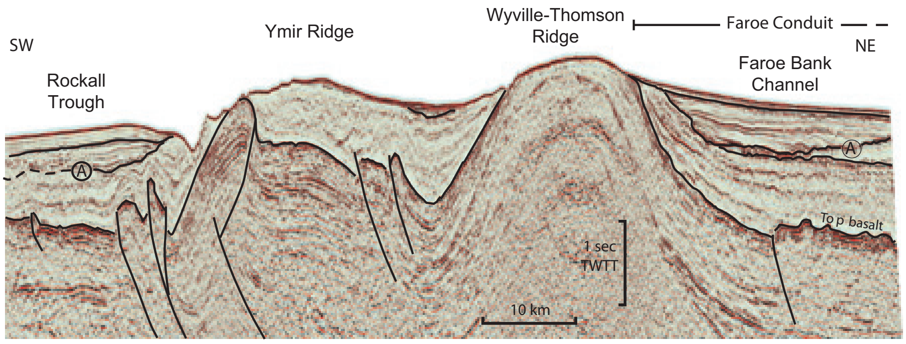
Plate tectonic processes alter the Earth's geography and influence long-term climate change. **Martyn Stoker** explains how the movement of tectonic plates in the North Atlantic may have triggered a progressive cooling of the northern hemisphere that has lasted for 12 million years or more.

Tectonic-scale climate change

Tectonic-scale climate change occurs over a timescale of millions of years — the slowest rates of change in the Earth's climate system. While most current research focuses on shorter-term oscillations in climate (on a scale of decades to millennia) and their potential impact on human populations, such relatively rapid changes remain embedded in, and superimposed upon, slower changes over longer timescales. Greenhouse gases generated by human activities are expected to affect climate change in the decades and centuries ahead. But the larger-scale tendency towards global cooling and bipolar glaciation that has been driven by plate-tectonic processes, especially over the past 15 million years, may well resume once the oceans have absorbed the excess carbon dioxide pulse caused by the burning of fossil fuels. Thus although we may have a warming climate in the short term, there is no doubt that the most fundamental changes in the Earth's climatic history are triggered by tectonic events. For example, in the North Atlantic region, the early Neogene record of climatic deterioration has recently been linked to tectonic forcing and the related development of an oceanic gateway off north-west Britain.

It is increasingly apparent that the opening and closing of 'oceanic gateways' — narrow passages linking the major ocean basins — has had a profound influence on the Earth's climate since at least the late Precambrian, by controlling the global circulation of oceanic currents. This, in turn, controls the transfer of heat and salt from the equator to the polar regions. The warm poleward flow of saline surface waters is balanced by the cold water sinking at high latitudes and moving as a cold deep current back towards the equator. This circulation, or thermohaline flow, helps to regulate the global heat energy budget. Any change to the configuration of oceanic gateways can therefore directly affect the transport of heat through the oceans, and hence alter the distributions of temperature, precipitation, ice and vegetation on the Earth.

In the North Atlantic region the Greenland–Iceland–Scotland Ridge (GISR) forms a major bathymetric high extending between the continental margins of south-east Greenland and north-west Britain. The main gateway for southerly directed deep-water exchange across the GISR is the Faroe Conduit, which incorporates the Faroe–Shetland and Faroe Bank channels. Oxygen and carbon isotope data, together with faunal and sedimentological evidence have been collected from either side of this ridge at ocean drilling sites tested by the Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP). These data indicate that the GISR acted as a barrier to the exchange of deep-water masses between the northern and southern

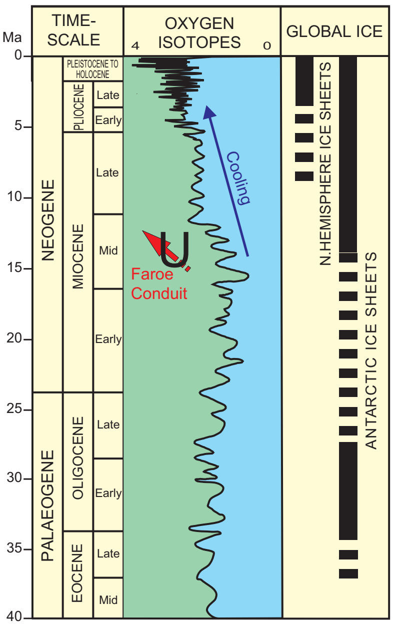


Seismic profile across part of the Faroe Conduit, showing folds best depicted by the Paleocene–Lower Eocene basalt surface and the shape of the early to mid-Miocene deep-water unconformity (A). For sediment thickness above the top basalt, one second two-way travel time (TWTT) is less than or equal to one kilometre.

hemispheres during the Palaeogene, but was breached sometime during the early Neogene.

This interpretation is supported by the results of the recently completed STRATAGEM project, a large-scale observational programme supported by the European Commission and co-ordinated by the BGS. This new evidence demonstrates that the accumulation of deep-water sediment-drift deposits, north and south of the GISR, has massively expanded since the mid-Miocene (about 12–15 million years ago). The progressive cooling of the northern hemisphere climate from the mid-Miocene, as revealed by the oxygen isotope record, suggests that the formation of the Faroe Conduit was a fundamental precursor to the present-day global pattern of thermohaline circulation and its associated sediment-drift deposits.

The North Atlantic margins are generally regarded as passive in their post-rift development. As a result, previous hypotheses suggest that thermal subsidence of the GISR caused the formation of the oceanic gateway as gradual submergence of the ridge

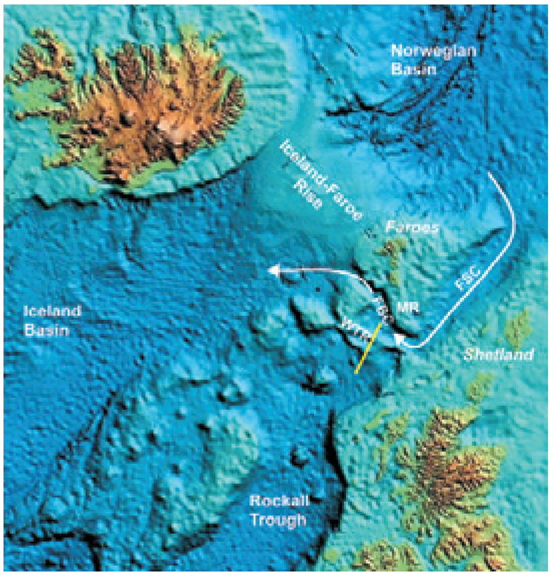


Timing of formation of the Faroe Conduit relative to the composite oxygen isotope record and hemispheric ice volume: partial ice cover (dashed bar); maximum ice cover (solid bar).

during the Miocene and Pliocene eventually allowed deep waters to overflow. However, the record of sediment-drift development implies a relatively sudden breaching of the GISR during the early to mid-Miocene. At this time a large part of the ridge was still a shallow marine bank, or even subaerial, with a sill depth too high (less than 500 m of water depth) for persistent exchange of deep waters.

This paradox is resolved by considering the structure of the GISR in the Faroe–Shetland region and specifically the Faroe Bank Channel. Seismic reflection profiles reveal that the Faroe Bank Channel is a syncline complementary to the large anticlines that form the adjacent Munkagrunnur and Wyville–Thomson ridges (see seismic profile). Although these anticlines underwent steady and continuous growth prior to the Neogene, their present profile was attained during an episode of more intense compressional deformation during early to mid-Miocene time, with the anticlines growing by about 1000 m. This early Neogene growth phase is revealed on seismic profiles by a marked and angular deep-water unconformity that truncates strata of Oligocene and older ages in both the Faroe Bank Channel and the Rockall Trough, and is onlapped and overlain by mid-Miocene and younger sediment-drift deposits that represent the sedimentary response to gateway formation. This has two main implications:

- The formation of the Faroe Bank Channel, linked to the existing Faroe–Shetland Channel, created the Faroe Conduit as a discrete gateway for the transfer of deep waters across the GISR, despite the bulk of the ridge remaining as a barrier to overflow.
- The development of the North Atlantic continental margins has been anything but passive.



Bathymetry at the south-east end of Greenland–Iceland–Scotland Ridge marked by the Iceland–Faroe Rise, showing route of southward-flowing deep water (white arrows) through the Faroe Conduit. The yellow line marks position of the seismic profile illustrated. FSC: Faroe–Shetland Channel; FBC: Faroe Bank Channel; MR: Munkagrunnur Ridge; WTR: Wyville-Thomson Ridge.

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The deformation responsible for this phase of early Neogene compression has been linked to a major reorganisation of the North Atlantic plate system, as it coincides remarkably closely in time to the progressive transfer of the mid-ocean spreading ridge from one side of the Jan Mayen microcontinent to the other. Although climate modellers remain cautious as to whether or not such tectonically forced gateway changes affect climate on a global scale, these changes definitely alter the production and flow of deep water through ocean basins. It may be no coincidence that since the formation of this gateway there has been a progressive deterioration of global climate.

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