few cases. The assemblage belongs to a high amphibolite or granulite facies.

The gneiss from the agglomerate at Croghan is very similar, though it lacks potash feldspar. That from the basalt is very altered; only coarse sillimanite and quartz remain in a matrix of secondary chlorite, fibrous amphibole and altered glass. Abundant pseudomorphs after garnet can be seen readily, however, and Watts[1] has observed garnet in xenoliths from the area.

The gneisses from the Dungolman River are undoubtedly of granulite grade: they contain the critical assemblage hypersthene–garnet. They are rich in basic plagioclase (about An_{60}), hypersthene, garnet and quartz, and are medium grained and weakly banded. There is some alteration to anthophyllite, chlorite and carbonates.

Other lithic fragments are abundant in the agglomerates. Many compare with phyllites and slates of currently accepted Ordovician age which are exposed in the surrounding Lower Palaeozoic massifs. These rocks are of an extremely low metamorphic grade. That is in strong contrast to the gneisses which are therefore likely to be Dalradian or older. Indeed, the only rocks of similar type in Ireland are pre-Dalradian. The Dalradian everywhere differs in lithology[2–4] and is generally of much lower grade, though it reaches middle amphibolite facies in places. The older Deer Park Schists[4] are also unlike the xenoliths. Gneissic rocks from north-western Mayo[5] and the Rosslare Complex[6,7], which may be Lewisian, are mica bearing and poor in garnet, and of a distinctly lower grade. The only comparable rocks are those from the Precambrian of the Ox Mountains, which Lemon[8] has tentatively referred to the Moinian. These differ in that they contain kyanite.

The gneisses are clearly much older than the Lower Palaeozoic sediments. It is most unlikely that the gneiss has been derived indirectly, from the Old Red Sandstone (ORS) for example. None of the 29 xenoliths has adhering sediment, and gneissic clasts do not occur in the ORS exposed in nearby areas, or in ORS blocks within the agglomerates themselves. The gneiss must have been derived from the sub-Palaeozoic basement.

That is of interest in view of recently proposed plate tectonic models of Precambrian and Lower Palaeozoic history. Most of those require oceanic crust to lie beneath the Southern Uplands and its structural continuation into central Ireland[9–13]. Though some are not clear on the point, others clearly show this to be present even after the final Caledonian deformation. Powell[14] has pointed out that the geophysical evidence conflicts with that idea, and proposed that there is a sialic basement "of Lewisian-type rocks" beneath the Southern Uplands. Jeans[15] has accepted this, and his model shows oceanic crust lying, virtually pinched out, beneath the Midland Valley. The evidence presented here strongly support the latter hypotheses.

It is improbable that the gneiss was derived from a detached slice of sialic crust thrust over the oceanic basement. The localities discussed here are separated by 35 km, and the furthest is 70 km from Strokestown, the nearest point on the northern subduction zone proposed by Dewey[6,7]. It is far more likely that beneath this area there is a true basement of high grade metamorphic rocks. It seems probable that this basement extends beneath the Down–Longford Massif and into the Southern Uplands.

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Reversals of the Earth's magnetic field and climatic changes

It has been suggested that evolution may be influenced by reversals of the Earth's magnetic field[1–3]. It was observed that there were correlations between discontinuities in microfossil assemblages (or evolutionary discontinuities) and reversals of the Earth's magnetic field in deep sea sediment cores[4–6]. This observation was put on a firm base when Hays[7] showed statistically that reversals directly or indirectly exert a selective influence on radiolaria. The explanation offered by Uffen[1,2] and Simpson[3] for the connection between evolution and reversals was that during reversals of the Earth's magnetic field, the intensity of the field would be reduced to a very low value, allowing organisms at the surface of the Earth to be bombarded by increased cosmic radiation normally shielded by the field. This increased radiation should then cause an enhanced mutation rate and hence produce an evolutionary discontinuity. It was, however, shown later that the estimated increase in the mutation rate would be small and unlikely to cause evolutionary discontinuities[8–10].

Two other ways have been suggested in which reversals of the Earth's magnetic field could influence evolution. One way is by the direct biological effect of a magnetic field on organisms; there is a short discussion of this by Crain[11]. The second mechanism proposes that a reversal of the Earth's magnetic field could cause a change in the climate of the Earth and hence indirectly produce faunal extinctions[10].

Here, we shall discuss the second proposed mechanism and speculate on a possible causal relationship between reversals and climate. Evidence has been previously presented (for example refs 12, 13) suggesting a connection between the Earth's magnetic field and climate. Wollin *et al.*[12] showed that the record of mean annual temperature (averaged over 10-yr periods) was inversely correlated with the magnetic field intensity at nearby magnetic observatories. They were, however, unable to suggest what the causal relationship between these two parameters was. King[13] has discussed the possibility that the Earth's field controls in some unknown way the variations in pressure to be found at high latitudes in the troposphere. King has also suggested[14] that solar ionising particles are responsible for some of the correlations to be seen between the yearly mean sunspot number and various meteorological phenomena.

Roberts and Olson[15] have demonstrated a relationship between one climatic parameter and geomagnetic disturbances and have also offered an explanation for this relationship. They have

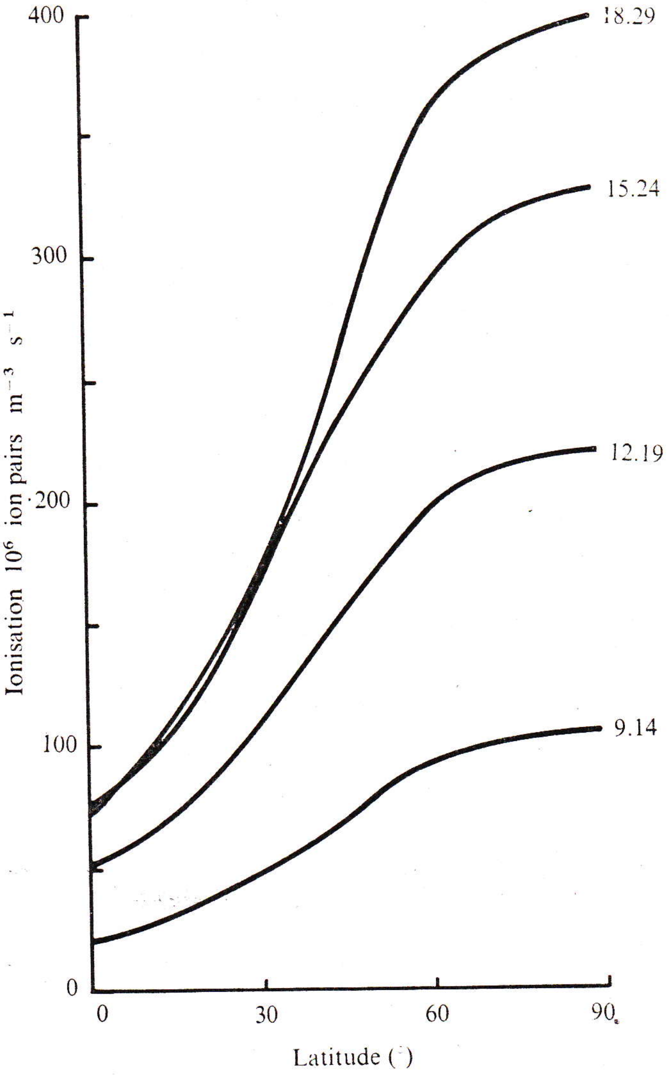

Fig. 1 Ionisation as a function of latitude. Curves are shown for four altitudes (measured in km).

shown[15] that troughs at the 300 mbar level are influenced by geomagnetic disturbances. They found that, during the winter, troughs which moved into the Gulf of Alaska between 2 and 4 d after a geomagnetic storm underwent a greater degree of intensification than did troughs which appeared at the same place and during the same season but not within the 2–4-d time lapse after a geomagnetic storm. They suggest that this intensification may be caused by modification of the black body radiation from the relatively warm North Pacific as a result of increased cirrus cloud cover. It is thought by Roberts and Olson that increased ionisation at the tropopause level, caused by the ionising particles associated with the geomagnetic disturbances, could cause ion-induced nucleation and, hence, enhanced formation of clouds; the increased cirrus cloud cover at high latitudes during the winter results in a decrease in cooling rate which, in turn, leads to the increased vorticity.

A reversal of the Earth's magnetic field must be classified as a major geomagnetic disturbance. It is believed that the period of reduced field intensity during a reversal lasts between 1,000 and 10,000 yr[16,17]. During the time of very low magnetic field intensity, the whole Earth would receive the present-day polar cosmic ray ionisation rate, all other factors being assumed to remain constant. We can estimate this rate by using the data of Saylor *et al.*[18] for latitudinal variations in cosmic-ray ionisation rate as a function of altitude.

Table 1 gives ionisation rates at three different altitudes and at the equator and pole, taken from ref. 18. The top figure in each category gives the rate during a solar activity maximum, and the lower figure gives the rate during a solar activity minimum. Means of the two values are given, and the polar/equatorial ratios of the means are shown in the last column.

Figure 1 shows the mean ionisation rate plotted as a function of latitude for four different altitudes. It can be seen that half or more of the Earth's area at these altitudes would have the ionisation rate increased by a factor of two or more during a reversal, if it is assumed that the polar ionisation rate is applicable to the whole Earth during a reversal. Using these curves and performing a simple numerical integration to determine average ionisation rates over the Earth's surface, it can be shown that the average ionisation increases by factors of 3.03 (for the lowest altitude curve), 2.87, 2.84 and 3.11 (for the highest altitude curve). If Roberts and Olson[15] are correct in assuming that ionisation at such levels in the atmosphere is important for the production of cirrus clouds, then we should expect profound changes in the Earth's climate during a reversal, due to increased cloud cover at lower latitudes.

Table 1 Ionisation rate, (10^6 ion pairs m^{-3} s^{-1}) (measured at a pressure of 101.3 kN m^{-2})

Altitude (km)	Equator	Pole	Ratio
9.144	14.3 28.6 } 21.4	102.4 107.1 } 104.7	4.9
12.192	33.3 71.4 } 52.3	211.9 226.2 } 219.0	4.2
15.240	69.0 85.7 } 77.3	285.7 366.7 } 326.2	4.2

The specific mechanism which Roberts and Olson[15] suggest as being responsible for the formation of cirrus, ion-induced nucleation, is highly speculative. Castleman[19] presents evidence that ions can promote water vapour nucleation at supersaturation ratios considerably below that required for homogeneous nucleation; he suggests, for example, that at the summer mesopause (130 K, water concentration 10^9 cm^{-3}) sufficient supersaturation exists for this nucleation process to be operative. But Castleman does not state if this process would be significant lower in the atmosphere. Montefinale *et al.*[20], in a review of recent advances in the chemistry and properties of atmospheric nucleants, decline to discuss the role of ions because of the lack of information on the primary chemical nature of the ions and, hence, on their modes of action; they exclude ions from the population of active condensation nuclei on the basis of the high water supersaturations necessary for the ions to become active. On the other hand, Montefinale *et al.*[20], suggest that ions, because they electrostrict conspicuous amounts of water molecules, may be responsible for the vertical transport of water under the influence of the electric gradients in the atmosphere. This transport may, in itself, have a significant role in effecting weather changes in response to geomagnetic events.

Because of the general lack of knowledge about the physical and chemical properties of the upper atmosphere, the questions concerning the nature of the mechanism linking geomagnetic disturbances and weather will most probably remain unanswered for some time. But we submit that the relationship between geomagnetic disturbances and weather warrants further invesigation not only because of the short term implications but also because such studies may lead to an explanation of climatic changes on the geological time scale.

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