the Bathonian of the East Midlands[6]. Upper Jurassic (?Kimmeridgian) tuffs have been recorded from the Brent area of the North Sea[7], and a possible tuff reported in the Kimmeridgian beds of Andøy, Norway[9].

If its inferred Jurasic age is correct, the Piper–Forties volcanic centre cannot have been the source of the Upper Jurassic pyroclastic deposits of Skye, although it is possible that the North Sea eruptions are represented in Skye by the high proportion of montmorillonite in Middle Jurassic beds (ranging from the Dun Caan Shales, Bajocian (Aalenian), *Ludwigia murchisonae* zone to the Ostracod Shales, ?Lower Bathonian).

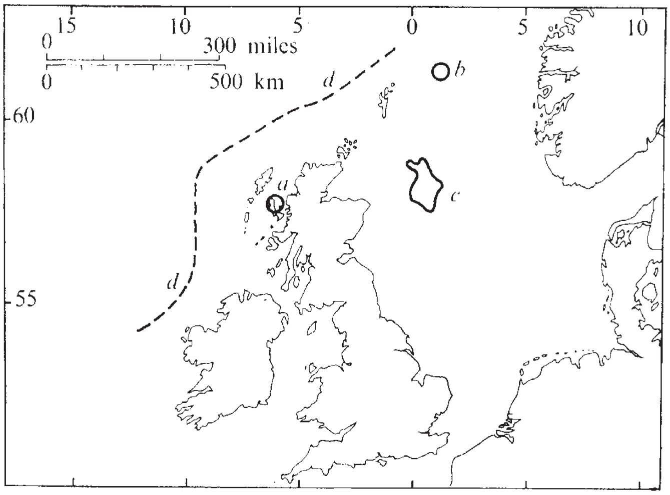

Fig. 1 Location of Upper Jurassic tuffs in Skye (*a*) and in the Brent area of the North Sea (*b*). The Piper–Forties volcanic centre (*c*) is essentially of Middle Jurassic age and Upper Jurassic volcanism may have occurred in a zone of potential rifting (*d*) to the west and north of Britain.

A possible alternative source area for the Upper Jurassic tuffs is the zone now represented by the series of NE–SW troughs[10] which follow the present-day shelf margin to the west and north of Scotland. The closest of these, the Rockall Trough, may not have developed until Cretaceous times but a period of initial rifting and volcanism may have begun as early as the Middle Jurassic[11]. With the limited information at present available it seems most likely that the volcanic source for the Skye and perhaps Brent tuffs lay within this zone of potential late Jurassic rifting (Fig. 1).

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Received October 26; accepted December 1, 1976.

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An unusual electromagnetic surface force

IN a recent experiment[1] a disk of high dielectric constant material (barium titanate) was suspended as a torsional pendulum in an intense axial magnetic field. It was found that if a radial electric field was applied to the disk in time quadrature with the magnetic field a substantial torque was produced which, to within experimental accuracy (<5%), was in agreement with a force density $\dot{\mathbf{P}}\times\mu_0\mathbf{H}$ in the disk. The surprising feature of the torque was that it had a time average, contradicting the 'Abraham force' which predicts a force density of $\partial(\mathbf{P}\times\mu_0\mathbf{H})/\partial t$ with zero time average. The experiment seemed to suggest that the quantity $\dot{\mathbf{P}}\times\mu_0\mathbf{H}$ does not produce a force since its time average would be equal but of opposite sign to the time average of $\mathbf{P}\times\mu_0\dot{\mathbf{H}}$.

In order to obtain a high electric field strength in the dielectric a thin metal coating was evaporated on to the outside edge of the disk and the edge of the central hole. The electrical resistance of these coatings was sufficiently high so that induced currents due to the time-varying magnetic field had a negligible effect on the total electric and magnetic fields. As a check, cuts were made in the coatings, thereby preventing any circulating current flow, with no observable change in the behaviour of the system.

On further investigation it seems that the metal coatings have a most unexpected effect, as may be seen from the following argument. Suppose that air gaps are created between the coatings and the dielectric surfaces, the gaps being small enough to cause no significant perturbation of the electromagnetic fields. Three mathematical closed surfaces can be described, one just outside and surrounding the dielectric and the other two just outside and surrounding the metal coatings. The moment of the electromagnetic surface stress for each surface can be obtained from the Maxwell tensor by evaluating the integral

$$\int \mathbf{r}\times[\varepsilon_0\mathbf{E}\,(\mathbf{E}.\mathbf{n})+\mu_0\mathbf{H}\,(\mathbf{H}.\mathbf{n})-\tfrac{1}{2}(\varepsilon_0\mathbf{E}^2+\mu_0\mathbf{H}^2)\,\mathbf{n}]\,\mathrm{d}S$$

For the surface enclosing the dielectric it may be shown that this has zero time average but for the surfaces enclosing the metal coatings the moment reduces to $\int\mathbf{r}(\varepsilon_0E_r)E_\theta\mathrm{d}S$ where the latter is taken over the parts of the mathematical surfaces in the air gaps. When this is evaluated the measured value of torque results. The interpretation is that an electrical charge of density $\varepsilon_{0r}E$ is induced on the surface of the coating adjacent to the dielectric and a drag action is exerted on this surface charge by the azimuthal electric field component E_θ.

In light of this, the experiment verifies that the total mechanical force on the dielectric has no time average, as is consistent with the Abraham force. That the term $\mathbf{P}\times\mu_0\dot{\mathbf{H}}$ produces a force can be understood by considering the Kelvin force $(\mathbf{P}.\nabla)\mathbf{E}$ which may be written $\frac{1}{2}(\varepsilon-\varepsilon_0)\nabla\mathbf{E}^2+\mathbf{P}\times\mu_0\dot{\mathbf{H}}$. In the above experiment $\mathbf{E}$ is independent of θ and so $\nabla\mathbf{E}^2$ does not contribute to the torque. A further conclusion to be drawn is that the experiment is consistent with a force density in the dielectric given by $\dot{\mathbf{P}}\times\mu_0\mathbf{H}+(\mathbf{P}.\nabla)\mathbf{E}$ provided $\mathbf{E}$ is the macroscopic internal field and not a 'local' field as proposed in different forms by a number of authors.

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Received October 26; accepted November 18, 1976.

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