PROCEEDINGS OF

THE GEOLOGICAL SOCIETY

OF GLASGOW

Standing on the mantle dunite on the small summit of Helgehornvatn (0322451,6879234). (photo M.Donnelly)

Session 155 2012-2013

SESSION 155 (2012-2013)

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	Dr. Ben Browne
	Vacancy
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	Dr. Brian Bell
Website coordinators	Dr. Bill Gray
	Miss Emma Fairley
Ordinary Members	Miss Alison Drummond
	Dr. Emily Unsworth
	Dr. David Brown
	Mr. Robert McNicol
Independent Examiner	Mrs. Beth Diamond

President's Report November 2013

This session, the Society has a membership of 376. Eight evening meetings took place, normally on the second Thursday of each month from October 2012 through to May 2013. Speakers were: Dr. Steve Jones (Birmingham University); Dr. Jim Morrison (Geological Society of Glasgow); Dr. Jon Mound (Leeds University); David McInroy (BGS Edinburgh); Dr. David Chew (Trinity College, Dublin). Miss Margaret Donnelly gave her Presidential address in December 2012 and the T. Neville George Medal lecture was given by Professor Jenny Clack of Cambridge University on *Populating Romer's Gap: rebuilding terrestrial ecosystems after the end-Devonian mass extinction.*

Our day excursions ran from April through to September 2013, and included the following day trips: April - Arrochar Alps (David Jarman); May - Barns Ness & Charlestown Lime Museum (Alistair McGowan); July - Carstairs Kames & the Falls of Clyde (John Gordon); July - Keltie Water & Bracklinn Falls (a Joint excursion with the Geological Society of Edinburgh) (Chris Burton); August - Cononish gold mine (near Tyndrum) followed by Glen Orchy (Chris Sangster); September - Glen Esk near Brechin.

Two residential field trips took place: The Scandinavian Caledonides in southwestern Norway, Leader: Simon Cuthbert (Saturday 22nd - Monday 24th June, 2013); and, Ben Lawers Synform and Ben Lui Fold, Leaders: John Mendum (BGS) and Graham Leslie (BGS) (Saturday 5th - Monday 7th October).

The Strathclyde Geoconservation Group (SGG), a subcommittee of the Society's Council, has continued to promote geology in the wider community, investigating a number of new sites as well as continuing work on others. Two other subcommittees, *Geodiversity: Argyll and the Islands* and *Geodiversity Dumfries and Galloway*, are also making progress and have investigated a selection of new sites. A 'hands on' geology event in conjunction with the Highland Games in Rouken Glen Park was held on Saturday 20th April.

Members of the Council attended Steering Group meetings for the refurbishing of the Fossil Grove building in Victoria Park. Progress has been disappointing due to a lack of funds, although the Trustees have appointed Glasgow Buildings Preservation Trust to prepare a Heritage Lottery Fund bid and it is hoped that this will be ready in June 2014. Funding was provided by Glasgow City Council for urgently required repairs to the roof and other parts of the building in Spring 2013. Visitor numbers were good for the Summer 2013 season and a leaflet describing and promoting the Grove was published.

Our Society is a member of the Scottish Geodiversity Forum, which includes Geoparks, Museums, SNH, BGS, Geoconservation Groups, other Geological Societies and interested groups/individuals. The aim of the Forum is to promote Scotland's Geodiversity and its value in education, community involvement and health, tourism and the wider economy.

One new guide, on the geology of the Island of Gigha has been published, and one on the geology of Southern Kintyre is in progress. A leaflet on the *Building Stones of the University of Glasgow* has been published with the help of funding from the University's

Chancellor’s Fund and will be distributed free of charge. A Guide to the geology of Tenerife is being prepared for posting on the Society’s website and a revised Guide to the geology of Arran is planned.
The Society’s website has been further developed, to advertise our activities and to provide a platform for the promotion of geology.

Margaret Donnelly

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Membership Secretary's Report

	At end Session155 30Sep 2013	At end Session154 30---Sep---2012
Honorary Members	5	5
Ordinary Members	289	271
Associate Members	66	70
Junior Members	16	16
TOTAL Members	**376**	**362**
New Members	24 (joining in Session 155)	18 (joining in Session 154)
Memberships Closed	15	40

Overall membership numbers in Session155 has increased slightly (2.5%) from the previous Session. The new members joining rate in Session 155 was a little higher than in session 154. There was a significantly lower number of memberships closed than in session 154 (memberships are closed by resignation , non-payment of fees or death)

R.A.Painter
November 2013

Library Report: 2012---2013

The Society's Library has continued to provide a first-class geological resource, one of the best in western Scotland, even in these days of internet access to vast amounts of data. Words on paper are still important, especially for those many publications that have not yet fallen within the reach of Google (or for which you have to pay for access!) and which the reader might want to consult at length. So our library is a continuing and valuable doorway into a very wide range of geological information at all levels - there's nearly always something for inquiring members, and if there isn't the Librarian can usually dig it up given some notice. So, don't neglect your library - use it!

Acquisitions:
There has been a healthy crop of acquisitions, both books and maps, during the session. A donation of books by Colin Braithwaite and via him the late Fred Hubbard has given us a list of classical titles in geology, including notably both volumes of Heddle's Mineralogy of Scotland, one volume of which replaces our copy which "went missing" some years ago. Other highlights include a copy of Dana's System of Mineralogy (1854). In all eleven titles have been donated.
The British Geological Survey continues to provide the Society with the latest geological maps and our collection grew rapidly during the session with maps from across Britain:

Scotland:
1:50 000 Sheet 51E/52W North Mull and Ardnamurchan Bedrock and Superficial.
1:50 000 Scotland Sheet 73W Invermoriston Superficial Deposits.
1:50 000 Sheet 74E Aviemore Superficial Deposits.
1:50 000 Scotland Sheet 84E Nairn Bedrock.
1:50 000 Sheet 101E Ullapool Superficial Deposits.

England/Wales:
1:50 000 Sheet 84 Wigan Bedrock.
1:50 000 Sheet 84 Wigan Bedrock and Superficial Deposits.
1:50 000 England and Wales Sheet 112 Chesterfield Bedrock and Superficial.
1:50 000 England and Wales Sheet 167 Dudley Bedrock and Superficial.

We now have coverage of much of Britain and, together with the maps belonging to Earth Sciences, which members can also borrow; we can provide maps for almost anywhere members might travel.
All the Society's maps can be borrowed and, importantly, can be used in the field. Unfortunately the maps are not on open access, but a request to the Librarian or the Assistant Librarian will produce what you want.

Personnel:
Our Assistant Librarian Seonaid Leishman is standing down this session and I would like to record my appreciation of the quite excellent job she has done over her time in office. Seonaid has been instrumental in so many aspects of the Library, not least in negotiating some of the larger donations (and transporting them to the Library!) and in applying her considerable organisational talents to the smooth running of the operation. Stepping into her place we welcome Margaret Anderson and, for a transitional period she, Seonaid and I will all be present on meeting nights. So come up and see us!

C. J. Burton,
Librarian

Scottish Journal of Geology Editors Report
December 2013

This has been a difficult year for the Journal. Our structural/metamorphic editor, Ian Alsop, after several years of service, found that he was unable to continue because of pressure of work. He was replaced after a brief hiatus by Maartin Krabbendam. Our Secretary, Alistair McGowan, who has also given good service, has experienced similar difficulty with his work load and has announced his intention to resign in the New Year, in which we will have to find not only a new stratigraphical/palaeontological specialist but also a new secretary.

Members will have noticed a relatively thin issue for part 1 of volume 48. This has reflected a downturn in the number of submissions to the Journal that the Board has attributed to a policy in Universities where staff are currently encouraged to submit their work only to relatively high profile Journals. Over the years we have seen a number of similar periods where the submission rate have been low but this is first time where we have been able to identify a specific influence. The good news is that we have a substantial number of papers in progress for the next issues.

Members will be aware of the efforts made by the Board to better publicise the material that we publish in order to gain wider exposure for our authors, thereby encouraging more submissions. We are happy to acknowledge at this point the work of our publishers, the Geological Society Publishing House (GSPH), in publicising the Journal, both on-line and in widely distributed printed material. Our initial foray into on-line publishing was via the company Ingenta, where we were able to make current issues accessible to members and to some searches. We were then invited to join the Geological Society's Lyell Collection. This is the largest Geological Database in the UK and generated a much wider interest in the journal, indicated by the number of reported 'hits' for articles viewed and downloaded. Our profile here includes the entire archive of the Journal, from 1965. In the last few months, through the good offices of GSPH, we have also been incorporated into the Geoscience World (GSW) database in California, the largest of its kind in the world. Searches in Google and similar search engines will now find relevant articles in the Journal whether or not the person searching is aware of the SJG. As part of the same agreement we have also been engaged in reproducing the entire archives (from 1860) of the Transactions of both the Edinburgh Geological Society, launched on-line within the last few weeks, and the Geological Society of Glasgow, which is expected to launch early in the New Year.

The Journal was first proposed in 1964 as a joint venture between the Edinburgh and Glasgow societies. Next year, 2014, is therefore our 50th anniversary.

Dr.Colin Braithwaite
Dr.Brian Bell

Publications Report
Session 2012--13

Initially the sale of publications was disappointing but improved quickly later in the year and some sales, particularly of the North West Highland Guide, were made to non-members at field trips. Several personal requests were received from members for books and maps and 5 new titles were added to the stock. Our link with the Edinburgh Society and National Museums Scotland in the publication and sale of the Moine Guide is continuing to be successful.

The highlight of the bookshop year was the publication by the Society of a new Field Guide written by Dr. J. G. MacDonald which explains the Geology of the island of Gigha and its smaller neighbour Cara. This adds to our other production, A Field Guide to the Geology of Madeira, also written by Dr. MacDonald along with Dr. C. Burton. The inclusion of our booklist on the internet has resulted in 18 e-mail requests for the Madeira guide from both mainland Europe and within the U.K. and 2 requests for the newly published Gigha and Cara field guide from Scottish sources.

During the year we received a gift of books belonging to a former well-known member, Rosemary McCusker, which we offered to members for a small contribution and we thank her family for the donation. Unwanted books, maps etc. are always welcome for resale.

Finally, I wish to say a big thank you to everyone who has helped me so much especially on Society nights, with finances and with the internet and also to those who have supported the bookshop with their purchases throughout the years.

M. Alexander

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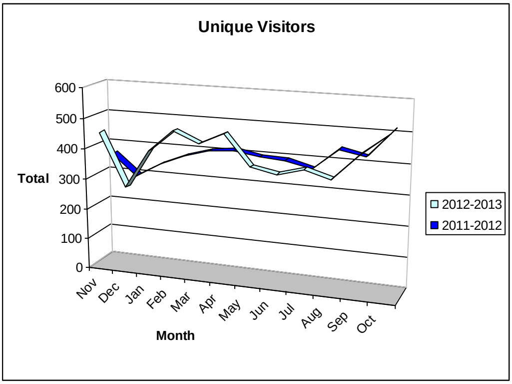
Report on the Geological Society of Glasgow's websitehttp://www.geologyglasgow.org.uk/ 2013

The website is up and running and has been now for nearly three years. It has not been without its share of difficulties though with crashes, mailing problems, and problems with the formatting. However, despite the problems, which have been mostly ironed out, we have had nearly 7,000 visitors since last November – an increase of nearly 900 visits (November 4th 2012 – November 5th 2013). This is a substantial increase in traffic to our website which has grown substantially since we converted to the new website in 2011. As in previous years, most of the visitors come from the UK with 5,658 visits – an increase of 20.5%

(Scotland 3,122 (2,625 in 2012), England 2, 284 (1,872), Northern Ireland 205 (136) and Wales 43 (39)). In terms of the cities our visitors came from, the majority came from Glasgow 1,546 (1,406), Edinburgh 608 (679) and London 894 (552). We also welcome the 1 visitor from Uganda.

The most popular pages on the website other than the homepage are the excursions page (4.4% of pageviews) and the events page (3.8%). The lectures, membership, Strathclyde Geoconservation and bookshop pages all have over 2.2% of pageviews. Referrals are up from the Edinburgh Geological Society (147 this year compared with 115 last year) and scottishgeology.com (138 this year and 89 last year), although slightly down from the Geological Society (London) (48 this year and 61 last year). New this year has been the production of the social media presence by Emma using both Twitter and Facebook. Referrals from Facebook (246) alone this year has been more than these other sources except Google (3,414).

Regular meetings of the website group have helped to resolve a number of issues relating to the running of the website and identified potential new avenues enhancing our internet presence. The Facebook page has been a runaway success with 102 'likes' since February 2013. Please remember to 'like' the Facebook page (http://www.facebook.com/GeologicalSocietyOfGlasgow)!



There was a major crash on the 19th September which resulted in problems with the website and email that took four weeks to fully resolve. Further improvements are being planned for the coming year including a geological map of the Glasgow area with possible links to self-guided field-trips to selected localities.

The responsibilities for the web services will change after the AGM. Bill Gray will be standing for election as Webmaster and Neil Clark will be standing for election to the office of Web Consultant.

The officers of the Society are thanked for continuing to update pages relevant to their duties and letting the web-team know of any issues they are having with the site, so that members can have information available as soon as is possible. The website will continue to improve and inform, but we rely very much on the members of the Society for content.

Officers: Dr. Neil D. L Clark, Emma Fairley, Bill Gray, Margaret Donnelly

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Strathclyde Geoconservation Group
Report 2012-2013

The East Dumbarton subgroup of SGG is working closely with EDC to provide data for Information Boards at selected sites. This includes communication with Historic Scotland with a view to having geology included in a new information board at Barr Hill.
These Boards are almost complete and funding has been arranged with 'Civic Pride'

The West Dumbarton has provided assessments and descriptions of selected sites for inclusion in the WDC Local Plans. WD has recently produced a map of Nature Conservation sites and has included a new symbol for Geodiversity sites within the area. Margaret Greene replied to this latest consultation and suggested that the next step may include the borders of the geodiversity sites.

The state of Boyleston Quarry, Barrhead, has been brought to the group's attention by a new member of the group and will be investigated early in 2013. This site is a SSSI but has been fenced off by the owner.

The Building Stones of Glasgow City Centre:- Margaret Greene has almost completed the leaflet . It now only needs profession layout and printing

Glasgow City Geology Audit:- A list of localities was sent to Glasgow City Council for inclusion in the BGS audit of the city.
BGS have completed this audit and MG has contacted GCC requesting access to it.

The Booklet 'The Building Stones of Glasgow University 'produced by Barbara Balfour and Alison Drummond is now in print and has been very well received. Copies have been made available to members of SGG and council and have been placed in several places around the University.

Fossil Grove:- A new leaflet has been produced by Margaret Greene and is now available in printed form at various venues and on the website
MG is attending meetings of the Trustees and the Steering group. A contract has been drawn up with Glasgow Buildings Preservation Trust. They have been asked to put forward a bid to the Heritage Lottery Fund; this should go in in June 2014.

Rouken Glen:- Several members of SGG assisted with the very popular Geology stand at the Highland Games event in April. A short report is posted on the website.

Overtoun Glen and Ballagan Beds:- A group visit was made to this site and there is concern about the density of planting being undertaken by the Woodland Trust. It is feared that the views of the Beds will be completely obscured once the trees are mature. MG, after consultation with N Everett of SNH, will write to the Woodland Trust in regard to this potential problem. It is hoped that the WT will agree to the thinning of the planting in this area

Archive for SGG data:- SL will be preparing a list of documents etc. reflecting the work of the SGG for archiving. The Action Plan has been separated into Current Projects and Completed Projects documents which may assist her in this endeavor.

SGG Geodiversity Leaflets: Rachael Ellen has contacted 'Visit Scotland' and arranged to have our Fossil Grove leaflet included in their website. She is still in communication with VS with respect to having more of our leaflets included on their site.

Scottish Geodiversity Forum – MG and SL continue to be on the Forum executive. An up-to-date version of the Charter has been produced. The Forum is involved in an SNH Sharing Good Practice event on 17th December 2014.

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Report from Geodiversity: Argyll and the Islands

Little more has been heard about the Argyll and Islands Coast and Countryside Trust since the Council became beset with political problems. We hope more may information may emerge in more positive times in 2014.

After our previous AGM members held a meeting at Barncarry near Kilninver visiting the exposures in the bay accessed by a private road to Barncarry House. The bay is divided by a fault between Dalradian slates to the west and late Silurian/Devonian rocks to the east. Attention was focused on the latter and studied in some detail. The site has good potential for a Local Geodiversity Site. The group went on to study the Barncarry road cutting formed when the road was rescued from collapse some 10 or so years ago Unfortunately hopes that this would also produce a possible geoconservation site were not supported by the results of the examination but it nevertheless remains an interesting site for some clearly exposed geological features.

There has been little field activity this summer due to other pressures on members of the group.

The idea of producing a simple Roadside Geology Guide to one of the main through routes of Argyll as a first step in bringing the geology of Argyll to the attention of the tourism market will be discussed at GAI AGM on 29th November. Some preliminary ideas for the sites along the road have been identified. We are grateful to Seonaid Leishman for producing a most attractive leaflet for the Knapdale area at a level of presentation which sets a very high standard for others to match.

The Scottish Association for Marine Sciences (SAMS) Centre, part of the UHI, recently opened their Ocean Discovery Centre on the campus of Dunstaffnage. As part of the associated public engagement they held an initial public outreach field event including a visit to a useful exposure of Devonian conglomerates. It was a very useful occasion which we hope will lead to further cooperation in future.

Alastair Fleming

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Proceedings Editors Reports

Another very enjoyable year was recorded in the proceedings for session 154. Panda Print produced 400 copies with their usual complete efficiency.

The trip reports are a highlight of the proceedings and many thanks are due to those members who provided such excellent records of both day and residential trips together with many lovely photographs for inclusion.

Mina Cummings

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THE GEOLOGICAL SOCIETY OF GLASGOW

Income and Expenditure Account for year ending 30th September 2013

	Session 155 2012-2013		**Session 154 2011-2012**	
Income	**£**	**£**	**£**	**£**
1 .Subscriptions				
Received by Bankers Order	4619		4902	
Received by payment to Memb. Sec.	1470		1140	
Deduct paid in advance this year	-80		-40	
Add received in advance last year	40	6049	40	6042
2. Investment Income				
Dividends	525		495	
National Savings	377	902	184	679
3. Tax Refund (gift aid payment accrual)	900		900	
Over accrual on 2012 gift aid	-9		160	
4. Conoco-Phillips prizes				
(EGS in advance for 2014)	83		133	1193
5A. Publications **Note 1**	551		473	

5B. Moine Guide	**Note 2**	200	1725	50	523
6. Saturday excursion income		2042		496	
	Expenditure	-2026	16	-277	219
7. Weekend excursion income		5418		1850	
	Accrual	0		430	
	Expenditure	-5718	-300	-2310	-30
8. Donations (coffee collections)			280		264
9. Miscellaneous income	**Note 3**		58		55
Total Income			**8730**		**8945**
Expenditure		**£**	**£**	**£**	**£**
1 .Meetings incl.speakers expenses etc.		645		515	
Meeting Secretary expenses		514		446	
Room hire	**Note 4**	2913		2200	
2. Publication of Proceedings		1044		420	
3. Dumbarton Rock leaflet sponsorship		0		150	
3A. Sponsorship		0		850	
4. Library and' Down to Earth'		112		104	
5. Insurance		187		180	
6. Conoco-Phillips prizes 2012		800		400	
7. Website		826		552	
8. Affiliation fees		350		416	
9. Admin. Costs:-postage, stationery etc.					
Hon. Secretary expenses		500		245	
Membership Secretary		332		707	
President and Vice President		122		46	
Treasurer		93		88	
10. Miscellaneous expenditure		62		143	
Total Expenditure			**8500**		**7462**
Profit/Loss			**230**		**1483**

	Session 155 2012-2013		Session 154 2011-2012		
<u>Balance Sheet as at 30th September 2013</u>	**£**	**£**	**£**	**£**	**£**
Members Funds					
Balance as at 30th September 2012	62457		60974		
Surplus/deficit for the year	230		1483		
Revised valuation fund for investment	0		0		
Balance as at 30th September2013		**62687**		**62457**	
Restricted Funds <u>T.N.George fund</u>		**380**		**380**	
Total Funds		**63067**		**62837**	
Represented by					
Current assets					
Cash at Bank					
Royal Bank of Scotland	2884		2959		
National Savings	33039	**35923**	32662	**35621**	
Cash in hand					
Publications sales officer	0		35		
Membership Secretary	200		200		
Hon. Secretary	95		95		
Meetings Secretary	0		0		
President/Vice President	161	**456**	98	**428**	
National Savings Income Bond	12000		12000		
Current valuation of Charifund					
investment **<u>Note 6</u>**	8355		8355		
Debtors					
Gift Aid	900		900		
Ben Lawers Hotel deposits	270		430		
Gigha sales not yet paid	210	**21525**	42	**21727**	
Stock of Publications –in house	4593		3988		
Moine Guide	1146	**5739**	1293	**5281**	**63057**
Less Liabilities					
Subscriptions paid in advance	-80		-40		
Conoco-Phillips prizes	-83		0		
Ben Lawers paid in advance	-413		0		
Insurance	0	**-576**	-180	**-220**	

Net Assests	**63067**	**62837**

These financial statements are prepared in accordance with the special provisions of part VII of the Companies Act 1985 relating to small companies.
The financial statements were approved on 8th December 2012 by the Trustees and signed on their behalf by

President	B. Bell (Dr.)
Independent examiner	Beth Diamond (Mrs.)

Notes to the Financial Statements for the year ending 30th September 2013.

Accounting Policies

Accounting convention

The financial statements have been prepared under the historical cost convention, and in accordance with applicable accounting standards. The accounts are also set out to comply with guidance from OSCR.

The principal accounting policies adopted in the preparation of the financial statements are as follows:-

All income from membership subscriptions, excursions, publications, bank interest and donations is accounted for on an accruals basis.

Resources expended are accounted for on an accruals basis and are recognized when there is a legal or constructive obligation to pay for expenditure.

All costs have been directly attributable to one of the functional categories of resources defined in the Statement of Financial Activities.

Expenditure on equipment is charged to Revenue in the year of purchase.

Notes on entries:-

1. Calculation of surplus on Publication sales
2.

Opening stock value	3988
Purchases	1398
Available for sale	5386
Closing stock	4593
Stock sold	**793**
Income received	1103
Income via Pay-Pal	331
Less cost of sold stock	793
Profit	**641**
Less postage expenses	(90)
Final surplus	**551**

3. Moine Guide. The publishing costs for the Moine Guide were shared between the national Museums of Scotland, Edinburgh geological Society and the Geological Society of Glasgow on a 50%/25%/25% basis and any profits are shared accordingly. GSG have no control over the majority of sales or stock management so accurate reporting of sales activity is difficult. Income received this year is£377 but we are advised by EGS that sales are effectively being made at around cost level. A conservative estimate of the profit level at £200 has been made and the GSG share of the closing stock recorded accordingly in these accounts.

Opening stock value	1293
Cost of stock sold	-147
Closing stock	1146

4. Miscellaneous income of £33 has been received as a commission on sales made on Amazon through the Society's website

5. Room hire for lectures this year has been paid for at £384 per evening

6. No sponsorship was granted this year

7. The Stock Market has performed better this year and the value of investments is slightly higher than in 2011. The Balance Sheet value of £8355 has been retained and is still a cautious assessment.

Michael Pell

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Meeting Secretary's Report

The session opened with Steve Jones of Birmingham University giving the latest instalment of our occasional "North Atlantic Opening" series with an excellent presentation on the Scotland-Greenland Ridge, the Iceland plume and their effects on glaciation and ocean currents.

Unfortunately, Tom Bradwell was unable to give his talk in November because of jury duty. To keep the lieges amused, your Meetings Secretary filled in some background on "North Atlantic Opening". This turned out to be a successful evening because of the enthusiasm with which the members participated with many questions and comments.

Hon President Maggie Donnelly had come to the end of her term and entertained and educated us with a talk on "Geological Journeys", splendidly illustrated from her extensive and intensive participation in so many of the Society's excursions. And so farewell to 2012 and hello to 2013 and Jon Mound from Leeds University with a fascinating talk about the earth's "Complex and Dynamic Inner Core". We were joined by members of the Astronomical Society for this talk.

In February 2013, David McInroy from BGS Edinburgh told us about the Rockall microcontinent and its progress from being part of Laurentia which was extended in pre-Palaeogene times prior to North Atlantic opening. As in the March of previous session, fossil fans were again delighted, this time by the very impressive Jenny Clark, from Cambridge University, who had been featured in the TV series 'Beautiful Minds'. She gave us a very entertaining and informative talk on Romer's Gap and the origin of tetrapods.

After last year's December gale fiasco, Dave Chew returned from Dublin and told us about the use of new isotope techniques which have allowed very precise dating of Palaeozoic rocks. Members' Night closed the season with the usual interesting and varied program of talks and demonstrations.

J.M.Morrison

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Meetings

11th October 2012
Dr. Steve Jones, Birmingham University
The relationship between the Greenland-Scotland Ridge, the Iceland Plume and Northern Hemisphere glaciation

Opening and closing of oceanic gateways between continents can influence global climate. For example, establishment of the Antarctic circum-polar current, following separation of Antarctica from South America and Australia, helped to allow growth of the Antarctic ice sheet. This talk will look at how a gateway in the North Atlantic Ocean near Iceland has affected oceanic circulation. Evolution of the Icelandic gateway influenced the onset of the Northern Hemisphere Glaciation and possibly other periods of global climate change.

At the head of the North Atlantic, between Scotland and Greenland, lies an important hub in the global oceanic circulation system. Here, warm Gulf Stream water that has flowed north near the ocean surface cools, sinks and returns southward along the seabed. This Atlantic circulation system carries warmth from the tropics to the Arctic, and changes in the circulation system can change the temperature gradient between the equator and the North Pole. The position of the circulation hub near Iceland and the strength of the circulation are both affected by the Greenland-Scotland Ridge, a shallow sill straddling Iceland where the sea floor rises to a depth of only several hundred metres.

The elevation of the Greenland-Scotland Ridge has fluctuated over the past 60 million years in response to three controls. First, the ridge is a hotspot track, built from the large volumes of magma formed when unusually hot mantle within the Iceland Mantle Plume rises up beneath the Mid Atlantic Ridge plate spreading axis. Secondly, like all young oceanic plates, the Greenland-Scotland Ridge subsides gradually as it spreads away from the mid-ocean ridge. Finally, the temperature of the Iceland Mantle Plume has fluctuated over time. The consequent waxing and waning of mantle convective support of the Greenland-Scotland Ridge has, from time to time, restricted or even cut off the connection between the main Atlantic and the ocean basin to the north. Oceanic crust south of Iceland preserves an excellent record of these mantle temperature fluctuations in the form of topographic features known as V-Shaped Ridges. Recent research cruises have clarified the long-held notion that V-Shaped Ridges are generated as pulses of hotter and cooler mantleflow outward from Iceland beneath the plates.

The Northern Hemisphere Glaciation began during the Pliocene (c. 3 million years ago). The preceding period was the most recent period in Earth's history in which global average temperatures were similar to those projected for the end of this century; however, state-of-the-art global climate models have great difficulty in reproducing the Pliocene warm period. The new data from the North Atlantic V-Shaped Ridges indicate that the most recent patch of cool mantle within the head of the Iceland Mantle Plume was positioned beneath the Greenland-Scotland Ridge lock-gate during the Pliocene. With cooler mantle beneath, the lock-gate would have been relatively low and allowed the strong Atlantic oceanic circulation that kept the high latitudes warm. As the cool mantle moved towards its present position, the lock-gate rose, oceanic circulation was inhibited and the Arctic ice expanded. It seems likely that the global climate models cannot reproduce pre-Northern Hemisphere Glaciation conditions because they do not yet correctly represent the Icelandic oceanic gateway.

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8th November 2012
Dr Jim Morrison, Geological Society of Glasgow
North Atlantic opening - an introduction

For more than a billion years, until the beginning of the Palaeogene, Scotland and NW Ireland were plastered against the edge of Laurentia. When Pangaea began to break up, the movement of Africa away from South America marked the start of Atlantic opening. About 150 million years later the mid-Atlantic Ridge had reached the position of the Azores Triple Point.

From there, the ridge continued to grow to what is now the Charlie-Gibbs Fracture Zone (well seen on Google Earth) and continued between Labrador and West Greenland. At this point, something dramatic happened and the ridge switched to the east of Greenland and continued, splitting Britain and Ireland from North America during Palaeogene times. This gave rise to the familiar British and Irish Palaeogene Province and eventually to Iceland.

Palaeogene opening occurred between Greenland and, not Ireland, but the Rockall-Hatton Bank (or microcontinent). This is partly underlain by Rhinnian basement and has moved away from Ireland by pre-Palaeogene extension.

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13th December 2012
AGM and Presidential Address
Miss Margaret Donnelly
Geological journeys

The oldest rocks in Scotland occur in the Lewisian Complex of the Northwest Highlands: the Scourian gneisses of the Outer Isles are dated at 2.75 to 3.12 Ga, and show greater affinities with the east coast of Greenland than with the Scottish mainland. The Lewisian Complex records a series of metamorphic events, followed by the emplacement of the Scourie dykes at c. 2.4 and at c. 2.0 Ga. Subsequently, the lengthy Laxfordian deformation took place, possibly from 2.1 – 1.5 Ga; juvenile rocks of Laxfordian age are also found – on the Rinns of Islay, c. 1.79 Ga. The later Grenville orogeny, c. 1.2 Ga, also left its mark on Scotland in the Glenelg-Attadale Inlier, and then the mainly fluvial Torridonian sandstones and the mainly shallow marine Moine were deposited between c. 1.2 – 0.9 Ga, the latter from the south in, possibly, a separate basin. There followed traumatic events – the 'Snowball Earth' of at least two major glaciations, between c. 800 and 650 Ma; the Port Askaig Tillite is our own excellent example. The Iapetus Ocean opened c. 600 Ma as evidenced by the Tayvallich volcanics, and closed in the Grampian orogeny c. 470 Ma. Much later the opening of the Atlantic, c. 55 Ma, gave rise to our Tertiary Igneous Province. This talk will focus on a selection of memorable field trips, including the Outer Isles, Northwest Highlands, Glenelg, Islay, Ardnamurchan, Mull and Skye.

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10th January 2013
Dr. Jon Mound, Leeds University
The complex and dynamic inner core
[Joint lecture with Astronomical Society]

It has been over 75 years since the discovery of the Earth's solid inner core, and for much of that time it has been viewed as a relatively inert and uniform sphere of iron and nickel. However, over the past decade the vast improvement in the quality and coverage of seismic observations has revealed a surprising amount of structure within the inner core. This internal structure points to the existence of dynamic processes that are constantly reshaping the inner core. Does the inner core rotate faster than the rest of the Earth? Is half of it melting? Does it affect the generation of the Earth's magnetic field? There is still much to learn in the decades to come.

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14th February 2013
David McInroy, BGS Edinburgh
Formation of the Rockall microcontinent: a result of pre-Palaeogene extension in the NE Atlantic region

Prior to Early Eocene sea floor spreading in the North Atlantic, a number of pre-Palaeogene extensional phases affected the Rockall region, offshore NW Europe. The area is underlain by crystalline basement terranes, assembled in Palaeozoic times during the Caledonian Orogeny. A number of poorly constrained late Palaeozoic to Mesozoic extensional phases substantially thinned the continental crust, leading to the development of sedimentary basins such as Rockall Basin and Hatton Basin, separated by basement highs such as Rockall High. Although the basin stratigraphies are poorly calibrated due to a lack of well control, several regional studies suggest that significant rift episodes affected the Rockall area during Permo-Triassic and Jurassic times, with the main phase of rifting during the Cretaceous.

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14th March 2013
T. Neville George Medal lecture
Professor Jenny Clack, Cambridge University
Populating Romer's Gap : rebuilding terrestrial ecosystems after the end-Devonian mass extinction

At the end of the Devonian, a mass extinction changed the faunal composition of terrestrial and freshwater faunas. The following 20 million years is a fossil-poor interval known as ‘Romer’s Gap’. This interval, the Carboniferous Tournaisian stage, saw the re-establishment of fully terrestrial ecosystems and the evolution of terrestrial tetrapods. Unfortunately, almost no fossils were known that could document these events. Now, for the first time anywhere, abundant fossils of tetrapods, arthropods, and fishes from this interval have been found – in Scotland. My talk introduces the finds and their significance, and the research planned to investigate this crucial stage in Earth history.

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18th April 2013
Dr. David Chew, Trinity College, Dublin
Measuring Palaeozoic time by isotopic dating

Precise absolute age dating of sedimentary sequences is extremely important in establishing the timing and duration of many geological processes, including climatic fluctuations or rates of evolutionary change. This presentation will consist of two case studies from Carboniferous sequences in NW Europe (Ireland, England and Belgium). The first case study employs precise U-Pb CA-TIMS zircon dating (the “gold standard” in Palaeozoic timescale calibration) of Carboniferous volcanic layers. These air fall tuffs are interspersed within glacio-eustatic sedimentary sequences with high-resolution biostratigraphy. These data are used to constrain the onset of Gondwanan glaciation and duration of Gondwanan glacial–interglacial cycles. The second case study involves dating sedimentary rocks by two relatively new isotopic methods (Re-Os dating of black shales and U-Pb dating of diagenetic xenotime). These methods are applied to the same sequences dated by the U-Pb zircon method, and allow us to determine the suitability of the Re-Os black shale and U-Pb diagenetic xenotime chronometers to dating older, fossil-free sedimentary units.

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9th May 2013
Members Night

Oral presentations (15 minutes each):

Jim MacDonald - Preview of the new Gigha Geology Guidebook
David Jarman - Lost mountains and outsize debris cones in the Tirol Alps
Iain Allison - Geology of the Scotia Arc
Margaret Donnelly - Australia geology, eclipse, stromatolites
- Field trip photo's 2011-12
Laptop "kiosk-style" slide shows:
Margaret Greene - Strathclyde Conservation Group

Bench displays:

Simon Cuthbert - Polished slab of Markle-type basalt, Gleniffer Braes, Paisley
Anne Gray - A weekend in Whitby
J Jocelyn - Mexican coconut agate
Robert McNicol - Some extracts from my geological field sketchbooks

Thanks go to all who contributed to a very enjoyable end to the indoor lecture season.

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Excursions Secretaries Reports

Day and Evenings excursions

There were 6 very successful excursions this year , probably due to early organisation and advertising in the third (February) Newsletter. All excursions were well attended, and trips 3, Carstairs Kames, & 5, Cononish & Glen Orchy, were full with waiting lists. Fortunately, the weather was extremely kind to us and ***too*** kind for trip 4 as temperatures topped 30^{0}C!! This was the Joint Excursion with the Edinburgh Society to Keltie Water and several professional geologists came along to revisit the different interpretations of this area. The meal in Callander was enjoyed by all. Excursion 5 to the Cononish Gold Mine was particularly popular but the maximum allowed into the mine was 16, in two groups of eight. We hope to run it again next year, to accommodate those on the waiting list, providing the mine is still open and accessible. It was a beautiful day for our first trip to Arrochar Alps, so that we were able to enjoy the magnificent scenery and topography, whilst the trip to Barnsness was a 'fossil lover's' delight and a rare chance to visit the Scottish Lime Centre. Excursion 6 was a splendid opportunity to investigate the Barrow zones north of Brechin. We used Essbee Coaches for all Excursions except 5, when we required 'off road' vehicles, and so travelled to Tyndrum in private cars and then used two range rovers, one belonging to Scotgold and one to an obliging friend, to take us up to the mine. (Volunteer minibus drivers are not forthcoming.)

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Residential Excursions

Residential Excursion Secretary's Report –1. Sat 22nd June – Mon 24th June.

Over the weekend of the summer equinox, 12 members of the society ventured abroad for an international excursion to Norway via planes, trains, speed boats, ferries and automobiles to indulge in all kinds of exotic Norwegian rocks. The adventure was led by Dr Simon Cuthbert, University of the West of Scotland. The trip started for most of us with a four hour speed boat trip along the coastline from Bergen to our weekend base in the north in the town of Maloey. This gave excellent opportunity to whet our geological appetites with some rock spotting. The trip started on the Saturday with a brief lecture from our Leader introducing us to the regional geology before hitting the road for a three day adventure exploring evidence of a subducting continental margin in a Himalaya-type continental collision, Caledonide mountain roots, the world's biggest ductile shear zone, Caledonian allochthons, supra-ophiolitic melanges, intramontane basins and a spectacular fragment of the Laurentian sub-continental lower lithosphere. The trip included a trip to a working quarry to sample mantle lithologies where we felt the earth move and a midsummer's night (*Sankthansaften)* excursion to the most northwesterly point of Norway where we admired the midnight sun over the sea along with a wee dram. Thanks to all those who attended this year's international weekend excursion, especially those who volunteered to write the Proceedings and the drivers. In particular, I would like to say a special thanks to our excursion leader, Dr Simon Cuthbert. I only wish the hotel food had been better…!

Katerina Braun.

Residential Excursion Secretary's Report –2. Sat 5th Oct – Mon 7th Oct.

Our second Residential Excursion was Joint with the Open University Geological Society and took 21 of us to the Killin area to investigate the Ben Lawers Synform and Ben Lui Fold. We were fortunate in that the weather stayed mainly fair for the whole weekend. Our leaders were Doctors Graham Leslie and John Mendum of BGS, and they *really* knew their geology!! Most of the company stayed in B&B accommodation in Killin and we had evening meals in the Killin Hotel. The excursion began in Glen Ogle where we were introduced to the local stratigraphy, and continued in the 'Lawers Road' over to Bridge of Balgie, and beside Lochan nan Lairige where the geology became more complex. On the second day we ventured north to Glen Lyon to continue our investigation of folded rocks, and to find the boundary between the Middle Argyll and Grampian Groups, previously described as the Iltay Boundary Slide, but now tentatively interpreted as a primary stratigraphic unconformity. The depleted numbers on the third day examined the Falls of Dochart, and some marvelous glacial features in Glen Dochart, before heading to Loch Katrine for a *brilliant* lesson on cleavage/bedding relationships. Our leaders were excellent, explaining the intricacies of the local rocks with great patience and fortitude…….and they were very good company too, so that altogether we had a ***lot*** of fun.

Margaret Donnelly

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Day excursion reports

Rock Slope Failures of the Arrochar Hills
27 April 2013
Participants 18
Leader: David Jarman, Mountain Landform Researcher
Report: *Seonaid Leishman*

At the AGM in January 2012 David Jarman gave a short talk on *Collapsing Munros – shaping the Highlands.* The time allotted was all too short and David could only introduce the topic of Rock Slope Failures. However he readily agreed to lead a future excursion to our own back-yard, the Luss Hills, Arrochar Alps and Cowal.

On a beautiful sunny April morning 16 of us met up at the foot of Glen Douglas and were taken on a road tour, with associated short hikes, via Loch Long, Glen Croe, Loch Goil, Hell's Glen and Loch Fyne. Our trusty friend Raymond negotiated the coach over some of these tricky single track roads.

David's full notes for a self-guided tour, including photographs, render this report rather superfluous. His Guide is on the website (www.geologyglasgow.org.uk). However it is worth giving a flavour of this excellent excursion to encourage you to take to the High Road!

Rock Slope Failures (RSFs) comprise large landslips, rockslides and slope deformations affecting square kilometres of hillsides and penetrating 100s of metres deep. They occurred around or soon *after* deglaciation periods and were first recognised and mapped by C T Clough in the 1890s. However following David's recent research 1000 or so have been identified in the Highlands, the greatest concentration being in our area of the Arrochar Hills. RSFs help to explain the shaping, enlargement or destruction of these mountain ridges, corries and glens.

I found the language of RSF to be helpfully evocative. Here are a few examples:

1. Glacial breaching. At the Rest and Be Thankful this cuts deeply into the pre-glacial watershed thus concentrating erosion and provoking RSF clusters. From Hell's Glen the fretted ridge down the west side of Loch Goil is a series of breaches in the making.

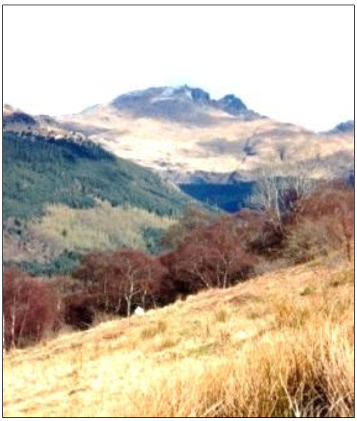
2. "The Great Landslip" (on early geological maps). This marks an RSF *rock* slide, *not* glacial debris. The sliding zone is a combination of jointing and foliation surface (in schist), aided by gravity. The huge creeping failure at Morelaggan, Loch Long continues to cause problems for the West Highland Railway - and the A814.

Morelaggan debris

NB don't blame the Rest and Be Thankful road closures on RSFs! They are the result of small debris flows in the *glacial till* plastered onto the steep side of U-shaped Glen Croe.

3. Source cavities (or 'cracking great holes'!). These are the source of the rock debris. In other words, the mountains are coming apart! _By walking the Carrick Glen_track you can view_many RSFs and imagine the huge caves and yawning chasms above as a slice of the valley headwall is collapsing. We were told that Creag na Saobhaidhe looks like a mini Whangie!

4. Anti-scarp array (uphill facing scarplets). These dip into_the_hillside. Some are 'cocked hat' breakouts, well seen in Glen_Douglas. Other RSFs can form hazardous tension fissures. At The Steeple_on East Loch Goil the fissures are 35 m deep.



5. Fanged peaks. The Cobbler's distinctive two-fanged peak is formed by a huge landslip off the back into Glen Croe. Ben Lomond's_peak has been similarly sharpened with its distinctive north end 'cocking a snook' at travelers up the Loch.

Cobbler from Morelaggan

6. Shrinking summits. As well as changing the shape of our mountains, RSFs are depriving some of their Munro status! Such as Beinn an Lochain.

7. Deranged drainage! Stream patterns which descend the mountains at odd angles, or dried out slopes with powerful springs at the foot. In some cases RSFs pre-date the Loch Lomond Readvance.

The illustrated Guide is designed to be self-guided. A set of binoculars – and some good weather – will help you interpret these features of RSF in the Arrochar Hills. I have only picked out a few of the aspects that fascinated me. Enjoy!

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Barns Ness and Charlestown Fife
11th May 2013
Leader Dr. Al McGowan
Participants 17
Report Marion Ballantyne

Barns Ness holds an abundance of fossils, probably the largest in Scotland. Many of the limestones are in fact coral reefs, preserved in three dimensions.

These were laid down in the Carboniferous, 320 Million years ago when Scotland lay at the Equator giving rise to warm and moist temperatures. Evidence of raised beaches can also be seen indicating the rise and fall of sea level.
We proceeded along White Sands and began searching for fossils.

An extensive area of basin-shaped hollows which are about one metre across and 30-60 cm deep could be seen extending out into the Forth. This is the most impressive Geological feature of this trail. Close inspection of the hollows revealed *Stigmaria*, roots of the *Lepidodendron*, an ancient ancestor of the mangrove tree. The Lepidodendrons grew in harmony with the coral as they do today in equatorial climates, another feature which would encourage the growth of the trees would be the delta that brought in muds with the coming and going of the tides.

The last major glaciation reached its peak 20,000 years ago leaving evidence of erratics [dolerite, fragments of Old Red Sandstone and Highland metamorphic and igneous rocks] which had been carried down the Valley of the Forth. The sea level has been at or close to its present height for about 35000 years.

The Catcraig lime kiln came into view as we left the beach on our way back to the bus.

We next visited the village of Charlestown at Scottish Lime Centre, where we were given an excellent presentation on the workings of the lime kilns which were built to produce lime for improving soil and mortar for the building trade. The limestone roasted in the kilns was broken down to give carbon dioxide and calcium oxide known as quicklime. Adding water to quicklime gives calcium hydroxide or slaked lime. This improves the soil condition; the soil becomes more friable and can be worked more easily. Today the Dunbar limestones are used to make cement.

Finally we walked down to the Forth river shoreline to view the massive lime kilns of the past, which had been in production many years ago and became aware that this was a dangerous and labour intensive process.

Names of Fossils viewed.

Body Fossil: Colonial coral. *Siphonodendron*. -->

Body Fossil: Solitary coral
Body Fossil: Crinoid *Parazeacrinites* Sea Lily.
Trace Fossil: *Zoophycos*.
Trace Fossil: *Rhizocora llium* [burrow]
Trace Fossil: *Thalassinoides* [burrow]
Rare Fossils: *Chaetetes*. Close to Headland, a common reef-building organism.

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Carstairs Kames.
Saturday 6th July 2013.
Leader John Gordon
Participants 25
Reporter: Margaret Greene

Carstairs Kames – one of the most famous landforms in Scotland
The following is from the SNH citation of the site
" Carstairs Kames Site of Special Scientific Interest (SSSI) lies less than 0.5km north of Carstairs and illustrates one of the most striking and important groups of glacial landforms in Britain. Extending over a distance of 7km, the site comprises a series of braided sand and gravel ridges (eskers) and mounds (kames) with intervening peat-filled hollows (kettle holes). These features, which reach an exceptional height of 25 metres above the surrounding topography, are the product of glacial meltwater charged with sediment draining out from the front of the last ice sheet as it retreated approximately 15,000 years ago. Carstairs Kames is a historically important site that has been a focus of scientific study for over 160 years, and it remains a key locality today for interpreting the processes and patterns of landscape development associated with ice sheet melting ".

On a warm and sunny morning we set off from the Gregory building, and met up with three others at the Ryeflat Peat Extraction site near Carstairs. From there we travelled a short distance to the south-eastern end of the ridge. Scotland experienced multiple episodes of glaciation especially in the past 1.7 million years – the landforms at Carstairs Kames relate to the last major ice sheet. The main phase of ice initially came from the north pushing south and eastward but following this the ice sheet came from the Southern Uplands pushing northwards – therefore the latest ice to arrive in the area was from the south. There is a long history of investigation of the site which is a series of anastomosing ridges with kettle holes in between the ridges. They are the remnants of a huge suite of deposits stretching from Lanark almost to Edinburgh left by the westward retreat of the last ice sheet. The composition of the ridges is variable, being mostly sand and gravel. They are not strictly kames as this refers to features on the edges of a glacier. Interpretation of the ridges has varied over the years from moraines to eskers (sub ice flows) to a recent more complex interpretation of a mix of glacial and subglacial rivers leading to the mix of coarse and fine sediments. Dead ice would result in forced river channels which would then appear as ridges. Despite the site being classified as a SSSI in the 60's work still went ahead on quarrying on the south side which is now a featureless flat area.

John pointed out that the fact that gorse has been cleared off the kames and animals allowed to graze there, is an example of land management playing its part in geoconservation, without which the outlines of the land forms would be obscured. Clasts of 'haggis' rock – a chert and quart micro conglomerate of the lower Ordovician could be seen in a small exposed section on the kames – this being evidence of the direction of ice flow from the Southern Uplands.

Lunch was eaten at Lanark Loch and after that it was decided to walk to New Lanark. Leaving Lanark Loch we walked up the road with the cemetery on our right then into a small side road to our left which leads to Bonnington Power Station. In the distance we could see the present workings at Hyndford Quarry. Cemex, who run the quarry have applied to extend it and this is the subject of a strong local protest. In extending the quarry Cemex have agreed to restore the original glacial features to the landscape and to carry out recording of sections for Geoconservation purposes. Andrew Highton, in the party, explained that he is involved in giving advice on restoring the features. One of the focuses of interest will be the investigation of a probable former channel of the river Clyde. Evidence of this channel had previously been uncovered during the building of the nearby power station.

The land on our right opened out to a large field with kettle holes, kames and eskers – a very good example of post glacial landforms.

Looking along the Esker Ridge

A Kettle hole

This hummocky surface marks a marginal ice position with outwash to the east where the flat land used for Lanark racecourse is to be found. Some of us descended into an abandoned section of the quarry on the left which had been worked out 10 years ago. The quarries here have a very high proportion of sand (69%) and the sides of the abandoned quarry show many crossbedded and ripple structures as well as differentiate layers of mud from glacial lake beds and more sandy lacustrine sediments – the latter interbedded with lignite – some fine particles and some coarser small pebbles – this is clear indication of the ice picking up Carboniferous sediments as it passed over these.

We then made our way towards New Lanark, passing the Bonnington Pavilion which the Victorians built and lined with mirrors in order to reflect the falls at Corra Linn. The highest of the falls here is Bonnington Linn which we did not ascend to but came down to Corra Linn via the pathway managed by Scottish Wildlife Trust. When the Clyde was diverted at the end of the last ice age it found this new route and the volume of water produced by glacial outflow soon scoured out this gorge through layers of Old Red Sandstone. The new channel is steeper and exploited joints in the bedrock – there are a number of right hand bends in the river reflecting joints in the bedrock with layers of harder more resistant sandstone interbedded with weaker layers of shale. Today there are four major falls here in the Clyde.

Falls of Clyde

John explained that this was one of the first sites of geotourism in the late 18th century when the Falls of Clyde became one of the iconic tourist destinations alongside Loch Lomond and Staffa. It was described in early tour guides and journals and visited by such as Wordsworth and Sir Walter Scott and painted by many famous artists including Turner. It was popular all through Victorian times and when the railways came along day trippers from Glasgow could visit the site.

Unfortunately the building of Bonnington Power Station in the 1920's has reduced the volume of water flowing over the falls. The mill at New Lanark was developed due to the water power from the third set of falls and is now a World Heritage Site.

The visit was finished here with a welcome ice cream to cool off after hot day. Chris Henderson gave the vote of thanks to John expressing all of our thanks for such a glorious day of sunshine and geomorphology.

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Keltie Water Joint Excursion with the Edinburgh Geological Society

Sat 20th July 2013

Leaders: Dr Chris Burton, Dr Jim MacDonald

Participants 40, 18(from Glasgow) 22(from Edinburgh)

Reporter *David Hollis*

The purpose of this visit was to explore the valley of the Keltie Water, north of Callander, and study the Highland Border Complex – a series of rocks lying within the

Highland boundary Fault zone between the Old Red sandstones of the southeast and the Ben Ledi (Dalradian) schists to the northwest.

Our leader, Dr Chris Burton of Glasgow University, provided us with a plan of the day's activities (1). There is controversy about the Border Complex because of conflict between stratigraphic, fossil, and dating evidence (2, p 154). Tanner (3) and Bluck (4) take opposing views on this subject. Indeed, Dr Jim MacDonald, our second leader, had a further suggestion – that of compressive extrusion of parts of the ocean floor as an ancient ocean closed. We visited six of the eight possible locations in order to "make up your own minds", as Dr Burton told us. We proceeded up the farm track past Braeleny Farm to a point south of Tom a Bhacain. From there the Keltie Water was followed downstream.

At location 1, NN 63933 11864, in a fault either side of the farm track are the black graphitic shales of ?Ordovician? age, and an orange weathered dolomite. Two felsite dykes cut these strata, and a Tertiary quartz dolerite dyke cuts all of these. Some members climbed up to a vantage point on the dolerite dyke. A short distance south of these, andesite of Old Red Sandstone age crops out. The presence of these rocks, and their correlation with those at the Keltie waterfall confirmed that location 1 is on the Highland Border Fault.

At location 2, NN 63977 12428, further up the farm track to its summit, Dalradian schist with schistose texture and quartz veining showed that we were north of the Highland Boundary Fault. This outcrop was examined and photographed.

Towards location 3, the group walked in an ENE direction towards the Keltie Water, through tussocky grass, over the Transition Member of the Keltie Water Grit (Tanner, 3) to the grey and white gritty sandstone which lies beneath the Keltie Water Limestone and Slate. At a sharp bend to the east the strata are strongly folded.

At location 4, about 120 m downstream, black graphitic shales, and a felsite dyke which forms a waterfall, appear.

Waterfall and Kelsite dyke

Just below the waterfall, a thin cream coloured dolomite horizon exists, as seen in location 1. Although no fossils have been found here, the fossils found in similar strata further west in Leny quarry are of Lower Cambrian age.

At location 5, NN 6450 1237, further gritstones, transitional between the Leny Limestone and slate member and the Keltie limestone and slate member, were examined, together with cobbles of limestone in the river bed.

At location 6, NN 64480 12275, a large waterfall empties into a gorge containing a plunge pool. Tanner (3) shows that the Leny Limestone and Slate Member is cut by a fault beyond which lies the Old Red Sandstone strata. This zone of faults and associated igneous rocks is similar to that elsewhere on the Highland Boundary Fault, including the Leny quarry. Some members of the group proceeded further to an erosional remnant of the former cover of lava, an example of which can also be seen on the east side of the Keltie Water opposite Braeleny Farm.

There are two more locations which were not visited by the group. By then, the group were suffering from the fierce heat about 30^{0}C and the difficult walking on the tussocky grass. They headed back to the farm track and some previously prepared “caches” of clean water until one of the coaches collected them and brought them back to the car park.

Location 7, NN 6376 1093, is a flat area just south of the lava ridge on which Braeleny Farm stands. Andesite’s intercalated with conglomerate layers can be observed. These overlie all the other strata.

Location 8, NN 6385 1010, is another waterfall which falls into a plunge pool into which a number of intrepid young men were jumping. This locality demonstrated the thick, almost vertical, beds of the Old Red Sandstone. Beds of grey sandstone are intercalated with conglomerates whose clasts are water rounded cobbles of material which is not of Highland origin, and whose weakly developed south-westerly palaeoflow indicated possible alluvial flood fans originating from high ground in the south.

The two Societies boarded the coaches and headed to the Old Rectory Inn in Callander for High Tea at which discussion of the day’s activities continued, and vast quantities of liquid refreshment revived the group. A vote of thanks to our leader was proposed, and seconded by enthusiastic applause from those present. The members of the two tired but happy groups bade their goodbyes at 6.30 pm and went their respective ways. Our sincere thanks go to Maggie Donnelly for organising this visit and high tea.

References.

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2. Stephenson D., Gould D., British Regional Geology, the Grampian Highlands (pp. 154). 4th ed., 1995, H.M.S.O. London.
3. P.W.G. Tanner, “Keltie Water” in Tanner P.W.G., Thomas C.W., Harris A.L., Gould D., Harte B., Treagus J.E., Stephenson D., 2013, “The Dalradian Rocks of the Highland Border Region of Scotland, *Proceedings of the Geological Association*, **124**, 240 – 5.
4. a. Bluck, B.J., 2010. “The Highland Boundary Fault and the Highland Border Complex, *Scottish Journal of Geology*, **46**, pp.113 – 4.
4. b. Bluck, B.J., 2011. Reply to the discussion by Tanner on (ref. 4a above). *Scottish Journal of Geology*, **47**, pp. 89 – 93.

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Cononish Gold Mine

Sat 24/8/13

Participants: 16

Leader Chris Sangster

Reporter: *M.Donnelly*

On a pleasant sunny morning we drove up the A82 in private cars to the Dal Righ car park (NN 285292) south of Tyndrum where we met Chris Sangster, CEO of Scotgold, at 9.30 am. A couple of trips in two range rovers, driven by Chris and an ‘obliging friend’, Rob Barbour of OUGS EoS, transported the company two and a half miles up to the mine.

We were divided into groups of eight, and once we were kitted out with safety gear, Chris gave us an introduction.

Geologists from Irish gold mines first identified these rocks as possibly 'gold-bearing' – there are prospects in Northern Ireland, and now one opencast gold mine called 'Omagh Mine' in Co.Tyrone but its productivity is very much higher than the potential of Cononish. BGS mapped the area in the 1960's, reported alluvial gold in streams and identified likely places to search for the ore. The Cononish gold and silver deposit was delineated by diamond drilling carried out between 1985 and 1988 and an underground development programme was started in 1990. A total of 1280 m of underground adits were also completed, of which 590 m was driven on the vein. This is the most important precious metal deposit discovered so far in Scotland this century. The mineralisation (450,000 tonnes at a cut and diluted grade of 11.3 g/t Au and 60.1 g/t Ag) is hosted by a steeply dipping breccia zone, the Eas Anie vein, silicified and haematised by the hydrothermal solutions which carried the minerals, and penetrated the rocks of psammite, pelite, amphibolite and impure limestone of the Grampian and Appin Groups. These same Dalradian rocks extend from Canada through Ireland and Scotland to Scandinavia where gold is also found. The vein extends for more than 1 km along strike and 500 m down dip. It is up to 8.3m wide, has an average width of about 2 m and fills a structure considered to have formed during left-lateral movement of the early Tyndrum Fault (Treagus *et al.* 1999) during the Caledonian orogeny.

The adit went into the side of the hill and the quartz breccia vein outcropped on top, marked with posts, about 800 m above. There were also lamprophyre dykes. Wearing wellingtons, hard hats and carrying 3 or 4 safety torches, we were led inside – it was cold and I couldn't see where I was going!! The diameter of the adit was about that of a Glasgow subway tunnel; it was very wet, and rough underfoot as the ground, though essentially flattish, was strewn with coarse pebbles and cobbles from blasting operations. About 200 m inside, we stopped at a big indent in the wall. It had been bored for samples, and now ground water had found a line of least resistance through the rock, bringing out iron and creating a brownish colour – this was a 'leaking borehole'. In the dim light, I asked what were the shiny things on the wet wall – they were in fact drops of water and ***not*** flakes of gold, as I had hoped! The quartz breccia here was not a good enough quality for extraction. We continued to a large vertical feature in the adit, extending from ceiling to floor and about 9 inches wide. It looked like an area of shearing and was in fact the Eas Anie Fault, which had had left lateral movement similar to the Tyndrum Fault. This fault (and related others) had provided the conduit for the thermal silica fluids to emplace the gold. From here on, the Eas Anie Vein, now named the 'Cononish Main Vein' was very obvious, running along the roof of the tunnel, and as wide – a sheet cutting through the hill at an angle of approximately 45^{0}.

About 200 m further on, we came to a second large indent on the other side of the adit – another 'leaking borehole', and beyond this, a quartz vein cut off by a fault

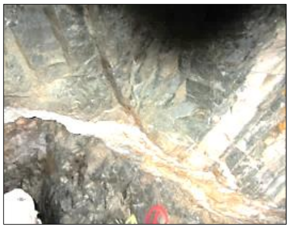

Photo B.Balfour

We came to a large black lamprophyre dyke which had displaced the vein, and so the adit took a left turn, continuing for about 400 m until it was back into the vein. Finally, here, there was good quality ore with abundant pyrite and minerals………and another indent in the wall – this time discoloured to a deep brownish, reddish pink by iron, an indication of thermal fluids bringing in the gold. This particularly deep colouration suggested good quality gold-bearing rock, as the discolouration is usually merely a pale pink. The gold occurs as flecks in the quartz, around the margins of the pyrite, in cracks within the pyrite and within the crystal structure of the pyrite itself. By now there was ***lots*** of pyrite in the quartz breccia vein on the roof.

In the process of mining, pipes about 20 or 30 cm diameter are drilled and explosive inserted. After blasting, the broken rock is removed in trucks, crushed to a small size on site and then treated by 'gravity separation' (mixed with water and stirred), during which the 'pyrite with gold' will sink to the bottom. There is then a frothing process – all the now tiny particles are stirred into a frothy slurry; the foam or scum at the top contains unwanted material, and again the 'pyrite with gold' sinks to the bottom. In this way 25% of the gold is recovered. This is then sent off to a 'plant' for a 'cyanide process' –apart from 'aqua regia', cyanide is the only chemical which will dissolve gold – and so all the 'nasty processes' are carried out offsite. One tonne of rock is required for 10 gm gold………..i.e. 2 gold rings!!

After all the 'gold rock' has been extracted from this tunnel, another will be dug into the hill immediately above, with stoping to prevent collapse. The mining will continue here, the broken rock dropped down through a hole into a truck in the first tunnel and then removed. When all the commercially viable ore is taken from here, a third tunnel will be dug below, and the broken rock brought up. Repetition of this on 3 or 4 levels will create a gallery of tunnels throughout the vein, until finally all the 'gold rock' has been extracted. On our way back out of the adit Chris pointed out the large amount of minerals, especially of galena (lead sulphide), present in the quartz in the roof, however there was not enough for commercial viability.

Back at the Dal Righ car park Chris provided us with more information concerning the background geology, and the methods and history of mining precious metals in the British Isles. One little gem was that Dr Geoff Tanner had produced a map, with plots predicting where the vein would be found. Scotgold had followed this carefully in their prospecting and proved Geoff to be almost ***exactly*** right every time!! We gave Chris, and our 'obliging friend', a 'great big thanks' for a marvellous experience, and then headed to the 'Green Welly' for lunch.

Afterwards, we drove north, and turned west into the Glen Orchy road, B8074, about I mile south of Bridge of Orchy. The geology of Glen Orchy is complex and has only recently been reinterpreted (Tanner & Thomas, 2010). The Glen Orchy/ Beinn Udlaidh / Glen Lochy area is bound to the northwest by the Ericht-Laidon Fault, to the southeast by the Tyndrum Fault and to the west by the Glen Etive Granite. The rocks belong to the Meall Garbh Psammitic Formation (top of the Grampian Group) underlying the Beinn Udlaidh Quartzite Formation and then the Coire Daimh Pelite Formation (bottom of the Lochaber Subgroup of the Appin Group), and all belong to the

Neoproterozoic–Lower Ordovician Dalradian Supergroup. The region is dominated by two major recumbent folds, the Beinn Udlaidh Syncline and the underlying complementary Glen Lochy Anticline, which demonstrate a sedimentary transition from the Grampian Group to the overlying Appin Group. They achieved their maximum deformation during D2, subsequent to the regional metamorphic peak, and are part of a stack of larger SE-facing recumbent folds created during the Grampian Orogeny, ~ 470 Ma. The core of the south-facing Beinn Udlaidh Syncline contains the Appin Group and, together with the underlying Glen Lochy Anticline, it is gently folded by an elongate, east-west regional structure, the Orchy Dome. There is an early fabric (S1), which is mainly destroyed by the D2 imprint, but *does* survive as inclusion trails in regional metamorphic garnets, which are highly oblique to, and wrapped by, S2. Dalradian rocks from below the Iltay Boundary Slide nearby are now believed to be in structural continuity with those of the Tay Nappe above, and the Slide is reinterpreted as a structurally-modified disconformity between the Leven Schist (Appin Group) and the overlying Ben Lui Schist (Argyll Group). There are also a number of later minor intrusions and explosion vents of the lamprophyre suite in the area, whose spatial distribution was probably influenced by the Orchy Dome

Driving along the first 2 or 3 miles of the road, we could see abundant glacial features on either side – drumlins, breached moraines, kames and kettle holes. After about 1.7 miles (~NN 287375), locality 1, our four cars squeezed briefly into a passing place to allow a view of the prominent quartz breccia dyke which runs through Beinn Udlaidh in a northeast – southwest direction. The pelite beds were on the northwest side of the crag, and we were looking directly at the Orchy Dome, whose fold axis runs approximately northeast – southwest. Some 400 m further, at locality 2, (~ NN 286373) we had a closer view of the dyke. The semi-pelite-psammite was dipping off the dome on the northeast side; there was an area of quartz-breccia, and a small knob at the end formed by an explosion breccia pipe. We continued for about 1.7 miles to locality 3, ~ NN 286373, below the Easan Dubha waterfall, and a sizeable parking area on the banks of the river – we got out to explore. The rocks were Grampian psammites and were clearly dipping to the northwest in the river. We endeavoured to find convincing evidence of the 'way up' of the rocks………… with limited success.

However, on the opposite bank of the river, we could clearly see a circular area of broken up material – it was one of the numerous explosive breccia pipes.

Grampian psammites dipping northwest and circular explosive breccia pipe, left centre.

Photo M. Donnelly

Driving a further two miles, we came to another large parking area beside a sizeable expanse of water in the river, below a set of rapids. This would be the highlight of the afternoon. We walked upstream along the bank through long grass and overgrown vegetation.

It was very wet underfoot and the going was not easy, but the rocks were amazing! We stopped a couple of times to examine them on the bank, in the river and on the far side – they were composed of large, intensely and isoclinally folded beds of Beinn Udlaidh Quartzite. We were, in fact, in the core of a major recumbent fold (considered to be the best-exposed example in the British Isles), which has itself been folded by the regional Orchy Dome – we were on the lower, right-way-up limb of the Beinn Udlaidh Syncline. After about 100 m we arrived at our target……… fabulous 'fold mullions', so called because the beds continue around them and are not broken into separate rods …….. ……..…*and* we were in the nose of the fold!

Sitting on the mullions

We spent considerable time crawling all over the rocks, examining them from every angle and taking photos. As a final bonus, we found cross-bedding in the quartzite which indicated that the beds were younging downstream, and that we were indeed on the lower limb.

Photo Nairn Balfour

At last, we made our way back to the cars, tired but exhilarated after another fascinating day of geology, and headed for home.

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Glen Esk
7th September 2013
Participants 20
Leader Dr. Ben Harte
Reporter: *David Martinage*

The bulk of our group left Glasgow 8.35am, with Raymond as our driver, and arrived in Edzell car park at 10.50 am. where we met our leader ,Dr. Ben Harte, and the remaining group members. The day was, and remained, dry with sunny intervals and a cool wind. Dr. Harte outlined the aim of the day and gave us a comprehensive handout based on work he had previously published.

He explained that the North Esk river cuts through a sequence of six metamorphic zones, first described by Barrow in 1893 and elaborated in his paper of 1912, referred to as Chlorite, Biotite, Garnet, Staurolite, Kyanite and Sillimanite. The metamorphism dates from the Dalradian orogeny, c.480Ma.

After a short ride in the bus we walked about half a mile to our first site beside the North Esk river. There we viewed rocks from the Highland Border Complex, notably greenstones (fine grained basic chlorite rich schists derived from basalts) and sandstones from the Margie series. Like the greenstones they are weakly metamorphosed. Small areas of green conglomerate could also be seen.

About 30m upstream we came to the first of the Dalradian zones comprising slates/phyllites composed of chlorite, muscovite, quartz and a little feldspar. Very small specks of partially oxidized pyrite could be seen. Dr. Harte commented on the absence of biotite. This location was in Barrow's chlorite zone.

Walking upstream over rough ground we came to a gorge with exposures of Margie 'grits', sandstones containing small pebbles. Ribs composed of regular, very small, parallel folds were visible on the surface of a large boulder.
We were now in Barrow's biotite zone.

The next zone up sequence is the garnet zone but we omitted this as Dr. Harte felt it was difficult to access. We had lunch at the top of the gully and proceeded back to the bus.

Our next stop was in Barrow's Staurolite zone, conveniently transected by a gravel road constructed for grouse shooting parties. A ten minute walk uphill revealed a number of rocks with grey nodules on the surface comprising Staurolite with its surface degraded to muscovite but we were also able to find examples of unaltered Staurolite as brown prisms. Small garnets were also sometimes visible.

Another short bus ride and walk brought us to the kyanite zone, the kyanite showing as attractive streaky blue crystals embedded in white quartz veins. Finally, after another short hop and fighting our way through deep bracken over rough ground, Dr. Harte showed us some examples of Sillimanite with a superficial appearance of grey felt but which, apparently, were composed of fine needles and likely to be enveloping garnet.

Back in Edzell car park at about 5.15pm. Alison Drummond gave a vote of thanks to Dr. Harte for a very enlightening day

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Residential excursion reports

Norway Field Trip

Day 1Saturday 22nd June – Subducting Baltica & Eclogite Extravaganza!

Reporter K. Braun

The day began with an introduction to the local geology at Selje Church Car Park. Bergen to Trondheim is essentially one big lump of gneiss that is referred to in geological literature as the Western Gneiss Complex, WGC (also referred to as the Western Gneiss Region, WGR). The Western Gneiss Complex exposes the roots of the Scandinavian Caledonian mountain belt. Rock types include large ultramafic to mafic and acid intrusive bodies that have been modified to orthogneisses with bands and lenses of paragneisses including high-pressure (HP) and ultra-high-pressure (UHP) rocks such as eclogites, garnet pyroxenites and garnet peridotites.

Locality 1 – Shoreline @ Selje Church

The Norwegian gneiss is exposed at this locality, which consists of about 50% plagioclase feldspar, 10 to 30% quartz plus biotite and muscovite micas. The Norwegian gneiss is foliated with mica poor and mica rich layering. Most of these gneissose rocks were once igneous granites that have later been subject to flattening and/or shearing. The effect of buoyancy, vertical flattening, shearing and thrusting has caused the rocks to flatten and thin and the alignment of minerals that are platy or rod shaped. In some instances, these rocks have partially melted, indicating temperatures of 700 Celsius or more. The combination of melting and shearing, led to the formation of anisotropic layering into mica rich layers and mica poor layers. Pink pods are present, which are evidence of an augen gneiss. The presence of augen gneiss about the strain pattern in the rocks. The ‘Augen’ can either be rod shaped or blade shaped. Where the augen are rod like, they have been stretched in one dimension. Where two-way stretching occurs, the augen are flattened and stretched simultaneously to form blades (pancakes!). The augen in this region are strongly rodded indicating stretching in one dimension. The protolithic age of these gneissose rocks is thought to be 1700 to 900 Ma.

These rocks must have been involved with at least three phases of orogenesis; firstly during their initial formation as granites, secondly during a period migmatisation and flattening and thirdly, a period of exhumation and uplift to the present day ground surface. It is thought that the original granodiorite/granitic body formed during a major crust forming event and was subsequently overlain by Neoproterozoic sediments, before

becoming entwined in the Silurian Caledonian orogeny about 420 Ma when they were converted to gneiss.
Meta basic amphibolite pods are also common and are wrapped within the body of the gneiss. It has been shown that these pods were once eclogites prior to conversion to amphibolite during exhumation. The wrapping of the gneissose material around the metabasalt material suggest that the metabasalt material is harder and less prone to melting compared with the surrounding granitic material; hence the more ductile gneissose material was effectively squashed around the harder metabasaltic material. Other metabasic pods are often found nearby either up or down the foliation to form lines of metabasic pods. These pods were once part of the same metabasic body that has been boudinaged. (.See plate 1)

Plate 1 **Boudin Pod**

Plate 2 En echelon

En echelon fracture sets are commonly visible in the gneissose material as well. These occur where stiffer bands of material fail by brittle failure when subject to stretching as opposed to rather than ductile deformation. .(See plate 2)

Locality 2 – Grytting

The rock at Grytting is a severely altered eclogite. The eclogites at this locality are designated as a national treasure. The name 'eclogite' comes from Greek and means 'choice', which is interesting, as eclogitse choose not to have any plagioclase minerals within it! Eclogites mainly consist of omphacite and garnet.
In 1984, Smith discovered relict coesite in a clinopyroxene grain and noted poly crystalline quartz pseudomorphs after coesite, as inclusions within clinopyroxenes and garnets. Coesite is a high density variety of silica, which is denser than the earth's mantle and forms at mantle depths of at least twice the thickness of continental crust. The presence of coesite is therefore an indicator of "ultrahigh" pressures (UHP) in the region of 35 kbar or more, i.e. depths of 200km or deeper! Interestingly, Smith did not observe any evidence of UHP metamorphism in the adjacent gneisses. The mineral assemblage of these rocks is indicative of continental crust of amphibolite facies; thus 10 to 20 kbar pressures and 60 to 70 degrees Celcius. Smith therefore interpreted the gneissose rocks as a product of low grade metamorphism.
Question - how did coesite bearing eclogite that formed at pressures of 35kbar come to be juxtaposed against gneiss bodies signifying much shallower depths and considerably lower

pressures of 10-20 kbar? Smith believed a ‘foreign origin hypothesis’; where the eclogite and gneiss bodies were brought to juxtaposition by tectonic forces. The problem with this theory is that does not explain how the denser eclogite bodies that are known to form at greater mantle depths than the gneiss, were brought together and mixed with the less dense gneiss that was thought to have formed at shallower mantle depths. An alternative hypothesis is that the eclogites formed in-situ from ordinary basalt or gabbro bodies that had been emplaced within the crust and that this crust was later plunged into the mantle at great depths and later uplifted to existing levels with evidence of higher grade metamorphism overprinted during uplift within the gneissose material but not the eclogites. This alternative hypothesis is referred to as the ‘in-situ origin hypothesis’. When these theories were being debated, it was believed that only oceanic crust could be subducted… Since 1984, relict coesites within garnet, omphacite and kyanite micro-inclusions and poly-crystalline quartz pseudomorphs after coesite have been identified across a number of other eclogite localities in the WGC, further supporting the idea that these eclogites have been subject to UHP and HP metamorphism. Further evidence for UHP metamorphism has recently been provided by the discovery of micro-diamonds in a garnet websterite lens within a small outcrop of peridotite at Bardane on Fjortoft island, well to the north of Selje. Coesite has since been found in the gneissose material as well – providing evidence that the eclogites and gneissose material were metamorphosed together. As the gneissose material is a crustal protolith, it has been interpreted that continental crust was actually subducted to great mantle depths!
The most spectacular rock-type at this locality is the “pegmatitic orthopyroxene eclogite”, originally described by the great Finnish petrologist Pentti Eskola (founder of the metamorphic facies principle). The rock is more correctly called a garnet websterite, and is similar to the coarse websterites of the Glenelg area in northwest Scotland. However the Selje rock has extremely coarse pale brown enstatite, pinkish red gemmy garnet and bright green diopside along with flakes of coppery-brown phlogopite mica and magnesite. Grains are up to 3cm long and rather randomly orientated, which is why the usually igneous term “pegmatite” has been used. Some recent research has led to the idea that this rock was originally a peridotite, but fluids rich in silica, potassium and carbonate have impregnated the rock and converted it into a websterite. Similar rocks are found among the “nodules” erupted in kimberlite pipes, and another outcrop of identical rock to the north of Selje near Molde contains metamorphic diamond! Back in 1921 Eskola deduced that such rocks were formed at very high pressures, and he would have been delighted to have been so well justified.

Locality 3 – Vetrhuset (Nordpollen)

The rock cutting along the road consists of gneiss with a pegmatite band. There is a high muscovite content, suggesting a sedimentary origin rather than igneous origin. Eclogite pods are visible in the road cutting, which are fine grained. The gneissose material appears to wrap around the eclogite pods. (See plate 3)

Plate 3

Eclogite pod

At the shoreline, the gneissose material includes garnets, quartz and kyanite suggesting this rock pre-metamorphism was a silty mudstone that was converted to a mica schist.(Plate 4) White micas are present, which are a special type of muscovite that has a low aluminium high silica content with some magnesium and iron. This type of muscovite mica has a higher density due to a tighter packed atomic mass and is called phengite. Phengites form at low temperatures and/or high pressures. The presence of eclogites within the rock mass here is also an indicator of high pressures. Phengites are stable at significant mantle depths providing temperatures remain low. The bedrock at this locality is therefore not an ordinary mica schist but a high pressure variety. The garnets are calcium rich, which is further evidence of high pressures when present alongside kyanite and quartz. A close look at samples taken from the meta-sedimentary material revealed the presence of coesite inside garnet rims with quartz inclusions in the cores. The presence of coesite in the garnet rims indicates that the continental crust was also subject to UHP metamorphism. This site therefore suggests that the eclogite pods and surrounding country rock were subducted into the mantle and metamorphosed together; hence the eclogites were formed in-situ and are not of foreign origin (see plate 4)

Plate 4 meta- sed rock

At the end of the shoreline outcrop, the quart grains exhibit a rod lineation that can be traced into garnet granular textures. The quartz lineation is thought to have once been a coesite lineation that has subsequently degraded to quartz. Conversion of quartz to coesite will increase the density of the country rock since coesite is a higher density variety of quartz. This densification could therefore aid subduction of continental crust!!!

Locality 4 – Flatraket Quarry, Nordpollen

The rock in the quarry is a quartz syenite that has an orbicular structure with massive, round plagioclase feldspar minerals that are purplish-brown in colour. (see plate 5) This rock is barely deformed with a matrix consisting of hornblende, plagioclase, quartz and augite. The rock formed 1600 Ma as a coarse grained quartz syenite that was later metamorphosed 1100 to 1000 Ma to a high temperature and moderate pressure within the range of the granulite facies. When this rock was metamorphosed, ductile deformation did not occur.

Plate 5 Flatraket Quarry

Instead, the rock dried out and shrunk leading to brittle failure and fracture formation. If the rock had been wet, ductile deformation would have occurred.

Locality 5 – Outcrop of The Day – Verpeneset

This gorgeous rock is one of the most perfectly preserved eclogites known. It was formerly a gabbro that has been subducted and converted to eclogite. The eclogite at this locality has zones rich in garnet and grass-green omphacite, or sugary zoisite, kyanite, phengite and quartz (formerly coesite). The garnets are speckled internally and have a dark red or even black, almandine-rich cores and a lighter red rims richer in the pyrope variety. Amphibole is trapped within the garnet cores, along with other low-pressure minerals like epidote, plagioclase and chlorite, and these give the cores their dark, speckly appearance. The omphacite rods are aligned and streaking is also evident at this location. This rock is therefore an L-S tectonite that has formed in response to being stretched and flattened. The zonation in the garnets shows that they grew during increasing pressure and temperature along a trend typical of subduction zones, but in this case the crust being subducted was continental, and the eclogite was probably an intrusion of Gabbro within it .

Plate 6 Gorgeous Eclogite

Norway Report (Bremanger)
Day 2 Sun 23/6/13
Reporter: *Maggie Donnelly (with* ***<u>lots</u>*** *of help from Dr Simon Cuthbert!!)*

At 9.00 am on a lovely morning, and forewarned by our leader – "Don't miss the ferry!!" – we sailed from MålØy out into Nordfjord bound for Bremangerland – 'the land of glaciers'. It was fabulous – the views were spectacular looking back at the town, the bridge linking the island of VågsØy to the mainland, the mountains and the islands.
The land we had left, to the north and far to the east, was part of the Western Gneiss Complex (WGC) of 'Caledonized' Baltic Basement, most of whose original crystalline rocks were formed during Proterozoic orogenies. They underwent recrystallization and

deformation during the Scandian orogeny, with the degree of "Caledonization" increasing systematically from minimal in the southeast to diamond-grade eclogite facies in the northwest. On top of this is an orogenic wedge consisting of four allochthons (thrust sheet assemblages) that were thrust E/SE over the autochthonous Baltic Shield when the Iapetus Ocean closed and Baltica subducted beneath Laurentia during the 430–385 Ma Scandian orogeny. These are the Lower Allochthon (pre-Scandian arenaceous sediments), the Lower and Middle Allochthon (crystalline slices and their sedimentary cover derived from the Baltica margin), the Upper Allochthon (oceanic terranes derived from Iapetus and its margins) and the Uppermost Allochthon (stranded Laurentian upper plate which does not occur in this southern area of Norway). Today we would make a traverse through these allochthons.

We arrived at Odleide on Bremanger, just beside the terminal, where there was a huge black cliff. We were now in the structurally highest part of the WGC, and very close to the edge of the Hornelen Basin, a large mass of Middle Devonian redbeds that extends over 40 kilometres inland towards the east. The islands we had sailed past were composed of augen gneiss units with layers of quartzite and meta-anorthosite (a plagioclase rich meta-igneous rock) enclosing small bodies of eclogite and serpentinite. Similar coesite-bearing eclogites on the north side of Nordfjord such as at Verpeneset (which we saw yesterday) have been metamorphosed at a maximum pressure of 27 kbars and 670^{0}C corresponding to a depth of about 90 km. It was remarkable to think that rocks of such deep origin were now found so close to almost unmetamorphosed sedimentary rocks which have never been deeper than a few kilometres from the surface. The rocks of the great cliff overlooking the ferry pier were flaggy, layered with small isoclinal folds and with a platy character, an extremely fine-grained grey gneiss with little bits of K-feldspar augen. We were now in a 5 km thick zone of mylonite with a consistent south-dipping foliation, extending a minimum of 40 km eastwards from the mouth of the Nordfjord. It is a ductile shear zone formed at 500 – 600^{0}C and 8 – 10 kbar in the Lower to Middle Crust. Lapworth coined the term 'mylonite', which means 'milled rock'; however**,** *these* rocks were not formed by milling or crushing, but by intense ductile shearing in which the rocks behave almost like plasticine – the grain size reduction was brought about by 'hot-working'. On the other hand, about 1 km south and up the structural section along the road towards the tunnel through the mountain, the mylonite behaves in a more brittle way – as an **ultra**cataclasite (a cohesive or welded tectonic breccia).

We made our way down to the shore where weathering had picked out the structure and grain size reduction in the rocks; they contained paper-thin layering and small deformed pegmatites.

Paper thin layering and asymmetric augen

They had originally been granites and diorites and had *en-echelon* veins – arrays of quartz-filled fractures which formed during shearing when the rock was coming up to the surface. As it did so, the pressure was released and fluid entered. There were asymmetric augen and mineral lineations that indicated top to the *west* shearing. This thick package of mylonites lies within the Vetvika Shear Zone (one of the world's biggest ductile shear zones) which caps the WGC and is part of the enormous Nordfjord-Sogn Detachment Zone that runs along the coast from MålØy to Bergen. Its top-west shear sense is consistently opposite to the direction of the main thrusts along which the overlying Caledonian allochthons had been moved hundreds of kilometres to the east. It is also younger than those thrust faults and often coincides with, and overprints them, showing that the motion on these major Caledonian thrusts has been reversed, apparently carrying the allochthons back to the west over the WGC (the Baltic cratonic margin) from where they had come, a process that was, when first discovered in the 1980's, called "orogenic collapse". It is almost identical to the geometry of the South Tibetan Detachment System in the High Himalaya of Nepal and the Tibetan Plateau.

The process is now thought to have occurred in a manner something like this: the cratonic margin of Baltica had collided with Laurentia and had followed the oceanic lithosphere down the subduction zone for a couple of hundred km – continental subduction! During this subduction the eclogites formed within the Baltica rocks, at around 425Ma. However, the oceanic lithosphere broke off from the continental leading edge and sank away from it into the deeper mantle. The buoyant continental material was now free to rise back up the subduction zone, and it slid up along the underside of the allochthons. So, although it looks as though the allochthons had slid back down to the west, in fact the WGC had slid back up to the east underneath them. Here it's better to think of the *upthrow* of the fault rather than the downthrow! It was a simple shear system, like a pair of scissors, in which the *footwall* of gneiss moved *upwards* and to the *east*. This had happened after eclogite facies metamorphism at 425 Ma – the WGC experienced very rapid decompression associated with early slip on extensional detachment horizons. It was exhumed rapidly with little loss in temperature, and then cooled quickly at this depth. (It was jokingly suggested that the process ***could*** be described as Ultra **<u>Low</u>** Pressure Metamorphism – ULPM..........although in fact it isn't!!) During this time the eclogites, and especially the gneisses, experienced retrogressive metamorphism such that most of the high pressure minerals were obliterated, with only some of the rare eclogites now survivingto show what had happened.

We drove up the hairpin road towards the south to a viewpoint over the Nordfjord, from where MålØy could be seen in the distance. Passing through a tunnel we crossed over the uppermost mylonites and, in a tunnel through a high ridge passed a thin belt of ultracataclasite (cohesive, welded fault breccia) and fault gouge. Here was a major tectonic break where we would leave the WGC and its cap of mylonites and enter the overlying allochthons. In the next part of the excursion, traversing the island of Bremanger, we would pass over the Middle and Upper Allochthons. The Middle Allochthon is a basement-cover thrust sheet complex similar to Assynt, with Baltic gneisses and their psammitic cover. This is equivalent to the giant Jotun Nappe Complex in the Jotunheim mountains far to our southeast. The Upper Allochthon comprises slices of the Solund-Stavfjord Ophiolite Complex and formed ~ 440 Ma, just offshore from Laurentia as Baltica approached, in a manner similar to, but later than, Dalradian events in Scotland. When collision occurred, this ophiolite, the youngest in the Caledonides, was thrust up and over the Baltica crust. However, there would be no sheeted dykes or pillow lavas in our visit today; instead the supra-ophiolitic Kalvåg Melange is found, intruded by an island arc granodiorite at about 440Ma, with accompanying contact metamorphism producing sillimanite and cordierite. This was overprinted by low-grade regional metamorphism, probably around 425 Ma associated with obduction of the ophiolite and collision with Laurentia.

Continuing up structural section southwards into the classic U-shaped glacial valley of Kongsdalen and then swinging west along strike, we arrived at Dalsbotn. The Bremanger Gneiss basement of the Middle Allochthon lay in the hills to the north, and unconformably overlying it in the valley side to our south was a bedded and folded quartzofeldspathic meta-psammite of a type commonly known in Norway as “Sparagmite”. This basement-cover pair is repeated several times in a thrust duplex, and here we were able to examine the psammite in one of these thrust slices, with occasional cross-beds showing younging away from the basement. There is a history of major sandstone deposition events on the northern continent from around 1000 to 600 Ma, suggesting erosion of the old Grenville, Sveconorwegian and Valhalla orogens. Examples include the Moine, Torridonian and Grampian Group in Scotland. It has been proposed that there was a Scandinavian shallow sea ~ 600 -700 Ma, whose sediments now form part of the Lower and Middle Allochthons. Turning to face south, the steep valley wall exposes greenstones of the ophiolitic upper allochthon that lie structurally above the Middle Allochthon; so exposed in this one valley is a cross section through a large part of the Scandian nappe pile, containing rocks which represent the tectonically telescoped Baltica continental margin through into the Iapetus Ocean that lay outboard of Laurentia. Not bad for a single viewpoint! The valley itself is cut along the trace of the parallel Dalsvatn and Kongsdalen normal faults that sole down into the Vetvika Shear Zone and are probably syn-sedimentary faults related to the nearby Hornelen Basin. The Old Red Sandstone fill of this basin unconformably overlies all the rock units in our field of view on the flanks of the spectacular peak of Hornelen just out of sight to our east.

We continued to the southeast, and then cut south up section into the upper allochthon ophiolitic rocks at Bremanger village, before driving round to the south shore of the Bremanagerpollen fjord, in deformed variants of the Kalvåg Melange, to arrive at

Loviknes by a lovely bay. Our leader pointed out the thrusts/detachments in the surrounding mountains as well as the different allochthons, before taking us into a quarry of quartzite with abundant graphite. This was the cover over the green schist volcanics of the Upper Allochthon, and was laid down originally as organic rich muds with silica – radiolarian chert – on a deep ocean bed. The chert had changed to quartzite, and then to quartz schist because of the layers of graphite and mica. There was chlorite and sericite (a mica) but no feldspar. Some distance to the south were greywacke turbidites, as well as enormous turbidite blocks and volcanic rock, the latter associated with the nearby Solund-Stavfjord ophiolite complex, which formed at 443 ± 3 Ma. These are interbedded in a mud matrix with chert beds. Folding occurred as the whole mass in great slabs slid down the submarine slope creating olisthostromes – a melange of continental- and oceanic-derived materials. The setting for this could well have been an island arc; the clastic sediment was deposited in a back-arc basin rather than open ocean, and was probably derived from the adjacent arc. There was an enormous boulder at the entrance to the quarry and we were able to examine it and identify many of its clasts…… huge, large, small and tiny.

From here we drove up into the hills for lunch in an intriguing valley bowl containing the lake Rylandsvatn. We sat on greywacke and could see paler diagonal sheets of granodiorite cutting across the darker rocks, and also in the distance, the igneous contact of the granodiorite, a pluton extending some 20 km and cutting across units in the Upper Allochthon. The greywacke had been hornfelsed by the granodiorite in contact metamorphism, and was now tough with little veinlets; it did not have a coherent stratigraphy but was badly disrupted – giant blocks in a granodiorite matrix. Thermal shock had fractured the greywacke into sheets that foundered into the granodiorite magma at temperatures of up to 900 -1000^{0}C in a process known as stoping. The granodiorite was an arc related magma, which had invaded the ophiolitic melange in the Iapetus Ocean. Ophiolite obduction had occurred at ~ 425 Ma (Wenlock) – at almost the same time as the WGC eclogite formation. All this had taken place just off Laurentia, with Baltica on the horizon. We walked over the greywacke, examining the granodiorite veins, dykes and stoping, and found hornfels with striking crystals of cordierite in the muddier beds.

Returning to the bus, we then drove further to the southwest end of the Bremangerlandet and parked just before the Bridge to the island of FrØya. Here at the side of the road, where some large blocks of the granodiorite lay, was the Kalvåg Melange type locality and again the hornfelsed contact. Cordierite had weathered out of the pelite bed and there was sillimanite indicating that the metagreywacke had experienced a very high temperature (850^{0}C) but low pressure (4 kb, 12 km depth). Across the bridge to the island was the 440 Ma FrØya gabbro, while across the sound of Frøysjøen, in the bare mountains and islands to the southeast lay the Middle Devonian sandstones of the central Hornelen Basin.

We headed back the way we had come but instead of returning through the tunnel to Odleide we continued eastwards on the road along the north of Bremanger and then through a sub-sea tunnel to the island of Rugsundøya. We had a comfort stop beside a small fjord, and in the 860 m high cliff face of Hornelen mountain across the water (the highest sea-cliff in Europe) we could see the unconformity of Devonian conglomerates and sandstones on top of augen gneiss and quartzite. Legend claims that Olav Trygvasson (Norwegian king 995 -1000) climbed this face, and the Viking raider fleets used to rendezvous below it. Our leader produced an amazing diagram of the Hornelen Basin geology, showing the proportion of different clasts he had found in the conglomerates, in the early days of his geological career. The whole basin had been formed by a huge listric fault, and the sediments had been sourced from the same Middle and Upper Allochthon rocks as we had seen on Bremanger. The setting was very similar to the fans of Death Valley, with alluvial fans at the sides and axial sandstones down the middle. A huge quantity of sediment had been deposited – up to 100 m thick units of clay, fine and coarse sandstone, with diagonal syn-sedimentary faulting. However………..the basin was now today's mountain range……………erosion had reversed the topography.

We drove on eastwards, crossing by a bridge to the mainland and then through the brand new 6 km Vingen Tunnel below the 750 m conglomerate arête of Vingen, then to the southwest, surrounded by high mountains and ice caps, to an old quarry in a gorge near the ferrosilicon smelter plant at Svelgen, where we could examine these massive Devonian sandstones with huge cross bedding. The sand had been transported from east to west in the basin, the coarsening up sequences fingered into each other and this was repeated for a stratigraphic thickness of 25 km, with all the beds dipping at about 25^{o} to the west. They had been originally red but were now green as a result of weathering, and mild metamorphism had formed chlorite, preserved in the lower slopes of the quarry face because these had been covered by glacial till. Over to the west was shale, sand and conglomerate from debris flow fans, and lacustrine deposits occupied the middle of the basin. There were regular cycles of sedimentation, the reasons for which are currently debated. They could be a result of regular fault movements on the basin which then filled up, **or,** as our leader favoured, of 100,000 year Milankovitch-type climatic cycles. There was, of course, no evidence for ice having been here in the Devonian.

We had a 'view stop' by the lake Dalsetevatnet to see the big picture – the basin fines interfingering with alluvial conglomerate, with mud at the base of each coarsening-upward cycle, was obvious. Simon has logged the clasts and they all derive from the Middle and Upper Allochthons. We continued west to a locality just before the Isane tunnel, to examine the Devonian conglomerate. It contained no WGC clasts of the High Pressure Zone; instead, sand and mud were eroding out. The basin is Middle Devonian (about 380 Ma) and so the Western Gneiss Complex, which has mica Ar-Ar ages also around 380 Ma had still lain at more than 30 km depth when these sediments formed at the surface. They must have emerged at the surface later, even as late as the Carboniferous – this would explain the lack of WGC clasts in the basin conglomerates.

We were now rushing for the ferry and another beautiful sail back north across Nordfjord towards home. Looking to the southeast from the ferry, the normal-sense low angle detachment fault between the mylonitic gneiss and the Devonian sediments was dramatic. Subducted Baltica crust with eclogites and entrained fragments of mantle peridotite (exposed in the mountains to the west) had risen up from the mantle to lie adjacent to the conglomerate, using the Nordfjord-Sogn Detachment shear zone, which had been the original subduction channel………this fault had a throw of over 100km!

We disembarked on the north shore and drove the considerable distance back west to MålØy, and to our 'very welcomed' dinner, after a fascinating and challenging day of geology.

Later, and suitably refreshed, as it was midsummer a number of us set off to Kråkenes fyr at the northernmost tip of VågsØy to see the midnight sun. We arrived at the lighthouse around 11.45 pm, in time to see the last of a bonfire set by some revellers. The local sheep were most unhappy to have their seclusion disturbed and were somewhat aggressive – I've never been accosted by a sheep before!! However, it was all worth the effort as we watched the sun sink down behind the clouds and then return in a very few minutes. We were a very merry band……. especially as someone had had the presence of mind to bring along some 'cheer'! And so, after a ***very*** long day, we got back to the hotel and so to bed.

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Day3 24/6/2013
Reporter; Julian Overnell (with a lot of help from Dr. Simon Cuthbert)

The main theme for the day: a visit to large area of mantle dunite in Almklovdalen and to a dunite mine at Aheim.

Tectonic background. The area of mantle rock is approx. 10 km^2 in the form of a vertical sheath fold with gneiss in the sheath core and surrounding the sheath. The rock is thought to be typical of mantle rocks and is similar to mantle xenoliths sometimes found in dykes. The bulk of the rock is high magnesium forsterite with a minor magnesiochromite spinel ($MgCr_2O_4$) and occasional flecks of phlogopite mica. Although the chromium content is less than 1%, this value is high compared with most crustal rocks. The emplacement is thought to be due to the subduction of Baltica deep into the mantle under Laurentia during the Scandian orogeny. The subduction presumably froze surrounding mantle, and when the continents subsequently pulled apart this piece of mantle was drawn up and is now at the present erosion level. Basalt, which forms the basis of most cratons, is the first melt of mantle rock, so the question arises: did this piece of mantle contribute to the formation of Baltica? Analyses of U-Pb ages in 4,000 to 5,000 detrital zircons in stream sediments from all over the Baltica craton have either mid proterozoic or Caledonian ages but no Archaean ages, except for streams draining this dunite mass which do show Archaean ages. Thus it seems that this mass was not responsible for any of the surrounding gneiss and is very much exotic. It probably lay beneath the margin of Laurentia immediately before the Caledonian orogeny.

The Excursion. The party drove to Almklov, parked near Lien Farm (0323466,6879335) and walked up a track through the woods before striking off left across rough countryside of moss, heather and scrub to finish at the small summit of Helgehornvatnet (0322451,6879234). This is a protected site for the geology (and plants); no collecting allowed. Before protection, the site had previously been dynamited by rock collectors. This had the effect of exposing bright garnets and an interesting fold structure – for us to see and enjoy.

Fig. 1. Bright “cape ruby” garnets and chrome diopside with some yellow-weathering olivine and yellowish-grey enstatite in loose clasts of garnet-pyroxenite at Helgehornvatnet. Secondary amphibole replacing the diopside is found in darker green patches.

Fig. 2.View of mantle dunite with folds of garnet pyroxenite.

The corrugated internal cast of a fold on the left of the picture has been interpreted as a structure which arose from mixing of two ductile rocks of different viscosity; in this case the surrounding dunite was more ductile than the pyroxenite. The folded garnet pyroxenite just above and below the handle of the walking stick and which abuts the corrugations has been interpreted as due to intrusion as dykes deep within the convecting mantle and is unrelated to the Scandian subduction/exhumation event.

Fig. 3. Close-up view of garnet pyroxenite bands *in situ*.

These garnet pyroxenite layers (darker weathering) do not have a basaltic composition and are therefore not eclogites, but are a more ultramafic, picritic composition and are thought to be igneous dykes intruded at mantle depths. The colours of the garnets in these bands range from purplish-red "cape ruby" Cr-rich pyrope in the orangey peridotite layers to orange almandine in the websterite layers, especially near their centres. The more purple colour of the garnets towards the edges of the websterites and in the peridotite are due to metasomatic uptake of Cr from the pre-existing chromite-bearing dunite. Likewise, as seen in other exposures at Lien, the garnet and pyroxene content in the peridotite tends to decline away from the pyroxenite layers until it disappears and the rock becomes a pure dunite. It is thought that the chemical components of the pyroxenite magma diffused a short distance into the dunite, causing garnet and pyroxene to develop, a process known as "refertilisation". This is thought to have taken place during the mid-Proterozoic

Other fold structures in the mantle rock were visible at this location, in chlorite-amphibole peridotites, but the folding was again spectacular, as in Fig. 4. The chlorite is pale purple and chrome-rich as it formed by retrogressive metamorphic breakdown of chromite or chrome-pyrope after the peridotite was emplaced into the crust, probably during exhumation. The darker layers are hornblendite formed by retrogressive metamorphism of the garnet pyroxenites.

Fig. 4. Spectacular folding of banding in mantle rock

<u>Visit to Sibelco Grubse olivine quarry</u>. The quarry produces forsterite sand. The main use of the sand is for slag "conditioning" in blast furnaces and basic oxygen furnaces in which role it is a suitable partial replacement for magnesite. It is also used for making refractory bricks for steel furnaces and casting sand for foundries.

The party was met at the gates by a production geologist Marte Kristin Tøgersen. After donning safety boots and hats and high visibility vests we were taken to see the crushing of the ore, then into the quarry where we witnessed one of the twice weekly blastings. The track followed the margin of the quarry where it had apparently been put through a band of eclogite or garnet pyroxenite which had undergone partial alteration to leave a selection of interesting-looking rocks in the roadway. "Cape ruby" garnets and green chrome-diopside/omphacite were visible in many rocks together with their contact alteration products including dark amphibole and purple chrome clinochore (kämmererite) having the appearance of mica. These were collected avidly.

<u>Visit to Oppedal</u> on the coast of Vågsøy near Måløy (0293978,6876946) to see the wave-sculptured gneissic rock formation called the "Kannesteinen".

After the visit to the quarry the party drove NW from Måløy to Oppedal and were suitably astonished by the rock,

Fig. 5. The Kannesteinen, with Hugh Leishman and Rhona Fraser.
Note. GPS positions are UTM segment 32V easting, northing.

Field Trip to Ben Lawers Synform and Ben Lui fold

Saturday 5th October 2013
Participants 20
Leaders: Dr. John Mendum (BGS) and Dr. Graham Leslie (BGS)
Report by *Ben Browne*

About twenty members both of The Geological Society of Glasgow and of The Open University Geological Society gathered at the car park at the head of Glen Ogle (NN558283). We were to be privileged to be led by Drs. John Mendrum and Graham Leslie both of the BGS over some ground covered by the forthcoming Killin Sheet of the BGS geological map of which they brought proof copies, having also previously distributed by email a comprehensive guide to our intended excursion. It was with regret that we learned that this might be the last such sheet to be printed by the BGS.

Objectives were explained. First to recognize the lithology of the three main stratigraphic units of the Argyll Group to be seen, viz:-Loch Tay Limestone, Ben Lui Schist, Ben Lawers Schist.

Secondly to identify their way up by their stratigraphic sequence, lithological markers of their way up being rare due to metamorphism. Thirdly to understand the large scale folding of the Tay Nap, the Ben Lawers Synform (anticline) and the Ben Lui Fold and fourthly to consider the nature of the unconformity observed in Glen Lyon where much of the lower Argyll and upper Appin Group are missing above the right way up Grampian Group. For this unconformity previously described as the Iltay Boundary Slide we were to be offered a new interpretation as a primary stratigraphic unconformity.

Firstly we were given a graphic demonstration of the geometry of the large scale overturned Tay Nap and the secondary folds of the Ben Lawers Synform and of the Ben Lui Fold using the brilliant model of a folded length of carpet in which the way up indicators, pile is top, were far more obvious than in the rocks to be examined.

We were at that point in the Loch Tay Limestone of the inverted lower limb of the Tay Nap at the northern limit of its flat belt.

We followed the burn immediately behind the car park up hill to the east examining rocks mainly where well exposed below a series of waterfalls. At the first significant fall was a good exposure of typical prominently folded dark grey Loch Tay Limestone with striking calcareous weathering complicated by an injected sheet of red felsite and cut up by faulting. Further up the burn, past the power cables, was a massive amphibolite. The presence of this basic volcanic rock, common in the Loch Tay Limestone, was taken as an indicator of an extensional regime related to, the opening of the Iapetus Ocean. Proceeding structurally up the burn, but stratigraphically down the sequence, we encountered more pellitic bands and less limestone then at the first high fall we found a garnetiferous schist with muscovite and biotite having come through a transitional sequence from the Loch Tay Limestone into The Ben Lui Schist which we were informed was only a little older than the underlying limestone.

The next stop was at a recently reopened quarry on the left 500m up the minor road from north Loch Tayside towards Bridge of Balgie at NN621368. Three large boulders carefully placed at the start of a forest road illustrate the local lithologies. One is of Loch Tay Limestone in which the quarry is excavated. One is of amphibolite, a metagabbro, found within the Loch Tay Limestone and in all probability responsible for the distinct horizontal ridges seen from that spot to run along the braes above the south shore of Loch Tay. The third was of garnetiferous Ben Lui Schist which we would be crossing next in proceeding up hill to the summit pass by Lochan nan Lairige. Examining the rock in the quarry it was found to dip NNW towards the Ben Lawers Synform to the north. We were encouraged to examine the fold hinges which being the least deformed zones stand the best chance of showing crenulation of a preserved former fabric. I must return to this task and persevere.

Further up the road just past the dam we pulled off left onto a short track at NN601394 leading down to the shore of Lochan nan Lairige. From here it was possible to appreciate the larger scale structure in the east slopes of Meall nan Tarmachan forming a steep hillside falling down to the western shore of the loch. The high central ground was formed of Ben Lawers Schist which despite being softer than the Ben Lui Schist is less jointed and so tends to form the higher ground but of rounded hills. To the south could be seen the Ben Lui Schist dipping north and to the north the Ben Lui Schist dipping south thus defining the Ben Lawers Synform (anticline). The foreshore gave a close up view of the complex highly folded and varied lithology of the Ben Lawers Schist. It is dominantly calcareous semi elite with abundant amphibolite. The generations of folds are interpreted as recording the staged collision of irregular continental margins and of island arcs between 470 and 450Ma, i.e. The Caledonian Orogeny.

A stop about two thirds of the way along the lochside road gave another good view of the slopes above the western shore topped by crags with clear vertical cleavage traces representing the hinge zone of the synform and the south dipping bedding in the lower crags to their north to be examined at the next stop.

At the north end of the loch we parked at NN595412 on a track leading down to the water. From the head of the loch we followed a fence up to the NW to a stile then left over irregular rising ground SW towards the face of the crags overlooking the northern end of the loch. The ground was formed at first of garnetiferous Ben Lui Schist first encountered in a loose block then in outcrop where quartzites were found interleaved with the schist. Further up to the SW good decimeter sized folds were found but the only convincing way up indicator was graded bedding but in a recently fallen block. However it became evident that the lithology was becoming progressively more heterogeneous with thinly bedded quartzite, garnet mica schist and calcareous schist with thin hornblende schist units. We were passing through a graded transition from the Ben Lui Schist to the Ben Lawers Schist first examined on the SE shore but now at a higher structural level on the northern limb of the synform.

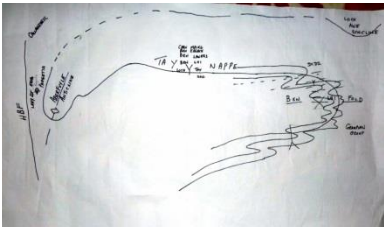
We concluded the first day well pleased that we had achieved the first of our objectives in recognizing the three principle lithologies, the way up subject to a given stratigraphy, and the structure of one of the major secondary folds, the Ben Lawers Synform.

Day 2
Sunday 6 October 2013
Report by *Con Gillen*

Day two started well, quite bright, cool breeze, high mist. After gathering, we went in convoy past yesterday's final stops at Lochan na Lairige and on down towards Glen Lyon. At our first stop in the Allt Bail a'Mhuilinn stream, beneath the impressive corrie in the Tarmachan Ridge, we were presented with fine outcrops of the Loch Tay Limestone, vertical, with two early fold phases, and easily recognised by its dark blue colour and coarse sugary texture.

Standing on the Loch Tay limestone

Upstream, we noted one of the amphibolites frequently associated with the Loch Tay Limestone, usually near the top of the succession and related to the 600 million-year-old Tayvallich Volcanic Formation, an important time-marker in Dalradian geology. Also, we saw the transition beds (towards the Ben Lui Schist) of semi-pelites with garnets. The introduction to the day was a most instructive résumé of yesterday’s geology.



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Graham’s drawing of the structures of the inverted limb of the Tay Nap

Emboldened and encouraged, we headed down valley to see something completely different: Grampian Group quartz-rich psammites with large muscovite flakes, right-way-up and dipping beneath the Loch Tay Limestone, and on the lower limb of the Ben Lui synform. We could easily see the evidence (in the pleasantly warm sunshine): original sedimentary slump folds, somewhat flattened and tightened up.

A lovely drive then followed, taking us into Glen Lyon, resplendent in autumn colours, peaceful and truly magical. In the bed of the River Lyon, beneath the slopes of Meall Ghaordaidh, with a nice example of a hanging valley, we found ourselves in Southern Highland Group rocks (garnet–biotite–hornblende schist or ‘greenbeds’ of possible volcaniclastic origin), in the hinge zone of the Ben Lui fold. On the hillside, these rocks are overlain by the Ben Lui Schists, separated by Loch Tay Limestone, recognised by the associated amphibolites which allow the structural repetitions to be traced easily.

Lunch beckoned. Our chosen spot was at the Giorra dam on Loch an Daimh. Having had our sandwiches, we went down to the lochside by the dam to have a look at the pale-weathering quartz-rich Glen Spean Subgroup, at the top of the Grampian Group (the lowest Dalradian group). Here we saw good convincing examples of slumping and cross-bedding, proving right-way-up. From the dam, we could see the target for the afternoon: a long walk along the lochside track to a prominent waterfall on the north shore (there was a boat, but we thought better of taking it and went on foot instead). On the way down, our civil engineering members pondered on the reasons for the dry spill way and empty stream bed: it seemed that entry and exit points were all in underground tunnels.

As we followed the track to the waterfall, a sudden short sharp shower of drizzle sprang up and took us by surprise. We had now gone up into the Lochaber Subgroup at the base of the Appin Group (above Grampian Group) – these are tightly folded and laminated semi-pelites (mica-rich) with hornblende schists. Some of the folds are really spectacular, with clear evidence of foliation being refolded, and with garnets in fold cores, all very photogenic.

Searching for garnets in Lochaber Subgroup

Excited, we carried on to the eagerly-awaited key locality at the waterfall. And it was a most unusual surprise: great jumbled blocks of quartz-rich rocks in a mass of more schistose material (Ben Lawers Schist). This looked like a slump formation, possibly some sort of basal unconformity.

Disrupted blocks in a possible intra-Dalradian unconformity or slump.

There was no evidence of high strain that would indicate a tectonic junction. Here, Ballachulish, Blair Atholl and Islay subgroups are all missing from the succession. After considerable discussion and debate here and at the lochside, it was concluded that the junction (Leven Schist against Ben Lawers Schist) represents onlap, a type of unconformity related to transgression, and not a result of shearing. The relationship is well seen on the new BGS 1:50k map of the area, and appears not to have been much commented upon in the past.

We then retraced our steps to the dam to collect our vehicles. At this point, Graham had to leave for work-related reasons, so we thanked both our leaders warmly for an extremely interesting, challenging and fulfilling two days, and for sharing the unpublished revised maps of the area. Those of us staying on until Monday then headed back to Killin for dinner (with copious helpings of peas, and tales of sailors' feet for some reason).

Ben Lawers and Ben Lui schists across Loch an Daimh

Day 3
Mon 7th Oct
Report by *Margaret Donnelly*

We said farewell to those of the group who were heading home, and nine of us, with leader John Mendum, drove along to the bridge over the River Dochart in Killin, and the Falls of Dochart which were in full flow and giving a spectacular display. We hung over the wall admiring them and taking pictures. The rocks are part of the Southern Highland Group of the Dalradian; psammites with a lot of pelitic material, they were flaggy, mainly flat-lying, and dipping a little, approximately to the north. We went through an opening in the perimeter wall and made our way down onto them – not an easy task as they were soaking wet and more than a *little* slippery. They contained muscovite, biotite, and some garnets indicating lower amphibolite grade – higher than most of the Southern Highland Group which is usually of greenschist facies. There were also crenulations related to the Ben Lawers Syncline. The deformation is stronger here than in Glen Ogle but less than at Ben Lawers, and is Syn/Post D1 – D2. There were numerous pot holes; these are post glacial and were gouged out by the current and loose rocks. We slithered around, some more than most, looking for 'way up' indicators with little success……..until we were on our way back onto the road when an eagle eye spotted an appropriate section showing clearly that the stratigraphy was, as hoped, upside down. Our leader explained that, near Bovain Farm in Glen Dochart, there had been a glacial lake which had broken through a terminal moraine dam; the vast torrent of water had eroded the landscape, and made a path for the waterfall.

Back in the cars we set off up the Auchlyne road along the north side of Glen Dochart where there were abundant glacial features – it was a typical flat bottomed U-shaped valley, with numerous moraine mounds and erratics. At our first stop we looked at the very full and very fast river, and the hillside, to determine the controls on the width and speed of river. Our next stop was beyond and west of the terminal moraine which had blocked the valley and produced the glacial lake at the end of the Loch Lomond Readvance.

Glen Dochart - huge terminal moraine

This moraine was simply huge, and stretched the width of the valley; the river had finally broken through and found its present course. Again in the surrounding landscape, there were abundant glacial features, mostly moraine mounds, while to the west was an enormous flat expanse – the floor of the lake, now mostly farmland.

We drove around this and stopped at the head of the lake, to view the huge extent of the lake from this different perspective. Our leader pointed out Corrycharmaig just opposite at the top of a ***big*** hill…I was relieved that we had decided not to investigate this!! However, we had only a few minutes here in this single track road, as other traffic soon piled up behind us and we were forced to move on. We headed for Glen Ogle, where a couple more folk dropped out, and our depleted group set off for Loch Katrine.

We drove to the Trossachs Pier car park and climbed a few metres up to the crags at the south end, NN 4957 0710, where there were alternating psammites and pelites, with beds dipping fairly steeply, and an obvious cleavage dipping more steeply, both to the northwest. It was difficult to find good examples of graded bedding but we were able to satisfy ourselves that the beds were inverted. Looking more closely, we realised that there was a second cleavage and set of axial fold planes, sub-parallel to bedding. Locally, open to tight northwest-verging minor F2 folds had deformed S1, and an associated secondary S2 spaced cleavage, whose spacing ranged from *c.* 5mm to several centimetres, had developed. These outcrops had originally been turbidites; the coarser, quartz-rich arenite beds and the finer more argillaceous ones were suitably contrasted by the varying intensity and style of both S1 and S2. The rocks belonged to lowest stratigraphical part of the Ben Ledi Grit Formation; the more dominant effects are D2 as this occurred at deeper structural levels.

We then walked to the loch and the road alongside it, where a selection of road cuts traverse stratigraphically downwards from the Ben Ledi Grit Formation through the thicker beds of the more arenaceous Creag Innich Sandstone Formation, with gritty to conglomeratic horizons, and into the Loch Katrine Volcaniclastic Formation. Our first stop was just past the kiosk where psammites of the Ben Ledi Grit Formation dipped steeply north-northwest, and we could examine S1 and F2 / S2 relationships. About a hundred metres further on, we were led from the road into a wooded area where there were two or three ***huge*** boulders lying on the grass - each about the size of a caravan. We came to a particular one - about 3 metres high and 5 metres in diameter. It had the same lithologies and bedding/cleavage relationships as the previous outcrops, but we were urged to walk around it……….when we realised that it was the complete nose of a fold!! Very impressive!! Unfortunately the lack of space among the trees and the poor light did not permit a photograph which would do justice to this enormous 'lump of mountain'! We were, however, able to examine in detail the axial planes, lineations and various features therein.

We continued along the lochside, stopping at each road cut; some were excellent, with good geological information, while others were not, because of their attitude and/or state of weathering. In the gritty, thickly bedded arenites of the Creag Innich Sandstone Formation, bedding, S1 and S2 were clear, as well as good examples of S1 folded by F2. Around (NN 4950 0765), we found obvious bedding, dipping gently to the north-northeast in interbedded thin pelites and coarse-grained arenites, with S1 orientated at a high angle to bedding. We were clearly in an F1 fold hinge at this point, although there was some superimposed D2 deformation, and minor F2 folding with cleavage development. Structurally all these outcrops, near and around Loch Katrine, lie to the south-east of the hinge zone of the Ben Vane Synform, on the common limb between the hinge zones of the latter and the Ben Ledi Antiform. The beds are generally inverted, but if corrected for the Downbend they would form part of a 'right way up' fold limb facing south-east within the overall hinge zone of the Tay Nappe.

We turned east away from the loch for a little way, through the woods near the Glen Finlas Reservoir outlet, and came to a former quarry whose face exposed typical volcaniclastic arenites ('Green Beds') of the Loch Katrine Volcaniclastic Formation. I was delighted as I had been looking out for 'Green Beds' for most of the weekend!! The rocks were massive with a distinct, soft bluish green-grey colour due to their significant chlorite and epidote content. They also contained beautiful pyrite crystals. Although we could identify bedding, evidence for the S1 and S2 cleavages was noticeably absent. The presence of these volcaniclastic rocks indicate a deepening of the basin, thinning of the crust and the early attempts of the Iapetus to open.

We had had a wonderful day; we returned to the cars and thanked John profusely for his time and expertise, and for all the information that he had imparted throughout the weekend, before saying our ‘goodbyes’ and heading for home.

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General Information

Early in the session the Society became a participant in the Amazon EU Associates Programme. Selected titles are listed on the Society’s website in the Bookshop section. Most of these can be purchased through the Amazon.co.uk link on the bookshop page. The Society can benefit from these purchases and from the purchase of any item from Amazon which takes place by using the link. Each purchase generates approximately 5% of the sale price (excluding V.A.T.) for the society. Further information can be obtained from GSG council member Bill Gray.

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Intimations

With regret we record the passing of

Dr. .John. A. Gibson member since session 121 (1979-1980) who died on 19th June 2013

Mr. M G. Paterson member since session 142 (1999-2000) who died on 1st April 2013