
NUMBER 146 OCTOBER



Quaternary Newsletter



A publication of the
Quaternary Research Association

QUATERNARY NEWSLETTER

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Instructions to authors

Quaternary Newsletter is issued in February, June and October. Articles, reviews, notices of forthcoming meetings, news of personal and joint research projects etc. are invited and should be sent to the Editor. Closing dates for submission of copy (news, notices, reports etc.) for the relevant numbers are 5th January, 1st May and 1st September. These dates will be strictly adhered to in order to expedite publication. **Articles must be submitted at least 6 weeks before these dates in order to be reviewed and revised in time for the next issue of QN, otherwise they may appear in a subsequent issue.**

Suggested word limits are as follows: obituaries (2000 words); articles (3000 words); reports on meetings (2000 words); reports on QRA grants (800 words); reviews (1000 words); letters to the Editor (500 words); abstracts (500 words). Authors submitting work as Word documents that include figures must send separate copies of the figures in .eps, .tif or .jpg format (minimum resolution of 300 dpi is required for accurate reproduction). Quaternary Research Fund and New Researchers Award Scheme reports should limit themselves to describing the results and significance of the actual research funded by QRA grants. The suggested format for these reports is as follows: (1) background and rationale (including a summary of how the grant facilitated the research), (2) results, (3) significance, (4) acknowledgments (if applicable). The reports should not (1) detail the aims and objectives of affiliated and larger projects (e.g. PhD topics), (2) outline future research and (3) cite lengthy reference lists. No more than one figure per report is necessary. Recipients of awards who have written reports are encouraged to submit full-length articles on related or larger research projects

NB: Updated guidelines on the formatting of contributions are now available via the QRA webpage and from the editor.

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Argraff/Printed by:

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Gwynedd, North Wales

Tel: 01248 601669 Fax: 01248 602634.

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COVER PHOTOGRAPH

Towing a GPR unit across the Miage Glacier in the Italian Alps (see NRWA article by Stefaniak in this issue) (photo credit: Anne Stefaniak)

SPOTLIGHT ON A SITE

QRA50: TOP 50(80) QUATERNARY SITES THE GIANT'S ROCK, PORTHLEVEN, CORNWALL, ENGLAND

This autumn, as we wrap up the last QN for 2018, we'll head to a Cornish site, to mirror the start of the year at the Annual Discussion Meeting at the University of Plymouth.



Figure 1. The Giant's Rock, Porthleven, Cornwall (Photo: P. Sargeant).

Here is a summary of the entry for from Silva and Phillip (2015, p35-36):

- The Giant's Rock is one of the largest glacial erratics within Britain, located on the south-west Cornish coast. It is located well south of the 'normal' glacial limit in Britain and even south of the glacier that came down the Irish Sea to reach the Isles of Scilly.
- It weighs around 50 tons, and rests in an eroded hollow on the intertidal platform.
- It is composed of a specific type of garnetiferous mica-shist, without a known UK provenance.

- The origin and source of this erratic has exercised the minds of earth scientists for over a century (Flett and Hill, 1912).
- The most recent interpretation suggests that this erratic may have been sourced from Greenland, where garnetiferous mica-schist is found, and the mechanism of transport could be in the toe of an iceberg, or beneath floating ice sheets (Campbell, 1998).
- If you want to spot it, it is normally only visible and accessible for two hours either side of low-water before it disappears below the crashing waves and blue sea of Mount's Bay.

References (and key sources for the site)

Flett, J.S., Hill, J.B. (1912). Geology of The Lizard and Meneage (explanation of sheet 359 1st edition), *Memoirs of the Geological Survey of Great Britain*. H.M.S.O., London.

Campbell, S., Hunt, C.O., Scourse, J.D., Keen, D.H. (1998). Quaternary of South-west England. *Geological Conservation Review Series no. 14*. Chapman and Hall, London. 439pp.

EVIDENCE FOR EXTENSIVE ICE COVER ON THE ISLES OF SCILLY

Brian John

Introduction

The Isles of Scilly have featured prominently in the literature because they support the southernmost coherent glacial deposits on land in the British Isles (Scourse, 1991, 1998; Hiemstra *et al.*, 2006; McCarroll *et al.*, 2010). These deposits, concentrated on the northern shores of St Martin's, Treco and Bryher, were once thought to be of pre-Devensian age (Mitchell and Orme, 1967), but radiocarbon, OSL and TCN dating and examinations of organic content have subsequently demonstrated convincingly that they were laid down at the margin of the Irish Sea Glacier near the LGM (Scourse, 1991; Smedley *et al.*, 2017) (Figure 1). Following work by Praeg *et al.* (2015), Clark *et al.* (2018), Glasser *et al.* (2018) and Small *et al.* (2018) have suggested that the LGM occurred around 27,000 years ago, and that the outer limit of the Irish Sea Ice Stream lay about 250 km SW of the Isles of Scilly, at the Celtic Sea shelf edge .

The basic Quaternary stratigraphy of the islands has been described by Scourse (1991, 1998), modified after Mitchell and Orme (1967). The oldest deposits described thus far are the raised beaches which are widespread on all of the island coasts. Above these are soliflucted granite breccias full of locally derived angular clasts. These slope deposits (in some locations stratified, as in West Wales) are suggestive of a cold climate, although it is by no means certain that the full thickness (over 4m in some places) was laid down under periglacial or permafrost conditions. Organic remains in layers of finer sediments suggest that at times the climate was suitable for a tundra grassland to thrive. Within the recorded glacial limit on the northern islands the lower slope deposits are intermittently overlain by diamictons related to a short-lived glacial incursion, and then by an upper slope deposit of granite debris which occupies the same stratigraphic position as the "upper head" in West Wales (Campbell and Bowen, 1989). There are also many exposures of a sandy reddish loess-like material. There are a number of different facies, affected by a range of processes, and Scourse (1991) suggests that at the time of original deposition there was a barren landscape and an ice edge not far away. Some of the fine-grained windblown material has been redistributed as colluvial "drapes" following deglaciation, and its uppermost layers incorporate the modern soil horizon.

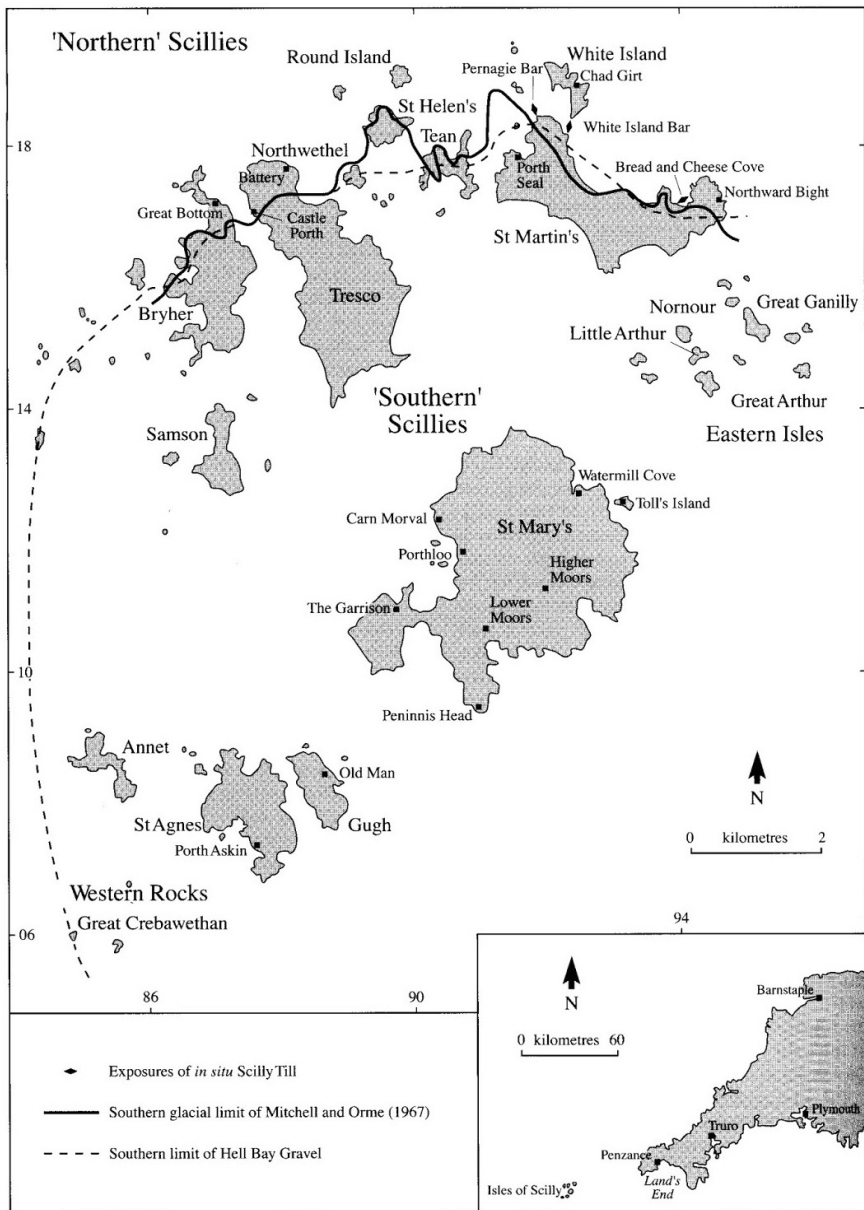


Figure 1. The previously proposed maximum extent of Devensian ice in the Isles of Scilly, defined by the limit of the Hell Bay Gravel. Source: Scourse (1991 and 1998).

Observations from the Isles of Scilly, April 2016

During the course of a week's visit to the islands in April 2016 it was possible to walk most of the coastline of the islands of St Mary's, St Martin's, St Agnes, Bryher and Treco. Visits were also made to Gugh and White Island. Unfortunately it was not possible to land on Samson, Annet, the Eastern Isles or the outer islets. Some of the exposures visible in April 2016 appeared quite fresh following winter storms, and some have changed appearance since Scourse conducted his detailed research on the islands in 1981-85 and since the QRS field meeting of 2006. Some of the exposures noted in this short paper may not previously have been investigated. It is emphasised that the following text is based upon a set of initial field observations, made under less than ideal conditions and interpreted in the light of the author's own field experience and following constructive comments from referees and the editor of this journal. There was no time for sample collection or meticulous stratigraphic recording or sediment analysis, and no attempt has been made to fit the author's stratigraphy into the lithostratigraphic units of Scourse (1991, 1998) or to define till exposures into categories related to mechanisms of formation (cf. Evans, 2017). However, the article is offered in the hope that it will provide food for thought, raise alternative hypotheses, and encourage further detailed studies of the sites described.

1. Lowest slope deposits

In most of the literature about the glaciation and geomorphology of the Isles of Scilly, the raised beach is referred to as the lowest and oldest deposit in the Quaternary stratigraphic sequence, resting directly on bedrock (Hiemstra *et al.*, 2006). However, two sites revealing lower deposits have now been discovered.

Near Browarth Point on St Agnes (SV878088), raised beach gravels, cobbles and boulders are solidly cemented and stained with manganese oxide, in a layer up to 50 cm thick. They lie on deeply rotted granite and "grus" which is also cemented with manganese and iron oxides. Most of the gravelly particles are less than 1 cm in diameter, and larger bedrock fragments appear to have rotted more or less in situ, with only a little downslope movement. More varied slope deposits are found under the raised beach near

Dutchman's Carn on the west side of Peninnis Head, St Mary's (SV909095). At this location (Figure 2) there are around 2 m (base not seen) of cemented coarse granite breccias made mostly of grus but with silty and sandy layers or lenses. There are signs of crude stratification, and many clast long axes are aligned with the bedrock slope.

2. The raised beach

Raised beaches are ubiquitous, and it is almost impossible to walk along the coastline of any one of the islands without seeing a cliff exposure somewhere.



Figure 2. Coarse blocky slope deposit with a matrix of grus beneath the raised beach on the west side of Peninnis Head, St Mary's.

They are unlikely to be misinterpreted, since the great majority of exposures lie adjacent to modern cobble beaches with very similar characteristics. Many of the locations were mapped by Mitchell and Orme (1967). The type locality is at Watermill Cove, on the east side of St Mary's Island (SV924123), where Scourse (1991) refers to it as the lowest (and oldest) of the Quaternary sediments in the archipelago. It contains unlithified sand beds and is overlain by a poorly-sorted breccia made of gravel, sand and angular granite clasts of many different sizes.

There are other exposures of the raised beach on the west side of St Mary's, between Porthloo and Carn Morval (SV907116). Some of these exposures are well below current HWM (high water mark), where they are distinguished from modern beach sediments by the fact that they are solidly cemented and blackened by manganese oxide. Closer to Carn Morval (SV906118) these cemented materials can be seen at the base of the sediment cliff, full of well-rounded erratic and local pebbles and cobbles. Scourse (1991, p 28) also noticed that some raised beach exposures contain "a considerable proportion of erratic clasts." In some sections the gravels and pebble bands are mixed with faceted erratics in a silt and clay matrix and are sealed beneath brecciated slope deposits.

There is a cemented raised beach resting on a rock platform at SV871148 on the south side of Gweal Hill on Bryher. At Porth Seal, St Martin's (SV918166) there is disputed evidence for two raised beaches, separated by a coarse breccia.

At present, the most accessible exposures of the raised beach are to be seen in the bay of Porth Killier (SV880086), at the northern tip of St Agnes Island (Figure 3). The cobbles exposed in cliff faces are for the most part well-rounded. In some parts of the beach they are packed together, and in others held in a sandy and silty matrix which may have been filtered into position at some stage following beach formation (Scourse, 2006). Scourse described the boulders and cobbles as being vertically-inclined; but this characteristic was not observed in 2016. Rather, it was observed that in many exposures the arrangement of long axes was somewhat chaotic, suggestive of post-depositional disturbance. The beach here is partly or solidly cemented with iron oxide and manganese oxide – this is a common feature, but there are some places where the beach is uncemented and friable enough to extract cobbles with ease from exposures. In all of the examples seen on St Agnes, there are rounded cobbles and pebbles of sandstone, chert, mudstone and some volcanics in the beach.



Figure 3. Raised beach exposure in Porth Killier, St Agnes. Here the beach materials are overlain by up to 2m of windblown deposits and colluvium.

At Porth Killier there are not many sediments above the raised beach, because there are no adjacent steep gradients which could supply slope materials over a prolonged period of time. However, in places there is an overlying layer of rich brown sand and silt (with signs of layering) and a modern organic-rich soil horizon. In some exposures at the northern end of St Agnes, thin clay-rich diamictos containing faceted non-local cobbles lie directly on the raised beach or on a capping layer of sandy loess and colluvium. This has apparently not been noticed by earlier investigators.

Most of the raised beach deposits are found at around extreme high-water mark, but some are found down to mid-tide mark, beneath the cobbles and boulders of the present-day beach. No raised beaches (apart from the Garrison Boulder Bed on St Mary's) were found more than 5 m above HWM.

3. Other slope deposits

Pseudo-stratified slope deposits are seen most clearly on the shore of Porthloo Bay (SV908115) in a cliff that can be followed along the beach at low tide for several hundred metres (Scourse, 1991) (Figure 4). The material, consisting for the most part of a granite breccia of angular clasts derived from an old buried



Figure 4. Coarse granite “solifluction breccia” with pseudo-stratification, exposed in the cliffs at Porthloo on the island of St Mary's.

cliffline, is up to 4 m thick. There are a number of discontinuous and sometimes contorted horizons of fine-grained materials. In places the lowest part of the cliff face consists of foliated or laminated sandy and gravelly layers which are relatively free of large clasts. There are also lateral variations along the cliff face, with lenses of finer debris adjacent to coarser brecciated materials.

Rockfall and slope deposits were referred to as “main head” and “upper head” by Barrow (1906) and by some later authors, as “ram” by Knight (2015), and as “Porthloo Breccia” and “Bread and Cheese Breccia” by Scourse (1998). These terms can be confusing, but they are useful in indicating that there are, in places, two lithostratigraphic units of different ages. As Scourse (1998) has pointed out, in some locations in the north of the islands the two stratigraphic units are separated by layers of other deposits, whereas in the south, in most sites, there appears to have been little or no discontinuity between the accumulation of the one and then the other.

At Bread and Cheese Cove (SV 940159), a site on St Martin’s which was not easy to examine in 2016, Scourse (1991) referred to a lower layer of “Porthloo solifluction breccia” which appears to be free of erratics, capped by a layer of Scilly Till with associated glaciofluvial gravels, and above that a layer of “Bread and Cheese solifluction breccia” which does contain occasional erratics.

In the cliffs on the east side of Porthcressa (SV908098) some of the brecciated slope deposits appear to have been churned both above and below an undulating layer of silt and sand about 10 cm thick (Figure 5). On the east coast of Bryher, south of Norrard and The Bar (SV881153), there are many exposures of reddish gravelly solifluction materials in the low cliffs. These are generally less than 2m thick in exposures, and contain no clear stratigraphic breaks, although in some sections the base seems to consist of rotted granite more or less in situ with soliflucted materials above, grading upwards into more sandy materials and then a darker organic-rich horizon near the surface. Pebbles with non-local lithology are seen on the beaches and occasionally in the cliff sections – red and pink sandstones, limestone, grey shales and mudstones, and some schists. There are also many different types of granite derived from local outcrops. Reddish gravelly slope deposits are also exposed in the cliffs of Rushy Bay (SV876142), at the southern end of Bryher. The gravels are partly cemented by iron and manganese oxides, and blocks of this material have fallen from the cliff face.

4. Glacial deposits and landforms

The northern tip of the island of Tresco lies just within the recorded limit of the Devensian glaciation of the British Isles (Scourse, 1998). A diamicton with highly variable clast sizes, shapes and lithologies is exposed in the cliffs to the north of Cromwell’s Castle (SV881161), and there are also patches of erratic-rich gravels to the south of Gimble Porth (SV891153).



Figure 5. “Churned” slope deposits of breccia in a sandy and gravelly matrix beneath silts and sands with a high organic content, exposed on the east side of Porthcressa on St Mary’s. There are no apparent fossil frost wedges.

Erratics and patches of similar material occur in cliff exposures even further to the south in the strait between Bryher and Tresco. Exposures of related diamictons have now been exposed in many other locations within the accepted ice limit, generally at the coast in low cliffs with granite breccia and other deposits, but sometimes at the ground surface inland.

On St Martin’s the exposure of clay-rich diamicton at Bread and Cheese Cove has been described by Mitchell and Orme (1967), Scourse (1991, 1998) and Hiemstra *et al.* (2006). It contains abundant erratics and complex structures (Figure 6). Other diamictons with erratics can also be seen in the core of White Island Bar (SV924171), and in the spectacular cleft called Chad Girt (SV925173). Scourse (1998) noted that no *in situ* “Scilly till” was exposed in the Chad Girt cleft at the time of his own field research, and suggested that the glacial debris which he examined had been soliflucted or redeposited. However, recent erosion along the cleft has revealed a c 2 m thick layer of massive clay-rich diamicton similar in appearance to the Irish Sea till of west Wales (Figure 7). From a visual assessment, the matrix appears to contain a higher percentage of clay and a lower percentage of gravel than the deposit at Bread and Cheese Cove. Unfortunately

the exposure was too wet to pick up any signs of deformation or re-deposition. The current stratigraphy at the site is as follows:

1. Cemented raised beach -- 50 cm
2. Lower slope deposits, cemented and heavily stained -- 2m
3. Massive clay-rich diamicton with erratics -- up to c 2 m
4. Upper slope deposits -- c 50 cm



Figure 6. The 2016 exposure of clay-rich gravelly diamicton (Scilly till) at Bread and Cheese Cove, containing abundant erratics and traces of sand lenses and shearing.

On Bryher there are many exposures of diamictons with erratics, on the western and northern flanks of Gweal Hill (SV873150), at the southern and northern ends of Popplestones Bay (SV874152), and in the west-facing cliffs of Hell Bay (SV876157). The material is associated with perched blocks at the western extremity of Gweal Hill (870148), and there are signs of depositional ridges nearby.

Inland, on the high plateaux of Bryher, Tresco and St Martins diamictons are found up to an altitude of 40m, with a scatter of erratics in a gravelly and sandy matrix. There are some gravelly diamictons on the slopes of Hell Bay. On Tregarthen Hill (SV886164) there are some sandy silts and also thin patches of undisturbed



Figure 7. Massive clay-rich diamicton exposed in the cleft at Chad Girt on White Island. The matrix of this material is similar to that seen at Bread and Cheese Cove on St Martin's, but there is a greater percentage of clay and silt.

clay-rich deposits containing abundant erratic pebbles and cobbles of up to about 20 cm in length. Some of these show clear striae. The erratic suite is described by Scourse (1991) as typical of all of the glacially derived deposits on the islands. Identifications of erratics by JR Hawkes (1991) include assorted sandstones (some pink and red pebbles), shale, greywacke, quartzite, chert, conglomerate, acid igneous rock and siltstone.

Other coastal exposures of erratic-rich diamicton have now been found to the south of the putative Devensian ice limit. On St Mary's there are traces of this material near Carn Morval (SV906118), close to the site described in detail by Scourse (1991). Here there has been substantial recent coastal erosion. The deposit is less than 1 m thick, and was seen in 2016 in close association with a cemented raised beach and granite breccia. However, it is distinct from those deposits in that both rounded cobbles and a wide range of faceted erratics are set in a matrix of silt and clay. It is separated from the underlying raised beach by an erosional contact and a band of relatively clast-free silt and clay up to 15 cm thick.

On St Agnes there are many exposures of similar diamictons. Most of these are on the north and west coasts. The material is nowhere more than 50 cm thick, and it is difficult to interpret because it is in some cases not particularly clay-rich, but it consists largely of reworked raised beach materials mixed with grus and occasional faceted non-local cobbles. To the south of Carnew Point (SV875079) a similar deposit (Figure 8) lies above 1m of light brown silts showing some bedding structures, and beneath 1m of gravelly granite breccia capped by 1m of darker silts and sands at the ground surface.



Figure 8. Diamicton exposure on the west coast of St Agnes, near Carnew Point. Note the wide range of far-travelled erratics. The deposit may have been redistributed following original emplacement at or near a glacier front.

At White Par (SV875078), near Long Point on the west side of St Agnes Island, a similar diamicton lies on top of 2.5 m of grus with granite clasts in a gravelly granular matrix. The silty and sandy material incorporates faceted pebbles, and also contains granite breccia blocks and some raised beach materials. This is the site stratigraphy:

1. Base not seen – masked by modern beach.
2. About 2.5 m of weathered granite debris / breccia with large angular granite clasts.
3. No sharp junction – layers grade imperceptibly one into the other
4. 50 cm of mixed diamicton with faceted pebbles of grits, sandstones, shales and unknown volcanics. Some cobbles of raised beach origin are incorporated.
5. Sharp junction
6. 1m of light brown stratified silts and sands – colluvium
7. Top – ~1 m of dark organic-rich silts and sands topped with modern soil.

The White Par diamicton with erratics is very similar to that seen at Popplestones and in parts of the long cliff exposure in Bread and Cheese Cove.

On Badplace Hill, Bryher (SV875163), there are rock surfaces that appear to be ice-scoured, intermittently covered with thin turf. There are also a number of constructional features which may be associated with glaciation, including a substantial ridge connecting White Island to St Martin's, the Pernagie Bar, an apparent boulder moraine on Shipman Head, and surface irregularities on the north-western flank of Bryher, running out to Popplestones and Gweal Hill (SV873149). These features are described by Hiemstra *et al.* (2006) and by McCarroll (2016). Other ridges described in Bread and Cheese Cove and on the northern tip of St Martin's, beneath Rabbit Rocks, are in the view of the present author not convincing since they could be related to bedrock outcrops.

5. Glaciofluvial deposits

Coherent glaciofluvial deposits are not widespread in the Isles of Scilly, and apart from thin traces none were seen on the 2016 visit which is the subject of this paper. However, they have been described in a few locations by Mitchell and Orme (1967) and by Scourse (1998), particularly near the northern coasts.

6. Aeolian deposits

In many coastal exposures there are layers or “drapes” of fine-grained reddish or dark-coloured deposits that are relatively stone-free (Figure 9). They occur in a number of stratigraphic positions. They are in places made of coarse sand, and sometimes they are silty, with or without an organic content. At Porth Seal there are both sand and silt layers beneath brecciated slope deposits. At Popplestones sandy deposits with included clasts overlie stratified gravels. These deposits contain occasional complex flow structures that pass over or under incorporated clasts. The foxy red sandless, sometimes more than 1 m thick, occurs near the top of many Quaternary sediment exposures, resting on granite breccia or raised beach deposits and incorporating a black or dark brown soil layer.



Figure 9. A “drape” of sandy and silty reddish material overlying erratic-rich diamicton at Popplestones on Bryher. In places there are apparent flow structures. There is a high organic content in the darker surface layers / soil horizon.

7. Other glacial traces

Faceted, sub-angular and sub-rounded pebbles and cobbles are found in the Porthloo Breccia and in all other deposits in coastal exposures well beyond the putative Devensian ice limit. For example, there are many erratics in the raised beaches around the head of Porth Killier Bay (SV880085), near the northern tip of St Agnes Isle. There are also small faceted erratics in the lowest breccia and grus on both sides of Beady Pool (SV884074). There are yet more erratics on the coasts of Wingletang Down, scattered through raised beach and solifluction materials. Near the southern tip of the island (SV884072) small faceted pebbles of red sandstone, grey shale and bluish rhyolite have been found in the granite breccia, 2m beneath its upper surface. These observations accord with Scourse (1991), who pointed out, there are erratics in most of the raised beaches of the islands.

On the east side of Gugh Island a striated cobble of chert has been found deeply embedded in weathered granite breccia or grus, in a position that could not have been related to the Devensian glaciation (SV892082) (Figure 10). On the east

coast of Bryher, on the shore of New Grimsby Harbour, an erratic cobble of red sandstone was found deeply embedded in gravel breccia or head (SV881151). On the east coast of Bryher, south of Norrard and The Bar (SV881153) the pebble lithology on the beach and in cliff sections (red and pink sandstones, limestone, grey shales, mudstones and some schists) are erratics. At Tregear's Porth, east of Watermill Cove on St Mary's island (SV926122) there are abundant red and pink sandstone boulders which are not of local origin.



Figure 10. Striated and fractured erratic cobble found in granite breccia and grus, on the east side of Gugh Island. There are other small erratics in the vicinity.

Interpretation

1. Lowest slope deposits

The Watermill Sands and Gravels (incorporating the raised beach) were referred to by Scourse (1998, p 258) as “the basal stratigraphic unit of the Quaternary succession on the islands”. However, the presence in some localities of grus and slope deposits with signs of mobilisation beneath the Watermill Sands and Gravels unit should not be a contentious issue. Indeed, it would be a surprise if across the whole archipelago, with a long coastline, the raised beach was always found to rest upon coherent bedrock. The most parsimonious explanation of the

deposits beneath the raised beaches on St Mary's and St Agnes is that they are slope deposits and rockfall debris accumulated from weathered granite debris prior to the period of beach formation. No evidence has been seen which might suggest the presence of permafrost, and no geochronological data is available for this debris.

2. The raised beach

The field observations of raised beach deposits made here are that most are found in the extreme high-water mark and some in the mid-tide mark. This accords with the observation made by Scourse (1991; 1998), who furthermore demonstrated that most of the accessible raised beach and associated deposits are of littoral origin, and that they must date from the last interglacial. The importance to geomorphology of the Watermill Cove (SV924123) lithostratigraphic unit, observed by Scourse (1991) lies not so much in its diagnostic beach characteristics as in the pollen content and dating of the overlying sediments (Scourse, 1991). It may have formed at a time of relatively high sea-level in the archipelago, somewhat above present MSL (mean sea level).

In all of the examples seen on St Agnes, there are rounded cobbles and pebbles of sandstone, chert, mudstone and some volcanics in the beach, suggestive of the incorporation of pre-existing foreign materials. Scourse (1991, p 441) noted that some exposures "contain a wide range of erratic clasts." Mitchell and Orme (1967) claimed that the raised beach deposits are occasionally strongly cryoturbated, and indeed there are some exposures where cobbles have their long axes vertically inclined, suggestive of post-depositional disturbance either by periglacial processes or by overriding ice. Mitchell and Orme also suggested that there are TWO raised beaches of different ages in the islands, since some beaches are cemented and stained with a black manganese oxide crust, while others are "fresh" in appearance. With respect to the suggestion, Scourse (1991) and other later researchers have disagreed and have argued forcefully that there is just one ancient beach, which dates from the Last Interglacial. This shows considerable variation in its altitude above OD and in its internal characteristics; stained layers sometimes cross stratigraphic junctions, suggesting that they are more influenced by groundwater conditions than age. In some places (as at Battery) the raised beach has been disaggregated and redistributed by slope processes and by glacial action. The same is true of the raised beach at Port Killier. Observations by the present author support the view that there is but one raised beach.

3. Other slope deposits

The crude stratification and clast alignment in these deposit types both suggest downslope movement, and the label of "solifluction breccia" is appropriate. Bands of iron oxide precipitate or hardpan appear to coincide with old surfaces in a sequence of accumulating slope deposits. Most of the angular fragments

of varied lithologies appear to have come from granite or related igneous rock outcrops seen in the vicinity, notably from buried clifflines or coastal slopes.

The structural characteristics of some deposits seen in the cliffs of Porthloo Bay suggest that they have been affected by occasional slumps, debris flows and other erosional episodes. However, in those locations beyond the putative Devensian ice edge the process of breccia accumulation seems to have continued without a break, and where there are signs of stratigraphic disruption the unconformities appear to be quite localised. The type locality at Porthloo is described by Scourse (1991 and 1998). There is uncertainty about the significance of signs of churning in some slope and sandloess deposits, as at Porthcressa (Figure 5). Cryoturbation in solidly frozen ground might have occurred, but rapid mass movement might also have occurred in places within a mobile active layer. In general, there seems no good reason for the use of the term “periglacial” in connection with the bulk of these deposits. However, Hiemstra *et al.* (2006) show, on the basis of the micromorphology and clast fabrics of the slope deposits in Bread and Cheese Cove, that at least some of them were periglacial gelifluctates.

4. Glacial deposits

The interpretation of assorted diamictons, exposed north of Cromwell’s Castle (SV881161), the south of Gimble Porth (SV891153) and in the strait between Bryher and Tresco, as glacial deposits within the putative Devensian glacial limit appears to be well founded (cf. Hiemstra *et al.*, 2006). The diagnostic characteristics of the till at Bread and Cheese Cove and elsewhere include striations and facets on pebble and cobble surfaces, a wide range of represented lithologies, and a clay-rich matrix with gravelly, sandy and silty layers. On the basis of detailed studies of fabrics, particle sizes and internal structures in the Scilly Till, Hiemstra *et al.* (2006) interpreted it as “a mixture of glactectonized and cannibalized glacialacustrine and marine deposits as well as primary subglacial tills.” They suggested that the Scilly Till at Bread and Cheese Cove was the only exposure of coherent Devensian till on the Isles of Scilly. However, the massive till at Chad Girt (Figure 7) deserves further study. It is quite possible that further exposures will be discovered in the future.

The thin diamictons outside the putative glacial limit also merit detailed examination, since they are similar in appearance to those along the coast from the type section in Bread and Cheese Cove, above the raised beach and in association with slope deposits. They may be in situ, and may not be; this does not much matter in the context of the present exercise, and even if they are “paraglacially remobilised” or tectonized, they must first have been carried in and deposited somewhere in the neighbourhood of the locations where they are currently exposed. As for erratic sources, the purple, pink and red sandstones and siltstones are reminiscent of certain Devonian and Cambrian sedimentary rocks found in Devon, Pembrokeshire and Ireland. Scourse (1991) provided accurate lithology

percentages for pebble groups in the three lithostratigraphic units deemed to be of glacial origin and identified possible offshore sources to the north. Without further petrographic and geochemical investigation more accurate provenancing is not possible here. Smedley *et al.* (2017) referred to a quartzite erratic on Tresco that may have come from Anglesey or the east coast of Ireland. The largest glacial erratic found on the islands is a 10 tonne block of olivine basalt found by Dr JR Hawkes on Great Crebawethan Rock (SV832070), about 3 km south-west of St Agnes. There is no way of knowing how long it might have been there; it may have nothing to do with the Devensian ice incursion. Since 1990 it has not been seen, but it must still be somewhere in the vicinity. Scourse (1998) and Smedley *et al.* (2017) suggest that the distribution of eroded or rounded tors on the islands, particularly on the northern and eastern coasts, provides a guide to the position of the Devensian ice limit; but there is so much variation in tor morphology that in the view of the present author much closer examination of the evidence is required.

The clay-rich diamictons described above, containing faceted erratic cobbles and pebbles and material derived from nearby raised beaches, found on the islands of St Mary's, St Agnes and Gough, lie several kilometres beyond the putative Devensian ice limit of other researchers. In the northern isles the distribution of glacial deposits on Tregarthen Hill and Castle Down to the east and Shipman Head Down to the west make it possible that a lobe of ice occupied the low land between Bryher and Tresco. The distribution of deposits on the coasts of St Mary's and St Agnes may also suggest that a lobe of ice pushed in from the west. Future investigations of Annet and Samson might reveal whether those islands have been affected by Devensian ice flowing from the west or north-west. The diamicton at White Par is interpreted here as the most southerly exposure of coherent glacial deposits on land in the British Isles.

5. Glaciofluvial deposits

No new glaciofluvial deposits were described during the field observations in this study. Scourse (1998) argued that pulses of glaciofluvial outwash deposition occurred at Battery (SV887165) on the north coast of Tresco at the end of the Devensian glaciation. He suggested that some of the sandy gravels and thin beds of cobbles are primary meltwater deposits which were later affected by aeolian and periglacial processes. Dates of around 19,000 yrs BP from the top of the sequence appear to confirm this (Smedley *et al.*, 2017). These authors also reported OSL dates of around 25 ka for the lower part of the Battery outwash sequence, representing the earliest part of deglaciation.

6. Aeolian deposits

The sandy and silty drapes observed in the field are interpreted to be of aeolian origin, which is consistent with Barrow (1906) and Scourse (1991, 1998), who argued that most of the drapes are aeolian accumulations formed by strong

winds in environments where extensive areas of glaciofluvial and old sea-floor deposits were not fixed by vegetation. Most of the exposures are classified as belonging to the Old Man Sandloess lithostratigraphic unit. Suitable windblown and relatively arid environments must have been extensive within and beyond the Scilly archipelago during and after the Late Devensian glacial episode, given that sea-level was depressed by at least 100m at the time. There may have been some redeposition under moist conditions, and indeed the term “colluvium” might be more appropriate than the term “sandloess” in some of the locations investigated. Scourse (2006) considered that some of the sandloess deposits exposed in cliff sections have accumulated in standing water or have been fluvially redistributed.

7. Pre-Devensian glacial deposits

There is ongoing uncertainty about older glaciations in the Isles of Scilly, and the observation of erratics in most of the raised beach units observed here, and by Scourse (1991, p437) support the idea that there was a more extensive pre-Devensian glaciation that affected the islands: “.....the late Devensian event was probably not the first glacial event to have influenced the Islands because erratics are widespread in some exposures of the Watermill Sands and Gravels, but this earlier event is quite distinct from the late Devensian advance”. However, Hiemstra *et al.* (2006, p308) stated that “the evidence suggests that an Irish Sea Glacier has only reached so far south on one occasion.” The observations presented in this paper suggest that Scourse was correct in suggesting an extensive ice cover on more than one occasion. The faceted, sub-angular and sub-rounded pebbles and cobbles found in the Porthloo Breccia, and in all other deposits in coastal exposures, are well beyond the putative Devensian ice limit. On the east side of Gugh Island the striated cobble of chert embedded in grus is in a position that could not have been related to the Devensian glaciation (SV892082) as currently defined (Figure 1). There is no reason to think that any of the boulders or cobbles identified as erratics were imported within the last few centuries as ship’s ballast, on the basis of their locations observed here and in the literature. The Wingletang Down erratics are most likely derived from disaggregated earlier glacial deposits, since it is difficult to envisage any other processes by which they could have been deposited upslope of their present locations. Near the southern tip of St Agnes erratic pebbles are set so low in the stratigraphic sequence, embedded in Porthloo breccias, that they could not have had anything to do with the Devensian glacial incursion. If it should be argued that they were introduced at or near the LGM, an explanation would have to be found for the lack of older Devensian /Ipswichian materials beneath them.

Discussion

It is now possible to suggest a revised Late Quaternary relative chronology for the Isles of Scilly. The lowest slope deposits and grus layers may be millions of years

old, but they are most likely to date from a pre-Ipswichian cold phase, given that there seems to be no unconformity or deeply weathered horizon between them and the overlying raised beach, which Scourse (1991; 1998) has demonstrated to date to the Last Interglacial (Ipswichian). Remarkably little is known about the landscape impacts of cold phases prior to this in the British Isles, but whether or not it was cold enough for an extensive glaciation in the Celtic Sea arena, it would be reasonable to suggest, in tune with climatic reconstructions (Polyak *et al.*, 2018) that prior to the last interglacial, periglacial conditions prevailed for thousands of years.

On the matter of early glacial deposits, McCarroll (2016) suggested that there are no erratics on the island of St Mary's, and that to the south of the Devensian ice limit "erratics are completely absent." However, glacially-derived erratics were found in all of the coherent Quaternary deposits on all of the islands visited by this author in April 2016. Without chronological data it is not possible to definitively place the timing of these early glacial deposits.

Scourse (1991) argued convincingly that there was no Wolstonian glaciation of the Isles of Scilly, the adjacent coast of Cornwall, or the Celtic Sea to the west. Gibbard and Clark (2011) and Rolfe *et al.* (2012), on the basis of evidence from other parts of South-West England and Wales, have suggested that the pre-Devensian Irish Sea Glacier which affected the Celtic Sea coasts can be dated to the MIS12 or Anglian glacial episode c 450,000 years ago. The abundance of erratics on east-facing coasts in the Isles of Scilly (observed in this study) means it is reasonable to assume that this same glacier overwhelmed the Isles of Scilly, leaving no part ice-free and terminating some way to the south and east. If so, it may have been more extensive and no less powerful than its Devensian successor (Praeg *et al.*, 2015; Glasser *et al.*, 2018). However, doubts about the age of the "Greatest British Glaciation" (GBG) persist, and without chronological evidence this remains a hypothesis. There are also doubts about the dimensions and glaciological characteristics of this early version of the Irish Sea Glacier.

One must also consider the possibility that the scattered erratics in the lower deposits in the stratigraphic sequence have been ice-rafted and incorporated into slope deposits and raised beaches; in other words, they might not be indicative of a complete glacial cover of the archipelago. In the view of the present author this would be a complex explanation. It is difficult to conceive of an episode of ice-rafting onto all the shores of the Isles of Scilly at a time when sea-level in the islands was higher than that of the present day. Conversely, sea-levels at times of ice rafting of glacial debris are most likely to have been more than 100m lower than the sea-level of today. A full glacial cover, leaving behind scattered glacial deposits which were later eroded away and reworked, is perhaps the most parsimonious explanation for the features described above. It is suggested that the ice crossed the islands from the north-west towards the south-east; if the cliffs of Cornwall acted as a barrier to ice progress, and if ice pressed into the

approaches to the English Channel, ice flow must have been perpendicular to the ice edge, and this greatly reduces the possibility of ice movement from north to south (Patton *et al.*, 2017).

Turning to the age and stratigraphic position of the raised beach, the most parsimonious explanation for its position in the regional sedimentary stratigraphy is that it still lies where it was formed in the Ipswichian interglacial (cf. Scourse, 1991). There appears to be no evidence that the raised beaches resting on slope materials at Browarth Point and Dutchman's Carn have been soliflucted down from a higher altitude on the cliff faces, thus coming to rest on top of slope deposits that are younger than the original raised beaches. These must be interglacial storm beaches thrown up onto pre-existing sediments. This is a situation commonly encountered in modern storm beach environments, for example at Porth Morran on St Martin's and at West Angle, Newgale and Aber-mawr in Pembrokeshire (Campbell and Bowen, 1989). Indeed, at Aber-mawr a storm beach ridge has migrated landwards in recent centuries across unconsolidated "submerged forest" deposits of peat with roots, fallen branches and tree trunks, without destroying them (Bell, 2007). On exposed headlands in the archipelago occasional clusters of well-rounded cobbles and even boulders are found in and on top of slope deposits, and even on grassy banks in association with damaged turf, having been thrown up during extreme storm events.

The observations recorded here support the view of Scourse (1991) and other authors that the brecciated slope deposits found above the raised beach around most of the coasts of the islands represent a prolonged cold period in which cold or periglacial conditions predominated, as in the coastal sections of Pembrokeshire and Gower (John, 1973; Campbell and Bowen, 1989; Hiemstra *et al.*, 2008). There are some signs of cryoturbation, suggesting the intermittent presence of permafrost. Outside the putative Devensian glacial limit the accumulation of these deposits (designated Porthloo Breccia) continued. Inside the limit it is possible to identify two horizons of brecciated solifluction material separated in some locations by glacial and glaciofluvial materials; as in West Wales, the upper horizon contains more non-local components, including faceted and striated erratics (Campbell and Bowen, 1989).

The fieldwork results reported in this paper do not support an Early Devensian glaciation on the lines proposed by Rolfe *et al.* (2012), since the Porthloo solifluction breccias occupy the stratigraphic position in which any glacial deposits of this age might be expected. The most parsimonious explanation of the diamictons described (for example at Chad Girt, Carn Morval, Popplestones and White Par) is that they are deposits of Late Devensian till, related in age and origin to the "stratotype" of the Scilly Till at Bread and Cheese Cove but displaying no signs of glacitectonic structures. However, diamictons are not necessarily diagnostic of a till. It is possible that the Carn Morval diamicton, for example, was deposited as a stony colluvium carried downslope across an eroding raised beach surface,

although the overlying unit of a clay-rich sediment containing erratics of many sizes, shapes and lithologies is indicative of a glacial incursion. It is suggested that glacier ice has pressed onshore in the vicinity of the cam and has overridden and incorporated a range of pre-existing deposits. The erratic-rich diamicton on the north and west coasts of St Agnes may either be a till, or a glacioteconite, formed as ice moved across an old coastline, overriding and incorporating large quantities of old storm beach and shingle beach materials and also introducing far-travelled erratics in the process. Further descriptions of the sediments are required to investigate this further.

It is not at all unusual for several broadly contemporaneous types of till to be exposed within a relatively small area, as in Pembrokeshire and Llyn (John, 1970b; McCarroll, 2001). The association of faceted and striated erratic pebbles of various sizes, beach cobbles, and clay-rich matrix, combined with a consistent stratigraphic position above the undisturbed raised beach and beneath upper solifluction breccia, wind-blown and colluvial sediments and modern soil, is best explained, in south Pembrokeshire and the perhaps the Isles of Scilly, as a consequence of a glacial incursion.

Some of the recorded Devensian Scilly tills appear to have moved into depressions or gaps between granite outcrops in an ice edge and ice wastage environment. There is no reason at this stage to suggest that all of the till was “redistributed” hundreds or thousands of years after the ending of the glacial incursion across the coastline, as suggested by Bowen (1984). Hiemstra *et al.* (2006) refer to the sequence of events in the islands as glacitectorization of sea-floor sediments pushed onshore, followed by paraglacial redistribution and then by periglacial disaggregation, all within the same recent glacial episode. The evidence collected in April 2016 broadly supports this interpretation, with the proviso that not all of the Devensian tills appear to have been glacitectorized.

The glaciofluvial materials described by Scourse (1991) at Battery and elsewhere are associated with ice wastage on the islands of Tresco and Bryher, and are normally assigned to the “Tregarthen Gravels”. However, on Tregarthen Hill and elsewhere the sands and gravels appear to grade laterally into patches of clay-rich and gravelly till with faceted and striated erratics, suggestive of near-contemporaneous deposition. Since the glacier ice that affected the islands must have had a crenulated margin, occupying the bays and sounds and leaving some higher adjacent land ice-free, it is suggested that most true fluvioglacial deposits and landforms will have been concentrated in areas now submerged by the sea. May (1980) suggests that glaciofluvial material could have later been disaggregated and redistributed as beach and sea floor deposits.

A suggested ice limit for the Late Devensian incursion by the Irish Sea Glacier would require only modest adjustments to the ice front positions portrayed by Scourse (1989) and Hiemstra *et al.* (2006) on the north coasts of the islands. However, the glaciogenic deposits described on the west coast of St Mary’s

and St Agnes suggests that Devensian glacier ice pressed into St Mary's Road and came into contact with the west coast of St Mary's and the north coast of St Agnes (Figure 11).

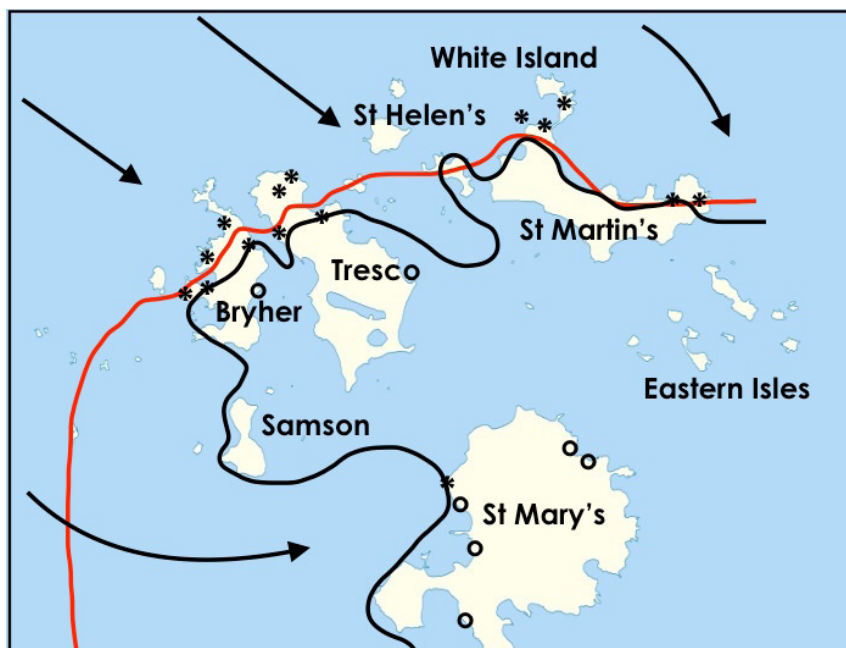


Figure 11. Modified glacial limits for the Devensian glaciation of the Isles of Scilly, based largely upon evidence presented in this paper. The red line represents the limit of the Hell Bay Gravels, taken by Scourse (1991) and others to represent the maximum extent of Devensian ice. The black line shows a revised Devensian limit, incorporating ice incursion from the west into the southern islands.

A Late Devensian ice incursion from the west would not be surprising given the till fabric evidence presented by Hiemstra *et al.* (2006) that suggested that the ice which affected the northern coasts of the islands came not from the north but from the northwest, flowing south-eastwards. It now seems probable from the work of Praeg *et al.* (2015) and Clark *et al.* (2018) that the ice of the BIIS (British Irish Ice Sheet) Celtic Sea lobe extended all the way to the shelf edge. There would have been no topographic constraint on the eastern edge of this lobe, and since ice in this situation must have flowed perpendicular to the ice edge, it is entirely reasonable to postulate that it pressed into the basin between Bryher and St Agnes, flowing broadly from west to east and impinging on some of the present-day coasts in the process, as supported by field observations in this study.

It is noteworthy that there is a very close match between the Quaternary stratigraphy of the Isles of Scilly and that of western and southern Pembrokeshire (John, 1970, 1973; Campbell and Bowen, 1989). The raised beach is ubiquitous around the coastline of both areas. Above it, the Devensian sequence of thick lower brecciated slope deposit, then till and related glaciofluvial deposits, and then a thin upper brecciated slope deposits, is replicated almost exactly. The greatest difference between Pembrokeshire and Scilly is that in the former, coastal exposures reveal occasional great thicknesses of till (sometimes in excess of 5 m), while in the latter the till is thin and patchy. In Pembrokeshire there is also greater relief, and accumulations of slope materials are, as expected, greater than in the low-lying islands of Scilly. Also, in Pembrokeshire many of the slope deposits show signs of permafrost active layer activity, whereas there appear to be no fossil ice wedges and related structures in Scilly, and just a few signs of cryoturbation.

Conclusions

From field observations made in 2016 it is suggested that two glacial episodes (and maybe more) have affected the Isles of Scilly. During the earlier of these, postulated as the Anglian or MIS-12 glaciation, the ice of the BIIS inundated the whole of the archipelago and terminated some distance to the east and south. Raised beaches occur in many different locations, at different altitudes and displaying different lithological characteristics. However, their relationship to other deposits is consistent, supporting the idea that they are of Last Interglacial (Ipswichian) age. The cold episode which followed culminated in a Late Devensian glacial incursion which affected only the northern and western coasts of the islands. The glacier ice must have flowed from northwest to south-east or from west to east.

The new observations reported in this paper, in part made possible by new coastal exposure conditions, contribute to a long and fascinating debate among Quaternary researchers. It is hoped that these observations may help to elucidate the glacial history of the Isles of Scilly and encourage more detailed field observations, sedimentological and geochronological analysis.

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LAND COVER CHANGE AND RESTORATION OF ANCIENT WOODLANDS IN NORTH WALES

Background and Rationale

Ancient woodlands, one of Britain's richest habitats (Rackham, 2003), are threatened by the introduction of conifers such as Western hemlock (*Tsuga heterophylla*) and Sitka Spruce (*Picea sitchensis*), invasive species (e.g. *Rhododendron ponticum*) and anthropogenic activity (Peterken, 2001). In the past, studies of the ecology of ancient woodlands have been based on old estate records and maps, although this can only provide information as far back as 1600 AD (Spencer and Kirby, 1992). In contrast, this research analyses the changes in vegetation cover and land use of the ancient woodland site 'Coed Felinrhyd & Ceunant Llennyrch', North Wales, (SH656389) during the past 7000 cal yr BP, through the use of fossil pollen from a long sequence record and moss polsters. This approach contributes to an understanding of long-term vegetation dynamics (Willis and Birks, 2006). The main aims of this research are to understand the ecological history of the woodland, determine the success of restoration practices, and demonstrate the importance of palaeoecological research for the management of ancient woodlands.

Results and wider significance

A peat core of 2000 mm depth was recovered from a bog located within the Felinrhyd-Llennyrch ancient semi-natural woodland and pollen analysis was undertaken following standard preparation and microscopic methods (Bennett and Willis, 2001). Three samples of wood macro-fossils extracted from the 2 m core for AMS radiocarbon dating (Table 1). The pollen record (Figure 1) shows that the site had a continuous woodland cover (Zones I-III) since around 6800 cal yr BP. The main taxa included oak (*Quercus*) and birch (*Betula*), and the humid Atlantic character of the woodland is revealed by the presence of *Ilex* and a strong representation of fern taxa, especially *Polypodium*. Decreases in arboreal pollen (AP) around 5900 cal yr BP, coupled with a large increase in charcoal micro-fragments (Zone II) are interpreted as slash-and-burn agriculture and clearing between the Mesolithic and Neolithic (Brown *et al.*, 1997). Around 5700-5500 yrs cal yr BP, the disappearance of pine (*Pinus*) is interpreted as an early demise in Scots pine (*Pinus sylvestris*) in the area, which may be linked to a widespread Scots pine decline around 4000 yrs cal yr BP (Blackford *et al.*, 1992), possibly caused by an expansion of waterlogged peatlands following

climatic deterioration or anthropogenic effects (Manning *et al.*, 2010; Mighall *et al.*, 2004). At this site, the pine decline is associated with the transition from a carr with alder (*Alnus*) and willow (*Salix*) (Zones I-II) to a bog setting, with increases in heather (*Calluna vulgaris*), sedges (Cyperaceae) and *Sphagnum* (Zones III-VI). Across this transition, cooler and wetter conditions may have favoured the expansion of *Betula* at the expense of *Quercus* in the wider landscape. Finally, the record shows the recent introduction of non-native taxa around 1800 AD including several conifers – hemlock (*Tsuga*), spruce (*Picea*), larch (*Larix*) – as well as *Rhododendron* (Zone VI).

Table 1. Radiocarbon data from Felinrhyd-Llennyrch

Lab ID	Core	Depth (mm)	Material	Conventional radiocarbon age (BP)	2 sigma calibrated age range (BP)	Median age (BP)
UBA-35435	FL16	790-800	Wood macrofossil	4716±33	5324-5581	5454
UBA-35436	FL16	1300-1310	Wood macrofossil	5160±35	5762-5992	5922
UBA-35437	FL16	1800-1810	Wood macrofossil	5998±35	6746-6932	6837

The radiocarbon dates indicate rapid peat accumulation rates of around 0.75mm/yr during the Mid-Holocene interval and a marked reduction to around 0.11mm/yr during the Late Holocene (Figure 1). This shift may be related to lower internal productivity at the site with the transition from carr to bog. However, a hiatus in the stratigraphy between ca. 5000 cal yr BP and the inferred introduction of conifers in 1800 AD cannot be ruled out based on the available radiocarbon dates. This could have been caused either by drying of the bog (as reflected in humified peats between 250mm and 500mm depth) or anthropogenic disturbance of the soil through agricultural practices. This leaves some uncertainties in the interpretation of the vegetation dynamics during the Late Holocene.

The highest biodiversity (19 pollen taxa) can be identified at sample depth 1200mm, around 6800 cal yr BP, which could be considered as an ecological reference point for restoration practices. Comparison with moss polsters (Figure 1) reveals how much current vegetation has changed from a particular period in the woodland's history. The data shows that even though the introduction of conifers has effectively reduced species richness at the site, restoration efforts of

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QUATERNARY RESEARCH FUND

RENEWED SURVEY AND EXCAVATIONS AT PNIEL, SOUTH AFRICA

Background and Rationale

For a century fossil fauna and stone tools have been reported from the banks of the lower Vaal River in the Northern Cape Province of South Africa, often brought to light by early diamond mining (Helgren 1979, Beaumont 1990). First excavations by the late P. Beaumont (McGregor Museum Kimberley, 1980s) and J. McNabb (University of Southampton, 2000) recovered artefacts and fauna from the Early and Middle Stone Age at Pniel 6. In 2017 we started a new excavation project at Pniel to locate, document and excavate the archaeologically significant levels with a modern excavation using a fully digital, integrated recording system. The project has a particular focus on palaeoenvironmental research as faunal remains are otherwise rare in open air sites in the arid interior of southern Africa. This leaves the climate and environment during the Mid-Pleistocene, the time of the first anatomically modern humans in the region, largely unknown. The first step towards developing a sustained project at Pniel was a detailed mapping across the area.

Approach

Excavations were conducted in full collaboration between Dr. M. Ecker (University of Toronto) and Dr. D. Morris (McGregor Museum Kimberley). QRA support allowed the addition of a GIS specialist (Dr. C. Green, University of Oxford) to the team during the two-week field season in June 2017 for comprehensive survey and mapping of the fossil bearing strata. Eight datum points were established in the vicinity of Pniel 6 (Figure 1) and translated into real world coordinates through repeated GPS measurements. This allows us to excavate anywhere in the vicinity with all trenches and finds recorded in three dimensions through the use of a total station. Furthermore, it enabled us to create an initial topographic map of the area through transect measurements. Three test excavation areas were opened this season (Figure 1) and in addition to the spatial recordings of finds and levels the areas were documented with photogrammetry. Walking in a controlled survey from Pniel 6 upstream along the Vaal river, we documented further exposures of artefacts.

Significance and further work

We confirmed the appearance of Early Middle Stone Age lithic artefacts associated with preserved fauna in discrete lenses at Pniel 6. Plans for the 2018 field season

include an extension the excavation to expose the vertical and horizontal extend of the find levels as well as preparing profiles for OSL dating. The site has the potential to make a significant contribution to understanding how early modern humans adapted to diverse environments in southern Africa.

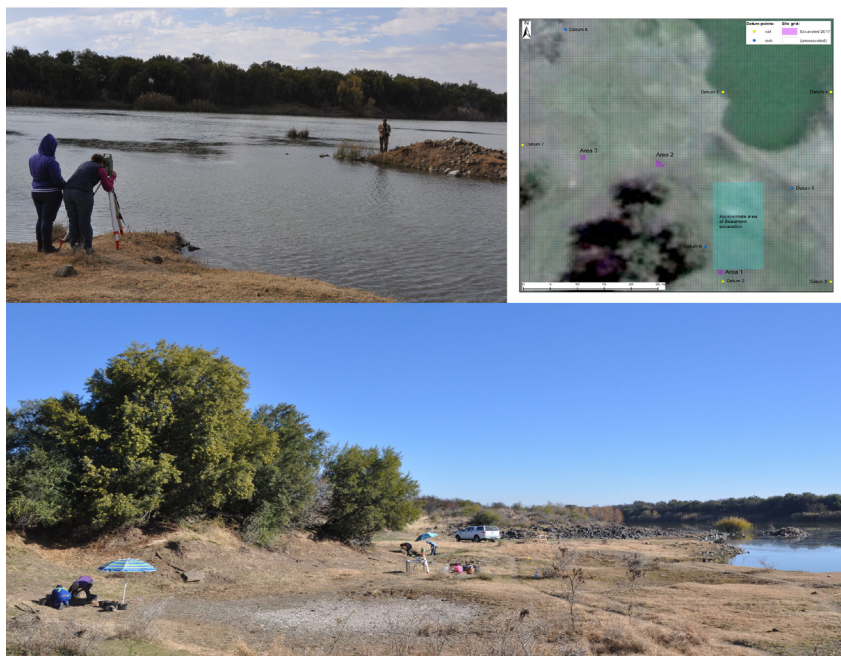


Figure 1. Overview over fieldwork at Pniel in 2017. Left: Surveying for datum points. Right: Overview over datum points and excavation grid created. Excavated test areas are highlighted. Below: Overview of work in excavation areas 1 and 2.

Acknowledgments

I would like to thank the QRA and the Rust Family Foundation for supporting the pilot field season at Pniel financially and the Archaeology Centre at the University of Toronto for logistical support. I thank the landowners for their consent to work at the site and the 2017 excavation team for all their hard work.

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NEW RESEARCH WROKERS AWARD

SURFACE TEMPERATURES FROM OXYGEN ISOTOPES IN MARINE MOLLUSCS IN MIDDLE AND LATER STONE AGE SITES, SOUTH AFRICA

Background and rationale

Much of the robust evidence for the early emergence of cognitively-complex human behaviour, including consistent use of marine resources, comes from Middle Stone Age sites along the southern Cape coastline, South Africa. Both the nature of marine resource use and the climatic and environmental contexts of these sites from the Last Interglacial into the recent Holocene has long been a focus of research, but the region lacks sufficiently detailed, well-dated environmental records to test hypotheses linking environmental and socio-cultural dynamics. This doctoral project aimed to construct a seasonally-resolved record of Pleistocene and Holocene sea surface temperatures (SSTs), embedded within archaeological records distributed along the southern Cape coast, using serial $\delta^{18}\text{O}$ measurements of marine shells found in these sites. These data also reveal the season of death for each mollusc, and thereby valuable archaeological detail into the annual scheduling of hunter-gatherer occupation of coastal sites.

The QRA New Research Worker Award (2015) enabled serial $\delta^{18}\text{O}$ analyses of *Turbo sarmaticus* opercula from the Later Stone Age terminal Pleistocene and Holocene sites of Nelson Bay Cave, Byneskranskop 1 and Hoffman's/Robberg Cave. Data from these comparatively well-dated Holocene contexts provide a test for climatic models that link near-shore SSTs and regional precipitation patterns (Cohen and Tyson, 1995). The Award also partially funded the fieldwork necessary to collect seawater samples from along the south coast, to better characterise regional seasonal variability of seawater $\delta^{18}\text{O}$.

Project results

Analyses from modern *Turbo* opercula demonstrate that the micromill serial sampling strategy captures seasonal SSTs and the season of death, allowing this species to be used for palaeoclimate reconstructions (Galimberti *et al.*, 2017; Loftus *et al.*, 2017). Loftus *et al.* (2017) presents the complete dataset of serial $\delta^{18}\text{O}$ shell analyses from the Holocene, terminal Pleistocene and MIS 5-4 deposits, for a long-term reconstruction of near-shore seasonal SSTs across periods of marked global climate change. Mean SSTs increased

by 4 °C from the terminal Pleistocene through to the late Holocene, while the interannual temperature amplitude decreased markedly from c. 7 °C in the terminal Pleistocene to only c. 4 °C during the mid-Holocene. This shift in seasonal SST amplitude across the glacial/interglacial transition mirrors that observed from the MIS 5/4 interglacial/glacial transition. These observations are consistent with models that link seasonality in the near-shore system with wind-driven upwelling, and the relative situation of the major rain-bearing wind belts (Cohen and Tyson, 1995). Season of death assessments indicate a marked shift in the annual timing of shellfishing, from more mixed and year-round patterning in Middle Stone Age contexts to a strongly (and unexpected) winter season of harvest during the Later Stone Age (Loftus *et al.*, in review).

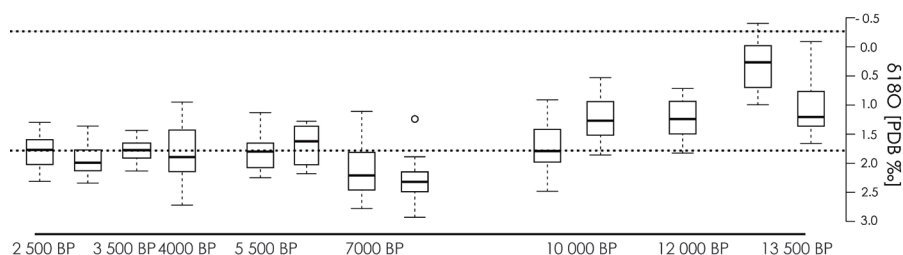


Figure 1. A) Serial sampled *Turbo sarmaticus* opercula (23 samples), with B) resulting $\delta^{18}\text{O}$ series showing seasonal temperature pattern. C) Full dataset from all archaeological shells showing shifts in means SST and interannual SST amplitude (seasonality) across late Pleistocene and Holocene ($\delta^{18}\text{O}$ have been adjusted for changes in global seawater $\delta^{18}\text{O}$ using Waelbroeck *et al.* (2002)). Figure adapted from Loftus *et al.* (2017).

Acknowledgements

I gratefully acknowledge the support of the Quaternary Research Association. Further support for this project came from the Boise Fund, the School of Archaeology, Merton College and the Clarendon Fund, all University of Oxford. I would also like to thank my supervisors Prof.s Julia Lee-Thorp and Judy Sealy; Chris Day, Chris Harris, Chris Richardson, Mariagrazia Galimberti, Andy Gledhill and Peter Ditchfield for help with analyses; and Wendy Black, Wilhelmina Seconna and Louisa Hutten for access to the collections at Iziko National Museum and the University of Cape Town.

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GPR OF THE MIAGE GLACIER: IMPLICATIONS FOR SUPRAGLAICAL LAKE FORMATION

Background and Rationale

Climate change and associated mountain glacier recession has resulted in increased presence of glacial lakes, presenting a risk of Glacial Lake Outburst Floods (GLOFs) and fluctuating water resources to downstream communities (Richardson and Reynolds, 2000). Hence, a detailed understanding of lake formation and evolution is required to better predict the occurrence of GLOFs and improve water resource management (Bolch *et al.*, 2011). This project aims to investigate the under-explored role of debris supply, ice dynamics and structural evolution in the formation and development of supraglacial lakes on the Miage Glacier, Italian Alps. The Miage Glacier is the largest debris-covered glacier in the Alps consisting of a ~11 km long glacier (Deline, 2005).

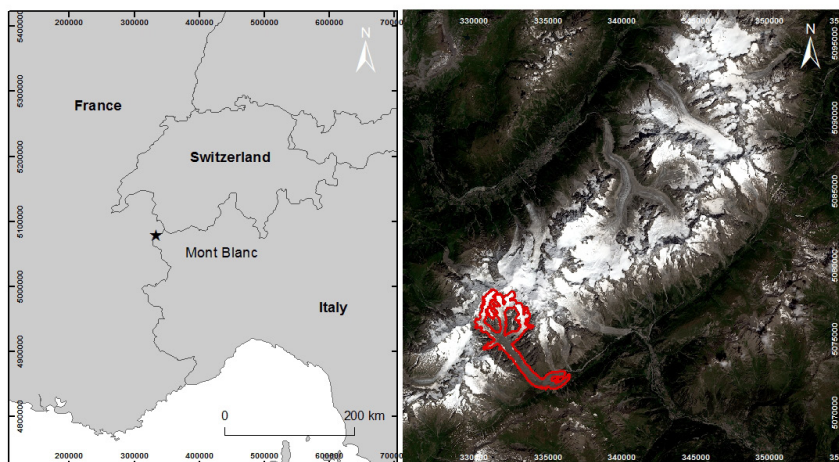


Figure 1. Location map of the Miage Glacier in the Italian Alps on the south-west flank of Mont Blanc.

Some controls on glacier lake formation are already known. Differential ablation rates on debris-covered glaciers (Østrem, 1959) have been shown to influence ice dynamics promoting the growth of supraglacial lakes and alter glacier response to climate change (Rowan *et al.*, 2015). Supraglacial lakes typically form on stagnating and down-wasting debris-covered glaciers with low slope gradients ($<2 - 6^\circ$) and low ice velocities (Quincey *et al.*, 2007). However, the extent to which ice structures, debris supply and ice dynamics influence lake formation and their consequent evolution is still relatively unknown. In addition, the Miage Glacier exhibits a steeper gradient than the $2-6^\circ$ yet still produces a number of

seasonal supraglacial lakes. This study therefore aims to investigate the controls on supraglacial lake formation by assessing sub-surface ice structures using Ground Penetrating Radar (GPR) and structural mapping from aerial and satellite imagery.

The funds from the QRA NWRA enabled winter fieldwork to be carried out in March 2018 to undertake GPR surveys. Multiple transects were taken across the glacier with two different GPR antennas and radar systems providing a wide coverage across the glacier.

Methods

Two GPR units were used to collect data on the Miage Glacier consisting of a Mala ProEx with a 100 MHz RTA unshielded antenna, and a PulseEKKO with a 200 MHz unshielded antenna. The 100 MHz RTA (Figure 2) was towed manually at a relatively constant speed of ~ 1 m/s along the transect lines taking samples continuously set to ice velocity of 170 ns. Locations were recorded with a Trimble Geo7x recording positions every 1 second with decimetre accuracy once post-processed. The 200 MHz antenna was towed on a sled with 0.5 m separation between the two antennas. The sled was towed slowly taking samples every 3 seconds at 10 cm intervals or on a continuous mode to enable faster coverage of the glacier. Due to difficulties with the GPS set up, the location data was recorded using a handheld GPS Garmin to track the route with an accuracy of ± 5 m.



Figure 2. Mala ProEx 100 MHz RTA with Trimble Geo7x attached.

In total 6 transects totalling a length of ~5000 m with the Mala ProEx 100 MHz RTA and 6 transects with the PulseEKKO 200 MHz consisting of 3 high resolution transects using a step by step approach and 3 on a continuous setting at walking speed (Table 1). Transect locations of the Mala ProEx system and the first transect using the PulseEkko system are identified in Figure 3. Transects were aimed to get a good coverage of the glacier including regions where lakes were previously located in 2017 and likely to reoccur in 2018. Due to the heavy snow coverage, it was difficult to determine in the field the exact locations of the lakes and it was unknown if the lakes had drained at the end of the ablation season prior to snowfall.

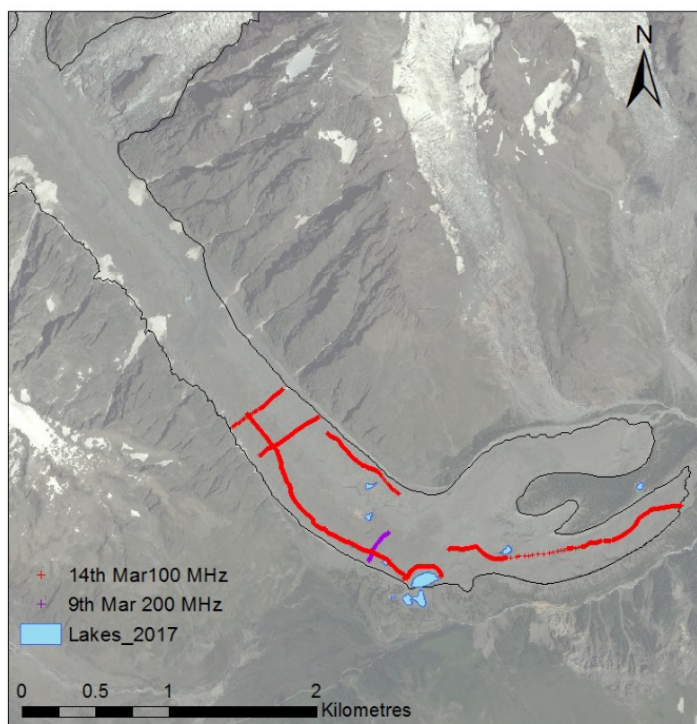


Figure 3. Map of transects across the glacier showing T1-6 100 MHz routes and H1, and C1-3 200 MHz routes.

Table 1. Summary of the transects taken with the different GPR set ups. Further data analysis of the 200 MHz is required.

Transect	Description	Distance (m)	Pace (m/s)	Samples	Traces
T1 – 100 MHz	Up left side	633	0.53	512	79494
T2 – 100 MHz	Across, lower	476	0.27	512	63116
T3 – 100 MHz	Across, upper	400	0.56	512	44217
T4 – 100 MHz	Down right side	1625	0.51	512	147056
T5 – 100 MHz	Around Lake Miage	320	0.82	512	26890
T6 – 100 MHz	Southern lobe	1702	0.97	512	106682
H1 – 200 MHz	Across lower 1	246	Step by step	-	-
H2 – 200 MHz	Across lower 2	-	Step by step	-	-
H3 – 200 MHz	Across higher	-	Step by step	-	-
C1 – 200 MHz	Up left side	-	Continuous	-	-
C2 – 200 MHz	Down right side	-	Continuous	-	-
C3 – 200 MHz	Southern lobe	-	Continuous	-	-

Preliminary Results

The data collected is currently being processed. Due to the nature of GPR data, a high level of processing is required prior to interpretation and analysis. Processing is being undertaken using ReflexW to filters and reduce the noise within the data. The filters and processing steps include:

- Time-zero correction
- Dewow filtering
- Topographic correction using GPS elevation data
- Gain
- Filtering
- Background subtraction –high pass filter or average trace removal

The data will be processed and analysed with regard to lake position and ice surface structures depicted from mapping of satellite and aerial imagery. This will then be investigated as to whether there are any controls on current or future lake positions on the Miage Glacier. Further fieldwork will be undertaken in 2018 to investigate future lake locations.

Significance

This data is vital determining the internal ice dynamics and controls on supraglacial lake formation. As the Miage Glacier does not succumb to previously theorised formation controls (e.g. $<2-6^{\circ}$), there are likely additional factors at play. This data will help untangle the intricate relationship between ice structures, dynamics and the locations and formation of supraglacial lakes. Although this data looks promising, further research is needed to continue to understand these complex relationships. Ongoing monitoring of the Miage will continue in summer 2018 to map supraglacial lakes to assess whether locations have changed or the previous lakes have undergone drainage events with potential for winter GPR fieldwork in 2019.

Acknowledgements

Thanks to QRA NWRA for financial support to enable the data to be collected. Thanks also to Nottingham Trent University who provided some additional funding for the trip. A big thank you to Catriona Fyffe and Matt Westoby at Northumbria University, Philip Deline and Pierre-Allain Duvillard (Univ. SMB Mont Blanc), and Remy LJ Veness (Sheffield University) without whose help the data collection would not have been possible.

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ICE-MARGINAL PROCESSES AND RETREAT DYNAMICS OF THE PLATEAU ICEFIELDS LANGFJORDJØKELEN AND ØKSFJORDJØKELEN, NORTHERN NORWAY

Background and rationale

Plateau icefields are particularly sensitive to changes in climate because the source area of these ice masses is situated on the low slope gradient of the plateau. If climate warming raises the equilibrium line altitude (ELA) to the height of the plateau any further warming will cause the ablation area to expand significantly, leading to rapid icefield recession (cf. Oerlemans 2012). The spatial distribution of ice-marginal moraines, associated with the retreat of plateau icefields, is generally assumed to reflect climatic variations over time (e.g. Bickerton and Matthews 1993). However, this moraine pattern may also reflect icefield response to local topographic factors, such as slope gradient and shading (Oerlemans 2012; Barr and Lovell 2014). Research on how these factors may affect the overall recession of plateau icefields is underexplored, leading to uncertainty in rates of glacier recession under future climate warming scenarios. With financial support from the QRA, this gap was addressed at the two northern Norwegian plateau icefields Langfjordjøkelen and Øksfjordjøkelen, which have undergone significant retreat since the Little Ice Age (LIA) maximum in ca. AD 1925 (cf. Wittmeier *et al.*, 2015).

Results

This work employed geomorphological mapping in the field, aided by the use of an unmanned aerial vehicle (UAV) to produce high-resolution aerial imagery (Figure 1) and DEMs. The fieldwork at Langfjordjøkelen and Øksfjordjøkelen has: (i) identified their maximum LIA extent and (ii) documented the recessional landforms and retreat patterns of both icefields from the LIA maximum to present. A detailed geomorphological map showing the maximum LIA extent and subsequent recession of Langfjordjøkelen and Øksfjordjøkelen is currently in preparation. Based on this data set, the next phase of the project will examine how the response of the two icefields to changes in climate has been influenced by local topographic and hypsometric factors.

Significance

The research allows the response of Langfjordjøkelen and Øksfjordjøkelen to climate warming since the LIA maximum to be assessed. These insights can be employed to predict the effect of future climate change on the retreat dynamics of small Arctic ice masses, which is particularly important because rises in Northern Hemisphere surface air temperatures will be amplified in the Arctic (Serreze *et al.*, 2009; Miller *et al.*, 2010).

The results of this project will also be useful in palaeo-icefield reconstructions, where it has often been difficult to extract a detailed climate signal from moraine spacing (cf. Lukas and Benn 2006) because the extent to which topographic and hypsometric factors control the overall response of a glacier to changes in climate is not yet understood, and may also vary between different ice masses.



Figure 1. Vertical UAV image of Langfjordjökulen's glacier tongue and foreland.

Acknowledgments

The QRA is thanked for supporting this research with a New Research Workers' Award.

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REVIEWS

GREENLAND BASAL TOPOGRAPHY : BEDMACHINE V3. 1:3,500,000 BAS THEMATIC MAP2, NERC.

Published by : British Antarctic Survey 2017

ISBN 978 0 85665 216 5 flat 978 0 85665 215 8 folded and cased

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Following on from mapping the bedrock topography beneath Antarctica, the British Antarctic Survey has produced a more detailed and higher resolution, seamless 1:3,500,000 map of Greenland and its surrounding waters in collaboration with the University of Bristol and University of California, Irvine. The front cover of the folded and cased version shows a half-scale reduced image of the isolated Baffin Bay basin and Davis Strait between the western coast of Greenland, with its much wider continental shelf, and the narrower margins off Baffin Island. The back of the cover shows the entire area covered by the map at a considerably reduced scale. This spans the Demark Strait and 750 km of the mid-Atlantic ridge along with varying portions of Iceland, Spitsbergen, the Arctic Ocean, Lincoln Sea and Ellesmere Island, depending on the extent of the topographic image on the front or the enhanced synthetic 3D poster printed on the reverse.

Apart from the exposed bedrock around the coasts, much of this image has been built up with radio-echo sounding to subtract the height and thickness of the overlying ice sheet by timing how long a signal takes to reach the bedrock and return to the surface. This method is normally much better than seismic reflection surveys on ground-based sledges, as it allows multifrequency radar equipment to be flown over the ice much more rapidly. However, coastal glaciers with lots of crevasses that reflect noise back instead of a clear signal, along with areas of warmer ice containing pockets of water which absorb much of the signal before it reaches the bedrock interface and deep valleys, are more problematic. Indeed, some unsurveyed glaciers have still had to be estimated using a simple U-shaped model as an approximation of the valley they are flowing down. Sometimes the underside of glaciers is able to mix with warm >2.5 °C Atlantic waters, while in other cases the presence of sills in some fjords is able to block this influx. In any

case, rather than interpolation to remove the estimated thickness of ice between measurements across the extensive interior of Greenland, a mass conservation approach has been used nearing the coast to model the ice thickness coupled with obtaining bathymetry data at the front of ice-calving glaciers to optimize the overall model.

The resulting map uses softer light blue tones for areas below sea level, which are clearly demarcated from those above with a white zero contour. This amounts to 426,000 km² out of a total ice-covered area including ice shelves of 1,799,000 km², which is just under a quarter. Above this there are pastel green and yellowish orange tones for bedrock up to 1,000 m with more intense colours for buried mountains and exposed bedrock above 2,000 m in dark red. Just like its Antarctic counterpart, even the Greenland map has remoter areas with a visibly lower resolution blurred image where the data is relatively poor. Coastlines are delineated in black, and yet this map lacks a green counter to stand out against the brown tones to denote the edge of exposed bedrock which forms significant mountainous areas along both coasts of the world's largest island, some 2,700 km long and 1,300 km wide. Once the continental shelf is reached the blue tones rapidly become significantly darker. Geographical coordinates and place names, including the narrow Nares Strait dividing Greenland from Ellesmere Island, are clearly shown in white along with bays, glaciers, sounds, and fjords along its coastlines. Inside the folds along the left-hand margin is a series of insert maps: first showing the approximate thickness of ice and exposed rock; another showing land classification which makes it easier to see at a glance the ice-free land, though it takes some time to spot glaciers with noticeable areas of floating ice in green; and a third showing the density of the data used to compile the overall image from ice-penetrating radar, bathymetry and satellite data covering ice free areas.

Printed on the back of the map is a neatly annotated poster for putting the flat version on a wall. This shows the same topography and colours with synthetic 3D without longitude or latitude lines, nor place names, apart from those referred to in the information boxes linked to points of interest on the poster. One of these highlights the sinuous paleofluvial mega-canyon first discovered by the analysis of ice-penetrating radar data in 2013: this is about 750 km long and links much of the areas below sea level with the northerly Petermann glacier. This probably acts as a major drainage route for much of the melt-water present underneath the ice sheet, while the glacier has the largest floating ice tongue in the northern hemisphere. Along the western coast the Jakobshavn glacier drains approximately a fifth of Greenland while the Gothåbsford (Nuup Kangerdlua) network of eight glaciers and Sermilik fjord are both given more detailed insert maps in the margins. These includes four cross-sections showing the 2 to 3 km thickness of the central ice sheet, and also the mountainous topography of the costal fjords.

Above the main image is a series of larger paragraphs detailing the methods used to make this map, firstly by "Looking underneath the ice sheet", which

explains how ice penetrating radar works, and notes that since 2009 over 90% of the data incorporated in BedMachine v3 was obtained as part of Operation Ice Bridge by NASA and the Center for Remote Sensing of Ice Sheets (CReSIS) at the University of Kansas. Other paragraphs explain how “Surveying the sea floor” is done and the methods used for “Data combination”, including kriging interpolation, mass conservation, spline interpolation, and even synthetic fjord geometry, where they have not yet been mapped. Finally a smaller box sets out some key statistics, including the fact that thickest ice is 3,488 m thick and that the ice covering Greenland has a total volume of 2.99 million km³ (compared to 26.92 million km³ for Antarctica), which if it melted would add 7.42 ± 0.05 m to global sea levels. However, one of the bullet points does not explain if the uplift generated by the removal of the current ice sheet’s weight from the underlying lithosphere is taken into account, the simple flexural loading for an ice sheet 700 km wide and 2½ km deep would result in nearly 700 m of depression of surface elevations in the middle of the ice sheet.

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REPORTS

LATE CENOZOIC EVOLUTION OF THE YELLOW RIVER AND ITS ENVIRONS

**Combined field and discussion meeting with the Geologists' Association
September, 2017, Lanzhou University, China.**

This meeting, modified from an original proposal for a FLAG biennial meeting, was a combined venture also involving the QRA, the British Geologists' Association and the Fluvial Archives Group (FLAG). It was based on collaborative work by **Jef Vandenberghe** (FLAG) with **Wang Xianyan** (Nanjing University) and by **David Bridgland** (Durham University) with the Lanzhou team of **Pan Boatian** and **Hu Zhenbo**. Participants from Canada, Germany, Portugal and Russia joined with a group of from the UK and a number of Chinese scientists for a one-day conference and then a six day field excursion, some staying on for an optional additional visit to the glaciated highlands of Tibet.

The one-day conference

This was convened at Lanzhou University. It began with a fulsome introductory session:

- Welcome Speech (Vice President of Lanzhou University)
- Welcome Speech (Nanjing University)
- Introduction to the environments around the Northeastern Tibetan Plateau (Ministry of Education)
- Introduction to Key Laboratory of Western China's Environmental Systems (President of Key Laboratory and College of Earth Environmental Sciences)

The discussion meeting followed the typical FLAG format of 15 minutes 5 for questions. Presenters covered a wide range of topics, as follows:

- Late Cenozoic fluvial history worldwide: a context for the Yellow River record. **David Bridgland**
- Coupling of river basins, delta and sea level under glacial/interglacial cycles. **Zhongping Lai**
- Loess Chronologies along a transect between the Huang He and Lái Yin He. **Manfred Frechen**
- The Chinese Loess and Red Clay: links to Quaternary climate. **Jef Vandenberghe**

- River history: how old are modern rivers? **Martin Gibling**
- Was the Atlantic drainage routing of the River Tejo (Tagus) in western Iberia formed by spill-over of the endorheic Cenozoic Madrid Basin? **Pedro Cunha**
- Earth surface processes and their effects on human behavior in monsoonal China during the Pleistocene-Holocene epochs. **Huayu Lu**
- Late Pleistocene glacial damming, flow rerouting and outburst floods in Northern Eurasia: state-of-the-art. **Andrei Panin**
- Steady state forms and transient fluvial incision on the Tejo and Douro rivers tributaries, a case study in mainland Portugal (Hesperian Massif). **António Martins**
- Climatic and tectonic controls on the fluvial morphology of the Northeastern Tibetan Plateau (China): a case from Huang Shui catchment. **Xianyan Wang**
- Origin of the Yellow River. **Baotian Pan**
- The staircases of fluvial terraces of River Vouga and tributaries (W. Central Portugal) - a contribution to understanding fluvial incision in western Iberia. **Alberto Gomes**
- Fluvial terraces and the tectonic deformation in the eastern Qilian Shan, NE Tibetan Plateau. **Xiaofei Hu**
- Was the proximal structure in the northern Chinese Tian Shan foreland active during Late Quaternary? Insight from fluvial geomorphologic investigations. **Honghua Lu**

The Yellow River Field Excursion

The Yellow River field excursion was led by Professors **Hu Zhenbo** (*Lanzhou University*), **Wang Xianyan** (*Nanjing University*), **David Bridgland** (*Durham University*), and **Jef Vandenberghe** (*Vrije Universiteit Amsterdam*). They were assisted by a wonderful group of Chinese colleagues and students who made the seven-day excursion thoroughly enjoyable. Crammed into two buses and resplendent in red baseball caps, the group visited outcrops along roads, ravines, and dams, experiencing spectacular geology, historic and modern China, and (not least) delectable food; they were accommodated along the way in mainly new and very well-appointed high-rise hotels.

The buses took the group several hundred kilometres from Lanzhou, traversing the rugged northeast margin of Tibetan Plateau, where stress from the Cenozoic collision of India with Asia continues to cause active faulting, partly expressed in the ‘basin and range’ nature of the high-level landscape. Thus the group travelled through a bewildering array of basins with Miocene to Quaternary sedimentary fills and evidence of later Quaternary river incision through the basin sediments and the intervening mountain ranges, the latter in spectacular gorges. Thus the group peered over the precipitous edge of Longyang Gorge (Figure 1A), the 600 m deep exit from the GongHe Basin, linking it to the GuiDe Basin (Figure 1D) and incised in perhaps as little as 250,000 years, based on interpretations

discussed on the trip. As the river cut down, a staircase of terraces formed, each mantled by gravel and perched on the hillsides high above the modern river. Only a small proportion of the GongHe basin is externally drained, however, much of it remaining endorheic.



Figure 1. Clockwise from top left: (A) peering into the Longyang Gorge; terrace gravel forming part of the staircase above the Longyang reservoir; (B) the party studies interesting and enigmatic structures in a road-cutting in the Doatanghe valley; prayer flags flutter above, (C) extraction adits in Yellow River gravel with thick loessic overburden, Lanzhou suburbs; the party deep in discussion, (D) Part of the group studies a section in very coarse Yellow River gravel, part

Where the rivers had eroded more widely through softer material, generations of villagers worked the landscape into an intricate array of agricultural levels where we saw a range of dry-season crops. These anthropogenic terraces have to be distinguished from the natural river terraces, made more difficult by the wind-blown overburden, often much thicker than any fluvial sediments marking the terrace level. The huge thicknesses of buff-coloured loess (up to 400 m thick and the largest accumulation of windblown dust on Earth) is certainly the most striking feature of the Yellow River valley in its Lanzhou

reach, with terrace gravels often indicated by lines of extraction 'adits' below cliffs of loessic overburden (Figure 1C); the gravel clasts have been extracted to cover the surface of agricultural land, to help retain moisture (gravelly field debris is no indication of a terrace outcrop in this region!). The formation of the loess commenced about 8 million years ago (in the Miocene). With abundant sediment accessible from the uplifting Tibetan Plateau, westerly winds transported enormous volumes of dust from the deserts and river plains of Central Asia, aided by the increasing aridity that accompanied global cooling. The loess accumulated in basins across the area and far out into the Pacific. Loessic dust is thought to have accumulated on terrace gravels as soon as the river abandoned them, an important axiom for using loess data for dating the terraces. The group's introduction to loess was at a building site where, among partly constructed skyscrapers, terrace gravels and a cap of loess was visible through green wrappings designed to control the dust.

Also unexpected by most (on a river excursion) was a series of lake basins, formerly isolated by tectonic activity, that were encountered. Hundreds of metres of sediment accumulated in these lakes during the Miocene and Pliocene, some perhaps of loess origin. As rivers incised gorges through inter-basin ridges, these lakes became connected to through-going drainage and emptied into the ocean via the Yellow River. One huge lake that was visited, 3000 m above sea level, is Lake Qinghai. This remains internally draining, although it is thought that it might once have been connected to the Yellow River but was isolated again, probably by tectonic activity. In the basin-fill areas of the old lakes impressive badland scenery has been formed by erosion and dissection of the lake sediments, the roads sometimes winding through an intricate fretwork of ravines, gullies and pinnacles.

Thus in its upper reaches the Yellow River has linked a series of disconnected river and lake-basin segments, finally draining these to the Pacific. Therefore the upper part of one of the world's largest rivers can be seen to be very young geologically.

Participants engaged in an active debate about whether the highest area visited on the NE Tibetan Plateau had ever been glaciated. Roadside sections in rubbly gravel and mud, high in the mountains, did not convince as till, seeming more likely to be debris-flow, or slope deposits. Most agreed on a non-glacial interpretation. But at another site, **Jef Vandenberghe** pointed out contorted sediments below the land surface – cryogenic features indicative of a former cold climate.

For further information see the field guide: Hu Zhenbo, Wang Xianyan, Pan Boatian, David Bridgland, Jef Vandenberghe., 2017. *The Quaternary of the Upper Yellow River and its environs: Field Guide* (Figure 2). Quaternary Research Association, London. 83pp.

THE QUATERNARY OF THE UPPER YELLOW RIVER AND ITS ENVIRONS

Edited by HU Z., WANG X., PAN B.
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Quaternary Research Association



2017

Figure 2. The front cover the 2017 field guide for the Yellow River and its environs.

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REPORT ON FIELD MEETING: GLACIAL LANDSYSTEMS OF SOUTHEAST ICELAND – QUATERNARY APPLICATIONS

August 31 – September 8, 2018

Organized by the Glacial Landsystems Working Group and Quaternary Research Association

In 1968, the three-year-old Quaternary Field Studies Group (later renamed the Quaternary Research Association) held their first international field meeting, which was focused on the forefield of Breiðamerkurjökull along the southern margin of Vatnajökull in SE Iceland. Fifty years later, the Quaternary Research Association together with the Glacial Landsystems Working Group returned to the area to hold a joint field meeting along the southern margin of Vatnajökull. The prime objective of the 2018 meeting was to examine the nature of landforms and sediments associated with modern glacial environments in the region. In particular, the field meeting allowed its participants to examine the changes that had occurred over the past half century and to help appreciate the significance of this region to the advancement of glacial geomorphology and sedimentology.

Some 36 early career and established Quaternary scientists and geomorphologists from the UK, Spain, Poland, and US attended the field meeting. The meeting was organized by **David Evans** from Durham University together with many colleagues including **Jez Everest** (*British Geological Survey*), **Marek Ewertowski** (*Adam Mickiewicz University, Poland*), **Ailsa Guild** (*Durham University*), **John Hiemstra** (*Swansea University*), **Emrys Phillips** (*British Geological Survey*), **David Roberts** (*Durham University*), **Zoe Robinson** (*Keele University*), **Andy Russell** (*Newcastle University*) and **Richard Waller** (*Keele University*).

Field logistics for the Quaternary Field Studies Group were challenging in 1968 and the only shelter was the Breiða Hut on the western foreland of Breiðamerkurjökull. Although 50 years had passed, the Breiða Hut has stood the test of time. The hut's cold metal frame conceals a history of cutting-edge studies on glaciology, and glacial geomorphology and sedimentology. Participants of the 2018 visited the hut and took the opportunity to reconstruct a photograph taken on the 1968 field meeting (Figure. 1). The new generations of experts, however, opted for the comforts of Reynivellir just a few miles east of Breiðamerkurjökull. Reynivellir provided excellent facilities, including a house and cabins with kitchens and showers, and, of course, easy access along Highway 1 to the southern outlet glaciers of Vatnajökull.



Figure. 1. The Breiða Hut in 1968 with members of the Quaternary Field Studies Group (later renamed the Quaternary Research Association) (upper

The locations visited and the associated science are outlined in great detail in a truly impressive field guidebook edited by **David Evans** (Evans, 2018). The field guide is beautifully illustrated and with comprehensive referencing. The weather conditions during the week were excellent; dry and sunny except for the second day when it rained for several hours. This, plus the superb organization and planning, helped make the field meeting a truly exceptional success.

The meeting started in Keflavik International Airport on the morning of August 31. The participants drove for about six hours across southern Iceland along Highway 1 to Reynivellir, stopping for the week's groceries at Selfoss. Some of the group was fortunate to briefly stop and examine part of the basalts formed by the Laki fissure eruption. Arriving late afternoon, this provided the participants

to get settled at Reynivellir and to begin to get to know the new members of the Glacial Landsystems Working Group.

The first field day was delightful, led by **Dave Evans** along the forefield of Breiðamerkurjökull (Figure 2). Dave emphasized the great significance of this region to the birth of some modern glacial geology, including the studies by Geoffrey Boulton and Douglas Benn that led to some of the formative ideas on subglacial deformation and till development. Also, it was here that some of the first process-form models were developed. Glacial landsystem maps from 1945, 1965 and 1998 were considered and compared to show the dynamic changes over the last seventy years. The participants saw impressive eskers for the first of many times on the trip, and they walked through a deep spillway at Fjallsjökull to examine collapse structures related to dead ice in the forefield of Hrutarjökull.



Figure 2. Dave Evans explaining glacial landsystem in front of Breiðamerkurjökull, with the help of Rob Storrar and Ailsa Guild.

The second field day was an absolute joy with reasonable weather in between some persistent rain showers. The day was led by **Andy Russell** who stretched the group to imagine the might of jökulhlaups that drain from Skeiðarárjökull. The group was reminded that Skeiðarársandur is the archetypal sandur. The evidence of the 1996 jökulhlaup was examined and the group was awed by the sheer size of the flood and huge quantities of debris that was transported by the immense flows (Figure. 3). All day, the crew wandered the area and were treated to fine descriptions of a range of landforms, both Andy's jökulhlaup-related forms as well as surge-related aspects such as drumlins and flutes by **Rich Waller**. The day culminated in examining an impressive push moraine with hydrofracture infills.



Figure 3. Lunch on the 1996 outwash flood deposits at Skeiðarársandur.

Day 3 began at Skaftafellsjökull, led by **Dave Evans** and appreciating the well preserved subglacial till sequences and relating the outcrop features to the seminal work of Geoff Boulton and Doug Benn on subglacial deformation in the region. **Zoe Robinson** then introduced the importance of groundwater hydrology by describing her research in the area. **Jez Everest** then provided an overview of the extensive work that has been undertaken on the three glacier forelands of Skaftafellsjökull, Svinafellsjökull and Virkis/Falljökull by the BGS and associated colleagues. This was followed by **Alisa Guild** who presented her impressive study of the structural elements/domains of Svinafellsjökull (Figure. 4). **Rich Waller** and **Rob Storrar** continued by providing some fascinating insights into basal debris-rich ice studies. The day continued to Virkisjökull and Falljökull where **Jez Everest** discussed his long-term monitoring study of the glacial system, followed by **Emrys Phillips** who provided a synopsis of his structural analysis of the glaciers. The day ended with a bonus stop at the Kota Fan where **Andy Russell** described catastrophic jökulhlaups that had ravaged the region over the past centuries and deposited some impressive melt-out pits and obstacle marks.

September 4th and the fourth day of the field meeting involved an examination of Fláajökull guided by **Dave Evans**. Crevasse fills, minor eskers, composite push moraines, flutes, lodged boulders, and till eskers were among the day's treats (Figure 5). A bonus stop at the end of the field day involved meeting local geoconservation expert Dr. Thorri Arnarson of the University Centre in Hofn in front of Hoffellsjökull, where the group examined recently deposited glacialacustrine sediments at the glacier margin.



Figure 4. Alisa Guild explains her work on Svinafellsjökull.



Figure 5. Dave Evans on a flute at Fláajökull (or was it a till esker?).

The fifth day in the field began by examining the historically important huge latero-frontal moraine of Kvíárjökull. Here, **Nick Eyles** and **Geoff Boulton** developed what is arguably the first glaciated valley landsystems model, which set the scene for much future work and numerous publications on landsystems and debris transport pathways. The importance of glacial clast shape in helping to determine the origin of the lateral moraines was discussed. As the day progressed the participants were treated to an excellent set of kame terraces. This was followed by an instructive trek on Kvíárjökull to examine close-up the glacier ice and entrained debris (Figure 6). The field trek ending by examining impressive fault scarps and kettle holes in the dead ice zone of the glacier. That evening, **Andy Russell** treated the group to a video of the 1996 Skeiðarárjökull jökulhlaups.



Figure 6. The working group walks onto Kvíárjökull to examine debris entrainment in the ice and get a view of some fine kame terraces.

Dave Evans led a wonderful trek around the forefield of Skálafellsjökull on the sixth field day. One of the highlights of the day was examining the glacially polished bedrock with superb examples of Nye channels, P-forms, roches moutonnées, and crag and tails. The walk out provided superb views of the Kolgríma River and sandur (Figure 7).

The last field day, September 7th came all too quickly. **Dave Evans** promised to show excellent examples of flutes in front of Heinabergsjökull. The participants were not disappointed (Figure 8). Impressive landforms created by jökulhlaup-related infilling of huge tunnels and re-entrants were then visited on the lower foreland, followed by the examination of ice-dammed lake features and an associated iceberg-pitted sandur later in the day at Heinabergsjökull; this included multiple shorelines, deltas and push moraines developed on the ice-contact face of an outwash head.

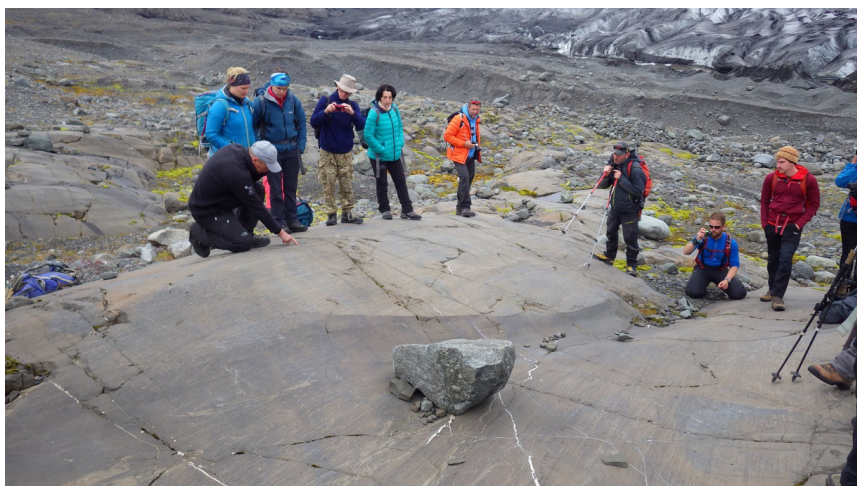


Figure 7. Glacially polished bedrock and P forms in front of Skálafellsjökull, presented by Dave Evans and Dave Roberts.



Figure 8. Mihaela Newton next to an exceptionally well-developed flute at Heinabergsjökull.

The following day, September 8th, the participants reluctantly drove back to Keflavik International Airport to get their flights home.

The whole field meeting was superb. The logistics were incredibly well organized and the science was extremely interesting and informative. There was a profound sense of collegiality amongst the group, and most notably was a healthy balance of scientists at different levels in their careers. Everyone appreciated having ample time to examining the landforms and sediments, and it was a delight to have long walks around the glacier forelands. All the participants were extremely grateful for the huge amount of work that the organizers put into the meeting, which made it an unprecedented success. We all look forward to the next meeting at Vatnajökull, which hopefully will be sooner than 2068!

Reference

Evans, D.J.A. (Ed) (2018). *Glacial landystems of Southeast Iceland: Quaternary Applications – Field Guide*. Quaternary Research Association, London, 311 pp.

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ABSTRACTS

HOLOCENE ENVIRONMENTAL CHANGE AND EARLY HUMAN IMPACT IN THE MIDDLE ATLAS MOUNTAINS, MOROCCO: A PALAEOECOLOGICAL INVESTIGATION

In semi-arid regions such as the Mediterranean, which are subject to rising temperatures and increased drought as a result of future global climate change, we need to develop our understanding of environmental responses to past climatic shifts. Mountainous regions are considered one of the most fragile environments across the globe, and are suffering from increased pressures from both climatic changes and anthropogenic activity. The biological and bioclimatic diversity of the Middle Atlas Mountains provides a crucial case study for semi-arid ecosystems, and the use of palaeoecology in this region will provide key insights into past vegetation dynamics under a range of boundary conditions.

Pioneering work in understanding Holocene environmental change in the Middle Atlas was conducted over 20 years ago, and the pace of work in the region is now accelerating. However, to date, few high-resolution, full-Holocene records from this region exist. After conducting an investigation into the comparability of vegetation records produced using the traditional method of pollen preparation (with hydrofluoric acid) and those produced using the dense-media separation method, this study presents three records from the Middle Atlas Mountains: two full-Holocene records from a lacustrine environment and a semi-terrestrial bog, and a late Holocene record from a second semi-terrestrial bog.

This study provides valuable insights into the long-term climatic trend over the Holocene, and the shift from dry, oceanic conditions with high seasonality in the early Holocene, towards more moist, continental conditions with lower seasonality in the late Holocene. The nature of the spread of *Cedrus* across the Middle Atlas during the Holocene is discussed in detail, indicating that altitude and geographical location were key controlling factors. This study also provides the first evidence of the 8.2 ka event in Morocco, as well as warming and cooling associated with the Medieval Climate Anomaly and the Little Ice Age, respectively, in the late Holocene. The first high-resolution, contiguous microcharcoal record from the Middle Atlas is presented here, highlighting Holocene fire regime changes and correlating key fire episodes with North Atlantic Bond Events. Finally, the study provides detailed insights into the nature and timing of anthropogenic activity in the region, with two clear phases of activity: low-level activity from c. 4500 years ago onwards, and much more intense activity over the last 1000 years.

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ADVANCING THE APPLICATION OF ANALYTICAL TECHNIQUES IN THE BIOLOGICAL CHEMISTRY OF SPOROPOLLENIN: TOWARDS NOVEL PLANT PHYSIOLOGICAL TRACERS IN QUATERNARY PALYNOLOGY

Palynology, the study of organic microfossils, is an important tool for improving our understanding of past environments and landscapes. Palynology provides a wealth of information from which climatic and environmental conditions can be inferred. However, inferred climatic and environmental conditions are often open to interpretation. Assumptions made about past climate conditions from pollen assemblages often rely on qualitative understanding of modern-day vegetation distributions, rather than empirical relationships. Historic anthropogenic impact on the environment must also be inferred, and assessments made as to whether vegetation changes are a result of climate change or human impact. This study seeks to address some of the questions that arise through the interpretation of pollen assemblages, by establishing empirical relationships between the geochemistry of modern pollen and climate or environmental controls. It focuses on the pollen of the climatically sensitive montane conifer *Cedrus atlantica*, which is distributed across the mountains of Morocco and Algeria.

The study investigates aspects of modern pollen geochemistry and morphology and finds a strong relationship between the stable carbon isotope composition of modern pollen and mean annual precipitation ($r^2 = 0.54$, $p < 0.001$) and summer precipitation ($r^2 = 0.63$, $p < 0.0001$). Furthermore, a stronger relationship exists with aridity measured using the self-calibrating Palmer Drought Severity Index ($r^2 = 0.86$, $p < 0.0001$), suggesting that the stable carbon isotope composition of *Cedrus atlantica* pollen is influenced by environmental moisture availability. The study also finds there is an increased abundance of ultraviolet absorbing compounds (UACs) in modern *Cedrus atlantica* pollen with increasing summer UV-B flux. This relationship was evident with samples growing in their native range ($r^2 = 0.84$, $p < 0.0001$), but not with samples from outside this range ($r^2 = 0.00$, $p = 0.99$), suggesting a possible genetic influence. Lastly, the study finds that grain size of *Cedrus atlantica* pollen is highly variable within and between samples, and we rule out climatic control on pollen grain size. These results suggest that quantitative relationships can be established between the geochemistry of *Cedrus atlantica* pollen and environmental and climatic influences. Stable carbon isotope analysis of fossil pollen could be used as a proxy for reconstruction of summer moisture availability, while analysis of UACs in fossil pollen could be used as a proxy for the reconstruction of summer UV-B flux. These proxies will enhance our understanding of climatic and environmental change in Northwest Africa and will complement existing palynological techniques for environmental and climate reconstruction.

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QUATERNARY RESEARCH ASSOCIATION

The Quaternary Research Association is an organisation comprising archaeologists, botanists, civil engineers, geographers, geologists, soil scientists, zoologists and others interested in research into the problems of the Quaternary. The majority of members reside in Great Britain, but membership also extends to most European countries, North America, Africa, Asia and Australasia. Membership (currently c. 1,200) is open to all interested in the objectives of the Association. The annual subscription is £20 with reduced rates (£10) for students and unwaged members and an Institutional rate of £35.

The main meetings of the Association are the Field Meetings, usually lasting 3–4 days, in April, May and/or September, a 2–3 day Discussion Meeting at the beginning of January. Short Study Courses on techniques used in Quaternary work are also occasionally held. The publications of the Association are the *Quaternary Newsletter* issued in February, June and October; the *Journal of Quaternary Science* published in association with Wiley; and the QRA Field Guide and Technical Guide Series.

The Association is run by an Executive Committee elected at an Annual General Meeting held during the Annual Discussion Meeting in January. Current officers of the Association are:

President: *Professor Neil F. Glasser*, Professor Neil F. Glasser
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All questions regarding membership are dealt with by the **Secretary**, the Association's publications are sold by the **Publications Secretary** and all subscription matters are dealt with by the **Treasurer**.

The QRA home page on the world wide web can be found at: <http://www.qra.org.uk>

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