Surface exposure dating of glacial features in Great Britain using cosmogenic chlorine-36: preliminary results

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The expansion and contraction of glaciers reflects fluctuations in the hydrological regime. Geological indications of glacial sediments and landforms where no glaciers are found today thus constitutes important evidence of past climatic and hydrological conditions. Unfortunately, glacial landforms (e.g., moraines, kames, eskers, smoothed bedrock, and erratic boulders) are typically difficult to quantitatively date because they are composed largely of redistributed rock and sediment. They typically contain little organic carbon (which might be dated by ^{14}C) or authigenic minerals (which might be dated by methods such as U/Th). As a result, glacial features have provided less information on past climate states than they potentially could if their chronologies were well constrained.

Recent advances in geochronology hold promise of overcoming this difficulty. Methods have been developed to measure extremely small amounts of cosmogenic nuclides in rocks. Cosmogenic nuclides are produced by the action of cosmic radiation on the nuclei of atoms near the surface of the earth. Rocks are effectively shielded from cosmic radiation by more than a few metres of overburden, hence the amount of cosmogenic nuclides accumulated reflects the time of exposure to cosmic radiation at the surface of the earth. Glaciers typically excavate deeper than a few metres, and thus cosmogenic nuclide accumulation offers a possible means of dating the time that glacially-derived landforms were created.In this paper we describe the application of ^{36}Cl to dating of glacial features in Great Britain. Chlorine-36 is the only long-lived unstable isotope of chlorine, with a half-life of 301,000 years. It is created by high-energy cosmic-ray neutron reactions on potassium and calcium and low energy neutron reactions on stable chlorine. Chlorine is extracted from rock samples by grinding them and dissolving in nitric and hydrofluoric acid. The chloride is precipitated as silver chloride by adding silver nitrate to the solution. The silver chloride is purified and the ratio of ^{36}Cl to stable chlorine is measured by accelerator mass spectrometry. All analyses reported here were performed at the Purdue Rare Isotope Measurement Laboratory.

Chlorine-36 buildup dating has successfully been applied to glacial moraines in the eastern Sierra Nevada (California) and to lava flows and meteorite impact craters in the western United States. All of these features are from relatively dry climatic conditions. Concern has been expressed that the very humid climate of Great Britain might either cause such rapid surface erosion, or such severe leaching of ^{36}Cl, that surface exposure dating using cosmogenic ^{36}Cl might not be possible. In order to test the feasibility of the method in Britain we have collected a limited number of samples from glacial features with relatively well-constrained independent ages. The independent ages ranged from approximately 180,000 to 11,000 years.

The oldest samples analyzed were three metamorphosed rhyolite erratics collected in the vicinity of Birmingham. Correlation with the fluvial terrace sequence of the Severn River Valley indicates that the glacial margin last occupied this area during marine oxygen isotope stage 6, approximately 180,000 to 135,000 years ago. Our three samples yielded ^{36}Cl buildup ages of 93,000 $\pm$ 12,000, 150,000 $\pm$ 9,000, and 170,000 $\pm$ 13,000 years. The first was a large boulder that had been shifted during a construction project. It seems likely that the boulder had been rolled during its removal and we sampled the bottom. The other two samples fall in the expected age range.

Two samples were analyzed that were related to the Late Devensian glacial maximum (*c.* 30,000 to 15,000 years ago). One was a large quartzite erratic on top of a Late Devensian end moraine on the Gower Peninsula, southern Wales. This gave a ^{36}Cl age of 23,200 ± 2,000 years, in the middle of the expected range. The second sample was a glacially smooth metamorphosed rhyolite bedrock collected from the summit plateau above Cwm Idwal in the northern Welsh mountains. The ^{36}Cl age for this sample was 32,900 ± 4,600 years. This age is older than expected because it is likely that the mountains in this area were covered by a regional ice cap during the Late Devensian glacial maximum, about 20,000 years ago. However, the bedrock in the area sampled was very hard and resistant, and we speculate that it may have retained ^{36}Cl produced during a period of exposure prior to the Late Devensian maximum, due to very low glacial erosion rates.

Finally, we analyzed two samples constrained by ^{14}C dating to the Younger Dryas period (11,600 to 12,900 calendar years ago). These were two metamorphosed rhyolite boulders on top of the moraine damming Llyn Idwal in the northern Welsh mountains. They gave ages of 12,900 ± 2,000 and 11,600 ± 1,3000 years. The ^{36}Cl ages are in very good agreement with the independent chronology for the Younger Dryas.

Although the number of samples dated so far is small, the results are encouraging. Chlorine-36 appears to be applicable to the dating of glacial deposits in Great Britain over a wide time range. We anticipate that widespread application of this method could significantly expand and improve the chronology of Quaternary glaciation in the British Isles.