EARLY TERTIARY FIELD REVERSALS RECORDED IN VOLCANIC ASH LAYERS OF NORTHERN DENMARK

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Measurements of the natural remanent magnetisation (NRM) polarity of the volcanic ash layers of Eocene age in Denmark have shown three reversely magnetised zones in the stratigraphical column. The existing evidence on the basis of both field and laboratory tests made to ascertain the stability of NRM, is indicative of the geomagnetic polarity reversals during the early Tertiary. A detailed study of the remanent magnetism of the whole series of ash beds may have potential applications in the local structural and correlation problems.

The origin of about 200 volcanic ash layers interbedded in the Mo-clay and other marine clays of Eocene age in Denmark, has been a subject of great interest to the geologists. The ash beds outcrop among other places in an area around the Limfjorden (see fig. 1), and the stratigraphical age of the Mo-clay in which the ashes are distributed has been established within a fair degree of certainty to be lower Eocene (Stolley, 1899; Gripp, 1964; Bonde, 1966). Petrographical investigations (Bøggild, 1918; Norin, 1940; Noe-Nygaard, 1965) and isopach studies (S. A. Andersen, 1937) led some workers to suggest that the volcanic centres which have furnished the ashes (mainly basaltic in character) should be looked for north or north-west of Denmark. This view is also supported by the recent geophysical investigations in the Skagerrak where the simultaneous occurence of a fairly extensive gravity high (O. B. Andersen, 1966) and a prominent aeromagnetic anomaly (unpublished maps of the U.S. Naval Oceanographic Survey and the Norwegian Geological Survey, 1965) strongly influenced by the remanent magnetisation (Sharma, 1969) is indicative of the location of a buried volcanic mount in the north-west part of the Skagerrak. Primarily to examine the possibility of any relationship between the Eocene ashes and the volcanic centre in the Skagerrak, a study of the remanent magnetisation of the ash beds was undertaken by the author. This communication presents the first results of the study of the direction of the remanent magnetisation of the ash layers, which although at present being far from comprehensive are nonetheless significant to warrant further detailed investigations.

For preliminary investigations sampling was made only at one locality, Feggeklit (see fig. 1). The natural remanent magnetisation (NRM) of oriented samples from a few layers as measured by a fluxgate millioersted-

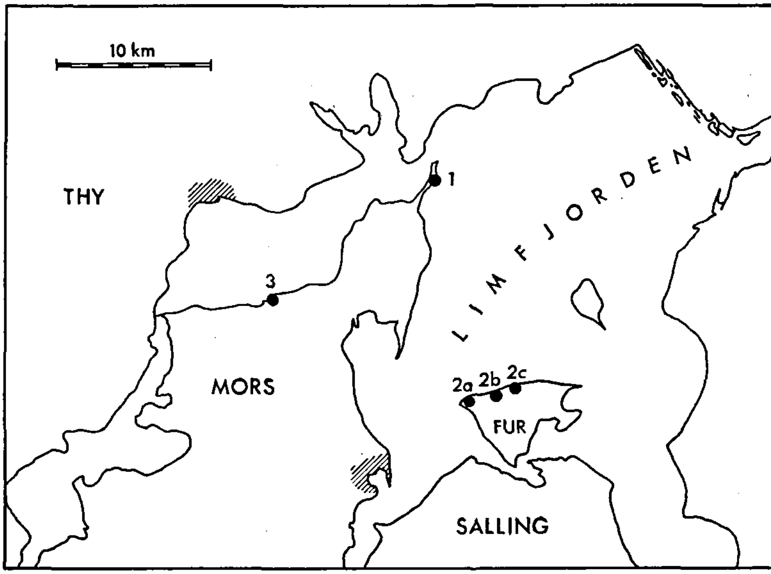

Fig. 1. Map showing the main sampling localities in northern Denmark. 1: *Feggeklit.* 2a: *Knuden.* 2b: *Stolleklint.* 2c: *Østklint.* 3: *Hanklit.*

meter showed reverse direction whereas the rest of the layers showed the direction of NRM to be parallel to the present geomagnetic field. In view of these encouraging results, sampling was extended to other localities. The three main localities where the sampling was undertaken for the current investigations are shown in fig. 1. Two distinct methods were employed for collecting oriented samples. For fairly compact and well cemented layers oriented blocks were chipped off, whereas relatively soft and less consolidated layers were sampled in hard plastic tubes (2.5 cm i diameter) and oriented with a especially designed core-orientation device. The orientation accuracy in both of these methods was better than 4° for most of the samples. Since the ash layers have been dislocated by Quaternary glaciers and show marked disturbances caused by ice-tectonics (Gry, 1940 and 1965) the original declination of the fossil magnetisation is indeterminable. However, the up and bottom of the layers being easily recognisable from the varying grain size of the ash particles (in the range ca. 0.5 mm to $<$ 0.01 mm), an interpretation solely based on the inclination of the NRM can be attempted. In order to ascertain whether the original direction of NRM has been appreciably altered by post-depositional effects (tectonic deformation, surface weathering etc.) certain layers were sampled at different sites on both sides of the folds at varying tilts.

For the current investigations the preparation of specimens was restricted to layers of thickness $\geqslant$ 4 cm, and cylinders 2.5 cm in diameter and length or cubes of varying size (2.5 to 5 cm in edge length) were cut. Almost all the prepared specimens showed NRM measurable by the four-probe fluxgate differential magnetometer device (Sharma, 1968). The intensity and inclination of the remanence vector was measured for each specimen. The stability of the primary remanent magnetisation (believed to be the depositional remanent magnetization, DRM) in relation to the secondary viscous magnetisation effect (VRM) caused by a continued action of the geomagnetic field over a long period had to be priorly ascertained. An a.c. demagnetiser for rock specimens recently built (details to be published elsewhere) at the palaeomagnetic laboratory of the Geological Institute was used for the above purpose. After making some tests on six pilot specimens of both basaltic and dacitic samples of varying grain size, a standard 'cleaning' intensity of 300 Oe (peak value) was used for all specimens to destroy the soft component of VRM while retaining a measurable fraction of the relatively hard original DRM. Those specimens which after 'cleaning' lost more than 60 % of the initial NRM intensity were considered magnetically unstable and as such rejected.

The results of measurements are summarised in the table below. It would be seen that in general the inclinations of NRM of both normal and reversely magnetised layers are less steep than the present geomagnetic field inclination of the sampling sites (approximately 70°) and also on average less than the palaeomagnetic inclination worked out for the early Tertiary Atlantic Province (Tarling, 1967). This may possibly be attributed to the effects of inclination and or bedding errors usually associated with the remanent magnetism of the deposited sediments (Griffiths *et al.*, 1957). The behaviour of few specimens of the layer no. 101 is rather abnormal and requires more detailed investigations.

Ash layer	Site 1		Site 2		Site 3	
No.	N	I_m	N	I_m	N	I_m
–13nb			5	–49°	3	–55°
–12nb			3	–42°	4	–38°
3ba	3	62°	4	53°	3	58°
9ba	2	51°	6	47°	3	45°
19da	4	–35°	5	–40°	4	33°
31ba			6	57°	3	48°
61ba	3	47°	5	55°	2	42°
94ba	2	52°	3	49°	3	51°
101ba	3	3°	5	–17°	3	–42°
102ba	4	–45°	6	–56°	4	–52°
114ba	2	–11°	4	–37°	3	–31°
118ba	4	57°	5	49°	3	54°
130ba			3	44°	3	50°

Table showing *NRM* vector inclination of some Eocene ash layer samples from Denmark. The samples are listed in stratigraphical sequence from bottom to top, numbering after Bøggild (1918). *N*, number of specimens measured. *Im*, the mean inclination, positive if measured above the horizontal. *ba*, basaltic in character. *nb*, nearly basaltic in character. *da*, dacitic in character.

The hitherto made measurements have shown at least three reversals of magnetisation in the stratigraphical column of ash beds, and the question whether these are due to 'field reversals' or 'self reversals' could now be examined. Judging from the stability criteria so far applied to the samples (fold test, a.c. demagnetisation analysis) together with the fact that reversals occur uniformly in the same layers at localities far apart, and that the three reversely magnetised layers are petrographically and chemically of different composition, the possibility of any physio-chemical self-reversal process affecting the NRM of the three layers at different horizons in a similar way at all the sampling sites is rather difficult to be entertained. Unless the more sophisticated physical tests (study of coercivity spectrum, hysteresis loop, thermal properties of magnetic grains) and mineralogical investigations (in particular the oxidation state of magnetic minerals) which are planned to be undertaken in future show a definite statistical correlation between petrology and polarity, the explanation based on the geomagnetic polarity reversals during Eocene seems at present to be acceptable.

In recent years there has been an overwhelming evidence for the frequent reversals in polarity of geomagnetic field especially during early Tertiary (Irving, 1964; Smith, 1967; Abrahamsen, 1967), and the latest estimate of the average duration of a normal or reverse polarity as determined from absolute dating of Quaternary and Tertiary lavas is about 0.4 m.y. (Cox & Dalrymple, 1967; Dagley *et al.*, 1967). The occurence of 3 or more polarity inversions in Eocene ashes might, therefore, be suggestive of a sedimentation period probably lasting about 3 m.y. or more for the whole series. For attempting to mark a well defined beginning and duration of each reversal in the stratigraphical column of ash beds, an extensive sampling of layers exposed at various other localities has recently been made. Many of the intermediate layers lying in between thick ones are of very small thickness < 1 cm, and as such demand special techniques for preparation of cylindrical specimens to be measured with great precision by a sensitive spinner type magnetometer (PAR SM-1 unit with digital display) recently installed at the palaeomagnetic laboratory of the Geological Institute of the University of Copenhagen.

At the present stage of investigations, it might be purely hypothetical to foresee the possibility of marking divisions of geomagnetic polarity epochs during lower Eocene and of their eventual comparison with the polarity records of the deep-sea cores from mid-Atlantic and Pacific (Heirtzler, 1968). Much, of course, would depend on whether or not any significant age difference is found between the normal and reversed zones. Nonetheless, some other applications seem more obvious. Magnetisation polarity may be used as a correlation tool in identification of ash beds lately exposed at new localities. Further, a detailed study of palaeomagnetism and magnetic properties of the ash layers might be helpful in geologic correlation of the Eocene ashes with the volcanic centre in the Skagerrak and other Tertiary igneous formations of Brito-arctic province and Fennoscandian border zone. Accurate measurements of declination of the NRM in the ash beds at a locality might indicate the direction of the relative rotational movement of beds during glacial dislocations.

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Dansk sammendrag

Målinger af den naturlige remanente magnetisme (NRM) i eocæne vulkanske askelag har vist tre reverst magnetiserede niveauer. Det kan ikke være en diagenetisk proces, da der er god overensstemmelse mellem de spredte lokaliteter. Den reverse magnetisering må være sket tidligt i Tertiær. De anvendte metoder kunne tænkes at få betydning for korrelation og strukturel analyse af de istektoniske forstyrrelser.

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