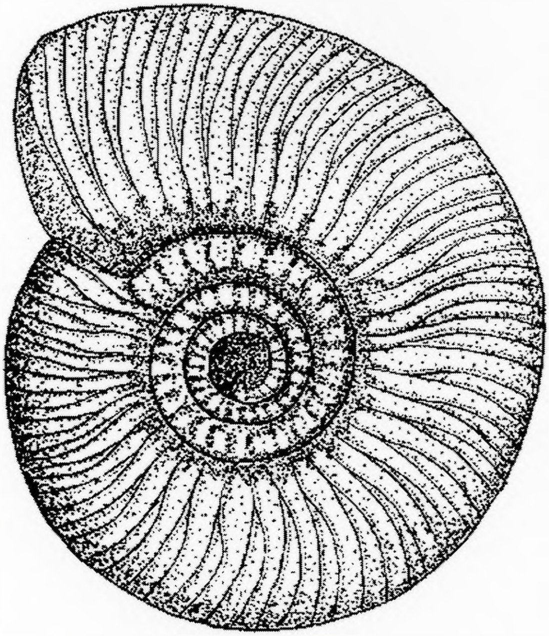
THE CUMBERLAND GEOLOGICAL SOCIETY



50th Anniversary Edition (1962-2012)

PROCEEDINGS

Volume 8 2010-2011 Part 1

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2010 – 2011

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Volume 8, Part 1

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2012

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EDITORIAL

The Society is celebrating its 50th Anniversary this year. As part of these celebrations we are pleased to publish this special, larger than normal, volume of Proceedings.

Anniversaries are times for reflection, looking back on the past, but also occasions for looking forward to future years. From small beginnings in 1962 the Society has gone from strength to strength. Starting as a small informal group in West Cumberland (as it then was), it has become established as a significant regional geological society, focussed on the magnificent geological terrain of Lakeland and N.W. England. The Proceedings has not only recorded our events and activities it has become an established journal for the publication of original work on the region.

We hope this present volume continues this tradition. In the following pages we have attempted to look back and recount some of the events and achievements in our first 50 years. The piece on 'The Landmarks in the History of the Society' records the tangible achievements, particularly the publications we have produced, but we hope it also portrays some of the people, the trends in our activities and how far we have come in half a century. Mervyn Dodd in his article on field excursions remembers from first hand experience all of these 50 years over what has remained as one of the Society's key activities – 'geology in the field'. The second part of the volume contains a further collection of original papers, again with the focus on Cumbria.

May we thank all our contributors. The authors for their papers, the many members and friends who have provided photographs and historical reminiscences, members who have recorded field excursions and to a series of people who have read parts of the text and suggested improvements.

Alan Smith (Editor).

Assisted by David Kelly.

LANDMARKS IN THE HISTORY OF THE SOCIETY 1962–2012

Alan Smith

The Society originated from a small gathering of people called the West Cumberland Geology Group which met initially in 1959 in the then Whitehaven College. Instigated by Charles Edmonds, Edgar Shackleton and a number of other enthusiasts in the west of the County, it met throughout 1960 and 1961. A series of winter talks were held in various venues when members introduced a variety of geological topics. Noted highlights were Edgar Shackleton on 'Mountains: their nature and origin' and Tom Shipp on 'Fossils'. Audiences of 50 were recorded and there are frequent references to displays of specimens and lectures illustrated by slides and film strips. Visits were arranged to local quarries and there were several underground visits to coal mines, notably the recently closed Walkmill Mine at Moresby and to Haig Pit. Visits to Borrowdale, St. Bees, Ennerdale and a number of other Lake District locations also appeared in the programmes.

West Cumberland Geology Group on a visit to Florence Mine. Edgar Shackleton is centre photo, holding lamp, with bag across shoulders.

THE WEST CUMBERLAND GEOLOGY GROUP

LEADERS

C.Edmonds Esq. M.Sc. F.G.S. J.P. E.H. Shackleton Esq. F.G.S.

Secretary.

R.E.O.Pearson Esq. 123, High Road, Kells, Whitehaven. Cumberland.

MEMBERS.

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Miss.E.M.Smith.
A.Trohear.Esq.
H.A.White.Esq. B.A.
Miss.P.M.Wareing.
H.H.Walmsley.Esq.

Above: Original list of membership of the West Cumberland Geology Group in 1960. Charles Edmonds and Edgar Shackleton designated as 'leaders' of the Group.

Of this list of members, five are still members of the Society today – Morley Burton, Mervyn Dodd, Miss D. Harrison, Miss E. Pimblett and Tom Shipp.

(Thanks are due to Mr R.E.O.Pearson – Founder member and then Secretary of the Group – for providing this list.)

A field meeting of the West Cumberland Geological Group at Broughton Crags Quarry in 1960. Standing at the extreme right (in cap) is Charles Edmonds. Edgar Shackleton is standing in the middle of the group, towards the back (in trilby, tie and dark jacket).

Local geologists form Society

THE West Cumberland Geology Group held its annual general meeting at the Workington College of Further Education, when the co-leader Mr E. H. Shackleton reviewed a very full year's activities. Due to the growth of the Group it was decided to form it into a society, under the title of The Cumberland Geological Society.

The President by unanimous vote was named as Mr C. Edmonds, M.Sc. F.G.S, J.P, who until recently was the Chairman of the Cumberland Education Committee, and is one of the leading authorities on the Carboniferous Limestones. The vice president of the newly formed Society is Mr E. H. Shackleton F.G.S. a co-founder of the Group, and well known in Cumberland for his lectures in geology under the auspices of the British Association.

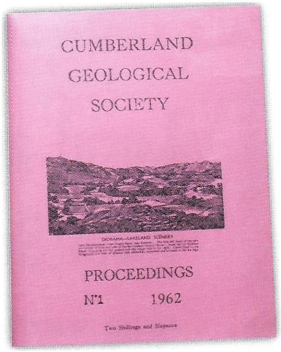
After the election of officers the newly-elected vice president reviewed the forthcoming year's activities. These included a detailed study of the limestone quarries of the district, a similar project for the old mineral mines of Borrowdale, first mined in prehistoric times; and a study of the beach drift at St Bees. The Society proposes to publish the findings of these projects.

Applications for membership of the Society should be addressed to the Secretary, R. E. O. Pearson, 123 High Road, Kells, Whitehaven.

The Society founded early in 1962.

West Cumberland Times February 1962.

1962 The Society had a very active first year, with excursions starting on January 22nd and February 23rd to local mines, and then further afield every month throughout the year. Edgar Shackleton gave a long address on 'Granite and Granitisation' to a large audience in February. The events were recorded in the first edition of Proceedings *(right)*, produced in a soft cover, with the contents typewritten and duplicated on stencils, with a cover price of two shillings and six pence.



A diorama of Lakeland Scenery adorned the cover. Volume 2 appeared later in the year and for several years the Society managed to produce two Proceedings per year in the same format. The colour of the cover changed each time and various designs were tried for the cover illustration.

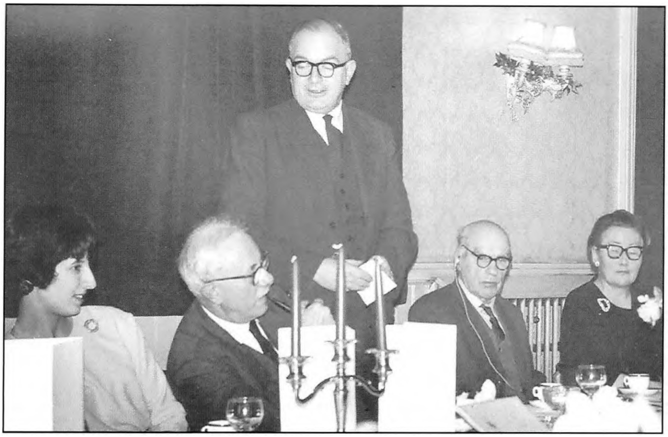
The early Proceedings make interesting reading. The Society relied entirely on its own membership for its events – talks, films, practical classes and excursion leadership. Membership grew quickly and by the end of 1962 had reached 95. There were discussions about the difficulties of having large numbers (as many as 60) on excursions. An early aim was to have its own duplicator to produce Proceedings – clearly a very onerous task. Bob Pearson (The first Gen. Secretary) and Tom Shipp (The First Editor) did a magnificent job in editing and producing these volumes. The large number of excursions and local visits were a very notable feature of this early period including weekend excursions and camping expeditions.

This ... "*brings back memories of endless hours of typing and stencilling on Gestetner "skins", black smudges of ink everywhere, aching shoulders through turning the handle to churn out copies, one page at a time! Fortunately, we had plenty of space in the apartment we rented in Hensingham, just a short way on from Edgar and Doris Shackleton's little semi in Lincoln Road.*"

Tom Shipp (November 2011)

* * *

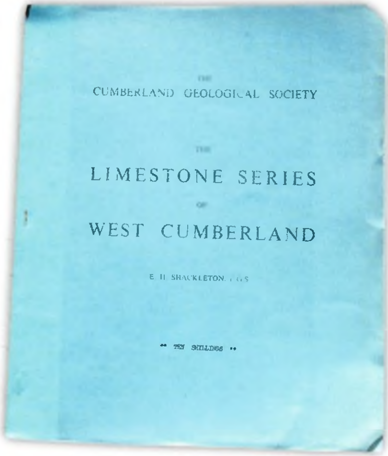
1963 saw increased activity. Membership had reached 110. The first Annual Dinner was held on January 4th at the Commercial Hotel in Workington with Professor Hemmingway of Kings College, London as the Guest speaker. Interestingly in his address he referred to the Society as only the second county Geological Society in the country after Yorkshire.



Above: At the first Annual Dinner.
Left to right: Helen Shipp, Geoffrey Gowing, Prof. John Hemmingway (standing), Alderman Charles Edmonds (President) and Mrs Hemmingway.

Above: At the Second Annual Dinner. March 1st 1964 (held in Keswick) Standing left to right Edgar Shackleton, Caroline Banner-Mendus, and Bob Pearson (first General Secretary). Seated left Dr. G. H. Mitchell and right, Geoffrey Gowing.

Field excursions again dominated the activity of the Society with continuing visits to mines, classic Lakeland sites and the limestones of West Cumberland. The year also marked the first special publication of the Society, a tradition which has marked out the Society ever since. Edgar Shackleton's *'The Limestone Series of West Cumberland'* (right) was a detailed inventory of West Cumberland limestones, their succession, fossil content and exposure locations – very much a personal record of the authors detailed knowledge of the area and its rocks.



Again it matched the Society Proceedings in its format – soft back, typewritten contents. Priced at ten shillings it marked the Society's first venture into commercial publishing.

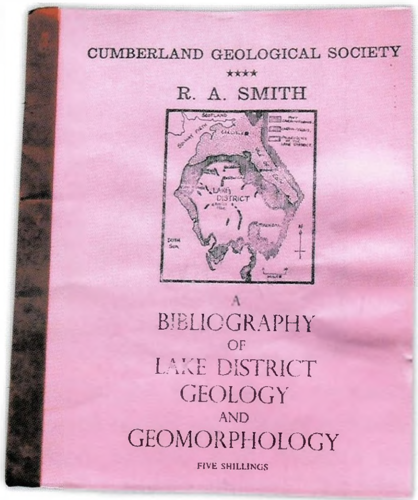
* * *

1964 started on a sad note with the death of Charles Edmonds, the first President, on January 2nd. An appreciation of his life and work was published in Proceedings and the Society put in train the setting up of the *Charles Edmonds Memorial Fund* in his memory (see later entry on this).

Edgar Shackleton took over the role of President of the Society, a position he continued to occupy for nearly 20 years until 1981.

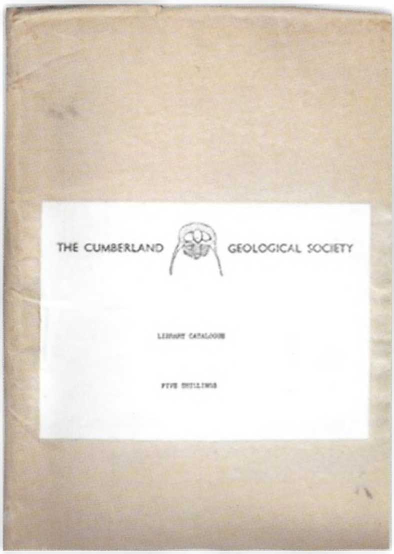
* * *

The Society's second occasional publication was produced in 1965 with Alan Smith's *'Bibliography of Lake District Geology and Geomorphology'*. This again matched the style of the previous Society publications and produced a listing of over 550 papers and publications in the field, together with an index and maps to locate references.



THE LIBRARY

Late in 1965 it was announced that a Society Library had been established, starting with a nucleus of books presented by Tom Eastwood (formerly Geological Survey Geologist in West Cumbria). The collection was organised by Morley Burton, who became the first Society Librarian. At first, the collection was quite modest – considerable runs of a number of journals, 25 bound volumes and 30 miscellaneous pamphlets and maps. A catalogue was produced listing the collection (below).



Since those early days the collection has grown enormously. A permanent space on the upper floors of Whitehaven Public Library continues to provide a home for this valuable facility. Over the years numerous bequests have been received so that today the collection is undoubtedly the most comprehensive geological collection in the County.

* * *

By 1967 membership had grown to 265, including many institutional members. Attendance at Lectures and field meetings was strong. The Proceedings in the late 1960's record not only details of the lecture meetings, film evenings, camping weekends and field excursions but also the advent of speakers coming from outside the Society and the first publication of papers on Cumbrian geology and geomorphology. The Society had established an identity as a regional geological society.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Volume 7 2008-2009 Part 4

PROCEEDINGS

In 1971 the Proceedings were revamped and a new format introduced. It was decided to publish on a bi-annual basis in a new A5 design, with four separate parts per volume, starting with Volume 3. A simple colour banded design was chosen, with the Society logo prominent in the centre of the cover. The four parts of Volume 3 all contained the trilobite logo from earlier Proceedings.

Volume 4 (1977-78) saw the introduction of the new Society Logo – a representation of the Carboniferous goniatite *Gastroceras cumbriense*. This has remained the Society Logo ever since and figures on all publications, letterheads, the web site and correspondence. In more recent volumes it has gained more definition and a larger size.

The colour banded design has continued through all subsequent volumes, with the printer being given the task each time to come up with a slightly different shade. The yellow Volume 6, part 3, had a special cover, bearing the words 'Millenium Edition'. Early Volumes were all folded and centre stapled. Since Volume 6, part 4, a perfect bound format has been adopted. Volumes 3-5 were variously printed by either Reeds Ltd, Penrith, or Bethwaites, Cleator Moor and Workington. Since Volume 6, part 2 our printer has been Imprint, Cleator Moor and Cockermouth.

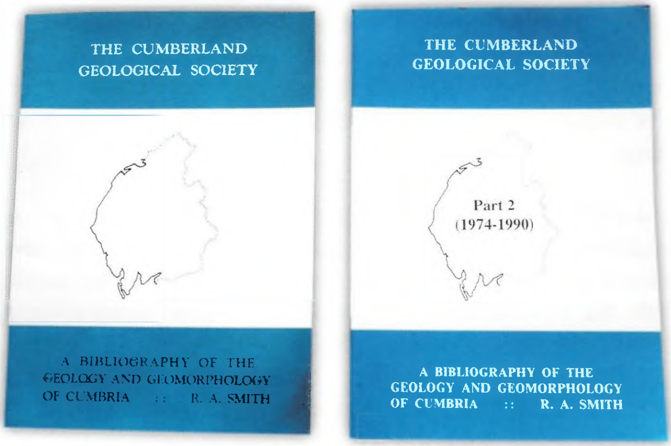
The 20 parts (Volumes 3-7) published to date are shown in order, top to bottom, opposite. Within these five volumes the Society has published 103 original papers, over 90 of which were on Cumbrian topics. In addition the Proceedings have recorded 50 summer field excursion seasons – well over 350 individual localities.

With the advent of the new format for the Proceedings in the early 1970's the Society had a channel for publishing original work on Cumbrian Geology, as well as a recognised record of its events. A regular programme of winter lectures, summer excursions and an Annual Dinner were well established.

* * *

In 1974 the first printed publication appeared with Alan Smith's 'Bibliography of the Geology and Geomorphology of Cumbria'. This was a much expanded version of the Lakeland bibliography published in duplicated format in 1965 and covered the then new County of Cumbria. It contained a listing of over a thousand published items on the county, along with an index and maps

In 1990 Part 2 followed, bringing the listing up to date. Both volumes were in the style of the new Proceedings with a colour banded cover, but in A4 format.



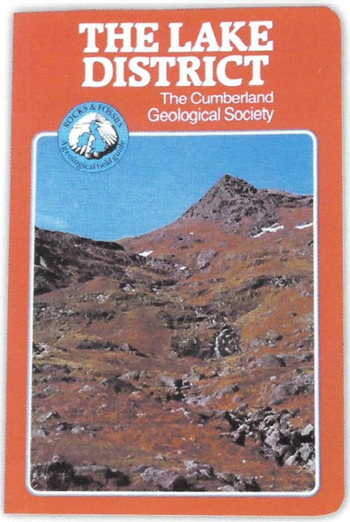
The 1980's were marked by a number of significant events in the life of the Society.

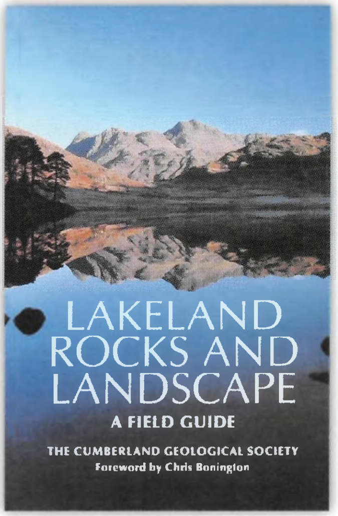
In 1981 Edgar Shackleton, with failing health, had to give up the Presidency of the Society, a post he had held for over two decades. Many of the Society events had centred around 'Shack' as he was affectionally called. He had delivered several Presidential Addresses and given many lectures. Many members, numerous groups of young people, summer visitors to the Lake District, WEA groups and countless members of the general public had been introduced to Cumbrian geology through his field excursions.

Edgar Shackleton with a group of young people at Bram Crag. (He died in March 1991).

His dictum of 'Go and See' inspired many. He continued to attend Society events in his later years, but his inability to cope with field meetings in particular, diminished his involvement.

The Constitution of the Society was changed shortly after the resignation of Edgar Shackleton as President. From that point on the President was able to serve a maximum of only two or three years in office.



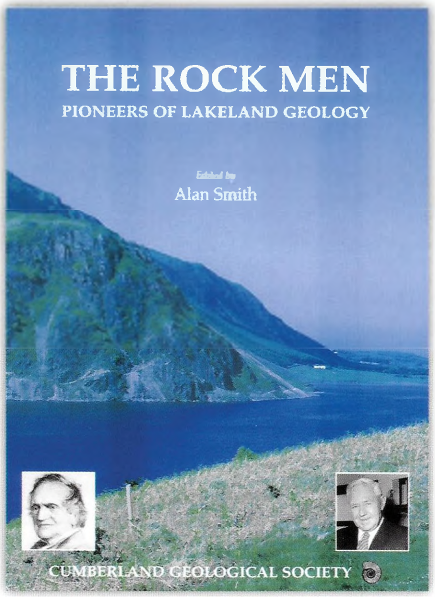


The 1980's also marked the beginning by the Society of the publication of Field Guides to the Lake District and Cumbria – a tradition which has continued up to very recent times. 1982 saw the publication of *'The Lake District'* a field excursion guide in a series published by Allen & Unwin. It was edited on behalf of the Society by Tom Shipp and was entirely written by eight members. It contained material on the geological background of the district, followed by 13 detailed excursions to classic Lakeland sites. Sales proved to be very good and this established the Society as a resource of local expertise, as well as bolstering the Society finances (above left).

Following the same pattern, *'Lakeland Rocks and Landscape: A Field Guide'* edited by Mervyn Dodd and first published for the Society by Ellenbank Press in 1992, proved to be even more successful. It ran to many editions and again became the best selling field guide to the district aimed at interested amateurs with some background knowledge of the earth sciences and for field study groups. It again contained some general geological background to the district, followed by descriptions of eighteen separate field excursions. It was written by members and friends of the Society (above right).

THE MILLENIUM

To mark the year 2000 the Society looked back at the work of some of the early geological pioneers who had first worked on Cumbrian geology and landscape. In the very early Proceedings Edgar Shackleton and others had contributed biographies of some of the early men who had worked in Cumbria – notably Jonathan Otley, Adam Sedgwick, J. F. N. Green, Alleyne Nicholson and Clifton Ward. For the Millenium, however, a large number of members researched more widely. Volume 6, part 3 of the Proceedings was a bumper edition, thicker than had ever been produced before, when accounts of the life and work of nineteen of these early pioneers was published. The summer field excursion programme followed up on this work, with the theme of *"... in the footsteps of...."* With trips to Cat Gill in the footsteps of Clifton Ward, to Glenridding *in the footsteps of* Thomas Hay, ...'In Charles Edmonds day' to Longlands and Clints, and 'The Furness of John Bolton'.



All this work was followed up and expanded and led to another publication by the Society – *'The Rock Men'* edited by Alan Smith and published for us by Dixons in Kendal. We were successful in gaining a substantial award from the *'Awards for All'* Lottery Grants for Local Groups Scheme which allowed this relatively expensive publication to go ahead. It presented portraits of 25 of the early 'Rock Men' who had deciphered the geology of the district from the early days of the science.

In 2001 Cumbria was devastated with the outbreak of Foot and Mouth disease when large areas of the County were out of bounds. This severely affected our field excursion programme. All was not lost however. Shortly before, Dr. Eric Robinson had effectively challenged the Society to consider the geology of the urban environment in two inspiring lectures to us, one on local building materials and a second on geology and walls. This led to some interesting work by members on local building materials and the use of stone in our urban areas. Excursions round Whitehaven, Buttermere, Keswick and Penrith ensued and generated considerable interest plus some subsequent writings in Proceedings

* * *

2002 SOCIETY SMALL AWARDS FOR STUDENTS launched.
This was designed to assist students who have limited funds with geological fieldwork projects. Preference is given to students at school, college or University with Cumbrian connections. The amounts of funding are small but it was mounted to fulfil part of our role as a Society to support education in the earth sciences.

* * *

May 2006 regrettably saw the death of Angela Marchant, the first time a President had died whilst still in office. Angela, our only female President to date, had played a major role in Society affairs. A very considerable sum of money was donated at her funeral to the Society. This now forms a Bursary fund in her name to support young people in their studies of geology and is now part of our small awards scheme.

* * *

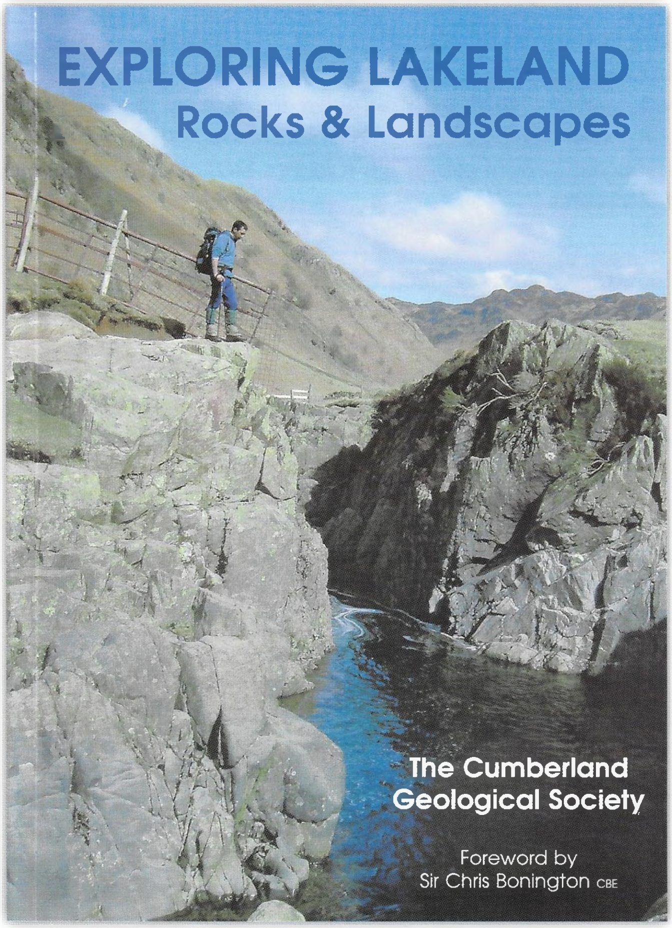
In October 2007 The Council of the Society bestowed Honorary Life Membership on three long standing members – Mervyn Dodd, Tom Shipp and Alan Smith. This is defined in the Constitution as "...awarded to any person who has rendered signal service to the Society or is distinguished in the pursuits of the objects of the Society".


Mervyn Dodd


Tom Shipp


Alan Smith

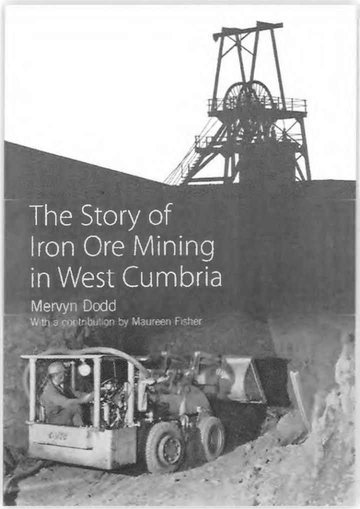
Continuing in our tradition of publishing local guides, 2008 saw the launch of *'Exploring Lakeland Rocks and Landscapes'* edited by Susan Beale and Mervyn Dodd. Yet again a group of members contributed to the volume with 17 excursion itineraries, several to new areas of Cumbria, written in a form for the general reader. For the first time we were able to use colour in the book, greatly enhancing the quality of the maps and illustrations. Fittingly it was dedicated to the memory of Angela Marchant who was very much involved with the planning of the volume before her death.



'Exploring Lakeland Rocks and Landscapes' won the Joint First 2008 Eni Challenge Award.

Mervyn Dodd receiving the prize with joint winner the Forest of Dean Local history Group from Mr Alessandro Gelmetti (centre right), Exploration Manager at Eni UK Ltd.

The most recent publication from the Society has been Mervyn Dodd's book on *'The Story of Iron Ore Mining in West Cumbria'*. Published in 2010 it brings together the history and geology of the distinctive haematite field of the area around Egremont and Cleator Moor. Based on Mervyn's extensive local knowledge of the geology of the field, it is a valuable record of an area which has been the venue for many Society field excursions.



The present membership of the Society (2011) is:

3 Honorary Members
5 Institutional Members
25 Joint Members
123 Ordinary Members
Overall total 156.

To the next 50 years!

PRESIDENTS OF THE SOCIETY

1962-1963	Charles Edmonds	1994-1996	Fred Lawton
1963-1981	Edgar Shackleton	1997-1998	Mervyn Dodd
1982-1984	Mervyn Dodd	1999-2000	Dennis Dickins
1985-1986	Jim Cockersole	2001-2003	Alan Smith
1987-1989	Tom Shipp	2004-2006	Angela Marchant
1990-1991	Ivor Gray	2007-2009	David Kelly
1992-1993	Ken Bond	2010-	John Rodgers

ANNUAL DINNER : GUEST SPEAKERS

1963	Professor J. E. Hemingway	1988	Russell Arthurton
1964	Dr. G. H. Mitchell	1989	Dr. John Boardman
1965	Professor Gordon Manley	1990	Brian Young
1966	–	1991	Dr. Jim Cockersole
1967	Dr. Angus Lunn	1992	Ian Francis
1968	–	1993	Jack Hartley
1969	Dr. A. W. Woodland	1994	George Bott
1970	Dr. Dorothy Rayner	1995	Dr. Stuart Munro
1971	Dr. D. A. Bassett.	1996	Dr. David Millward
1972	–	1997	Eric Skipsey
1973	–	1998	Professor David Huddart
1974	Professor M. H. P. Bott	1999	Dr. Brian Irving
1975	Dr. Patrick Brenchley	2000	David Grech
1976	Sir Kingsley Dunham	2001	Andrew Williamson
1977	Mr Colin Rose	2002	Alan Diggles
1978	Dr. Winifred Tutin	2003	Dr. John Lackie
1979	Dr. Frank Moseley	2004	Ian Forbes
1980	Dr. Jack Soper	2005	Charlotte Vye & Stu Clarke
1981	Dr. G. A. L. Johnson	2006	Simon Webb
1982	Professor Lewis Penny	2007	Chris Darmon
1983	Dr. Denys Smith	2008	Dr. Hugh Tuffen
1984	Wyndham Evans	2009	Dr. Alan Smith
1985	Murray Mitchell	2010	Professor Joe Cann
1986	Dr. Angus Lunn	2011	Dr. Ron Barker
1987	Dr. Peter Allen	2012	Professor Peter Kokelaar

THE CHARLES EDMONDS PRIZE

Charles Edmonds M.Sc., F.G.S.
1886-1964

Charles Edmonds was born in Bigrigg and spent all his working life connected with mines and mining in West Cumbria. Through his working experience in the haematite fields he developed a lifelong interest and expertise in limestones.

His knowledge of geology was self taught. Over many years his enthusiasm for the subject and his detailed exploration of the West Cumbrian limestones brought him recognition in geological circles. He was elected to a Fellowship of the Geological Society and to the Geologists' Association, and in 1929 The Geological Society awarded him The Lyell Fund in recognition of his work. In 1954 the University of Durham presented him with an honorary M.Sc. Degree for his contribution to geological science.

The Award was established by the Society in 1964 to perpetuate the memory of Charles Edmonds. A fund was raised by public subscription and vested in Trustees appointed by the Council of the Society.

The prize is awarded to candidates who have furthered geological knowledge of the North of England.

AWARD WINNERS

Clive Nicholas	1967	Jim Cockersole	1991
Aynsley Shilston	1968	Tom Shipp	1993
Alan Smith	1971	Mervyn Dodd	1995
Edgar Shackleton	1973	Eric Skipsey	1997
Dennis Jackson	1976	Richard Clark	1999
Frank Mosley	1979	Audrey Brown	2002
Peter Allen	1987	David Kelly	2005

THE FIRST 50 YEARS' FIELD EXCURSIONS OF THE CUMBERLAND GEOLOGICAL SOCIETY

Mervyn Dodd

I attended my first CGS field trip in either 1962 or 1963, I can't remember which! Since then I have been at many of the field excursions in all kinds of weather. There have been many changes, certainly not a case of *"plus sa change, meme sa chose"*. As the Society had developed from the West Cumberland Geology Group it was no surprise that many of the early excursions were within West Cumbria, or to the Lower Palaeozoic rocks of the Lake District proper. Members mainly lived and worked in West Cumbria and there were many associate members from schools and colleges. Today the "heartland" of the Society is around Keswick and Penrith, where most of the members, healthy, lively, retired folk, mainly incomers, live.

Sir Kingsley Dunham (left) in conversation with Edgar Shackleton (centre). At right, – front, Stan Gate, behind Mike Nutt and Doreen Slater. Winder Mine Tip, Frizington, July 1983.

There were two rather different styles of trip in the 1960s. One set arising out of the previous Geology Group excursions were "DIYS". "Let's go to have a look and see what we can find", sums up that approach. At times the geological interpretations were distinctly ad hoc and quite imaginative. The other style, much more like the present day, was to have a designated leader who had walked the ground and consulted the relevant literature. While the charismatic Edgar Shackleton was active he led both styles with distinction until the late 1970s, but there were problems maintaining the two approaches. The excursion calendar in some years was distinctly sketchy, often repeating trips in the same or following year for members who missed the first visit, especially to the several coal mines still open. Many of the trips visited many sites in a day, often distant from one another. Some of the visits must have been quick 'look sees' or extremely long days. Annual camping weekends, variously in the East of Cumbria, Southern Scotland or the Yorkshire Pennines were regular, highly organised and well attended events. Excursion leaders were almost all members of the Society or professionals who worked locally. Gradually the more formal, more geological approach became more common. Initially, excursion handouts were unusual, as reprographic methods were primitive, while reports in Proceedings were often rather verbose and distinctly chatty.

Mervyn Dodd (left) in conversation with Sir Kingsley Dunham.
Winder Mine Tip, Frizington, July 1984.

Whitbarrow Scar, July 1983.

Standing left, Alan Smith, seated Kath Smith. Bending down at back, Murray Mitchell. Standing at right (in shorts looking at specimen) Norma Giannini. Other two members unknown.

Members on excursions were generally dressed in what today seems rather formal gear, gabardine raincoats, sports jackets and cords rather than today's anoraks, cagoules and action trousers. As today, wettings were still all too common and even then excursions had to be cancelled or abandoned. Attendances were often larger than today with up to 40 present, rewarding for the leader but not easy to manage. Often there were three distinct groups, keen types hanging on the leader's every word at the front, a chatty social group in the middle and, on occasions, elderly dog walkers bringing up the rear.

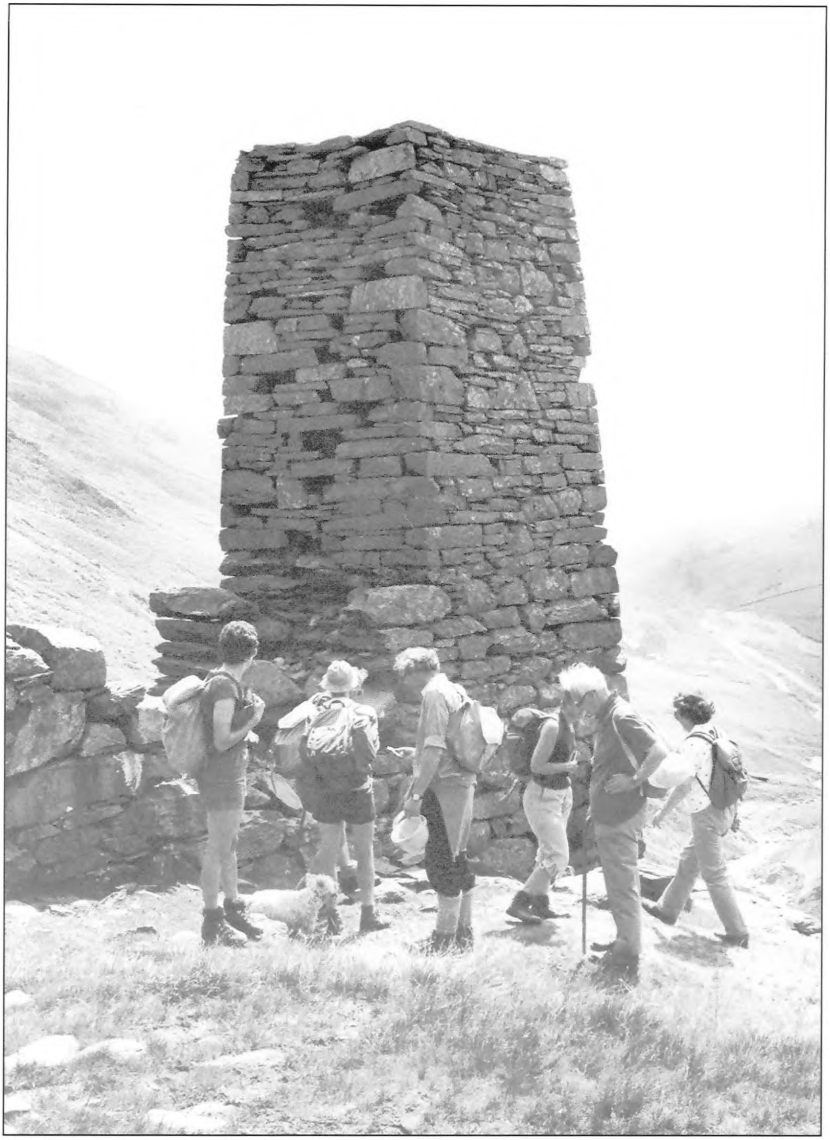
Tom Shipp (left), with Harold Eccles.

There were relatively few excursions in the early 1970s, continuing the trend of the late '60s. From 1976 onwards there were more or less regular programmes of short Wednesday evening trips, perforce within West Cumbria and the Western Lakes. Tom Shipp led many trips to a wide range of localities and different rock groups, the field week on the Isle of Arran being particularly successful, besides organising and running "training days" for beginners. Together with Jim Cockersole, Tom worked hard and successfully to raise the academic standards of the Society, and the quality of Proceedings. The weekend excursions and annual camps continued almost to the end of the decade, including visits to the east of Cumbria and the Furness area. Occasional visits to the Morecambe Bay limestones and to the Southern Lakes took place. More excursions, often to the more distant locations at weekends, were led by geologists who were not members of the Society. The fruitful and long continued support by what is now the British Geological Survey began then. Staff from the Universities of Durham and Newcastle, and members of the then fledgling Westmorland Geological Society were also much appreciated leaders. Joint meetings with other geological societies were arranged in the later 1970s.

Our field excursions in the 1980s and 1990s benefited from the greatly increased national interest in the geology of Cumbria, The resurvey of the geology of Cumbria especially of the Lower Palaeozoic rocks from 1982 onwards until at least 2003 by the British Geological Survey and contracted teams of University staff generated many revised interpretations of well known locations, besides highlighting new or previously overlooked exposures of interest. The very detailed investigations of the possible suitability of rocks in the area around Sellafield for a depository for high active nuclear waste (until its rejection in 1997) aroused much passion as well as interest. This provided much more information about the complicated glacial sequences in West Cumbria. The Excursion Guides written by members of the Society and published by Allen and Unwin in 1982 and by Ellenbank Press in 1992 provided easily accessible information for an audience much wider than our members.

This new found interest allowed us to have excursions led by many experts who were not members of the Society. Officers of the British Geological Survey, staff from many universities in the north of England and in Scotland gave us authoritative, well organised and fascinating field trips. Another aspect was the much increased cooperation with other geological societies, seen in the number of joint meetings, particularly with the Open University Geological Society and our neighbour, the Westmorland Geological Society. We organised and ran weekend field trips for several societies, some far more academic than us and some from the Home Counties

The pattern of our field trips changed. The weekend camps and full week excursions disappeared, as did the "training days". In their place were longer day trips, particularly to more remote locations in the north and east of Cumbria and to Southern Scotland. Thus excursions to the northern Pennines and to the varied rocks of the Eden valley were more common. The very varied trips in the 1990s, which also included North Lancashire and West Yorkshire, were run by a wide range of leaders. Excursions for beginners were a welcome departure at this time. The Nirex investigations allowed us to see previously unknown or ignored sites, much improving our appreciation of the complexities of the local west Cumbrian landscape. Visits to the old mines of the county were to an increasing variety of sites, especially in the 1990s. Opencast coal sites provided trips to excellent but temporary exposures. Towards the end of the century we had short trips to RIGGS (Regionally Important Geological and Geomorphological Sites) locations. Many of these had been identified and researched by Society members. Attendances at our field trips were often very good in these years.



Water wheel support tower at the Bonser Mine, Coniston Copper Mines valley, July 1984.

Left to right – Norma Giannini, Tom Shipp and Tyson Loftus (standing together), then Mervyn Dodd (facing left). On right Jim Cockersole (with stick) and Connie Loftus at extreme right. Other member at back unknown.

The first decade of the 21st Century brought more changes to our field trip programmes. Excursions in 2000 were thematic, designed to illustrate the sites associated with the pioneers of Lakeland Geology, the subject of a book the Society had just published. 2001 was a difficult year when Cumbrian farms were devastated by the foot and mouth outbreak. A skeleton programme looking at urban and coastal landscapes was all that was possible. Weeklong field trips, both to more distant parts of the UK and to overseas lands like Iceland and Cyprus of outstanding geological interest, became regular events. Nearer home a very successful series of trips to the Skiddaw massif allowed members to find many of the elusive *graptolite* fossils so vital for working out the stratigraphy of Skiddaw Group rocks. This was a really effective research project successfully carried out by members of the Society. The Society's publication in 2008, "Exploring Lakeland Rocks and Landscapes" added new places to visit when the opportunity allows. So 2000 to 2010 added a new dimension, as yet another very different decade of very good, well supported excursions.

We have been blessed as a Society by a very loyal membership, many of whom are prepared to turn out on very poor days and who suggest visits to new sites. There is just one problem remaining. As of now (2011) we are finding it hard to persuade members to lead our trips. This is a great pity as we feel we have a rich, untapped resource of many members who are very keen but who are unnecessarily and inappropriately modest about their geological competence.

Mervyn Dodd
[redacted]

NOTES ON MISSISSIPPIAN (LOWER CARBONIFEROUS) CRINOIDS FROM NORTHERN ENGLAND

Stephen K. Donovan

The recent, delightful paper by Mitchell (2010) on the Egglestone Marble was particularly welcome for its comments on crinoids in Mississippian (Lower Carboniferous, Namurian) limestones from the north of England. Although the Mississippian has been called the 'Age of Crinoids' (Kammer and Ausich, 2006), the abundant remains of these most beautiful of fossils remain underappreciated. Mitchell's paper prompts me to make some comments on fossil and living crinoids in general, and crinoids from both the Namurian of the area around Barnard Castle and the Mississippian of Cumbria in particular.

Fossil and extant crinoids

Mitchell was right to emphasise the importance of crinoids in the Palaeozoic. Although very few examples are preserved as complete specimens (Fig. 1), their remains may be so abundant as to be rock-forming and can form beds covering tens or hundreds of square kilometres (regional encrinites of Ausich, 1997). But the crinoids never recovered their previous diversity and abundance after the end Permian mass extinction; the youngest regional encrinite is in the Jurassic of Poland (Ausich, 1997, table 19.2). To further stress a point made by Mitchell (2010, p. 357), the only two crinoid-rich deposits that I have ever seen in the Cenozoic are in the Danian (Paleocene) of Denmark (Rasmussen, 1961) and the Middle Miocene of Carriacou in the Lesser Antilles (Donovan and Veltkamp, 2001). These were both laid down in deep-water settings and the stalked crinoids have been confined to such environments throughout the Cenozoic (Bottjer and Jablonski, 1988).

Modern crinoids are divided into the stalked, deep-water forms and the much more diverse comatulids, which evolved in the Jurassic. It is the comatulids that occur in shallow (but also deep) water, such as the Great Barrier Reef (Mitchell, 2010, p. 357). But, however common the comatulids may be, it is improbable that they could ever be present in rock-forming abundance. This is because their stem has been reduced to a single plate or columnal. It is the columnals and longer fragments of stem (pluricolumnals) of the stalked Palaeozoic crinoids that are the principal rock-forming components of the skeleton (e.g., Smith, 2010, fig.112). Comatulids have just too few columnals to make a rock.

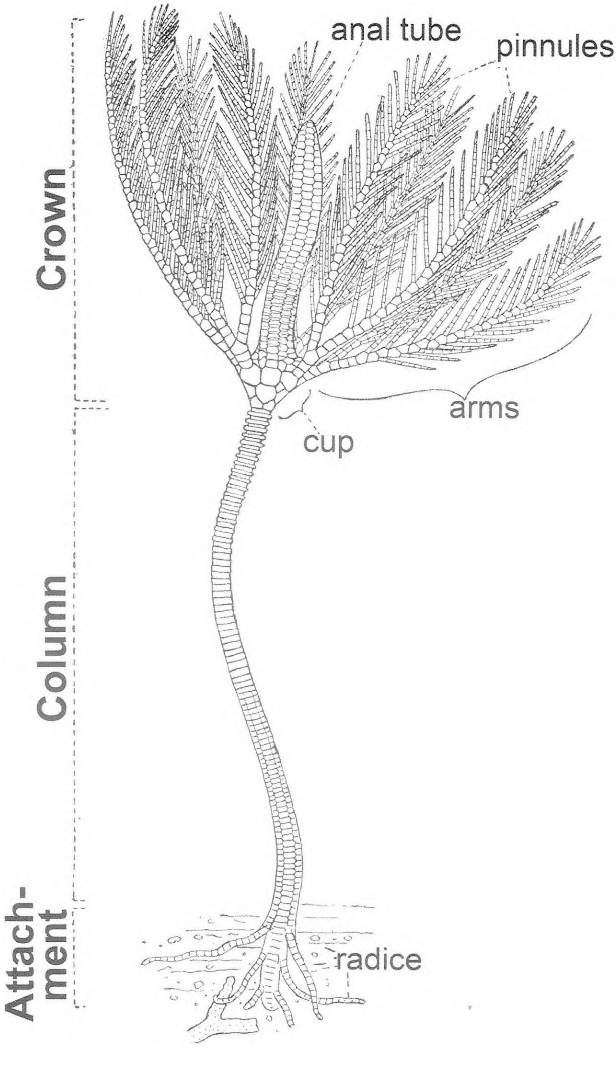


Figure 1. The Silurian (Wenlock of Dudley, West Midlands) Dictenocrinus decadactylus (Salter), reconstructed (probably incorrectly) in a low energy environment (relabelled after Bather, 1900, fig. 3). Principal morphological features are labelled. A modern reconstruction of such a crinoid would place it in a higher energy environment with the anal sac in a down-current orientation and the arms more outstretched to form a radiating filtration feeding fan (Clarkson, 1998, fig. 9.34b).

Namurian crinoids of northern England

I have not examined the Egglestone Marble nor its crinoids, but I was interested that Mitchell (2010, p. 358) reported rare, large columnals, 10-11 mm in diameter. The nominal crinoids of the Namurian (Pendleian) of England and Wales are few, including only seven genera (Ausich and Kammer, 2006, table 2). Of these, one is a possible match for Mitchell's large diameter columnals, namely Rhabdocrinus swaledalensis Wright. Recent fieldwork in the Namurian succession in the River Tees to the east of Barnard Castle has revealed locally common, long, robust pluricolumnals assigned to Rhabdocrinus sp. cf. R. swaledalensis (see Donovan and Birtle, 2011). It is speculative, but Rhabdocrinus may also be present in the Egglestone Marble.

Mississippian crinoids of Cumbria

"A short time was spent here [=Mississippian Melmerby Limestone] searching for corals and brachiopods" (Rodgers, 2010, pp. 421-422).
If I had been there, I feel sure the same rocks would have yielded some interesting fragments of crinoids. It is peculiar to recognise that the thick and extensive outcrops of Mississippian limestones that surround the Lake District are almost devoid of nominal crinoids except for one location. The quotation above fails to mention crinoids, but I am sure they were present, albeit preserved mainly as columnals and pluricolumnals, fragments that are unloved and ignored by most collectors (Donovan, 1991). Such fragments of stem can be locally common (Smith, 2010, fig. 112), but at best difficult to identify, whereas identifiable cups and crowns are rare.

Ausich and Kammer (2006, appendix B) published a comprehensive table of Mississippian crinoid sites in England and Wales, and only one locality was in Cumbria, in the Tournaisian (lower Chadian) of Kirkby Lonsdale [approximate NGR SD 608 788]. Six genera were listed, including nine species: Actinocrinites triacontadactylus Miller; Amphoracrinus gilbertsoni (Phillips); Amphoracrinus portlocki Wright; Dichocrinus elongatus (Phillips); Pleurocrinus mucronatus (Austin and Austin); Pleurocrinus pileatus (Goldfuss); Cyathocrinites mammillaris (Phillips); Cyathocrinites planus Miller; and Bollandocrinus conicus (Phillips). Illustrations of these species may be found in Wright (1950-1960). Such an assemblage is similar to that of coeval crinoids of, for example, the Clitheroe area of Lancashire (Donovan *et al.*, 2003; Donovan and Lewis, 2011), although the latter is more diverse.

What are we to make of this dearth of described crinoids from the Lower Carboniferous of Cumbria? That it is an artifact is undoubted and mainly derives from two influences separated by 300 million years. Crinoids were locally common in the Cumbrian region during the Mississippian. They are abundantly preserved in limestones and shales of this age surrounding the

Lake District, but they almost invariably occur as disarticulated remains, principally columnals and pluricolumnals. The first influence is therefore taphonomic; crinoids are common Mississippian fossils in Cumbria, but they are very incomplete and dominated by fragments of stem.

The second influence is modern and relates to our methodology of classification. Crinoids, particularly Palaeozoic crinoids, are described and classified mainly on the features of the crown, that is, the cup and arms. These are rare fossils compared with fragments of stem. This is because in most species the stem is much longer and columnals are consequently more abundant than plates of the cup, and are larger and more likely to be preserved partially articulated than the plates of the arms, called brachials. Well preserved crowns are the product of exceptional conditions such as rapid burial of living specimens. It is possible for an expert to classify some disarticulated plates of the stem and crown (a good recent example is Webster *et al*, 2011), but such expertise is not widespread. Further, most collectors are discouraged by common, anonymous crinoid fragments; other common invertebrates are more attractive because they are more easily identifiable.

Despite these problems, the crinoid remains are still there. I suspect that further identifiable remains – cups, crowns, perhaps even complete specimens – may lurk in private collections. If they are to be found in your collection, then the Proceedings would be an obvious place to advertise their occurrence in Cumbria.

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Stephen K. Donovan,
[redacted] [redacted]

HOW DO TOPOGRAPHY AND AVAILABILITY OF TILL INFLUENCE DRUMLINS EAST OF KENDAL, CUMBRIA?

Arthur Robinson

Introduction: Literature review.

Drumlins are common landforms created subglacially and composed of glacial drift or till. They vary in length from 50m to over 1000m (Clark *et al* 2009). The classic shape is an egg-shaped hill with a steep, blunt, stoss end facing up-glacier and a long, gentle, pointed lee slope facing down-glacier, the long axis being orientated in the direction of glacier flow. Thus, the summit is nearer the stoss end than the lee so there is longitudinal asymmetry. Its lateral position relative to the width of the drumlin has not been discussed; presumably, it has been assumed that there is lateral symmetry. Overall shape has also often been described by the elongation ratio whose value tends to be between two and three (Menzies 1979) but they vary from spindle shaped forms to almost circular hills (Shaw *et al* 1989, and Knight and McCabe 1997). Drumlins exist in swarms or fields consisting of many individuals with similar orientations.

Many quantitative studies have now questioned this simple view of drumlin morphology but none seems to have been carried out in the Lake District although data has been collected from the area for larger scale, including national, studies. These have used remotely sensed data which is appropriate at ice sheet and regional scales. It has enabled studies of variations in non-dimensional properties such as elongation ratio and asymmetry (Hess and Briner 2009) and spatial properties such as drumlin density and pattern (Mitchell 1994). It has also provided information about the size and shape of whole populations of drumlins such as 37,043 in Britain and 21,940 in Ireland (Clark *et al* 2009, and Spagnolo et al 2010). They have shown that morphometric properties change with different ice flows and even in relation to distance from the ice margin as glacial driving stress decreases towards it, resulting in smaller and more packed drumlins (Knight 2010). Variations in drumlin density have also been linked to systematic instability of the over-lying ice sheet and its self-organisation (Mazo 1991).

It is thought that one of the most important processes by which sediments are moved subglacially and contribute to the development of bedforms is that basal sediments can be deformed by the stress of overlying ice (Hart and Boulton 1991) and is then moved towards the emerging drumlin. An important control on subglacial processes is the basal thermal and hydro-logical regime. Basal ice above the pressure melting point can maintain high water pressure at the base of the glacier, thus maintaining ice velocity, and high water content in the sediment, promoting its deformability (Boulton *et al* 2001). Variations in the regime produce variations in sediment deformability and may determine the locations and rates at which subglacial sediments can be accreted into drumlins (Piotrowski *et al* 2004).

There has been surprisingly little research into the influence of subglacial lithology on bedform characteristics. Phillips *et al* (2010) showed that large faults and major lithological boundaries in Anglesey, north-west Wales, and the Rhins of Galloway, south-west Scotland, are important indirect controls on bedform morphology because less durable bedrock lithologies, being more easily eroded, control the location and lateral extent of faster flowing portions of the ice sheet. The effect of scale on the importance of substrate lithology was explored by Greenwood and Clark (2010). They found no relationship at the ice sheet scale between lithology of either bedrock or till substrate and bedform occurrence, size and packing. At regional to local scales there is often an abrupt shortening or lengthening of drumlins at lithological boundaries, but lithology is only a contributory factor combining with or being subordinate to topographic setting and/or ice dynamics. They proposed, therefore, that there is a hierarchy of controls with ice dynamics being dominant at ice sheet scale and lithological properties only modifying bedform distribution and morphology under certain unknown conditions at a local scale.

As drumlins are formed by glaciers, their nature indicates glaciological properties, especially ice velocity and direction of flow (Stokes and Clark 2002). There are marked differences in the morphology of bedforms beneath ice streams and elsewhere under an ice sheet (King *et al* 2007), as well as along the length of ice streams. There are patches of high-strength and low-strength sediment (Knight 2002) which lead to stick-slip behaviour in the overlying ice. Strain accumulates over the high-strength areas during the stick phase and is then released by fast ice flow during the slip phase. Variations in the hardness or permeability of the sediment, meltwater availability or drainage, or the presence of bedrock can all lead to stick-slip behaviour. Such self-organisation of glacier flow determines where and when ice streaming and surging occur (Payne and Dongelmans 1997) and this affects the longitudinal shear stress and thus the amount of subglacial sediment transported to sites of drumlin formation (Fowler 2000). These conclusions have led to the first numerical modelling of how ice sheets create bedforms, in this case ribbed (rogen) moraine (Dunlop *et al* 2008). Their Bed Ribbing Instability Explanation (BRIE) proposes that these ridges, which are transverse to the direction of ice flow, grow spontaneously due to instability in the coupled flow of ice and till, and it predicts their wavelength (spacing between ridges).

Aims of the study

Although drumlin fields surround the mountainous core of the Lake District no modern morphometric studies have been published about them. Research has also concentrated on data that is easy to collect. Maps and remote sensing provide information on spatial parameters but very little has been done using the heights of drumlins. This is probably for reasons such as the fact that drumlins are relatively small and common so Ordnance Survey maps have spot heights on only some of them and it has been difficult to measure the altitudes of the rest. This means that characteristics of drumlins linked to height have not often been explored fully; they include their relief and volume, and no studies have referred to their height in relation to width. Longitudinal symmetry has been calculated from the shape of the base rather than the position of the summit so inferences have not been made about the three-dimensional nature of drumlins, a requirement for satisfactory understanding of their origin. This study employs a larger number of morphometric parameters than has been given in published reports.

Research has often explained how topography affects the direction of ice flow and thus the orientation of drumlins. Because it is such an important modifier of ice dynamics, it is necessary to analyse whether it has created different populations in terms of their morphology and other characteristics such as orientation and location if further quantitative analysis of them is to be carried out.

There have been few analyses of the influence of substrate lithology. Solid geology has been studied because characteristics are readily found on maps. Analyses have used the presence or absence of till but its thickness is very difficult to measure without geophysical techniques because it usually blankets the land surface. This was not the case in the study area where rock outcrops are fairly frequent amid the till cover and so present a rare opportunity to explore the influence of the current thickness of till on drumlin morphology.

The aims of the study can be summarised as:

1. To explore whether the drumlins in the study area are typical of British drumlins and to analyse whether the classic view of drumlin morphology is correct.
2. To analyse the effects of topography on drumlin characteristics
3. To analyse the influence of the availability of till for drumlin formation
4. To present a model for drumlin formation and to suggest ideas for further research.

Study area

The study area is the upper part of the River Bela drainage basin east of Kendal in Cumbria, an area of about $73Km^2$. The boundary is along the Hay Fell-The Helm ridge in the west (Figure 1), the Hay Fell-Firbank Fell divide in the north and Firbank Fell-Scout Hill watershed in the east. The southern boundary was taken arbitrarily along the A590 road. There are two large tributaries occupying the main valley, Saint Sunday's Beck and Peasey Beck separated by a low ridge around Summerlands. The upper part of Peasey Beck is east of the prominent Roan Edge-Scout Hill ridge and then crosses it to join the main valley. The relief reflects the geological structure as the valley has been eroded along NNE-SSW faults but the area has uniform lithology being fine-grained micaceous sandstones of the Silurian Kirkby Moor Formation except for a small area of Carboniferous Limestone in the south-west corner (Stone 2006). Solid rock lithology is not, therefore, a factor affecting drumlin morphology here.

Methods

Planar morphometric parameters

The locations of drumlin boundaries and their summits were recorded during fieldwork at a scale of 1:25,000, the use of field boundaries permitting an accuracy of about 25m (1mm on the map). The location of the summit was used as the measure of drumlin location. Length (L), width (W) and orientation (of the long axis from Grid North) were measured from the map and derived parameters calculated. These were:

1. Elongation ratio (L/W) where L is the longest axis and W is the longest axis perpendicular to it.
2. Planar longitudinal symmetry is a measure of basal symmetry used by Spagnolo *et al* (2010). It is the length of the long axis from the up-glacier end (ice flow was from the north) to the crossing of the width axis divided by L.
3. Planar lateral symmetry is the similar measure along the width axis with distance from the right-hand end (facing in the direction of ice flow) to the intersection of the axes divided by W.
4. Summit longitudinal symmetry is the length of the long axis from the up-glacier end to the summit divided by L.
5. Summit lateral symmetry is the similar measure along the width axis using the distance from the right-hand end to the summit divided by W.

The last three parameters have not been used in other studies.

Height-related parameters

Of the 157 drumlins, 62 have spot heights marked on Ordnance Survey maps at their summits. Others were found using Google Earth and their accuracy assessed by comparing the 62 spot heights with Google Earth values for the same summits. With 95% confidence, the 95 altitudes had an accuracy of ±5.1m.
The altitude of the base of the drumlin was found by extending a line through the summit parallel to the width axis and averaging the altitudes where it intersected the drumlin boundary. Drumlin height could then be calculated.

Figure 1 – Topography of the study area

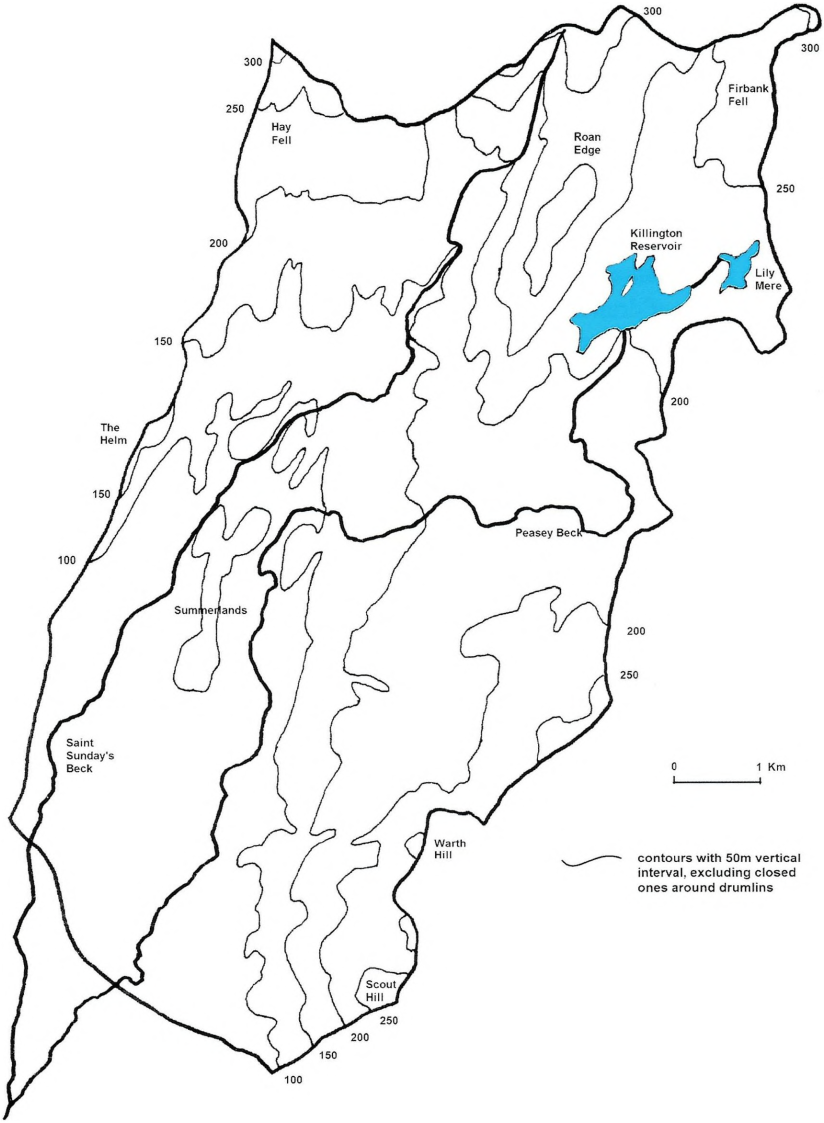


Figure 2 – Depositional and erosional features

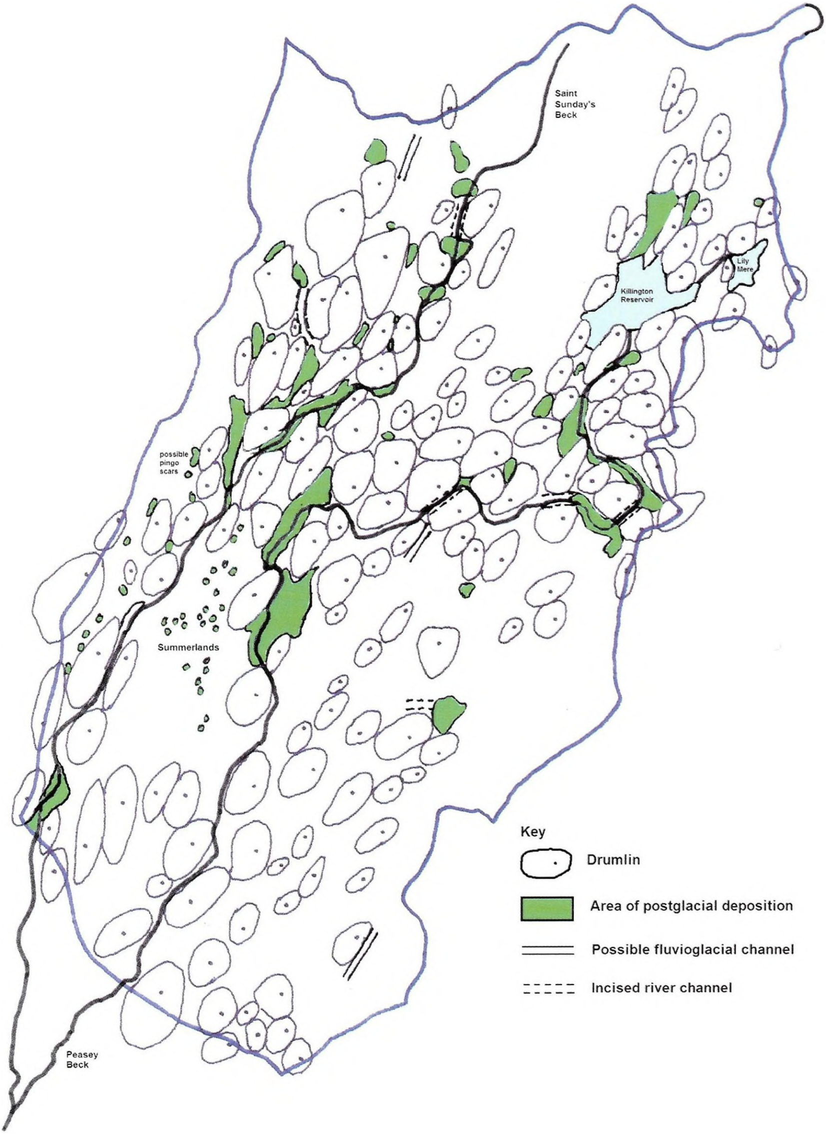
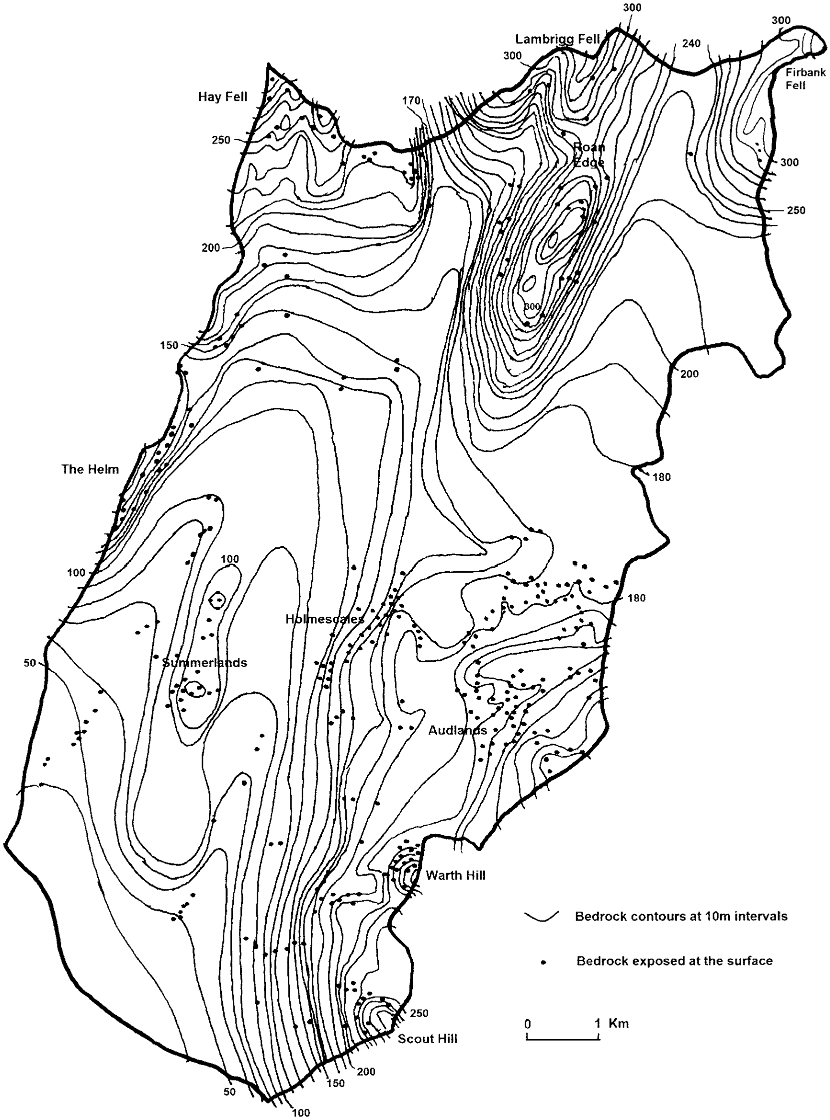


Figure 3 – Rock outcrops and the interpolated bedrock surface



Peakedness is the ratio of drumlin height to width. It is the equivalent in the vertical dimension of the elongation ratio in the horizontal. It has not been used in other studies.

Drumlin volume was calculated by measuring the area enclosed by each contour within the drumlin by counting squares of 2mm-by-2mm on the Ordnance Survey map and multiplied by the vertical interval of 10m. Where the drumlin base was not along a contour, the area of the base was also measured and multiplied by 5m. The part above the highest contour was calculated as the volume of a cone using the area enclosed by the highest contour and knowledge of the height of the summit above it. The accuracy of the resulting total drumlin volume cannot be assessed. It is primary data and was felt to be a more reliable method than assuming a regular shape such as an ellipsoid and calculating volume from length, width and height.

Post-depositional modification of drumlins could affect their characteristics. All areas of deposition and erosion were mapped in the field (Figure 2). Many temporary lakes formed where drumlins dammed rivers and deposition in them reduced the height and extent of drumlins. Erosion of the lake outlets formed narrow valleys between drumlins. There are also three channels with cross-sections similar to railway-cuttings that are typical of subglacial meltwater channels. They do not contain streams and are parallel in the direction of regional ice sheet flow. Small areas of deposition have also occurred in eroded hollows in rock around Summerlands. It is concluded that all these features cover only a small part of the study area and have had little effect on drumlin characteristics.

Availability of till, and topography

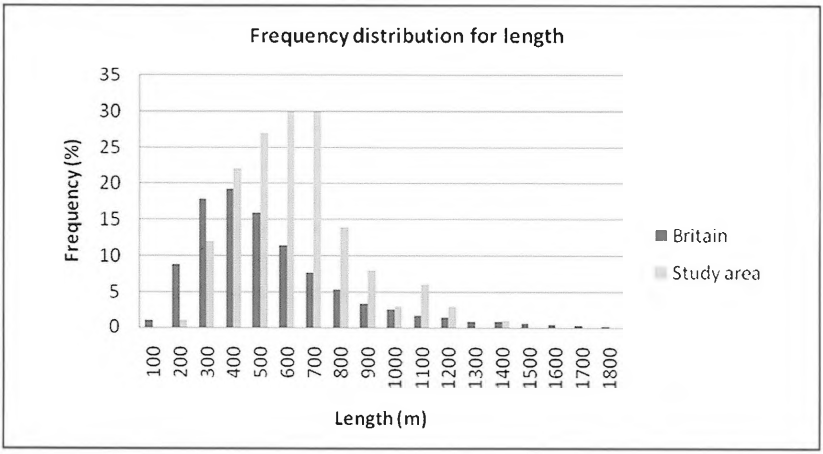
The thickness of till in areas between drumlins has not been used previously as an indicator of the availability of till for drumlin formation. As it may vary spatially, the thickness preserved under the base of drumlins is a more appropriate measure. Rock outcrops were located by fieldwork. Many are on the ridges. They are also in lowland fields and where rivers have eroded through the overlying till. Drumlins and till areas are smooth but where there is no till the ground is distinctively irregular. This information allowed bedrock contours to be drawn by interpolation (Figure 3). The high density of outcrops suggests that most contours are accurately placed to within 5m vertically but the greatest inaccuracy is likely to be around Killington Lake where no outcrops were found. The map then allowed the thickness of till underneath drumlins to be calculated:

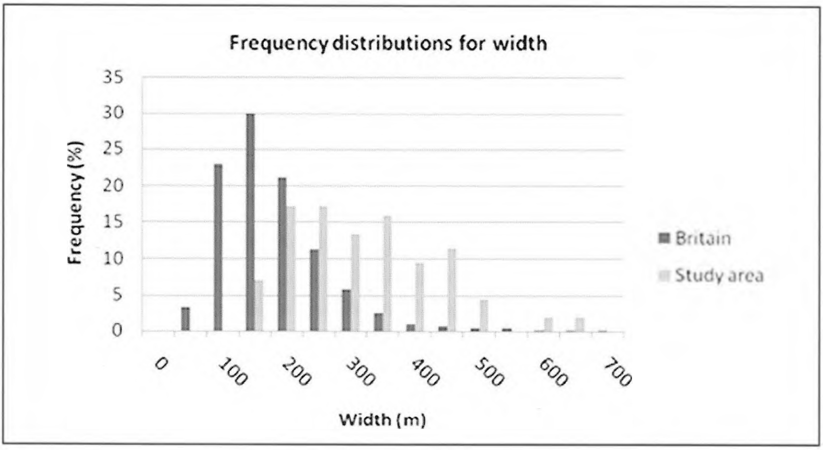
Thickness of till = summit altitude – drumlin height – altitude of bedrock surface

While thickness of till could be an indicator of till available for movement to a site for drumlin formation, the volume of a drumlin shows how much was received. The two parameters are different aspects of the availability of till.

Topography also has two aspects: altitude of the drumlin base under the summit and relief. Calculation of the former has been described above and the latter information, the presence of valleys and uplands, was taken from Ordnance Survey maps.

Figure 4 – Length and width characteristics of drumlins in Britain and the study area



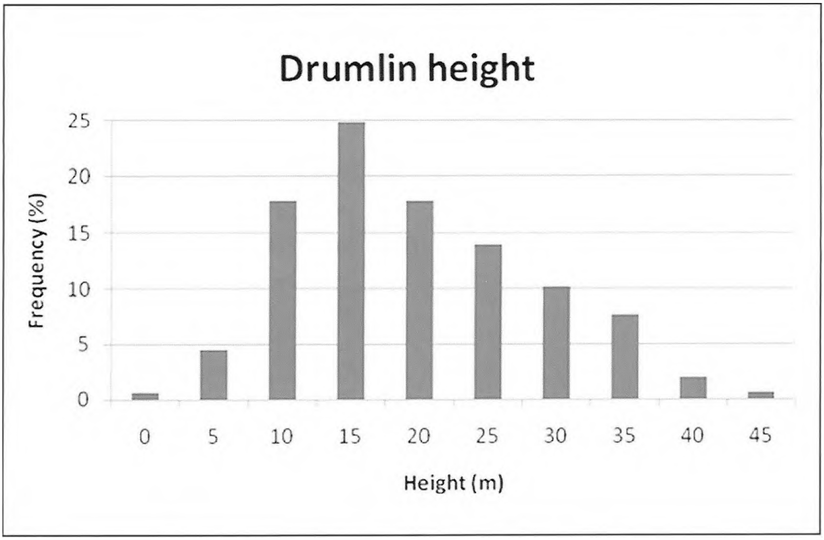


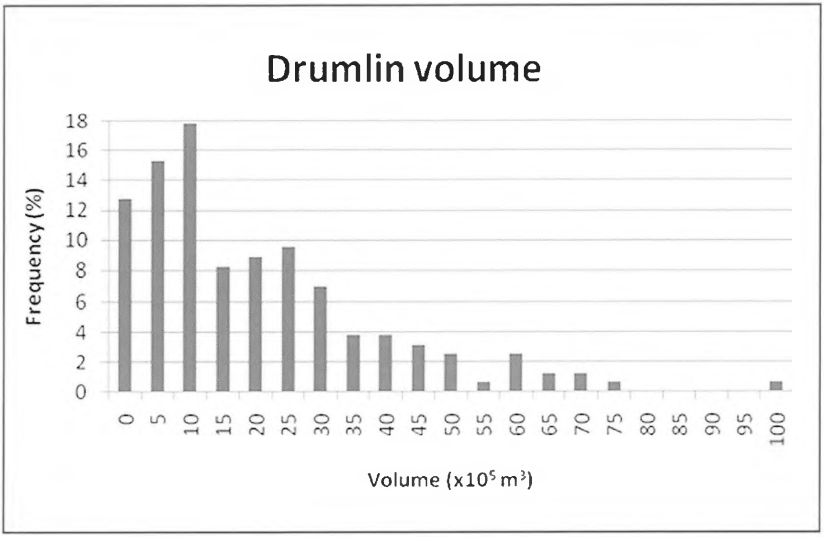
Summary statistics:

		Britain	Study area
Length	mean	601	660
	median	510	625
	standard deviation	359	219
Width	mean	209	334
	median	192	325
	standard deviation	86	115

Data for Britain is from Clark et al (2009)

Figure 5 – Height and volume characteristics of drumlins in the area





Summary statistics:

	Mean	Standard deviation	Median
Height (m)	21.5	8.7	20.0
Volume (m^3)	2.3 $x10^6$	1.85 $x10^6$	1.86 $x10^6$

Statistical techniques

Many of the frequency distributions of parameters in the study are skewed so the assumptions of parametric tests cannot be satisfied. Consequently, non-parametric techniques (Siegel 1956) have been used throughout.

Analysis and discussion

Characteristics of drumlins in the whole study area

Size characteristics are summarised in Figures 4 and 5; they have been presented as histograms so that workers in other areas can make comparisons. Drumlins in the study area are 23% longer (at 625m judged from medians) and 69% wider (at 325m) than in Britain as a whole, suggesting more sediment was available for their formation. No British figures exist for height and volume; in the study area their medians are 20.0m for height and 1.86 x 10^6m^3 for volume. All frequency distributions are positively skewed showing that some drumlins were able to grow much larger than normal.

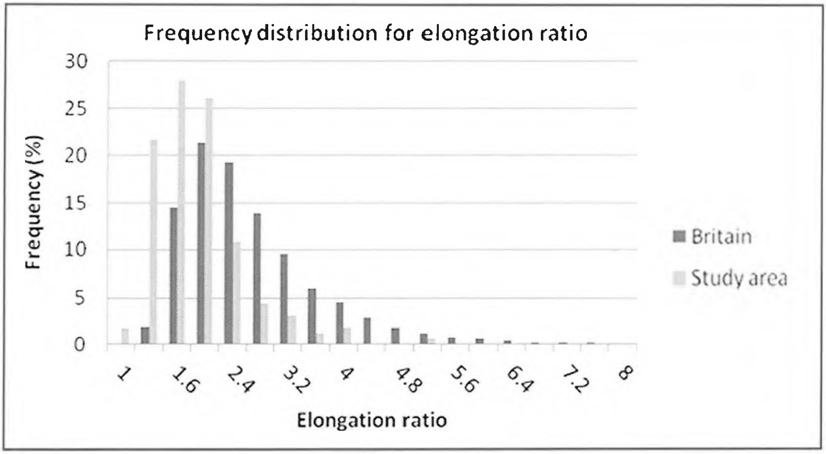
Shape characteristics show that elongation (Figure 6) is 28% smaller (at 1.9) than in Britain implying that ice flow was slower. Planar longitudinal symmetry was almost the same (0.46) in the two populations. The two measures of longitudinal symmetry yield distributions (Figure 7) that are not significantly different ($p>0.05$ with the Mann-Whitney test). They both show that the classic view of this parameter is incorrect; most drumlins are longitudinally symmetric. Similar results exist for lateral symmetry (Figure 8), the two measures of it producing distributions that are not significantly different ($p>0.05$) and most drumlins are symmetrical about the long axis. Most drumlins are also low compared with their width (mean peakedness ratio of 0.065) (Figure 7).

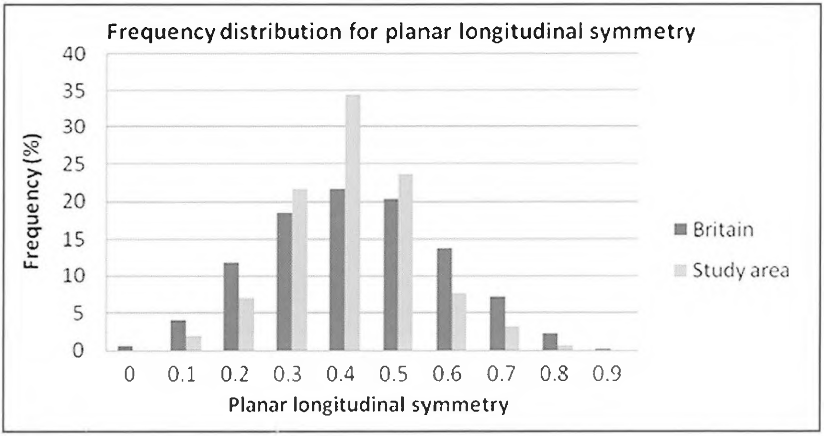
There is only a little variation in the orientation of drumlin long axes (Figure 9) with the mean bearing being 213.8°, the regional direction of ice flow. This is confirmed by numerous Shap Granite erratics, as at The Helm (SD 5290 8863). Drumlins occur at all heights in the drainage basin, being especially common at about 100mOD, the floor of the main valley, and about 180m in the upper Peasey Beck valley. One third of drumlins have almost no till under their bases but it varies up to 26m.

The effects of topography on drumlin characteristics

When analysing the whole study area as one dataset of drumlins there is an assumption that it is one population. Beneath the till cover (Figure 3), the western half of the study area is a glacial trough with a 3km wide flat floor and steep sides, especially on the east. At its northern end there is a deep 1km wide trough, perhaps a glacial spillway eroded by transfluent ice from the

Figure 6 – Elongation and planar longitudinal ratios of drumlins in Britain and the study area



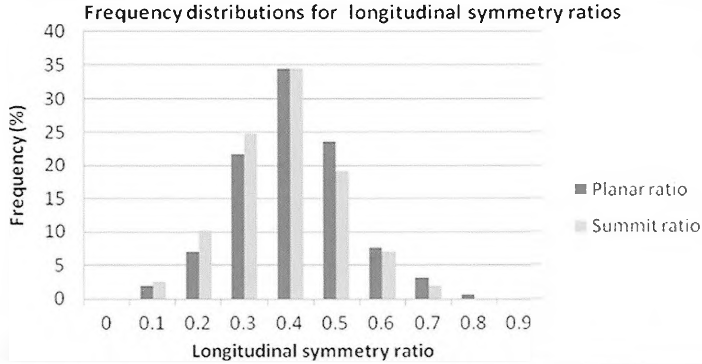


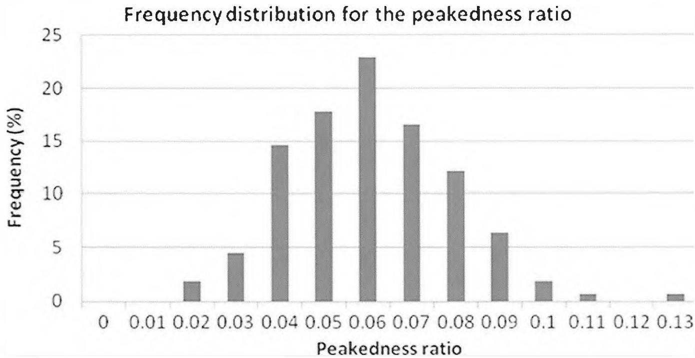
Summary statistics:

		Britain	Study area
Elongation ratio	mean	2.9	2.1
	median	2.6	1.9
	standard deviation	1.2	0.7
Planar longitudinal symmetry	mean	0.47	0.46
	standard deviation	0.17	0.12

British data for elongation ratio from Clark et al (2009) and for planar longitudinal symmetry from Spagnolo et al (2010)

Figure 7 – Longitudinal symmetry and peakedness ratios in the study area





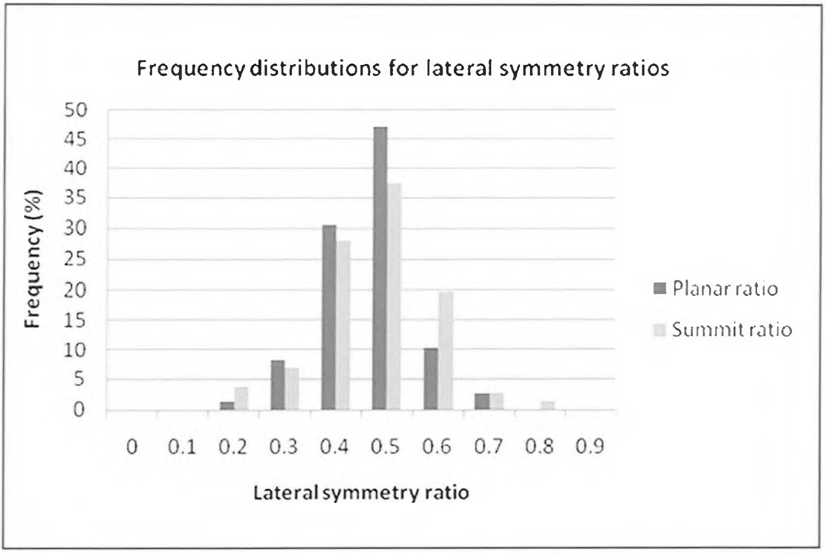
Summary statistics:

	Mean	Standard deviation
Planar longitudinal symmetry ratio	0.46	0.12
Summit longitudinal symmetry ratio	0.43	0.12
Peakedness ratio	0.065	0.018

Frequency (%) of shapes in the study area and Britain (from Spagnolo et al 2010):

Longitudinal symmetry shapes	Numerical limits	Planar ratio	Summit ratio	Planar ratio in Britain
Classic	0.0 to 0.332	15	18	22
Symmetric	0.333 to 0.666	79	77	64
Reversed	0.667 to 1.000	6	5	14

Figure 8 – Lateral symmetry in the study area



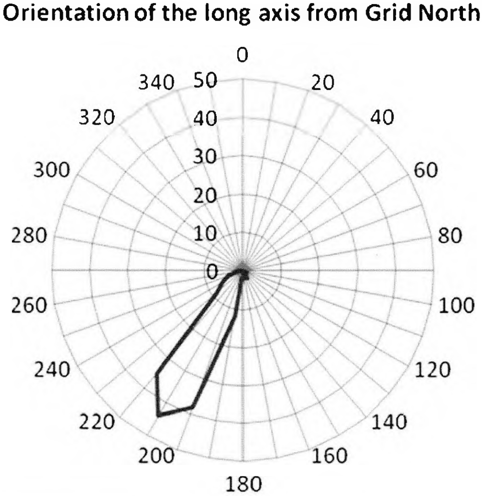
Summary statistics:

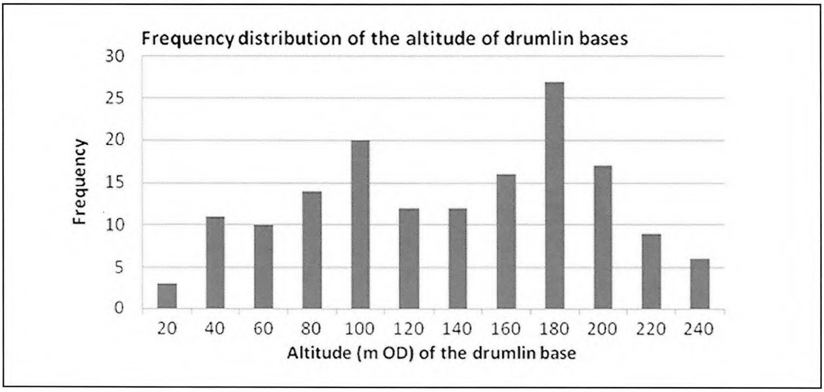
	Mean	Standard deviation
Planar lateral symmetry ratio	0.503	0.513
Summit lateral symmetry ratio	0.091	0.108

Frequency (%) of shapes:

	Numerical limits	Planar ratio	Summit ratio
Steep on the right	0.0 to 0.332	2	5
Symmetric	0.333 to 0.666	92	88
Steep on the left	0.667 to 1.0	6	7

Figure 9 – Orientation and altitude of the drumlins and thickness of till under them.





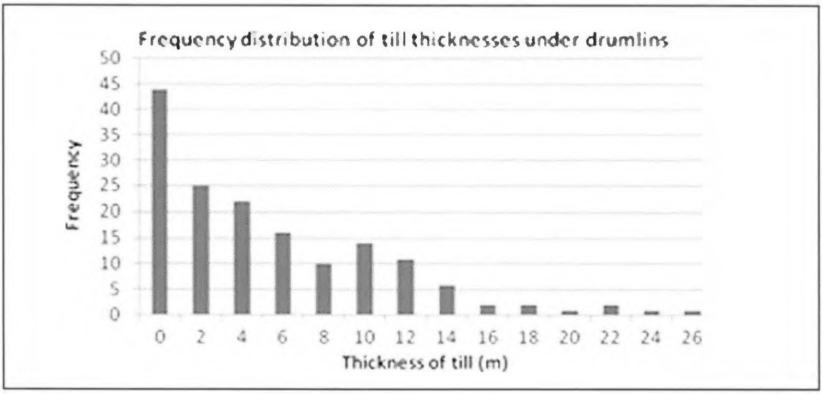


Figure 10 – Sub-areas in the drainage basin

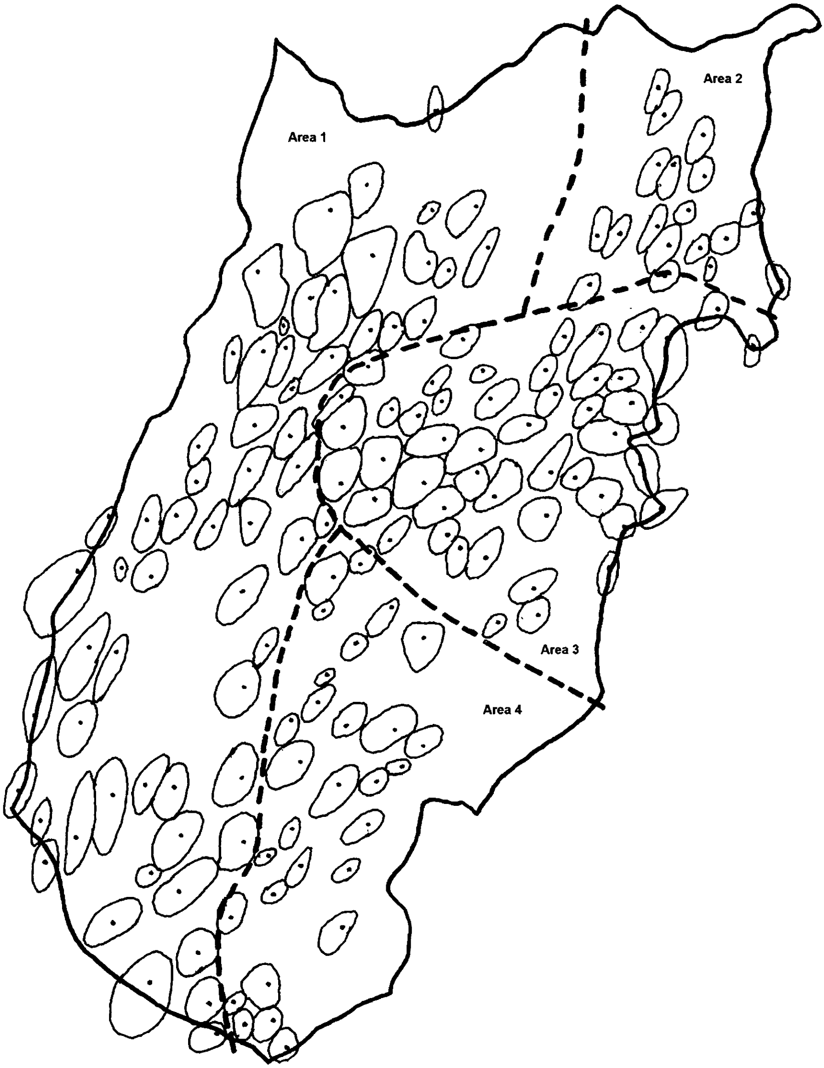


Figure 11 – Significance of differances between characteristics in the four sub-areas

* The significance of differences was assessed by the Kruskal-Wallis one-way analysis of variance

		Area 1		Area2		Area 3		Area 4		Significant differences at p=0.05*
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	
Size	**Length (m)**	779	255.4	542	115.4	620	150.8	547	156.8	✓
	Width (m)	359	127.6	256	55.7	353	105.0	296	100.7	✓
	Height (m)	24.3	10.0	17.1	5.9	21.4	6.6	18.2	8.4	✓
	Volume ($x10^6m^3$)	3.128	2.239	0.998	0.685	2.121	1.386	1.627	1.279	✓
Shape	**Elongation ratio**	2.289	0.792	2.194	0.635	1.852	0.529	1.933	0.472	✓
	Peakedness ratio	0.068	0.020	0.067	0.017	0.062	0.017	0.062	0.017	
	Longitudinal symmetry(S)	0.413	0.113	0.472	0.138	0.453	0.111	0.424	0.127	
	Lateral symmetry(S)	0.499	0.105	0.466	0.110	0.520	0.113	0.556	0.094	✓
	Longitudinal symmetry(P)	0.457	0.119	0.464	0.142	0.455	0.125	0.448	0.109	
	Lateral symmetry(P)	0.507	0.097	0.474	0.058	0.498	0.089	0.518	0.094	
Orientation		207	11.1	207	14.8	221	24.6	220	15.3	✓
Altitude of drumlin base (m OD)		101		228		176		143		

River Mint valley, but it is now partly filled by a drumlin at Birks. Another glacial trough is to the east of Roan Edge, perhaps another glacial spillway, and joins the broad col from the Lune valley east of the study area which hangs 40m over the floor of the main glacial trough in the west as it enters it. Relief is a major influence on ice flow direction and dynamics so if the drainage basin contains different drumlin populations, relationships are obscured. Thus, it is necessary to divide it into smaller areas of similar relief.

Four sub-areas were recognised (Figure 10):

Area 1 The main valley floor in the west (61 drumlins)

Area 2 The upper Peasey Beck valley east of Roan Edge. Although it has the same orientation as area 1 it cannot be assumed that the drumlins in it are part of the same population. (17 drumlins)

Area 3 The gap through the eastern watershed and the Roan Edge/Scout Hill ridge. The western boundary was taken to be the 100m contour. (50 drumlins)

Area 4 The eastern valley side extending down to 100m which forms the south-eastern quarter of the drainage basin. (29 drumlins)

There are significant differences (Figure 11) between the sub-areas in several respects which show that relief is very important. Drumlins in area 1 have the same orientation (207°N) as area 2 (Figure 12) and their shapes are similar but in all aspects of size they are significantly larger. The ice flowed from the same direction and elongation shows that it was at the same speed in both areas but more till was deposited in area 1. It might have been due to its 127m lower altitude. Thicker ice might have caused more pressure melting, releasing more till from the overlying ice. The same explanation might account for drumlins in area 1 being larger in volume than in areas 3 and 4. Here the lower elongation ratios show that the ice was also flowing slower so it is likely that less till was brought to the sites of drumlin formation.

Areas 3 and 4 are similar in some respects. Their orientation of 220°N shows that the ice flowed more from the east than in areas 1 and 2. This might have been due to diffluent ice flowing westwards from the neighbouring Lune valley ice stream over the broad col lying between Firbank Fell and Warth Hill. Drumlins in areas 3 and 4 do not differ in shape and not quite in volume but tests on their three dimensions show that those in area 3 are longer, wider and higher. Ice would flow directly to this area from the col but area 4 is on the lee side of the high Warth Hill/Scout Hill ridge restricting the flow of ice and till towards sites of drumlin formation.

Figure 12 – The significance of pairwise differences between the four sub-areas

The table shows z values for U in the Mann-Whitney U test.
The critical value of z for p=0.05 is 1.96

** indicates that the difference is significant at p=0.05

		Areas 1 v 2	Areas 1 v 3	Areas 1 v 4	Areas 2 v 3	Areas 2 v 4	Areas 3 v 4
Size	**Length (m)**	3.758**	3.633**	4.213**	1.707	0.102	2.044**
	Width (m)	3.183**	0.151	2.193**	3.364**	1.195	2.253**
	Height (m)	2.784**	1.713	2.702**	2.385**	0.159	2.426**
	Volume (m^3)	3.946**	2.128**	3.216**	3.667**	1.309	1.836
Shape	**Elongation ratio**	0.290	3.215**	2.102**	2.017**	-1.388	0.773
	Peakedness ratio	0.284	1.932	1.455	1.117	-0.717	0.239
	Longitudinal symmetry (S)	1.392	1.559	0.099	0.411	-1.309	1.241
	Lateral symmetry (S)	1.610	0.833	2.236**	2.183**	2.776**	1.495
	Longitudinal symmetry (P)	0.151	0.018	0.617	0.108	0.614	0.656
	Lateral symmetry (P)	1.313	0.498	-0.458	0.670	1.468	-0.946
Orientation (of long axis from Grid North)		0.702	5.198**	4.623**	3.588**	3.539**	0.946

Apart from the elongation ratio and summit lateral symmetry, it is evident that shape characteristics do not vary significantly between the four areas. Peakedness, summit longitudinal symmetry and the planar measures of symmetry are similar whatever the velocity and direction of ice flow. Summits tend to be displaced to the left of the long axis creating a steeper side there in areas 3 and 4 while in areas 1 and 2 drumlins are symmetrical about the long axis. In the last two areas, drumlin formation was subjected to the regional ice flow so one would expect symmetry but in areas 3 and 4 dominant ice flow from the Lune valley ice stream would be deflected to the left by the regional ice flow creating the observed asymmetry in the location of summits.

Except for those exposed postglacially in river channels, the distribution of rock outcrops indicates features of the ice's dynamics (Figure 3). The Helm, Hay Fell, Roan Edge, Warth Hill and Scout Hill are the highest parts of the study area and exposures of rock are common. This might be due to faster ice as high areas were above the wider lowland contact between the ice sheet and bedrock where friction was greatest. It might also be caused by the ice containing little till at these higher levels. This might also explain the number of exposures on the low ridge around Summerlands in the middle of the main valley. It does not explain the numerous outcrops to the east of Holmescales and Audlands. These are on the southern side of the gap through the Roan Edge/Scout Hill ridge. Perhaps the ice stream flowing along the 220°N bearing from the Lune valley was pushed southwards by the regional ice flowing along the 207°N bearing and into this valley side increasing pressure and erosion there. The group of rock outcrops at Holmescales is on the corner of the col and the main valley where ice flowing along the valley would impinge directly and would also squeeze ice flowing from the gap. However, a model of drumlin formation must explain how isolated drumlins were deposited on this rock surface while the northern half of the col is covered with till. They must have been formed by different ice dynamics after the phase of bedrock erosion and after any till layer extending from the northern half of the col had been removed. The problem is not confined to these two areas alone as rock outcrops can be found between many drumlins and it has been calculated that one-third have 1m or less of till under their bases.

The packing of drumlins varies. In some parts they are separated by postglacial deposition but these are few while in localities such as near Audlands they are scattered and surrounded by exposed bedrock. Around Summerlands, on the bedrock high in area 1, there are no drumlins but immediately to the south of it at Endmoor there is a group of large elongated drumlins which suggests that sediment being transported by the ice that could not be deposited on the low ridge was deposited as soon as the ice moved off it. In contrast, the middle east-west section of area 3 has densely packed drumlins which are more circular, perhaps due to the ice being slowed in its flow south-westwards as it met the ice stream flowing southwards through area 1.

Figure 13 – Correlations within area 1

		Altitude of drumlin base		Till thickness		Drumlin volume	
		r_s	r^2 (%)	r_s	r^2 (%)	r_s	r^2 (%)
Size	**Length**	-0.113		-0.0595		0.8149*	66.4
	Width	-0.188		0.0651		0.8428*	71.0
	Height	-0.228*	5.2	-0.0493		0.8162*	66.6
	Volume	-0.170		0.0912		-	
Shape	**Elongation ratio**	0.060		-0.1067		0.0393	
	Peakedness ratio	-0.177		-0.1023		0.2338*	5.4
	Longitudinal symmetry (S)	-0.228*	5.2	0.1510		-0.2138*	4.6
	Lateral symmetry (S)	-0.188		0.1178		0.0611	
	Longitudinal symmetry (P)	0.009		0.0376		0.1011	
	Lateral symmetry (P)	0.087		0.0531		0.2109	
Orientation		-0.079		-		-	

* Significant at p=0.05 using the one-tailed Spearman Rank Correlation test

The influence of topography and availability of till in one sub-area

As the study area has four populations of drumlins, it is necessary to analyse the influence of topography and availability of till in one sub-area where the factor of relief has been controlled. Area 1 was selected because it has the most drumlins (61).

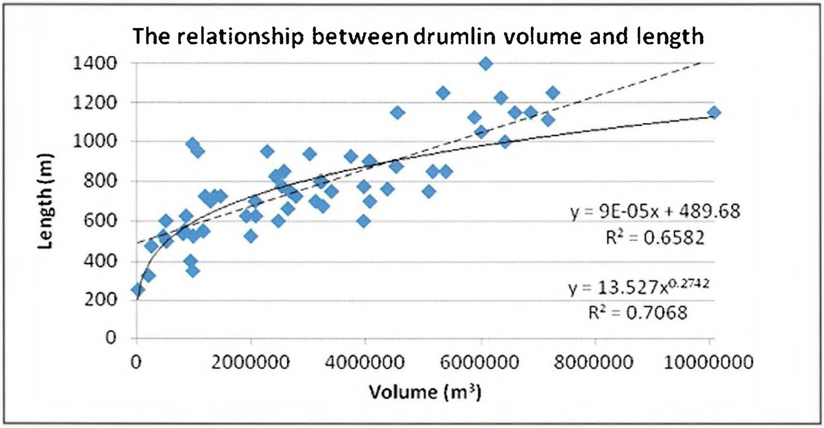
Drumlin bases in area 1 vary from 34 to 225m OD, but altitude has little correlation with their characteristics (Figure 13). Height increases at lower altitudes as does summit longitudinal symmetry but these are weak relationships accounting for only 5% of the variance.

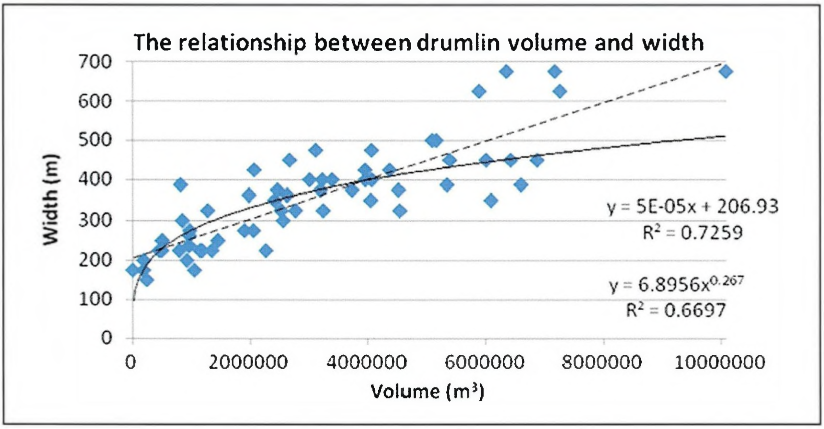
The depth of till under the base of drumlins in area 1 has no significant correlation with any drumlin characteristic, showing that it is an unimportant factor.

The amount of till received at the site (drumlin volume) is strongly positively correlated to the size characteristics, explaining more than 66% of the variation in them. The nature of the relationships (Figure 14) has been modelled with both linear and power functions, the R^2 value (explained variance) showing which is the stronger. [The linear values are slightly different from Figure 13 because the former uses rank correlation while the latter uses a parametric method]. As the volume of till increases, drumlins become wider in a linear relationship which suggests they continue to widen at the same rate. However, adding till increases length and height in a power relationship which means that they lengthen and grow higher quickly at first and then more and more slowly as volume further increases after about $2.0 \times 10^6 m^3$. This is the descriptive reason for the observation in studies elsewhere that drumlins tend to have a similar size and morphology characteristic of each drumlin field (Clark *et al* 2009). The explanatory reasons are probably that as height increases, the summit rises into ice which is faster as it is farther from the zone of friction at the base. Faster ice is less likely to deposit debris. Till not deposited on the sides or top is deposited at the down-glacier end making drumlins longer. However, the elongation ratio is not significantly correlated with the amount of till received; it is a function of the velocity of ice flow.

Relationships with other aspects of shape are fewer and weaker. Peakedness increases as a power function too (Figure 15); drumlins tend to become higher compared with their width until about 1.0×10^6 m^3 of till has been deposited and then peakedness increases very slowly, but little of the variance is explained by drumlin volume. In contrast, summit longitudinal symmetry decreases as volume increases. The smallest are symmetrical but quickly become more asymmetric until $0.5 \times 10^6 m^3$ of till has been deposited and the summit is nearer the stoss end but then there is little change. Such change must be linked to changing ice dynamics over the growing drumlin but their nature is not known. The increasing asymmetry supports the classic view of drumlin longitudinal shape but 75% of them remain symmetric. However, these conclusions do assume that higher till volume represents a time sequence; it might be that all the till is deposited at the same time.

Figure 14 – Relationships between volume and drumlin dimensions in area 1





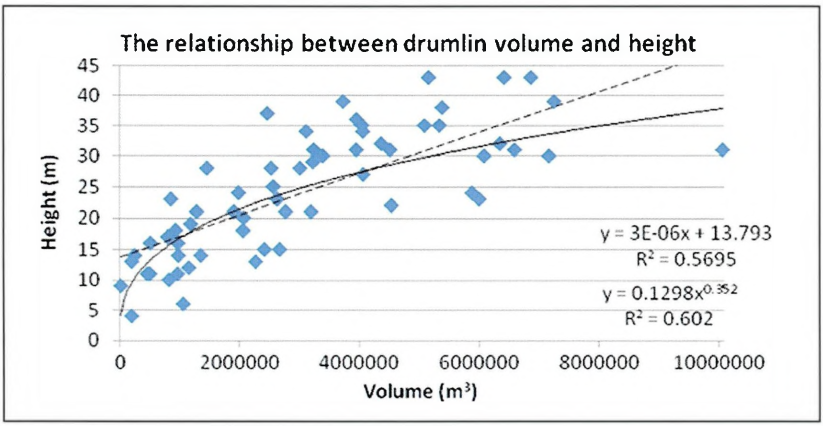
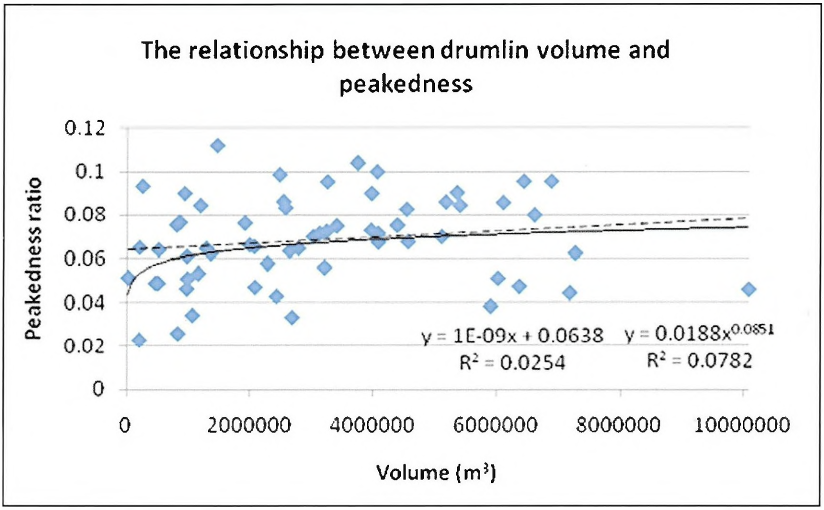


Figure 15 – The relationships between drumlin volume and shape in area 1



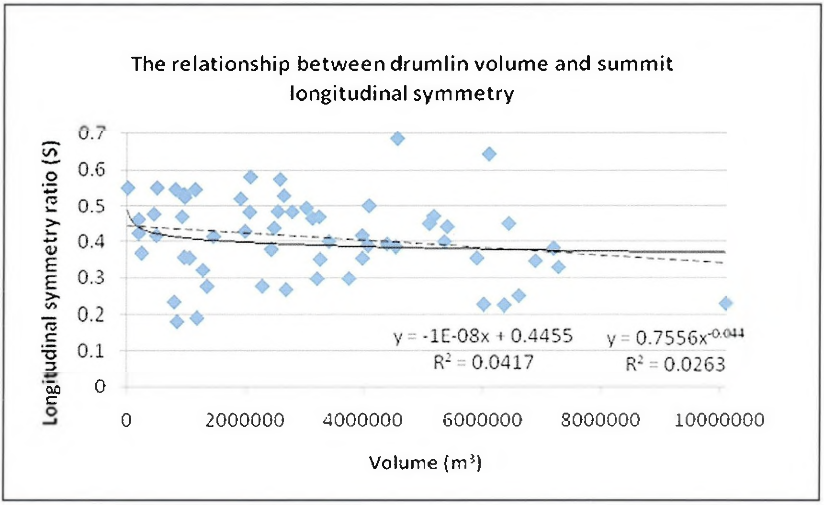
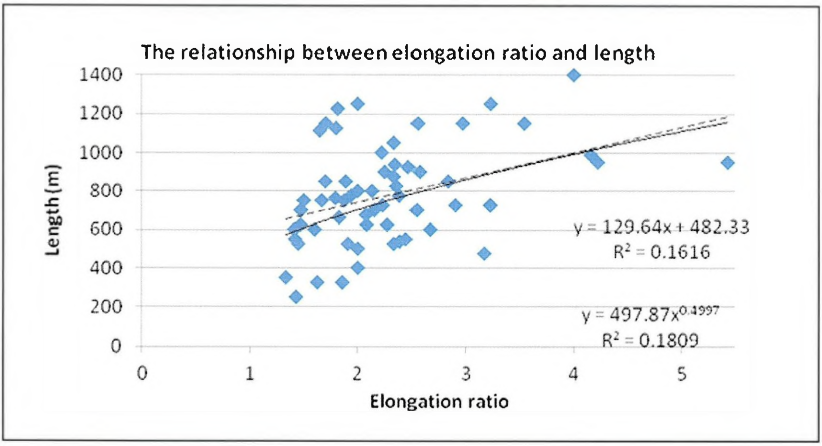


Figure 16 – Relationships with drumlin elongation in area 1

		r_s	r_s^2 (%)
Size	Length	0.3983*	15.9
	Width	-0.4400*	19.4
	Height	-0.1549	
	Volume	0.0394	
Shape	Peakedness ratio	0.2447*	6.0
	Longitudinal symmetry (S)	-0.1126	
	Lateral symmetry (S)	-0.3419*	11.7
	Longitudinal symmetry (P)	0.1187	
	Lateral symmetry (P)	-0.0483	

* Significant at 0.05 probability using a one-tailed Spearman Rank Correlation test



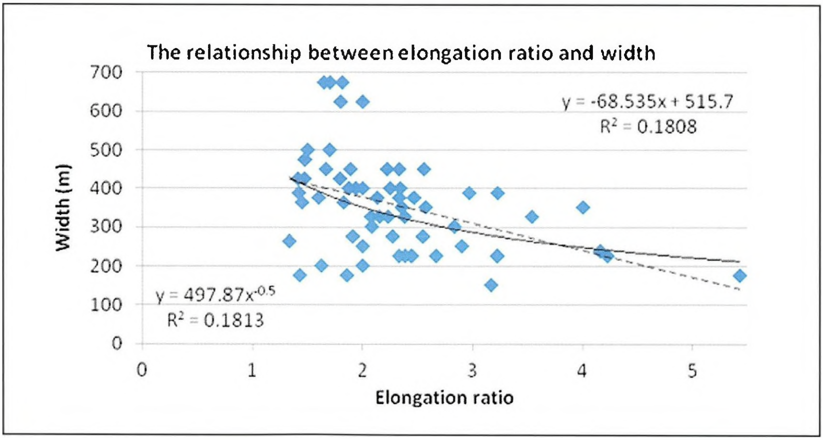
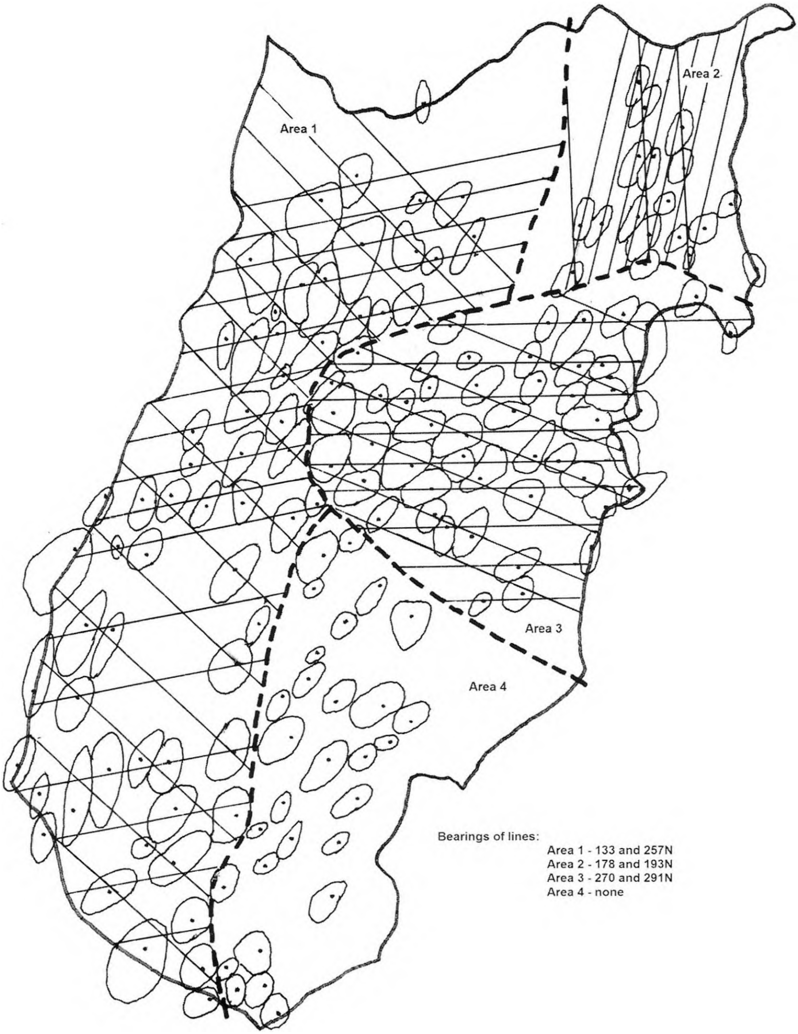


Figure 17 – Some lines of drumlin summits



The importance of ice dynamics can be analysed by assuming that the elongation ratio is proportional to the velocity of ice flow, an assumption made by other workers. Faster ice and more elongation are positively related to longer drumlins (Figure 16) but at the same time their width decreases. Perhaps some till is removed from the sides and redeposited at the down-glacier end. These changes cause drumlins to become slightly more peaked. Their summits become less symmetrical laterally but the reason for this is unknown.

The influence of topography and availability of till on drumlin distribution

Drumlin summits in several of the areas seem to be in lines but the human eye can see lines in random distributions of points, such as in the ley line controversy (Johnson 2009). An objective technique was used to identify the strongest lines in each area and to test whether they are statistically significant. Bearings of possible lines were analysed at 1° intervals around the compass. The positions of the summits were projected onto orthogonals to the lines. If lines of summits existed on a particular bearing, they were distributed in clusters along the orthogonal to it. The statistical significance of the distribution was tested using the linear nearest-neighbour statistic (LRn) (Pinder and Witherick 1975). It is not an ideal technique because of the problem of scale. Summits along a line would yield a cluster of points on a small part of the orthogonal which would produce a value between 0 and 1.0 for LRn. Random distributions of points yield values around 1.0. However, over the full length of the orthogonal many lines would produce a regular spacing of clusters of points and single points and LRn would lie between 1.0 and 2.0. The technique is sensitive to the length of the orthogonal. Use of the outermost points to define the length would have inflated LRn and use of the edges of each sub-area would have included localities where glacial erosion occurred and no till was deposited. Accordingly, the length of each orthogonal was measured between the absolute limits of the zone of drumlin deposition.

Two lines of summits were statistically significant ($p<0.05$) in each of areas 1 to 3 and none in area 4 (Figure 17). The values of LRn show that there is significant regularity along the orthogonals so summits cluster at regularly spaced points. In some parts the lines seem to be describing the en echelon packing of the drumlins and so, where the drumlins are close together as in the northern part of area 1, their spacing is likely to be a function of drumlin basal area. In other parts drumlins are separated by zones of bare rock or thin till and yet the summits lie along lines, implying that the lines are more to do with the ice depositing the drumlins than the drumlins themselves. The bearings of the lines and the angles between them are different in each area, perhaps due to the differing directions of ice flow and velocity.

An explanation of lines of parallel ribbed moraine has been proposed based on the notion of instability in the combined glacier/till system. It has been developed into a numerical model for ribbed moraine termed BRIE (Bed Ribbing Instability Explanation) (Dunlop *et al* 2008). It shows that the system can become unstable under commonly occurring glaciological and till conditions and positive feedback mechanisms then lead to rapid growth of the bedform as the flow of the combined till and ice increasingly changes from a laminar to a wave pattern. Instability can be triggered when there is initial relief of as little as 100mm with the result that ribbed moraine can grow in 100 years to wavelengths of 100-1000m while the growing bumps migrate down-glacier distances of 1-100m. The model assumes that the features grow from a uniform till cover, till from the troughs of the waves being moved forwards into the crests so that the resultant ribbed moraine is twice the thickness of the original till layer.

Ribbed moraine is formed transverse to the direction of ice flow. The lines of drumlins in area 1 are not simply modified ribbed moraine as their orientation and the ice flow direction is 207°N while the lines have bearings of 133°N and 257°N rather than 297-117°N. The lack of agreement can be resolved by considering the different topography under which ribbed moraine is formed. It is typically found in areas of low relief in Ireland, Scandinavia and Canada and the BRIE model assumes this condition as well. In contrast, the study area has three peaks along the northern watershed reaching 319m, 338m and 324m with deep valleys between whose bedrock floors are at 170m and 240m. Ice dynamics would have been changed by the peaks causing changes in the wave forms in the ice. Analogies can illustrate this idea. Just as a ship sailing through oncoming waves diverts them so that they become bow waves which form inverted "V" patterns from the bow, so moving ice impacting stationary mountains would form inverted "V" patterns in its internal waves and these would then form ribbed moraine at angles to the direction of ice flow. This model predicts that the angles would be the same on each side of the direction of flow but that assumes that the form of the gaps between the mountains is symmetrical; in the case of the gap between Hay Fell and Lambrigg Fell, the western slope is much gentler than the eastern which might have produced different angles in the "Vs" around Hay Fell and Lambrigg Fell.

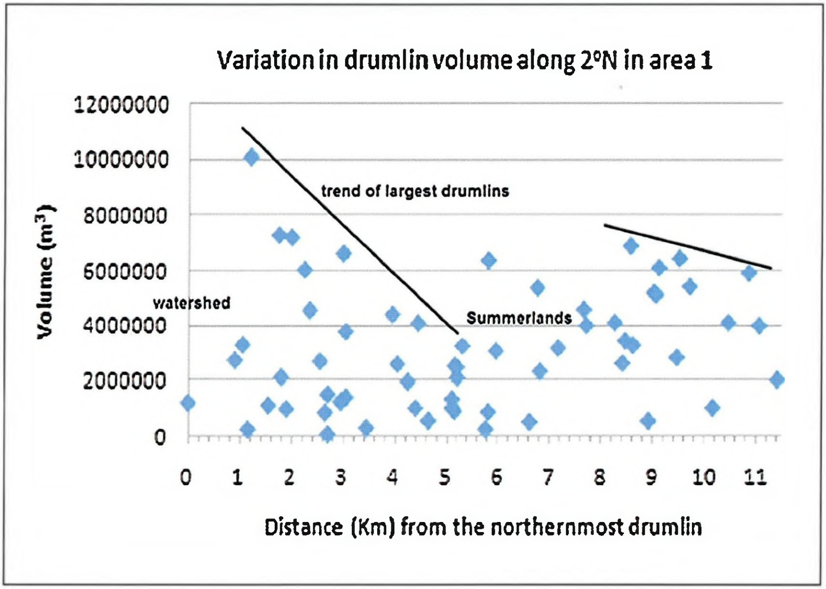
Some workers (Hindmarsh 1998 and 1999, and Fowler 2000) have extra-polated the BRIE model to explain drumlin formation but it was admitted in retrospect that this was based on two-dimensional vertical- plane flow in the direction of the main ice flow (Dunlop *et al* 2008). The problem with explaining drumlin formation as an extension of the model for the formation of ribbed moraine is that lateral forces are needed and their origin has been unclear. The idea proposed here overcomes this difficulty. When two ships pass, their bow waves cross and where the crest of one intersects the trough of the other they cancel out and a hollow forms in the water surface. Similarly, where both crests cross the combined crest results in a 'hill' of water. Such higher wave crests in the ice-till complex could be the sites of drumlin formation. Waves are also movements of energy. Energy from two directions would produce two converging forces which could sweep and deform till forwards into mounds. They would be in lines along the crests of both wave forms.

There is evidence in the study area both for and against this extended BRIE model:

1. The ice flowed through gaps of different sizes and shapes to reach areas 2 and 3 so lines of drumlins would be expected to be along different bearings. In the case of area 3, ice flowed through a broad gap in the eastern watershed and then the narrower one in the Roan Edge/Scout Hill ridge. Different lines of drumlin summits are apparent (Figure 17).

2. The model states that the till layer on the up-glacier side is moved to the site of deposition and Dunlop *et al* (2008) quoted field evidence of the till layer between ribbed moraines being thin or absent. This means that the ridge grows to a maximum height which is double the thickness of the till layer. This would not be the case for drumlins as till would be concentrated from the up-glacier area towards a point but there should be a broad relationship between the area of exposed up-glacier bedrock, or distance from the next up-glacier drumlin, and the volume of the drumlin. In area 1, the zone with no drumlins over the watershed in the north is followed immediately down-glacier by the largest drumlins (Figure 18). The volume decreases southwards and then there is a big increase in volume on the down-glacier side of the Summerlands bedrock high [drumlins in the Summerlands zone on Figure 18 are located at the sides of the low ridge]. This evidence for the idea is opposed by the fact that there is no uniformity of drumlin volumes along the lines although it could be suggested that these are caused by harmonics of the larger energy wave. They could also be due to local variations in initial relief or other local factors. The model also assumes that all ribbed moraines in an area (and thus drumlins by extension) are deposited at the same time; energy conditions in the ice sheet might have varied through time resulting in different sizes of drumlin being deposited, the idea of a palimpsest landscape. Waves might have existed within unstable ice alone while flowing over a bedrock surface forming zones of higher and lower pressure. Sediment within the ice would then be released at the sites of drumlin formation if the higher pressures caused pressure melting.

Figure 18 – Trends in the size of the largest drumlins down-glacier of exposed bedrock areas



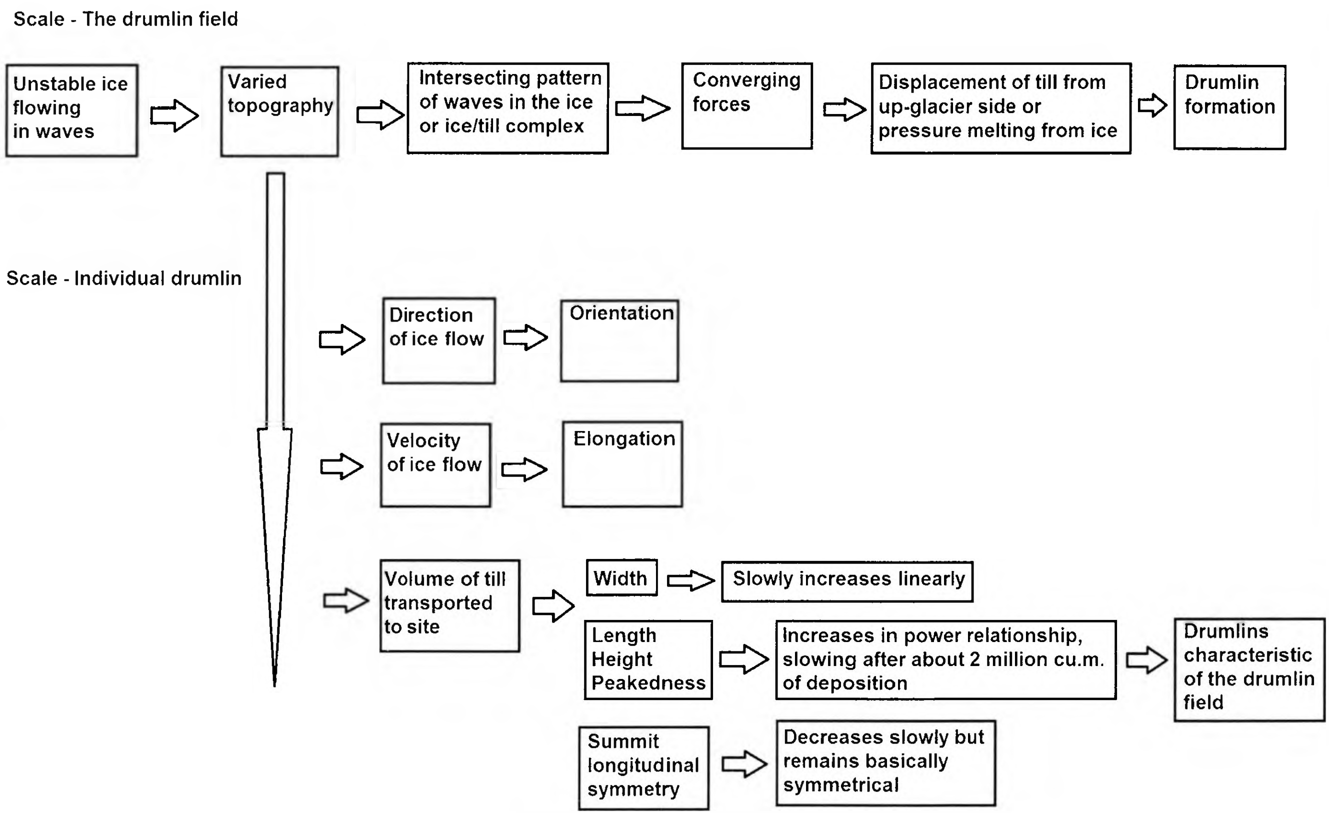


Figure 19 – A model for drumlin devolpment

Conclusions :

Aim 1 – Drumlin morphology

The study area has larger and less-elongated drumlins than the British population measured by Clark *et al* (2009) but they are well within the ranges of the parametric distributions. This implies that the conclusions of the study could also apply to the whole British population. However, there were four different sub-populations within the study area of 73Km^2 which shows the importance of identifying single populations if relationships are to be analysed.

In some respects, the classic view of drumlin morphology is incorrect. They are isolated hills with sizes up to about 1200m long, 500m wide, 50m high and containing 7x10^{6}m^3 of till. In shape they are elongated up to five times their length but are symmetrical rather than egg-shaped in their long profiles. They are also laterally symmetrical and the ratio of height to width (peakedness) is about 0.06.

Significant relationships exist mainly for parameters to do with size. The main one for shape is the elongation ratio, peakedness and summit longitudinal symmetry being of minor importance. Lateral symmetry and measures of planar shape might be of interest in themselves, but have no value in terms of understanding relationships and how drumlins are formed.

Aim 2 – Topography

Topography is a major factor influencing drumlin characteristics. In the four sub-areas they are different especially in size characteristics, elongation ratio and orientation. Topography influences the direction and speed of ice flow and thus size characteristics and elongation and peakedness. The distribution of drumlins suggests that topography also affects the pattern of their summits and why they formed at particular sites. The suggested extensions of the BRIE model explain why they appear to be in a network of lines and why areas of exposed bedrock are up-glacier of the largest drumlins.

Aim 3 – The availability of till

The thickness of till, a measure not investigated previously, was found to have no statistical significance in its relationship with any factor. However, this might be a significant geomorphological result in two different ways: drumlins may be formed by ice bringing sediment to the site of drumlin formation from some distance away or it may imply that the till layer formerly present was changed as described in the BRIE model.

The volume of till received is strongly related to drumlin dimensions but in a minor way to shape features, peakedness being the strongest. This suggests that shape is largely independent of drumlin size.

Aim 4 – A model for drumlin formation and ideas for further research

A model incorporating the results of this study forms Figure 19.
The study was based on much fieldwork and subsequent map analysis. The quality of its results depends on the accuracy of the data. Interpolation of the sub-till bedrock surface is clearly less accurate than geophysical measures and provides some uncertainty about the importance of the existing till layer. The accuracy of drumlin volume too could be improved using remotely sensed data. Conclusions about parameters not employed elsewhere need to be confirmed by further studies in drumlin fields with different characteristics and larger populations of drumlins.

The results of the study suggest that further research should focus on drumlin fields rather than drumlins themselves. Larger drumlin fields would permit more confidence in the question of whether drumlins occur in lines and, if so, whether they are related to disturbances in ice flow caused by high land. The area up-glacier of drumlins could be the source of till. If its area is proportional to drumlin volume, the BRIE model of a displaced till layer would be supported. If it is not, the till is more likely to have been accumulated by pressure melting of ice, the debris having been brought from afar.

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Dr. Arthur Robinson
[redacted]

A SUB-LATERAL BOULDER MORAINE IN DUNNERDALE, SW LAKE DISTRICT

Peter Wilson and Alan Smith

Introduction

Ice-marginal moraines can be seen in most Lake District valleys; some have been described and their age, origin and/or glaciological significance discussed on numerous previous occasions. Moraine ridges and mounds in the upper reaches of many valleys have been ascribed to glaciation during the Loch Lomond Stadial (LLS; 12.9-11.7 ka BP), and moraine configurations and limits have been used to map the lower lateral and terminal margins of these glaciers (Manley, 1959; Pennington, 1978; Sissons, 1980; McDougall, 2001). Although the number of LLS valley glaciers and areal extent of some are subjects of dispute, there are some moraines that are located well beyond the limits conventionally associated with LLS glaciers (e.g. Ward, 1876; Gresswell, 1952, 1962; Sissons, 1980; Wilson, 2004; Clark, 2006) and these are generally taken to represent stillstands or readvances of the ice margins during overall withdrawal of valley glaciers in the interval between the Last Glacial Maximum (LGM; ~24 ka BP) and the LLS.

Most Lake District valley moraines have a closed vegetation cover, dominated by grasses, and a scatter of surface boulders. Where moraines have been incorporated into agricultural enclosures surface boulders are normally few or absent, having been cleared away. A good example can be seen at Thorneythwaite in Borrowdale; here a sector of the ridge on which the farm is located has been cleared of its boulders but closer to the valley side the ridge remains boulder strewn. Although there are rather few descriptions concerning the internal composition of Lake District moraines, those that do exist (e.g. Wilson, 1977; Wilson & Clark, 1999; Wilson, 2002; Graham & Hambrey, 2007) indicate the presence of matrix-supported and clast-supported diamictons, gravels, bedded sands and gravels, and laminated silts and clays. In detail, therefore, some morphological and sedimentological diversity is evident both within and between clusters of moraine ridges and mounds.

A moraine that is markedly different in several respects from other recorded moraines in the Lake District exists in Dunnerdale. Although this feature is not unknown, having been described by Mackintosh (1871) and again by Smith (1912), it has largely been forgotten. The intention of this short paper is to describe the moraine, to highlight the contrasts between it and moraines elsewhere in the Lake District, and to outline some associated implications.

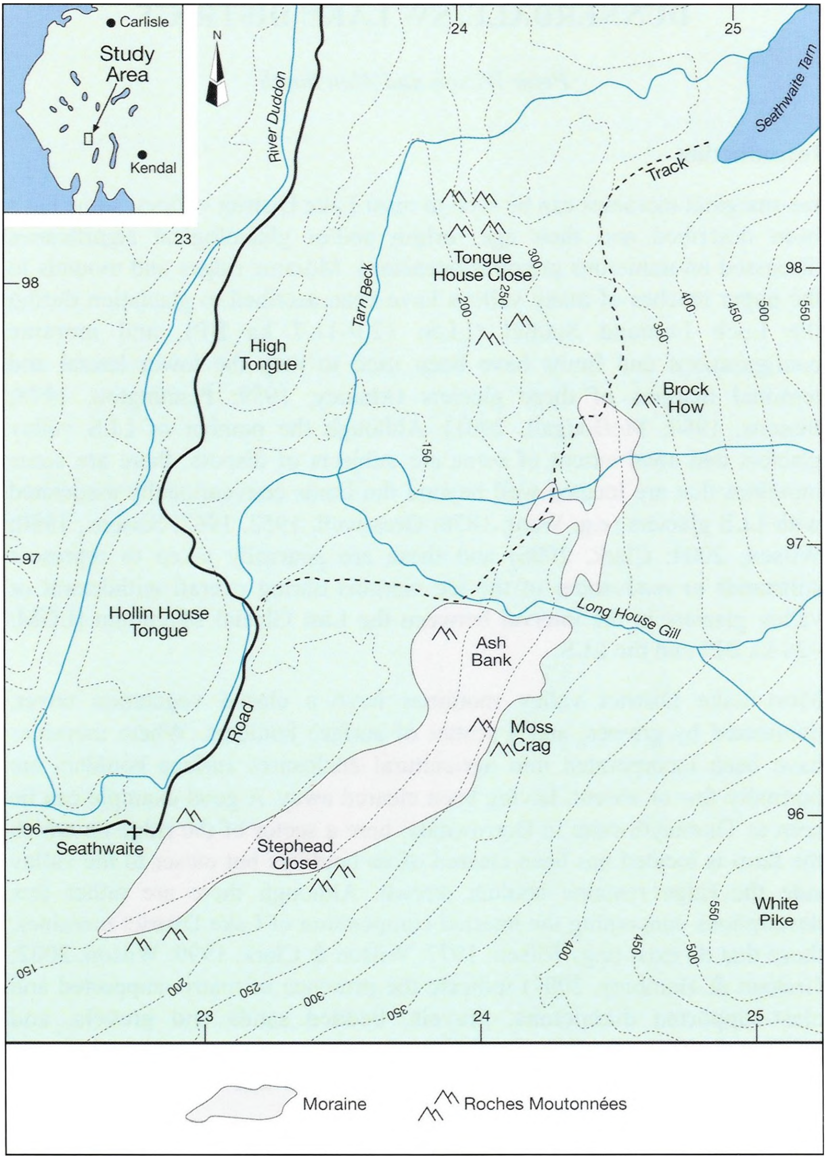

Figure 1. Location and outline of the Dunnerdale boulder moraine. Scale is given by 1 km marginal grid and the contours are in metres.

The Dunnerdale moraine

The Dunnerdale moraine is unlike most other Lake District valley moraines in being composed predominantly of large openwork boulders of Borrowdale Volcanic Group rocks. It is situated on the lower slopes of the west-facing valley side, that here rises to over 700 m OD, and it extends in a broad arc for ~3 km from 320 m OD below Brock How to 120 m OD near Seathwaite (Fig. 1). The outline of the moraine as shown in Fig. 1 encompasses those areas within which there are concentrations of boulders. However, this does not imply that the boulders are everywhere of uniform concentration. It is also the case that boulders are absent or sparsely distributed in some places; this may be because they have been used in the construction of dry-stone walls or have been buried by the accumulation of peat.

The whole of this west-facing valley side is underlain by a sequence of bedded lavas, tuffs and volcaniclastic rocks of the Borrowdale Volcanic Group. A significant west-east transverse fault cuts across the area approximately along the line of Long House Gill and exposes rocks higher in the sequence in the southern section. North of the fault, beds of tuff and volcaniclastic sandstones of the Birker Fell Formation dip very steeply eastwards (into the hillside). The strike of the rocks (north-south) is thus aligned parallel to the contours and consequently with the direction of former ice flow. South of the fault structurally similar volcanic sequences of the Lickle, Caw and Lag Bank Formations occur.

Figure 2. Downvalley view of the upper part of the boulder moraine between Brock How and Long House Gill. Some of the boulders in the Ash Bank enclosure can be seen at the upper right.

Figure 3. Part of the boulder moraine north of Long House Gill. The survey pole is 1 m in length

The northern limit of the boulder moraine is slightly north of a prominent double bend in the track to Seathwaite Tarn and downslope from the roche moutonnée of Brock How. Here there is a dense concentration of boulders on a 100-200 m wide hillside bench with slope of ~5°; maximum boulder size is 4.5 m. Boulders have also been deposited on the steeper frontal slope of the bench but are less common in this area. To the south, towards Long House Gill, the zone of boulders varies from <100 m to 300 m in width (Fig. 2). For most of its length within this area the upslope part of the boulder moraine occupies a hillside bench, and the downslope part is on a steeper slope below. Within this tract there are localised, dense concentrations of boulders and wet, peaty areas with sparse boulder coverage. Near the southern end of the hillside bench the boulder moraine is divided by a wet, rush-infested embayment. At the head of the embayment many boulders exceed a length of 2 m (Fig. 3) and maximum boulder length is 8 m. The western arm of the moraine rises as a low (<2 m high) boulder ridge on the outer edge of the hillside bench, and boulders are also spread across the steeper slope below.

South of Long House Gill the boulder moraine attains its maximum width (~500 m) in the Ash Bank enclosure (Fig. 1). The greatest concentrations of boulders occur in the upper and middle parts of Ash Bank, on both a narrow hillside bench and its longer and steeper frontal slope. On the latter slope there are lobe-like fronts to some boulder areas suggesting, perhaps, that these concentrations have undergone some downslope movement since their deposition by the glacier. On the lower hillside of Ash Bank boulders have a more localised distribution, and there are several roches moutonnées with adjacent boulder clusters.

In the vicinity of Moss Crag (Fig. 1) the moraine descends obliquely across a slope with prominent moutonnée outcrops. Boulders are less abundant in this area but dominate the lower ground of Stephead Close and neighbouring enclosures (Fig. 4), with many boulders 1-2 m in length either resting on or projecting from a diamicton. Towards the southern limit of the moraine there are areas that are almost devoid of boulders and, as in the woodland south of Seathwaite, areas with an almost complete cover of boulders, with some boulders 2-3 m in length. Moutonnée outcrops are present alongside the moraine margins in this terminal zone.

Visual assessment of boulder angularity/roundness at various locations along the moraine indicates that boulders with a length in excess of ~0.5 m are generally angular and sub-angular, and boulders less than ~0.5 m in length are generally sub-angular and sub-rounded (Figs 3 & 4). In contrast, rockfall boulders of all sizes on the flanks of Brock How are very angular (Fig. 5).

Figure 4. The boulder moraine in Stephead Close showing surface and embedded boulders.

Figure 5. The western face of Brock How showing part of the accumulation of rockfall boulders and slipped rock masses (arrowed).

Discussion

Both Mackintosh (1871) and Smith (1912) thought the Dunnerdale boulders represented a lateral moraine and in general we concur with this interpretation given the valley side location and oblique downvalley alignment. However, the feature may be more appropriately termed a sub-lateral moraine because the angularity/roundness evidence strongly suggests that the boulders have undergone some abrasion, most likely as a result of subglacial transport.

Given that similar moraines have not been recorded in other Lakeland valleys it is important to try and determine why this feature occurs where it does and for what reason(s). Two competing hypotheses to explain boulder derivation can be considered: 1) supraglacial rockfall, and 2) subglacial plucking.

In some upland areas supraglacial rockfall from valleyside crags is thought to have delivered large quantities of coarse debris to glacier margins (Benn, 1989; Wilson, 2004). Such material is usually transported supraglacially (passively) and dumped alongside the glacier. However, major rockfall is unlikely to have occurred from the slopes above the moraine because those slopes are not steep and crag-girt. Although the hillside rises to over 700 m OD crags are small and scattered, and are set back sufficiently far from the moraine that rockfall boulders from them could not have reached the site.

It is possible that a rockfall source for the boulders lay further north, from either the slopes above Seathwaite Tarn, where there are extensive steep crags on the eastern valley side, or the slopes of upper Dunnerdale. The only time that there could have been a major rockfall onto the glacier is during its build up and again during its decay. During build up of the glacier prior to the LGM maximum any rockfall boulders that accumulated on or alongside the ice are likely to have been transported out of the valley; during glacier recession the decaying ice mass would have had to downwaste sufficiently to expose crags, thus facilitating rockfall, and to have remained active enough to move the debris several kilometres down valley. This possibility cannot be discounted. However, there is no morphological evidence (i.e. prominent source cavities) to indicate that major rockfall(s) occurred from crags in the Seathwaite Tarn basin or upper Dunnerdale.

The efficacy of subglacial plucking (rock fracture and entrainment) as a mechanism of boulder production, particularly with regard to the formation of roches moutonnées and ice-scoured terrain, has been discussed on several previous occasions (e.g. Carol, 1947; Sugden *et al.*, 1992) and is generally accepted to be an important means by which glaciers erode landscapes (Benn & Evans, 2010). In general terms, with increasing distance down-ice from a zone of plucking very angular boulders usually show evidence of wear to both facets and edges as a result of abrasion, and as a consequence they develop sub-angular to sub-rounded outlines. Abrasion and comminution of boulders produces fine-grained material that forms the basis for the matrix of diamictons.

An origin for the boulders by subglacial plucking is supported by the up-valley abundance of roches moutonnées and ice-scoured bedrock. Brock How, rising above the northern end of the moraine (Fig. 1), is one such roche moutonnée. Its west face displays evidence for rock-slope instability in the form of rockfall boulders and larger-scale slipped rock masses (Fig. 5). That instability most likely occurred after disappearance of the last glacier and was probably aided by the outcrop having near vertical bedding planes striking north-south. We suggest therefore that Brock How was previously a more substantial rock boss from which boulders were easily plucked and carried downvalley by the former glacier. However, we cannot be certain that the entire boulder moraine derives from Brock How. Indeed, there are numerous roches moutonnées and areas of ice-scoured bedrock to the north of Brock How (e.g. in Tongue House Close, Fig. 1), and also in both the Seathwaite Tarn basin and upper Dunnerdale, as well as to the south, within the area of or adjacent to the moraine, that could have contributed boulders to the lower reaches of the moraine. The absence of a concentration of boulders to the north of Brock How does not necessarily mean that the boulders did not come from that area. Rather, it may indicate that subglacial conditions changed and plucking suddenly ceased to be effective; the boulders that had previously been plucked were carried away and deposited further downvalley.

The concentration of boulders within the moraine may be taken to indicate that they have not travelled far and, following the instance of a concentration of plucked boulders described by Sugden *et al.* (1992) from the Cairngorm Mountains, they may represent a pulse of erosion during the general withdrawal of the Dunnerdale valley glacier. Had the boulders been produced earlier in the last glacial cycle they would likely have been transported considerably further downvalley and would not occur in the dense concentrations that characterise certain parts of the moraine.

There are no exposures in the Dunnerdale boulder moraine. Where boulders occur on hillside benches the impression gained is that they rest on or very close to bedrock, but the nature of any intervening material is unknown. In Stephead Close and adjacent enclosures the boulders are clearly part of a diamicton that may have undergone some erosion by overland flow, accounting for the numerous partly exposed boulders (Fig. 4). Shallow scars in this area show that the boulders are a component of a silt/clay-rich diamicton, and this may be taken as further evidence for the boulders having undergone subglacial transport.

If, as we believe, the boulder moraine is a product of subglacial plucking, the absence of similar glacier-derived boulder trails elsewhere in the Lake District is rather surprising given the abundance of roches moutonnées and ice-scoured terrain. It may be the case that in Dunnerdale the alignment of outcrop bedding and strike was a critical factor that enabled the glacier to pluck large volumes of rock.

Although Manley (1959) indicated the existence of a LLS glacier in Calf Cove above Seathwaite Tarn, pollen analytical evidence from the sediments of the tarn demonstrates that glacier ice has been absent from the site for approximately the last 15-16 ka BP (Pennington, 1964, 1996). The maps of Manley (1959), Pennington (1978), Sissons (1980) and Brown *et al.* (2011) indicate the existence of a LLS glacier above Wrynose Bottom (a tributary of upper Dunnerdale) ~7 km from the boulder moraine. Therefore the boulder moraine cannot be attributed to the LLS. The moraine probably formed during a stillstand or readvance of the Dunnerdale glacier during the general decay of the Lake District ice dome following the LGM. From elsewhere in the Lake District Ballantyne *et al* (2009) have reported a cosmogenic isotope (^{36}Cl) surface exposure age of 17.3±1.1 ka from bedrock at Lingmell Col (750 m OD) and McCarroll *et al.* (2010) obtained a ^{10}Be surface exposure age of 13.5±1.4 ka to 14.2±1.7 ka from a roche moutonnée in Wasdale (190 m OD). These ages provide some indications for the timing of deglaciation at a high level site and a valley floor site respectively. The pollen analytical data for Seathwaite Tarn suggest that the valley glacier that created the boulder moraine did not persist into the Lateglacial (Windermere) Interstadial (14.7-12.9 ka BP) as may have been the case with the Wasdale valley glacier.

Downvalley projection of the long axis trend of the moraine towards the valley floor indicates that the snout of the glacier was probably about 1 km west of Seathwaite at the time of moraine construction, but there is no end moraine ridge at that place to support this proposal. The up-valley extent of the glacier is likewise difficult to determine; the glacier may have occupied the entire valley and have been sourced in the headwater region of Dunnerdale (Mosedale, Wrynose Bottom and adjacent high ground) or the moraine may have been constructed by a smaller and shorter glacier extending from Calf Cove and the Seathwaite Tarn basin at a time when the terminus of the Dunnerdale glacier was further north.

In both a Lake District and a wider British context the moraine is unique in terms of its composition, length and width. Elsewhere in the Lake District moraines with a high concentration of boulders are described by Sissons (1980), but in general these are short (<700 m long) and quite narrow (few tens of metres at most) end and lateral moraines associated with LLS glaciers, as can be seen in Greenburn below Swirl How (NY 277 010) and in Bleaberry Gill below Caw Fell (NY 120 112). Another boulder-dominated feature, in Burtness Comb above Buttermere, regarded as a lateral moraine by Sissons (1980), has since been re-interpreted as a rock avalanche deposit (Clark & Wilson, 2004). Short lengths of LLS end and lateral moraines composed almost entirely of boulders have also been mapped in several parts of the Scottish Highlands and Islands (e.g. Sissons, 1972, 1979; Benn, 1989; Ballantyne, 2007). The features that are most similar to the Dunnerdale moraine are Sgriob na Cailliche (the Witch's Slide) on the Isle of Jura and the Strollamus moraine on the Isle of Skye. The former is a 3.5 km long moraine made up of a linear suite of parallel belts of quartzite boulders up to 1.3 m in length; however, the exposed hillslope location of the moraine led Dawson (1979) to conclude that it was a medial moraine, and boulder angularity was taken as indicative of a supraglacial origin. The latter is a 2.5 km long double boulder moraine up to 2 m in height; it was interpreted by Ballantyne (1988) as a lateral moraine and by Benn (1991) as a medial moraine of the last Scottish ice-sheet. Both Sgriob na Cailliche and the Strollamus moraine are associated with the phase of general ice decay following the LGM, as is the Dunnerdale moraine.

Conclusions

A sub-lateral moraine composed predominantly of coarse openwork boulders exists on the lower, west-facing valley side above Seathwaite in Dunnerdale. The moraine was described briefly over one hundred years ago but has largely been forgotten, yet because of its length, width and composition it is unique in both a Lake District and broader British context, and deserves wider recognition. It is inferred that the boulders result from a phase of intensive subglacial plucking that occurred during wastage of the Dunnerdale glacier following the LGM. There is a need for direct dating of this moraine and those other Lake District valley moraines situated beyond the limits of LLS ice margins in order to determine the timing of stillstands or readvances during the general decay of the local ice dome subsequent to the LGM.

Acknowledgements

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Peter Wilson
[redacted]

Alan Smith
[redacted]

THE DISTRIBUTION AND MORPHOLOGY OF PINGO SCARS IN THE WHICHAM VALLEY, SOUTH WEST CUMBRIA.

Hannah Thomason

Introduction

'Pingo' is an Inuit word proposed by Porsild (1938) to describe ice cored mounds or conical hills formed via the intrusion of ice under pressure in the subsurface (Figure 1). These perennial frost mounds are common in the latitudinal range 65-75°N and currently exist in the contemporary permafrost regions of Alaska, Siberia and Arctic Canada (Mackay, 1971) where the ground is frozen.

Pingo mounds are generally circular or oval in plan and can achieve diameters of 600m and heights of 50m. They also develop in a variety of unconsolidated sediments such as till, slope deposits, alluvial silts, sands and gravels (Ballantyne and Harris, 1994).

Since the distribution of pingos correlates to permafrost environments, evidence of their previous existence can be used to infer the presence of former permafrost and are therefore highly useful for paleoclimatic reconstruction. "Pingo scar" is the general term used to represent the morphological effects of melting of the ice core of a pingo (DeGans, 1988).

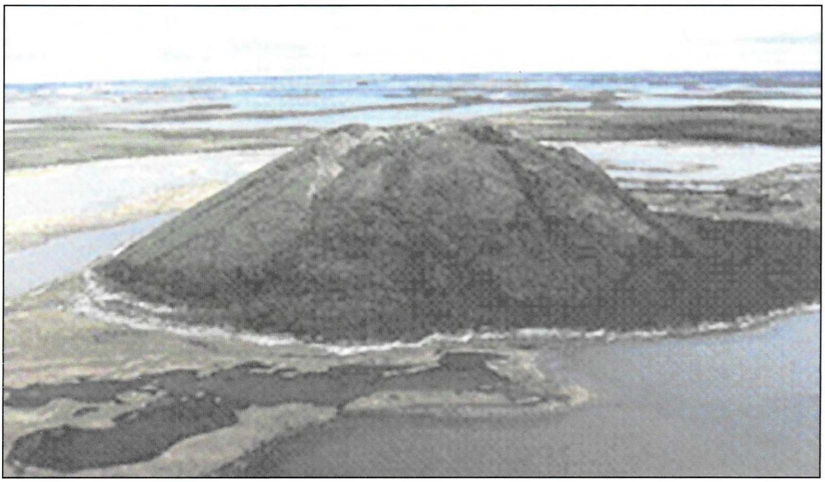

Figure 1: Ibyuk pingo near Tuktoyaktuk, Mackenzie Delta, Canada.

Literature review:

Classification of pingos is based upon the way in which water is supplied to the ice core and is traditionally thought to be two-fold: hydrostatic (closed-system) and hydraulic (open-system).

Hydrostatic form during permafrost aggradation as a result of water expulsion and are usually isolated and located in the continuous permafrost regions of the Mackenzie Delta, usually on the site of former lake basins (Mackay, 1973). (Figure 2.)

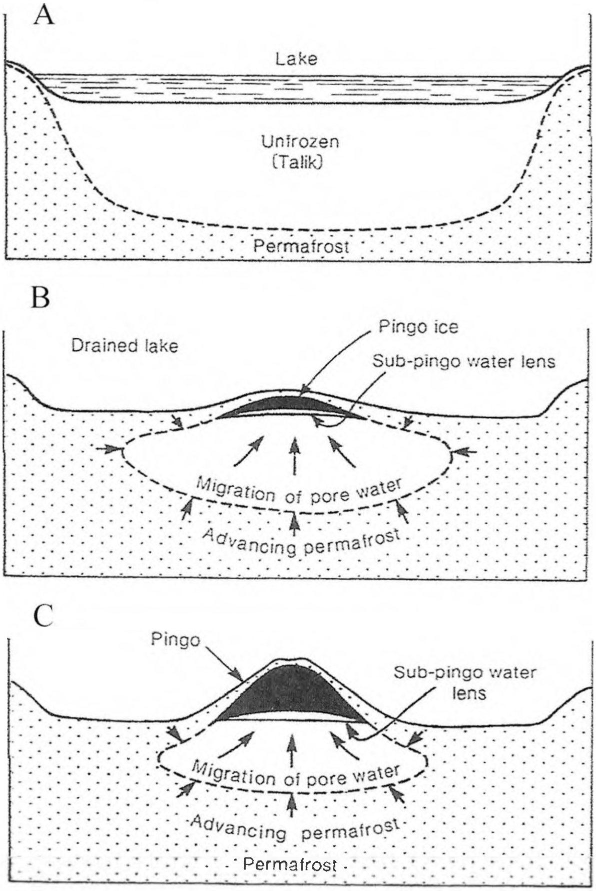

Figure 2: Formation of a closed system pingo.
A) unfrozen talik beneath a thaw lake.
B) Lake drainage causes formation of a sub-pingo water lens.
C) Progressive freezing leads to pingo formation.
(Ballantyne and Harris, 1994: 67).

Hydraulic are those fed by subpermafrost groundwater percolation (Muller, 1959) (Figure 3). They are synonymous with the discontinuous zone in Alaska and East Greenland where water moves under a relatively thin layer of permafrost and reaches the subpermafrost position by entering through areas of the ground surface that are free of permafrost (Pissart, 1988). Such pingos are restricted to low lying areas with sufficient local relief to generate the necessary water head. As identified by modern analogues, they are generally smaller and occur in clusters as opposed to the larger, solitary hydrostatic forms.

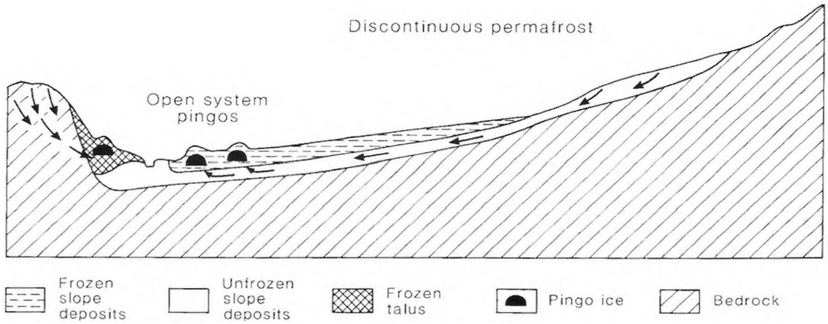

Figure 3: The formation of open-system hydraulic pingos (Watson, 1971: 382)

All pingos undergo a cyclic process of growth and decay, primarily a result of exposure of the ice core through slumping of the overburden material, leading to a centrally located summit crater which converts the original mound into a depression (DeGans, 1988). Figure 4 is a visual representation of the processes involved in the formation of a pingo scar. Such pingo scars may be infilled with a pond or bog and are surrounded partially or wholly by a rampart. Large numbers of pingo scars have been reported from past periglacial landscapes and are generally assigned to the last glacial period (Pissart, 1988). In Britain, identified pingo scar sites include East Anglia, Wales and the Whicham Valley, Cumbria.

Unfortunately, the suggested periglacial origin of pingo scars has not always been on the basis of firm evidence and claims are dubious due to the risk of confusion with other features such as palsas (Seppala, 1986). As a result, DeGans (1988) proposed a list of identifiable characteristics in order to recognize pingo scars: the minimum depth of the depression is 1.5 m and the minimum diameter 25m; the bottom of the depression lies below the level of the surrounding ground and is floored by permeable sediment and at least part of a rampart is present.

Bryant and Carpenter (1985) suggest the main difficulties in defining pingo scars originates from equifinality as different types of ground-ice mounding may produce similar landforms, such as palsas and lithalsas. Palsas are peat-covered mounds formed in the discontinuous permafrost zone via accumulation of segregation ice fed by cryosuction. This is where the frozen peat attracts water from the warmer, unfrozen surrounding mire (Sepalla, 1986). Lithalsas are similar mounds without any peat cover but after melting leave behind ramparted depressions similar to those of pingo scars.

Genesis can be used to differentiate between remnants of palsas and lithalsas since the latter cannot exist without an accumulation of segregation ice and are found in silty materials. In contrast, pingos require permeable material at depth for easy circulation of water and formation of injection ice (Pissart, 1988).

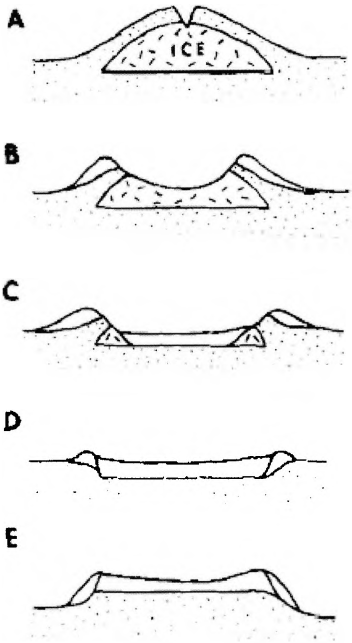

Figure 4: Five tentative stages in the decay of a pingo, showing the development of the central depression and rampart. Stages C-D represents modern pingo scars, whilst E represents an ancient pingo scar (Flemal, 1976: 40)

Study aims and objectives

The overall aims were to determine whether the enclosed depressions identified in the Whicham Valley, Cumbria are in fact pingo remnants or of an alternative periglacial origin; whether there is a morphological relationship between the depressions and their distribution and whether they are of a hydrostatic or hydraulic type.

Site location and Methodology:

The study site was the Whicham Valley located in South West Cumbria in the north-west of England (Figure 5).This study site was chosen to test and develop previous conducted research where a series of enclosed depressions were identified and dated to the Younger Dryas cold episode (11,000 and 10,000 BP) by Bryant *et al* in 1985.

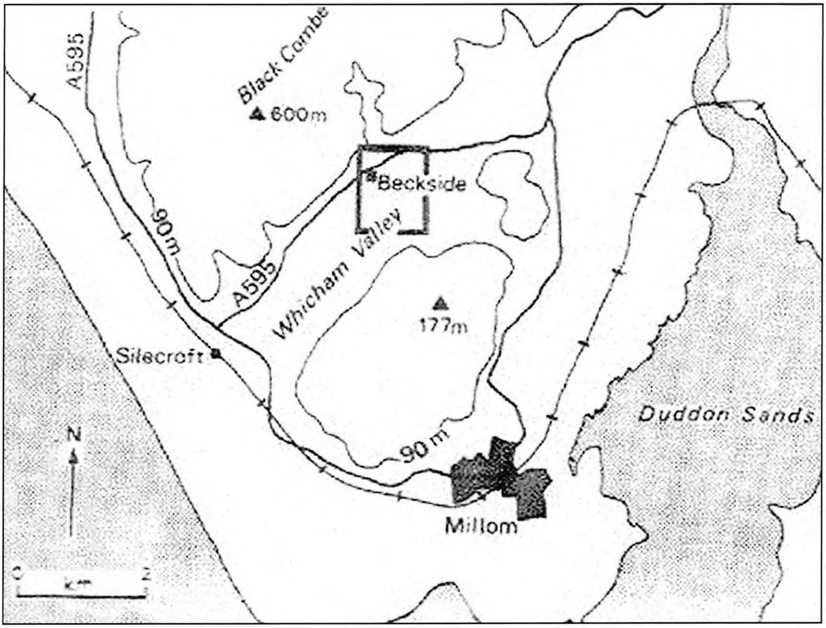

Figure 5: Location of the study site: the Whicham Valley, South West Cumbria (Bryant *et al*, 1985: 48)

Mapping and coring techniques were conducted at the study site in February 2010 to address the research aims and objectives. Morphological mapping was carried out by a ground based field survey, whereby observed enclosed depressions were plotted onto Ordnance Survey (OS) Landranger maps with a scale of 1:50,000. Depressions were colour coded according to the size of their diameter with semi-circles representative of a partially preserved rampart feature.

A series of measurements were carried out on each identified depression using a 100m tape measure to assess whether they fulfilled DeGans (1988) research criteria of what constitutes a pingo scar. The maximum diameter (X); maximum depth (Y) and rampart height (Z) (where visible) were recorded. A clinometer was used to assess the angle of the slopes.

A sediment core sample was obtained from the centre of the depression of pingo scar B using a standard surface corer, as a means of comparison with pingo scar A previously cored by Bryant *et al* (1985) – see Figure 6. An attempt to core pingo scars C-F failed due to a lack of organic material. Sediments from pingo scar B were described using the Troels-Smith (1955) scheme of stratigraphic notation whereby a five class scale was used to characterise each deposit within the core, with 0 implying an absence of and 4 indicating the maximum presence of the quality in question.

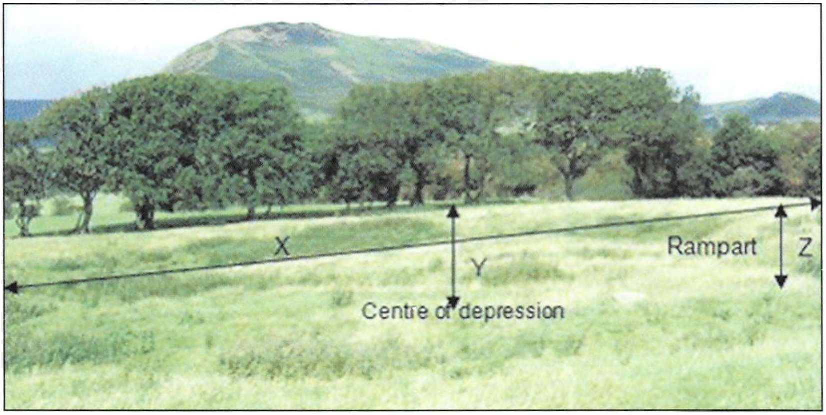

Figure 6: Measurements X-Z taken from pingo B.
Photograph taken from the west facing east.

Results

Figure 7 – the discovery of pingo scars C-F which were absent from Bryant *et al's* (1985) study show a mutually interfering association by overlapping circles indicative of adjoining ramparts located on arable land to the west of Sicklemill Beck. Diameters of the mapped depressions range between 10-50m+ with the modal range lying in the 50m+ category. Pingos A and B are both solitary features, elliptical in plan situated on undisturbed, boggy fields in the northern region of the valley achieving diameters of 58 m and 52 m and depths of 2.8 and 3.2 m respectively. Heights of the ramparts for pingos A, B and C were 1.8 m, 2.4 m and 1 m respectively whereas rampart heights for pingo scars C-F were less than 1 m where discernable.
Figure 8 showing the results obtained by Bryant *et al* (1985) demonstrate pingos A and B are located within the margin of lacustrine clay whereas all other pingo scars (including C-F in this study) are located beyond this clay tract. This is dissected by several relict gulley systems, two of which are shown to feed into the head of enclosed depressions.

Figure 9 presents the results obtained from the stratigraphy from pingo B and confirms the findings by Bryant *et al* (1985) as a depth of 3m was obtained from pingo B which was shown to be floored by thick, impermeable clay deposits (2.32-3 m). Due to the limited depth core 2 was able to penetrate, remnants of the domed sand and gravel deposits found in core 1 are not evident, nor is there any evidence of dumped material. There are similarities between the two cores as both are covered by a thin layer of sandy, mineral topsoil, a thick peat layer and a layer of gyttja soil.

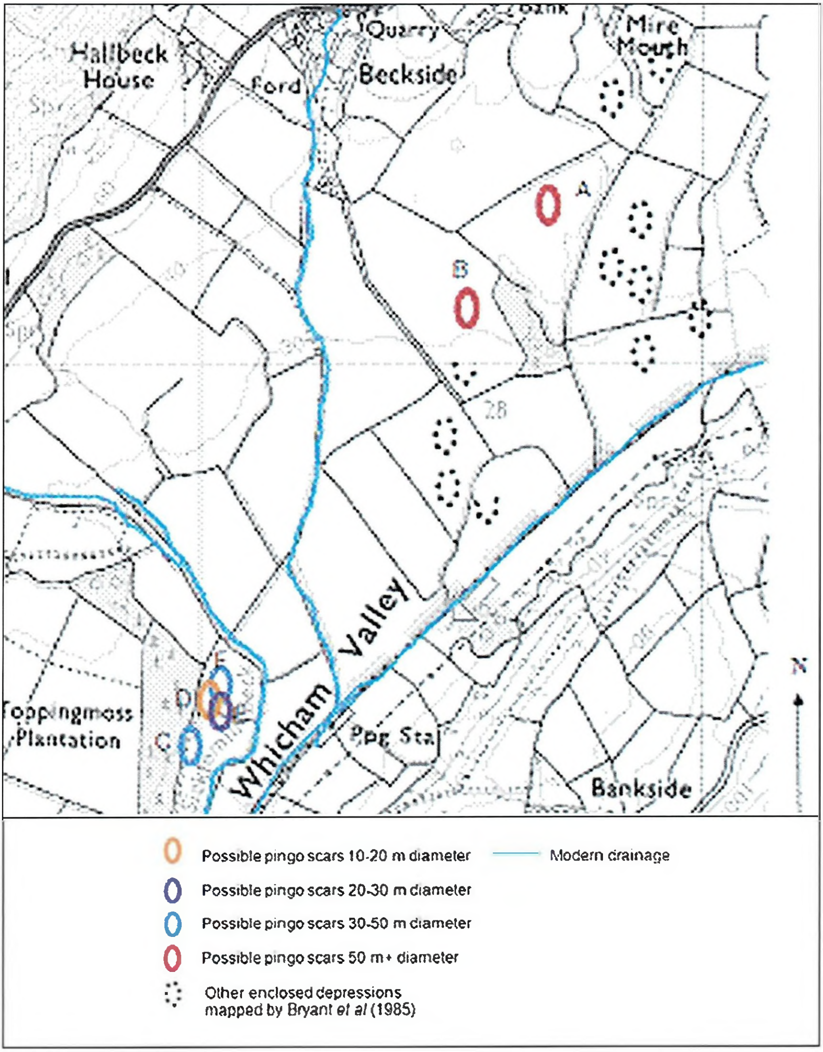

Figure 7: Relict ground ice depressions in the Whicham Valley, Cumbria

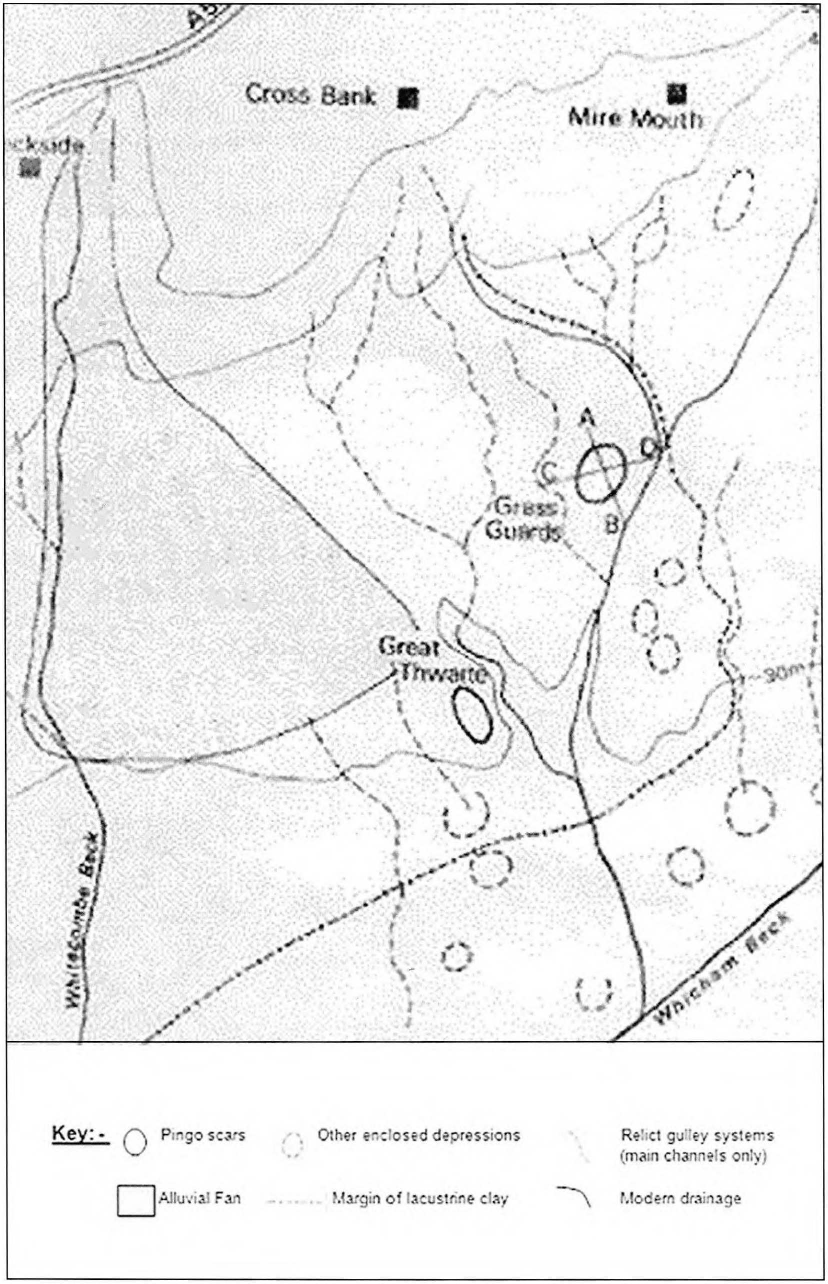

Figure 8: Geomorphological features previously identified at the Whicham Valley by Bryant *et al* (1985).

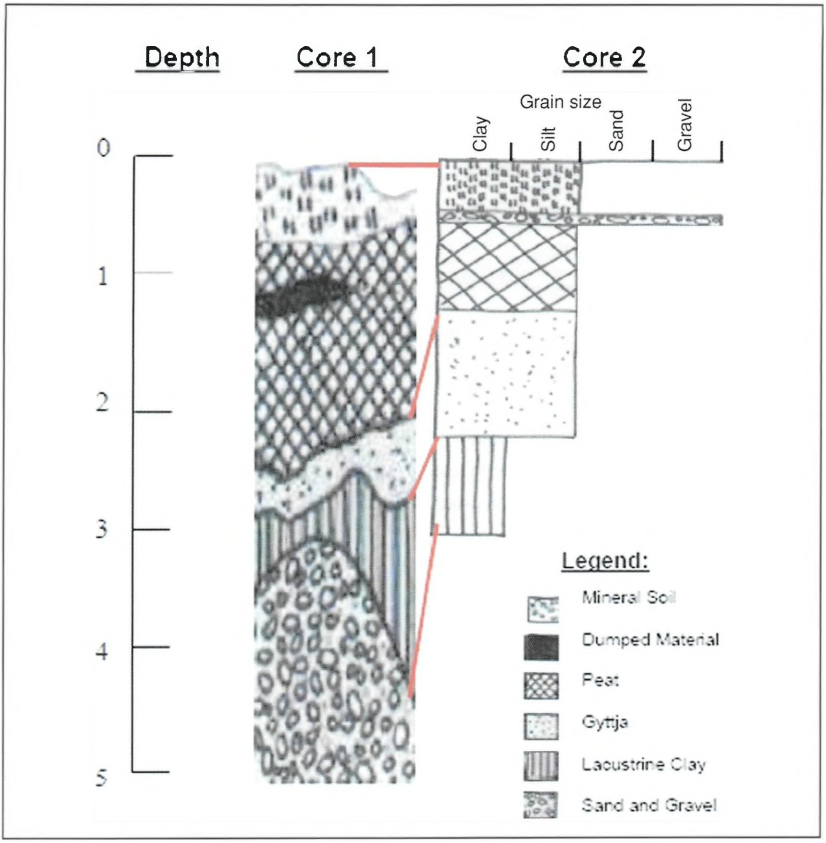

Figure 9: Stratigraphic cross section of pingo scars A and B. A previous core obtained by Bryant *et al* (1985) (core 1) is on the left and core 2 taken from this study on the right. Areas of correlation between the two cores are marked in red.

Conclusions:

- The preservation of circular to horseshoe-shaped ramparts with a maximum height of 1.5 m, surrounding the often solitary depressions found at the Whicham Valley are interpreted as pingo scars. These well-spaced forms are likened to the modern active pingos in the Canadian Arctic. Depressions found at this location generally appear to fulfil DeGans (1988) criteria of what constitutes a typical pingo scar. A palsa origin was considered but was later rejected on the basis that palsas exhibit a poor preservation potential and occur in densely packed clusters. Indeed, the lack of discernable ramparts for pingos C-F was attributed to anthropogenic interference as a product of land cultivation.

- This study affirms that there is a relationship between the distribution of pingo scars and morphology. Pingo scars reside upon gently sloping ground with gradients between 5° and 9°, and are located in close proximity to former and present water sources. All the depressions are distributed at the foot of the valley slope, to the north and within 500 m of Whicham Beck; pingos C-F are also located to the west of Sicklemill Beck, both natural current water sources. Former drainage patterns are marked by asymmetric dry gulley systems (as shown in Figure 8) thought to have been initiated by the rapid drainage of Glacial Lake Whicham.

- The isolated, low density of depressions at the Whicham Valley have been correlated to modern, hydrostatic analogues in the Mackenzie Delta region, Canada and are therefore thought to infer past existence of continuous permafrost. Such a form would have been produced via the rapid drainage of Glacial Lake Whicham (Bryant *et al*, 1985). A hydraulic genesis was considered for pingos C-F due to them lying beyond the margin of Glacial Lake Whicham and the presence of the elevated source of Black Combe residing 600m in elevation and north-west of the discovered ground ice depressions with the hill slopes acting as a good aquifer for the provision of groundwater. This was rejected on the basis that all the pingo scars reside upon similar topography and it would not be plausible for both continuous and discontinuous permafrost to reside in one location.

To summarise, the evidence outlined from the study indicates there is reasonable proof of the presence of pingo scars within the UK. A re-evaluation of work previously conducted by Bryant *et al,* (1985) has led to the discovery of additional relict pingos implying that the distribution may be of greater widespread occurrence in former permafrost locations than the present documentation of features would suggest. It also highlights the importance for future work in investigating pingo scars since conclusions must remain somewhat tentative due to problems of equifinality in identifying pingo remnants.

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Hannah Thomason
[redacted]

THE RUSKIN ROCKS PROJECT

Bobbie Millar

The Ruskin Rocks Exhibition at Brantwood, Coniston provides visitors with a novel, exciting and imaginative experience to listen to the sound of the Lake District by playing stone instruments made from a range of local rocks. The aim of the project was to enliven people's interest in geology and to engage them in a greater understanding of the landscape of Cumbria.

To do this we built relationships with aggregate quarries in Cumbria to identify and obtain musical rocks for the instruments. We took school children to their local quarries with geologists so they could collect their own rocks to make their own musical instruments, gain an introduction to basic scientific concepts in geology, music and materials science and some understanding of the role of the aggregates and slate industry.

During the project we set out to illustrate and explain how and why selected rocks make musical sounds, identify the rock types of aggregate quarries and to design and build rock instruments for Brantwood using different rocks to illustrate igneous, sedimentary and metamorphic rocks. We also created educational materials for use by schools and family visitors: information sheets, geology, computer and acoustic activities and visual displays.

The Exhibition would be launched by Dame Evelyn Glennie. We would then organise workshops, talks and seminars about the musical properties of rocks in the Lake District and provide further information on a dedicated website to support quarry visits and other educational activities.

John Ruskin and Brantwood

In 2005 Bob Dickinson began research for a programme about the 1840 Richardson *Rock Bell and Steel Band* made of 63 bars of hornfels from Skiddaw and housed in the Keswick Museum and Art Gallery. Jamie Barnes, then assistant curator at the Keswick Museum, suggested that he should talk to the Yorkshire Quarry Arts (YQA) team who were researching the musical properties of different rocks using computer and earth sciences. During the recording of the programme, presented by Dame Evelyn Glennie on BBC Radio 4 in January 2006, Bob Dickinson, Dame Evelyn and Bobbie Millar, Director of the YQA project, visited the Ruskin Museum and Brantwood on their way to Keswick.

Brantwood was the home of philosopher John Ruskin. Ruskin first encountered musical stones as an eleven year old when he visited the Crosthwaite Museum in Keswick with his parents in 1830. In 1884 he commissioned William Till to build him an instrument with hornfels for his house to amuse visiting children.

The Launch of the Project at Brantwood, Coniston August 19th, 2010. Left Dr. Kia Ng, Centre Professor Bruce Yardley and right Dame Evelyn Glennie with the Lithophone.

Slices of tuff from Burlington Quarries ready for transportation.

The idea of an instrument constructed of materials so directly related to its surroundings appealed to Ruskin. His lifelong fascination with landscape and geology and his collection of rocks and minerals would have made an instrument made from rocks taken from the landscape a true synthesis of art and nature.

In 1900 this instrument was removed from Brantwood to the Ruskin Museum in Coniston where it has been ever since; though now damaged and no longer a good example of ringing hornfels. It seemed a shame that there was no longer a stone instrument at Brantwood and so in conversation with Sally Beamish, the Brantwood Estates Manager, and Dame Evelyn we decided that it would be fun to make a twenty-first century rock instrument for Brantwood, using local stone and local stone workers. A synthesis of music and nature would stimulate an interest in the local landscape, geology and music. The Richardson instrument took thirteen years to complete. Assuming funding could be found it ought to be possible to complete an instrument using twenty-first century science and technology in less than two years.

Background

In 2003 geologist Murray Mitchell had read about the Richardson Stones in an article in the *Friends of the Lake District Journal* and had suggested that the YQA team might look for similar ringing rocks in North Yorkshire because of similarities in the geology. Subsequently Alan Smith, Murray Mitchell and Bruce Yardley had an excursion to investigate the site where Alan had deduced the old Keswick instruments were sourced from. According to a report from Bruce Yardley 'The trip was very productive; the rocks rang to plan.' (Proc. Cumb. Geol. Soc. Vol. 7, part 3, pp 285-295).

Peter Crosthwaite, Joseph Richardson and William Till had discovered that 'hornfelses' close to the Skiddaw granite often ring beautifully and after years of patient collecting to get all the requisite notes, constructed large Lithophones (effectively stone xylophones) that were a minor Victorian sensation.

Getting funding proved problematic until we realised that if we used a range of different rocks from aggregate quarries we could access the Aggregates Levy Sustainability Fund. A key part of the project was to make links between local communities and the quarries and to create educational resources. To do this, we involved local geologists Eric Johnson and Alan Smith and a number of aggregate companies.

Howard Hull, Director of the Brantwood Trust and Ruskin Foundation at Brantwood, Coniston offered the use of a separate building, the Linton Room, next to the main house at Brantwood, for a permanent display. This meant that we could prepare geological educational materials to go alongside the instruments and explain something about the different rocks that were used. It was autumn 2009 before all the delays with the funders were sorted out and the project could begin in earnest with the school activities.

Why do rocks ring?

There is still much to learn about why rocks ring.

From a musical perspective, Kia Ng explained, 'Vibration makes sounds. Objects make a sound when they are hit because they vibrate. The vibration produced when we strike most objects quickly diminishes and we hear only a dull thud. However, some objects are able to sustain vibrations and these will ring. For an object to ring, it must be made from the right material and have the right shape to keep on vibrating.'

'A vibrating object moves the air molecules closest to it, pushing them together (compression) as the object moves in one direction, then pulling them apart (rarefaction) as it moves in the opposite direction. Then these air molecules bang into their neighbours, causing them to move; and so the vibration spreads, radiating away from the source in all directions.

'We can stop a ringing rock key by touching it, because we stop or damp the vibrations. When the air's vibration reaches the ear, it causes the eardrum to vibrate. Our brain processes this as sound. The rate at which an object vibrates determines the pitch of the sound.'

Bruce Yardley, a structural geologist, added, 'One of the most satisfying aspects of using Cumbria for musical outreach is the diversity of rock types that ring.' During the project we found 16 sites which had ringing rock. 'There are igneous, metamorphic and sedimentary examples, and so children can be introduced to the rudiments of geology along the way. What all the ringing rocks have in common is a very tight grain boundary structure, either with a very low porosity or with any pores completely isolated. However, as well as these intrinsic characteristics, any piece of rock must also be free of hairline cracks.

He explained: 'For a rock to ring, the grains must be grown tightly together so that vibrations pass from one grain to the next without losing energy. In the case of limestone, these are calcite crystals which grew in sediment near the sea floor, cementing it from muddy ooze into a hard rock. For the hornfels, the crystals are a more complex mix of different minerals, formed as the original slate was heated up by the nearby granite, but because they grew as an interlocking network, the effect on the passage of vibrations is the same.

Neville Walker at High Fell Quarry, Tilberthwaite cutting slices of the volcanic tuff.

Chris Ellinson (left) and Kia Ng (right) testing ringing rocks in the University of Leeds.

‘It was also possible to see how metamorphic petrology of the hornfels had conspired with weathering to produce slabs suitable for instrument making, by picking up on subtle differences between cm-scale beds and exaggerating them by producing different proportions of cordierite (weathered) and andalusite (resistant).’

What we discovered was that each type of rock has a distinctive sound and resonated for a different length of time. This created challenges for building a Lithophone that worked musically. Initially we thought we would use found rocks, but it was not possible to release the vibrations or control the pitch within an irregular piece of rock.

Choosing the rocks and making the instruments

The original idea was to make the instruments from local stone to reflect Ruskin’s philosophy to use local materials and local workers. The nearest working quarry to Brantwood is High Fell Quarry at Tilberthwaite. There was a plentiful supply of ringing stone and readymade rock bars discarded by the stone masons in their ‘scrap’ piles. One of the disadvantages was that the pieces of rock came from different parts of the quarry and the vibrations varied depending on the quality of the rock and differences in shape and size. It was subsequently decided to select large pieces of rock, sliced to a particular thickness, polished and then cut into bars using a mathematical model and music technology to determine the dimensions for the ringing slabs so they could be cut and tuned with precision.

When we decided to use rocks from aggregate quarries Bobbie Millar toured quarries in Cumbria with Murray Mitchell, Alan Smith or Eric Johnson to ensure we found different kinds of rock: igneous, sedimentary and metamorphic. We thought we might choose different rocks for the ‘white and black notes’ as that would be visually striking, and we sourced sufficient different ringing rocks to do this. However, Kia Ng thought that would not lead to a satisfying musical instrument as it would not be possible to have sufficient consistency in timber and resonance within each octave.

We collected samples of each rock, initially of the size we could pick up and carry and at least 200mm long. We then set about having these sliced into bars. We decided that we should go for bars between 14 and 15mm thick, 42mm wide and no shorter than 190mm. We managed to get some cut with help from several local stonemasons. This was quite challenging: stone masons specialised in different types of rocks and it took some considerable time to achieve consistency in thickness and width within and between each bar. Also because all these companies were providing the cutting ‘in-kind’ we were dependent on gaps in production runs and their normal paid work.

Sometimes the rocks crumbled or fractured and we had difficulty having sufficient for our tests. Burlington Stone, High Fell Quarry and Blencathra Stone Craft each provided us with the rock bars of high quality and consistency.

At the same time the University of Leeds geologists led by Bruce Yardley made thin sections and SEM images in order to classify the different rock structures and to identify individual rocks that ring from those that did not when they were taken from the same source and type of rock.

Kia Ng then asked us to use only four different rocks for the Lithophone, preferably with the longest vibrations. We chose a Borrowdale Volcanic Group Green slate from High Fell Quarry, Tilberthwaite, for the lowest octave, which although did not vibrate as well as many others was important geologically and because of its proximity to Brantwood; next we chose Shap Blue from Shap Blue Quarry, a metamorphosised igneous rock or type of hornfels; next the classic hornfels from the mountainside at Skiddaw; and for the top octave Carboniferous Park Limestone from Stainton cum Adgerley near Barrow in Furness. We decided on the design of the instrument in consultation with Dame Evelyn and agreed that each note would be the same width 42mm, roughly the same thickness between 13 and 15mm depending on rock type and the stone masons precision and the lengths would range from about 190mm at the high end to about 800mm at the lower end, arranged in a curve and tilt formation to make playing more comfortable.

This meant that we had to go back to the source quarries and select large boulders sufficient to cut long bars which could then be cut down and tuned. It was quite challenging to be sure that the selected boulder would ring when sliced and cut into bars. It was also surprising that although we found ringing boulders they were few and far between. Also we had to work out which way a rock had been lying before it had been blasted from the hillside. This was easier with the green slate which was quarried for building stone. Also the rock that had been quarried for aggregate had been blasted so violently that the rocks contained numerous fractures and indeed the quality of the minerals and particle sizes varied enormously. One soon learned the particular sounds that were a prerequisite to harvesting ringing rock bars. It was quite daunting to select a large boulder, some two or three tonnes, hoping that when sliced, polished and sawn into bars they would then ring as well as our small samples had done. We also then had to hire vehicles to transport the rocks to Burlington Stone where the majority of rocks were cut. The National Park Rangers helped us to gather the Skiddaw hornfels and Blencathra Stone Craft in Keswick cut them for us.

The support of aggregate and quarrying companies throughout Cumbria was outstanding, despite the economic climate, and the project could not have happened without them.

We also had interesting discussions with the stone masons. They have been cutting stone for generations and know what they mean by a quality piece of rock. However, it was not always easy to convince them to lay a rock in a particular orientation or that a beautifully polished slice of rock was no good because it did not ring. We also collected 50 bars of limestone from Sandside which we expected to produce an excellent, long, bright ringing tone and found that none of them rang. However, after a few months, we discovered that after they had dried out sufficiently, and if we dropped them onto a concrete floor to find all the minute cracks, the remaining pieces of rock rang well and could be tuned. However, they were also very fragile. We then found a particular area of Stainton which produced some very good ringing bars and which were slightly stronger.

Tuning the rocks was time-consuming. Kia Ng reckoned that it took four people a week to tune one octave of rock bars. After creating a mathematical model, he used a sophisticated software programme to record the vibrations and identify the pitch, Gary Keech, the Earth Sciences Technician, worked the diamond saw and pads and a music student with 'perfect pitch' checked the result. The most promising bars were selected by tapping them with a special mallet (designed by Dame Evelyn which she used for playing the Marimba). He then held each bar a foot above a concrete floor and dropped them. If they broke he picked up the longest section and tested its ringing qualities.

The Kirby Blue slate bars normally used for roofing bounced as they were so strong. In the case of the limestone this often had to be repeated. Fortunately we chose to make the highest and shorted notes from the limestone. We actually made 4 sets of the limestone keys for the Lithophone as they were potentially more fragile. Having sawn the rock to a little longer than predicted by the mathematical model, Kia Ng tested the pitch and passed the rock back to Gary Keech to fine tune by sawing or rubbing rock away. The final tuning involved just polishing off a few tens of microns at a time. This was repeated until Kia Ng was satisfied that the rock was tuned to within 1/100th of a hertz.

Making a frame for the Lithophone was yet another challenging task. It had to be flexible for the few occasions the instrument would need to be moved so it was made in four sections, one for each octave. We had hoped to use men from HMPS Haverigg wood workshop, and indeed they made us excellent frames for the pilot instrument, the *i*Rock and for school workshops, but Marcus de Mowbray working with a skilled carpenter created the frame for the Lithophone.

The Linton Room, Brantwood, Coniston with the Lithophone on public display. Stained Glass panel in window to left, display boards on back walls, large geological map on wall to right.

The *i*Rock in the Linton Room, interactive TV screen above.

Having decided on bars we had to find a way of supporting the rocks at their nodal points and to secure them so that visitors would not be able to help themselves to keys from the instruments; the Linton Room was not a supervised space. We discussed our challenge with Andrew Marsden at Keyworth Rapid Manufacturing, a University of Leeds spin-out company. Andrew Marsden and Kia Ng designed brackets for the rocks using 3D printing techniques and the models were tested before being cast in polished stainless steel. Then holes had to be drilled in exactly the right place and the rocks were suspended in the brackets using small brass rods which were stuck in with special glue supplied by Loctite.

The rocks had to be re-tested to ensure that the pitch had not changed during this process. They did discover that it was possible to mend a rock with this glue and to retain the same ringing tone albeit a slightly different pitch. This proved to be invaluable as a bar was broken on the Friday before a recital on the Sunday in March. The bar was mended and when it was replaced on the instrument there was no discernable change; although had Kia Ng used his electronic programme he would have detected a minute change in pitch.

Each musical bar reveals a number of notes which can be heard if you listen carefully. All the rocks were tuned to the fundamental note. Some people listening to the rock will hear the fundamental clearly, whereas others will hear the principal note and others the harmonics. This is why when you strike two notes not everyone will agree which is higher as each person hears differently. However, in tuning the rocks in this way some people are finding it difficult to hear the pitch of the green slate, the lower octave. We are still looking at ways of striking these keys to bring out the tuned note. Hard beaters tend to produce the sound of the beater striking the rock rather than the resonance of the rock.

While the rocks were being tuned Kia Ng worked closely with instrument maker Marcus de Mowbray and his team to create a frame to support the rock brackets and hopefully provide a resonating chamber. Given the phasing of the funding we were a little tight for time and on the Monday before the launch on the Thursday the frame was in London, the bars in Leeds, the press was wanting to photograph the completed instrument on the Tuesday and Dame Evelyn needed time to try out the instrument before the launch!

After a lot of hard work, the instruments were assembled in a marquee on a field by Coniston Water at Brantwood a full day before the launch demonstration by Dame Evelyn. The rain held off and people arrived in their scores. We provided instruments made by the schools during the project for the visitors to play. We gave away at least a hundred tuned bars which we did not need and other slates were provided by Coniston Stone Crafts for visitors to examine, paint and take home.

The Exhibition

The exhibition at Brantwood opened on 21st August 2010. It contains the Lithophone, the *i*Rock and seven information panels, a stained glass panel and a carved quotation from John Ruskin.

The Lithophone

This is the centrepiece of the Exhibition. It is a rock xylophone or Lithophone made from four different rocks from across the Lake District, sliced and sawn into bars and tuned to concert pitch allowing visitors to play the landscape. The instrument is best played gently and with concentration as the lower notes of the green slate are very quiet. Beaters have to be chosen with care to ensure that it is the resonance that is heard and not the sound of beater on the stone. A recording has been made of a recital using the Lithophone and is available on CD.

The *i*Rock

Because we had found so many different ringing rocks we decided to make a second instrument to demonstrate the properties of 14 different rocks.The main instrument we built is unique and incorporates a whole range of innovative design features developed by Kia Ng, but from a geological standpoint, it is the *i*Rock that is the most fun. Not only are the keys wired up so that you can generate different electronic sound effects from them using a keypad controller, there is also a large screen wired in.

The *i*Rock (interactive Rock) is an interactive multimedia instrument which explores the natural beauty of rock vibrations through the rich geological diversity of Cumbria. The *i*Rock software contains a database of information and images for each rock type. The vibrations from each individual key of *i*Rock are monitored continuously, allowing detection of which key has been struck, and with how much energy. If a strike is detected, the computer software goes into action.

The left side of the *i*Rock display shows different visualizations of the *i*Rock sounds. On the right side and to show the crystal structure of *i*Rock keys, images from a scanning electron microscope have been stored in the *i*Rock database so when the rock is struck gently a magnified image of the rock shows the interlocking crystals that allow it to ring.

Play the instrument slowly, and a roll call of Cumbrian quarries passes before your eyes. Play them fast and it is just a blur! This aspect of the technology has much wider potential for getting across basic information about rocks.

Information Panels

There are 7 panels explaining the geology of the Lake District, a geological map of the Lake District and the location of the quarries where we gathered the rocks, a brief history of musical stones and an explanation of why rocks ring.

A stained glass panel reveals the underlying geology of the view across Coniston Water to the hills above by Nick Claiden and a carving on a piece of Elterwater Slate by Lida Kindersley Cardozo presents a phrase from John Ruskin – *this rock trembles through its every fibre.*

A large jigsaw of a geological map the Lake District by art student Patrick Kirk Smith has been added and shortly there will be a rock ladder of 16 rocks from across Cumbria showing their diverse patterns, colours and surfaces.
For opening times visit: www.brantwood.org.uk.

Outreach

Since the Launch evaluation forms have continued to be completed by visitors. A review of these forms at the end of the funded project in March 2011 was made. The response of visitors of all ages was extremely positive and a few of their comments are included here to give a flavour of the interest the exhibition has stimulated in geology of the Lake District. Updates of the evaluation will be posted on the web site www.ruskinrocks.org.uk as new material continues to be added to it.
The exhibition provided 'good hands on creativity', and that it 'gives a new perspective to geology and the Lakeland scenery' providing 'fascinating information about rocks and their qualities' whilst being 'fun to play'.
The electronic *i*Rock was 'excellent', 'fascinating' and 'brilliant'.
Interpretation panels demonstrated 'really good interpretation, concise and good pictures', and 'excellent they fill in the whole picture'.
In response to the question 'What have you learned about the geology of the Lake District?' A large number of people commented on 'learning how diverse the rock types (slate in particular) are in the Lakeland, a comparatively small area of the country'. The majority of respondents commented that they had learned lots of varied new things that they previously didn't know, for example: 'on the volcanic area, rock and the formation of the rocks and landscape'. Several people commented their surprise on 'learning the musicality of Lakeland rocks'.

Stained Glass window panel by Nick Cladden in the window of the Linton room. The panel interprets the distant view of the Coniston Fells seen from Brantwood.

Murray Mitchell with students from Barrow Sixth Form College at Sandside Quarry.

Visitors have come from not only the local area but from all over the world including: the United States, New Zealand and Northern Ireland, Yorkshire, Lancashire, London, Avon, Sussex, Norfolk, Nottinghamshire, Devon, Somerset, Aberdeenshire, Middlesex, Cheshire, Cambridgeshire and Derbyshire.

Since the Launch there have been a number of workshops for schools, quarry visits and recitals. These will continue. Opportunity is taken at these events to relate the music, geology and landscape and to stimulate the sense of wonder and enquiry and promote a greater understanding of Ruskin and geology. In 2013 there will be a programme of courses at Brantwood including some illuminating the Brantwood Musical Stones. Composer Christian Mason has composed some fragments which help to reveal the different qualities of each octave of the Lithophone. We hope he will develop these into a longer work for Dame Evelyn to perform.

Funding and Contact Information

The Ruskin Rocks project was funded in two phases by Natural England through Defra's Aggregates Levy Sustainability Fund (ALSF) between December 2008 and March 2011 with additional funds from the Fluor Foundation and the University of Leeds. There was a brief pilot project from mid December 2008 to March 2009, followed by a delay and then the main project from mid October 2009 to March 2011.

This collaborative project was dependent on considerable 'in-kind' support from Cumbrian aggregates and stone industrial partners, primary and secondary schools, independent geologists and the Brantwood Trust. It was generated during the YQA projects which were funded by Minerals Industry Research Organisation (MIRO) between 2003 and 2007.

Bobbie Millar set up Yorkshire Quarry Arts in 2003 with geologist, Jane Francis, artist, David Walker Barker and musician, Kia Ng, at the University of Leeds. These projects have been funded through the Minerals Industry Sustainable Technology (MIST) programme managed by the MIRO through the Aggregates Levy Sustainability Fund (ALSF).

Bobbie Millar helps to create innovative interdisciplinary projects which engage university researchers with communities and industry. She has worked in many departments in the University of Leeds following a range of roles in schools and higher education, including initial and in-service teacher training. She is currently coordinating an EPSRC Network: Novel Applications for Cement (NACNet) and is establishing YQA as an independent organisation supported by the aggregate industry.

Pupils from Haverigg C of E Primary School with the Lithophone in the Severn Studio, Brantwood, March 2011.

Old Hutton Primary School pupils at Holmescales Quarry.

Kia Ng, Director of the Interdisciplinary Centre for Scientific Research in Music at Leeds is leading researchers to study how to augment sound, and elongate the signal, enhancing the natural sound. For more information visit www.ICSRiM.org.uk.

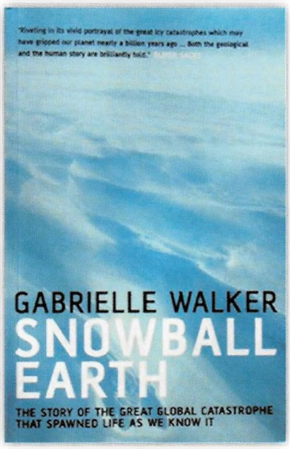
Geologists involved between 2003 and 2011 included Jane Francis, Noelle Odling, Bruce Yardley, Murray Mitchell and Rebecca Hildyard from the University of Leeds and Eric Johnson and Alan Smith.

We were supported by Dame Evelyn Glennie, Mike Adcock and Rob Mackay, musicians and the Brantwood Trust, Bardon Aggregates, Blencathra Stone Craft, British Gypsum, Burlington Stone, CEMEX, Coniston Stonecrafts, Gordon Greaves (Slate) Ltd, Hanson Aggregates, High Fell Quarry, James Walker, Lafarge, Tarmac Limited, Tendley and the Lake District National Park Authority Rangers; Coniston, Gosforth, Haverigg, Hawkshead, Old Hutton, Shap and St. Bridget's C of E and Black Combe Primary Schools; John Ruskin and Millom School and Barrow 6th Form College; and HMPS Haverigg. Kirsty Schofield provided administrative support throughout the project.

For further information about Ruskin Rocks visit: www.ruskinrocks.org.uk and www.brantwood.org.uk. www.yorkshirequarryarts.org.uk is currently being revised but should be on line again in the near future.
There are a few CDs and DVDs from these projects. If you would like more information please contact Bobbie Millar at: b.j.millar@leeds.ac.uk or bobbie@bobbiemillar.com

SHETLAND 'CAP CARBONATE' LIMESTONES AND 'SNOWBALL EARTH' GLACIATION

Sylvia Woodhead



The Cumberland Geological Society has an interesting book in its library. *'Snowball Earth'* (Gabrielle Walker 2003) describes a wealth of evidence that the world was fully glaciated several times in the Precambrian, and that each glaciation ended dramatically with CO_2 emissions from volcanoes causing temperatures to rise to 40ºC. The evidence centres around ancient ice-derived rocks, reddish rock mixtures, like boulder clay, and striated boulders or 'dropstones', from a melting iceberg, found in the middle of tropical limestones all around the world. Gabrielle Walker gives a fascinating insight into the motivation of field geologists, with vivid descriptions of their worldwide field sites.

She tells a story, much like that of plate tectonics, how first Louis Agassiz, then others, including Douglas Mawson and Brian Harland of Cambridge, suggested that the Earth had once been glaciated at equatorial latitudes. Despite palaeomagnetic measurements showing that these ancient 'ice' rocks formed at the equator, equipment and techniques in the 1960s were not sufficient to persuade most geologists to believe in a Snowball Earth. For example M.I.Budyko, in 1969 modelled an 'Ice World' showing that ice which reached the tropics was unstoppable, but he concluded that this could not happen.

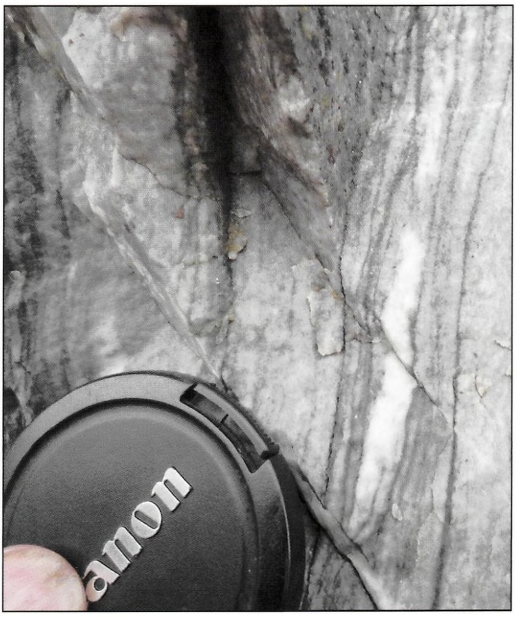
It was not until 1992 that Joe Kirschvink, a Caltech geologist, coined the term 'Snowball Earth', for this 'outrageous hypothesis', as W.M. Davis might have called it. Snowball Earth, in proposing extreme planetary conditions in the past, challenges the basic geological concept of uniformitarianism. It has many critics. Walker's book is a racy account of some amazing ideas and great geological characters.

On the Cumberland Geological Society trip to Shetland we encountered some unusual Dalradian limestones (Figure 1). These ancient marbles are yellow banded dolomitised chemical precipitates, deposited along the eastern margin of Laurentia during an extensional phase. As they directly overlie glacial deposits they are termed 'cap carbonates', and are generally believed to have formed during the melting of a global Marinoan glaciation episode 635Ma, a Snowball Earth event (Prave *et al* 2009).

There is a wealth of research on the formation of cap carbonates, their relationship with Snowball Earth and possibly the development of multicellular life. Carbon isotope analysis in particular is providing a growing data base to help analyse these previously undatable and ancient rocks. The origin of cap carbonates figures prominently in the current controversy around the Snowball Earth idea.

Figure 1. Dalradian Cap Carbonates limestones in Shetland

1a. Yellow banded dolomitic Whiteness Limestones at Quoyness, Loch of Strom, Shetland (HU 395485), interpreted as a cap carbonate deposited chemically during violent climatic perturbations following a Precambrian 'Snowball Earth' glaciation



1b. Vertical Whiteness Limestone at Kirkhouse Quarry, near Voe, Shetland (HU 404628) with clear banding, or rhythmic sedimentation, caused by oscillations of global climate, is interpreted as a precursor to a cap carbonate of a global glaciation.

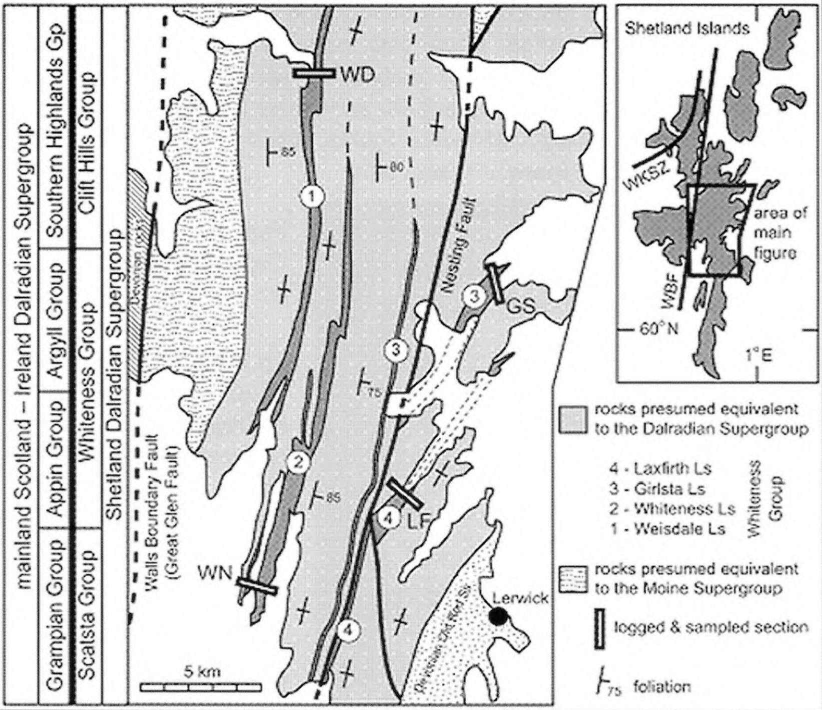


Fig. 2. Dalradian Supergroup rocks of Shetland mainland (after Flinn 2007). Locations of sampling sites for isotope analysis of the four main marble units, including the Weisdale and Whiteness Limestone (Prave *et al* 2009).

1. The formation of Cap Carbonates

The Whiteness and Weisdale Limestones are part of the Neoproterozoic Dalradian Supergroup succession of Shetland (Figure 2). Their narrow north-south outcrop is easily recognisable and can be traced across mainland Shetland (Prave *et al* 2009). They have been identified as cap carbonates, chemically deposited limestone or dolomite (dolostone), distinctive rocks which form the uppermost sedimentary sequences of major glaciations. Similar rocks have been found overlying Neoproterozoic glacial deposits, worldwide, and have been recognised in China, Australia, Brazil, Namibia, Canada and Svalbard. Glacial origin of the underlying rocks has been established by the presence of 'dropstones' with multiple striations. They rest sharply on underlying strata, the Whiteness Limestone has a thin basal dolomite, and pass up into rhythmic sedimentation (rhythmite), giving a banded appearance (Figure 3). Their upper layers may contain peculiar tube-like structures, whose origins are still strongly debated (Font *et al* 2010).

Cap carbonates are part of an unusual geological succession of tropical limestone directly overlying glacial deposits. Their base is said to represent the post Marinoan sea level rise, estimated as 500m by Hoffman (2002) in Namibia. They are postulated to have formed in immediate post glacial times, when rapid melting and sea level rise led to acid rainfall, with accelerated weathering of glacial deposits and exposed rocks. This released large amounts of calcium into the oceans, termed a 'global alkalinity dump', resulting in precipitation of aragonite crystals as textured layers of cap carbonate sediments. Their sharp contact, leaving no evidence of a significant time gap, represents a profound disequilibrium in the Earth's climate system (Kennedy 2008).

Such a radical change in Earth's temperatures, from glacial to tropical, is believed to need very rapid melting and deglaciation, with extremely high temperatures, up to 50°C being advanced by Hoffman & Schrag in 2000. Very high CO_2 levels are postulated for this 'ultra-greenhouse event'. Debate continues as to whether this very rapid deglaciation was unique to Precambrian times (Knauth & Kennedy 2009) or whether it could be said to be occurring at present.

The rhythmic layers in many cap carbonates have been likened to seasonal cycles, leading to assertions of very rapid deposition, over only two thousand years, (Allen & Hoffman 2005). Turbidite-like upper layers in some cap carbonates have been attributed to episodes of uplift (Hoffman *et al* 2002), though this is difficult to reconcile with such a short time period. Unusual chevron, tube-like structures in some upper layers have been identified as caused by methane seeps or as megaripples due to strong winds on deglaciation. These latter could have aggraded quickly (Font *et al* 2010). New evidence from magnetic reversals and earth climate models is leading to a realisation that a postulated time scale of 2000 years is too short to explain all the unusual features of cap carbonates (Font *et al* 2010).

There is debate about whether cap carbonates were deposited in a totally sterile sea. Severe Precambrian global glaciation, with sea ice effectively blocking photosynthesis, may have caused oceans to become lifeless. Post glacial recovery of life forms has been claimed to be related to the proliferation of multi cellular life in Cambrian times. Reports of stromatolites (or tube like structures) in some cap carbonates in Namibia (Hoffman 2002) may call into question the idea of a lifeless sea. Font *et al* 2007 postulated the deposition of cap carbonates in suboxic conditions by sulphate reducing bacterial action, explaining some of the sedimentary structures as microbial mats. Despite the abundance of research, the mode of formation of cap carbonates has not been definitively established.

Figure 3

Figure 3a. The characteristic sharp basal contact of tropical cap carbonates over glacial deposits is seen here with Shetland Whiteness Limestone (right) over underlying schists, which contain occasional lonestones. This unusual succession shows dramatic and rapid warming following a global Precambrian glaciation

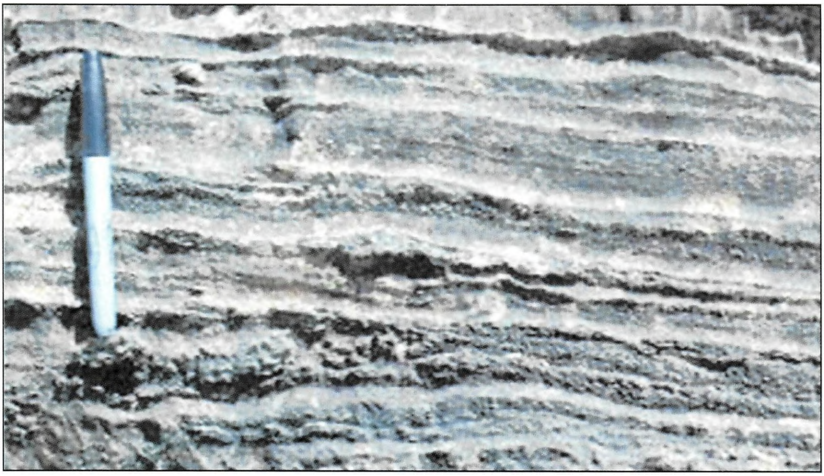


Figure 3b Fine wavy laminae in the basal dolomitic cap carbonate are believed to have been deposited very rapidly during an extreme greenhouse event following a 'Snowball Earth' glaciation

Figure 3c Rhythmites in the limerstone above the basal dolomite are characteristic of cap carbonate deposits.

Figure 3d Granitoid lonestone clasts in Dalradian schist are believed to be of glacial origin, formed during Precambrian 'Snowball Earth'. They lie 3.5m below the carbonate unit and record a rapid climate change from glacial to tropical. (after Corsetti *et al* 2006)

All photographs are within several hundred metres of Grid reference HU 3837 4591. (Prave *et al* 2009).

2. A Snowball Earth

A Snowball Earth is the commonly accepted explanation of the formation of cap carbonates. In 1992 Professor Paul Hoffman of Harvard University began to advocate this return to an earlier idea of a fully glaciated Precambrian planet. At least three global Precambrian glacial episodes, 710, 635 and 585Ma, have been identified from glacial deposits in Australia, although the use of Australian terminology is now being disputed (Corsetti *et al* 2006). Marinoan is the middle of the three glaciations, when evidence for low latitude glaciation is considered compelling, (Shields 2005).

Global glaciation was possibly aided by the dominantly tropical location of the Earth's landmasses around 635Ma, when palaeo-geography suggests that most of the continents were located from 40°N to 60°S, (Font *et al* 2010). Even equatorial latitudes were thought to have been ice covered in late Proterozoic glaciations (Jiang 2003). Hoffman *et al* (1998) estimated only a thin cover of land ice, due to an assumption of the complete cessation of the hydrological cycle as all oceans froze over. Hoffman *et al* 1998 believe that palaeomagnetic evidence suggests that the oceans, even near the equator, were covered by sea ice about 1.5m thick at this time, blocking photosynthesis. There are different estimates of the effect this had on the unicellular life in Precambrian oceans.

Views differ as to the extent and thickness of the ice at each glaciation. Data from the last glacial period suggests that each ice sheet behaved differently, in terms of its accretion and melting. Each piece of Snowball Earth evidence is now being re-evaluated, because of its potential relevance to present day climate change.

3. Carbon Isotope ratios – a link to past life and temperatures?

Modern methods now allow analysis of $^{13}C/^{12}C$ isotope ratios in Precambrian limestones. Prave *et al* (2009) have measured $^{13}C/^{12}C$ isotopes in samples of Shetland Whiteness and Girlsta Limestones and conclude that isotope analysis can help document extreme climatic episodes recorded in Precambrian rocks. The database of isotope analysis continues to proliferate (Halverson 2005), with a 'gold rush' of carbon isotope studies in Neoproterozoic rocks (Corsetti *et al* 2006).

Sea water contains two stable isotopes of carbon, ^{12}C and the rarer ^{13}C, which together form about 1% of carbon atoms. Photosynthesis preferentially incorporates the lighter ^{12}C isotope into body parts and skeletons of marine organisms, so sea water tends to become very slightly depleted in ^{12}C, relative to primary volcanic sources of carbon. Hence there is a slight enrichment in ^{13}C if oceanic productivity is high, and $^{13}C/^{12}C$ values are thus more positive. Positive $^{13}C/^{12}C$ values indicate high oceanic productivity and warm temperatures, while negative carbon isotope values indicate low productivity. Glacial deposits, if enough carbon is present to analyse, may be expected to exhibit negative C isotope values, signifying a rapid decrease in oceanic algae and photosynthesis due to cold temperatures.

This carbon isotope value and enrichment is believed to be recorded in sediments precipitated out in Precambrian times. Tropical limestone might be expected to show a positive carbon isotope signature. However cap carbonates are moderately depleted in ^{13}C and have a 'glacial', negative, carbon isotope signature or 'excursion', whose origins appear unresolved (Jiang 2003). Kaufman 1997 notes that the ^{13}C minima coincide with the maximum flooding of the post glacial transgression.

Despite the flood of research, the usefulness of the carbon isotope record is questioned. Corsetti *et al* 2006 believe that carbon isotope data alone is not very useful in understanding life during a Snowball Earth, as much of the interpretation is speculative. Halverson *et al* 2005 consider the ^{13}C record as preliminary, and note that diagenetic overprinting is a concern. A major question is whether the carbon isotope record is reset by lithification processes (Knauth & Kennedy 2009), and metamorphism, though most researchers assume it is not. On balance carbon isotope records may not in fact prove to be reliable support for a Snowball Earth.

4. Melting a 'Snowball Earth'

High CO_2 levels, high temperatures and possibly a runaway greenhouse effect would be needed to melt a 'Snowball Earth' (Hoffman 1998). At the end of a glaciation, high CO_2 is postulated to cause acid rain, causing increased weathering, and resulting in distinctively textured chemical precipitates, that is cap carbonates. The commonly presumed origin of cap carbonates is that they formed as ice sheets melt in 'Snowball Earth' conditions but at least two other mechanisms have been proposed.

- Increased weathering giving a large input of ^{12}C into the oceans; the Snowball Earth (Hoffman)
- Breakdown of methane-rich permafrost and submarine gas hydrates (Kennedy)
- Upwelling of alkaline deep ocean water and deep ocean outgassing caused by extreme winds: overturn model (Kaufman)

All three models explain the ^{13}C anomaly, but each is plagued by inconsistencies (Corsetti *et al* 2006). The tropical glaciers of Snowball Earth may have melted very rapidly, but the duration of this post glacial transition is uncertain.

Evaluation of three competing hypotheses for the formation of cap carbonates in the aftermath of a Neoproterozoic low latitude glaciation (after Corsetti *et al* 2006)

	Snowball	**Methane model**	**Stagnant ocean**
Hypothesis	Global ice cover separates ocean from atmosphere. CO_2 from volcanism builds up, causing global warming, ending glaciation	Gas hydrates form during glaciation, destabilise during deglaciation	Glaciation is caused by CO_2 being drawn down into deep ocean by biological pump. Overturn returns CO_2 to atmosphere, and ends glaciation
Cap Carbonate	Resumption of hydrological cycle causes intense weathering, flushing ions into oceans, increasing alkalinity	Anaerobic oxidation of methane in water column increases alkalinity	Sulphate reduction in anoxic water column increases alkalinity
Negative ^{13}C in Cap	Volcanic CO_2 is transferred from atmosphere into ocean	Gas hydrates input depleted ^{13}C into oceans	Turnover brings deep ocean depleted of CO_2 up to surface waters
Potential weaknesses	Ice rafted debris suggests active hydrological cycle during glaciation	Cap carbonates only mildly depleted in ^{13}C. Postulated alkalinity is too small. Methane seeps are seen throughout geological record not just in glacial deposits	Overturn nutrient flux may be too low to account for widespread cap carbonates

Evaluation of three competing hypotheses for the formation of cap carbonates in the aftermath of a Neoproterozoic low latitude glaciation

5. The role of methane.

Methane hydrates, that is methane trapped in water or ice, have been found under present day ocean floor sediments worldwide, and in deep Antarctic ice cores. They form in cold conditions, possibly from reduction of CO_2. Destabilisation of methane hydrate is occurring in the world today, as a result of post glacial flooding and warming, providing data for global warming research, (Kennedy 2005). Methane destabilisation causes very low $^{13}C/^{12}C$ ratios. Methane oxidised in sea floor sediments is hypothesised as providing a source of excess CO_2 driving carbonate sedimentation, and an explanation for the timing and magnitude of the observed carbon isotopic anomaly in cap carbonates. This hypothesis is supported by distinctive tube-like sedimentary structures found in many cap carbonates, and claimed to occur only in methane seep environments, (Jiang 2003). Allen & Hoffman 2005 alternatively explain these tube-like structures as ripples caused by very strong winds during the intense deglaciation following a Snowball Earth glaciation.

Carbonates precipitated in modern methane seeps have low ^{13}C values. Analysis of 600Ma cap carbonates in the Yangtze platform of South China show that these are also characteristic of seep facies. Jiang 2003 believes that cap carbonates relate to postglacial destabilisation of gas hydrates, but acknowledges that isotopic signature of cap carbonates may have been modified through diagenesis. Halverson & Hoffman 2005 conclude that even altered carbonates, as all Precambrian rocks are, appear to conserve their original ^{13}C composition. They also note that incorporation of ^{13}C depleted carbon from oxidation of methane can alter carbon isotope ratios. The latest ranges of oxygen isotope values are likely to be from mixing of ice-derived meteoric waters with destabilization of equatorial permafrost (Kennedy *et al* 2008). Permafrost destabilisation on the Marinoan shelf could provide the trigger for deglaciation, positive feedback and carbonate deposition (Kennedy *et al*). There is discussion as to the degree of alteration of carbon isotope values during lithification and hence their reliability (Font *et al* 2010). Some of the evidence appears contradictory.

Evidence from China (Jiang 2003), and many letters to *Nature*, appear to support the methane release hypothesis. Jiang 2003 notes that it is puzzling that cap carbonates, deposited in a warm sea, have a negative carbon isotope excursion, which is associated with cool conditions. Kennedy 2005 suggests a chemical oceanographic origin, details of which remain unresolved. Kennedy 2008 suggests that methane release could trigger abrupt warming, cause cap carbonate precipitation and create a marine oxygen crisis. He concludes that methane hydrate is suggested as an important positive feedback to climate change.

6. Stagnant Ocean

Upwelling and mixing of deep anoxic, carbonate-enriched water and surface ocean waters has been proposed (Grotzinger *et al* 1995) as the mechanism for massive sea floor precipitation of aragonite and calcite. Oceanic carbon cycling was proposed as a mechanism to explain the association of cap carbonates with deglaciation by Kaufman *et al* (1997). Their suggestion is that rapid turnover of anoxic deep oceans, possibly driven by cold deep ocean circulation, would bring CO_2 to the atmosphere and melt ice sheets, while excess HCO_3 in surface water drove rapid precipitation of cap carbonates depleted in ^{12}C. They suggest that cap carbonates were precipitated in ocean basins affected by upwelling, though some of their carbon isotope analyses in Spitzbergen do not support this assertion. They concluded that oceanic turnover could provide only a short time scale mechanism to explain the formation of cap carbonates. In 2005 Shields proposed an alternative 'plumeworld' hypothesis. He argued that cap carbonates formed by microbial action of carbonate whitings during algal blooms in low salinity meltwater plumes created by massive and abrupt deglaciation. Evidence in Namibia may explain carbonate precipitation above the cap carbonates by an upwelling process.

7. Snowball Earth and major extinctions

A Snowball Earth postulates cap carbonates being deposited chemically in a lifeless calcium rich sea (Hoffman 1992). It was suggested that all marine life was cut off when equatorial oceans were ice covered, blocking light and photosynthesis. Kennedy *et al* 2008 believe that post Snowball Earth methane release led to anoxic sea, also killing life. Methane release during Neoproterozoic deglaciation may have led to significant drawdown of oxygen and perhaps to oceanic anoxia, and possibly influencing biological innovation in the Ediacaran Period (635-543Ma). This link with evolutionary processes is considered speculative by other researchers (Corsetti *et al* 2006). The stagnant ocean idea postulates that marine life would continue during global glaciation, albeit reduced in diversity. Evidence of bacteria in sea ice at the present supports this. Corsetti *et al* 2006 have analysed silicified microfossils, possibly cyanobacteria, in Neoproterozoic deposits in Death Valley, USA, which they believe show merely a decline in diversity during Snowball earth events. They do not support Kennedy's assertion that glaciation pushed evolution.

8. Discussion

The deposition of cap carbonates in Precambrian times was part of a global geochemical cycle, involving processes in the atmosphere and oceans. Their distinctive chemistry and global distribution has led to suggestions for a global Snowball Earth event. Their origin is unresolved and debated, and has been related to at least three mechanisms. At least some of the evidence appears to be rather contradictory, (Knauth & Kennedy 2009).

Recent research (Font *et al* 2010) has examined many lines of evidence, the sedimentary record, sea level rise, palaeomagnetism, continental weathering and microbial record, in an investigation of the rate of post glacial melting linked to cap carbonate formation. Several aspects of Snowball Earth are questioned. Strontium isotope evidence suggests that weathering rates were most rapid after, not during, the deposition of cap carbonates. Five geomagnetic field reversals around 635Ma in Brazilian Matto Grosso cap dolostones question the short duration (2000 years) initially suggested for the sedimentation of cap carbonates. Post Snowball Earth climate has been explored using general atmospheric circulation models, 635Ma palaeogeography and a weather model (all based on assumptions). The models produce four curves of CO_2 versus time, which together with strontium and carbon isotope evidence suggest that post glacial temperatures were not as hot as previously postulated. They conclude that cap carbonates were deposited after a Snowball Earth event, in a period of around 40,000 years.

Cap carbonates are distinctive limestones which record an epoch in geological history when the Earth's climate was violently changing from glacial to tropical. It is salutary to think that modern analytical techniques can link rock outcrops in Shetland to similar rocks worldwide, and may have implications for our understanding of the mechanisms of current global environmental change.

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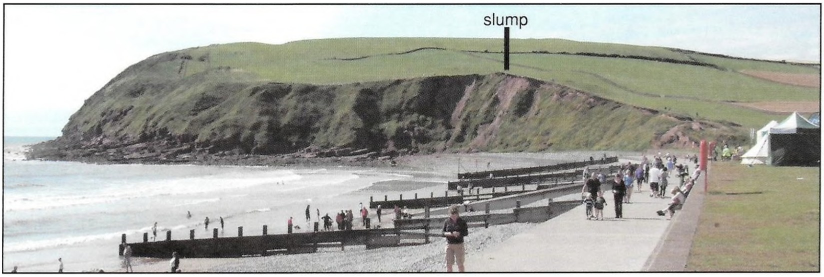
Sylvia Woodhead,
Oakleigh, Back Road, Lindale,
Grange-over-Sands, Cumbria LA11 6LQ

Short Communication.

A RECENT, CLIFF EDGE SLUMP AT ST. BEES

Mervyn Dodd



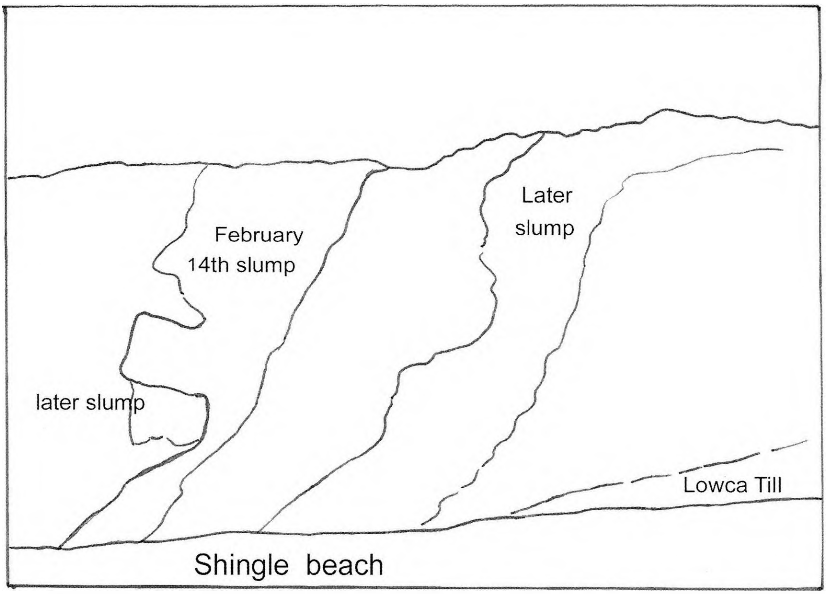
This small slump was located in the morainic debris attributed to the Irish Sea Advance at the northern end of St. Bees Promenade (see above). A section of the 30-40m high cliff edge collapsed down on to the shingle beach below near to the outlet of Rottington Beck (NX 957118) on February 14th, 2011. This led to the temporary closure of the Cumbria Coastal Path which was 1m or so from the edge of the overhang and featured on a BBC Look North Programme on February 15th, 2011. The slump followed a period of very heavy rainfall, fellow member of the Society, David Powell recording between 50 and 60mms of rain in the fortnight before in Workington. The site was monitored for changes over the next two months and revisited in late July 2011 when the photograph (figure 1) was taken.

The initial slump was from the cliff top cobble horizon, through sandy, poorly bedded, incoherent material to the beach, where it has obscured the outcrop of the Lowca Till. The 10m wide fan of material extending 3-5m from the base of the cliff was close to spring high tide mark so its base has been occasionally trimmed. Later movements of the slump face occurred part way down the cliff where water percolated out, creating temporary minor recesses and small 1m high fans. The exact locations where the water seeps out may be where minor differences in the permeability of the morainic material are most pronounced. Bedding above the mid cliff slumps has become more obvious. In late July water was digging a small channel into the original fan and moving fine sand over the shingle.

From early March onwards smaller slumps began to develop either side of the original fall. The very wet one on the seaward (west) side has only affected the bottom half of the cliff. There is another slump 10-20m to the east from the cliff top to the shingle forming a fan so far unaffected by the tides. This fan extends 5-10m from the base of the cliff. This slump face appears to be entirely in sandy material with no trace of bedding. Immediately east of this later slump are three or so incipient slope failures in the top 10m or so of the sandy cliffs. Will these in time become slumps down to the beach below?

Since February there does not seem to have been any noticeable loss of material from the original coastal path which is now grassed over. A new fenced section of the Cumbria Coastal Path has now been sited approx 5m further in land.

Figure 1. (July 2011).



Mervyn Dodd 'Arfryn' Main Street, Frizington, Cumbria CA26 3PH

EXCURSION REPORTS 2010

* * *

CROSTHWAITE CHURCH, KESWICK

Leader: Alan Smith

Wednesday April 28th 2010

A large group of members and friends assembled at Crosthwaite Church on the outskirts of Keswick for a geological walk around the church and the extensive churchyard.

Research on the building stones of the site had been conducted by the leader in 1997 and formed the substance of a detailed paper published in the Proceedings of the Society in 1998 (Vol. 6, part 2, pp 233-252). (Readers are referred to the diagrams and maps in that paper for all the data on the site).

Three geological points of particular interest in the church itself provoked much discussion. First, the leader illustrated the fact that much of the exterior of the church is now rendered with a dull grey mortar, so little of the stone work is visible. It is clear however from the interior that the stone used for the earliest part of the church (1181), is a cream/white sandstone that probably came from the Chalk Beck area of the St. Bees Sandstone outcrop in N.Cumbria. Second, the bulk of the building, constructed around 1523, is of a noticeably fine-grained, pink sandstone with distinct blotches of haematite. The origin of this is unclear. Originally the leader assigned this also to the St. Bees Sandstone, but further observation suggests it is similar to some Lower Carboniferous Sandstones exposed in the Greystoke-Penrith areas. The third point of interest in the church was the impressive slab of Egglestone Marble on the tomb of Sir John Ratcliffe on the south side of the altar. An article on this material and its uses in Cumbria was published in the last volume of the Proceedings (Vol. 7, part 4, pp 355-364).

Outside the church the leader explained the site and situation of the church on a drumlin to the west of Keswick. The difficulties of using local materials from the Keswick area (Skiddaw Group rocks and the Borrowdale Volcanics) was emphasised and demonstrated by the near absence of these materials in the church itself.

A detailed analysis of the gravestones within the church environs and across the extensive graveyard was explained. A detailed count of the almost 2000 headstones had revealed a breakdown in their geology as follows:

Buff Sandstones (probably Carboniferous)	5.5%
Red Permo/Triassic Sandstones	5.9
Silurian Mudstones	20.0
Borrowdale Volcanic Group tuffs	63.0
Marble	2.6
Granite (various)	1.8
Others	0.3

When the geology of the headstones was correlated with their dates some interesting facts emerged. All the volcanic headstones date from post 1850, explained by the availability of this material from quarrying after that date, and the earliest headstones were primarily the buff and red sandstones. Mudstone and other rocks extend across the timescale.

Examples of all the different types of headstones were seen and their geological provenance explained. The grave of Jonathan Otley, the 'Father of Lakeland Geology' was pointed out and the leader gave a brief incite into his geological work around Keswick.

The excursion touched on many aspects of the use of different geological materials and pointed to ways detailed work on churchyards can be enlightening in the way they not only reflect local geology but illustrate many facets of local history.

* * *

THE CARBONIFEROUS – PERMIAN UNCONFORMITY AT BARROWMOUTH, WHITEHAVEN

Leader David Kelly (CGS)

Wednesday May 12th 2010

Members met at the north end of the former Marchon chemical plant at Kells. The leader explained that the Saltom Bay/Barrowmouth area is a classical geological locality and a SSSI. It is one of the few localities in the area where much of the succession shown below is exposed. Other knowledge comes from mines and boreholes used in exploration for coal, hematite and evaporites. The purpose of the visit was to examine the upper part of the Carboniferous, of fluvial origin, and the overlying predominantly red Permo-Triassic rocks, deposited in terrestrial and marginal marine arid environments.

The succession in the area

System	Group	Formation	Thickness
Triassic	Sherwood Sandstone Group	St. Bees Sandstone Fm	600-1000m
Permian	Cumbrian Coast Group	St. Bees Shale Fm	c100m
		St. Bees Evaporite Fm	4m of dolomite + overlaying shale and gypsum/anhydrite
	Appleby Group	Brockram/basal breccia	1-2m
Carboniferous		Whitehaven Sandstone	300m+

The party walked close to the site of the former Ladysmith Colliery, noting where the workings of the Haig Colliery extended under the sea. It then paused close to Hutbank Quarry (NX 961159, sometimes referred to as Lingydale Quarry). This is possibly the only exposure of the St. Bees Shale in south and west Cumbria. There is a transitional boundary, seen in the quarry, with the overlying St. Bees Sandstone which forms the cliffs at the top of the section. The boundary between the two formations is used as an arbitrary boundary between the Permian and Triassic systems in south and west Cumbria. The boundary can be traced in the topography as the cliffs drop gradually down to sea level, due to the gentle south westerly dip. Hutbank Quarry contains good examples of sedimentary structures such as ripple marks, desiccation cracks and rip-up clasts. The red, micaceous shale is predominantly a waterlain, mudflat deposit. It is a lateral equivalent of the St. Bees Evaporites, rather than an overlying unit.

The party then made its way down the steep grassy slope down to the shore. The St. Bees Shale underlies the slope. Evidence of slope failures is abundant: the slope is uneven, has "scar and toe" features, an old mine tramway is distorted and the mine buildings are tilted back to the slope by rotational slip.

From a distance, the party viewed the ruins of the alabaster mine (NX 956155) which operated in the middle of the 19th Century. The mine worked the St. Bees Evaporites for alabaster which was used decorative purposes. These beds are not exposed but specimens can be found on the surface. Specimens of anhydrite and one specimen showing three forms of gypsum: satin spar, alabaster and selenite, were examined. The mine closed due to increasing amounts of anhydrite which was too hard to carve. The old mine buildings and springs at the entrances to adits can be seen, as well as the tramway incline leading down to the mine. A more modern drift mine within the former Marchon chemical plant worked anhydrite for the manufacture of sulphuric acid between the 1950s and 1970s. The mine was visited by the Cumberland Geological Society during this period. Boreholes show the presence of three evaporite cycles in the area and these have been interpreted as supra-tidal sabkha deposits.

The party then examined the oldest unit in the area, the Whitehaven Sandstone. This is exposed on the wave-cut platform (NX 957158) and is red-purple at this locality. It represents a series of sand bodies deposited in channels on a delta plain. Clasts of red mudstone are found within it. There is strongly developed trough cross bedding which shows a consistent palaeocurrent direction towards the south west, showing that the channels were not sinuous and indicating a sediment source in the Southern Uplands. The formation represents the upper part of the Carboniferous in West Cumbria and its relationship with the underlying Coal Measures has long been a contentious issue. Some workers have argued that it is the upper, oxidised part of the Coal Measures, while others have interpreted it as a separate formation with an unconformity at its base. The 1997 Whitehaven Memoir favours the latter explanation.

The unconformity between the Whitehaven Sandstone and the overlying breccia is very irregular with clasts filling hollows and open joints.

Although very thin here, the breccia thickens eastwards and has been shown to be 150m thick in boreholes. It also occurs higher in the succession elsewhere in Cumbria. The Brockram has been interpreted as forming in a series of alluvial fans which spread out from the mountain core of the Lake District. At this locality it may represent a thinner gravel layer deposited on a desert pediment. The clasts are up to 40cm in size and include Carboniferous sandstones and limestones, and rocks from the Borrowdale Volcanic Group. Specimens of Ennerdale Granite have been reported but were not found on this visit. The Carboniferous limestone clasts are "potato stones", with their dolomitised shells intact but the inner parts dissolved out. The origin of the clasts indicates a palaeocurrent direction towards the west and also shows that all these rocks were already exposed when the breccia was deposited. There was clearly a vast amount of erosion at the start of the Permian. There is some imbrication and cross bedding but these features are not well-developed.

A yellowish, well-bedded dolomitic limestone was seen forming the low cliff above the wave-cut platform. This rock, formerly referred to as Magnesian Limestone, represents a marine transgression. It is also present in boreholes in west Cumbria and in the Furness peninsula. The lower part incorporates clasts from the underlying breccia. In the lower part, calcite filled vugs and small bivalves occur. The upper laminated part is interpreted as being of algal mat origin and could represent inter-tidal or supra-tidal conditions.

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ANOMALIES IN THE NORTHERN FELLS

Leaders: Susan and David Beale (CGS)

Saturday May 22nd 2010

On a warm sunny day a large group of members assembled at the Friends carpark in Mosedale. From the foot of Mosedale valley the local geology was described. Carrock Fell, forming most of the northern side of the valley, is composed largely of plutonic rocks in contrast to the metasediments of Bowscale Fell, which forms the southern side of the valley and consists of Skiddaw Group (SG) rocks which make up most of the Northern Fells.

Carrock Fell, the first anomaly of the day, is unlike any other intrusion in the Lake District. It is a complex plutonic body consisting mostly of gabbros and granophyre emplaced about 468Ma at a depth of several kilometres. It may have been intruded subhorizontally at the base of the Eycott Volcanics (EV) at the junction between the EV and the SG and then subsequently modified by the Arcadian Orogeny. Today a south to north traverse along the foot of Carrock Fell encounters range of different igneous rocks which have been interpreted as vertical sheets. The party began this traverse just to the north of Mosedale at a small quarry (NY 357324). Even within the quarry, members were able to contrast darker, more mafic rich gabbros with lighter gabbros rich in feldspars. While at this stop members scattered over the lower slopes to the south and located the contact of the gabbro and the SG hornfels which forms the topographically very lowest part of the Mosedale valley on its northern side.

A short drive northwards along the foot of Carrock Fell brought the party to the next stop at Further Gill Syke (NY 355334), where large boulders of gabbro give way to those of granophyre, the scree obscuring the exact contact between the gabbro and the younger granophyre. Here the fellside slope becomes less steep and overall the granophyre blocks are smaller than those of the gabbro, perhaps because of the close jointing in the granophyre assisting the breakdown of the rock. Workings at base of hill reveal blocks of both gabbro and granophyre, which originated from cliffs above. The range of size and the angularity of these blocks supports the interpretation that they have not travelled far.

A broad boulder platform spreads from the foot of the cliff eastwards on to the wide valley. The valley is filled with boulder clay, as this was a main route of ice sheets originating in the central fells and flowing north to the Solway. Looking south-eastwards across the valley a large area of green pastures contrasting with the surrounding boggy valley floor indicates the better drained area of the alluvial fan formed by the River Caldew as it emerged from the relatively narrow Mosedale valley.

The party then walked northwards along the foot of the fell where the remains of mining for copper and lead were identified. These included several adits, and indications of an impressive pump rod system which once connected to a waterwheel situated in a stream several hundred feet to the east. Mining has been carried out probably from as early as the 16th century through to the late 19th.

Crossing the road the party explored the esker at Long Hill (NY353345) which runs NE-SW. Quarrying within the esker has provided a cross-section of this feature revealing very rounded pebbles indicative of the high water pressure of this once subglacial stream. This is the second anomaly of the day with a subglacial feature preserved on the boulder clay. Lunch was taken here in the sunshine.

After lunch a small exposure of EV andesite in Carrock Beck, close to the ford (NY349350), was identified. The party then walked up the Carrock Beck valley, noting kame features at Rospow Hills and the surrounding area (NY345349) and the landslide of 2008 on the north-facing flank of Carrock Fell. At Drygill (NY326346) an impressive wall of quartzite marks a fault above which a variety of minerals were collected. This area has been worked for copper and lead and adits and various leats, spoil heaps and remain of dressing floors can still be seen. The Drygill Shales, immediately above the fault, were also examined and a number of deformed brachiopods collected.

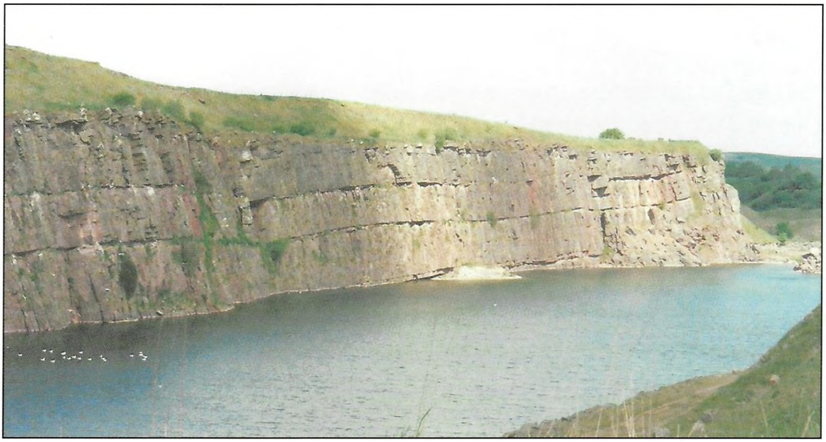
Returning to the cars, the leaders were thanked for an interesting day.

* * *

SOME LIMESTONE QUARRIES AT LAMPLUGH

Leaders: Mervyn Dodd and David Powell (CGS)

Wednesday June 2nd 2010



On the evening after the tragic shootings in West Cumbria, a small party of members visited two very different abandoned quarries.

The first of these, Salter Hall Quarry (NY 059165), had been earmarked by Bardon Aggregates for possible working from the mothballed Eskett facility when the economy recovers. The photograph on this page shows the west face of the quarry. Salter Hall is in the thick Eskett Limestone Formation of the Great Scar Limestone Group (formerly known as the Fourth Limestone) which provided so much of the limestone used in the iron and steelworks at Workington. The eastern (up-dip) side exposes the late Asbian White Limestone which is normally pink! Strong hematite staining and veining follow wide, vertical joints. In places large blocks had slipped down the bedding planes which dip at 10° towards the north north west. Several of these blocks and other loose quarried blocks were richly fossiliferous. Large colonial corals up to 5m across and solitary corals 1-2m long were found. Various *Productid* brachiopod species were common but crinoids were much fewer. At the northern end of this slope was what was probably a haulage way. This was rectangular in cross section with rock bolts in place and appeared to lead north to the abandoned Rowrah Hall Quarry.

The floor of the quarry is filled by a lake which is 500m from north to south. Above it to the west are five or six horizontal limestone beds, each over 10m thick. These have been quarried along the almost north-south strike. The cross section shows the succession of these beds which are mainly in the overlying Brigantian. The potholing and minor channelling of the tops of at least two of the limestone beds suggests exposure above sea level. Separating the thick limestone beds are thinner, laterally-variable shale and sandstones which complete the series of cyclothems. The permission to visit the quarry and the help given by the manager of Bardon Aggregates' Eskett Quarry is much appreciated.

The second part of the excursion was to the much shallower Stockhow Hall Quarry (NY 065185) which is 'bridged' by the Rowrah and Kelton Fell railway. This quarry is almost entirely in the older, more variable and less useful late Asbian Fifth and Sixth Limestones, and appears to have been long abandoned. The lime kiln at the south eastern corner suggests that it was open soon after the early 19th Century Enclosure Act for this part of Lamplugh parish. Unusually for a limestone area, the quarry is almost encircled by scots pines. The section north of the railway has heavily dolomitised limestone with vugs once filled with large aragonite needles, now almost stripped by collectors. The biggest quarried exposures are in the south east corner where the rock is less dolomitised, stronger, in thicker beds and in well-developed cyclothems. In the narrow cutting connecting this area to the central area is the *Chonetes* Shale marker band between the Fifth and Sixth Limestones. This is a friable, dark, finely bedded horizon a few centimetres thick. It is full of the Chonetes brachipods, each a centimetre or so wide with well-developed growth rings. These seem to be in many stages of growth with many detached spines, suggesting that this is a death assemblage. Despite the fading light the party was able to find plenty of the all too fragile specimens.

The very wet, heavily vegetated central area has also dolomitised limestones rather like the northern section, with water seeping underground after heavy rain.

* * *

THE ARMBOTH DYKE AND NEARBY BORROWDALE VOLCANIC GROUP ROCKS

Leader: Michael Coates (Westmorland Geological Society)

Sunday June 27th 2010

A group of around 20 members spent an excellent day on Armboth Fell, fortunately in good weather, with the ground quite dry on this notoriously boggy upland area.

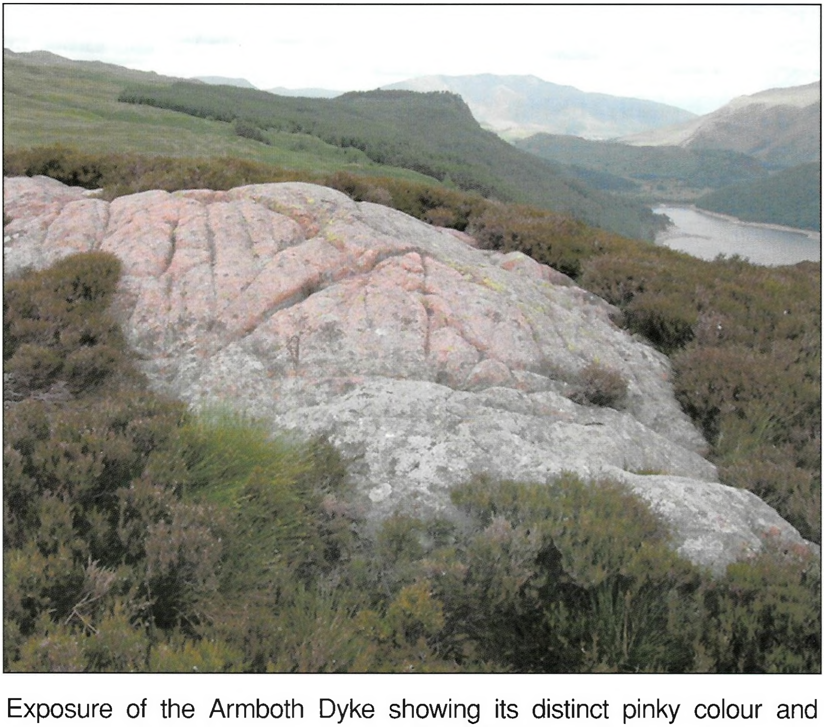
The Armboth dyke is a quartz-felspar phyric microgranite dyke that vertically intrudes both the upper and Lower Borrowdale Volcanic Group in a NW to SE trending course across Armboth Fell. It is approximately 3km long and typically 10-15m wide. It extends from near the head of Shoulthwaite Gill to just south of Fisher Crag. Five wrench faults disrupt the line of the dyke, with the largest displacement being about 400-500m. Topographically the dyke is not a prominent feature, but its distinctive petrology makes its outcrop easy to recognise. It is remarkably homogeneous with little variation along its outcrop. The margins are finer grained where chilled, with the centre of the dyke noticeably porphyritic. The dyke is thought to be early Devonian in age.

Location 1 (see map) was reached on the ascent from Thirlmere up the deeply incised Fisher Gill. The gill is aligned along a fault which downthrows on its northern side. A cairn of rocks marks the outcrop of the dyke across the footpath. The rock is a distinct pink colour with large phenocrysts of quartz and pink orthoclase within a fine-grained matrix of quartz, orthoclase and oligoclase. The dyke is very silica rich (75%). Many of the phenocrysts of orthoclase are often rectangular and are in excess of 1cm long. The quartz phenocrysts frequently weather to form cavities.

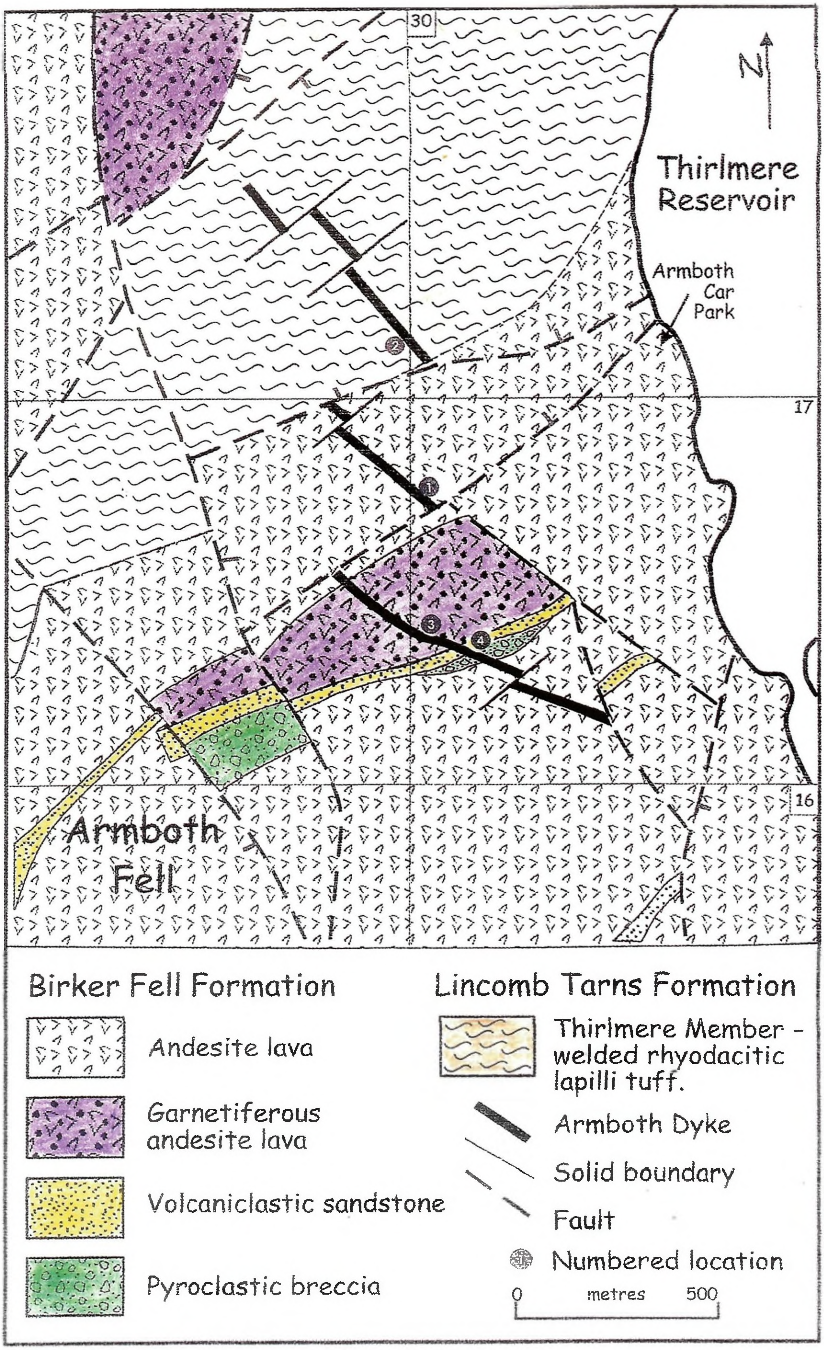
A short upland walk brought the group to locality 2 where several exposures of the dyke cutting into rhyodacitic tuffs of the Lincomb Tarn Formation were examined.

The afternoon part of the excursion crossed Fisher Gill and examined two locations (3 and 4) where there are very clear exposures of the dyke cutting across heavily glacially abraded surfaces and rocky knolls. In this area several places were found where the vertical faces of the dyke are exposed. Most interesting were the Borrowdale Volcanic Group rocks of the Birker Fell Formation into which the dyke is intruded. At location 3 the dyke cuts into a garnetiferous andesite. Close by at location 4, is a narrow band of volcaniclastic sandstone. This lies on top of the andesite of location 3 and is a useful stratigraphic marker. It dips steeply in SE direction and is likely to have been significantly eroded prior to the emplacement of the overlying lavas. Above this is a very distinctive pyroclastic breccia. This small unit is the only outcrop of the andesitic rocks west of the Coniston Fault, which runs N-S along the line of Thirlmere. The clasts of the breccia have been etched out by weathering

The leader was thanked for an excellent day. It was an opportunity for members to see a unique dyke and decipher the pattern of its outcrop across this open hillside.



Exposure of the Armboth Dyke showing its distinct pinky colour and strong, massive jointing close to location 4. Thirlmere in the background



Armboth Fell

ROCKS, STRUCTURE AND LANDFORMS AROUND THE NORTHERN END OF ULLSWATER

Leader: John Rodgers (CGS)

Saturday July 10th 2010

The area between the villages of Pooley Bridge, Dacre and Watermillock is underlain by four quite different rock groups: the Skiddaw Group, Borrowdale Volcanic Group, Mell Fell Conglomerate (Devonian) and Carboniferous Limestone. Landforms in this area are strongly controlled by lithology, large faults and folds, and glacial and post-glacial processes.

The first stop was the lake viewing terrace close to the jetty just outside Pooley Bridge. This normally provides a useful panoramic display of the limestone of Heughscar Hill on the horizon above the villages, giving way to the volcanic crags of Barton Fell on the eastern shore of the lake. The low-lying fields on either side of Ullswater represent areas where the older, underlying slaty rocks of the Skiddaw Group have been brought up in the axial region of a large anticlinal fold. The core of the fold has been relatively easily eroded, resulting in the glacially-overdeepened basin of the Ullswater valley. Further to the west, a series of rolling hills from Little Mell Fell through Soulby Fell to the wooded slopes of Dunmallard immediately behind the viewing point, indicate the outcrop of the conglomerate. Unfortunately on this visit part of the panorama was obscured by scaffolding, there as part of the repair work necessitated by damage caused by the previous November floods.

The party then clambered over the small wall next to the jetty and moved on to the conglomerate exposures on the lake shore (NY 466242). Some time was spent noting the size and shape of the clasts, almost all of which are of greyish-green sandstone, greatly resembling the Silurian greywackes of the Windermere Supergroup. It was proposed that the size, shape and sorting of these deposits indicated their origin in torrential flash floods from eroding mountains formed during the early Devonian Arcadian Orogeny.

Moving on to Dacre, stream bed sections in Dacre Beck were examined at Low Bridge (NY 460263) and High Bridge (NY 452261). Both localities displayed bedded and much finer conglomerates than at Pooley Bridge, suggesting that the form of the original deposit was one or more large alluvial fans fed by a northerly flow from high ground to the south.

The next stop involved inspection of a small, disused quarry at Cove (NY 430239). This proved to be a hard, crystalline, black, probably basaltic rock intruded into the conglomerate. A vertical margin with a zone of vesicles was found at the south end but the north end showed a low-angle contact with the overlying conglomerate. Discussion about the form of the igneous body was inconclusive, based on the evidence examined. Another exposure of similar rock nearby may be more conclusive but the planned visit and ascent of Little Mell Fell was abandoned because of rain and low cloud.

After a brief lunch stop the party took the path between Priests Crag and Watermillock Church in order to confirm the volcanic nature of the craggy exposures on this side (north west) of Ullswater. Exposures of dark green andesite were located on the fellside adjacent to the path. A brief examination of the rocky elevation of Gate Crags (just south of the sheep fold at NY 425224) revealed steeply dipping cleaved tuffs. The north north west – south south east trending ridge of resistant volcanic rock in this area is parallel to the "kink" roughly halfway down the lake and is related to the offsetting movement of the Howtown Fault. Mention was made at this point of the low lying area of Swinburn's Park between Birk Crag and Gowbarrow Fell, in which there appeared to very few, if any, exposures of the Skiddaw Group. However, despite now being very wet, the party gamely proceeded along the road to the bridge over Pencillmill Beck (NY 434223). Peering over the parapet was enough to show the presence of black, slaty bedrock but further proof was provided by specimens collected by the leader scrambling down to the stream.

An evening excursion in 2011 completed that part of visit which had been planned but curtailed by poor visibility.

* * *

SHETLAND GEOTOUR

18 – 24th August 2010

This 7-day tour visited nearly 50 geological locations, 2 archaeological sites, and covered over 800 miles. It was ably and enthusiastically led by Allen Fraser, and the 13 CGS members were equipped with an excellent set of detailed background and itinerary notes and geological maps. The theme was to explore the geodiversity of Shetland. The islands were awarded membership of the European and Global Geoparks Network in 2009.
The Shetland Islands are a monadnock or remnant of ancient Caledonian mountains stretching from the Appalachian Mountains to Scandinavia. Shetland consists of three different terranes, or blocks of crust with different geological histories, which are correlated with those on the Scottish mainland.

To the west is the oldest, Hebridean craton of Lewisian basement, Moine to the centre and Dalradian to the east, each separated by major faults; the Melby, Walls Boundary/ Great Glen Fault, and Nesting faults. Shetland's rocks have had a complex geological history, experiencing many rock cycles. The Caledonian orogeny has imparted a strong north-south lineation. The Dalradian succession has been folded in major monocline and tilted to give an almost vertical dip, younging to the east. The rocks then suffered regional metamorphism, the development of gneisses and intrusion of innumerable veins of granite. There are also several late Caledonian granites. Narrow outcrops, road building and coastal erosion have created large numbers of easily accessible geological locations. Some of the tour's highlights were; Dalradian limestones postulated as forming at the end of a global 'Snowball Earth' event; chisel marks on a cliff face where Vikings excavated soapstone for cooking vessels; chromite ore on Unst; the fault plane cliff of the Walls Boundary Fault; Devonian fossil fish skeletons; an erratic boulder from Tonsberg in Norway; huge blocks thrown up on to cliff tops at Esha Ness by storm waves and the spectacular variety of pebbles on beaches.

Day 1 Dalradian rocks of central Mainland

Allen Fraser explained the background to Shetland geology, with the aid of a new 'interpretive' geological map summarising much of the work of Prof Derek Flinn, who has researched Shetland rocks since the 1950s. Our introduction was to the Dalradian rocks which dominate the Shetland Mainland, two 'Cap Carbonate' limestones, an intrusive complex, two outcrops of Valayre gneiss and an exposure of the Nesting Fault. This latter has moved younger Dalradian rocks westwards over older Moine rocks, causing the sequence to be repeated (Figure 1).

Phyllites of the Clift Hills division at Scalloway viewpoint HU 412397.

Dark Dalradian metasediments cropping out in a roadside exposure were seen to be vertical, but very rotten with weathering. Flinn 2007:128 noted their very uniform 'inscrutable' appearance in the field. These rocks form much of the north-south upland core of Shetland. By contrast outcrops of limestone form linear valleys, some with lochs. These lower green farmed areas show clearly on Landsat images of Shetland. North from Scalloway the Tingwall valley follows the line of the Nesting Fault.

'Cap Carbonate' Whiteness Limestone at Quoyness, Loch of Strom 395485.

Yellowish-grey rock, which fizzed with acid, could be seen in contact with dark underlying rocks. These may be glacial deposits, a record of a 'Snowball Earth' global glaciation in the Proterozoic Period. The dolomitised and altered limestone has been interpreted as a cap carbonate, and is believed to have been chemically precipitated at the end of a snowball earth glaciation. Like other cap carbonates this limestone directly overlies glacial deposits, with abrupt lower and upper margins, and has unusual negative carbon ($^{13}C/^{12}C$) isotope values. Isotope analysis of these Shetland marbles has proved useful in documenting extreme climatic episodes of Neoproterozoic 'Snowball Earth' glaciation. Events recorded by the $^{13}C/^{12}C$ ratios within the Whiteness Limestone link the Shetland limestones to cap carbonate sediments from the 635Ma Marinoan glaciation in other parts of the world (Prave *et al* 2009).

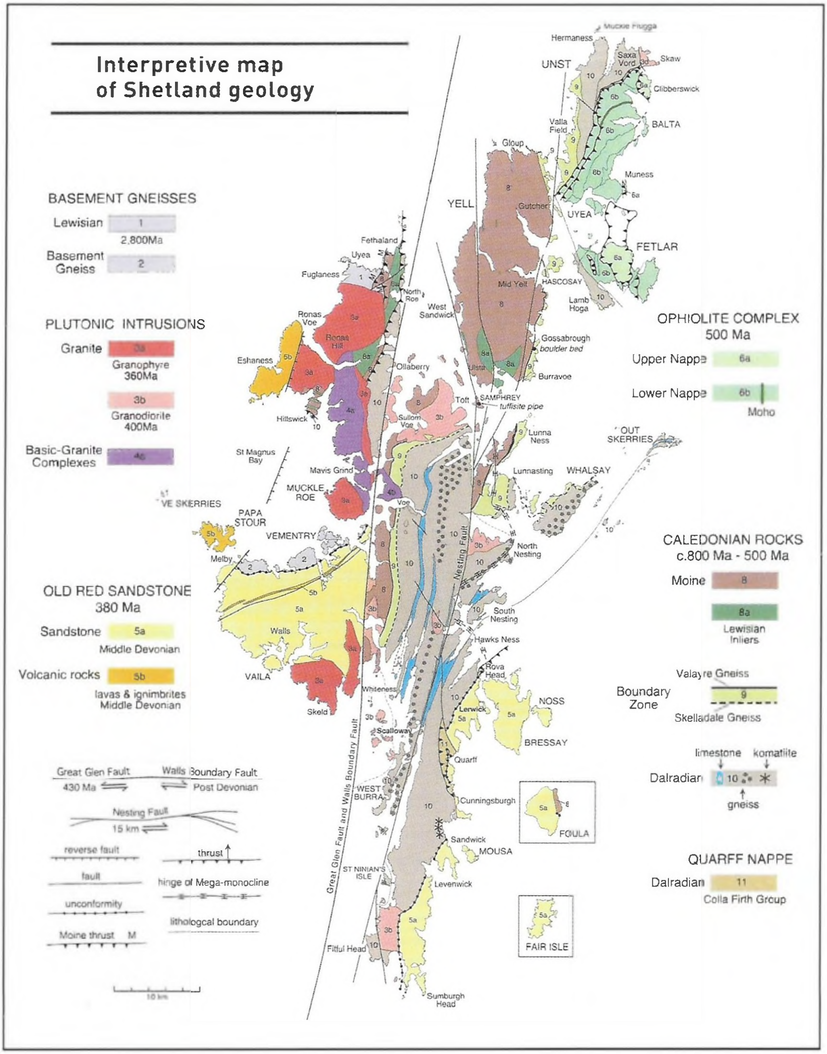


Figure 1 Interpretive map of Shetland geology by Professor Derek Flinn shows three terranes, with the oldest Hebridean to the west, Moine in the centre and Dalradian to the east, separated by major faults

Aith-Spiggie intrusive complex in Ward of Tumblin roadside quarry 342521. In this former roadstone quarry, a coarse-grained igneous intrusion, termed monzonite, was seen. The rock was characterised by aligned dark pyroxene crystals. The alignment was interpreted as stress at the time of emplacement. Adjacent rocks with unlineated crystals were possibly part of later aplite-like intrusions. Partly digested dark xenoliths, both large and small, were also seen. A fault plane with breccia at its foot was exposed. All the rocks in the quarry showed pervasive red weathered surfaces. The unweathered rock was said to be white though none was seen. Granite of this complex forms some minor islands to the south.

Valayre Gniess at Hill of Lee (west coast) 370822. This small roadside quarry is cut into augen gneiss, a narrow band of very distinctive rock, which extends for 70km, the full length of Shetland. The 'eyes' of microcline feldspar, which have been dated to 956Ma, weather out. The Valayre Gniess delineates the wedge of Boundary Zone rocks, but here is very weathered with no clear exposure of the junction with the older Moine rocks.

Weisdale Limestone, Kirkhouse Quarry, near Voe 404628. This limestone lies at the base of the Dalradian Whiteness Division. The limestone (marble) is vertical, folded and roughly banded due to rhythmic sedimentation, and is distorted with small irregular fault planes. It was deposited as mud/sand in a basin which deepened in the first opening of the Iapetus Ocean. Weisdale limestone is interpreted as a precursor to a cap carbonate of a global glaciation, (Prave *et al* 2009). In the adjacent Burn of Kirkhouse a thick quartz vein showed competent stretching and boudinage under tension. This exposure was not directly accessible due to high water levels.

Calc silicate Dalradian rocks across the Nesting Fault, to granite of the Graven Complex, Laxo shore 460835. On the east coast, opposite the ferry terminal to Whalsay, white calcite was seen in spectacular distorted Dalradian boulders on the beach. Associated with the Nesting Fault and considered as typical of Moine disturbance and thrusts, crush breccia, including a ½m block of dark weathered dyke, was seen. Further along the beach red granite, dated about 400Ma, with dark hornblende intrusions was seen.

Valayre Gneiss in Grutwick quarry on Lunna Ness peninsula 507706. A walk across rocks of the Yell Sound Division showed scenery of 'knockan and lochan', glacially scoured roches moutonnees. The end of one of these was cut into by the quarry track, exposing gneiss banded around microcline eyes, showing how the mineral grew and distorted the gneiss (Figure 2). The gneiss exposed here is more competent; the eyes do not weather out. Intrusions of dark dyke-like structures with edges of quartz and 'cooked' altered country rock were intriguing. Field relations were difficult to establish, and there was much discussion. The scope for further research seemed large.

Day 2 Upper Dalradian rocks of South West mainland

Possible pillow lavas on Mail beach, Cunningsburgh (east coast) 433279. On the narrow beach was a coastal section with greenish outcrops of altered basalt, the Dunrossness spilite. These have been interpreted as pillow lavas associated with early opening of Iapetus, but 'the pillow lavas are difficult to see in the field' (Flinn 2007). Rounded masses possibly pointing downwards could be discerned with some difficulty. The beach, like many on Shetland, had interesting pebbles.

Soapstone extraction Catpund 426272. A hillside track, cut in 1987 by a French company testing for a commercial talc quarry, showed a sequence of interesting exposures of rocks very variable in colour and texture. Light coloured soapstone in a breccia contrasted with greenish serpentinite within graphitic phyllite. Olivine, altered to serpentinite, here shows a rare texture called spinifex on weathered surfaces. These rocks were interpreted as lava flows of komatiite, erupted from the mantle at 1600°C and quickly quenched. Flinn 2007 interprets komatiite as submarine lava, from total melting of the mantle due to instantaneous rifting. In the quarry rocks are quite rotten, despite their Lower Ordovician/ Dalradian age. Soapstone, or steatite, in this locality was chiselled out by Vikings to make cooking pots and fishing weights. The site is designated of archaeological significance and has helpful interpretation boards.

Figure 2 'Eyes' of microcline in Valayre Gneiss, dated to 965Ma, make a distinctive delineator of the Boundary Zone across its 700km N-S narrow outcrop

Figure 3 An obduction thrust at Norwick Bay, north Unst. Nappes of mantle rock (harzburgite) were thrust against Dalradian metasediments of an ancient American continent as ophiolites during the closure of Iapetus Ocean

Figure 4 This 5cm layer of light coloured sand, exposed in a stream section on the east side of Sullom Voe, was deposited by a tsunami 7300 years ago generated by the Storegga submarine slide off Norway

Figure 5 The 20m high fault plane at Ollaberry of the Walls Boundary Fault, an extension of the Great Glen Fault, 'the best exposure of a major fault in Britain'. The rocks either side moved over 100km

Maywick beach west coast 378248. Maywick Bay is probably eroded along the Maywick fault, which is possibly a splay of the Nesting Fault. Across the east side of the bay are whitish cliffs of Dunrossness Phyllite, while to the west the rocks mapped as lower Bigton Grits appear as metasediments, a fine sand quartzite, bedded, with channel infill. The rocks are disrupted by many small faults. These include a possible fault-bounded block of strikingly red coloured sandy uniform deposit whose cement was so completely incompetent that the rock could be crumbled between the fingers, amazing for Dalradian rocks. Explanations possibly relate to alteration due to hydrothermal fluids rising up the fault plane from the nearby Spiggie granite.

Sand tombolo or ayre to St. Ninians Isle, 375206. This classic example of a sand spit joining an island to the mainland is said to be the largest active sand tombolo in Britain. The beach is about 500m long, curved to reflect wave crest lines from opposing directions, and is occasionally overtopped by waves. Sand was extracted in the 1970s, and the system is probably now operating on a diminishing sand supply.

Spiggie granite on Spiggie beach 368178. Visited on a later day in better weather, rocks of the Clift Hills division (Bigton Grits) could be seen across the small bay. The contact with the Spiggie granite could not be seen. When examined in the cliffs the granite was seen to be coarse and speckled with large phenocrysts, and later intruded by aplite and quartz veins and broken by minor faulting.

Copper mineralisation Garth's Ness 365112. The ore body, interpreted as island arc sulphide, and coloured as at Parys Mountain, Anglesey, had been worked in a failed attempt around 1800 to extract copper, though the ore may have been worked much earlier. Despite re-exposure for the Geopark, no copper ores were seen in the pouring rain and high wind.

Day 3 Ophiolite complex on Unst

A long day, with an 8.00 a.m. start for a drive across Mainland to the Yell ferry, a drive across Yell, brought alive by accounts of Allen's former home and school, and then the Unst ferry to Belmont. The ancient and complex rocks of Unst are now interpreted as several obducted nappes of mantle rock and ocean floor sediments thrust up as ophiolites during the closure of Iapetus Ocean. The ophiolite complex is tectonically cut up, is now vertical and much altered to serpentinite. Flinn (2001:90) notes that relationships are difficult to recognise in the field. The day was designed to provide a west-east section through the Moho.

Upper Nappe Harzburgite in contact with Norwick graphitic schist, Belmont Quarry 565005. Most of the quarry faces in the ferry car park are in serpentinite of the Upper Nappe of the mantle peridotite. Graphitised phyllite shattered rocks probably represent metamorphosed continental shelf sediments, and were seen in contact with the obduction thrust.

Layered gabbro and sheeted dykes, Mu Ness 683013. A walk to the south east coast was followed by a search for layered gabbro at the top of the Lower Nappe. Layering is considered to have occurred in a magma chamber. This was hard to see as the rocks were heavily lichen covered, though at a locality marked by a Geopark cairn, a layered dyke was apparent as harder and softer bands exposed on weathered surfaces. At neither of these localities was the geological history easily apparent in terms of what is exposed at the surface today.

A walk across the Moho at Nikka Vord 639107. Small flooded chromite mines and waste tips dot the hillside, while further up a slight break in slope approximates to the Moho, the crust/mantle boundary at the base of the magma chamber. The evidence here is orange coloured dunite/ harzburgite with no chromite ore, which represents the mantle, and crystals said to be pyroxene but weathered white to antigorite or serpentinised dunite.

Hagdale Chromite quarry 639103. The quarry operated for only 30 years, from 1839 to 1865. Chromite was used for yellow paints and dyes. The ore was crushed by horse drawn mill, recently restored and interpreted, though there was much discussion as to whether the interpretation was accurate. Geological interpretation boards were more useful, for the quarry and its wide range of unusual minerals; long crystals of antigorite, bright green of lizardite, purple of kammerite, yellow of pyrrotite, white aragonite, uvarovite and theophrasite.

Norwick beach 652147. Rocks exposed in a small headland on the beach revealed an obduction thrust, where mantle harzburgite of the ophiolite (Iapetus Ocean) was thrust up on to Dalradian metasediments of ancient America or Laurentia. A narrow band of serpentinite outcrops between the two (Figure 3).

Skaw granite, Skaw 661166. This granite, the most northerly granite in the British Isles, outcrops only on the NE coast of Unst and appears unrelated to other Shetland granites. Its contact with, and xenoliths of, dark phyllite could be seen. Skaw granite has prolific large tabular red K feldspar phenocrysts, which appear gneissose and oriented due to late deformation. It is late Caledonian in age, 425±26Ma (Flinn 2005), an effect of the final closure of Iapetus.

The day concluded with an excellent meal on Unst then a late evening return to Lerwick.

Day 4 Northmaven

Northmaven plutonic rocks were emplaced around 350Ma in the early Carboniferous, after the Caledonian orogeny. Both west and eastern margins are faulted. The intrusion probably covered a long time period, from early ring dykes, gabbro magma and later granite sills and dykes to the granophyre plug of Ronas Hill. The intrusion is cut by later dykes, crushed by the Walls Boundary Fault, together with scapolitization (hydrothermal alteration) of the rocks. Geological interpretation was made more difficult by inclement weather.

Stream section of tsunami sand layer, east side of Sullom Voe, 396728. In fierce onshore winds and rain, a section in a small stream in a shallow bay currently at 9m above sea level showed a thin 5cm layer of light-coloured coarse sand, with a sharp lower boundary (Figure 4). The underlying peat contained 15cm long pieces of wood, possibly pine from the Boreal period, below which a layer of sand and gravel, possibly outwash, could be seen. This distinctive and widespread sand layer was identified in 1993, dated at 5500BP and interpreted as a tsunami deposit (Birnie *et al* 1993). Bondevik *et al* 2003 & 2005 found the same sand layer all round Sullom Voe, with better outcrops on the western side, where they were able to trace the sand sheet from the shore to 9.2m above present sea level. Models suggest that the sand was deposited by a tsunami, generated by the Storegga submarine slide 7300BP off the continental slope of Norway, which overtopped a shallow coastal lake, which preserved the sand deposit. This interpretation is supported by evidence from eye witness accounts of recent tsunamis in Japan. A sand sheet is the most common tsunami deposit. The earlier 14C date may have been due to roots penetrating the dated peat and transferring modern atmospheric CO_2, thus reducing the 14C age. Holocene sea level was 10-15m lower, meaning that the tsunami reached 20 m above sea level at the time.

Gabbro of the Northmaven complex, intruded by granite sills, Virdins Quarry, Mavis Grind (the narrow gate) 340686. The upper quarry proved an excellent site, of dark gabbro, with granite veins, some with sharp chilled/ baked margins, and others with digested/ wavy margins with the growth of crystals. Veins of aplite clearly cut the gabbro in places, while the opposite face appeared to show gradation of dark greyish gabbro at the base to pinkish granite above, interpreted as two magma chambers. The quarry had many interesting features, provoking many discussions, and was felt to be well worth Geopark status. We were impressed by the interpretation signs and a most attractive interpretive rock wall constructed of local rocks.

Ultrabasic and granite contact with scapolite veining, Haggrister quarry, 337705. This small quarry exposed highly decorative rocks; pink granite with vertical cracks and intrusions of black ultrabasic rock with alteration to white scapolite crystals.

Walls Boundary Fault, Ollaberry, Sullom Voe 371805-372810. Visited later in glorious weather, the Walls Boundary Fault has had a long and complex history, linked with the Great Glen Fault, and was active from Devonian to Jurassic times, moving over 100km. It lies in a broad crush zone of shattered rock. A walk across the headland where a shallow depression marked the line of the fault, showed red granite cliffs on one side, and dark Dalradian schist at the other side of the fault. A scramble down to the shore at Back Sand Bay showed a massive smooth cliff of the fault plane, covered in haematite-stained fault gouge (Figure 5). Dalradian metasediment rocks exposed along the shore show intense and complex folding on a variety of scales. Competent white quartzite folded without fracture, the folds being lubricated by black graphitic phyllite, while the phyllites show smaller-scale crenulate zig-zag folding.

Roadside exposure of Ronas Hill granophyre, The Brig 356864. The granophyre contained some xenoliths of possible Lewisian gneiss, and dark dolerite, intruded by a dolerite dyke with good spheroidal weathering.

Ronas Hill granophyre and altered schist, Beorgs of Housetter, 362850. Ronas Hill granophyre could be seen in the hill above this roadstone quarry. The quarry had worked gneiss/ schist altered to green serpentinite along a fault.

A possible additional visit to see banded Lewisian Gneiss at Skea on Yell Sound was abandoned in the face of inclement weather.

Day 5 SE Shetland Old Red Sandstone Sedimentary Basin

This day was a north-south traverse in the youngest sedimentary basin of Shetland, formed in Upper Devonian times, around 375Ma when Shetland lay at about 20°S. In this NNW-SSE elongated basin, possibly a rift valley, sedimentation varied laterally and with time. Earlier beds were coarser river-lain deposits, with coarse scree and alluvial fan deposition to the north, eroded from Dalradian schists and gneisses of the Caledonian mountains, braided rivers and lakes. The sandstones are arkosic, suggesting erosion in a semi-arid environment followed by rapid transport and burial. To the south and east are finer deposits, where lacustrine conditions occurred. Mud cracks show that the lakes periodically dried up, while wave action in the ephemeral lakes left ripple marks. Cyclic sedimentation has resulted in repeated silt and limestone layers. Fish fossils were preserved, probably as the lakes became hot and anoxic.

Alluvial fan conglomerate, Scottle Holm, north of Lerwick 471449. On a headland north of Lerwick's recycling point, cliffs of rounded conglomerate contain finer sandstone layers with small scale cross bedding (Figure 6). Pebbles are mostly of quartzite and granite, and the deposit is unsorted and matrix-supported in part. Changing conditions in the river channels left lenses of finer grey sand, now broken by small faults. The headland is cut by a fault, and small fault planes cutting through pebbles could be seen. The rocks dip generally to the north, possibly related to the Bressay folding, which brought up Carboniferous magma and led to copper mineralisation. The sediments were deposited as thick gravel sheets by water flowing east and north in flash floods.

Basal breccia, Quarff, 436356. Scree of unsorted angular blocks of reddish granite and schists, some imbricated, is exposed on the hillside. An uneven unconformity surface with the underlying Quarff Nappe metasediments, at the base of the exposure, shows that the scree was deposited in a mountainous environment. The breccia would originally have covered the conglomerate seen previously, but is now part of an upthrust.

From near this site was a view of a large valley cutting the Clift Hills to Wester Quarff. Despite its apparent U-shaped cross profile, this is not thought to be ice eroded. It lies in the wrong direction for known ice movement, (Peach and Horne mapped out Shetland ice movements in 1879) and insufficient ice accumulated on Shetland to carve a valley of this magnitude. The valley is thought by Flinn to be a relic Devonian river valley.

Figure 6 Old Red Sandstone alluvial fan conglomerate, north of Lerwick

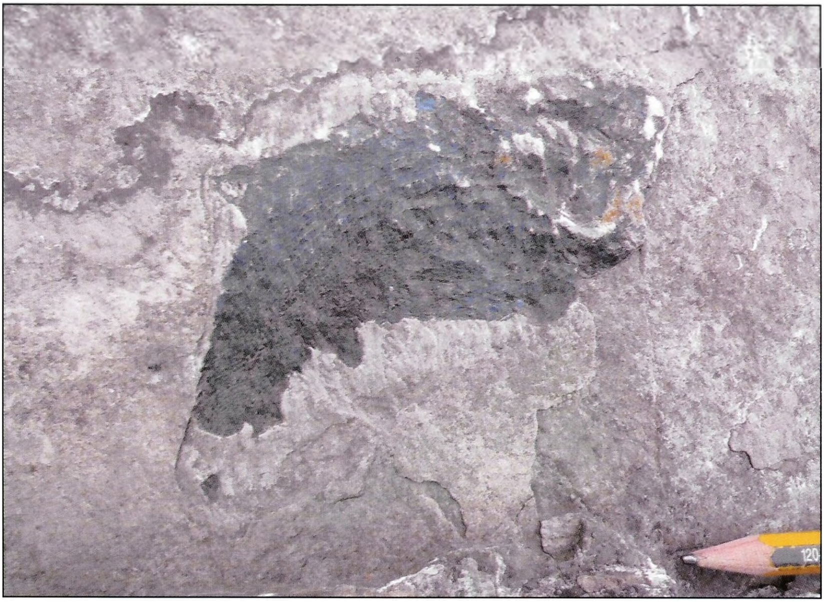


Figure 7 *Stegotrachelus finlayi,* an early Devonian armoured fish, Exnaboe Fish Beds, SE Shetland

Figure 8 Grind of the Navir, a fault gap in the ignimbrite of the Esha Ness cliffs, excavated by extreme storm waves

Figure 9 ORS lavas erupted into sandstones have produced some perplexing structures, at this well interpreted Geopark site on Braewick beach

The Dalsetter erratic 403160. On a round boulder in a rough stone wall along a minor road, despite its lichen cover, reddish crystals of feldspar could be seen. The rock is believed to have been excavated from glacial till during road repairs in the 1930s. Microscopic examination of the feldspar crystals reveals an unusual structure identified only in Tonsbergite, a type of red syenite, found only at Tonsberg, near Larvik in southern Norway. This provides the only known evidence that ice from Norway reached Shetland. As no Norway ice reached Shetland during the Devensian 25,000 years BP, the erratic records an earlier glaciation, possibly 100,000 years ago.

Reworked alluvial fan conglomerate, Ness of Burgi 338087. A walk from Scatness south to the Iron Age blockhouse of Ness of Burgi revealed many fine coastal sections of interbedded layers of finer rounded pebbles, and cross bedded sands with ripples and desiccation cracks.

Lake shore flagstones and Exnaboe Fish Beds, Shingly Geo to Broken Bough 406124 - 409135. A walk along the cliff top revealed a section in a variety of sediments formed along a Mid Devonian lake shore. Fine dark sandstones with siltstones have been interpreted as lake marginal sediments. Ripple/cross laminated siltstones with plant remains suggest an environment exposed to wave action. Laminated calcareous silt and mudstones, with fish remains are found in darker grey laminated rocks. A 3m thick unit of fish-bearing lacustrine laminite was discovered by Finlay in 1926. Now a GCR site, complete carbonised skeletons can still be seen on exposed surfaces of eroded blocks. The pattern of scales and fins identify some of these as *Stegotrachelus finlayi,* a mid-Devonian armoured fish found only in Shetland, (Figure 7), although the commonest fish is *Dipterus*, an early lung fish. Further to the north the cliffs show larger scale cross bedding in arkosic sandstones, interpreted as desert barchan dunes formed by a prevailing southerly wind.

Day 6 Volcanic rocks of the Esha Ness peninsula

Volcanic rocks in the Old Red Sandstone Melby basin, west of the Melby Fault are now folded into a gentle NNE-SSW syncline, and the sequence plunges to the south west. An ignimbrite in the sequence has been dated as Upper Devonian 365Ma. The cliff tops reveal fine sections of lava flows and pyroclastic rocks, whose large scale features are well preserved, although in detail the rocks have been altered, with the development of secondary minerals. A section along the NW coast crosses progressively older flows and presents a cross section through the flanks of a volcano. The southern coast of Esha Ness cuts through progressively younger rocks. Here the Melby fault is obscured by till and beach deposits, but at Braewick a small ORS inlier is exposed.

The many faults are exploited by the sea to form a highly indented coast; the cliffs are honeycombed with geos, stacks and blow-holes. Esha Ness cliffs are prone to formidable wave action. Wave attack has focussed on progressively higher parts of the coastline as the sea level around Shetland has risen. The cliffs of Esha Ness drop into deep water which precludes basal cliff abrasion. Near sea level is a zone of inundation, with a spray zone above, where water droplets from breaking waves smite the cliffs. Waves have a large Atlantic fetch and fierce storm waves up to 20m high can approach the shore, while wave action reaches 40m on some cliffs. These storm waves strip vegetation and loose debris, and throw up huge blocks and rock fragments on to cliff tops. These cliff top storm deposits have been the focus of some recent research.

Andesitic lavas, agglomerate and tuff, Lighthouse 204782-205785. Glacial striae on cliff top bedrock, indicating a NW ice flow, were unconvincing. The cliff top is littered with a variety of 'erratic' rocks thrown up by storm waves. Below the lighthouse pillow/eye shaped structures could be seen in the cliffs. The deep blowhole here is possibly formed by the collapse of a lava conduit. From the lighthouse a small offshore island, Muckle Ossa stack, could be seen, which may have been the source of the volcanism.

Andesitic tuff, Calder's Geo 209787. The cliffs here expose layers of lava, pillows, tuff and agglomerate. The well jointed rocks are exploited by the sea to form a very long, deep and narrow inlet with, at its head, a cobble beach, only mobilised in extreme storm events. The many geos are possibly a reflection of very deep water on exposed coasts.

Basalt lava and tuff, Drid Geo to Moo Stack 209790-209793. Successive lava flows with pancake surfaces, showing that upper lava flows filled in underlying channels.

Lava flows and cliff collapse, Blackhead of Beigeo 211799. The cliffs here are composed of relatively thin lava flows, separated from thicker underlying flows by a thick band of soft light green material, which make acts as a zone of wetness. The upper cliff has collapsed to leave a sort of amphitheatre halfway up the cliff face. Allen took the more intrepid of the party on a descent, by a small scramble to a lava layer beneath the cliff. This allowed examination of the lava structure, the green clay and lighter, possibly rhyolitic lava. The lower lava surface was domed and irregular. We were astonished at the fresh appearance of the scoriaceous lava tops. Storm erosion constantly reveals new faces.

Ignimbrite and storm beach, Grind of the Navir 213804. At this exceptional locality the sea has eroded a 10m wide and 13m high gap, or 'gate', in the cliffs 26m above sea level, along a fault in heavily jointed rhyolitic welded ignimbrite (Figure 8). Storm wave action, concentrated through this opening and acting directly on the upper cliffs, exploits the joints, tears out rocks, leaving fresh scars, splits rocks into large blocks over 2m across, which are then carried an amazing 80m inland by the force of the waves. The resulting storm beach (cliff top storm deposit) is an exceptional height, 15m, above sea level, in the air throw zone above wave splash, and is composed of large angular unsorted imbricated blocks up to 3m long. These exceptional cliff top storm deposits, for which the Shetland Museum holds a photographic record for 100 years, hold an archive of extreme storm events (Hall *et al* 2006 & 2008).

Collapsed cave and geo, Hols o' Scraada 213794. This geo and partially collapsed sea cave, passed on our return, extends over 100m inland. The fields here have gravel spreads thrown far inland by extreme storm waves.

Beach section, Braewick 245786-244784. Purple vesicular lavas have erupted into dark red sandstones, producing a variety of perplexing features (Figure 9). Interpretation boards here were excellent, imaginatively made from ground up rock set in resin to show the relationships. A leaflet for 'Shetland's Volcano Heritage Trail' explained that eruptions caused thunderstorms creating lakes in which banded red/grey sandstones were deposited. These contain lapilli. Jumbled rocks in the cliff section are interpreted as lahar or mudflow deposits.

Day 7 Geology meets Archaeology

Clickimin Broch, Lerwick 464408. Allen's local knowledge and reconstructions greatly aided this guided visit. The broch is a series of circular structures with a surrounding defensive ditch. It was built from local Old Red Sandstone in the late Iron Age around 300 BC. Inside is an inner wheelhouse, which was built later around 200 BC, and the well-made stone steps within the wall were possibly used only during construction. Broch building has been related to a period of global climate cooling. Their exact function is the subject of much debate; they were possibly grain stores. They reveal a highly complex society; quarrying was to order. The rocks utilised in their construction were carefully chosen, their size and shape being estimated prior to quarrying out; a process which possibly took 2-3 years. The precision of construction was impressive.

Viewpoint over Mousa Broch 430261. In a lay-by are interpretation boards, for the rather distant broch on the isle of Mousa, and for Sandwick, once Shetland's largest copper mine. There is no tin ore on Shetland, so it is thought that tin must have come from Cornwall for Bronze Age tools.

Scatness Iron Age Village and Broch 389107. Discovered only in 1976 when cut into by an airport road, excavations have revealed a complex series of round stone houses around a central broch. The stonework is of exceptional quality, with the rocks probably brought from Caithness, and expertly laid. It was occupied and altered many times, as explained by our excellent guide. We took shelter from the strong wind in a reconstruction, where, over a peat fire, Pictish implements were explained by members of Shetland's 'Living History Team'.

A final visit to the excellent Lerwick Museum, which opened in 2002, rounded off the Geo-tour. Shetland geology is well interpreted and specimens were seen, together with reminders of the many localities visited.

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Further reading

Shetland landscape web site records many of the localities visited and has a full bibliography

This account was provided by Sylvia Woodhead.

* * *

BORROWDALE VOLCANIC GROUP ROCKS ON HIGH RIGG AND ST JOHN'S IN THE VALE

Leader: Sue Loughlin (British Geological Survey, Edinburgh)

Saturday June 12th 2010

Unfortunately this planned visit had to be cancelled.

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EXCURSION REPORTS 2011

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THE SKIDDAW GROUP ABOVE LOWESWATER

Leader: Alan Smith (CGS)

Wednesday May 4th 2011

Twenty-two members met in the car park next to Loweswater on a glorious spring evening; Dr. Smith explained that his co-leader, Mervyn Dodd, was unable to attend.

The party walked to an old quarry on Darling Fell (NY 1255 2222). This lies in the Loweswater Formation which is 500 - 600m thick in the area. The beds in the quarry where relatively undisturbed, displaying very gentle dips to the west. The rocks are grey turbidite sandstones and siltstones which are well-bedded with some more massive units. The view across Loweswater to Burnbank Fell also showed the Loweswater Formation with the same dips clearly visible in old quarries. These are not landslips despite their appearance.

The quarry provided a good view of Loweswater with its anomalous drainage inwards towards the centre of the Lake District. Evidence from striations and Ennerdale Granophyre erratics shows that ice moved outwards along the valley away from the Lake District, meeting other ice on the coastal plain. The lake surface is 121m asl and it is 16m deep. The col at the north western end of the lake lies at 153m asl. This is probably a rock barrier with very little moraine. The other end of the lake is impounded by alluvial fans. The Holme Beck fan was clearly visible. This low angle fan of Skiddaw group debris has been built out into the lake. The catchment area is only 1.5km^2. The High Nook Beck fan has developed from a catchment of 5.8km^2. The Mosedale Beck fan, not visible from this location, has a catchment of 6.8km^2. The fans probably developed soon after the glaciation.

The party then examined a series of natural exposures further along the fell to the south east, keeping to a similar altitude. At NY 1276 2211 there was little change in the rocks which still dipped gently to the north west. However further on the deformed rocks of the Loweswater Formation were in marked contrast to the undisturbed beds seen previously. These lie close to the axis of the Loweswater anticline. At NY 1279 2203 the dip was getting progressively steeper towards the south east, culminating in vertical beds with a north east – south west strike. At NY 1275 2203 there was a synclinal axis trending east north east – west south west with the vertical beds (seen previously) on the north west side and dipping beds on the south east side. An identical syncline was seen a little further on at NY 1274 2200, however there was no intervening anticlinal axis exposed.

Some members visited a disused quarry a little lower down the slope at NY 1268 2205. Here distorted beds had been thrust over beds dipping gently to the north west. The thrust plane dipped to the west north west.

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THE BORROWDALE VOLCANIC GROUP AT SEATHWAITE

Leader: Alan Smith (CGS)

Saturday May 21st 2011

The party met at Seathwaite Bridge (NY 239128) where the leader explained that the purpose of the short morning excursion was to examine key localities close to the junction of the upper and lower Borrowdale Volcanic Group (BVG) near to the valley floor.

The lower BVG crops out in the more northerly part of Borrowdale and is dominated by effusive activity which chiefly produced andesitic lavas and sills with some interbedded volcaniclastic and sedimentary and primary tuff horizons. The upper BVG in the south of Borrowdale was a product of explosive activity and is mainly silicic pyroclastic fall, flow and surge deposits. The excursion began on the north west side of the valley, walking from north east to south west towards the Borrowdale Yews and Sour Milk Gill, to progressively younger rocks.

The first part of the walk was on the largely debris covered slopes of the lower BVG, the south east side of the valley being formed from the upper BVG. Looking south, the steep southerly dip of the bedded upper BVG was clearly visible.

The first exposure examined was close to the Borrowdale Yews. This was a fairly coarse, massive tuff of the lower BVG. Near to this point, in the river bed, a large block showed a coarse, matrix-supported agglomerate. Just before Sour Milk Gill was reached, an exposure (possibly a very large block) showed a fine, flinty, greenish blue ash at the base with a coarse, angular breccia above.

South of Sour Milk Gill the southerly dipping succession in the upper BVG was examined. The first rock examined was a lahar deposit which showed large, rounded and angular, matrix-supported clasts. (At this point the leader pointed out the andesitic sill on the skyline close to the threshold of Gillercomb.) The next slab above was a fine, thinly-bedded tuff, which probably settled from suspension in water. Evidence of currents was provided by a 25cm thick, strongly cross bedded layer and other layers showing ripple marks. The exposure above this showed another lahar deposit which contained an andesite boulder about 2m across. Two thirds of the way up this slope is the site of a rare trace fossil find. The fossil, now housed at the BGS in Keyworth, is of tracks of a millipede-like creature made in wet ash. This is one of the few fossil finds in the BVG. The leader passed around a photograph of the fossil and posed the question: did the creature that made the tracks live on land?

The party then made its way to the foot of the slope to examine a series of loose boulders. These showed finely laminated sediment with some extremely fine, pale layers. This represents an ash fall into water. Some ripple marks indicate weak currents. The deposit shows some minor faults, erosional horizons and (not seen on this visit), rip-up clasts.

To complete the visit the party walked via Seathwaite Farm to the east side of the valley at NY 237121. Here the well-bedded tuffs of the Whorneyside Formation have been interpreted as a subaerial deposit. A characteristic feature of the formation is volcanic bombs within the layered ash with one just visible beneath a cover of moss on the rock face at this location. This formation provides a marker horizon at the base of the upper BVG. The leader noted that higher up the fellside at Capell Crag the formation is cut by stream channels which have been draped by the next airfall tuff.

Views to the north west showed the tips and adits of the Seathwaite graphite mine along a fault which continues to Burtness Combe.

* * *

LITTLE MELL FELL

Leader: John Rodgers (CGS)

Wednesday June 8th 2011

This evening excursion was arranged to finish the trip to this area that was cut short in 2010 because of bad weather. Members gathered at The Hause on the minor road south of the fell (NY 425235), approximately on the boundary between the Mell Fell Conglomerate and the Borrowdale Volcanic Group rocks of Priest's Crag. Immediately over the style is a small patch of woodland with a slightly raised ridge that extends downhill with a roughly east – west strike. Blocks of hard, fine-grained, black material were found at the western edge of this feature and a brief but inconclusive discussion followed on whether or not this represents an exposure of a dyke, although there is no indication of such on the BGS sheet of the area.

The group then made the short but steep ascent of the fell, on this occasion free from summit cloud. From here the main geological and landscape features were described. The low areas of drift covered ground around Ullswater are where the softer underlying Skiddaw Group rocks have been brought up in the core of a large anticlinal fold, the axis of which runs more or less down the centre of the lake. The elevated, rugged topography to the south is composed of Borrowdale Volcanioc Group rocks, consisting mainly of andesites with inter-bedded pyroclastics. Contrasting with this area is the area of rounded rolling hills, stretching from Great Mell Fell in the west to Dunmallard Hill in the east. This is the outcrop of the Mell Fell Conglomerate, an exposure of which was examined halfway down the fell on the eastern side, where pebbles and cobbles, up to 20cm in size, were contained in a red-stained, sandy matrix. The origin of these formations is described in these Proceedings, in the account of the visit in July 2010. Mention was also made of the limestone escarpment of Dacre Bank to the north which forms part of the Carboniferous fringe around the north eastern Lake District.

Further discussion took place about the effect of the Howtown strike-slip fault offsetting the axis of the Ullswater anticline and ultimately being the reason for the dog-leg shape of the central section of the lake. There was also speculation about the glacial and post-glacial processes that may have been responsible for the wide valley between Great and

Little Mell Fells, and for the apparent diversion of Aira Beck from a north easterly direction to a southerly one, in which it has cut through the hard, volcanic ridge of Gowbarrow Fell.

To finish the evening, a descent was made to the prominent north-south trending low ridge on the eastern side of the fell. This was one of three mafic dykes displayed on the BGS sheet and the exposure of which is emphasised by the ditch of a small stream which has been deflected along the relatively impervious barrier of the intrusion on its uphill side. Another of these intrusions was examined on the previous year's visit in the small, disused quarry just below this site. Members returned to the vehicles via the minor road past the caravan sites and then back up the steep road back to The Hause.

* * *

THE OLD MINES OF THE WHITEHAVEN AREA

Leader: John Brown (CGS)

Sunday June 26th 2011

14 members met in the cliff top car park next to the old Haig Pit. The aim of the excursion was to look at the sites of a number of the old mines, to appreciate their geological setting and the scale of the colliery undertakings. The leader explained that there were 140 shafts and bearmouths in the vicinity of the town which were gradually joined underground. Working began at outcrop and gradually moved to the concealed and undersea areas. The position of the various seams was demonstrated using cross sections from the 1929 Whitehaven Memoir. Mining started in the 1600s. Annual production in the 1700s was about 10,000 tons, increasing to half a million tons by the late 1800s.

Workings beneath the town are divided by a northwest – southeast trending fault, the 'Norway Dyke'. The Whingill area to the east was originally mined separately to the Howgill area to the west but the two were eventually connected.

The party made its way down to the coast to examine the remains of Saltom Pit. The shaft was a figure of eight, with a central partition. This was sunk in 1729 to the Main Band at 456 feet and later deepened (c.1820) to the Sixquarters horizon at 838 feet. Coal was brought to the shaft top 49 feet above sea level but was then raised to the cliff top via another shaft. The Ravenhill Fault just to the north has been responsible for a number of slope failures. These have partially covered the shaft with debris which may engulf the whole of the site in the future. Saltom Pit played a significant part in the drainage of the Whitehaven Collieries, being the furthest down the dip of all the mines. It drained a big area including James Pit (on the other side of the Norway Dyke) and the Preston Isle area. Coaling ceased in 1848 but the pit stayed open for pumping until 1866 when Wellington Pit took over. When the old buildings were examined, the leader pointed out that they housed a winding engine and not a beam engine as wrongly stated in some literature.

The party then walked south along the old colliery railway line (used to take waste from Haig Pit to be tipped on the coast) towards the site of the Ladysmith/Croft Pit. This lies within the confines of the former Marchon chemical works site and no evidence of the site remains. The mine was worked until December 1931. There was some speculation regarding the coalfield to the south, concealed beneath Permo-Triassic rocks. The leader noted that the Main Band was at about 3000 feet depth in the St. Bees area and that there was drilling in the St. Bees-Rottington area in the 1970s. The site of the anhydrite mine in the Permo-Triassic behind the former Marchon works was noted. The leader pointed out that this was a Davy Lamp mine because of gas seeping from the Coal Measures beneath.

In the Woodhouse estate, the leader pointed out the area of the small Greenbank Colliery, worked from shallow pits and day holes. He explained how, up to the closure of the last mine, water levels in the old shafts throughout the area were regularly monitored to give information on drainage. One of these, Fish Pit, was in the garden of a house at Woodhouse. The party paused at the top of Howgill, site of the Howgill Colliery where the upper seams were mined at outcrop. One issue for all the mines in the Kells-Woodhouse-Greenbank area was getting the coal down to the main railway in the valley bottom for shipment to the docks or elsewhere. The Croft Pit lowered wagons down an incline, late to be re-used by the Marchon chemical works.

The party crossed the top of the Croft Incline and made its way into the town via the Parker Pit Wagonway – used to take coal from some of the earliest mines to the valley floor. Along the Wagonway, the site of Arrowthwaite Pit (pre-1742) is marked by a monument. Further down, the site of Parker Pit is difficult to trace and may have occupied a flatter area on the steep slope.

Looking over the town, the leader explained the system of water levels which drained the mines on the Howgill side of the Norway Dyke and discharged into Pow Beck. The Bannock Band drained by gravity but water from the Main Band (below the level of the valley floor) had to be pumped up to the Bannock.

At the bottom of Monkwray Brow, the leader pointed out a gas discharge pipe at the Ginns Engine Pit, one of several still functioning in the area.

Just south of Coach Road, the site of the Pottery Road/Ginns bearmouth was visited. This was an adit into the Bannock Band and is now a gas outlet. Until 1969 it could be used as an emergency egress from the mines system.

The party then walked along Coach Road and up the main path through Crow Park, crossing the outcrop of the Main Band. The leader pointed out the site, close to Somerset House, of a fatal inrush in the late 1700s. Further along the path, and beyond Crow Park, the leader pointed out various features on the Howgill side. These included the Pedlar, Haig, Duke and Wellington Pit sites, the site of the Newtown housing, the Parker Pit Wagonway which the party has earlier walked down and the 1813 and 1923 Inclines, used to bring coal down to the railway and docks.

The site of James Pit, opened c.1800, was visited in James Pit Road! At one point this was used as the upcast shaft for William Pit. The main road down from the Harras Moor/Loop Road area is the tramway down from George and Lady Pits. The wagons then crossed the Bransty Arch over Tangier Street to get to the docks. The water level which drained the pits on the Whingill side (although not James Pit) had its discharge close to the bend in the New Road at the bottom of Wheelbarrow Brow.

After crossing the docks system, the party visited the site of Wellington Pit. The sites of Number 1 and 2 shafts are in the car park and that of Number 3 shaft is just below the Candlestick. The Candlestick was a boiler flue, although in more recent times vented gas has been diverted to exit via the chimney.

The party then crossed the 1923 and 1813 Inclines to Duke Pit. The leader pointed out the sites of the two shafts, one of which was used as an upcast shaft for Wellington Pit. The famous fan house was examined, the leader explaining that the fan succeeded furnace ventilation.

After walking back up the brow past the site of King Pit to the starting point, the leader explained some of the factors that led to the final closure of the last mine (Haig Pit) in 1985. He was warmly thanked for an exceptionally enjoyable and detailed visit, of which this account is merely a short summary.

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KNOCKMURTON MINES

Leader: David Powell (CGS)

Wednesday July 6th 2011

Twenty-two members met at the Leaps above Kirkland Village (NY0871182) on a sunny evening which later turned to rain and a visit from the local midges! The purpose of the visit was to examine the evidence of the Knockmurton hematite mines in the Harris Side area of Knockmurton Fell. This is the earliest part of the Kelton and Knockmurton Iron Mines complex. The first working of iron ore at Knockmurton was in 1852 with a lease granted on the 1st January 1852 (officially dated 20th February 1856), to Thomas Carmichael by the Lords of Lamplugh, for 14 years. The mine ownership changed over the life of the mine – John Sterling from 1866 to 1868, followed by William Baird and Co. from 1869 until 1914. During that time the mine stood idle for some years. The mines closed in 1914 and were reopened in 1920 by Fergus Watson, but did not last long and finally closed in 1923. William Baird had the most impact on the whole mine complex. This company sank three shafts at Kelton Fell and built the railway from Rowrah to the pit head.

The ore occurred in lenticular form as veins in the Loweswater Formation of the Skiddaw Group. The veins at Knockmurton were much thinner than at Kelton, very rarely opening out to much more than 6 feet and often pinching out into 3 inch strings. The bearing of the veins is north west – south east and the hade is towards the north east, varying from 45° to 80°. The veins can be traced on the hillside by the lines of old tips. The mining method used in this mine was mainly overhead stoping and this can be seen on the hill by the different levels.

The party started the excursion by viewing the mine from Cross Rigg, looking over the valley of Leaps Beck to Harris Side. There are five veins on the face of Harris Side named A, B, C, D and E, lettering from the east to the west in a total distance of about 500 yards. The trenching that can be seen at the top of the hill is the early mining and has followed the vein through the hill. There was a separate mine on the other side of the hill (North West Mine) this gives the indication that the veins go right through the hill. From here you can see the waste heaps from the different mine adits. Some of the adits are now hidden inside the forest along with the manager's house, workshops and stables foundations. The approach to the mine was along the old abandoned Rowrah and Kelton Fell (Mineral) Railway built by William Baird and opened January 1877. Leaving the old railway, the party continued on the forest road past the suspected location of E vein and the west drifts (later No. 13 workings), and the new deep level of 1861. The location of the Smithy was also pointed out. The party entered the forest and examined the old accommodation foundations. Not far from here the low bottom level of 1861 and then the Knockmurton No. 1 shaft were found. Continuing through the forest, two more levels were found and evidence of subsidence. The party then moved out of the forest on to the footpath that took us up to Cogra Moss. From here there is a panoramic view of the old reservoir and you can see the old waste heaps from the Cogra Moss adit. This adit was to prospect the ground between here and the mine and for drainage. At this point the midges discovered the party which then retreated back down the forest road to the forest gate. At the gate the party turned up the tree line to the Cat Gallows mine (B vein) and investigated the waste heaps. There is more evidence of subsidence in this area. The weather had taken a turn for the worse and a rather wet drizzle was falling. The party cut across the fell to the Jack Roll level (C & D veins) and then climbed up the early trench workings but by now the rain and wind were not very pleasant and the excursion was terminated and everyone retreated to the cars!

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THE COAL MEASURES NORTH OF WHITEHAVEN

Leader: David Kelly (CGS)

Saturday July 9th 2011

A group of about 15 members met just north of Whitehaven railway station and spent the morning looking at the Bransty cliffs, north and south of Redness Point. The leader explained that our knowledge of the Coal Measures in west Cumbria has come from the extensive deep mines, which worked up until 1985, and their associated boreholes. Knowledge was extended in the 1970s, by the new exposures in open cast workings. This allowed a more detailed correlation across the district, particularly of the thin seams not worked in the deep mines. The BGS commenced re-mapping of the area in the 1980s, assisted by new information from geophysical logging. The *Geology of West Cumbria* district memoir published in 1997 summarises current knowledge. Today exposures of the Coal Measures are mostly limited to the coast.

The Coal Measures are 300m - 400m thick onshore but possibly up to 1000m thick offshore on the north west side of the Maryport Fault which appears to have been active during deposition, allowing thicker accumulations as the Solway Basin subsided more rapidly.

The Coal Measures were deposited on a gently subsiding delta plain. Within this overall context a series of sub-environments can be identified and the purpose of the visit was to examine these.

The first locality visited was the site of William Pit shafts (NX 9750 1880). William Pit closed in 1955 after an explosion which occurred on August 15th 1947, resulting in 104 deaths. The party viewed the memorial to the miners and John Brown explained how the mine was worked. There were two circular shafts. The downcast shaft was 3.6 metres in diameter and was used for the winding of men, coal and materials. The upcast shaft was 4.2 metres in diameter, and was used as a second means of egress but not for winding coal.

The shafts were sunk in c.1806 to the Sixquarters Seam at a depth of 272 metres. The lower parts of the shafts were abandoned and winding was carried on from an inset 10 metres below the Main Band Seam which was intersected by the shafts at a depth of 190 metres. A roadway connected the workings of the William Pit with those of Wellington Pit. The Bannock

Band, Main Band and Sixquarters have been worked at William. The workings in the Main Band were the most extensive. Working was mostly by the board and pillar method.

In 1933 the Whitehaven Coal Company sold the pits to Messrs. Priestman Whitehaven Collieries, Ltd. In 1936, the pits were acquired by the Cumberland Coal Company (Whitehaven) Ltd. At this time William Pit had been standing idle for two years and was re-opened by the new owners. With the nationalisation of the coal mines, the ownership passed to the National Coal Board, and William Pit became a unit in the No. 10 or Cumberland Area of the Northern Division of the Board.

William Pit had a history of trouble from fires due to spontaneous combustion. An explosion in 1941 occurred in a large sealed off area of workings in the Main Band which had been abandoned in 1928. From the re-opening of the pit in 1937 until June 1941, the output came from longwall workings in the Bannock Band. The workings in this seam were also sealed off and abandoned at that time, following the explosion which occurred in old workings in the Main Band Seam which seriously affected the workings in the Bannock Band. Work was then started in the Sixquarters Seam from a cross-measure drift which had previously been driven to catch this seam. Thereafter it was from the Sixquarters Seam that practically the whole of the coal output after 1941 was obtained.

From the site of William Pit, the cliff section is visible to the right of a warehouse. This shows the Whitehaven Sandstone Formation, a red bed succession up to 300m thick overlying the true Coal Measures, with an erosional base demonstrated by boreholes and not at outcrop. The purple sandstone beds seen in the cliffs north and south of Whitehaven are the Whitehaven Sandstone Member within this formation.

The Whitehaven Sandstone Member is fine to medium grained with strong cross bedding and ripple lamination. There is tabular cross bedding showing current directions to the south east. The beds are interpreted as sand bars migrating in a large, probably braided, compound channel system. The purple colour is due to secondary oxidation due to the onset of hot, dry conditions at the end of the Carboniferous.

The party then walked further along the coastal path to the north. This follows the raised beach which was the route of a horse-drawn tramway built along the foot of the cliffs to convey coal from the pit at Parton which opened shortly after 1817, to the port of Whitehaven. The coal was mined some distance inland and brought to Parton along a tunnel called the Parton Drift, which also drained the mine workings. The colliery closed early in the 20th Century.

There is an almost continuous cliff section from the disused quarry (NX 9748 1904), along the cliffs for about 500m to north. The section is too dangerous to view close to the cliff. The quarries were used for the building of Whitehaven docks and the unstable face threatens the houses at its foot. The first 20m high quarry section shows the same sandstone seen at William Pit. There are three units separated by erosional surfaces with lag gravels. The individual beds are not continuous over large distances and are seen to thin out and form lens-shaped cross sections. This is due to deposition in a series of migrating bars in a braided channel system.

The party examined the cliffs north east of Redness Point close to the ruins of the old brickworks (NX 9770 1990). The micaceous, dark grey siltstone at the base of the cliffs contains abundant plant material, sometimes in growth positions. This indicates an overbank flood inundating the flood plain next to a channel. There are thin layers of sandstone and iron stone nodules. Various leaf fragments were tentatively identified as Neuropteris, Alethopteris and Astrophyllites.

The cliffs from here northwards to Parton are in the Countess Pit Sandstone. (Countess Pit was at Lambhill, just north of the town; there has been a stone quarry worked there in the recent past.) A fault between here and Whitehaven throws the Countess Pit Sandstone against the younger Whitehaven Sandstone. The position of the fault was identified on the return walk to and it appears to be normal. The Countess Pit Sandstone is encountered in boreholes throughout the district and marks the upper limit of seams workable by deep mining. Inland and northwards from this point the succession between the Countess Pit and Whitehaven Sandstones contains more mudstones and thin coal seams, with various local names.

The sandstone is yellowish-brown and represents another delta-top channel deposit. There is an erosional base with flute casts and a lag gravel of coaly and siderite clasts. The stream had probably cut through peat. There is low angle, trough cross bedding which indicates a palaeocurrent to the south west. (Previous visits have recorded, within the conglomerate, a slumped block about 2m across with the bedding crumpled into small folds with a wavelength of about 2cm. This probably represents a channel bank collapse. The block may have been removed by cliff falls). The boundary between the shale and sandstone is displaced by about 1m by a normal fault which appears to be a smaller version of the larger one further south.

The cliff, with sandstone overlying shale, is extremely unstable and there is ample evidence of previous slope failures and rotational slippage.

In the afternoon the party met at the shore car park north of Parton (NX 979213). This provided an excellent view of the reclaimed coal tips of the Harrington No. 10 and 11 Pits at Lowca. Lowca also had a brickworks at Micklam. There is ample evidence of the effect of land slips and groundwater pollution.

To reach the next locality there was a slow walk of about 1.5km along the shore to Four Foot Rock (NX 9780 2290), this only being accessible at low tide. In the five weeks prior to the visit extensive sea defence work was underway and the party had to climb across piles of limestone boulders brought here as part of this. The work had also disturbed a pale seat earth with plant fragments but the exposure could not be traced.

Between Parton and Cunning Point the dips are gentle but variable. At Cunning Point the dips are to the north. There is a series of exposures on the foreshore. The sandstone units form raised areas and mudstone and siltstones form the intervening depressions.

Part of the Harrington Four Foot Sandstone between the Harrington Four Foot and Albrighton seams was be examined. (The sandstone formed the roof rock to the Harrington Four Foot seam in the Harrington to Siddick area. There is considerable lateral variation in the succession, as shown by the section in the west Cumbria memoir. At Harrington the sandstone is 46m thick but elsewhere there are coals). A minor channel deposit was seen in a fining upwards sequence. There is an erosional base, with a lag gravel of coaly and quartz clasts. The upper part has cross bedding then cross lamination. Palaeocurrent was to the south west. At the top of this sequence, in a depression on the shore, is a dark mudstone. The party found several large specimens of Stigmaria. These were three-dimensional and orientated north east – south west. There was also one large stem, similar to Calamites which was at least 45cm in width and about a metre long.

The next raised area on the shore was Top Four Foot Rock (NX 9800 2320). This coarsening upwards sequence has been interpreted as a lacustrine delta deposit which formed as the delta prograded. The sequence starts with mudstones then laminated siltstones with occasional horizontal and vertical burrows (Arenicolites). This is followed by sandy siltstones and fine grained sandstones, first with ripple lamination, then cross bedding. Above the cross bedding are planar beds.

* * *

GEODIVERSITY OF THE CROSS FELL INLIER: MURTON BECK (GASDALE) AND MURTON PIKE

Leader: Sylvia Woodhead (CGS)

Saturday July 23rd 2011

Murton Pike and Murton Beck (Gasdale Gill) lie within a 'Classical Area of British Geology', the Cross Fell Inlier, an area of older rocks within the younger sedimentary rocks of the Pennine limestones and the Eden Valley sandstones. Here, in a very small area, is a huge diversity of geology, ancient rocks, faults, a major unconformity, mineral veins and spectacular glacial & fluvioglacial landforms. Geodiversity is the term for this great variety of geological environments.

The Cross Fell Inlier is a fault-bounded belt of deformed Ordovician-Silurian rocks (akin to those of the Lake District), exposed along the foot of the North Pennine escarpment. A series of major faults, the Pennine Fault system, have downthrown the younger Permo-Trias red sandstone rocks of the Eden Valley against older rocks. These ancient rocks, with their distinctive conical hills, lie between the bedded Carboniferous rocks of the North Pennines to the east and the red Permo-Triassic rocks of the Eden Valley to the west. Murton Pike is one of these distinctive conical hills, isolated by cross faults: the Swindale Beck crosses Murton Beck.

The area is cross-cut by mineral veins and has an associated rich mining heritage, and a complex glacial history has left a legacy of superb landforms. The faults have caused a significant change in slope, the Pennine scarp, from the Eden valley to the Pennine hills. This major relief feature creates a great contrast in scenery. Open Pennine moorland contrasts with the lower, gentler more wooded terrain of the Vale of Eden developed on younger Permo-Triassic rocks.

The Murton area is part of the North Pennines Area of Outstanding Natural Beauty, which was designated the first UNESCO Geopark in UK in 2003. The Geopark designation means this area has world-class geology, an outstanding geological heritage, and provides an 'outdoor classroom'.

Greywackes and siltstones of the Lower Palaeozoic Murton Formation rocks were followed by graptolitic mudstones, interbedded with andesitic tuffs of the Kirkland Formation, deposited in a north east trending island arc with several volcanic centres. These rocks were then folded, uplifted and deeply eroded before the deposition of Borrowdale Volcanic Group and Silurian rocks. At the end of the Silurian period, the rocks were further folded and cleaved in the Arcadian Orogeny, when the Weardale granite was emplaced, forming the core of the Alston Block. The faults delineating the edge of this block have been intermittently active since the end of the Silurian. During the Devonian Period the area was uplifted and deeply eroded. In early Carboniferous times, hollows were filled with pebbles derived from the west, at first in a marine environment. The Whin Sill was intruded in late Carboniferous-early Permian. Later the Eden valley subsided to form an intermontane basin in which dune sandstones built up. Further downward movement of the valley occurred in Tertiary times.

A party of thirty members met at the Murton Fell Gate car park (NY 730220) where the leader explained the background geology. The areas of interest in Gasdale include the Kirkland and Murton Formations (part of the Ordovician Skiddaw Group) and the Carboniferous Basement Beds, Orton Group and Melmerby Scar Limestone. Faults of the Pennine Fault System, including the Swindale Beck and Murton Pike faults, cut across the hillsides and Murton Beck in a roughly north west – south east direction. Murton Beck is a glacial overflow channel, with an intricate pattern of glacial and fluvioglacial landforms, kame & river terraces. The fault scarps and eroded valleys are actively undergoing downslope soil movement and slope collapse. There are also former hushes and dams, reservoirs and leats for White Mines and Murton Bobbin Mill. In the 1800s the bobbin mill, providing wooden bobbins for the Lancashire cotton industry. A system of leats and a reservoir provided water to power a water wheel. The mill closed in the 1880s because it ran out of wood supplies. At the time Murton-with-Hilton parish council noted that there was not enough wood for a township gate for Langton.

The car park is near to the location of the Hilton Fault, which downthrows Triassic St. Bees Sandstone against Ordovician Kirkland Formation. The route for the day followed Murton Beck, returning via Murton Pike.

The first exposures examined were stream bed alluvium deposits near Murton holding reservoir (NY 731221). Murton Beck still regularly floods, bringing down mine debris and rock exposed further up the valley and derived from drift. Deposits in the stream bed gave a foretaste of the geological diversity of the rocks exposed further up its course. The dominant rock types was brownish Carboniferous Sandstone but pieces of Whin Sill and softer Ordovician mudstone were also present.

Further up the beck from NY 732221 to NY 733222 stream bed exposures are of the Kirkland Formation. These are black mudstones of Lower Ordovician age Skiddaw Group, similar to those of the Lake District. Graptolites, sporadic andesitic tuffs, and the faulted base and top were not seen on this visit.

A small dolerite dyke intruded into the Kirkland Formation is recorded in Murton Beck, although its location could not be verified with confidence on this occasion.

Further up the beck the Swindale Beck Fault (not exposed) is crossed. This fault is part of the Pennine Fault System, with a major downthrow to the west. Here the younger Kirkland Formation has been down thrown, to be exposed lower in the valley than the older Murton Formation. The fault has been active since the end of the Silurian, with major movements in later orogenies. The line of the fault was located by a change in slope angle and a line of boggy ground, although it is obscured in part by later landslips.

Further up Murton Beck exposures of the Murton Formation were examined. They are siltstones, mudstones and pale grey sandstones, giving a slightly striped appearance. Bedding is seen as faint colour bands or variations in grain size. The rocks are highly deformed with some secondary chlorite. The rocks were darker and more deformed than the Kirkland Formation. As the stream skirts Cringley Hill, sporadic exposures of Murton Formation were seen in the valley and hillside until the Murton Pike Fault was crossed. This fault is a thrust carrying Murton Formation rocks of the Cross Fell Inlier eastwards on top of younger Carboniferous rocks. The thrust follows a wavy line across the hillside, marked by a line of springs, with quartz pebbles and red staining. The exposure in the south side of Murton Beck 100m downstream of the fell wall was not visible on this visit.

The next rocks encountered in the stream bed were the Carboniferous Basement Beds at NY 740225. These rest directly on the lower Ordovician Murton Formation, in a major unconformity, and are well exposed in Gasdale. In this time interval the Shap Granite was intruded, with associated mineral veins. The Basement Beds are divided into threeunits, all of which were seen in the traverse up the stream bed. The lowest Basal Conglomerates (here <30m thick) have an unconformable base, with pebbles of vein quartz and Ordovician rocks of the Lake District. The overlying Roman Fell Shales, are about 20m thick and consist of purple-red siltstones and silty muds with thin bands of sandstone and conglomerate. They are generally poorly exposed, often obscured by scree from the Roman Fell Sandstones. The overlying Roman Fell Sandstones (5-30m) contain numerous quartz pebbles and fragments of purple mudstone.

The party then climbed the slope on the south side of the beck to the White Mines (NY 745226). The mines worked the Murton Fell North Vein. The vein was emplaced after the Whin Sill intrusion, around 280Ma, from low temperature brines, 220-50°C. Mineralisation included galena, barite, witherite and fluorite. The vein trends eastwards into Scordale, and was exploited along its length, with three levels in Gasdale, lower, intermediate and top level, where the buildings, including a blacksmiths were located. Galena was mined by the London Lead Company, from 1824-1876. Ore was taken away by packhorse along the upper track. The ores were of low grade due to the admixture of fluorite. The mine reopened in 1896 for witherite, $BaCO_3$ and worked until 1919.

Just upstream from the White Mines is the base of the Orton Group of Carboniferous Limestone. This was seen clearly in the hillside by a line of springs. The Orton Group is overlain by the Melmerby Scar Limestone and Robinson Limestone. The dolomitic upper part of the Orton Group was well-exposed in the stream bed. The stream appears and disappears, possibly due to alternating layers of limestone and sandstones or siltstones.

The Whin Sill outcrop is marked on the BGS map in upper Murton Beck but an extensive search failed to verify any definite exposures, although boulders are very common in the beck.

The party then followed the path out of the valley, up to the Army road, and towards Murton Pike, noting the changes in slope angle and vegetation, benches and lines of shake holes as different rock layers were crossed. In particular the change from Carboniferous Limestone to Ordovician Murton Formation was seen as the Murton Pike Fault was crossed. The possible line of the thrust fault was discernible on the ground as a break of slope.

At Murton Pike summit small exposures of dark shale are of the Murton Formation. From the summit the party noted the extensive views, north along the Cross Fell Inlier to Dufton and Knock Pikes, High Cup Gill with cliffs of Whin Sill, (not traceable across Gasdale), east across the nearly horizontal rocks of the Pennines, to Cross Fell, Great Dun Fell, Mickle Fell, and south to Scordale, and Roman Fell, west to the drumlin-covered Vale of Eden, and beyond to the Lake District.

The party then descended from Murton Pike, following the trace of the Murton Pike fault. Evidence for a channel sandstone, an ancient river channel, possibly 100m wide, by 20m deep, shown on the BGS map as cutting down through the Robinson Limestone into the Melmerby Scar Limestone, may be seen by a line of sandstone boulders descending the hillside, although no exposures were visible.

Further down the hill the fluvioglacial landforms of Moley Hill, High and Low Trough and Cringley Hole were examined. During deglaciation meltwater was ponded back to different levels, and successive meltwater channels were cut by meltwater adjacent to a waning ice sheet. Two systems of channels may have formed: early high level channels, along and in the ice, with a later subglacial system draining to the Eden valley as the ice wasted. Murton Beck is one of these channels. Some channels were cut into solid rock and others were cut into drift. Typical cross sections are U shaped. Channels formed deltas where they entered glacier-blocked lakes. Middle Tongue is a sand and gravel kame terrace. High and Low Trough on the slopes of Murton Pike are superlative examples of glacial meltwater channels.
It was noted that there was no modern summative research on these striking features.
Back at Murton Fell Gate the leader noted that the St. Bees Sandstone used in walls and buildings in Murton village.

Selected References

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GEOLOGY ON THE CUMBRIA-SCOTTISH BORDER

Leader: Judy Suddaby (CGS)

Saturday August 20th 2011

About eighteen members met at Penton Bridge (NY 433775) over the Liddel Water on the Cumbria-Scottish border. The leader explained that the visit would look at rocks of Brigantian (lower Carboniferous) and Namurian (upper Carboniferous) age. The rocks show a series of coarsening-upwards cyclothems, interpreted as deltaic deposits. Thin coal seams are succeeded by limestones, mudstones, siltstones and sandstones.

From the bridge, the party walked along the path high on the side of the gorge, downstream on the right (Scottish) bank of the river. At three points the party descended to the river to examine exposures in the river bed. The first location was at the core of a plunging, asymmetrical anticline, possibly in the Penton Limestone. Fossils found were crinoids and *Siphonodendron junceum.*

At the second locality, higher up the succession, the Tombstone Limestone and shales were exposed, dipping very steeply at the apex of the bend in the river. Further downstream from the path high above the river the Catsbit Limestone, marking the base of the Namurian, was seen forming a pavement-like feature in the river bed.

At the third locality, coarse Namurian sandstones with coaly fragments formed the heavily potholed river bed, succeeded by the dark Blae Pot Limestone.

The afternoon was spent at localities previously visited by the Society in May 1994 and described in Proceedings Vol. 6 Part 1 p72.

At Harelaw Hill (NY 791428), the Harelaw Hill Limestone was worked either side of the road with working ceasing in 1966. The party examined the area on the north side of the road where the rock was worked down the dip, eventually by underground pillar and stall workings. The thick shale above the limestone yielded fossil fragments of plants, brachiopods and a possible goniatite.

The final stop of the days was at Gilknockie Bridge on the River Esk (NY 782385). The party made its way to the right bank of the river on the south side of the bridge. Beneath the central pillar of the bridge the Coal Measures lie unconformably on Namurian rocks. The river cliff immediately next to the bridge is a remarkable exposure. The Namurian rocks have been folded into an anticline with some distortion of the more incompetent beds. This is overlain unconformably by the gently dipping Coal Measures. The sequence is displaced by a small reverse fault with fault gouge. The Namurian rocks are exposed immediately to the north of the bridge. 50m or so further upstream lower Carboniferous limestones are exposed. Between the two lies the Gilknockie Fault, although it is not exposed.

OBITUARY

FRANCIS JAMES COCKERSOLE

Jimmy on Rannerdale Knotts in his 80th year

Francis James (Jimmy) Cockersole died on April 7th, 2011, aged 92. He came to West Cumbria in 1960 as consultant obstetrician and gynaeocologist at the West Cumberland Hospital and the Workington Hospital. His integrity and professionalism, demanding high levels of precision and accuracy, together with his caring nature, won him the wholehearted approval and respect of our local communities. For a decade or so he was the voluntary Medical Officer for the Cockermouth Mountain Rescue team.

Jimmy joined the Cumberland Geological Society in 1965. One of Edgar Shackleton's WEA courses in Geology and Edgar's Lakeland Geology book had inspired him to understand more about the fells he so loved. The family tribute at his funeral said, "Jimmy Cockersole never did anything by halves", which worked greatly to the benefit of our Society. He was a dedicated and very active member until the middle of this decade, when he and his wife Mary were still attending our Annual Dinners.

Jimmy edited our Proceedings from 1973 until 1983. His aims were (1) for our Proceedings to become the natural vehicle for at least a proportion of the (geological) scientific work written about Cumbria, (2) to develop the academic quality of contributions to Proceedings for the benefit and interest of members of what became a highly respected amateur Geological Society. He certainly succeeded in both of these aims. As our Editor he developed very happy relationships with the officers of the British Geological Survey and the Open University who wholeheartedly approved and supported his work.

Over the years he led most authoritatively several excursions for the Society, particularly to sites on the upgraded A66 where engineering works exposed previously unknown aspects of Cumbrian geology. His other particular specialism was the Permo-Triassic sandstones of the Vale of Eden. This was the theme of the research component of his 1st Class Honours degree of the Open University, as always meticulously and accurately presented. The Society was delighted to use this expertise in a chapter in the 1992 *Lakeland Rocks and Landscape, A Field Guide.*

Jimmy was a most popular and effective President of the Society between 1984 and 1987, and remained as an active member of Council until 1990. His much appreciated work for the Society was recognized by the award to him of our Charles Edmonds Prize in 1991. Older members of the Society will remember his infectious enthusiasm and his unfailingly gentle courtesy.

Mervyn Dodd

LECTURE MEETINGS
WINTER 2010-11

22nd September 2010
Methodist Church Hall, Penrith
The geology of the Rhins of Galloway: a geological tale of Scottish independence and a vanished ocean
Dr. Emrys Phillips, British Geological Survey

20th October 2010
Friends Meeting House, Cockermouth
Patterns of Upland Erosion – its all downhill from here
Dr. Jeff Warburton, Durham University

17th November 2010
Friends Meeting House, Keswick
Use of ground water models in protecting the aquatic environment of East Anglia
Mr. Tim Lewis, Entec UK

8th December 2010
Friends Meeting House, Keswick
Members evening
Shetland Field trip highlights
Judy Suddaby's global overview
Geological fun with John Rodgers

19th January 2011
Tullie House, Carlisle. Joint meeting with Carlisle Natural History Society
Solving the Bassenthwaite mystery: magnetic fingerprinting of fine sediment sources
Professor Barbara Maher, Lancaster University

23rd February 2011
Friends Meeting House, Cockermouth
Taming the Tsunami: learning the lessons from December 2004, and preparing for the next one
Dr. Gordon Curry, Glasgow University

9th March 2011
Friends Meeting House, Keswick
Presidential address: Geological Gems of the North Western USA
John Rodgers

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2011

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ANNUAL GENERAL MEETING
2011

The 50th Annual General Meeting of the Society was held on Wednesday 9th March 2011 at the Friends meeting House, Cockermouth at 7.30 p.m. The President, John Rodgers took the chair.

It was noted that no student bursaries given and members were asked to look out for possible candidates.

Mervyn Dodd's new book was in profit after accounting for Curry Fund loan and £3000 plus made from Lakeland Rocks.

Total funds were £14,407, which was considered to be a fairly health state.

Acceptance of accounts was proposed by M. Dodd and seconded by C. Thompson.

Membership – 184 members currently with 8 joining this year.

2012 Birthday celebrations. After some debate over when Society started February 1962 has been accepted. A special dinner will be held. There will be a special edition of Proceedings for the 2012 and some articles have already been received.

The meeting was advised of intention to ask someone to speak about proposed underground nuclear waste storage. The Society will not become involved in the debate, individual members can feel free to become involved but only as individuals.

Following the meeting the President gave an address entitled *Geological Gems of the North Western USA.*

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Telephone 01900 825647