Scottish Landform Example: isolation basins of Arisaig

Louise Best[a]* and Ian Shennan[b]

[a]School of Education and Science, University of Gloucestershire, Cheltenham, United Kingdom; [b]Department of Geography, Durham University, Durham, United Kingdom

Corresponding author* lbest1@glos.ac.uk

Louise Best ORCiD: 0000-0003-3731-054X

Ian Shennan ORCiD: 0000-0003-3598-0224

Word count: 7704

Scottish Landform Example: isolation basins of Arisaig

Abstract

An isolation basin is a geomorphological landform that enables the precise reconstruction of the former height and age of relative sea level. A series of isolation basins at different elevations within a small geographical area can provide a high-resolution record of the timing and magnitude of relative sea-level change. Arisaig, on the west coast of Scotland, provides the longest post- Last Glacial Maximum record of relative sea-level change in the UK, produced from the analysis of a series of 16 isolation basins. The records produced from these basins continue to provide important constraints that inform understanding of processes acting from local to global scales, such as glacial and climatic transitions, glacio-isostatic adjustment and global meltwater pulses.

Keywords: sea level; isolation basin; glacio-isostatic adjustment; NW Scotland

Introduction

Isolation basins are landforms in ice-scoured areas of Scotland that have experienced significant glacio-isostatic uplift following the Last Glacial Maximum (LGM). They are rock basins that at one time were below sea level and have been raised above, therefore isolating them from the sea. Sediments accumulating in the basin record the change from marine to freshwater conditions. Over time, a basin may have remained a loch or been completely infilled with sediments. Depending on the balance between the controls on relative sea level (RSL), primarily the rates of glacio-isostatic uplift and global sea-level rise, they can also record a rise in relative sea level with a return to marine conditions. It is common usage to use the same term, isolation basin, for those that also record a period of ingression.

The most complete record of RSL comes from Arisaig on the west coast of Scotland (Figure 1 and Figure 2), a location beyond the limits of the Loch Lomond Stadial (Younger Dryas) glaciers (Figure 1), and where a sequence of 16 basins forms a staircase that traces RSL from the Dimlington Stadial through the Late Glacial Interstadial, the Loch Lomond Stadial and the Holocene. This is one of longest, near-continuous records on Earth of post-LGM RSL change and the longest in the UK.

[Figure 1 near here]

[Figure 2 near here]

Overview of Isolation Basins

An isolation basin is characterised by a closed bedrock depression. In the contemporary landscape, basins appear as either a loch or a relatively flat area, typically within a topographic hollow, including the classic cnoc-and-lochan landscape of West Scotland (Figure 2), but also in areas of greater relief, including deeply incised glaciated valleys. Isolation basins are enclosed by a topographic sill; the minimum height of this sill is the threshold for the sea to flood or isolate the basin (Figure 3). The sill may either be exposed in a stream bed or covered by surficial sediment, primarily peat (e.g. Shennan et al., 1993; Shennan et al., 1994).

[Figure 3 near here]

Isolation basins can provide precise indicators of RSL change. The methodology of using isolation basins to provide age and elevation constraints of RSL were first widely developed in Scandinavia. The review by Hafsten (1983) summarises the progress of the methods, evolving from the earliest studies made well before the development of radiocarbon dating. With continual development of methods for both dating the sediments and reconstructing the changes in salinity status of the water in the basin as the sediment accumulated, isolation basin approaches became widely adopted around the world to provide records of RSL change. Examples beyond Scandinavia include Canada (Hutchinson et al., 2004), Chile (Björck et al., 2021), Greenland (Long et al., 1999), Iceland (Brader et al., 2017), New Zealand (Dlabola et al., 2015), and Antarctica (Bentley et al., 2005), as well as the UK (Figure 1).

In addition to the studies around Arisaig, isolation basins provide constraints on RSL reconstructions at numerous locations across Scotland (Figure 1): including Northton, Outer Hebrides (Jordan et al., 2010), Skye (Best et al., 2022; Birks, 1973; Selby & Smith, 2016), Loch Duart, Assynt (Hamilton et al., 2015), Dubh Lochan, Coigach (Shennan et al., 2000), Gairloch (Simms et al., 2022), Fearnbeg, Applecross (Shennan, Rutherford, et al., 1996), Loch nan Corr, Kintail (Lloyd, 2000), Ardtoe, Moidart (Shennan, Green, et al., 1996) and Knapdale (Birks, 1993; Shennan et al., 2006). The concentration of isolation basin studies in western Scotland reflects the relief and cnoc-and-lochan landscape, and absence of large tidal inlets with extensive marshes traditionally used to reconstruct RSL. Most of the isolation basins studied in Scotland have spatial dimensions in the order of tens to hundreds of meters. Loch Lomond and Loch Shiel are examples of very large, multi-kilometre scale isolation basins. Both of these were glaciated during the Loch Lomond Stadial, and provide evidence of Holocene RSL changes (Dickson et al., 1978; Thompson & Wain-Hobson, 1979).

Basins that have experienced a RSL fall, and isolation, record a typical stratigraphic sequence of marine to brackish sediments, overlain by freshwater lake sediments as the basin threshold is raised above the mean high water spring (MHWS) tide level and then extreme high tide (Figure 3). Many basins subsequently completely infill under lacustrine conditions, followed by peat formation. In some basins, reconnection to the sea, caused by RSL rise, sees a return to brackish and marine conditions, followed by a second isolation. Since most isolation basins record a single isolation event, we require several basins within close proximity in order to reconstruct RSL change over time (Figure 4). The RSL record that can be reconstructed from a location is therefore limited by the presence and altitudinal range of isolation basins. In locations where RSL fell below contemporary sea level, any basins that record the RSL low point are currently submerged, making them challenging to use to accurately detect the RSL low stand.

[Figure 4 near here]

An isolation, and similarly an ingression, takes several forms within a stratigraphic sequence due to the sedimentary and hydrological controls within the system. The biostratigraphy, typically diatoms and foraminifera, are commonly used to identify the phases from marine to freshwater conditions during isolation from the sea. Depending on numerous factors, including the rate of RSL change, rate of sedimentation and tidal range, the change in a sediment core may occur in <1cm or across 10s of cm. Tidal range is important as it affects the duration of the period of variable, brackish, salinity between the fully marine stage, when the basin is connected to the sea at all stages of the tide, i.e. the sill is below all low tides; and the fully freshwater stage, when the sill is above extreme high tides (Lloyd, 2000; Shennan, Green, et al., 1996). With the more gradual transitions it may be possible to identify different contacts in the isolation process. Kjemperud (1981, 1986) identifies the hydrological isolation contact, representing the ceasing of marine ingress into a basin, and typically coincides with the diatomological isolation contact, the former sediment-water interface at which the photic zone became fresh, and is denoted by the shift to freshwater diatom species. The sedimentological isolation contact is the change from predominantly allochthonous minerogenic sediments, and typically occurs before the hydrological and diatomological isolation contacts (Kjemperud, 1981, 1986). In addition to microfossil evidence, other proxies used to differentiate between marine and freshwater sediments include biomarkers, carbon isotopes, osmium isotopes and C/N ratios (Bendle et al., 2009; Mackie et al., 2005; Mackie et al., 2007; Taylor et al., 2023).

Whichever approach is taken, to provide a precise indicator of former RSL and the direction of change we require the age of the contact, the estimate of the position of the sill with respect to the contemporaneous tidal range, and the height of the threshold sill of the rock basin. Radiocarbon dating provides the age estimate for all basins described below. The calibrated ages in Table 1 derive from IntCal20 (Reimer et al., 2020), and differ from those in the original publications, reflecting updates to the calibration procedures. Where possible, AMS dating of herbaceous macrofossils rather than bulk sediment samples aims to minimise the potential influence of hardwater error. Some the earliest studied basins were therefore redated (Shennan et al., 2000). Recent tephrostratigraphic studies demonstrate a method to test the radiocarbon based RSL chronology. At the single site studied from the Arisaig sequence, the tephra evidence (Weston et al., 2021) conform with the age of the RSL sample.

[Table 1 near here]

Proxy evidence, in particular diatom, charophyte and foraminiferal assemblages, along with sediment lithology help to define the indicative meaning of each dated sample. Indicative meaning is the term used in sea-level reconstructions, applicable to all types of sedimentary environments, not just isolation basins, to define the relationship between the sample and the contemporaneous tidal range (Shennan, 2015). It comprises two values, the Reference Water Level (e.g. Mean High Water Spring Tides) and the Indicative Range, an estimate of the 95% uncertainty. For contemporaneous tidal range we use the values for the nearby tidal station, Mallaig, where Mean High Water Spring Tides is 2.38m OD, Mean High Water Neap Tides is 1.18m OD and Mean Sea Level is 0.28m OD (Admiralty Tide Tables, 2006). Modelling studies indicate changes in tidal range through time, with MWHST around Arisaig more than 4m above MTL at 16ka, reducing to approximately the current value by 8ka (Ward et al., 2016).

The height of the threshold sill of basin is first identified, sometimes visible in the base of the outflow stream, and where buried by peat, estimated by making a 3D reconstruction of the surface beneath the peat using a 1x1 m grid of boreholes. Once identified, the sill is instrumentally levelled to OD. Finally, RSL is calculated as the sill elevation (m OD) minus the value of Reference Water Level of the indicative meaning. The predicted changes in tidal range (Ward et al., 2016) are not included in the values for RSL in Table 1 but could be added at any stage in an analysis.

Isolation Basins of Arisaig

Marine sediments near Loch nan Eala were initially described by Mapleton (1868) as part of an archaeological reconnaissance, and subsequently investigated as an isolation basin by Shennan et al. (1994) alongside other locations around Arisaig (Figure 5). As a result of these investigations, Arisaig has a 16,000 year long, high resolution record of RSL change, reconstructed from isolation basins in the area (Figure 5) (Shennan et al., 2006; Shennan et al., 2005; Shennan et al., 1993; Shennan et al., 1994; Shennan et al., 2000; Shennan, Rutherford, et al., 1996; Shennan et al., 1999).

[Figure 5 near here]

These series of basins provide a staircase of constraints that trace RSL from the Dimilington Stadial through to the Holocene, spanning an elevation range between 37 m OD to 4.8 m OD, equivalent of an overall RSL fall from ~35m to present day (Table 1). The basins between 37 m OD to 9 m OD record RSL fall, whereas the lowest basins between 6.4 and 4.8 m OD record a subsequent RSL rise and fall during the Holocene.

Each of the basins above 9m OD, whether a lake is present today or not, shows the following typical lithostratigraphy:

Unit 5: Surface peat or open water

Unit 4: Organic limnic mud (often called gyttja or limus)

Unit 3: Minerogenic horizon

Unit 2: Organic limnic mud (often called gyttja or limus)

Unit 1: Minerogenic horizon

Microfossil analyses (diatoms, foraminifera, charophytes) at each site show whether the boundary between units 1 and 2 represents the isolation of the basin from the sea or indicates that the basin was above the marine limit. Unit 3 represents sedimentation in freshwater during the Loch Lomond Stadial (Shennan et al., 1993; Shennan et al., 2000).

The lowest basin with freshwater conditions in Unit 1, Coire Camas Drollaman III, sill at 38.4m OD (Figure 2A), and the highest basin with marine/brackish indicators in Unit 1, Upper Loch Dubh, sill at 36.5m OD (Table 1), constrain the elevation and age, c. 16 ka BP, of the local marine limit. Just to the north of Arisaig, at Mointeach Mhor (Figure 5), raised beach landforms at 41 m and 20 m OD mark the fall in the marine limit as ice retreated during the Dimlington Stadial and Late Glacial Interstadial (Peacock, 1970).

Loch Camas Drollaman (Figure 2A) is a typical example of an Arisaig isolation basin that records a fall in relative sea level. The litho- and biostratigraphic sequence follows that anticipated by the conceptual model in Figure 3. Diatom analyses of a core illustrate the evidence used to establish the isolation of a basin (Figure 6). In this example 57 species of diatoms were identified, and more than 250 individuals counted in each sample. Most published papers use summaries of the microfossil data, illustrated here by showing the most abundant species, those reaching >5% in at least one sample, and a summary classification based on salinity preference of the total counts in each sample. Both the individual species and the summary groupings illustrate the isolation of the basin across 3 or 4cm at the transition from

Unit 1, clay-silt in this core, to Unit 2, silty organic limnic mud, dated to c. 15.9 ka BP (Figure 6; Table 1).

[Figure 6 near here]

As relative sea level fell, each basin was isolated in turn, the highest first, when high tides no longer crossed the sill of the basin. The close proximity of the basins give a staircase constraint that coupled with biostratigraphic and chronstratigraphic data record RSL fall c. 16 to 13 ka BP, from Upper Loch Dubh, at 36.5m OD, to Rumach Iochdar, at 9.3m OD (Table 1).

Unlike the higher basins, the three lowest basins, Rumach VI, 4.8m OD, Loch nan Eala main, 5.2m OD, and Loch nan Eala upper, 6.3m OD, (Figure 5, Table 1) each have a second marine minerogenic unit. They record, first a late glacial relative fall of sea level, subsequent reconnection to the sea during the early Holocene, followed by another, final isolation, as shown in the schematic model in Figure 4. The isolations and ingression of each basin have offsets in ages in line with their different sill elevations.

Rumach VI (Figure 7) is the lowest basin of the Rumach staircase of five linked basins and the lowest in the Arisaig record (Table 1). Multiple cores reveal the typical bedrock depression morphology, with a distinct rock sill at 4.8 m OD extending 200m to the west before it descends to contemporary mean high water of spring tides at the coast. The outflow stream reaches the coast at a tidal pond with an intertidal sill, creating a modern analogue for isolation basins (Figure 7C). Bendle et al., (2009) record the sill height of the tidal pond as 0.27 m OD and salinity 7 to 33 psu, depending on the spring-neap tidal cycle and freshwater input from the catchment.

[Figure 7 near here]

Figure 8A shows the sequence from a core towards the edge of the Rumach VI basin. In contrast to the initial isolation, c. 12.1 ka BP, which occurs across a few centimetres of sediment in the core, both the Holocene ingression, c. 9.8 ka BP, and the final isolation are more gradual. A core from the centre of the basin, Figure 8B, records the final isolation of the basin in most detail (Shennan et al., 1999). The isolation process extends across more than 2m of sediment, with the change from fully marine diatom assemblages c. 5.5.ka BP to fully freshwater assemblages by c. 2.8 ka BP, and exemplifies how the different types of isolation contacts identified by Kjemperud (1981, 1986) may not coincide. This extended isolation reflects the much-reduced rate of isostatic uplift during the middle- and late Holocene compared to the Late Glacial Interstadial.

[Figure 8 near here]

Relative Sea-Level Changes and Wider Implications

While the primary focus of research has been on RSL changes, the litho- and biostratigraphy within isolation basins can also provide insights of other environmental changes during the glacial to interglacial transition. For example, dated pollen records from Rumach Iochdar and Rumach Meadhonach (Figure 5) correlate well with the established regional pollen stratigraphy associated with the climatic transitions through the Late Glacial Interstadial, Loch Lomond Stadial, and into the Holocene (Shennan et al., 1993), and analysis of temperature sensitive dinoflagellate cysts suggest movement in the oceanic Polar Front and corresponding change in the North Atlantic Current within the Late Glacial Interstadial (Shennan, Rutherford, et al., 1996). These broader environmental changes fit alongside the near continuous high-resolution record of RSL from the latter stages of the Dimlington Stadial and through the Holocene, from c. 16.0 ka BP to c. 2.8 ka BP (Figure 9).

The highest basins around Arisaig, above 38 m OD, record only a freshwater sequence and in a sea-level context are therefore terrestrial limiting points that help constrain the marine limit.

But in the broader environmental change their radiocarbon ages, at the onset of organic deposition, provide minimum ages for deglaciation, c. 16.1 ka BP at Coire Camas Drollaman III. The two highest basins with basal marine sediments record RSL fall from c. 16.0 ka BP (Figure 9 and Table 1). These ages fit well with those for the optimum ice limits reconstructed by the BRITICE-CHRONO Project, that estimated the coast at Arisaig becoming ice free between 17 and 15 ka BP (C. D. Clark et al., 2022).

All the basins between 37 m OD and 9 m OD record one episode of RSL fall, whereas the lowest basins, 6.4-4.8 m, OD also record a subsequent Holocene RSL rise and fall. The phase of RSL fall c. 16 ka to c. 12 ka BP reflects the considerable rate of glacio-isostatic uplift that occurred in the area during and immediately after deglaciation, outpacing the rate of global sea-level rise. As well as vertical displacement of the Earth's surface, RSL change recorded in coastal sediments and landforms also includes gravitational and rotational effects on the oceanic geoid (Lambeck, 1993; Peltier, 1998, 2002, 2004). For simplicity we use the term glacio-isostatic uplift to describe the net effect of all these three.

A RSL minimum is constrained by the fall below the sill at Rumach VI, 4.8m OD, at c. 12.1 ka BP and subsequent rise above the same threshold at c. 9.8 ka BP (Figure 9). The three lowest basins record RSL rise during the early Holocene to a mid-Holocene sea-level highstand. They do not provide a precise constraint on the maximum elevation of the highstand, only that RSL was higher than the sill of Loch nan Eala upper basin, 6.3 m OD. The highstand maximum is better recorded by paleo-salt marsh sediments, below peat and resting on solid rock, at Mointeach Mhor (Figure 5), with a maximum elevation of intertidal minerogenic sedimentation at 9.62m OD, indicating RSL 6.7 ± 0.2m c.7.6 to 7.4 ka BP (Shennan et al., 2005). The three lowest basins and other raised marsh sequences at Mointeach Mhor record the RSL fall to present (Figure 9B).

[Figure 9 near here]

The Holocene rise, highstand, and fall in RSL reflects the complex interplay of GIA and global sea level processes acting at varying spatial scales. By the early Holocene, the rate of global sea-level rise outpaced the rate of glacio-isostatic uplift in Arisaig, resulting in the RSL rise and highstand. As the rate of global sea-level rise slowed following the final deglaciation of the Laurentide ice sheet, glacio-isostatic uplift, albeit at a slower rate than the initial GIA uplift witnessed in the late Dimlington Stadial and Late Glacial Interstadial, once again outpaced the rate of global sea-level rise, leading to the RSL fall to present. A continuous GPS station at Arisaig harbour, operational since 2009, records ongoing vertical and horizontal land motions.

As one of longest, near-continuous records on Earth of post-LGM RSL change the Arisaig data help constrain and validate global GIA models. While small in global terms the icesheet across Scotland was sufficiently large for GIA processes to produce vastly contrasting RSL changes at different locations around the coastline of Scotland, ranging from net emergence since deglaciation, like et Arisaig, in areas beneath the thickest ice, to net submergence in more peripheral areas (Shennan et al., 2018). Explanation of this range requires understanding and modelling of both Earth rheology and global meltwater influx, usually expressed as eustatic or ice-equivalent sea level. The glacial isostatic component of RSL change in the region is extremely sensitive to the model parameters for shallow Earth structure, especially lithospheric thickness and the viscosity of the upper mantle (Bradley et al., 2011; Lambeck et al., 1996; Peltier, 2002; Shennan et al., 2000). In contrast, predicted RSL changes for regions beneath much larger ice sheets, Scandinavia and North America, show greater sensitivity to deeper Earth structure (Lambeck, 1993; Lambeck et al., 1996; Peltier, 1998, 2004). These studies led to important modifications to global GIA models (Peltier, 2004; Peltier et al., 2002) and their adoption in a range of geological, geophysical and geodetic applications (e.g. Tamisiea (2011)).

Currently, no single GIA model provides a solution that fits with all locations around Scotland (Shennan et al., 2018), and at Arisaig, GIA model predictions differ from the isolation basin constraints (Figure 9B) in two key periods, first, an apparent meltwater pulse 1A (MWP1a) signal at c. 14.5 ka BP, and second, the early Holocene RSL rise (Figure 9B).

There is significant discourse over the source and magnitude of MWP1a, the most rapid global sea-level rise event of the last deglaciation. A reduction in the rate of RSL fall or the presence of an RSL oscillation predicted at Arisaig at the time of MWP1a differs depending on the GIA model (Figure 9B). Continuous RSL fall, though at a reduced rate, across the time of MWP1a indicates that the acceleration of global meltwater discharge was insufficient to outpace glacio-isostatic uplift (including the gravitational and rotational effects on the oceanic geoid), and therefore provides a maximum constraint on the magnitude of MWP1a. Conversely, evidence of an oscillation in RSL indicates the acceleration of global meltwater discharge was large enough to outpace glacio-isostatic uplift and provides a minimum estimate of the magnitude of MWP1a. Constraints from two or more basins may constrain the magnitude of the RSL oscillation and a more precise constraint on MWP1a.

Three of the models of RSL at Arisaig (Figure 9B) illustrated share a global ice model that has a predominant MWP1a source of Antarctica (Bassett et al., 2005; Bradley et al., 2016). At Arisaig, all of the basins across the time of MWP1a record RSL fall. There is no stratigraphic evidence at Arisaig, or at other locations in NW Scotland, to support the oscillation predicted by the three GIA models. This evidence of RSL fall from the isolation basins has been crucial in testing the possible contributions of ice sources on a global scale. Following the principles of sea-level fingerprinting (P. U. Clark et al., 2002; Lin et al., 2021; Mitrovica et al., 2001), the Arisaig and northwestern Scotland isolation basin RSL records would refute an Antarctic dominant source of MWP1a and are more consistent with GIA models with a MWP1a source dominated by a North American contribution as well as a substantial Fennoscandiavian contribution (Lin et al., 2021).

The early Holocene misfits between GIA model predictions and the RSL evidence are not unique to the Arisaig record and are found for many other locations around the coasts of Britain and Ireland (Shennan et al., 2018). Explanation of the misfits remains a challenge for future research. Plausible factors for consideration include improved local-scale paleotidal modelling, choice of regional-scale GIA model parameters, such as the ice sheet history of the BIIS, and at a global scale, the model representation of the final deglaciation of the Laurentide ice sheet and the continued melting of Antarctica (Shennan et al., 2018).

The constraints from isolation basins therefore contribute not only to the refinement of local ice and GIA models, but also for global sea level.

Conclusion

The concentration of isolation basins around Arisaig provides a remarkable record of environmental and RSL change that continues to contribute to the understanding of processes acting at both local and global scales. The records not only provide crucial constraints on the rate and magnitude of RSL change, but also provide minimum ages for deglaciation, insights into climatic transitions, as well as critical tests for GIA model predictions and important data to inform their refinement. Ongoing developments in chronological and proxy techniques continue to refine and expand the records produced from isolation basins. The interplay of processes that contributed to the development of the records at Arisaig make the area of interest to geomorphologists, sea level scientists and glaciologists alike.

Whilst Arisaig currently provides the longest RSL record, the geomorphological conditions are not unique and there are many other isolation basins in western Scotland, and many more to be discovered, with great potential for enhancing our understanding of environmental and RSL changes.

Access Information

The easiest place to view a selection of the basins is from the roadside at the end of the Rumach peninsula (Figure 10), ~4.5km along the road to Rhu southwest out of Arisaig. There are two potential places for parking, as shown in Figure 10 (grid reference/coordinates: NM 62915 85400 / 56° 53' 54.1"N 05° 52' 45.5"W, and NM 63862 85260 / 56° 53' 54.1"N 05° 52' 45.5"W). Passing places along the singletrack road should not be used for parking. Summary details and corresponding reference(s) for each basin are in Table 1. The western carpark directly overlooks a tidal pond that is a modern analogue of an isolation basin.

[Figure 10 near here]

Acknowledgements

James Colston, Arisaig Estate, for logistical support over many years.

Disclosure Statement

The authors report no potential conflict of interest.

Funding

Funding information are detailed in the respective original research articles cited in Table 1.

References

Admiralty Tide Tables. (2006). *Admiralty Tide Tables, 2006, Volume 1, United Kingdom and Ireland including European Channel Ports*. United Kingdom Hydrographic Office.

Bassett, S., Milne, G., Mitrovica, J., & Clark, P. (2005). Ice Sheet and Solid Earth Influences on Far-Field Sea-Level Histories. *Science (New York, N.Y.)*, *309*, 925-928. https://doi.org/10.1126/science.1111575

Bendle, J. A. P., Rosell-Melé, A., Cox, N. J., & Shennan, I. (2009). Alkenones, alkenoates, and organic matter in coastal environments of NW Scotland: Assessment of potential application for sea level reconstruction. *Geochemistry, Geophysics, Geosystems*, *10*(12). https://doi.org/https://doi.org/10.1029/2009GC002603

Bentley, M. J., Hodgson, D. A., Smith, J. A., & Cox, N. J. (2005). Relative sea level curves for the South Shetland Islands and Marguerite Bay, Antarctic Peninsula. *Quaternary Science Reviews*, *24*(10), 1203-1216. https://doi.org/https://doi.org/10.1016/j.quascirev.2004.10.004

Best, L., Simms, A. R., Brader, M., Lloyd, J., Sefton, J., & Shennan, I. (2022). Local and regional constraints on relative sea-level changes in southern Isle of Skye, Scotland, since the Last Glacial Maximum. *Journal of Quaternary Science*, *37*(1), 59-70. https://doi.org/https://doi.org/10.1002/jqs.3376

Bickerdike, H. L., Evans, D. J. A., Ó Cofaigh, C., & Stokes, C. R. (2016). The glacial geomorphology of the Loch Lomond Stadial in Britain: a map and geographic information system resource of published evidence. *Journal of Maps*, *12*(5), 1178-1186. https://doi.org/10.1080/17445647.2016.1145149

Bickerdike, H. L., Evans, D. J. A., Stokes, C. R., & Ó Cofaigh, C. (2018). The glacial geomorphology of the Loch Lomond (Younger Dryas) Stadial in Britain: a review. *Journal of Quaternary Science*, *33*(1), 1-54. https://doi.org/https://doi.org/10.1002/jqs.3010

Birks, H. J. B. (1973). *Past and present vegetation of the Isle of Skye: a palaeoecological study*. Cambridge University Press.

Birks, H. J. B. (1993). *Loch Cill an Aonghais*. Chapman and Hall.

Björck, S., Lambeck, K., Möller, P., Waldmann, N., Bennike, O., Jiang, H., Li, D., Sandgren, P., Nielsen, A. B., & Porter, C. T. (2021). Relative sea level changes and glacio-isostatic modelling in the Beagle Channel, Tierra del Fuego, Chile: Glacial and tectonic implications. *Quaternary Science Reviews*, *251*, 106657. https://doi.org/https://doi.org/10.1016/j.quascirev.2020.106657

Brader, M. D., Lloyd, J. M., Barlow, N. L. M., Norðdahl, H., Bentley, M. J., & Newton, A. J. (2017). Postglacial relative sea-level changes in northwest Iceland: Evidence from isolation basins, coastal lowlands and raised shorelines. *Quaternary Science Reviews*, *169*, 114-130. https://doi.org/https://doi.org/10.1016/j.quascirev.2017.05.022

Bradley, S. L., Milne, G. A., Horton, B. P., & Zong, Y. (2016). Modelling sea level data from China and Malay-Thailand to estimate Holocene ice-volume equivalent sea level change. *Quaternary Science Reviews*, *137*, 54-68. https://doi.org/https://doi.org/10.1016/j.quascirev.2016.02.002

Bradley, S. L., Milne, G. A., Shennan, I., & Edwards, R. (2011). An improved glacial isostatic adjustment model for the British Isles. *Journal of Quaternary Science*, *26*(5), 541-552. https://doi.org/https://doi.org/10.1002/jqs.1481

Clark, C. D., Ely, J. C., Hindmarsh, R. C. A., Bradley, S., Ignéczi, A., Fabel, D., Ó Cofaigh, C., Chiverrell, R. C., Scourse, J., Benetti, S., Bradwell, T., Evans, D. J. A., Roberts, D. H., Burke, M., Callard, S. L., Medialdea, A., Saher, M., Small, D., Smedley, R. K., Gasson, E., Gregoire, L., Gandy, N., Hughes, A. L. C., Ballantyne, C., Bateman, M. D., Bigg, G. R., Doole, J., Dove, D., Duller, G. A. T., Jenkins, G. T. H., Livingstone, S. L., McCarron, S., Moreton, S., Pollard, D., Praeg, D., Sejrup,

H. P., Van Landeghem, K. J. J., & Wilson, P. (2022). Growth and retreat of the last British–Irish Ice Sheet, 31 000 to 15 000 years ago: the BRITICE-CHRONO reconstruction. *Boreas*, *51*(4), 699-758. https://doi.org/https://doi.org/10.1111/bor.12594
Clark, P. U., Mitrovica, J. X., Milne, G. A., & Tamisiea, M. E. (2002). Sea-Level Fingerprinting as a Direct Test for the Source of Global Meltwater Pulse IA. *Science*, *295*(5564), 2438-2441. https://doi.org/doi:10.1126/science.1068797
Dickson, J. H., Stewart, D. A., Thompson, R., Turner, G., Baxter, M. S., Drndarsky, N. D., & Rose, J. (1978). Palynology, palaeomagnetism and radiometric dating of Flandrian marine and freshwater sediments of Loch Lomond. *Nature*, *274*(5671), 548-553. https://doi.org/10.1038/274548a0
Dlabola, E. K., Wilson, G. S., Gorman, A. R., Riesselman, C. R., & Moy, C. M. (2015). A post-glacial relative sea-level curve from Fiordland, New Zealand. *Global and Planetary Change*, *131*, 104-114. https://doi.org/https://doi.org/10.1016/j.gloplacha.2015.05.010
Hafsten, U. L. F. (1983). Shore-level changes in South Norway during the last 13,000 years, traced by biostratigraphical methods and radiometric datings. *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography*, *37*(2), 63-79. https://doi.org/10.1080/00291958308552089
Hamilton, C. A., Lloyd, J. M., Barlow, N. L., Innes, J. B., Flecker, R., & Thomas, C. P. (2015). Late Glacial to Holocene relative sea-level change in Assynt, northwest Scotland, UK. *Quaternary Research*, *84*(2), 214-222.
Hutchinson, I., James, T., Reimer, P., Bornhold, B., & Clague, J. (2004). Marine and limnic radiocarbon reservoir corrections for studies of late- and postglacial environments in Georgia Basin and Puget Lowland, British Columbia, Canada and Washington, USA. *Quaternary Research*, *61*, 193-203. https://doi.org/10.1016/j.yqres.2003.10.004
Jordan, J. T., Smith, D. E., Dawson, S., & Dawson, A. G. (2010). Holocene relative sea-level changes in Harris, Outer Hebrides, Scotland, UK. *Journal of Quaternary Science*, *25*(2), 115-134. https://doi.org/https://doi.org/10.1002/jqs.1281
Kjemperud, A. (1981). Diatom changes in sediments of basins possessing marine/lacustrine transitions in Frosta, Nord-Trøndelag, Norway. *Boreas*, *10*(1), 27-38. https://doi.org/https://doi.org/10.1111/j.1502-3885.1981.tb00466.x
Kjemperud, A. (1986). Late Weichselian and Holocene shoreline displacement in the Trondheimsfjord area, central Norway. *Boreas*, *15*(1), 61-82. https://doi.org/https://doi.org/10.1111/j.1502-3885.1986.tb00744.x
Lambeck, K. (1993). Glacial rebound of the British Isles—I. Preliminary model results. *Geophysical Journal International*, *115*(3), 941-959. https://doi.org/https://doi.org/10.1111/j.1365-246X.1993.tb01503.x
Lambeck, K., Johnston, P., Smither, C., & Nakada, M. (1996). Glacial Rebound of the British Isles—Iii. Constraints On Mantle Viscosity. *Geophysical Journal International*, *125*(2), 340-354. https://doi.org/https://doi.org/10.1111/j.1365-246X.1996.tb00003.x
Lin, Y., Hibbert, F. D., Whitehouse, P. L., Woodroffe, S. A., Purcell, A., Shennan, I., & Bradley, S. L. (2021). A reconciled solution of Meltwater Pulse 1A sources using sea-level fingerprinting. *Nature Communications*, *12*(1), 2015. https://doi.org/10.1038/s41467-021-21990-y
Lloyd, J. (2000). COMBINED FORAMINIFERAL AND THECAMOEBIAN ENVIRONMENTAL RECONSTRUCTION FROM AN ISOLATION BASIN IN NW SCOTLAND: IMPLICATIONS FOR SEA-LEVEL STUDIES. *Journal of Foraminiferal Research*, *30*(4), 294-305. https://doi.org/10.2113/0300294
Long, A. J., Roberts, D. H., & Wright, M. R. (1999). Isolation basin stratigraphy and Holocene relative sea-level change on Arveprinsen Ejland, Disko Bugt, West Greenland. *Journal of Quaternary Science*, *14*(4), 323-345. https://doi.org/https://doi.org/10.1002/(SICI)1099-1417(199907)14:4<323::AID-JQS442>3.0.CO;2-0

Mackie, E. A. V., Leng, M. J., Lloyd, J. M., & Arrowsmith, C. (2005). Bulk organic δ13C and C/N ratios as palaeosalinity indicators within a Scottish isolation basin. *Journal of Quaternary Science*, *20*(4), 303-312. https://doi.org/https://doi.org/10.1002/jqs.919

Mackie, E. A. V., Lloyd, J. M., Leng, M. J., Bentley, M. J., & Arrowsmith, C. (2007). Assessment of δ13C and C/N ratios in bulk organic matter as palaeosalinity indicators in Holocene and Lateglacial isolation basin sediments, northwest Scotland. *Journal of Quaternary Science*, *22*(6), 579-591. https://doi.org/https://doi.org/10.1002/jqs.1081

Mapleton, R. (1868). Description of stockaded remains recently discovered at Arisaig, Inverness-shire, in a letter to John Stuart, Esq., Sec. SA Scot. (Ed.),^(Eds.). Proceedings of the Society of Antiquaries of Scotland.

Mitrovica, J. X., Tamisiea, M. E., Davis, J. L., & Milne, G. A. (2001). Recent mass balance of polar ice sheets inferred from patterns of global sea-level change. *Nature*, *409*(6823), 1026-1029. https://doi.org/10.1038/35059054

Peacock, J. D. (1970). Some aspects of the glacial geology of west Inverness-shire. *Bulletin of the Geological Survey of Great Britain*(33), 43-56.

Peltier, W. R. (1998). Postglacial variations in the level of the sea: Implications for climate dynamics and solid-Earth geophysics. *Reviews of Geophysics*, *36*(4), 603-689. https://doi.org/https://doi.org/10.1029/98RG02638

Peltier, W. R. (2002). Global glacial isostatic adjustment: palaeogeodetic and space-geodetic tests of the ICE-4G (VM2) model. *Journal of Quaternary Science*, *17*(5-6), 491-510. https://doi.org/https://doi.org/10.1002/jqs.713

Peltier, W. R. (2004). GLOBAL GLACIAL ISOSTASY AND THE SURFACE OF THE ICE-AGE EARTH: The ICE-5G (VM2) Model and GRACE. *Annual Review of Earth and Planetary Sciences*, *32*(1), 111-149. https://doi.org/10.1146/annurev.earth.32.082503.144359

Peltier, W. R., Shennan, I., Drummond, R., & Horton, B. (2002). On the postglacial isostatic adjustment of the British Isles and the shallow viscoelastic structure of the Earth. *Geophysical Journal International*, *148*(3), 443-475. https://doi.org/10.1046/j.1365-246x.2002.01586.x

Reimer, P. J., Austin, W. E. N., Bard, E., Bayliss, A., Blackwell, P. G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Hajdas, I., Heaton, T. J., Hogg, A. G., Hughen, K. A., Kromer, B., Manning, S. W., Muscheler, R., Palmer, J. G., Pearson, C., van der Plicht, J., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Turney, C. S. M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S. M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., & Talamo, S. (2020). The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon*, *62*(4), 725-757. https://doi.org/10.1017/RDC.2020.41

Selby, K. A., & Smith, D. E. (2016). Holocene Relative Sea-Level Change on the Isle of Skye, Inner Hebrides, Scotland. *Scottish Geographical Journal*, *132*(1), 42-65. https://doi.org/10.1080/14702541.2015.1051102

Shennan, I. (2015). Handbook of sea-level research: framing research questions. In I. Shennan, A. Long, & B. Horton (Eds.), Handbook of Sea-Level Research (pp. 3-25). John Wiley and Sons. https://doi.org/10.1002/9781118452547

Shennan, I., Bradley, S. L., & Edwards, R. (2018). Relative sea-level changes and crustal movements in Britain and Ireland since the Last Glacial Maximum. *Quaternary Science Reviews*, *188*, 143-159. https://doi.org/10.1016/j.quascirev.2018.03.031

Shennan, I., Green, F., Innes, J., Lloyd, J., Rutherford, M., & Walker, K. (1996). Evaluation of Rapid Relative Sea-Level Changes in North-West Scotland during the Last Glacial- Interglacial Transition: Evidence from Ardtoe and Other Isolation Basins. *Journal of Coastal Research*, *12*(4), 862-874. http://www.jstor.org/stable/4298536

Shennan, I., Hamilton, S., Hillier, C., Hunter, A., Woodall, R., Bradley, S., Milne, G., Brooks, A., & Bassett, S. (2006). Relative sea-level observations in western Scotland since the Last Glacial Maximum for testing models of glacial isostatic land movements and ice-sheet reconstructions. *Journal of Quaternary Science*, *21*(6), 601-613. https://doi.org/10.1002/jqs.1048

Shennan, I., Hamilton, S., Hillier, C., & Woodroffe, S. (2005). A 16000-year record of near-field relative sea-level changes, northwest Scotland, United Kingdom. *Quaternary international : the journal of the International Union for Quaternary Research.*, *133-134*, 95-106.

Shennan, I., Innes, J., Long, A., & Zong, Y. (1993). Late Devensian and Holocene relative sea-level changes at Rumach, near Arisaig, northwest Scotland. Norsk Geologisk Tidsskrift 73, 161–174.

Shennan, I., Innes, J. B., Long, A. J., & Zong, Y. (1994). Late Devensian and Holocene relative sealevel changes at Loch nan Eala, near Arisaig, northwest Scotland. *Journal of Quaternary Science*, *9*(3), 261-283. https://doi.org/https://doi.org/10.1002/jqs.3390090307

Shennan, I., Lambeck, K., Horton, B., Innes, J., Lloyd, J., McArthur, J., & Rutherford, M. (2000). Holocene isostasy and relative sea-level changes on the east coast of England. *Geological Society, London, Special Publications*, *166*(1), 275-298. https://doi.org/10.1144/GSL.SP.2000.166.01.14

Shennan, I., Rutherford, M., Innes, J., & Walker, K. (1996). Late glacial sea level and ocean margin environmental changes interpreted from biostratigraphic and Iithostratigraphic studies of isolation basins in northwest Scotland. *Geological Society, London, Special Publications*, *111*, 229-244. https://doi.org/10.1144/GSL.SP.1996.111.01.15

Shennan, I., Tooley, M., Green, F., Innes, J., Kennington, K., Lloyd, J., & Rutherford, M. (1999). Sea level, climate change and coastal evolution in Morar, northwest Scotland. *Geologie en Mijnbouw*, *77*, 247-262.

Simms, A. R., Best, L., Shennan, I., Bradley, S. L., Small, D., Bustamante, E., Lightowler, A., Osleger, D., & Sefton, J. (2022). Investigating the roles of relative sea-level change and glacio-isostatic adjustment on the retreat of a marine based ice stream in NW Scotland. *Quaternary Science Reviews*, *277*, 107366. https://doi.org/https://doi.org/10.1016/j.quascirev.2021.107366

Tamisiea, M. E. (2011). Ongoing glacial isostatic contributions to observations of sea level change. *Geophysical Journal International*, *186*(3), 1036-1044. https://doi.org/10.1111/j.1365-246X.2011.05116.x

Taylor, J., Selby, D., Lloyd, J. M., Podrecca, L., Masterson, A. L., Sageman, B. B., & Szidat, S. (2023). Palaeoenvironmental reconstruction of Loch Duart (NW Scotland, UK) since the Last Glacial Maximum: implications from a multiproxy approach. *Journal of Quaternary Science*, *n/a*(n/a). https://doi.org/https://doi.org/10.1002/jqs.3566

Thompson, R., & Wain-Hobson, T. (1979). Palaeomagnetic and stratigraphic study of the Loch Shiel marine regression and overlying gyttja. *Journal of the Geological Society*, *136*(3), 383-388. https://doi.org/10.1144/gsjgs.136.3.0383

Ward, S. L., Neill, S. P., Scourse, J. D., Bradley, S. L., & Uehara, K. (2016). Sensitivity of palaeotidal models of the northwest European shelf seas to glacial isostatic adjustment since the Last Glacial Maximum. *Quaternary Science Reviews*, *151*, 198-211. https://doi.org/https://doi.org/10.1016/j.quascirev.2016.08.034

Weston, D. J., Matthews, I. P., Lowe, J. J., Palmer, A. P., & Vircavs, L. H. (2021). Investigating the sequence of glacial retreat and sea-level change: a Last Glacial to Interglacial Transition (~16-8 ka BP) case study from Loch Torr a'Bheithe, Arisaig, North-Western Scotland. In A. P. Palmer, Lowe, J.J., Matthews, I.P. (Ed.), *The Quaternary of the West Grampian Highlands: Field Guide*. Quaternary Research Association.

Table 1: Location, height, reference water levels and radiocarbon ages for the published relative sea level record from isolation basins at Arisaig.

Labcode	Site and borehole number	Latitude	Longitude	Radiocarbon age and 1σ uncertainty (a BP)		Median Age (cal a BP)	Age 2σ Uncertainty (cal a)		Sill elevation (m OD)	Sample Reference Water Level (m OD)	RSL and 2σ uncertainty (m)		Type	Reference Year (all Shennan *et al.*)
							+	-						
Be174064	Upper Allt Dail an Dubh-Asaid	56.93	-5.83	12680	70	15116	215	232	61.9	2.4	59.5	0.4	limiting date	2005
Be174063	Cnoc Pheardir 2	56.92	-5.84	12650	70	15073	228	442	42.5	2.4	40.1	0.6	limiting date	2005
SUERC3009	Coire Camas Drollaman III	56.88	-5.87	13400	108	16130	322	339	38.4	2.5	35.9	1.1	limiting date	2006
AA22343	Upper Loch Dubh ULD95-4	56.89	-5.83	13280	110	15961	324	311	36.5	2.4	34.1	0.4	isolation	2000
AA22344	Loch nan Tri Chriochan TC95-52	56.9	-5.81	13320	100	16018	290	295	33.4	1.2	32.2	0.4	isolation	2000
AA22345	Torr A' Bheithe TB95-35	56.89	-5.87	12750	95	15211	338	266	33.2	2.4	30.8	0.4	isolation	2000
AA22346	Loch Torr A' Bheithe LTB95-5	56.89	-5.86	12630	95	15022	309	571	24	2.4	21.6	0.4	isolation	2000
AA22342	Allt Achadh Na Toine AAT95-1	56.9	-5.82	12890	100	15412	289	287	22.5	1.8	20.7	0.4	isolation	2000
AA22341	Loch Dubh LD95-3	56.9	-5.82	13080	100	15676	296	338	20.4	1.2	19.2	0.4	isolation	2000
AA44935	Loch Camas Drollaman LCD99-3	56.88	-5.88	13230	110	15892	339	310	17.8	1.2	16.6	0.4	isolation	2005
AA28093	Rumach Meadhonach RM92-12	56.9	-5.88	12605	85	14986	295	528	17.8	1.2	16.6	0.4	isolation	1993; 2000
AA28094	Rumach IV RIV93-F5	56.9	-5.88	12730	85	15182	313	244	16.3	1.2	15.1	0.4	isolation	1996; 2000
AA22339	Loch A' Mhuilinn LAM95-2	56.89	-5.87	12390	85	14510	427	375	15.5	1.2	14.3	0.4	isolation	2000
AA28092	Rumach Iochdar RI92-5b	56.9	-5.88	10980	85	12907	170	148	9.3	1.2	8.1	0.4	isolation	1993; 2000
SRR4865	Loch nan Eala upper basin 67	56.9	-5.84	10500	90	12475	231	420	6.3	0.9	5.3	0.4	isolation	1994
SRR4864	Loch nan Eala upper basin 67	56.9	-5.84	8310	45	9329	126	192	6.3	1.2	5.1	0.4	ingression	1994
AA28100	Loch nan Eala upper basin 92-65	56.93	-5.84	8115	75	9062	330	337	6.3	0.9	5.4	0.4	ingression	1994; 2000
SRR4863	Loch nan Eala upper basin 66b	56.9	-5.84	6630	50	7512	64	83	6.3	0.6	5.7	0.6	oscillation	1994
AA28099	Loch nan Eala upper basin 92-65	56.93	-5.84	4245	50	4790	167	208	6.3	1.2	5.1	0.4	isolation	1994; 2000
AA28096	Loch nan Eala main basin 92-200b	56.91	-5.83	10250	70	11975	489	321	5.2	1.2	4	0.4	isolation	1994; 2000
AA28097	Loch nan Eala main basin 92-200b	56.91	-5.83	8925	65	10037	192	258	5.2	1.2	4	0.4	ingression	1994; 2000
SRR4738	Loch nan Eala main basin 16b	56.9	-5.83	3745	50	4103	182	175	5.2	1.2	4	0.6	isolation	1994
SRR4737	Loch nan Eala main basin 1b	56.91	-5.83	3440	50	3697	138	129	5.2	1.6	3.6	0.6	isolation	1994
Be91307	Rumach VI 95-1	56.9	-5.89	10290	60	12066	398	243	4.8	1.2	3.6	0.5	isolation	1999
SRR5488	Rumach VI 94-3	56.9	-5.89	8790	70	9823	322	268	4.8	1.2	3.6	0.5	ingression	1999
Be91306	Rumach VI 94-4	56.9	-5.89	5690	50	6474	156	153	4.8	-1.5	6.3	0.4	start of isolation	1999
Be91305	Rumach VI 94-4	56.9	-5.89	4760	40	5515	72	186	4.8	-1	5.8	0.4	within isolation	1999
SRR5487	Rumach VI 94-3	56.9	-5.89	3350	70	3582	241	175	4.8	1.2	3.6	0.4	isolation	1999
Be91304	Rumach VI 94-4	56.9	-5.89	2670	50	2786	84	60	4.8	2	2.8	0.4	end of isolation	1999

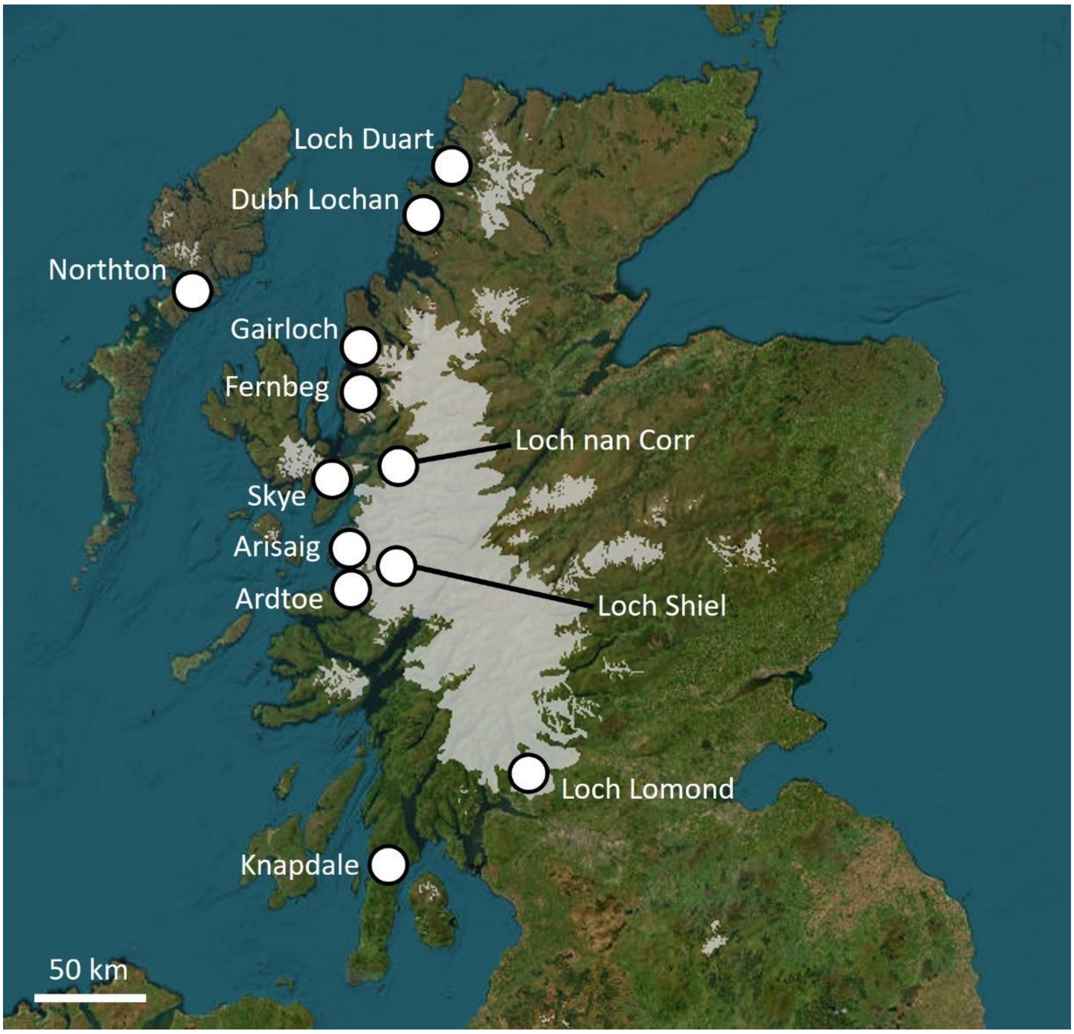

Figure 1: Locations of isolation basins in Scotland used to reconstruct relative sea-level changes. There are other isolation basins along the west coast, including on Rum, Ardnamurchan and Raasay, but they have not yet been analysed in detail and/or lack radiocarbon dating (Best and Shennan, unpublished). Loch Lomond Stadial ice limit extent based on Bickerdike et al. (2016); Bickerdike et al. (2018). Imagery Earthstar Geographics, hosted by Esri.

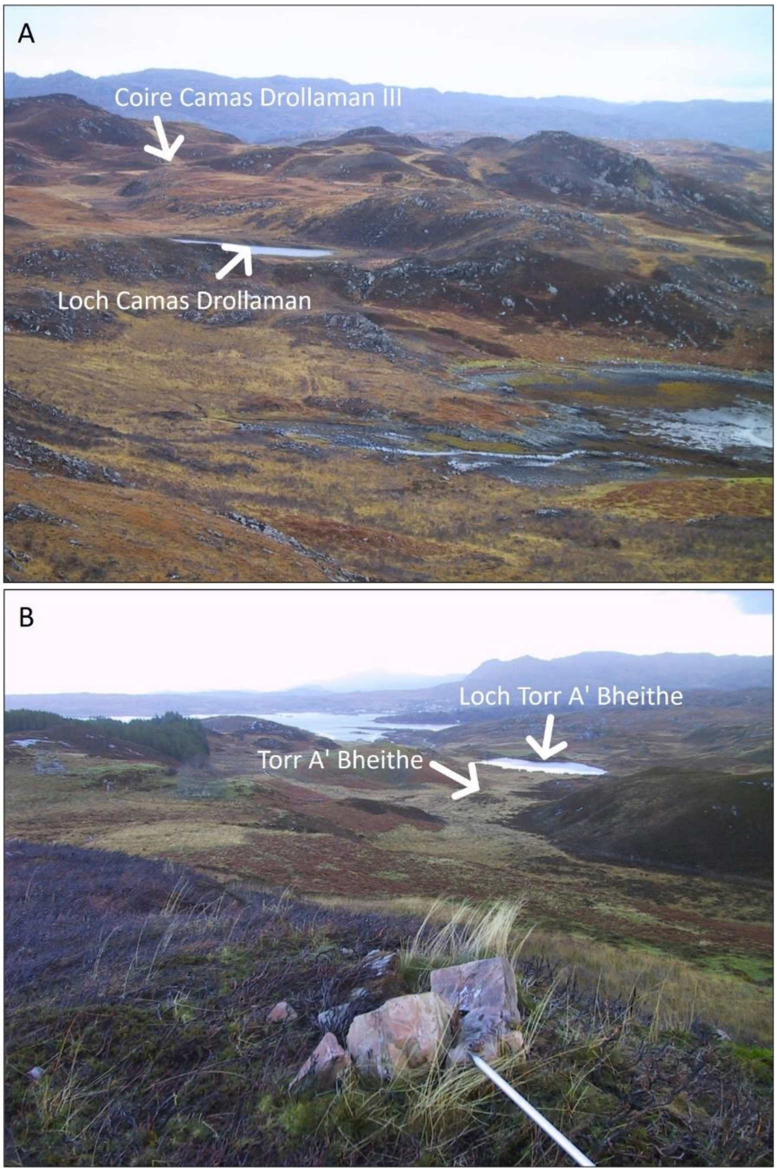

Figure 2: Photographs of the Ru Peninsula, Arisaig. A) South side, looking NNE across the intertidal zone of Camas Drollaman and Loch Camas Drollaman which drains over the lowest point of the visible rock ridge at 17.8m OD, and a higher, sediment filled basin, Coire Camas Drollaman III, at 38.4m OD. Loch Camas Drollaman was isolated c. 15.9 ka BP, while the higher basin helps constrain the local marine limit: see main text, Figure 6 and Table 1 for more details of these sites. B) North side, looking N to the sea and Arisaig village. Arrows mark two isolation basins, Loch Torr A' Bheithe, at 24.0m OD, and the infilled basin, Torr A' Bheithe, at 33.2m OD, with isolation contacts dated c. 15.0 and c. 15.2 ka BP respectively (Table 1). Original photographs © Ian Shennan.

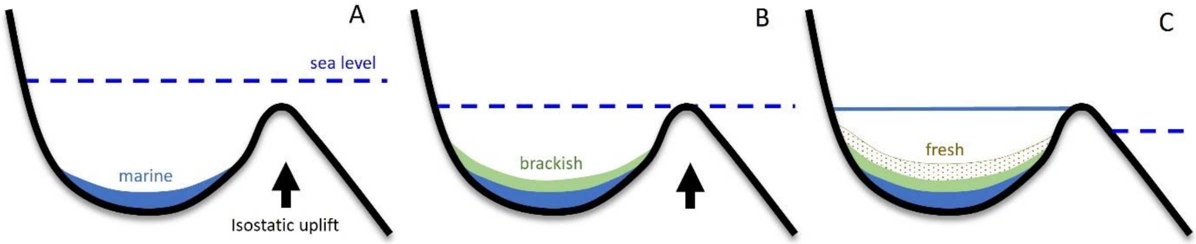

Figure 3: The classic model of an isolation basin (redrawn from Hafsten (1983) itself a modified figure from a Norwegian Geological Survey publication of 1953) illustrating depositional conditions commencing with a basin below sea level at all stages of the tide (A). Isostatic uplift, causing relative sea level fall, gradually isolates the basin, progressively through a brackish phase (B) to complete isolation and freshwater conditions.

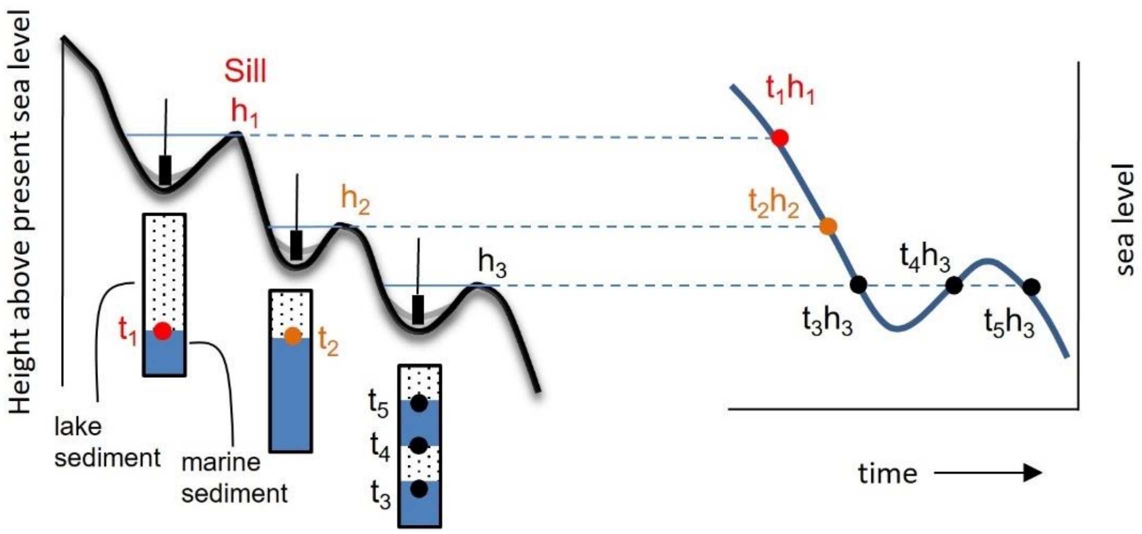

Figure 4. A staircase of three (schematic) isolation basins and the reconstructed sea-level curve. The highest and middle basins record the fall of sea level below sill h_1 at time t_1 and sill h_2 at time t_2. The lowest basin shows an isolation event at time t_3, when sea level fell below sill h_3, followed by an ingression at time t_4, when the sea re-entered the basin. At time t_5 a second isolation event records a fall in sea level.

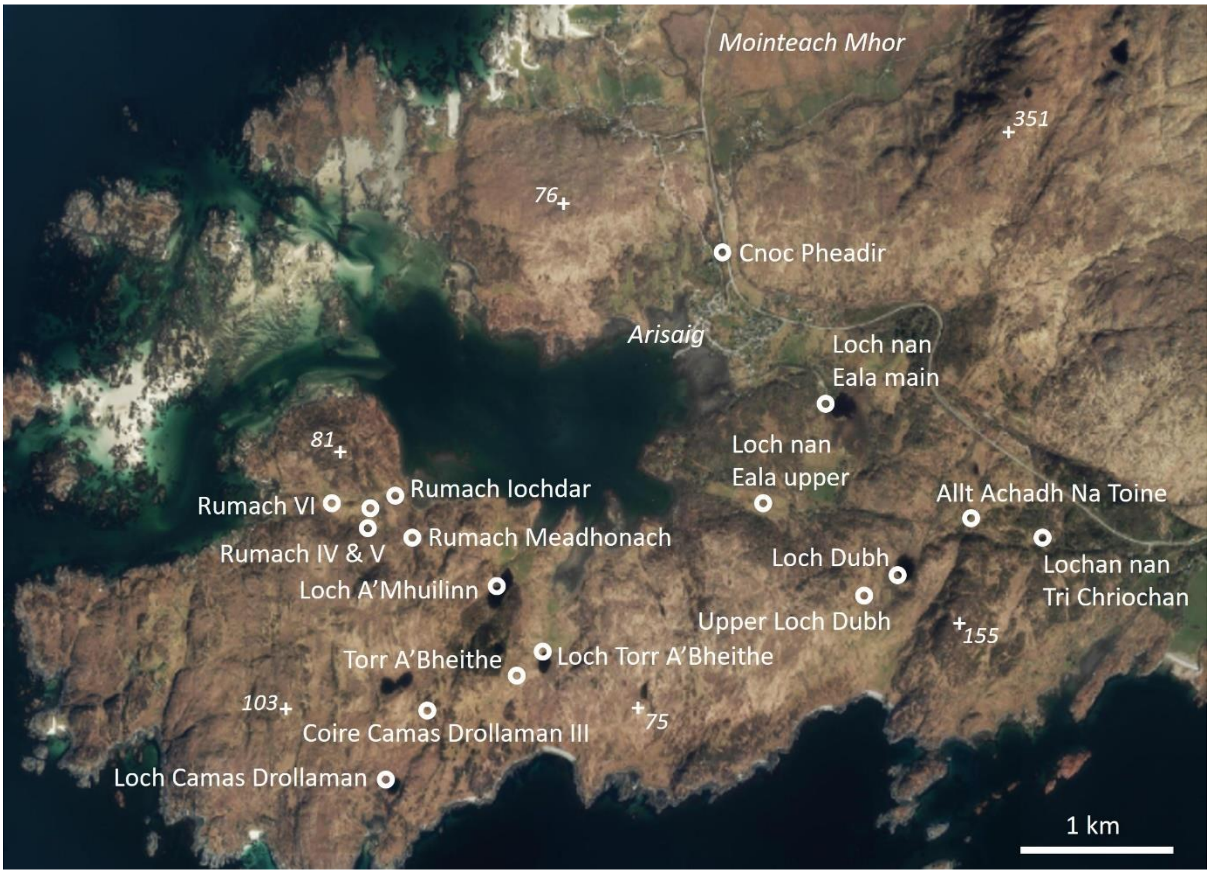

Figure 5: Arisaig location map and basins (open circles) used to reconstruct relative sea-level changes. Upper Allt Dail an Dubh-Asaid, Table 1, is just off the top of the image.

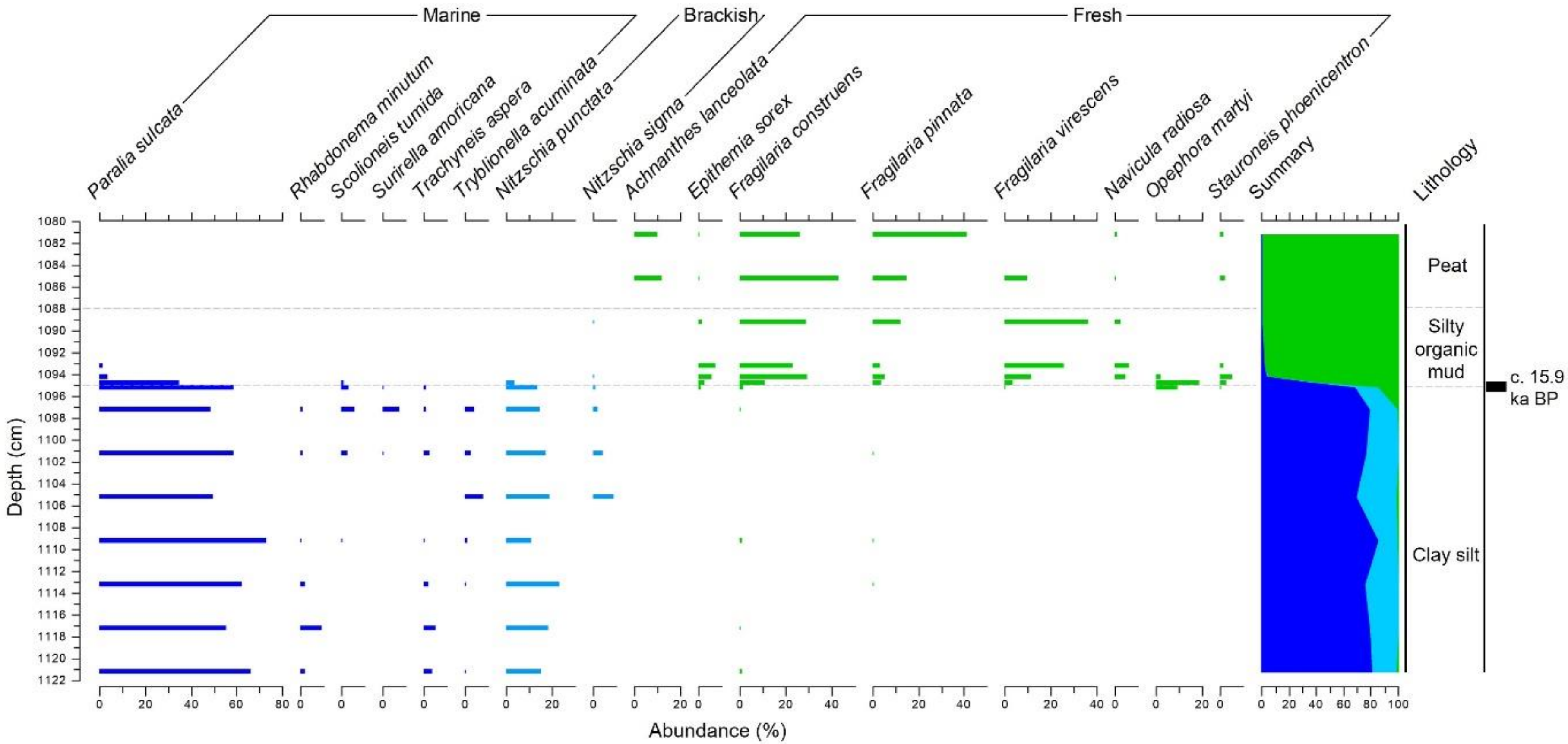

Figure 6: Summary stratigraphy, radiocarbon and diatom evidence of a sediment core at Loch Camas Drollaman; radiocarbon age and site interpretation (Shennan et al. 2005), stratigraphy and diatom data (not previously published), showing species with abundances >5% and summary classes based on total diatom counts.

Figure 7: Rumach VI basin and tidal pond. A) Photograph from the sill of the higher basin, 16.3 m OD, Rumach IV, looking west across Rumach VI towards the coast. The linear drainage ditch leads to the rock sill of Rumach VI, 4.8 m OD. Arrow indicates a team taking a core in 2010, at a location close to the earlier core 95/1 (Shennan et al., 1999). B) Field photograph of part of the 2010 core, from 350cm (left) to 400cm (right), showing the isolation contact at~373cm. Core taken with a Russian corer, with no removal of surface smears before photographing. C) Rumach tidal pond at mid to low tide, showing water still covering the sill, the low point at the right hand end of the intertidal rock ridge. Photograph taken from the parking area, looking west towards Eigg and Rum. Original photographs © Ian Shennan.

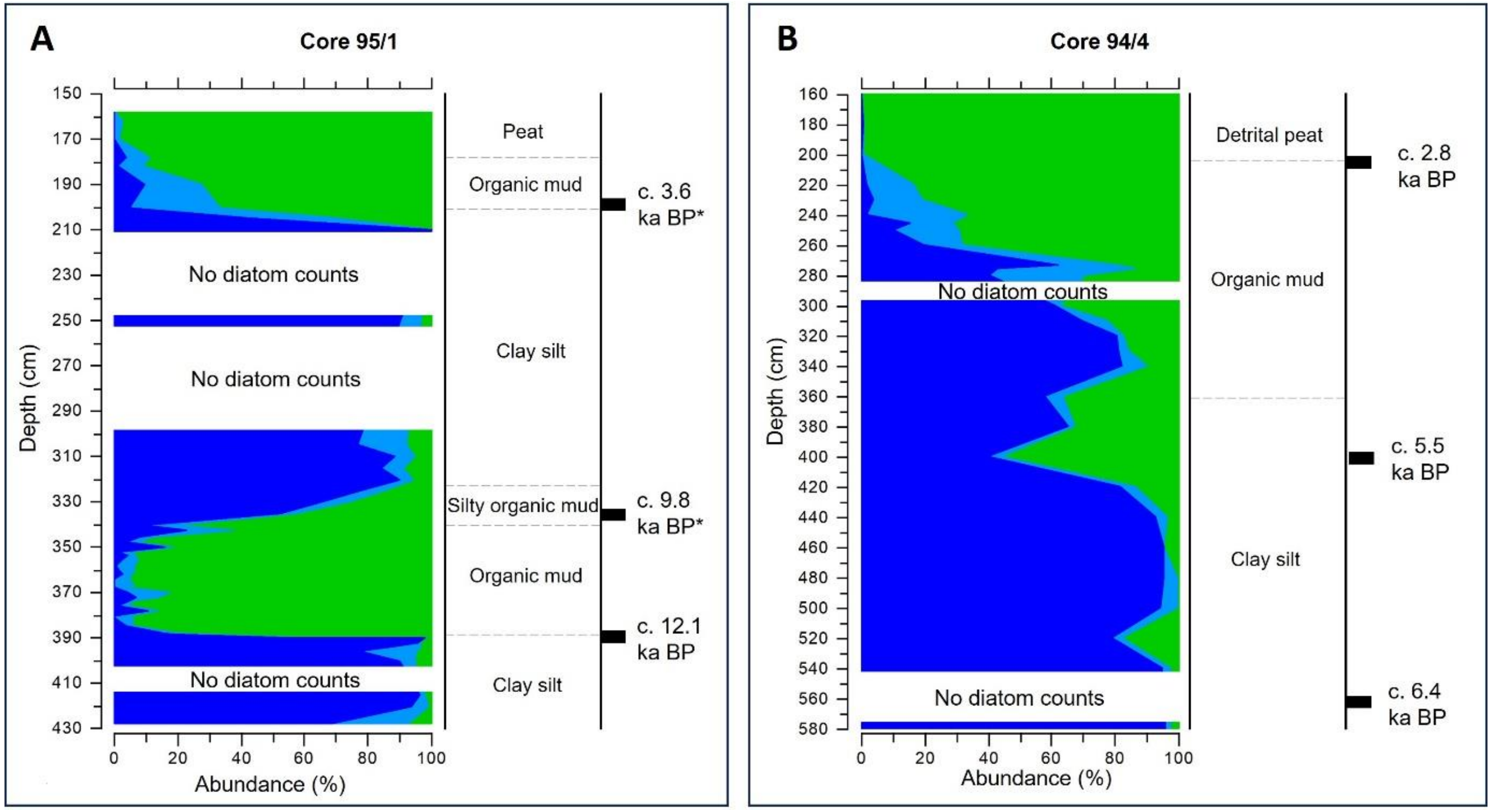

Figure 8: Summary diatom, stratigraphy and radiocarbon ages from Rumach VI. Diatom summary colours correspond to those in Figure 6: dark blue- marine; light blue- brackish; green- fresh water. A) Core 95-1 (Shennan et al., 1999), located close to the core shown in Figure 7. The date on the lower isolation contact is from core 95/1, those for the other contacts (with asterisks) are from another core from towards the side of the basin. B) Final isolation of Rumach VI in a core from the central part of the basin, core 94-4, adjacent to the linear drain visible in Figure 7A (Shennan et al., 1999).

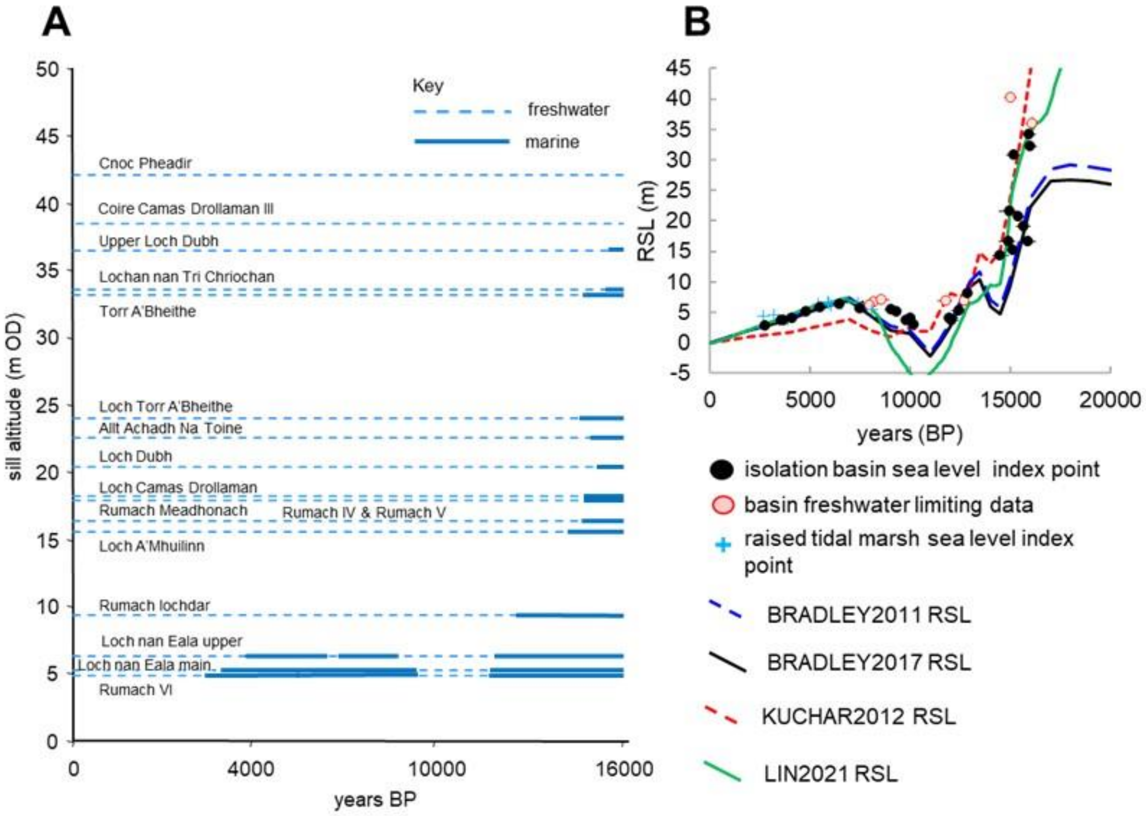

Figure 9: Isolation basin sequence at Arisaig. A) Elevation of basins, m OD, and the phases of marine and freshwater sedimentation. The change in sedimentation is shown at the median of the calibrated radiocarbon age (Table 1). B) Reconstructions of relative sea level (RSL) from the isolation basins and nearby raised tidal marshes at Mointeach Mhor (Figure 3), and four GIA model predictions of RSL (Lin et al., 2021; Shennan et al., 2018). The RSL plot incorporates the indicative meaning of different types of sea-level index point, so trends to zero at present. The elevation of basins, frame A, are to Ordnance Datum, therefore reflect change relative to approximately present MHWST, 2.38 m OD.

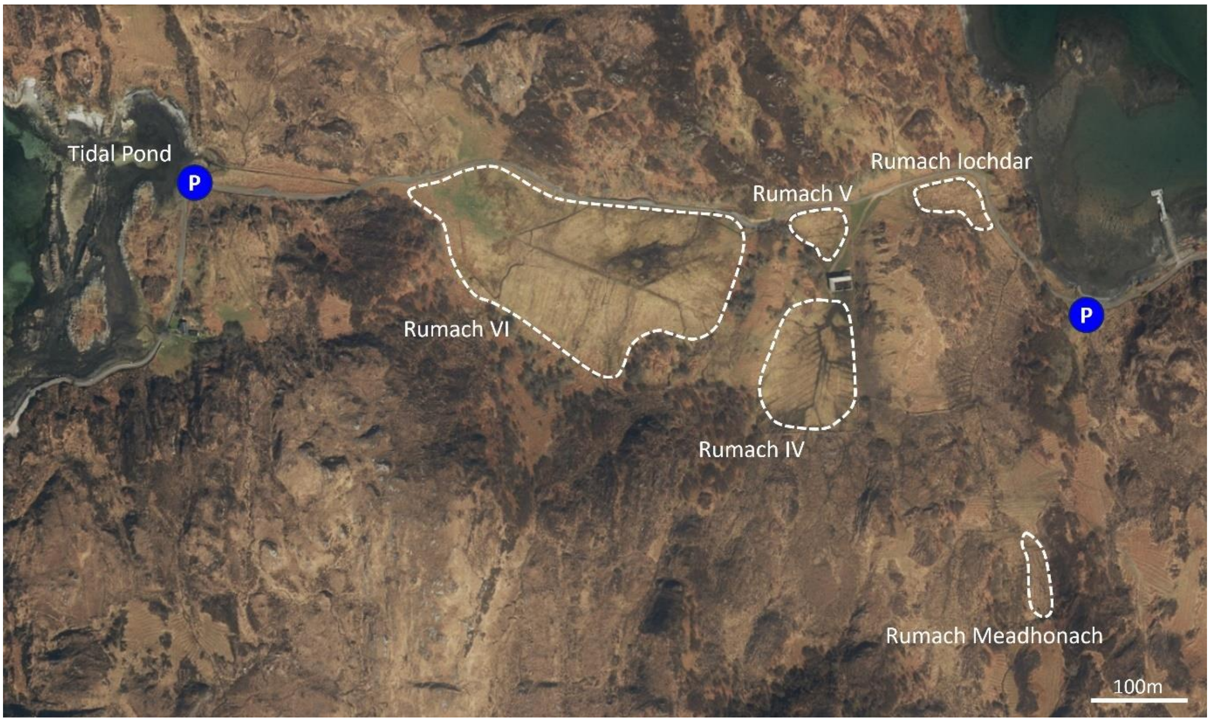

Figure 10: Rumach isolation basins, tidal pond, and parking locations. Imagery © Getmapping Plc.