Glacier Erosion Factory: Using $^{26}Al/^{10}Be$, soils, and geomorphology to study relief development

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Quantifying the influence of glaciers on landscapes of active and ancient orogens has been elusive because of the difficulty in (1) linking erosion rates and processes, and (2) extrapolating measured erosion rates over the duration of one or more glaciations and over the scale of a mountain range.

Hypothesis

In orogens with high plateaus, ice caps may reach an equilibrium state that maintains a non-erosive condition where the ice is frozen to its bed. Among other variables, the rate of achieving this equilibrium depends on the permeability and hydrological character of the substrate and the thickness of ice cover (and indirectly the size of the plateau). Ice cap outlets drain through plateau-dissecting valleys. The outlet lobes are thicker and flow faster under convergent flow, maintaining wet-based conditions and inducing glacial erosion by several mechanisms. Relief is increased during glaciations as valleys are deepened but summits are unscathed.

Initial test results

Cosmogenic nuclide exposure history results in Atlantic Canada partly test the validity of this hypothesis. The Torngat Mountains and Long Range Mountains, with up to 1600 m relief, have broad coastal summit plateaux. The post-glacial valleys maintain their glacial form although incipient post-glacial stream incision is evident ubiquitously. The plateaux and valleys have been covered with ice as recently as the Younger Dryas (^{10}Be ages on erratics on all dated Torngat summits fall within the YD chron). However, bedrock surfaces on the summits record as much as 600 kyr of exposure history (minimum duration based on $^{26}Al/^{10}Be$ on summit tor-like features; the ratio indicates burial, probably by non-erosive ice). Despite being glaciated 11 ka, summit soils also indicate antiquity with anomalous abundances of gibbsite and kaolinite relative to soils on valley sides and bottoms, and geomorphic indicators of weathering (gnammas, weathering rinds) are strongest on the plateau summits. Furthermore, on the flanks of the plateaux ^{10}Be concentrations in bedrock increase with altitude, reflecting the increasing importance of wet-based erosive processes lower in the valley. Absence of inheritance in valley bottom bedrock implies glacial erosion rates ~ 2 m per 20 kyr in the valleys (negligible erosion on the summits).

Geodynamics implications

We propose that until the plateaux are diminished by valley widening and lateral migration of headwalls, glaciers can generate relief in hypsometrically-immature orogens.

On early solar system chronology

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Extinct short-lived radionuclides such as ^{26}Al, ^{53}Mn, ^{182}Hf and others have been extensively used as chronometers for a variety of early solar system processes (see references in [1]). The possibility of building a coherent chronology relies on the assumption that short-lived radionuclides were homogeneously distributed in the accretion disk. This assumption was not unreasonable when the nebula was thought to be hot, well-homogenised, and when the extinct radionuclides were thought to come form a late-stage star such as a supernova [2]. Recent data from a diversity of fields question these assumptions. Here we review new data and ideas on extinct radionuclides, and critically discuss the possibility of building an early solar system chronology.

Astronomical observations of accretion disks around protostars of solar type suggest that the nebula was cold. Building on these observations, a new model for the formation of chondrites has been developed by Shu et al. [3], in which most of solar system matter is thermally processed close to the sun, and ejected to the cold accretion disk *via* an “x-wind”.

The isotopic homogeneity of the accretion disk is questioned by FUN CAIs that contain much lower levels of short-lived radionuclides such as ^{26}Al than normal CAIs [2]. The strong dependence of ^{53}Mn abundance with heliocentric distance also supports the view of a heterogeneous distribution of short-lived radionuclides in the accretion disk [4]. This heterogeneity can be explained in the context of the x-wind model [5], where short-lived radionuclides and their host phases (CAIs) are formed close to the Sun and tossed to asteroidal distances by a fluctuating x-wind.

The discovery of ^{10}Be in CAIs [6] has cast a shadow on a supernova origin for short-lived radionuclides. This isotope cannot form in stars, although Cameron has recently suggested ^{10}Be could form in a supernova jet [7]. The presence of ^{10}Be in CAIs is however readily explained by irradiation [8] based on the x-wind model [5], which can also account for the production of ^{26}Al, ^{41}Ca and ^{53}Mn.

From these data, a new picture of the solar system is emerging, where some of the short-lived radionuclides (^{10}Be, ^{26}Al, ^{41}Ca, ^{53}Mn) were distributed heterogeneously in the accretion disk. For these short-lived radionuclides, homogeneity in the disk is not satisfied. Early solar system components were instead a mixture of irradiated an un-irradiated material, and using short-lived isotopes as a chronometer will depend on now characterising their initial microscopic and macroscopic distribution in early asteroids.

[1] Hutchison et al (2001) *Phil Trans. Roy. Soc.* A **359**,1351ff [2] Cameron *MAPS* **30**,13 [3]Shu et al (1997) *Science* **277**,1475 [4]Lugmair and Shokolyukov (1998) *GCA* **62**, 2863 [5] Shu et al (2001) *ApJ* 548,1029 [6] McKeegan et al (2000) *Science* 289,1334 [7] Cameron *ApJ* **562**, 456 [8] Gounelle et al. (2001) *ApJ* **548** 1050