and ascribed this to low primary productivity of the newly upwelled water[11], but my results suggest that low concentrations of DOC are not caused by low primary productivity, although the concentration of DOC may be low in the source water of the Equatorial Undercurrent.

DOM excreted by phytoplankton and zooplankton may be utilized by microorganisms soon after it has been excreted and this would probably obscure any clear-cut relation between the concentration of DOM and biological activities.

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Geomagnetic Reversals and the Position of the North Magnetic Pole

THE principal magnetic field of the Earth, often called the dipole field, is thought to be caused by a homogeneous dynamo action in the Earth's fluid core[1]. The flow pattern in the core is not known, and there is even controversy as to whether it is in a state of turbulence[2] or whether the flow pattern is smooth and of a scale comparable with the circulation patterns in the atmosphere and oceans. If the flow is large scale and smooth it must be reasonably complicated, for the most simple flow patterns have too great a symmetry and have been shown definitely not to work as regenerative dynamos[3-5].

Evidence is mounting that a further theorem prohibiting symmetry may exist, which is even more restrictive. Braginskii[6] and Tough[7] have derived it in limiting cases, and it is demonstrated by the theoretical dynamo of Herzenberg[8]. It would be that the streamlines of flow cannot have planes on either side of which they show mirror-image symmetry. Thus Herzenberg's dynamo fails to work when the axes of the two rotors are co-planar.

The original Bullard–Gellman dynamo[9] perhaps suffered from this defect, in that further work demonstrated that the numerical process on which it depended did not converge[10]. My recent work[11] on a modification of the early Bullard–Gellman model shows that the dynamo may work when the planes of symmetry are destroyed. Fig. 1*a* shows the original $T_1S_2^{2c}$ dynamo of Bullard and Gellman, with the planes of streamline symmetry marked in as A–A′ and B–B′, and Fig. 1*b* shows my recent $T_1S_2^{2c}S_2^{2s}$ dynamo, in which the two planes of symmetry have been destroyed. Nagata has pointed out[12] that this is perhaps a mechanism for geomagnetic reversals: the flow pattern, usually asymmetric, approaches symmetry and the dipole field decays. Though there has been no generalization of Braginskii's theorem, it nevertheless seems reasonable to expect at this time that the flow in the core has a certain asymmetry.

The great uncertainty of the core motions has been referred to, in spite of the progress made by downward continuation of the observed secular variation[13]. There is, however, one fact on which nearly all dynamo workers are agreed: this is the importance of the Coriolis force, caused by the Earth's rotation, in controlling the core flow pattern[14]. The evidence for this is the coincidence of the geomagnetic dipole with the rotation axis, averaged over periods of geologic time, and tested by palaeomagnetic studies.

The dipole field, controlled by the Coriolis forces, would therefore be expected to be symmetrical about the axis of rotation. When examined closely, of course, it is not exactly parallel: the present geomagnetic dipole deviates by $11\frac{1}{2}°$ (approximately the co-latitude of the North magnetic pole).

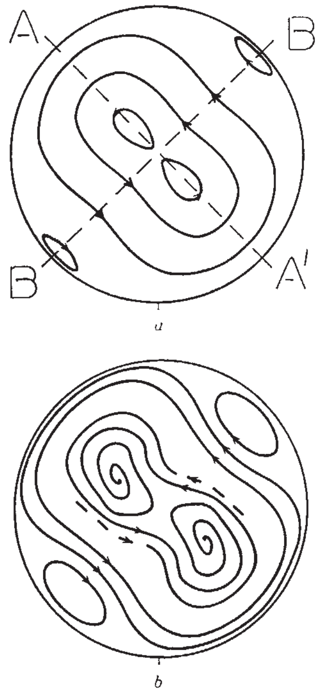

Fig. 1. Streamlines in the equatorial plane of a sphere. *a*, The $T_1S_2^{2c}$ dynamo of Bullard and Gellman, with A–A′ and B–B′ marking the planes of symmetry of the flow pattern; *b*, the $T_1S_2^{2c}S_2^{2s}$ dynamo of Lilley, with the planes of symmetry destroyed.

The purpose of this note is to advance the hypothesis that this deviation of the geomagnetic axial dipole from true North, the expected axis of symmetry, is in fact an expression of asymmetric motion in the Earth's core. It follows that a wandering of the magnetic poles to coincide with the geographic poles may be an indication of the flow in the core becoming symmetrical. If this should happen dynamo action will be lost and the dipole field will decay, perhaps to grow again in the opposite direction (that is, reverse), when the flow pattern once more becomes asymmetric. As a corollary, strong dipole fields may accompany a large deviation of magnetic North from true North.

It may be possible to test this hypothesis using palaeomagnetic data from secular variation studies, such as that of Doell and Cox[15], and from studies of geomagnetic reversals. Not only would one look for small displacements of the magnetic from the geographic pole at times of reversals, but also the corollary of strong palaeo-fields coinciding with large displacements should be examined. Confirmation of the hypothesis would provide valuable information on the fundamental problem of the dynamo process in the core.

The recorded measurements of the geomagnetic field over historic time give some support to this idea. As discussed by Nagata[16], the recent secular variation has consisted of a decrease in the strength of the dipole field of 0·05 per cent per year, accompanied by a rotation of the dipole towards the geographic axis of 0·02° of latitude per year. These figures are reasonable if a 100 per cent decrease were to accompany a $11\frac{1}{2}$° rotation.

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Eclogites as Products of Thermal Metamorphism

STUDIES of reported eclogites associated with gabbroic rocks and recent experimental data suggest that eclogites can occur as products of thermal metamorphism. This observation seems evident when the descriptions of certain rock series are reviewed, but it is rather unexpected given the general context accorded to the concepts of the eclogite or eclogite facies. The mechanism which produces these eclogites is the intrusion of a basic magma into a series of rocks constrained at high pressures (> 6 Kbar).

The original definition of the term eclogite, and consequently the eclogite facies, given by Haüy[1] has been interpreted and modified many times. In the context of present petrographic knowledge and petrologic interpretation, the following definition will be used here: an eclogite is a rock composed primarily of omphacite (diopsidic clinopyroxene in which jadeite predominates over Tschermak's molecule) and almandine-pyrope-grossular garnet[2,3]. The most important petrographic criteria used to establish the existence of the eclogite facies is that omphacite and garnet are stable together in rocks of approximately basaltic composition.

A general definition of the pressure–temperature conditions under which the eclogite facies exists is given by Turner[3] and more precisely by Velde *et al.*[4] for lower temperatures, and O'Hara[5] and Ringwood and Green[6] for higher temperatures. The notable character of this facies is that it is separated from the amphibolite facies by a boundary of negative slope ($P=x$, $T=y$) and from the granulite facies by a positive slope (Fig. 1).

A number of petrographic studies report spatial relations between amphibolite, eclogite and granulite facies rocks and gabbros over short geographic distances. These studies can be divided into three groups.

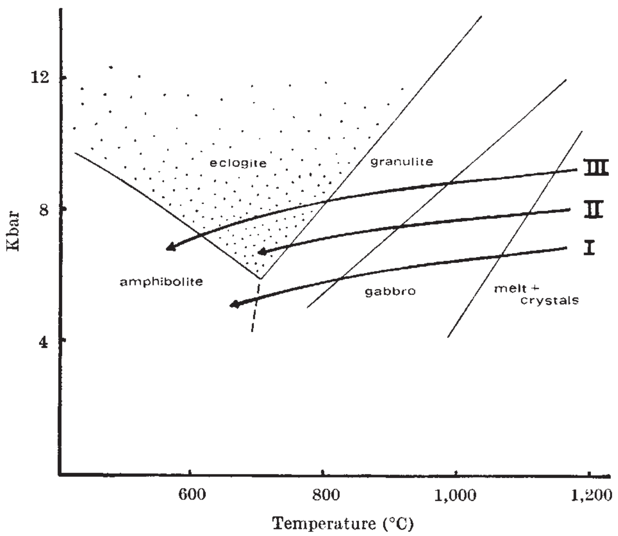

Fig. 1. Representation of the pressure-temperature limits of the eclogite facies and its relation to the amphibolite and granulite facies and the conditions of plutonism at high pressures. I, II, and III indicate the cooling path taken by magmas intruded at different pressure conditions as discussed in the text.

(1) Coronites or garnet hyperites[7–9] show the transition between gabbro, granulite facies rocks and amphibolites. Typically, newly formed garnets are found as reaction rims between plagioclase and olivine or hypersthene grains, but the gabbroic texture of the rock is usually preserved in spite of the partial destruction of the original igneous mineralogy. The new assemblage is augitic pyroxene, garnet and plagioclase. This association is, in its turn, replaced by a garnet amphibolite rock at the outer margins of the basic bodies as they come in contact with a gneissic country rock. The thickness of the original plutonic rock units varies between metres and kilometres.

(2) A study by Vogel[10] in northern Spain illustrates the transition between granulite and eclogite facies rocks. Mineral data show that the passage between granulite (garnet-clinopyroxene-plagioclase) and eclogite (garnet-omphacite) is accompanied by a change in pyroxene jadeite content from 6 per cent to 20 per cent while Tschermak's molecule content remains near 6 per cent. Relicts of gabbroic mineralogy and texture found in the granulite facies rocks demonstrate the plutonic origin of the massif.

(3) The transformation of gabbro to amphibolite through an intermediate granulite and eclogite stage has been described in France[11,12] and in Japan[13–15]. The authors in the first case justify the eclogite terminology largely through the observed disappearance of plagioclase and the occasional presence of kyanite in essentially garnet-clinopyroxene rocks. The Japanese studies, however, indicate a decided increase in jadeite content in the clinopyroxene towards the exterior of a basic massif (Jd_0 to Jd_{10}). Each of the studies denotes a pronounced concentric aspect of the zones in the intrusive bodies. Frequently a gabbroic texture is preserved in the central parts, passing successively into garnet pyroxenite, eclogite and eventually amphibolite at the borders. Piboule and Coffrant[12] describe garnet or epidote amphibolites, and Shido[15], Miyashiro[14] and Seki and Banno[13] a succession of first epidote amphibolites and then glaucophanites as the border assemblages. In each case the amphibolitized outer portion of the basic body is in the same metamorphic facies as the country rock.

Fig. 1 shows the probable pressure–temperature gradients under which the basic intrusives crystallized for the three cases I have discussed. The original intrusive material is considered to have been originally of basaltic composition. In all three examples the centre of the