Manchester Geological Association
Williamson Building, University of Manchester
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A Virtual Tour of the Outer Hebrides, North West Scotland

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The Outer Hebrides form the north-western cornerstone to Europe, but their geology owes more to its Greenland and North American counterparts than to its Baltic or other European cousins. The island chain, stretching for over 200 km, is a fragment of a large North Atlantic basement craton against which the Caledonides and other mountain belts were formed. It is composed mainly of ancient gneissose rocks that constitute the largest onshore outcrop of the Lewisian Gneiss Complex. These rocks formed from a range of intrusive igneous rocks with subsidiary meta-sedimentary intercalations and thin successions. The formation of the gneiss protoliths, their complex deformation and metamorphic history, and subsequent uplift extended over some 1500 million years, a time period that occupied half the geological time scale encompassed by the rocks of the British Isles. The scenery and topography of the islands reflect both their Atlantic position and their ancient geological origins.

The Lewisian Gneiss Complex was largely formed during the Archaean between c. 3000 Ma and 2700 Ma when early-formed mafic and ultramafic rocks with some small meta-sedimentary enclaves were invaded by voluminous tonalitic and granodioritic intrusions, probably mainly as sheets, at mid- to deep crustal depths. These dominantly igneous protoliths were then penetratively deformed and metamorphosed under amphibolite and locally granulite facies conditions during an extensive Scourian event (c. 2800-2600 Ma). Towards the end of the Archaean at around 2550 Ma smaller granite plutons, and monzonitic and dioritic intrusions were intruded locally. These are best represented in SE Barra. In the Early Proterozoic at about 2400 Ma the gneisses and other igneous elements were intruded by numerous dolerite (tholeiite) dykes, here termed the Younger Basic Suite, marking a period of rifting that seems to be replicated on other N Atlantic cratons. The dykes were intruded and crystallized at mid-crustal levels giving rise to varied metamorphic mineralogies and deformational textures. Subsequently at around 1880 Ma, arc-related sedimentary and mafic volcanic rocks were deposited in an oceanic trench environment in the South Harris area, where they were intruded at depth by anorthositic, dioritic and gabbroic plutons. The whole assemblage was subducted to deeper crustal levels and then exhumed during an arc-continent collision or continent-continent collision. This plate tectonic event is unique in the Outer Hebrides. It effectively marked the start of Laxfordian reworking during which the Archaean gneisses, late-Scourian intrusions, Younger Basic Suite dykes and the South Harris assemblage were subject to widespread deformational and metamorphic events. These Laxfordian events were largely responsible for the structural pattern in the islands and for the metamorphic assemblages now found in the gneisses. During the waning phases of this penetrative reworking sheeted granite plutons were emplaced, mainly in Harris and SW Lewis, where they locally dominate the geology. Uplift and local pegmatite formation marked the end of the Laxfordian at around 1500 Ma.

The gneisses on the eastern side of the Outer Hebrides have been affected by thrusting, widespread fracturing and mylonite formation. This zone has been termed the Outer Hebrides Fault Zone (OHFZ) and the fault rocks include pseudotachylite, cataclasite and brecciated rocks (termed 'mashed' gneiss). The major concentrations of pseudotachylite lie along an ESE-dipping thrust feature that now forms the prominent mountains of the Uists and Barra. Farther north in Lewis and Harris the OHFZ is wider and the gneisses and fault rocks have been subject to a greater degree of retrogression and alteration under greenschist facies conditions. In these northern islands fault rocks are also widespread farther west, notably in southern Lewis. The OHFZ here shows evidence of formation under different pressure and temperature conditions and at different times. The zone may well have formed initially by westwards thrusting during Grenvillian orogenesis between about 1200 and 980 Ma, as implied by some ages obtained from pseudotachylites both from the Outer Hebrides and the Scottish mainland. The fault zone was reworked during the Caledonian orogeny, with lower greenschist facies mylonite belts developed on the eastern fringes of the islands. The structural geometry of some of the mylonites suggests that the OHFZ may have acted at least as an extensional structure for a least part of this time.

The eastern seaboard of the Outer Hebrides is near coincident with the Minch Fault for much of its length. This fault marks the western boundary of the Minch Basin, which contains a sequence of mainly Permo-Triassic and Jurassic sedimentary rocks with a thin Cretaceous and Eocene cover, in total reaching 5.5 km in thickness. The only exposures of these rocks seen on land in the Outer Hebrides occur around Stornaway, where Permo-Triassic conglomerates, sandstones and mudstones form a series of westerly derived alluvial-fan deposits up to 1200m thick. The next major geological event was the emplacement of numerous Palaeogene mafic dykes linked to Skye and Mull Tertiary igneous centres and to opening of the North Atlantic Ocean. The majority of the dykes are analcite-bearing olivine dolerites ('crinanite'), although some olivine-free dolerite (tholeiite) dykes are present in South Harris.

Perhaps the main agents responsible for the present-day landforms of the Outer Hebrides have been the Quaternary glaciations and the subsequent development of peat, sand dunes, machair, etc. during the Holocene. The erosive effects of glaciation are immediately apparent in some parts of the Outer Hebrides, notably in North and South Harris, but also on the mountains of the Uists, and in the Sounds of Harris and Barra. Till is only well-developed in northern Lewis with patchy deposits in North Harris and the Uists. Moraines are developed peripheral to the North Harris hills but rare elsewhere. Most of the glacial deposits can be linked to the Last Glacial Maximum (LGM) that occurred in the early part of the Late Devensian, but interstadial lake deposits and earlier tills (Mid Devensian) have been documented at Tolsta Head in NE Lewis. Ice movement directions radiate out from North Harris in all directions, but in the Uists and Barra ice movement has been to the ESE into the Little Minch and Sea of the Hebrides. In northern Lewis ice apparently first moved WNW across its northern tip but later the area seems to have been somewhat stagnant. The increase in offshore data on the sea bed features and the nature of Quaternary deposits, combined with C isotope dating from offshore cores and cosmogenic dating of on-land exposures, have allowed the reconstruction of the British Ice Sheet (BIS) during the LGM. This work has shown that ice extended to the edge of the northwest continental shelf and that major ice streams existed in the Minch and Sea of the Hebrides, feeding sediment to the Sula Sgeir and Barra fans, respectively. The ice sourced in the Outer Hebrides was a minor component to the BIS, but as sea level was over 100m lower during maximum glaciation the land area extended westwards as far as the continental edge, a distance of some 70 to 110 km. Growth of the BIS occurred relatively early on the northwest shelf and Outer Hebrides with its maximum extent being attained here at around 26 to 27000 years (kA) BP. By 23kA years BP the ice front was retreating in the northwest but still expanding at its southern margins in England and Ireland. Calving and thinning of the ice sheet intensified at around 18-19kA BP as the ice front receded rapidly eastwards across the shallow Hebrides shelf. On land ice sheet decay was slower, the lower ground in Harris being ice-free by 15.5Ka, with the last icefield remnants persisting in the North Harris hills until about 14kA. During the waning of the ice sheet ice-dammed lakes formed at Uig in SW Lewis. Following the warmer Windermere Interstadial, arctic conditions returned again at around 12.7kA BP, marking the start of the Younger Dryas (≡ Loch Lomond Stadial). During this short-lived period (12.8 to11.6 kA BP) valley and small corrie glaciers developed in the North Harris hills.

The Holocene Epoch was marked by warming and re-establishment of vegetation and further rising sea levels. This was a time of peat development and the formation of the 'Machair', the latter mainly on the western seaboard of the Outer Hebrides. The term derives from the Gaelic *mhachair* or *machar* for an extensive beach or plain and describes a low-lying grassy coastal plain composed mainly of calcareous sand. It encompasses an integral 'system' of beach, sand dunes, lagoons, saltmarsh and vegetated sandy plains or sloping surfaces, underlain by sand or sandy soil. Machair is an ephemeral dynamic ecosystem that is subject both natural and man-made effects. Natural controls include the weather, sea level variations, storms, tides, sediment supply, and vegetation types. Man-made effects have included agriculture, exploitation of sand, grass-cropping and changes in local infrastructure.

During the seminar there will likely be time for discussion on the various aspects of the geology of the Outer Hebrides and on some of the related problems. Contentious subjects include:

The nature of the early crust, its igneous protoliths, and tectonic development in the Archaean and Proterozoic.

The nature, age and significance of some of the major ductile shear zones. Plate-tectonic models and reconstructions.

The Quaternary pre-late Devensian history of the Outer Hebrides.

The role of the Outer Hebrides Fault Zone during the Grenvillian and Caledonian orogenies.