

Climate change and methane

SIR—Among the many explanations of the rapid climate changes that occurred at the end of the last glaciation is the suggestion that warming was initially driven by methane emitted from northern gas fields and gas hydrates, during a time of rising insolation^{1,2}. This explanation is compatible with the recent reports^{3,7}, that warming took place in two abrupt pulses, 13,000 and 10,500 years ago.

The 'methane-led' account of deglaciation invokes the strong positive feedback that would follow evasion of gas stored at high latitude during glaciation. In the model, increasing insolation destabilizes methane that accumulated during glaciation. The methane became trapped in hydrate when upward seepage was blocked by low temperatures, in areas such as the giant West Siberian fields, north-west North America, or the southern North Sea. Methane is incrementally a much more effective greenhouse gas than CO₂, and the rupture of one or two large gas pools (for example, 10¹³⁻¹⁴ g CH₄), or emission from an area of permafrost, could have initiated a thermal runaway, liberating more gas (possibly 10¹⁵ g CH₄ per yr) and rapidly raising planetary temperatures. The liberated gas would have been converted to CO₂ in the air, and the atmospheric warming would have induced oceanic warming and discharge of further CO₂, thus replenishing the inventories of carbon both on land and in the air.

The positive feedback would have decayed as the thermal pulse penetrated into the strata of the gasfields, according to the square root of time elapsed. Thus the initial methane-pumped runaway would be chaotic and short-lived — a few centuries — followed by a sharp decline in atmospheric CH₄, which has a lifetime of a few years, together with a slower decline in atmospheric CO₂ as the land biosphere captured carbon and the oceans again cooled. A second warming pulse might then follow, induced by the destabilization of hydrate in the extensive regions inundated after the first pulse by marine transgression and ice-dammed lakes, and aided by the further increase in insolation.

The hypothesis has the merits that it explains the speed and linkage of the rises in atmospheric CH₄ and CO₂ (refs 4, 5), and the brief standstill in the ¹⁴C record⁶. It demands, in particular, a sharp initial thermal pulse. The initial melting of the icesheets around 13,000 yr BP was very abrupt³, with a sea-level rise of 24 m in less than 1,000 yr. This pulse occurred at the same time as the ¹⁴C age plateau, followed by a much slower change in sea level and then a second melting pulse around 10,500 yr BP. Insolation in the Northern Hemisphere was at a maximum around 11,000

yr BP and varied smoothly: there is no astronomical explanation for the sharply defined melting pulses. The Younger Dryas cooling episode which has a much stronger signal in the Northern Hemisphere is best explained as the record of a transient⁸ response to a decline in methane forcing.

The sharpness of the pulses, especially the first, is consistent with runaway methane-driven warming. There are, of course, many other possible explanations of the melt pulses, such as those involving surging and collapse of ice sheets, but models that invoke degassing of oceanic CO₂ alone as the prime cause of warming find it difficult to explain the rapidity of change, the rise in CH₄ and the ¹⁴C age plateau. Emission of CH₄, especially from western Siberia, may have been a critical factor in triggering deglaciation.

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Bird migration

SIR—Recent experimental work carried out in Germany^{1,2} has shown that 'migratory restlessness' (*Zugunruhe*) in the Blackcap (*Sylvia atricapilla*) and other passerines has a strong genetic component, thus lending support to the widely held view that so-called partial migration in birds is mainly under genetic control. As discussed by J. Greenwood in a recent News and Views article³, partial migration may be maintained by natural selection as a mixed evolutionarily stable strategy (mixed ESS), with the two strategies having equal pay-offs at equilibrium. Here we argue instead that partial migration could be a conditional strategy in which external, non-genetic factors strongly influence the migratory behaviour of individuals.

Although Berthold's experiments did show that timing and direction of migration were very similar in caged and free-living populations, nothing is known about the link between migratory restlessness in the laboratory and the actual decision making by an individual under natural circumstances. Moreover, recent theoretical work (see ref. 4 and references therein) has shown that a strong genetic component in the migratory trait is no unambiguous proof for partial migration

being a mixed ESS, and that partial migration may well be a conditional strategy in which balanced pay-offs are not necessary. Migratory individuals may simply make the best of a bad job. But the evidence to distinguish between these hypotheses is lacking¹.

The partial migration of the European robin (*Erithacus rubecula*) also has a strong genetic component in captivity⁵. Our work in north Belgium⁶ has shown that most residents are males, whereas other males and most females migrate south. We found that local survival of resident adult males was on average 2–3 times higher than that of migratory individuals (50 per cent versus 17 per cent), and that even during the extremely cold winter of 1984/85, survival of residents was not lower than that of migrants. Resident males were almost twice as likely as migratory individuals to obtain a partner (74 per cent versus 44 per cent). Combining survival and mating success shows that the expected reproductive success of migratory males is 2–4 times lower than that of resident males. It seems highly unlikely that a migrant's lower probability of surviving and mating can be compensated by an equivalently higher breeding success: migratory males arrive later in the season and cannot extend their breeding season in summer because they have to prepare for migration. Our results also demonstrate the conditional character of the migratory trait: females migrate more than males, migratory and resident males tend to use different habitats, and young of early broods are more migratory than those of later broods.

We think, therefore, that partial migration in the European robin is a conditional strategy with unequal payoffs, where individuals are forced to migrate unless they can find a territory in which they have a good chance to survive the winter. Therefore, socially dominant individuals are more likely to be resident.

This conclusion does not contradict the strong genetic basis of migratory restlessness in the species⁵, but it does show the importance of external factors (habitat, social status and so on) in the final decision making. This conditional-strategy hypothesis could be valid for partial migration in general¹, but, given the robin's peculiar winter social system and/or the possible multiple evolution of migratory behaviour³, this remains to be shown.

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