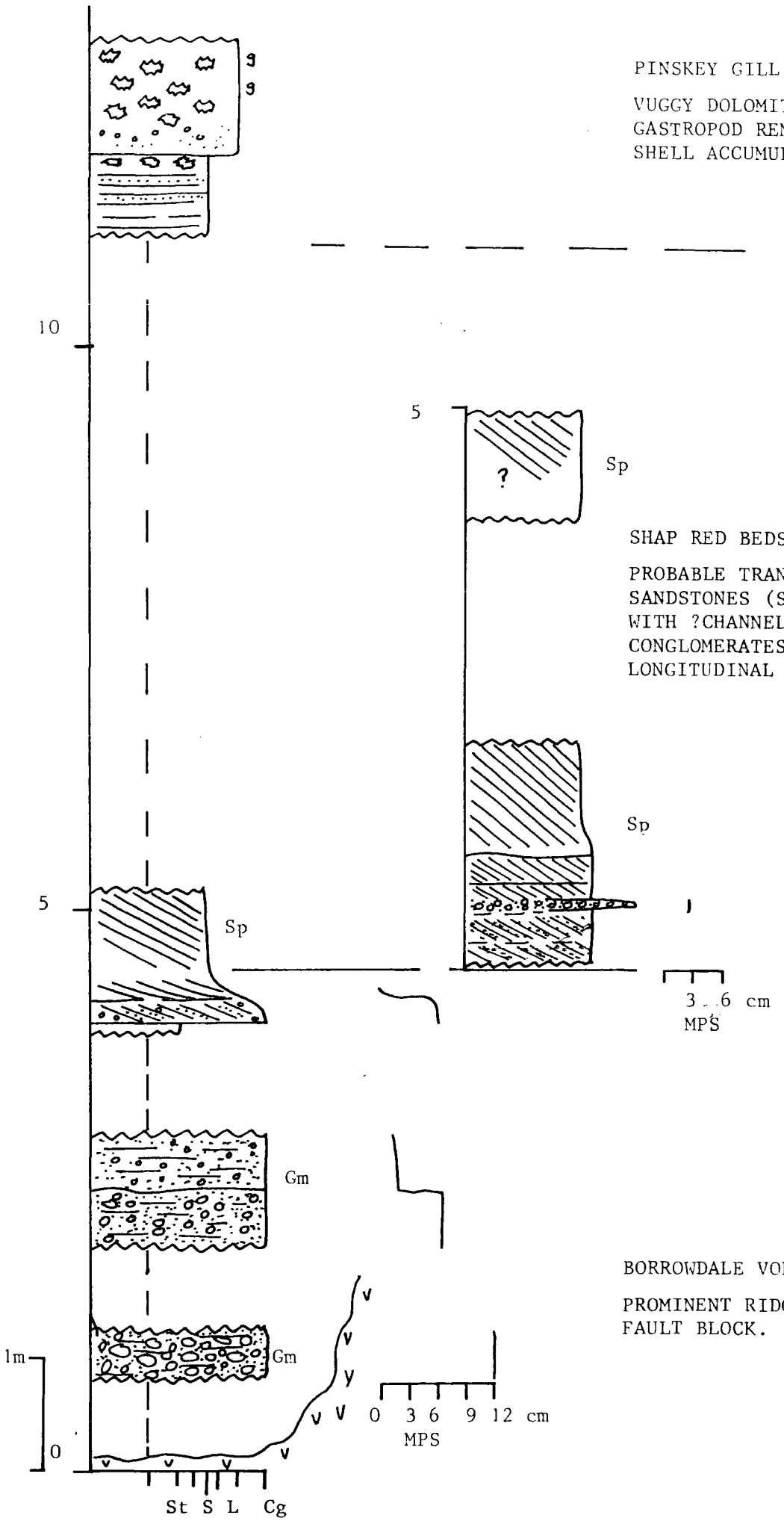


PLATE 3.1

Plate shows view of well exposed trough-cross-bedded sandstones, seen here in 3-D plan view from Shepherds Bridge, Shap. Note the note-book (20cm long) for scale aligned along a trough-axis and pointing down dip (into plate). At least 3-4 sets can be seen, each set with a distinct trough-base on the set below. (NGR NY 590077)

PLATE 3.2

Plate shows cross-section through trough-cross-bedded sandstones, Tebay Services locality, Shap. Note distinct trough-defined foresets and scooped base to each set. The 'vugs' are infact gaps vacatated by mud intraclasts. Tape-measure (60cm extended) for scale. (NGR NY 604066).

PLATE 3.1.



PLATE 3.2.



PLATE 3.3

Plate shows view of longitudinal bar cobble-boulder conglomerate (facies Gm), well exposed along Stakeley Beck (N.G.R. NY 589076), Shap. Hammer (28cm long) is placed along general imbrication (B axis) direction, towards 315°. Note underlying silty mudstones (facies Fl), separated from facies Gm by undulating, erosive basal contact.

PLATE 3.4

Plate shows view of longitudinal bar pebble conglomerate (facies Gm) with sheet geometry, underlain and overlain by horizontally laminated silty sandstones (facies Sh) and silty mudstones (facies Fm/Fl), exposed between Shepherds Bridge and Docker Force, Shap (approx. N.G.R. NY 589080). Sequence reflects abandonment of longitudinal gravel bar by predominantly overbank fine deposits. Scale (bottom left of picture) is clip board, 30cm long.

PLATE 3.3.



PLATE 3.4.



PLATE 3.5

Plate shows crudely defined trough-cross-bedded pebble conglomerate (facies Gt) exposed at river-bed level Birk Beck, Shepherds Bridge, Shap (N.G.R. NY 591077). Bedding plane surface exposed in foreground contains abundant mud intraclasts. Note book (20cm long) and Ruc-sack for scale.

PLATE 3.6

Plate shows close-up view of a slab of very fine grained silty sandstone containing syneresis cracks, between Shepherds Bridge and Docker Force, Shap (approx. N.G.R. NY 587085). Note 'eye-shaped' delicate structures which radiate from a single point resembling a 'birds-foot'. In cross-section these features are crenulated reflecting deformation of the syneresis cracks during formation Lens-cap (6cm) for scale.

PLATE 3.5.



PLATE 3.6.



PLATE 3.7.

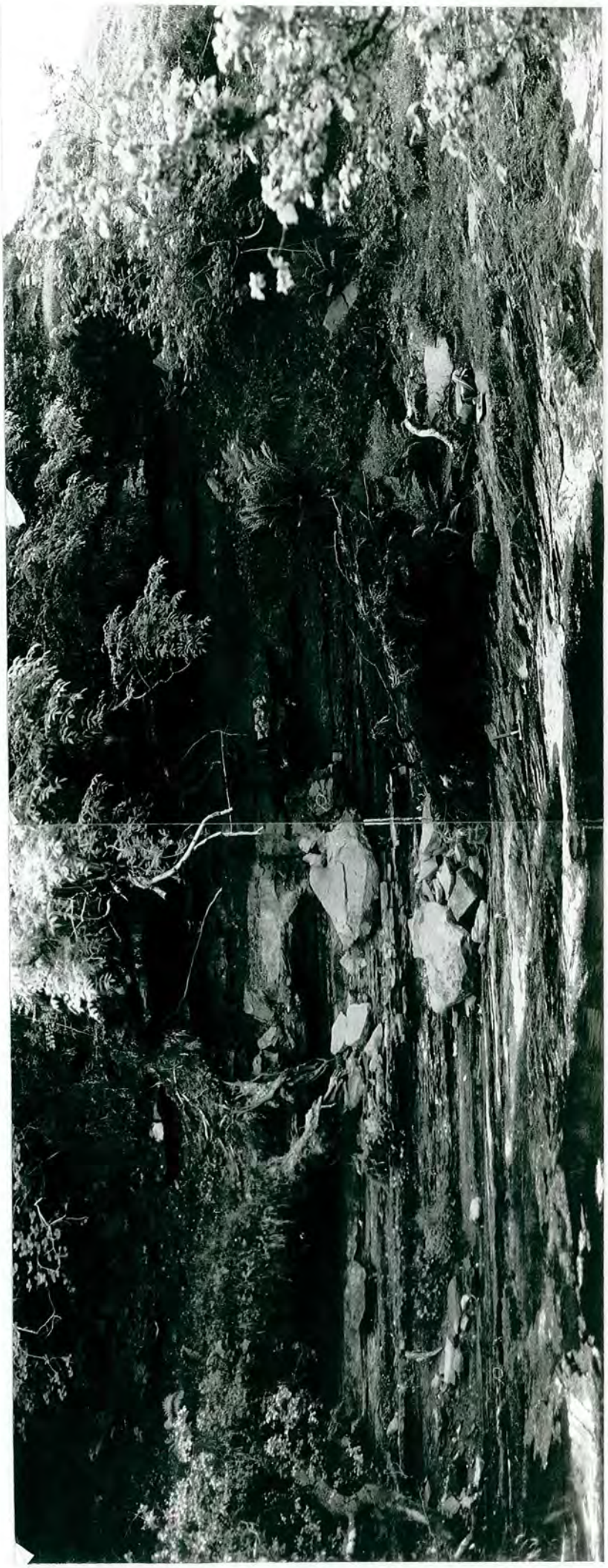


PLATE 3.7

Plate shows view of horizontally laminated sandstones (facies Sh), well exposed at Salterwath, Shap. Trough-cross-bedded sandstones form the base of the cliff (3m high), exposed at river-bed level. Sandstones are dominantly, horizontally laminated (see Figure 3.5b) but contain minor planar-cross-bedded horizons (facies Sp), for example seen here in the centre (above loose block) of view. At the top of the section, planar-cross-bedded sandstones (facies Sp), forming a larger-scale set, contain distinct tabular-planar foresets 'downcutting' to the left of the field of view, i.e. in a northerly direction. Hammer (35cm long) for scale. (N.G.R. 584092)

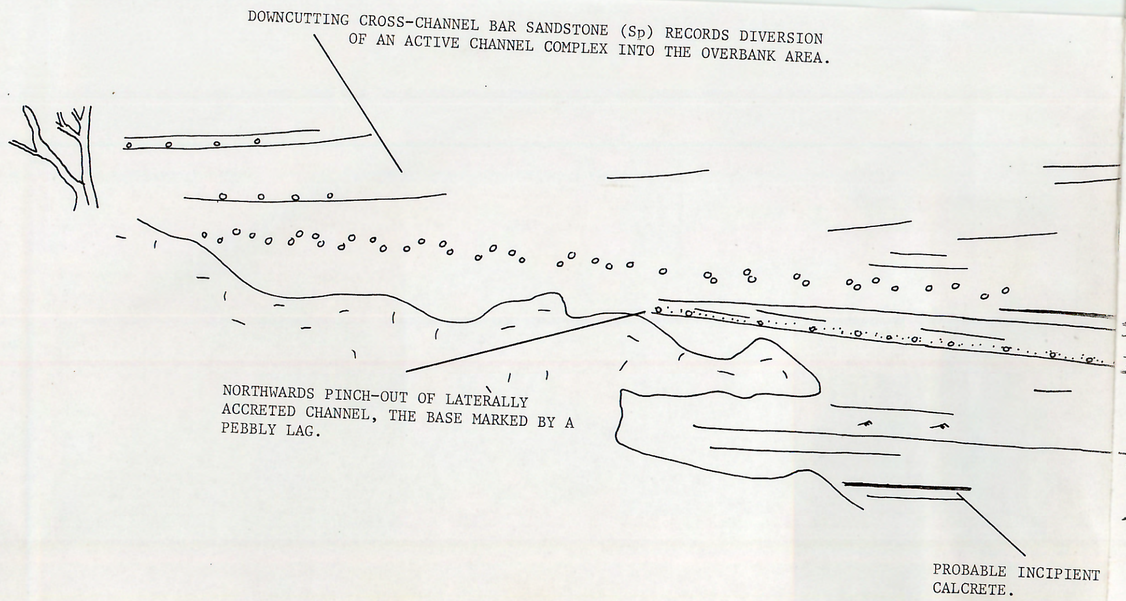


PLATE 3.8.



DOMINANTLY SEQUENCE THROUGH OVERBANK FINES, PRESERVED BY ACCUMULATION AT HIGHEST TOPOGRAPHIC LEVEL WITHIN THE CHANNEL SYSTEM. NOTE THE DISTINCT LATERALLY ACCRETED CHANNEL WHICH PROVIDES EVIDENCE FOR AT LEAST SEMI PERMANENT FLOW IN OVER BANK AREAS. THE CALCRETE ABOVE RECORDS ABANDONMENT OF THE THIS CHANNEL-FILL. THIS SECTION IS REPRESENTED IN THE TOP PART OF FIGURE 3.5a. (NGR NY 587085)

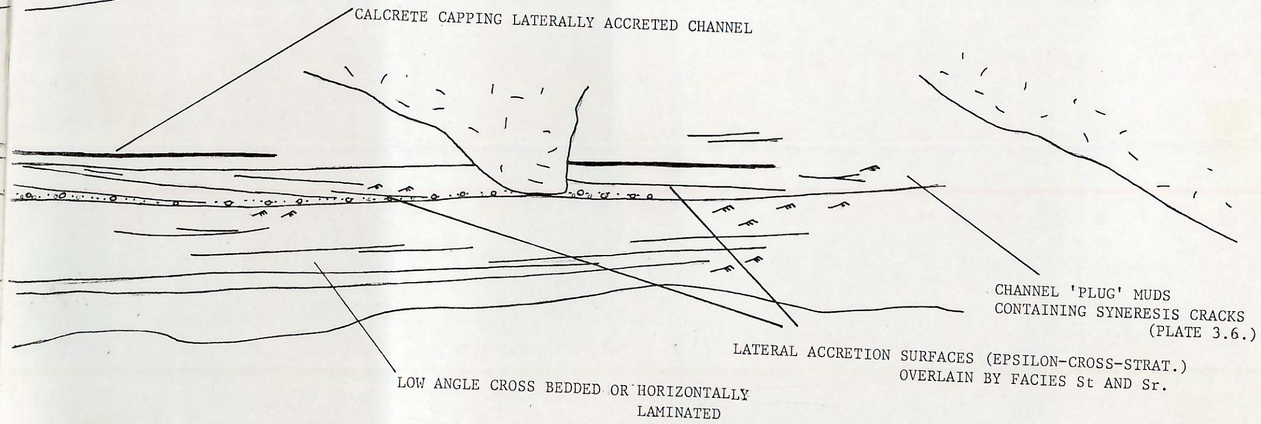


PLATE 3.8.



CHAPTER 4 MELL FELLS (MELL FELL CONGLOMERATE)

4.1 INTRODUCTION

The Mell Fell Conglomerate is exposed near to Ullswater and centred on the 'Fells' of Great Mell and Little Mell, in the west and east of the study area respectively (Figure 4.1). The unconformable junction with the underlying Lower Palaeozoic basement (Skiddaw Slates and Borrowdale Volcanic Group) is nowhere exposed but can usually be placed in the field to within 20m-25m horizontal distance. Estimates as to the thickness of the Mell Fell Conglomerate have been based on two assumptions and hence published literature records a wide range of thicknesses. Capewell (1955) derived a thickness of 1500m by considering the Conglomerate to comprise three distinct stratigraphical groups. Wadge (1978), however, discusses the case as originally put forward by Dakyns et al., (1897) which took the dipping structures present within the Conglomerate to be mainly depositional instead of tectonic in origin. Consequently on this basis, lithological groups are lateral equivalents instead of succeeding each other vertically. As a result, the estimated thickness calculated by Wadge (op.cit.) is nearer 275m, a value accepted by the author in the present study.

4.2 MEASURED SECTION DESCRIPTIONS

Eight sections have been studied in detail, outcrop data being supplemented from the cores of the Dalemain borehole, put down by

Sheffield University in 1979. The facies data are summarised in Tables 10-14 (Appendix 1).

4.2.1 Targets (N.G.R. NY 394255; Figure 4.1; Table 10)

The Mell Fell Conglomerate at this locality is represented by 2.2m of boulder conglomerates exposed as a series of crag outcrops on the north-west facing slope of Great Mell Fell overlooking the old firing range targets. A disused quarry by the main road exposes the Skiddaw Slates and suggests that the unconformity is present close by, possibly being located at the break of slope below the crags. The principal lithology present at this section consists of poorly sorted boulder (up to 33cm) conglomerates (facies Gm) with a coarse grained infilling matrix. Clasts are coated in iron oxide (?haematite) and are dominantly composed of greywacke sandstone with rare volcanic rock types also being present. No stratification or clast grading was observed at outcrop.

4.2.2 Lowthwaite Cottages (N.G.R. NY 416238; Figure 4.1; Tables 10,14)

At this locality conglomerates (facies Gm) total 3m (exposed) being exposed behind the farm cottages at Lowthwaite. Two massive conglomerate units are poorly sorted, containing boulders up to 47cm across, these units being separated by an undulating contact of 48cm erosive relief. Within 5m along strike, parallel laminated medium grained argillaceous sandstones (Facies Sh, 12cm-15cm thick) form a wedge shaped drape over the top of the lowermost conglomerate unit. Clast compositions of the largest size clasts are mainly red coloured, fine grained, laminated micaceous sandstones and greywackes which account for 90% of the maximum clast size component. Capewell (1955)

also records an amygdaloidal basalt volcanic rock clast from this locality.

4.2.3 Folly Lane (N.G.R. NY 429245; Figures 4.1, 4.4; Tables 10,14; Plate 4.4)

Conglomerates (4m, exposed) crop out on the east side of Little Mell Fell near to the farm track above Folly. At the base, poorly sorted, clast supported boulder conglomerates (facies Gm) contain a coarse grained infilling matrix, which is locally cemented by calcite. These conglomerates at least 1.5m thick, are massive with no apparent clast imbrication, the contained clasts being predominantly blocky sub-angular and rounded with only rare elongate clasts being observed. This basal conglomerate unit is capped by discontinuous silty very fine grained sandstones (facies Fm/Fl) up to 10cm thick. Above here ,horizontally stratified cobble conglomerate (Facies Gm) forming a unit, 50cm thick, contains an erosive basal contact and infilling coarse grained matrix (containing abundant granules) again locally cemented with calcite. The central part of the section comprises two graded planar-cross-bedded units (Plate 4.4) which form a coset (facies Gp), 1.4m thick, the two units separated by a thin, 1cm thick, mud drape (facies Fm). Within each unit, boulder-cobble conglomerates at the base are imbricated (B axis) towards 200°, and are overlain by planar-cross-bedded pebble comglomerates and pebbly sandstones, planar foresets dipping at 6° towards 200°. The top part of the section comprises boulder conglomerate (facies Gm) similar to those at the base.

The composition of the largest size clasts (Appendix 2), from the maximum clast size component of the conglomerates averaged throughout the section, is mainly (80%) greywacke sandstone.

4.2.4 Waterfoot Beck (N.G.R. NY 457247; Figures 4.1, 4.2; Table 11)

The section comprises approximately 21m (exposed) of predominantly boulder and cobble conglomerates (facies Gm), these being arranged as 'stacked' units, boundaries between the units only identified through local variation in the maximum clast size. Throughout the main part of the section, conglomerates are massive and show no dominant clast size grading although towards the tops of some units, clast size does show a minor decrease. One such horizon occurs at 16m above the base, where pebble-granule conglomerates are crudely statified formed by the close packing of elongate clasts ('rodded' texture). Conglomerates are clast supported and contain a coarse grained infilling matrix which comprises abundant granules and coarse sand grains forming a 'rodded' texture. At the top of the section, elongate clasts are imbricated (B axis) towards a northerly direction.

From the maximum clast size fraction (Appendix 2), over 92% of clasts are composed of greywacke sandstone rock types with approximately 6% of clasts being volcanic. The latter include andesites with a felted lath groundmass of plagioclase crystals and possible amygdales infilled with calcite. Rare vein quartz and finely crystalline limestone cobbles were also identified.

4.2.5 Ullswater Road Outcrops (N.G.R. NY 459239-463243; Figure 4.1; Table 11

A number of minor outcrops (2m-3m high) occur along the main Ullswater to Patterdale Road close to Pooley Bridge. Poorly sorted massive boulder conglomerates (facies Gm) form units between 70cm and 1.5m thick, these being commonly draped by discontinuous pebble conglomerates, up to 50cm thick, and minor pebbly sandstone units (20cm thick) the former containing a distinct tightly packed rodded framework of elongate clasts. Clast types are predominantly sub-angular and blocky in shape with rare elongate and more rounded clasts imbricated (B Axis) towards the north-east (050°-040°).

From the maximum clast size fraction, up to 90% of clasts are composed of red-green coloured greywacke sandstones with 9% of clasts composed of finely crystalline limestone. Rare (1%) tuffaceous clast types are also present these being characterised by a fine grained groundmass containing 'glass shards'.

4.2.6 The Hause (N.G.R. NY 426236; Figures 4.1, 4.3; Tables 11,14; Plates 4.1-4.3)

The Mell Fell Conglomerate is well exposed at the Hause, on the south side of Little Mell Fell, where approximately 10.5m of coarse, boulder conglomerate (facies Gm, maximum clast size up to 80cm) is observed. The lower 3.5m (Plate 4.1) of the section consists of clast supported boulder conglomerate (facies Gm) containing an infilling coarse grained matrix of abundant granules, locally cemented by calcite. Clasts are predominantly elongate in shape and sub-rounded, with clast

base (i.e. parallel to A axis) orientated sub-horizontal and parallel with the top of the unit. Within this basal section, no observed breaks in maximum clast size or breaks defined by interbedded sandstone are present.

The top of the basal section is marked by a wedge-shaped pebbly unit (Plate 4.1; facies Gm/Sh) which has a sharp basal contact and 'drapes' protruded clasts of the conglomerate below (Plate 4.2). Within the unit, maximum clast size decreases towards the north-west and grades into horizontally laminated medium grained sandstone, forming a more sheet-like unit up to 45cm thick. Towards the south, this pebbly unit appears to 'pinch-out' and 'merge' with the matrix of the conglomerate below, the maximum clast size fraction increasing from granule and small pebble (5cm) grade to boulders up to 16cm across.

The wedge-shaped pebbly unit divides the section into two parts, the top part of the section above comprising clast supported boulder conglomerates (facies Gm) with maximum clast size increasing to 80cm near to the top. Locally, these conglomerates contain intercalated minor lensed units, 15cm thick, containing granule and pebbly conglomerate preferentially cemented by calcite.

4.2.7 Holghyll Gorge (N.G.R. NY 429272; Figure 4.1; Plate 4.5, Table 12)

This section exposes the Mell Fell Conglomerate in close juxtaposition to the Carboniferous limestone (of ?Chadian or Arundian age) which outcrops on the opposite side of the gorge (Skitwath Beck)

and south of Penruddock. Field relationships suggest that the junction between typical Mell Fell Conglomerate lithologies and the Carboniferous Limestone is sharp and not transitional.

The section at Holghyll Gorge exposes at least 7m-8m of trough-cross-bedded pebble and granule conglomerate (facies Gt) and pebbly coarse grained sandstone (transition to facies St). The whole section contains trough-cross-bedded sets which are grouped as festoon cosets these apparently arranged in sheet like units, varying in thickness from 80cm to 1.5m-2m, the boundary between each 'unit' or coset marked by a pebble/cobble lag conglomerate. From the basal part of the cliff section, trough-defined structures are on average 25cm deep and measure up to 1.1m across, the base of each unit often marked by horizons containing elongate pebbles imbricated (B axis) towards 322°-050°. Trough axes trend between 360°-180° and 044°-244°.

Clast compositions from this section (maximum clast size fraction Appendix 2) contrast markedly from the boulder/cobble conglomerates exposed in the sections described above. At Holghyll Gorge, greywacke lithologies are relatively rare (12%), the clasts being predominantly composed of a variety of volcanic rock types (up to 75%), mainly rhyo-dacites or felsites (Plate 7.11), and quartz-felspar-rich porphyries (similar to Plate 7.8), the former being typically flinty and red coloured in hand specimen. Relatively minor finely crystalline limestone (6%) and calcareous siltstone (6%) clasts are also present, along with rare quartzite pebbles. Vein quartz in the maximum clast fraction is absent.

4.2.8 Dacre Beck (Figure 4.1; Plates 4.6-4.7; Tables 12-14)

The Mell Fell Conglomerate is exposed at a number of localities along Dacre Beck, and although some outcrops exposed up to 4.5m-5m of clastic rocks, a vertical section of the whole succession was not able to be constructed. Instead, the facies present are described below and illustrated in Figures 4.1, which show the regional facies distribution, and also in selected plates (4.6-4.7).

4.2.8.1 Dacre Lodge (N.G.R. NY 457263-460264)

Massive, clast supported boulder conglomerates (facies Gm) up to 1.3m being exposed, are overlain by a trough-cross-stratified cobble conglomerate (facies Gt) unit, 15-20cm thick. This unit contains approximately 2 sets, up to 10cm in thickness. Clast types within both these conglomerate units are sub-rounded and blocky in shape, mainly composed of greywacke sandstone with rare minette clasts (e.g. Plate 7.6) also being recorded. Facies Gt is overlain by sub-horizontally stratified cobble conglomerate (facies Gm) which fines up into pebbly sandstone, up to 30cm thick. Bedding surfaces within these units dip at 3°-4° towards 120°.

4.2.8.2 Dacre Lodge - Dacre High Bridge (N.G.R. NY 455261-453261)

Between these two localities, clast supported boulder conglomerate (facies Gm), at least 1.3m in thickness, is overlain by crudely stratified cobble conglomerate (facies Gm), up to 2m thick. Within both of these conglomerates, the framework is infilled by a coarse grained sandy matrix which locally forms discrete sand intercalations up to 5cm-6cm thick. Clast types are subangular to subrounded and blocky in

shape and mainly composed of greywacke sandstone (of varying grain size) with minor angular vein quartz and porphyritic volcanic rocks also being observed.

West of Dacre High Bridge, a section, 2.85m to 3m in thickness comprises a fining upward sequence from boulder conglomerate (facies Gm, 1.15m thick) to cobble (55cm thick) and cross-stratified granule conglomerate near to the top. The latter is overlain by pebble conglomerate, 20cm thick forming a unit at the top of the section. The boulder conglomerate unit at the base contains a clast support framework, infilled by a coarse grained sand matrix. Clasts are sub-rounded and blocky in shape, with up to 96% (Appendix 2) of clasts from the maximum clast size fraction being composed of red-green coloured greywacke sandstone. The remaining 4% of clasts are composed of finely crystalline limestone and feldspar rich andesite rock types.

4.2.8.3 Dacre Low Bridge towards Langfield Banks (N.G.R. NY 460264-463263)

A locality very close to Dacre Low Bridge comprises stratified pebble conglomerates (facies Gm), forming a unit at least 50cm-60cm thick. Clasts within this conglomerate unit are mainly composed of greywacke sandstone (over 96%) with minor angular vein quartz pebbles, finely crystalline limestone and porphyritic volcanic rocks also present.

Further downstream towards Langfield Banks farm medium to coarse grained sandstones (facies Ss) infill a scour-shaped depression 40cm

thick and up to 1.8m wide. The base of the scour infill is draped by mudstone and suggests that infill occurred at a later stage to initial 'scour' formation. The scour-shaped depression is orientated 031°-211°, the infilling sandstones containing isolated pebbles aligned along some foresets. A pebble lag (facies Gm) is also present along the base of the scour structure.

These cross-bedded sandstones are sharply overlain by a thin (50cm thick) well stratified pebble conglomerate unit (facies Gm) and in turn by medium grained ripple-cross-laminated sandstones (facies Sr), 20cm thick containing individual sets up to 7cm thick.

4.2.8.4 Rucroft Wood (N.G.R. NY 447267; Plate 4.6)

A locality near to the edge of Rucroft Wood exposes a well-bedded sequence, 2m-2.5m thick, comprising pebble-granule conglomerate (facies Gm) graded units between 50cm and 80cm thick, overlain by ripple-cross-laminated medium to coarse grained sandstones (facies Sr). Planar-cross-bedded medium to coarse grained sandstones form a set, 30cm thick at the top of the section, foresets dipping towards 010°.

4.2.8.5 Galley Bridge (N.G.R. NY 442265; Plate 4.7)

At this locality, near to Galley Bridge, pebbly medium to coarse grained sandstones (facies Ss) are cross-stratified and infill two scour-shaped depressions, 2.5m wide and 50cm/70cm deep, the base of the lower unit containing a pebbly lag (facies Gm) base. Throughout isolated clasts up to 12cm are imbricated along crudely defined trough-shaped foresets, the axis of the 'top' unit trending 142°-322°.

Clasts are composed (Appendix 2) of a variety of clast types; greywacke sandstone (49%), basic porphyritic tuffs (34%), containing pyroxene and plagioclase phenocrysts (similar to Plate 7.9), acidic tuffs (9%), with a welded 'fiamme' texture of glass shards, and minor limestone (up to 6%). Minor ash tuffs, quartzite and vein quartz pebbles are also present.

4.2.9 Dalemain Borehole (Figures 4.1, 4.5; Plates 4.8-4.10)

The Dalemain borehole was put down by Sheffield University in 1979 and cored 55m of Mell Fell Conglomerate. The core is now kept by the British Geological Survey, to which the author extends his thanks for permission to describe it.

Throughout the core (Figure 4.5), three principal lithofacies have been recognised, conglomerate (coded facies A), sandstone (coded facies B) and sandstone/mudstone (coded facies C), these lithofacies being described in the following sections.

4.2.9.1 Conglomerate (facies A)

Conglomerates, mostly pebble to granule grade, form units between 40cm and 1.2m to 2.5m thick, with occasional cobbles at least 7.2cm (core size) across being present. Conglomerates are clast supported with a framework infilled by a coarse grained sand matrix, locally being calcite cemented within well sorted horizons. These conglomerate units (Plate 4.8) form the lower parts of fining upward sequences overlying an erosive basal contact and overlain by sandstone horizons, draped over 'protruded' clasts of the conglomerate unit (e.g. at 4m above base).

Medium to coarse grained sandstone is intercalated with conglomerate at various horizons, some (e.g 40m above base) containing mud intraclasts. Mud drapes are relatively rare (e.g at 0.8m above base) usually not more than 1mm thick and draped over the protruded clasts of the conglomerate unit below.

Fining upward sequences of facies A comprising conglomerates with intercalated sandstone horizons, form the dominant part of the lowest 16m of the borehole core. As demonstrated in Figure 4.5 and discussed in the following sections, the relative proportion of conglomerate: sandstone decreases from 100:0 to 0:100 towards the borehole top. This upward decreasing grain size trend is also reflected by an upward decrease in maximum clast size.

4.2.9.2 Sandstone (facies B)

Facies B consists of fine through to coarse grained sandstone, which mainly form cross-bedded sets, arranged as cosets on average 1.3m to 1.5m thick (e.g. between 27m and 28.35m above base) reaching 3m-4m near the top. Foresets are often graded (e.g. Plate 4.9), with a coarse grained base fining up into predominantly fine to medium grained tops. Foreset angle of dip also varies throughout each coset, and also foreset thickness which commonly decreases upward throughout the coset (e.g. 1.4cm to 0.8cm between 24m and 25m above base). Cosets occasionally contain a thin pebbly lag along the base, these being no more than 10cm-20cm thick.

These cross-bedded cosets are commonly overlain by or contain thin fine grained cross-laminated units up to 20cm thick. Horizontally laminated sandstones are also evident throughout the core, e.g. at 35.5m above base.

Facies B forms the main part of the cored interval above 16m, increasing in dominance towards the top. The 'middle' 22m of the core consists of interbedded conglomerate and cross-bedded sandstone, the thickness of individual conglomerate units decreasing significantly upwards from near 25cm at the base to less than 10cm thick at the top. This 'interbedded' sequence is coded facies A-B.

4.2.9.3 Sandstone/mudstone (facies C)

Facies C predominantly comprises very fine grained and silty cross-laminated sandstones forming units up to 1m thick, with individual sets on average 1.3cm-1.5cm thick. Mudstone drapes and mottled/ disrupted silty horizons (Plate 4.10; e.g 34m-35m above base) are also included in this facies, mud drapes being common (e.g. 0.8m above base) as <1mm thick horizons overlying protruded clasts of the conglomerate below.

Facies C does not form a significant portion of the core, only being present locally, interbedded with cross-bedded sandstone and as a silty 'cap' to cross-bedded sandstone (e.g. 34m-35m above base).

4.2.9.4 Thin Section Petrography

4.2.9.4.1 Conglomerate matrix

Thin sections of conglomerate matrix (Appendix 3) were studied from samples taken between 2.45m and 22.5m above base. The samples are predominantly poorly sorted containing sub-rounded to rounded grains, being fine through to granule in grain size. Pebble clasts occasionally reach 14mm across. Detrital grains are dominated (up to 86%) by lithic rock fragments, specifically volcanic rock and igneous rock grains, with mud intraclasts also being very common and compacted to form pseudomatrix. Detrital monocrystalline quartz grains only comprise between 4% and 7% of grain types. Authigenic mineral cements are mainly calcite, which passively infills intergranular pore spaces and haematite which coats and stains grains less than fine sand in grain size.

4.2.9.4.2 Sandstone

Similar petrographic features are present in sandstone samples as those described for conglomerate matrix. Grain size is mainly coarse grained with rare pebbles up to 13mm and 18mm also being present. Detrital grains are again dominated by volcanic and igneous rock fragments accounting for 52%-78% in the modal analysis. Detrital quartz is rare. Haematite coats grains, forming rims up to 300μm in thickness and also stains fine grained clasts. Calcite passively infills intergranular pore spaces.

4.3 ENVIRONMENTAL INTERPRETATION

4.3.1 Facies relationships and interpretation

The Mell Fell Conglomerate consists of a general north-east depositional trend mainly comprising a fining of grain size and maximum clast size towards this direction (summarised in Figure 4.6). Superimposed on this fining trend is an increase in the abundance of cross-bedding and development of fining upward units and sequences towards the north away from the massive and relatively less structured boulder conglomerates outcropping in the southern part of the outcrop area. Conveniently the outcrop area falls into two distinct lithological and 'sedimentary structural' groups - those localities in the south and central parts of the area (boulder - cobble conglomerates, cross-bedded conglomerates: Hause, Waterfoot, Folly Lane, Lowthwaite, Ullswater Rd, Targets) and those toward the north (cobble-pebble conglomerates and pebbly sandstones, cross-stratified and trough-cross-bedded: Dacre Beck, Holghyll Gorge, Dalemain Borehole).

Facies Gm (massive to stratified and imbricated conglomerate) is the dominant facies type throughout the Mell Fell Conglomerate and shows a northward fining of the maximum (M.P.S.) clast size (over a distance of 3-4km) fraction: 33cm-80cm (M.P.S. - southern localities) to between 17cm-30cm (M.P.S. - Folly Lane, 'Central' area) and 3cm-31cm (M.P.S. northern localities, Dacre Beck, Holghyll Gorge).

Average maximum clast size shows a similar trend: 17.5cm-37.4cm (south), 8.6cm-20.2cm (central) and 2cm-18.cm (north). In the southern

part of the area, boulder conglomerates form thick monotonous sections (Figures 4.2, 4.3; Plates 4.1, 4.3), units only being occasionally defined by upward fining clast size and relatively uncommon well sorted cobble-pebble conglomerate units (e.g Ullswater Rd). The sections at Lowthwaite and the Hause (e.g Plates 4.1, 4.2) do contain sheet-like cobble-pebble conglomerate units which grade laterally (rapidly) into horizontally laminated sandstones (facies Sh, sections 4.2.2, 4.2.5, 4.2.6).

The Folly Lane Section (Section 4.2.3; Figure 4.4; Plate 4.4) comprises cobble-boulder conglomerates interbedded with planar-cross-bedded conglomerates (facies Gp) which are organised into 2 sets, showing within each set an upward fining trend into planar-cross-bedded pebbly sandstones. The sets are separated by a mudstone drape.

In the central to northern parts of the outcrop area, around Dacre Beck, facies Gm occurs as fining upward units, shown by upward fining clast size, and probably forms the basal part of fining upward sequences (at least up to 3m thick), being overlain by finer grained and stratified pebble conglomerate units and crudely trough-cross-bedded conglomerates (facies Gt). The latter contains sets, approximately 10cm thick (section 4.2.8.1). Facies Gm contains a clast supported framework infilled by a coarse grained sand matrix which locally forms discrete intercalations up to 5-6cm thick.

Facies Gm is interpreted as the deposits of gravel bars accumulating within coarse bed-load braided channels. In the northern part of the area (Dacre Beck), fining upward conglomerates, overlain by trough-cross-bedded conglomerates (facies Gt) compare closely with the 'channel-bar complexes' described extensively in Chapters 3 and 6. The sandstone intercalations record the deposition of sand during waning flow stage on the bar surface, facies Gt reflecting the infill of minor scours and depressions on the bar surface, again during waning flow stage. Further evidence that the gravel bars were susceptable to fluctuations in flow stage are seen in the current rippled sandstones (facies Sr) overlying a pebble conglomerate unit at Langfield Banks (Section 4.2.8.3) and also in the mudstone drapes at the Folly Lane Section (Section 4.2.3). Fining upward clast sizes within facies Gm (not always apparent) are consistent with both the downstream and bar top to channel fining of clast size and suggests that bars were most probably of the longitudinal type (see Chapter 3).

The preservation of waning flow and low flow stage deposits suggests that topographic differentiation within the channels must have been present, relatively fine grained deposits being 'protected' from erosion (cf. Costello and Walker, 1972) at higher topographic levels on the bar during the next high flow stage (see discussion in Chapter 6). Indeed further evidence that topographic differentiation was at least locally significant within these 'gravel bar complexes' is seen in the cross-bedded conglomerates at the Folly Lane Section. The development of facies Gp and subsequent finer grained cross-bedded pebbly sandstone (facies Sp) within the same set or 'couplet' is interpreted as the

growth of foresets along the gravel bar margin during waning flow stage (cf. Ramos and Sopena, 1983, Rust, 1984, Ramos et al., 1986, see Chapter 6) , producing a possible wedge-shaped cross-bedded unit accreted onto the bar margin/bar surface as flow stage continued to decrease. Support for this argument is seen in the mudstone drape separating the two 'couplets' and deposited from suspension at lowest flow stage. The generation of these structures suggests that the bar had reached a certain height producing enough relief between the bar top and base for foreset growth to develop on waning flow stage.

The relatively coarser grained boulder conglomerates which outcrop in the southern part of the area, in contrast, comprise thick sequences of conglomerates with only occasional finer grained deposits separating out individual units. These conglomerates are interpreted as the deposits of low relief gravel bars, forming in response to high stage flow (M.P.S. up to 80cm). These are probably the significant factors in resolving the lack of fine grained deposits preserved in these sequences. That these conglomerates most probably do represent gravel bar deposits are seen in the local presence of fining upward clast size, and the horizontally laminated sandstone 'sheet' deposits, these reflecting the fining of clast size over the bar and deposition of sand over the bar surface respectively. The latter, being laterally transitional to cobble conglomerates (Plate 4.2), reflect the deposition of sand under planar-bed-flow, spreading out laterally away from the channel over the bar surface and probable adjacent channel margin area. Indeed, these sheet sandstone deposits add evidence that the bars were of low relief, flood water easily being able to overflow channel and bar

margins (cf Ramos and Sopena, 1983). It is accepted that these deposits may have been deposited by sheetfloods (cf. Hogg, 1982; Nilsen, 1982; Rust and Koster, 1984) on an alluvial fan surface and reflecting the lateral extension of flow from streamflow channels. As discussed in section 4.3.2, a 'typical' alluvial fan setting for the Mell Fell Conglomerate could not be conclusively determined and considering that deposits of alluvial fans can, in the ancient record, be hard to distinguish from proximal braidplain deposits (cf. Ori and Penney, 1982) the former interpretation is preferred (see Section 4.3.2 for a more detailed treatment). The flat-lying structure of the clasts within these conglomerates (see Section 4.2.6, Plates 4.1, 4.3) is probably due to the accretion of these Conglomerates in 'sheet' form, probably originating from the vertical stacking of the diffuse gravel sheets (cf. Hein and Walker, 1977).

The coarse boulder conglomerates closely resemble the proximal gravel bar deposits documented by Boothroyd and Ashley (1975) and Boothroyd and Nummedal (1978) from a study of glacial outwash fans from North Alaska (Scott, Yana, Sheridan, Fountain, Alder) and Iceland (Gija, Skeidara). Miall (1977) took the Scott outwash fan as his type model for proximal gravelly braided rivers. These 'fans' show a number of proximal to distal variations, reflecting the downstream transition from coarse grained braided channels into progressively finer grained distal reaches. Clast size and gradient within the fans are interdependent with maximum clast size (45cm from the Alder and Sheridan fans) associated with steepest gradient (up to maximum of 50m/km). Clast size decreases to sand-sized sediment in the distal fan segment accumulating

on more gentle gradients (2m/km, recorded from the Scott and Gija fans). Rust and Koster (1984) also provide a synthesis of the variation in maximum grain size versus distance downslope for various alluvial fans and braided rivers. Channel patterns also change in relation to the downstream depositional trend within the fan systems (Boothroyd and Ashley, 1975; Boothroyd and Nummedal, 1978). The proximal reaches of the outwash fans have between one and three channels, incised in coarse gravel and grade downstream (within 2.5km from source) into larger channels that 'bisect around individual and longitudinal bars' (Boothroyd and Nummedal, op.cit.). Changes in gravel stratification is also related to this proximal to distal trend, with cross-bedded gravel (facies Gp) only developing in areas where sufficient channel depth allows flow to separate over the bar surface to allow foreset growth. Rust and Koster (1984) indicate that the dominance of facies Gm within proximal reaches of braided channels reflects the 'low ratio of mean particle size to water depth, in turn a function of the relatively low relief of bars within proximal reaches'. The relief of the bars within these reaches, according to Boothroyd and Ashley (1975) for the Scott/Yana fans, may not be more than the size of the largest clast size, these gravel bars accreting gravel in thin sheets, a result of the large clast size, compared to distal reaches, and the higher velocity of the flow (occasionally greater than 2m/s). Assuming that facies Gm in the southern part of the Mell Fell Conglomerate outcrop area was deposited in a similar way, then a tentative estimate of the velocity required to transport the largest clast size (80cm) can be obtained from the equation $Vb = 9d^{\frac{1}{2}}$ (Vb = velocity in feet/second; d = clast diameter; from Turner, 1980). Substituting this equation derives a value of

4.4m/s, a value outside the range for the Scott/Yana fans, but this value would have been the considered maximum (based on the largest clast size measured in the field).

From the study by Boothroyd and Ashley (1975), longitudinal bars in the medial reaches of the Scott/Yana Fans, are composed of smaller grain sizes and are susceptible to bar growth and modification during lower flow stages, accumulating a relatively greater amount of sand, deposited during dissection of the bars by minor, shallow channels and movement of sand along the bar margins.

From the discussion above, the author thus considers the observed northward variation in facies Gm within the Mell Fell Conglomerate to reflect the proximal to distal change from coarse grained conglomerate bar deposits to progressively finer grained and more evolved conglomerate 'channel bar complexes'.

The Holghyll Gorge Section (Plate 4.5) demonstrates the characteristics of trough-cross-bedded conglomerates (facies Gt) within the Mell Fell Conglomerate. Along Dacre Beck, where facies Gt is interbedded with facies Gm, it reflects the infill of minor channels or scours on the gravel bar surface (see above). At Holghyll Gorge, however, facies Gt forms the dominant facies of the 7m-8m high exposure, comprising crudely defined sets about 25cm deep and arranged as festoon cosets from 80cm to 1.5m-2m thick. The cosets have a slight lensoidal to sheet-like geometry, the base of each coset marked by a pebble/cobble lag conglomerate. Faces Gt is normally of cobble-pebble grade but

apparently fines up within each set to coarse - very coarse grained pebbly sandstones (facies St).

Facies Gt and St are interpreted as the deposits of migrating gravelly dunes along the base of coarse bedload channels, each channel being floored by a pebbly lag. Each coset is thus interpreted as representing the infill of a separate channel, the section reflecting the infill of a channel network or system. Considering that facies Gt varies little throughout the section, and is not apparently interbedded with other facies (except facies St), suggests to the author that facies Gt represents the infill of a series of channels comprising a channel system which developed by the easy lateral switching of channels across an alluvial plain. This argument is further supported by the absence of floodplain fine deposits, perhaps indicating that the channels were shallow, channel switching aided by the low-lying nature of the alluvial plain or braidplain. Migrating gravelly dunes have been described from the modern environment by Fahnestock and Bradley, and Galay and Neill (both from Rust and Koster, 1984) within the Knik River, Alaska and the North Saskatchewan River, Yukon respectively, the dunes, identified from echo sounding, being crescentic gravel bed forms. In the ancient record, facies Gt has been recorded by Rust (1978b, 1981) from the Upper Member of the Carboniferous Cannes de Roche Formation, and reflects the migration of gravel dunes along the base of principal channels, developing upward fining sequences which record the infilling of an active channel complex. Rust (op.cit.) uses the Upper Member Cannes de Roche Formation (dominated by facies Gt) as his model for distal gravelly braided rivers (his facies assemblage GIII).

Sandstone within the Mell Fell Conglomerate is only properly developed in any great abundance, in the Dalemain Borehole (Figure 4.5; Plates 4.8-4.10) where it forms cross-bedded cosets (facies B) reaching 4m in thickness towards the top of the core. Significantly the upward increase in sandstone content throughout the core is a reflection of the overall northward depositional fining trend observed at outcrop. Significantly the paucity of quartz in both conglomerate matrix and sandstone thin sections demonstrates the immaturity of these channel-fill sandstones, a reflection of the volume of rock fragment debris and the inability, even within these considered 'distal' deposits, of the streams to breakdown the grain types into more mature types.

At outcrop, crudely trough-cross-bedded sandstone (?facies Ss) infill scour-shaped depressions (Plate 4.7, Galley Bridge; also Langfield Banks), initially lined by pebble conglomerate. These deposits resemble, in structure, the multistorey scour and fill sandstone facies of Tunbridge (1984) from the Middle Devonian Hangman Sandstones Group, North Devon and possibly analogous to the shallow scour and channel-fills of Sweet (1985), the latter deposited in a distal fan to sandflat environment from shallow streams or sheetfloods. The channel-fills of Tunbridge (1984) reflect repeated episodes of channel cutting and infilling within a low sinuosity channel system.

Facies Ss at both the Langfield Banks and Galley Bridge localities (Plate 4.7) are overlain by pebble-cobble Conglomerates, these facies relationships suggesting that facies Ss more appropriately reflects the

infill of scoured depressions dissected the gravel bar surfaces. The section of Rucroft Wood (Plate 4.6) exposes sheet-like units comprising pebble-granule conglomerates (facies Gm) overlain by current-rippled (facies Sr) and planar-cross-bedded (facies Sp) sandstones. These may be analogous to the sheetflood graded units of published literature (e.g Tunbridge, 1984) but as a result of the poor exposure in this region they may represent waning flow deposition within a 'channel bar complex'.

Pebble conglomerates (facies A; Plates 4.8) from the base of the Dalemain Borehole, forming units up to 2.5m thick, are interbedded with thin cross-laminated and cross-bedded sandstones (facies A-B) which may reflect the deposits of 'channel-bar-complexes'. The upward change into thinner conglomerate units (40cm-10cm thick) with relatively thicker cross-bedded sandstones (facies B, Plate 4.9) reflects the increase in sand as the dominant channel bed-load. The transition from facies A dominated sequences into those of facies B is, it is suggested, analogous to the section through facies Gt/St at Holghyll Gorge. In this context, the core of the Dalemain Borehole reflects the downstream transition from gravel bar channel complexes into an area dominated by cross-bedded (?trough-cross-bedded) sandstones, representing the migration of dunes along channel bases. Significantly the general rarity of mudstone and cross-laminated sandstone (facies C, Plate 4.10), reflecting low flow stage drape deposits, suggests that flow velocities were still generally too high for their preservation, this, indirectly indicating that topographic differentiation within the channel system was probably also low.

4.3.2 Depositional Model

The Mell Fell Conglomerate thus exhibits an interpreted south to north depositional trend reflecting the downstream transition from coarse grained gravel bar deposits into progressively more evolved and finer grained 'channel-bar-complexes' and areas dominated by migrating channel-base gravelly dunes. This downstream trend resembles the proximal to distal variations within an alluvial fan to braidplain system, characterised by a downstream decrease in gradient with a corresponding increase in fluvial processes. Modern day alluvial fans are mostly dominated by facies Gm, deposited in proximal reaches by streamflow and sheetflood processes (Nilsen, 1982; Rust and Koster, 1984, see also Chapter 6). Streamflow processes operate within channels which show a downfan transition from straight and incised forms in the inner and mid fan to braided channels in the outer fan setting. Streamflows commonly spread out laterally from the channel margins producing sheet-like flows (sheetfloods). Sheetfloods deposit sheet-like graded units, reflecting decelerating flow and water depth with progressive distance from the channel margin (Nilsen, 1982).

Streamflow and sheetflood processes commonly grade 'upfan' into proximal debris flows and distally merge into braided rivers or extensive, gently sloping braidplains. Debris flows, most commonly present within semi-arid alluvial fans, are promoted by steep slopes, a lack of vegetation and short periods of abundant water supply with a source region exposing unsorted debris with a muddy matrix (Wasson, 1977, Rust and Koster, 1984). Humid alluvial fans are mainly dominated by streamflow and fluvial processes although debris flows can be

present, (e.g. cases cited in Rust and Koster, 1984; Iwaniw, 1984), again promoted by a muddy source rock terrain and short term fluctuation in precipitation.

In the Mell Fell Conglomerate, the apparent absence of debris flows within the outcrop area may in part be due to non-exposure, debris flows may have been present in more proximal areas (now eroded), further south than the localities exposing the coarse boulder conglomerates. However, considering that within an alluvial fan environment, a succession may comprise an interbedded sequence of debris flows and streamflows (e.g. Steel, 1971, 1974a; Nilsen, 1982; Nemec and Steel, 1984), and that debris flows have been reported extending into the braided river environment (e.g Miall, 1977), it seems that the absence of debris flow in the Mell Fell Conglomerate is more appropriately due to non-deposition. This may be the result of a lack of abundant short-term water supply and/or a relatively non-argillaceous source rock area. That the proximal boulder conglomerates contain abundant (locally greater than 90%) Silurian greywacke sandstone clasts (see Chapter 7) and these conglomerates were deposited by the maintainance of high-velocity channel flow, does suggest that the main contributing factor which inhibited debris flow development was probably a lack of argillaceous rock debris in the source rock area.

The author considers, however, that the most significant factor in developing a model is the downstream transition throughout the outcrop area from proximal gravel bar conglomerates into progressively finer grained 'channel-bar-complexes' and possibly extensive channel-fill

sandstones. This transition reflects the downstream decrease in slope and probably, in turn, reflects the downstream increase in fluvial dispersion as channels were able to migrate over a more gentle land surface. In this way, the Mell Fell Conglomerate can be related to a braided river or braidplain model. Kraus (1984) documents the principal facies differences between braided river and braidplain models, the latter being characterised by rapid grain size and facies changes associated with the lateral spread of flow and relatively shallower depths. The braidplain deposits described by Kraus (op.cit.) from the Early Tertiary of Northwest Wyoming, are characterised by a proximal to distal trend from coarse grained longitudinal bars (facies Gm) to shallow, cross-bedded channel-fills (facies Gt). Indeed, in terms of Miall's (e.g. 1977) braided river model types, the proximal to distal trends in the Mell Fell Conglomerate, can be represented by the Scott to Donjek and possibly South Saskatchewan models (Figure 9.1), the latter suggested by the increase in cross-bedded sandstone towards the top of the Dalemain Borehole core. The Donjek type sequences are represented by the 'channel-bar-complex' deposits in the central and northern part of the outcrop area, and reflect the aggradation of gravel bars within a channel system that contained a certain degree of topographic differentiation (see discussions in Chapter 3).

Mapping of the Mell Fell Conglomerate by Capewell (1955) revealed a broad 'Cone-like' distribution of lithologies, the proximal conglomerates to the south apparently forming the 'inner' part. It is suggested that the Mell Fell Conglomerate comprises a distal 'cone-like' braidplain, built out infront of an inner 'fan' area, constructed by

braided channels on relatively steeper slopes, thus being comparable to the braided river 'fans' of Boothroyd and Ashley (1975) and Boothroyd and Nummedal (1978). The proximal 'fan' conglomerates were sourced from the highest parts of the Lake District (see Chapters 7 and 9) which most probably provided the initial topographic relief necessary for alluvial fan development.

Published accounts of alluvial fan and braidplain deposits, reflecting 'Scott', 'Donjek' and 'South Saskatchewan' transitions include the studies of Ethridge et al., (1984), Middleton and Trujilo (1984) and Varley (1984). Ethridge et al., (op.cit.) describe an alluvial fan complex from the Precambrian quartz-pebble conglomerate, Southwestern Colorado, characterised by proximal Scott, medial Donjek and distal South Saskatchewan braided streams, the proximal conglomerates occasionally interbedded with debris flows. The fans were principally constructed by the vertical aggradation of longitudinal bars and progradation of dune bed forms in high-gradient, short duration, peak discharge braided streams. The proximal to distal trends are generally reflected by the overall fining upward succession of the deposits, the downstream trend caused by scarp retreat and lowering of source area relief.

Middleton and Trujilo (1984) have documented a high-energy alluvial fan - proximal braided system from the Scanlon Conglomerate (Upper Proterozoic), central Arizona. A vertical change from proximal to distal fluvial settings is reflected in the increase in coarse grained sand, a result of decreasing stream gradient with decreasing source area

relief. These authors attribute the general absence of 'fines' and the coarse grained texture of the Conglomerate to vigorous bedload transport and extensive winnowing of fine grained sediment.

From the Lower Cretaceous Cadomin Formation, Alberta, Varley (1984) also described proximal to distal variations reflecting Scott to Donjek type braided channel deposits within an alluvial fan-distal gravel dominated braidplain setting. The change from the alluvial fan to braidplain environment is compared to the Kosi River Fan, India (Gole and Chitale, in Varley, op.cit.). Uplift in the rising mountain front, increased the gradient and sediment supply, reworked by braided rivers which migrated laterally and downstream across the pediment area developed in front of the alluvial fan complex.

The author suggests that the depositional model for the Mell Fell Conglomerate can be closely compared to the model developed for the Ordovician Van Horne Sandstone, Texas by Mcgowen and Groat (1971). The Van Horne Sandstone is interpreted as a large alluvial fan system again comparable in size to the fan built by the present day Kosi River, India. Proximal to distal variations reflect the decrease in depth of flow, confinement of flow and slope in a downstream direction. Coarse grained boulder conglomerates, containing clasts up to 3 feet across, were deposited in the proximal fan position under confined flow within canyons, as it was only under these conditions that streams were competent enough to transport such large boulders. The upper parts of the proximal facies contains deposits which accumulated under more shallow and less confined conditions, as longitudinal bars. Sand was

mainly deposited in shallow channels across the bar surface and as planar-bed-flow during waning flow stage.

Mid fan reaches, gradational with the proximal conglomerates, were characterised by longitudinal gravel bars and associated channel-fill and gravel bar-top deposits. Bars became emergent on waning flow, with flow confined to shallow braided streams flanking the bars and across the surface. These channels were filled by transverse sandy bars or by 'short, discontinuous crested dunes'. The mid fan facies also contains evidence of scour-channel-fills, these infilled by conglomerate, or lined by conglomerate and infilled by trough-cross-bedded sandstone.

The distal fan facies, characterised by numerous shallow braided streams, infilled by transverse bars (where bedload:discharge ratio was highest) and migrating dunes, was constructed by braided stream systems comparable in size to the Kosi River fan, this being braided for up to 100 miles long and 10 miles wide. Slope, depth of flow and stream competency were all less than the proximal and mid-fan facies.

As demonstrated in Figure 4.7, the Mell Fell Conglomerate was probably deposited in a comparable environment setting to the Van Horne Sandstone. Support for this alluvial fan-braidplain model comes from the clast composition data, which reflects retreat and lowering of relief within the source area, such that varying clast compositions are present in different parts of the succession (cf. Heward, 1978; discussed in Chapter 7 and summarised in Kimber and Johnson, 1986). The proximal conglomerates in containing mostly Silurian greywacke clasts,

reflect derivation from a more local source, with deposition occurring on steep slopes within a proximal fan setting indicating that these clasts were sourced from the highest parts of the Lake District. The observed increase in Borrowdale Volcanic, Eycott Volcanic, Coniston Limestone Group, and minette clasts within the finer grained distal facies is a reflection of the removal of the Silurian greywacke cover from the highest parts of the Lake District, producing a dissected source terrain and exposing older formations beneath (Figures 7.1, 7.2). The presence of minette clasts, intruded within the Silurian cover in association with the Shap Granite (see Chapter 1) strengthens this argument of direct erosion of the Silurian whilst the variable clast compositions were a product of the erosion of the Silurian cover to reveal the lithologically varied Borrowdale Volcanics, in particular. They were also a result of the interpreted increased fluvial dispersion pattern (unable to be determined conclusively by palaeocurrents, as a result of poor exposure) enabling braided streams to tap a more varied source terrain over a larger area.

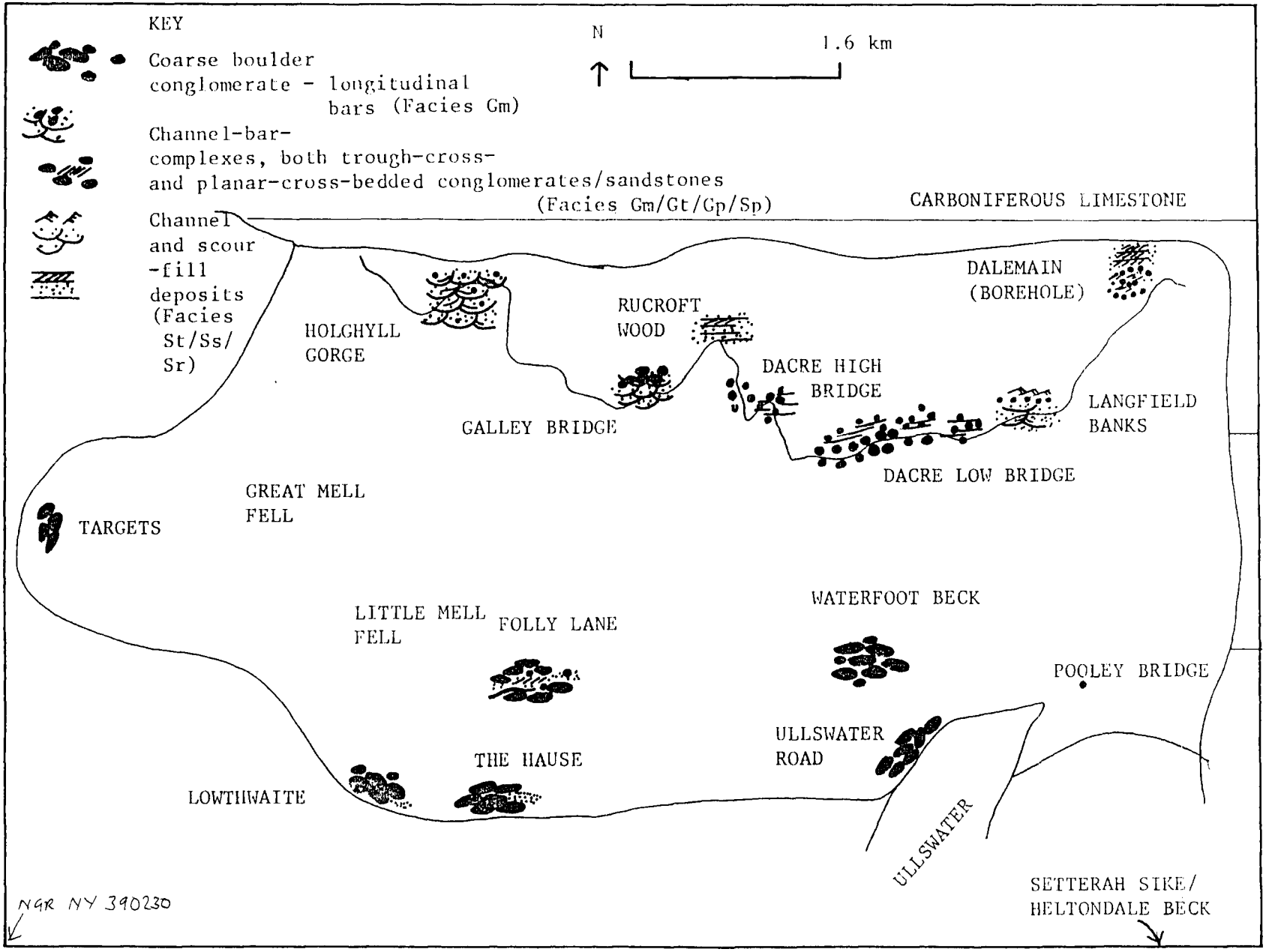


FIGURE 4.1. MELL FELL CONGLOMERATE LOCALITY MAP AND PRINCIPAL FACIES DISTRIBUTIONS.

FIGURE 4.2. MEASURED SECTION - WATERFOOT BECK (NGR NY 451241)

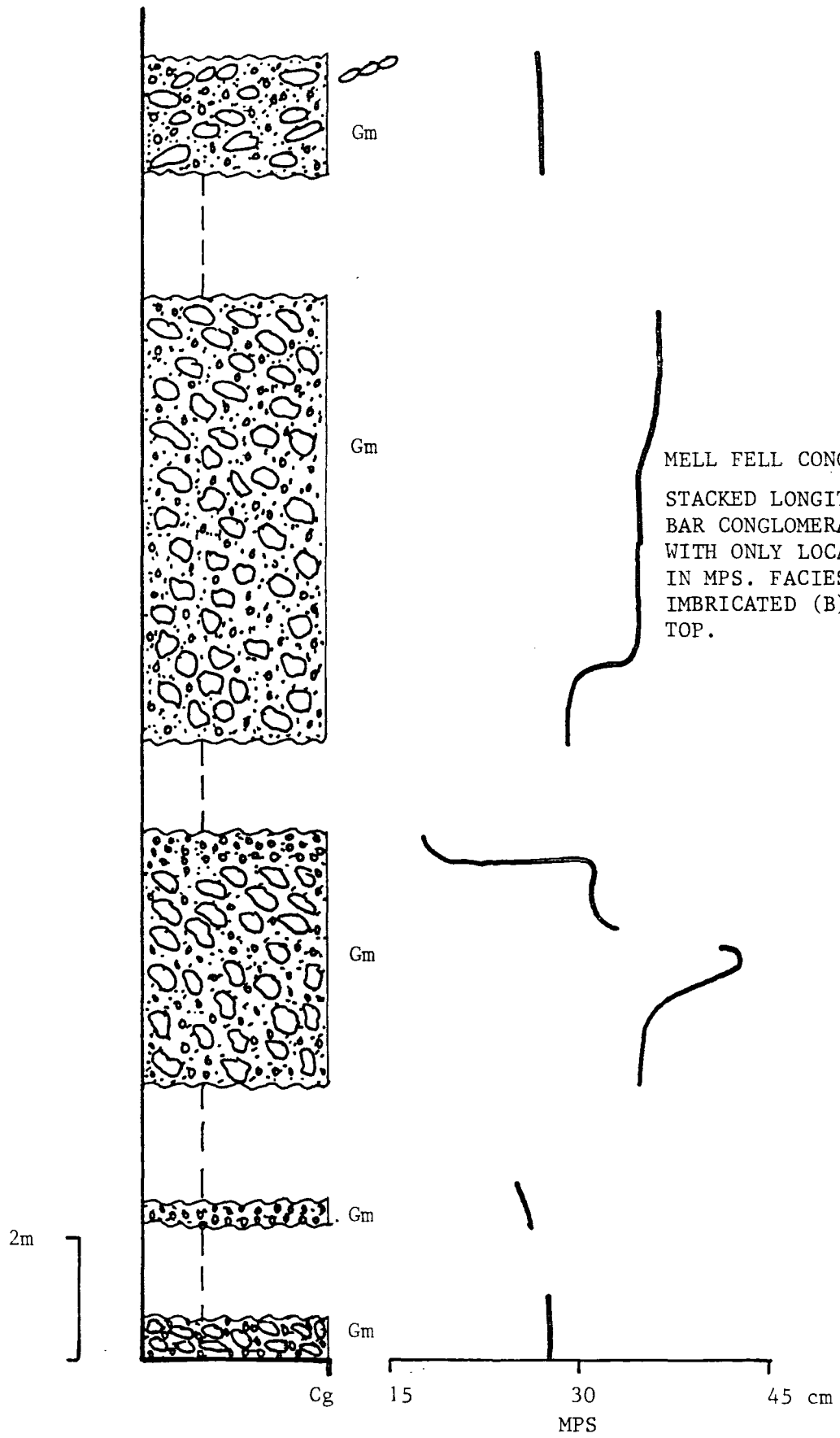


FIGURE 4.3. MEASURED SECTION - THE HAUSE (NGR NY 426236).

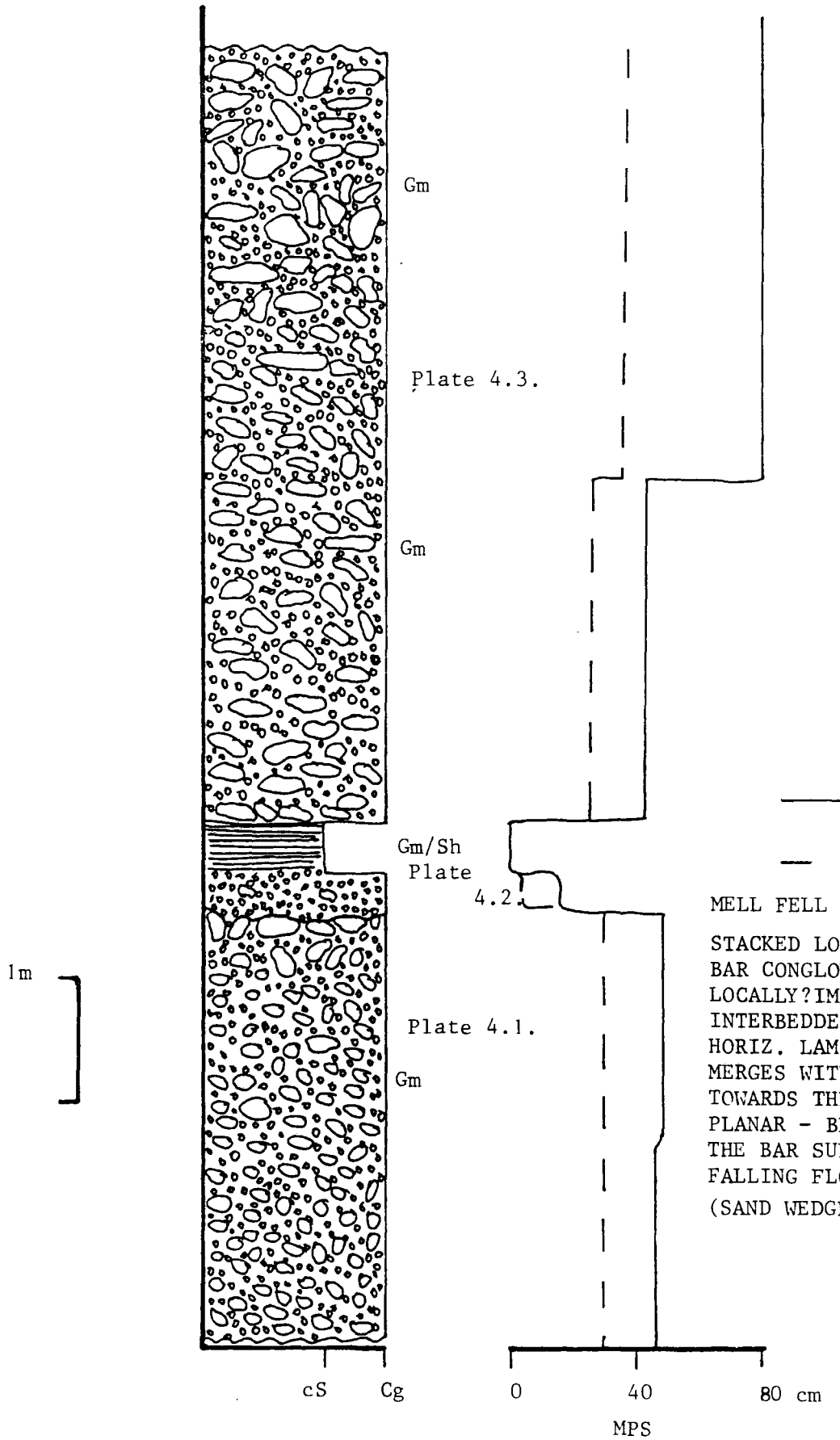


FIGURE 4.4. MEASURED SECTION - FOLLY LANE (NGR NY 429 245).

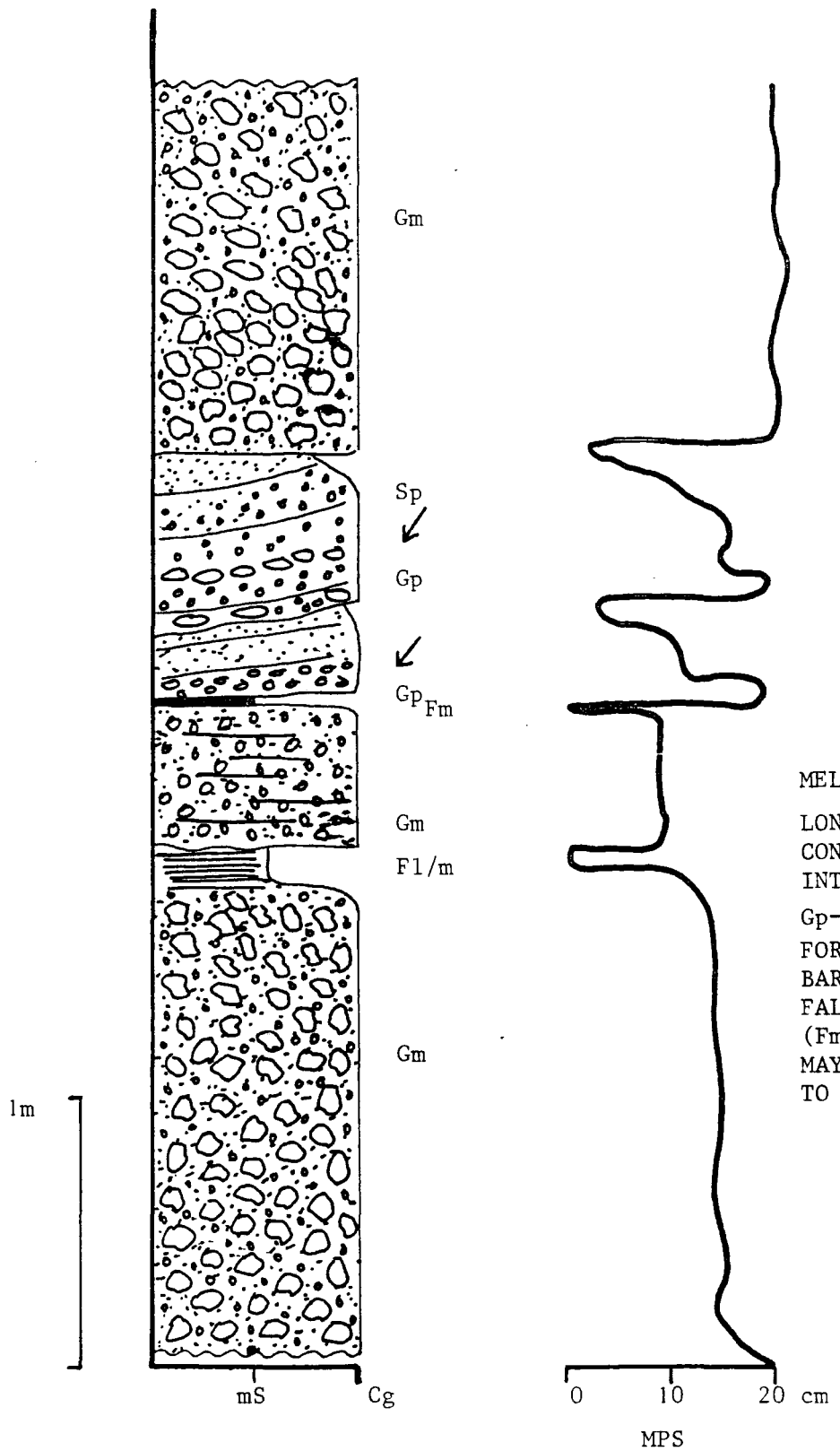


FIGURE 4.5

Logged Section - Dalemain Borehole.

Facies A = Conglomerate
Facies B = Sandstone
Facies A/B = Conglomerate / Sandstone transition.
Facies C = Sandstone / mudstone.

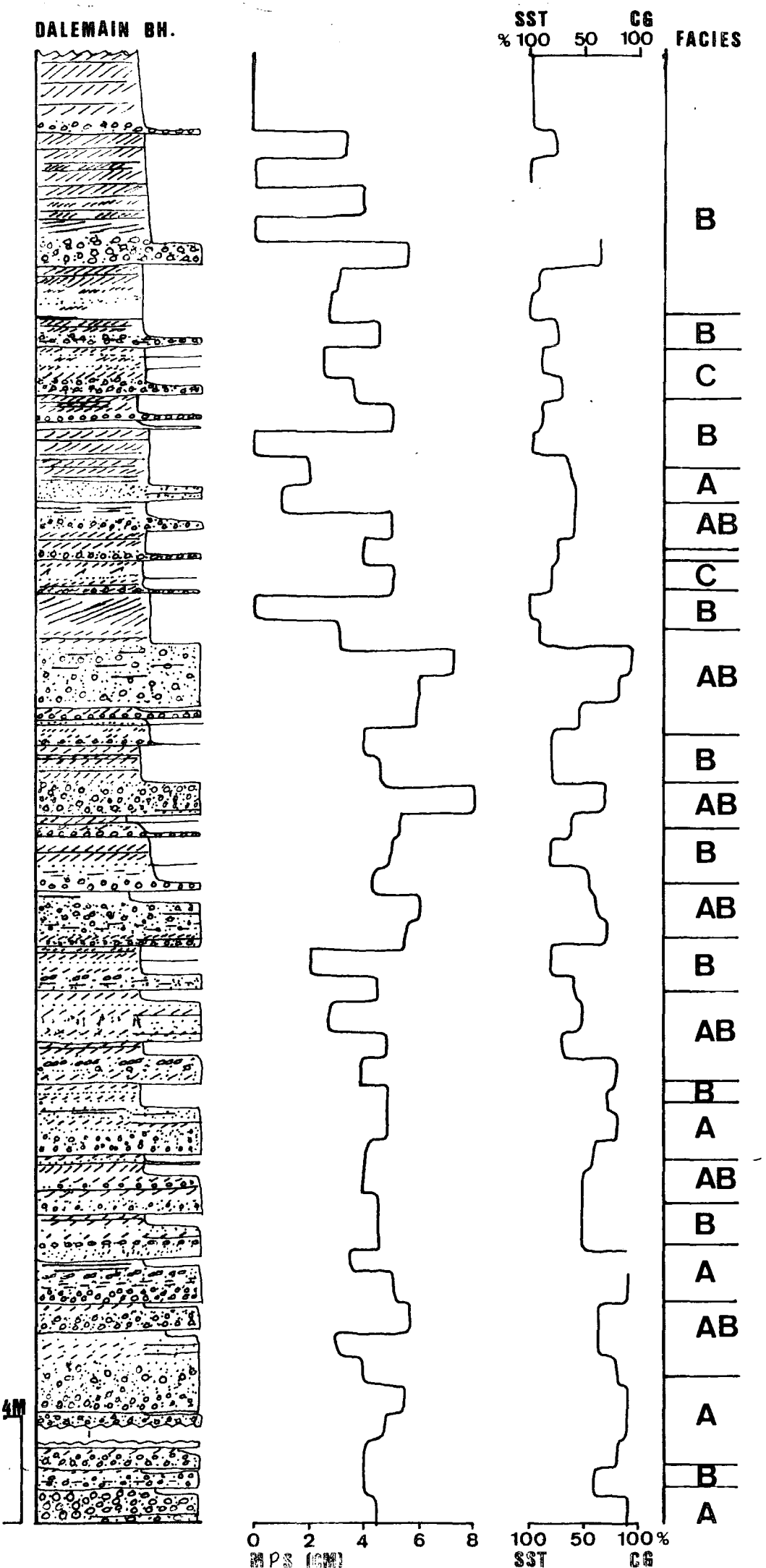

DALEMAIN BH.
SST
% 100 50
CG
100
FACIES
B
B
C
B
A
AB
C
B
AB
B
AB
B
AB
B
AB
B
A
AB
B
A
AB
A
B
A
4M
0 2 4 6 8
MPS (CM)
100 50 100 %
SST CG

FIGURE 4.6

Summary diagram illustrating the principal clast compositions, lithofacies distribution and depositional trend of the Mell Fell Conglomerate.

IRF = Igneous Rock Fragments (intrusive).
VRF = Volcanic Rock Fragments.

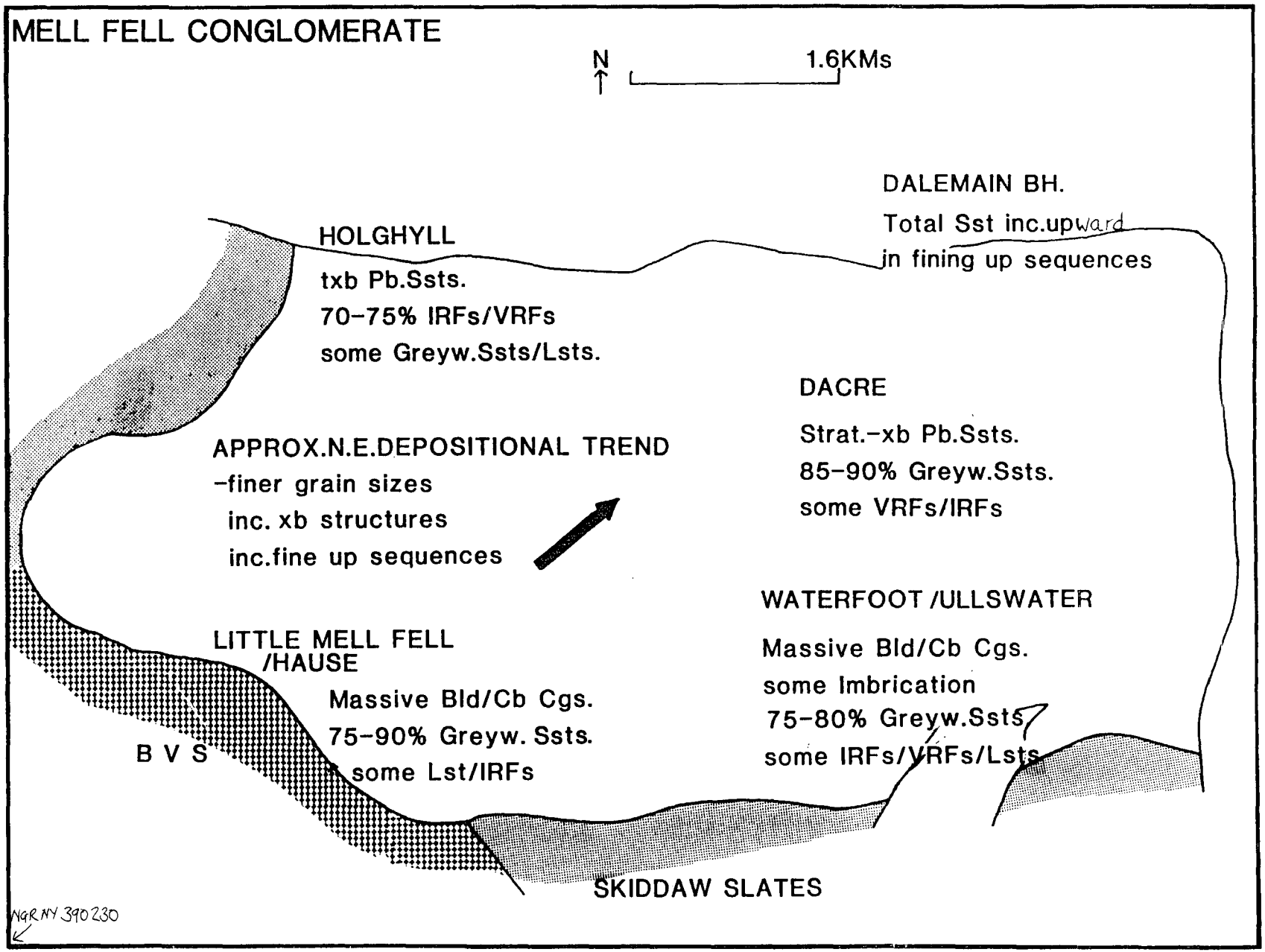

MELL FELL CONGLOMERATE
N
1.6KMs
DALEMAIN BH.
Total Sst inc.upward
in fining up sequences
HOLGHYLL
txb Pb.Ssts.
70-75% IRFs/VRFs
some Greyw.Ssts/Lsts.
DACRE
Strat.-xb Pb.Ssts.
85-90% Greyw.Ssts.
some VRFs/IRFs
APPROX.N.E.DEPOSITIONAL TREND
-finer grain sizes
inc. xb structures
inc.fine up sequences
WATERFOOT /ULLSWATER
Massive Bld/Cb Cgs.
some Imbrication
75-80% Greyw.Ssts
some IRFs/VRFs/Lsts
LITTLE MELL FELL
/HAUSE
Massive Bld/Cb Cgs.
75-90% Greyw. Ssts.
some Lst/IRFs
B V S
SKIDDAW SLATES
NGR NY 390230

FIGURE 4.7

Suggested depositional model of the Mell Fell Conglomerate

(from Mcgowen and Groat, 1971 - for the Van Horne Sandstone)

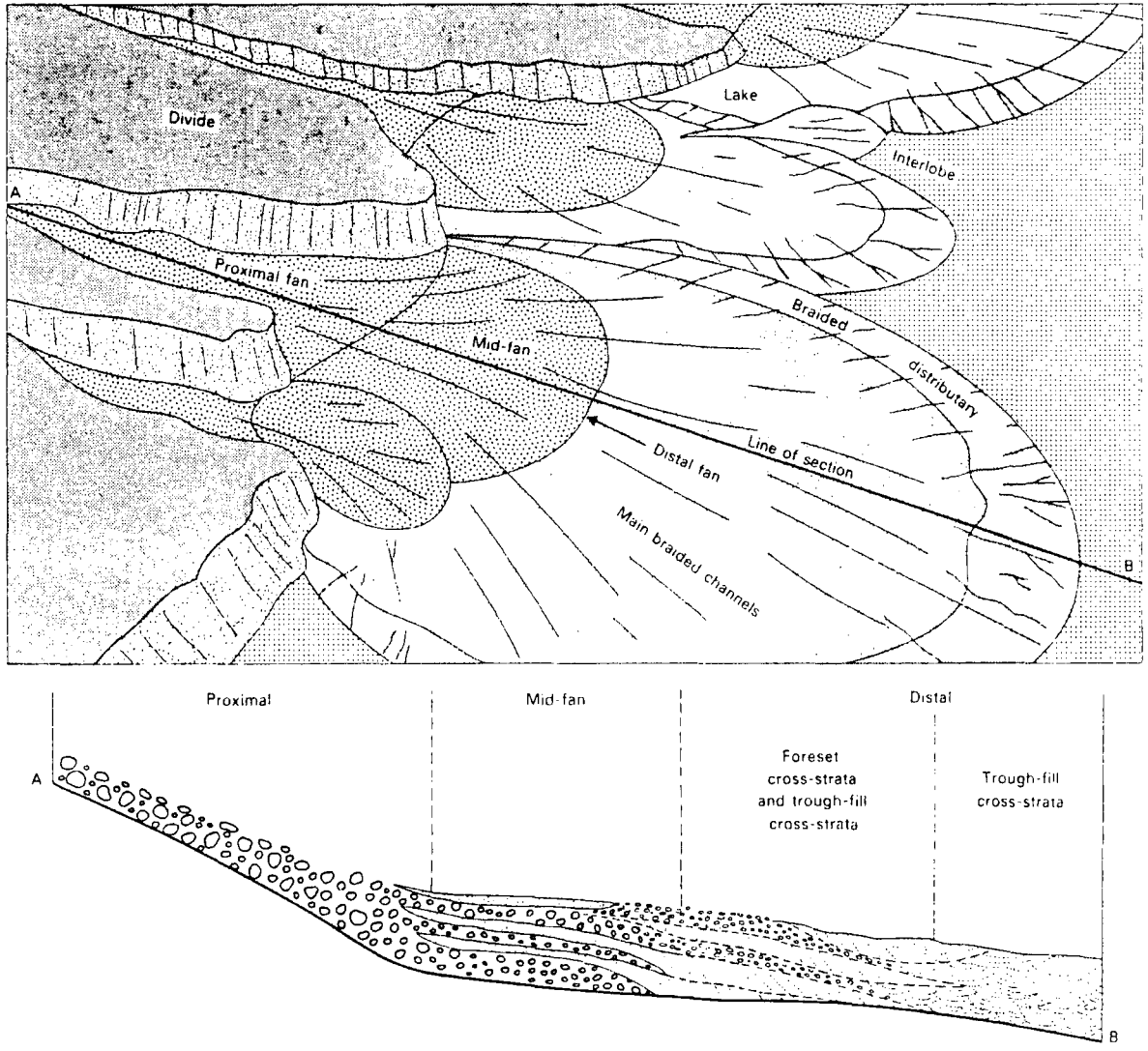

Divide
Lake
Interlobe
A
Proximal fan
Mid-fan
Braided
distributary
Line of section
Distal fan
Main braided channels
B
Proximal
Mid-fan
Distal
A
Foreset
cross-strata
and trough-fill
cross-strata
Trough-fill
cross-strata
B

PLATE 4.1

Plate shows massive gravel bar boulder conglomerate (maximum clast size up to 46.4cm, average clast size 30cm-30.5cm) at the base of the Hause Section, Mell Fells (N.G.R. NY 425236). Elongate clasts are aligned with the longest 'A' axis parallel with bedding shown by interbedded sheet-like pebble-cobble conglomerate/medium to coarse grained sandstone (facies Gm/Sh) forming wedge-drape unit at top of the field of view. Hammer (35cm long) for scale.

PLATE 4.2

Plate showing lateral 'pinch-out' of pebble - cobble conglomerate (facies Gm) wedge-drape unit, the Hause, Mell Fells, and seen at top of Plate 4.1. Conglomerate unit drapes the protruded clasts of boulder conglomerates below. Hammer (35cms long) for scale.

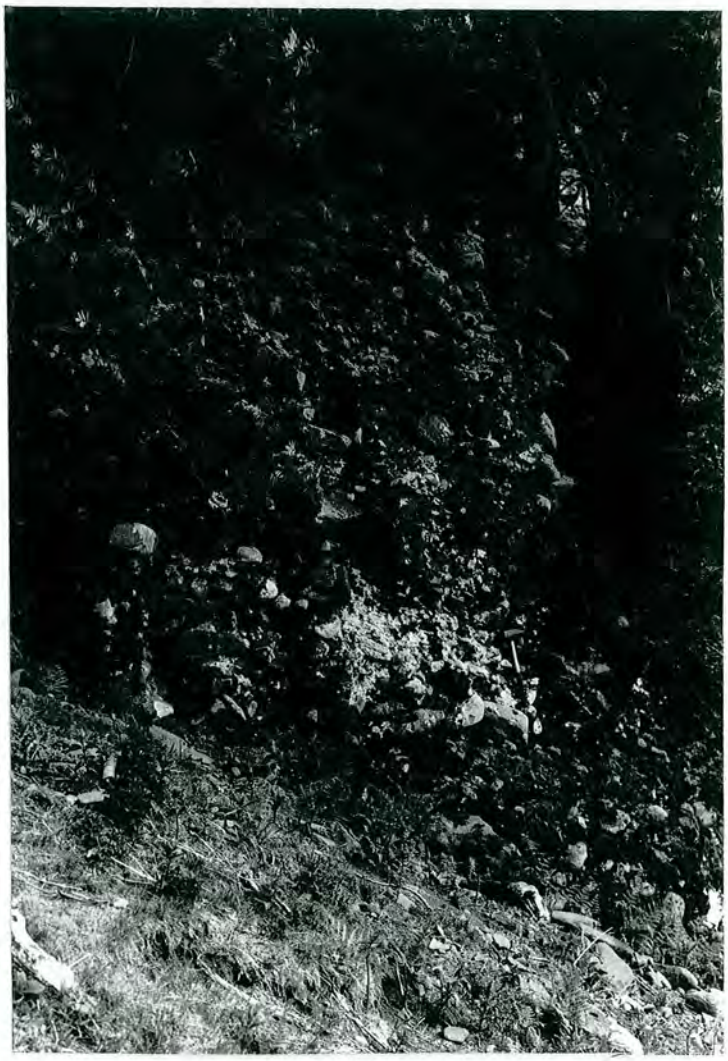


PLATE 4.1.

PLATE 4.2.



PLATE 4.3

Plate showing very coarse (maximum clasts size up to 80cm) boulder conglomerate (facies Gm) at top of the Hause Section, Mell Fells (approx. N.G.R. NY 425236). Sequence represents stacked gravel bar deposits, similar to the 'Scott' type gravels of Miall (1977). Hammer (35cm long) for scale.

PLATE 4.4

Plate shows close-up view of central portion (2m-3.5m above base) of the Folly Lane section, Little Mell Fell. Note imbricated and cross-bedded (facies Gp) cobble conglomerate in top part of section (above compass), overlain by cross-bedded very-coarse grained sandstone (facies Sp). Unit between compass and hammer, comprises cobble-boulder conglomerate (facies Gm) with clasts supported, imbricated framework, with coarse granule infilling matrix. Poorly sorted boulder conglomerate (facies Gm) at the base of the view is overlain by a thin silty mudstone drape. Hammer (28cm long) and compass (10cm long) for scale. (NGR NY 429 245)



PLATE 4.3.

PLATE 4.4.



PLATE 4.5.



PLATE 4.5

Plate shows 7m-8m high section at Holghyll Gorge, Mell Fells. The section comprises extensive development of shallow (average 25cm) trough-cross-bedded pebble conglomerates (facies Gt) and pebbly sandstones (facies St). Cobble-stringers locally define the base of sheet-like cosets, probably reflecting infill of an individual channel, the section representing a series of stacked-channel-fills. Ruc-Sac for scale. (NGR NY 429 272).

PLATE 4.6

Plate shows, well-bedded sequence at Rucroft Wood (NGR NY 447267), Mell Fells, exposing 2-2.5m of pebble-granule conglomerate (facies Gm). These appear to form graded units, between 50cm and 80cm thick, overlain by current rippled sandstones (facies Sr). Crudely defined (faith of eye) cross-bedding is present near to the top, above hammer (28cm long).

PLATE 4.7

Plate shows pebble-cobble conglomerate (facies Gm) with an erosive basal contact, overlying medium to coarse grained sandstones at Galley Bridge (NGR 442265), Mell Fells. Sandstones are crudely cross-stratified (facies Ss), and appear to infill 2 scour-shaped depressions, the basal 'set' comprising a pebbly lag base.

PLATE 4.6.



PLATE 4.7.



PLATE 4.8.



PLATE 4.8

Plate shows core section from Dalemain Borehole, between 21.4m and 21.6m above base. Section comprises thin conglomerate lag overlain by probable cross-bedded medium grained sandstone. Note clasts types within conglomerate unit: greywacke sandstone and porphyritic volcanic rock types. The matrix is locally cemented by calcite. The overlying sandstone horizon appears to be transitional with coarser grained pebbly sandstone above and pebble conglomerate (out of view), suggesting this cross-bedded sandstone forms a bottomset unit to cross-bedded conglomerate above.

PLATE 4.9.



PLATE 4.10.

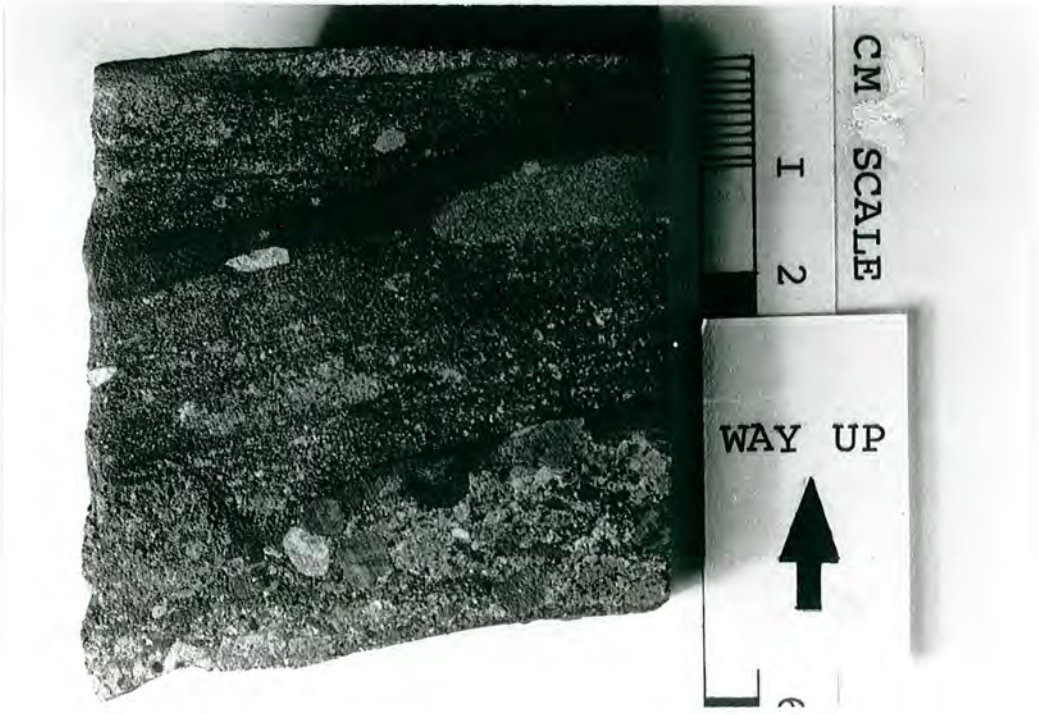


PLATE 4.9

Plate shows cored section (38-86m-38.97m above base) from Dalemain Borehole. The section comprises pebbly coarse grained sandstone/granule conglomerate units separated by fine grained sandstone tops. These units may represent graded foresets within a cross-bedded set.

PLATE 4.10

Plate shows cored section (34.45m above base) within Dalemain Borehole. The section comprises 2 fine grained drape deposits: lower horizon, less than 1mm thick draping the protruded clast of a pebbly conglomerate; Upper horizon, silty sandstone drape over a pebbly cross-laminated horizon. These muddy drape deposits are relatively rare within the Dalemain Borehole and indeed within the Mell Fell Conglomerate. They do provide, however, evidence for the deposition of fine grained sediment at low flow stage, indicating that the lack of fine grained deposits throughout the Mell Fell conglomerate is a result of erosion rather than non-deposition.

CHAPTER 5 SEDBERGH (SEDBERGH CLASTIC ROCKS)

5.1 INTRODUCTION

In the Sedbergh area, clastic rocks, belonging to the Carboniferous basement, outcrop along three main sections: The River Rawthey, Hebblethwaite Hall and Settlebeck Gills. These sections are described below with the facies being discussed in terms of their environments of deposition in Section 5.3. The facies data are summarised in Tables 15-17 (Appendix 1). A vertical measured section over the succession was not able to be constructed. However, a measured section is presented for Settlebeck Gill (Figure 5.2), while Plates 5.1, and 5.2 illustrate outcrop sections along the River Rawthey. The author, in considering the patchy exposure distribution, could not confidently resolve the probable thickness of the succession. However Dakyns et al., (1891) suggest the thickness may be as much as 270m.

5.2 OUTCROP AND MEASURED SECTION DESCRIPTIONS

5.2.1 River Rawthey (Figure 5.1; Plates 5.1, 5.2, 7.3; Tables 15, 16)

5.2.1.1 Scrogg House (NGR SD 677923; Clast compositions A-Appendix 2)

Massive boulder conglomerates (facies Gm) crop out at river bank level immediately south of Straight Bridge close to Scrogg House. The estimated exposed thickness is 1.55m and consists of sharply-based, massive, poorly sorted and clast supported boulder conglomerate (Facies Gm) units, at least 50cm-90cm in thickness, separated by finer grained,

pebble-cobble conglomerates (Facies Gm) with a 'tightly packed' clast supported framework. Clasts vary from elongate to blocky in shape with B axis imbrication (possibly towards 222°) developed at the top of the exposed section. The framework is infilled by a coarse grained matrix. The interbedded, 15cm thick, cobble conglomerate units with tightly packed clast supported frameworks are preferentially calcite cemented.

5.2.1.2 Burnt Mill (NGR SD 678924-678926; Clast compositions B-Appendix 2)

Poorly exposed massive boulder conglomerates (facies Gm) crop out as a 4m high cliff section, between Straight Bridge and Burnt Mill. Clast supported conglomerates at the base of the exposed section, are, at least 2m thick, these being overlain by a finer gained conglomerate unit (Facies Gm) containing elongate clasts imbricated along the B axis towards 049°. This unit has a sharp basal contact which dips toward 052° at 10°.

Immediately below Burnt Mill, facies Gm consists of poorly sorted, clast supported boulder conglomerate containing a coarse grained infilling matrix. Cobble conglomerate (Facies Gm), 50cm thick, which erosively overlies the basal conglomerate unit, coarsens up into a topmost boulder conglomerate unit (Facies Gm). The former conglomerate contains elongate clasts which are imbricated (B axis) towards 350°.

5.2.1.2 Buckbank to Lowridding (NGR SD 680927-683937; Clast compositions C,D,E-Appendix 2)

One isolated outcrop near Buckbank exposes two boulder, clast

supported conglomerate units (Facies Gm), up to 2.3m thick, separated by a sharp basal contact with erosive relief up to 20cm. At the base Facies Gm contains a tightly packed infilling matrix consisting of 'rod' shaped pebbles. Elongate clasts within the conglomerate unit are imbricated towards 350°-359°, with the dip of the AB plane of elongate clasts towards the south imparting a crude stratification. The topmost conglomerate unit has a similar structure, elongate clasts being imbricated (B axis) towards 356°-053°.

A 20m long section between Buckbank and Lowridding, about 3.7m high, exposes cobble-boulder conglomerates (Facies Gm) which overlie poorly sorted boulder conglomerates (facies Gm) separated by a broad, and possibly erosive basal contact (plate 5.1). The imbricated cobble conglomerates (facies Gm) at least, are clast supported with a coarse grained infilling sandstone matrix. The AB axial plane dip of elongate cobbles imparts a cross-stratified structure to this conglomerate unit, dipping (8°-9°) towards 135°. Measurement of the B-axis imbrication derives a vector mean of 344°. Measurement of the A axis of subhorizontal lying elongate clasts derived a vector mean trend of 056°-236°, the deduced B axis trend from this being 146°-326° (at right angles) which compares closely with the direct imbrication measurement direction and the AB dip direction of the dipping clasts.

Northwards of here a waterfall section, approximately 12m high, contains cobble-boulder conglomerate (facies Gm) units, less than 1m thick, unit basal contacts being marked by boulder clast 'stringers'. Throughout each unit maximum clast size fines upwards (Tables 15-17,

Appendix 1). Approximately 6m above base, pebbly sandstones, which form a unit about 20cm thick, are interbedded with facies Gm and appear to be cross-bedded. Conglomerates at the base of the section are clast supported, with a coarse grained infilling matrix consisting of tightly packed rod-shaped clasts, and appear to be imbricated towards a north-north-east direction. At the top, better exposure shows that cobble conglomerates are locally imbricated (B axis) towards 039° (vector mean) with the AB dip of clasts dipping 2-3° in a general southerly direction.

Further upstream and near to Lowridding Farm, a section about 12m long and 3.5m high exposes massive unsorted boulder conglomerates (facies Gm). An apparently steeply dipping and undulating contact, which dips towards 053° at 20°, separates a basal unit from a slightly finer grained topmost unit (Plate 5.2). No clast orientation was observed although some elongate boulders in the basal unit are aligned with the A axis trending north-east to south-west.

Clast compositions were determined for the largest 15-20 clasts at every conglomerate unit whenever possible (Appendix 2). Between Scrogg House and Burnt Mill, up to 68% of clasts are composed of grey-green coloured micaceous greywacke sandstones. For the Sedbergh clastic rocks, a distinction can be made between red and grey greywacke sandstone lithologies, although red sandstones do tend to be relatively coarser grained. Both sandstone types are rich in chlorite. Between Buckbank and Lowridding red coloured greywackes account for 77% of the clast compositions and are more abundant than the grey-green coloured

greywackes. Vein quartz, like in the other clast compositions for other areas along the west side of the Vale of Eden, are very rare and only reach a maximum recorded amount of 2.7% at Burnt Mill. Distinctive red coloured crystalline limestone clasts account for over 14.5% of compositions (at one locality) and always seem to be present as clasts within conglomerates throughout the area. Garwood (1912) and Burgess (Pers. comm.) believes the red coloured limestone clasts were derived from the Kiesley Limestone, which correlates with the Ashgill Series, upper Ordovician (Section 1.6 see Chapter 7).

5.2.2 Hebblethwaite Hall Gill (NGR SD 684927; Table 16; Figure 5.1)

A large section, approximately 30m long and 10m high on the north bank of Hebblethwaite Hall Gill stream exposes conglomerates which are generally moderately sorted with a clast supported framework and coarse grained infilling matrix (facies Gm). The main part of the section consists of cobble-boulder conglomerate with poor clast orientation, although the B axis of some elongate clasts apparently dip towards 198°-222°. Conglomerates in the top part of the section contain an erosive basal contact with relief up to 30cm measured over a distance of 2m-3m. In the basal 1.6m, boulder conglomerates are well sorted and have a tightly packed clast supported framework consisting of sub-rounded and elongate boulders with a coarse grained infilling matrix of rod-shaped pebbles. The B axis of some elongate clasts dips towards 203°-222° these being imbricated towards 023°-042°. Towards the south part of the section, facies Gm is sharply overlain by pebble-granulestone conglomerate, 40cm thick, which is seen to 'wedge' out in a northward direction within 4.3m.

5.2.3 Settlebeck Gill (NGR SD 662925-661927; Table 17; Figures 5.1, 5.2)

Above Castlehaw farm the section exposed in Settlebeck Gill is about 21m thick, the top part being faulted against the Coniston Grits. In the basal part of the section cobble-boulder conglomerates (facies Gm) are poorly sorted and contain boulders up to 24cm across. Units vary in thickness from 25cm to 90cm with clast size commonly fining up rapidly in the top part of each unit. The fine grained unit tops are overlain by horizontally laminated (facies Sh) coarse grained sandstones, 10cm thick, conglomerate basal contacts being sharp with slight erosive relief. Matrix within the conglomerates is coarse and where pebbles are abundant is preferentially cemented with calcite.

Maximum and average maximum clast size fines up such that average maximum clast size in the top part of the section is 9.1cm. Between 10 and 21m above the base of the section, pebble conglomerates (Facies Gm/?Gt) are cross stratified comprising crude sets, 10-15cm thick, with foresets dipping towards 348° at 4°-5°. Conglomerates contain medium-coarse grained sandstone intercalations, up to 8cm thick, and fine-medium grained sandstone units, 20cm thick, which separate conglomerate units over 1m thick. At some horizons conglomerates are imbricated, e.g. in the topmost 2m, the B axis of elongate clasts being crudely imbricated between 326° and 357°.

Clast composition analysis (Appendix 2) from this section is similar to those compositions from conglomerates exposed along the River Rawthey. Red coloured, possibly slightly arkosic greywacke sandstones

are abundant and comprise 59% of the maximum clast size compositions. Vein quartz is very rare indeed and only accounts for 1% of clast types.

5.3 ENVIRONMENTAL INTERPRETATION

The Sedbergh clastic rocks are predominantly composed of massive and locally imbricated clast supported boulder-cobble conglomerates (facies Gm) with only minor interbedded sandstone being observed. The following facies characteristics and facies relationships are considered to be significant in their interpretation and development of a depositional model:

1. Massive, boulder conglomerates (facies Gm), containing a clast supported framework, infilled by a coarse grained sand matrix. Individual units are poorly defined although occasionally coarse conglomerates are overlain by finer grained pebble horizons (facies Gm) containing a tightly packed clast supported framework. Undulating basal contacts with probable erosive relief to some units (Plate 5.2).

2. Boulder-cobble conglomerates locally contain a well developed 'B' axis imbrication (Plate 5.1), which imparts a crude cross-stratification formed by the 'upstream' dip of the AB axial plane. These imbricated units are potentially laterally extensive, as seen in Plate 5.1, which show one unit extending for at least 20m, overlying with a broad basal contact coarser grained boulder conglomerates below. The sequence at Burnt Mill (Section 5.2.1.2)

suggests that imbricated conglomerates locally coarsen up into boulder conglomerate units.

3. The section at Settlebeck Gill comprises an overall fining upward sequence (Figure 5.2) containing a transition from cobble-boulder conglomerates, with upward fining clast size and interbedded with thin horizontally laminated sandstones (facies Sh) into finer grained crudely cross-stratified pebble conglomerates (facies Gm/Gt) and slightly thicker (up to 20cm thick) sandstone intercalations and discrete units.

4. Palaeocurrents, measured predominantly from imbrication within conglomerates (90° to the dip of the AB plane; direct B axis imbrication; 90° to trend of the A axis) suggest that the main palaeoflow direction was towards the north-west. This direction is supported from palaeocurrents measured from the cross-stratified pebble conglomerates/sandstones (Settlebeck Gill), indicating a palaeoflow towards the north-north-west (348°).

The predominance of facies Gm throughout the Sedbergh clastic rocks suggest that conglomerates accumulated mainly as gravel bars. The texture and structure of the massive boulder conglomerates are very similar to those present within the Mell Fell Conglomerate and does suggest that gravel bars accumulated within possible confined channels on steep slopes (see discussion in Chapter 4). Furthermore, gravel bars probably grew from diffuse gravel sheets, the resultant bar form probably having little topographic relief. That very little sand is

preserved within these conglomerates suggests that bar surfaces provided no protection from erosion from the next flood stage. However, the presence of a coarse grained sand matrix, particularly in the finer grained conglomerates (Hebblethwaite Hall Gill section) indicates that sand infiltrated the framework on waning flow stage, and was protected from winnowing, being sheltered in between large clasts.

The well imbricated cobble-boulder conglomerate units overlie coarser grained boulder conglomerates, and in some sections are interbedded, breaks between more massive and imbricated units being difficult to determine. This suggests that imbricated conglomerates probably formed an integral part of the gravel bar accumulation, interdigitated with coarser grained boulder horizons (e.g. Waterfall section along River Rawthey, section 5.2.1.2; Hebblethwaite Hall Gill, section 5.2.2). Rust (1984) indicates that the development of imbrication is promoted by the presence of elongate clasts and particularly the maintenance of steady, high-velocity flow. In fluvial regimes elongate clasts develop a distinct B axis, or A axis transverse (to flow) imbrication as the result of downstream 'rolling' of clasts along the gravel bed. Well-imbricated conglomerates have been observed forming an longitudinal gravel bars from the proximal reaches of braided outwash fans by Boothroyd and Ashley (1975; see Chapter 4 discussions). It is suggested that these imbricated conglomerates developed at the topographically highest parts of the bar surface and may be comparable to the well-imbricated suprabar-platform gravels described by Bluck (1971, 1976, see Chapter 6), these lying topographically above bar platform gravels and are the most susceptible to flow fluctuation. The

section at Burnt Mill which shows an upward coarsening profile, from imbricated conglomerate into more massive and unstructured boulder conglomerate, may reflect the progradation of the bar head gravels over finer grained imbricated gravel further downstream.

Boulder conglomerate units overlain by finer grained pebble units with a tightly packed clast supported framework represent the deposition of the finer bedload fraction on waning flow stage across the bar surface. The tightly packed framework has probably resulted from the repeated reworking and winnowing of previously deposited waning flow deposits.

Coarse grained boulder conglomerates, with a massive and both unstructured and ungraded clast supported framework (seen in Plate 5.2), separated by undulating and steeply dipping basal contacts, are interpreted as the infill of steeply incised channels cut at high-flow stage and filled as flow wanes and the coarse debris is deposited as flow competency decreases. It is possible that these deposits more appropriately reflect the deposits of streamflows on an alluvial fan surface (see Chapter 4). These deposits, infilling incised channels do grade into braided stream channels 'down-fan' (Nilsen, 1982) and thus within the ancient record such channels may be indistinguishable from braided channel-fill counterparts. Infact these channel-fill conglomerates may infact be accommodated within a proximal braided river setting; Boothroyd and Ashley (1975) show that incised channels occur within the steeper slopes of the proximal outwash fans (Scott, Yana of Alaska), these branching out into a network of braided channels.

Furthermore, gravel longitudinal bars within the proximal Scott fan occur within 'interstream areas between incised erosional channels' (Boothroyd and Ashely, op.cit.). In view of the interpreted longitudinal bar conglomerates within the Sedbergh clastic rocks and in relatively close juxtaposition (present day horizontal distances, see Figure 5.1): along River Rawthey), to these coarser channel-fill boulder conglomerates, the latter most probably reflect the infill of incised and erosional channels within a proximal gravel-bed-load channel system.

The finer grained cobble-boulder conglomerates (facies Gm) and cross-stratified pebble conglomerates (facies Gm/?Gt) exposed at the Settlebeck Gill section (Figure 5.2) provide evidence for the establishment of more ordered conglomerates deposited as longitudinal gravel bars. Towards the base of the section, cobble-boulder conglomerates (facies Gm) are commonly arranged as upward fining units, overlain by horizontally laminated (facies Sh) coarse grained sandstones. Conglomerates are clast supported and contain a coarse grained sand matrix, reflecting infiltration of sand during waning flow stage. Facies Gm is thus interpreted as the deposits of longitudinal gravel, the upward fining clast size throughout each unit reflecting both the fining of clast size downstream and across the bar top. Facies Sh represents planar-bed-blow during waning flow stage deposited across the shallowing bar top as the gravel bar became emergent. Significantly the preservation of sand, in contrast to the coarser grained conglomerates with little preserved sand along the River Rawthey sections, indicates that topographic relief within the braided channels

was relatively greater, depressions on the bar surface protecting sand from erosion.

Towards the top of the Settlebeck Gill section, the decrease in clast size and increase in the abundance of intercalated and interbedded sandstone, is combined with the development of cross-stratification within the cobble-pebble conglomerate (facies Gm/Gt). These relationships further reflect the increased topographic relief of the gravel bars, with possible minor channels or scoured depressions on the emergent bar top being infilled by finer grained sediment during waning stage of flow.

The interpreted overall possible northward to westward fining of the Sedbergh clastic rocks, as far as the exposure allows, is considered by the author to represent the deposits of proximal gravel-bed-load braided rivers and as such resemble the Scott type of Miall (1977, 1978) and 'model 2' of Miall (1985a). It is uncertain as to whether the Sedbergh Clastic Rocks actually represent the accumulation of gravel within braided channels on a stream-dominated alluvial fan surface or whether they represent the proximal reach of a proximal braidplain. Comparison with the proximal facies of the Mell Fell Conglomerate (Chapter 4) suggests that in this case the former interpretation may be more appropriate, although as noted in Chapter 4 and considered by Ori and Penney (1982) in the ancient record such deposits may be indistinguishable and indeed transitional. Evidence of possible channel incisement (Plate 5.2) shows that these conglomerates do indeed represent poorly sorted channel-fills, although the more 'ordered'

imbricated gravel sequences suggest that longitudinal bars were commonly developed in interstream areas. The lateral fining of the conglomerates is thus a reflection of gradient decrease and increase in sorting characteristics (see Chapter 9 discussion) as well relatively greater topographic differentiation which allowed greater preservation of sand. In terms of Miall (1977) this probably infers, towards the north, a change to 'Donjek type' deposits may have been occurred (now eroded).

The abundance of greywacke sandstone clasts within the Sedbergh Clastic rocks, as discussed in Chapter 7, is interpreted as reflecting derivation from a southeasterly provenance, this being most probably the Askrigg Block. Indeed, the close proximity of the Askrigg Block, marked by the Dent Fault suggests to the author that this block area, influenced by fault movement (see Chapter 9), may have formed a positive influence during clastic deposition (Figure 7.2). The locally abundant limestone clasts suggests that within the Askrigg Block region at this time, an equivalent lithology to the 'Kiesley Limestone' of the Alston Block may have been exposed.

FIGURE 5.1. DIAGRAM SHOWING THE MAIN LOCALITIES AND PALAEOCURRENTS - SEDBERGH CLASTIC ROCKS

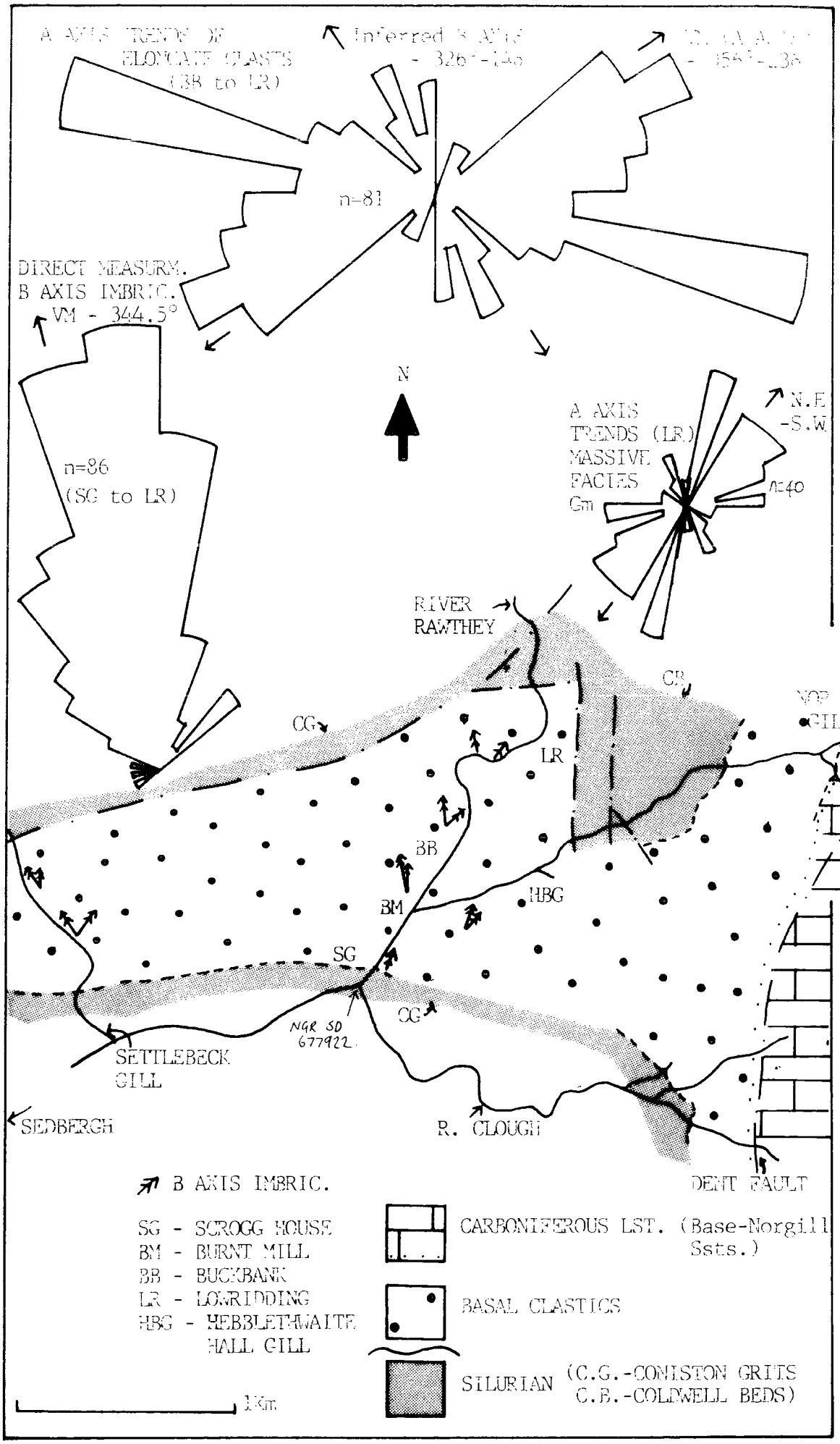
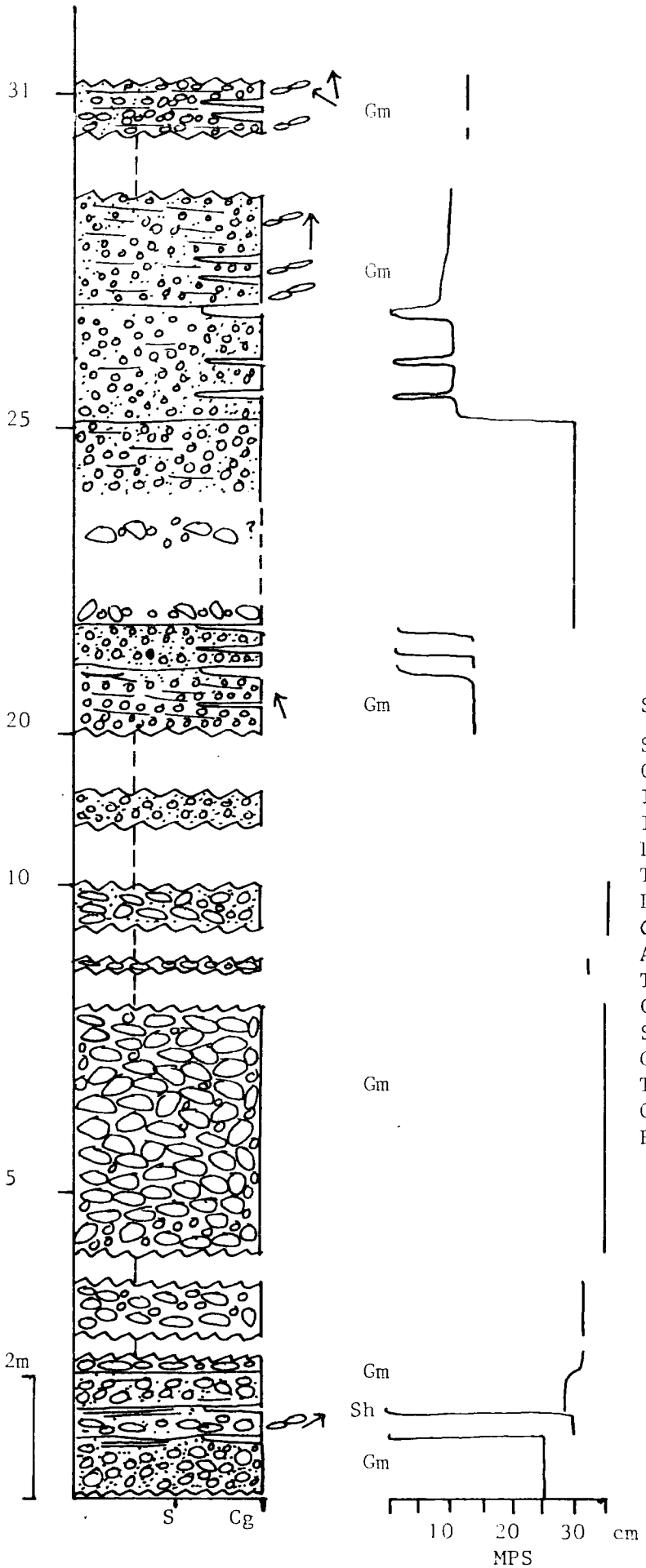


FIGURE 5.2. MEASURED SECTION - SETTLEBECK GILL (NGR SD 662925) BASE



SEDBERGH CLASTIC ROCKS

STACKED LONGITUDINAL BAR CONGLOMERATES (Gm), LOCALLY IMBRICATED (B- N,NW) AND INTERCALATED WITH MINOR LAMINATED SANDSTONES (Sh). THESE REFLECT LOW FLOW STAGE DRAPES DEPOSITED IN DEPRESSIONS ON THE BAR SURFACE AND PROVIDE A MEASURE OF SLIGHT INCREASE TOPOGR. DIFF. IN THE CHANNEL COMPARED WITH OTHER COARSER SECTIONS (R.RAWTHEY). FACIES GM IS LOCALLY CROSS-STRAT. AT THE TOP, COMBINED WITH AN OVERALL UPWARD CLAST SIZE FINING.

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PLATE 5.1

Plate shows approximately 20m long section of boulder-cobble conglomerates (facies Gm) exposed along the River Rawthey, between Buckbank and Lowridding, Sedbergh (N.G.R. SD 681 931). The section comprises 2 units, separated by an apparently broad and possibly erosive contact (marked by notebook and hammer). The topmost unit consists of imbricated cobble conglomerate with a distinct clast supported framework. The well developed imbrication, towards 344°, imparts a cross-stratified structure to the conglomerate formed by the dip of the AB plane of elongate clasts (towards 135° at 8°-9°). The lowermost conglomerate unit is poorly exposed but consists of poorly sorted massive boulder conglomerate.

The section reflects the accumulation of conglomerate as longitudinal gravel bars, comparing well with the 'Scott' gravels of Miall (1977). The topmost unit probably reflects the downstream migration of the bar head gravels within the supra-bar platform (cf. Bluck, 1976).

Interestingly enough, the present River Rawthey contains imbricated cobble-boulder gravels accumulating as gravel bars, as seen in the foreground of the picture. Hammer (28cm long), note-book (20cm long) and ruc-sack for scales.

PLATE 5.1.

PLATE 5.2

Plate shows massive, poorly sorted boulder conglomerates (facies Gm) exposed along the River Rawthey, close to Lowridding, Sedbergh (N.G.R. SD 684933). The section, 12m long, 3.5m high, consists of 2 boulder conglomerate units separated by a steeply dipping and undulating contact marked by hammer), which dips towards 053° at 20°. Maximum clast size varies from 61cm (basal unit) to 45cm (topmost unit), but no grading is evident, both units being massive with a crude A axis alignment of elongate clasts (NE-SW) present near the base of the section.

Again, these conglomerates probably reflect the accumulation of gravel as gravel bars. The steeply dipping contact present in the section may, it is tentatively suggested, reflect a channelised base, indicating that these conglomerates did form within channels. Hammer (35cm long) and note book (20cm long) for scale.



PLATE 5.2.

CHAPTER 6 CROSS FELL ESCARPMENT (CROSS FELL CLASTIC ROCKS)

6.1 INTRODUCTION

Sections studied within the Cross Fell Inlier are mainly restricted to the northernmost part of the area, i.e. north of Crowdundle Beck, exposure south of here being minimal until the Sink Beck Section is reached near to Knock Village. Facies data from the Cross fell Inlier measured sections are summarised in tables 18 to 26, (Appendix 1) the subdivision of facies following the same scheme as that used extensively in Chapter 3. In this chapter, Section 6.2 describes each measured section in detail, while Sections 6.3 and 6.4 integrate the facies data observed in the Cross Fell Inlier area and develop a depositional model respectively.

6.2 MEASURED SECTION DESCRIPTIONS

Within the study area (Figure 6.1) twelve main sections have been studied in detail, the principal facies and facies relationships present within each of the four lithological groups, Polygenetic Conglomerate, Quartz Conglomerate, Red Sandstones and Green Sandstones (introduced in Chapter 2), being described in the sections below.

6.2.1 Grey Mares Tail (NGR NY 625401; Tables 18, 23; Figure 6.2)

The Polygenetic conglomerate crops out at the base of the section and according to Shotton, (1935, p.643) is faulted against the Coniston Grits and St. Bees Sandstone. Actual exposure of the Polygenetic

Conglomerate is restricted to isolated outcrops no more than 2m in thickness, but total minimum thickness of the conglomerate must be at least 22m although Arthurton et al. (1981) record a maximum thickness of 70m. Due to the faulting at the base of the section, beds are steeply dipping and probably overturned.

Conglomerate units are poorly sorted the clasts supported by a matrix of varying grain size ranging from fine to coarse (facies Gms). Massive clast supported conglomerates are also present (facies Gm) these having a coarse grained sandy matrix. One outcrop, 1.7m in height, consists of deeply weathered granite boulders (Plates 6.1, 7.24) with clasts aligned along the longest 'A' axis, although this orientation is now in a vertical position. The clasts are heavily coated in haematite and are mostly composed of slate lithologies with some porphyritic igneous clasts also being present. Greywacke clasts are rare and vein quartz clasts are absent. Boulders up to 18.5cm (Table 18) are square and blocky in shape with roundness varying from angular to sub-rounded.

X-ray fluorescence and petrological analysis of one (Plates 6.1, 7.24) of these deeply weathered boulders suggest that they classify as weathered granites. The sample, 'Poly 1', is depleted in SiO2, 60.4% comparing with a typical value of 72.16% for typical Weardale granite from the Rookhope Borehole (Dunham et al., 1965; Holland , 1967). Poly 1 is further enriched in Al, Fe, Mg, Ti, Mn, Zn, and depleted in Sr and Na. When compared with a sample of 'weathered' granite, sample 'D' of Dunham et al (1965), sampled above 1286 feet in the Rookhope Borehole, Poly 1 shows similar gains and losses in 'majors and traces'. Weathered

granite, with a similar strong depletion in SiO2 to Poly 1, contains feldspars heavily degraded into muscovite and clay minerals (Holland, pers. comm.). A possible cause of the low SiO2 content in Poly 1 stems from the fact that the boulders, have been redeposited and thus have experienced multiple cycles of weathering prior to that now. Furthermore, a blue-dyed impregnated thin section shows that alkaline feldspars are strongly altered to clay minerals and quartz crystals are fractured the latter most probably the result of shattering associated with nearby faulting.

Overlying the Polygenetic Conglomerate a sharp change in clast composition and conglomerate type is associated with a decrease in maximum clast size. Vein quartz pebbles, equant in shape and angular to sub-angular roundness support a coarse sandstone matrix. Clast supported conglomerates (facies Gm) at the base of the 'Quartz Conglomerates' are crudely stratified and do not exhibit clast imbrication. Individual units are less than 1m thick, with total measured thickness of the Quartz Conglomerates being at least 15m. From thin section study (Appendix 3) of conglomerate matrix, up to 35% of grains are quartz with polycrystalline quartz usually being far more abundant than monocrystalline quartz. Haematite stained matrix content is usually high, (25%), although this value includes abundant pseudomatrix consisting of mud intraclasts compacted between more resistant grains. Rare feldspar grains are preferentially replaced by calcite. Granite fragments (16%) up to 4mm across contain plagioclase intergrown with polycrystalline quartz, muscovite and biotite, the feldspars locally being replaced by calcite.

Pebbly sandstones present at 12m above the base of the Quartz Conglomerates overlie 1.5m of red siltstone. In thin section (Appendix 3) the sandstones contain abundant rock fragments (72%), 39% of these being mainly pelite sedimentary rock fragments and feldspar rich volcanic rock fragments. A further 4.8% of clasts are composed of crystalline calcite, interpreted as being probable calcrete intraclasts, possibly derived from interbedded siltstones. Quartz overgrowth cements are absent but calcite passively infills intergranular porosity. Planar-cross-bedded medium grained sandstones (facies Sp) are present as two cosets 8m and 10.5m above base interbedded with quartz-rich conglomerates. Sets are 35cms thick with gently dipping planar foresets (5°-10°) orientated towards 342°-349°. Silty partings are locally present inbetween some sets.

The Quartz Conglomerates are overlain by the 'Red Sandstones', 15m in thickness, these containing cross-bedded sandstones overlying pebbly bases and forming cosets up to 50cm thick (facies Sp, St). Facies St consists of trough-cross-bedded medium grained sandstones arranged in sets 20cms thick. Tentative palaeocurrents derived from trough axes (tectonic dip is steep, 60° to the N.E.) are orientated towards 049°-072°. Ripple-cross-laminated fine grained sandstones (facies Sr) which usually overlie facies St contain possible plant remains and desiccation cracks. In the top part of the section laminated red siltstones (facies Fl) are present.

The 'Green Sandstones' which overlie the Red Sandstones are 16m-17m thick but are poorly exposed underlying bryozoan rich bioclastic

limestones belonging to the Orton Group. The Green Sandstones consist of well-bedded fine grained calcarenites which may be locally trough-cross-bedded.

6.2.2 Melmerby Fell Track (NGR NY 628371; Tables 18, 23; Figure 6.1)

The unconformity between the Polygenetic Conglomerate and the Skiddaw Slates can only be recognised by the change in soil cover. The junction between these Conglomerates is now very poorly exposed and the reader is referred to published reports (Arthurton and Wadge, 1981; Short, 1954) for detailed descriptions.

Poorly sorted matrix supported conglomerates (facies Gms) belonging to the Polygenetic Conglomerate consist of angular boulders composed of 'Phyllitic' textured slates heavily coated in haematite. The 'A' axes of more elongate boulders are crudely aligned 120°-300° at an angle of 37°, i.e. approximately parallel with bedding plane surfaces in the overlying Quartz Conglomerates, with thickness of the conglomerate estimated at 20m-25m.

Further up the fell track, stratified Quartz Conglomerates (facies Gm) overlie the Polygenetic Conglomerate and dip towards 110° at 10°. Thin section of the conglomerate matrix shows it to be coarse grained and consisting of quartz grains and abundant pelite sedimentary rock fragments. At least 50cms of fine grained red coloured sandstones are exposed overlying the Quartz Conglomerates.

6.2.3 Rake Beck (NGR NY 633369; tables 18,19,23; Figure 6.3)

In all 82m of Quartz Conglomerates and Red Sandstones are exposed above the unconformity near to Gale Hall farm. Above the unconformity poorly sorted pebble conglomerates, (facies Gm) 2m thick, which do not contain vein quartz clasts are interbedded with thin siltstone (facies Fl/Fm) and may belong to the Polygenetic Conglomerate.

The Quartz Conglomerates comprise conglomerate units up to 2m thick and total 35m in thickness. Maximum clast size reaches 18cm across but on average is restricted to 6-8cm. Conglomerates (facies Gm/Gp) have sharp basal contacts and are commonly overlain by planar-cross-bedded pebbly sandstones (facies Sp) in sets up to 40cm thick. Facies Sp, 17m above base, wedges out within 4.5m along strike, such that conglomerates above and below facies Sp form one continuous unit. Conglomerates up 20 metres above base are clast supported and exhibit planar-cross-bedding in lensed sets up to 30cm thick. Graded foresets formed by close packing of rounded clasts dip towards 353°-015° at 15°. Tightly packed clasts at the base contain an 'open framework' with no infilling matrix, but units exhibit an upward fining trend such that clasts near set tops are less tightly packed and contain a coarse grained infilling matrix. Conglomerates above 20m are less well exposed but are more massive and do not appear to contain interbedded sets of facies Sp.

Maximum clast compositions from this section (Appendix 2) show that 50% of clasts are composed of vein quartz, with typical red arkosic sandstones accounting for 42%. Rare intraclasts and acidic volcanic rock clasts are also present.

Exposure of the Red Sandstones is far from complete but thickness totals about 30m. Medium to coarse grained sandstones (Facies Sp) form cosets up to 2m thick consisting of sets, on average 30-40cm thick. Foresets are steeply dipping and have sharp tangential bases. Palaeocurrents are oriented towards 224°-346° at 10°-25° although these are very tentative.

Sandstones (see Appendix 3) from facies Sp are medium-coarse grained, moderately sorted, have a high (18%) matrix content and are cemented by passive calcite cement. Quartz grains are cemented by syntaxial quartz overgrowths. Sedimentary rock fragments are similar to those from conglomerate matrix but also include possible calcrete intraclasts most probably derived from a local source. Volcanic rock fragments are abundant, (19%) mostly comprising devitrified feldspar rich rhyolites (felsites). Rare orthoclase grains and biotite flakes suggest that granite may have supplied some of the material.

6.2.4 North Fell Track (NGR NY 636376; tables 19, 23; Figure 6.9)

Cross-bedded coarse to very coarse grained sandstones, pebbly sandstones and conglomerates (7m thick) crop out 25m horizontal distance from the top of the Fell Track. At this point the base of the Quartz Conglomerates are repeated due to the Gatecastle fault which downthrows the succession to the west.

Very coarse grained sandstones are planar-cross-bedded (facies Sp) near the base of the section and form a coset 88cm thick overlying a

more massive basal unit. Foresets are steeply dipping towards 286°-317° at 18°-10° and contain isolated imbrication of vein quartz pebbles.

Trough-cross-bedded coarse grained sandstones (facies St) form a solitary set 40cm thick, 1.75m above base and contain a pebbly basal lag, 35cm thick. Trough axes are orientated towards 330°.

Towards the top of the section, i.e. 3.35m above base, medium-coarse grained sandstones form a solitary planar-cross-bedded set (facies Sp) 50cm thick which thickens 10m-12m in an eastward direction. Here, a 1.1m thick coset consists of 3 sets (35cm thick) overlying a pebbly basal lag. Foresets are 1.5cm thick and dip gently towards 044°-027° at 8° with tangential foreset bases dipping towards the east. Pebble conglomerates (facies Gm) form the top part of the section and overlie, facies Sp.

6.2.5 Dale Beck (NGR NY 650365-651363; Tables 19, 20, 23, 24; Figure 6.4; Plate 6.6)

Two sections have been measured along the two tributaries of Dale Beck termed, 'Dale Beck 1' and '2'. In each case the very base of the section occurs within the Quartz Conglomerates, the basal Carboniferous unconformity being cut out by the Ladslack fault. The top of each section is taken at the level of the lowermost limestone horizon of the overlying Orton Group which occurs at the top of the Carboniferous Basement rocks throughout the area. Quartz Conglomerates are 26m thick in Dale Beck 2 but only reach 8.5m in Dale Beck 1. Red Sandstones vary

in thickness from 59.5m-70.5m while the Green Sandstones obtain a maximum thickness of 24m in Dale Beck 2.

The Quartz Conglomerates are massive and locally horizontally stratified (facies Gm) being arranged in units up to 2.5m thick interbedded with planar-cross- bedded, fine-medium grained sandstones (facies Sp). The framework is clast supported with a coarse grained infilling matrix except in units where the clasts are tightly packed and no matrix is present (open framework). Basal contacts have minor erosive relief, with the overlying unit fining up into a stratified top, e.g. 19.2m-21.8m above base (Dale Beck 2). Clasts vary from sub-angular to round, are blocky in shape and show a bi-modal composition with vein quartz, (up to 65%), and red coloured 'quartz arenites' (27%) the dominant rock clast types.

The Red Sandstones in these sections contain both planar-cross-bedded (facies Sp) and trough- cross-bedded (facies St) sandstones. In Dale Beck 1 facies St occurs as medium to coarse grained sandstones and forms thick festoon cosets up to 5m thick consisting of sets 15cm thick each set containing a 2cm thick pebbly base. The basal contact to each coset is erosive, sharply overlying ripple cross-laminated fine grained sandstones (facies Sr). Facies Sr occurs as very fine grained sandstones and forms the top to fining upward sequences, 6m-7m thick. At 14m above base facies Sr is arranged as a coset 1.6m thick comprising individual sets 5-7cm in thickness. Crests preserved at the top of one bedding plane surface are asymmetrical with palaeocurrents towards 052°. In Dale Beck 1 facies Sp is limited to

isolated cosets up to 1.3m thick generally occurring as fine grained sandstones. A coset of three individual sets occurs at 44m above base (Plates 6.6) and shows three main trends: fining upward grain size, decreasing foreset angle from 23° to 8°, with foresets becoming increasingly asymtotic upward through each set, and varying palaeocurrents, ranging from 172° to 092° at the top of the coset.

In contrast to Dale Beck 1, sandstones within Dale Beck 2 are mainly planar-cross-bedded (facies Sp), although the exposure is not as complete as in Dale Beck 1. At 65m above base (Plate 6.6) facies Sp consists of fine to medium grained sandstones arranged as three sets, 40cm thick, forming a coset. Within the coset, a reactivation surface is present separating 'Set 2 from Set 3'. Palaeocurrents range from 122° to 032°. Foresets are steeply dipping, 21°-22° on average, with asymtotic foresets present at the base of the coset. Individual foresets may be up to 8cm thick and are frequently graded with thin, coarse grained bases and medium-coarse grained tops. Pebbly lags of vein quartz clasts up to 1cm are present at the base of some sets.

Interbedded with facies Sp are red coloured, laminated siltstones forming units up to 50cm thick. Facies St in Dale Beck 2 is limited to a solitary set at 62.8m above base.

In thin section (Appendix 3), sandstones from both measured sections are fine to coarse grained, moderate to poorly sorted and cemented by calcite and also 'baroque' dolomite. Patchy quartz overgrowths are present occurring outside 'clear' haematite dust rims

which show quartz grains to be rounded. Calcite passively cements intergranular porosity post-dating quartz overgrowth cement. Grains from facies Sp are generally more rounded than those from facies St. Matrix content (up to 22%) includes abundant pseudomatrix formed from the compaction of mud intraclasts. Deformed muscovite mica flakes indicate significant compactional effects, even though quartz cement probably stabilised the grain framework. Minor late pore filling kaolinite clay cement, up to 4.4% in Dale Beck 2, is present. Rare zircons represent the only heavy mineral fraction.

Clast composition analysis shows similar trends to other measured sections (Appendix 2). From maximum clast size analysis, clasts are mainly vein quartz (64%) and red 'quartz arenites' (27%). Combined conglomerate matrix and sandstone thin section modal analysis shows that polycrystalline quartz is more abundant than monocrystalline quartz, 25% to 15% respectively. Rock fragments (up 58%) are composed of pelite, chert and rare lithic greywacke sedimentary grains, with igneous clasts mainly being of volcanic composition. In thin section, abundant quartz rich detrital grains are likely to be remnants of fine grained groundmass from volcanic rock fragments, very easily confused with chert.

The Green Sandstones in thin section are moderately sorted very fine-fine grained calcarenites. X-ray diffraction of bulk sample shows that chlorite content is high occurring as both grain coating and grain replacing (mica) clay. Calcite infills intergranular pores post dating chlorite grain coats. Monocrystalline quartz grains are more abundant

than polycrystalline quartz which are restricted to rare fine, sand sized grains in complete contast to sandstone from the Quartz Conglomerate and Red Sandstones. At outcrop the Green Sandstones are hard, compact and well-bedded to horizontally laminated (facies Sh). In Dale Beck 2 at 111m above base, facies Sp also forms a coset 75cm thick. Two sets within the coset contain planar foresets with palaeocurrents orientated towards 138°-157°. Ripple-cross-laminated horizons (facies Sr) may be present at 97m above base. Cross-bedded horizons at 82m and 88m above base in Dale Beck 1 show trough defined foresets.

6.2.6 Musca Hill Crags (NGR NY 649359; Tables 20, 21, 24, 25; Figure 6.5; Plate 6.2)

Two sections, up to 13m thick, expose the basal part of the Quartz Conglomerates. The unconformity at the base overlying the Murton Formation is not exposed.

Conglomerates are poorly sorted with a clast supported framework and infilling coarse grained matrix (facies Gm). Conglomerates are arranged in units up to 2.5m thick, with erosive basal contacts overlying, cross-bedded pebbly sandstones, erosive relief being up to 20cm. In both sections (Musca Hill 1,2) conglomerates at the base are massive and fine up into trough-cross-bedded (facies Gt) horizons, 50cm thick, 3m-4m above base. Trough axes trend 065°-245°. Stratified horizons, 1.9m thick, near the top of both sections are imbricated with the B axis of elongated clasts aligned in a dominant 069° direction. In Musca Hill 2 section, stratified conglomerates 8m above base transitionally overlie a planar-cross-bedded base (facies Gp), 30cm

thick, in which rounded tightly packed clasts form planar foresets dipping towards 020°.

Interbedded medium to coarse grained pebbly sandstones form solitary cross-bed sets (facies Sp) which vary in thickness from 30cm to 80cm. In Musca Hill 1 section, planar-cross- bedded sandstones (facies Sp) form a coset, 1.5m thick, overlying a pebble conglomerate base. Planar foresets dip steeply (22°-32°) towards 073°-052° and contain vein quartz pebbles which are imbricated along the foreset plane. In Musca Hill 2 section, facies Sp forms a coset at 6m above base. Two sets are seen with graded (medium to coarse) foresets dipping (15°-16°) towards 070°-059°. Basal contacts are sharp, overlying facies Gm below.

Maximum clast size analysis (Appendix 2) shows that 69% of clasts are composed of vein quartz. From combined conglomerate matrix and sandstone petrography, polycrystalline quartz is more abundant than monocrystalline quartz grains, 51% to 11.9% respectively. Sedimentary rock fragments consist of fine grained pelite and rare greywacke sandstone lithologies and account for 32% in the modal analysis. Rare felsitic volcanic rock fragments are also present. In thin section (Appendix 3) sandstones are poorly sorted and poorly cemented with rare quartz overgrowth cement and patches of passive-fill calcite. Minor Kaolinite clay also fills intergranular porosity. Rare polycrystalline grains, intergrown with spherules of muscovite crystals are similar to crystals, from the Eskdale Granite (see Section 1.6; Plate 7.23) and thus might have been derived from a granitic source rock.

Windy Gap (NGR NY 647355; tables 21,25; Figure 6.6)

Steeply dipping clastic rocks belonging to the Quartz Conglomerates crop out at Windy Gap Col, the unconformity being lost due to the Windy Gap fault. The 39m long section which in places is up to 4m thick, consists of massive, poorly sorted cobble conglomerate (facies Gm) forming a basal unit at least 2m thick. Maximum clast size within this unit shows little variation (9.5cm to 12cm) over the length of the section. Over 76% of clasts are composed of vein quartz, the remaining clasts composed of 'red quartz arenites', limestones and acidic volcanic rocks.

At the north end of the section, trough-cross-bedded medium to coarse grained pebbly sandstones (facies St) sharply overlie facies Gm, facies St being arranged in sets 20-25cm thick. Vein quartz pebbles are aligned along foresets, with trough axes orientated towards 061° and trending 071°-257° in topmost sets. Parallel laminated coarse grained sandstones (facies Sh), 20cm thick, are also interbedded 2m above base, erosively overlain by facies St. Cross-bedded coarse grained sandstones with tangentially based planar foresets (facies Sp) form a solitary set, 50cm thick, these being laterally equivalent to facies St and also directly overlie facies Gm at the northernmost part of the section. Foresets contain scattered vein quartz pebbles and dip towards 060°-040° at 30°.

The southern end of the section is separated by a horizontal gap of 11m. Here facies St forms a coset at least 2m thick comprising individual sets 28cm-40cm thick. Well preserved trough axes measure up

to 1.5m across, each set containing a pebbly basal lag comprising vein quartz pebbles. Palaeocurrents derived from trough axes are orientated towards 028°-060°.

In thin section medium to coarse grained pebbly sandstones are poorly sorted, detrital grains being dominated by polycrystalline quartz these being more abundant than monocrystalline quartz, the latter only comprising 5% by modal analysis (Appendix 3). Quartz-rich lithic rock fragments with intergrown muscovite spherules (similar to those noted at Musca Hill) may have been derived from a granitic source. Matrix content is high (19%) and contains compacted mud intraclasts. Authigenic mineral cements are minor, limited to calcite which also partially replaces plagioclase feldspar phenocrysts in volcanic rock fragments. These latter grains are possibly minettes derived from igneous dyke rocks and are similar to the biotite rich minette fragments occurring in the Mell Fell Conglomerate (Chapter 4) and Shap Red Beds (Chapter 3). Other volcanic grains are feldspar-rich and felsitic in composition. Sedimentary rock fragments include pelite and veined greywacke sandstone lithologies.

6.2.8 Ardale Beck (NGR NY 652344-655346; Tables 21, 22, 25; Figure 6.7)

Clastic rocks assigned to the Quartz Conglomerates and Red Sandstones crop out in the lower part of Ardale Beck, the thickness of the section being at least 36m. At the base, 2m of poorly sorted matrix supported conglomerate (facies Gms) contain no vein quartz clasts which suggests they belong to the Polygenetic Conglomerate. Clasts, up to 2.5cm across, are mostly composed of fine grained slate lithologies with

rare volcanic fragments and greywacke clasts also being present. Clasts from this conglomerate are heavily coated in haematite.

In contrast, conglomerates overlying a 3m gap, are clast supported (facies Gm), and well sorted containing well rounded clasts and horizons with no infilling matrix (open framework). In contrast to conglomerates of the Polygenetic Conglomerate below, vein quartz amount increases from nil to over 59%. Conglomerate units, up to 1m thick, have a tightly packed clast support framework and common upward fining maximum clast size. Basal contacts to units are broad and sharp. Conglomerates are locally planar-cross-bedded (facies Gp) e.g. 6.8m, and 19m above base, foresets, which dip towards 020° at 12° formed by the close packing of rounded, elongate clasts. Facies Gp is locally overlain by planar-cross-bedded fine-coarse grained sandstones (facies Sp).

Conglomerate matrix in thin section (Appendix 3) is poorly sorted, grains varying in size from 0.6-4mm across. Polycrystalline quartz grains are abundant being more abundant than monocrystalline quartz. Sedimentary rock fragments include fine grained pelite lithologies and acidic volcanic grains which together account for 57% in the modal analysis of some samples.

The Red Sandstones are cross-bedded between 18m and 26m above base and comprise both planar-cross-bedded (facies Sp) and trough-cross-bedded (facies St) fine to coarse grained sandstones. Facies Sp occurs as thin (<1m) grouped sets or cosets and also as isolated sets. Isolated sets at 19.7m above base consist of planar foresets, 1cm thick

containing scattered quartz pebbles aligned along the foresets, which dip towards 038° at 13°. At 31m above base, facies Sp forms a coset containing two sets, 30cm thick, with tangentially based foresets dipping towards 323° and 027° at 7°-17°.

Facies St form cosets up to 2m thick consisting of individual shallow pebbly sandstone sets. 20-25cm thick, containing foresets which are less than 1cm thick. At 26m above base, facies St erosively overlies cross stratified pebble conglomerates (facies Gm) the relief along the basal contact being 10cm. Trough axes are orientated towards 356°-004°.

In thin section (Appendix 3) sandstones are dominantly coarse grained and poorly sorted with abundant compacted mud intraclasts forming pseudomatrix. Rock fragments, especially slate pelite grains, are more abundant than quartz grains and account for up to 58% in the modal analysis. Quartz grains have been well cemented by well developed quartz overgrowths cements, clear haematite dust rims showing grains to be dominantly well-rounded in shape. In some samples baroque dolomite crystals may replace originally displacive calcite intergranular cement.

6.2.9 Cocklock Scar (NGR NY 655338; Tables 24, 25; Figure 6.8; Plates 6.3-6.5)

This section exposes the basal part of the Quartz Conglomerates very close to the basal unconformity near Kirkland Beck. The conglomerates crop out over a distance of 35m-40m but only a thickness of 4.5m is actually observed. The section comprises well structured

cobble-boulder conglomerates (facies Gp/Gm) interbedded with medium-coarse grained planar-cross-bedded sandstones (Plates 6.4, 6.5).

Conglomerates (facies Gm/Gp) form laterally extensive units bounded at the top and base by planar-cross-bedded coarse grained sandstones (facies Sp) up to 2.1m thick. Facies Gm is clast supported and develops a strong clast alignment with the mean longest 'A' axis of elongate cobbles aligned 124°-304°. The mean dip direction of the bounding surfaces, obtained from the finer grained horizons is 018° and suggests that the 'B' axis of elongate clasts (perpendicular to the 'A' axis) are probably imbricated in this direction. The units have a tabular geometry and are defined by broad planar basal contacts, units on average being 40cm-60cm thick. Clast size remains constant throughout each unit and fining upward trends were not observed. Facies Gp is seen at one horizon, 1.5m thick (Plate 6.3) and extending over a distance of 4.5m. Lensed sets up to 45cm thick are orientated towards 050°.

At the southern part of the section, trough-cross-bedded very coarse grained pebbly sandstones (facies Gt) consists of at least 3 individual sets, up to 46cm thick, probably forming a coset over 2m thick. Foresets are 2cm thick and the palaeocurrent vector mean calculated along trough axes is 031°.

Minor, medium to coarse grained planar-cross-bedded sandstone intercalations (Plate 6.4), up to 25cm thick, occur within facies Gm in the north part of the section. Palaeocurrents measured from one horizon dip toward 325°.

At the base of the section, coarse grained sandstones, up to 60cm thick, contain slightly asymtotic planar-foresets (facies Sp) which dip gently (4°-6°) towards 018°-032°, and overlie poorly exposed cobble conglomerates (facies Gm). At the top of the section, facies Sp forms a coset, 2.1m thick, containing 3 sets up to 60cm thick. The planar foresets dip (12°) towards 023°-032° and contain scattered vein quartz pebbles up to 3cm. The vector mean calculated for facies Sp is 026°, indicating palaeoflow towards a North-North-East direction.

In thin section (Appendix 3), coarse grained sandstones are poorly sorted and contain granules up to 5mm across. Quartz grains have patchy overgrowth cements outside diffuse haematite dust rims. Kaolinite (up to 4.4%) infills intergranular porosity. Rock fragments account for up to 43% of detrital grain types and include quartzose grains most probably derived from the fine grained groundmass of acidic, volcanic rock types.

Composition of clast types analysed from study of maximum clast size (Appendix 2), show that 64% of clasts are composed of vein quartz. Over 31% of clasts are composed of 'red quartz arenites' and quartz veined greywackes as described from other sections. Rare porphyritic igneous clasts comprise two compositional types: Quartz and hornblende phenocrysts within a finely crystalline groundmass, and altered plagioclase feldspar lath-shaped phenocrysts within a coarse crystalline groundmass of lathe shaped plagioclase. These compositions are similar in composition and texture to Borrowdale Volcanic Group andesitic rocks as described in Chapters 1 and 7.

6.2.10 Crowdundle Beck (NGR NY 683321; Table 20; Figure 6.10)

The Quartz Conglomerates are poorly exposed overlying the basal unconformity, which is not exposed, and crop out as weathered crags on the northern bank of Crowdundle Beck. Tightly packed pebble-cobble conglomerates occur in units of varying thickness (80cm to 1.5m) and total at least 5.75m. Above base, massive clast supported conglomerates have a coarse infilling matrix these being overlain by horizontally stratified conglomerate at least 70cm thick. Here, elongate clasts are aligned parallel with the base of the sedimentary unit which dips towards 040° at 13°. More massive conglomerates overlying these with a sharp, basal contact, contain upward fining clast size.

Higher up in the section, well-bedded conglomerates have a tightly packed clast supported framework and dip gently (8°) towards 326°. Basal contacts between units are flat and sharp, the maximum clasts size remaining constant throughout each unit. In thin section, conglomerate matrix is poorly sorted, containing granules and small pebbles between 0.5mm-1cm across. Cements are poor but mud matrix content is high (13%) although this includes mud intraclasts compacted to pseudomatrix. Polycrystalline quartz grains are abundant with strained fragments probably being derived from a metamorphic source rock.

At the top of the exposed section, 1.5m of poorly sorted coarse grained sandstone with abundant granules contains diffuse cross-stratification in the top 1.05m. Scattered vein quartz pebbles are present up to 5.5cm across. In thin section granules up to 7mm across are present. Quartz grains (34%) are the dominant grain type

although there is no evidence for quartz overgrowth cements. Minor amounts of kaolinite clay locally infills intergranular porosity. Pelite sedimentary rock fragments are most abundant and account for 45% of detrital grain types.

Analysis of maximum clast size compositions from these conglomerates (Appendix 2) proves over 66% of clasts are composed of vein quartz. Limestone clasts take up 18%, with red coloured quartz 'arenites' and acidic igneous rock clasts present only in minor amounts. From the combined study of conglomerate matrix and sandstone petrography, polycrysalline quartz is generally more abundant than monocrystalline quartz grains, sedimentary rock fragments, pelite and less common greywacke fragments (14%). Igneous rock fragments (14%), include felsitic grains and quartz porphyries with a fine grained groundmass.

6.2.11. Sink Beck (NGR NY 697292; Table 26; Figure 6.11)

The Quartz Conglomerates and overlying sandstones reach a minimum thickness of 89.41m along Sink Beck, this being measured from the basal unconformity, which is not exposed, to the lowermost limestone horizon belonging to the Orton Group above the Basement clastics. The top of the Quartz Conglomerates is faulted, marked by a zone in which conglomerates have been highly sheared.

The Quartz Conglomerates (Facies Gm) are at least 25m in thickness. Massive cobble and boulder conglomerates have a tightly packed clast supported framework with a coarse grained sand infilling matrix. The

B-axis of some clasts are imbricated at some horizons, towards a general 068°-061° direction, but mostly unit structure is massive. Conglomerates are arranged in units of variable thickness (50cm to over 2m) and have sharp, possibly erosive, basal contacts, which dip (13°) towards 106°. Coarse-very coarse grained sandstones 'cap' the top of some conglomerate units. Finer grained pebble to cobble conglomerates are horizontally stratified and some units coarsen up from granulestone conglomerate bases. Maximum clast size compositions show that over 75% of clasts are composed of vein quartz with 18% composed of buff, micaceous quartz 'arenites' and quartzites.

Sandstone horizons (5cm-28cm) 'capping' the top of conglomerate units are commonly horizontally laminated (facies Sh). Basal contacts vary from transitional to sharp, with top contacts also commonly being sharply overlain by the conglomerate unit above. Carbonaceous material was recorded from one horizon. In thin section, sandstones are poorly sorted and poorly cemented with only patchy quartz overgrowths recorded from quartz grains. Rock fragments and polycrystalline quartz are the most abundant grain types. Grains have locally been severely compacted shown by 'squeezed' mud intraclasts and deformed and fractured mica flakes. Kaolinite clay cement fills intergranular pore spaces and accounts for up to 11% in the modal analysis.

Approximately 25m above base, buff to purple coloured laminated medium-coarse grained sandstones, (facies Sh/Fl, 7.50m thick) overlie the Quartz Conglomerates with a sharp basal contact. Sandstones occur as well-bedded units up to 70cm thick with sharp basal contacts and

showing erosive relief up to 15cm. Finely laminated purple coloured siltstones (facies Fl), containing rare plant debris, occur 20cm above local base.

A disused quarry at the top of the section exposes 2.8m of buff to cream coloured coarse grained sandstones which fine up from a granulestone conglomerate base. The sandstones occur as well-bedded tabular units dipping towards 055° at 11°, these dipping surfaces most probably representing planar-cross-bedding (facies Sp) but due to the massive nature of outcrop this is hard to determine. In thin section (Appendix 3), sandstones are well sorted (coarse grained) with quartz grains accounting for 96% of all grain types, monocrystalline quartz taking up to 79.5% of grain types. Quartz grains are rounded and exhibit well developed, euhedral quartz overgrowth cements. Illitic clay dust rims present in contrast to haematite rims and this along with the high kaolinite content imparts the cream colour to the rocks. Kaolinite accounts for 16% in the modal analysis and infills intergranular pores post-dating quartz overgrowths cement. Muscovite flakes are not deformed and suggest that compaction was low, the rocks being cemented by quartz relatively early leaving a high porosity to be infilled by kaolinite at a later stage. Feldspars are absent at present although replacement by kaolinite cannot be discounted. Rock fragments are rare but include greywacke sandstones and felsitic volcanic rock grains.

6.2.12 Roman Fell Summit (NGR NY 753204; Table 26; Figure 6.12; Plates 6.7-6.10)

Red coloured fine to coarse grained sandstones which are lithologically similar to the Red Sandstones, are well exposed at the top of Roman Fell although as a result of the area being within the military firing ranges access is restricted. The study of this section does, however, show a vertical thickness of 18m-22m (exposed) mostly of trough and planar-cross-bedded sandstones (facies St and Sp respectively).

Sandstones are fine to coarse grained being mainly medium grained on average with graded foresets commonly showing medium grained tops overlying coarse grained bases. Pebbly horizons are also present with scattered imbricated pebbles of vein quartz up to 2cm across occurring along some foresets, while oval mud intraclasts commonly line trough bases. In thin section, sandstones (Appendix 3) are well sorted containing well rounded quartz grains, monocrystalline quartz grains being more abundant (62%) than polycrystalline quartz. Quartz overgrowth cements are locally well developed outside distinct haematite dust rims, detrital grains commonly having concavo-convex and point grain contacts suggesting that establishment of a 'rigid' grain framework by quartz cementation has inhibited severe compaction. Minor amounts of kaolinite clay infills some intergranular pore spaces. As with Sink Beck, quartz grains account for 91% of detrital grain types with rare greywacke and felsitic volcanic rock fragments also being recorded.

Trough-cross-bedded sandstones (facies St) are divided into two subfacies characterised by different cross-bed set size. Subfacies St1 are large scale trough-cross-bedded sandstones arranged in cosets up to 3.5m-4m in thickness and consisting of sets between 50cm and 60cm thick (Plate 6.7). 'Scooped' shaped basal contacts contain mud intraclasts. Foresets are 1cm-1.5cm thick and foreset angle of dip decreases from 24° at the back of the trough structure to sub-horizontal and horizontal along the trough axis. Trough axes measure up to 3.5m across. Deformed foresets are present within a set, 4m above the base of the section, these most probably, a result of dewatering of newly deposited and water saturated sand.

Subfacies St2 is characterised by trough-cross-bedded sandstones comprising sets up to 25cm thick and arranged in cosets up to 2m. Commonly this subfacies consists of thin, shallow pebbly trough-cross-bedded units, 50cm thick, interbedded with planar-cross-bedded sandstones (Subfacies Sp2). At 18.5m above base, a thin trough-cross-bedded unit, 10cm thick, forms a bottomset unit to the planar foresets of subfacies Sp2.

Palaeocurrents from facies St are markedly unimodal in distribution and show a vector mean orientated towards 037.7°, indicating palaeoflow towards a general north-easterly direction.

Planar-cross-bedded sandstones (Plates 6.8-6.10; facies Sp) are again divided into two subfacies, Sp1 and Sp2 characterised by different set size. Subfacies Sp1 consists of individual large-scale

planar-cross-bedded sets up to 1m in thickness being present at 3m, 12.5m, 14.5m and 17.5m above local base. Basal contacts are broad, gently concave upwards and show localised minor relief of 10cm over a distance 2m. Top contacts are irregular, e.g at 17.5m above base the thickness of Sp1 varies from 31cm to 65cm over a distance of 3.7m. Reactivation surfaces are common (Plate 6.8) and are comparable to those described for the Tana River, Norway by Collinson (1970). Along these horizons (see Section 6.3.3), planar foresets are discordant (e.g. 14.5m) with those above the surface, and reflect periods of non deposition, possibly erosion and followed by redeposition. Foresets vary in thickness from 1cm-3cm and have two main types of basal contact, angular and tangential as discussed in Section 6.3.3.

Subfacies Sp2 (Plate 6.9), consists of relatively thinner cross-bed sets up to a maximum thickness of 40cm-45cm. Cosets are 80cm to 1m thick and are commonly interbedded with subfacies St2 forming composite sequences up to 2.5m-3m thick. Sets are bounded by flat, planar basal and top contacts developing wedge-shaped units. Foreset angle of dip is high although it decreases within some sets with tangential contacts present at 19m and 21.5m above base. Reactivation surfaces are present at 13m and 19m above base.

Palaeocurrent analysis of facies Sp has more a varied distribution than facies St. Vector mean of facies Sp is orientated towards 017.8°, a 20° difference to facies St. Furthermore, within facies Sp, subfacies Sp2 has a more polymodal distribution compared with subfacies Sp1 which is markedly unimodal.

At 11.5m above the base of the section, coarse grained pebbly sandstones form a probable trough-cross-stratified unit, 90cm thick, containing vein quartz pebbles up to 4cm across. Due to poor exposure accurate determination of the primary sedimentary structures was not possible, but they are tentatively assigned to facies Gt.

6.3 LITHOFACIES INTERPRETATION

This section summarises the facies present within each of the four lithological groups, Polygenetic Conglomerate, Quartz Conglomerate, Red Sandstones and Green Sandstones, and interprets each facies in terms of the depositional environment. Although the sandstones outcropping at Roman Fell have been assigned to a different Group they are included, as far as the facies interpretation is concerned within the Red Sandstones. Certain aspects of the facies interpretation are referred back to the respective environmental interpretation presented in Chapter 3.

6.3.1 Polygenetic Conglomerate

The Polygenetic Conglomerate has a 'patchy' distribution being restricted to isolated outcrops at Grey Mares Tail, Rake Beck, Melmerby Fell track and Ardale Beck sections. It mainly consists of matrix supported boulder conglomerate (Facies Gms) forming units at least 50cms thick, with relatively minor interbedded clast supported conglomerate (Facies Gm) and rare siltstone horizons. Significantly, as discussed below, these deposits differ from those belonging to the overlying lithological groups in lacking vein quartz, instead containing abundant haematite coated 'phyllitic' textured slate and greywacke clasts with

weathered granite ('Poly 1' up to 18.5cm, Plates 6.1; 7.24) and porphyritic igneous clasts. At the Melmerby Fell Track Section, 'A' axes of elongate clasts are crudely aligned with the bedding plane surfaces of Quartz Conglomerate units above. Thickness of the Polygenetic Conglomerate was not able to be conclusively determined although its restricted distribution suggests it varies considerably in thickness. Observations by Arthurton and Wadge, (1981) show the Polygenetic Conglomerate, near Melmerby, to 'pinch-out' laterally within 250m horizontal distance. The section at Grey Mares Tail exposes a minimum thickness of 22m, although Arthurton and Wadge, (1981) suggest that up to 70m may be present.

The Conglomerate has been considered in past years by a number of authors (e.g. Goodchild, 1889, Marr, 1899; Shotton; 1935; Dunham, 1948; and Short, 1954) who mainly correlate it with the Mell Fell Conglomerate and assign a Devonian age to it.

The matrix supported conglomerate units (Facies Gms) are interpreted as the deposits of mudflows. They resemble published descriptions for ancient mud or debris flows (e.g. Bull, 1964, Miall, 1978, Rust, 1978b, Collinson, 1978, Rust, 1979, Nilsen, 1982, Rust and Koster, 1984), such units being poorly sorted and lacking internal grading or stratification although imbrication along the 'A' axis may be present. Mudflows, principally occurring on alluvial fans, are promoted by steep slopes, a lack of vegetation, short periods of abundant water supply and a source area combining debris and a muddy matrix. They move in surges down a stream channel but commonly overlap the banks at the

lower, 'distal' end of the channel forming sheetlike deposits (Bull, 1964). The transport medium is mud, which moves more like a plastic than a liquid, having a finite strength to support large clasts (Ethridge, 1985).

Bluck (1967) has shown that a positive relationship exists between maximum clast size and bed thickness, this association reflecting flow competency and flow size of the individual mudflow. Consequently, flow competency and size decrease in a down-slope/fan direction, reflected in a corresponding decrease in maximum clast size and bed thickness in the ancient record. Unfortunately, in the present study, the lack of reliable field data, the result of extremely poor exposure, has meant that such analyses proved unrealistic.

Clast supported conglomerates (Facies Gm) with an infilling coarse grained sand matrix are interpreted as possible streamflow deposits (Bluck, 1967; Steel, 1974a; Nilsen, 1982) deposited within fluvial channels. This interpretation is largely based on the association with matrix supported conglomerates, the lack of field exposure inhibiting a more precise environmental interpretation.

The minor interbedded siltstones (Facies Fm) observed at Rake Beck section accumulated at low flow stage and probably form impersistent 'drapes' deposited over conglomerate units. Within an alluvial fan setting, fine grained sediment accumulates on 'fan abandonment' and in particular within inter-channel areas and bordering channel margins (Nilsen, 1982).

The author considers the Polygenetic Conglomerate to comprise mudflows, interbedded with possible streamflow deposits and deposited within a broad alluvial fan setting. Although the restricted field data inhibit a more precise interpretation, nevertheless in the context of the depositional model for the Cross Fell clastic rocks (Section 6.4), the Polygenetic Conglomerate reflects local alluvial fan development (Trollheim type of Miall, 1982, based on Hooke, 1967) lateral to more extensive braided-fluvial channel sedimentation. As such the immature deposits of the Polygenetic Conglomerate reflect local 'stripping' of easily eroded material and contrast markedly to the relatively more mature quartz rich deposits of the overlying lithological groups. Evidence for local provenance, reflected in abundant slate type clasts and igneous rock types (Section 7.3) is supported by the observations of Shotton (1935). Similar conglomerates probably reflecting local 'stripping' of debris, were observed by the author at the base (overlying the basal unconformity) of the Carboniferous in Kirkudbrightshire (White Port, Kirkudbright, N.G.R. NX 723433), these conglomerates lacking vein quartz but again overlain by quartz rich clastic sediment. The reader is referred to Deegan (1970, 1973) for information on these conglomerates.

6.3.2 Quartz Conglomerates

The Quartz Conglomerates group is locally well exposed within the Cross Fell area. North of Swindale Beck (Knock) the group thickens towards Dale Beck/Musca Hill where it is up to 45m thick, thinning again towards the north, (17m-18m at Grey Mares Tail). In the south, the group apparently 'pinches' out near to Crowdundle Beck (Figure 6.1). As

discussed in Chapter 2, this variation in thickness reflects topographic relief of the lower Palaeozoic basement, and represents the infill of a 'palaeo-depression', at least 17km wide with the axis centred about Dale Beck.

The boundary between the Quartz Conglomerates and the Polygenetic Conglomerate is today nowhere exposed. According to Arthurton and Wadge, (1981), however, the boundary is an unconformable one, tectonic dips within the Polygenetic Conglomerate exceeding those within the Quartz Conglomerates (their 'basement beds') by 10°. The author is not in total agreement with this view point and, as proposed in Section 6.4, puts forward a depositional model which would account for a conformable junction (forming at the same time, i.e. laterally equivalent). Nevertheless, the change in vein quartz content across the boundary is striking, this being one of the principal criteria for distinguishing these two conglomerates in the field.

The Quartz Conglomerates Group comprises three main facies types: massive to crudely stratified/imbricated conglomerate (Facies Gm), planar-cross-bedded conglomerate (Facies Gp) and trough-cross-bedded conglomerate (Facies Gt). Out of these facies, facies Gt and Gp only account for 25% of the total number of conglomerate units described in the field (Tables 18-26, Appendix 1). Facies Gm is by far the most abundant, comprising usually well rounded cobble-pebble conglomerate with a coarse grained infilling sand matrix. Conglomerates commonly form upward fining units, up to 2.5m thick, these being generally crudely stratified and imbricated. The Cocklock Scar Section (Figure

6.8; Plates 6.3-6.5) contains crudely stratified conglomerates with a well developed clast alignment, the 'A' axis of elongate clasts aligned 124°-304° (Figures 6.8, 6.13) this trend being approximately perpendicular to the mean dip direction (018°) of the unit bounding surfaces. This, it is suggested, infers that the B axis of these clasts lies parallel to the plane of the unit bounding surface. Facies Gm is locally laterally equivalent to facies Gp and overlain by facies Gt, being interbedded with cross-bedded sandstones (mainly facies Sp).

Planar-cross-bedded conglomerates (Facies Gp) form 'lensed' sets, 30cm-45cm thick (Rake Beck and Cocklock Scar:sections 6.2.3, 6.2.9; Figures 6.2, 6.8; Plates 6.3, 6.4), containing planar foresets formed by the close packing of clasts. Foresets (Rake Beck, Cocklock Scar) are orientated towards 050°-004°. Graded foresets, identified at Rake Beck, contain a coarser grained base with an 'open-work' clast supported framework, overlain by a finer grained top with a clast supported framework infilled by sand matrix.

The textural features within these structures are similar to those described by Steel and Thompson (1983) and Rust (1984), attributed to the rate of gravel accumulation versus sand infiltration on the foreset slope. Where the rate of gravel accumulation is high, sand is unable to infiltrate the whole of the gravel foreset, resulting in an openwork framework beneath a framework infilled with sand (Rust, 1984). At Cocklock Scar (Figure 6.8; Plate 6.3), Facies Gp forms a coset, 1.5m thick and extending for approximately 4.5m along strike.

Trough-cross-bedded conglomerates (Facies Gt) are restricted to relatively minor sets, 40cm-50cm thick, overlying facies Gm at Musca Hill Crags (Figure 6.5) and Cocklock Scar. At the former locality (Section 6.2.6) facies Gt contains crudely defined trough-shaped foresets, with trough axes trending 065°-245° and 105°-285°.

The Quartz Conglomerates contain interbedded and intercalated sandstone horizons, occurring mostly as cross-bedded wedge-shaped units (Facies St, Windy Gap; facies Sp, Rake Beck, Dale Beck, Musca Hill, Windy Gap, Cocklock Scar) and minor horizontally laminated 'drape' units (Facies Sh, Windy Gap). At Windy Gap (Figure 6.6), Facies Sp forms a solitary set, 50cm thick overlying cobble-boulder conglomerates (Facies Gm) at the base and which appear to be laterally equivalent to Facies St (sets up to 25cm Thick) which occurs no more than 30m along the strike of the section. Palaeocurrents measured from both Facies St and Sp at Windy Gap indicate a dominant palaeoflow towards 040° and 071°. The wedge-shaped geometry of facies Sp is best displayed at Rake Beck (Figure 6.3) where 17m above base, Facies Sp interbedded with Facies Gm, 'pinches out' within 4.5m.

The following factors are thus considered significant in the interpretation of the Quartz Conglomerates:

1. Predominance of facies Gm, forming massive to crudely stratified and imbricated conglomerate units interbedded and laterally equivalent to cross-bedded conglomerate (Facies Gp, Gt).

2. Vertical stacking of conglomerate units (e.g. Rake Beck, Crowdundle Beck, Sink Beck) forming common fining upward profiles, interbedded and intercalated with sandstone locally forming prominent planar-cross-bedded wedge-shape sandbodies.

These facies types and the vertical and lateral facies associations are consistent with the deposits of gravel bars within coarse-bedload braided rivers and similar to the conglomerate facies (facies zones 1-3, Shap Red Beds) discussed extensively in Chapter three. The predominance of facies Gm, as in the Shap Red Beds, suggest that most conglomerates represent the accumulation of gravel as gravel bars. The massive, and locally stratified and imbricated (A axis transverse to flow) structure of facies Gm combined with common upward fining clast size throughout the unit suggests that bars were mostly of the longitudinal type, again considered in Chapter 3 (Figure 3.12). Longitudinal bars result from the growth during high flow stage of 'diffuse gravel sheets' (cf. Hein and Walker, 1977). During periods of high water and sediment discharge, longitudinal bars accrete vertically and laterally downstream by the addition of clasts in these directions, the decrease in clast size from channel to bar top and from the upstream to downstream portions of the bar constructing a fining upward profile, this being represented by upward fining maximum clast size.

Planar-cross-bedded conglomerates (facies Gp) are interpreted as reflecting the development of foresets and the growth of a lee-side slip-face within a gravel accumulation. Slip-face development within a gravel bar occurs in areas of relatively lower sediment discharge,

allowing faster growth in a vertical direction than that downstream. Consequently greater relief between the bar top and channel-bed is obtained and the bar will tend to build out into deeper water. As such, the gravel bar advances in a transverse direction to channel flow. Transverse bars have been described by Gustavson (1978) from the modern-day Nueces River, Texas. These bars have amplitudes up to 2m and lengths which may exceed 100m in a downstream direction. Some bars, with well developed slip faces are laterally continuous with gravel sheets, the latter between one clast and several clasts thick, and being similar to the diffuse gravel sheets described initially by Hein and Walker (1977) which form the nuclei for gravel bar growth. Massari (1983) describes the development of Facies Gp from Miocene fluvial channel conglomerates, Southern Alps, Italy. Facies Gp in that study are interpreted as the deposits of transverse bars, comparable to the bars of the Nueces River, developed at the lower lateral accretion face of gravel meander lobes. More importantly, transverse bars are inferred to reflect a deepening and increase in sinuosity of the channels compared with facies Gm (longitudinal bar gravels).

Bluck (1971, 1976) in his extensive study of low sinuosity Scottish Rivers, defines a variety of medial and bank-attached lateral bars, these being characterised by a coarse subaqueous bar platform and supra-bar platform. The latter is most susceptible to fluctuations in depth and velocity and therefore the supra-bar platform is most diverse in morphology. The supra-bar platform is characterised by a coarser bar head which fines downstream into the bar tail region. Significantly, cross-stratified gravel is formed by the downstream and lateral

migration of the barhead slipface over the bar tail deposits. During falling and low flow stages, the bar surfaces contain a variety of abandoned channels and other surface irregularities, with the bar tail region characterised by sand deposition in the form of minor sand bars, deltas, and megaripples forming cross-stratified sand sheets and cross-bedded channel-fills. These bar types of Bluck (op.cit.) develop in areas of relatively high channel sinuosity, lateral bars forming from medial, 'mid-channel' bars by attachment to one of the channel banks. These bar types in the ancient record (e.g. Bluck, 1980) generate upward coarsening profiles by the downstream migration of the bar head over the bar tail. Significantly, however, lateral accretion of the bar head gravels toward the inner 'accretionary' bank over the infilled 'slough' channel deposits has the capacity to generate a wide variation in palaeocurrents. Recognition of these bar types, therefore, relies on excellent exposure and detailed palaeocurrent measurement.

Steel and Thomson (1983) also relate the growth of planar-cross-bedded conglomerate, in the Bunter Pebble Beds, to the lateral accretion of the supra-bar platform across the rifle into the channel pool.

Ramos and Sopena (1983) and Ramos et al., (1986) describe planar-cross-bedded conglomerates, interbedded with massive 'sheet' conglomerates, from the Permian and Triassic of central Spain. These conglomerates were deposited by longitudinal gravel bars, the cross-bedded conglomerates reflecting modification by lateral accretion along the bar margins either during falling flow stage or when the bar

had reached a certain height such that clasts could not be transported over the bar. Rust (1984) also attributes the development of planar-cross-bedded conglomerates (facies Gp), from the Middle Devonian Malbaie Conglomerates, Gaspé, Canada, to modification of longitudinal gravel bar margins during waning flow stage.

In consideration of the factors described above the dominance of facies Gm within the Quartz Conglomerates with only relatively minor recognition of facies Gp suggests that longitudinal gravel bars were the major morphological element. Once again the lack of three-dimensional exposure has inhibited a more conclusive reconstruction of the exact bar types. However, for the identification of Bluck's (e.g. 1976, 1980) bars, an overall coarsening upward profile from 'bar tail sands' into cross-bedded 'bar-head conglomerates' might be expected. Furthermore palaeocurrents within these bars should show a wide spread reflecting both downsteam and lateral accretion elements. In the Quartz Conglomerates, the presence of a marked, generally north-east unimodal palaeocurrent distribution in conjunction with a similar palaeoflow direction obtained from interbedded cross-bedded sandstones provides evidence that the gravel bars and wedge-shaped sandstones were deposited within a channel system that flowed consistently towards the north to north-north-east. This relationship further indicates that gravel bars most likely originated from diffuse gravel sheets, accumulating at high flow stage, the corresponding bar form accreting in a downstream direction without evolving complex 'bank-attached' bars such as those of Bluck (op.cit.).

The fact that facies Gp apparently seems laterally equivalent to facies Gm suggests a relationship such as that described by Rust (1984) and Ramos et al., (1986) in which facies Gp reflects waning flow modification of longitudinal bar margins allowing foresets to 'grow' into the adjacent channels as flow diverges away from the bar axes towards the bar margins.

Trough-cross-bedded conglomerates (facies Gt) and pebbly trough-cross-bedded sandstones (Facies St) e.g. seen at Musca Hill crags and Windy Gap respectively, are interpreted to reflect the infill of minor channels or scoured depressions during progressively waning flow stage on the bar surface when flow is diverted from adjacent major channels toward the minor bar surface channels. In this context these 'channel-bar complexes' are comparable to those described for the Shap Red Beds (Chapter 3, Figure 3.10). More evidence for possible significant channel-bar relief is provided by the presence of facies Sp (planar-cross-bedded sandstones), these 'sand-wedge sandstones' accreting in the lee of bar depressions. They are thus comparable to the sand-wedge deposits described by Rust (1972) from the Donjek River, Yukon. In the manner of Rust (1984) the relative abundance of these deposits within the Quartz Conglomerates (e.g. especially at Musca Hill) does suggest that the 'relief factor' was critical in their preservation; Rust (op.cit.) citing the Donjek river which lacks abundant wedge deposits as a result of relatively less channel-bar relief.

6.3.3 Red Sandstones

The Red Sandstones stratigraphically overlie the Quartz Conglomerates, the junction being an arbitrary one taken where cross-bedded sandstone becomes the dominant lithology. The most complete sections through the Red Sandstones are Dale Beck and Rake Beck, (Figures 6.3, 6.4) the former best illustrating the junction with the underlying Quartz Conglomerates. The thickness of the Red Sandstones again reflects the infill of the palaeo-depression, centred around Dale Beck and Musca Hill, measured thickness in this area reaching 59.5m-70.5m (Dale Beck 1 and 2). As shown in Figure 6.1, the Red Sandstones apparently thin both to the north and south although exposure south of Dale Beck is far from complete. At Sink Beck, an estimated thickness of 40m was obtained with observations by the author and from published literature (Arthurton and Wadge, 1981), indicating that the Red Sandstones overstep the Quartz Conglomerates in the region of Great Rundale Beck and High Cup, the Lower Palaeozoic basement forming a 'high' in this area. Significantly despite 'apparent thinning', the Red Sandstones are more laterally extensive than the Quartz Conglomerate as discussed in Chapter 9.

The Roman Fell Sandstones exposed around Roman Fell thicken considerably south of the Swindale Beck fault (Hilton) according to Burgess and Harrison (1967; Figure 6.1). They overlie a sequence of shaley deposits (the Roman Fell Shales) which in turn are underlain by a basal conglomerate. These latter deposits have not been studied in detail by the author but comments as to their possible mode of deposition are made in Chapter 9.

Facies within both the Red Sandstones and the Roman Fell Sandstones are virtually identical, the relatively better exposure at Roman Fell allowing a more complete facies analysis for the latter. Both contain trough-cross-bedded (facies St) and planar-cross-bedded (facies Sp) sandstones with relatively subordinate horizontally laminated (facies Sh) and current rippled (facies Sr) sandstones also being present.

Facies St within the Red Sandstones (Sink Beck to Grey Mares Tail sections) consists of festoon cosets, up to 5m thick, comprising individual sets between 15cm (Dale Beck) and 20-25cm (Ardale Beck) thick. Sets are commonly graded containing a thin (2cm) pebbly lag base, with foresets being on average less than 1cm thick (e.g. Ardale Beck). Facies St locally overlies a basal conglomerate unit (facies Gm, e.g. Ardale Beck) and commonly forms the main part of fining upward sequences overlain by facies Sr and relatively minor laminated silty mudstones (facies Fl).

Facies St within the Roman Fell Sandstones (described extensively in Section 6.2.12) can be subdivided into 2 subfacies (St1, St2) based on the mean set size; facies St1 comprises largerscale sets up to 60cm thick arranged as cosets up to 4m in thickness. Smaller scale sets (facies St2) are only up to 25cm in thickness.

Facies Sp within the Red Sandstones is normally arranged in cosets (e.g. Dale Beck 1) up to 1.3m thick, but commonly occurs as isolated sets (e.g. Ardale Beck) less than 1m in thickness. Cosets within the Dale Beck 2 section, show trends comprising upward decreasing grain

size, upward thinning set size and an upward decrease in foreset dip and change in dip direction (Plate 6.6). Reactivation surfaces (e.g. 65m above base, Dale Beck 2) are locally present. Again within the Roman Fell Sandstones facies Sp is subdivided on set size into larger scale (facies Sp1) and smaller scale (facies Sp2) sets (described in detail in Section 6.2.12). Facies Sp1 commonly comprises sets up to 1m in thickness, containing sigmoidal foresets with locally highly asymtotic foreset bases. In contrast, facies Sp2 comprises sets no more than 45cm thick but with more angular foreset bases. Minor development of possibly trough-cross-bedded conglomerate (facies Gt) was also noted within the Roman Fell Sandstones forming a 'basal lag' deposit overlain by facies Sp1 (Plate 6.9).

Palaeocurrents from both the Red Sandstones and Roman Fell Sandstones show similar trends with an interpreted palaeoflow between the north (NNW) and east (wide spread may be locally due to inaccurate palaeocurrent measurement as a result of poor exposure). Significantly, as discussed below, palaeocurrents from facies St differ from those from facies Sp, e.g. 049° (facies St), and 086° (facies Sp) at Dale Beck (Red Sandstones); 037.7° (facies St), and 012.8° (facies Sp) at Roman Fell (Roman Fell Sandstones).

The lateral facies relationships are important in considering the environmental interpretaion of these sandstones. Lateral facies variation within the Red Sandstones is readily demonstrated by reference to the Dale Beck sections (see Figure 6.4). Facies St is the dominant facies within Dale Beck 1 with facies Sp only occurring as minor sets.

In contrast in Dale Beck 2, 200m south of Dale Beck 1, facies Sp forms the major facies with only minor development of facies St present. Other sections, particularly Rake Beck and Sink Beck, are dominated by facies Sp while at Grey Mares Tail, and Ardale Beck the Red Sandstones comprise a more interbedded development of both facies.

Within the Roman Fell Sandstones, facies St1 is laterally equivalent to facies Sp1, although both these facies are not seen (as far as exposure allows) in direct vertical juxtaposition. Instead, both these facies are overlain by an interbedded sequence comprising facies St2 and facies Sp2.

In consideration of the vertical and lateral facies relationships present, both the Red Sandstones and the Roman Fell Sandstones are interpreted as representing the deposits of sandy braided channels. Facies St (and St1) reflect the migration of larger-scale dunes at the base of principal channels, which had an overall north-east palaeoflow direction. Following on from the method of Turner (1980), discussed fully in Section 3.3.1 the approximate channel dimensions are presented below:

Red Sandstones	Roman Fell Sandstones
1. Depth: mean cross-bed thickness -15cm (Dale Beck 1) = 1.29m.	1. Depth: mean cross bed thickness -50cm = 4.3m.
mean cross-bed thickness	mean cross-bed thickness

-25cm (Ardale Beck)

= 2.15m.

2. Width:

Depth = 1.29m, Width = 58.05m.

Depth = 2.15m, Width = 96.75m.

-60cm

= 5.16m.

2. Width:

Depth = 4.3m, Width = 193.5m.

Depth = 5.16m, Width = 232.2m.

Facies Sp (and facies Sp1) reflects the aggradation of in-channel sandy bars, these being laterally equivalent to facies St (and facies St1) as suggested by reference to the Dale Beck Sections (Figures 6.4) and Figure 6.12. The planar-cross-bedded sets and cosets are considered to be comparable to those described in published literature, e.g. Cant (1978) and Haszeldine (1981, 1983) from ancient braided river deposits. Cant (1978) and Cant and Walker (1976) describe larger-scale solitary planar-cross-bed sets from the Devonian Battery Point Formation, Quebec, reflecting the aggradation of larger-scale transverse bars within a sandy bed-load channel system. Significantly and providing a comparison to the present study, palaeocurrents have high deviation to those of trough-cross-bed sets (facies St) reflecting the cross migration of bars within the channels (also see discussion in Chapter 3, for the Shap Red Beds).

Haszeldine (1981, 1983) describes a hierarchy of planar-cross-bed sets, arranged as cosets, from the Upper Carboniferous of N.E. England. These sets reflect the aggradation of a large fluvial bar, the hierarchy of cross-bedding representing successively smaller-scale bedforms migrating across the back of the bar. The bar itself is marked by

larger scale planar foresets forming a basal set, 2m-3m thick, recording the advance of the bar into the channel pool. In the present study, it is suggested that upward decreasing set size within cosets, e.g. the examples cited from the Red Sandstones (Plate 6.6) and from the Roman Fell Sandstones (Plates 6.8, 6.9) probably reflect migration of bedforms at successively higher levels within the sandy bar structure. Furthermore the divergence in palaeocurrents between facies Sp and St indicate bars were probably of the transverse type, aggrading transversly to the general channel flow direction shown by facies St.

From the modern braided river environment Smith (1970, 1971b, 1972, 1974) describes planar-cross-strata developed by the downcurrent migration of the avalanche faces at the margins of transverse bars from the Platte River, Nebraska. The Loup, Platte and South Platte Rivers, east of Colorado, are fine to coarse grained sand-bed channels which are dominated by transverse bars. Blodgett and Stanley (1980) further the work of Smith (op. cit.) and Ore (1964) of the study of the bars within the Platte River System. At high flow stage channels are dominated by linguoid (transverse) bars which occur in both 'staggered and nested arrays'. These bar types are characterised by larger-scale planar-cross-bed sets up to 2m in height (thus comparable to facies Spl, Roman Fell Sandstones) these overlain by a range of smaller scale cross-bedding types (both trough and planar-cross-bedding) and horizontal stratification.

Collinson (1970) also extensively documents the migration and aggradation of linguoid bars from the Tana River, Norway. These

linguoid or mid-channel bars are, as in the Platte Rivers, the dominant in-channel bedforms. The bars are convex in the downstream direction and have sharply defined downstream slip-faced margins which vary in height from 50cm to 2m. From excavations in shallow submerged bars, Collinson (op.cit.) notes that foreset bases are angular. In contrast deeper sections made through the downstream limits of the bars, reflecting deposition at relatively higher flow stage, show that foreset bases become more tangential or asymptotic. Jopling (1965, in Collinson, 1970) has shown that tangentially based foresets form under conditions of higher bed shear stress and depth ratio, with a high suspended load content, and at higher stage of flow than do more angular-based foresets. Jopling (op.cit.) also notes the presence of coarser grained foreset bases formed by slip-face avalanching, and the downward thickening of foresets towards the base.

Comparable features are also observed within the Roman Fell Sandstones. Facies Sp1 largely contains asymptotic foresets, some within distinct coarser grained bases (e.g. Sections 5, 6, 7, within Figure 6.12; Plate 6.8), facies Sp1 being overlain by smaller scale cross-bed-sets (facies Sp2) which mostly contain more angular-based foresets (e.g. Section 4, within Figure 6.12; Plate 6.9). It is taken that these facies relationships principally reflect the migration of progressively smaller-scale bedforms (?sandwaves, minor bars) at successively higher parts on the bar and at progressively decreasing flow stage.

Both Collinson (1970) and Blodgett and Stanley (1980) have documented the effects of falling stage of flow and subsequent modifications to the bar bedforms. During gradually falling stage of flow and under lower discharge (cf. Jones, 1977), current patterns are controlled more by the bars themselves with flow confined mainly to topographically low areas between the bars. Shallow channels (up to 0.45m deep according to Smith, 1971b) may form between bars and on the lee side of the bar, floored by migrating dunes and creating localised flow patterns. Blodgett and Stanley (1980) have documented four stages of linguoid bar modification on falling flow stage: 1, erosion of bar flanks by active channels; 2, planation of bar tops by shallow, rapidly flowing water; 3, dissection of bar tops by slack water channels; 4, bar front progradation by 'multilobe' small-scale deltas. Accretion of these relatively minor bedforms on to the linguoid bar forms composite structures, comparable to the sandflats of Cant and Walker (1976) and Cant (1978, 1982) from the South Saskatchewan River. Smith (1970, 1971b) relates the bedform on the bar top to water depth: plane-beds less than 25mm water depth; ripples between 25mm-76mm and dunes within water depths greater than 76mm. He (1971a) also recognised low amplitude sand waves with low angle slip faces formed in water depths between 5mm and 15mm. Bar top aggradation may also include the development of minor (up to 0.1m high) sinuous slip-faced bounded bars on the major bar surface.

The vertical sequence of facies established within the Red Sandstones but especially within the Roman Fell Sandstones, is considered to compare closely with the features of modern day bar

structures discussed above. The interbedded sequences comprising facies Sp2 and St2 reflect the development of minor sandwave or bar bedforms on the major bar (facies Sp1, Plate 6.8) surface and infilling of minor channels respectively (Section 4 within Figure 6.12, Plate 6.9). The presence of current rippled units both within the Red Sandstones and Roman Fell Sandstones (e.g. Section 3, within Figure 6.12) and mudstone horizons (Dale Beck) were also deposited during low flow stage conditions. Further evidence for differing flow stage and fluctuating discharge are the presence of interpreted reactivation surfaces (shown by discordant foresets, e.g. Plate 6.8) within facies Sp1. As described by Collinson (1970) reactiviation surfaces reflect renewal of slip-face migration on a rise in flow stage following a period of planation and deposition of minor bedforms during low flow stage.

The facies relationships discussed for both the Red Sandstones and Roman Fell Sandstones thus reflect the aggradation of major bar structures and accumulation of bar-top deposits within major sand-bed load channels (shown diagramatically in Figures 3.11, 6.14). The presence of larger scale trough-cross-bedding (facies St1) suggests that the channel system contained distinct channel relief, allowing the development of a scale of structures from channel base to bar top. In this context, the channel system was probably more appropriately comparable to the South Saskatchewan River than to the Platte Rivers, the latter not containing appreciable channel-base dune deposits.

Significant topographic differentiation within the channel system can develop under conditions of more steady discharge with less

ephemeral flow (Cant, 1982) and it is suggested such conditions were probably applicable to the present study. The South Saskatchewan River (see idealised diagram, Figure 6.14, from Cant, 1978), Yukon, Canada, contains channels between 3m to 5m in depth and on average 150m wide (broadly within the range of dimensions cited earlier in this section for the Red and Roman Fell Sandstones), these being floored by migrating dunes and channel lags, which from trough-cross-bed-sets up to 1m thick (Cant, 1978, 1982). Large, cross-channel bars deposit sets of planar-cross-bed-sets which average 1m in thickness. Topographically higher areas on the bar top may merge to form 'sand-flats' characterised by a variety of vertically accreted bedform deposits and cohesive mud. Fluvial sequences may be generated by channel aggradation and diversion of flow to another segment of the river, and by sand flat growth or by a combination of these (Cant, 1982). Consequently vertical sections through an 'idealised' part of the channel system will contrast a 'channel sequence' (compare Dale Beck 1 Section, Figure 6.4, and Sections 1, 8, within Figure 6.12 (Plate 6.7) with 'position '6' on Figure 6.14) with a 'bar/sandflat sequence' (Compare Dale Beck 2, Figure 6.4 and Rake Beck, Figure 6.3/Sections 4, 5, 6, 7, on Figure 6.12 (Plates 6.8, 6.9, 6.10) with positions 3 and 5 on Figure 6.14).

6.3.4 Green Sandstones

The Green Sandstones, stratigraphically the highest group within the Cross Fell area, have an estimated thickness between 17m and 24m, which as shown on Figure 6.1 appears to be consistent throughout the northern part of the Cross Fell area. These characteristically green coloured sandstones (the Greywacke Beds of Arthurton and Wadge, 1981)

are very fine to fine grained and argillaceous, being very chlorite rich, as confirmed by x-ray diffraction. It is suggested that, by their very fine grained, argillaceous nature, the chlorite probably reflects an original high detrital clay content rather than an authigenic precipitate, and as such may reflect a high chlorite rich source area.

Although the Green Sandstones are poorly exposed (mainly Grey Mares Tail, Dale Beck Sections), they are apparently well-bedded and probably horizontally laminated in part (facies Sh). Isolated planar-cross-bedded sandstone sets (facies Sp) are locally present as are minor ripple-cross-laminated sandstone (facies Sr) horizons. At Grey Mares Tail (Figure 6.2) crudely defined trough-cross-bedded sandstones (facies St) may also be present. The change from the dominantly cross-bedded Red Sandstones into the well-bedded Green Sandstones is sharp, although the generally fining upward grain size suggests that the boundary is conformable.

The Green Sandstones are interpreted as probable floodplain deposits of planar-bed-flow probably occurring within a muddy, low lying 'flood basin' environment (cf. Williams, 1970, Hubert and Hyde, 1983). The general lack of cross-bedding suggests that the Green Sandstones do not represent the infill of a major channel system, such as the Red Sandstones, although the presence of isolated planar-cross-bedded horizons suggests migration of slip-faced margin bedforms possibly within a channel. The high, probably detrital, mud content suggests that if any channels were present, they may have migrated laterally between cohesive mud banks. The occurrence of facies Sr, suggests that

the environment was subject to fluctuating discharge and flow stage, with deposition possibly occurring in the form of flood-pulses. The author is not certain if the environment contained permanent bodies of water or was dominantly an ephemeral system in which flood water quickly percolated into the ground. The possible migration of channels suggests that flow was at least semi-permanent, at least locally. Graham (1983) attributes a green-grey colour within the Upper Devonian Munster Basin, Ireland, to reflect a high water table during deposition, and as such a parallel might be sought here. Again, with reference to Graham (1983), his 'Green' coloured sandstones are interpreted (also based on other features) as a fluvial coastal plain facies, this facies characterised by the presence of numerous, multi-storey sandstone bodies. Relatively stable, sinuous channels may have been present. Other features include levée and crevasse splay sandstones interbedded with lacustrine mudstones. Insufficient evidence is present in the current study to make a comparison with the work of Graham (op.cit.) although the presence of marine limestones above (Orton Group) may suggest that a coastal plain environment can not be ruled out (see Chapter 9).

6.4 DEPOSITIONAL MODEL

The Cross Fell Clastic rocks comprise an overall upward fining sequence of deposits, represented by the four lithological groups. The generation of a large scale fining upward sequence, up to 120m thick (Dale Beck 2) may result from the gradual retreat and lowering of source area relief leading to the superposition of gradually finer grained

deposits on coarser grained deposits through time (cf. Steel, 1974a, Heward, 1978).

The Polygenetic Conglomerate contains deposits suggestive of alluvial fan sedimentation, the restricted exposure possibly indicating that the distribution of these alluvial fans may have been local. It may be, however, that the Polygenetic Conglomerate represents the distal edges of a more extensive alluvial fan complex which is not presently exposed (or now eroded). Denny (1967; in Heward, 1978) states 'the prime requisite of fan formation is the setting of highland and lowland side by side'. Most alluvial fans are associated with fault scarps, which provide the initial relief for fan formation, and can extend into lowland areas for distances up to 5km. Indeed Arthurton and Wadge, (1981) and Wadge (1978) have suggested that the Polygenetic Conglomerate represents the deposits of coalesced alluvial fans (cf. Rust and Koster, 1984, their Figure 6) associated with a fault scarp (located near Melmerby) connected with the Deep Slack and Fellside faults. Clast composition data (Chapter 7) indicates that the Polygenetic Conglomerate was sourced locally and indeed contains weathered granite clasts (Plates 6.1; 7.24) that might have come from the Alston Block granites. As a result of the local provenance and believed restricted distribution in this part of the Cross Fell area, the author agrees with Arthurton and Wadge, (1981) and Wadge (1978) insomuch as local faults might have provided initial relief. However Burgess and Wadge (1974) suggest that derivation from higher ground close to the west is probable, sourced from east-facing scarps. Given the evidence of derivation from the

Alston Block it seems likely that the Polygenetic Conglomerate was perhaps more appropriately associated with westerly facing scarps.

The Quartz Conglomerates represent the deposits of gravel bars within a gravel-bed load braided channel system. Longitudinal gravel bars were the main morphological element, these being modified on falling stage of flow developing slip-faced margins. Minor channels on the bar surfaces were locally infilled by trough-cross-bedded conglomerate and pebbly sandstones, with depressions the site for wedge-shaped cross-bedded sandstone and sandstone drape deposition.

The vertical sequence of facies resembles the idealised profile of the modern day Donjek River, Yukon, and taken by Miall (1977) to represent the deposits of a proximal to medial braided river (Donjek type; Figure 9.1). The presence of modified longitudinal bar margins (facies Gp) and common occurrence of sandwedge deposits (facies Sp) suggest that topographic differentiation within the 'Quartz Conglomerates' channels was greater than in the modern-day Donjek counterpart (cf. Rust, 1972, 1984).

The author accepts that increasing importance is being attributed to the deposits of coarse grained meandering streams, the idealised vertical profiles of which can be mis-interpreted as the deposits of braided channels. Jackson (1978) highlighted the problem by recognising five lithofacies classes of meandering streams, including three classes (sand-bed streams without mud; graveliferous sand-bed streams; streams with coarse gravel and little sand) containing features previously

deemed typical of non-meandering streams. Various accounts of both modern and ancient coarse grained meandering stream deposits now exist in the literature (e.g Mcgowen and Garner 1970; and Nijman and Puig defabregas, 1978), these being characterised by coarse grained gravelly point-bar deposits capped by chute bars (planar or wedge-shaped cross bed sets in the upper point bar position). Significantly, however, such streams may still preserve a greater amount of mud by floodplain accretion than that expected in a true braided environment (Jackson, 1978).

While the development of facies Gp (planar-cross-bedded conglomerate) may be interpreted as being deposited as part of a gravelly meander lobe/point-bar type sequence (cf. Gustavson, 1978; Massari, 1983), the author considers the dominance of facies Gm to be the most important factor in the interpretation of a braided environment (cf. Rust, 1978b). It is suggested that the presence of a unimodal palaeocurrent distribution both within facies Gm and the interbedded sandwedge deposits (facies Sp) adds support to the argument that longitudinal gravel bars were the main morphological element: flow principally maintaining a downstream (as opposed to lateral) element, i.e. parallel with the bar margins, during high flow stage with perhaps some diversion during falling flow stage on bar modification.

Facies developed both within the Red Sandstones and Roman Fell Sandstones exhibit very similar lateral and vertical facies relationships. In consideration of these relationships, these sandstones are interpreted as the deposits of extensive braided

sandy-bedload channel systems, accumulating migrating dunes along major channel bases, separated by larger scale cross-channel sandy bars with possible local development of extensive 'sandflat' accretion deposits through the emergence of bar top deposits. As such these deposits compare closely to the deposits of the modern day South Saskatchewan River, Yukon, Canada, taken by Miall (1977) as one of the type rivers for his sandy braided river models (South Saskatchewan type, Figure 9.1). Approximate dimensions of the palaeo-channels were between 2.15m and 5.16m deep and between 96m and 230m wide, these being broadly within the range of the principal channels within the South Saskatchewan (150m wide, 3m deep on average, Cant, 1978). The South Saskatchewan model is considered more appropriate than the Platte River model (Miall, 1977; Figure 9.1) as a result of the presence of relatively greater in-channel topographic differentiation, and preservation of channel base dunes. According to Cant (1983), the presence of channel-base dunes and higher topographic differentiation is a result of relatively greater and more stable discharge.

The author believes that sufficient evidence has been put forward to indicate that facies within the Red Sandstones and the Roman Fell Sandstones are very similar and represent deposition within similar channels and may, therefore represent the same stratigraphic interval. These are problems which have been questioned by a number of authors in previous years. Goodchild (1874) originally considered that the 'Roman Fell Beds' represented the same formation as the 'Basement Series' further north and this view was upheld by Shotton (1935). A different approach was taken by Capewell (1956) who believed that there exists a

close resemblance between the Roman Fell Beds and the 'Red Sandstone Group' of the Shap area (Birk Beck: Shap Red Beds of present study, Chapter 3) and that the former represent the remaining portion of a thrust slice from the direction of the Shap area. Turner (1927) considered that the Roman Fell Beds were of Devonian in age. Capewell (1956) also documented strong petrographic differences between the Roman Fell Beds and the Basement Series north of Swindale Beck fault, a view discounted by Burgess and Harrison (1967) who, in a detailed petrographic study considered that the 'Roman Fell Sandstones (equivalent to those of the present study) form part of the normal Carboniferous sequence in this area..... The Carboniferous Strata south and north of the Swindale Beck fault are similar in sequence and Petrography'. Barraclough (1983) noted north-east palaeocurrents and concluded that the Roman Fell Sandstones represent braidplain deposits, thus being in agreement with the present study.

The Green Sandstones are considered by the author to represent the 'end member' of fluvial deposition in the northern part of the Cross Fell area (insufficient data/exposure is present to conclusively determine their extent in the southern part of the area; i.e around Roman Fell) and occupy the top of the overall fining upward sequence.

They were probably deposited within a low lying floodplain or coastal plain area which was probably characterised by laterally migrating channels that accumulated relatively thick to fine grained deposits through overbank flooding (and ?crevassing). It is stressed that this interpretation is tentative, although it is considered important that

the Green Sandstones do reflect relatively distal fluvial deposition at possibly close to palaeo-base level. As stated by Rust (1978b) and considered by Turner (1982), there probably exists a continuum between braided and meandering rivers although there are no absolute criteria for distinguishing between the two types.

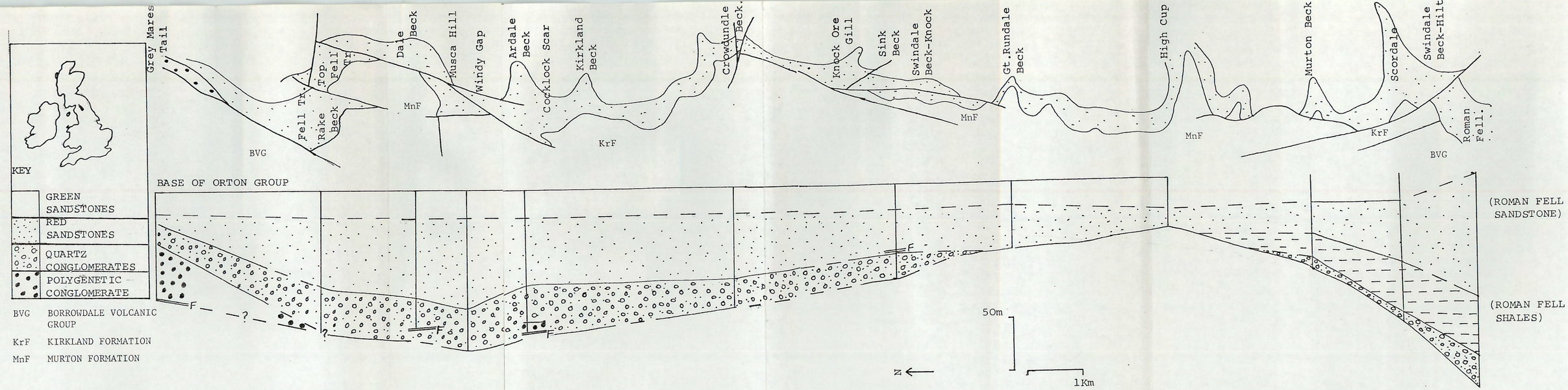
Palaeocurrents from the Quartz Conglomerates and both the Red Sandstones and Roman Fell Sandstones are shown in Figure 6.13, demonstrating that there was a general north-easterly palaeoslope throughout the deposition of these sediments. As has been demonstrated, the change from the Quartz Conglomerates into the Red Sandstones in the northern part of the area reflects the gradual evolution of a proximal, gravelly braided-fluvial system into a relatively more distal sandy equivalent through time. As discussed in Section 3.6, this reflects the gradual downstream decrease in grain size and slope (cf. Galloway, 1985), such that as the channel gradient decreases coarser particles are deposited when they cannot be transported over the lower gradient. Also, as discussed in Section 3.6, this downstream transition is also represented by the increase in the amount of transverse bars relative to longitudinal bars and an increase in the ratio of planar-cross stratification to horizontal stratification (Smith, 1970, Rust, 1972).

Many braided river systems are built on to the lower slopes of alluvial fan complexes constructing alluvial plains which show proximal to distal variations and downstream change in fluvial style (cf. Mcgowen and Groat, 1971, Turner, 1982). Steel (1971; 1974a) describes a sequence of New Red Sandstone alluvial deposits from the Hebridean

Province, Scotland, these characterised by a downstream change from alluvial fan into braided stream and floodplain (low and high sinuosity channels) segments. The transition from alluvial fan into a braided-river system would expect to follow the proximal to distal sequence through debris-flow, streamflow and braided-fluvial depositional processes (cf. Steel, 1971, 1974a; Steel and Wilson, 1975, Rust and Koster, 1984). In the humid alluvial fan environment in which streamflow processes dominate a transition from sheet-like bars into more evolved longitudinal bars would be expected (e.g Boothroyd and Ashley, 1975). However, in the present study, the rapid change from alluvial fan deposits into the proximal braided channel facies of the Quartz Conglomerates suggest that braided rivers probably did not build out directly infront of the distal edges of alluvial fans. This reasoning would explain the very distinct change from deposits containing no vein quartz into conglomerates comprising rounded vein quartz as the dominant clast type. Instead the palaeocurrent evidence suggests that the braided-fluvial system constructed an alluvial plain with a north-east palaeoslope trending obliquely (see Ramos and Friend, 1982) to alluvial fan accumulation. Rust and Koster (1984, their Figure 5) show that alluvial fans that are tributary to braided rivers or braidplains have significantly higher slopes than their braided river counterparts.

Alluvial fans were localised and probably accumulated against westward facing scarps, associated with possible marginal faults, and sourced locally from the Alston Block. This model (Figure 6.14) is supported by the clast composition data (Chapter 7) which suggest that clast types

generally reflect source from the quartz veined Skiddaw Slates and Borrowdale volcanics, probably from the Lake District although it is suggested that material could also have been locally derived from the Alston Block area.



NOTE: Data mostly from measured sections, supplemented (particularly Roman Fell) from data in Burgess and Wadge (1974) and Arthurton and Wadge (1981).

FIGURE 6.1

Map and cross-section showing the main localities and lithological groups, Cross Fell clastic rocks.

FIGURE 6.2. MEASURED SECTION - GREY MARES TAIL
(NGR NY 625401)

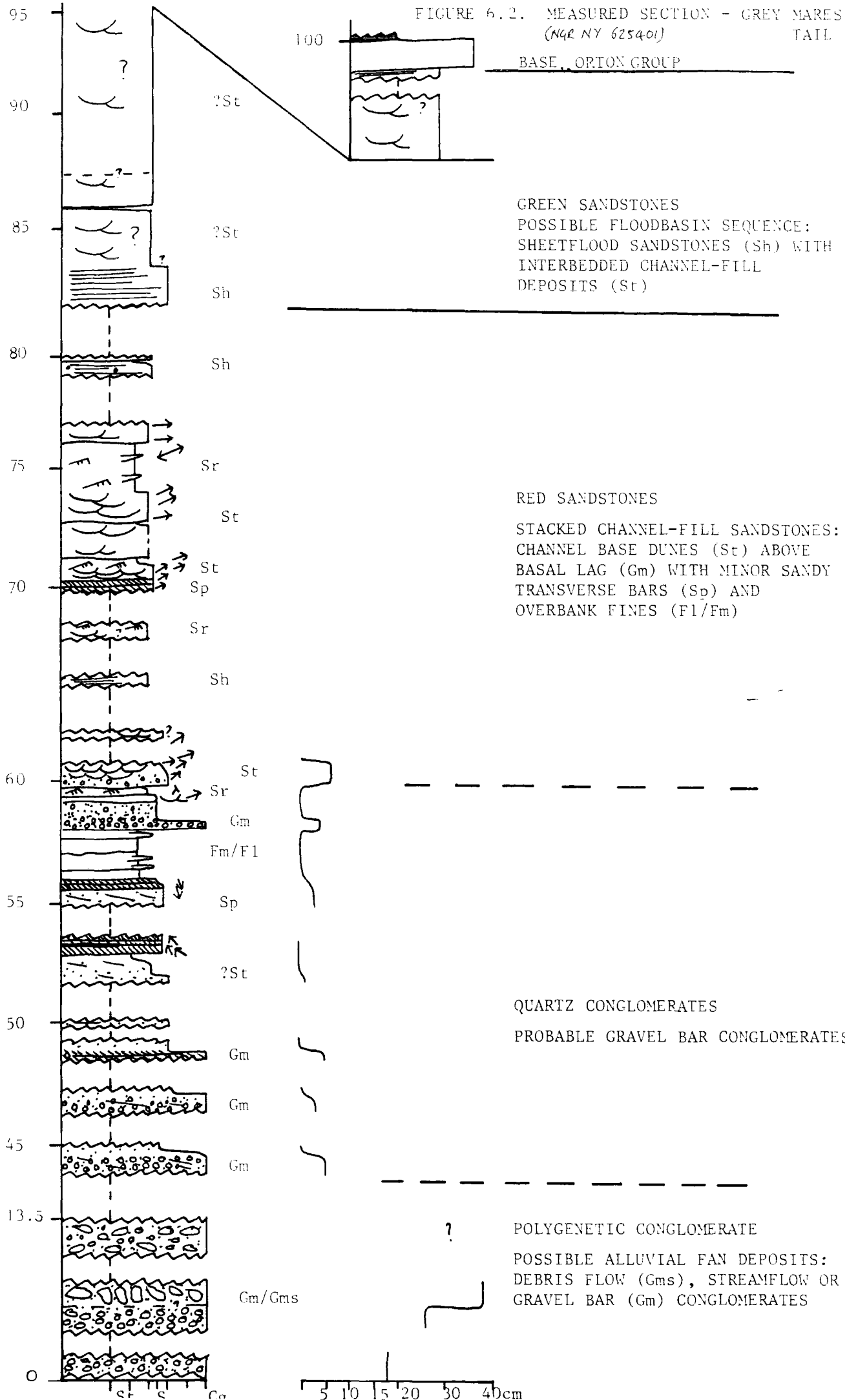
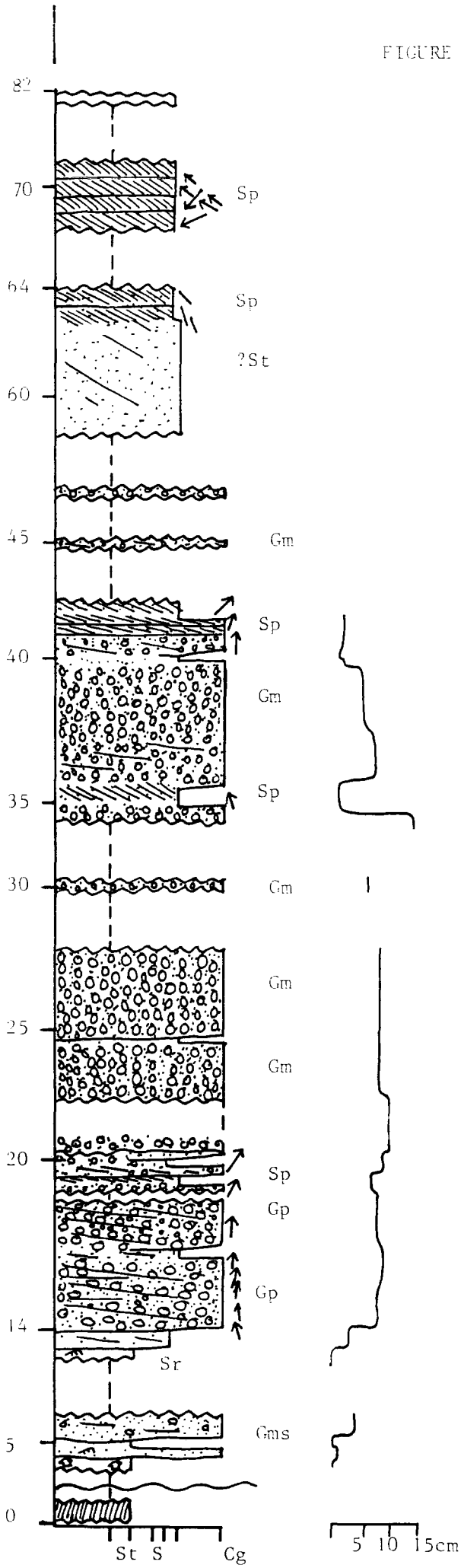


FIGURE 6.3. MEASURED SECTION - RAKE BECK
(NGR NY 633369)



RED SANDSTONES

STACKED SANDY TRANSVERSE BAR SANDSTONES (Sp) WITH MINOR CHANNEL LAG CONGLOMERATES (Gm) AND DUNES (St)

QUARTZ CONGLOMERATES

STACKED LONGITUDINAL (Gm) AND TRANSVERSE (Gp) BAR CONGLOMERATES. FACIES Sp DEPOSITED AS SAND WEDGE UNITS ON WANING FLOW STAGE.

POLYGENETIC CONGLOMERATE

POSSIBLE DEBRIS FLOW CONGLOMERATES

MURTON FORMATION

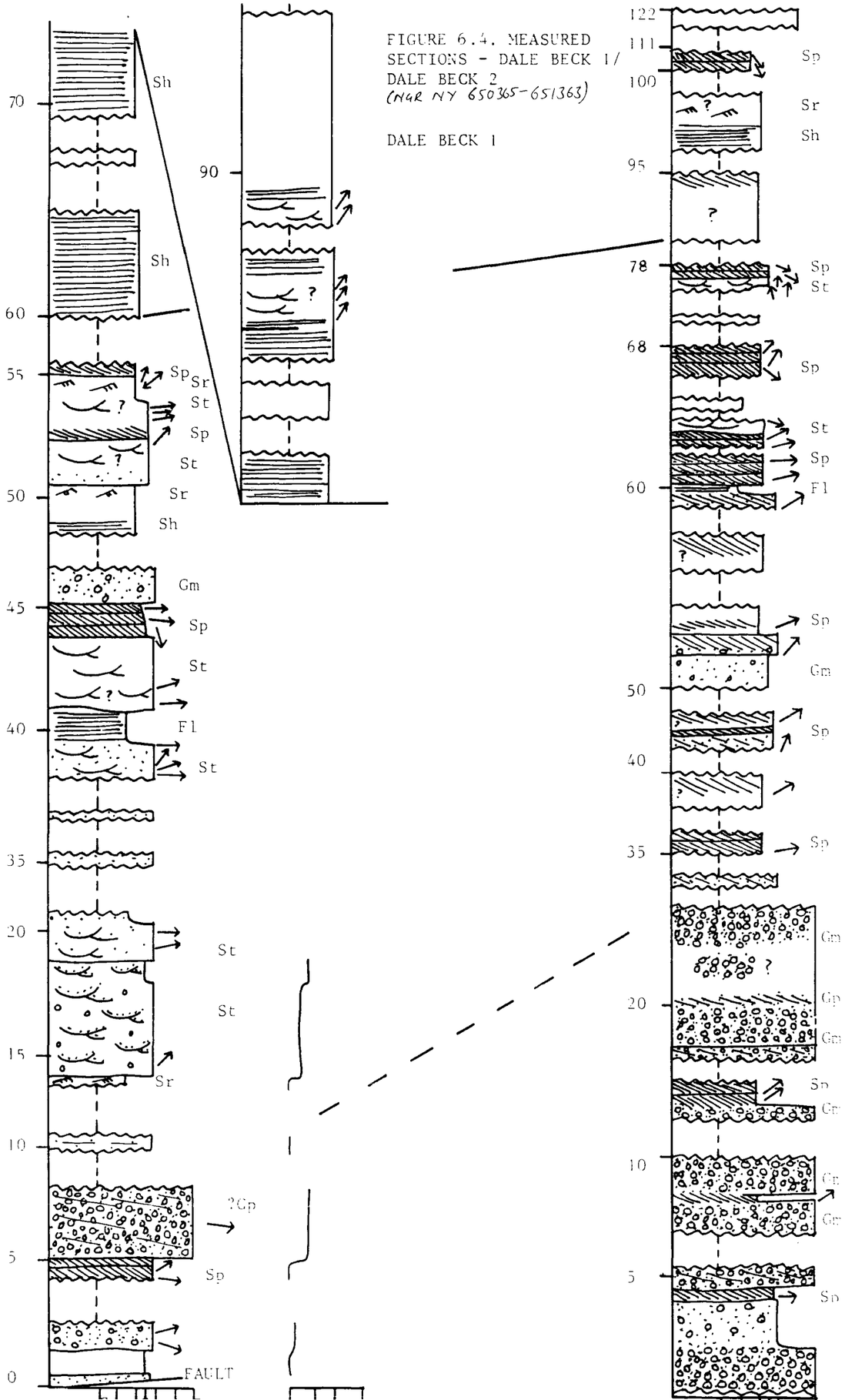


FIGURE 6.4. MEASURED SECTIONS - DALE BECK 1/ DALE BECK 2 (NGR NY 650365-651363)

DALE BECK 2

GREEN SANDSTONES

FLOODBASIN DEPOSITS - SHEETFLOOD SANDSTONES (/MINOR SANDY TRANSVERSE BARS (Sp) AND LOW STA SANDSTONES (Sr)

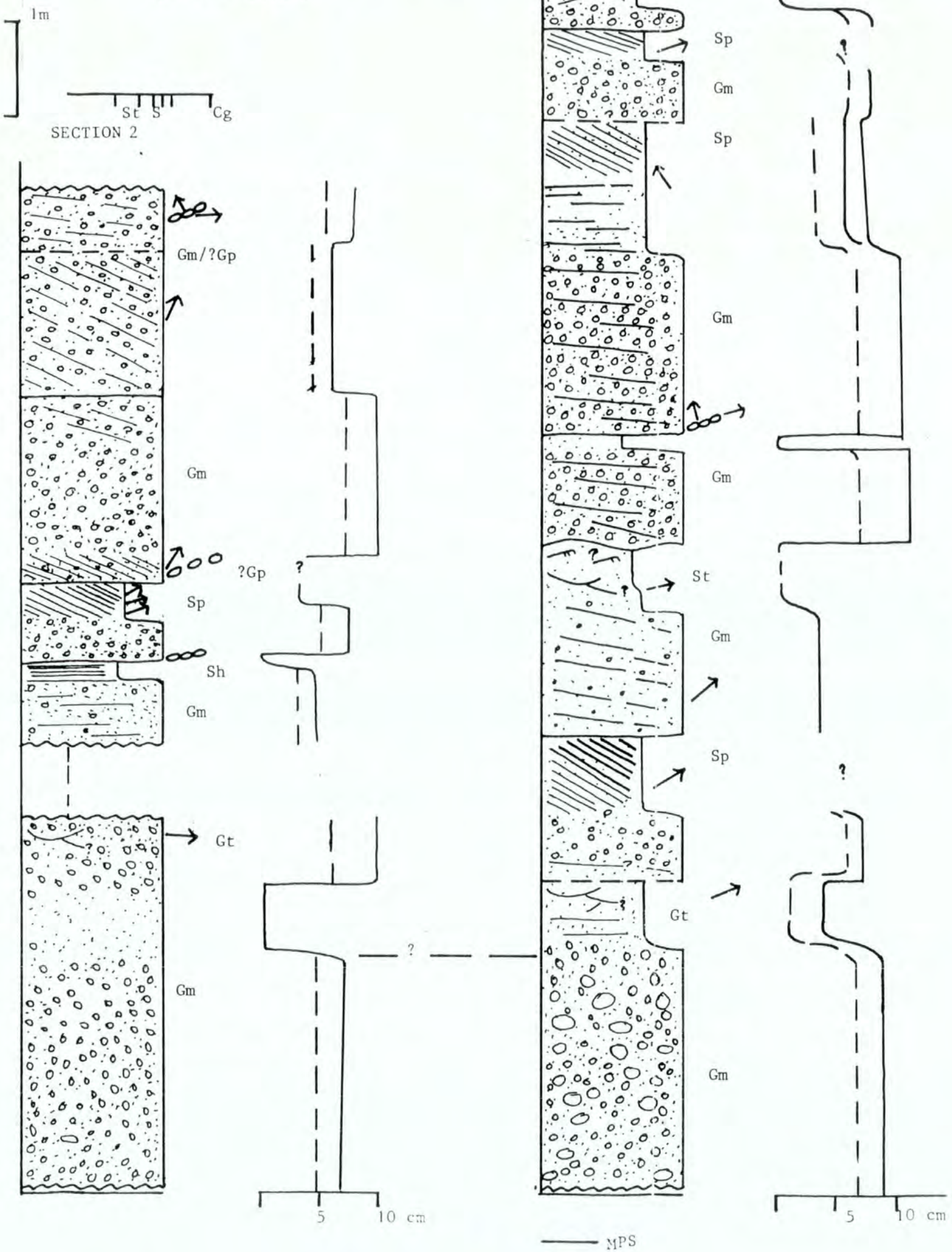
RED SANDSTONES

THE TWO SECTIONS DEMONSTRATE LATERAL VARIATIO WITHIN SANDY CHANNEL SYSTEM: FACIES St REFLEC MIGRATION OF DUNES ALONG CHANNEL BASE, FACIES Sp REPRESENTS TRANSVERSE BAR AGGRADATION, WHI FACIES Sh/Sr REFLECT DEPOSITION DURING WANING FLOW STAGE ON SHALLOWING CHANNEL FLOOR. FACI Fl ACCUMULATED FROM SUSPENSION AT LOW FLOW STAGE

QUARTZ CONGLOMERATES

STACKED LONGITUDINAL (Gm) AND MINOR TRANSVERSE (Gp) BAR CONGLOMERATES. FACIES Sp DEPOSITED AS SAND WEDGE UNITS DURING WANING FLOW STAGE

FIGURE 6.5. MEASURED SECTION - MUSCA HILL CRAGS
(NGR NY 649359)

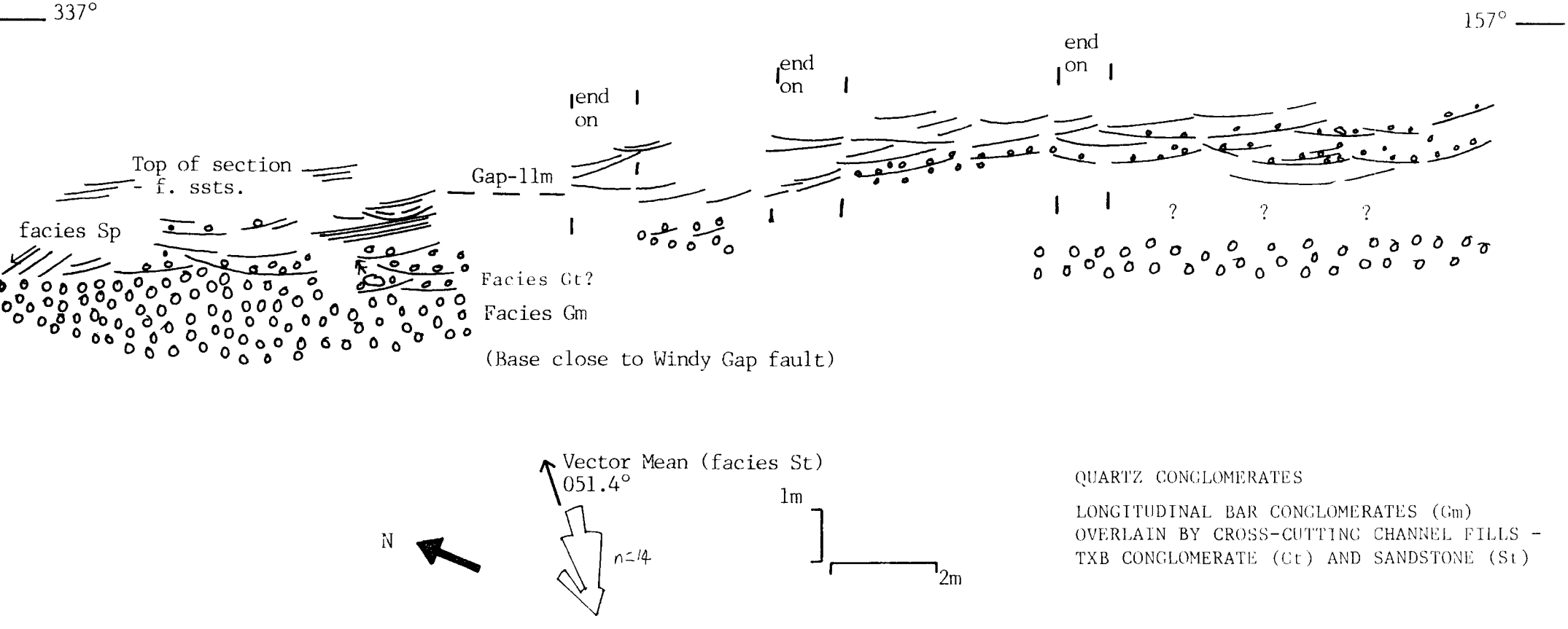


QUARTZ CONGLOMERATES

MAINLY STACKED LONGIT. BAR CONGLOMERATES WITH MINOR CHANNEL-FILLS (Gt,St) AND SANDWEDGE PXB SSTs (Sp), CURRENT RIPPLED SSTs (Sr) REFLECT LOW FLOW STAGE DEPOSITION AT TOP OF MINOR CHANNEL-FILLS.

FACIES Gp MAY REFLECT MODIFICATION OF BAR MARGINS ON FALLING FLOW STAGE

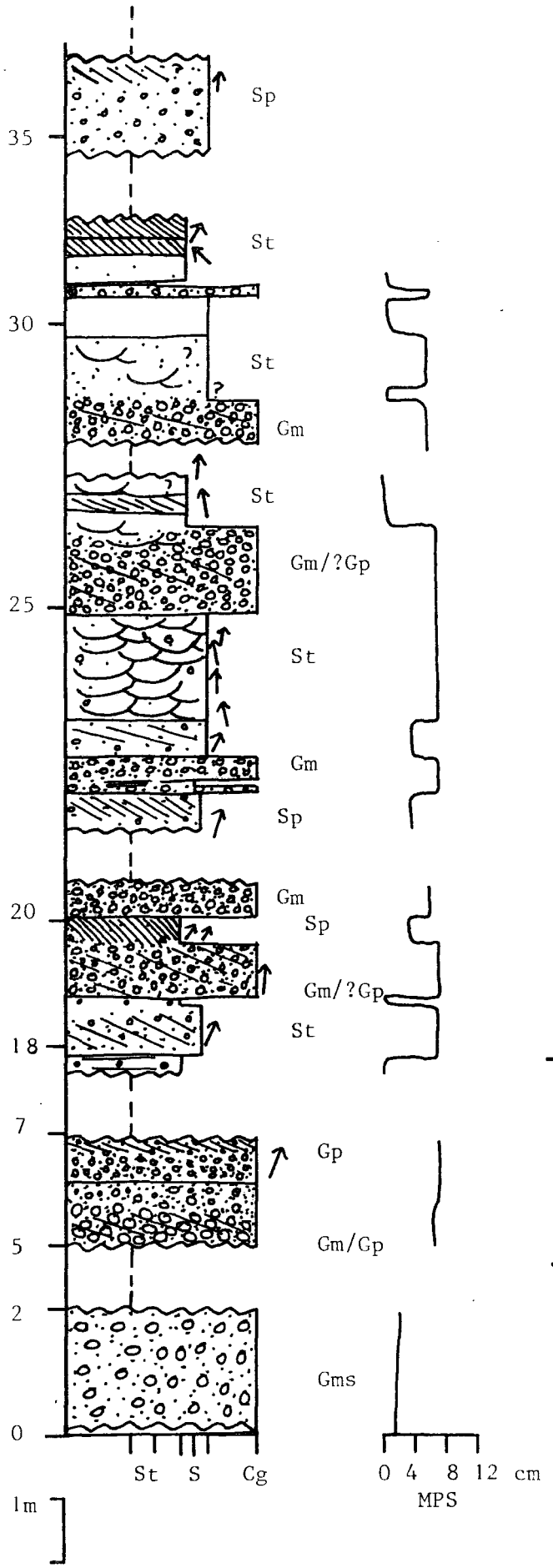
FIGURE 6.6. MEASURED SECTION - WINDY GAP
(NGR NY 647355)



QUARTZ CONGLOMERATES

LONGITUDINAL BAR CONGLOMERATES (Gm) OVERLAIN BY CROSS-CUTTING CHANNEL FILLS - TXB CONGLOMERATE (Ct) AND SANDSTONE (St)

FIGURE 6.7. MEASURED SECTION - ARDALE BECK
(NGR NY 652344)



QUARTZ CONGLOMERATES/
RED SANDSTONES

DOMINANTLY SANDSTONE SUCCESSION COMPRISING CHANNEL-FILL DUNES (St) AND TRANSVERSE BARS (Sp - ISOLATED SETS). COMMON FACIES Gm - OCCURRING AS CHANNEL-BASE LAGS AND AS THICKER LONGITUDINAL BARS, THE LATTER WITH ASSOCIATED MINOR CHANNEL-FILLS (St, e.g. 27m) AND SANDWEDGE SANDSTONES (Sp, e.g. 20m).

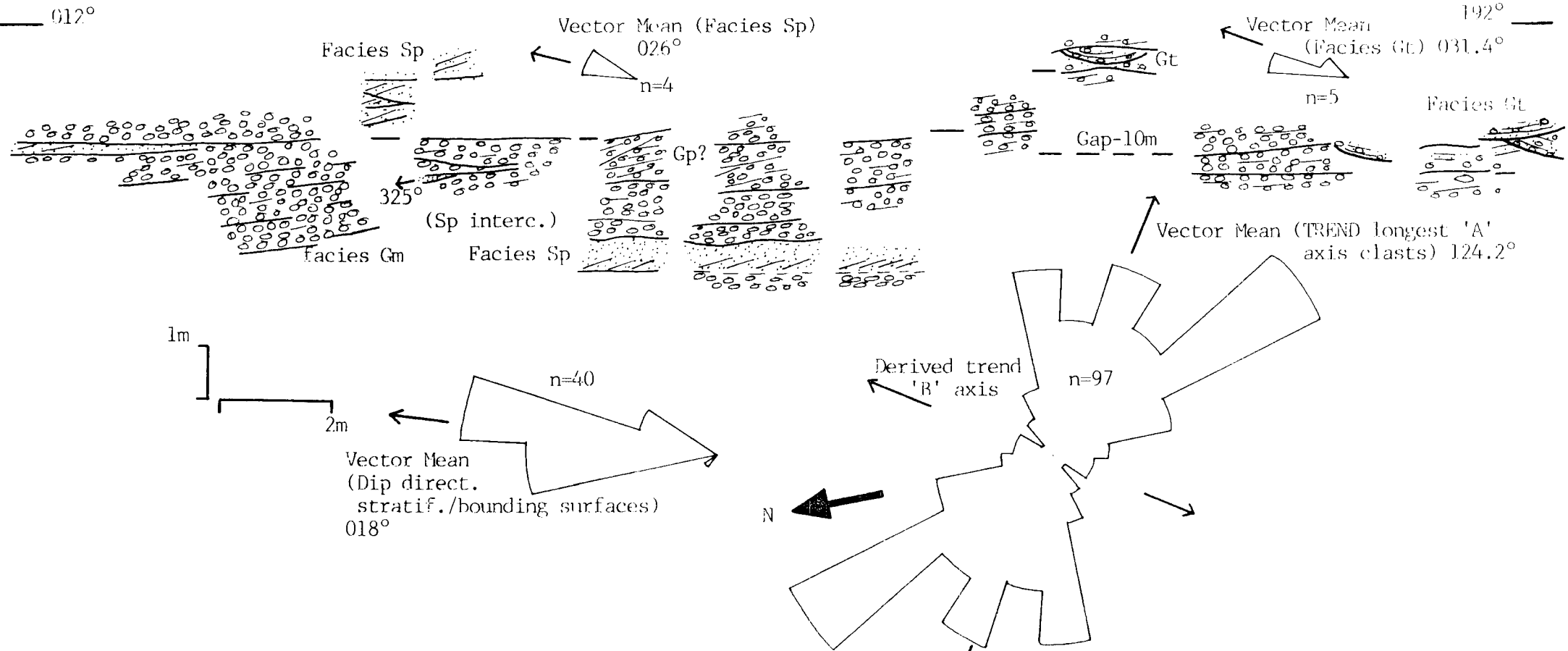
QUARTZ CONGLOMERATES

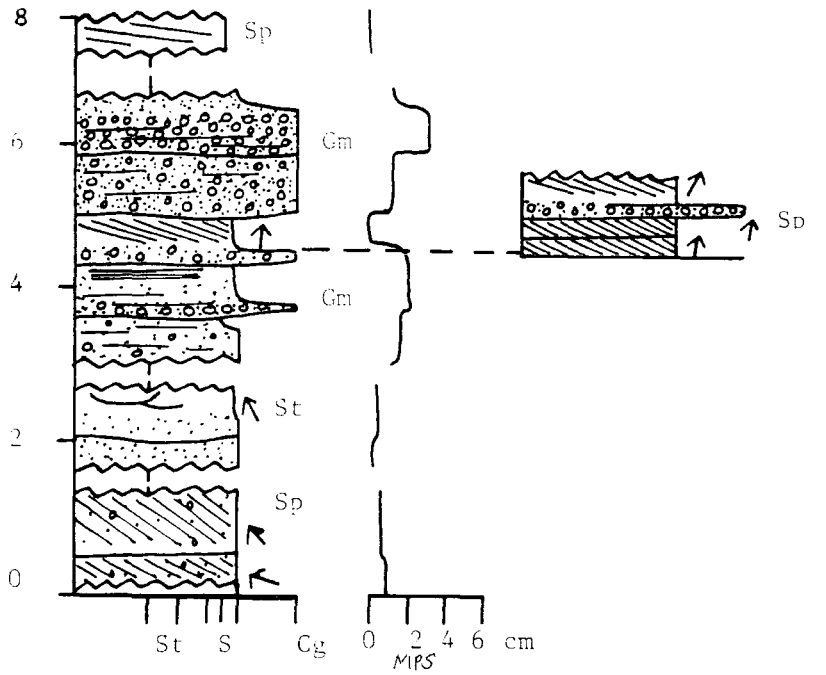
LONGITUDINAL BAR CONGLOMERATES (Gm) LOCALLY MODIFIED DURING FLOW STAGE (Gp)

POLYGENETIC CONGLOMERATE

POSSIBLE DEBRIS FLOWS CONGLOMERATES (Gms).

FIGURE 6.8. MEASURED SECTION - COCKLOCK SCAR
(NGR NY 655338)





RED SANDSTONES/QUARTZ CONGLOMERATE

TRANSVERSE BAR SANDSTONES (Sp) WITH INTERBEDDED CHANNEL-BASE DUNES (St) AND ?LONGITUDINAL BAR CONGLOMERATES (Gm)

FIGURE 6.9. MEASURED SECTION - NORTH FELL TRACK (NGR NY 636376)

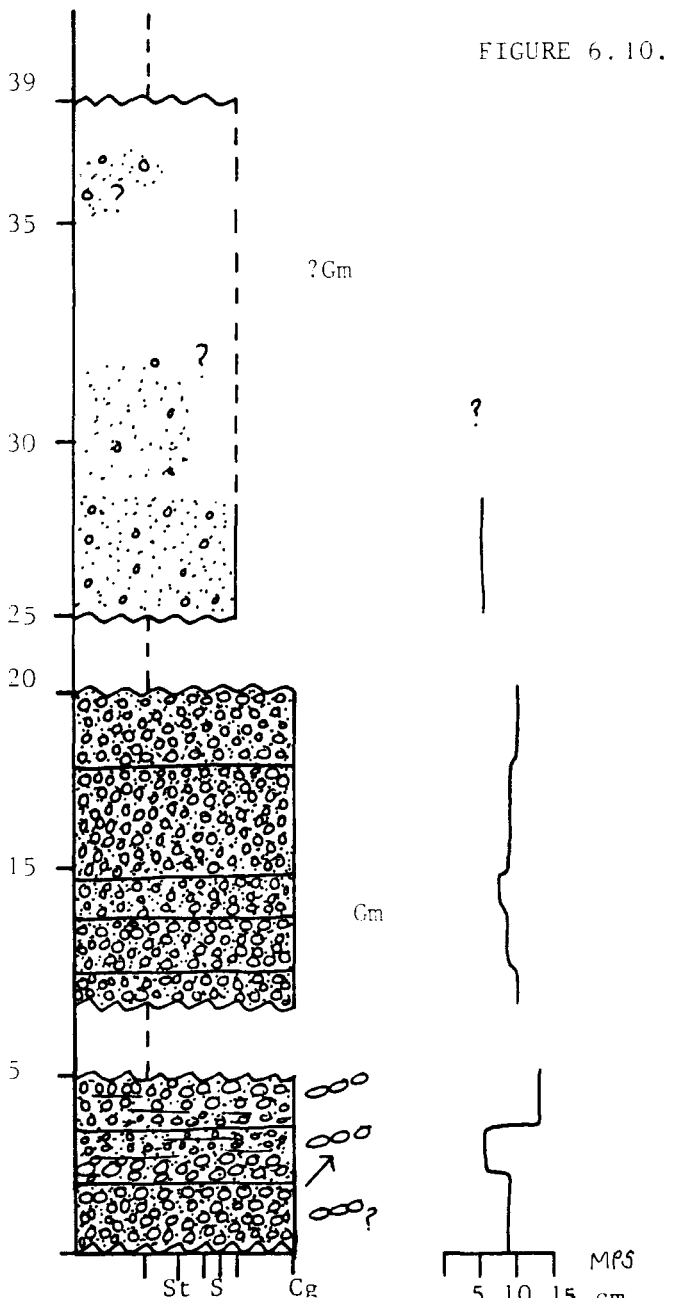
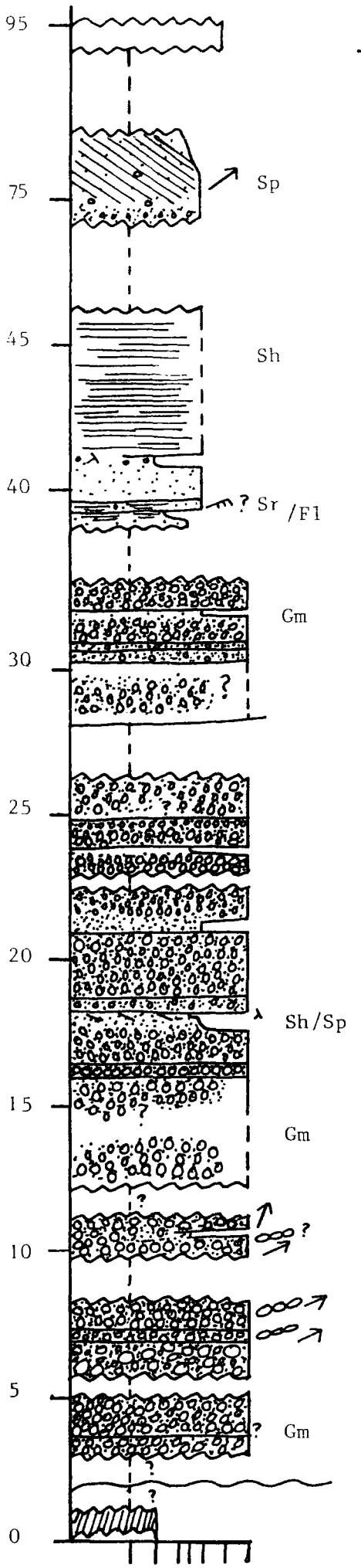


FIGURE 6.10. MEASURED SECTION - CROWDUNDLE BECK (NGR NY 683321)

QUARTZ CONGLOMERATES

STACKED PROBABLE LONGITUDINAL BAR CONGLOMERATES (Gm)

FIGURE 6.11. MEASURED SECTION - SINK BECK
(NGR NY 697292)



BASE ORTON GROUP

RED SANDSTONES

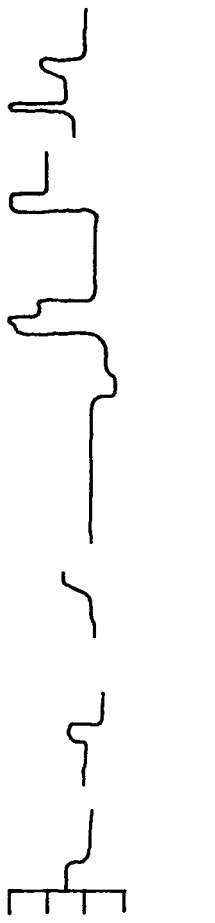
PROBABLE TRANSVERSE BAR SANDSTONES (Sp). NO EVIDENCE OF GREEN SANDSTONES ALTHOUGH COULD BE PRESENT IN GAP.

PLANAR-BED FLOW (Sh) DURING LOW FLOW STAGE - WITHIN PROBABLE CHANNEL-MARGIN SETTING - WITH MINOR CURRENT-RIPPLED (Sr) SANDSTONES AND SILTY MUDSTONES (Fl, WITH PLANT FRAGS.) DEPOSITED FROM SUSPENSION.

?Fault

QUARTZ CONGLOMERATES

STACKED LONGITUDINAL BAR CONGLOMERATES (Gm) WITH MINOR SANDWEDGE DRAPE SANDSTONES (Sh).



MURTON FORMATION

FIGURE 6.12.

MEASURED SECTION - SUMMIT OF ROMAN FELL
(NGR NY 753204)

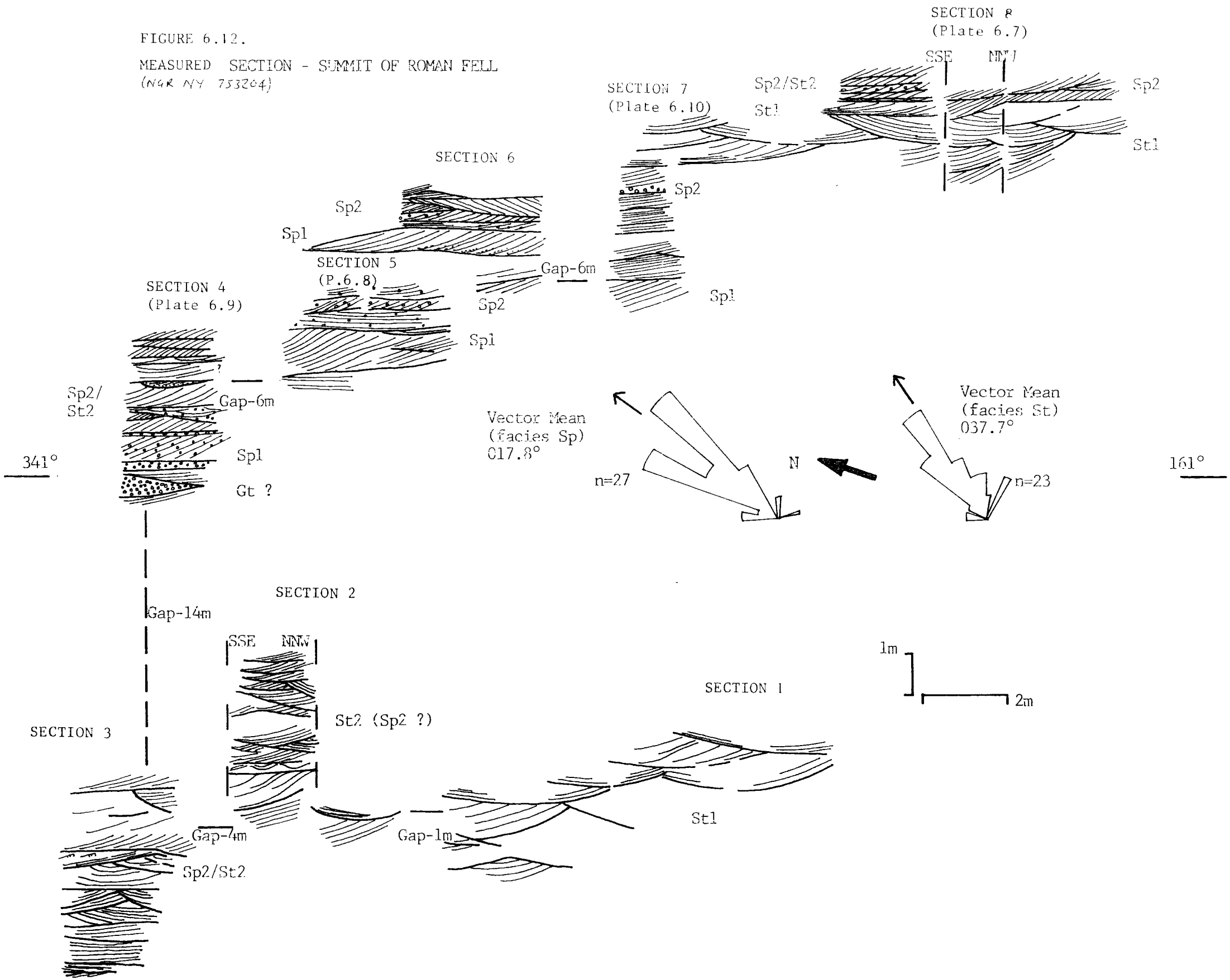


FIGURE 6.13.

PALAEOCURRENT DISTRIBUTIONS: CROSS FELL ESCARPMENT

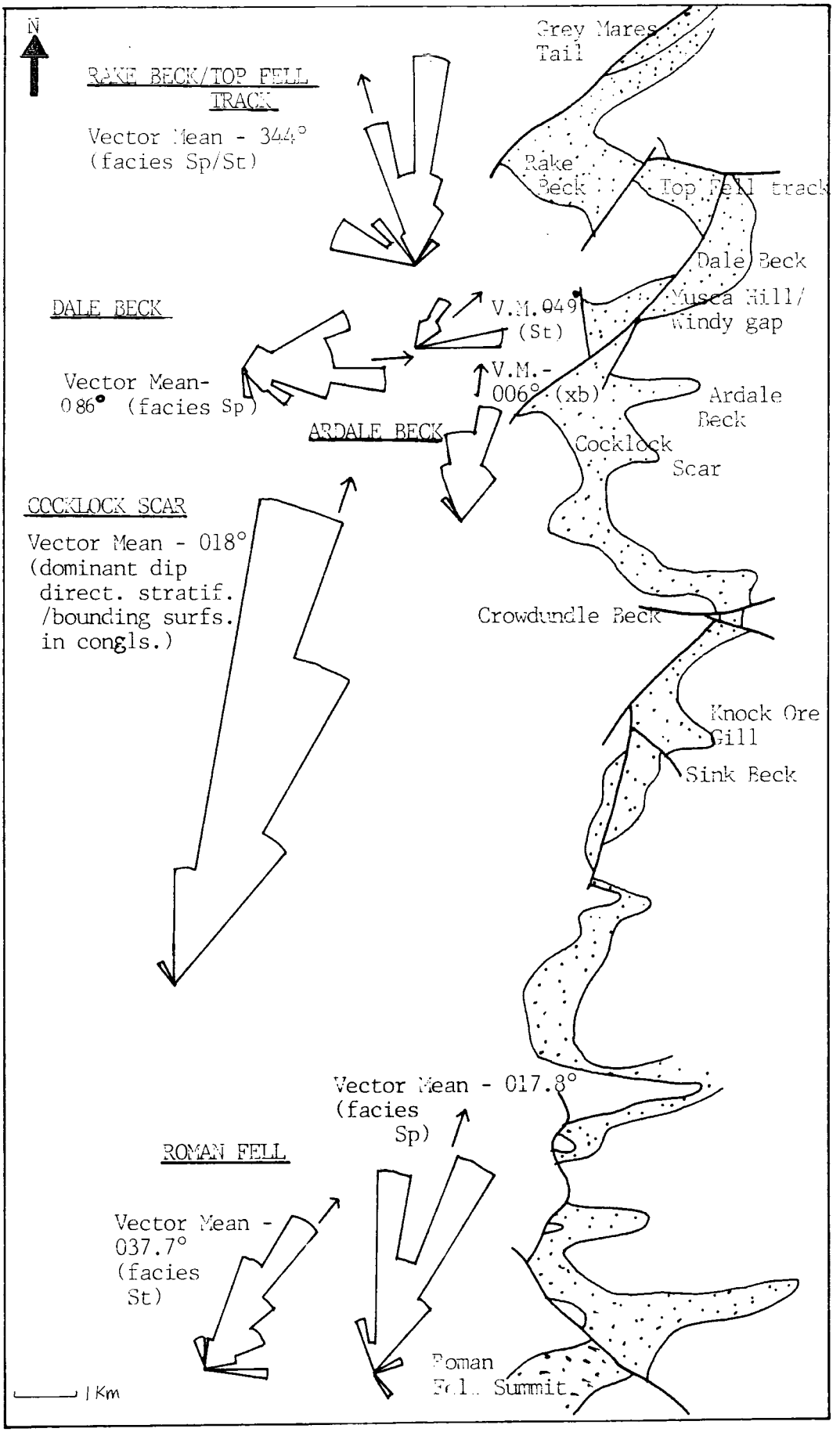


FIGURE 6.14. DIAGRAM ILLUSTRATING THE MORPHOLOGICAL ELEMENTS OF THE SOUTH SASKATCHEWAN RIVER (FROM CANT, 1978)

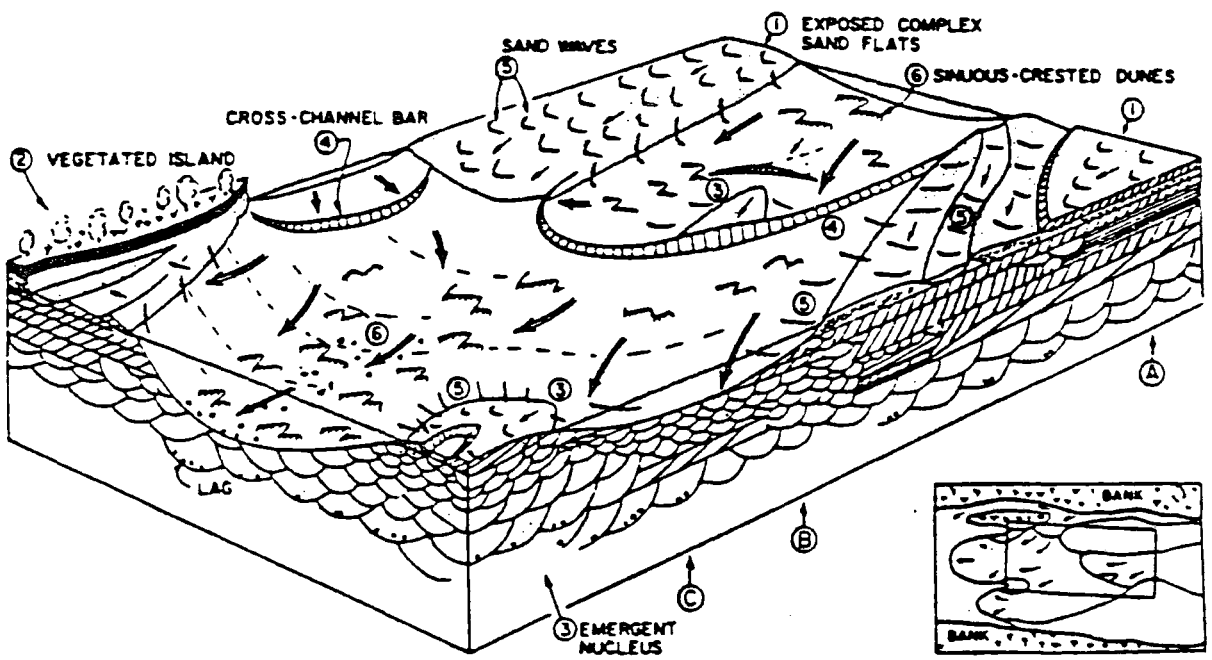


FIGURE 6.15. DEPOSITIONAL MODEL , CROSS FELL CLASTIC ROCKS (Not to scale).

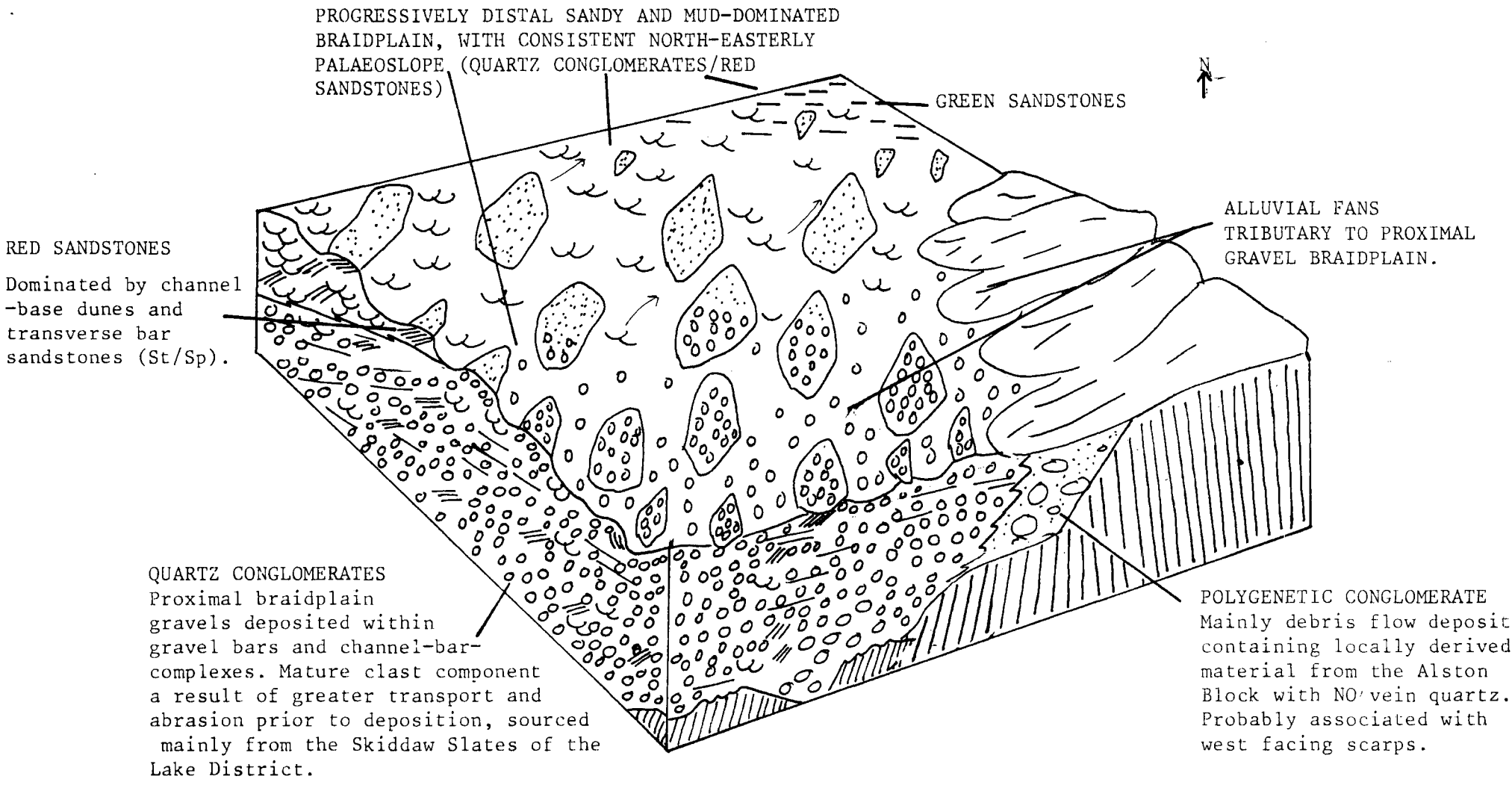


PLATE 6.1

Plate shows highly decomposed granite boulders within the Polygenetic Conglomerate, exposed near the base of the Grey Mares Tail Section, Cross Fell (N.G.R., NY 625401). These boulders are supported by a muddy matrix forming a matrix supported unit (facies Gm) which was probably deposited by mudflows within an alluvial fan environment. The boulders were sampled (POLY 1) for thin section petrographic and X-ray fluorescence analysis. The results show that these granite clasts are heavily depleted in SiO_2 and it is suggested that they may have been derived from weathered Weardale Granite exposed at the time within the Alston Block. The present vertical orientation of the boulders is probably related to the nearby Deep Slack fault which downthrows the Permian St. Bees sandstone at the base of the section. Tape measure (approximately 40cm extended) for scale.

PLATE 6.2

Plate shows typical exposure of interbedded cobble conglomerates (facies Gm) and cross-bedded sandstone (facies st, sp) within the Quartz Conglomerates, in this view at Musca Hill Crags (N.G.R. NY 649359), Cross Fell. The section (Musca Hill Crags 1) contains massive cobble conglomerate (facies Gm) at the base and interbedded planar-cross-bedded sandstones (facies Sp), the latter forming the two prominent horizons, near the top and at the very top. These units form cosets up to 1.5m thick and give palaeocurrents towards 073°-052°. Hammer (35cm long) for scale.

PLATE 6.1.



PLATE 6.2.



PLATE 6.3

Plate showing planar-cross-bedded cobble-boulder conglomerates (facies Gp) exposed at Cocklock Scar, Cross Fell (N.G.R. NY 655338). This cross-bedded horizon, 1.5m thick extends over a distance of 4.5m and consists of crudely defined 'lensed' sets up to 45cm thick with planar foresets orientated towards 050°. Note-book (20cm long) for scale.

PLATE 6.4

Plate shows crudely horizontally stratified cobble conglomerate (facies Gm) exposed at Cocklock Scar, Cross Fell (N.G.R. NY 655338). Facies Gm at this section forms laterally extensive units, these being clast supported and containing a locally well developed clast alignment with mean 'A' axis of cobbles aligned 124°-304°. The units have a tabular geometry and are defined by broad planar basal contacts. Minor low angle cross-bedded sandstones (facies sp) from intercalations up to 25cm thick, the one in view (below note book) containing planar foresets dipping towards 325°. Notebook for scale (20cm long).

PLATE 6.3.



PLATE 6.4.



PLATE 6.5

Plate shows exposure of planar-cross-bedded coarse grained sand-wedge sandstones (facies Sp) forming the base of the Cocklock Scar Section; Cross Fell (N.G.R. NY 655388). In fact these conglomerates and sandstones at the section are very close to the unconformity at the base of the Carboniferous. Facies Sp in this view forms a wedge-shaped set up to 60cm thick, with asymptotic planar foresets orientated towards 018°-032°. The vector mean calculated for all facies Sp units at this section is 026°. Facies Sp is sharply overlain by cobble-boulder horizontally stratified and cross-bedded conglomerates (Plates 6.3, 6.4). Notebook (20cm long) for scale.

PLATE 6.6

Plate shows a planar-cross-bedded sandstone coset (facies Sp) from the Red Sandstone exposed along the Dale Beck 1 Section, Cross Fell (N.G.R. NY 650365). The coset, 1.4m thick, contains 3 sets which show upward decrease in foreset dip (23°-8°), dip direction varying from 172° (base) and 110° (middle) to 092° (top) probably reflecting migration and abandonment (top set) of a sandy transverse bar. Notebook (20cm long) for scale.

PLATE 6.5.



PLATE 6.6.



PLATE 6.7

Plate shows excellent exposure of larger scale trough-cross-bedded sandstones (facies St1) at the top of Roman Fell (N.G.R. NY 753204). Set size averages 50-60cm and these are grouped into cosets 3.5m-4m in thickness. The palaeocurrent vector mean for facies St at this locality is 037.7°. Notebook (20cm long) for scale. Facies St1 is interpreted as the deposits of migrating channel-base dunes within a sandy bed-load braided channel.

PLATE 6.8

View of largerscale planar-cross-bedded sandstones (facies Sp1) exposed at the top of Roman Fell (N.G.R. NY 753204). Facies Sp1 comprises sets up to 1m thick, often forming stacked sequences, overlain by smaller scale sets (Facies Sp2). The larger scale set in the centre of this picture extends for at least 4m, and contains sigmoidal shaped and asymptotic-based foresets dipping between 018° and 360°. Note probable reactivation surfaces (discordant foresets) by notebook and immediately to right. Facies Sp1, interbedded with facies St1 (Plate 6.7) reflects the migration of large slipface-bounded bars (transverse bar) within braided fluvial channels (sand bed-load). Notebook (20cm long) and hammer (35cm long) for scale.

PLATE 6.7.



PLATE 6.8.



PLATE 6.9

Plate shows interbedded planar-cross-bedded (facies Sp) and trough-cross-bedded (facies St) sandstones at the top of Roman Fell (N.G.R. NY 753204). In this picture, larger scale planar-cross-bedded (facies Sp1) sandstones (immediately below notebook) are overlain by an interbedded sequence of smaller scale trough-cross-bedded (facies St2 position 'A') and planar-cross-bedded (facies sp2, position 'B') sandstones. This sequence probably reflects the accumulation of minor transverse bars (sand waves with minor channel-fills and forming a 'sand-flat', comparable to the South Saskatechewan River, Yukon (cf. Cant, 1978). At the base of the section (Position 'C') a pebble conglomerate (facies Gt) which may contain crudely defined trough-shaped foresets, probably forms a channel-based lag deposit. Notebook (20cm long) for scale.

PLATE 6.10

Plate shows general view of well exposed planar-cross-bedded sandstones (facies Sp1) at the top of Roman Fell (N.G.R. NY 753204). Facies Sp1 appears to be interbedded with low angle to horizontally bedded sandstones (?facies Sh, immediately above notebook) which probably represent planar-bed flow across a transverse bar top. Notebook (20cm long) and hammer (35cm long), for scale.

PLATE 6.9.

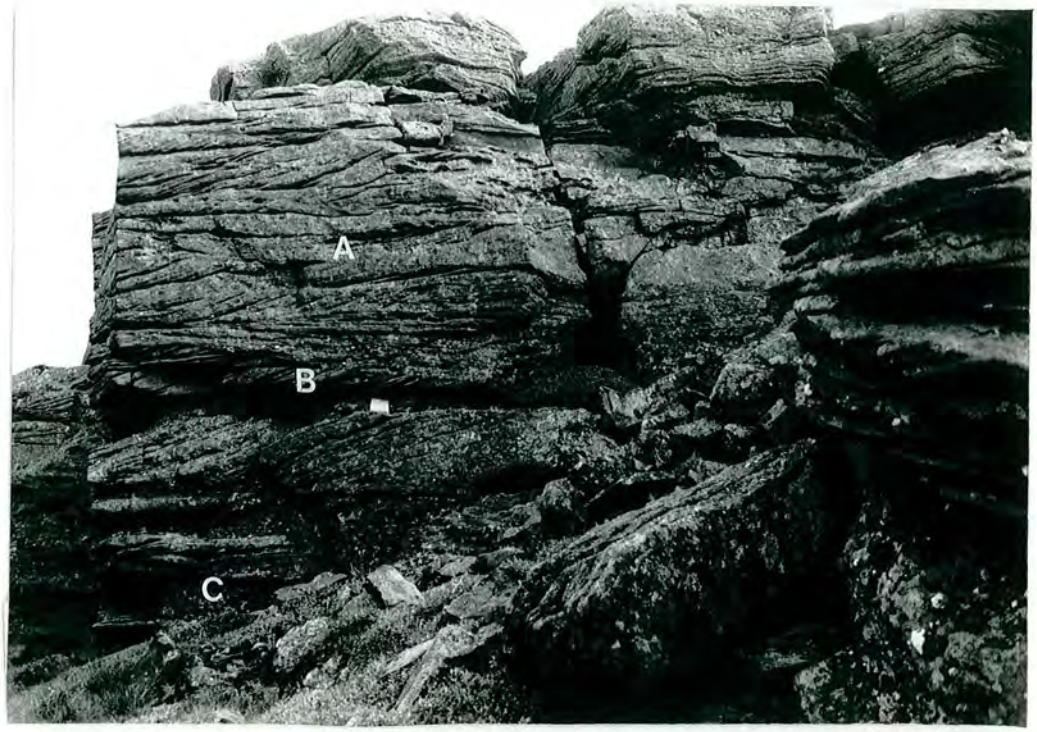
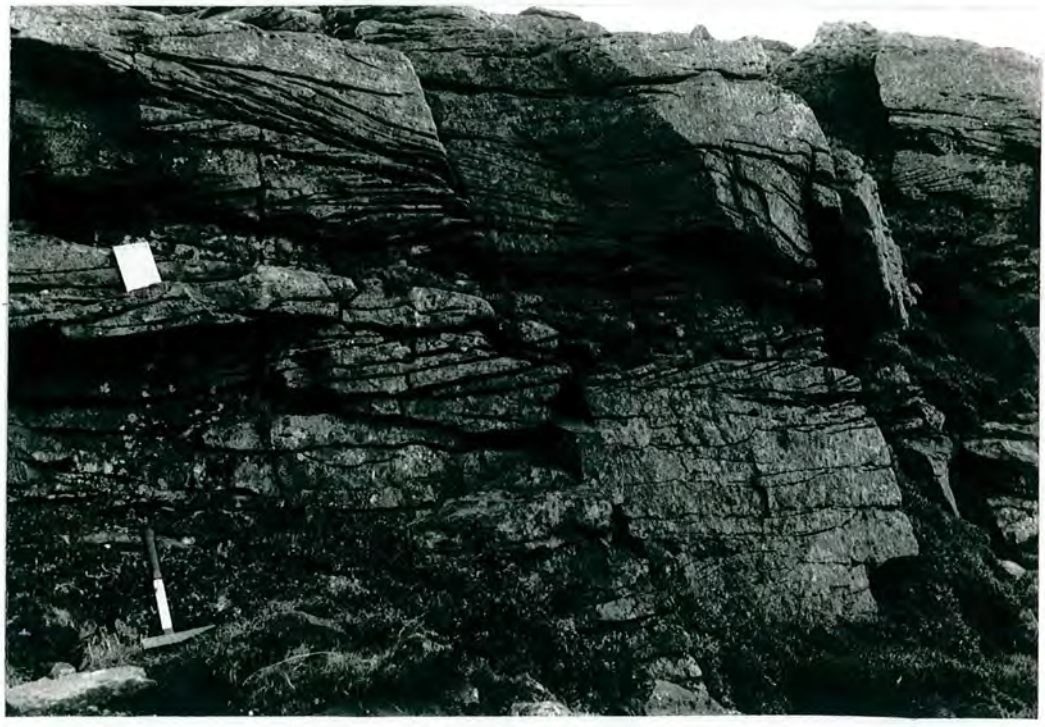


PLATE 6.10.



CHAPTER 7: CLAST PROVENANCE

7.1 INTRODUCTION

The compositions of the clasts, both from maximum clast size and sandstone/conglomerate matrix petrography, are discussed for both the west and east sides of the Vale of Eden in the sections below, data being presented in Figures 7.1 and 7.2 and in Appendix 2.

7.2 WEST VALE OF EDEN

Clast compositions in this section include those present in the Mell Fell conglomerate, Shap Red Beds and Sedbergh clastics.

Abundant green to red coloured greywacke sandstones (80%-97%) form the dominant clast compositions in the coarse boulder conglomerates of the Mell Fell conglomerate, Shap Red Beds and Sedbergh clastics typical greywacke sandstones of these three areas being seen in plates 7.1 to 7.3. The greywacke sandstones are fine to coarse grained, generally quartz arenites although arkosic sandstones are present at some sections in the Mell Fell Conglomerate. In the Sedbergh clastics a distinction can be made on colour: both red and green coloured greywackes being present. Green coloured greywackes are chlorite rich whereas red coloured greywackes are commonly coarser in grain size.

Clasts composed of these distinctive greywacke sandstone lithologies can be closely matched with the Silurian Coniston Grit

sandstones (first recognised by Ward, 1879 and Postlethwaite, 1897) which crop out today at localities between Shap and the Howgill Fells. The distribution of main clast compositions for both sides of the Vale of Eden are shown in Figure 7.1 which demonstrates the large percentage of greywacke sandstone clasts in each area. Indeed little variation in lithology and texture is observed between clasts from Sedbergh to the Mell Fells, a distance of 40km.

This automatically poses a very interesting problem. Because the coarse boulder conglomerate in the southern part of the Mell Fells were deposited close to source it is considered that large boulders up to 80cm across can not have been transported a great distance from source prior to deposition. Considering the nearest present day exposure of Coniston Grits is at Shap, 20km south of the Mell Fells, the Silurian must have covered a greater part of the Lake District during the Basal Carboniferous times extending to at least the southern margin of Ullswater. The clasts in the Sedbergh Conglomerates may have been derived from the southern part of the Askrigg Block (extension of palaeo-outcrop of Coniston Grits from ?Howgill Fells).

More evidence that this is so is shown by the presence of minor (11%) laminated fine grained sandstones and siltstones in the Mell Fell Conglomerate. Capewell (1955, p.31) states that these have been derived from the Coniston Flags (Brathay and Coldwell Beds) and Bannisdale Slates, confirmed by the discovery of Monograptus colonus (lower ludlow) in one pebble. Recent evidence of the graptolite Saetograptus varrans (again, Lower Ludlow) found by Miss K.V.G. Miller (Durham student,

Trevelyan College), again supports the findings of Capewell (1955) and this study of a Silurian greywacke source.

Clasts composed of crystalline limestone are abundant in the Sedbergh clastics (23%), and common in the Mell Fell conglomerate but are apparently absent in the Shap Red Beds. In hand specimen limestone clasts are coloured red and vary from fine to coarsely crystalline; under the microscope the limestone fragments from the Dalemain Borehole (Plate 7.4) are bioclastic, one grain (Plate 7.5) containing a fragment of the tabulate coral Favosites. The presence of this coral suggests that at least some of these limestone clasts were derived from the Upper Ordovician (G.A.L. Johnson 1984, Pers. comm.) limestones (e.g. Coniston limestone). Capewell (1955, p.31) suggests that limestone clasts in the Mell Fell Conglomerate resemble the Kiesley Limestone, which belong to Ashgill series of the Cross Fell Inlier. Garwood (1912) and Burgess (pers. comm.) also suggest that red crystalline limestone clasts in the Sedbergh clastics are similar to the Kiesley Limestone and thus would compare closely to those from the Mell Fell conglomerate. As noted in Chapter 1, the Kiesley Limestone is the Ashgill equivalent of the Lake District succession in Cross Fell. Their presence in the coarse boulder conglomerates at Sedbergh suggests derivation from the Upper Ordovician /Silurian limestones in the Howgill Fells (Cautley area) to Askrigg Block region associated with the Upper Ordovician to Silurian transgression from north to south.

Minette clasts and sand-size grains are common in the Mell Fell Conglomerate (31%), but apparently rare in the Shap Red Beds (1%), with

no Minette clasts being observed in the Sedbergh clastics. According to Hatch, Wells and Wells (1972) these Minettes lithologies are intrusive igneous rocks rich in alkaline feldspar and abundant biotite which belong to the Lamprophyre group of rocks. A minette clast in thin section from the Dalemain Borehole (Plate 7.6) contains the characteristic corroded biotite phenocrysts contained within an altered groundmass which are typical of these rocks. Hatch, Wells and Wells (op.cit. p.423) write 'minettes and kersantites occur as narrow dykes over an area from Teesdale to Furness and from Barrenthwaite to Ingleton - a circular area with a diameter of 50 miles, centred on Shap Fell. On account of their radial disposition about the Shap Granite the lamprophyres are considered to be genetically related to it'. The dyke rocks were intruded into the Silurian cover (Moseley, 1978 p.159) and clearly the presence of these minette clasts in the finer grained conglomerate/sandstone facies of the Mell Fell Conglomerate suggest that erosion of the Silurian took place over a wider catchment area than that 'tapped' by the coarser grained conglomerate facies which contain only rare minette clasts (Figure 7.1).

Clasts from the Borrowdale Volcanic Group (Figure 7.1) are very common in the Shap Red Beds and abundant in the finer grained facies of the Mell Fell Conglomerate but are absent from the Sedbergh clastics. Clearly their distribution within these conglomerates and sandstones particularly in the finer grained facies points to a source rock terrain with a less extensive outcrop area than the Silurian which forms the dominant clast type for the whole of the west side of the Vale of Eden. This is what would be expected if the Silurian covered the highest

ground and was actively being eroded back by braided rivers and perhaps alluvial fans (see Chapter 4 discussion).

The Borrowdale Volcanic Group consists of a 'common association of lithologies rather than a particular rock type' (Milward et al 1978). A wide range in lava composition is present although generally lavas of more basic and intermediate compositions are most abundant. Flow brecciation was a common feature of the lava flows and as a result the lavas are frequently flow-banded. Porphyritic lavas contain characteristic feldspar phenocrysts which are now altered to secondary minerals especially sericite, calcite and epidote (Milward et al op.cit.); basic lavas contain pyroxene phenocrysts. Rhyolites form the highest part of the Borrowdale volcanic group 'pile' overlying basic and intermediate lavas below. Rhyolites have normally been devitrified, such rocks being termed felsites. Several of the rhyolites are intrusive and so welded-tuffs or ignimbrites are common (Hatch, Wells and Wells, 1972 p.480).

Volcanic clasts from the Mell Fell conglomerate and the Shap Red Beds can be matched with these common lithologies from the Borrowdale Volcanic Group and demonstrate the wide range in composition and texture (Plates 7.7 to 7.11; 7.13 to 7.15). A flow-banded tuff (ignimbrite) in which the groundmass is extremely glassy and contains quartz feldspar phenocrysts is shown in Plate 7.7. Glass shards are common and in the central part of the photograph have been replaced to green fibrous chlorite. Plate 7.8 is similar to Plate 7.7 but this tuff is more acidic in composition and contains sanidine phenocrysts with glass

shards. Locally these glass shards form the 'fiamme' texture, characteristic of ignimbrite (see Plate 7.14).

Plate 7.9 illustrates a tuff of basic composition with characteristic feldspar and clinopyroxene phenocrysts. The feldspar crystals are particularly noticable in hand specimen as they are commonly decomposed, the rock type being especially common in the Mell Fell Conglomerate. The feldspars have locally been partially replaced by calcite which is a common feature observed in thin section of sandstones sampled from the Dalemain Borehole.

A quartz felsite is illustrated in Plate 7.11 and is quite characteristic throughout the study area as clasts both from maximum clast size and conglomerate/sandstone petrography. In hand specimen these clasts are hard and flinty and coloured pink-red providing a striking contrast to the porphyritic clasts described above which are commonly decomposed. In thin section the felsite rocks have been devitrified to a mosaic of ill-defined grey polarising areas which bear no relation to the original structure. Felsites are, infact, classified as mainly devitrified rhyolitic glasses, although the term felsite is a broad one applied to varying composition.

The rock shown in Plate 7.10 is andesitic in composition and consists of a felted lath fabric composed of feldspar phenocrysts within a glassy groundmass, this texture being characteristic of andesite rocks. The voids in the photomicrograph, may be amygdales consisting of narrow necks and infilled with minerals, including zeolite and calcite.

Figure 7.1 demonstrates the variation in clast amount (%) and distribution throughout the study area. The finer grained facies of the Mell Fell Conglomerate contain the greatest variety of clast types, the reason for this, it is suggested, being related to greater fluvial dispersion and derivation from the Borrowdale volcanics (Kimber and Johnson, 1986; Chapter 4). These finer grained clastics were deposited by braided streams dispersed over a wider area than those streams at work nearer source and bordering alluvial fans. The coarser boulder conglomerates were deposited probably within steep channels under reduced fluvial influence reflecting local derivation of clasts and thus indicate that topography and degree of slope must have been highest in these parts. Furthermore, this would imply that the Silurian greywacke sandstones, present as clasts in high amounts in these conglomerates, must have covered the highest parts of the land surface immediately to the south of the Mell Fell area. The presence of volcanic and minette clasts probably stratigraphically higher in the succession within finer grained conglomerates and sandstones combined with a decrease in greywacke sandstone content within these deposits suggests the following conclusions (Figure 7.2). Firstly, a wider fluvial dispersion pattern which deposited the finer grained clastics was able to derive material from a wider catchment area exposing the Borrowdale Volanics. Secondly, the Silurian can not have been exposed everywhere and very likely was restricted to highest relief. Thirdly, the presence of minette clasts which intruded the Silurian cover, indicates that the Silurian was being eroded back thus exposing the highest parts of the Borrowdale Volcanics below and creating a dissected source terrain.

Capewell (1955, p.30-32) points out that the decomposed porphyritic lava clasts containing large feldspar phenocrysts may have been derived from the Eycott lavas. The Eycott lavas belong to the Ordovician Eycott Group of volcanics which are presently exposed around Caldbeck Fells and Eycott Hill in the northern part of the Lake District with small inliers being present just south of the Mell Fells. Wadge (in Moseley, 1978) defines the Eycott Group as being transitional from the Skiddaw Group (see chapter 1) and unconformably overlain by the Borrowdale Volcanics. Considering that 'Eycott' type clasts are found in sections in the north-west part of the Mell Fell area and at Setterah Sike/Heltondale Beck, it is possible that these areas provided a local source of Eycott lava rocks.

The section through the Shap Red beds along Wasdale Beck contains volcanic clasts similar to those from the Mell Fell Conglomerate. Infact over 92% of clasts along the section are composed of altered acidic volcanic clasts and minettes. Plate 7.15 is a typical example and shows quartz phenocrysts in a highly altered quartz rich granulose hornfels groundmass.

The other clasts identified from the Shap Red Beds include devitrified rhyodacites, spherolithic rhyolites and minettes, with most clasts having this granulose groundmass. Commonly these clasts contain secondary minerals such as epidote, chlorite and dolomite with feldspars locally heavily altered to sericite. Plate 7.14 shows glass shards contained within a crystalline groundmass being a good example of an ignimbrite. A spherulitic rhyolite clast from conglomerates exposed at

Beckside, south of Shap Wells is seen in Plate 7.13 this rock type having typical rosettes of radially disposed crystals. Adjacent to the Shap Granite, the Borrowdale Volcanics have undergone metasomatism in fissures along pre-granite fractures (Firman, 1978 p.158). Firman (op.cit.) writes 'Within the aureole, chloritised andesites, tuffs and Silurian siltstones, were metamorphosed into biotite hornfels with quartz and plagioclase'. The proximity of these conglomerates to the Shap Granite aureole strongly suggests that the altered volcanic and hornfels clasts present in the clastics of Wasdale Beck were derived from these rocks. Pink orthoclase granules and sand size grains (Plate 7.12) are the only direct evidence for the Shap Granite being exposed and providing clastic material. The orientation of clast imbrication and sandstone cross-bedding indicates a south-west to west-south-west provenance for the Wasdale Beck section which is consistent with derivation from the metamorphosed volcanics and Silurian siltstones (e.g. Brathay Flags). The Shap Granite and associated metamorphosed country rocks from this area thus provided a limited source especially as clasts present in clastics at other sections in the Shap Red Beds and exposed further south are composed of greywacke sandstones. The strong southerly provenance derived from the orientation of cross-bedding within trough-cross-bedded sandstones (facies St) suggests that the Silurian greywackes were extensively exposed south of Shap, very much as they are today and may indicate that the present day Howgill Fells may have provided a source terrain.

7.3 EAST VALE OF EDEN

Clast compositions of the clastic rocks exposed within the Cross Fell Inlier along the eastern side of the Vale of Eden are markedly different from those exposed along the western side (Section 7.2). Whereas vein quartz clasts are virtually absent from the maximum clast size component within clastics from the 'west side', up to 67% of the maximum size clasts in the Cross Fell clastics are composed of distinctive rounded cobbles and boulders of vein quartz. Vein quartz clasts and sand-size grains as seen in thin section have a distinct 'milky texture', this being typical of a hydrothermal origin. Some clasts are probably metamorphic quartzite; as seen in Plate 7.17, an example of such a quartzite showing characteristic straining. The most likely source for these vein quartz and quartzites is from the quartz veins known to be present in the Skiddaw Slates. The Skiddaw Slates within the Cross Fell Inlier are known as the Murton Formation (Burgess and Wadge, 1974 p.9). Actual 'Skiddaw Slate' lithologies do not form clasts large enough to be included within the maximum size clast component but 'pelite' grains are abundant in sandstones and conglomerate matrix thin sections (Plate 7.21) suggesting derivation from a Skiddaw Slate 'source terrain'. Furthermore, evidence that the Skiddaw Slates formed a prominent source rock terrain is seen in Plate 7.16 which illustrates a 'spotted slate' grain, being very similar to the spotted slate lithologies occurring within the aureole of the Skiddaw Granite (Firman, 1978 p.156). These slate and pelite grains were probably derived from the Skiddaw slates of the Lake District, although it is possible especially as these grains might break upon

prolonged transport, they may have been derived from the Murton Formation rocks surrounding the Alston Block granites (Burgess and Wadge, 1974 p.10). This argument is supported by the evidence for Weardale Granite exposure (see below) and the northerly palaeocurrent direction derived from the measurement of palaeocurrents of cross-bedding in the Red Sandstones. Muscovite spherules, intergrown with quartz (Plate 7.23) are similar to textures present in the Eskdale Granite, further evidence from a Lake District source (perhaps from the Skiddaw Granite).

Red coloured 'quartz arenite', greywacke and quartz-veined greywacke sandstone and quartzite lithologies account for the remainder of clast compositions comprising up to 42% of clast compositions. Plate 7.18 illustrates a typical red coloured 'quartz arenite'/greywacke sandstone lithology from the conglomerates exposed at Cocklock Scar. In hand specimen these greywacke and 'quartz arenite' (informal classification for field identification) clasts are significantly different from the typical Silurian fine grained greywacke sandstones the former being coloured red, are coarser in grain size and often possess a shiny lustre suggesting that they have been subjected to a higher grade of alteration than the Silurian greywackes. Frequently they are quartz veined possibly being related to the quartz veining associated with the Skiddaw Slates. Quartz veining in the Silurian greywacke sandstones was not observed. The most probable source for these sandstone clasts is from the sandstone horizons in the 'Skiddaw Slates'. The Skiddaw Group in the Lake District is divided into four formations (Wadge, 1978 p.69) while in the Cross Fell Inlier 'the Murton

Formation (Burgess and Wadge 1974) includes both the striped siltstones of Murton Pike and Brownber and the flaggy greywacke sandstones around Cuns Fell. Burgess and Wadge (op.cit.) tentatively correlate these siltstones with the Kirkstile Slates and the sandstones with the Loweswater Flags of the main Lake District outcrop. These rocks contain a significant proportion of sandstones belonging to a 'greywacke suite' and containing 'bands' of quartz that have recrystallised along foliations (Burgess and Wadge, 1974 p.9). As such this evidence suggests that the Murton Formation may well have provided a source terrain. Capewell (1956, p.221) also suggests that the greywackes are derived from the sandstone horizons in the Skiddaw Slates (? Murton Formation), being richer in chlorite than the Silurian greywackes of north-west England.

Igneous rock fragments make up only a maximum recorded 7% of clasts in the Cross Fell clastics. Plate 7.19 demonstrates an acidic prophyry containing sericitised feldspars and probably hornblende phenocrysts within a fine grained quartz rich groundmass. In thin section study from the Red Sandstones, grains are commonly composed of feldspars contained in a fine grained groundmass the feldspars often being partially replaced by calcite. Very rare sand size grains in thin section are biotite rich and similar to the minettes described from the sandstones along the west side of the Vale of Eden. In fact, it is suggested, common biotite flakes observed in thin section could have been derived from the breakdown of these 'minette' dyke rocks intruded at the end of the Silurian providing more indirect evidence of a Lake District source terrain.

Plate 7.20 illustrates an igneous rock probably, basic in composition. The groundmass consists of Ilmenite crystals replaced by leucoxene set within a groundmass containing feldspar lath-shaped crystals. These rare clasts may have been derived from dolerite sill-like bodies, the oldest intrusive suite in the Cross Fell Inlier and probably of lower Ordovician age (Burgess and Wadge, 1974 p.36).

Volcanic rock fragments account for a maximum 33% of grain compositions in the analysis of sandstone and conglomerate matrix petrography. These grains are predominantly felsitic and similar to the felsite grains described for the Mell Fell Conglomerate and the Shap Red Beds. It is suggested that these grains have been derived from the Borrowdale Volcanic Group and possibly the Kirkland Formation the latter being the equivalent to the Eycott Group in the Cross Fell Inlier.

Small granite fragments (Plate 7.22) were observed within sandstone thin section samples from the Grey Mares Tail Section. Biotite, muscovite, quartz and sericitised plagioclase feldspar are intergrown forming crystals up to 2mm-3mm across, the mineralogy comparing well to published descriptions of the Weardale Granite (Dunham et al., 1965 p.389). Plate 7.23 illustrates a typical occurrence of intergrown quartz and spherolitic muscovite crystals. Firman (1978) describes similar a mineralogical texture to this from the Eskdale granite. Thus, it is suggested, here is further evidence that a granitic source terrain was present at this time. In the present day the Shap and Skiddaw granites are the nearest to the Cross Fell clastics, although it seems possible that the Weardale Granite or adjacent cupolas, being very near

to the present clastic rock exposures also provided a source terrain. According to Holland (Pers. comm.) there is no geochemical difference between the Lake District and Alston Block Granites although differences in mineralogy may be present.

Given that there is no geochemical difference between the Lake District and Alston Block granites, further evidence that the Weardale Granite was exposed and providing clastic material is shown by the weathered granite clasts (Plate 7.24) present in the Polygenetic Conglomerate. Although very highly altered and fractured, intergrown quartz, feldspar and mica are clearly present and X-ray fluorescence of these clasts has clearly proved that geochemically at least the clasts are almost identical to the primary weathered top to the Weardale Granite recorded in the Rookhope Borehole. Shotton (1935, p.643, 644) records the presence of two types of granite clasts in the Polygenetic Conglomerate, one similar to those described above and also a biotite rich granite. Both granite types he states could not be matched with rocks from the immediate neighbourhood. He further states that the well rounded clasts must have been transported a fair distance. Arthurton and Wadge (1981, p.22) also note biotite granite from the Melmerby Fell Track (not observed by the author). Considering the new evidence that the weathered granite clasts at Grey Mares Tail are geochemically similar to the weathered Weardale Granite from the Rookhope Borehole, it is suggested that the Weardale Granite was exposed and supplying clastic material at this time, at least during deposition of the Polygenetic Conglomerate.

Very fine grained micaceous sandstones (Plate 7.25) are common clast types within the Polygenetic Conglomerate and as considered by Arthurton and Wadge (1981) were probably derived from Skiddaw Group slate lithologies. Shotton (1935) records rare felsite and lamprophyre clasts within the Polygenetic Conglomerate similar to those already described for the Quartz Conglomerates and Red Sandstones. Arthurton and Wadge (op.cit.) also record a variety of igneous clast types (andesites and feldspar porphyries)

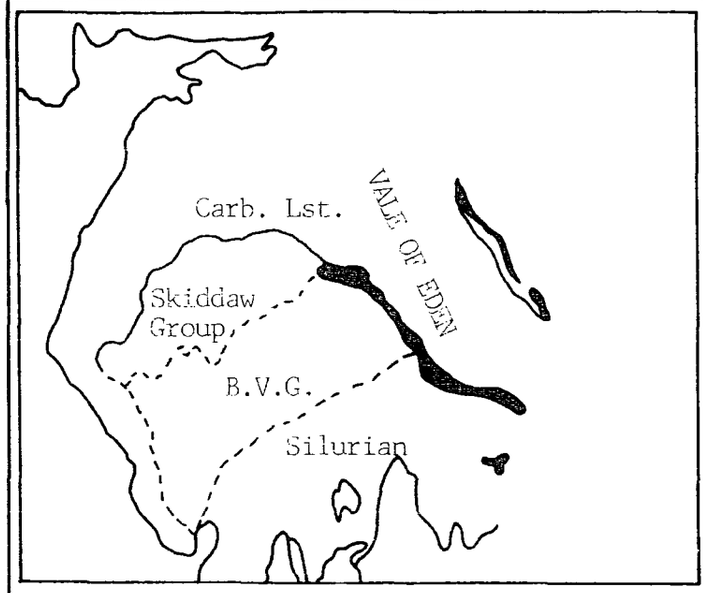
The principal difference between the Polygenetic Conglomerate and the Quartz Conglomerates is the absence of vein quartz as clasts within the former. Inspite of the absence of vein quartz in the Polygenetic Conglomerate, source terrains may be similar for both conglomerates; clasts derived from the Skiddaw Slates (Murton Formation in Cross Fell), Borrowdale Volcanics and associated minor intrusive rocks are present in both. In addition granitic clasts, derived from both the Alston Block and possibly Lake District granites, are again present in both the Polygenetic and Quartz Conglomerates. The Polygenetic Conglomerate, as discussed in Chapter 6, reflects deposition mostly by debris flow processes on alluvial fans and as such represents the 'stripping' of clastic material nearby. Furthermore, this locally derived clastic detrital sediment would have been the most easily eroded material, particularly fine grained slaty rocks from the Skiddaw Slates (Murton Formation). However, the sharp change to vein quartz rich conglomerates is striking and cannot be easily explained by postulating that the Polygenetic Conglomerate just reflects local stripping of easily eroded material. The palaeocurrents from the Quartz Conglomerates and Red

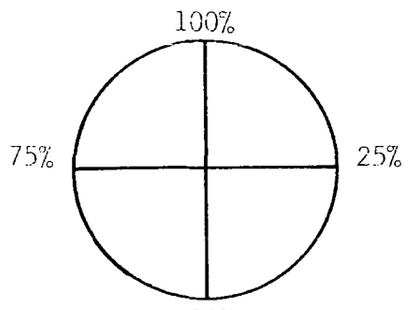
Sandstones indicate a dominant south-west/west provenance, indicating the source was from the Skiddaw Slates of the Lake District rather than the Murton Formation of the Alston Block. The model developed in Chapter 6, shows that alluvial fans, rather than being the proximal equivalent of fan-fed braided rivers, were tributary to braided streams that flowed obliquely to fan trend. Thus the Polygenetic Conglomerate was derived locally, while the Quartz Conglomerates mostly reflect derivation from the Lake District.

The deposition of the Quartz Conglomerates and subsequently, the Red Sandstones, reflect sedimentation under a more 'evolved' fluvial system, transporting clasts over a much wider area than the local 'streams' and mudflows which deposited the Polygenetic Conglomerate. In this way, the retention of more resistant and rounded clasts types will be predominant over less resistant argillaceous rock types as the latter quickly become disintegrated.

FIGURE 7.1

Main clast compositions of the basal clastics from maximum clast size and sandstone petrography





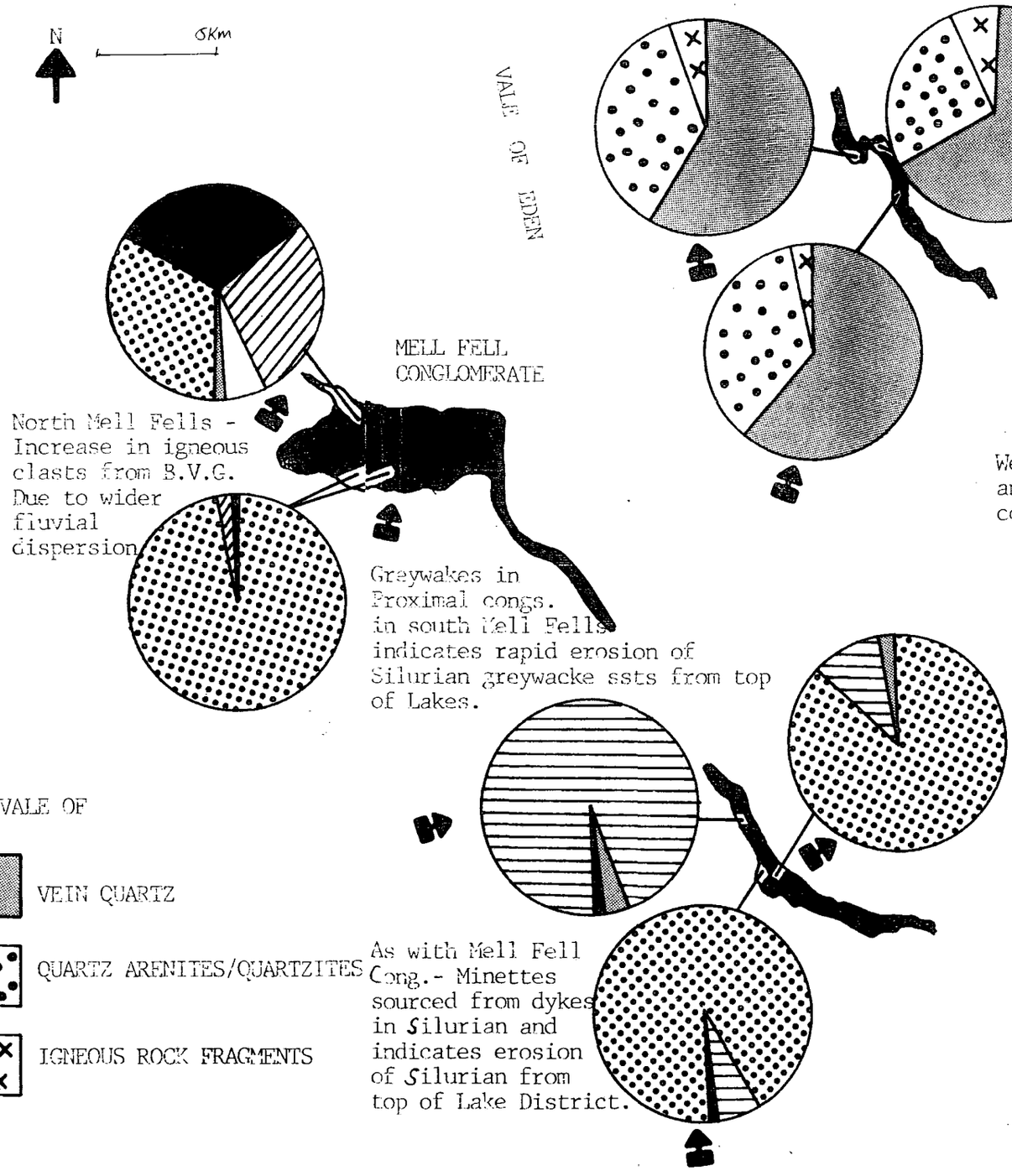
WEST VALE OF EDEN

- GREYWACKE SANDSTONES
- LIMESTONE
- VEIN QUARTZ
- MINETTE
- ALTERED RHYOLITES
- TUFFS AND PORPHYRIES

EAST VALE OF EDEN

- VEIN QUARTZ
- QUARTZ ARENITES/QUARTZITES
- IGNEOUS ROCK FRAGMENTS

MAIN CLAST COMPOSITIONS OF BASAL CLASTICS FROM MAXIMUM CLAST SIZE



CROSS FELL CLASTICS

Vein quartz from veins in Skiddaw Grp. Arenites eroded from coarser ssts. Igneous clasts from B.V.G. (Kirkland Fr.) intrusions.

Weardale Granite exposed and producing clasts in Polyg. conglomerate.

SHAP RED BEDS

Mixed clast compositions due to 2 provenances -B.V.G and silurian greywackes. Increase in B.V.G. rhyolites in north where sourced from volcanics altered from exposed Shap Granite which produced feldspar clasts and granite fragments.

SEDBERGH CLASTICS

Bi-modal clast composition - sourced from Silurian greywake ssts of Askrigg Block and Howgill Fells (?). Limestone clasts from Ashgill lsts. (Kiesley Lst.).

FIGURE 7.2

Distribution of Lower Palaeozoics during basal Carboniferous deposition

DISTRIBUTION OF L. PALAEOZOICS DURING BASAL CARB. DEPOSITION

Basal Carboniferous Clastics

Granite

Silurian Greywacke Ssts/Siltsts.

U. Ordovician Lsts.

B.V.G.

Eycott Volcanic Group

Skiddaw Group

Weardale Granite (exposed)

Alston Block
Cupolas (?exposed)

Skiddaw Group Slates / Greywackes
-quartz veined extends to Teesdale

Increase in Minettes & BVG clasts in finer facies from wider fluvial dispersion

Within main area possible outliers B.V.G. - form common sand grains

BVG / Lst outcrops in west.

No clastic dep. on ridge underlain by granites.

B.V.G. lavas and intrusions formed land in south but limited extent.

Silurian Greyws. rapidly eroded back from edge of high land marked by north edge of Lake District Granites.

Shap Granite and Metam. volcanics - limited source.

South edge of granites marks north limit to Shap Red Beds.

? No clastic deposition

Stockdale Fault line may have formed southerly limit to high land.

Silurian formed extensive cover over Howgill Fells and south Lakes.

N

5Km

Dent Fault may have been positive influence.

?clastic dep. to South of Howgills.

Arenig greyws./siltsts. proved on Askrigg Block by Raydale BH.

Southern border to clastic deposition marked by limetones on unconformity.

Silurian and U.Ord. lst inliers s.e. Sedbergh.

Wensleydale GR.

PLATE 7.1 Greywacke Sandstone Clast, Mell Fell Conglomerate

Plate shows typical greywacke lithology, this sample being a fine grained red coloured micaceous sandstone from the Folly Lane Section. This sandstone is feldspar rich, containing abundant detrital plagioclase grains, monocrystalline and polycrystalline quartz, intraclasts and heavy minerals (rutile).

PLATE 7.2 Greywacke Sandstone Clast, Shap Red Beds

Plate shows a typical greywacke lithology from the Stakeley Beck Section, Shap. Again this clast type, fine grained micaceous sandstone, is very similar in texture and detrital mineralogy to the clast in Plate 7.1, from the Mell Fell Conglomerate. These clasts most probably originated from the Silurian turbidite sandstones, particularly the Coniston Grits and possibly the Brathay flags.

PLATE 7.3 Greywacke Sandstone Clast, Sedbergh Clastic Rocks

Typical green-coloured (chlorite rich) greywacke (medium grained) sandstone from the River section, Sedbergh. Note the closely comparable lithology to the clasts in Plates 7.1 and 7.2, from the Mell Fell Conglomerate and Shap Red Beds respectively.

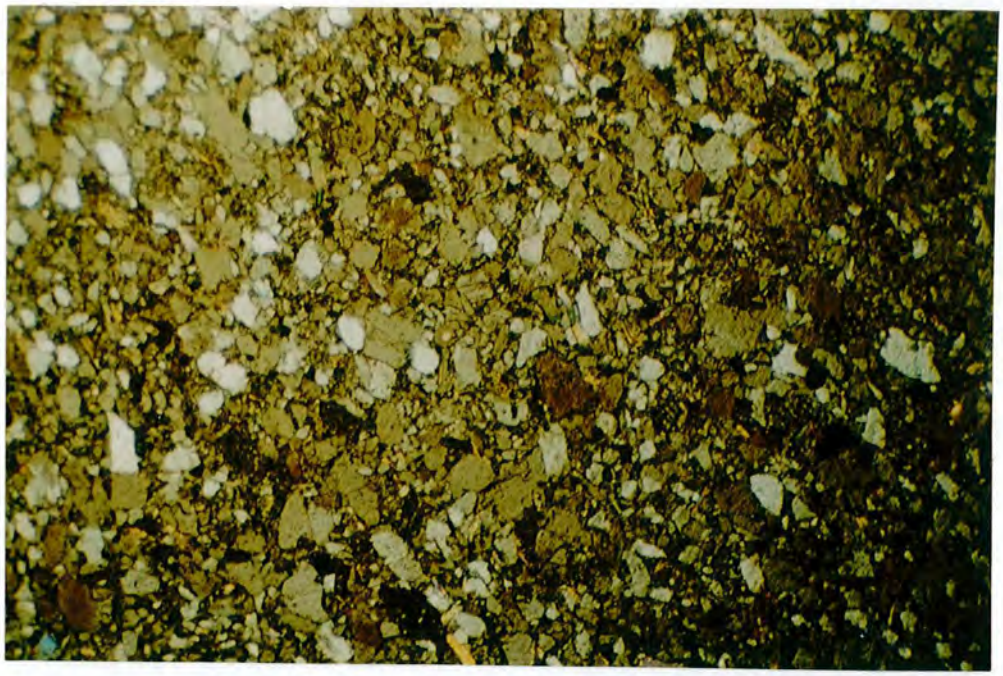


PLATE 7.1.

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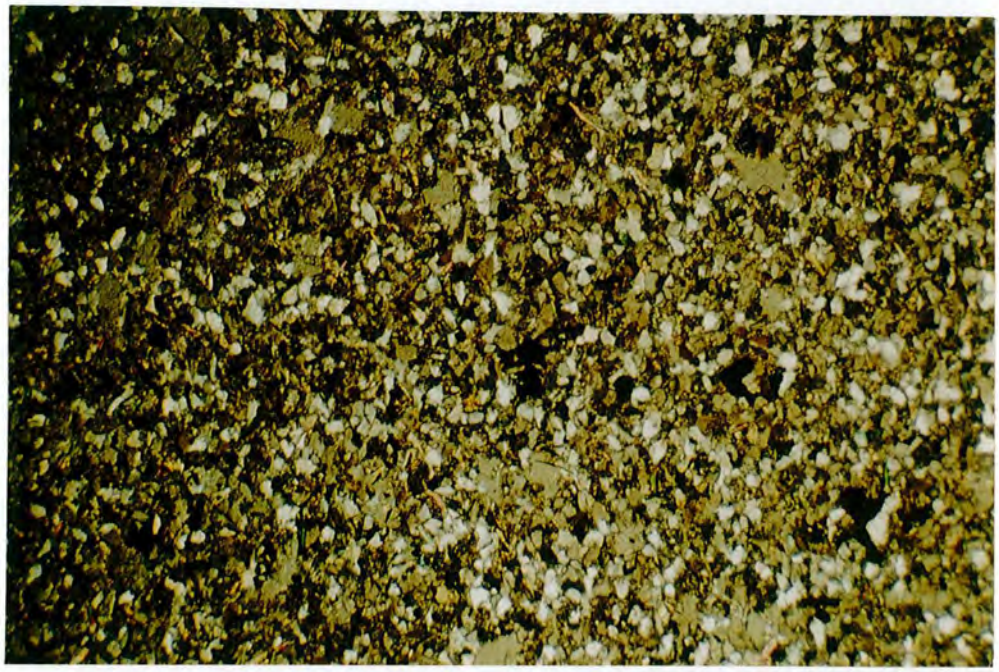


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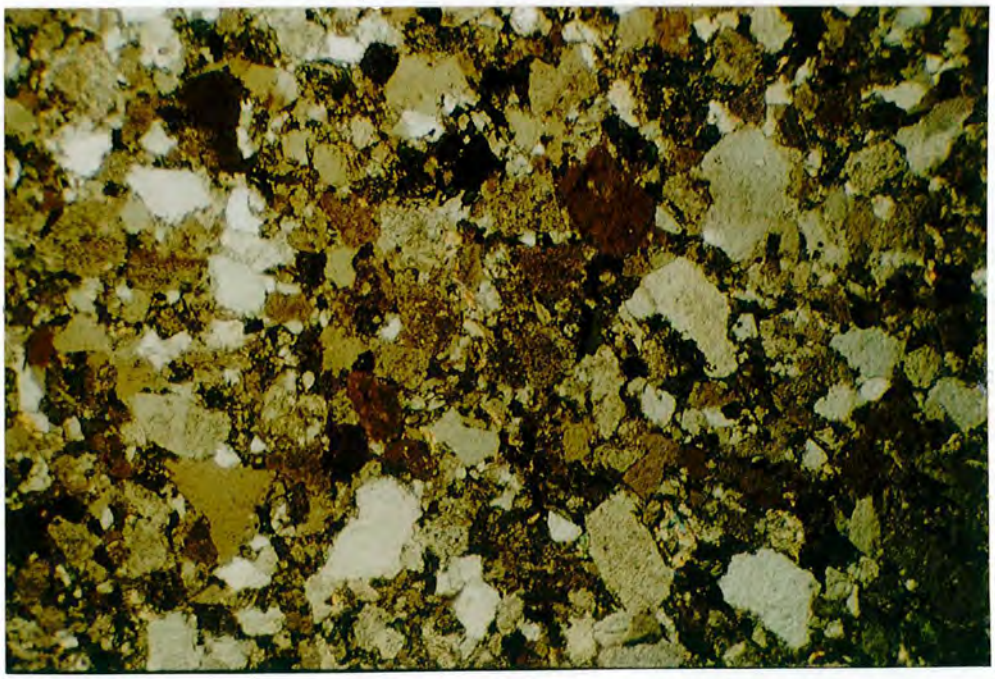


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PLATE 7.4 Bioclastic Limestone Clast, Mell Fell Conglomerate

Lithoclast grain from sandstones of the Dalemain Borehole. This limestone fragment contains common silicified fossil fragments within a microcrystalline carbonate matrix.

PLATE 7.5 Favosites Coral Clast, Mell Fell Conglomerate

Plate shows fragment of the tabulate coral, Favosites from a sandstone in the Dalemain Borehole core. The presence of this particular coral, and other limestone fragments (Plate 7.4) indicates that these limestone clasts are mainly Upper Ordovician in age and most probably sourced from the Coniston Limestone Group lithologies. Note minette fragment (lower left) - similar to Plate 7.6.

PLATE 7.6 Minette Dyke Rock Clast, Mell Fell Conglomerate

Plate shows large fragment of a minette dyke rock from a conglomerate matrix sample, Dalemain Borehole. Note crystalline, feldspar rich groundmass and common corroded biotite crystals (dark brown crystals). These minette dyke rocks, belonging to the Lamprophyre group of rocks, were intruded as narrow dykes over a circular area of 50 miles into the Silurian cover, centred on Shap Fell and probably associated with the intrusion of the Shap Granite. Significantly their presence both in the Shap Red Beds and Mell Fell Conglomerate indicates direct erosion of the Silurian.



PLATE 7.4.

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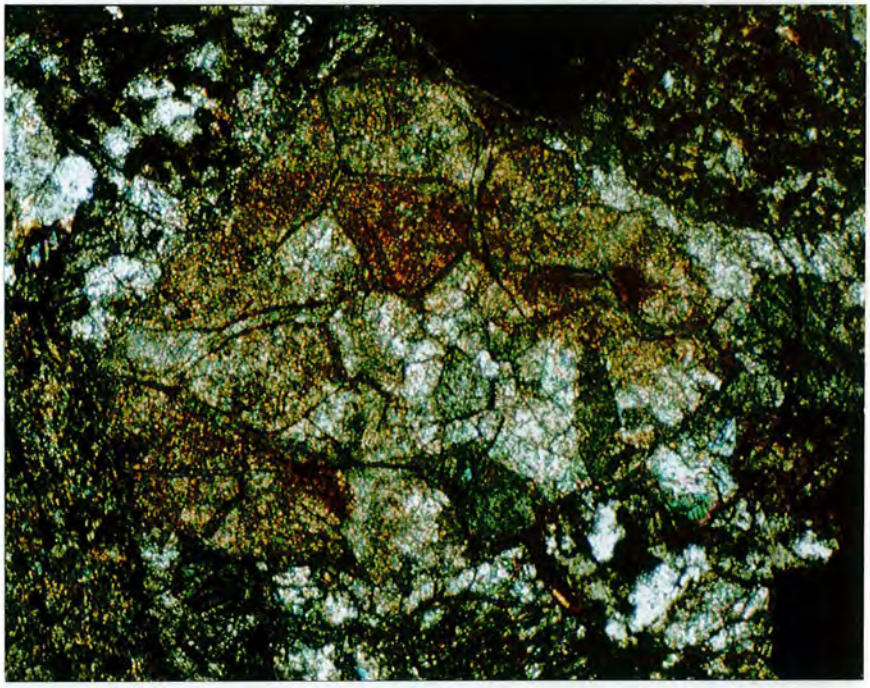


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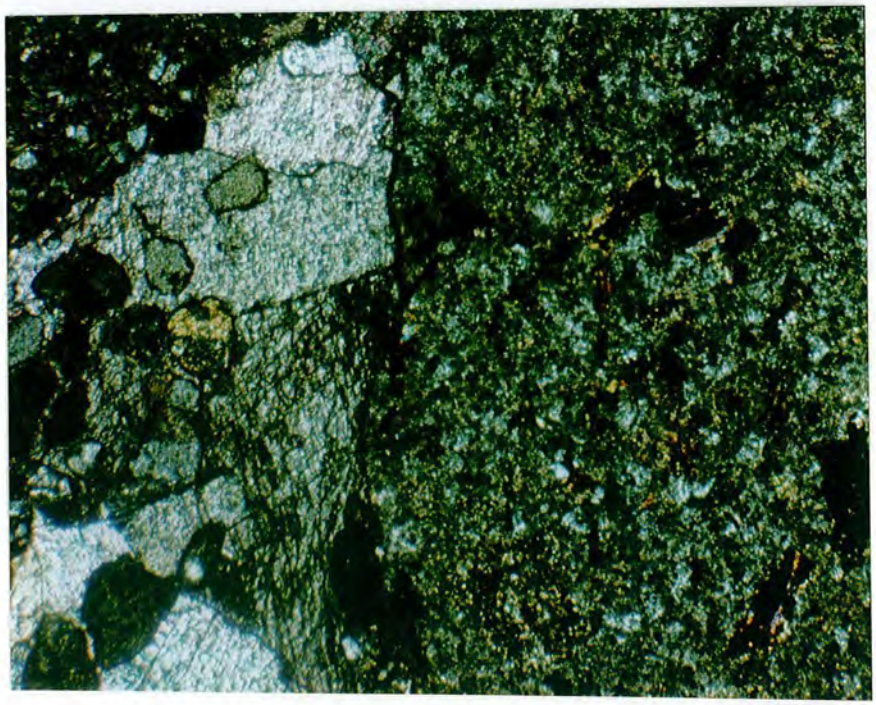


PLATE 7.6.

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PLATE 7.7 Flow Banded Tuff Clast, Mell Fell Conglomerate

Flow banded texture consisting of glassy groundmass with quartz and feldspar phenocrysts, the latter often heavily sericitised. Glass shards (dark, crystalline areas) are a common constituent suggesting an intraclastic origin. The greenish, fibrous mineral occurring as the rounded 'blebs' is probably chlorite. The sample is from a clast from facies Gm along the Ullswater Road section.

PLATE 7.8 Acidic Porphyritic Clast, Mell Fell Conglomerate

Plate shows a clast, probably from the Borrowdale Volcanic Group, composed of a microcrystalline groundmass comprising possible glass shards (dark mottled areas) and sanidine feldspar phenocrysts (lower right). The sample is from the Setterah Sike/Heltondale Beck locality.

PLATE 7.9 Basic Porphyritic Tuff Clast, Mell Fell Conglomerate

Plate shows probable clast of basic igneous composition, the field of view showing phenocrysts of pyroxene (lath-shaped crystal, weathered, lower left) and feldspar (larger lathe shaped crystals). This clast, from Setterah Sike/Heltondale Beck. In hand specimen, these clasts are often highly decomposed due to the weathering of feldspars (although some may be replaced by calcite), and may be typical of igneous clasts from the Eycott Volcanic Group.

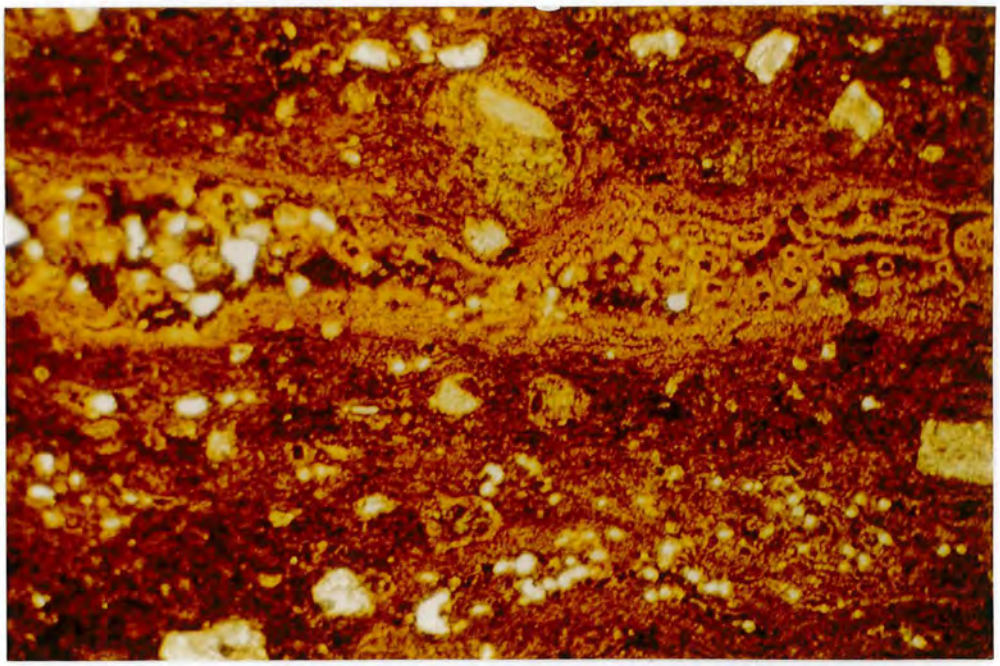


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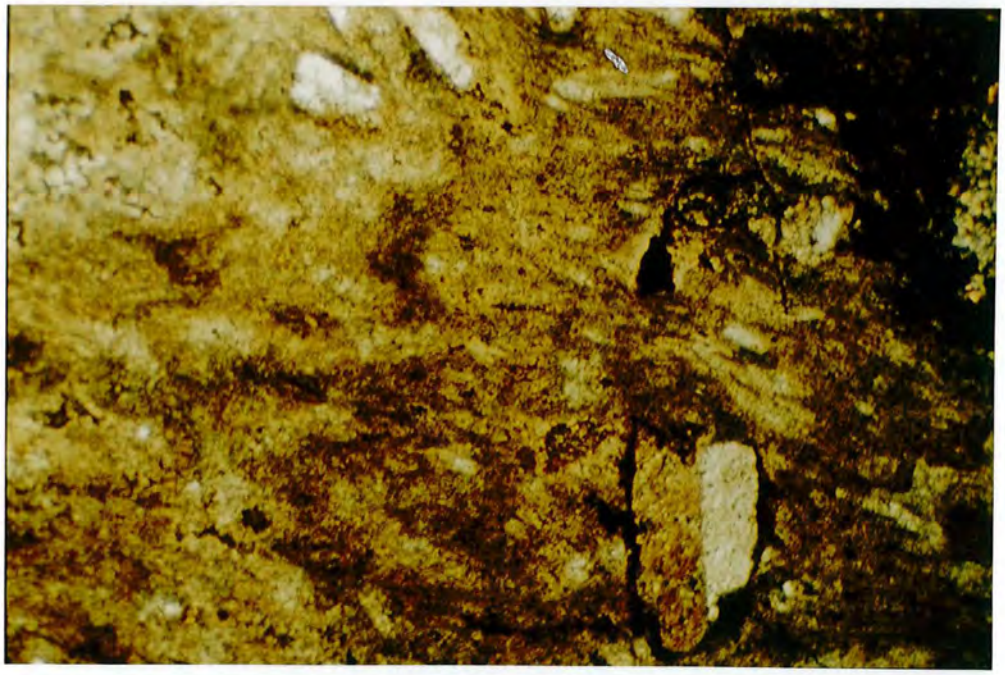


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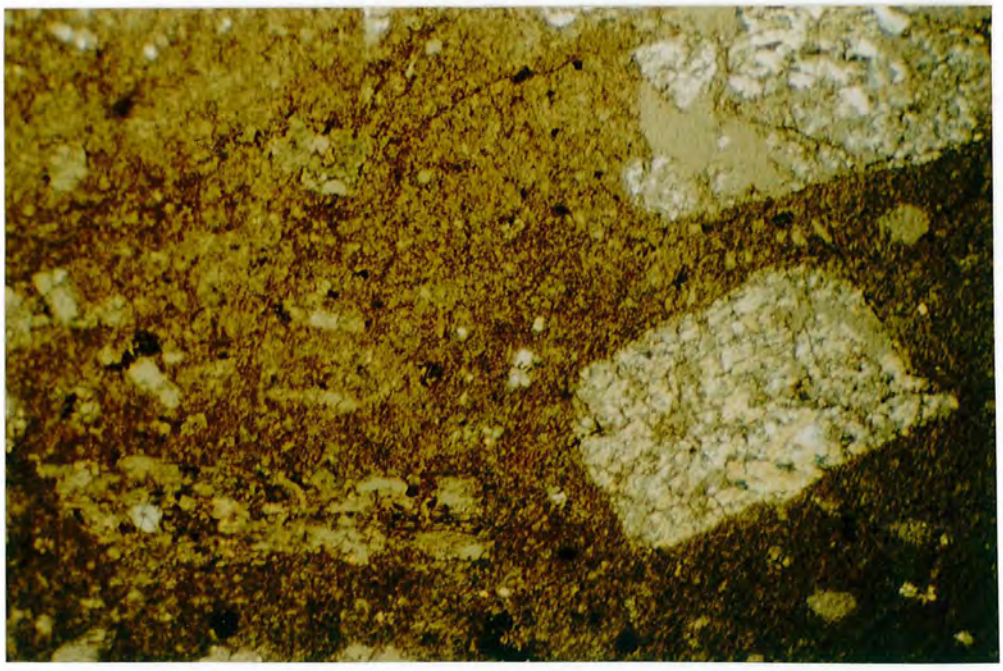


PLATE 7.9

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PLATE 7.10 Probable Andesitic Lava Clast, Mell Fell Conglomerate

Plate shows volcanic clast, from the Holyghyll Gorge Section. The groundmass contains an abundant 'felted-lath' texture of plagioclase crystals, similar to Borrowdale Volcanic andesite rocks. Calcite in the field of view has probably infilled amygdale-like voids, containing narrow neck features.

PLATE 7.11 Felsite Clast, Mell Fell Conglomerate

Plate shows typical view of a probable rhyolitic glass comprising grey polarising of possible quartz and feldspar crystals. At outcrop, these clasts are very characteristic, coloured pink-red and being hard and flinty. Sample from Holghyll Gorge. These clasts are thought to be derived from the Borrowdale Volcanic Group.

PLATE 7.12 Feldspar Crystals, Shap Red Beds

Plate shows twinned feldspar crystals from a pebbly sandstone sample from the Wasdale Beck section, Shap Wells. These crystals are the 'classic' pink crystals observed at outcrop, being characteristic of the Shap Granite, and thus indicate that the Shap Granite was exposed and supplying detritus at the time of Shap Red Bed deposition.

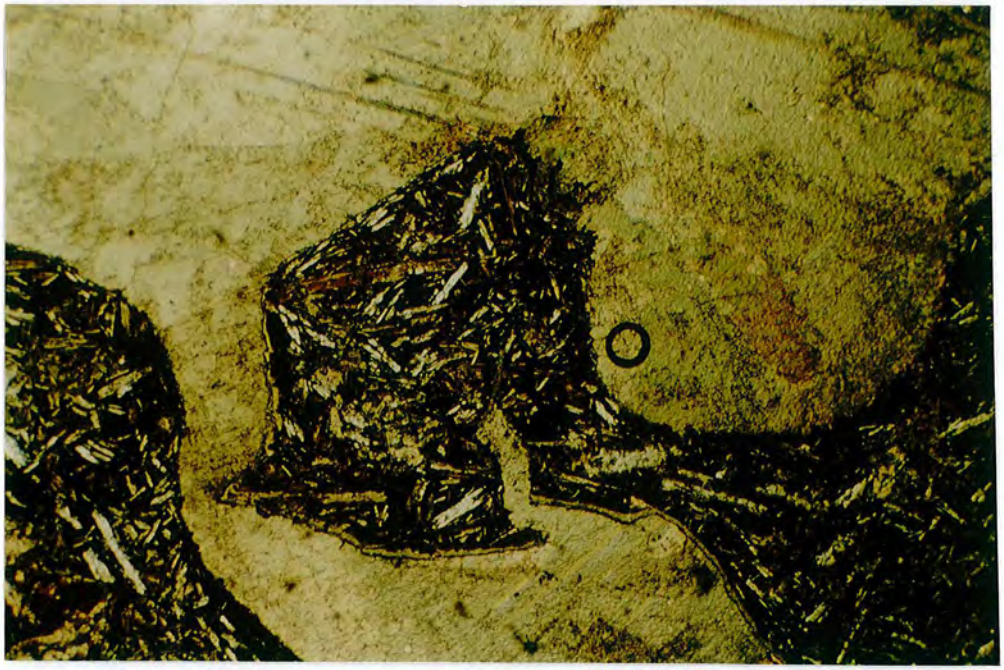


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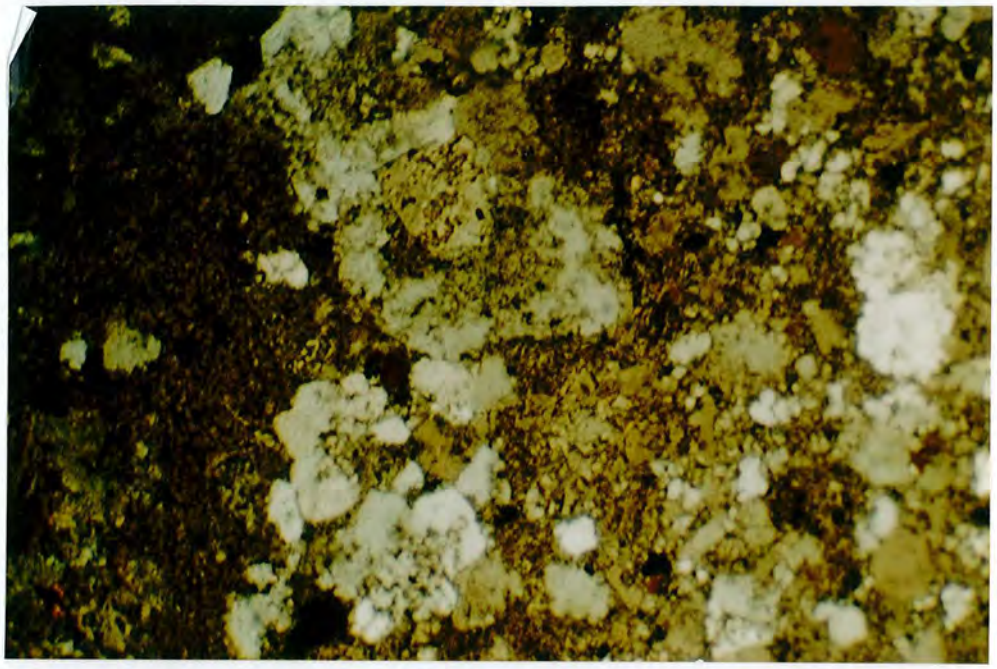


PLATE 7.11.

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PLATE 7.12.

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PLATE 7.13 Spherulitic Rhyolitic Clast, Shap Red Beds

Clast type very similar in lithology and composition to the felsite clast shown in Plate 7.11. This rock type, although from Beckside, Shap is also very common at the Wasdale Beck Section. The groundmass comprising radial spherules of quartz and feldspar suggests a high degree of alteration and suggests that these clasts may have been derived from the altered Borrowdale Volcanics, associated with the Shap Granite aureole.

PLATE 7.14 Ignimbrite Clast, Shap Red Beds

This plate shows a quartz rich microcrystalline groundmass, locally altered to sericite (feldspar), and containing abundant glass shards (dark areas), these with the characteristic 'fiammé', texture. The rock is probably an ignimbrite or welded tuff, from the Borrowdale Volcanic Group.

PLATE 7.15 Altered Rhyolite Clast, Shap Red Beds

Plate shows rock type comprising a highly altered groundmass with quartz phenocrysts, from the Wasdale Beck Section, Shap wells. Considering that other clasts from this section were probably sourced from the altered Borrowdale Volcanics, associated with the Shap Granite aureole, this rock is probably a hornfelsed rhyolite.

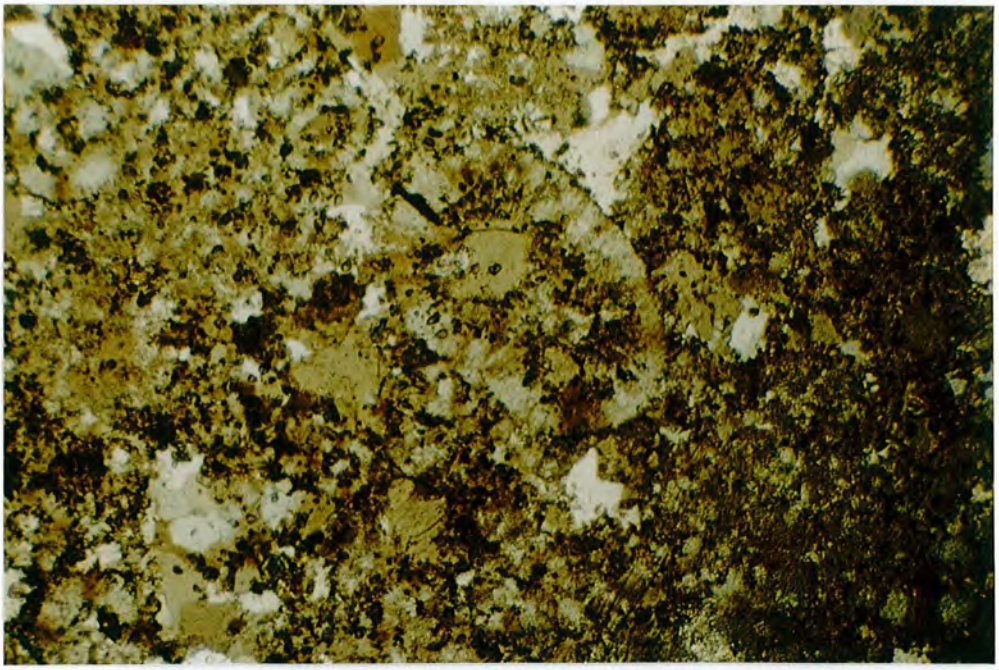


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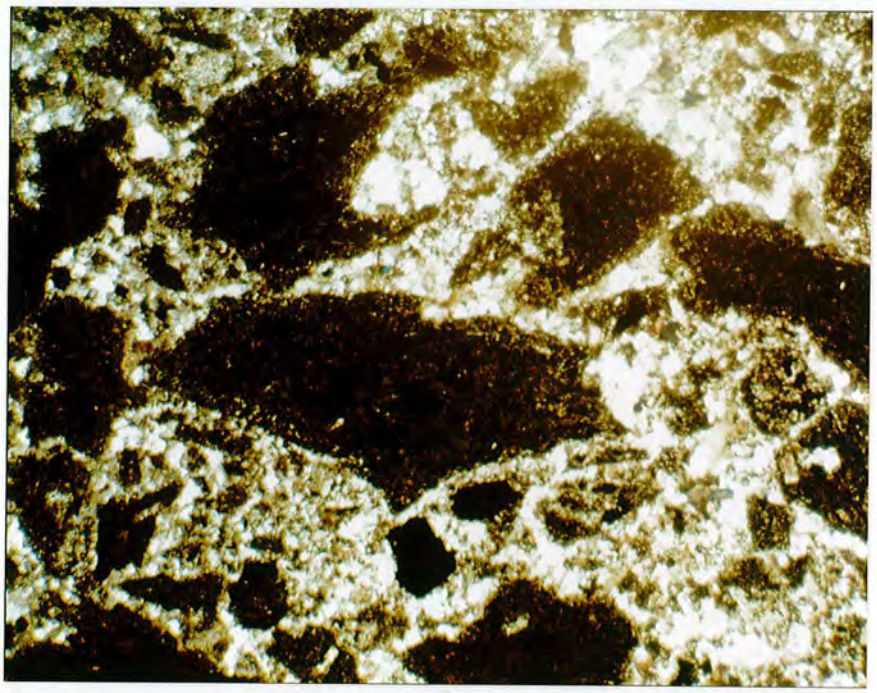


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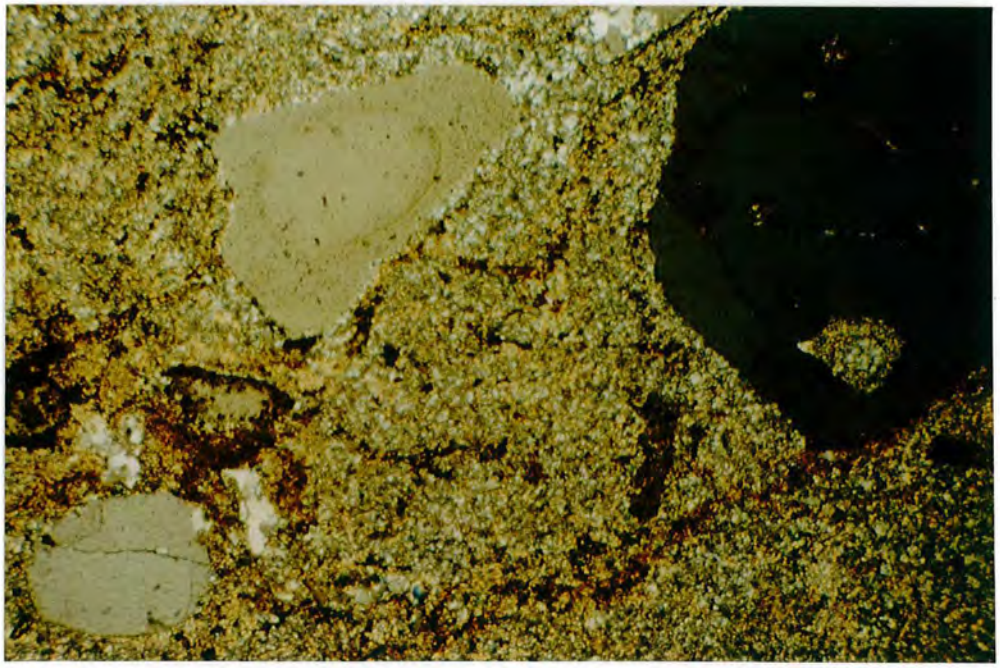


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PLATE 7.16 'Spotted Slate' Clast, Cross Fell Clastic Rocks

Slate clast fragment from a sandstone sample, Cross Fell Clastic rocks (Grey Mares Tail Section) comprising possible (?) andalusite crystals and characteristic of spotted slate rock types from the Skiddaw Slate aureole. It is suggested that these may have been derived from the Skiddaw area, although it is possible, given similar rock types around the Alston Block granite aureoles, that they may have been sourced from the Murton Formation of the Cross Fell Inlier.

PLATE 7.17 Possible Quartzite Clast, Cross Fell Clastic Rocks

Plate shows an example of a 'Vein quartz' clast from the Cross Fell Clastic Rocks (Sink Beck Section), the plate possibly being more of a quartzite and derived from the Skiddaw Slates.

PLATE 7.18 Quartz Arenite Clast, Cross Fell Clastic Rocks

Plate shows a typical fine to medium grained sandstone clast (from the Cocklock Scar Section. In hand specimen, these sandstones are red coloured (Quartz rich at outcrop) and are coarser in grain size and lithologically different to the Silurian greywacke clasts from the West Vale of Eden areas.

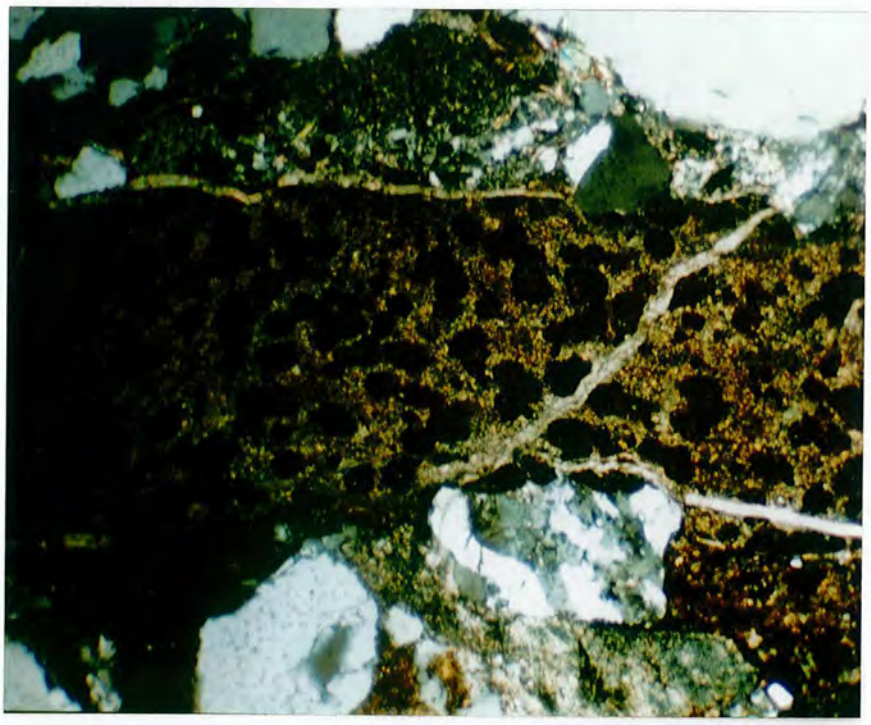


PLATE 7.16.

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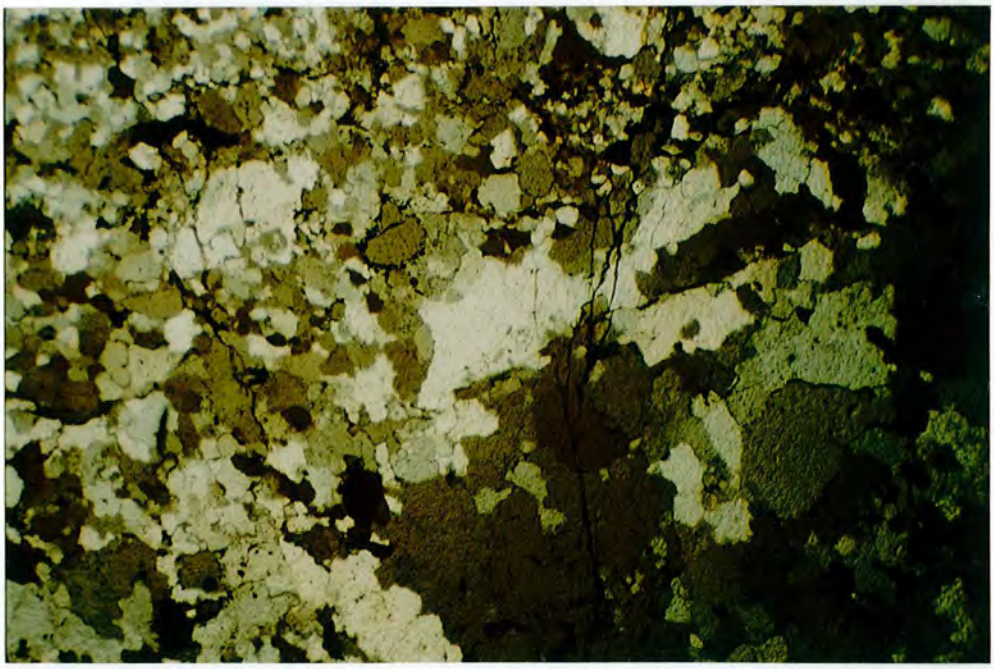


PLATE 7.17.

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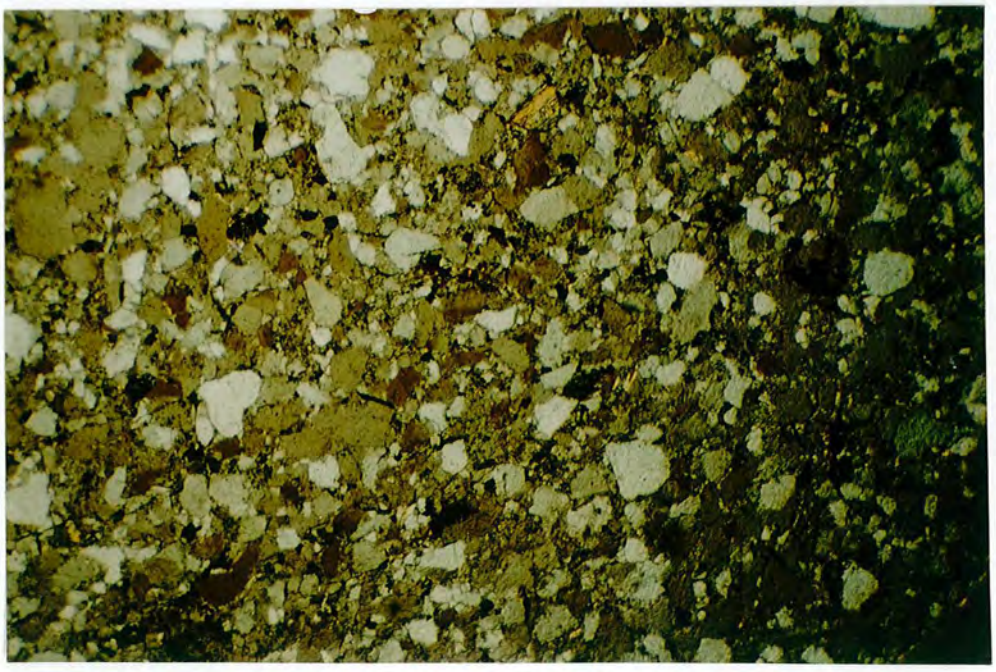


PLATE 7.18.

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PLATE 7.19 Altered Acidic Porphyry Clast, Cross Fell Clastic Rocks

This plate illustrates a quartz rich igneous rock containing feldspar phenocrysts and ?weathered hornblende (Centre top). Igneous rock clasts are relatively rare in the Cross Fell Clastics, although within sandstone thin sections, quartz rich fragments may have been derived from such quartz rich igneous clasts.

PLATE 7.20 Altered dolerite clast, Cross Fell Clastic Rocks

Plate shows an igneous clast comprising a groundmass of altered lath-shaped feldspars. Large euhedral crystals may be ilmenite, replaced by Leuxocene. This rock type is tentatively interpreted as an altered dolerite type rock, possibly derived from the dolerite sills reported from the lower Ordovician by Burgess and Wadge, (1974).

PLATE 7.21 Pelite Sedimentary Rock Fragments, Cross Fell Clastic Rocks

Plate shows photomicrograph of a sandstone demonstrating the presence of locally common 'pelite' or slate rock fragments suggesting derivation either from the Skiddaw Slates or Murton Formations.

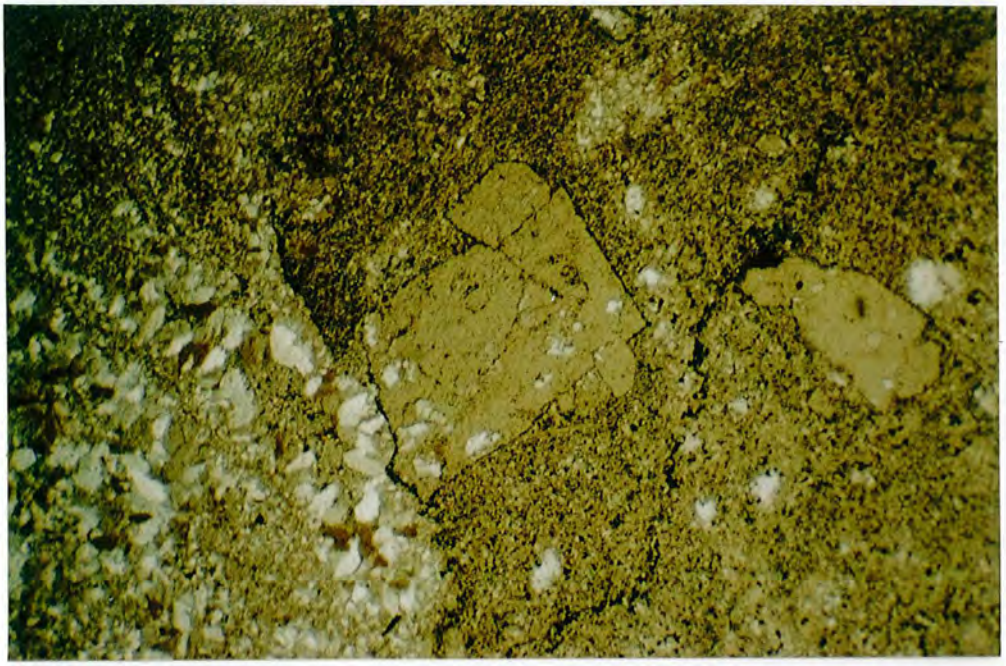


PLATE 7.19.

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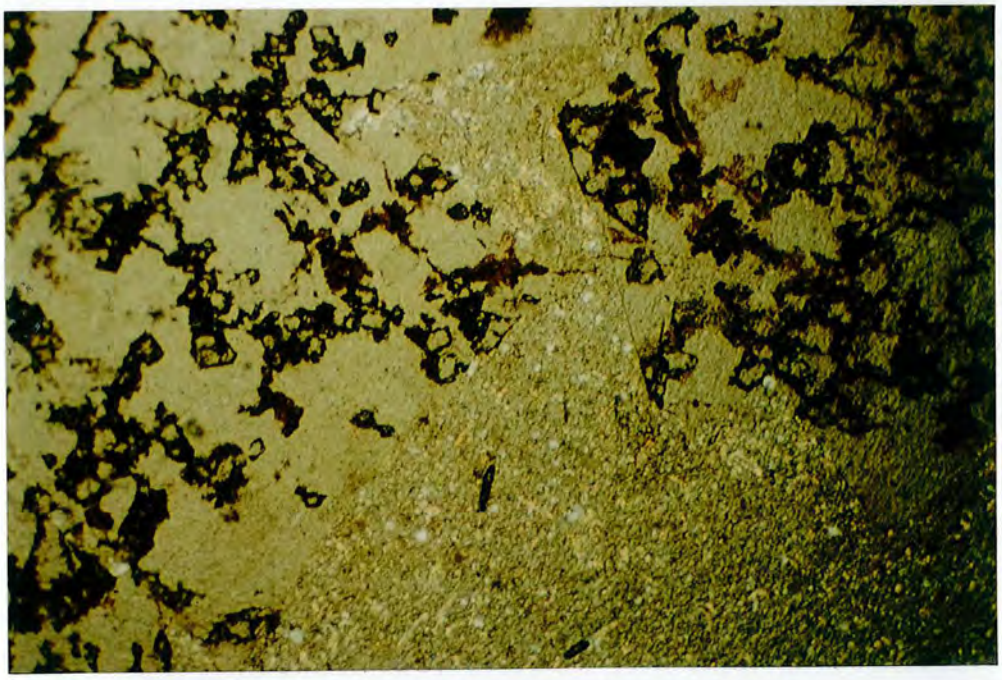


PLATE 7.20.

1mm



PLATE 7.21.

1mm

PLATE 7.22 Probable Granite Clast, Cross Fell Clastic Rocks

Plate shows rare intergrown quartz, feldspar, musovite and biotite most probably being derived from a granitic source rock. These clasts could have been equally sourced from the Lake District as well as the Alston Block granites.

PLATE 7.23 Granite Clast, Cross Fell Clastic Rocks

Plate shows muscovite spherules intergrown with quartz crystals, this texture, it is suggested, being comparable to the textures described from the Eskdale Granite by Firman (1978).

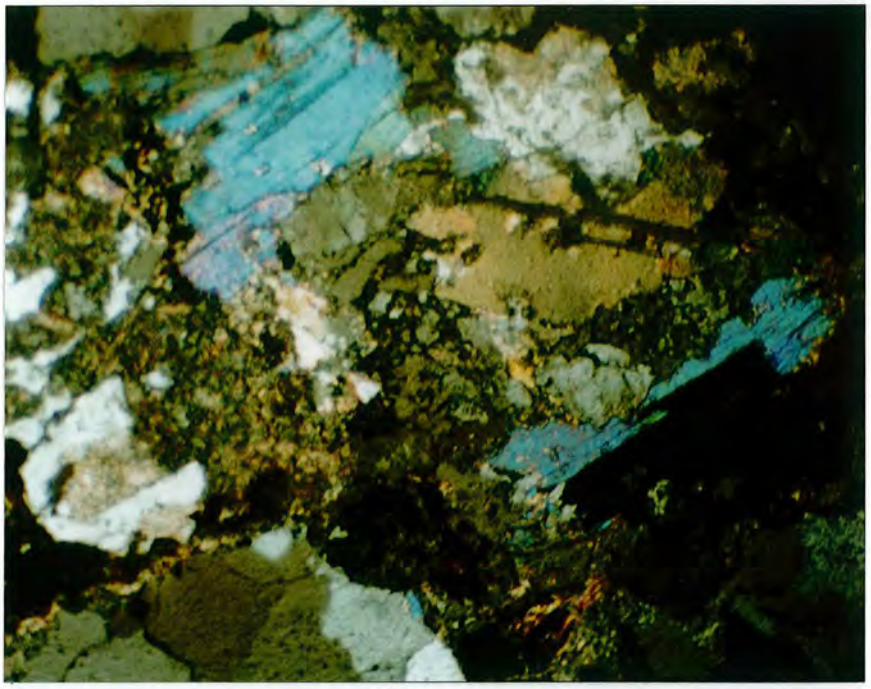


PLATE 7.22.

1mm



PLATE 7.23.

0·5mm

PLATE 7.24 Weathered Granite Clast, Cross Fell Clastic Rocks

Plate shows photomicrograph of the POLY 1 sample (Polygenetic Conglomerate, Grey Mares Tail see Plate 6.1), interpreted as weathered granite, being very similar both in chemistry and mineralogy to weathered Weardale Granite, recorded from the Rookhope Borehole. The highly fractured nature of this sample is probably due to the highly decomposed state in hand specimen and ?as a result of nearby faulting.

PLATE 7.25 Very Fine Grained Micaceous Sandstone, Cross Fell Clastic Rocks

Typical altered very fine grained silty micaceous sandstones, characterised in hand specimen by a 'phyllitic lustre'. These clasts were probably derived locally from Skiddaw Group Slate lithologies.

PLATE 7.24.

1mm

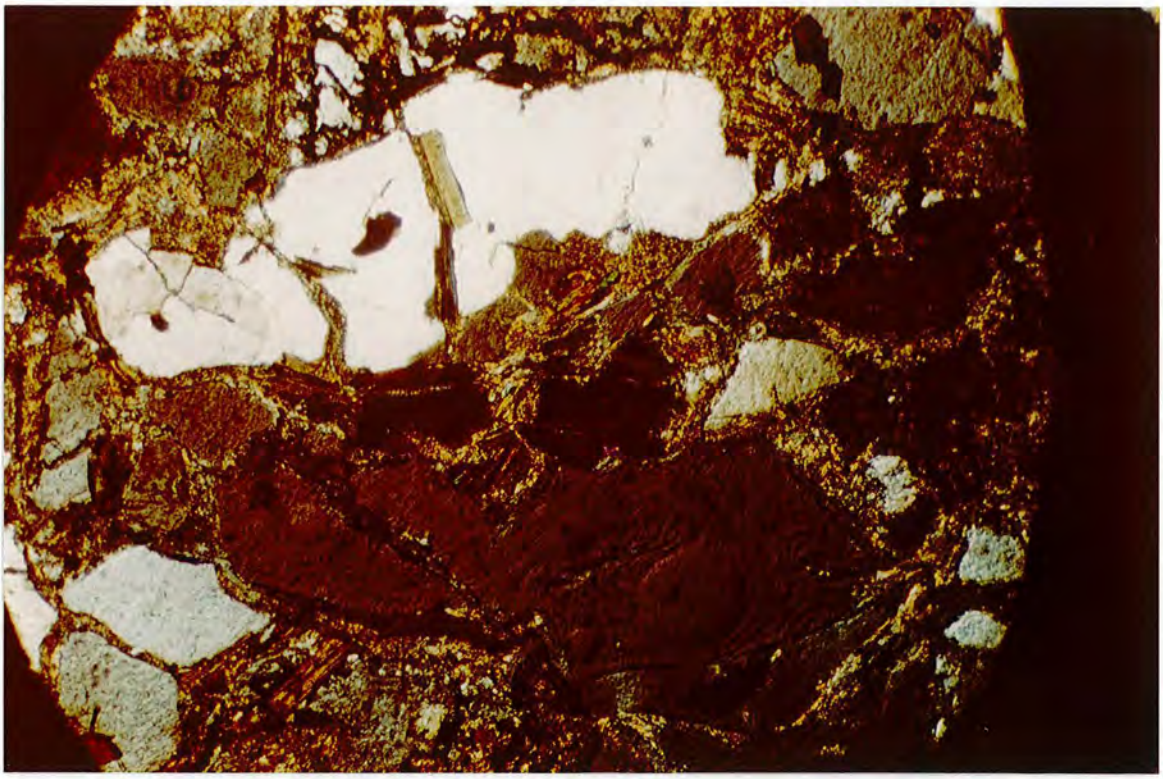


PLATE 7.25.

1mm.



CHAPTER 8: RAVENSTONEDALE (PINSKEY GILL BEDS AND 'SHAP CONGLOMERATE')

8.1 INTRODUCTION

In his classic study of the Lower Carboniferous of north west England, Garwood (1912) took the region about Ravenstonedale village to be his type area. The best section near the base of the Carboniferous he found at Pinskey Gill and named the basal part of the Lower Carboniferous in the region the Pinskey Gill Beds. These were placed within the *Athyris glabristria* zone which correlates with Vaughan's (1905) zone for the Bristol district.

Capewell (1955) considered the Pinskey Gill Beds to be laterally equivalent to his Lower Conglomerate Group of the Shap region and further suggested that the so-called 'Shap Conglomerate' seen at the top of the Pinskey Gill Beds could be equated with his Upper Conglomerates.

Johnson and Marshall (1971) established a Tournaisian age for the Pinskey Gill Beds and Ramsbottom (1973) included them within his 'major cycle I' at the base of the Carboniferous. The Pinskey Gill Beds are now placed within the Courceyan stage which is considered to be equivalent to the Tournaisian in northern Britain and which may include the uppermost part of the Old Red Sandstone (George et al, 1976; Ramsbottom and Mitchell, 1980). More recent work by Varker and Higgins (1979) and Higgins and Varker (1982) has established a mid Courceyan age for the Pinskey GIll Beds using conodont faunas.

In the present work, three main sections have been studied and these have been supplemented by borehole sections put down by Sheffield University (Holliday et al, 1979) and kindly lent by the British Geological Survey.

8.2 MEASURED SECTION DESCRIPTIONS

8.2.1 Pinskey Gill (NGR NY 698039; (Figures 8.1, 8.2; Plates 8.1, 8.3)

This is the type section for the Pinskey Gill Beds and exposes approximately 15.5m in vertical section. At the base, immediately above the unconformity (Section 2.1.2), green to buff coloured very fine-medium grained silty and laminated sandstones, 1.75m-2m thick, are exposed at stream bed level. In thin section monocrystalline quartz grains are distinctly more abundant than polycrystalline quartz and take up more than 70% in the modal analysis, porosity being cemented by meniscus cements reflecting cementation at point contacts. These features may be indicative of near-surface cementation in the vadose zone (cf. Scholle, 1978). Rare sedimentary rock fragments include fine grained greywacke sandstones and shale clasts, the latter being locally compacted to pseudomatrix.

Dark grey bioclastic limestones, at least 1.8m thick, form the base of the main part of the section after a short gap. Above, these limestones become argillaceous and here, Spirifer pinskeyensis is abundant (plate 8.3) with less common specimens of Athyris sp. also being present (Garwood, 1912 classified Athyris as between A. glabristria and A. concentrica). Spirifer pinskeyensis is unique to

this area as Garwood (1912 p. 497) reports; it is not known in Vaughan's (1905) type Bristol district. Garwood also notes Orbiculoidea at this horizon. Sampled thin section of the top of this horizons shows it to be largely composed of a mosaic of dolomite rhombs containing silt grade detrital monocrystalline quartz grains.

The central part of the section was divided into two parts for ease of logging, both parts being correlated by a distinct orange-buff coloured weathering marker horizon (Plate 8.1). Both parts are characterised by silty, micaceous sandstones and siltstones, although in thin section they appear as a mosaic of finely crystalline dolomite with scattered detrital quartz. This central part contains a sequence, 1.5m thick, of thinly bedded, sharply-based sandstone units interbedded with shale horizons up to 15cm thick. Towards the top (see Plate 8.1) sandstones show a slight coarsening and upward thickening trend. At outcrop rocks are laminated and streaked with carbonaceous matter with common pyrite cubes up to 2mm across.

Silty sandstones have yielded abundant bivalves, mostly Myalina sp. and (?) Nuculana sp. Myalina belongs to the order Myoida being thin-shelled, inequivalved and having well developed siphons for shallow burrowing (Clarkson, 1979). Three horizons containing these bivalves are suggested (as noted in Figure 8.2), the top horizon being immediately below the orange marker bed. At the base of 'log B', the basal silty sandstone fines up into a horizon packed full of probable rootlet remains.

The orange marker bed is seen at the top of both sections and consists of a basal part, 30cm thick, with carbonaceous streaks and few fossil remains. This basal unit grades up into 20-30cm of a 'honey-combed' dolomite rock which is packed with mollusc remains of which gastropods are the most abundant (Naticopsis sp. according to Garwood 1912). According to Clarkson (1979) and supported by thin section, these gastropods are thin-shelled with a wide aperture. Thin section of this horizon shows it to consist of a non-ferroan dolomite matrix with bioclasts composed of non-ferroan calcite. Calcareous vugs are present in the top part of the bed. Fine grained laminated sandstone, 55cm thick, above the marker bed in 'log B' contains convolute laminations associated with probable water escape. Grazing traces are present 10cm above the base of this unit.

The main section continues downstream from the second bend in the stream. Argillaceous limestones and dolomitic limestones, up to 5.5m thick, are interbedded with shale horizons 30cm thick. Three horizons contain trace fossils, interpreted as probable 'grazing trails' one section showing the trails in plan view. In plan, trails are sharply to gently meandering features with curved ridges 3.2mm apart, convex in the direction of travel and forming indented outer margins. Typically, the trails are 0.5cm to 1cm wide and reach more than 43cm in length. Short, straighter trails are usually more indented than the longer and smoother trails although the internal features are the same. These trace fossils are probably the form Teinidium formed by grazing 'slug-like' feeding gastropods (G.A.L. Johnson Pers. comm.). In many ways the trials are similar to Eione (Cuvier's order Abranchiata) and possibly Cosmoraphe in

containing bead-shaped rings but containing no deep sulcation on the upper surface. Significantly, however, the traces do not overlap, a factor which points to a grazing trace, made by mobile deposit feeders at or under the substrate surface, as opposed to a crawling trace (cf. Frey and Pemberton, 1984). One thick limestone bed, 2m-3m thick, contains crenulated laminae along one horizon, probably formed by algal growths.

Varker and Higgins (1979) in sampling this part of the section for conodonts found an important horizon (their PG3) approximately mid-way through the large limestone bed. On separation this produced a 'heavy' fraction consisting of 'muscovite, pyrite, clusters of quartz grains contaminated with heavier minerals, fish fragments, coprolites and a total of 91 conodonts'. Conodonts are dominated by Bispathodus aculeatus aculeatus, B. stabilis and Clydagnathus unicornis.

Above the limestones, laminated, light grey coloured shales, 1.2m thick, which according to Garwood (1912) contain plant material, are interbedded with dolomite horizons, packed with broken mollusc fragments. One short-spired gastropod was noted, while under the microscope some shells may be brachiopods. At the top of the section, 50cm of shales are interbedded with coarser grained horizons with grazing trails visible on lower bedding plane surfaces.

A large gap, possibly 29.5m calculated from Holliday et al's (1979) thickness of 45m, is present until a point a few metres north of the road bridge is reached. Here, an extremely weathered outcrop consists

of red pebble-granulestone conglomerate with pink orthoclase clasts up to 1.5cm across. This is the so-called 'Shap Conglomerate' named by Garwood (1912) and subsequently described by many authors (e.g. Johnson and Marshall, 1971).

8.2.2 Flakebridge (NGR NY 666048; Figure 8.3)

The basal 3.5m of the Pinskey Gill Beds is exposed here a few metres south of the farmhouse. Thinly-bedded dolomitic siltstones and sandstones are similar to those described at Pinskey Gill. Above the unconformity pebbly sandstones, 10cm thick, contain locally derived clasts from the Bannisdale Slates and possible litho-clasts of the unconformity brecciated zone, 0.5cm across (see Appendix 3). In thin section, unimodal quartz is more abundant than polycrystalline quartz taking up 58.8% of grain types. Dolomite cement, possibly replacing an original calcite cement, produces displacive grain fabrics. The probable breciated zone 'calcrete' clasts take up over 21% of grains and appear identical to those described in the unconformity zone in Section 2.1.2. Slate fragments and relatively rare volcanic grains are also present.

Above base, fine grained dolomitic sandstones contain groove casts producing 'cross-cutting' ridges on one bedding plane surface. Also noted at this horizon were small 'hopper-shaped' crystals, their distinctive outline suggesting they may be pseudomorphs after halite. Near to the top, dolomitic siltstones contain scattered quartz grains, molluscan remains, carbonaceous debris and possible 'peloidal' grains up to 7cm across (?reworked oncolites).

8.2.3 Scar Sikes (NGR NY 683041; Figure 8.4)

A short 2m thick section exposes the very base of the Pinskey Gill Beds close to Scar Sikes Farm. Black and slightly carbonaceous, unfossiliferous shales, at least 50cm thick, are overlain by a vuggy dolomite cemented conglomerate. Under the microscope scattered quartz grains, rare volcanic rock fragments, chert and possible 'calcrete' clasts (?from the unconformity zone) are enclosed in a dolomitic matrix. Abundant shell remains are present and include brachiopods which Turner (1959) identifies as Camarotoechia mitcheldeanensis.

8.2.4 Shawmire (NGR NY 721028)

Poorly exposed quartz arenites, which under the microscope are medium grained sandstones containing monocrystalline quartz grains cemented by patchy quartz overgrowth cement, possibly equate with the Shap Conglomerate. According to Turner (1959) the section here was once more extensive and infact the section may probably be the same as that in Thackwaite Gill (Johnson and Marshall, 1971).

8.2.5 Wyegarth Gill Boreholes (Figure 2.3, 8.5; Plate 2.2)

In order to investigate the unexposed parts of the Dinantian succession in the Ravenstonedale district and to prove the sequence from the base of the Stone Gill Limestones (of Chadian age) to the basal unconformity, six shallow boreholes were drilled by Sheffield University along Wyegarth Gill (Holliday et al., 1979). The author was fortunate enough to describe three of these cores and extends his thanks to the British Geological Survey.

8.2.5.1 Borehole no.5 (NGR NY 71560304)

The borehole cored through a total thickness of 6m of Pinskey Gill Beds above the unconformity zone (Figures 2.3, 8.5, Plate 2.2). Immediately above base green-grey coloured micaceous sandstones grade into light green-grey coloured mudstones with shale clasts up to 2cm. Small core slabs show that sandstones are frequently wispy laminated and convoluted in places.

Above the 9m mark, argillaceous limestone, 6.5cm thick, overlies a laminated siltstone horizon. Crenulated laminations above base, 0.5cm thick with relief up to 1cm, may have been produced by algal growth (stromatolites) and compare to those described at outcrop in Pinskey Gill.

Between 6.6m and 4.2m core recovery was good. Here silty sandstones are laminated and cross-laminated and are interbedded with thin, 2cm-3cm, bioturbated horizons consisting of transverse sections through trace fossils produced by the burrowing activity of organisms. Figure 8.6 is a direct tracing of a 30cm portion, 60cm from the top of the borehole. It demonstrates certain points of interest which are common to this part of the borehole and discussed below.

Repeated bioturbated horizons between essentially cross-laminated sediments are related to differing energy levels and flow stage within the environment. Cross-laminated horizons suggest deposition was relatively more rapid and hence the rate of infaunal reworking was less simply because organisms colonising the substrate could not keep pace

with a higher rate of sediment deposition. Escape structures, seen at position 'A' in Figure 8.6, demonstrate horizons where organisms climbed to higher levels through newly deposited sediment. The reader is referred to Frey (1978) for a detailed discussion for comparable features.

In contrast to this, higher rates of infaunal reworking, i.e. intense bioturbation, are associated with lower energy levels and slow rates of deposition. Thus organisms have time to rework and 'digest' the substrate. Position 'B' in Figure 8.6 is an example of such intense infaunal reworking. Chamberlain (1978) discusses thicker, rapidly deposited units in which the tops are rapidly colonised after deposition rates had declined. Along these horizons any sedimentary structures would probably be obliterated. A return to relatively slower rates of sedimentation above allows greater infaunal reworking. The author suggests position 'C' is a good example of such a condition.

Howard (1978) states four typical cases in which varying rates of infaunal reworking can be related to differing rates of deposition. Slow continuous deposition gives rise to complete bioturbation as infaunal reworking is allowed to keep 'pace' with deposition. Rapid continuous deposition deposits short term events and mainly thicker units characterised by cross-laminated sediment with burrow-escape structures.

Slow discontinuous deposition on the other hand would expect to give rise to cyclic units recognised by textural changes. In this way

infaunal reworking is intense but finer sediment can be overlain by coarser sediment in which different organisms may inhabit. Thus textural changes are important features. Intermittent deposition and erosion produces discrete horizons with no bioturbation present, interbedded with horizons characterised by intense reworking by organisms. An example cited is the case of storm deposition and erosion with organisms re-colonising a substrate above an erosion surface produced by storm activity. In the case of positions 'A, B, C', it seems probable that intervals of rapid deposition alternated with periods of slower deposition with rapid colonisation of the substrate after deposition rates had declined.

An idea of the kind of organisms producing this profile can be found in the body fossils described for Pinskey Gill. Abundant shallow burrowing bivalves, Myalina sp. and semi-infaunal bivalves, Nuculana sp., are present throughout the section and would give rise to vertical burrows in section. Ridges and grooves along the bases and tops of bioturbated horizons ('hyporeliefs' and 'epireliefs' respectively, in the terminology of Basan, 1978) could easily have been produced by feeding gastropods. Further, semi-infaunal burrowing bivalves (cf. Clarkson, 1979) are known to construct escape structures similar to those seen in the core.

8.2.5.2 Borehole no. 4 (NGR NY 71630323, Figure 8.5)

Borehole no.4 lies stratigraphically above borehole no.5 and cores through the top 29.9m (maximum thickness) of the Pinskey Gill Beds. The top 11.3m of core belongs to the 'Shap Conglomerate'. No core was

available between 40.8m and 18.9m (below ground surface) although Holliday et al (1979) record 5.5m of argillaceous limestones and sandy limestones and dolomite.

The basal 8m shows good recovery comprising lithologies similar to those present in the Pinskey Gill stream section and Borehole no.5. Limestone units occupy the top part while the basal 4m consists essentially of silty mudstone with interbedded and interlaminated fine grained sandstone horizons. Three bioturbated horizons occurring between cross-laminated horizons were noted. One horizon, contains both lenticular bedding (3.7m above base) and water escape structures. Above here, argillaceous limestones with interbedded sandstones and siltstones occupy the next 4m of core. The sandstone units locally contain lenticular bedding with some flaser bedding also noted in places.

At 18.9m a sharp change in lithology is associated with the base of the Shap Conglomerate. At the base granule-conglomerate, 6cm thick, fines up into medium-coarse grained, green-buff coloured calcareous sandstone 17cm thick. Clasts within the conglomerate are composed of vein quartz and possible acidic igneous rock fragments. Significantly no pink orthoclase clasts were observed.

The sandstone unit contains plant debris concentrated along cross-laminae.

Approximately 1m above the base of the Shap Conglomerate pebble conglomerates, 29cm thick, contain pebbles up to 4cm across, composed

mainly of porphyritic acid volcanic rock types. Again this unit fines up into coarse grained sandstone. Very coarse grained sandstones at 15.2m (below ground surface) contain sub-rounded to sub-angular pebbles composed of acidic volcanic rocks and vein quartz. Thin sections from this horizon contain displacive calcite cement with little evidence for any detrital clay present. Rock fragments are common and take up 62% of grain types, with over 54% of these being felsite volcanic fragments with some flow banded tuffs also present. One grain is more basic in composition consisting of pyroxene phenocrysts set in a fine grained groundmass. Granule size carbonate grains, containing detrital quartz may reflect erosion of the 'unconformity brecciated zone'. The clast compositions suggest a derivation mostly from Borrowdale Volcanic Group lithologies.

The top part of the borehole consists largely of broken core but some slabs show that pebble conglomerates are the dominant lithology with maximum clast size not exceeding 3cm. At the very top sandstones fine up from the conglomerates below.

8.2.5.3 Borehole no.2 (NGR NY 71850335, Figure 8.5)

In borehole no.2 pebble conglomerates comprise only 60cm out of the total thickness of the core (26m). The majority of the core is sandstone, most probably belonging to the Shap Conglomerate, as the interbedded limestone/siltstone lithology typical of the Pinskey Gill Beds are apparently absent.

A conglomerate unit at the base erosively overlies cross-laminated siltstone which contain plant debris aligned along laminae. Vein quartz clasts up to 3cm across are present within the conglomerate.

Sandstones throughout this core are predominantly cross-bedded and arranged in fining upward sets up to 1.5m thick, overlain by silty mudstones. One set, 23.6m below ground surface, contains green coloured mud intraclasts aligned along the base with plant debris concentrated along the foreset laminae, some identified as Lepidodendron (H. Johnson, pers. comm.). A rhynchonellid brachiopod was recorded at 27.4m (below ground). Thin section of these sandstones show that rock fragments are more abundant than detrital quartz and include greywacke sandstones, chert and pelite grains. Pseudomatrix, comprising deformed mud intraclasts, is present with pores partially cemented by patchy quartz overgrowth cements. These sandstones are predominantly red in colour, although mudstone horizons are locally reduced green in colour, possibly due to the inclusion of plant material.

Near the top of the core, silty mudstone becomes the dominant lithology, these containing minor cross-laminated silty sandstone units, again containing common plant remains.

Holliday et al. (1979) indicate that there is a conformable junction with the overlying Stone Gill Limestones, proved in Borehole No:1 (not described by the author), the interbedded sequence containing thin limestones and shelly siltstones.

8.2.6 'Pinskey Gill Beds' in the Shap area

In the Shap area, deposits which are lithologically similar to the Pinskey Gill Beds at Ravenstonedale, are exposed at Shap Summit, (Figure 3.13; Plate 8.2) and as far as the author believes this is the first time they have been considered to be similar to the Pinskey Gill Beds. Short Sections at Scoutgreen Crossing (Figure 8.7) and at the top of Micklegill (Figure 3.6; Capewell's, 1955 'Upper Conglomerate') equate with the same stratigraphic level and could therefore be laterally equivalent to the Pinskey Gill Beds as well. Similarly they could be representative of the 'Shap Conglomerate', although the latter appears to be a distinctive facies (characterised mostly by sandstone and silty mudstone) which may be restricted to the Ravenstonedale area.

8.2.6.1 Shap Summit (Figure 3.13; Plate 8.2)

At the top of Shap Summit, a 2m thick section comprises 75cm of laminated to well bedded medium grained argillaceous and dolomitic sandstones, which are sharply overlain by 1.25m of yellow-buff coloured dolomite rock packed with indeterminate moulds of bivalves and gastropods (?Naticopsis, very similar to the forms described at Pinskey Gill). Vugs, some being filled with calcite are locally up to 7cm across. The base (15cm thick) of this dolomite unit is sandy and contains angular vein quartz clasts up to 1.5cm across. The Pinskey Gill Beds at this section are at least 8m thick, (being underlain by a gap of 6m) overlying the Shap Red Beds (described in Chapter 3).

8.2.6.2 Scoutgreen Crossing (Figure 8.7)

Two short sections (4m, 4.3m thick) outcrop close to the railway

line near Scoutgreen Crossing (NGR NY 593082) and comprise light green-grey coloured well cemented calcarenite-conglomerate units, up to 1.75m thick. These contain a variety of clast types (up to 1cm across) including vein quartz, chert, ignimbrite, sandstone (intraclastic), pyrite nodules (limonitised), framboidal pyrite crystals up to 0.5cm and rare indeterminate brachiopods (?rhynchonellids). These deposits are interbedded with light green-grey and locally black coloured silty mudstones, locally containing highly contorted laminae and pyrite nodules up to 3cm across (Plate 8.4).

8.2.6.3 Micklegill Beck (Figure 3.6)

At the top of Micklegill Gill Beck, at least 7m of green-grey coloured pebble-granule conglomerates (1.8m thick) are interbedded and fine up into medium to coarse grained 'calcarenite' sandstones, similar in lithology to those described at Scoutgreen Crossing. Similarly, these contain a variety of vein quartz, chert, volcanic igneous and sandstone/siltstone (intraclasts) lithoclasts, up to 3cm across. These units are mainly massive to crudely horizontally statified with no observed clast grading or imbrication. The sequence contains minor (50cm thick) grey-green coloured dolomitic mudstones, and is overlain by grey-light brown coloured argillaceous and laminated dolomitic limestones.

8.3 STRATIGRAPHIC RELATIONSHIP WITH THE SHAP RED BEDS (see Figure 9.3)

The Shap Red Beds are, whenever in close juxtaposition, sharply

overlain by deposits (upper Conglomerate of Capewell, 1955) which resemble the Pinskey Gill Beds and because of this it seems likely that the Pinskey Gill Beds do infact stratigraphically ovelie the Shap Red Beds.

These beds between Ravenstonedale and Shap are mapped out ('Transition Beds') as a linear strip as shown in Figure 8.1. The Shap Conglomerate, which in the present study is referred to the conglomerate-sandstone-mudstone-limestone sequence in the Wyegarth Gill boreholes (cf. Holliday et al., 1979) may be between 36m and 42m (36.5m, measured at Thackwaite Gill by Johnson and Marshall, 1971; no longer well exposed) thick, appears to be a restricted development within the Ravenstonedale area. Previous accounts of the Pinskey Gill Beds (e.g. Capewell, 1955; Johnson and Marshall, 1971) have considered the Pinskey Gill Beds and Shap Conglomerate (Feldspathic Conglomerate division of Johnson and Marshall, op.cit) to be laterally equivalent of Capewell's (op.cit.) Lower Conglomerate and Red Sandstone division respectively (Facies Zones 1-5 of the Shap Red Beds in the present study).

Considering the new evidence, from the Shap region that the Pinskey Gill Beds do stratigraphically overlie the Shap Red Beds and that the former undoubtedly had connections with the marine environment in contrast to the widespread braidplain deposits of the Shap Red Beds, suggests that the Pinskey Gill Beds appropriately reflect time-dependent changes associated with the basal Carboniferous marine transgression. Indeed, it seems likely that the marine Carboniferous transgressed from the east (Johnson and Marshall, 1971), a trend obviously strongly

oblique to the consistent northward orientated palaeocurrents of the Shap Red Beds.

8.4 ENVIRONMENTAL INTERPRETATION

8.4.1 Pinskey Gill Beds

The Pinskey Gill Beds contain a fine grained succession, comprising silty mudstones with interbedded, sharply-based silty dolomitic sandstones and argillaceous limestones. The dominantly fine grained nature suggests deposition within a muddy environment, the presence of sharply-based sandstone suggesting sediment input in the form of probable sheet-like flows. Indeed, the 'trace fossil profiles' discussed in Section 8.2.5.1, demonstrate that intervals of rapid deposition alternated with periods of slower deposition with rapid colonisation of the substate by burrowing and grazing organisms (Myalina sp., Nuculana sp., Teinidium) after deposition rates had declined. The presence of possible algal laminae, plant remains, carbonaceous streaks and locally carbonaceous mudstones (e.g Scar Sikes and Scoutgreen Crossing) suggest that deposition took place within a shallow water environment which may have become periodically emergent. Indeed the contorted carbonaceous mudstone seen at Scoutgreen Crossing suggests accumulation deposition within swampy, saturated ground. It is suggested, however, that the contorted laminae may be associated with the development of algal marsh deposits, these forming in intertidal flat areas inbetween tidal channels (Leeder, 1982a, p.213). The presence of pyrite nodules suggests precipitation under reducing conditions probably promoted by the bacterial decay of organic matter.

In fact the abundance of plant remains and carbonaceous matter in the Pinskey Gill Beds and the overlying Shap Conglomerate, in total contrast to the Shap Red Beds, adds support to the contention that deposition of these rocks occurred in two contrasting depositional systems, especially as the Shap Red Beds contain pedogenic calcrete. As discussed in Chapter 9, these changes have fundamental implications as to palaeo-climate and are related to time-dependent changes associated with the Carboniferous marine transgression (cf. Graham, 1983).

Throughout the Pinskey Gill Stream section and Wyegarth Gill Borehole No.4; the Pinskey Gill Beds comprise minor coarsening upward sequences (e.g Figure 8.5, 48.8m-44.2m, Wyegarth Gill Borehole No.4; Plate 8.1), consisting of an upward transition from silty mudstones and interbedded sandstones into dolomitic vuggy limestones (comparable to the vuggy 'shell' dolomite of Pinskey Gill and Shap Summit). These sequences are probably superimposed on a largerscale coarsening and thickening upward profile which reflects the upward transition into argillaceous limestones (containing Spirifer Pinskeyensis and Athyris sp.), as evident at Pinskey Gill (Figure 8.2).

Although not observed at Pinskey Gill itself, the calcarenite granulestone/pebble conglomerates at Shap are lithologically very similar to the vuggy dolomitic conglomerates at Scar Sikes and, partly on this basis, these units are considered to be the likely lateral facies equivalent to the dominant fine grained Pinskey Gill Beds succession. Significantly these coarser grained units, interbedded with silty and locally carbonaceous mudstones, do contain fossil remains

(?rhynchonellids) which suggests to the author accumulation in a setting associated with, or near, the marine environment.

In consideration of the discussions above, the Pinskey Gill Beds and associated lateral facies 'variants' at Shap, are interpreted to reflect deposition within both marginal and more 'open' marine environments. The postulated transition from 'restricted' to more 'open' setting is reflected by the overall upward increase in limestone content and associated contained marine fauna. As such, the Pinskey Gill Beds resemble the lagoonal/tidal flat environments of both siliciclastic and carbonate shorelines (Hayes, 1979; Elliott, 1986; Sellwood, 1986). Sellwood (op.cit) has demonstrated that the tidal flat environment contains a complex of 'sub-environments including intertidal flats, channels, levees, ponds and beach ridges', the lower intertidal area being infested with browsers and grazers which inhibit the growth of algal mats. The channels occur as a complex of tributary and distributary systems and form the main pathways for exchange of water during storm surges. According to Sellwood (op. cit.), these channels contain a variety of sediment from carbonate mud to shell coquina with tidal bars also containing a variety of shells, intraclasts and pellets. Channel margin levees which grade into the background mud of the tidal flat commonly contain coarser grained sediment and, significantly, under strong evaporation (in both arid and humid settings) may be the sites for dolomite replacement of argonite during early diagenesis (Sellwood, op. cit.).

It is suggested that the general coarsening upward trend of the Pinskey Gill Beds reflects progressive infill of a lagoonal tidal flat area, the minor coarsening upward sequences representing local infill of a low-lying area or depression (?pond) associated with flood input from adjacent channels, and capped by an accumulation of shell debris , which possibly accumulated from storm activity. These shell accumulations locally became the sites for early dolomitisation. It is tentatively suggested that the calcarenite - conglomerate facies, best developed at Shap, reflect infill of channels or, and possibly from washover or spill-over fans associated with adjacent beach-ridges. The fact that these deposits sharply overlie carbonaceous mudstones (localised swamps or ponds) supports these interpretations, reflecting 'influx' of coarser grained sediment into a low-lying ponded area. Washover fans associated with beach ridges of Andros Island, comprise intraclast gravels and rippled sands (Leeder, 1982a). It is suggested that the presence of the varied clast types is a reflection of a source from a marine environment, and possibly sorted by longshore drift processes.

A tidal flat interpretation for the Pinskey Gill Beds has also been considered by Barraclough (1983), while Holliday et al., (1979) consider a totally marine origin, laid down in shallow, hypersaline water. The presence of conodonts, particularly Clydagnathus and Bispathodus (from Varker and Higgins, 1979; Higgins and Varker, 1982), adds support for a broad lagoonal or supratidal environment, Clydagnathus being especially common in supratidal settings and offshore banks and lagoons of shallow brackish to normally saline water, commonly occurring with algae (Austin, 1976; Sandberg, in Higgins and Varker, op. cit.). Bispathodus

is wholly associated with a shallow, shelf carbonate facies (Varker and Higgins, op.cit).

8.4.2 The 'Shap Conglomerate'

The Shap Conglomerate succession appears to be a restricted development of mostly clastic deposits, which show an upward gradation into the overlying Stone Gill Limestones (Holliday et al., 1979). The overall fining upward sequence (Figure 8.5., Wyegarth Gill Borehole No.2) with an increase in mudstone toward the top, suggests abandonment of a dominantly muddy environment. Indeed the presence of abundant plant remains and presence of rhynchonellid brachiopods suggests a vegetated, muddy environment marginal to a marine setting, the increase in limestone towards the top supporting this contention. Fining upward pebble-granule conglomerate and sandstone sequences nearer the base are interpreted as reflecting the infill of minor channels which, in view of the thickness of interbedded mudstone and abundant plant remains, probably migrated across a low-lying floodplain environment. The association with a probable marginal marine setting suggests that a coastal floodplain setting is most appropriate for the Shap Conglomerate and suggests a comparison with the coastal fluvial facies of Graham (1983). Significantly the variety of clast types within this conglomerate, being very different to those of the Shap Red Beds, may indicate reworking of previously deposited sediment, possibly accounting for the presence of the 'Shap orthoclase phenocrysts' observed at Pinskey Gill.

8.4.3 Depositional Model

The Pinskey Gill Beds by overlying the Shap Red Beds are considered by the author to have reflected the establishment of a marginal marine, lagoonal-tidal flat environment over the Shap-Ravenstonedale (and South Vale of Eden) region associated with the basal Carboniferous marine transgression which took place from the east. As discussed elsewhere in this Chapter and in Chapter 9, the observed increase in carbonaceous and plant remains in the Pinskey Gill Beds and overlying Shap Conglomerate, in striking contrast to the Shap Red Beds, suggests the result of climatic change probably associated with the encroaching marine Carboniferous over the braidplain deposits of the Shap Red Beds. Such a model has been described by Graham (1983) for the Upper Devonian 'Munster Basin in Ireland. The Shap Conglomerate, may reflect a local establishment of a fluvial coastal plain environment at Ravenstonedale on regression or minor shoreline progradation.

Leeder (1971) mentions the establishment of 'restricted' and marginal environments during the basal Carboniferous, associated with basin initiation and marine transgression. These 'restricted' deposits are the cementstones of Northumbria and Scotland and these, it is suggested, compare closely with the development of the Pinskey Gill Beds in Ravenstonedale. The cemenstones have been well documented by Belt et al., (1967), Read and Johnson (1967) and Smith (1967); they are interpreted as lagoonal deposits, deposited in a marginal marine environment.

FIGURE 8.1

Map showing the main localities, Ravenstonedale.

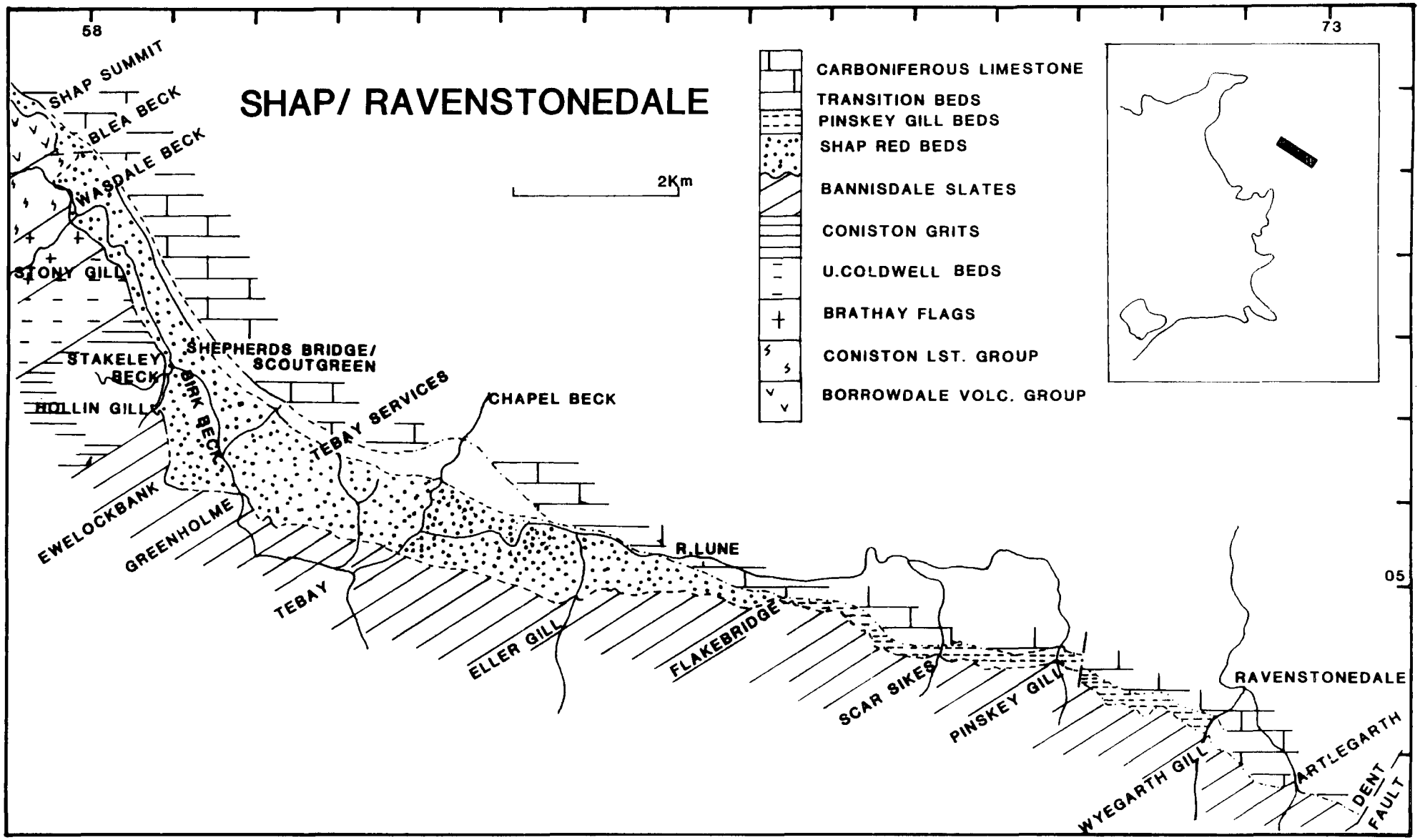

58
73
SHAP/ RAVENSTONEDALE
2Km
CARBONIFEROUS LIMESTONE
TRANSITION BEDS
PINSKEY GILL BEDS
SHAP RED BEDS
BANNISDALE SLATES
CONISTON GRITS
U.COLDWELL BEDS
BRATHAY FLAGS
CONISTON LST. GROUP
BORROWDALE VOLC. GROUP
SHAP SUMMIT
BLEA BECK
WASDALE BECK
STONY GILL
STAKELEY BECK
HOLLIN GILL
SHEPHERDS BRIDGE/ SCOUTGREEN
BIRK BECK
TEBAY SERVICES
CHAPEL BECK
EWELOCKBANK
GREENHOLME
TEBAY
ELLER GILL
R.LUNE
FLAKEBRIDGE
SCAR SIKES
PINSKEY GILL
RAVENSTONEDALE
WYEGARTH GILL
ARTLEGARTH
DENT FAULT
05

FIGURE 8. 2. MEASURED SECTION - PINSKEY GILL
(NGR NY 698039)

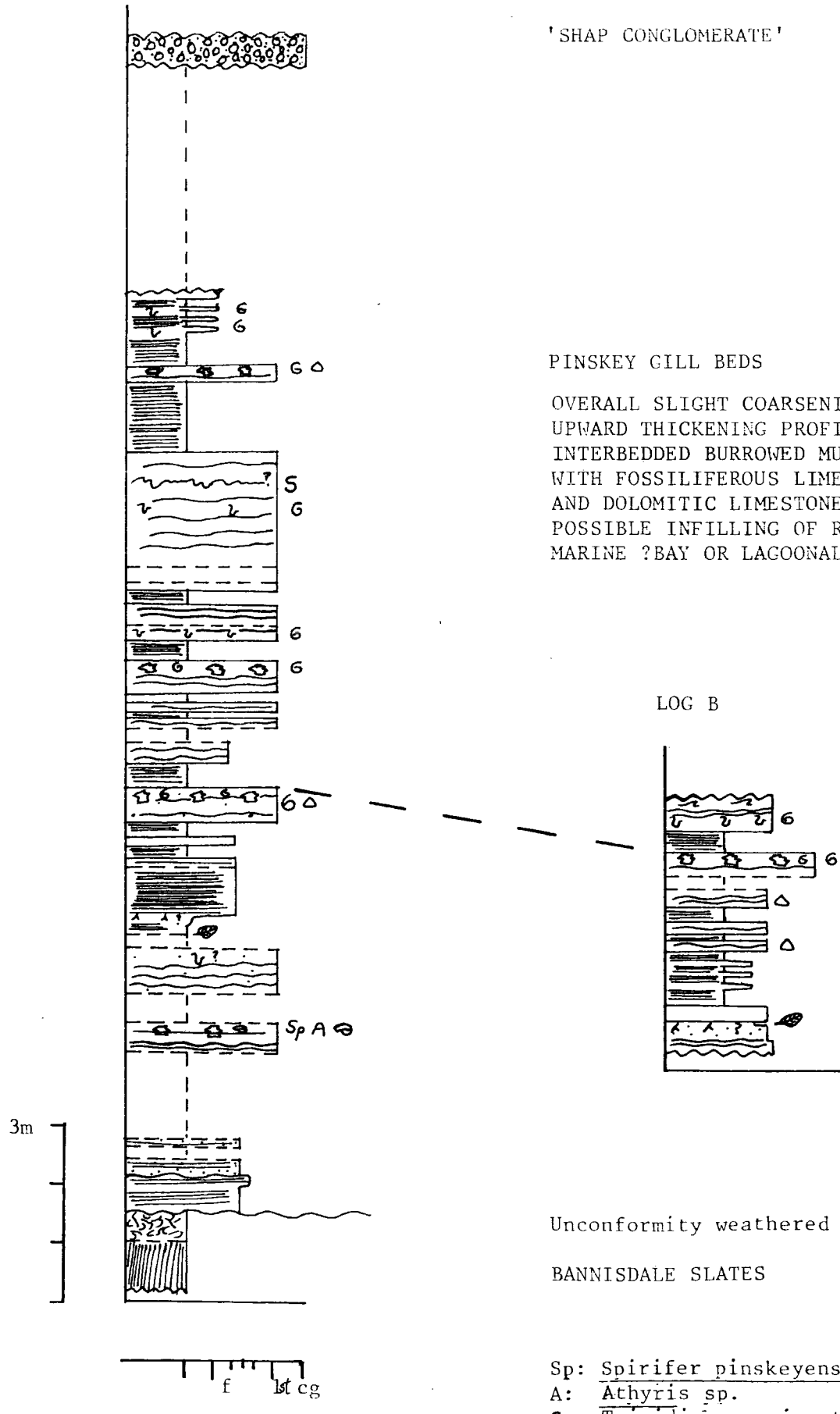
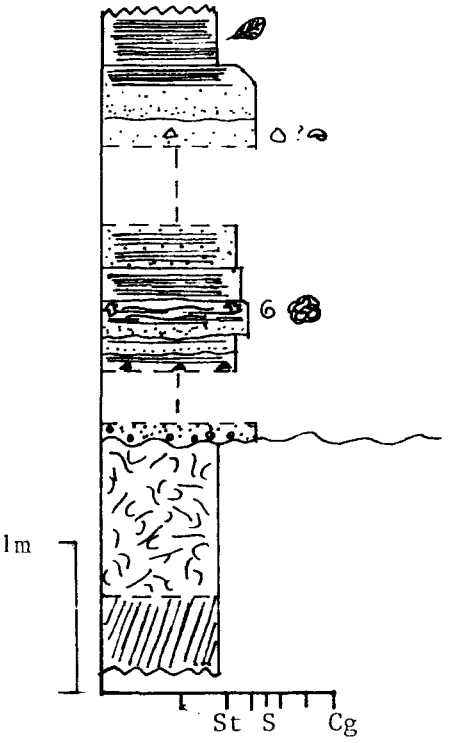


FIGURE 8.3. MEASURED SECTION - FLAKEBRIDGE
(NGR NY 666048)



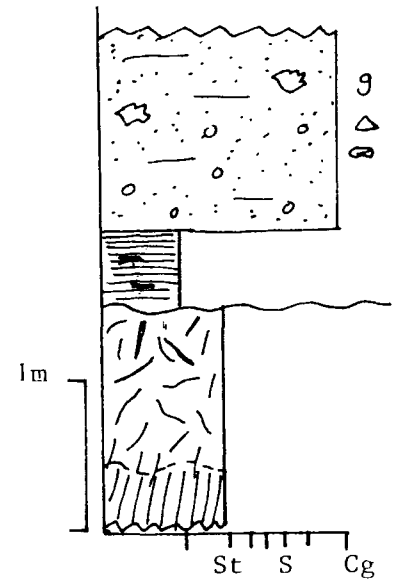
PINSKEY GILL BEDS

SECTION EXPOSES THE VERY BASE OF THE PINSKEY GILL BEDS. DOMINATED BY LAMINATED SILTY SANDSTONES AND MUDSTONES, POSSIBLY ACCUMULATING WITHIN A LAGOONAL TIDAL FLAT SETTING. CONTAINS RARE ?HALITE PSEUDOMORPHS - EVIDENCE FOR LOCAL EVAPORATION. COMMON 'CALCRETE' LITHOCLASTS FROM THE UNCONFORMITY.

UNCONFORMITY ZONE CALCRETE

BANNISDALE SLATES NOT VEINED WITH CARBONATE.

FIGURE 8.4. MEASURED SECTION - SCAR SIKES
(NGR NY 683041)



PINSKEY GILL BEDS

AGAIN THE VERY BASE OF THE PINSKEY GILL BEDS, THE UNCONFORMITY OVERLAIN BY CARBONACEOUS MUDS AND A POSSIBLE WASH-OVER FAN DEPOSIT, CONTAINING *Camarotoechia mitcheldeanensis*

UNCONFORMITY BRECCIATED ZONE INTENSELY VEINED WITH DOLOMITE ALONG CLEAVAGE AND JOINTS.

UNALTERED BANNISDALE SLATES.

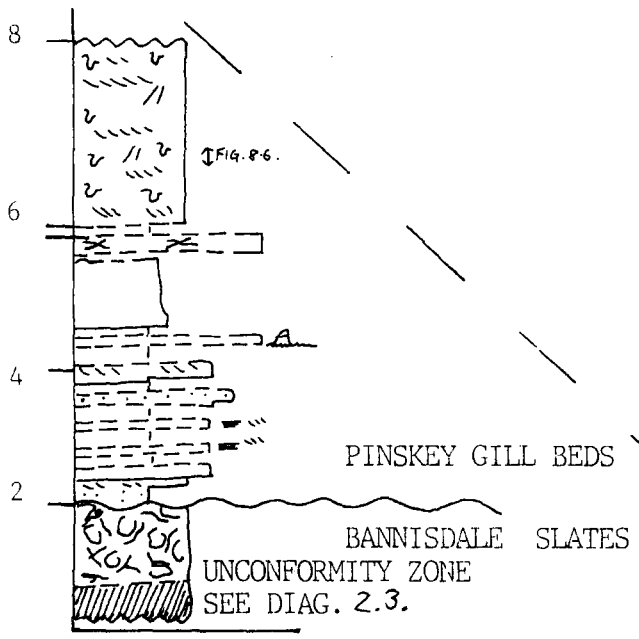
FIGURE 8. 5. LOGGED SECTIONS - WYEGARTH GILL BOREHOLES

GRAIN SIZE

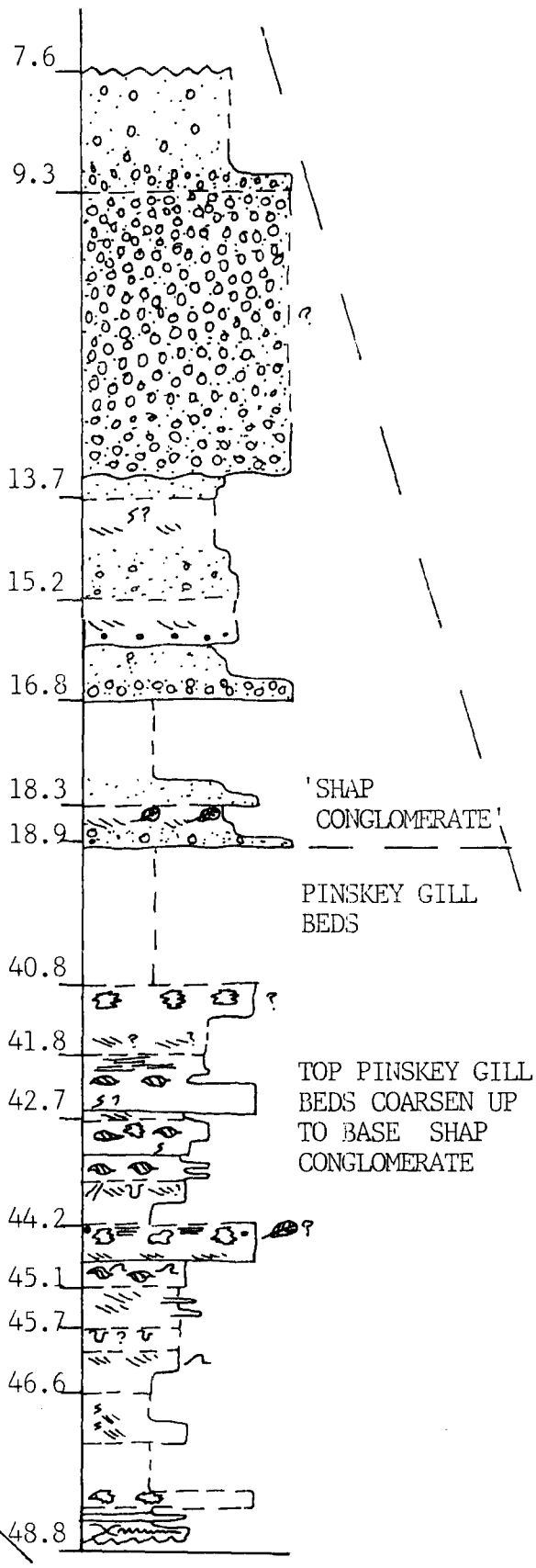
Sh St fmc Sst Ls Cg

HEIGHTS IN METRES BELOW GROUND SURFACE

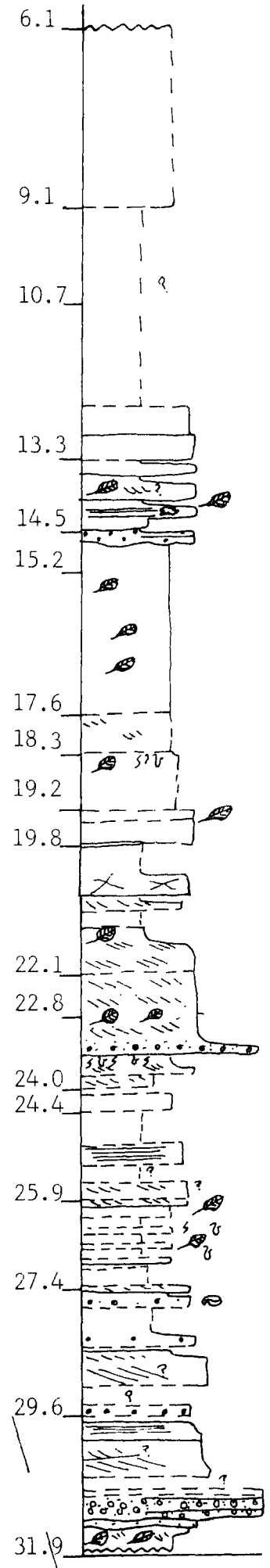
WYEGARTH GILL BOREHOLE NO. 5
(NGR NY 715030



WYEGARTH GILL BOREHOLE NO. 4
(NGR NY 716032)



WYEGARTH GILL BOREHOLE NO. 2
(NGR NY 718033)



OVERALL FINER GRAIN SIZE SUGGESTS BASE IS HIGHER THAN TOP BOREHOLE 4.

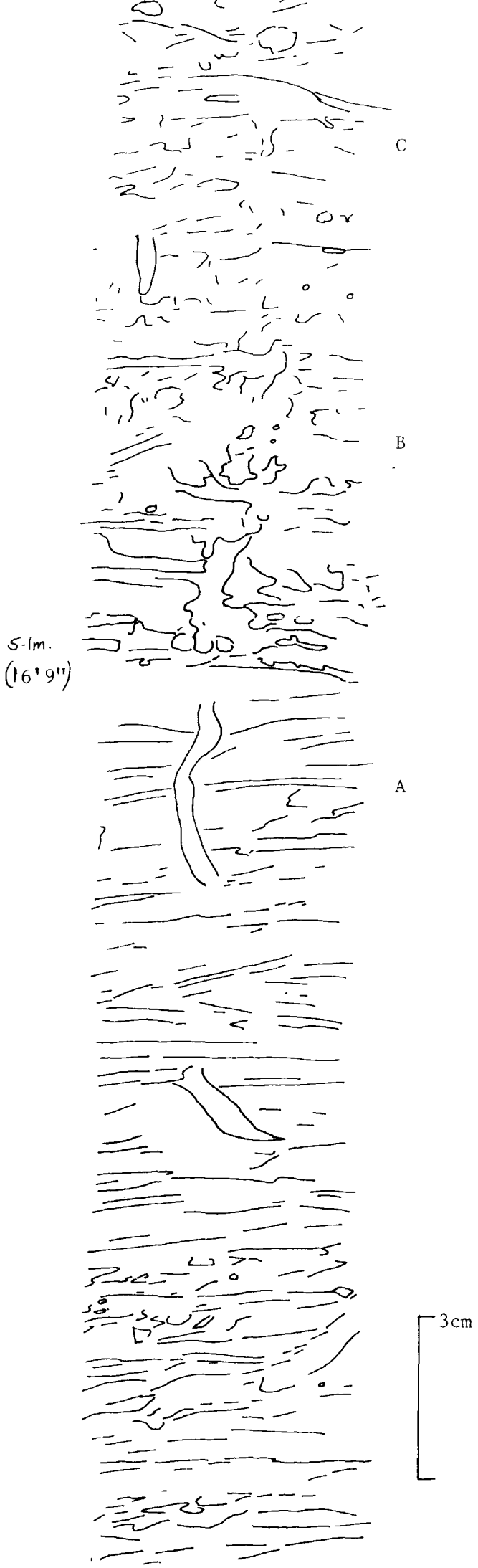


FIGURE 8.6.
TRACE FOSSIL PROFILES IN THE PINSKEY GILL BEDS (WYEGARTH GILL BOREHOLE 5)

POSITIONS B AND C

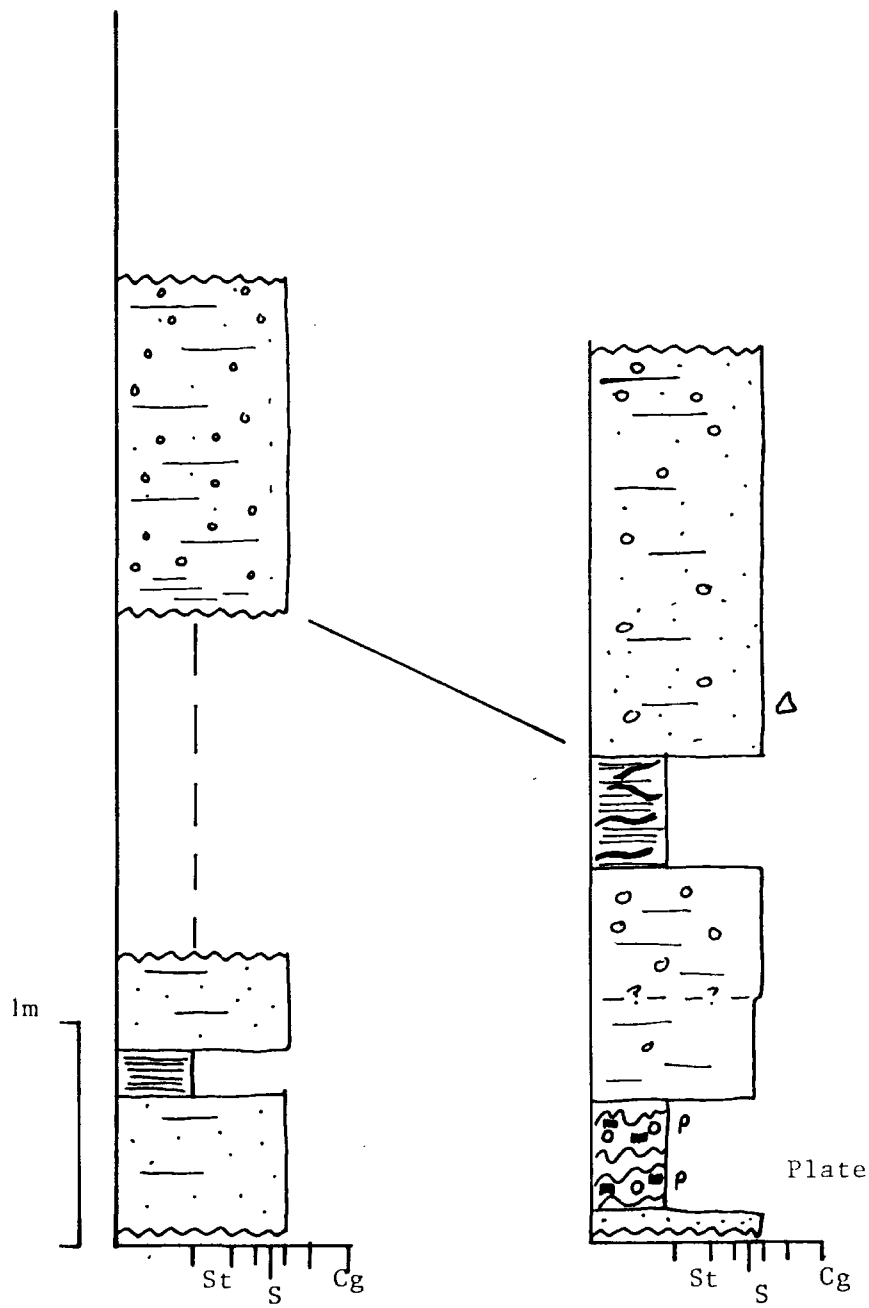
Lower energy levels enable burrowing organisms to digest the sediment substrate during periods of low to very low sediment input. In the former case, any sedimentary structures will be obliterated while slightly higher rates will still preserve both the burrow and sedimentary structure forms.

POSITION A

ESCAPE BURROW STRUCTURES

Reflect the escape of burrowing organisms to higher levels in the substrate during periods of relatively rapid sediment deposition.

FIGURE 8.7. MEASURED SECTIONS - SCOUTGREEN CROSSING
(NGR NY 593082)



PINSKEY GILL BEDS (SHAP)

LOCALLY CALCITE CEMENTED SANDSTONES/PEBBLE-GRANULE CONGLOMERATES WITH WIDE RANGE OF CLAST TYPES AND RARE FOSSILS. DEPOSITED EITHER WITHIN CHANNELS OR AS POSSIBLE SPILL/OVER-WASH-OVER FANS. INTERB. CARBONACEOUS MUDSTONES AND POSSIBLE ALGAL-MARSH DEPOSITS WHICH ACCUMULATED IN A LAGOONAL -TIDAL FLAT SETTING.

Plate 8.4.

PLATE 8.1.



PLATE 8.2.



PLATE 8.1

Plate shows lower part of the Pinskey Gill Stream section, Ravenstonedale, showing a dominantly well-bedded sequence comprising silty mudstone/shale with sharply-based silty sandstone units, which coarsen slightly and thicken up towards the top of the section in view. The very top bed in the field of view is a characteristic 'orange' unit, packed full with gastropod remains. Lens cap (6cm across) for scale, in foreground. (NGR NY 698039)

PLATE 8.2

Plate shows very similar sequence, to that shown in Plate 8.1, this section from Shap Summit, Shap, the Shap Red Beds being exposed 6m below the field of view. Note the very characteristic vuggy dolomite unit (to left of hammer, 35cm long), packed full of gastropod remains, overlying a dolomitic argillaceous sandstone unit, comparable in lithology to those from Pinskey Gill Beds, and seen in Plate 8.1. (NGR NY 512108)

PLATE 8.3

Plate shows view (X2) of the pedicle valve of Spirifer pinskeyensis (see Garwood, 1912), within an argillaceous limestone bed, Pinskey Gill stream section, Ravenstonedale.

PLATE 8.4

Plate show highly contorted and carbonaceous mudstones, from Scoutgreen Crossing, Shap. Note abundant pyrite concretions. These mudstones may have accumulated within an organic rich swamp or pond, or, it is tentatively suggested, the highly contorted laminae may reflect algal growth, perhaps within 'algal marshes' (cf. Leeder, 1982a, p.217). These develop inbetween channels in the inter-tidal lagoon environment under humid climatic conditions. The plate is overlain (out of view) by pebble-granular calcarenites, which may represent channel-fill deposits or the deposits of washover fans associated with nearby beach ridges. Tape measure (6cm across) for scale. (NGR NY 593082)

PLATE 8.3.

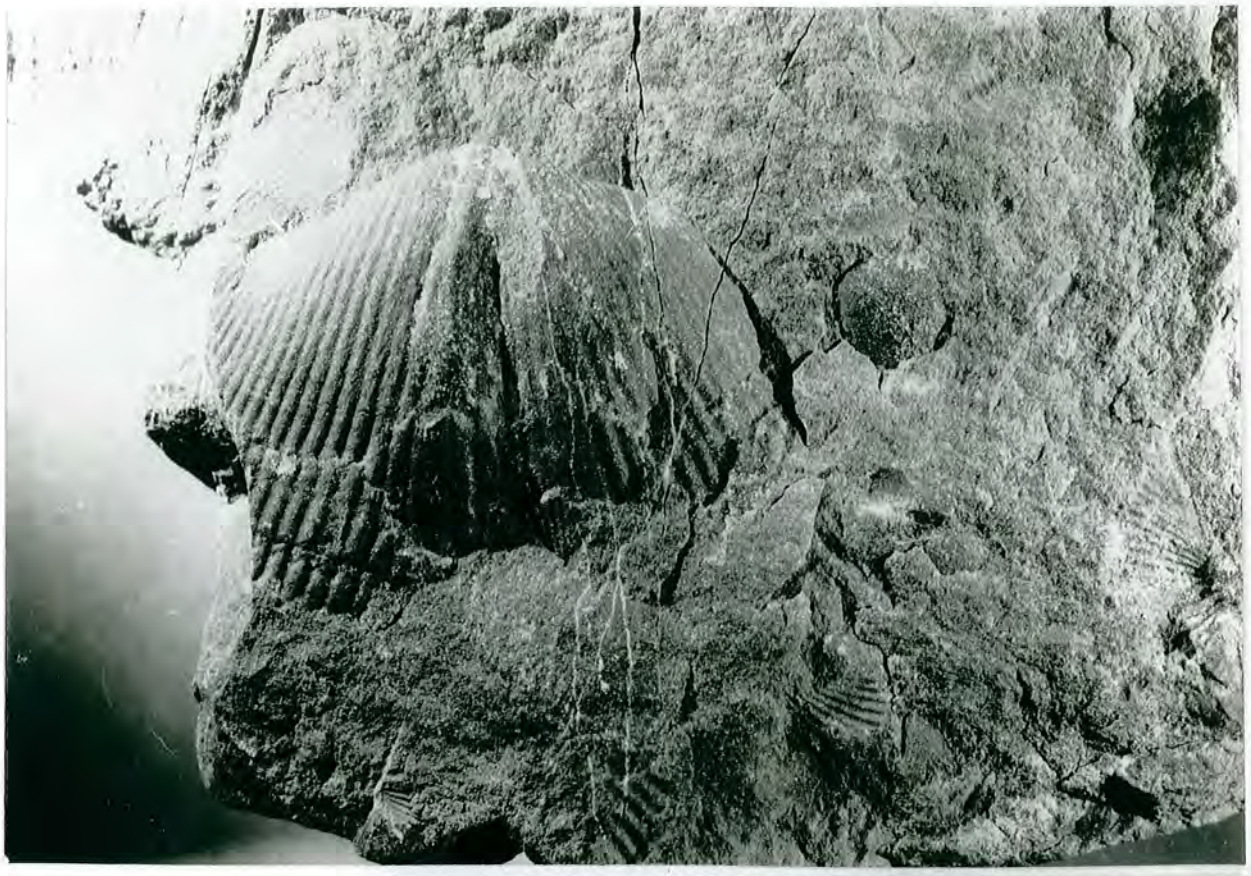
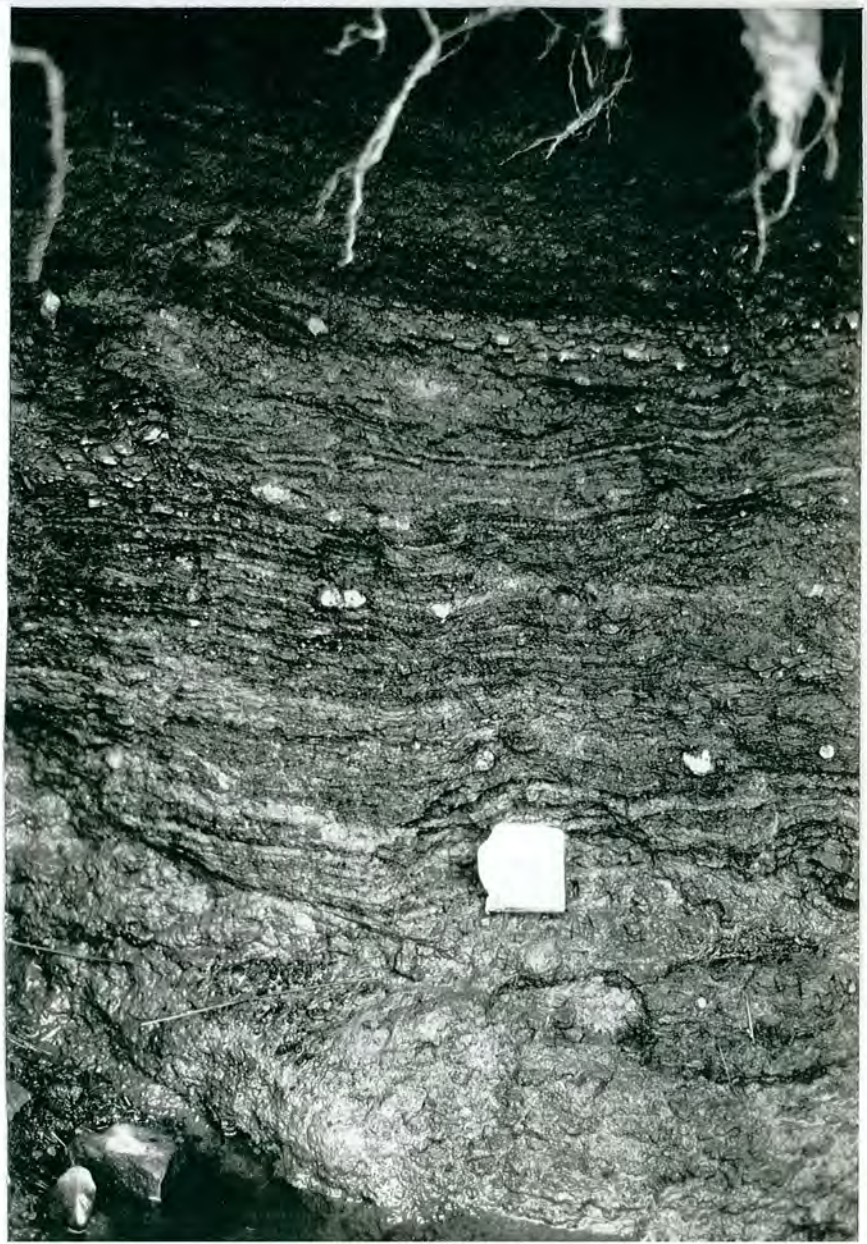


PLATE 8.4.



CHAPTER 9 REGIONAL DEPOSITIONAL MODEL AND PALAEOGEOGRAPHY

9.1 INTRODUCTION

This chapter summarises the depositional models developed for each of the five main study areas. By integration of proximal to distal variations observed within each model with clast composition data it attempts to predict facies relationships throughout the study region, i.e. Vale of Eden and surrounding areas, and to reconstruct the palaeogeography.

Modern sedimentological understanding, particularly with regard to alluvial and fluvial systems, has progressed to the point where a fully integrated facies model necessitates detailed examination of three-dimensional outcrop to determine both vertical and lateral facies variation. Much emphasis in recent years has been made to the detailed reconstruction of the channel environment and especially bar-forms, for example the recognition of 'macro forms', comprising a variety of genetically related bedforms which enable a clearer understanding of fluvial style to be elucidated (see examples of Allen, 1983, Crowley, 1983, Haszeldine, 1983, Miall, 1985a). Such 'architectural element analysis' (cf. Miall, op.cit.) allows a greater understanding of the building mechanism of channel sandstone bodies and channel behaviour (cf. Friend et al., 1979).

In the present study the author has attempted to combine an understanding of channel and bar morphology at one level with evolution

of channel systems at a second level to produce a depositional model which can be used as a basis to predict behaviour of channels and associated facies over the region.

9.2 WEST VALE OF EDEN

9.2.1 Shap (Shap Red Beds)

The facies identified from the Shap Red Beds reflect the aggradation of gravel bars within gravel-bedload braided channels, comparable to the modern Donjek River. Throughout the area and in particular the Birk Beck Section, an upward change to a sand dominated succession reflects the aggradation of sandy transverse bars within shallow but wide sand-bedload channels floored by migrating dunes, the channel system closely resembling the facies present within the modern day South Saskatchewan River. Thickness of the Shap Red Beds has been measured at 55m along Birk Beck but may reach a tentative calculated thickness in the order of 130m in the region of Tebay (as originally suggested by Capewell, 1955, although he gives a thickness of about 600 feet). What is evident is the observed thinning both to the north and east. At Ravenstonedale, facies such as those present at Shap are absent, instead the unconformity (Bannisdale Slates, Chapter 2) is directly overlain by the probable lagoonal tidal flat deposits of the Pinskey Gill Beds. Similar deposits to the Pinskey Gill Beds are clearly present overlying the Shap Red Beds at Shap Summit (Figure 3.13; Plate 8.2), the latter thinning north of Wasdale Beck to a thickness of ca 11m. Similar deposits are again evident at Rosgill Hall Wood (N.G.R. NY 543158) where ca 2m-3m of buff-brown calcarenites overlie the Skiddaw

Slates. Last exposures of typical Shap Red Beds facies are present at Shap Abbey (N.G.R. NY 547153), close to Rosgill Hall Wood, where approximately 4m of cobble-pebble conglomerates (facies Gm) are interbedded with crudely-stratified pebble-granule conglomerate (facies Gm) and horizontally laminated medium to coarse grained sandstones (facies Sh).

In a westward direction and as shown by the clast composition data (Chapter 7), transport of clast debris from the Shap Granite and associated metamorphosed Borrowdale Volcanic Group rocks, clearly took place. This evidence suggests that the original extent of clastic deposition at Shap most probably extended westwards of the present day exposure limit (marked by 'palaeo-rock wall' along the line of Stakeley Beck to Blea Beck) although clearly in the vicinity of Blea Beck and Shap Summit, as noted above, the limit of clastic deposition was probably close to present day outcrop restriction.

To the south, considering facies along Birk Beck reflect the deposits of gravel bedload - sandy bedload channels, 'up palaeoslope', i.e. to the south, more proximal facies, most probably a transition of the 'Scott type' gravels of Miall (1977) would be expected. This facies trend is predicted by the depositional model and, in particular the palaeocurrents (south to south-south-west provenance) and clast compositions (Silurian greywackes) which both predict a southerly provenance. Further support for this, is perhaps suggested by the 'clean' unconformity at Greenholme, no evidence for the brecciated type zone being observed (Chapter 2). It is interesting to speculate that

the absence of the brecciated zone was promoted by active sediment input into this area, inhibiting calcrete forming processes. In contrast, it seems the presence of the zone implies that calcrete processes were able to operate and this correlates with areas where clastic deposition either 'thins' or, more importantly is absent, the case of Wasdale Beck and Pinskey Gill sections respectively.

9.2.2 Mell Fells (Mell Fell Conglomerate)

The Mell Fell Conglomerate exhibits an upward fining sequence which reflects the genetically related components of an alluvial fan - distal braidplain sequence showing proximal to distal facies variations. Coarse, proximal boulder conglomerates toward the south of the outcrop area most probably accumulated on alluvial fans constructed by stream processes and characterised by possible steep-sided braided streams, accumulating gravel on longitudinal bars. Stream dominated alluvial fans tend to develop where a lack of argillaceous fine grained sediment is present in the source area, and are usually associated with deposition under humid climatic conditions where high levels of precipitation would generate appreciable discharge. Within the Mell Fell Conglomerate, no direct evidence for the likely climatic conditions was observed, and at the outset a humid climate might seem appropriate. However, it is suggested that the most likely climatic conditions were semi-arid, as indicated by the presence of calcretes in the Shap Red Beds (see Chapters 2 and 3). Collinson (1986) shows that stream channel dominated alluvial fans can develop within semi-arid climates subject to sporadic floods. What is clear, is that within the Mell Fell Conglomerate a network of braided streams built out a

cone-like body of sediment in front of the proximal alluvial fans, the probably wide (see Section 9.4) extent of the braidplain developing in response to a decrease in gradient. This is reflected in upward fining of both clast and grain size and an increase in abundance of upward fining sequences the latter being generated by the development of 'channel-bar-complexes' which accumulated progressively finer grained sediment at relatively higher topographic levels of the channel/bar system. As such, the Mell Fell Conglomerate can be considered as representing the transition from the Scott to Donjek and possibly the South Saskatchewan type braided models of Miall (1977; see Figure 9.1). If the analogy with the Van Horne Sandstone (Mcgowen and Groat, 1971) is appropriate, then the braidplain could have extended for up to 100 miles with a width of about 20 miles (based on the Kosi River Fan).

The increase in fluvial dispersion associated with the decrease in gradient accompanying the change from proximal 'fan' to braidplain, is the dominant factor, the author believes in resolving the distribution of clast types observed (see Figures 4.6 and 7.1, 7.2). Heward (1978) considers that the lowering of source area relief through the process of scarp retreat will generate differing clast compositions within the alluvial fining upward sequence. Erosion of the Silurian greywacke cover is reflected in the abundance of greywacke clasts within the proximal conglomerate facies. Downstream, the increase in areal extent of the braidplain facies as a result of flow expansion and increased fluvial dispersion was able to 'tap' a larger area of the eroded source terrain. A corresponding increase in Borrowdale Volcanic, Upper Ordovician limestone, Eycott Volcanic and minette clasts is present in

the relatively distal facies, especially within the deposits cored by the Dalemain Borehole. Local distributions of clasts may also (as considered by Wadge, 1978) reflect local variation in source rock, e.g. the abundance of decomposed volcanics within the conglomerates exposed at Setterah Sike/Heltondale Beck, were probably sourced from the Eycott volcanics, exposed, possibly as in the present, south of the Mell Fells around the Tarn Moor area. Wadge (1978) also considers that the presence of basic lavas and porphyries in the north-west portion of the Mell Fell Conglomerate area may reflect a source from the north-west.

Thickness of the Mell Fell Conglomerates, as noted in Chapter 4, is in the order of 275m, and the author agrees with the argument put forward by Wadge (1978) i.e., that the Mell Fell Conglomerate exhibits a fining trend and that proximal conglomerates grade laterally into distal conglomerates towards the North. Towards this direction the extent of the relatively coarser grained facies can be judged by reference to the Dalemain Borehole core. Here, 55m of pebble conglomerate and pebbly sandstones are present and may thus represent the top part of a thicker sequence of coarser grained conglomerates not cored below. If the model developed for the Mell Fell Conglomerate is appropriate, then it must predict that by a process of lowering of source area relief, the coarser grained facies probably did extend further north, the position of the finer grained facies then migrating southwards in conjunction with the scarp retreat process to its present location, due to the superposition of fine on progressively coarser sediment (diagramatically represented in Figure 9.4). By this process, the Mell Fell Conglomerate probably did extend much further north than the present outcrop pattern suggests.

Certainly, by the same argument the extension of the proximal conglomerates may be taken further south, although now of course these deposits have been eroded. Thinning of the Mell Fell Conglomerate, however, towards the south is demonstrated by the Setterah Sike/Heltondale Beck locality (Figure 4.1) where pebble-cobble conglomerates, probably reflecting a proximal-medial (channel-bar) position on the braidplain, have an exposed thickness of 3m-4m. The observations of the unconformity being overlain by Carboniferous Limestone south of here, supports the contention that the area between the Shap and the Mell Fells was an area lacking clastic deposition (Kimber, 1984).

9.2.3 Sedbergh (Sedbergh Clastic Rocks)

Facies developed within the Sedbergh clastic rocks are closely comparable to the coarse grained boulder conglomerates of the Mell Fell Conglomerate. In fact the Sedbergh conglomerates again most probably accumulated on alluvial fans constructed by braided stream channel processes and may exhibit an overall downstream fining into a braided channel network, in which relatively greater in-channel topographic differentiation influenced the greater preservation of sand (Settlebeck Gill section, Figure 5.2). Clast compositions, mainly Silurian type greywackes and locally abundant 'Keisley Limestone' type lithologies, in conjunction with a north-west to north-north-west palaeoflow (from conglomerate imbrication) suggests a source terrain provenance from near the southern part of the Askrigg Block. The Askrigg Block, underlain by the Wensleydale Granite, (see Wilson and Cornwell, 1982) in the region of the Beckermonds Scar and Raydale Boreholes, was certainly an area of

non-clastic deposition, basal Carboniferous Limestones, of Chadian age, unconformably overly an Arenig greywacke basement. To what extent the Silurian greywackes were exposed within the Askrigg Block area is not known by the author. The evidence of these greywackes as clasts within the Sedbergh conglomerates with limestone clasts believed to be Upper Ordovician or Lower Silurian similar to the Keisley Limestone suggests more of a local source terrain, particularly considering the coarse grained 'proximal' conglomerate lithology, and given the accumulation within an alluvial fan environment.

To what extent clastic deposition occurred between the Sedbergh and Kendal area, i.e. north and west of the Sedbergh clastics ('down' the interpreted palaeoslope) is very uncertain. It may well be that the Sedbergh clastics were only locally developed. Minor exposures, however, observed by the author near Kendal (Mealbank Hotel/Laverick Bridge, N.G.R. SD 535952) comprise cobble-pebble conglomerates (facies Gm/Gt) and cross-bedded sandstones (facies St), palaeocurrents tentatively measured towards 340°-360°. West of the Kendal area, exposure of the basal Carboniferous is scant and information relies on borehole data (M. Mitchell, pers. comm.). Nicholas (1968) in a study of the basal part of the Carboniferous (C_2S_1 - Seminula gregaria sub-zone of Garwood, 1912) in the Grange, Furness and Millom areas interprets the Carboniferous Limestone as being deposited from the south and onlapping northward against the Southern Lake District land surface, 'sculptured' during post-Caledonian erosion. Nicholas (op. cit.) also follows Garwood (1912) in indicating that north-east of this area, i.e. towards Kendal, there is no trace of clastic Carboniferous basement rocks, and

infact the basal Carboniferous limestones north-east of Millom thin very rapidly.

South of Sedbergh, as shown in Figure 9.2, the steepening of the Upper Palaeozoic landscape is readily demonstrated by the absence of clastic rocks in the Ingleborough and Horton-In- Ribblesdale areas, where basal Carboniferous is represented by Holkerian limestones (see Scott, 1984). In the Kirkby Lonsdale area, Capewell (1950) reports calcareous, mottled coloured sandstones and fine grained conglomerates unconformably overlying the Kirkby Moor flags (N.G.R. SD 608820). Unfortunately the author could not find these exposures and is thus in doubt as whether they can be considered part of the clastic sequence at the base of the Carboniferous.

9.2.4 Ravenstonedale (Pinskey Gill Beds and 'Shap Conglomerate')

The demonstrated overall upward thickening and coarsening upward profile is interpreted as reflecting the progressive infill of a probable lagoonal tidal-flat area by minor channels and possible spill-over deposits associated with a beach ridge (not directly observed; see Chapter 8). The change into the overlying 'Shap Conglomerate', which mainly comprises finer grained cross-bedded sandstones and mudstones probably represents a local return to fluvial deposition around the lagoon margin, perhaps during a regression period. The possible spill-over lobe or washover fan deposits, present in both the Shap area and at Scar Sikes do contain fossils (e.g. gastropods ?Naticopsis); Camarotoechia mitcheldeanensis) supporting a marine origin.

In the Shap region, similar deposits to those of the Pinskey Gill Beds occur at Shap Summit and at Scoutgreen Crossing (equivalent to Capewell's, 1955, Upper Conglomerate) and suggest that lagoonal tidal-flats (cf. Barraclough, 1983) were established during the Courceyan over the Shap-Ravenstonedale region, stratigraphically overlying the Shap Red Beds. Significantly these deposits are associated with the initial marine transgression of the basal Carboniferous, from the east (see Wilson and Cornwell, 1982, Barraclough, 1983) over a much reduced landscape levelled by the extensive braidplain system developed during deposition of the Shap Red Beds (Figure 9.4).

9.3 EAST VALE OF EDEN

The Cross Fell clastic Rocks comprise an overall fining upward succession reflecting the downstream change from proximal (Quartz Conglomerates) to medial (Red Sandstones/Roman Fell Sandstones) and distal muddy (Green Sandstones) parts of a braidplain system. The dominant palaeoslope was towards a general north-east direction, as determined from palaeocurrents from both the Quartz Conglomerates and Red/Roman Fell Sandstones. Although no palaeocurrents were obtainable from the Polygenetic Conglomerate, the complete lack of vein quartz, combined with clear evidence for derivation from locally sourced debris suggests that these conglomerate units were derived from the Alston Block. The sharp and very striking change into the overlying Quartz Conglomerates which contain an abundance of rounded vein quartz clasts and interpreted as reflecting derivation mostly from the quartz veined

Skiddaw Group of the Lake District, reflects the change from locally derived alluvial fans which acted as tributaries to more extensive and texturally more mature proximal braidplain deposits. Ouma (in Richards, 1982) has shown that clasts become progressively more rounded as clast size decreases downstream, suggesting that upstream, i.e. up palaeoslope and southwards to the Lake District, the Quartz Conglomerates may be gradational not only to coarser conglomerates but to texturally less mature conglomerates as well. This observation is probably a result of progressive downstream sorting processes, a function of both downstream fining of grain size and more importantly downstream gradient decrease (cf. Richards, 1982).

The Red and Roman Fell Sandstones are considered to reflect the progressive downstream fining of clast and grain size with decreasing gradient, these variables principally a function of lowering of source area relief. Infact evidence for the 'on-going' denudation of surrounding high ground, particularly in the Cross Fell/Alston Block area, is provided by the greater lateral extent of the Red Sandstones (Figures, 6.1; 9.4), overstepping the Quartz Conglomerates toward the south. The Red Sandstones represent the deposits of a more extensive sandy braidplain system, and in this study are considered to be laterally equivalent to the Roman Fell Sandstones in the south of the Cross Fell area (see discussion below).

The Green Sandstones are considered to reflect the most distal part of the braidplain accumulating in a dominantly low-lying muddy environment which probably compares with the floodbasin 'fines' of Steel

and Aasheim (1978) and the distal fluvial facies of Graham (1983). Minor preserved cross-bedded horizons probably record the aggradation of channel bars and the presence of channels; in view of the background mud these may well have been high sinuosity. Although there is not any direct evidence, the fact that the Green Sandstones are overlain by the marine Orton Group limestones (contain bryozoa at Grey Mares Tail Section), it is possible that they may reflect a transition into a coastal plain environment, and as such may resemble the coastal plain facies of Graham (1983). Significantly the Green Sandstones represent aggradation in a low-lying environment, where deposition probably occurred at or close to base-level. Galloway (1981) has shown that in such a coastal plain environment, rivers will radiate from a point source in an attempt to aggrade the depositional surface as evenly as possible.

The Cross Fell Clastic Rocks which outcrop around the area of Roman Fell in the southern part of the Cross Fell escarpment, as discussed in Chapter 6 have always proved a matter of contention. Exposure in this area is far from complete and access is limited as a result of the Army Firing Range in the vicinity. Burgess and Harrison (1967) provide, however, a detailed account of the geology and while the author has studied the Roman Fell Sandstones in detail (well exposed at the top of Roman Fell), speculation with respect to the Roman Fell Shales and basal conglomerate is kept to a minimum as he regards there is insufficient evidence to conclusively determine the environment of deposition.

The conglomerate at the base of the Roman Fell Succession (up to 50 feet thick according to Burgess and Harrison, 1967) has been shown by Burgess and Harrison (op.cit.) to infill local topography apparently locally 'banked' against steep-sided ridges. The conglomerate contains a variety of clast types (Skiddaw Slate, acid and basic tuffs, vein quartz, Brathay flags and Caradocian mudstones) which Burgess and Harrison (op. cit) consider to have been locally derived. Barraclough (1983) considers the conglomerate to represent alluvial fan deposits.

As regard to the Roman Fell Shales, Shotton (1935) recorded the finding of 30 large scales, which he assigned to the Carboniferous marine fish Rhizodus hibberti. This fish belongs to the family Rhizodontidae, these fish being very similar in form, often very common in rocks of the Upper Devonian and Carboniferous but are generally poorly known and poorly described, generally as a result of their large size (e.g R. hibberti may have been up to 7m, Andrews, 1985). While the author is not fully aware of the preservation of the scales of Shotton's (1935) fish, it is believed that misinterpretation could have been possible given that all the rhizodont fish are similar in form. Most significantly, however, rhizodonts are known from both fresh water and marine environments (A.A. Bray, pers. comm.). In a recent study, Barraclough (1983) interpreted the Roman Fell Shales as representing tidal flat deposits, and probably equivalent to the Pinskey Gill Beds of Ravestonedale (see Chapter 8), associated with the basal Carboniferous marine transgression. In this context, the overlying Roman Fell Sandstones, with a westerly provenance, were interpreted by Barraclough

(op. cit.) as braidplain deposits reflecting renewed clastic deposition during subsequent shoreline progradation.

Exposure of the Roman Fell shales is far from complete, and as far as the author is aware, the best exposure (4m-5m) is near the junction of Scordale and Swindale Beck, Hilton (N.G.R. NY 754214) the locality of Shotton's, (1935) fish. At this exposure, the Roman Fell Shales comprise well-bedded and laminated fine grained argillaceous sandstones interbedded with siltstones and silty mudstones. Sandstones are possibly horizontally laminated and may fine upward. Given the relatively poor data and the fact that Shotton's (1935) fish may have been a non-marine rhizodontiform, the author should like to propose that the Roman Fell 'Shales' represent fine grained deposits which accumulated in a floodplain or floodbasin environment. Their position above the basal alluvial fan conglomerates suggest they accumulated on alluvial fan abandonment. Steel et al., (1977) and Steel and Aasheim (1978) describe a sequence of floodbasin/lacustrine deposits, deposited by flood processes within the Hornelen Basin, Norway. These deposits accumulated at the distal segment of a sandy alluvial plain but also accumulated in a 'lateral' basin position, against alluvial fans and associated with basin-margin faults. It is therefore suggested that a comparable situation may have arisen in the Roman Fell succession, the Roman Fell Shales deposited as a floodplain or floodbasin sequence (with standing bodies of water) against alluvial fans, especially as both Burgess and Harrison (1967) and Barraclough (1983) have interpreted thickening of the Roman Fell Shales (to 200 feet) as a result of penecontemporaneous movement along the Swindale Beck Fault.

The overlying Roman Fell Sandstones, by representing the deposits of a sandy bedload braided channel system, comparable in size to the South Saskatchewan River (channels up to 150m wide and 3m deep), reflect diversion of this channel system into the Roman Fell area. In doing so, and in view of similar extensive sandy braidplain deposits from Shap and the northern part of Cross Fell, the Roman Fell Sandstones are thus considered to be laterally equivalent to the Red Sandstones and to form part of the same extensive braidplain system. Burgess and Harrison (1967) again report southerly thickening of the Roman Fell Sandstones across the Swindale Beck Fault (up to 350 feet), these being sourced locally. While palaeocurrents from the Roman Fell Sandstones (Figures 6.12, 6.13) indicate palaeoflow towards a north-north-east to north-east direction, this clearly suggests that the Roman Fell Sandstones were not sourced locally and that the Swindale Beck Fault did not form such a positive topographic influence as postulated by Burgess and Harrison (op.cit.).

9.4 PREDICTIVE DEPOSITIONAL MODEL AND PALAEOGEOGRAPHY

The proximal to distal relationships used to develop depositional models for each study area have been used as a basis to predict facies relationships over the study region and the palaeogeography. The six braided river models proposed by Miall (1977, 1978, 1982) as presented in Figure 9.1 make an attempt to construct vertical facies profiles from both gravel and sand dominated modern braided rivers. As a guideline Miall (e.g. 1985a) indicates that a proximal to distal transition exists between the Scott, Donjek and South Saskatchewan types, with limits of

gravel within these systems estimated as >90%(Scott), 10%-90% (Donjek) and <10% (South Saskatchewan). As such these models have been used or partly used as a basis by a number of authors (e.g Boothroyd and Nummedal, 1978; Hobday, 1978; Minter, 1978; Turner, 1982; Buck; 1983; Steel and Thomson, 1983; Brady, 1984; Ethridge et al., 1984; Middleton and Trujilo, 1984; Varley, 1984 and Ramos et al., 1986) to model proximal to distal relationships in alluvial fan to braided fluvial channel regimes. In addition very marked proximal to distal variations have also been documented by Steel and Aasheim (1978) and Turner (1978). Steel and Aasheim (op.cit.) describe the deposits of the Hornelen Basin, Norway characterised by both 'longitudinal' and 'lateral' basin fill elements. The former comprises an alluvial plain or 'sandy fan delta' consisting of ephemeral, low sinuosity streams which prograded into a distal floodbasin/lacustrine setting. The lateral basin fill sequence comprises a transition from the 'axial' alluvial plain sediment into progressively finer grained floodbasin 'fines' accumulating against basin margin alluvial fans.

Turner (1978) documents proximal to distal variations in the Upper Permian Beaufort Group, Southern Karoo (South Africa). The succession comprises an overall upwards fining trend, consisting of a downstream transition from upstream braided channels transporting a heavy traction load over steep gradients, into a distal environment characterised by a change from low sinuosity to high sinuosity channels. This change may have been attributed to denudation of the source area, which promoted a decrease in sediment supply and channel gradient and a progressive

'sourcewards' shift increasing quantities of fine grained sediment into the basin.

In the present study the significant evidence suggesting that the succession buried beneath the Vale of Eden was the proximal to distal parts of a braidplain system are the dominant north to north-east palaeoslope and the upward fining trend recognised in each area. Erosion of upland regions, mainly southwards of each region, is shown convincingly by the clast composition types particularly the Mell Fell Conglomerate which documents quite closely the progressive removal of the Silurian greywackes (mostly Coniston Grits) from the northern Lake District probably during the Tournaisian. On-going denudation promoted decreasing sediment supply, decreasing channel gradient in progressively distal areas away from source, and this was accompanied by a change in channel bedload and downstream fining of clast and grain size.

On palaeoclimatological grounds the local presence of calcrete nodules and minor thin calcrete horizons (Shap Red Beds) and particularly the evidence for calcrete-forming processes within the unconformity zones (Chapter 2) indicate that climate was probably mainly semi-arid. The lack of debris flows within the alluvial fan environments within the Mell Fell Conglomerate and Sedbergh Clastic Rocks has been attributed to a lack of argillaceous source rock in the source area. In this case, the alluvial fans being constructed by braided streams most probably reflect a semi-arid climate which was dominated by sporadic floods (cf. Collinson, 1986). Indeed 'run-off' might have been appreciable considering the lack of organic debris, only

signs of which occur at Sink Beck, Cross Fell, which suggests a lack of vegetation in the study region. Evidence, in the form of mud drapes overlying conglomerate bars and sandstone wedge drapes in gravel-bar surface depressions (e.g. Mell Fell conglomerate, Shap Red Beds), for fluctuating discharge is a common feature, and in fact standing bodies of water were also present in floodplain/overbank areas (e.g. syneresis cracks, Shap Red Beds; fish in Roman Fell shales). Graham (1983) in his study of the Upper Devonian Munster Basin, Ireland, suggested that limited development of pedogenic calcrete was one factor in interpreting the climate as being seasonally humid and indeed a lack of sediment-binding vegetation decreased channel-bank cohesion and allowed rapid widening of channels during floods. In fact a parallel is sought with Graham (op. cit.) as he considers that the change to an environment characterised by a high water table (his fluvial coastal plain facies, possibly resembling the Green Sandstones of Cross Fell) was associated with climatic changes in relation to the subsequent Carboniferous marine transgression. Indeed in the present study, evidence for abundant plant remains is present within the Pinskey Gill Beds and 'Shap Conglomerate' (Wyegarth Gill Boreholes) and Carbonaceous mudstones (Scar Sikes; Scoutgreen Crossing, Shap, Plate 8.4) and suggests to the author that by the Courceyan, climate had most likely become more humid.

The interpreted depositional model and reconstruction of the palaeogeography is shown as a series of 'time-lapse' maps within figure 9.4 and documents the evolution of a proximal gravel braidplain into sand and distal braidplain facies associated with the denudation of the source area relief. Assuming that an average thickness of 100m of

clastic rocks might not seem unreasonable over the region, a crude calculation of basin-fill produces a figure of 60km^3.

Topographically high ground was located over the Lake District, both the Alston and Askrigg Blocks and in the region South of Sedbergh and West of Kendal (based on works of Scott, 1984 and Nicholas, 1968). The Lake District massif and the Alston and Askrigg Blocks are underlain by granite (see Chapter 1; Section 9.5) these areas remaining stable throughout the Carboniferous by the 'buoyancy' effect of the deep-seated granite plutons (see Johnson, 1967). The possibility exists that granite is also present beneath the central part of the Vale of Eden (see Figure 7.2; cf Bott, 1978) and, as discussed below, may have had a limiting effect on gravel deposition in this region (Time-lapse 1, Figure 9.4), especially as the ridge corresponds with reduced conglomerate deposition in Cross Fell (South of Sink Beck, Knock) and absence of clastics in the area between Shap and the Mell Fells. The Howgill Fells area, south of Ravenstonedale, may have been an upland area although it seems possible that a connection between Kendal and Shap (in the area West of the Howgill Fells) may have been present (discussed below; also see Section 9.5).

In the northern part of the Vale of Eden, similar north-east depositional trends from the Mell Fell Conglomerate and the Cross Fell Clastic Rocks suggest that gravel deposition was continuous over this region (Figure 9.3). Further support is shown by the texturally more mature Quartz Conglomerates, containing a dominant component of most resistant vein quartz, a probable result of increased sorting and

removal of less resistant clast compositions with distance from source (cf. Richard, 1982 p.232). However, it is most probable that the increased vein quartz component, accompanied by the 'red quartz arenite' clasts may be more appropriately a reflection of a derivation from the quartz veined Skiddaw Group and may indicate a source from north of the Mell Fells and possibly input from the area between the Mell Fells and Shap (underlain by the Skiddaw Group). It is most striking that throughout the whole region vein quartz is only present as the dominant maximum clast size component within the Quartz Conglomerates, undoubtedly a reflection that the Mell Fell Conglomerate, Shap Red Beds and the Sedbergh clastics were derived from source terrains lacking vein quartz (i.e. from the Silurian greywackes).

Along Cross Fell, alluvial fans (Polygenetic Conglomerate) built out perpendicular to the braidplain trend, and provided sediment input of locally derived material from the Alston Block. South of Cross Fell, Quartz Conglomerate deposition was restricted by high ground south of Sink Beck, and this is reflected in the southward 'pinch-out' of the Quartz Conglomerates (Figure 6.1). Correspondingly, probable alluvial fans accumulated against the Swindale Beck Fault at Roman Fell, these deposits (Basement Conglomerate) overlain by the Roman Fell Shales reflecting floodplain/floodbasin fines, deposited in a distal braidplain setting. Infact, if gravel deposition was restricted in the central part of the Vale of Eden, then it is suggested this region could have also accumulated distal braidplain fines forming an extension of the Roman Fell Shales into this area.

In the southern part of the Vale of Eden, conglomerates comprising facies zones 1 and 2 of the Shap Red Beds represent deposits of typical 'Donjek' type braided channels, the north to north-north-east palaeocurrents predicting extension of gravel deposition northward towards the central part of the Vale of Eden. In facies Zones 1 and 2 of the Shap Red Beds conglomerates and interbedded sandstones are organised into distinct fining upward sequences capped by silty mudstones. The greater proportion of preserved floodplain fines is not typical of other coarse grained braided fluvial conglomerates in the other areas, and it is suggested that their preservation is a result of increased topographic differentiation in the Shap area with the development of district topographic levels (cf Williams and Rust, 1969; Figure 3.10) within the channel system. This could be a consequence of increased channel incisement, a possible result of the Shap Red Beds being surrounded by high ground both to the north-west, west and east, 'funnelling' discharge through a relatively narrower reach of the braidplain (<10km, perpendicular to palaeoslope).

Certainly, in view of the presence of Donjek type braided river deposits at Shap, a southerly transition, i.e. up-palaeoslope, predicts that Scott type braided river gravels would have been present (now eroded). In veiw of this, the presence of Scott-type gravels in the Sedbergh area suggests to the author, particularly in view of the north-west to north-north-west palaeocurrents (Sedbergh Clastic Rocks), that a transition towards Shap may have been present. Indeed Ashton (1971) considers that the area north of Kendal formed part of a depression (Kendal Depression) and that Carboniferous rocks in the north

part of the depression are absent due to uplift and erosion of the Howgill Fells. Certainly, clastic rocks, typical of the Shap Red Beds (Facies Gm, Facies Gt/St) are exposed near to Kendal (Section 9.2.3).

The gravel-dominated braidplain may have extended for at least 35km (north to south, parallel to palaeoslope) in length and up to 25km wide (west to east, Mell Fells to Cross Fell). The dimensions of proximal, gravelly braidplains have been shown by Rust and Koster (1984) to vary tremendously, and may extend parallel to palaeoslope for distances up to 500km. McClean (in Rust and Koster, op. cit.) describes a sheet-like braidplain (Lower Cretaceous Cadomin Formation, Alberta) in which clast sizes decreases very gradually downstream for 300km from sediment source. In contrast the Scott braided glacial outwash fan, Alaska as documented by Boothroyd and Ashley (1975), deposited on relatively steep gradients (see Chapter 4) comprise coarse gravel (>10cm) which extends for 8km from source and grades into finer gravel and sand 16km from the ice front.

Denudation of the highland source areas, probably by a process of scarp retreat (cf. Heward, 1978; Turner, 1978), promoted the establishment of an extensive sandy braidplain with time (Time-Lapse 2, Figure 9.4) and reflects further gradient decrease with corresponding decrease in clast size. The distal sandy facies of the Mell Fell Conglomerate, reflecting the construction of a 'cone-like' braidplain by reduction in relief of the northern Lake District, extended into the Cross Fell region and is thus considered synonymous with the Red Sandstones of Cross Fell. Within the Cross Fell and Roman Fell areas,

retreat, through continued denudation, of the high ground which existed, during deposition of the Quartz conglomerates, South of Sink Beck (Time-Lapse 1, Figure 9.4), resulted in extensive sand deposition between Cross Fell and Roman Fell, indicating that the Roman Fell Sandstones are laterally equivalent to the Red Sandstones in the north. Certainly evidence of continued sand braidplain deposition in the southern part of the Vale of Eden is recorded within facies Zones 3 to 5 and at the Tebay Services section at Shap (Shap Red Beds), again the dominant north to north-north-east palaeoslope suggesting that the Vale of Eden was covered by a sandy braidplain characterised by wide and shallow (possibly up to 5.16m deep, 232m wide) braided channels comparable to the South Saskatchewan River. Distally, fine grained fluvial braidplain deposits, (Green Sandstones) probably had become established in the area north of Cross Fell and the Alston Block, predicted by the upward transition from the Red into the Green Sandstones.

The southerly 'migration' of the distal braidplain (?coastal plain) 'fines', in response to the sourcewards shift in fine grained deposition is demonstrated in Time-Lapse 3 of Figure 9.4. Thus, in response to decreasing source area relief, decreasing gradient, decreasing sediment supply and discharge (cf. Turner, 1978), fine grained deposition of the distal braidplain facies (represented by the Green Sandstones, Cross Fell Clastic Rocks), was established over the central and northern part of the Vale of Eden and it is possible that the facies may have extended into the Mell Fells area (now possibly eroded). In the south part of the Vale of Eden, it is considered that lagoonal or tidal flats (Pinskey

Gill Beds,) were widely established extending between Ravestonedale and Shap. These were probably associated with encroachment of the marine Carboniferous transgressing from the east along the Stainmore Trough and developing the Ravenstonedale Gulf in the present region (see Barracough, 1983). It is probable that the distal braidplain fines, accumulating further north, provided a transition into a coastal plain environment and as such the dominant northerly palaeoslope might have changed in response to the westerly transgression, cf. Galloway (1981) who has shown that in such a flat-lying environment channel patterns will radiate to aggrade as much of the plain as possible. Continuation of the tidal flat/lagoonal environment may have extended further south, reflected in Chadian (?or Courceyan) 'floodplain' deposits in the Sedbergh area (Nor Gill Sandstones of Barracough, 1983 and Burgess, 1986). Northward extension of the Ravestonedale Gulf (perhaps draining into the Northumberland Basin, cf. Barraclough, 1983) took place with time, reflected in the relatively younger (Arundian) limestones overlying the Mell Fell Conglomerate.

9.5 REGIONAL STRUCTURAL CONTEXT

The presence of the Block and Basin structure of the Carboniferous, particularly in northern Britain, has been the subject of a number of authors in previous years (e.g. Johnson, 1967) and it is accepted that the stable block areas, principally in this region, the Lake District and the Alston and Askrigg Blocks, were separated by basin areas which received sediment by a process of differential subsidence along basin margin faults. The relatively stable blocks are underlain by deep

seated granites (see Chapter 1) and provided the main form of upland areas, as demonstrated, during deposition of the fluvial clastic rocks surrounding the Vale of Eden. In particular the high ground immediately south of the Mell Fells, which provided initial high relief for alluvial fan development, was most probably marked by the 'northern wall' of the deep seated granite underlying the Lake District (Figure 1.2). Indeed, Bott (1974) provides evidence that the Lake District granites may be responsible both for the present elevation and for the past tendency for the region to be uplifted in relation to its surroundings, and suggests that the uplift associated with the granites took place in response to faulting in the upper crust.

The development of 'marginal' alluvial fans (Polygenetic Conglomerate, Roman Fell basement Conglomerate) may also have been associated with relative uplift of the Alston Block compared with ground to the west and possibly with marginal faults. Although much evidence is provided for southward thickening of the Roman Fell succession associated with penecontemporaneous movement along the Swindale Beck Fault (south margin of the Alston Block; e.g Burgess and Harrison, 1967; Bott, 1974; Barraclough, 1983), the author considers that the north-east to north-north-east palaeocurrents from the Roman Fell Sandstones suggest that the Swindale Beck Fault may not have been such a positive influence during deposition of these sandstones. In much the same way, relative uplift of the Askrigg Block created relief in the development of the coarse proximal conglomerates at Sedbergh although the author is unsure as to the influence of the Dent fault during clastic deposition in this area.

Johnson (1967) postulated a ridge in the area of the Howgill Fells which separated the Ravenstonedale Trough from the Bowland Trough to the south, it appears the 'ridge' is closely underlain by magnetic Precambrian basement. In consideration of the discussions in section 9.2.3 and 9.4, clastic deposition undoubtedly took place south of the Howgill Fells, palaeocurrents suggesting a southerly provenance, even though the clast compositions at Sedbergh (Coniston Grit greywackes) could have equally been derived from the Howgill Fells area. Proximal to distal relationships, particularly at Shap indicate that a transition southwards to 'Scott' gravels would have been present and suggests that a connection south of Shap towards the Kendal and Sedbergh area may have been possible. Support for this argument comes from Ashton (1971) who considered that clastic deposition took place within this region, in the 'Kendal Depression', Carboniferous rocks in the northern part of the depression being absent due to uplift and erosion of the Howgill Fells. It has also been postulated that the Ullswater - Skiddaw anticline formed a 'barrier' to the north of the area and was not breached until at least the mid-Visean (see Capewell, 1956, George, 1958, Johnson, 1967). Due to the extensive northward flowing braided fluvial deposits in the north of the area which, it is tentatively suggested (see below) could have formed part of the same fluvial system as that documented by Leeder (e.g. 1973), the influence of this 'barrier' is probably under question.

Significantly, Bott (1974) has indicated a 'thick' succession of basement Carboniferous rocks beneath the Vale of Eden Permian cover, also demonstrating the thickening of the Carboniferous in the south

particularly towards Ravenstonedale and Kirkby Stephen. Leeder (1976, 1982) and Bott et al. (1984) both indicate the block and basin structure of Northern England to have been initiated as a result of the plate tectonic regime in the period spanning the Upper Devonian to Lower Carboniferous. The blocks and intervening basins developed as a result of lithospheric stretching which caused regional tension and rift/graben formation in areas of less buoyant crust. Bott et al. (op. cit.) attribute the lithospheric tension to the slabpull force resulting from the subduction of the attached oceanic part of the plate which formed the closing Hercynian marginal sea to the south. Significantly, as discussed by Leeder (1982), the development of these rift/graben basins adjacent to the blocks, was a product of the position of the Caledonide granite plutons, but 'more driving force for subsidence came from the Hercynian plate margin to the south'.

It has been argued that the dominantly fluvial clastic rocks which surround the Vale of Eden, deposited possibly during the Tournaisian, were a product of uplift of the 'block' areas, i.e. underlain by buoyant granite, and it was this uplift that was the dominant cause of subsidence, resulting in the broad northerly dipping palaeoslope over the region. Indeed, although data are inhibited by a lack of exposure, palaeocurrents do not seem to be influenced by the 'block' margin faults, e.g. in the case of the Swindale Beck fault. Also, the encroachment of the marine transgression from the east (Stainmore Trough, Ravenstonedale Gulf) had a trend almost perpendicular to the northerly palaeoslope. It seems more than likely that the fluvial clastic rocks developed primarily in response to post-intrusive uplift

of the granite plutons, their deposition only probably being affected (switch in palaeoslope, see Figure 9.4) by the initiation of the block and basin structure and relative subsidence during encroachment of the marine Carboniferous during the Courceyan.

The author believes that the fluvial clastic succession documented in the present study can be compared to the dominantly fluvial Upper Old Red Sandstone succession described by Leeder (1971, 1972, 1973a) for the Northumberland Borders. Significantly, the north to north-easterly palaeoslope is more or less identical for both areas, the clastic rocks of Leeder (op.cit.) showing a broad coarsening upward trend into a dominantly braided-fluvial succession which reflects post-intrusive uplift of the Galloway 'Newer Granite' province to the south-west of the Northumberland area. Significantly, this uplift formed the north-easterly palaeoslope, relative to the north-east towards an interior drainage basin ('Border Basin') which lay to the west and north-west of the Cheviot Hills. Indeed, initiation of the Northumberland Basin at the base of the Carboniferous, (in this area marked by local volcanicity - the Birrenswark Lavas) led to distinctive 'restricted' marginal facies, for example the cementstones of Northumberland (Belt et al., 1967) and the Pinskey Gill Beds of Ravenstonedale (Johnson and Marshall, 1971). The author, therefore, would like to propose that the 'Carboniferous Basement Rocks' documented in this study may more appropriately be representative of an Upper Old Red Sandstone succession which, it is tentatively suggested, may have formed part of the same 'extensive' north-easterly drainage system as that described by Leeder (op. cit.), the palaeoslope, the result of post

intrusive uplift of the Caledonide granite plutons causing a broad north-easterly 'downwarp' over the region.

Significantly, the present study has shown that although stratigraphic relationships are difficult to determine accurately within non-marine and particularly fluvial clastic rocks, the relative timing of clastic deposition can be 'pieced' together using a combination of proximal to distal variations, clast composition data and palaeocurrents. Importantly, the author believes the present study is the first to consider the Mell Fell Conglomerate to have formed part of the same braidplain system as the remaining clastic successions underlying the lowermost Carboniferous limestones in the Vale of Eden, documenting erosion of the Upper Palaeozoic landscape and prior to marine transgression at the base of the Carboniferous.

FIGURE 9.1. BRAIDED RIVER DEPOSITIONAL PROFILES
(From Miall, 1985b)

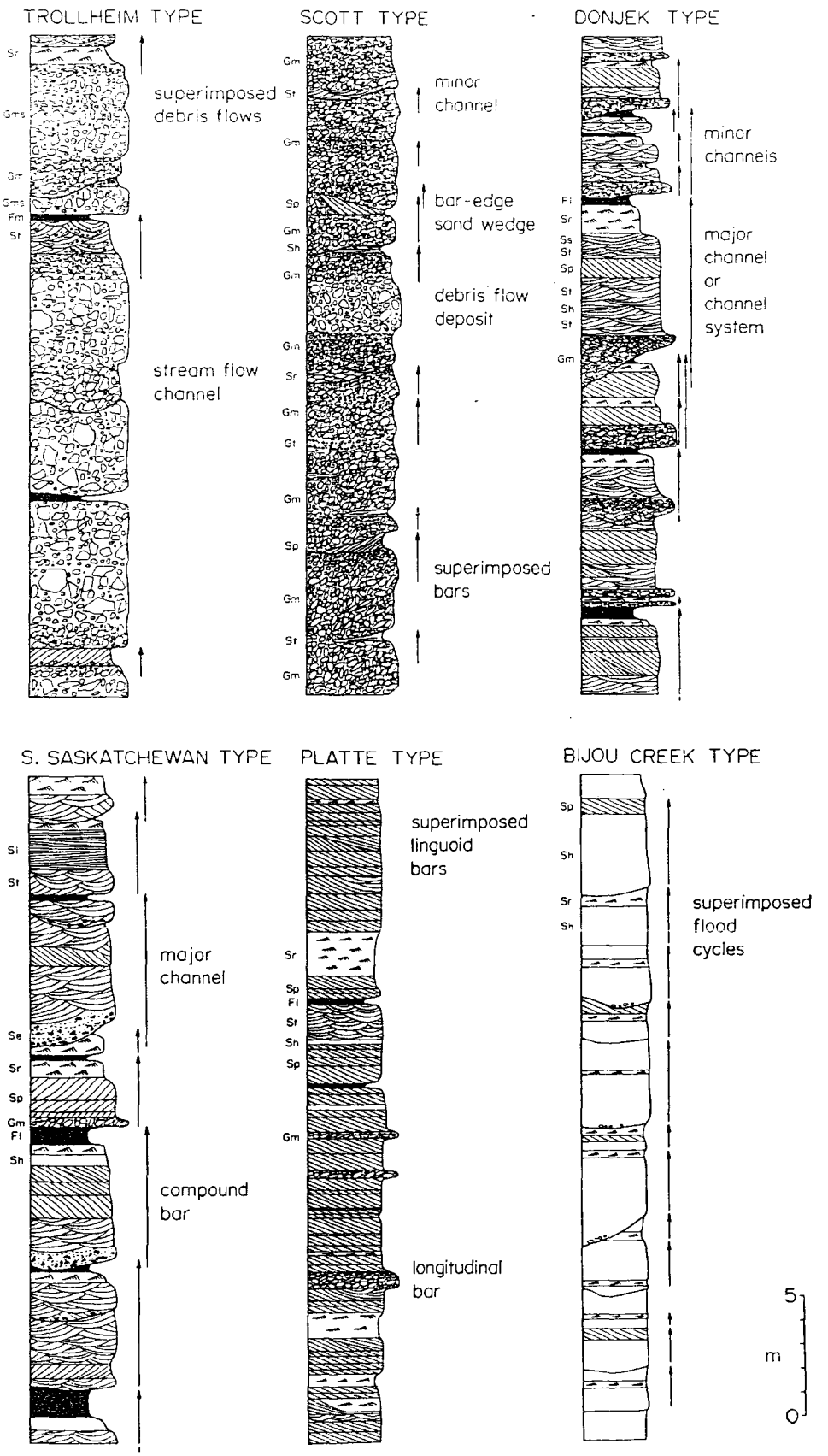


FIGURE 9.2

Cross-section, West Vale of Eden

NNW - NGR NY 426236
SE - NGR NY 698039
S - NGR SD 677922
SE - NGR SD 803707

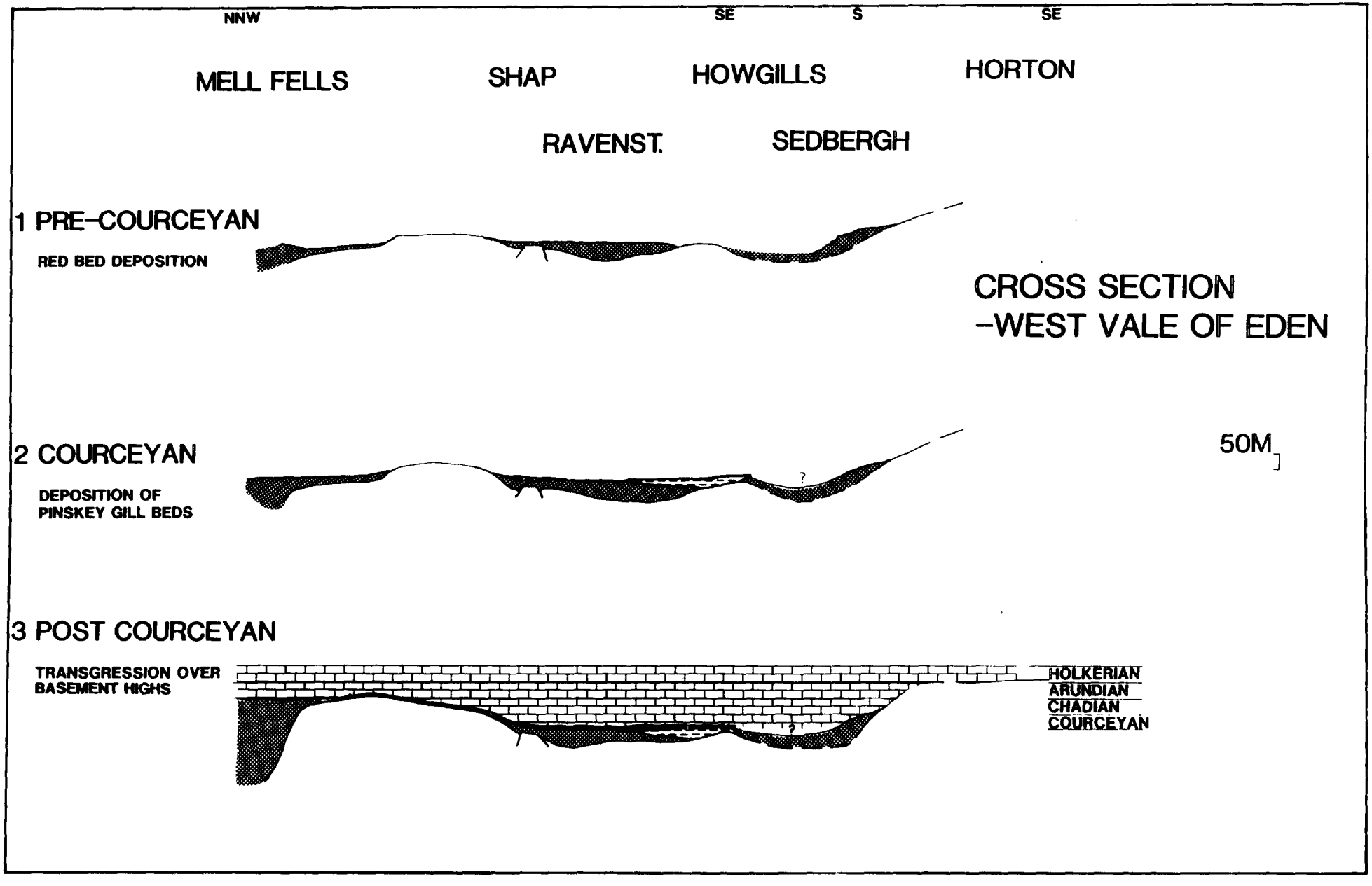

NNW
SE
S
SE
MELL FELLS
SHAP
HOWGILLS
HORTON
RAVENST.
SEDBERGH
1 PRE-COURCEYAN
RED BED DEPOSITION
CROSS SECTION
-WEST VALE OF EDEN
2 COURCEYAN
DEPOSITION OF
PINSKEY GILL BEDS
50M
?
3 POST COURCEYAN
TRANSGRESSION OVER
BASEMENT HIGHS
HOLKERIAN
ARUNDIAN
CHADIAN
COURCEYAN
?

FIGURE 9.3. SCHEMATIC CROSS - SECTIONS, VALE OF EDEN

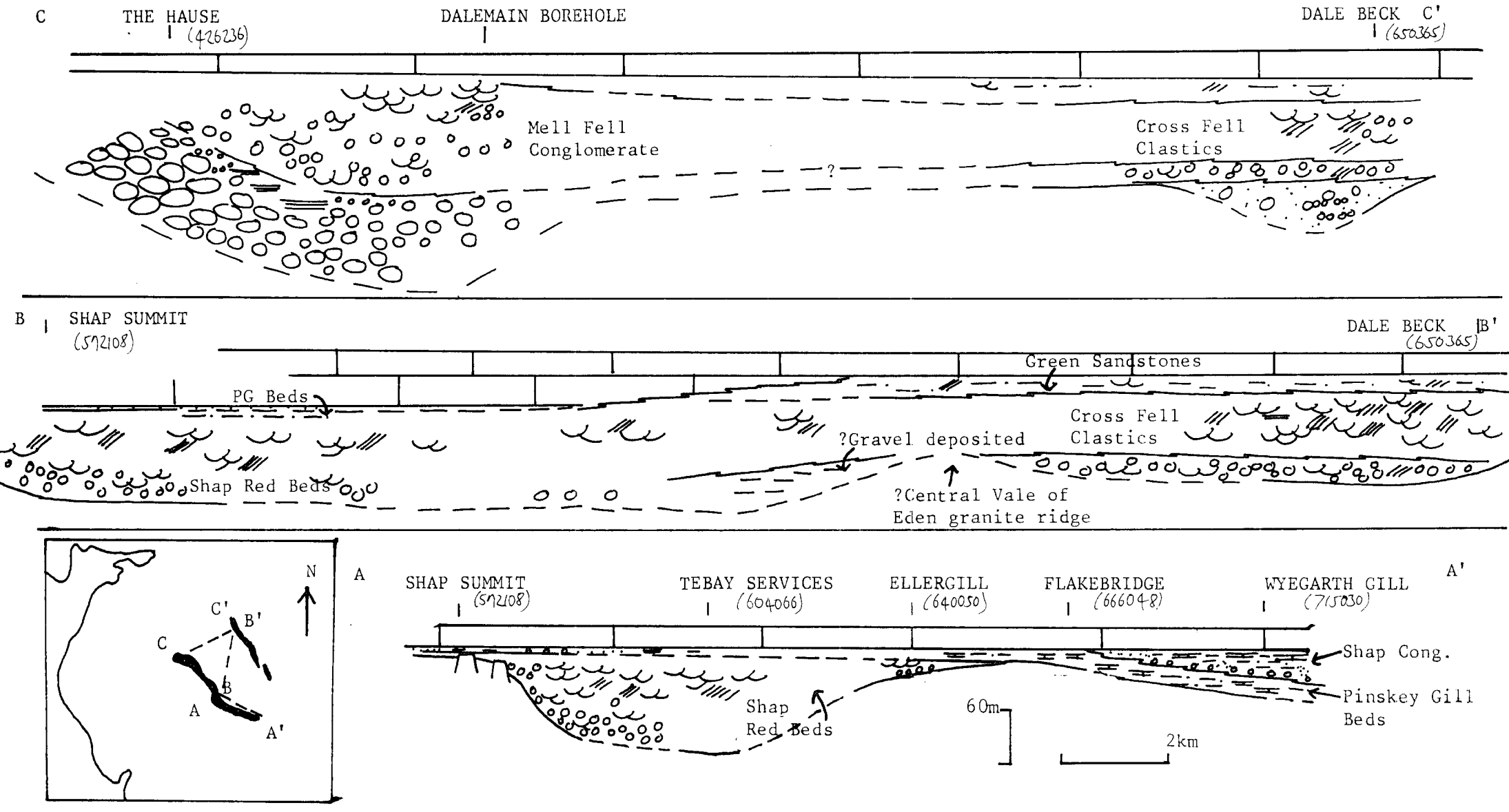


FIGURE 9.4. REGIONAL DEPOSITIONAL MODEL AND PALAEOGEOGRAPHY DURING THE EVOLUTION OF THE CLASTIC ROCKS AT THE BASE OF THE CARBONIFEROUS IN N.BRITAIN

TIME-LAPSE 1.

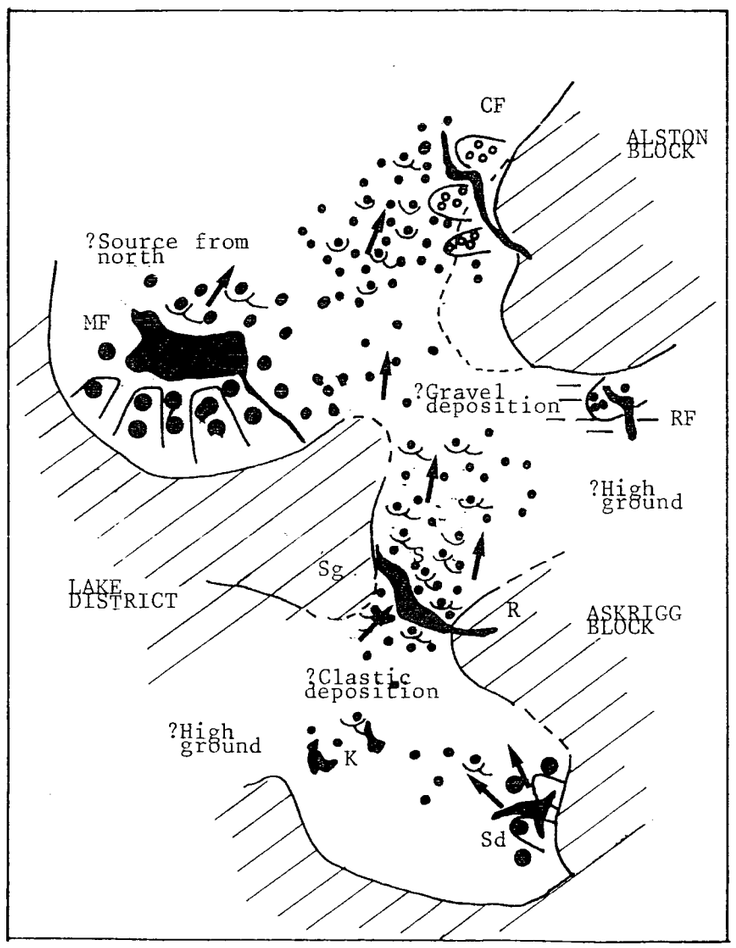
Extensive gravel deposition within gravel bed-load braided channels across most of the region. Cross Fell Clastics represent continuation of gravel deposition in the north part of the Vale of Eden, with high ground separating Roman Fell (RF) from the north part of Cross Fell (CF). Distal braidplain fines accumulating in Roman Fell area, possibly extending into central Vale of Eden along area underlain by granite. Extensive proximal alluvial fan gravel in Mell Fell (MF) area. Alluvial fans (Polyg. Cg.) tributary to proximal braidplain gravel (Qz.Cg.) in Cross Fell area. Possible extension of alluvial fan gravel in Sedbergh (Sd) northwards to Shap (S).

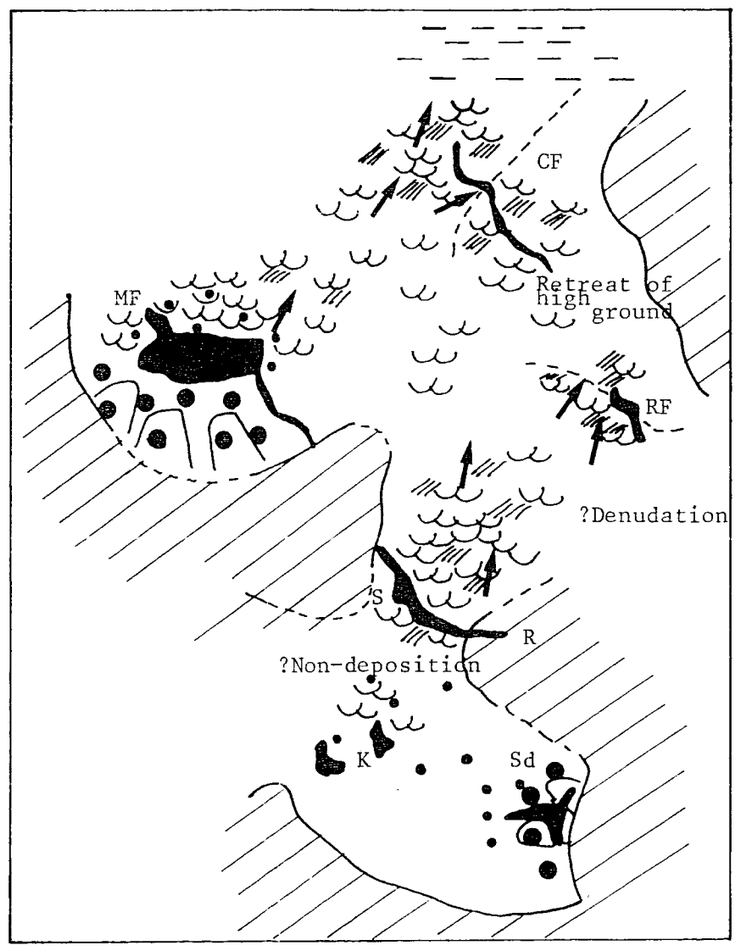
TIME-LAPSE 2.

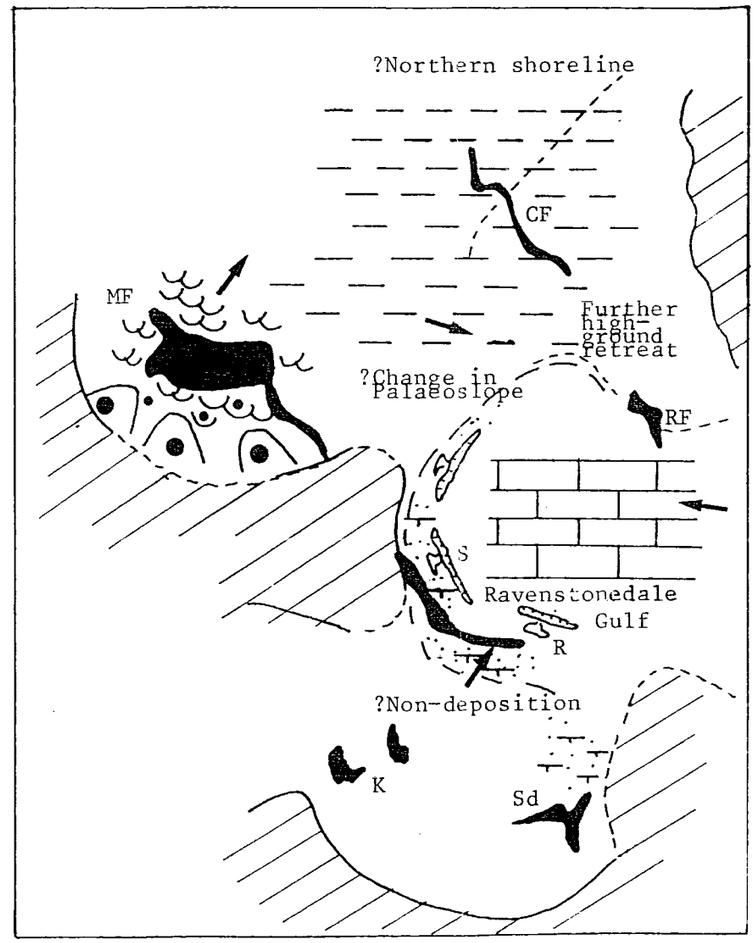
Lowering of source area relief with time established widespread sandy braidplain over most of the Vale of Eden region. Dominant north to north-east palaeoslope. Retreat of high ground particularly between north Cross Fell and Roman Fell, and extension of fluvial deposition in Roman Fell area. Distal braidplain fines within northern part of Alston Block. Continuation of braidplain south of Shap towards the Kendal (K) area.

TIME-LAPSE 3.

Retreat of source areas in Lake District and possibly over Alston and Askrigg Block areas accompanied by southward 'migration' of distal braidplain fines to cover both north and central Vale of Eden. Northern shoreline cf. Barraclough 1983, Establishment of lagoonal or tidal flats over southern part of Vale of Eden and possibly extending to Roman Fell. Deposition of Pinskey Gill Beds at Ravenstonedale (R) to Shap region and also to south of Ravenstonedale. Marine transgression during Courceyan from the east along the Stainmore Trough and Ravenstonedale Gulf.







Area of high ground, underlain by granite in Lake District and Alston/Askrigg Blocks

Downstream fining of gravel from proximal alluvial fans (braided stream)

Alluvial fans dominated by debris flow

Gravel bed-load braided streams

Sand bed-load channels (migrating dunes)

Sandy transverse bars

Distal braidplain fines

Lagoonal/tidal flat deposits

Spill-over deposits associated with nearby ?beach ridge

Open marine deposition

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APPENDIX 1

Facies Tables (1-26)

TABLE 1

LOCALITY		FACIES (MIALL)	CLAST SIZE cm MAX.	CLAST SIZE cm AV.MAX	STRUCTURE
GREENHOLME	1	Gm	25	10	B axis imbrication directed towards 044°. Unit 1 fines up into 2.
	2	Gm	15	8.6	
	3	Gm		3	
HIGHSCALES	1	Gm	19	12.4	Units 1/2 form part of the same massive conglomerate, fining up into facies Gt (PCs orientated towards 044°/050°).
	2	Gm	24	14.6	
	3	Gm/Gt	18	13.5	
BECKSIDE	1	Gm	14	9.3	Massive, with no observed B axis imbrication.
	2	Gm	11	6.1	
EWELOCKBANK	1	Gm	18	3-4	Crudely stratified conglomerates, forming fining upward units.
	2	Gm	15		
HOLLIN GILL	1	Gm	36	15.8	Upper part of section, difficult to define any breaks in conglomerate sequence. In places conglomerates become trough - cross - bedded ? Imbricated locally - 096°.
	2	Gm	33	16.9	
BECKSIDE SCOUTGREEN	1	Gm	8	6	Conglomerates - massively bedded units, overlain by facies St (?Gt), PCs - 064°.
	2	Gm/Gt	11.5	6.8	
	3	Gm	9	5.4	
	4	Gp	6		
SCOUTGREEN		Gt		3	Abundant mud intraclasts Crude TXB sets. PCs - 016°.
STAKELY BECK	1	Gm	20		Unit 1 is banked up on either side of a lamprophyre dyke (minette) palaeoridge. Units 2 and 3 are massively bedded. Unit 4 forms a PXB basal unit below a PXB pb.sst, with PCs - 032°. Unit 5 - well imbricated (B) - 315°. Unit 6 - possibly crudely TXB.
	2	Gm	24	14.6	
	3	Gm	29	19	
	4	Gp?	7		
	5	Gm	33	19.8	
	6	Gt?	7	4.3	

TABLE 2

LOCALITY		FACIES (MIALL)	CLAST SIZE cm		STRUCTURE
			MAX.	AV.MAX.	
SHEPHERDS BRIDGE	1	Gm	30	20	Massive conglomerate overlain by TXB conglomerate
	2	Gt	7	<3	- Crude sets, (20cm), PCs - 350°. 003°.
SHEP.BR.TO DOCKER FORCE	1	Gm	5	3	Well imbricated (B-010°) and stratified unit, fines to top.
	2	Gm		<3	
DOCKER FORCE	1	Gm	13.5	9.3	Massively bedded unit, fines to top.
	2	Gm	4.5	3.2	
WASDALE BECK	1	Gm	30	5.2	Units 1/2 - cross - stratified (PC - 046°), fines to top.
	2	Gm	7	4.1	
	3	Gm	13.5	8.1	Units 3-5, form 1 stacked sequence. Unit 3 - imbricated (B-075°). Units 4/5 - finer forming top of sequence.
	4	Gm	5	3.3	
	5	Gm	6	3.6	
	6	Gm	5.5	3.7	Unit 6 - imbricated (B) - 050°.
	7	Gp		3	Unit 7 - PXB, PC - 054°.
BLEA BECK		Gm	9	7.1	Imbricated (B) - 130°.

TABLE 3.

LOCALITY		FACIES	CLAST SIZE CM.		STRUCTURE
			MAX.	AV.MAX.	
ELLERGILL BECK.	1.	Gm	15	10	Clast supported framework with infilling coarse matrix.Mod. sorted with rodding of finer clasts.Crudely stratified -dips >360°/10-12° (dips taken from 15cm thick fine sst. intercal.)
	2.	Gm	5-6	2-3	Tightly packed clast supported framework.Rodded coarse matrix. Probably fines up from facies Gm below.Overlain by facies Sh.
	3.	Gm	16	10.7	Clast supported framework. Crudely stratified with rodded coarse matrix.Above base - 35cm wide,15cm deep scour pockets lined with larger cobbles.
	4.	Gm	6-7	1.5-3	Pebbly base to facies Sr above.
BLEA BECK		Gm	9	7.1	Clast supported framework.? matrix.A axis of clasts aligned >130°-310°.Sharp base on xb sst below.Overlain by facies Sr.
SHAP SUMMIT.	1.	Gm	12		Poorly exposed against B.V.G. ridge.?crudely stratified clast supported framework with s.r. B.V.G. boulders.Poorly sorted.
	2.	Gm	6.5-2		Stratified pebble conglomerate transitional to stratified pb. c. ssts.

TABLE 4.

LOCALITY		FACIES (MIALL) /GRAIN SIZE	STRUCTURE
GREENHOLME	1	Sh f sst	Flat lying immediately above Unconformity
	2	Sh/Sp m-c ssts	1.38m sequence above Gm.Forms coset TXB sets with interbedded PXB set.Basal contact is planar.Imbrication of pebbles along foresets in PXB set. Pal.currents ± TXB 040° - 050° PXB 338°
HOLLIN GILL	1	Sp? m sst	Unit 50cm thick overlying Gm. Planar foresets inclined 20° towards 050°
	2	Sh/Sr f sst	Unit up to 15-20cm thick interbedded with Gm.Flat laminated to RXL crests trend 107°-287°
STAKELEY BECK	1	Sh f sst	
	2	Sh f sst	10cm unit interbedded with unit of facies Gm
	3	Sh f sst	50cm unit transitional from unit facies Gp
	4	m-c ssts	Calcite cemented ssts below facies Gm
BECKSIDE	1	St/Sh m sst	Quartz arenites with mud intraclasts forms solitary TXB set 35cm thick transit. from Gm.Pal.current - 050°. Overlain by thin unit facies Gm and then transit. to Lam. m ssts.
	2	Sp? f sst	40cm unit with planar foreset s below unit facies Gm.

TABLE 5

LOCALITY		FACIES (MIALL) /GRAIN SIZE		STRUCTURE
BECKSIDE (CONT.)	3	Sh/St	f/m sst	15cm lam. sst intercalated with facies Gm. Facies Gm transit. to solitary set TXB 25cm thick. Pal.current - 354°.
BECKSIDE TO SCOUTGREEN	1	St	m-c ssts	Coset TXB of sets 20-25cm thick. Transitional from facies Gt below. Coset approx. 2.5m thick. VMs - 351°, 012°, 019°.
	2	Sh	m sst	Interbedded with facies St at top of coset. Exhibits PCL trending 358° - 178°.
	3	St/Sh	m-c/ f sst	70cm sequence - interbedded TXB ssts / thin ssts. Transit from facies Gt? Sequence above - interbd. f ssts / lam. siltsts.
SHEPHERDS BRIDGE		St	m sst	Coset 2-2.5m thick with scoop base on facies Gt. Very well sorted Qz. arenites with RARE intracls. Troughs extend 3m+ down axis-sub. horiz. Sets - 20 - 25cm thick, foresets 2-3cm. VMs - 333°, 005°.
SHEPHERDS BRIDGE TO DOCKER FORCE	1	Sh	f-m sst	Laminated to thinly bedded ssts transit.? from TXB coset

TABLE 6.

LOCALITY	FACIES (MIALL) / GRAIN SIZE	STRUCTURE
SHEPHERDS BR.TO DOCKER F. (CONT). 2	Sh f sst	Sharp basal contacts interbd. with siltsts.above unit facies Gm.
3	St f-m ssts	Coset TXB sets.VMs - 026°,017° Contain intracls.
4	St f-m ssts	Coset TXB sets.Trough axes extend 3m+ down Pal. slope. Trough crests approx.1.5m wide VM - 354°.
5	Sh ?f sst	Transit. from St below.Ssts-thinly bedded.PCL -359°-179°.
6	Sr/St f/m ssts	Above facies Sh.1.8m Ssts-RXL in part,contains scattered clasts.2 units- Unit 2- erosive based contains shallow trough stes up to 10cm deep. Pcs.- 042°,039°,037°.RXL ssts - top part of section trend-038° -218°.
7	Sp f-m ssts	1.35m unit with erosive base marked by pebbly lag(10cm). Lateral accretion surfaces dip 10° towards 120° - tangential at base.Above 45cm finer silty ssts are TXB-shallow sets trend 032°-212°.
8	Sp m sst	2m+ unit with planar foresets cut down towards north.Foreset s tangential at base - above unit facies Gm.Pcs. - 359°.
9	St m sst	TXB sets VM- 359°.Forms lateral extension of section 4.
DOCKER FORCE 1	Sp? m sst	Forms base at waterfall.Planar foresets above scoured base -inclined towards 351°. May corralate with section 8 above
2	St m sst	Above facies Sp - TXB coset 2-3m thick at Docker Force. Sets -20cm deep.VM - 003°.

TABLE 7.

LOCALITY	FACIES (MIALL) / GRAIN SIZE	STRUCTURE
DOCKER FORCE TO SALTERWATH	St m sst	Probably few Cosets TXB sets 15-20cm thick GVM- 355°.80cm thick PXB sets contain intr.cl s. Pcs. - 068°,098° with high VM variance from TXB.
SALTERWATH	Sh/Sr/ Sp f-m/ m-c ssts	6m section - transit. from facies St below.Dominantly thinly bd./horiz.lam. ssts - PCL - 164°-344°.Sh becomes RXL near to top of individ.units. RXL trends 074°-254°.2.1m above base - PXB set- Scoured base ,Pcs - 357°,009°.At top Facies Sp- tangential base to foreset s - Pc -358°.
SALTERWATH TO SHAP WELLS	St f-m ssts	TXB sets in Cosets (?thickness) - interbed. pb. ssts in part (Trundale Beck).Sets approx. 20-25cm thick, Pcs - 342°,339°, 360°(Wasdale Beck).TXB Coset at Salterwath - extension of Salt. /Docker F. section,Pcs - 340°-010°.
WASDALE BECK	Sp m-c sst	20cm unit erosive on mudst. drape overlying unit facies Gm.Planar foresets Pc- 070°.
BLEA BECK	Sh/St/ Sp f-m ssts	Poorly exposed units horiz. bd /lam. ssts and ?intbd. TXB sets. Facies Sp-radiating foresets away from Coniston Lst. Grp. ridge - Pcs - 059°-132°.Dips decrease away 38-12.

TABLE 8.

LOCALITY	FACIES/GRAIN SIZE		STRUCTURE
ELLERGILL BECK 1.	St	f-m	60 cms coset trough-cross-bedded sets 20-30 cms thick with scooped base. Trough axes oriented >326°-359°.
2.	Sr	m	Cross-laminated with scattered granules.
3.	Sh	v.f-f	Parallel laminated intercalated/interbed. facies Gm in lower part of section. At top - 60 cms parallel laminated-well-bedded (2-5 cms) unit above facies Sr. Contains mud intraclasts and Primary-current-lin.> 060°-240°.
SHAP SUMMIT	Sp	f-c	Coset, 2m thick above basal facies Gm. Sets- 20-25 cms thick-1m thick at top of coset. Sharp and steeply dipping foresets (12°-15°), 2cms thick have coarse bases and face >340°-350°-355°.
MICKLEGILL BECK 1.	St	f-m	Poorly exposed section through mainly cosets (up to 2-2.5m thick) txb sets- 20 cms thick. Occasional scattered pebble horizons. Foresets are on average- 1cm. Tentative pal.currs. >009°-020°-060°.
2.	Sr	f	Thin cross-laminated (30cm) horizon near base interbed. facies St.
3.	Sh	f	20 cm exposed unit at base. Parallel lamin.
TEBAY SERVICES 1.	St	m	Large scale trough-cross-bedded ssts. Arranged in cosets at least 1.5 m thick. Sets up to 33cm thick. Trough axes sub-horizontal and increase up to 26° at back . Laterally equivalent to facies Sp. Smaller scale troughs are interbedded with facies Sp. V.M.>012°.
2.	Sp	m	Planar-cross-bedded ssts. Toesets vary from angular contact to tangential. Sets are up to 80 cm thick. Foreset angle reaches 27°. Foresets descend to a lower level in one place. Interbedded with facies Sh. Foresets are 1cm thick. Vector Mean >317°.
3.	Sh	f-m	Laminated ssts. drape over top of facies Sp. Up to 10cm thick.

TABLE 9

LOCALITY		FACIES (MIALL)	OCCURRENCE
BECKSIDE TO SCOUTGREEN		F1	Interbedded siltst./vfsst in deeper pools of water.
SCOUTGREEN		F1	Laminated siltsts., in places more massive horizons containing ? calcrete nodules. Overlies and interbd. with facies Sh, St.
STAKELY BECK		F1	1-1.25m laminated siltsts. overlain by facies Gm. Contain calcareous nodules.
SHEPHERDS BR.TO DOCKER F.	1	Fm	Siltst. transit. from thinly bd. f sst (Sh).
	2	F1/Fm	Lam. - RXL siltsts. interbd. f ssts above Sh/St. Fm above Sp (Sh.Br./D.F. - 7) contains syneresis cracks and capped by 15cm calcrete horizon.
	3	F1	Deeper pools of water suggest siltsts. present.
WASDALE BECK		F1/Fm	Present as thin 10-15cm drapes overlying facies Gm. 35cm unit with scattered granules above unconformity.
SHAP SUMMIT		Fm (Siltst).	Thin 20cms unit immediately below facies Sp.

TABLE 10.

LOCALITY	FACIES	CLAST SIZE CM		STRUCTURE
		MAX.	AV.MAX.	
TARGETS	Gm	33	17.3	max. 2m exposed - clast supported framework, c sst infilling matrix.
LOWTHWAITE COTTAGES 1.	Gm	46	32	2 units seperated by erosion surface 45cms relief.2.5 m along strike contact represented by m sst wedge, draped over clasts of basal unit.thins to 12-15 cm westwards. Poorly sorted clast supported framework.
2.	Gm	47	29.1	
FOLLY LANE 1.	Gm	21	15.6	Basal unit (1.8m) poorly sorted with large sub-angular blocks. matrix- coarse with abundant granules.Patchy calcite cement. Overlain by silty sst drape.
2.	Gm	17	8.6	Erosional contact on m sst drape .Clast supported framework and B imbr.>090°.Calcite cement in coarse matrix of granules.
3.	Gp	18	11.1	Massive base fines up into pb. conglomerate with planar foresets facing > 200/06°. Rodding at top along foresets. Well sorted at top.Unit thins from 42-28 cms within 2-3m.
4.	Gp	29	12.8	Similar unit to 3. Foresets face > 200°. Fines up to pebble top from boulder base.Base is erosive on unit below.
5.	Gm	30	20.2	Similar to 1:1.5m exposed thickness.Poorly sorted clast supported framework.

TABLE II.

LOCALITY		FACIES	CLAST SIZE CM		STRUCTURE
			MAX.	AV.MAX	
WATERFOOT BECK	1.	Gm	45	26.6	Whole section consists of stacked conglomerate units with no major breaks except at no.6. Clast supported framework with granule and pebble matrix. Calcite is present cementing finer fraction in matrix especially in units 1/2. Sorting varies from moderate to poor. Unit 6 contains crude planar foresets. Some units are stratified with rodding of finer pebble fraction.
	2.	Gm	40	23.8	
	3.	Gm	48	53	
	4.	Gm	59	38	
	5.	Gm	50	29	
	6.	Gm/Gp	35	16.7	
	7.	Gm	42	27.2	
	8.	Gm	60	32.5	
	9.	Gm	51	34.8	
	10	Gm	40	25.3	
ULLSWATER ROAD	1.	Gm	56	32	Poorly exposed sections, 2-3m high, on side of main Ullswater road. Poorly sorted boulder-cobble conglomerates forming main units. These are overlain by finer and better sorted discontinuous pebble tops. Some parts are imbricated > 050°/040°.
	2.	Gm	51	32.8	
	3.	Gm	53	35	
THE HAUSE	1.	Gm	46.4	30-30.5	Total exposed thickness-10.5m. At base- massive bld. conglom. with infilling coarse matrix with preferential calcite cement. Clasts are aligned with a axis parallel with base. Unit 2 forms a finer cobble-pebble top which drapes over top of unit 1. This fines to the N.E within 2.5m to facies Sh. Unit 3 above is better sorted with a more open framework. Lenses up to 15cm with rodded pb.cg. occur. Top unit 4- massive and ?poorly sorted - but clast supported.
	2.	Gm-Sh	16	4-5	
	3.	Gm	43	27.6	
	4.	Gm	80	37.4	

TABLE 12.

LOCALITY	FACIES	CLAST SIZE CM		STRUCTURE
		MAX.	AV.MAX	
HOLGHYLL GORGE	Gt	15	7.8	(clast sizes taken from base) Total exposed thickness- 7-8m. Section consists of tabular - lensed shaped bodies approx.1.5-2m thick. Bases marked by pebble lags, 1 clast thick. Internally, the units contain trough shaped structures 1.1 m across and approx. 25-30 cms deep. Clasts line base of troughs.Grain size is predominantly granulestone - v.coarse sandstone supported conglomerate. Trends from trough axes are oriented 017°-197°.
DACRE BECK (Dacre Lodge)	Gm/Gt?	31-26 -19	10- 11.6- 18.2	Massive boulder conglomerates (1.3m) fine up to thin (10-30cm) units cobble-peeble conglomerates.These are matrix supported and crudely stratified.
(Dacre High Bridge) 1.	Gm	29-24 -26- 27	14.5- 11.5- 15.5- 18.5	4 units boulder-cobble congloms. Base- massive / clast supported. Infilling coarse matrix- pebbles /granules.Becomes stratified and fines upward with rare blds. Unit 3- pb congl. with rare blds .Top unit- poorly sorted massive with coarse matrix.Thin (5-6cm) c.sst intercalations.
2.	Gm	27-8- 14	18.3- 4.7- 7.8	2 units massive boulder conglomerates with no imbric. Fines up into stratified pebble conglomerate top.Top unit- massive with clast supported framework.

TABLE 13.

LOCALITY	FACIES	CLAST SIZE CM		STRUCTURE
		MAX.	AV.MAX	
4. DACRE BECK (Cont.)	Gm	18- 10.5- 3- 9	11.7- 8- 4.9	Basal unit- massive- crudely stratified bld. conglomerate; clast supported framework, poorly sorted. Fines to cobble congl. Unit above coarsens up from granulestone conglomerate to rodded pebble conglomerate. Matrix- coarse infilling.
(Low Bridge -Langfield 1. Banks)	Gm	6.4		Pebble conglomerate to pebbly c. sst - stratified, exposed at river bed level close to Low Bridge.
2.	Gm	3-4	2-3	Thin (50cms) stratified - well bedded pebble conglomerate above scour infill structure. Pebbles line base of scour and display isolated inbrication within trough-cross-bedded infill. Imbric. >026°-092°.
(Galley Bridge)	Gt/Gm	6- 12- 11.5	3- 7.5	Basal unit - scour infill with pebble conglomerate base. Fines up - pebbly sst trough infill with isolated imbrication. Trough infill measures 2.5m wide - 1.2 m deep. (2 txb sets). Foresets dip 10-12° into trough axis oriented > 142°.
(Rucroft Wood)	Gm	5-10	3-5	Well bedded section (2-2.5m thick). Consists of units 0.8 - 1m thick - Stratified pebble - cobble conglomerates with erosive bases. These fine up to planar-cross-bedded (facies Sp) and cross-laminated (facies Sr) sandstones.

TABLE 14.

LOCALITY	FACIES/GRAIN SIZE		STRUCTURE
LOWTHWAITE COTTAGES	Sh	m sst	Parallel laminated wedge, 50-12 cms thick, between 2 units facies Gm.
FOLLY LANE	Sp	c-v.c.	Cross-bedded (?planar) top to facies Gp. Foresets face >200°/06°.
ULLSWATER ROAD	Sh	Pb.sst	Thin, 20 cm thick, discotinuous wedge forming a fine top to facies Gm below.
THE HAUSE	Sh	m-c.	Parallel laminated sandstone wedge unit above and laterally equivalent to pebble conglomerate forming a thinning wedge (in a S.W. direction) on top of facies Gm.(45-50 cms thick).
DACRE BECK.			
(High Bridge)	Sh ?	c sst.	Thin units, 5-6 cms thick, intercalated facies Gm.
(Low Bridge)1	Ss,Se	Pb.sst - m-c.	Scoured basal contact forming trough structure - 1.8m across, 40 cms deep. Base is ligned with marl and infilled with facies Gm; above base, fines to Cross-bedded m-c ssts with isolated clast imbrication.
2	Sr	m sst.	Ripple-cross-laminated sets 7cms thick forming coset 20 cms thick.FOrms part of scour infill?.
(Rucroft Wood)	Sp,Sr	m-c.	Ripple-cross-laminated sets above stratif. granulest.-pebble congls.forming erosive based basal units.Planar-cross-bedded sandstone near top of exposed section is erosive on Rxl unit below.Set- 30cms thick with foresets facing >010°
(Galley Bridge)	Ss	m-c.	Cross-bedded scour infill with isolated clast imbrication.Trough shaped scour trends >142°-322°.
FOLLY LANE	Fl/Fm	mudst-siltst	Laminated siltstone, 15cms thick, above facies Gm. Mudstone drape, 2.5-5 cms thick, above rodded pebble-cobble congl.
DACRE BECK (Low Bridge)	Fm	marl	Shaly lining, 2-3 cms at base, on soured structure - 1.8m wide and 40 cms deep.

TABLE 15.

LOCALITY		FACIES	CLAST SIZE CM		STRUCTURE
			MAX.	AV.MAX	
RIVER RAWTHEY (Scrogg House)	1.	Gm	62-65	38.8-41.8	Massive, poorly sorted clast supported framework with coarse infilling matrix.? imbricated.
	2.	Gm	15	8.8	Cobble-pebble congl. with rodded matrix.Finer top to facies Gm below.
	3.	Gm	50	38	Poorly sorted clast supported framework.B axis imbricated > 022° above base.Similar in lith. to facies Gm 1 at base.Basal contact is sharp on facies Gm unit 2.
(Burnt Mill)	1.	Gm	58	36	Poorly exposed section,2m thick ,bld.-cb. congl.Poorly sorted, massive clast supported framew.
	2.	Gm	20-25		Lies above basal unit.Contact is hard to determine-maybe non-erosive.B axis imbricated >049°.
	3.	Gm	27	18	Poorly sorted clast supported framework with infilling coarse matrix.
	4.	Gm	34	15	Clast supported framework with coarse matrix.Moderately sorted with B axis imbricated >350°. Basal contact is erosive on Facies Gm below.
	5.	Gm	29	21.1	Poorly sorted massive unit. Coarsens up from facies Gm unit 4.Clast supported framework.
(Buckbank -Lowridding)	1.	Gm	23.5	17.6	Clast supported framework with infilling coarse matrix.B axis-imbricated >350°-359°.Crude stratification formed by dipping B axis (from elongate clasts). 'Rodded' finer pebbles/granules.
	2.	Gm	28	20.8	Overlies facies Gm 1. basal contact is undulating.Moderate sorting, clast supported framew. B axis imbricated >356°-053°.
	3.	Gm	20-25		Poorly exposed basal unit (only 1m exposed) to facies Gm 4.

TABLE 16.

LOCALITY	FACIES	CLAST SIZE CM.		STRUCTURE
		MAX.	AV.MAX.	
RIVER RAWTHEY (Cont.) 4.	Gm	26-35	18.8-19.1	Approx. 20m long exposure through well imbricated clast supported bld.-cb. congl.Coarse matrix,Mod.Sorted-strong.B axis imbricated >344.5° (vector Mean) .B axis dips >135°/8-9°.
5.	Gm	22-16-17.5-26	11.4	10-12m high section showing finer cb-bld congl. with breaks (<1m thick) marked by boulder stringers.General dip >030°-040° .Rodded coarse matrix appears stratified.Elongate clasts show strong B axis imbrication >026° (base) - 039° (top).Occasional pebbly sst intercalated horizons .Clast supported framework with coarse matrix.
6.	Gm	61-45	28.8	Section 12m long,3.5m high.2 massive,poorly sorted clast supported congls. seperated by a steeply dipping and undulating contact (dips >053°/20°).Elong. boulders aligned crudely N.E.-S.W. on A axis with base parall. with unit bounding surface.
HEBBLETHWAITE HALL GILL	Gm	62-39.5 (top) 41 (base)	30.8-22.6 28	Exposure- cliff 8-10m high, 30m long.Main part- bld. congl.- clast supported framework.Poorly sorted with poor clast orient. Basal contact- undulating up to 30cms relief on facies Gm unit ,up to 1.6m thick forming the basal part of the section.This is better structured with B axis imbrication >023°-042°.This contains wedge structure, 40 cms thick, in top part below upper contact with top facies Gm. - Stratif. /rodded pb. congl.
NOR GILL.	Gm			Close to Dent Fault.Appears well-bedded cobble-boulder congloms. Steeply dipping -N.E.Matrix is strongly sheared.

TABLE 17.

LOCALITY	FACIES	CLAST SIZE CM		STRUCTURE
		MAX>	AV.MAX	
SETTLEBECK GILL 1.	Gm	24-30 -28.5 -31-31 -35 (base) 13-13 -15.5 -13 (top).	17.8 9.1	Section through stacked congl. units.Thickness 20-21m. Congls. on average 0.8-1m thick bounded by erosive contacts on thin sst tops (10cms thick).Clast supp. framework with coarse infilling matrix with preferential calcite cement.Poor-moderate sorted.Well cemented rodded horizons are imbricated >325°-035°.Near to top congls. are stratified with pb.sst lensed intercalations up to 20cms. Stratif. foresets dip >348°/5°. Clast size fines to top.At top-B axis imbrication >326°-357°.

TABLE 18.

LOCALITY	FACIES	CLAST SIZE CM		STRUCTURE
		MAX.	AV.MAX	
GREY MARES TAIL 1.	Gms	18.5	10.7	Very weathered exposure.
2.	Gm	26	10.6	Poorly sorted bld. conglomerate with coarse matrix. No apparent structure.
3.	Gms	38	17.3	Steeply dipping bed due to nearby fault.Apparent A axis alignment.Matrix supported. Contains weath. granite clasts.
4.	Gm	5	3.3	Moderately sorted - pebbly sst. stratified. Contains Vein quartz clasts in abundance.
5.	Gm	3		Pebbly sst with preferential calcite cement. Fines up into m-c ssts.
MELMERBY FELL TRACK 1.	Gms	28	11.4	Poorly sorted bld.-cb. congl. Matrix supported framework. Slight A axis alignment >120°-310°.Similar to Gr.Mares Tail facies Gms-contains NO quartz.
2.	Gm	25	17.4	Stratified ? clast supported framework.Dips> 110°/10° and decreases to 09° along strike. Fines up into f-m ssts.
RAKE BECK 1.	Gms	4	2.8	Coarse pebbly matrix supported conglomerate with ?intraclasts (?calcrete nodules).Variety of clasts with No vein quartz.
2.	Gm/Gp?	8-9	6.8	Cross-stratified with planar foresets at top facing >353°-015
3.	Gp	8	4.6	Clast supported framework,fines up to pb.sst wedge. Planar-cross-bedded with foresets> 004°/22°.
4.	Gp	6.5-9	4.4-5.3	2 cobble conglomerate units seperated by intercalated planar -cross-bedded pb.sst.

TABLE 19.

LOCALITY	FACIES	CLAST SIZE CM.		STRUCTURE
		MAX.	AV.MAX	
RAKE BECK (Cont.) 5.	Gm	10	5.4	Poorly exposed cb-pb congl.
6.	Gm	8	5.4	Massive clast supported cobble conglomerate.Coarse pb sst matrix and intercalations.
7.	Gm	18		Poorly exposed pebble-cobble conglomerate with intercalated planar-cross-bedded calcite cemented c.ssts.
8.	Gm(?Gp)	8	4	Stratified- ?planar-cross - bedded above c. ssts.
9.	Gm	7.5	4	Base is erosive on facies Gm -8. Fines up to cb.-pb. congl. Overlain by pxb pb. ssts.
NORTH FELL TRACK.	Gm	7	6.4	Erosive base on pxb m sst. Stratified.Clast supported with coarse infilling matrix.
DALE BECK 1.	Gm	4	0.4	Crudely cross stratified.Clast supported with coarse infilling matrix.Cross-straf. planes face > 100°/20°.
DALE BECK 2.				
1.	Gm	2.5		Base is cut out by Musca Hill Fault.Massive base fines up after 2.4m to pb. c.sst.
2.	Gm	3-6	1.5-4.2	Pb. congl. above erosive base. Coarsens up to cross-stratified pb. congl.
3.	Gm	7	4.9	Massive, poorly sorted and clast supported framework.Coarse sst infilling matrix.F. sst.intercs. -pxb > 053°/13°.
4.	Gm	4		Base is not exposed.Fines up to pxb f sst.

TABLE 20.

LOCALITY		FACIES	CLAST SIZE CM		STRUCTURE
			MAX.	AV.MAX	
DALE BECK 2 (Cont.).	5.	Gm	5	3.7	Base is not exposed. Poorly sorted pb. conglomerate.crudely cross-strarified.
	6.	Gm	7.5	4.8	Erosive base.Clast supported framework- coarse infilling matrix.
	7.	Gm	5		Unit which fines up from no.6. Stratified at top.
	8.	Gm	7	5.3	Poorly exposed unit. In top part moderately sorted with tightly packed clasts.C sst. infilling matrix.
MUSCA HILL CRAGS 1.	1.	Gm	9	6.2	Base of section is not exposed-close to Windy Gap fault.CLast supported poorly sorted framew. Massive.
	2.	Gt	4	1-2	Forms fine top to unit 1.Crude trough structure in coarse pb. sst. Trough axis trends >065° - 245°.
	3.	Gm	7.5	5.7	Clast supported framework with coarse matrix. Overlain by pxb m-c sst.
	4.	Gm	3.5-4		Stratified granulestone congl. Fines up into txb m sst.
	5.	Gm	11.5-10	7-6.4	Well Imbricated cobble congls. 2 units seperated by f.sst intcl .Erosive base on facies Sr. B axis dips 249°/07°.Fines up to c. sst.
	6.	Gm	8	6	2 units seperated by pxb m-c ssts.

TABLE 21.

LOCALITY		FACIES	CLAST SIZE CM		STRUCTURE
			MAX.	AV.MAX	
MUSCA HILL CRAGS 2.	1.	Gm	4.6	4.6	Base is not exposed. Clast supported framework with infill. coarse matrix.Fines up after 2.5 m - granulestone conglomerate.
	2.	Gt	9.5	5.6	Crude trough structure- axis trends >105°-285°. Fines up to strat. granulest. congl.
	3.	Gm	7.5	4.7	Base is well imbricated >052°. Fines up to pxb c.sst.Clast supported framework with infill. coarse matrix.
	4.	Gp/Gm	10	6.9	Massive clast supported framew. Planar-cross-bedded at base,with foresets facing >020°.Pebbles display isolated imbric. along foresets.Top part- stratified.
	5.	Gm	6-8	6	Imbricated and stratified mod. sorted congl. with tightly packed clasts.B axis faces >080°.
WINDY GAP.		Gm	9.5-10.5-12.	6.8-8.6-7.	Clasts measured through 1 unit along strike for approx.20m. Imbricated (B axis faces >075°) clast supported cb.-bld. congl. Infilling coarse matrix.Unit over 2m thick and forms base to pebbly cross-bedded ssts. above.
ARDALE BECK.	1.	Gms	2.5		Poorly exposed pebble matrix supported congl.Similar to Gr. Mares Tail- NO vein quartz.Base is not exposed.
	2.	Gms	2.5		Similar poorly sorted matrix supported congl. with variety of rock clasts but NO vein quartz. Calcite cemented.
	3.	Gm/Gp	8-8.5	5.6-6.7.	2 units- clast supported with Vein quartz.Coarse matrix. Preferential calcite cemented. Stratified at base fines to pxb gran. congl. - foresets face > 020°/12°.

TABLE 22.

LOCALITY	FACIES	CLAST SIZE CM		STRUCTURE
		MAX.	AV.MAX	
ARDALE BECK (Cont.) 4.	Gp	9	6.1	Crudely defined lensing sets 20-25 cms deep. Axes trend >008°.
5.	Gm	8-6	4.1	Thin (0.3-1m thick) cb.-pb. cong units basal to cross-bedded f-c ssts.
COCKLOCK SCAR.	Gm/Gp/Gt	15-13.5-11-11-11-10-10 10-9.5 9.5-9	7.	Clast supported congls. with infilling coarse matrix. Clasts aligned along stratif. planes which dip >056°-024°/5-8°. Above laterally extensive basal congs. units become planar-cross-bedded - foresets >056°-024°/11°. Pebbly ssts. contain crude c-well defined troughs (isolated) - axis trend >022°. Forming the base of the section (exposed) is interbedded pxb m-c sst. Within the basal congl. unit is inter . v.c. sst.
CROWDUNDLE BECK . 1.	Gm	9	5.7	Tightly packed cobble congl. Infilling coarse matrix. ?imbr.
2.	Gm	5.5	3.2	Stratified unit above basal cg. A axis is aligned with base which dips >040°/13°.
3.	.Gm	13	6.8	Tightly packed clast supported congl. with clasts aligned with bases parallel with base as unit below.
4.	Gm	10-8-8.5-9-10	6.4	5 cb. congs. with well-defined sharp bases. Poorly exposed and apparently massive.
KNOCK ORE GILL.	Gm	?		Tightly packed congl. 2m thick. Flat base- interbedded with facies Sh.

TABLE 23.

LOCALITY		FACIES	GRAIN SIZE	STRUCTURE
GREY MARES TAIL	1.	Sp	f-c	Planar-cross-bedded cosets formed of sets 15-20 cms thick, lie above pebbly bases and stratified m-c ssts. Pal.currents > 068°;342°/8-10°;165°/8°.
	2.	St	f-c	Poorly exposed cosets: trough-cross-bedded sandstone sets approx. 20 cms thick. Axes trend >049°;072°.
	3.	Sh	f sst.	Isolated unit parallel laminated sandstone 15-20 cms thick.
	4.	Sr	silt-f sst.	Cross-laminated horizons above facies Sp/St. Overlain by facies Fl which contains dessication cracks and plant material.
MELMERBY FELL TRACK		Sh?	f-m	red, fine-medium sandstones, parallel lamin. above facies Gm.
RAKE BECK.	1.	Sp	m-c	Coset: planar-cross-bedded sandstone approx 2m thick. Individual sets 30-40 cms thick. Foresets- sharp and steeply dipping >290°-346°/10°-25°. Foresets 1.5-2 cms thick. Isolated clast imbric. seen in places. Other solitary sets, foresets dip >224°/19°;254°/10°. At 42m above base- pxb set above facies Gm, foresets dip >004°/23°.
	2.	Sr.	silt-f sst.	Cross-laminated horizon at base (above basal unconformity) contains intraclasts (? calcrete nodules).
NORTH FELL TRACK.	1.	Sp	m-c	Coset pxb sandstones, 88 cms thick, of 2 sets. Isolated clast imbrication along foresets - dip >286°/12°;317°/18°-10°. Solitary set above pebbly base and below facies Gm, foresets dip >027°.
	2.	St	c ssts.	Crude trough structure above pebbly base. Axis trends >330°-150°.
DALE BECK	1.	St	c ssts.	Pebbly sandstones forming large cosets up to 5m thick formed of shallow trough sets approx. 15 cms thick. Each set contains 1.5-2 cms pebbly base + fines up to m-c sst 54m above base, coset is capped by facies Sr. (pal.currents hard to determine).

TABLE 24.

LOCALITY	FACIES/GRAIN SIZE		STRUCTURE
DALE BECK 1 (Cont.) 2.	Sp	f-(m-c)	Cosets: pxb sandstones 0.8m-1.4m thick. Wide variation in foreset dip direction within coset; 44m above base- foresets dip >177°/23° (base) - 110°/20° - 092°/08 (top of coset) with dip decreasing to the top of the coset. Thus at the top, foreset angle of dip is nearly parallel with set base.
3.	Sr	v.f.	Ripple-cross-laminated sets 5-8 cms thick. Top surface at one horizon shows asymm. straight crests oriented >227°.
DALE BECK 2.			
1.	Sp	f-c	Cosets, up to 1.2m thick, formed of pxb sets 40-45 cms thick. Sharp steeply dipping foresets (14-12°). Pebbly bases to set. Pal. currents >088°/14° - 084°/12°. Reactivation surfaces are present. Foreset thickness up to 8cms. Above base- solitary sets interbedded with facies Gm - Pal. cur >091°/24°; 053°/13°. Near to base- pal. curr vary >025°/10° - 064°/14°. Mud intraclasts are present lining the bases of some sets
2.	St	f-m	Solitary sets, 50 cms thick. Crude trough structure.
3.	Sh?	m	Parallel laminated to thinly bedded. Could be low dipping toesets to pxb foresets.
4.	Sr	f	Thin cross-laminated horizons within Green Sandstones.
MUSCA HILL 1.			
1.	Sp	c-m	Occurs as solitary sets, 35-80 cms thick. Toesets are sharp - slightly asymtotic. Foresets dip >073°/22° - 052°/32°. (326°/09°). Isolated clast imbrication.
2.	St	c	Crudely defined trough structure at top of facies Gm. 20 cms thick. Axis trends >080°-260°.
3.	Sr	f-m	Cross-laminated horizons containing scattered vein quartz pebbles.

TABLE 25.

LOCALITY		FACIES	GRAIN SIZE	STRUCTURE
MUSCA HILL CRAGS	1.	Sp	c-m	Coset: planar-cross-bedded sets. Foresets have coarse bases and m sst tops. Dip > 056°/14° - 070°16°.
	2.	Sh	m	Parallel laminated with scattered vein quartz granules.
WINDY GAP	1.	St	c-pb.	Crudely defined trough structure in pb. sst. Lies above basal unit facies Gm. Axis trends >044° - 224°.
	2.	Sp	?c	Solitary pxb set above facies St. Foresets dip >057°/11°. Isolated clast Imbrication along foresets.
	3.	St	m-c	Festoon coset formed by 20-30 cms thick txb sets. (coset- approx. 1.9 m thick). Grain size fines to top. Pal. currents at top oriented >060°. At base transitional with facies Gm. Laterally equivalent to facies Sp.
ARDALE BECK	1.	Sp	f-c	Isolated pxb sets with foresets steeply dipping (15-20°) >020° - 038°. At top of exposed section, pxb coset, 60 cms thick, - 2 sets - foresets dip >323°/17° (base); 027°/27° (top). Sets contain scattered Pbs.
	2.	St	f-c	Crudely defined truogh structures in cosets up to 1.8 m. Pal. currents >348° - 010° /5-8°.
COCKLOCK SCAR	1.	Sp	m-c	Isolated sets up to 60 cms thick. Foreset thickness averages 1-1.5 cms. Foresets are sharp with set bounding base. Foresets dip >057° - 018°/6°.
	2.	St	c	Seen end on. Coset- 2.1m thick of 2 sets. Foresets dip >023° - 031°/1-16°.
KNOCK ORE GILL		Sh?	f-m?	Poorly exposed. Well-bedded structure but possible internally cross-bedded. 2 units interbedded facies Gm.

TABLE 26

LOCALITY	FACIES (MIALL)	CLAST SIZE cm MAX.	CLAST SIZE cm AV.MAX.	STRUCTURE
SINK BECK	Gm	7.5, 10.5, 10, 8, 12.5, 10.5, 11, 7.5, 14, 14, 13, 11.5, 8.5, 7.5, 10,	6, 7.26, 7.46, 5.3, 8.4, 7.5, 7, 4.6, 8.3, 7.8, 8.9, 7.1, 5.5, 5.5, 6.6,	Conglomerates - massively bedded occasionally forming fining upward units overlain by finer grained/stratified horizons. Units have sharp, ? erosive basal contacts. Locally - B axis imbricated towards 068° - 061°. Units between 50cm and 2m thick. Interbedded with facies Sh.

LOCALITY	FACIES (MIALL)	GRAIN SIZE	STRUCTURE
SINK BECK	Sh	c-vc	Units, 5cm - 28cm thick, capping to facies Gm.? Contain plant material. Horizontally laminated.
	Sh	m-c	Laminated, well-bedded /? current rippled. Fines to siltstone, with plant debris.
	Sp?	c	Tabular/planar - cross - bedded. PCs 055° /11°. = Kaolinitic.
TOP ROMAN FELL	St	f-c	Trough - cross - bedded, 2 set sizes - St1 (50-60cm);- St2 (25cm).Forms festoon cosets up to 4m. Locally deformed foresets (? water escape). PCs (St1/St2):- 037.7° (V.M.). Troughs - locally pebbly (? facies Gt).
	Sp	f-c	Planar - cross - bedded, 2 set sizes -Sp1 (1m);- Sp2 (40-45cm). Sp1 - large scale, Sigmoidal foresets, broad basal contacts and asymtotic foreset bases. Sp2 - stacked sets - mainly angular foreset bases. PCs (Sp1/Sp2) - 017.8°.
	Sh	f-m	= horizontally laminated or highly asymtotic laminate to base (toeset) of facies Sp1.
	Sr	f	Minor current rippled sets,? bottomset to facies Sp/St.

APPENDIX 2

Clast Composition Data

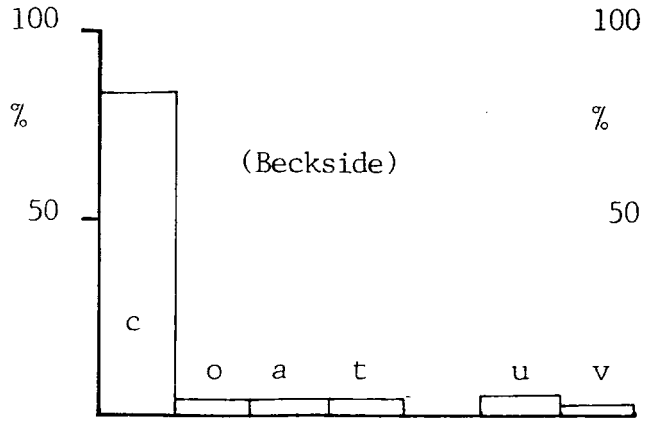
CLAST COMPOSITIONS - SHAP, MELL FELLS, SEDBERGH

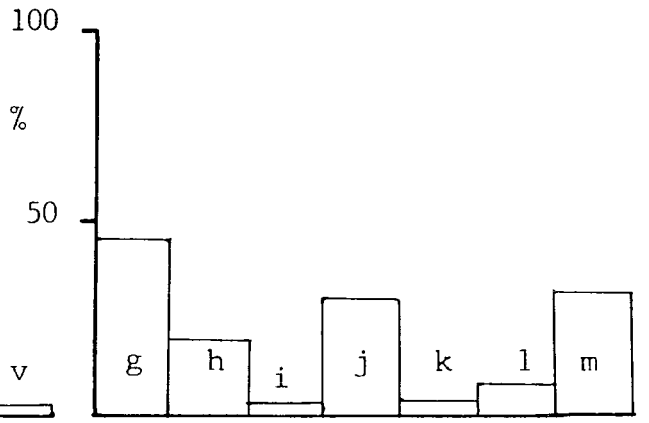
MAXIMUM CLAST SIZE

a	Vein Quartz
b	Arenites
c	Greywacke Sandstones (Grey)
d	Crystalline Limestone
o	Laminated f.Ssts / Siltstones
p	Intrusive Igneous - Minettes
q	Basic Tuffs
r	Acidic Porphyries
s	Amygdaloidal Basalts
t	Altered Rhyolites (felsites)
u	Spherolitic Rhyolites
v	Ignimbrites
w	Intrusive Igneous (?)
x	Greywacke Sandstone (red)

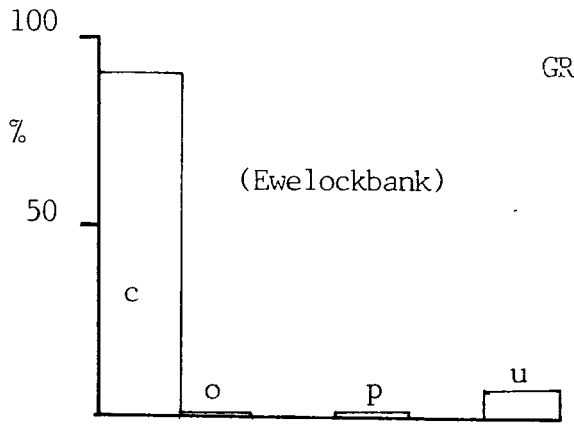
CONGLOMERATE/SANDSTONE PETROGRAPHY

g	Unimodal Quartz
h	Polycrystalline Quartz
i	Feldspars
j	Sedimentary RockFragments (Ssts, pelites, chert)
k	Volcanic Rock Fragments (porphyritic, felsitic + minettes)
l	Intrusive Igneous (Granite)
m	Intraclasts
n	Crystalline Limestone

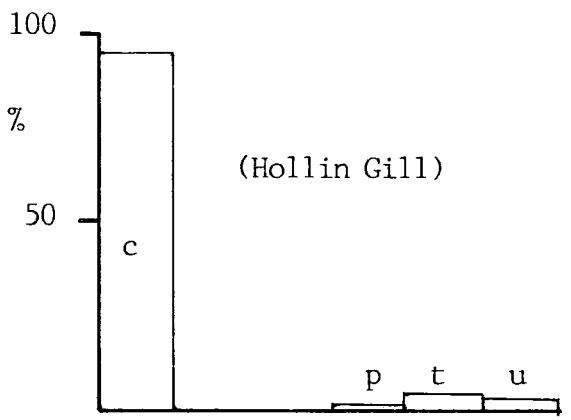




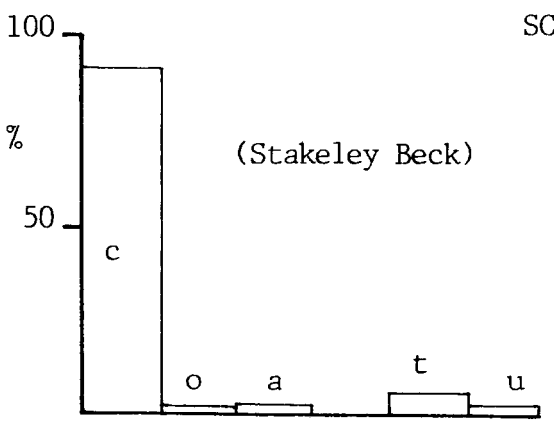
GREENHOLME TO SCOUTGREEN

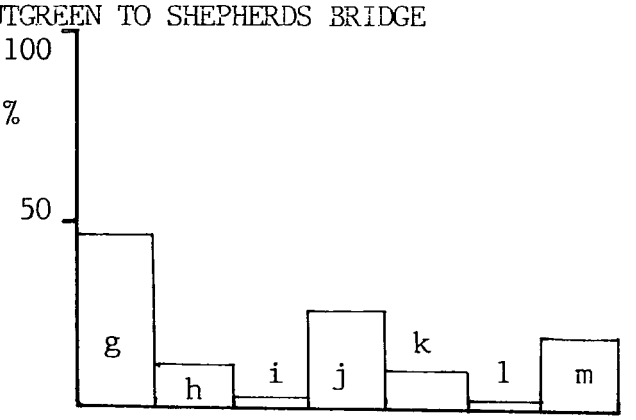


CLAST COMPOSITIONS - SHAP

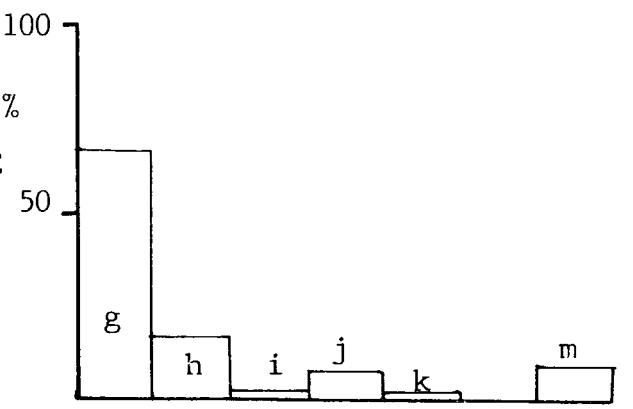


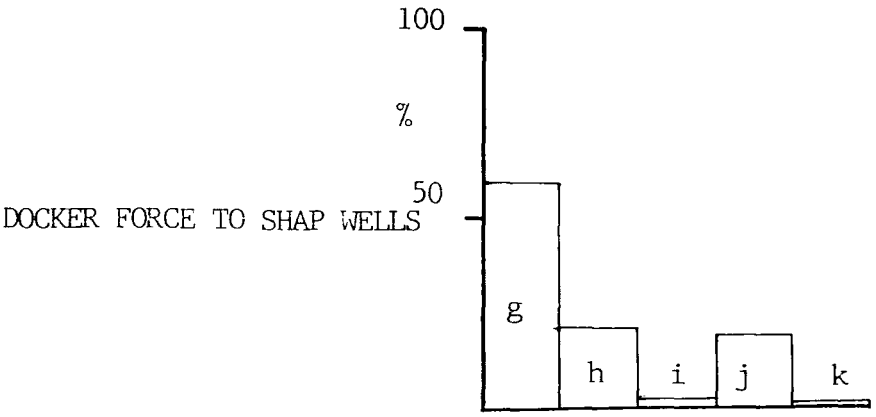
SCOUTGREEN TO SHEPHERDS BRIDGE

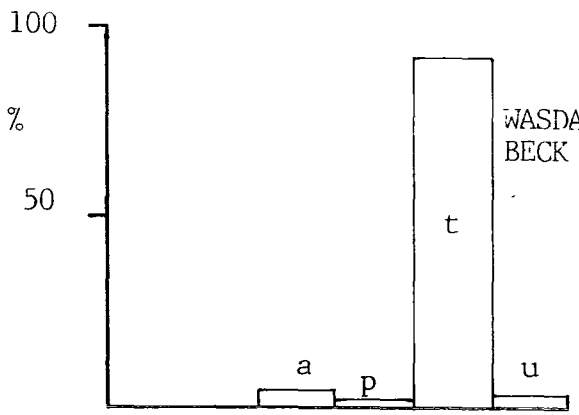


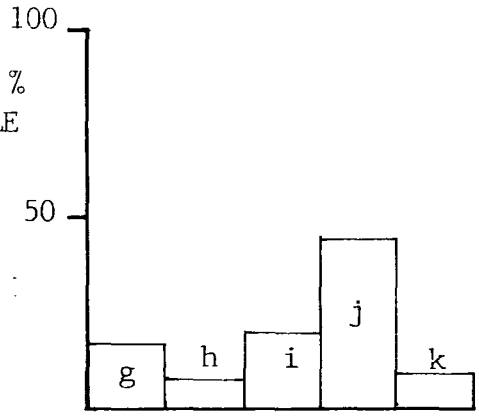


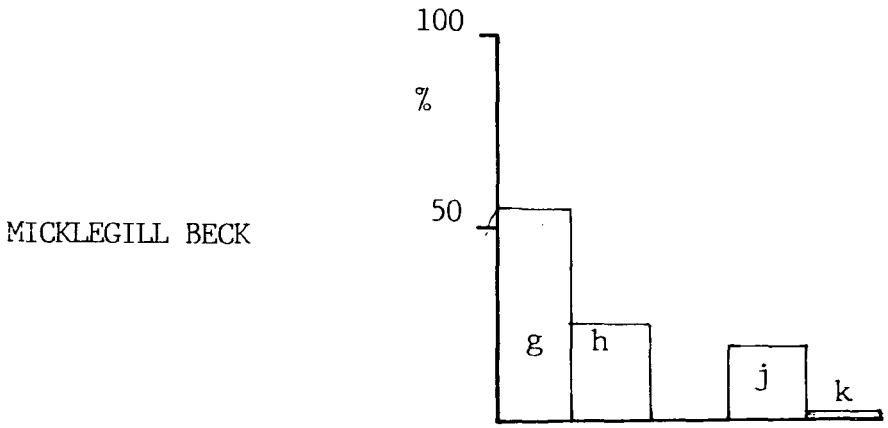
SHEPHERDS BRIDGE TO DOCKER FORCE

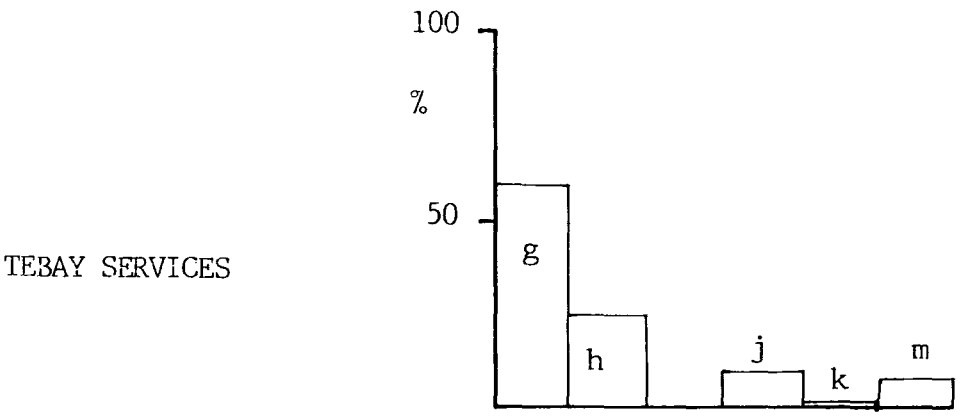


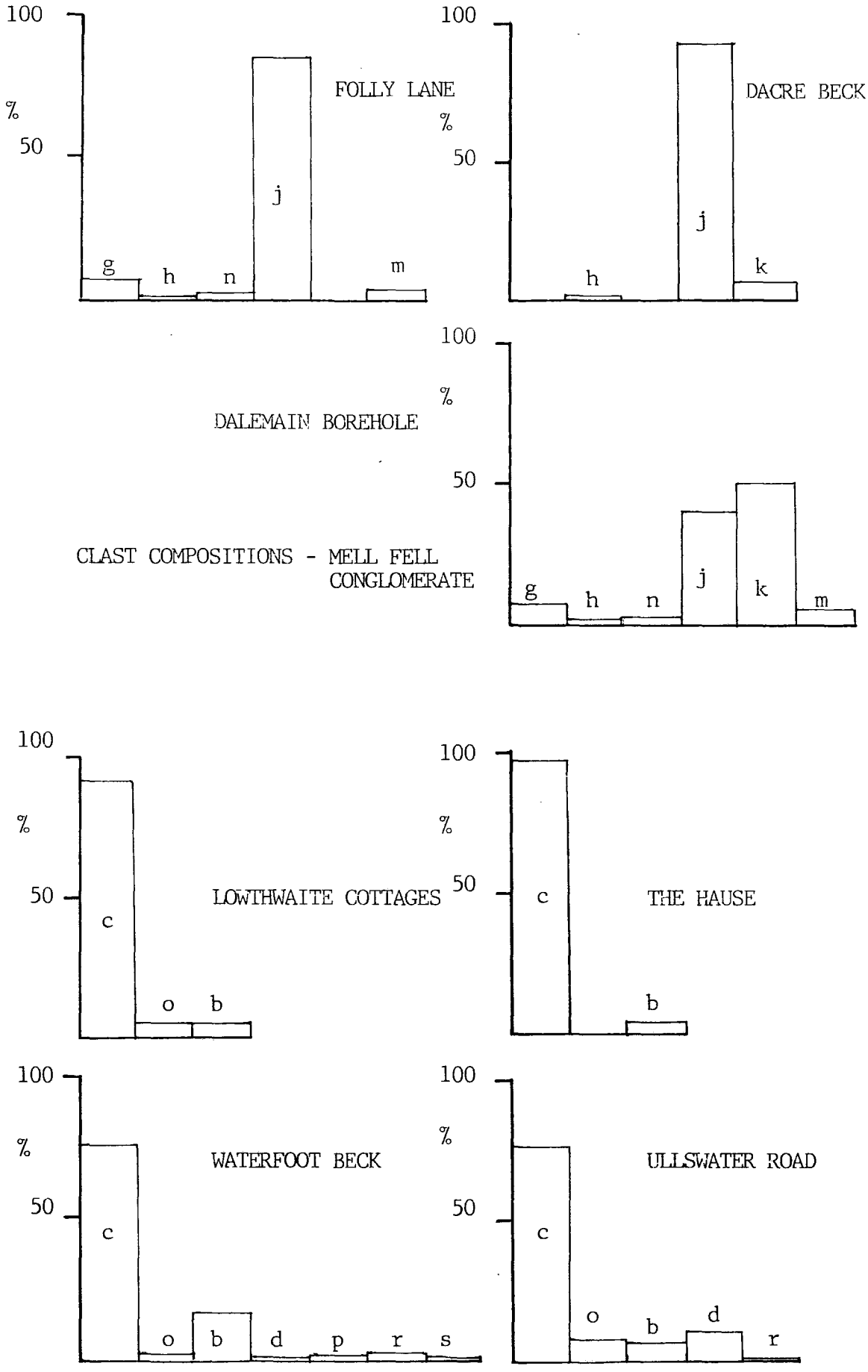

100
%
50
DOCKER FORCE TO SHAP WELLS
g
h
i
j
k

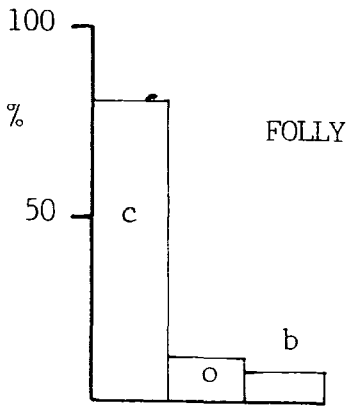

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WASDALE
BECK
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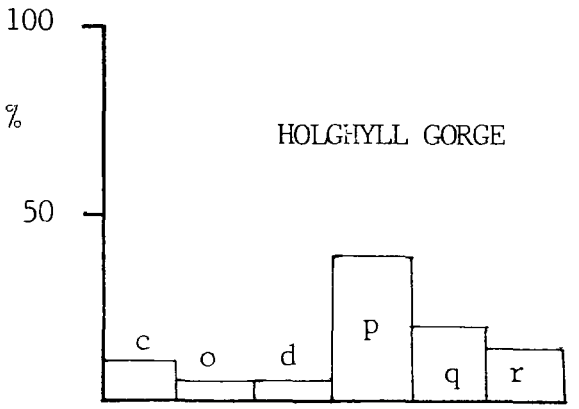

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MICKLEGILL BECK
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TEBAY SERVICES
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m

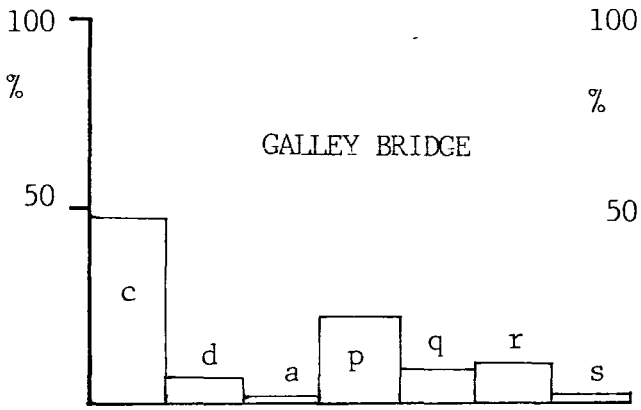

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FOLLY LANE
g
h
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m
100
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50
DACRE BECK
h
j
k
100
%
50
DALEMAIN BOREHOLE
g
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j
k
m
CLAST COMPOSITIONS - MELL FELL CONGLOMERATE
100
%
50
LOWTHWAITE COTTAGES
c
o
b
100
%
50
THE HAUSE
c
b
100
%
50
WATERFOOT BECK
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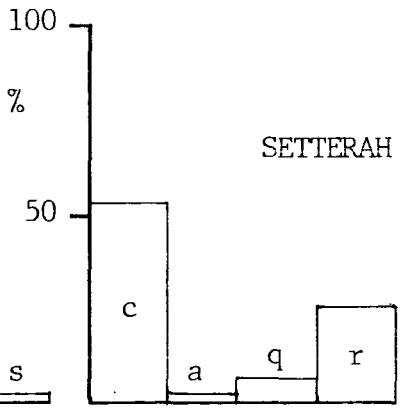
FOLLY LANE



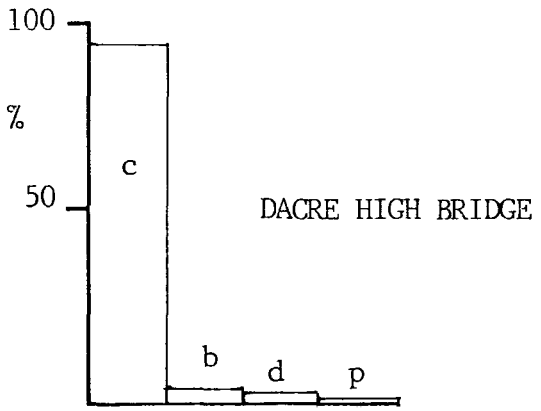
HOLGHYLL GORGE



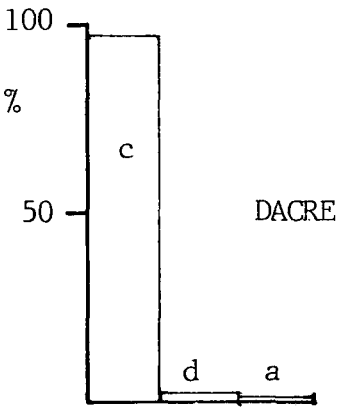
GALLEY BRIDGE



SETTERAH SIKE



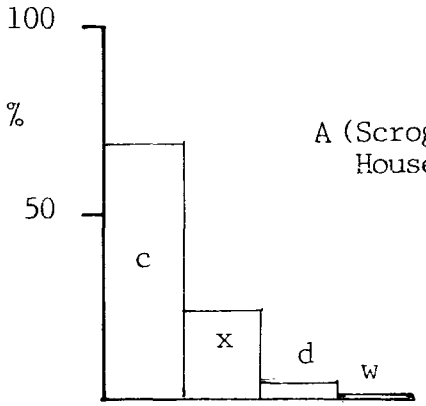
DACRE HIGH BRIDGE



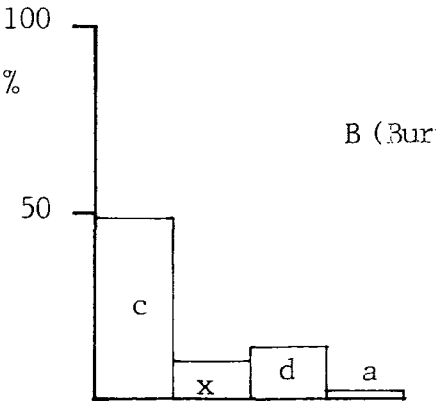
DACRE LOW BRIDGE

CLAST COMPOSITIONS - SEDBERGH

RIVER RAWTHEY

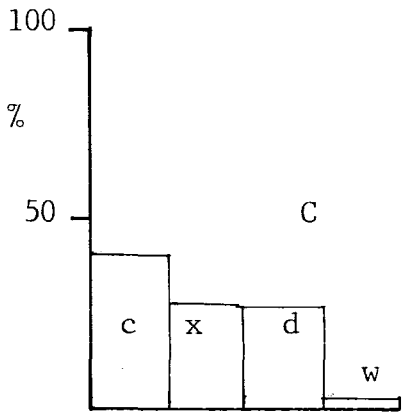


A (Scrogg House)

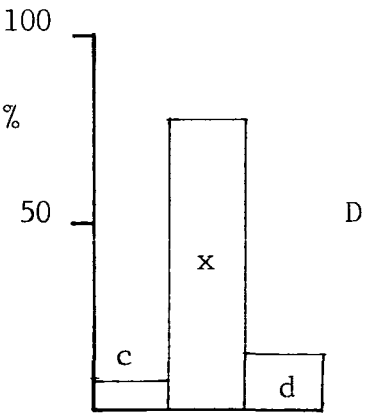


B (Burnt Mill)

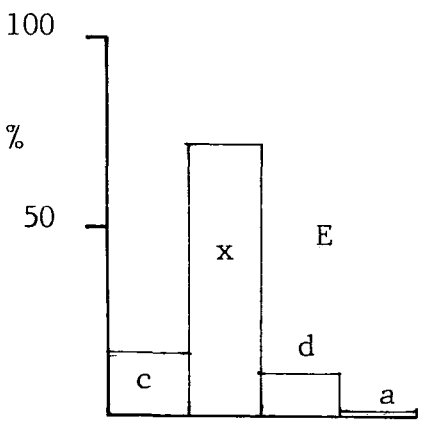
C, D, E - (Buckbank to Lowridding)



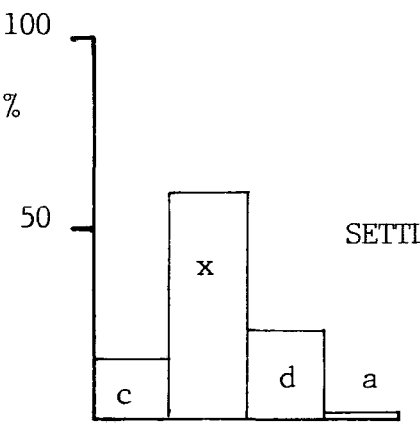
C



D



E



SETTLEBECK GILL

CLAST COMPOSITIONS - CROSS FELL ESCARPMENT

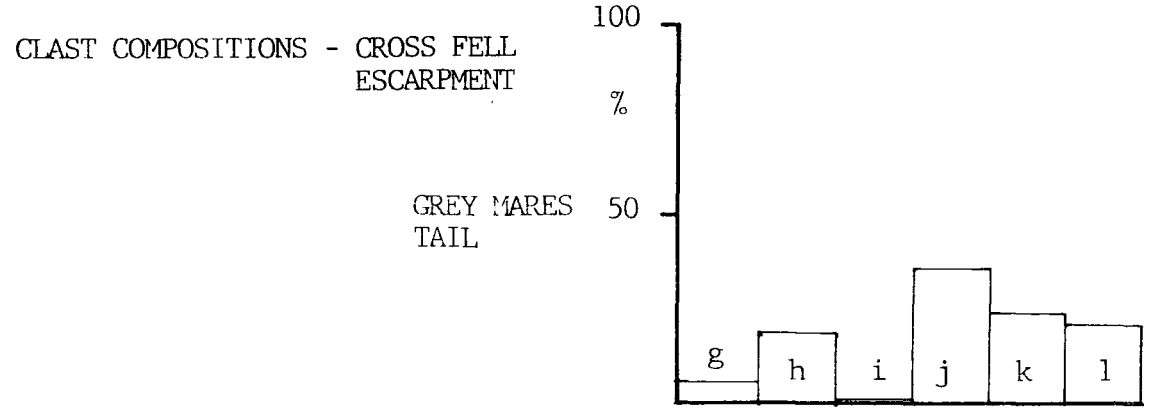
MAXIMUM CLAST SIZE

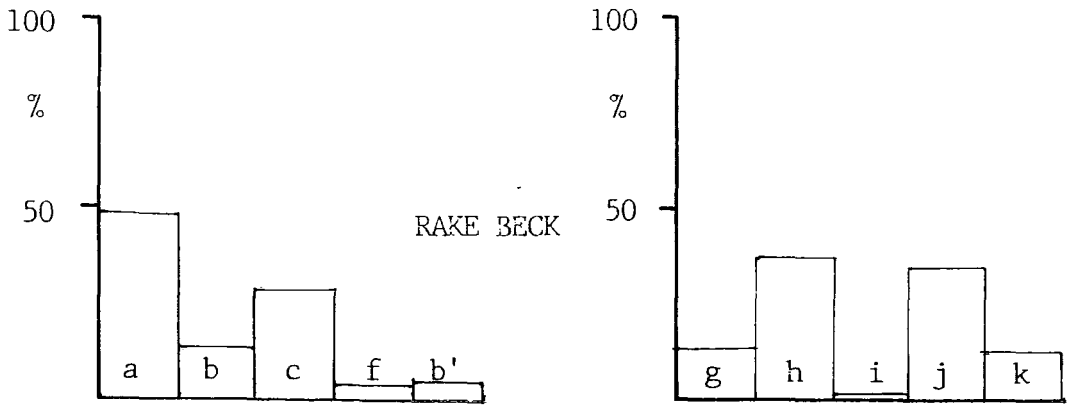
- a — Vein Quartz
- b — Arenites / Quartzite
- c — Greywacke / Qz. veined Greywacke
- d — Limestone
- e — Igneous Rock Fragments
- f — Acidic Volcanic Rock Fragments
- b' — Intraclasts

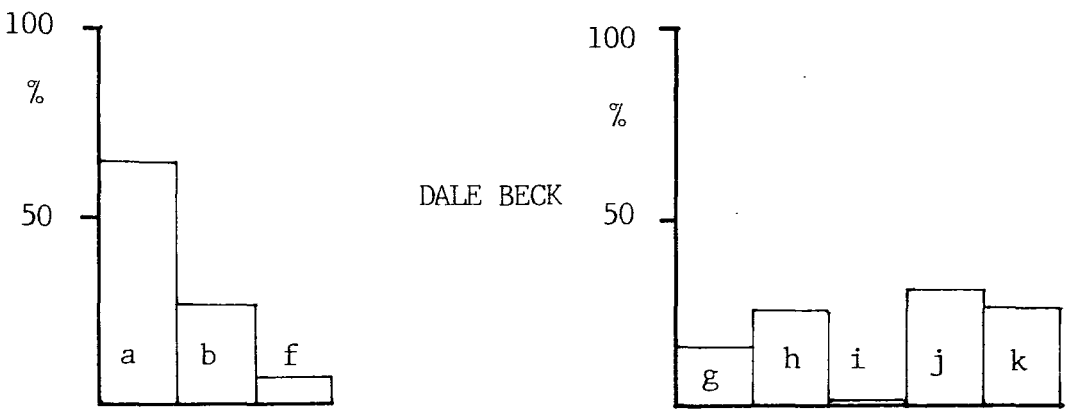
CONGLOMERATE/SANDSTONE PETROGRAPHY

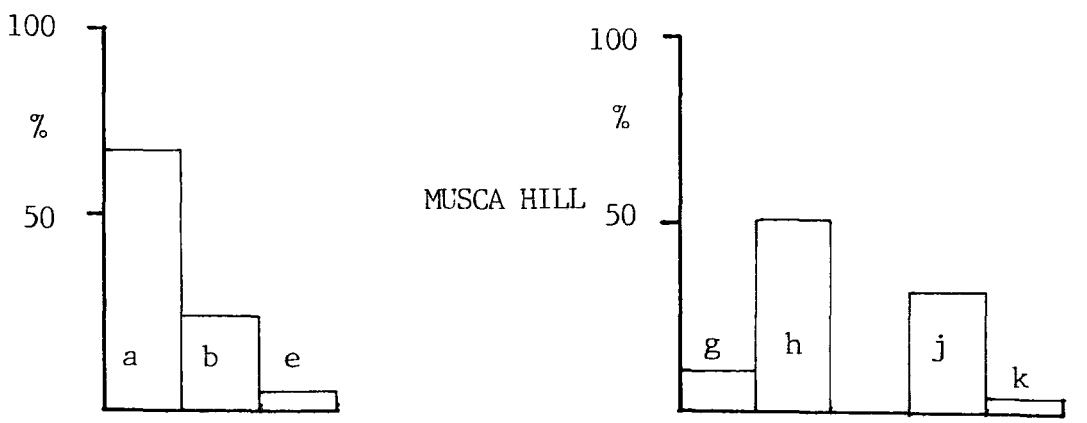
- g — Unimodal Quartz
- h — Polycrystalline Quartz
- i — Feldspars
- j — Sedimentary Rock Fragments (Pelites, Chert, Limest., Greyw.)
- k — Volcanic Rock Fragments (Porphyritic, Felsitic)
- l — Intrusive Igneous Rock Fragments (Granitic)

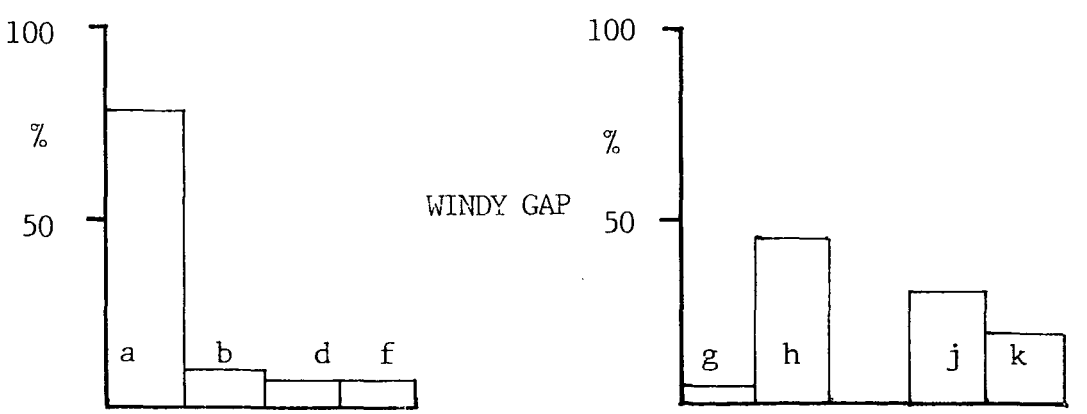
CLAST COMPOSITIONS - CROSS FELL ESCARPMENT

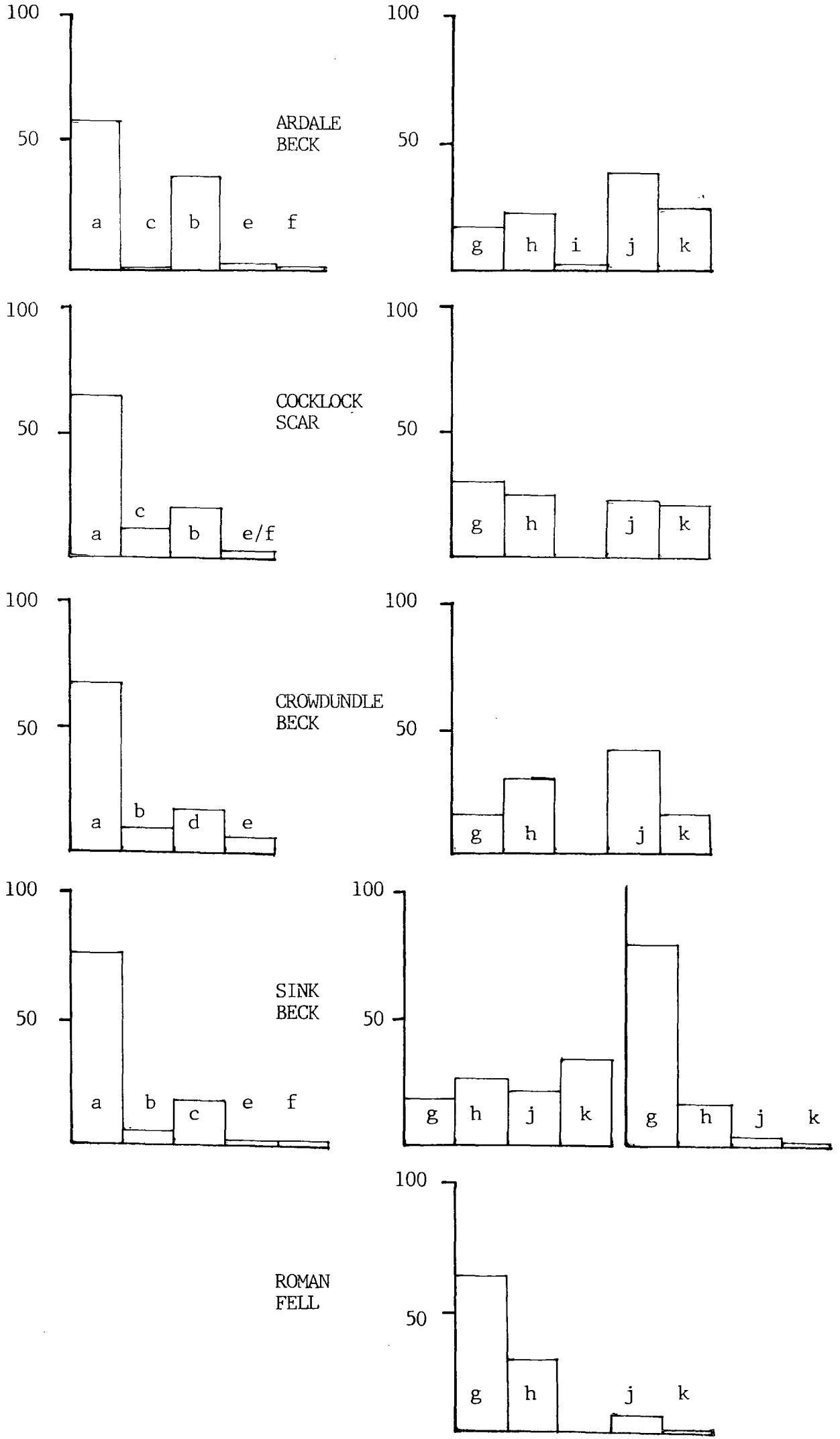











100
50
ARDALE BECK
a
c
b
e
f
g
h
i
j
k
COCKLOCK SCAR
e/f
CROWDUNDLE BECK
d
SINK BECK
ROMAN FELL

APPENDIX 3: THIN SECTION POINT-COUNT DATA

Legend

250 counts unless otherwise stated (e.g. 200 CTS).

MONO QZ	=	Monocrystalline quartz
POLY QZ/MRF	=	Polycrystalline quartz/Metamorphic rock fragments
FELDSP.	=	Feldspar
SRF/INTR.	=	Sedimentary rock fragments/mud intraclasts
DETRITAL/A. CLAYS/ PSEUDOMATRIX	=	Detrital/authigenic clays/pseudomatrix
IRF	=	Igneous rock fragments
HEAVIES	=	Heavy minerals

SRB	=	Shap Red Beds
MFC	=	Mell Fell Conglomerate
QC	=	Quartz Conglomerates
RS	=	Red Sandstones
PGBS	=	Pinskey Gill Beds, Shap
PGB	=	Pinskey Gill Beds

SRF/INTR.	IRF	CEMENT
g = greywacke	V = undiff. volcanics	q = quartz
int = intraclasts	gr = granite	d = dolomite
hr = hornfels	rh = rhyolitic	ca = calcite
ch = chert	por = quartz/feld porphyry	he = haematite
sl = slate		
cac = unconformity zone intraclasts	mn = minette	

Heavies	Clays	Mica
Zr = zircon	i = illitic	mu = muscovite
	k = Kaolinite	bi = biotite

SAMPLE NO:	LOCALITY	GRAIN SIZE	MONO QZ	POLY QZ/MRF	FELDSP.	MICA	DETRITAL CLAY/ A CLAYS/ PSEUDOMATRIX.	SRF/ INTRACL.	IRF	CEMENT	PORES	HEAVIES
1/52	SHAP: Shepherd's Br. (SRB)	f-m	170	46	7	-	3	24 g	-	-	-	-
4/17	SHAP: Tebay Servs. (SRB)	f-m	129	54	-	-	-	37 g	2	3 q	25	-
1/35 I	SHAP: Beckside (SRB)	m-c	52	31	-	-	20 k	97 g,int	2	48 d	-	-
1/15b I (200 CTS)	SHAP: Greenholme (SRB)	m	77	22	-	-	6	50 g	4	6 q	35	-
1/20 I	SHAP: Ewelockbank (SRB)	c	51	22	-	-	30	79 g	9	56 q	3	-
1/30	SHAP: Beckside (SRB)	m-c	106	55	1	1 mu	41	31 g	1	2 d,12 q	-	-
1/41	SHAP: Shepherd's Br. (SRB)	f-m	120	30	8	1 mu	5	50 int, 16 g	5gr	13 q	-	2 zr
1/40	SHAP: Shepherd's Br. (SRB)	f-m	134	37	1	2 mu	16	21 g	4gr	34 q	-	1zr
1/14a	SHAP: Greenholme (SRB)	m	123	50	-	-	18	24 g	1	33 q	-	1zr
1/43	SHAP: Shepherd's Br. (SRB)	m	26	3	-	-	-	23 int 96 g, hr	15rh	84 d	3	-
4/48	CROSS FELL: Roman Fell (RFS)	m	105	50	-	1	-	51 int 12 g	2rh	26 q	3	-
1/71b	SHAP: Shepherd's Br. - Docker F. (SRB)	m	100	23	2	-		28 int 11 g	2	67 d 17 q	-	-
1/37b	SHAP: Beckside - Scoutgreen (SRB)	f	50	13	1	-	99 10 k	50 g,ch	8 por rh	5 q 2 d 3 he	9	-
1/61b	SHAP: Wasdale Beck (SRB)	c	33	8	28	6 bi	20 17 k	45 g	9rh,gr	81 d	3	-
1/58	SHAP: Wasdale Beck (SRB)	c	8	10	18	7 bi	27 9 k	54 g	12gr,rh	97 d	8	-
2/3b	SHAP: Docker F. (SRB)	m	86	30	3	-	19 7 k	27 g	1rh	20 d 41 q	16	-

SAMPLE NO:	LOCALITY	GRAIN SIZE	MONO QZ	POLY QZ/MRF	FELDSP.	MICA	DETRITAL CLAY/ A CLAYS/ PSEUDOMATRIX.	SRF/ INTRACL.	IRF	CEMENT	PORES	HEAVIES
2/8	SHAP: Micklegill (SRB)	f-m	107	48	-	-	-	30 int 38 g	1	5 he 21 q	-	-
2/13b	SHAP: Micklegill (PGBS)	m-c	47	22	1	-	34	111 ch,g	5 rh	4 he 26 q	-	-
C/56a	MELL FELLS: Dalemain BH (MFC)	vc	7	-	-	3 bi	-	11 int 93 g,st	86 mn, rh, por	6 he 44 ca	-	-
C/8	MELL FELLS: Dalemain BH (MFC)	vc	14	1	-	5 bi	60	71 g,sl, hr	80 por mn	9 he 9 ca	-	1 zr
8a CRE	MELL FELLS: Dalemain BH (MFC)	vc	9	2	-	2 bi	45	120 g,sl, hr	44 mn	7 he 21 ca	-	-
10b CRE	MELL FELLS: Dalemain BH (MFC)	f	11	7	1	3 bi	67	3 lst 82 g,sl,hr	43 mn	6 he 27 ca	-	-
C/54b	MELL FELLS: Dalemain BH (MFC)	vc	10	-	-	6 mu, bi	-	30 g,sl, hr	109 mn, por	67 he 28 ca	-	-
C/48b	MELL FELLS: Dalemain BH (MFC)	vc	17	-	-	3 bi	-	48 g, int.	100 por rh	63 he 19 ca	-	-
4a CRE	MELL FELLS: Dalemain BH (MFC)	c	8	3	-	-	-	107 g, hr	88 por rh	11 he 33 ca	-	-
10a CRE	MELL FELLS: Dalemain BH (MFC)	c	23	1	-	-	8	76 g, hr	60 por rh,mn	35 he 47 ca	-	-
2/30(247 CTS)	MELL FELLS: Folly Lane (MFC)	c	16	3	-	-	-	185 g, sl 4 lst 7 int	-	12 he 20 ca	-	-
C/38(200 CB)	MELL FELLS:	vc	2	-	-	-	5	84 g,sl 3 lst	67 por rh	19 he 20 ca	-	-
3/61b	CROSS FELL: Grey Mares Tail (PG)	m-c	19	70	3	-	64	35 g,sl	40 gr 17 v	2 ca	-	-
3/64	CROSS FELL: Grey Mares Tail (QC)	m-c	5	7	-	-	-	98 g, sl 5 int 12 lst	83 por, v	40 ca	-	-
3/54 (150 CTS)	CROSS FELL: Crowdundle Beck (QC)	vc	15	49	-	-	20	40 hr, sl 8 int	18 rh	-	-	-

SAMPLE NO:	LOCALITY	GRAIN SIZE	MONO QZ	POLY QZ/MRF	FELDSP.	MICA	DETRITAL CLAY/ A CLAYS/ PSEUDOMATRIX.	SRF/ INTRACL.	IRF	CEMENT	PORES	HEAVIES
4/8	CROSS FELL: Rake Beck (QC)	c	23	112	2	3 mu	40	61 g,ch, sl	3 rh	6 he	-	-
4/10b	CROSS FELL: Rake Beck (QC)	c	29	82	1	3 mu	50	63 g,ch, sl	16 rh	6 he	-	-
4/15	CROSS FELL: Rake Beck (RS)	m-c	21	24	2	2 mu	42	74 g,sl	48 v, rh	4 he 32 ca	-	1 zr
4/26a	CROSS FELL: Dale Beck (RS)	m-c	40	33	-	-	27 i	72 ch,g int.	30 rh, v	48 d	-	-
4/28b	CROSS FELL: Dale Beck (RS)	m-c	21	19	1	1 bi	39	66 g,sl, ch	51 rh, v	6 he 46 d	-	-
4/38	CROSS FELL: Windy Gap (QC)	m	10	89	-	-	40	63 g,sl, ch	39 rh	8 he	1	-
4/42	CROSS FELL: Musca Hill (QC)	f	20	86	-	3 mu	60 3 k	55 g,sl, ch	7 rh	13 he	3	-
4/53b	CROSS FELL: Dale Beck 2 (QC-RS)	m	35	83	2	6 mu	56 11 k	44, sl,g	6 rh	-	7	-
4/57	CROSS FELL: Dale Beck 2 (RS)	m-c	24	53	1	-	52	57 sl,g	63 rh v	-	-	-
4/59b	CROSS FELL: Dale Beck 2 (RS)	m	16	35	-	-	30	37 sl,g	90 rh por v	8 he 33 ca	-	1 zr
5/2a	CROSS FELL: Ardale Beck (QC)	c	20	34	-	1 bi	60	73 g,sl, int.	62 por rh	-	-	-
5/3b	CROSS FELL: Ardale Beck (QC)	vc	25	63	-	3 mu	40	67 g,sl, int.	52 por rh	-	-	-
3/52a	CROSS FELL: Ardale Beck (QC-RC)	m-c	43	54	4	1 mu	17	99 g,sl	31 por, rh	1 q	-	-
3/55a	CROSS FELL: Crowdundle Beck (QC)	c	43	42	-	3 mu	13 k	114 g,sl int.	32 por, rh	3 d	-	-
3/56a	CROSS FELL: Sink Beck (RS)	c-vc	163	17	-	-	42 k	3 g, int.	-	25 q	-	-
3/56b	CROSS FELL: Sink Beck (RS)	c-vc	111	39	-	3 mu	48 i 21 k	9 g,int.	2 rh	17 q	-	-

SAMPLE NO:	LOCALITY	GRAIN SIZE	MONO QZ	POLY QZ/MRF	FELDSP.	MICA	DETRITAL CLAY/ A CLAYS/ PSEUDOMATRIX.	SRF/ INTRACL.	IRF	CEMENT	PORES	HEAVIES
1/1b	RAVENSTONEDALE: Pinskey Gill (PGB)	f-m	156	21	-	-	66	7 g	-	-	-	-
1/9b	RAVENSTONEDALE: Flakebridge (PGB)	m	147	33	2	-	-	13 g, ch 53 cac	2 rh, v	-	-	-
4b CRE	MELL FELLS: Dalemain BH (MFC)	c	9	7	-	1 mu	26	131 g	45 mn, rh	9 he 22 ca	-	-
C/33	MELL FELLS: Dalemain BH (MFC)	c	8	-	-	-	76	39 g	114 mn, rh	13 ca	-	-
2/53 (100 CTS)	MELL FELLS: Dalemain BH (MFC)	c	-	1	-	-	-	67 g	5 mn	1 he 26 ca	-	-
C/48a	MELL FELLS: Dalemain BH (MFC)	vc	9	2	1	-	5	35 g	125 mn, rh	45 he 28 ca	-	-
C/46	MELL FELLS: Dalemain BH (MFC)	c-vc	17	2	0	1 bi	5	8 g	148 mn, rh	46 he 23 ca	-	-
5/12	CROSS FELL: Ardale Beck (RS)	f-m	46	31	1	-	61	76 g,sl	35 rh v	-	-	-
5/15	CROSS FELL: Cocklock Scar (QC)	m-c	54	45	-	2 mu	61 11 k	40 g,sl	37 rh, v	-	-	-
5/22	CROSS FELL: Sink Beck (QC)	m-c	34	48	-	-	28 k 38	40 g,sl, ch	62 rh v	-	-	-
WG4	RAVENSTONEDALE: Wyegarth Gill BH4 (SC)	c	57	38	-	-	-	18 ch, cac	137 rh v	-	-	-
C2/41	RAVENSTONEDALE: Wyegarth Gill BH2 (SC)	f-m	50	30	-	-	10	15 g, ch	140 rh, v	5 he	-	-
C2/40	RAVENSTONEDALE: Wyegarth Gill BH2 (SC)	f-m	59	32	2	-	30	25 g,ch, sl	94 rh, v	8 he	-	-

