THE PALAEOMAGNETISM OF SOME PRECAMBRIAN ROCKS FROM THE ITIVDLEQ REGION OF WEST GREENLAND

by

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ABSTRACT

Palaeomagnetic investigations of dykes and gneisses at 22 sites in a high grade Precambrian terrain in the Itivdleq region of West Greenland reveal that all rocks are similarly magnetized and yield a mean pole at 13.4°N, 284.0° E ($dp = 4.6°$, $dm = 6.5°$). The palaeomagnetic results show many features attributable to magnetization during very slow cooling caused by gradual uplift and erosion, some of these features being analogous to the slow cooling effects seen in the radiometric record of many high grade terrains.

It is shown that if erosion rates in the Precambrian were approximately similar to those at the present time then the resulting cooling rates were probably of the order of a few degrees per million years, and that with the range of magnetic blocking temperatures typical of many rocks this implies a magnetization period of tens of millions of years for each specimen. These erosion rates also imply that rocks from any original structural level would have passed through the isotherms corresponding to their effective range of blocking temperatures tens of millions of years earlier than rocks originally a few kilometers deeper. If apparent polar wander (a.p.w.) was occurring during this cooling period then rocks at different structural levels would acquire different magnetizations, and within any rock grains with different blocking temperatures would also acquire different magnetizations.

Most sites show low within-site scatter so that the site mean poles are precisely defined, thus allowing the effects of slow cooling to be more clearly recognised. Site mean poles fall along a linear trend which apparently represents a segment of the Laurentian a.p.w. path. There is some evidence that this may be due to the sampling sites having been originally at different structural levels. Between-site scatter (apart from that due to a.p.w.) is unusually low and appears to be due to the fact that slow magnetization has averaged out the effects of secular variation. Progressive

a.f. demagnetization at medium and high fields caused the mean pole at many sites to move systematically along the linear trend, presumably due to the demagnetization of grains with successively higher blocking temperatures and therefore successively older magnetizations, and so defines the sense of time along the a.p.w. path segment. All specimens were magnetized with the same polarity, and this implies that the terrain cooled through its range of blocking temperatures either during a long period of constant polarity of the earth's field, or in a period of biassed reversals when one polarity was dominant.

The magnetizations were probably acquired over a period during the interval approximately 1650 - 1850 m.y. when K-Ar clocks in the area were being set, and are in good agreement with results from rocks of similar age from many other parts of Laurentia.

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Chapter 1

INTRODUCTION

This thesis describes the results of palaeomagnetic investigations carried out by the author on material collected with Dr. G. E. J. Beckmann in the Summer of 1973 from an area around the settlement of Itivdleq, about 40 km south of Holsteinsborg on the west coast of Greenland (see Figures 2.1 and 2.2). During the course of the field-trip material was also collected from the island of Sagdlerssuaq and adjacent islets some 15 km north of Itivdleq, and this material has been the subject of a separate palaeomagnetic and geochronological investigation at Newcastle University (Beckmann and Mitchell, 1976), the results of which are discussed in the latter part of Chapter 8.

The sampling area is located on the boundary between the Proterozoic Nagssugtoqidian mobile belt to the north and the Archaean craton to the south, and consists of high-grade (amphibolite and granulite facies) gneisses cut by more or less undeformed dolerite dykes. At the beginning of this study it was thought that the gneisses might yield an ancient pole corresponding to the Nagssugtoqidian metamorphism, and that the dykes would yield a younger pole corresponding approximately to the time of dyke intrusion. It was also thought that a proposed second field-trip visiting localities up to 100 km south of Itivdleq would allow material to be collected from sufficiently far into the Archaean craton for poles corresponding to Archaean metamorphic events to be obtained. Thus it was originally hoped that this study might define three separate points on the North American Precambrian apparent polar wander (a.p.w.) path. However, as the author's understanding of the geology of the area, and of the significance of palaeomagnetic results from high-grade plutonic terrains, gradually increased, and as the palaeomagnetic results themselves began to appear, it became apparent that the original objectives of the project would not all be achieved, but that other and possibly more interesting investigations might take their place.

It was clear from the earliest results that both dykes and gneisses had practically identical magnetizations, and therefore had probably been magnetized at the same time. As none of the gneisses sampled were adjacent to dykes it was evident that this was not a "baked contact" effect, but was due to some event which had caused the simultaneous magnetization of all the rocks in the area. The obvious candidate for this event was cooling caused by gradual uplift and erosion of that area of the crust some time after dyke intrusion. This idea was consistent with several lines of geological evidence which indicated that the country rock gneisses were at high metamorphic temperatures, probably at least 400 - 600° C, at the time the dykes were intruded. Also, it was being noted by several workers that the very slow rates of cooling inevitably experienced by high-grade metamorphic terrains probably causes magnetic blocking temperatures to be considerably reduced, possibly to as low as 200 - 300° C. Thus it appeared that at the time of dyke intrusion the temperature of the country rock gneisses (which of course would also be the temperature to which the dykes initially cooled) was far higher than the effective magnetic blocking temperatures, and so it was to be expected that the dykes and gneisses would have the same magnetization, as both would have become permanently magnetized only when subsequent unroofing reduced the temperature of that level of the crust to about 200 - 300° C.

Thus it was realised that the magnetizations being measured in the Itivdleq rocks were "uplift and cooling" magnetizations which probably post-dated the Nagssugtoqidian metamorphism and dyke intrusion by at least tens and possibly hundreds of millions of years, and that these earlier events had taken place at such elevated temperatures that no record of the magnetic field at the time had been preserved. As it happened the proposed second field-trip to sample material in the Archaean craton to the south of Itivdleq did not materialise due to lack of funds, but it is likely that if it had taken place the rocks collected would have shown magnetizations similar to those found at Itivdleq. In fact Fahrig and Bridgwater (1975) sampled along the west coast of Greenland from Itivdleq down to Godthaabsfjord (in the centre of the Archaean block) and found magnetizations which were essentially the same at all localities and which were virtually identical to those reported here for the Itivdleq area. As discussed further in Chapter 8 it appears that this whole area of crust experienced uplift and cooling to magnetic blocking temperatures at about the same time, and so contains magnetic information about this time interval only.

Thus instead of yielding two or possibly three ancient pole positions it became clear that the study would produce essentially only one ancient pole. However, as the study progressed various interesting and unusual features of the palaeomagnetic results became evident, features which were explicable in terms of the very slow cooling that these rocks had experienced. This prompted the author to make a detailed analysis of the various effects which slow cooling should have on the palaeomagnetic record of a plutonic terrain, and to ascertain how many of these effects could be detected in the palaeomagnetic results of this study. As the study proceeded it became apparent that many if not all of the slow cooling effects which could be predicted theoretically were evident in the results, and consequently the theoretical and practical investigation of these effects became one of the main parts of the project. As explained in later chapters it is believed that these slow cooling effects allow a whole segment of the a.p.w. path to be defined with unusual accuracy, and also indicate the sense of time along the segment. They may also be useful in solving certain structural problems.

This introductory chapter concludes with a brief review of the way in which the material of this thesis is arranged. Chapter 2 includes a general introduction to the geology of south-west Greenland, and a more detailed account of the region containing the sampling area. (Detailed descriptions of the individual sampling sites are given in Appendix A.) Chapter 3 contains a brief account of the field techniques used, and a description of the equipment available in the palaeomagnetic laboratory. It also includes an account of the re-design of some of this equipment which the author carried out in the early stages of the project. Chapter 4 (together with appendices B and C) contains all the basic palaeomagnetic results, and also includes a certain amount of interpretation of these results. Chapter 5 includes discussions of erosion rates at the present time, the relationship between erosion rate and cooling rate, and also the possible cooling rates that may have been experienced during erosional cooling in the distant past. The chapter concludes with a description of the effects that slow cooling due to this cause has had on the radiometric record of plutonic terrains. Chapter 6 is a detailed analysis of the various effects that slow erosional cooling might be expected to have on the palaeomagnetic record, and in Chapter 7 the slow cooling effects evident in the Itivdleq palaeomagnetic results are described and discussed in detail. Finally, in Chapter 8 the age of the Itivdleq magnetization is discussed, and also its relationship to other magnetizations of approximately similar age from North America.

Chapter 2

REGIONAL AND LOCAL GEOLOGY

2.1 INTRODUCTION

The rocks whose palaeomagnetism forms the subject of this study were collected from an area about 25km across in the region around Itivdleq, a small settlement on the west coast of Greenland about 40 km south of Holsteinsborg. In order that the regional setting of this area can be appreciated a general review of the geology of south-west Greenland is given, followed by a more detailed account of the geology of the region containing the sampling area. Detailed descriptions of the individual sampling sites will be found in Appendix A.

2.2 THE GEOLOGY OF SOUTH-WEST GREENLAND

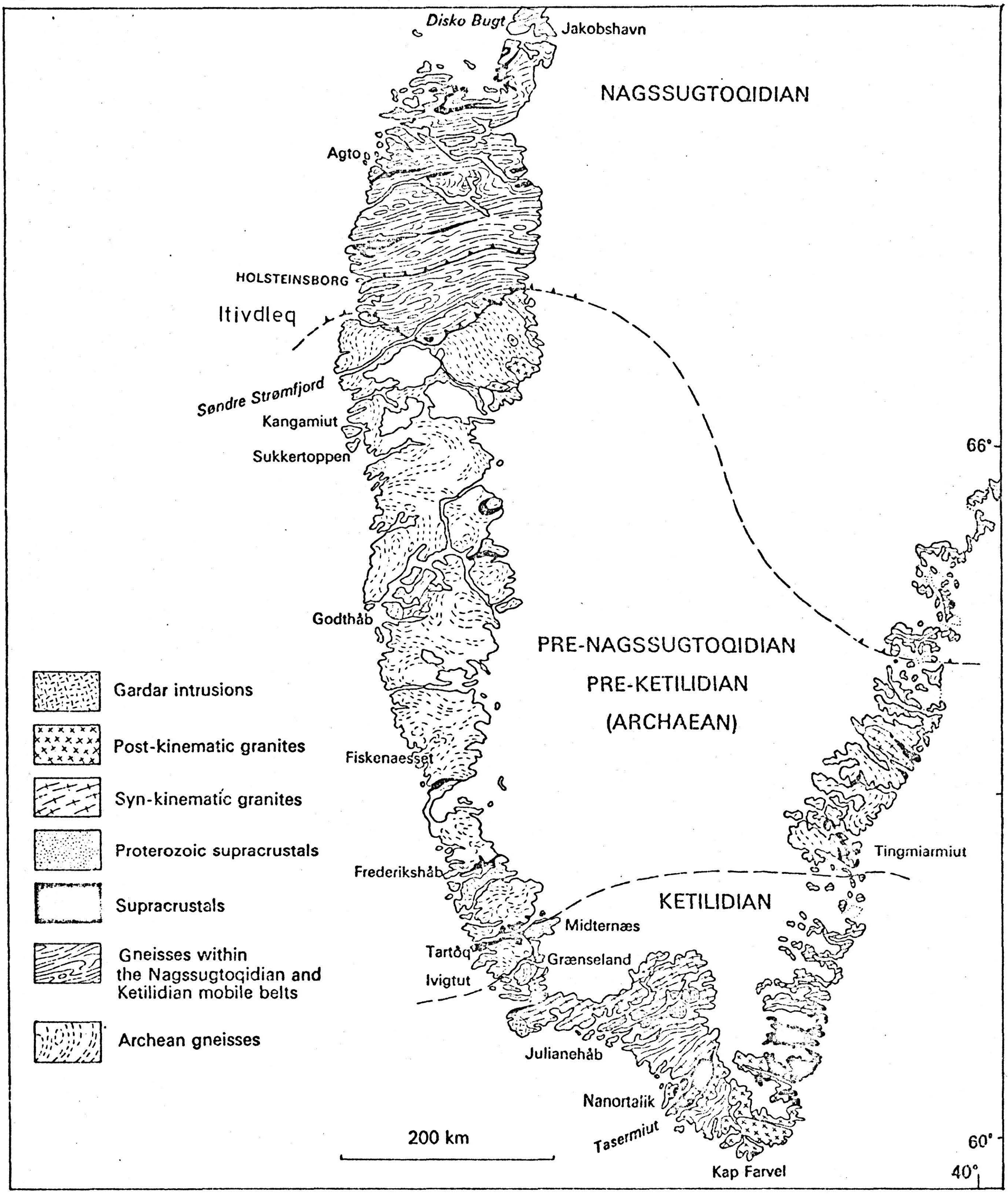
2.2.1 Introduction

The main features of the geology of south-west Greenland are shown in Figure 2.1. It can be seen that all the rocks exposed are Precambrian, there being a central block of Archaean age bounded by the younger Nagssugtoqidian and Ketilidian Proterozoic mobile belts to the north and south respectively. It will be noted that the sampling area lies in the region of the Archaean/Nagssugtoqidian boundary.

There are several recent general papers covering various aspects of the geology of south-west Greenland, for example Bridgwater, Escher and Watterson (1973), Bridgwater, Watson and Windley (1973) and Allaart, Escher and Kalsbeek (1974), and much of the following review is based on these articles.

2.2.2 The Archaean Block

This block forms the major part of the North Atlantic Archaean craton, smaller segments of which are now located along the Labrador coast



THE GEOLOGY OF SOUTH-WEST GREENLAND

(From Allart et al., 1974)

FIG. 2.1

of Canada and in north-west Scotland. The block is dominated by amphibolite or granulite facies gneisses of tonalitic to granitic composition. Supracrustal sequences, generally at high metamorphic grade, typically make up less than 15% of the exposed area. The block is therefore of the high-grade gneiss type, and contrasts with some other Archaean terrains such as the Superior province of Canada and the Rhodesian-South African craton, which are composed mainly of low-grade supracrustal greenstone belts and massive granites. It has been suggested (Windley and Bridgwater, 1971) that the high-grade gneiss terrains may represent a deeper crustal level than the greenstone belt - granite terrains, and that some of the small supracrustal belts found in high-grade terrains represent the root zones of originally much more extensive greenstone belts.

This Archaean block is currently of some interest as it contains the oldest rocks yet discovered on the earth's surface. For example, the Amitsoq gneisses from the Godthab area have yielded ages of 3700 - 3750 m.y. by Rb-Sr and Pb-Pb whole rock isochron dating, and by U-Th-Pb dating of zircons. In the Isua area about 150 km north-east of Godthab a sequence of medium-grade supracrustal rocks which includes clearly water-lain sediments has been dated at 3760 ± 70 m.y.

Large areas of the block were affected by a metamorphic and tectonic episode which terminated between about 2900 and 2800 m.y. ago, and it is only in "windows" which escaped this reworking, such as Godthab, Isua and a few other localities, that the older geological and isotopic events can be recognised. It is considered that at 3800 m.y. a granite basement similar to the Amitsoq gneisses extended over much of the block, and had probably been formed by the recrystallisation and deformation of an originally more uniform granite suite. Between 3800 and 2800 m.y. ago, as far as can be determined from the isolated windows available, most of this early basement was reworked, and interleaved with highly metamorphosed supracrustals, with layered anorthositic complexes, and particularly with abundant tonalitic gneiss derived from the deformation of younger intrusions.

The metamorphic episode which terminated at about 2800 m.y. was of high amphibolite or granulite facies, and the broadly contemporaneous deformation produced the characteristic structural style of the block described below. Assemblages of cordierite granulite facies are widespread, and relict granulite facies assemblages partly replaced by assemblages of amphibolite facies are probably even more common, suggesting that a large part of the block may have approached granulite grade at the height of the metamorphism. In the Godthab window which escaped the effects of the 2800 m.y. reworking the gneisses are of amphibolite facies and show no evidence of having suffered retrogression from granulite facies.

The structural style produced during the 2800 m.y. reworking over much of the block is typical of several other high-grade gneiss terrains. On a regional scale there is a lack of a dominant linear trend, and the tectonic pattern is characterised by fold interference structures such as domes, basins and refolded folds. These are on a scale of a few kilometres up to a few tens of kilometres and typically have steeply dipping foliations. In some cases these structures can be shown to have been formed by the superposition of one fold phase on another, but more often they were probably produced by vertical movements, possibly caused by gravitational instability in a system where a predominantly dense basic supracrustal sequence overlies a basement of granitic composition.

Following the widespread 2800 m.y. metamorphic and tectonic episode further activity became localised in specific areas. Scattered relics of low-grade supracrustals giving ages of 2800 to 2500 m.y. were incorporated in the craton, and numerous calc-alkaline intrusions and some carbonatites were intruded in the general period 2800 to 2000 m.y. Between 2600 and 2000 m.y. several widespread swarms of basic and ultrabasic dykes were intruded, including the two basic dyke swarms emplaced in the northern part of the block which are discussed below. Extensive faulting lasting until about 1850 m.y. appears to have marked the final stages of stabilisation of the block.

2.2.3 The Ketilidian Mobile Belt

The Ketilidian mobile belt is characterised by low to medium pressure high temperature metamorphism and by the develonment of very large quantities of massive intrusive granites.

In the marginal zone of the belt on the west coast a particularly interesting transition is seen. In the Midternaes - Graensland area peneplained Archaean gneisses and metasupracrustals are unconformably overlain by 6000 metres of Proterozoic supracrustals. Traced southwards over a distance of 50 km the original unconformity is gradually destroyed first by thrusting and then by ductile deformation which brings the basement and cover structures into parallelism. Both basement and cover rocks suffered amphibolite facies metamorphism and were intruded by granites. South of this marginal zone no evidence for the presence of the Archaean basement has yet been found, and it appears that the isotope systems of any older rocks present were reset by the younger events.

The main metamorphic and igneous event so far dated occurred at about 1830 m.y., and this is thought to be simply the final regional high-grade event following a complex sequence of magmatic, tectonic and metamorphic episodes. This was followed at about 1870 m.y. by a suite of post-tectonic intrusions of generally granitic composition. Regional uplift marked by the closure of the K-Ar and Rb-Sr mineral systems occurred at about 1600 to 1500 m.y. Finally, the deposition of graben-controlled continental sandstones, the intrusion of major dyke swarms, and the emplacement of the plutonic centres of the Gardar alkali province occurred at between 1400 and 1000 m.y.

2.2.4 The Nagssugtoqidian Mobile Belt

The Nagssugtoqidian mobile belt is approximately 300 km wide, its southern boundary on the west coast passing through the region of Itivdleq. On the west coast the Nagssugtoqidian rocks are exposed in a coastal strip about 150 km wide before being covered by the inland ice. On the east coast the coastal strip is very much narrower, but it has been possible to identify the southern boundary of the belt as indicated in Figure 2.1. Most of the following description applies to the Nagssugtoqidian on the west coast, but the geology of the east coast seems generally similar.

The Nagssugtoqidian consists mainly of reworked Archaean basement gneisses, locally with interlayered and folded relics of Archaean and possibly early Proterozoic supracrustals. The belt has a pronounced regional fabric with a predominant ENE trend approximately parallel to its boundary with the Archaean. In contrast to the Ketilidian belt, where igneous activity was widespread, igneous activity in the Nagssugtoqidian belt was very limited, there being only a few small isolated granites, although one large folded quartz diorite has been found in the central part of the belt.

The southern boundary of the Nagssugtoqidian was originally recognised by the deformation of two swarms of dolerite dykes. In the Archaean to the south of the boundary the dykes are undeformed and discordant to the country rock structure. In moving north over the boundary the dykes, together with their country rocks, are progressively deformed and metamorphosed resulting in the dykes and country rock structures being brought into parallelism. The situation in the boundary area is now considered to be rather more complex than originally thought, and this is discussed further in section 2.3 below.

In a very general way it is possible to subdivide the complex into linear belts where the regional ENE fabric is well developed, and areas where a preferred direction is not so obvious. This pattern has been compared to a large-scale augen structure, with the generally lens shaped lacunae of less deformed material corresponding to the augen. In the lacunae there are basin and dome structures, lacking any dominant strain direction, and very similar to the structures described above as being typical of the Archaean block to the south, and it has been suggested that these areas represent more competent zones in which the Archaean structures have been largely preserved. In the linear belts, on the other hand, the Archaean structures have been completely deformed and reoriented by the Nagssugtoqidian movements, which appear to have been mainly produced by ductile simple shear strain.

The gneisses of the Nagssugtoqidian belt are mostly granodioritic to quartz-dioritic in composition. The supracrustals are largely represented by metasediments, and are found mainly to the north of the Holsteinsborg area. They form thin belts interlayered and deformed together with the basement gneisses, and nowhere showing any evidence of a basal unconformity. Some of the supracrustals are Archaean in age, and show evidence of pre-Nagssugtoqidian deformation and metamorphism, while other supracrustals appear to have been formed in the interval between the end of the last main Archaean event and the first Nagssugtoqidian event. In the southern part of the belt the deformation was generally accompanied by a retrogression of the Archaean granulite facies to amphibolite facies. In the central parts of the belt granulite and amphibolite facies rocks co-existed during the Nagssugtoqidian deformation, the differences in metamorphic facies being probably due to local variations in original composition and water pressure, rather than to differences in intensity of metamorphism. The occurrence of sillimanite and the absence of cordierite throughout the Nagssugtoqidian of West Greenland shows that the pressure was probably high, and this is in contrast to the situation in the Ketilidian belt where the fairly widespread occurrence of andalusite and cordierite suggests low to medium pressures.

Regional K-Ar dating within the Nagssugtoqidian belt gives ages between 1790 and 1560 m.y., but preliminary U-Pb dating of recrystallised zircons suggests that the main phase of Nagssugtoqidian deformation and metamorphism is much older and probably occurred between 2600 and 2200 m.y. ago. The results of radiometric dating studies in the Nagssugtoqidian belt in general, and in the region of the sampling area in particular, are discussed in much greater detail in Chapter 8 below.

On the west coast, extending north for about 300 km from Jakobshavn, and therefore not shown in Figure 2.1, there is a terrain which gives the same K-Ar ages as the Nagssugtoqidian belt, but which lacks a dominant ENE fabric, and which consists essentially of an older, presumably Archaean, basement overlain by a major group of metasediments. This area has been referred to as the Rinkian mobile belt. The western, i.e. seaward, side of this same coastal strip is occupied by the vast quantities of predominantly basic volcanic material of the West Greenland Mesozoic and Tertiary igneous province.

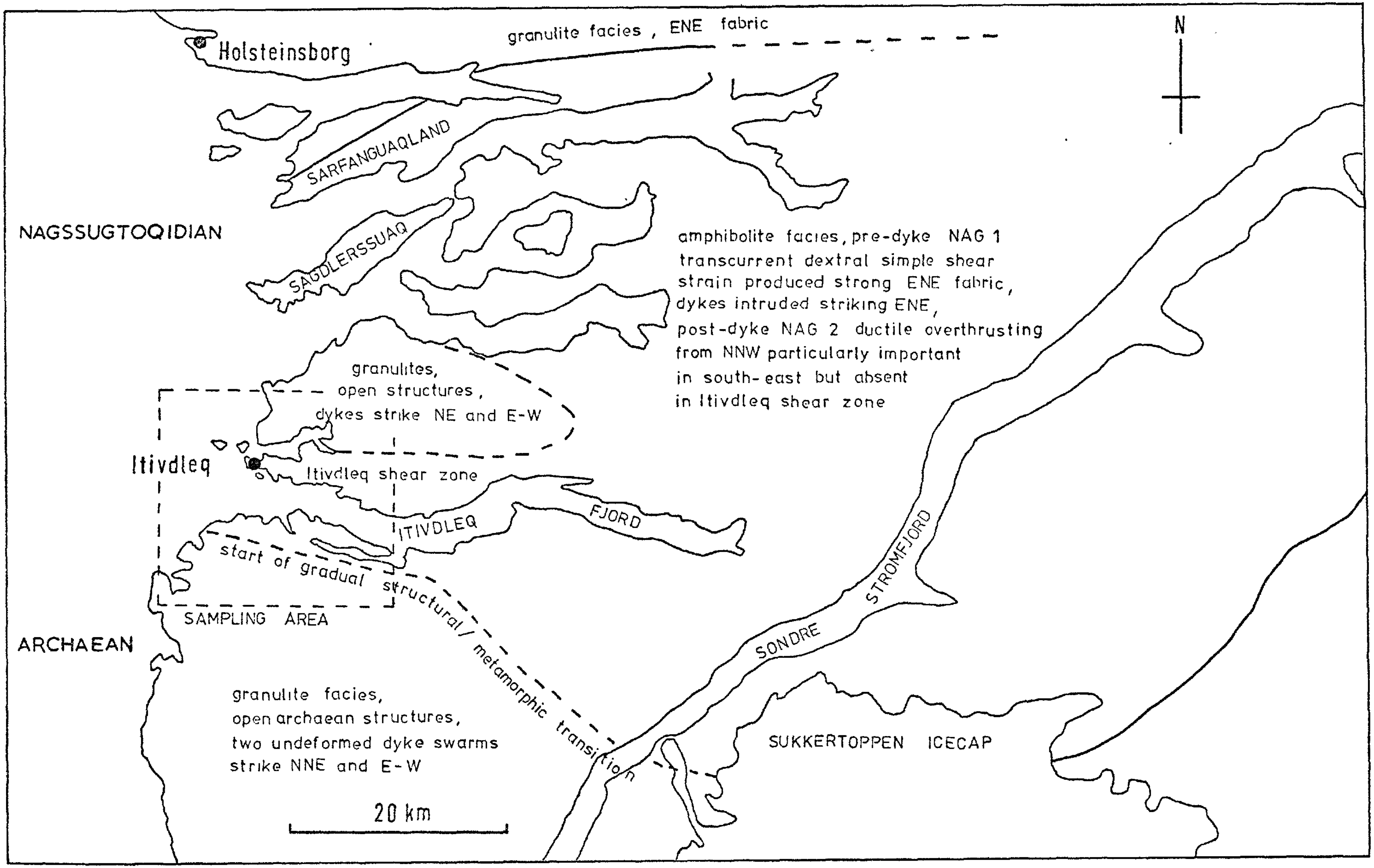
2.3 THE ARCHAEAN/NAGSSUGTOQIDIAN BOUNDARY REGION BETWEEN SONDRE STROMFJORD AND HOLSTEINSBORG

A very generalised diagram showing the main geological features of this region is shown in Figure 2.2. It must be borne in mind that much of this area has only been mapped at a reconnaissance level, and that even in those areas where detailed mapping has been carried out this has only been in progress for at the most three brief summer seasons. The area around Itivdleq from which the palaeomagnetic samples were taken is enclosed by a dotted line.

Geological investigations in this region have been carried out jointly by the University of Liverpool and the Gronlands Geologiske Undersogelse (the Geological Survey of Greenland), and this work, which is still continuing, has been reported by Escher, Escher and Watterson (1970), Bridgwater, Escher, Nash and Watterson (1973) and Watterson (1974). The following account is based largely on these reports, and on discussions with Dr. Juan Watterson.

In the southern part of the area shown in Figure 2.2 there are Archaean granulite facies gneisses in which banding and foliations are often indistinct or absent, and in consequence the area lacks any dominant linear fabric. The most important feature of this southern area is the presence of two swarms of basic dykes; a dominant NNE striking swarm (the Kangamiut dyke swarm) post-dates a less-dense E-W swarm. Most of the dykes, which are fresh and undeformed, are of dolerite, but a few are composite with centres of leucogabbro.

In the northern part of the area the rocks have been deformed and metamorphosed during the Nagssugtoqidian. The gneisses have acquired a pronounced foliation with an ENE trend, and the two dyke swarms have been reoriented into concordance with this foliation, both effects giving the area



OUTLINE OF GEOLOGY BETWEEN SONDRE STROMFJORD AND HOLSTEINSBORG

FIG. 2.2

a typical Nagssugtoqidian fabric. It was originally thought that the change in strike of the two dyke swarms across the boundary, involving a clockwise reorientation of the Kangamiut swarm and an anticlockwise reorientation of the E-W swarm, was due to ductile deformation (simple shear strain) which occurred after the emplacement of the dykes. As discussed further below, however, it is now considered that the predominant ENE strike of the dykes north of the boundary is in many places essentially a primary feature, and that considerable Nagssugtoqidian deformation occurred before the dykes were intruded.

One area that has been studied in some detail, and which demonstrates the primary nature of the reorientation of the dykes, is the region, about 5 km wide, on the north shore of Itivdleq fjord, extending from Itivdleq settlement at least 20 km inland. In this zone, which has been termed the Itivdleq shear zone, and which is more or less in the centre of the palaeomagnetic sampling area, the dykes have a predominantly ENE strike, and the gneisses have a pronounced concordant foliation. In the areas immediately to the north and south of the zone, on the other hand, the gneisses lack a pronounced planar fabric, and the two dyke swarms are quite distinct in their strike, although the Kangamiut dykes strike NE rather than NNE as further south. Furthermore, within the shear zone the dykes often have a pronounced pinch and swell form, and at least one dyke has separated into discrete "pips" along its strike. The gneiss foliation is always wrapped concordantly around these structures, and the first impression given is that these forms have been produced by tectonic boudinage.

The various features of the shear zone, the reorientation of the dyke swarms, the parallelism of dykes and country rock foliation, and the boudinage structure in the dykes, might at first sight appear to be consistent with both dykes and country rocks having been deformed together in a major tectonic episode after dyke emplacement. Closer examination, however, indicates that this interpretation is untenable. The reason for this is that the dykes in the shear zones, including those that show pinch and swell forms, show virtually no textural evidence of having suffered deformation subsequent to solidification. The dykes have an original isotropic igneous texture, sometimes sub-ophitic, and do not show any internal foliation parallel to the country rock fabric, such as would be expected if dykes and country rocks had been deformed together.

The only reasonable explanation for this appears to be that the dykes have not suffered any deformation since their crystallisation, and that their ENE trend and pinch and swell forms are original, i.e., they date from the time of dyke emplacement. The ENE trend of the dykes in the shear zone was presumably controlled by the pre-existing tectonic fabric of the country rocks, i.e. the country rocks had previously experienced ductile deformation to produce the ENE fabric of the shear zone, and the dykes were intruded along planes of weakness parallel to the foliation. The pinch and swell forms are therefore clearly not due to tectonic boudinage, but must be due to ductile deformation of the country rocks when the dykes were intruded. This and other lines of evidence described below argue very strongly that the country rocks were at high temperatures when the dykes were emplaced.

It is now considered that the main phase of Nagssugtoqidian deformation (referred to as Nag.1) throughout most of the boundary area, and not just in the Itivdleq shear zone, occurred before the dykes were emplaced. This Nag. 1 deformation consisted of ductile simple shear strain, involving mainly transcurrent dextral displacements, and imposed intense steep ENE tectonite fabrics on previously isotropic rocks. At some time after the end of the Nag. 1 deformation episode the two dyke swarms were intruded, first the E - W swarm and then the Kangamiut swarm. In those areas unaffected by Nag. 1 deformation the swarms were intruded striking NNE and E - W, but in those areas affected by Nag. 1 the strike of both swarms was controlled by the Nag.1 fabric.

A later phase of deformation (Nag.2) which occurred after dyke intrusion, consisted essentially of ductile overthrusting from the NNW in discrete zones, and was particularly important in the south-east part of the area. In the coastal region south of Sagdlerssuag (i.e., including the sampling area and the Itivdleq shear zone), the effects of Nag.2 have not been recognised. It is because the Nag. 2 deformation has not obscured the earlier events that the Itivdleq shear zone demonstrates so clearly the true relationship between the Nag. 1 deformation and dyke emplacement.

In the eastern part of the area, to the north-east of Sukkertoppen icecap, fairly intense Nag. 2 deformation was superimposed on Nag. 1, and as a consequence the Archaean/Nagssugtoqidian tectonic boundary can be drawn here with some precision, trending NE from the icecap. It is now thought that only within about 10 - 15 km of this eastern boundary have the dykes been tectonically reoriented (by Nag. 2) to any considerable extent.

In the coastal region, west of the icecap, the structural changes are more gradational, and it is not possible to draw the tectonic boundary with the same precision as further east. In the area south of Itivdleq fjord the structure is typically Archaean, with the two dyke swarms in their original orientation, and the country rock structures lacking any dominant trend. Approximately 5 - 10 km south of Itivdleq in the outer part of the coastal region, and further south inland, the Kangamiut dyke swarm gradually changes its strike from NNE to NE, and the country rocks begin to acquire a NE fabric. In the Itivdleq shear zone, as described above the rocks have a strong ENE foliation with which the dykes are concordant. In the area immediately north of the shear zone the Kangamiut dyke swarm reverts to the NE strike found just south of the shear zone, and the country rock structures become more open. From the southern tip of Sagdlerssuag northwards the rocks again acquire a strong ENE fabric. The area between the northern margin of the shear zone and the southern tip of Sagdlerssuag can be considered as an augen in which Archaean structure has been largely preserved, and is similar to the lacunae found further north with the Nagssugtoqidian belt as described above in section 2.2.4.

In Figure 2.2 the Archaean/Nagssugtoqidian boundary to the west of the Sukkertoppen icecap has been drawn in where the Kangamiut dyke swarm first appears to swing round from its original NNE strike towards the NE. This information has been obtained from Figure 4. of Bridgwater, Escher and Watterson (1973) which shows the reorientation of the dyke swarms on a regional scale. However, as this diagram was based largely on reconnaissance level mapping, and the reorientation is often a gradual process anyway, the position of this boundary is somewhat arbitrary. The boundary to the north-east of the icecap has been drawn using information from the same source, but here the transition appears to be sharper and so the position of this boundary is more certain.

The Archaean/Nagssugtoqidian tectonic boundary also generally coincides with a gradual retrogression of the Archaean granulite facies mineralogy to amphibolite facies. Within most of the border area north of the tectonic boundary the rocks show an amphibolite facies mineralogy. The only exception known so far is the coastal area between the northern margin of the Itivdleq shear zone and the southern tip of Sagdlerssuag, which is at granulite facies. This granulite block roughly coincides with the augen which largely escaped Nagssugtoqidian deformation.

Dykes, typically less than 2 metres wide, of the lamprophyre-carbonatite-kimberlite suite are found throughout the boundary area, and appear to post-date all the main tectonic events. They have provisionally been considered to be Cambrian in age, but this conclusion is based on a single K-Ar date. Brittle movement zones, generating pseudotachylite veins and breccias, appear to have been active throughout the boundary area over a long period of time. The earliest pseudotachylites pre-date the intrusion of the basic dyke swarms, and the latest ones are possibly Phanerozoic as they post-date the dykes of the lamprophyre suite. These brittle movement zones are generally parallel to the Nagssugtoqidian fabric.

In the northern part of the area shown in Figure 2.2 another prominent boundary occurs, extending approximately ENE from the west coast of Sarfanguaqland. North of this boundary the rocks again show granulite facies mineralogy, and although they show a regional ENE Nagssugtoqidian fabric they do not appear to have suffered the same intensity of ductile deformation as the rocks to the south of this boundary. The boundary also defines the northernmost limit at which reoriented and deformed Kangamiut dykes can be recognised, and it is also a lithological boundary in that the rather featureless banded gneisses to the south are replaced north of the boundary by supracrustals and granitic rocks.

The region between the southern margin of the Itivdleq shear zone and the boundary just described passing through Sarfanguaqland has been referred to as the Ikertoq shear belt, and is considered to be one of at least four major Precambrian shear belts on the west coast of Greenland (Bak et al., 1975). The Ikertoq shear belt extends inland with an ENE strike for 150 km before it is covered by the inland ice, and maintains a width of about 40 km throughout most of this length. From the above description of the boundary area it will be clear that the Ikertoq shear belt is essentially a belt of highly deformed amphibolite facies gneisses that have suffered ductile simple shear strain with dominantly transcurrent dextral movement. To the north and south of the belt are granulite facies gneisses which are unaffected or only slightly affected by the transcurrent shear movements. In the Itivdleq shear zone, where the original characteristics of the shear belt (i.e. those produced by Nag. 1) have not been complicated by the ductile overthrusting of Nag. 2, estimates of the shear strain, when extrapolated across the full width of the Ikertoq shear belt, indicate a minimum displacement of over 150 km.

The Ikertoq shear belt is considered to be the deep-level continuation of what at higher tectonic levels and at the surface would have been a major transcurrent fault. Although the main movement in the belt in the early part of its history was, at the level now exposed, due to ductile deformation, this probably alternated with minor brittle movement indicated by the early pseudotachylites mentioned above. These brittle movement zones occur throughout the Ikertoq shear belt, but are particularly concentrated along its northern margin. The alternation between ductile and brittle behaviour in the early deep-level history of the belt is considered to be due to the variation in strain rate rather than to changes in temperature or tectonic level. Brittle movements have probably continued in the Phanerozoic, as evidenced by pseudotachylites cutting the supposedly Cambrian lamprophyre dykes, and offshore seismic work (reported in Watterson, 1975) has shown that movement along the northern margin of the belt occurred as recently as the Mesozoic. There thus appears to have been at least intermittent activity along the Ikertoq shear belt over a period of at least 2500 m.y.

From the palaeomagnetic point of view, as discussed further in later chapters, it is useful to have some geological evidence as to the probable temperature of the country rocks at the time the dykes were intruded. There are at least three lines of evidence which indicate that the gneisses were at high temperatures during dyke emplacement:- (1) While the dykes were still liquid the gneisses behaved in a completely ductile manner to accommodate the pinch and swell structures described above. This is probably the most compelling evidence. (2) The dykes cut, and are cut by, the same set of ductile shear zones, implying that the dykes were intruded during an interval of time when the country rocks were responding to stress by ductile shearing. (3) There is petrographic evidence, for example the nature of the kelyphitic rims around pyroxenes, that the dykes experienced metamorphism in a regime of falling temperature, thus implying that they were intruded into country rocks which were at metamorphic temperatures, and then suffering primary auto-metamorphism. Had these metamorphic effects been produced by a later and distinct heating event there would have been mineralogical changes indicative of both rising and falling temperature.

The distribution of granulite and amphibolite facies assemblages in the boundary region probably does not reflect distinct episodes of metamorphism, nor different intensities of metamorphism. It is thought that granulite and amphibolite facies assemblages are essentially contemporaneous, and that their distribution is probably only a reflection of differences of water content, which in turn are the result of varying intensities of deformation, intensely deformed areas being generally at amphibolite facies and less deformed areas at granulite facies. No increase in temperature necessarily coincided with the onset of the various Nagssugtoqidian events; these events, including dyke intrusion, probably occurred at such a deep crustal level that metamorphic temperatures and pressures were normal, and these conditions may have continued for a long period after the end of tectonism and dyke intrusion.

2.4 THE SAMPLING AREA

A map of the sampling area showing the main outline of the geology and the locations of the individual sampling sites is given in Figure 2.3. It will be seen that the Itivdleq shear zone runs east - west approximately through the centre of the area. As described above the rocks in this shear zone suffered intense pre-dyke Nag. 1 deformation giving them a strong ENE to E fabric, while the rocks to the north and south of the shear zone were virtually unaffected and have a more open, Archaean, structural style. When the dykes were intruded their strike was controlled by the strong fabric in the shear zone, and they were emplaced concordant to the foliation. North and south of the shear zone the country rock structure had less influence and the dykes were intruded striking E - W and NE. Apart from some narrow local shear zones there has been no deformation in the area subsequent to the intrusion of the dykes.

Dykes were sampled at 20 sites, and the country rock gneisses at six sites. At most sites at least ten cores were drilled, and these were usually spaced more than 1 m apart.

Thin sections were prepared from one or more cores from each sampling site, and at two sites, dykes D10 and D20, thin sections were made from every core collected. These thin sections were examined by the author and much of the following account is based on the results of these investigations.

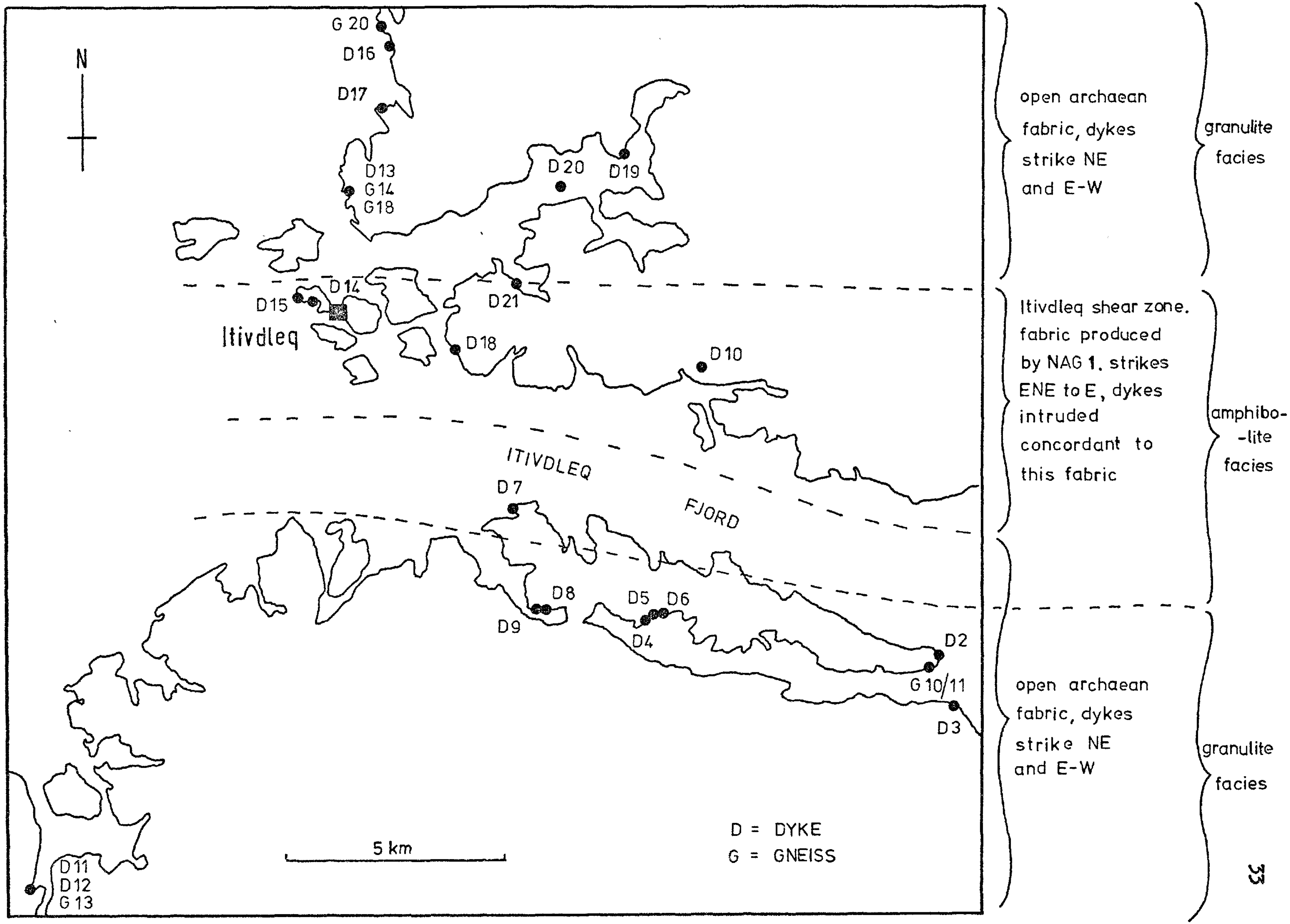


FIG. 2.3 THE SAMPLING AREA

The details of the individual sampling sites are described in Appendix A, and the purpose of the remainder of this section is to consider some general points concerning the mineralogical and textural variations shown by the dykes. There is, in a very general and imperfect way, a gradual transition from virtually unaltered dykes in the south-east part of the area to partially metamorphosed (presumably autometamorphosed) dykes showing considerable alteration in the north-west. In unaltered dykes, such as D2 and D3, there is a typical igneous texture and doleritic mineralogy, with pale purplish clinopyroxene (about 45%) sub-ophitically enclosing euhedral laths of lamellar-twinned plagioclase (about 50%), and an opaque ore content of about 5-6%. Marginal and internal alteration of the clinopyroxene to hornblende is either absent or very minor, the total amphibole content of the rocks being generally less than 1%. Garnet is completely absent and there is no evidence of any recrystallisation under metamorphic conditions. These unaltered dykes typically have average grain sizes of between 1 and 3 mm.

Moving north-west the most obvious change is in the increasing alteration of the original clinopyroxene to green pleochroic hornblende, which occurs at the margin of the pyroxenes and to a lesser extent internally, often along cracks. In the more altered dykes this new amphibole commonly appears as a more or less fine-grained granoblastic aggregate of hornblende and quartz, often replacing between 40% and 70% of the original pyroxene. There is also an increasing tendency for the euhedral feldspar laths to be replaced by a fine-grained granoblastic mosaic of untwinned feldspar and quartz, and also for the appearance of small, often euhedral, granules of garnet. These small garnet granules, which are often aggregated together to form larger grains, make up more than 20% of the rock in some of the northern dykes. The garnet is often intimately associated with the opaque ore, and occurs most commonly between ore and feldspar. The ore content of the altered dykes is similar to, or slightly less than that of the unaltered dykes, and is typically 3-5%.

The mineralogical changes are also accompanied by changes in texture.

With increasing recrystallisation producing mineral assemblages with a granoblastic texture the sub-ophitic relationship becomes gradually obscured, and in some of the northern dykes cannot be recognised at all. Except in a few instances where they have been affected by later local shear movements the altered dykes, like the unaltered ones, are completely isotropic and show no internal foliation either in hand specimen or in thin section.

There is a particularly marked variation in the mineralogy and texture shown by narrow dykes. For example, D12, an 0.5 m wide dyke in the south-west corner has a typical fine-grained igneous intergranular texture and doleritic mineralogy, with randomly oriented laths of feldspar between the interstices of which are granules of completely unaltered clinopyroxene. Garnet appears to be completely absent. D13, on the other hand, an 0.2 m wide dyke from the northern part of the area, shows a typical metamorphic texture and mineralogy. It is a fine-grained completely granoblastic mosaic of feldspar, quartz, hornblende and garnet, with very minor pyroxene. The dyke is in fact a non-foliated garnet amphibolite.

The completely granoblastic texture of D13 indicates that it formed by metamorphic recrystallisation in the solid, and not by primary crystallisation from a magma. It is therefore not comparable with the "homogenous garnet amphibolite" layers in multiple Kangamiut dykes from the Sukkertoppen region about 150 km to the south, described by Windley (1970). These garnet amphibolite layers have an igneous sub-ophitic texture and are thought to have been produced by primary crystallisation from a basic magma with a relatively high water content.

There is, again in a very general way, a tendency for the pyroxenes in the south-east part of the area to be pale purplish to colourless, and in the north-west to be very pale green. This variation in what appears to be a primary mineral may reflect a variation in environmental conditions at the time of intrusion.

The reason for this gradual (although admittedly imperfect) variation in the degree of alteration of the dykes, and colour of the primary pyroxene, across the sampling area is not immediately obvious. It does not appear to be related to the metamorphic facies of the country rocks, as the dykes in the north and the south are both in granulite facies terrains, yet the dykes in the north are generally more altered than those in the south. Neither does it seem to be related to grain size, as the narrow dyke D13 is completely recrystallised, while another narrow dyke D12 is completely unaltered. Further, the fine-grained margin of the "pip" D10 (see below) has also suffered only very minor alteration. It seems possible, therefore, that this variation may reflect a lateral change of temperature at the time of intrusion, or possibly a depth variation, the latter implying of course that the area has been subsequently tilted.

The thin sections of dyke D10 from the central region of the Itivdleq shear zone proved to be of particular interest. This dyke shows the pinch and swell structure in an extreme form, in that it has separated into a series of discrete "pips". These "pips" are typically 200 m long and 60 m wide, and are spaced at intervals of at least 500 m along the E - W strike of the dyke. At the particular "pip" sampled cores were taken at intervals along a S - N traverse from the southern margin to near the centre, and a thin section was made from each core.

In the field the "pip" shows no sign of internal foliation, and this was confirmed on examining the thin sections. However, not only do all the thin sections show a completely isotropic fabric, but they all show undoubted primary igneous textures. For example, the core drilled 8 cm from the margin shows a microporphyritic texture, with randomly oriented euhedral laths of feldspar set in a fine-grained intergranular matrix, and all other cores show randomly oriented euhedral feldspar laths in a perfectly developed sub-ophitic relationship with large irregular grains of pyroxene. This sub-ophitic texture is still very clearly preserved even when the pyroxenes have been completely replaced by a granoblastic mosaic of hornblende and quartz.

It should be noted that the argument concerning the original nature of the pinch and swell structures in the Itivdleq shear zone hinges not so much on the isotropic fabric of the dyke rocks as on the recognition of original igneous textures. It could be argued for example that an isotropic fabric and texture in a pinch and swell dyke is due to metamorphic recrystallisation under static conditions, and that this has destroyed the anisotropic fabric produced during the tectonism which formed the pinch and swell structure. The presence of igneous textures, however, which are unknown in any metamorphosed rock, indicates quite clearly that the dyke has not suffered any recrystallisation subsequent to its original emplacement, and that the pinch and swell structure must have formed prior to the original solidification of the dyke. The presence of perfectly developed igneous textures in all 19 cores from D10, a dyke showing pinch and swell in its most extreme form, must therefore be regarded as conclusive evidence of the original nature of this structure, and also of course of the E - W strike of the dyke.

Of the remaining four dykes sampled in the Itivdleq shear zone one, D14, is strongly foliated in parts, and appears to have been cut by a later local shear zone. The other three dykes show a very minor and crude tendency to foliation, but it is nowhere near as intense as would be expected if their present E - W strike was due to post-intrusion deformation. Further, in two of the dykes, D15 and D18, the original sub-ophitic igneous texture is still recognisable.

Thus all the petrographic investigations of this study support the opinion of the Liverpool and G.G.U. geologists that the E - W strike of the dykes in the Itivdleq shear zone, and the pinch and swell structures displayed by them, are both primary features.

Chapter 3

EQUIPMENT AND TECHNIQUES

3.1 FIELD WORK

Oriented cores 2.45 cm nominal diameter and typically 5 - 8 cm long were collected using a portable coring drill and accessories very similar to those described by Doell and Cox (1967). The azimuth of the core axis was generally determined using a sun compass, but on the few cloudy days that were experienced a magnetic compass was used, and accurate values of local magnetic declination obtained by taking bearings on distant features and comparing the bearing so obtained with that determined from local 1:20,000 maps. The sun compass used was constructed in the Geology Department workshop under the supervision of the author, and was based on an instrument described by Stone (1967). This particular sun compass has the advantage that the core azimuth can be read off directly, whereas in earlier types of instrument several calculations had to be carried out after the instrument had been read.

3.2 THE PALAEOMAGNETIC LABORATORY

The laboratory, situated in an unscreened room close to engineering laboratories in a busy city centre, is not an ideal location for carrying out palaeomagnetic research. However, in spite of the high magnetic and mechanical noise levels, and the large magnetic gradients present, the equipment appears to operate surprisingly well, as the various tests described below, and the quality of the palaeomagnetic results themselves, testify.

The apparatus available in the laboratory consists of an astatic magnetometer, a spinner magnetometer, and a.f. demagnetizing equipment. There is also a portable fluxgate magnetometer which is used for checking the fields at the centre of the various Helmholtz coils systems. The magnetometers were already in the laboratory at the beginning of this project, and apart from one modification to the astatic magnetometer they were used unaltered. They are therefore described below rather briefly. The a.f. demagnetizing equipment, however, was extensively redesigned and rebuilt by the author at the beginning of the project, and so is described in greater detail.

3.3 THE MAGNETOMETERS

3.3.1 The Spinner Magnetometer

This instrument, which was constructed in the Geophysics Department in 1967, has a f.s.d. range from 1.0×10^{-3} emu/cm^3 to 30.0 emu/cm^3. It was used only for those specimens having an intensity of magnetization greater than about 6.0×10^{-3} emu/cm^3, which were too strongly magnetized to be measured on the astatic magnetometer.

3.3.2 The Astatic Magnetometer

The astatic magnetometer (Beckmann, 1973) is a moderate sensitivity instrument of fairly conventional design. In addition to the two main magnets the magnet system also has two trimming magnets of Platinax wire. The specimen is placed in a receptacle in the "on-centre" position below the lower magnet, and the receptacle is rotated at 1.85 revs. per second about an axis parallel to the specimen axis whose component is being measured. This rotation averages out the effects of inhomogeneities in magnetization about the axis being measured (Collinson, 1970). Also, the rotation effectively averages out to zero the two components normal to the component being measured, and so simplifies the measuring procedure and reduces by a factor of four (compared to the stationary-specimen method) the number of measurements which have to be carried out (McMurry, 1968). The magnet system and specimen receptacle are located at the centre of three pairs of Helmholtz coils which cancel the earth's field, and the vertical position of the specimen receptacle can be adjusted between about 3 cm and 11 cm below the lower of the two main magnets, thus providing a range of instrument sensitivities. Deflections of the magnet system are measured by an optical lever with a light path of about 4.25 metres, terminating in a light spot on a scale of length 50 cm each side of an arbitrary zero.

For measurement (and demagnetizing) the 2.54 cm long specimen is held in a cubic perspex specimen holder, and the holder is placed in the specimen receptacle and the specimen rotating motor switched on. The component to be measured is the one which is parallel to the rotating axis, i.e. the horizontal axis normal to the magnet axes. The position of the light spot is noted with this axis pointing in one sense, and then the receptacle is turned through 180° about a vertical axis, and the position of the light spot noted again after 20 seconds. Half the difference in the position of the light spot indicates the deflection due to the remanent magnetization along that particular specimen axis. The effect of any induced component is eliminated by this procedure, but in any case should be very small due to the cancelling of the earth's field. The measurement is then repeated to check that no significant drift occurred during the first measurement, and if the two "half deflections" are within 0.5 cm the mean value is taken as the correct measurement for that component. The two other components are then measured in a similar manner, and from the three components of magnetization, together with core orientation and sampling site latitude and longitude, the direction and intensity of magnetization and the corresponding pole position are calculated, using a routine computer program.

At the very beginning of the project an accident to the astatic magnetometer resulted in the torsion fibre being broken, and the shock experienced by the magnet system moved the trimming magnets to such an extent that the astaticism and hence sensitivity were greatly reduced, the half-period of oscillation being reduced from about 15 seconds to less than 5 seconds. The subsequent task of re-astaticizing the magnetometer, and overcoming the associated problem of drift, proved to be long and tedious. The method of astaticizing eventually adopted is described below as it might be of interest to anyone unfortunate enough to be faced with the task of astaticizing a magnetometer in an environment where large magnetic gradients exist, and where there is a high magnetic noise level.

The sources of the more or less continuous small random fluctuations in the ambient field in the laboratory are probably sufficiently distant for them to be regarded as variations of an essentially uniform field. In order that these variations do not produce drift in the magnetometer the magnet system should be astaticized in a uniform field. When this has been done the residual magnetic moment of the system should be near to zero, and so the magnet system should be insensitive to uniform field changes. However, because of the gradients which are undoubtedly present at the site of the magnetometer a uniform field is difficult to obtain. The desired astaticism was, therefore, obtained in two stages. The approximate setting was achieved by adjusting the trimmers in the earth's field until a half-period of about 10 seconds was obtained. The final astaticism was then achieved by adjusting the trimmers until a change of uniform field, produced by altering the current through one of the two vertical pairs of Helmholtz coils, resulted in the smallest deflection of the magnet system.

It was then found, however, that with the Helmholtz coils switched on the half-period was only about 6 seconds, far short of the 15 seconds necessary for the required sensitivity. The reason for this low sensitivity was not difficult to explain, as described below.

The sensitivity of an astatic magnetometer can be given (Nagata, 1961) by:-

$$\left(\frac{d\,\theta}{d\,h}\right)_0 = \frac{M_1}{(M_1H_1 - M_2H_2) + \tau}$$

where M_1 and M_2 are the moments of the lower and upper magnets respectively, H_1 and H_2 are the horizontal components of the ambient field at M_1 and M_2 respectively, and τ is the torsional constant of the suspension fibre. Now when astaticizing we maximise the sensitivity by making M_1 H_1 as nearly equal to $M_2 H_2$ as possible, and when astaticising in a uniform field, where $H_1 = H_2$, this clearly involves making $M_1 = M_2$. In practice, however, due to the gradients present, H_1 is almost certainly not equal to H_2. Now because in the original astaticising, described above, M_1 was made equal to M_2, this meant that M_1H_1 could not equal M_2H_2, and so low sensitivity (indicated by the short half-period) naturally resulted.

This situation clearly posed something of a problem, because to astaticise the magnet system for the required sensitivity would clearly involve re-adjusting the trimming magnets, and so the insensitivity to uniform field changes would be destroyed, and drift problems would result. The drift problem was in fact a very real one, for on those occasions where the desired sensitivity was obtained with a magnet system which had not been very carefully astaticised against uniform field changes, the instrument always proved to be unusable due to continuous random drift which moved the light spot at velocities of typically 2-3 cms per 20 seconds.

The problem was eventually overcome by using small external trimming magnets. The magnet system was first of all astaticised against uniform field changes as described above using the trimmers on the magnet system. These trimmers were then not touched again, and the desired half-period of about 15 seconds with the Helmholtz currents switched on was obtained by trial and error adjustments in the positions of two small external trimmers at distances of 10-15 cms from the magnet system. When the desired sensitivity was obtained the external trimmers were firmly fixed into position. This method clearly had the advantage of combining minimum sensitivity to ambient field fluctuations with maximum sensitivity to the field produced by the specimen. Although it was not possible to check on this, the external trimmers presumably produce a vertical gradient in the horizontal field which more or less cancels the gradient naturally present. It was suggested to the author that these external trimmers might somehow affect the linearity of the magnetometer response, but careful checks using the calibration coil revealed that this was not so.

The astatic magnetometer so modified was capable of measuring specimens with intensities of magnetisation between about 5.0×10^{-6} emu/cm^3 and 6.0×10^{-3} emu/cm^3. The natural half-period was 15 seconds, and, with almost critical damping, the measuring period was 20 seconds. The time required to measure all three components in a specimen was about four and a half minutes. Although the instrument was more or less completely insensitive to the small continuous fluctuations of ambient field in the laboratory, it did respond to the larger changes in field which occurred four or five times during the course of an average day. These changes caused the light spot to suddenly move 20-30 cm, and necessitated re-zeroing of its position by means of the torsion head adjustment.

The precision of the instrument in its middle sensitivity range was determined by measuring one specimen eight times. The specimen holder was removed and replaced in the receptacle between each measurement so that the precision includes the accuracy of aligning the specimen holder in the receptacle. The eight direction measurements yielded a precision parameter, k, of 24,420, which corresponds to an angular standard deviation of 0.48°, and the eight intensity measurements were all within 0.45% of the mean. Considering the situation of the laboratory these figures seem very reasonable. It was noted, however, that re-zeroing the light spot after a movement of about 20 cm changed the sensitivity by about 4%, so that the accuracy of the intensity measurements cannot be better than this. When re-zeroing had to be carried out in the middle of measuring a specimen, it was necessary, therefore, to begin the measurement again to ensure that all three components were measured at the same sensitivity. The accuracy of the direction measurements is discussed below in section 3.5.

3.4. THE A.F. DEMAGNETIZING EQUIPMENT

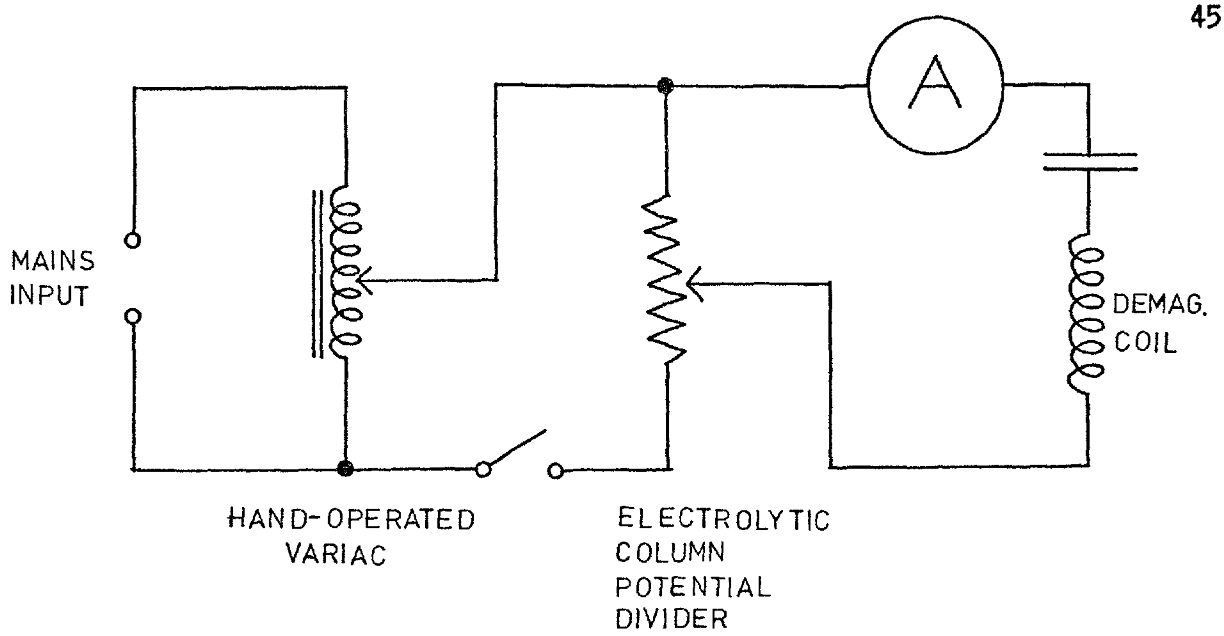
3.4.1 The Original Equipment

3.4.1.1 Description of Equipment

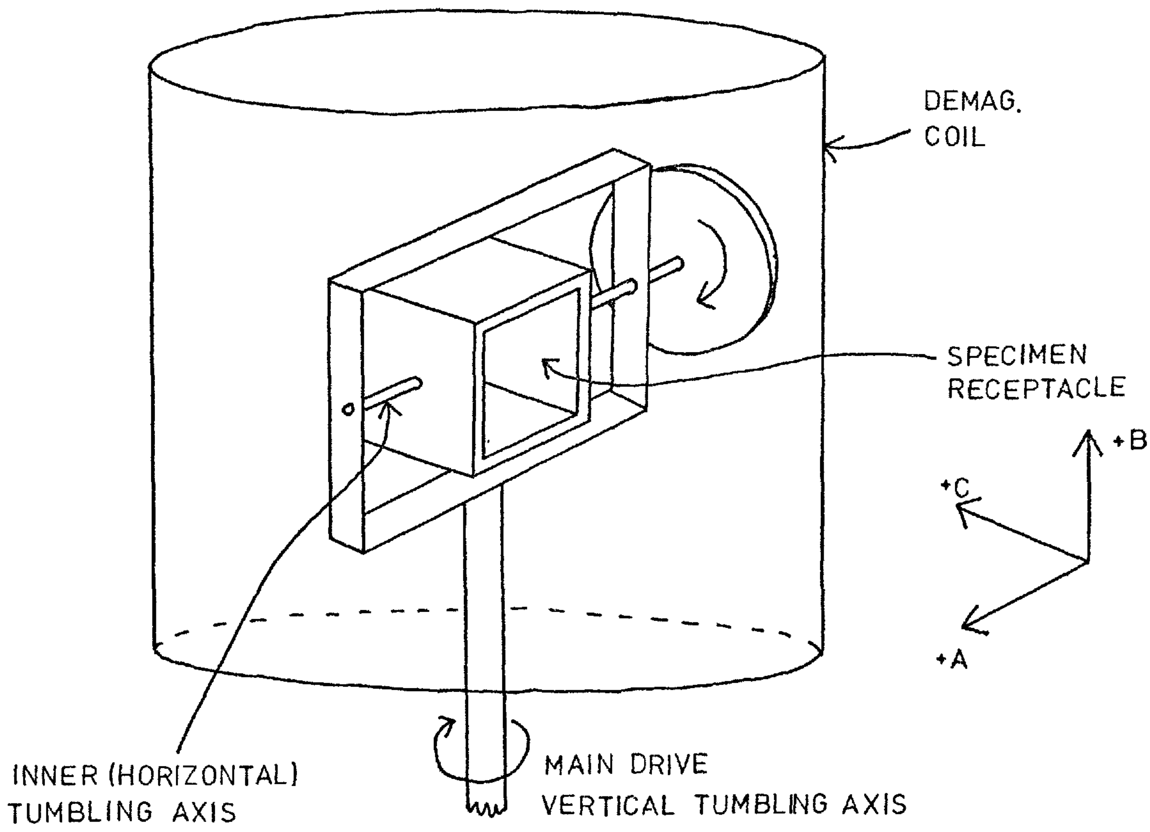
The a.f. demagnetizing equipment already present in the laboratory at the beginning of this project is illustrated in Figure 3.1. The demagnetizing coil and capacitors formed a series tuned circuit resonant at 50 Hz, and mains voltage was applied to this circuit via a Variac transformer which could be pre-set to the required value at the beginning of each demagnetizing run. Connected in parallel with the series tuned circuit was an electrolytic variable potential divider. This consisted of a glass column filled with copper sulphate solution, with fixed electrodes at the top and bottom of the column, and another electrode which could be raised up the column by an electric motor. This allowed the voltage across the tuned circuit to be reduced more or less smoothly from the maximum value (determined by the setting of the Variac) down to almost zero. During demagnetization the specimen was tumbled at the centre of the demagnetizing coil about two axes as indicated in the diagram. The demagnetizing coil was located at the centre of three pairs of Helmholtz coils which cancelled the earth's field to within about 100 gammas.

3.4.1.2 Using the Equipment

Soon after returning from Greenland with the rock collection a programme of measurements of remanent magnetization with progressive a.f. demagnetization was commenced, using the equipment described above. It very soon became apparent, however, that the demagnetizing equipment was unsatisfactory because it introduced a spurious component of magnetization into the specimen being demagnetized. This was particularly noticeable in the case of unstable material in which the component introduced was apparent at fields as low as 25-50 oe, but it was also noticeable even in moderately stable specimens at fields of 100-150 oe. Furthermore, the spurious component was not introduced in a random direction, but was always aligned along the inner (horizontal) tumbling axis, and always in the same sense. With the specimen receptacle in the tumbler assigned orthogonal axes, A, B and C, as defined in Figure 3.1 (b), the spurious component was always introduced along the +A axis. Spurious components introduced along the B and C axes were generally less than 10% of the intensity of the +A spurious component, and



(a) Circuit Diagram (after Beckmann, 1973)



(b) Tumbling System (Schematic)

THE ORIGINAL DEMAGNETIZING EQUIPMENT

FIG. 3.1

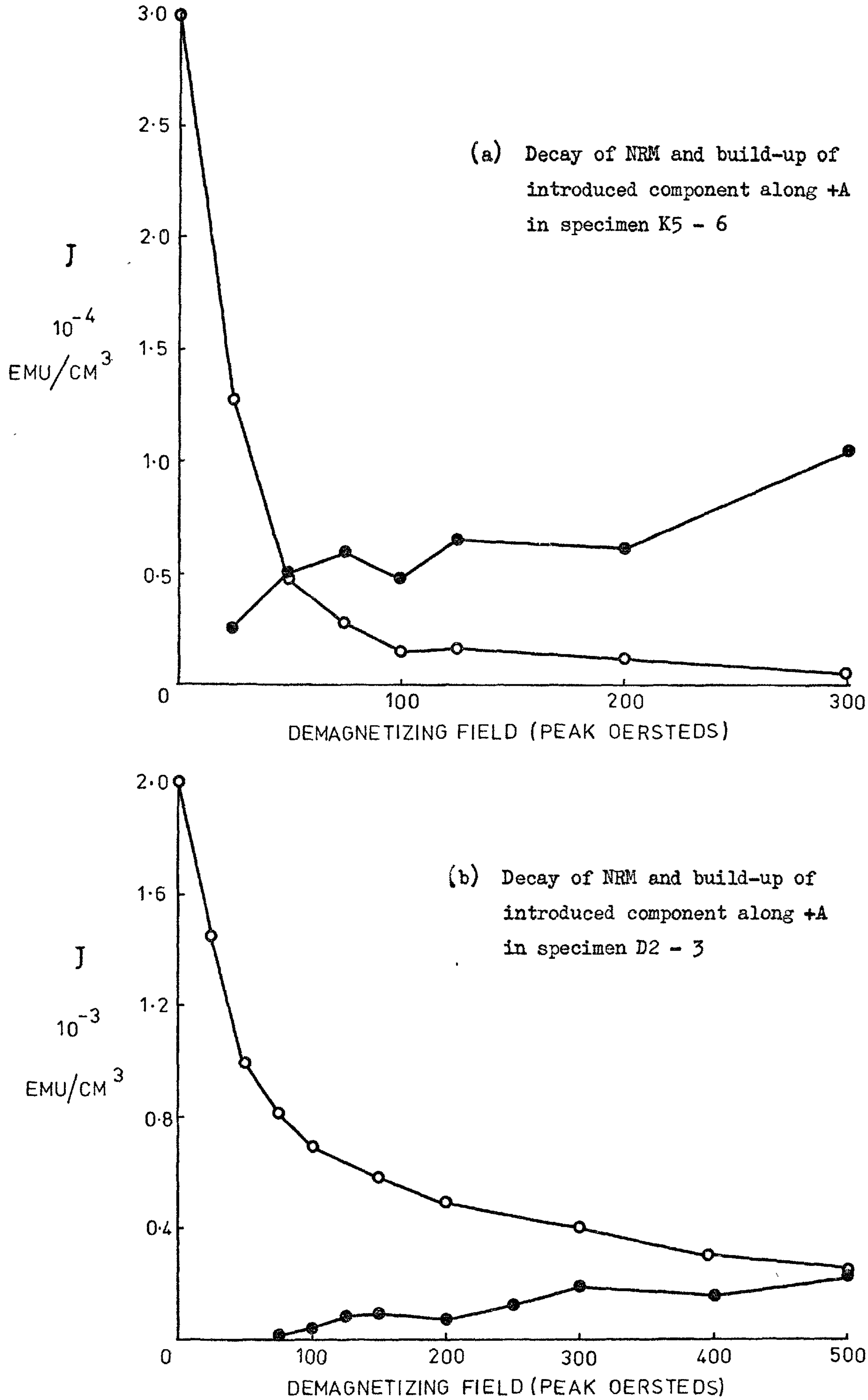
often less than 5%.

The fact that the spurious component was introduced in such a systematic manner enabled the natural remanence at any demagnetizing step to be determined fairly readily. This was done by demagnetizing first with a given specimen axis aligned along +A, and then measuring, and then demagnetizing with the same specimen axis aligned along -A, and measuring again. The spurious component along the A axis was in opposite directions in the two measurements, so that by taking their mean the spurious component was eliminated. The B and C components, as they were virtually unaffected by spurious components, could be obtained from either measurement. In this way it was possible to monitor the decay of the total natural remanence with progressive a.f. demagnetization as well as the build-up of the introduced component.

Diagrams illustrating the decay of the natural remanence and the build-up of the introduced component along the +A axis are shown in Figure 3.2. Figure 3.2 (a) illustrates the process in an extremely unstable kimberlite, and it can be seen that the introduced component increased in intensity as the demagnetizing field strength increased, and that by 75 oe it was already double the intensity of the natural remanence remaining at that step. Figure 3.2 (b) illustrates the process in a moderately stable basic dyke, and again it can be seen that in a general way the intensity of the introduced component increased with increasing demagnetizing field strength, but that it is not until 500 oe that the intensity of the introduced component approaches that of the natural remanence.

This state of affairs was clearly unsatisfactory, as not only did it necessitate demagnetizing and measuring every specimen twice at each demagnetization step, which was very time consuming, but also it appeared that at fields higher than about 300 oe substantial spurious components also began to appear along the other tumbler axes. It was decided, therefore, to investigate the cause of this behaviour, and if possible to rectify it.

Fortunately, the source of the trouble was not difficult to locate,



OPERATION OF ORIGINAL DEMAGNETIZING EQUIPMENT

FIG. 3.2

as a perusal of publications on a.f. demagnetization apparatus quickly revealed that in the building of the original equipment a cardinal design principle had been overlooked. Thus Creer (1959) and Parry (1967) point out that in a two-axis tumbler the two axes should be perpendicular to each other, and also perpendicular to the axis of the demagnetizing coil. In the original equipment, however, the axis of the demagnetizing coil was vertical, i.e. parallel to the vertical tumbling axis.

This was clearly a major design fault, as it meant that directions in the specimen parallel to the inner tumbling axis (i.e. the A axis) remained perpendicular to the applied field throughout the tumbling procedure, and that only specimen directions perpendicular to the A axis were ever brought completely into alignment with the field. Thus a major design objective of tumbling systems, that all directions in the specimen should be brought as nearly as possible into alignment with the applied field, was not even remotely achieved, and there clearly could not have been equal demagnetization of all directions in the specimen.

This, however, did not explain the systematic <u>introduction</u> of the spurious component along the +A axis, and for some time this remained a mystery (but see section 3.4.3 below). It was evident, nevertheless, that the equipment needed to be modified in order that the two tumbling axes should be perpendicular to the coil axis, and it was hoped that this might somehow prevent the introduction of the spurious +A component. This and other improvements to the demagnetizing equipment are described in the next section.

3.4.2 The New Equipment

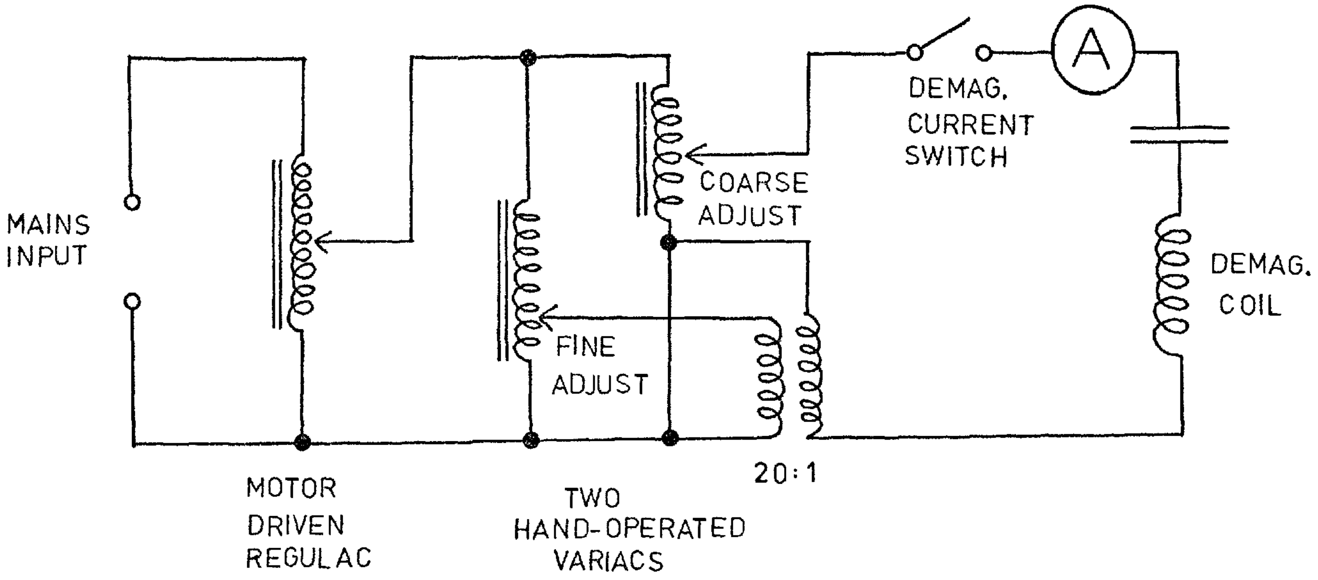
3.4.2.1 Redesigning the Tumbler and Demagnetizing Coil

It was decided that the simplest way to make both tumbling axes perpendicular to the coil axis was to reposition the coil so that its axis was horizontal. It is impossible, of course, to make a two-axis tumbler in which both axes are permanently perpendicular to the coil axis; the best that can be achieved is that one tumbling axis (in this case the vertical one) is permanently perpendicular to the coil axis, and the other (inner) tumbling axis precesses about the vertical, becoming perpendicular to and parallel to the coil axis twice during every rotation of the vertical axis.

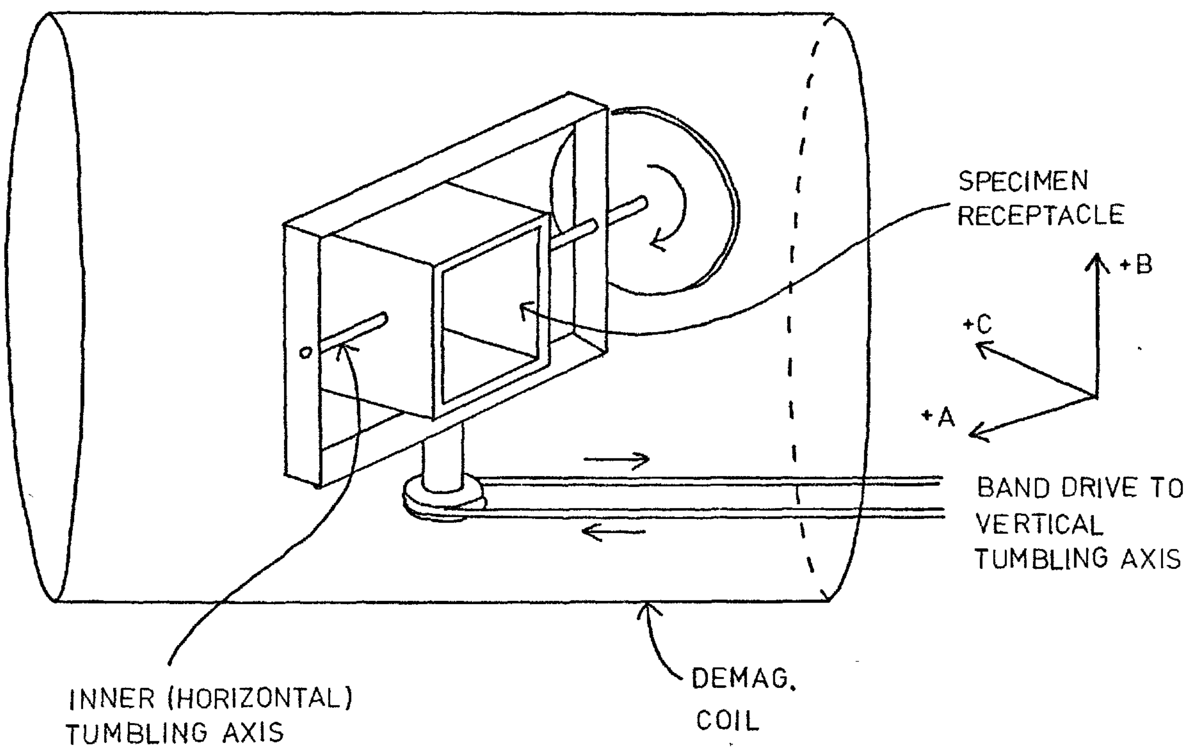
This change necessitated altering the drive arrangement to the tumbler, because it was now necessary to bring in the drive to the vertical axis from the side, and it was decided to at the same time alter the tumbling ratio (the ratio of the angular speed of the vertical axis to that of the inner axis). The tumbling ratio chosen was 11:16. With this ratio, during one complete cycle, i.e. 11 rotations of the vertical axis, all directions in the specimen approach to within 5° of the coil axis, therefore receiving at least 99.6% of the applied field. Further, even for only two rotations of the vertical axis all directions approach with 25° of the coil axis, therefore receiving 90% of the applied field (McElhinny, 1966). The angular speed about the vertical axis is 100 r.p.m., so that a complete tumbling cycle takes 6.6 seconds. A schematic illustration of the new tumbling arrangement is shown in Figure 3.3 (b).

In redesigning the tumbler it was obvious that the inevitable increase in size would make it impossible to use the existing demagnetizing coil, and so a new coil with a larger internal diameter was built, and again the opportunity was taken to effect an additional improvement. This was to design a coil capable of producing a higher maximum field strength than the 700 oe possible with the original coil. In designing this coil the conflicting requirements of attaining maximum field strength on the one hand, and minimising size, weight and heat production had to be finely balanced, and the author found that the design data in Roy, Reynolds and Sanders (1973) was of great assistance in this respect.

The coil finally selected was 16 cm long and had an internal diameter of 12.8 cm. It consisted of 2,715 turns of 1.40 mm gauge copper wire, had a resistance of 15 ohms, and an inductance of 0.715 henrys. The coil was found to produce 209.0 oe peak field per one ampere r.m.s., in remarkably close agreement with the theoretically predicted value of 208.5 oe per ampere. A bank of high voltage capacitors giving approximately 14 μF capacitance are



(a) Circuit Diagram



(b) Tumbling System (Schematic)

THE NEW DEMAGNETIZING EQUIPMENT

FIG. 3.3

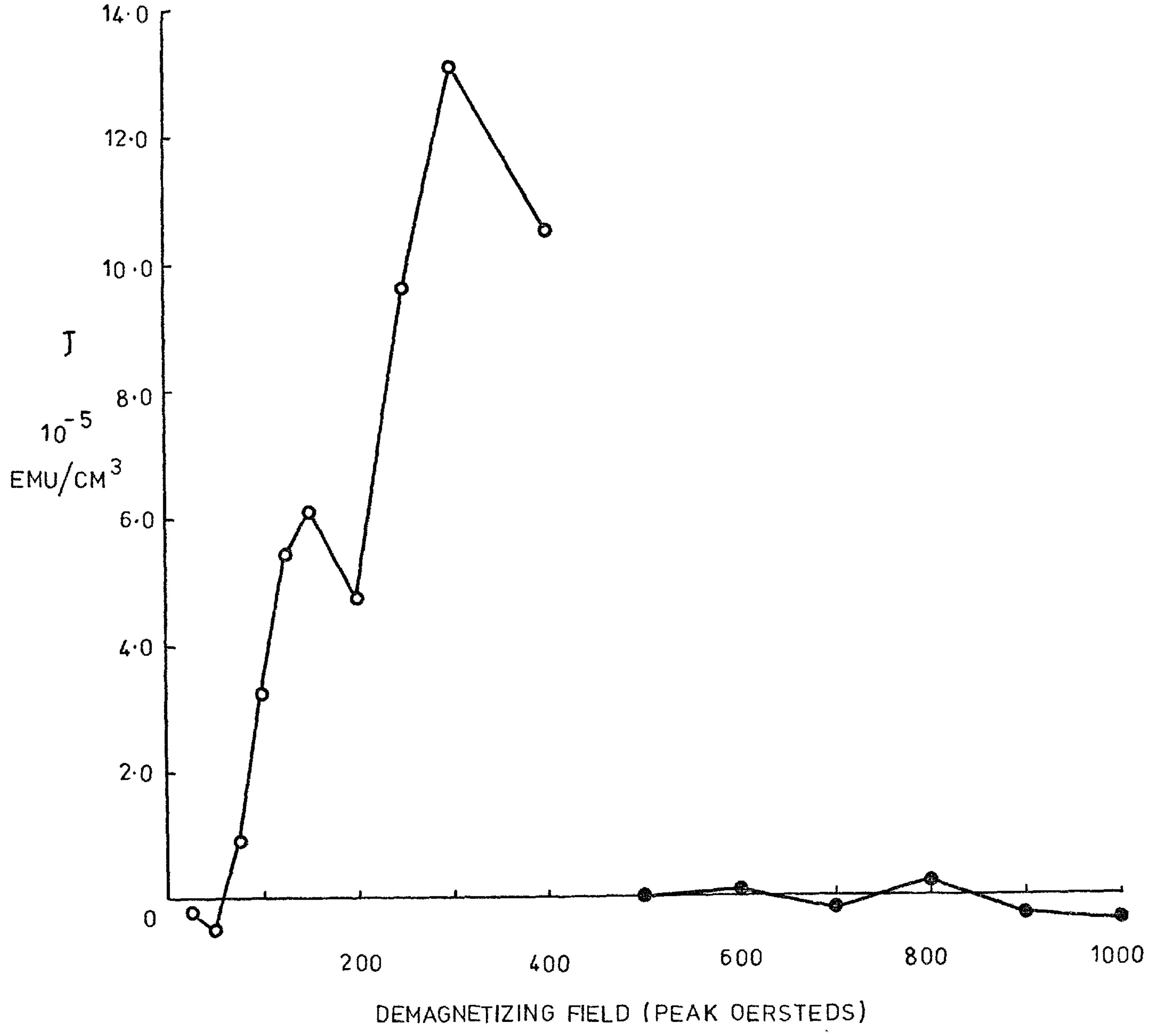
connected in series with the coil to produce a tuned circuit resonant at 50 Hz, thus effectively reducing the impedance of the coil and so minimising the voltage which has to be supplied. Access to the tumbling system, which is fixed at the centre of the Helmholtz coils, is obtained by having the demagnetizing coil mounted on a platform which can be moved horizontally on phosphor-bronze bearings a sufficient distance to expose the tumbler.

Up to the present the equipment has been used to produce demagnetizing fields up to 1200 oe, the limiting factor being the 2000 volt rating of the tuning capacitors. At 1200 oe the heating effect on a single run, starting from cold, is barely noticeable, but after 5 consecutive runs at this field strength the temperature rise of the coil is judged to be approaching an unacceptable level, and a cooling period is allowed. If the 1200 oe run has been preceded by runs of gradually increasing field strength, then of course fewer runs at 1200 oe are possible. During routine work at fields below 1000 oe the heating of the coil is not normally detectable.

3.4.2.2 Results Using the Redesigned Tumbler and Coil

Demagnetization experiments using the new tumbling system and coil showed a spectacular improvement in performance. It appeared that the problem of the systematically introduced spurious component along the +A axis had been completely eliminated, and that those spurious components which were introduced along the A axis were random in sense, and small in magnitude. The spurious components introduced along the B and C axes were, unfortunately, not systematically tested, but they again appeared to be of a random nature, and of small magnitude, but surprisingly, not so small as the A components.

The improvement in operation is illustrated in Figure 3.4, which shows the build-up of the +A spurious component in specimen D2-1 before the redesign (0 - 400 oe) and the small random A components in the same specimen after redesign (500 - 1000 oe). The average intensity of the +A spurious component with the old equipment at 250, 300 and 400 oe was 11.1 x 10^{-5} emu/cm^3, and the average intensity of the A spurious component (without regard to sign)



Build-up of introduced component along +A with old equipment (0 - 400 oe), and random introduced component along A with new tumbler and coil (500 - 1000 oe) and with same specimen, D2 - 1.

DEMAGNETIZING WITH NEW TUMBLER AND COIL

FIG. 3.4

after redesign between 500 and 1000 oe was 0.2×10^{-5} emu/cm^3, a reduction to 1.8% of its earlier value. The actual improvement is probably better than this figure suggests, as we have compared the new equipment at 500 - 1000 oe with the old equipment at only 250 - 400 oe.

The results of more comprehensive tests on the demagnetizing equipment, carried out after the next stage of redesign, are described in section 3.4.2.5 below. These again confirmed that the problem of the systematically introduced +A component had been eliminated, and that all introduced components were, in general, small in magnitude and random in sense.

3.4.2.3 Replacing the Copper Sulphate Tube

In view of the markedly non-linear and rather uneven manner in which the demagnetizing field was reduced by the electrolytic variable potential divider, and also the ever-present leakage problem, it was decided to look for an alternative method of reducing the current supplied to the demagnetizing coil. The ideal replacement appeared to be a variable induction type voltage regulator (eg. the General Electric Co. "Inductrol") used by workers in North America. The output voltage of this device varies with the coupling between its primary and secondary windings. This coupling can be varied by an electric motor, and it is therefore possible to reduce the output steplessly from its maximum value to virtually zero.

An extensive search revealed however that regulators of the above type are not available in this country, and it was therefore decided to use a motor-driven variable auto-transformer (Claude Lyons "Regulac"). This would allow the current to be reduced linearly to almost zero, but suffered from the possible disadvantage that as the output is taken from brushgear moving over the transformer windings, the output would be stepped. However, as the influence of small steps on the effectiveness of demagnetization was unknown, and there appeared to be nothing else available, it was decided to use this device.

3.4.2.4 The Final Demagnetizing Circuit

A circuit diagram of the demagnetizing system that was finally adopted, and which was used for the major part of this project, is given in Figure 3.3 (a).

The motor-driven Regulac is a Type RK6H-M, which was selected as it has a large number of turns (724) and therefore produces smaller amplitude steps in the output. Because of the large number of turns the wire gauge is smaller, and therefore the current rating is only 3 amps. This is less than the 5.76 amps required to produce 1200 oe in the demagnetizing coil, and so a step-down transformer was required. This function is performed by the "Course Adjust" hand-operated auto-transformer (Claude Lyons "Variac" Type 100R), to which has been fitted a mechanical stop to prevent the turns ratio ever becoming less than approximately 2:1. This "Coarse Adjust" Variac allows the initial current through the demagnetizing coil to be roughly set at the beginning of the demagnetizing run, but because the Variac has only 255 turns, which corresponds to 12 oe per turn, accurate adjustment was impossible. Therefore the "Fine Adjust" Variac and 20:1 step-down transformer were included in the circuit. This corresponds to 0.6 oe per turn, and so allows fine adjustment of the initial current.

The above circuit has the advantage that for every demagnetization run, at even the lowest field strength, all the turns of the motor-driven Regulac are utilised. This has been achieved using only one motor-driven transformer, whereas As (1967), in order to reduce the step size in the low field range, simultaneously adjusted three variable auto-transformers in parallel.

The output envelope of the Regulac during run-down was examined on an oscilloscope, and the steps appear to be rounded rather than sharp. The output envelope during the first few seconds of run-down from maximum did, however, appear to be slightly irregular, and so in practice the Regulac was only turned up to 98% of its maximum at the beginning of each run.

During a demagnetization run the specimen in its holder is placed in the tumbler receptacle, and the tumbling system switched on. The motor-driven Regulac is manually wound up to about 98% of its maximum setting and the "Demag Current" switch set to on. The "Coarse Adjust" and then "Fine Adjust" Variacs are set to give the current (read from the Avometer) corresponding to the required field strength. Fields of 125 oe and below can be obtained using the "Fine Adjust" control only. Having set the current, about 13 seconds is allowed to elapse (corresponding to two complete cycles of tumbling) before the Regulac motor is switched on, and the Regulac begins to wind down. The run-down time is 4 min. 11 sec., corresponding approximately to the time required to carry out a complete measurement on the astatic magnetometer. When the Regulac reaches the zero position a micro-switch is operated which switches off the Regulac motor. The small remaining current (0.5% of its starting value) is reduced to zero by manually winding down the two Variacs, and finally the "Demag Current" switch is set to off and the tumbler stopped.

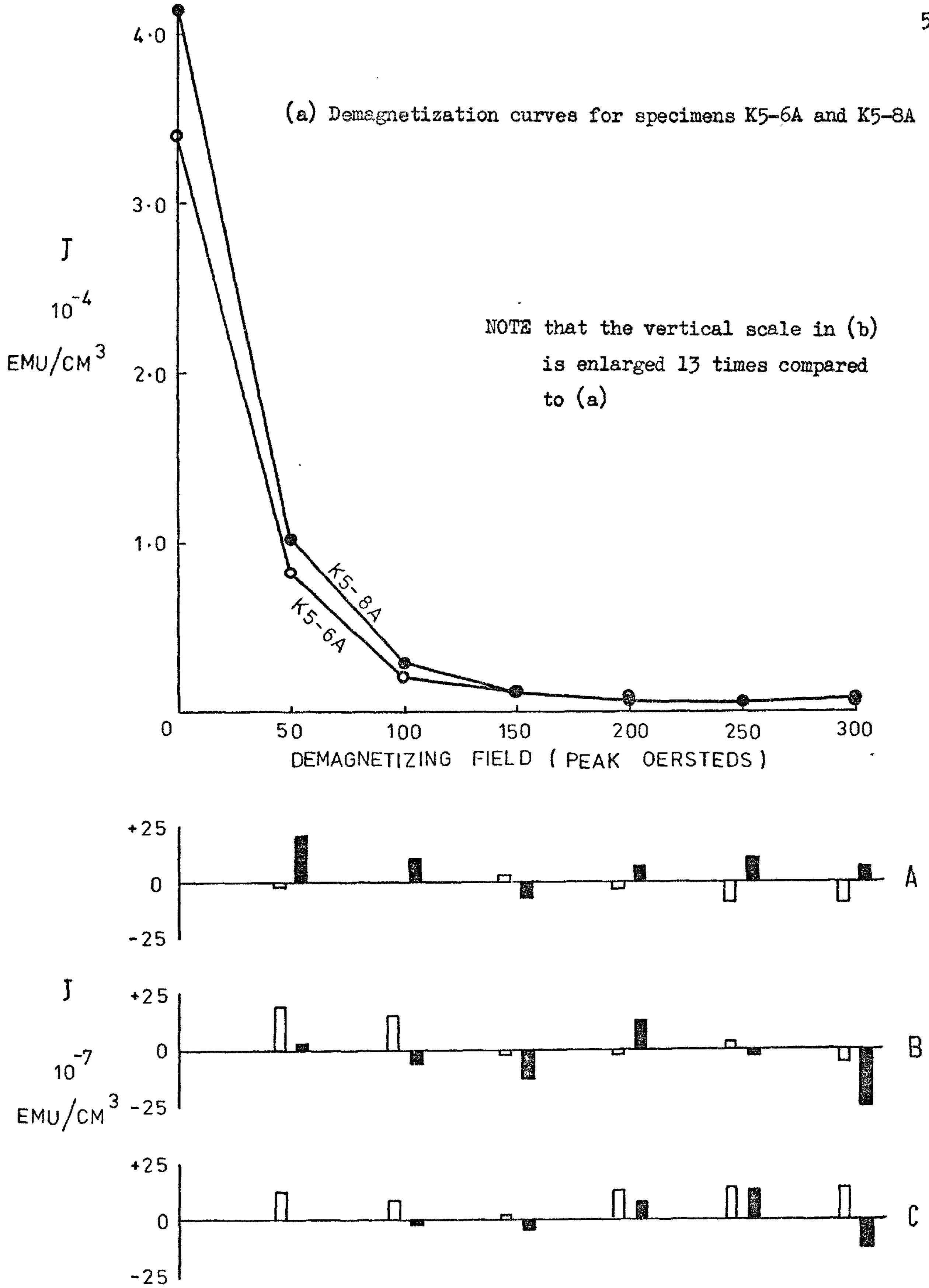
3.4.2.5 Results Using the Final Equipment

Tests were carried out with the final equipment to determine the nature of the spurious components introduced along each of the three tumbler axes. This involved measuring the magnetization along a given specimen axis after demagnetization first with that specimen axis aligned along a given tumbler axis, and then with the specimen axis aligned in the reverse direction. The mean of the two measurements was assumed to be the true magnetization along that specimen axis, and the deviations of the two individual measurements from the mean were considered to be the spurious components associated with that tumbler axis. To check all tumbler axes at least once required that the specimen be demagnetized and measured three times at each field strength.

The first tests were carried out on specimens K5-6A and K5-8A from an extremely unstable kimberlite. These specimens were from the same cores as K5-6 and K5-8, which were tested with the original equipment, and one result of which has been illustrated above in Figure 3.2 (a). Being adjacent specimens from the same cores they should have similar magnetic properties and so should allow comparison of the operation of the new equipment with the original. The results of these tests are illustrated in Figure 3.5 (a), which shows the demagnetization curves for these specimens, and in Figure 3.5 (b), which shows (with an enlarged vertical scale) the spurious components introduced along the A, B and C axes at each demagnetization step. It can be seen that the spurious components appear to be randomly introduced along the A and B axes, but that there is the suggestion of a slight bias towards +C compared with -C. The magnitude of the spurious components appears to be similar along all three axes, and, bearing in mind that these are extremely unstable specimens (at 200 oe the average J is only 2.2% of its NRM value) the levels appear to be reasonably small. In fact about half of the spurious components shown in Figure 3.5 (b) may not be introduced components at all, as they are within the noise level (approximately 0.25 cm) of the astatic magnetometer used for measuring them.

Figure 3.6 (a) shows the spurious components systematically introduced along the +A axis in K5-6 and K5-8 using the original equipment, and Figure 3.6 (b) shows the spurious components randomly introduced along the A axis in K5-6A and K5-8A using the new equipment. This diagram clearly illustrates that the problem of the systematically introduced +A component has been completely eliminated in the new equipment. Not only are the spurious A components randomly introduced, but they are also much smaller in magnitude. Thus, at 300 oe with the old equipment the average +A component was 12.5×10^{-5} emu/cm^3, but with the new equipment the average A component (without regard to sign) was only 8.3×10^{-7}emu/cm^3, a reduction to 0.66% of its earlier value.

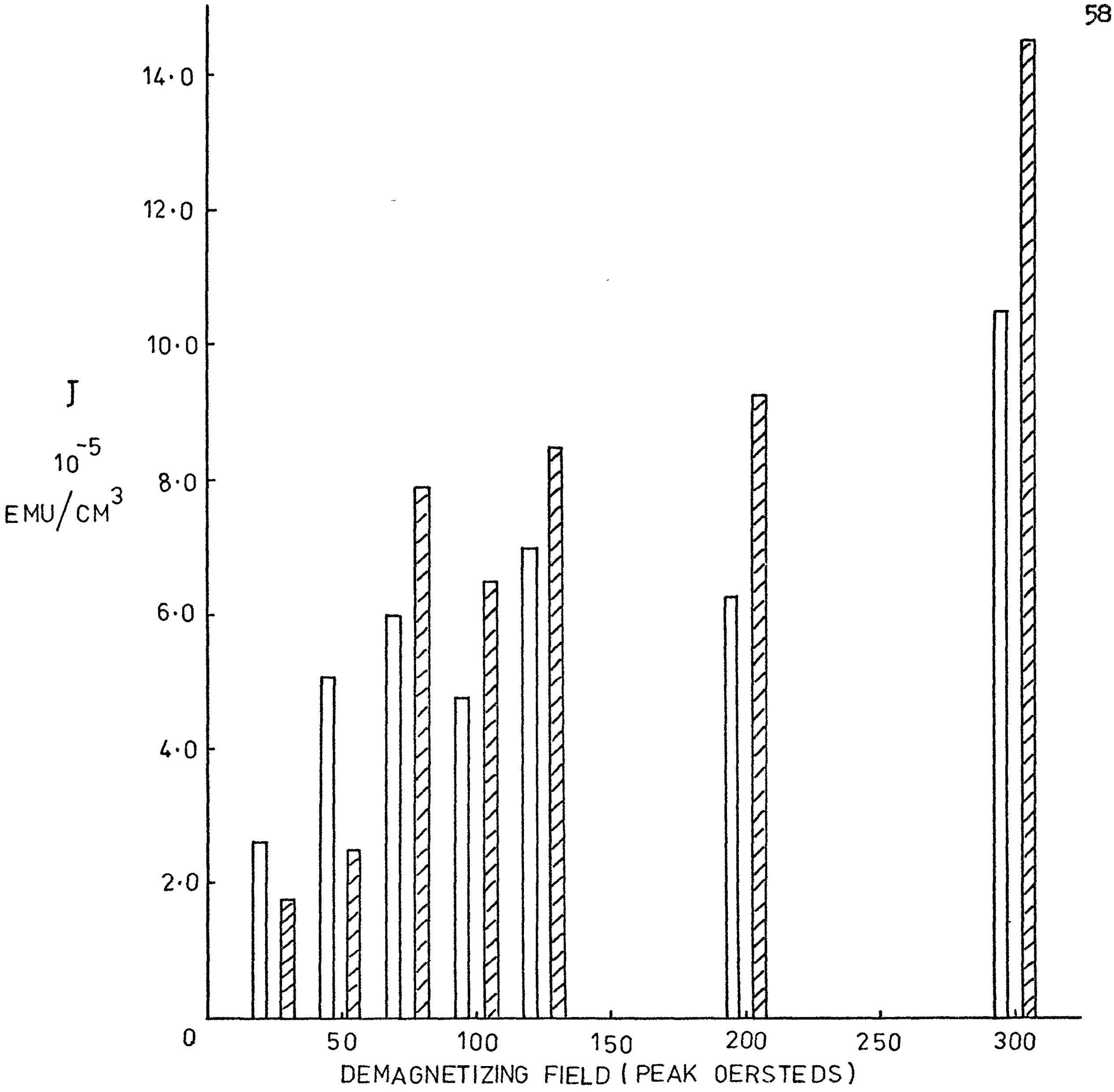
Figure 3.7 shows the results of similar tests on specimens D13-6 and D13-8 at demagnetizing fields up to 1200 oe. These specimens were very stable to a.f. demagnetization, at 200 oe the average J still being 66% of its NRM value. Although these were not the most stable rocks in the collection, they



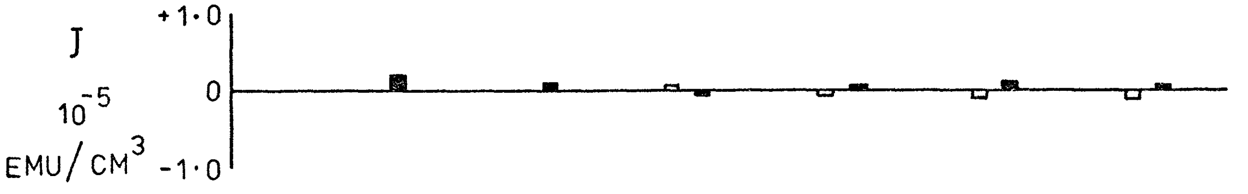
(b) Spurious components added along A, B and C axes in K5-6A (unshaded) and K5-8A (shaded). Abscissae are demagnetizing field strengths with same scale as in (a).

TESTING THE DEMAGNETIZING EQUIPMENT WITH EXTREMELY UNSTABLE SPECIMENS

FIG. 3.5



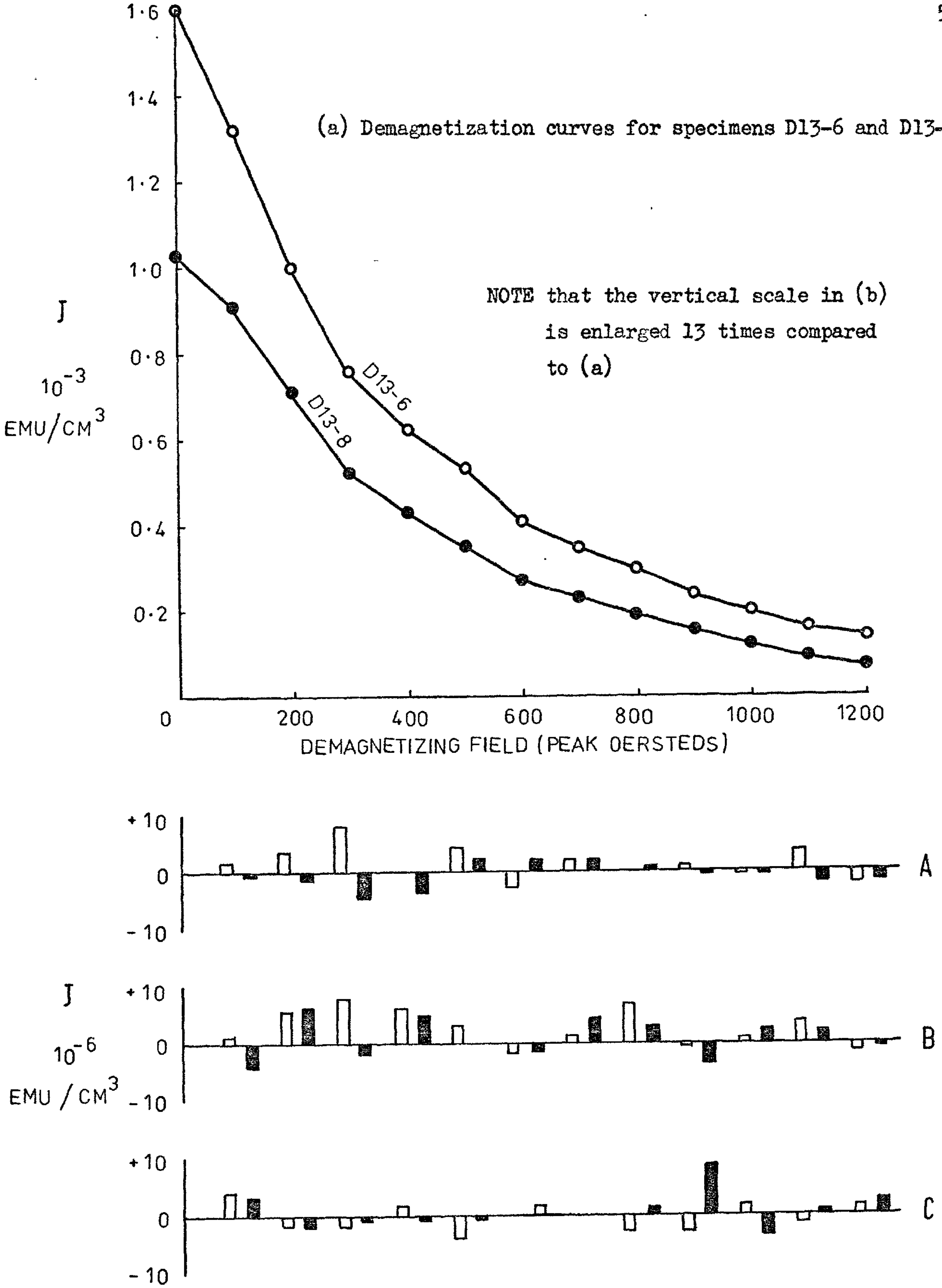
(a) Spurious components added along "+A" direction in specimens K5–6 (unshaded) and K5–8 (shaded). Old equipment.



(b) Spurious components added along "A" direction in specimens K5–6A (unshaded) and K5–8A (shaded). New equipment. Note the vertical scale is the same as in (a).

COMPARISON OF OLD AND NEW DEMAGNETIZING EQUIPMENT USING SPECIMENS FROM THE SAME CORES

FIG. 3.6



(a) Demagnetization curves for specimens D13-6 and D13-8

NOTE that the vertical scale in (b) is enlarged 13 times compared to (a)

(b) Spurious components added along A, B and C axes in D13-6 (unshaded) and D13-8 (shaded). Abscissae are demagnetizing field strengths with same scale as in (a).

TESTING THE DEMAGNETIZING EQUIPMENT WITH STABLE SPECIMENS

FIG. 3.7

were rather more stable than the average material. The spurious components introduced along the A axis again appears to be completely random, as also do the C components, but there appears to be a very slight bias towards +B. Taken together with the results shown in Figure 3.5 (b) these tests appear to indicate that the spurious components introduced along the A, B and C axes are essentially random.

The magnitudes of the spurious components introduced into D13-6 and D13-8 are very small, and again about half of the spurious components shown are within the noise level of the magnetometer. Up to 600 oe all spurious components are less than 1.1% of the natural remanence remaining at that step, and on average are only 0.46% of the natural remanence. Between 700 and 1200 oe all spurious components are less than 5.7% of the natural remanence at that step, and on average only 1.3%. It is worth noting that a spurious component with 0.46% of the intensity of the natural remanence will produce a maximum deflection of the remanence vector of 0.3°, and a spurious component of 1.3% a maximum deflection of 0.8°.

These results for specimens D13-6 and D13-8 appear to compare favourably with results of similar investigations carried out by Doell and Cox (1967) using their demagnetization equipment and a specimen of a "hard lava". Their equipment included a three-axis tumbler, and the demagnetizing field was reduced steplessly using an "Inductrol" voltage regulator. At 800 oe the spurious components introduced along the three axes of the Doell and Cox tumbler appear to average about 6.6×10^{-6} emu/cm^3, whereas at 800 oe the spurious components introduced into D13-6 and D13-8 average only 2.22×10^{-6} emu/cm^3. It would seem, therefore, that the small steps in the output envelope of the motor-driven Regulac have no adverse effect on the demagnetizing process.

3.4.3 Rotational Remanent Magnetization

Wilson and Lomax (1972) described experiments which show that a permanent remanence can be induced into many rock specimens when they are rotated in a decreasing alternating field. They called this new type of remanence rotational remanent magnetization (RRM), and showed that the intensity of RRM was related to the maximum strength of the alternating field, and also that it varied from a maximum when the rotation axis was perpendicular to the applied field, to zero when the rotation axis was parallel to the applied field. Further, they found that in all their experiments where RRM was produced, it was always induced exactly along the rotation axis, and always in the opposite sense to the sense of rotation, i.e. along -w. Wilson and Lomax were unable to provide a theoretical explanation of RRM, but they tentatively suggested that either gyromagnetism, or a solution to Maxwell's equations for a rotating conducting ferromagnetic grain in an alternating field, might be possible lines of approach.

More recently Brock and Iles (1974) have also described experiments on RRM, and have reported that although in most of their material RRM was developed along -W, in some specimens it developed along +W. They also found that as well as developing along the axis of a single axis rotation system (as described by Wilson and Lomax), it could also be induced along the inner axis of a two-axis tumbler. They refer to the former as RRM1 and the latter as RRM2. Their published curves indicate that in the same specimen RRM1 is six or seven times as strong as RRM2.

Bearing these observations in mind it is constructive to consider the origin of the spurious component systematically introduced along the +A axis in the original equipment. Due to the fact that the inner tumbling axis was permanently perpendicular to the applied field, and because of the radial symmetry of the field about the coil axis, the original tumbling arrangement was effectively equivalent to having a single rotation axis perpendicular to the applied field, as in the experiments of Wilson and Lomax. Furthermore, the +A axis corresponded to the -w direction of the inner tumbling axis, i.e. the direction along which the RRM was induced in all the experiments of Wilson and Lomax, and most of those of Brock and Iles. It seems very probable, therefore, that the spurious component systematically introduced along the

+A axis in the original equipment was, in fact, an RRM. Unfortunately, at the time the investigations were being carried out on the original equipment, the author had not yet seen either of the papers on RRM, and so the crucial test, that of reversing the sense of rotation and checking that the RRM changed sign, was not carried out. By the time the papers on RRM had been noted, the new equipment had already been completed and further investigations with the original system were not possible.

It is unlikely that the spurious +A component was an anhysteretic remanent magnetization (ARM) for two reasons. Firstly the ambient field was cancelled to within about 50 to 100 gammas, and secondly, the tumbling arrangement would have effectively randomised any ARM that was acquired. With regard to this latter point it is worth noting that although the original two-axis tumbler was effectively a one-axis tumbler as far as the a.c. field was concerned, it was still a two-axis tumbler to any steady d.c. component of field present, and so would have been quite effective in randomising any ARM components.

It is of interest to note that in the one-axis rotation experiments of Wilson and Lomax any small steady field present (unless it happened to be exactly perpendicular to the rotation axis) produced an ARM that was not randomised, and so these authors had to adopt a procedure for eliminating the ARM. This they did by measuring the RRM induced first with one sense of rotation, and then with the opposite sense. By taking the mean of the two measurements any ARM was cancelled out. It appears, therefore, that the original demagnetizing equipment was, in this respect, a more convenient way of inducing RRM than any experimental arrangement yet described, as it did not require two treatments to eliminate the ARM! The two-treatment method does have the advantage, however, of cancelling out any NRM present, but if the NRM has previously been eliminated by demagnetization at high fields, this would not be an important point.

3.5 THE PRECISION AND ACCURACY OF THE PALAEOMAGNETIC RESULTS

The precision (i.e. repeatability) of the astatic magnetometer measurements, and of the a.f. demagnetizing process, have already been briefly discussed above. Here it is proposed to make some further comments on precision, and also to comment on the accuracy of the results, that is, the degree to which the results represent the true magnetization at the sampling site.

At one stage in the project it was decided to carry out further demagnetization experiments on many specimens which had some time previously been demagnetized at lower fields. When this further work was begun all specimens were always demagnetized and measured again at the highest field to which they had previously been subjected. Thus a body of data was obtained which allowed the precision of the complete laboratory procedure to be assessed. Any angular difference between the previous and new measurement of a specimen could be caused by (1) errors in aligning the specimen in the specimen holder, (2) errors introduced in the demagnetizing process, (3) errors in aligning the specimen holder in the receptacle in the magnetometer, and (4) errors in the measuring process. Thus the precision determined from these observations included all the above factors. A total of 112 specimens were treated in this way, and it was found that the mean angular movement of the measured magnetization directions was 2.32°. The largest contributor to this error is probably the accuracy with which the specimen can be positioned in the specimen holder, which involves aligning by eye the orientation marks on the specimen with similar marks on the holder. The angular movement between the previous and new site mean directions were generally smaller than the movements in individual specimen directions, indicating that the individual errors are approximately random and tend to cancel out when the site mean is calculated.

Some indication of the accuracy of the palaeomagnetic measurements is shown by the high values of the precision parameter, k, obtained from some sampling sites. For example, eight specimens from dyke D5, all drilled in different orientations, yielded k values of 2078, 2060 and 2629 respectively at demagnetizing fields of 100, 200 and 300 oe. These k values correspond to angular standard deviations of 1.9°, 1.9° and 1.7° respectively. Now if all eight specimens were magnetized in precisely the same direction then these values of deviation would be due entirely to field and laboratory errors. However, if the specimens did not have precisely the same direction of magnetization, then part of this deviation must have been due to variations in magnetization. Thus these results indicate, at least for dyke D5, that the accuracy of the complete experimental procedure, from core orientation in the field to demagnetization and measurement in the laboratory, was equivalent to an angular standard deviation of something less than about 1.9°. As the observations of the last paragraph indicate that a deviation of this order is probably produced by laboratory errors, this implies that the direction of magnetization is virtually identical in each of the eight specimens.

Chapter 4

THE PALAEOMAGNETIC RESULTS

4.1 INTRODUCTION

This chapter, together with appendices B and C, contains all the basic palaeomagnetic results. Although some points of interpretation are included here as the results are described, the main interpretation and discussion of the results are left until later chapters.

In general at least ten cores were drilled at each of the 26 sampling sites, and a single 2.54 cm (1 inch) long specimen was cut from the unweathered end of each core. Usually eight of these specimens from each site (i.e. a total of 208 specimens) were then subjected to progressive a.f. demagnetization and measurement and it is the results of these measurements which form the greater part of the data of this study, and which are described in section 4.3 below. It was found that the palaeomagnetic results from many sites showed similar features and to prevent undue repetition some general aspects of the results are discussed in section 4.2 before the results are described in detail.

In addition, a total of 23 specimens from 12 of these sites were sent to Dr. G. E. J. Beckmann at Newcastle University for both thermal and a.f. demagnetization treatment, and the results of these investigations are described separately in section 4.5. Also ten specimens from six sites were sent to Dr. E. Irving at the Geomagnetic Laboratory of the Department of Energy, Mines and Resources in Ottawa, Canada, for demagnetization at higher fields than were available at Imperial College. The results of this work are described in section 4.6.

The full palaeomagnetic results for all specimens are given in Appendix B, and the results of combining individual specimen data into site means, etc., are given in Appendix C. Site mean results were generally calculated at every demagnetization to which the site specimens had been subjected, i.e. all the specimen results at the NRM stage (0 oe) were combined to give an NRM mean result, all the specimen results at 50 oe were combined to give a 50 oe mean result, etc. Both appendices contain introductory notes explaining the symbols and abbreviations used.

4.2 SOME GENERAL COMMENTS

4.2.1 Some remarks on precision and stability

During progressive demagnetization the precision parameter k at most sites generally increased to a maximum at between 50 and 200 oe, and then gradually decreased at higher fields, for example see the D12 results in Appendix B. The early increase in k was probably due to the removal of unstable viscous components acquired at low-temperatures. Some of these components were probably acquired in random directions during storage, but most were acquired along the earth's present field direction when the rocks were in-situ. Although the latter were more or less parallel they were probably present in different proportions in the various specimens and so helped to produce the initial relatively high scatter. The decrease in k at higher fields was probably related to the gradual decrease in the stable component residing in magnetically hard grains relative to the randomly directed unstable component representing the minimum intensity of magnetically softer grains. This random component is not a remanence in the normal sense but represents the state of least energy of the demagnetized grains. (Irving, 1964, pages 93-96).

At this point it is worth noting that to describe rocks as being either magnetically stable or unstable is not strictly correct. Probably most rocks contain both stable and unstable components, and it is the relative proportion of these that determines the behaviour of a specimen during demagnetization. In rocks generally regarded as stable the stable component predominates, and it is only at high demagnetizing fields, when the stable component has been reduced to a level comparable to the unstable components, that erratic behaviour of the measured magnetization in a specimen begins to occur. In rocks regarded as unstable the unstable components predominate and so mask the stable component even at low fields. There will of course be all types of intermediate behaviour between these two extremes, and in general the greater the proportion of the unstable components in a specimen the lower will be the demagnetizing field at which erratic behaviour begins to occur.

When this erratic behaviour of individual specimens commences the site dispersion will increase, and so the k value will decrease. However, because the unstable components in each individual specimen will tend to be randomly directed, when the site mean is calculated they should be largely averaged out, and because the mean unstable component will be so small compared to the mean stable component the direction of the site mean magnetization should not at first be significantly altered. During this phase of behaviour progressive demagnetization should cause the mean magnetization to show small random movements within a few degrees of the average position, and at the same time k will begin to gradually decrease. A point is eventually reached, however, where the mean stable component is reduced to such an extent compared to the mean unstable component that it is significantly modified, and at this point large random movements of the mean magnetization begin to occur, and k decreases to very low values.

Even when a site mean magnetization begins to show large random movements it should still be possible to obtain further information about the underlying stable component, provided that the movements of the individual specimen magnetizations are themselves random. The point at which large random movements of the site mean magnetization begin will be controlled by the number of specimens used, as clearly the greater the number of specimens the larger will be the mean stable component compared to the mean unstable component, and so the erratic behaviour of the site mean magnetization will occur at a higher demagnetizing field. Thus if a site magnetization begins to show large random movements at 600 oe, and for some reason it was crucial to observe the stable magnetization up to 1000 oe, then this should be possible by suitably increasing the number of specimens. Alternatively, and more simply, the same effect should be obtained without collecting more specimens by repeatedly demagnetizing and measuring individual specimens at the same field strength. If the unstable component in an individual specimen after demagnetizing is randomly directed, then by demagnetizing and measuring it a number of times and taking the mean, the unstable components will tend to be averaged out and the mean unstable component will be made much smaller compared to the mean stable component. If this is done for each specimen at a site then again clearly the erratic behaviour of the site mean magnetization will commence at a higher field than if specimens were demagnetized and measured only once at each field.

The technique of demagnetizing and measuring each specimen more than once was in fact commonly used during this study at high demagnetizing fields, but because of the time involved never more than two demagnetizations and measurements were ever carried out on one specimen at any demagnetization step. During each of the two demagnetization runs the specimen was placed in the tumbler specimen receptacle in a different orientation in case the unstable components were related to any of the tumbler axes, although the tests described in Chapter 3 indicated that this was unlikely. This technique was used in order to improve the precision of the mean pole positions at high fields, but it was also found useful during actual measuring as it allowed one to monitor the behaviour of individual specimens during progressive demagnetization. When repeat demagnetization and measurement at the same field strength began to yield grossly different results no further work on that specimen was carried out. In Appendix B results which have been obtained by this technique, (i.e. averaging the measurements after two demagnetization runs) are indicated by a 2 printed in the final column after the J/Jo value. In Appendix C any mean result which includes individual specimen results obtained by this method is indicated by a number printed after the final (DM) column, this number referring to the number of such specimens included. When this number is the same as the number in the N column then clearly all the specimen results used in calculating the mean were of this type. It is worth noting that the within-site precision k is normally actually a measure of the scatter of the true individual specimen directions plus an additional scatter due to errors in measurement and also to any unstable random components present. By tending to reduce the two latter effects the "double measuring" technique gives a k which more truly reflects the real scatter of the stable magnetizations at the site.

4.2.2 Systematic movements of magnetization

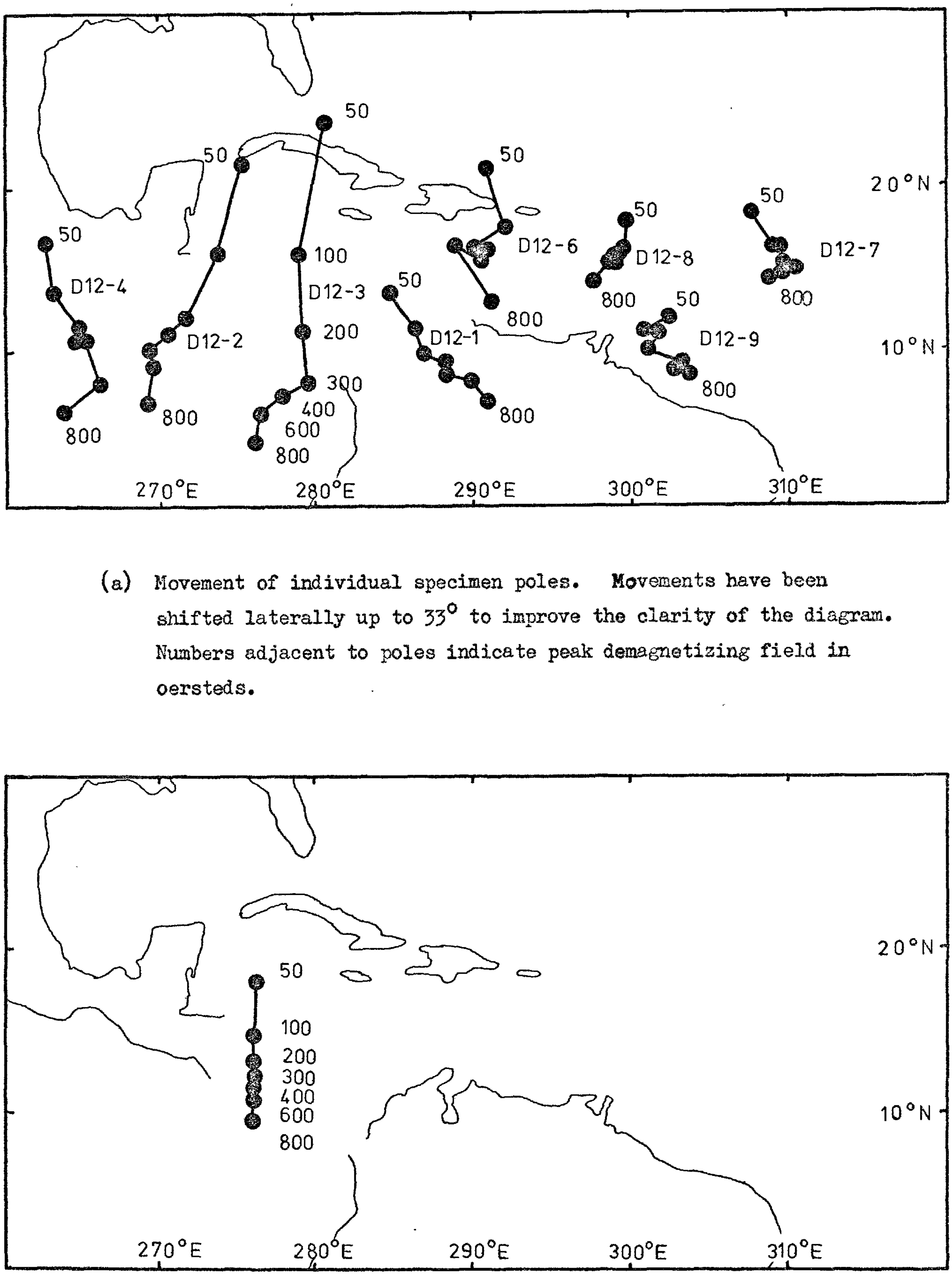
Quite early in this study it was noted that when the site mean results were examined they often showed small but more or less systematic movements of the mean direction of magnetization, and hence of the mean pole, with progressive a.f. demagnetization. Most sites showed a generally southerly movement of the mean pole between the NRM position and 50 oe, presumably due to the removal of unstable viscous components acquired mainly while the rocks were in-situ, and partly during storage. Between 50 and 300 oe the movements were generally more systematic, and two types of behaviour were commonly observed. Most sites showed a continuation of the southerly movement, but in a more nearly exactly southerly direction, presumably due to the fact that the random storage components had now been completely destroyed and only components acquired in-situ were being removed. At a few sites, however, a change in direction was observed, and the mean pole began to show small but generally very systematic movements in a south-easterly direction. The significance of these south-easterly movements, which were eventually found at eight sites, is discussed in Chapter 7.

At many sites, these systematic movements of the mean pole, both southerly and south-easterly, were still evident at the highest field (generally 300 oe) to which most specimens had been subjected during initial routine demagnetizing. Further, they were commonly continuing at fields higher than those (commonly 50-200 oe) which gave the best k value. It was apparent, therefore, that it would not be satisfactory to simply select as representative of each site the mean pole which had the highest k, but that at least for the sites showing only the southerly movements, progressive demagnetization should be continued to higher fields until the end-point of the southerly movement was reached. By so doing all components aligned along the earth's present field would then have been removed, and an ancient pole free of this disturbing influence would be obtained. Further demagnetization of these sites also seemed to be required to check whether at higher fields they would also show the south-easterly movements. For the sites already showing the south-easterly movements it also seemed that demagnetization to higher fields was required in order to investigate this unusual phenomenon further, and if possible to establish its end-point.

(It would clearly be possible to describe and illustrate the systematic movements which occurred during progressive demagnetization either in terms of the movement of directions of magnetization or of the movement of the corresponding poles. Throughout this study the latter alternative has been adopted as plotting the poles on a map allows the movements to be shown on a larger scale than could easily be obtained with directions plotted using a stereonet, and also it is considered that discussing poles rather than directions presents the reader with a more easily visualised picture of what is happening).

It thus became apparent that a great deal of further demagnetizing and measuring was required, far more than is usually done in such a study. It was eventually found necessary to take in general all eight specimens from virtually every site in 100 or 200 oe steps up to demagnetizing fields of between 600 and 1200 oe, the latter being the highest field available. It was largely because of the great expenditure of time that this entailed that examination of the magnetic minerals under the ore microscope, which would normally form part of a study such as this, was not carried out.

At low demagnetizing fields the southerly movements of the site poles was often quite large, sometimes as much as 35^{0} for the NRM - 50 oe step, but the systematic movements above 100 oe, both southerly and south-easterly, were almost invariably much smaller, movements of 2 - 5^{o} for a 100 oe step being typical for many sites. It is of interest to note that systematic movements of this scale would often be quite difficult to accurately define if only individual specimen poles were examined. A good example of this was shown by the southward movement of D12 poles between 50 and 800 oe (Figure 4.1). The movement of the eight individual specimen poles for D12, shown in Figure 4.1 (a) all showed a generally southerly trend, but each also showed considerable irregularities, and there was also a considerable variation in the amount of southerly movement. The movement of the site mean pole for D12, however, shown in Figure 4.1 (b), showed a regular systematic movement in an almost exactly southerly direction, the total change in latitude of the pole being 9.0^{o}, while its longitude always remained constant within $\pm$ 0.1^{o}. The irregular movement of the individual specimen poles was probably due to inevitable errors in measurement, and also to the presence of small random components as described in section 4.2.1. The fact that the site mean pole moved in such a regular manner confirms that these sources of dispersion are essentially random and are therefore almost completely averaged out when mean poles are calculated. Examining the site mean pole thus allows one to see through the various types of noise present and to determine the direction of any systematic movement for the site as a whole with some accuracy. In the case of D12 for example a movement in a virtually due south direction was revealed, providing convincing evidence that the movement was due to the removal of components with, on average, an almost exactly northerly alignment, and therefore almost certainly acquired fairly recently by viscous build-up along the earth's <u>axial</u> dipole field direction. This indicates that the viscous components removed between 50 and 800 oe were acquired over a time interval sufficiently long for the effects of secular variation to have been averaged out, and that over this period the average field direction approximated to that of an axial dipole. It is possible that very careful demagnetization work of this type, preferably using the thermal method, together perhaps with experimental work on the viscosity of the rocks concerned, might provide



(a) Movement of individual specimen poles. Movements have been shifted laterally up to 33° to improve the clarity of the diagram. Numbers adjacent to poles indicate peak demagnetizing field in oersteds.

(b) Movement of mean pole

SOUTHERLY MOVEMENTS OF D12 POLES BETWEEN 50 AND 800 OERSTEDS

FIG. 4.1

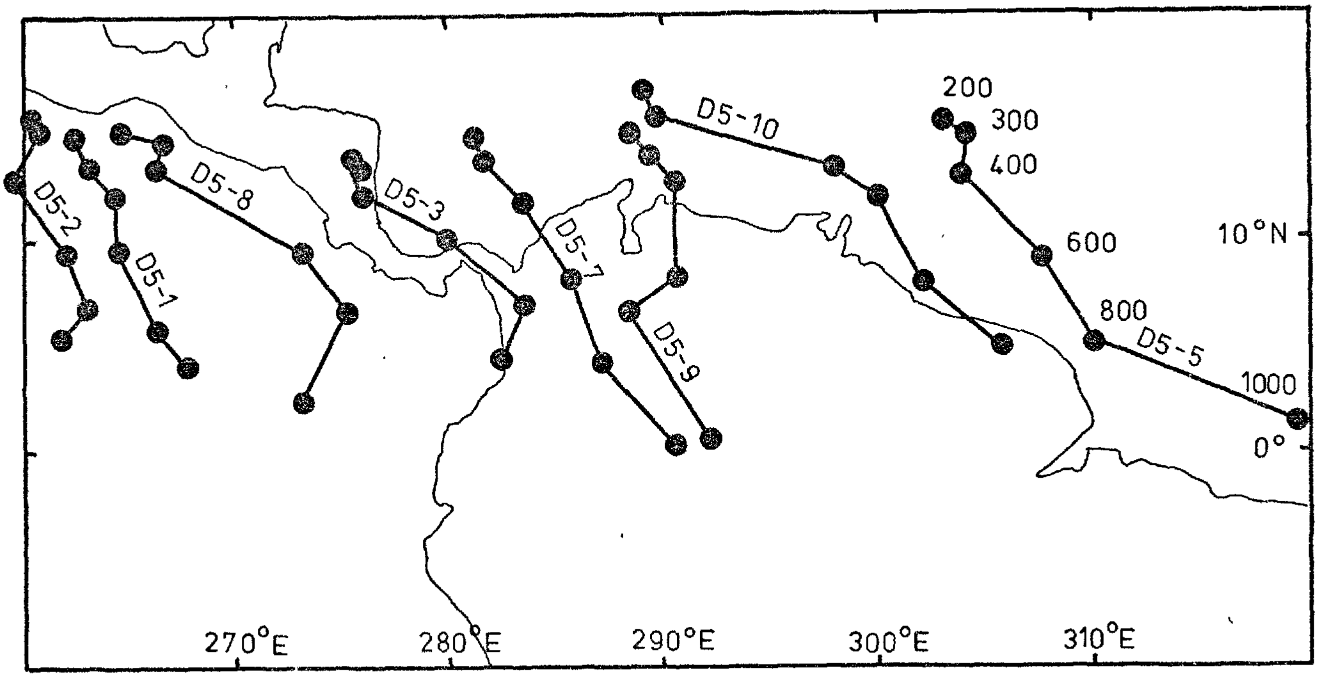
valuable information on the behaviour of the earth's field during the past tens or hundreds of thousands of years.

An example of systematic south-easterly movement was shown by D5 over the five steps between 200 and 1000 oe. The movements of the individual specimen poles, which are shown in Figure 4.2 (a), were generally rather irregular, but the movement of the site mean pole, shown in Figure 4.2 (b) was very systematic. This again indicates that the sources of dispersion of the individual specimen poles were random and hence averaged out when mean poles were calculated. From Figure 4.2 (a) it can be seen that the movements of each of the individual specimen poles, although having irregularities, showed a definite overall trend which was approximately constant for each specimen, and that this varied from almost southerly (D5 - 2), through south-south-easterly (D5 - 7) to just north of south-easterly (D5 - 10). It thus appears that the regular movement of the mean pole in a 145° direction was in fact the result of combining individual specimen directions which varied from 120° to 170°.

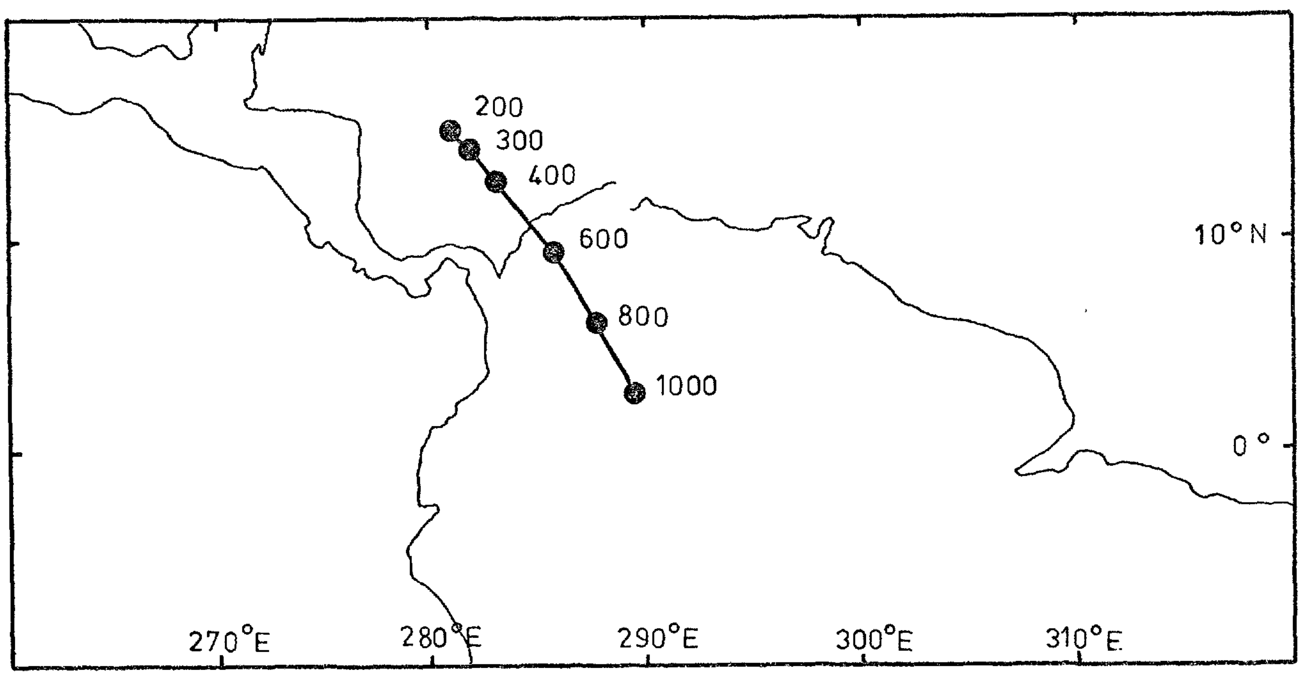
Another example of systematic south-easterly movements was shown by D17 over the five steps between 50 and 600 oe (Figure 4.3). The situation here was slightly different in that the movement of most of the individual specimen poles was more regular, and the variation in direction shown by the various specimen movements was also less, varying between 110° (D17 - 4) and 145° (D17 - 10).

The variation in direction shown by the various specimen movements at the sites which show south-easterly movements of the mean pole is considered further when the whole subject of these south-easterly movements is discussed more fully in Chapter 7.

The very regular movements shown for example by the D12 mean pole between 50 and 800 oe, and by the D5 mean pole between 200 and 1000 oe, clearly belong to the phase of demagnetization behaviour where the mean stable component is large compared to the mean unstable component, and so appreciable random movements of the mean pole do not occur. This is also



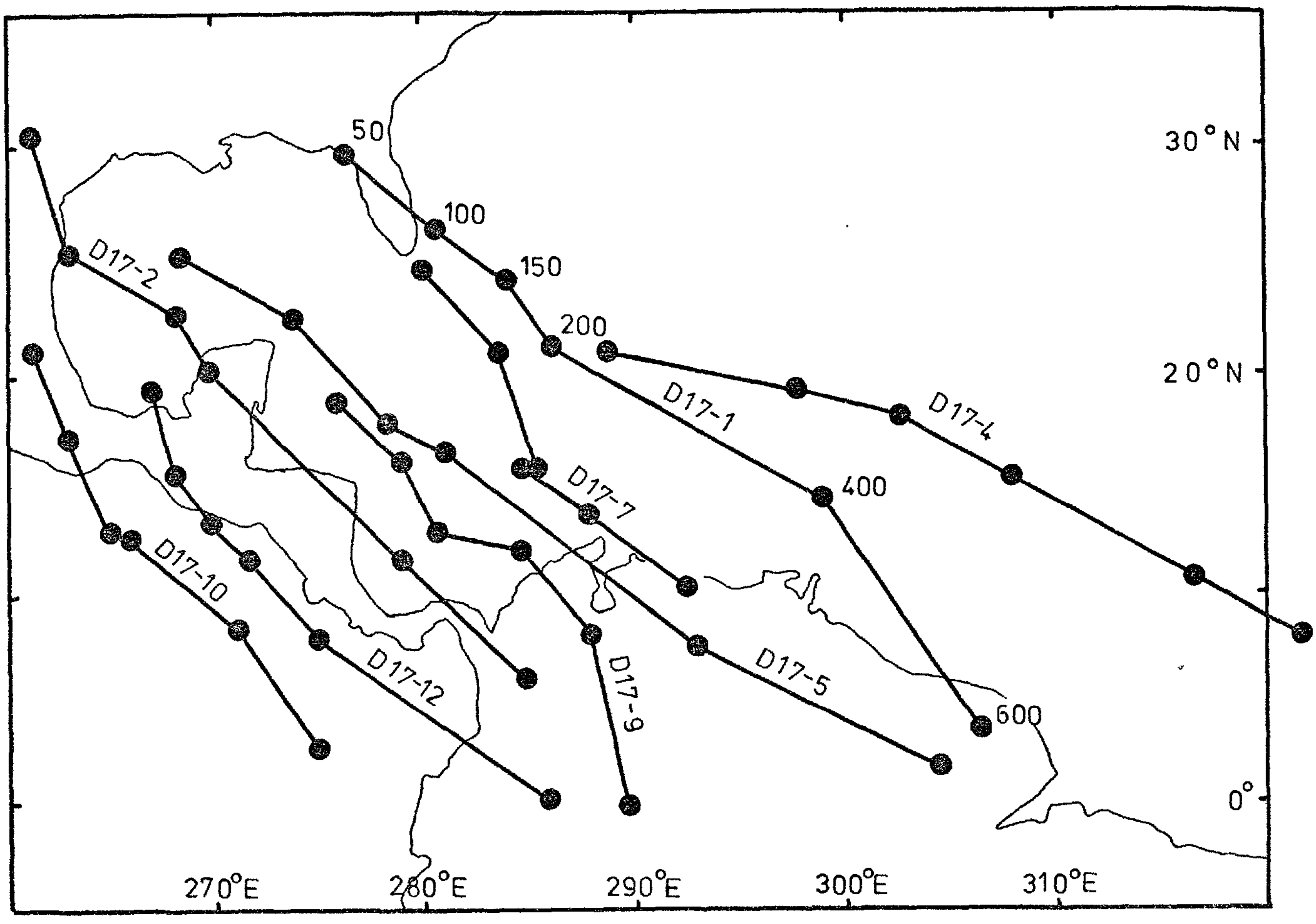
(a) Movement of individual specimen poles. Movements have been shifted laterally up to 20° to improve the clarity of the diagram.



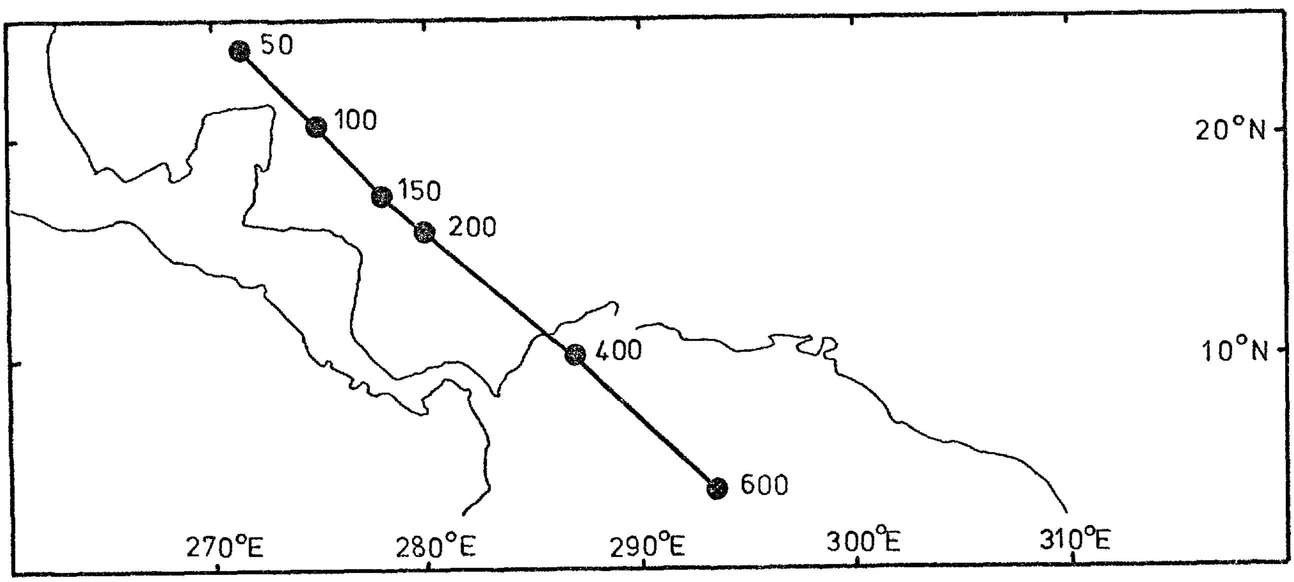
(b) Movement of mean pole

SOUTH-EASTERLY MOVEMENTS OF D5 POLES BETWEEN 200 AND 1000 OERSTEDS

FIG. 4.2



(a) Movement of individual specimen poles. Movements have been shifted laterally by up to 30° to improve the clarity of the diagram.



(b) Movement of mean pole.

SOUTH-EASTERLY MOVEMENTS OF D17 POLES BETWEEN 50 AND 600 OERSTEDS

FIG. 4.3

indicated by the high k values, for example the k for the D5 1000 oe pole still has the relatively high value of 228.0, and the 800 oe D12 pole still has a k of over 150. (It should be noted that throughout this study k and α_{95} have always been calculated from directions of magnetization and not from corresponding poles, even though in discussion they are often quoted with reference to a mean pole).

In several cases, however, it appears that the stage of appreciable random movement of the mean pole was reached before the end-point of the south-easterly movement had been clearly established. For example, the systematic south-easterly movement of the D16 mean pole (Figure 4.8) between 100 and 600 oe gave way in the 600 - 800 oe step to a southerly movement, and in the 800 - 1000 oe step to a south-westerly movement. This was accompanied by a sudden decrease in k from 94.7 at 600 oe to 16.6 at 800 oe and 5.4 at 1000 oe. The south-easterly movement of the D16 mean pole did not necessarily end at 600 oe; this was simply the point at which the mean unstable component became sufficiently large to mask any further systematic movements that might have occurred.

4.2.3 Selection of mean pole representing the stable magnetization

In an ideal case, where the rocks have a single large stable component of magnetization and a small unstable component acquired by viscous build-up along the present field, then progressive demagnetization would initially cause the site mean pole to move southwards. When all the viscous components have been removed the southerly movement ceases, and an end-point is achieved. This end-point represents the stable magnetization present at the site, and further demagnetization at moderate fields should cause the site mean pole to make small random movements centred about this point. As described in section 4.2.1, however, a stage is eventually reached where large random movements of the site mean pole begin to occur, and the pole may then move far away from the end-point.

In cases of the type just described a pole position corresponding to the stable magnetization is easily obtained, either by selecting a pole which appears to be most nearly central in the group of poles at the end-point, or by calculating the mean of the group. Examples of this type of behaviour were shown by several sites, including D3 and D20 (Figures 4.5 and 4.10 respectively). In D3 the end-point region was reached at 100 oe, and in the six demagnetization steps between 100 and 500 oe the mean pole showed small random movements always within 2.0° of the average position. Because it was felt that an end-point corresponding to a stable magnetization had been clearly established no further demagnetization was carried out, and so the stage of large random movements of the mean pole was not reached. In the case of D20 the stable magnetization was not so clearly defined. The end-point of the southerly movement appeared to have been almost reached at 300 oe, and the 300, 400 and 500 oe poles, although showing a southerly trend, are all separated by 0.5° or less. In view of this very close grouping these three poles are considered to represent a stable magnetization. The south-easterly movement of the pole between 500 and 600 oe may represent the first of progressively larger random movements, or it may represent the beginning of the systematic south-easterly movement found at other sites. Clearly on the evidence of one movement only it is impossible to distinguish between the two alternatives.

At many sites the selection of a pole representing the stable magnetization was complicated by systematic movements persisting up to high demagnetizing fields. For example, at sites D12 and D18, which both showed systematic southerly movements (Figures 4.11 and 4.12 respectively), this movement was still occurring at the 600 - 800 oe step, and in a less perfectly southerly direction in the final 800 - 1000 oe step. In cases such as these the end-point of the southerly movement was apparently not reached even at 1000 oe, although in view of the small size of the individual southerly steps it was presumably not far south of the 1000 oe poles. The deviation from the exactly southerly direction in the 800 - 1000 oe steps possibly indicates that the mean stable component had been reduced to such an extent that it is beginning to be appreciably modified by the mean unstable component. This again illustrates the fact that even with demagnetizing equipment capable of higher fields it might not always be possible to establish an end-point in such a case, as large random movements of the mean pole might begin to occur before the end-point was reached.

One commonly observed feature at many sites, and particularly well demonstrated by D12 and D18, was that systematic southerly movements of the mean pole continued to much higher fields than that which gave the highest k value. For example at D12 and D18 the highest k occurred at 100 and 50 oe respectively, whereas the end-point of the southerly movement had apparently not been reached at 1000 oe. This illustrates the danger of selecting as the representative pole at a site the one which has the highest k value, as this does not necessarily represent the stable magnetization. As indicated above in section 4.2.1 there are generally two factors influencing precision during progressive demagnetization; on the one hand the gradual removal of recently acquired viscous components causes precision to increase, while on the other hand the gradual decrease of the mean stable component compared to the mean unstable random component causes precision to decrease. The point at which precision is a maximum is therefore simply a function of the relative "rate" at which these two processes operate. At many sites in this study this point happened to occur before the complete removal of all the northerly directed viscous components acquired while the rock was in-situ, and hence the best k pole was deflected northwards from the position representing the stable magnetization. At one site G10/11 (see section 4.3 (xxi) below) the best k pole appeared to be deflected approximately 50° north of the position corresponding to the stable magnetization.

An interesting aspect of these systematic southerly movements persisting to high fields is that magnetization acquired by low-temperature viscous build-up along the present field apparently requires demagnetizing fields of up to 1000 oe for its removal. This implies that the magnetization resides in grains which combine low blocking temperatures with high coercivity.

This topic is discussed in greater detail in Chapter 7.

At those sites where the initial southerly movement of the mean pole gave way at higher fields to a systematic south-easterly movement, for example D16 and D17 (Figures 4.8 and 4.12) there are further problems in selecting a pole representative of the stable magnetization. It is argued below in Chapter 7 that each of the poles along the south-easterly movement at these sites represents stable magnetization. It is therefore not strictly accurate to represent the stable magnetization at these sites by a single pole, but as it is generally convenient to do so it is further argued in Chapter 7 that the pole at the beginning of the south-easterly movement is probably the best approximation that can be made. Therefore, at the eight sites showing this type of behaviour a pole occurring at the transition between southerly and south-easterly movement was generally selected as best representing the stable magnetization.

4.2.4 "301" type poles

At many sites the original investigation consisted of demagnetizing two specimens up to a high field, typically 1000 oe, and demagnetizing the remaining six specimens up to much lower fields, generally 300 oe. When at a later date it was decided that all specimens at these sites should be demagnetized to high fields then certain problems arose. These were mainly due to the fact that although specimens were not removed from the specimen holder while progressive demagnetization and measurement were in progress, they were removed at the end of each such investigation. The reason for demagnetizing to higher fields was to examine the movement of the site mean pole, and it was therefore essential that the results of the second phase of investigation should be completely compatible with the earlier results. However, as noted in section 3.5 the errors associated with aligning the specimen in the specimen holder are typically of the order of 2 - 3°. Even allowing for the fact that these errors are probably random and so tend to be reduced when the site mean is calculated, it is still likely that an appreciable error in mean pole position could be due simply to the fact that the specimens had been removed from and then replaced in the specimen holders. Thus if the new phase of demagnetization had been continued at the next highest field, typically 400 oe, then the direction of movement between 300 and 400 oe would have been subject to considerable error, especially as the actual movement being investigated was itself often less than 5^{o} over such a step.

In order to overcome this problem it was decided that in the new phase of demagnetization specimens would be demagnetized and measured again at the highest field to which they had previously been subjected. If this was 300 oe then the new measurement was referred to as "301" oe, if it was 200 oe the new measurement was referred to as "201" oe, etc. When the "301" mean pole was calculated it was generally found to be a few degrees away from the original 300 oe mean pole, and the difference represented the error between the two phases of investigation. Therefore when the movement of site mean poles were plotted the 400 oe and all higher poles were moved so as to exactly correct for this error, and so bring the two sets of results into alignment. Thus many of the higher field poles plotted in the diagrams showing movements of mean poles do not correspond exactly to the pole positions given in Appendix C, which gives the uncorrected results.

The fact that the poles resulting from the second phase of investigation were moved into alignment with the poles from the first phase of investigation does not of course imply that the latter poles are any more correct than the former. Both sets of poles probably incorporate some errors and the purpose of the correction is simply to ensure that the same error applies to all poles in the sequence. Therefore, when, as in several cases, the selected mean pole at a site was obtained in the second phase of investigation, although the second set of poles was "corrected" when all diagrams were prepared, for all other purposes the selected pole was not corrected in this way.

When a "301" oe mean pole was calculated it was of course necessary to include all eight specimens, even though often two of them had been demagnetized up to 1000 oe in the original investigation and so did not have any errors of the type described above. For each of these specimens the "301" oe result used in calculating the mean was made identical to their

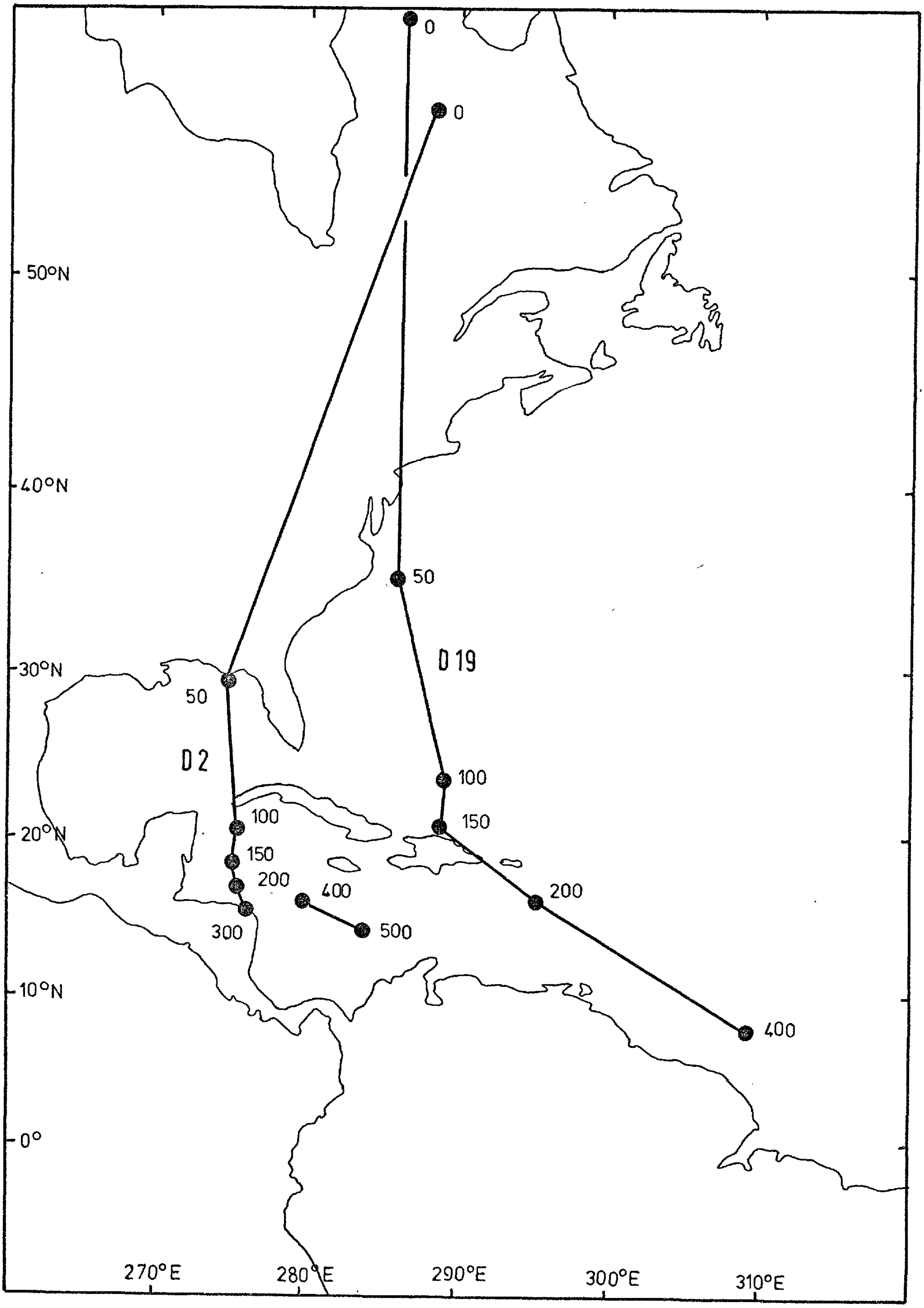
300 oe result, so that the "301" oe mean pole indicated the error for the site as a whole. In Appendix B it was more conveneient to include "301" results for specimens of this type, and they can be recognised by the fact that they are identical to the preceding 300 oe result.

4.3 THE MAIN PALAEOMAGNETIC RESULTS

(i) Dyke D2

As for all other sites the results for individual specimens are given in Appendix B, and the full statistical details of the site mean results are given in Appendix C. The movement of the D2 mean pole with progressive a.f. demagnetization is shown in Figure 4.4. (In all the following descriptions of site results the movement of the site mean pole during demagnetization is illustrated in the Figure whose number is given immediately after each site heading).

The SSW movement of the mean pole between its NRM position and 50 oe, and its almost exactly southerly movement between 50 and 150 oe, conforms to the general behaviour described above in section 4.2.2. Between 150 and 300 oe a SSE movement is apparent, possibly representing a transition to the south-easterly movement shown between 400 and 500 oe. The easterly movement between the 300 and 400 oe poles represents a kink in the otherwise smooth overall movement, and is probably largely spurious and due to a shortcoming of the measuring technique at this site. When the second phase of demagnetization was commenced at this site the six specimens which had previously only been demagnetized up to 300 oe were unfortunately not treated again at 300 oe to give a "301" pole (as discussed above in section 4.2.4), and so the movement between the 300 and 400 oe poles was subject to an appreciable error. For this reason the 300 and 400 oe poles in Figure 4.4 are not joined. The movement between 400 and 500 oe however, was reliable and was in a south-easterly direction. Whether this movement represents the beginning of the systematic south-easterly movement found at a number of other sites, or whether it merely represents the first of a series of random movements cannot be



MOVEMENT OF D2 AND D19 MEAN POLES DURING DEMAGNETIZATION

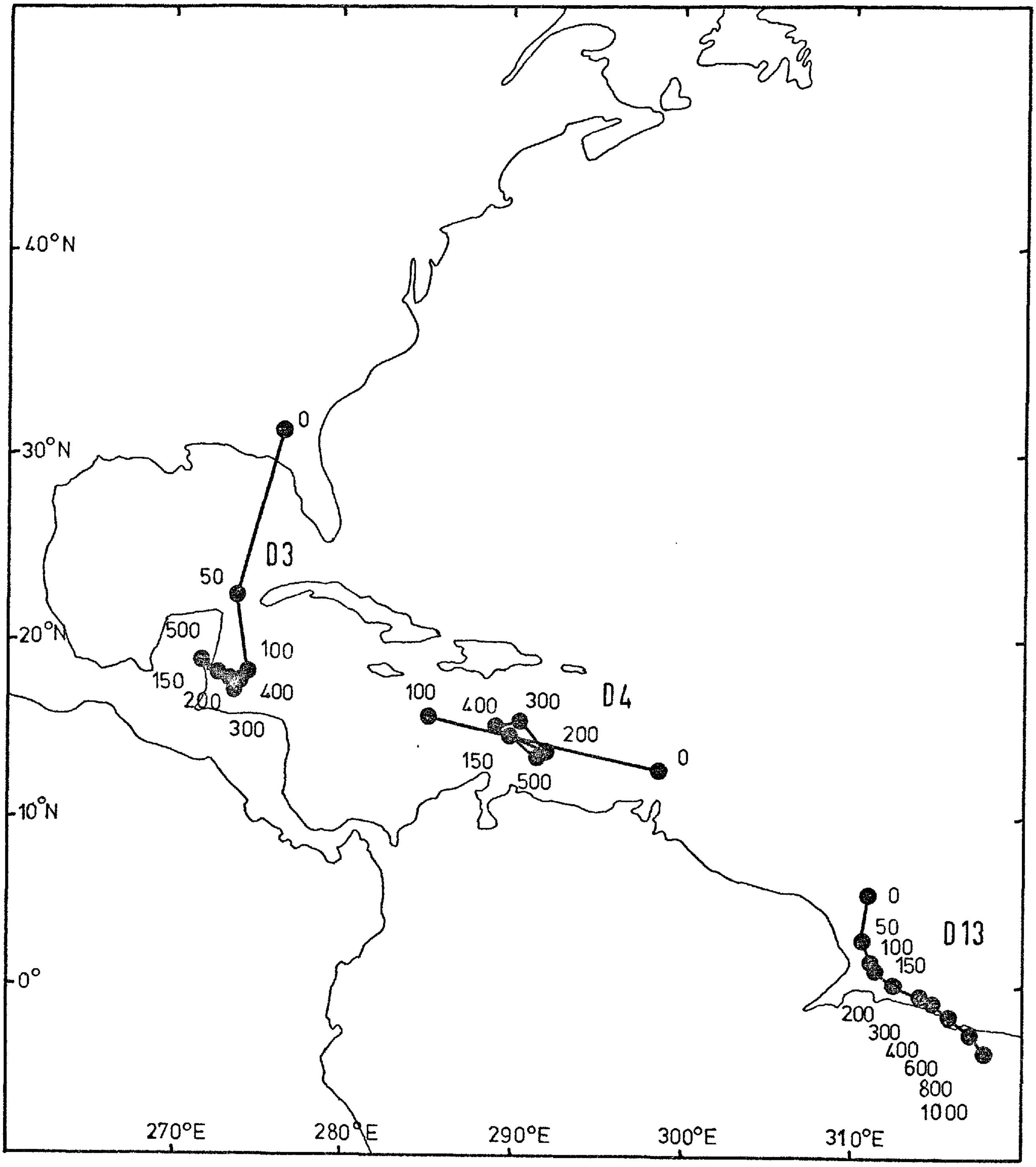
FIG. 4.4

decided, as clearly it requires at least two or three successive movements in the same direction to establish that a movement is systematic. Two pilot specimens demagnetized up to 1000 oe behaved rather erratically above 500 oe and showed no indication of any systematic movement, so it was decided not to demagnetize the remaining specimens above 500 oe.

All eight specimens showed broadly similar changes of intensity during demagnetization, with J/Jo at 200 oe varying between 0.203 and 0.493. A typical demagnetization curve, that for D2 - 3, is shown in Figure 4.16 (a). Low stability components are clearly present in moderately large amounts, and this is presumably why the NRM pole is in such a northerly position. The fact that all specimens have approximately the same proportion of unstable components is probably responsible for the relatively high k (50.0) at the NRM stage. Demagnetization appears to very successfully remove these unstable components, as indicated by the southward movement of the mean pole, and the increase in k to 655.0 at 100 oe. The end-point of the southerly movement of the pole appears to be at 300 oe, and so this pole was selected as representative of the stable magnetization at this site.

(ii) Dyke D3 (Figure 4.5)

The D3 mean pole moved generally southwards up to 100 oe, and then, except for small random movements, remained in essentially the same position up to 500 oe. There was a wide range of intensity changes during demagnetization, with J/Jo at 200 oe varying between 0.231 and 0.788, and averaging 0.580. (This does not include D3 - 6, which showed an increase in J with demagnetization, presumably due to the removal of an unstable component oppositely directed to the stable one, and which cannot therefore be compared with the other specimens). These figures indicate that at this site unstable components are generally present in minor amounts. The demagnetization curve of the most stable specimen, D3 - 4, is shown in Figure 4.16 (a). k rose from 37.8 at the NRM stage to a maximum of 459.3 at 150 oe, and remained high (over 239) up to 500 oe. The 200 oe pole was reasonably central in the close



MOVEMENT OF D3, D4 AND D13 MEAN POLES DURING DEMAGNETIZATION

FIG. 4.5

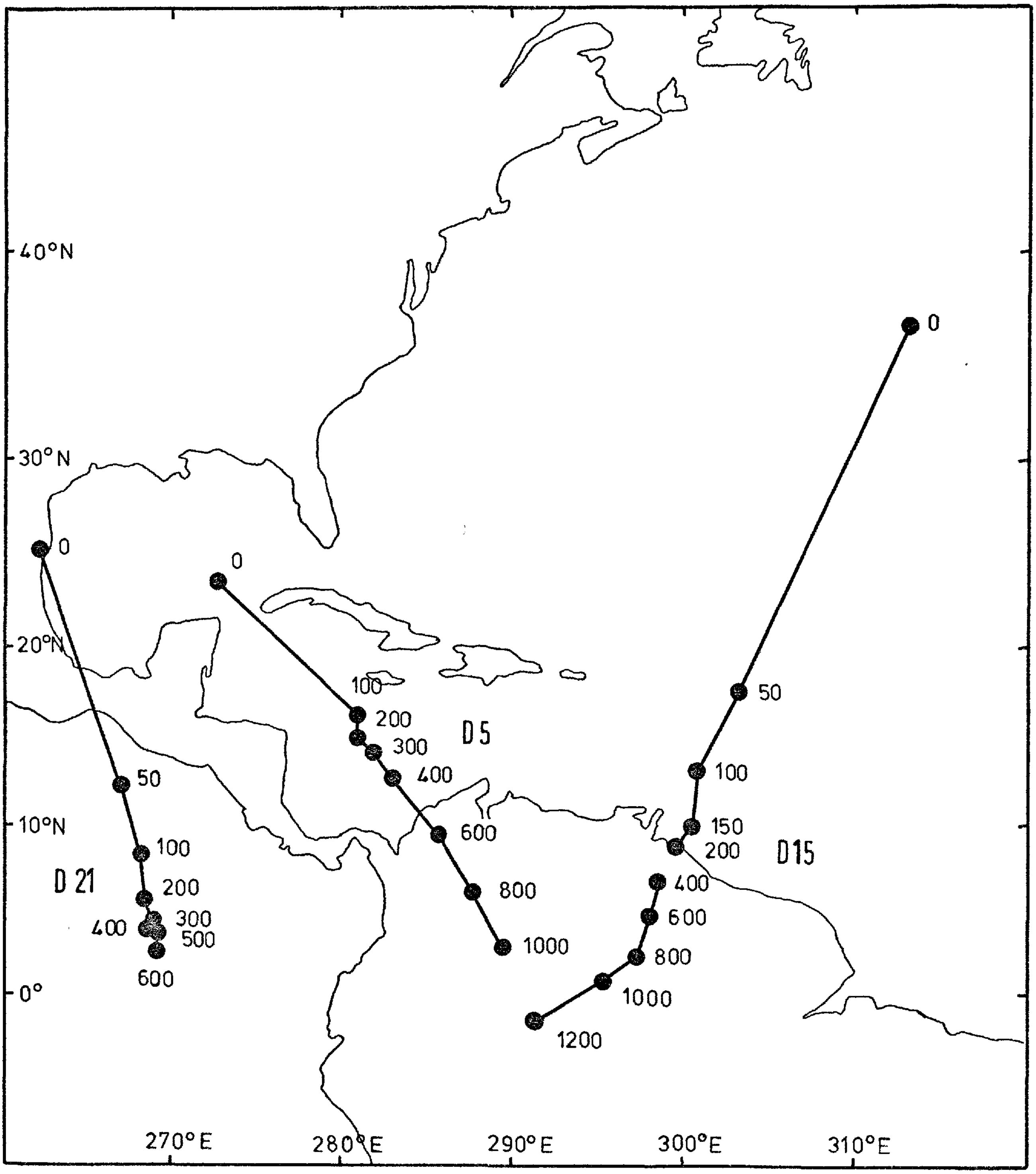
group of poles between 100 and 500 oe, and was selected as representative of the stable magnetization at this site.

(iii) Dyke D4 (Figure 4.5)

Between its NRM position and 100 oe the D4 mean pole moved approximately westward, and between 100 and 150 oe it moved in exactly the opposite direction, presumably due to the removal mainly of very unstable random components acquired during storage. Between 150 and 500 oe the mean pole remained in virtually the same position, except for small apparently random movements. Very variable intensity changes occurred during demagnetization, J/Jo at 200 oe varying from 0.167 to 0.745, with an average of 0.449. The demagnetization curve for D4 - 8 is shown in Figure 4.16 (a). Probably due to the very variable proportion of unstable components in the different specimens the k value at the NRM stage was only 5.3. However it increased to a maximum of 502.0 at 400 oe, and was generally high (over 233) at all steps above 100 oe. The 150 oe pole was placed approximately centrally in the 150 - 500 oe group of poles, and was therefore selected as representative of the stable magnetization at this site.

(iv) Dyke D5 (Figure 4.6)

The south-easterly movement of the mean pole between the NRM position and 100 oe, and the exactly southerly movement between 100 and 200 oe again conform to the general pattern described in section 4.2.2. In the five steps between 200 and 1000 oe the pole showed a remarkably systematic movement in a south-easterly direction. Of the eight specimens examined five were almost entirely lacking in low stability components, with J/Jo at 200 oe varying from 0.868 to 0.962, and three specimens had moderate amounts of unstable components with J/Jo at 200 oe of 0.316, 0.689 and 1.308. The demagnetization curve of a stable specimen, D5 - 2, is shown in Figure 4.16 (b); this specimen appeared to have virtually no unstable components at all as its NRM pole was less than 2.0° away from its 200 oe pole, and so the curve is of interest as it presumably represents the demagnetization characteristics of purely high



MOVEMENT OF D5, D15 AND D21 MEAN POLES DURING DEMAGNETIZATION

FIG. 4.6

stability material. The demagnetization curves of the other four stable specimens are very similar. The demagnetization curve of the most unstable specimen, D5 - 5, is also shown in Figure 4.16 (b). This shows that after a sharp decrease in intensity up to 100 oe the curve thereafter had exactly the same shape as that of the stable specimen. This implies that specimen D5 - 5, in addition to containing some low stability material, also contains the same very high stability material as the stable specimens.

The scatter at this site after demagnetization was exceptionally low, with a higher maximum k value (2629.5) than the author has ever seen reported in any study. The k and α_{95} values with progressive demagnetization are repeated here in Table 4.1 for convenience, and it can be seen that there was not simply one anomalously high k, but that it was persistently high throughout the demagnetization range, being over 2000 between 100 and 300 oe, and over 1000 at 400 and 600 oe. These persistently very high k values are particularly remarkable when it is remembered that above 200 oe the mean pole was moving in a south-easterly direction, the implication being that the movements were very similar in each specimen. It might be mentioned here that the eight cores were generally drilled with at least 1 metre separation between them, and that although the dips of the cores were generally similar, their azimuths were highly variable. As mentioned in section 3.5 the scatter at 100, 200 and 300 oe is probably almost entirely accounted for by field and laboratory errors, and at each of these steps the eight specimens were probably magnetized in virtually identical directions.

The sharp change in the direction of movement of the mean pole at 200 oe from southerly to south-easterly indicates that at 200 oe the low stability components acquired while the rocks were in-situ have been completely removed, and so the 200 oe pole was selected as representative of the stable magnetization at this site.

TABLE 4.1

DISPERSION STATISTICS FOR D5

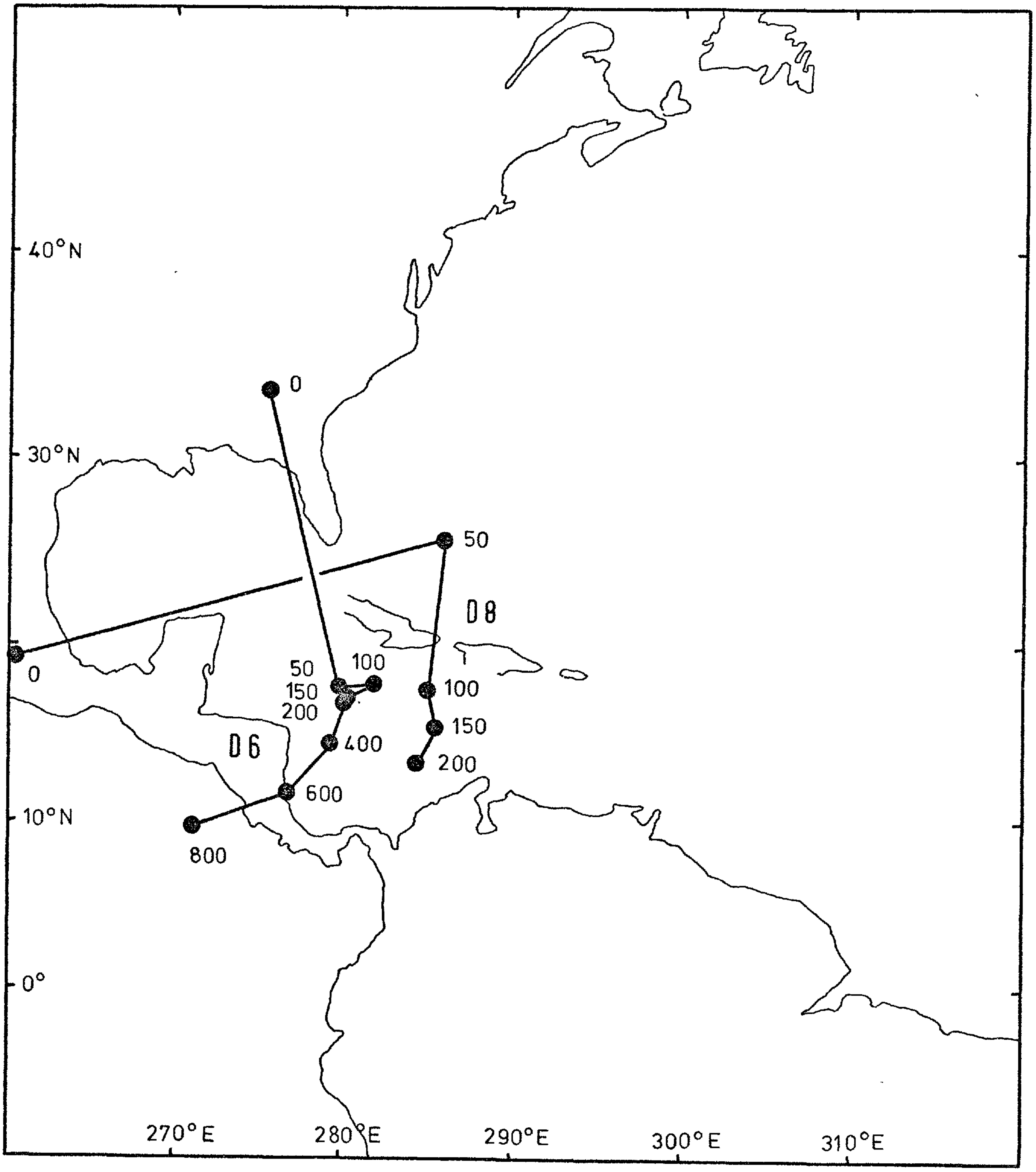
DEMAG. FIELD (oe)	NUMBER OF SPECIMENS	k	α_{95} (°)
0	8	30.6	10.2
100	8	2078.9	1.2
200	8	2060.6	1.2
300	8	2629.5	1.1
301	8	2287.7	1.2
400	8	1145.2	1.6
600	8	1242.7	1.6
800	8	826.1	1.9
1000	8	228.0	3.7

(v) Dyke D6 (Figure 4.7)

The end-point of the initial southerly movement of the mean pole appeared to be at 50 oe, and between 50 and 200 oe there were small random movements of the pole close to the 50 oe position. Between 200 and 800 oe, however, there was a movement which is rather difficult to interpret. The movements were all in a generally south-westerly direction, but were sufficiently different for there to be doubt as to whether this reflected a real movement of the stable magnetization, or was simply the beginning of larger random movements which by coincidence happened to be very approximately in the same direction. All specimens showed a fairly similar change of intensity with demagnetization, with J/Jo at 200 oe varying between 0.137 and 0.439, and averaging 0.258 (ignoring D6 - 1 and 4 which show initial increases in J). The demagnetization curve for D6 - 7 is shown in Figure 4.16 (b). The preponderance of low stability components is probably reflected in the low k of 16.6 at the NRM stage, but demagnetization produced a great improvement in precision with a maximum k of 934.1 at "201" oe. The close grouping of the four poles between 50 and 200 oe is taken to correspond to the stable magnetization present, and the pole with the best k, i.e. "201" oe, was selected as representative.

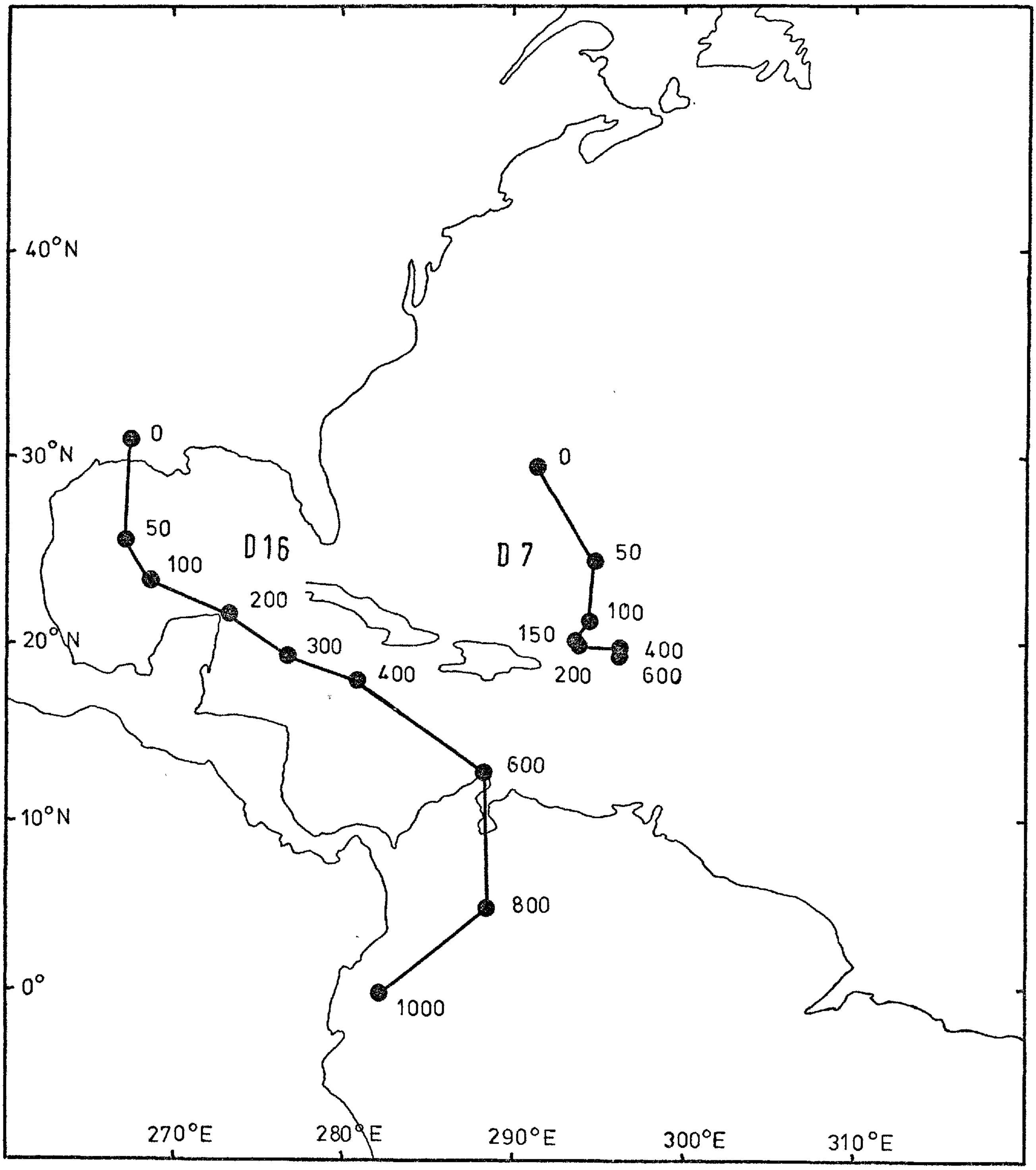
(vi) Dyke D7 (Figure 4.8)

The end-point of the southerly movement of the D7 mean pole was apparently reached at 150 oe, as no further significant southward movement of the pole occurred above this. The small movements of the pole between 150 and 600 oe appeared to be essentially random. All eight specimens showed a very similar decrease in intensity during demagnetization, with J/Jo at 200 oe varying only between 0.336 and 0.486, and averaging 0.420. The demagnetization curve for D7 - 3 is shown in Figure 4.16 (a). The best k of 473.5 was obtained at "151" oe, and this pole was selected as representative of the stable magnetization at this site.



MOVEMENT OF D6 AND D8 MEAN POLES DURING DEMAGNETIZATION

FIG. 4.7



MOVEMENT OF D7 AND D16 MEAN POLES DURING DEMAGNETIZATION

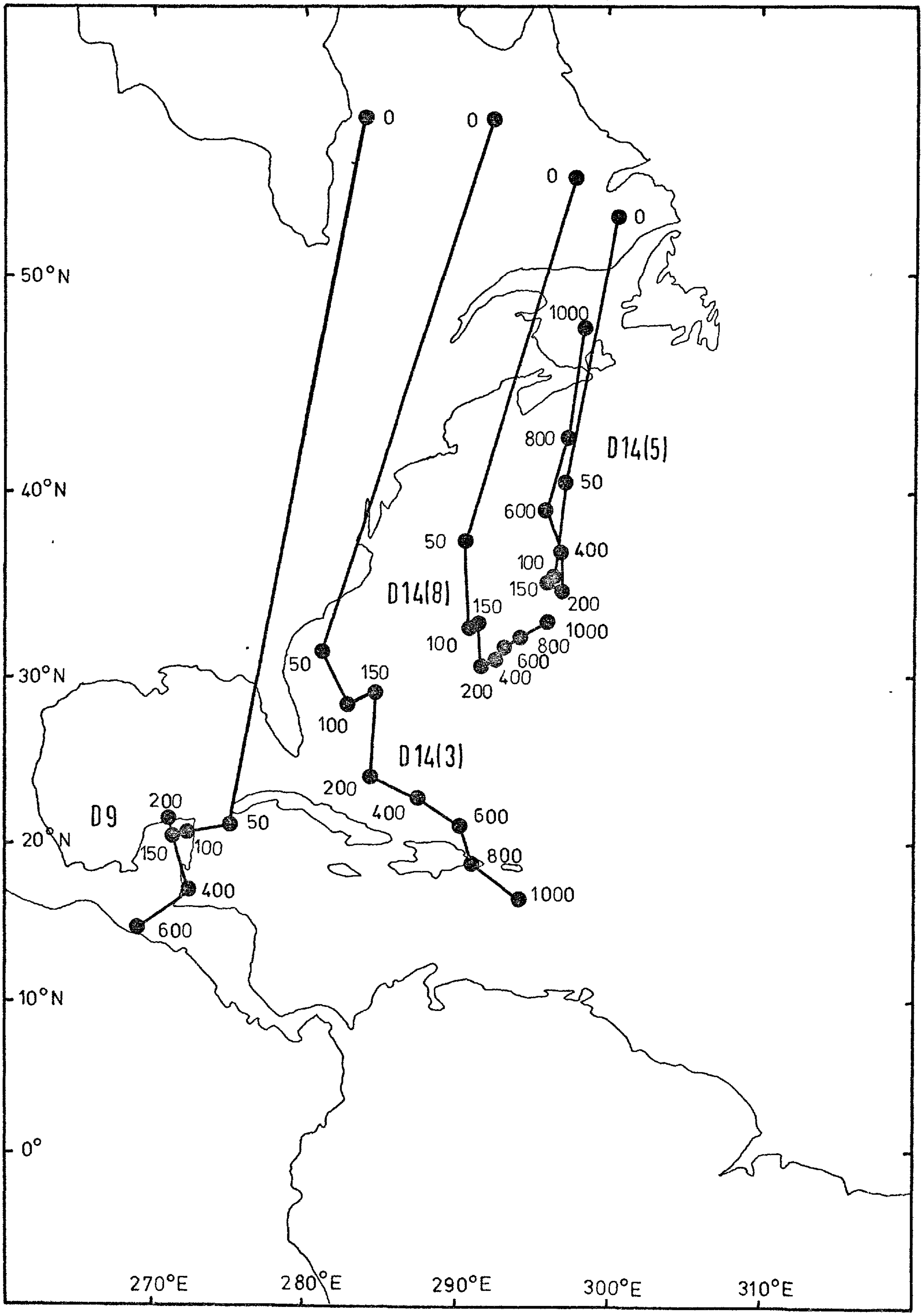
FIG. 4.8

(vii) Dyke D8 (Figure 4.7)

Only four specimens from this site yielded reliable results above 200 oe, the other four being either extremely weakly magnetized or showing unacceptably large differences between repeat demagnetizations at the same field. Mean results were therefore only computed up to 200 oe. Five specimens at this site were dominated by low stability components, with J/Jo at 200 oe typically less than 0.100, and three specimens had moderate amounts of unstable components, with J/Jo at 200 oe around 0.300. The demagnetization curve for the least stable specimen, D8 - 7, is shown in Figure 4.16 (b). The scatter at the NRM stage was very high, with a k of only 2.1, clearly reflecting the large proportion of unstable components present, but demagnetization was again extremely effective in improving precision and at 100 oe k had increased to 227.9. The ENE movement of the pole between the NRM and 50 oe stages presumably indicates removal mainly of very unstable random storage components, and the southerly movement between 50 and 200 oe the removal of unstable components acquired in-situ. This movement was still occurring at 200 oe, and obviously it would have been desirable to continue demagnetization of all eight specimens to higher fields. As this was impossible, however, there was no alternative but to select the 200 oe pole as the best available representative of the stable magnetization at this site. As the southward movement between 150 and 200 oe was only 2.0° the end-point of this movement was probably only a few degrees south of the 200 oe pole.

(viii) Dyke D9 (Figure 4.9)

A large southerly movement between the NRM position and 50 oe was followed by small movements between 50 and 200 oe lacking any obvious southerly trend. The slightly larger movements between 200 and 600 oe presumably represent the beginning of appreciable random movements. There was a wide range of demagnetization curves at this site, with J/Jo at 200 oe varying from 0.117 to 0.596, with an average of 0.346. The curve for D9 - 10 is shown in Figure 4.17 (a). k rose from 30.5 at the NRM stage to a maximum



MOVEMENT OF D9 AND D14 MEAN POLES DURING DEMAGNETIZATION

See text for further explanation of D14 poles

FIG.4.9

of 231.5 at 100 oe. All recently acquired viscous components appear to have been removed at 50 oe, and the 150 oe pole, which is more or less central in the close group of the three poles between 100 and 200 oe, was selected as representative of the stable magnetization at this site.

(ix) Dyke D10

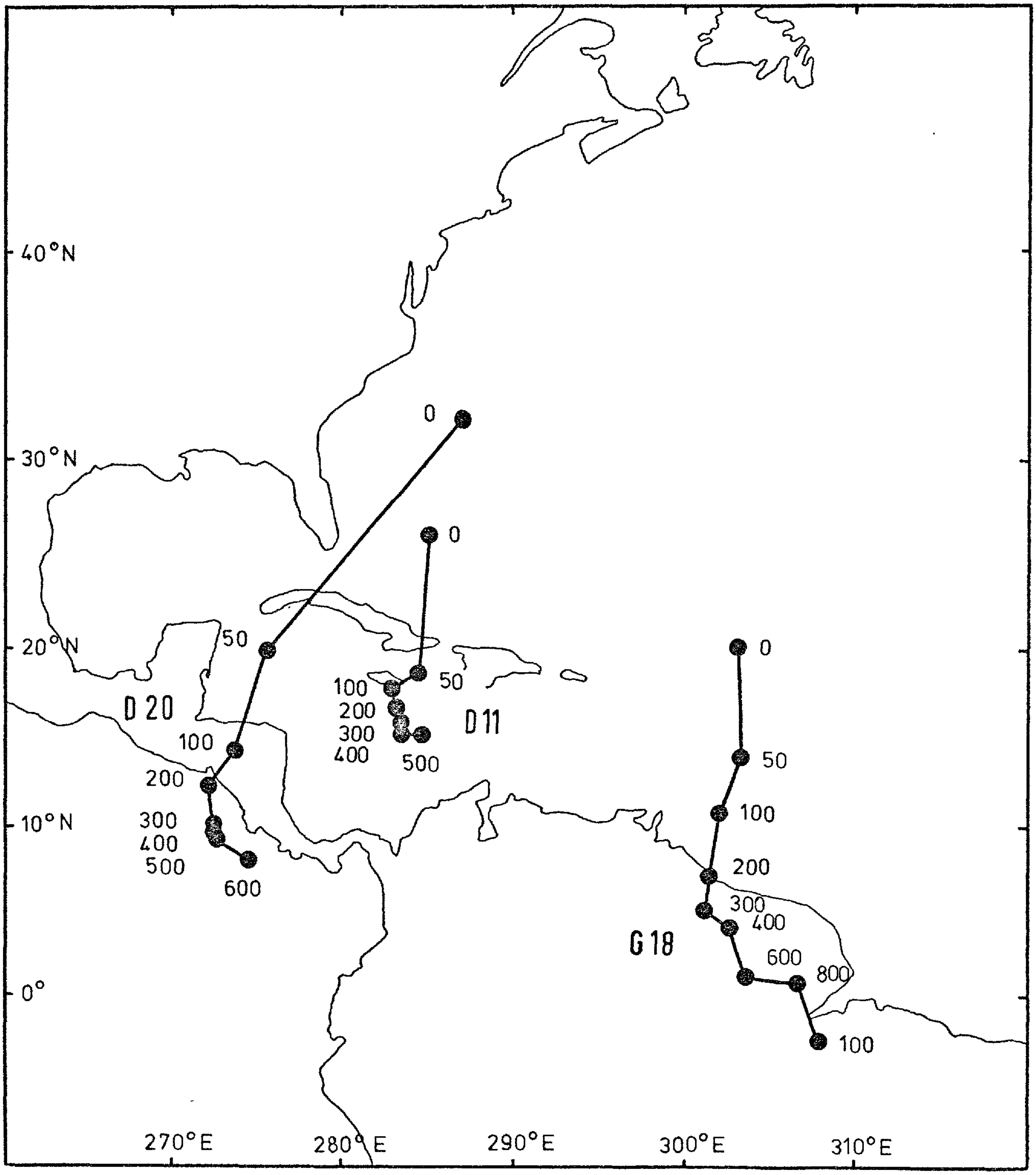
Nineteen cores, more than at any other site, were obtained from dyke D10, but unfortunately, due to adverse weather conditions, the core identification marks on almost all of them became illegible, making normal palaeomagnetic investigation impossible. This was probably not such a loss as first thought, however, as demagnetization studies on nine specimens indicated that they were generally much more weakly magnetized than any other dyke encountered in this study, and were dominated by unstable components.

(x) Dyke D11 (Figure 4.10)

After fairly small and generally southerly movements between the NRM position and 100 oe the D11 mean pole moved southwards in very small steps (all 1.0° or less) up to 400 oe, and then between 400 and 500 oe moved 1.2° due east. All cores showed a rather similar decrease in intensity during demagnetization, with J/Jo at 200 oe varying from 0.401 to 0.681. The demagnetization curve for a typical specimen, D11 - 9, is shown in Figure 4.17 (a). Presumably due to the relative unimportance of unstable components at this site, and their presence in similar proportions in all specimens, the scatter at the NRM stage was unusually low, with a k of 193.9. This increased to a maximum of 736.2 at 400 oe, and as the 400 oe pole seemed to represent the end-point of the southerly movement it was selected as representative of the stable magnetization at this site.

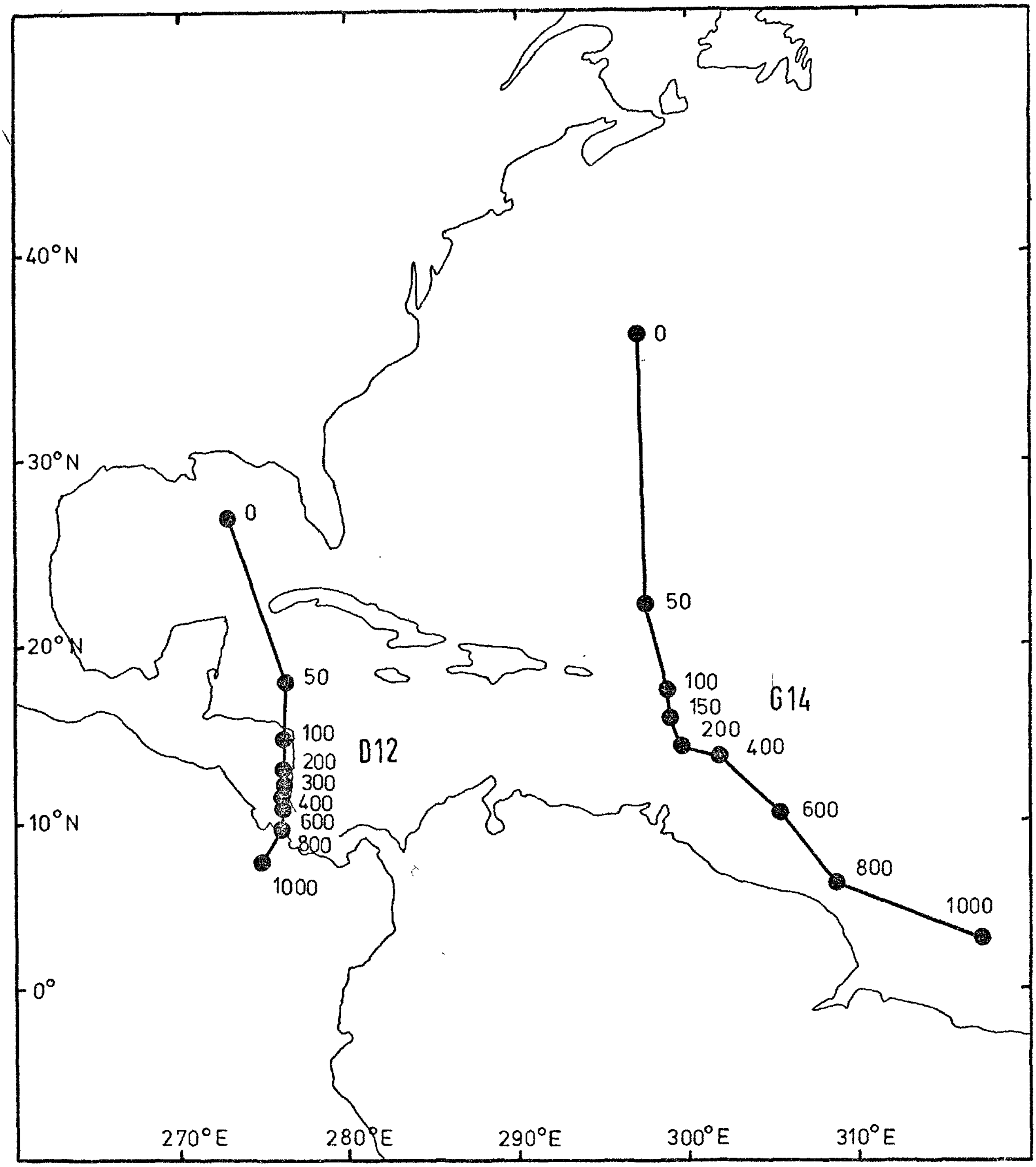
(xi) Dyke D12 (Figure 4.11)

The SSE movement of the D12 mean pole between the NRM position and 50 oe, and the exactly southerly movement between 50 and 800 oe has already been discussed in section 4.2.2 above. The SSW movement between 800 and



MOVEMENT OF D11, D20 AND G18 MEAN POLES DURING DEMAGNETIZATION

FIG. 4.10



MOVEMENT OF D12 AND G14 MEAN POLES DURING DEMAGNETIZATION

FIG. 4.11

1000 oe possibly represented the beginning of random movement of the mean pole, but it probably also contained a component of real southerly movement. All specimens showed a broadly similar decrease in intensity with demagnetization, with J/Jo at 200 oe varying between 0.290 and 0.606. The demagnetization curve for a typical specimen, D12 - 7, is shown in Figure 4.17 (b). k increased from 169.5 at the NRM stage to a maximum of 492.3 at 100 oe, and then decreased gradually to 78.7 at 1000 oe. It is difficult to decide whether the end-point of the southerly movement had been reached at 1000 oe, but in view of the small size of the steps above 200 oe it was probably close, and so the 1000 oe pole was selected as the best available representative of the stable magnetization at this site.

(xii) Dyke D13 (Figure 4.5)

Between the NRM position and 50 oe there was a small southward movement of the mean pole, and between 50 and 200 oe the movement gradually swung around to south-easterly. Between 200 and 1000 oe the movement continued to be south-easterly, although in detail it appeared to move in a smooth arc, being ESE initially and gradually changing to south-east. All eight specimens had very similar demagnetization curves, with J/Jo at 200 oe varying only between 0.502 and 0.662. The demagnetization curve of D13 - 3 is shown in Figure 4.17 (a). The small and approximately constant proportion of unstable components at this site was probably responsible for the exceptionally low scatter at the NRM stage, which had a k of 378.9. The maximum k of 471.6 was obtained at 50 oe, and k remained high, never falling below 363.2 in the seven steps up to 800 oe, and even at 1000 oe it was still 276.1. The 150 oe pole, occurring approximately centrally within the transition from southerly to south-easterly movement, was selected as representative of the stable magnetization at this site.

(xiii) Dyke D14 (Figure 4.9)

The end-point of the southerly movement of the D14 mean pole (labelled D14(8) in Figure 4.9) appears to have been reached at 200 oe, and between 200 and 1000 oe there were small systematic movements in a north-easterly direction. All eight specimens showed a remarkably similar decrease in intensity during demagnetization, with J/Jo at 200 oe varying only between 0.320 and 0.401. The demagnetization curve for D14 - 9 is shown in Figure 4.18 (a). Scatter was exceptionally low at the NRM stage, with a k of 406.7, but then k decreased to 147.4 at 50 oe, and after increasing to 186.0 at 100 oe gradually decreased at higher fields. The fact that by far the highest k was obtained before demagnetization, that the end-point of the southerly movement (at 200 oe) occurred with the pole further north than at any other site, and that this site was the only one where the rocks showed appreciable foliation (see Chapter 2), indicated that the results of this site should be examined with great care.

When the palaeomagnetic results of the individual specimens are examined (Appendix B) it can be seen that there are two distinct types of behaviour. Five specimens (D14 - 2, 3, 4, 5 and 9) all had 200 oe poles between 32° and 37°N, and at higher fields their poles moved progressively northwards. On the other hand specimens D14 - 6, 7 and 10 had 200 oe poles between 21° and 27°N, and at higher fields their poles moved progressively south-east. The movement of the mean pole for the five specimens (labelled D14 (5)) and the three specimens (D14 (3)) are shown in Figure 4.9, and these clearly indicate that two quite regular and distinct types of behaviour are present at this site. It is also apparent that the north-easterly movement of the site mean pole (i.e. all eight specimens) above 200 oe was an artifact produced by the combination of northerly and south-easterly movements. What is of particular interest, however, is that when the actual specimens are examined it is found that their texture is correlated with their demagnetization behaviour. Thus, specimens D14 - 2, 3, 4, 5 and 9 all show very pronounced and obvious foliation in hand specimen, whereas foliation in specimens D14 - 6, 7 and 10 is much less evident or absent.

The demagnetization behaviour of the five specimens, which was unlike that of any other specimens encountered in this study, is thus possibly related in some at present poorly understood way to their pronounced anisotropy. This does not necessarily mean that when the rocks were magnetized it was in a direction deflected from the ambient field by the anisotropy of the magnetic minerals. It is possible that the recrystallisation which resulted in the foliation produced changes in the magnetic grains, for example in their shape or size, which gave them different magnetic properties to the grains in the unfoliated specimens. As further discussed in Chapter 7, some of the grains in the foliated rock might combine low blocking temperatures with high coercivity, and so be capable of acquiring a viscous magnetization along the present field which cannot easily be removed by a.f. demagnetization. This would result in a pole position apparently corresponding to the stable magnetization being located too far north. There is of course no evidence that this has happened in this particular case, it is merely put forward as one possible explanation for the observed behaviour. Arguing against this explanation in this case is the fact that all eight specimens have very similar demagnetization curves, implying that they have similar magnetic properties.

The southward movement of the D14(5) mean pole between the NRM position and 100 oe was clearly due to the removal of unstable components acquired along the present field. The systematic northward movement of the pole between 200 and 1000 oe is more difficult to account for, but one possible explanation is that it represents the removal of viscous components acquired during the last epoch of reversed field. The behaviour of specimens D14 - 6, 7 and 10 is generally similar to that of specimens from many other sites in this study in that with progressive demagnetization their poles showed first a southerly and then a south-easterly movement. However, because the D14(3) mean pole was based on only 3 specimens, and because two of these show some evidence of foliation and hence their behaviour might be slightly influenced by D14(5) type characteristics, it was decided that a pole reliably representing the stable magnetization could not be obtained from this site.

(xiv) Dyke D15 (Figure 4.6)

Between the NRM position and 100 oe there was a fairly regular movement of the mean pole in a SSW direction, between 100 and 800 oe the movement was approximately southerly, and between 800 and 1200 oe the movement was south-westerly. When the second phase of demagnetization of this site was commenced specimens were not, unfortunately, demagnetized and measured again at the highest field (200 oe) to which they had previously been subjected. Thus, as discussed in section 4.2.4 the movement between 200 and 400 oe was subject to an appreciable error, and so in Fig.4.6 these poles are not joined. There was a fairly wide range of intensity changes during demagnetization, with J/Jo at 200 oe varying from 0.232 to 0.615. The demagnetization curve for a typical specimen, D15 - 9, is shown in Figure 4.18 (a). k rose from 62.0 at the NRM stage to a maximum of 653.5 at 200 oe, and then gradually decreased to 64.6 at 1200 oe. The significance of the two south-westerly movements between 800 and 1200 oe is problematical, and they may possibly represent a real movement of the stable magnetization. The 800 oe pole, as it appears to represent the end-point of the purely southerly movement, was selected as representative of the stable magnetization at this site.

(xv) Dyke D16 (Figure 4.8)

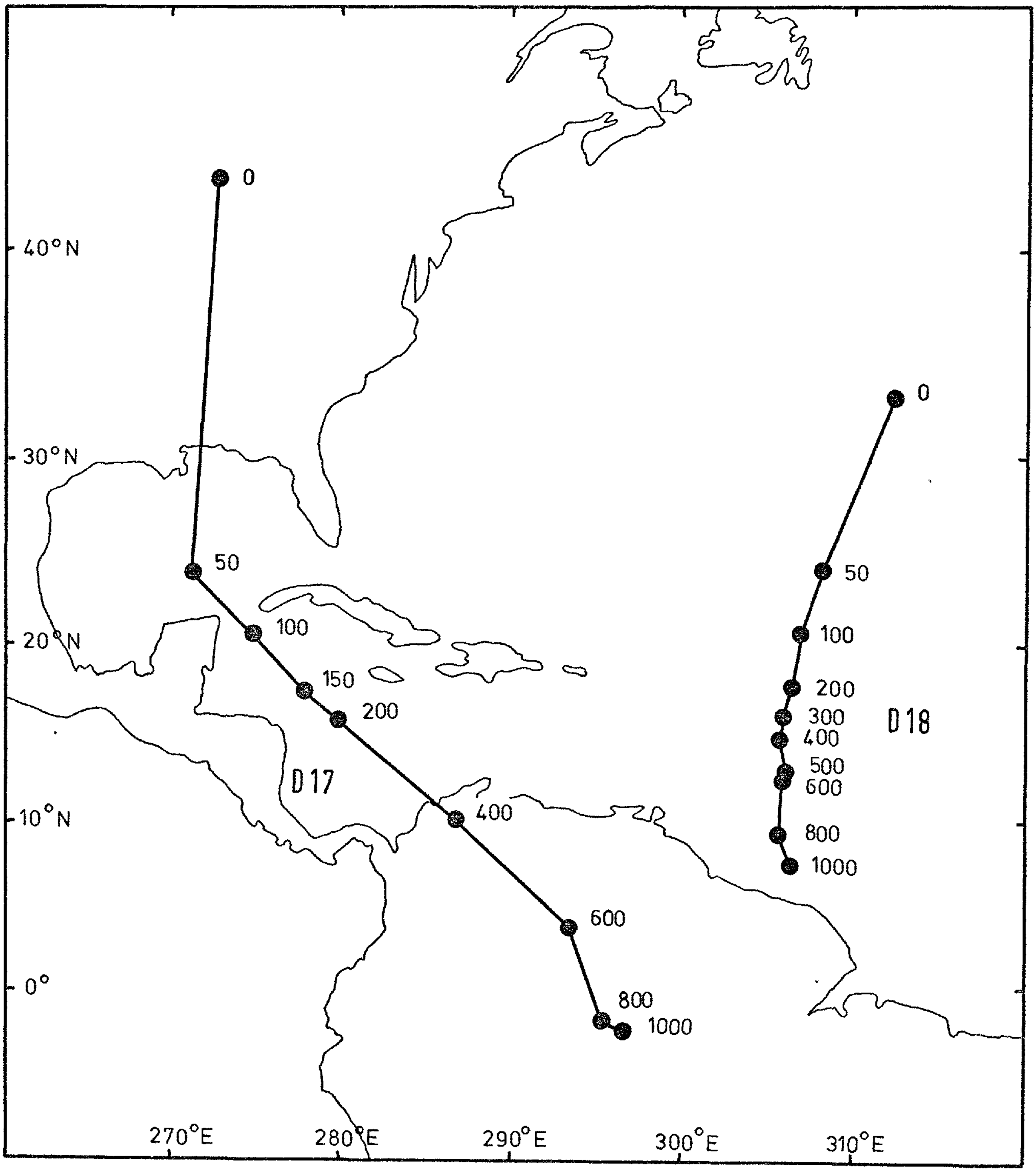
The D16 mean pole moved almost exactly due south between the NRM position and 50 oe, SSE between 50 and 100 oe, and systematically to the south-east in the four steps between 100 and 600 oe. As discussed above in section 4.2.1 the movements above 600 oe are probably caused by random unstable components becoming dominant. All eight specimens had very similar demagnetization curves, with J/Jo at 200 oe varying from 0.287 to 0.417. A typical demagnetization curve, for D16 - 3, is shown in Figure 4.18 (a). k rose from its NRM value of 237.8 to its maximum of 417.1 at 50 oe, and thereafter decreased gradually at higher fields. The 100 oe pole, which occurred at the end of the transition from southerly to south-easterly movement, was selected as representative of the stable magnetization at this site.

(xvi) Dyke D17 (Figure 4.12)

Between its NRM position and 50 oe the mean pole moved approximately 20° in an almost exactly southerly direction, and in the five steps between 50 and 600 oe the pole moved very systematically in a south-easterly direction. In the two steps above 600 oe the general south-easterly movement was continued, but in a less regular manner. The eight specimens showed a reasonably similar decrease in intensity during demagnetization, with J/Jo at 200 oe varying from 0.213 to 0.391. A typical demagnetization curve, that for D17 - 2, is shown in Figure 4.18 (b). k rose from 11.9 at the NRM stage to a maximum of 177.1 at 50 oe and then gradually decreased, falling to the low value of 8.8 at 1000 oe. The very small movement between 800 and 1000 oe might indicate the approach of the end-point of the south-easterly movement, but on the other hand, in view of the less regular direction of the previous movement, and the very low k value, it might be due to random unstable components beginning to mask the true movement of the stable magnetization. The 50 oe pole, which showed the highest k and was located at the transition from southerly to south-easterly movement, was selected as representative of the stable magnetization at this site.

(xvii) Dyke D18 (Figure 4.12)

During progressive demagnetization the D18 mean pole initially moved in a SSW direction, with a gradual change around 100 - 300 oe to a more southerly direction, which was continued up to 800 oe. Between 800 and 1000 oe the movement was in a SSE direction. The eight specimens had similarly shaped demagnetization curves, with J/Jo at 200 oe varying from 0.394 to 0.575. The demagnetization curve for D18 - 1 is shown in Figure 4.17 (b). k began with the high value of 322.8 at the NRM stage, rose to a maximum of 510.9 at 50 oe, and then decreased slowly at higher fields, still being 148.3 at 1000 oe. It is evident that a completely satisfactory end-point to the southerly movement was not obtained at this site, and further demagnetization to higher fields would have been desirable, although of course it is possible that even



MOVEMENT OF D17 AND D18 MEAN POLES DURING DEMAGNETIZATION

FIG. 4.12

then the real movement of the mean pole might have been masked by unstable random components before the end-point was reached. The 1000 oe pole was selected as the best available representative of the stable magnetization at this site.

(xviii) Dyke D19 (Figure 4.4)

The mean pole moved in a southerly direction between the NRM position and 150 oe, and in a south-easterly direction between 150 and 400 oe. Most specimens were not demagnetized at higher fields because at 400 oe they were generally weakly magnetized, and already showing appreciable differences after repeat demagnetizations. Except for D19 - 9 all specimens were dominated by unstable components, with J/Jo at 200 oe varying between 0.044 and 0.171. This doubtless accounts for the high latitude (almost 60°N) of the NRM pole. The demagnetization curve of D19 - 8 is shown in Figure 4.17 (a). k rose slightly from its NRM value of 44.6 to a maximum of 55.1 at 100 oe, and then decreased to 13.5 at 400 oe. It is clear that none of these poles was very precisely defined, and on the strength of two movements only it is impossible to be completely certain that the south-easterly movement above 150 oe represented a real effect similar to that found at other sites. However, as the movement between 150 and 400 oe is almost exactly parallel to the south-easterly movements at other sites, and as the two specimens which were taken to 600 oe also show a south-easterly movement between 400 and 600 oe, it was decided that the movement was probably real. Accordingly the 150 oe pole, at the transition between southerly and south-easterly movements, was selected as representative of the stable magnetization at this site.

(xix) Dyke D20 (Figure 4.10)

As already discussed in section 4.2.3 the end-point of the generally southerly movement appears to be represented by the very close grouping of the 300, 400 and 500 oe poles, and the south-easterly movement between 500 and 600 oe may represent the beginning of a systematic south-easterly movement or it might have been a random movement. All specimens showed a fairly similar decrease in intensity with progressive demagnetization, with J/Jo at 200 oe varying between 0.202 and 0.392. The demagnetization curve for D20 - 8 is shown in Figure 4.17 (b). The variation in the value of k during demagnetization was rather unusual. After a relatively high NRM value of 105.5 it decreased to below 90 for the five steps between 50 and 400 oe, and then rose to 138.7 at "401" oe and 162.8 at 500 oe, decreasing to 116.6 at 600 oe. The increase in k between 400 and "401" oe is difficult to explain, but the increase between "401" and 500 oe may have been due to the fact that the double measuring technique (see section 4.2.1) was commenced at 500 oe. The 500 oe pole, being the most southerly of the close group of three poles, was selected as representing the stable magnetization at this site.

(xx) Dyke D21 (Figure 4.6)

The end-point of the southerly movement of the mean pole appears to be represented by the very close grouping of the 300, 400 and 500 oe poles, which all plot within 0.5° of each other. The small southerly movement between 500 and 600 oe presumably represents a random motion. All specimens had fairly similar demagnetization curves, with J/Jo at 200 oe varying between 0.234 and 0.448. The demagnetization curve for D21 - 6 is shown in Figure 4.17 (b). k rose from 132.0 at the NRM stage to a maximum of 453.2 at 50 oe, and then showed a gradual but irregular decrease. The 400 oe pole from the group of end-point poles was selected as representing the stable magnetization at this site.

(xxi) Gneiss G10/11

With the exception of G10 - 4 the 18 specimens from sites G10 and G11 were dominated by unstable components. The 17 unstable specimens had an average J/Jo at 200 oe of only 0.090, and often began to show erratic movements of their measured magnetization at low demagnetizing fields. In view of this, and also because the two sites were only 100 metres apart and showed similar lithologies, it was decided to treat the two sites as a single site G10/11, and to combine the results of all 17 specimens in calculating the site means. The stable specimen G10 - 4 showed rather unusual behaviour and was not included in the combined results; it is discussed separately below. Although it was not possible to obtain a completely reliable mean pole for G10/11 the results of combining 17 unstable specimens proved to be sufficiently interesting to warrant the following discussion.

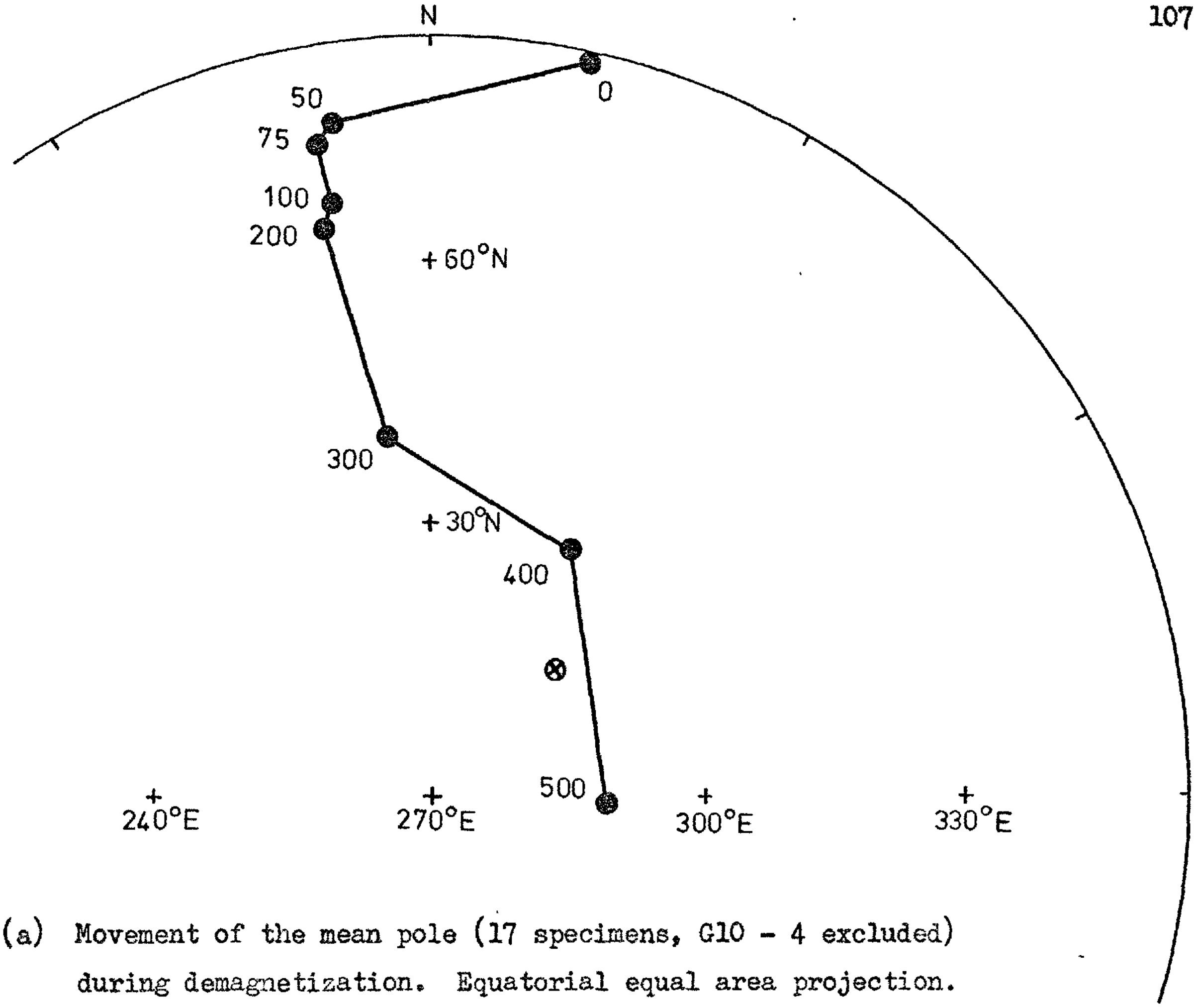
In spite of the fact that erratic movements of the specimen magnetization, often with quite large angular jumps, commonly began at 100 - 200 oe, it was decided to take all 17 specimens up to 500 oe. It was hoped that, as discussed above in section 4.2.1, the random components masking the stable components in individual specimens might be averaged out when the mean of 17 was calculated, and hence reveal some information about any underlying stable component. The main points of the G10/11 site mean results are given in Table 4.2, the full site results will of course be found in Appendix C. It will be seen that between 200 and 400 oe only 15 specimens contributed to the statistics, and at 500 oe only 14 specimens. This was because two specimens were too weakly magnetized to be measured above 100 oe, and a further one too weakly magnetized to be measured above 400 oe. The movement of the site mean pole with progressive demagnetization is shown in Figure 4.13, an equal area projection being used as many of the poles plot in very high latitudes and the usual projection would greatly distort the movements between them. Figure 4.13 also shows the pole eventually selected as best representing the mean of all stable magnetization found in this study (see section 4.4.2). The demagnetization curve for a typical specimen, G10 -21, is shown in Figure 4.13.

From Figure 4.13 it can be seen that between its NRM position and 50 oe the mean pole moved in an approximately westerly direction, between 50 oe and 300 oe it moved fairly systematically in an approximately SSE direction, and for the 300 - 400 and 400 - 500 oe steps it moved less systematically but still in a generally SSE direction. Table 4.2 shows that k began with the low value of 2.1 at the NRM stage, increased to 26.7 at 75 oe, and then

TABLE 4.2

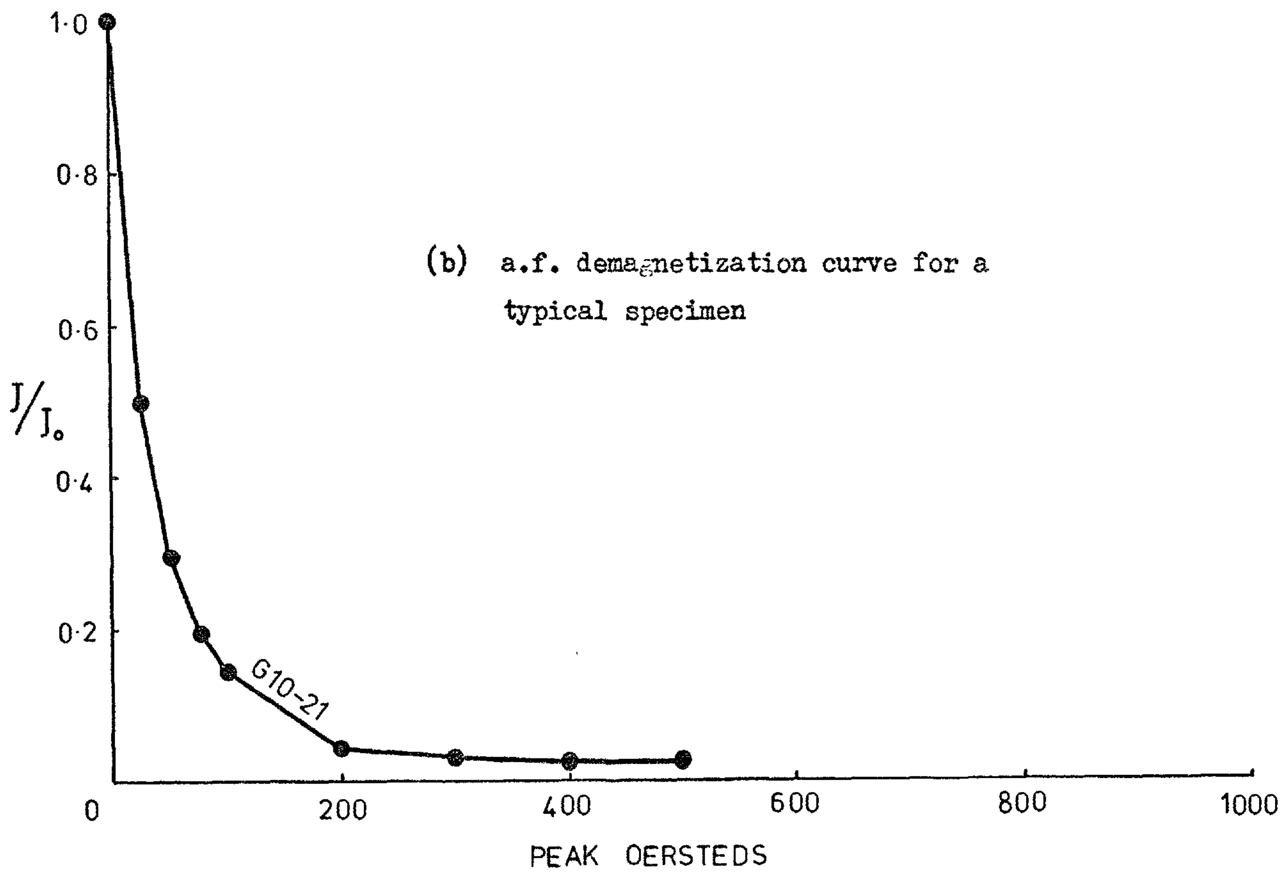
MEAN RESULTS FOR SITE G10/11

DEMAG FIELD (oe)	NUMBER OF SPECIMENS	MAGNETIZATION		POLE
		k	α_{95}	
0	17	2.1	33.7°	77.7°N, 353.9°E
50	17	17.9	8.7°	75.9°N, 234.2°E
75	17	26.7	7.0°	72.8°N, 234.8°E
100	17	24.4	7.4°	65.8°N, 248.5°E
200	15	10.2	12.6°	63.1°N, 248.1°E
300	15	6.3	16.6°	39.0°N, 264.7°E
400	15	3.3	25.2°	25.7°N, 286.4°E
500	14	1.3	69.6°	1.1°S, 288.9°E



(a) Movement of the mean pole (17 specimens, G10 - 4 excluded) during demagnetization. Equatorial equal area projection.

⊗ indicates the mean pole for all 22 sites in this study with stable magnetization.



(b) a.f. demagnetization curve for a typical specimen

RESULTS FOR SITE G10/11

FIG. 4.13

gradually decreased to only 1.3 at 500 oe.

These results can be interpreted as follows. The very high latitude NRM pole indicates that the site is dominated by low stability components acquired by viscous build-up along the earth's present field direction, and the very low k indicates that there are probably also appreciable very low stability randomly oriented viscous storage components. The latter point is confirmed by the fact that the NRM - 50 oe movement was westward, i.e. along an apparently meaningless direction, and also because of the increase in k to 17.9. As the latitude of the pole only decreased by 1.8^{o} the main effect of the 50 oe demagnetization appears to have been the removal of the randomly oriented storage components. Between 50 and 500 oe the mean pole showed its most interesting behaviour, and two aspects of this behaviour are of particular note. Firstly, the pole moved generally systematically in that over six steps the same approximately SSE movement was maintained. Secondly, it moved in a direction which is significant in that it is towards the pole which has been selected (section 4.4.2) as best representing the mean stable magnetization of this study. It therefore appears that between 50 and 300 oe viscous components acquired approximately along the earth's present field were being removed, the mean pole was therefore moving towards a position corresponding to its underlying stable magnetization, and that this was similar to the stable magnetization found at other sites in this study. The decrease in k from 26.7 at 75 oe to 6.3 at 300 oe was probably due to the fact that within individual specimens the stable component was gradually being reduced to a level comparable to the unstable random component, so that random movements of specimens magnetizations were becoming increasingly large. The fact that the overall movement of the mean magnetization remained fairly regular up to 300 oe indicates that in spite of the low k values, because of the large number of specimens used when the means were calculated the mean random unstable component was sufficiently small compared to the mean stable component that it did not significantly affect it.

The movement of the mean pole in the 300 - 400 and 400 - 500 oe steps was generally in the same direction but was less systematic, probably because the mean stable component was now so reduced that it was appreciably affected by the mean unstable component. At the same time k was reduced to 3.3 at 400 oe and 1.3 at 500 oe, reflecting the increasing ratio of unstable to stable components in individual specimens.

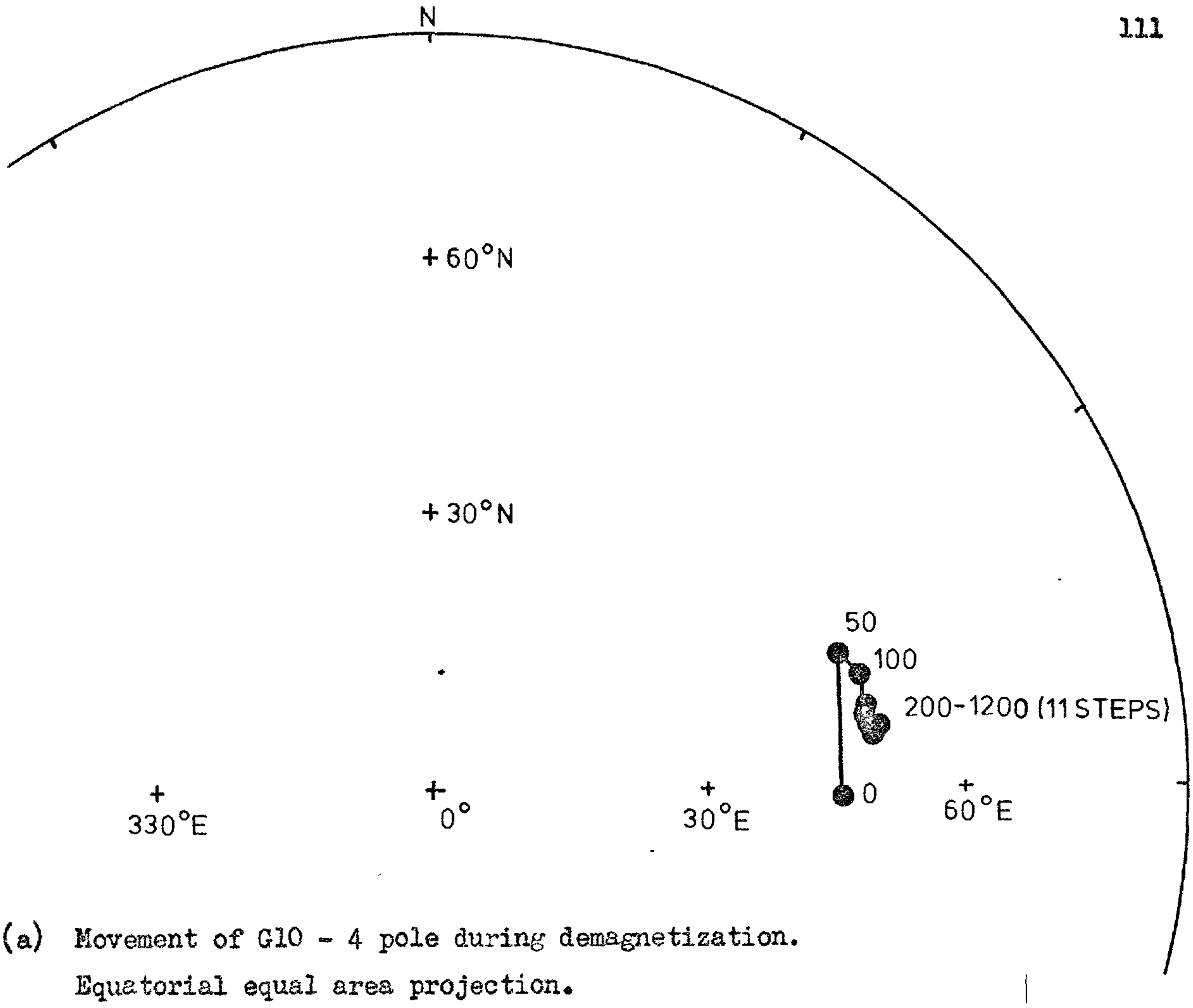
The rather erratic behaviour of the mean poles at 400 and 500 oe, and their very low k values, make it difficult to define the end-point of the southerly movement, i.e. the position of the stable component pole, with any accuracy. Therefore it was not possible to select a pole from G10/11 which reliably represented the stable magnetization at this site. However, the movement of the mean pole between 50 and 500 oe is considered to provide strong evidence that site G10/11 contains a small stable component of magnetization similar to the stable component found at almost all other sites in this study.

It might be argued that the poor precision with which the mean magnetizations are defined, with α_{95} increasing from 7.0° at 75 oe to 69.6° at 500 oe, makes the above interpretation invalid. Thus it might be pointed out that the angular movements at each step above 50 oe were always within the circle of confidence of the magnetization at one end of the step. If there was only one movement in a random direction within a circle of confidence then that clearly would have no significance, but here the movements were in approximately the _same_ direction over six demagnetization steps, and this direction is towards a position representing a magnetization which a priori might be expected to be present at this site. It seems very unlikely that these facts can be explained by mere coincidence, and so the SSE movement is considered to be a real effect, and best interpreted as described above.

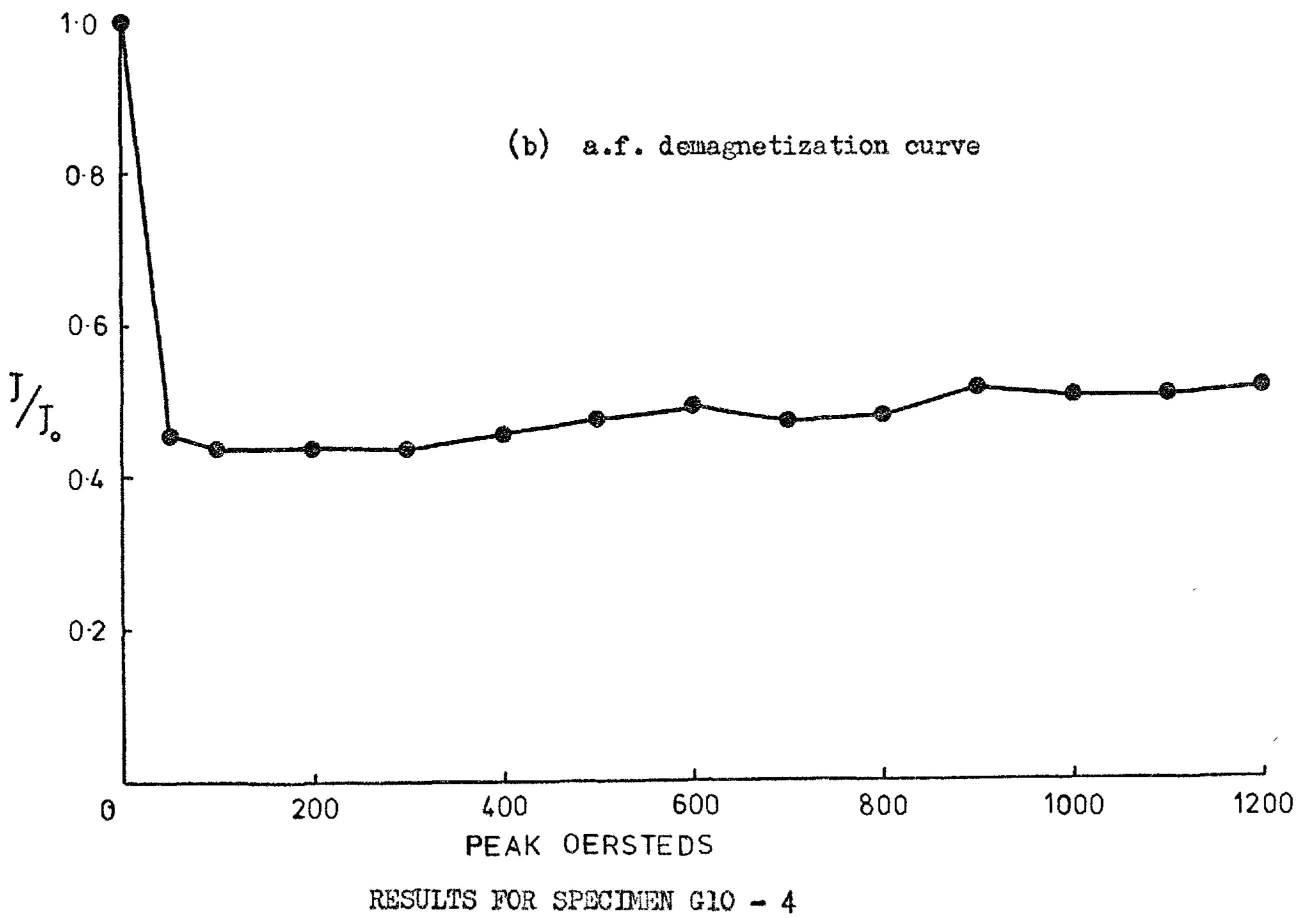
The main point about these results is that they illustrate that by progressively demagnetizing a large number of specimens up to quite high fields and then examining the mean results useful information can be obtained from very unpromising material. In this case it was considered worth all the demagnetizing effort to ascertain that this gneiss almost certainly contains a small stable component similar to that at the many stable sites studied. It might be noted that in a conventional examination of this material this information would probably not have been obtained. The usual pilot study of a few specimens to determine the optimum demagnetizing field would probably have indicated that fields of 75 or 100 oe gave the best k, and that the precision decreased very rapidly at higher fields. Because of the small number of specimens the mean pole would probably have shown completely random movements above 100 oe. Thus, even if it had been decided to proceed with the investigation, demagnetization of the remaining specimens would probably have been carried out at 75 or 100 oe only. If all 17 specimens had been used this would have given a k of about 25 and an α_{95} of about 7°, and this might have been considered a reliable pole, although its high latitude may have caused some concern. This highlights another interesting point to come out of the investigation of G10/11, and one which has already been commented on in section 4.2.4 above, namely that the pole with the best k does not necessarily represent the stable magnetization. At this site the pole with the best k appears to be at least 50° away from the pole which would represent the stable magnetization.

The demagnetization curve for the stable specimen G10 - 4 is shown in Figure 4.14 (b), and the movement of its pole with progressive demagnetization is shown in Figure 4.14 (a). J/Jo was reduced to 0.455 at 50 oe, remained approximately constant at this value up to 300 oe, and then showed a small and rather irregular rise up to about 0.520 at 1200 oe. After its initial northward movement between the NRM position and 50 oe the magnetization remained remarkably constant in direction up to 1200 oe, and in fact in the eleven steps between 200 and 1200 oe the pole never departed from its average position by more than 1.5°.

The form of the demagnetization curve and the directional stability of the measured magnetization indicate that this specimen contains an extremely stable component which is virtually unaffected by a.f. demagnetizing fields up to 1200 oe, and is therefore almost certainly carried by haematite or



(a) Movement of G10 - 4 pole during demagnetization.
Equatorial equal area projection.



(b) a.f. demagnetization curve

RESULTS FOR SPECIMEN G10 - 4

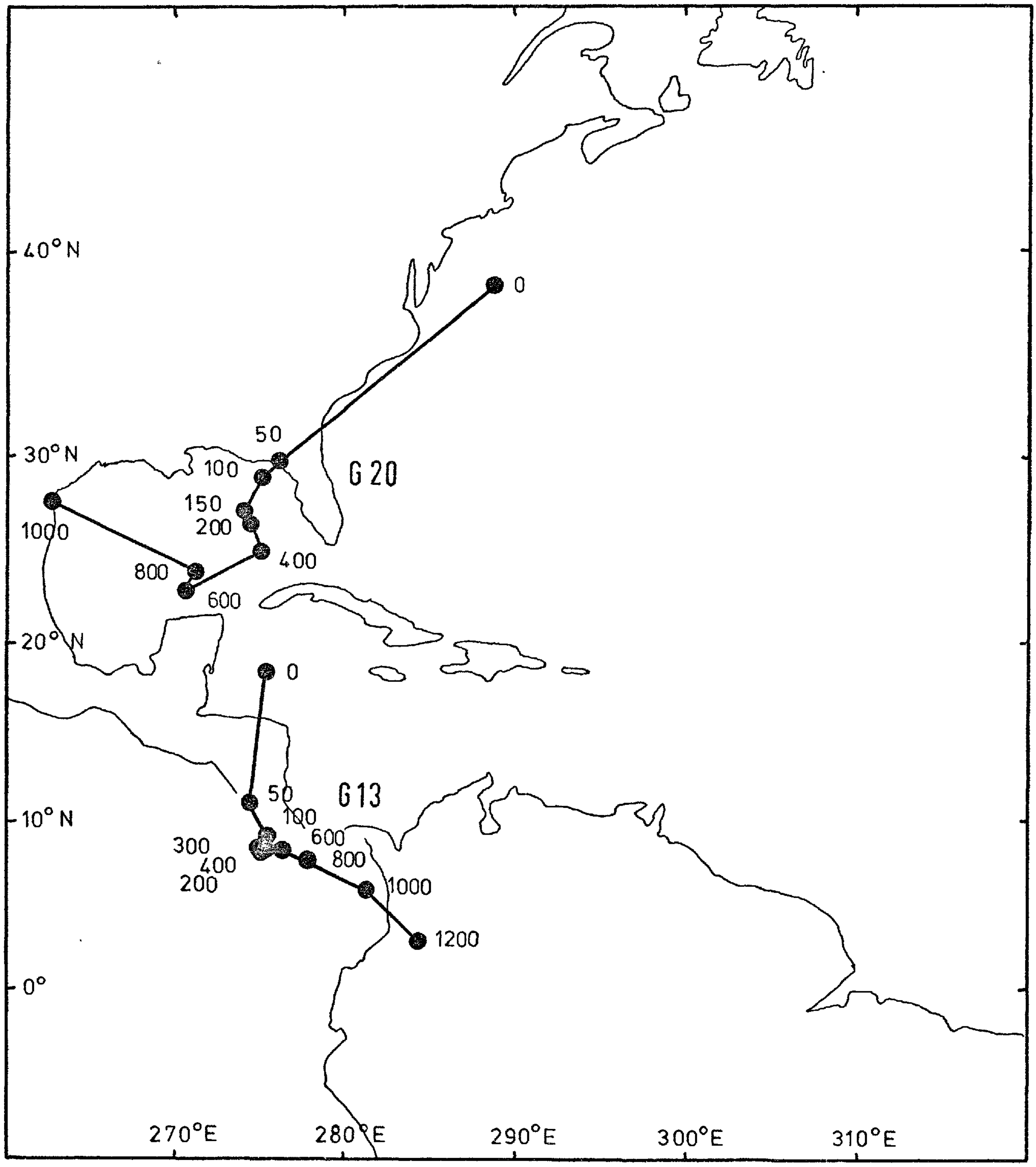
FIG. 4.14

titanohaematite. The initial sharp decrease in intensity at 50 oe was probably due to the removal of low stability components carried by magnetite, and the gradual slight increase between 300 and 1200 oe was probably due to the removal of stable components also carried by magnetite but aligned approximately in antiphase to the larger haematite component.

The stable haematite component gives a pole at 6°N, 49°E, and is unlike all other stable components found in this study, which always yielded poles in the general region of 14°N, 284°E. The stable magnetite component removed between 300 and 1200 oe cannot be defined accurately, but it could be very approximately in the same direction as the stable components found at other sites. Of all 201 specimens examined in this study this was the only one which had demagnetization characteristics indicative of haematite.

(xxii) Gneiss G13 (Figure 4.15)

The end-point of the initially southerly movement of the G13 mean pole is clearly represented by the very close grouping of the five poles between 100 and 600 oe, all these poles being within 0.7° of their mean. In the three steps between 600 and 1200 oe the pole moved systematically in a south-easterly direction. Above 300 oe only seven specimens contributed to the mean results as at these field strengths G13 - 3 showed grossly different results after repeat demagnetizations and so was not included. Apart from G13 - 3, which had a J/Jo at 200 oe of only 0.187, the specimens had generally similar demagnetization curves, with J/Jo at 200 oe varying from 0.494 to 0.731. Unstable components were therefore generally unimportant at this site, and a typical demagnetization curve, that for G13 - 10, is shown in Figure 4.17 (b). k began at 27.9 at the NRM stage, and showed a gradual though slightly irregular increase up to a maximum of 51.7 at 1000 oe, and then decreased to 45.1 at 1200 oe. The demagnetization of G13 was carried out in three separate phases, NRM - 300 oe, "301" - 1000 oe and "1001" - 1200 oe. Among the sites that showed systematic south-easterly movements G13 was unique in that there was a very clear grouping of poles at the end-point of the southerly movement and before the south-easterly movement commenced, whereas



MOVEMENT OF G13 AND G20 MEAN POLES DURING DEMAGNETIZATION

FIG. 4.15

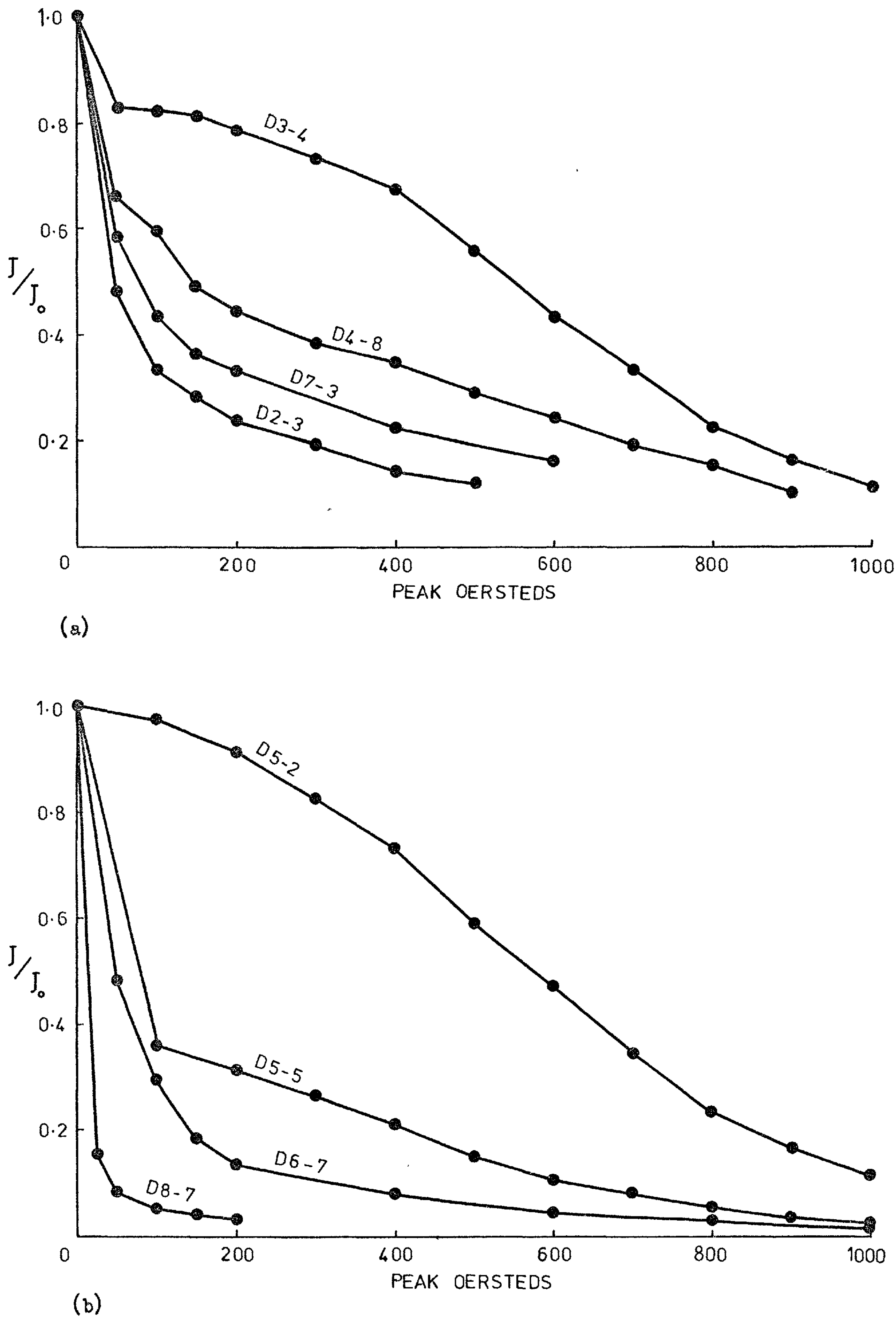
normally there was an immediate transition from one movement to the other. This is discussed in Chapter 7. The 300 oe pole was selected as representative of the stable magnetization at this site.

(xxiii) Gneiss G14 (Figure 4.11)

Between the NRM position and 200 oe the mean pole showed regular movements in an almost exactly southerly direction. Over the four steps between 200 and 1000 oe the pole moved in a slightly less regular manner but nevertheless with an overall south-easterly motion very clearly evident. The slight irregularity of this movement may have been due to the fact that in order to economise on time only six specimens were demagnetized above 200 oe. The various specimens showed a broad range of intensity changes during demagnetization, with J/Jo at 200 oe varying between 0.132 and 0.495, and averaging 0.295. The demagnetization curve for G14 - 6 is shown in Figure 4.18 (b). Except for an increase from 72.0 to 104.6 between 400 and 600 oe k remained very approximately constant throughout the demagnetization range. This increase may have been caused by the commencement of double measuring (section 4.2.1) at 600 oe. The 200 oe pole, being at the transition from southerly to south-easterly movement, was selected as representative of the stable magnetization at this site.

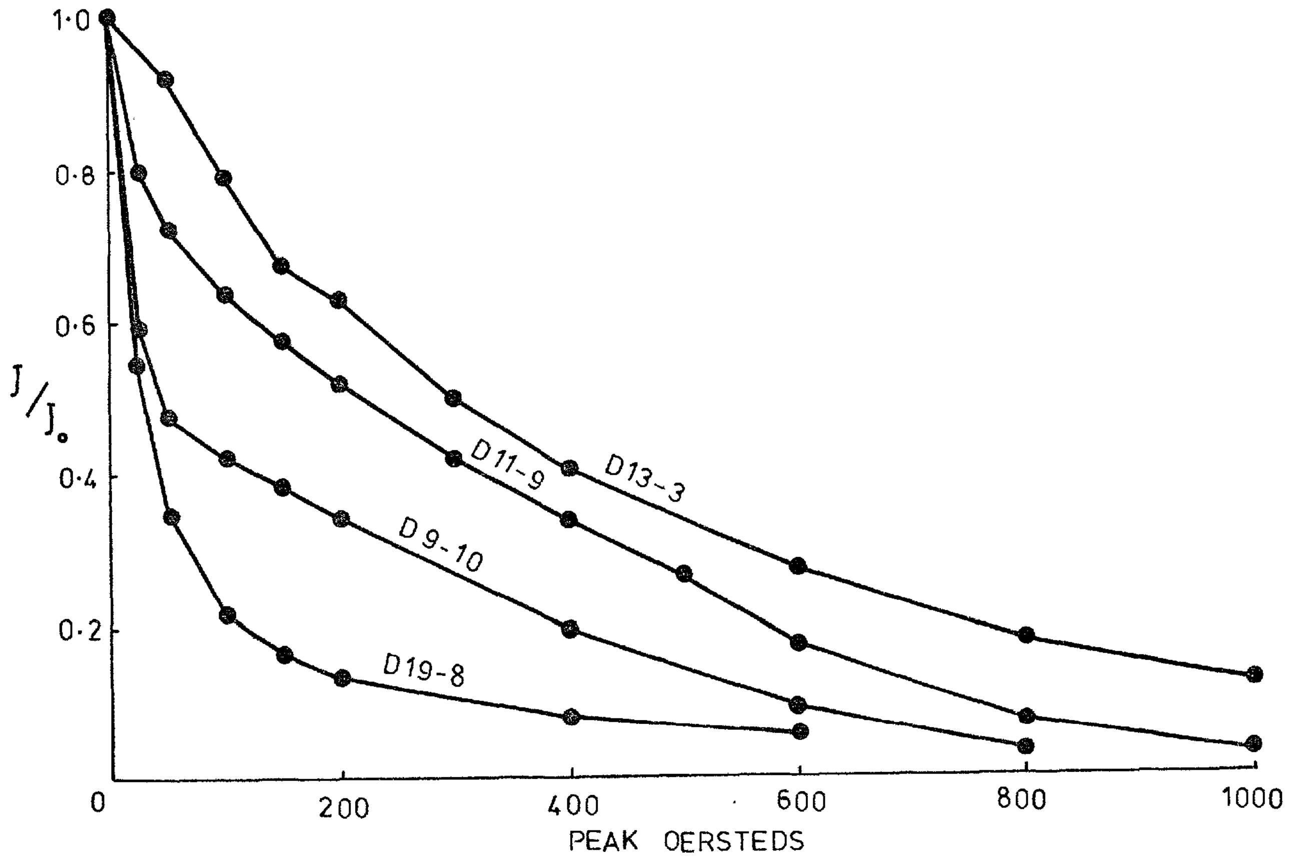
(xxiv) Gneiss G18 (Figure 4.10)

A generally southerly movement of the mean pole between the NRM position and 300 oe was followed in the four steps between 300 and 1000 oe by a rather irregular south-easterly movement. There was a moderate range of intensity changes during demagnetization, with J/Jo at 200 oe varying from 0.353 to 0.676, and averaging 0.523. The demagnetization curve for G18 - 8 is shown in Figure 4.18 (b). k remained remarkably constant during demagnetization, varying only between 34.9 and 61.1 over the ten steps. The 300 oe pole at the transition between the southerly and south-easterly movements was selected as representative of the stable magnetization at this site.

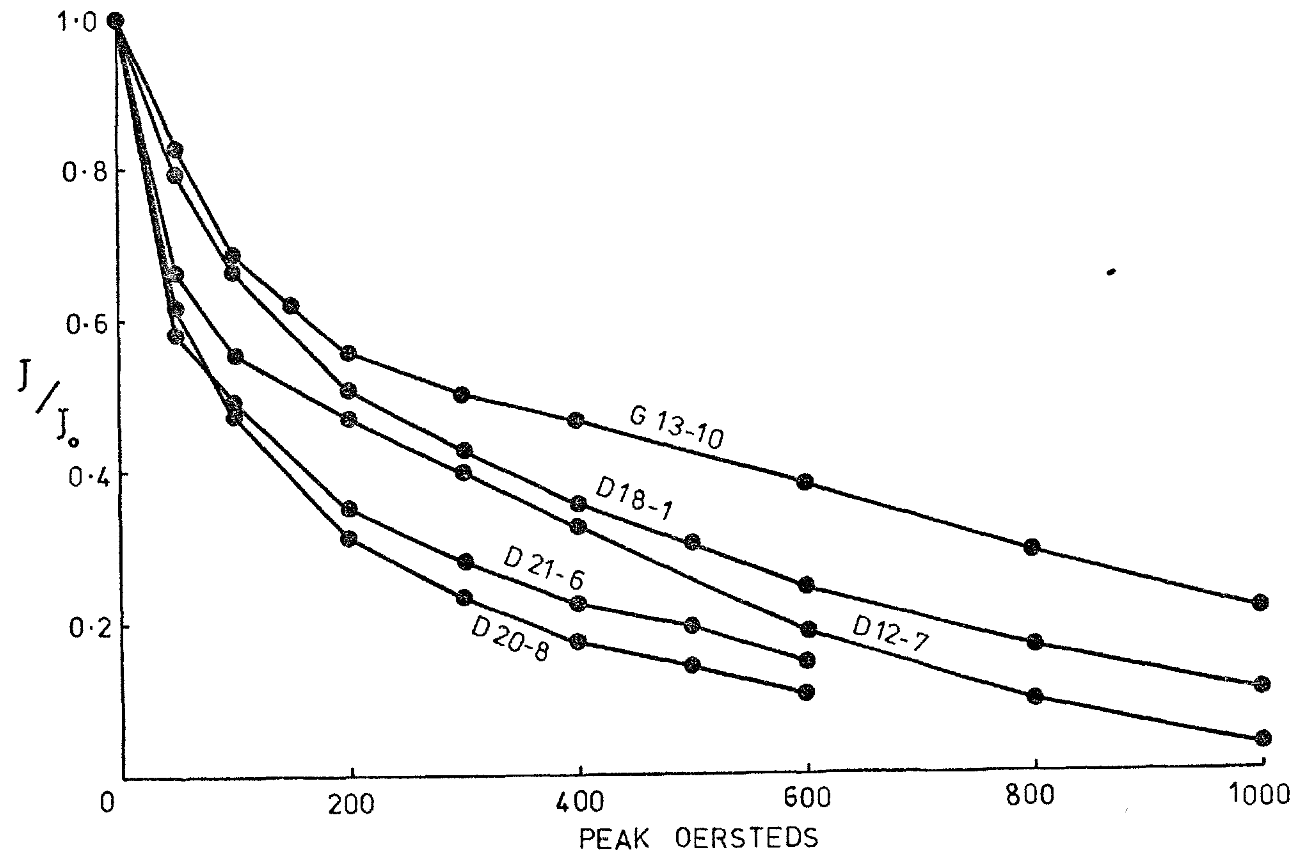


A.F. DEMAGNETIZATION CURVES

FIG. 4.16



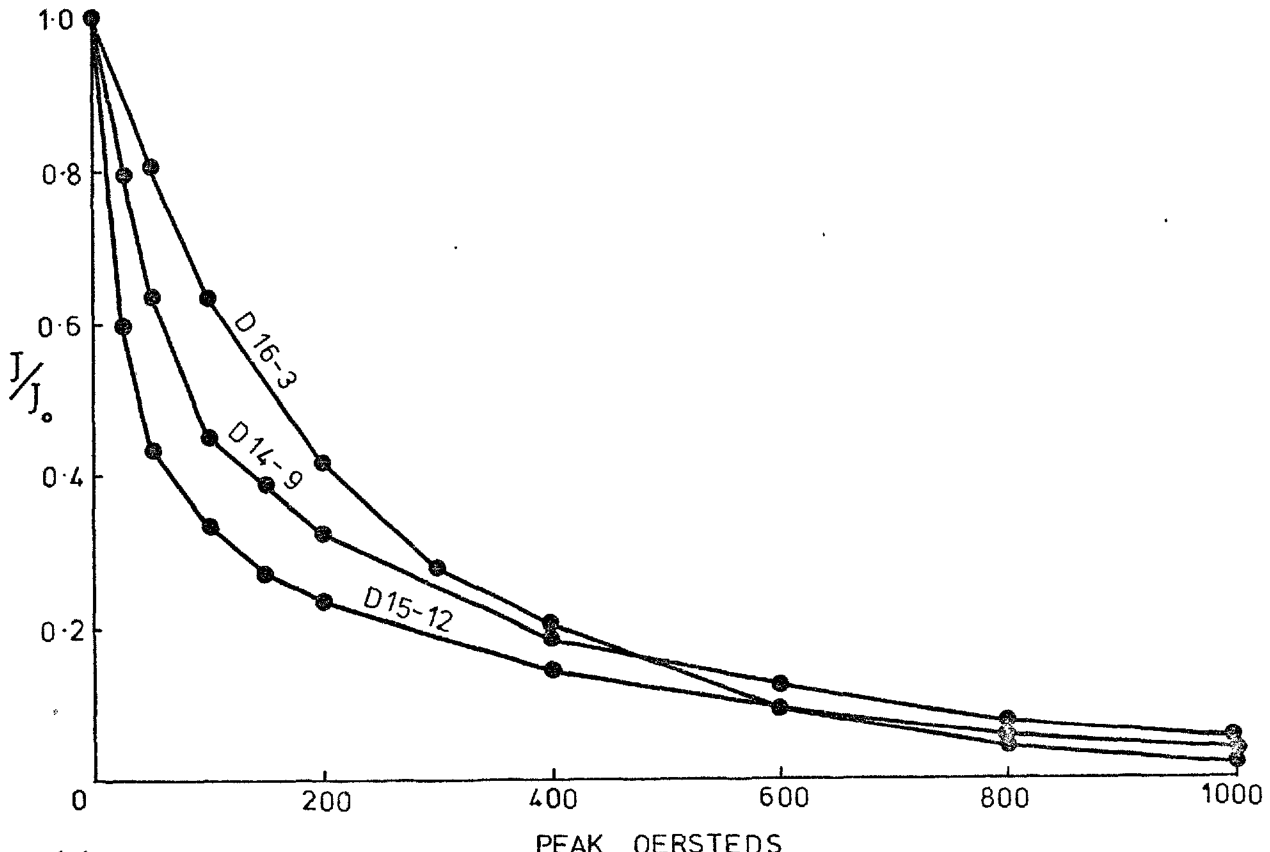
(a)



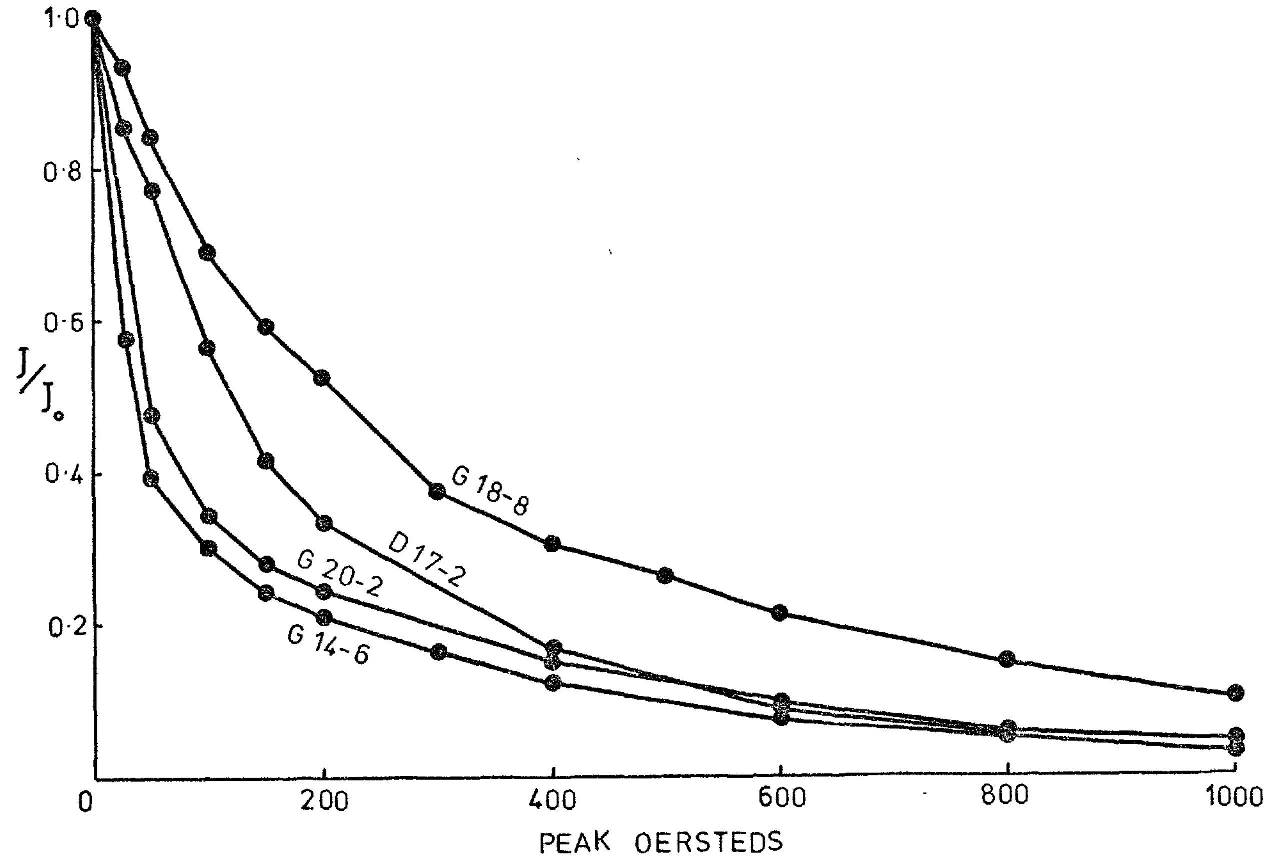
(b)

A.F. DEMAGNETIZATION CURVES

FIG. 4.17



(a)



(b)

A.F. DEMAGNETIZATION CURVES

FIG. 4.18

(xxv) Gneiss G20 (Figure 4.15)

Between the NRM position and 150 oe the mean pole moved in a south-westerly direction, and this seemed to be in the process of changing to a south-easterly movement at 200 and 400 oe, but the three steps between 400 and 1000 oe showed apparently quite random movements. There was a wide range of intensity changes on demagnetization, with J/Jo at 200 oe varying between 0.071 and 0.458, and averaging 0.264. The demagnetization curve for G20 - 2 is shown in Figure 4.18 (b). In order to save time only six specimens were demagnetized above 200 oe, the two specimens not demagnetized further being the two least stable specimens at the site. k rose from 17.2 at the NRM stage to 87.1 at 100 oe, and then decreased to 37.0 at 200 oe. There was then a sudden increase to 283.3 at "201" oe and 352.6 at 300 oe, followed by a rapid decrease to 20.3 at 1000 oe. The large increase between 200 and "201" oe was due to the fact that the two relatively unstable specimens not demagnetized above 200 oe were also the two whose magnetization deviated most widely from the mean. The 150 oe pole, which appeared to represent the transition from southerly to south-easterly movement, was selected as representative of the stable magnetization.

4.4 REVIEW OF THE MAIN RESULTS

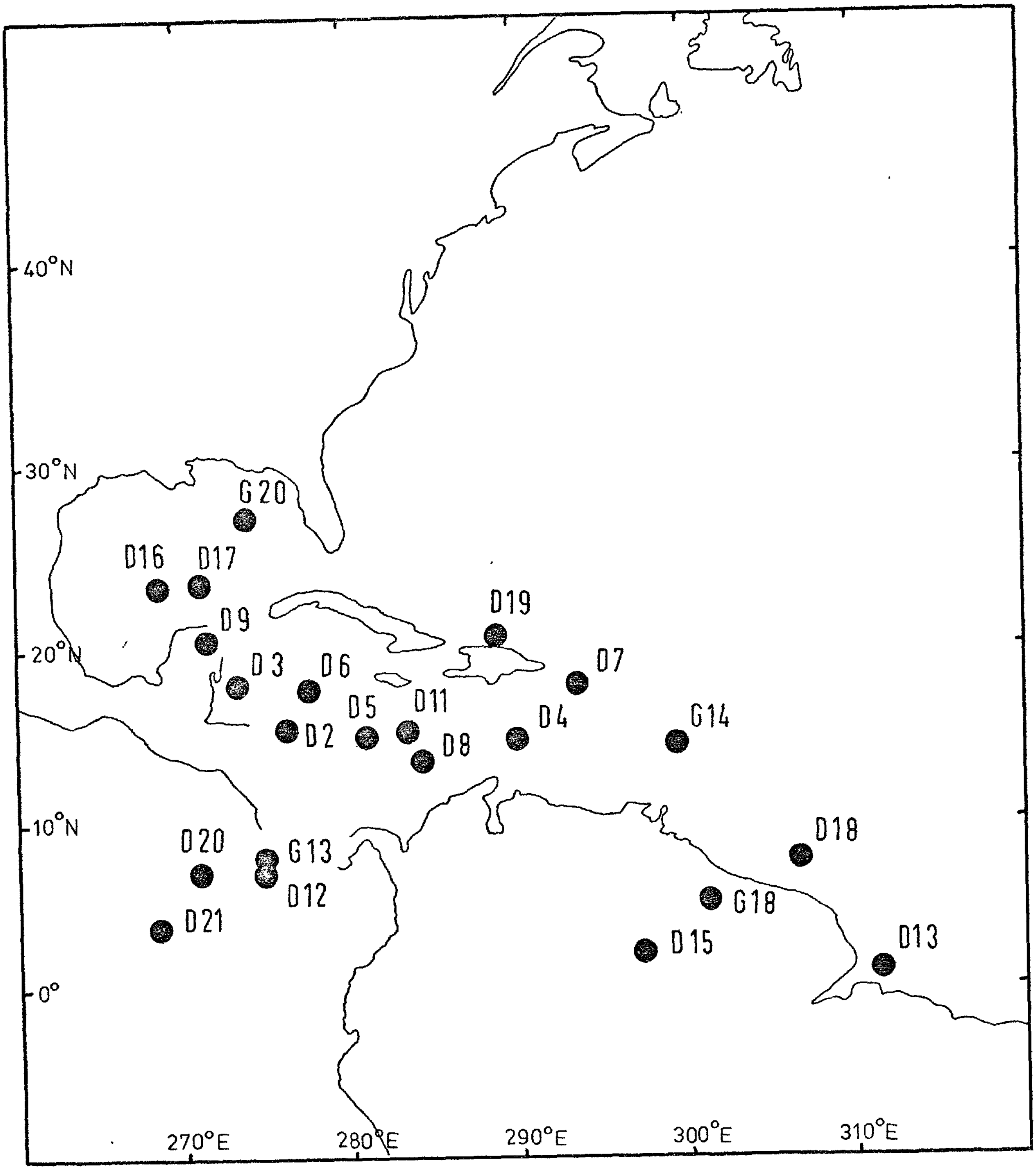
4.4.1 The 22 selected site poles

In section 4.3 it was shown that of the 26 sites investigated 22 sites yielded reliable stable magnetization, and that at each such site the mean magnetization and corresponding mean pole at one particular demagnetization step were selected as being best representative of that stable magnetization. Details of the 22 selected magnetizations and poles are given in Table 4.3, and the positions of the poles are shown in Figure 4.19, from which it can be seen that all 22 poles plot in the same general area, but that their distribution is unusual in that 18 of them appear to form a linear trend approximately 47° long and 12° wide, stretching from D16 and G20 in the north-west to G18 and D13 in the south-east. The remaining

TABLE 4.3

MEAN MAGNETIZATION AND POLES SELECTED AS BEST REPRESENTING THE STABLE MAGNETIZATION AT EACH SITE

SITE	NUMBER OF SPECIMENS	DEMAG FIELD (OE)	MAGNETIZATION				POLE			
			DIP	DECL	K	α_{95}	POSITION		dp	dm
D2	8	300	54.3°	216.8°	224.0	3.7°	15.4°N,	276.3°E	3.7°	5.2°
D3	8	200	56.3°	220.9°	414.4	2.7°	18.0°N,	273.4°E	2.8°	3.9°
D4	7	150	56.4°	200.3°	279.4	3.6°	14.7°N,	290.0°E	3.8°	5.2°
D5	8	200	55.2°	210.9°	2060.6	1.2°	14.0°N,	281.1°E	1.2°	1.7°
D6	8	"201"	56.9°	215.7°	934.1	1.8°	17.5°N,	277.6°E	1.9°	2.6°
D7	8	"151"	59.9°	196.5°	473.5	2.5°	18.0°N,	293.6°E	2.9°	3.8°
D8	8	200	54.3°	206.6°	71.9	6.6°	13.4°N,	284.5°E	6.5°	9.3°
D9	8	150	58.1°	223.9°	176.6	4.2°	20.4°N,	271.4°E	4.5°	6.2°
D11	8	400	56.0°	207.8°	736.2	2.0°	15.2°N,	283.5°E	2.1°	2.9°
D12	8	1000	45.4°	215.3°	78.7	6.3°	7.1°N,	275.0°E	5.1°	8.0°
D13	8	150	42.0°	174.6°	411.5	2.7°	0.9°N,	311.4°E	2.1°	3.4°
D15	8	800	43.2°	190.1°	294.6	3.2°	2.1°N,	297.4°E	2.5°	4.0°
D16	8	100	59.9°	228.3°	331.3	3.0°	23.6°N,	268.5°E	3.5°	4.6°
D17	8	50	60.9°	225.3°	177.1	4.2°	23.8°N,	271.2°E	4.9°	6.4°
D18	8	1000	50.3°	179.8°	148.3	4.6°	7.6°N,	306.8°E	4.1°	6.1°
D19	8	150	61.5°	202.6°	31.6	10.0°	20.6°N,	289.0°E	11.9°	15.4°
D20	8	500	44.0°	219.9°	162.8	4.4°	7.2°N,	271.1°E	3.4°	5.5°
D21	8	400	39.0°	221.6°	182.8	4.1°	3.9°N,	268.6°E	2.9°	4.9°
G13	8	300	46.5°	215.5°	42.3	8.6°	8.1°N,	275.0°E	7.1°	11.1°
G14	8	200	57.1°	188.5°	55.8	7.5°	14.5°N,	299.6°E	7.9°	10.9°
G18	7	300	47.3°	186.1°	47.6	8.8°	5.2°N,	301.2°E	7.4°	11.5°
G20	8	150	64.0°	223.1°	55.5	7.5°	27.0°N,	274.2°E	9.5°	12.0°



THE 22 SELECTED SITE POLES

FIG. 4.19

four poles, for D12, D20, D21 and G13, are located in a fairly tight group just to the south-west of the main trend. The significance of this linear distribution of poles is discussed further in Chapter 7.

4.4.2 Overall mean magnetization and pole

As shown in Table 4.4 the 22 selected site mean magnetizations yield an overall mean magnetization with a k of 46.0 and an α_{95} of 4.6°, and giving a pole at 13.4°N, 284.0°E. This table also shows the mean magnetization and pole for the selected magnetizations at the 18 dyke sites only, and also for the four gneiss sites only.

4.4.3 Within-site scatter

Another feature of interest in the palaeomagnetic results is the unusually low within-site scatter of directions found at many sites. From Table 4.3 it can be seen that at 15 sites the selected pole had a k of greater than 100 (with 8 specimens per site corresponding to an α_{95} of 5.8°), at six sites the selected pole had a k of greater than 400, corresponding to an α_{95} of 2.8°, and at three sites the selected pole had a k of greater than 700, corresponding to an α_{95} of 2.1°. Even the selected pole with the greatest within-site scatter, D19, had the reasonably high k of 31.6 (α_{95} = 10.0°). Furthermore it will be recalled that the mean result selected as best representing the stable magnetization at each site was only rarely that which showed the lowest within-site scatter, i.e. the highest k value. When the results with the highest k value at each site are examined (Table 4.5) it can be seen that the figures are even more remarkable, no fewer than 19 sites out of the 22 having a k of more than 100, and 13 sites having a k of greater than 400, while the case of D5, which had a best k of over 2,600 has been referred to several times already. The site with the lowest best k value, G13, still had a k of 51.7 (α_{95} = 8.5°). These low values of within-site scatter, which are rather difficult to explain, are discussed further in Chapter 7.

At many sites the within-site scatter of directions was quite low

TABLE 4.4

OVERALL MEAN MAGNETIZATIONS AND POLES

	MAGNETIZATION				POLE		
	DIP	DECL	k	α_{95}	POSITION	dp	dm
ALL 22 SELECTED SITE MEAN MAGNETIZATIONS OF TABLE 4.3	54.2°	207.0°	46.0	4.6°	13.4°N, 284.0°E	4.6°	6.5°
SELECTED SITE MEAN MAGNETIZATIONS (18 DYKE SITES ONLY)	54.0°	208.1°	46.4	5.1°	13.4°N, 283.1°E	5.0°	7.2°
SELECTED SITE MEAN MAGNETIZATIONS (4 GNEISS SITES ONLY)	54.8°	202.1°	35.6	15.6°	13.3°N, 288.2°E	15.6°	22.1°

TABLE 4.5

k AND α_{95} FOR MEAN MAGNETIZATION SHOWING THE LOWEST WITHIN - SITE SCATTER AT EACH SITE

SITE	NUMBER OF SPECIMENS	DEMAG FIELD	k	α_{95}
D2	8	100	655.0	2.2°
D3	8	150	459.3	2.6°
D4	7	400	502.0	2.7°
D5	8	300	2629.5	1.1°
D6	8	"201"	934.1	1.8°
D7	8	"151"	473.5	2.5°
D8	8	100	227.9	3.7°
D9	8	100	231.5	3.6°
D11	8	400	736.2	2.0°
D12	8	100	492.2	2.5°
D13	8	50	471.6	2.6°
D15	8	200	653.5	2.2°
D16	8	50	417.1	2.7°
D17	8	50	177.1	4.2°
D18	8	50	510.9	2.5°
D19	8	100	55.1	7.5°
D20	8	500	162.8	4.4°
D21	8	50	453.2	2.6°
G13	7	1000	51.7	8.5°
G14	8	600	104.6	6.6°
G18	7	200	61.1	7.8°
G20	6	400	352.6	3.6°

even before demagnetization, for example eight sites had a k of greater than 100 at the NRM stage, but at those sites where the initial scatter was high demagnetization often produced a spectacular improvement in precision. Some examples of particularly marked improvements in precision are given in Table 4.6, and the improvements in the scatter of directions at three sites, D5, D6 and D8, are shown diagramatically in Figures 4.20 to 4.22. These diagrams illustrate the efficiency of the demagnetizing equipment in removing unstable secondary components of magnetization.

4.4.4 Some individual specimen results

In the descriptions of the palaeomagnetic results in section 4.3 attention was mainly focussed on the site mean results, more particularly on the behaviour of site mean poles during progressive demagnetization. In this section some individual specimen results are examined, and to allow comparison with the site results they are described in terms of the movement of specimen poles with progressive demagnetization. As with the site results there were in general three types of behaviour shown by individual specimens; the specimen pole moved southwards and reached an end-point, the pole moved southwards and continued to do so up to the highest field available, or the pole moved first in a southerly direction and then in a south-easterly direction. Examples of all three types of behaviour will be described and illustrated, but it must be noted that the examples that are described were chosen because they showed their particular type of behaviour in a perfect and regular manner, and so are not representative of all similar specimens, some of which showed less regular behaviour. However, inspection of Appendix B will indicate that many other specimens showed behaviour just as regular as in the examples described, and this again is a reflection of the efficiency of the demagnetizing equipment and also of the precision of the astatic magnetometer.

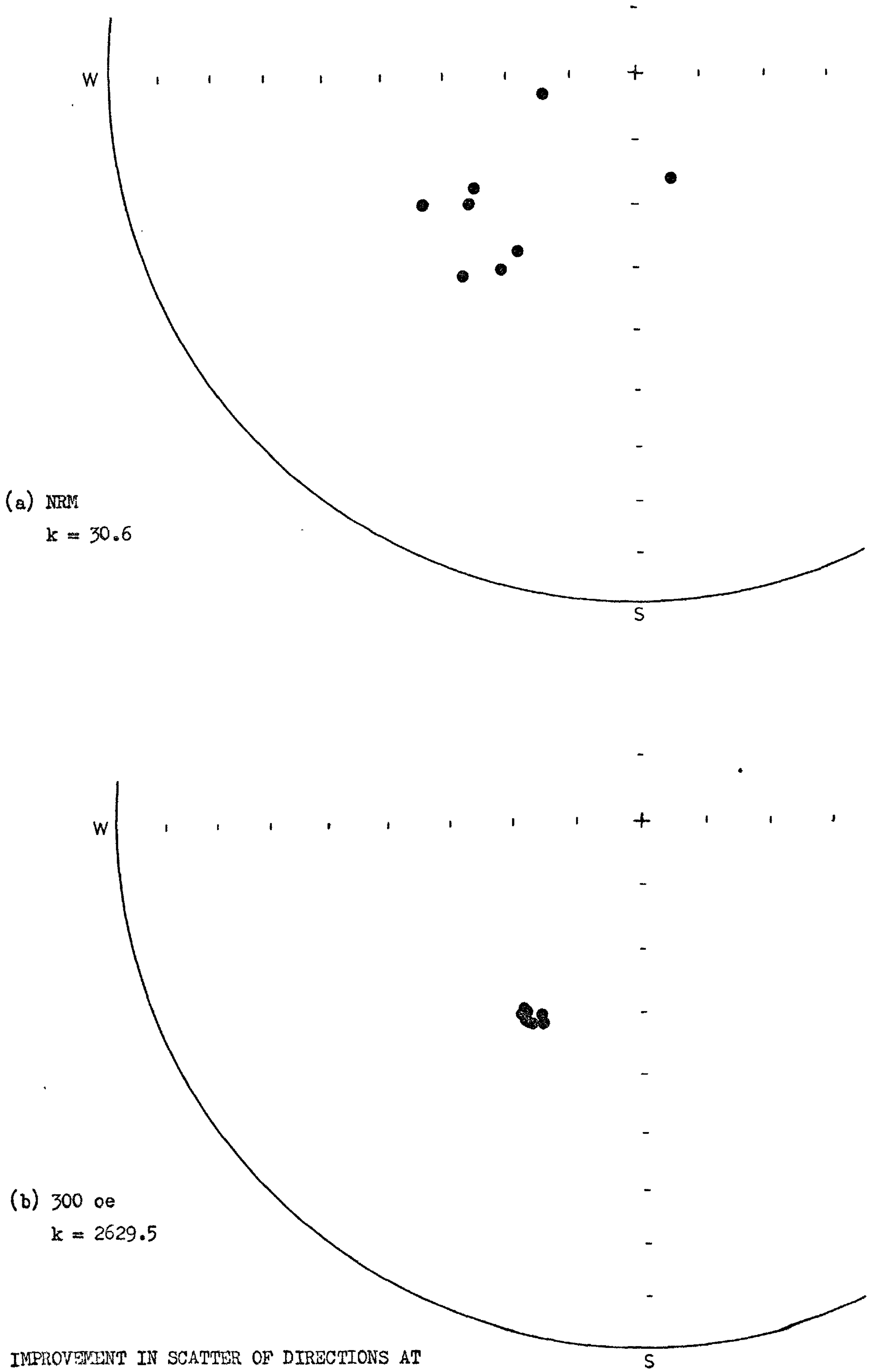
Figure 4.23 illustrates the demagnetization behaviour of five specimens which showed southerly movement terminating in an end-point, and

TABLE 4.6

EXAMPLES OF LARGE INCREASES IN PRECISION

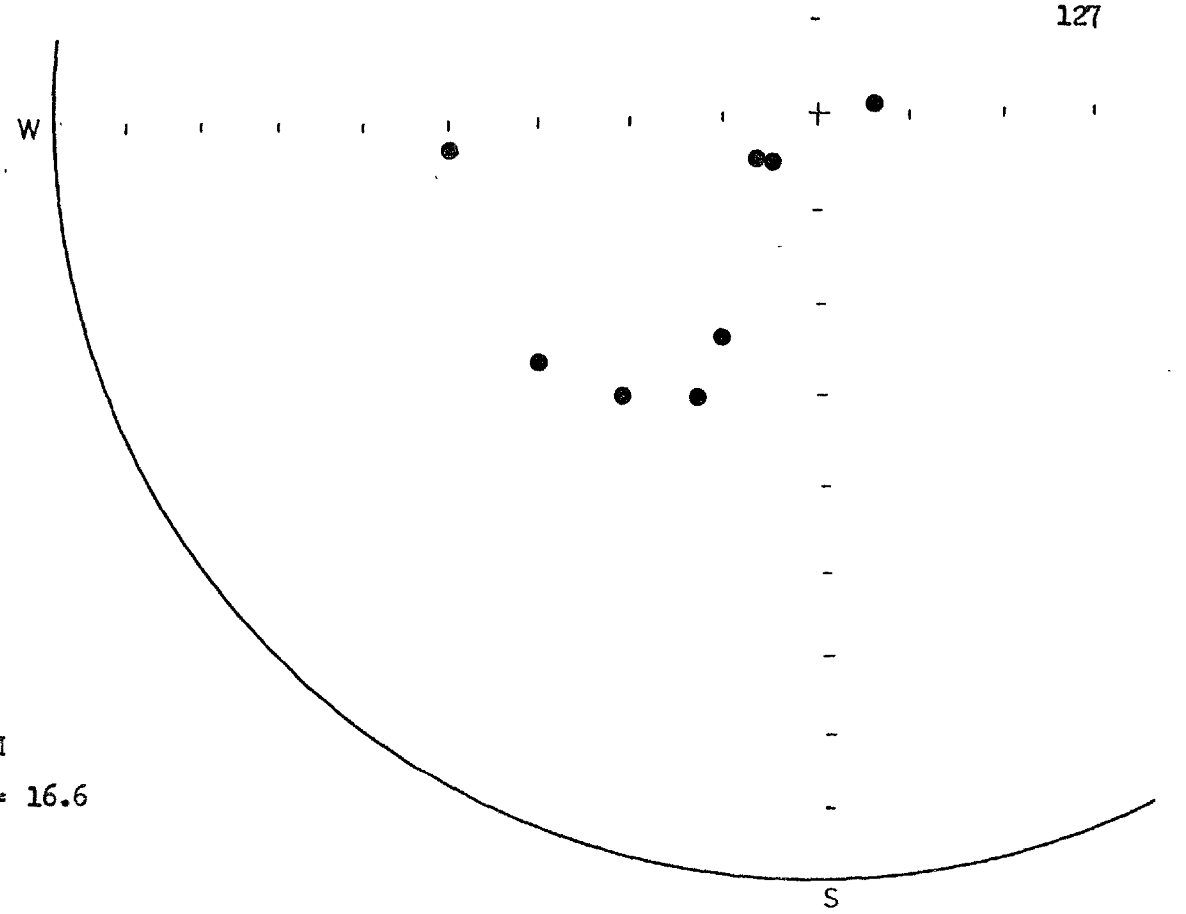
DURING DEMAGNETIZATION

SITE	NRM k	BEST k	DEMAG FIELD (oe)
D2	50.0	655.0	100
D3	37.8	459.3	150
D4	5.3	502.0	400
D5	30.6	2629.5	300
D6	16.6	934.1	"201"
D7	19.0	473.5	"151"
D8	2.1	227.9	100
D15	62.0	653.5	200
G20	17.2	352.6	400

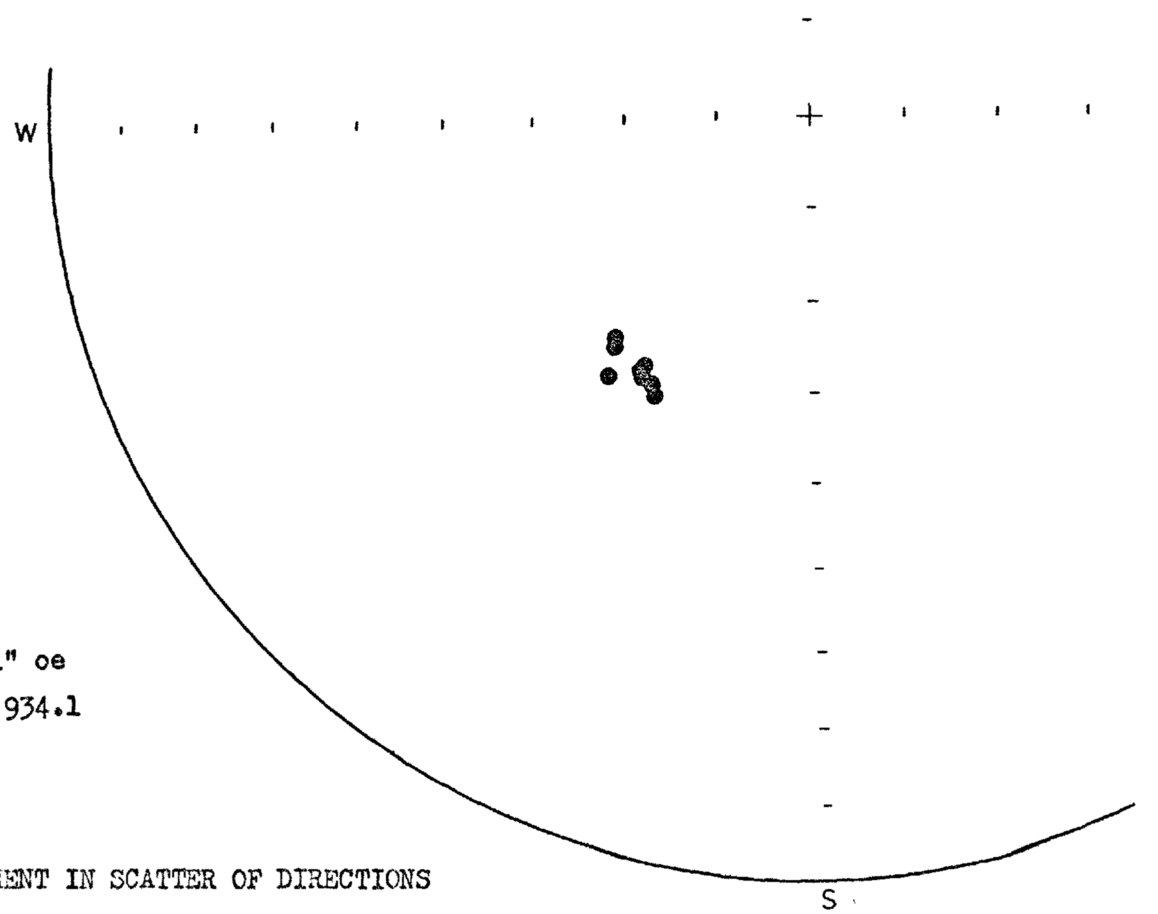


IMPROVEMENT IN SCATTER OF DIRECTIONS AT SITE D5. Equal area projection.

FIG.4.20



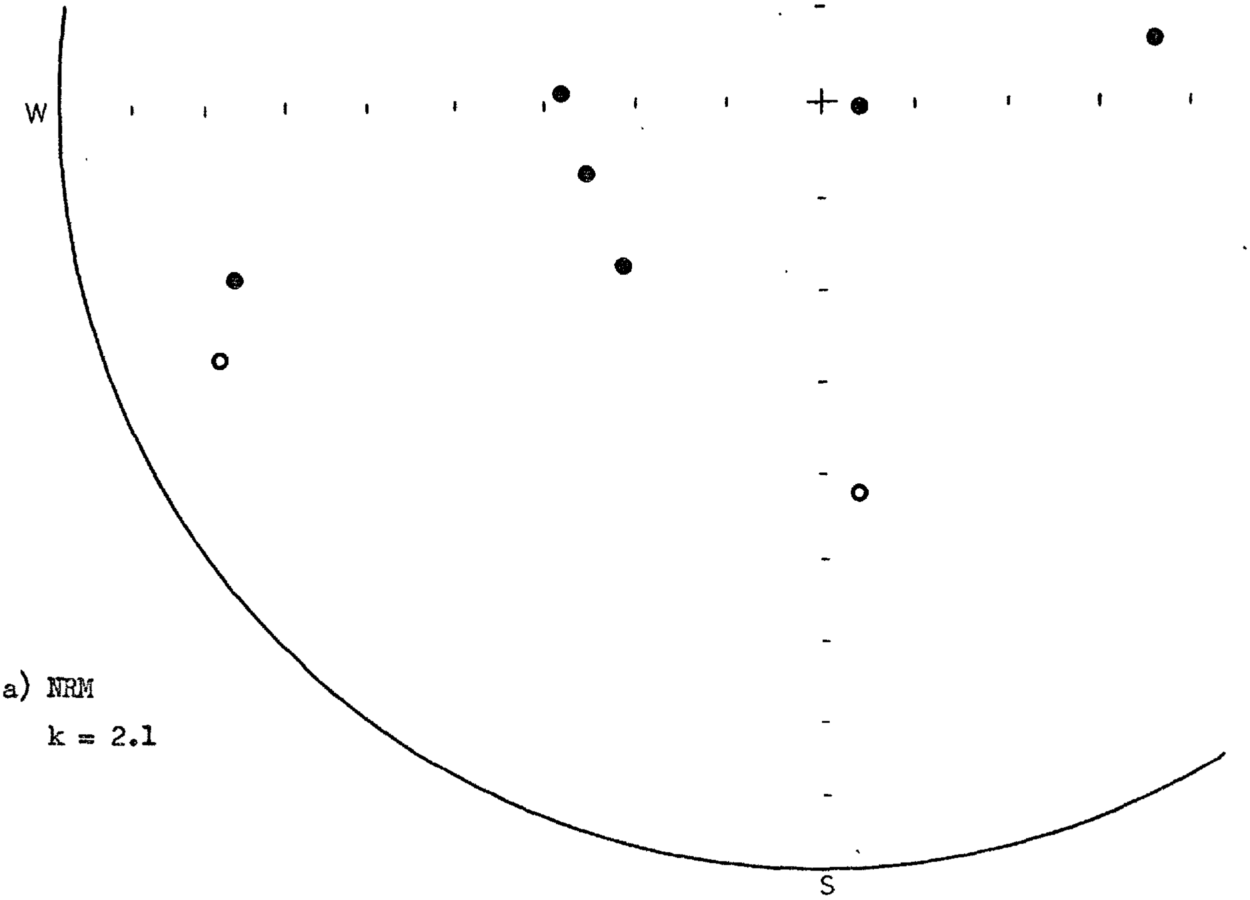
(a) NRM
k = 16.6



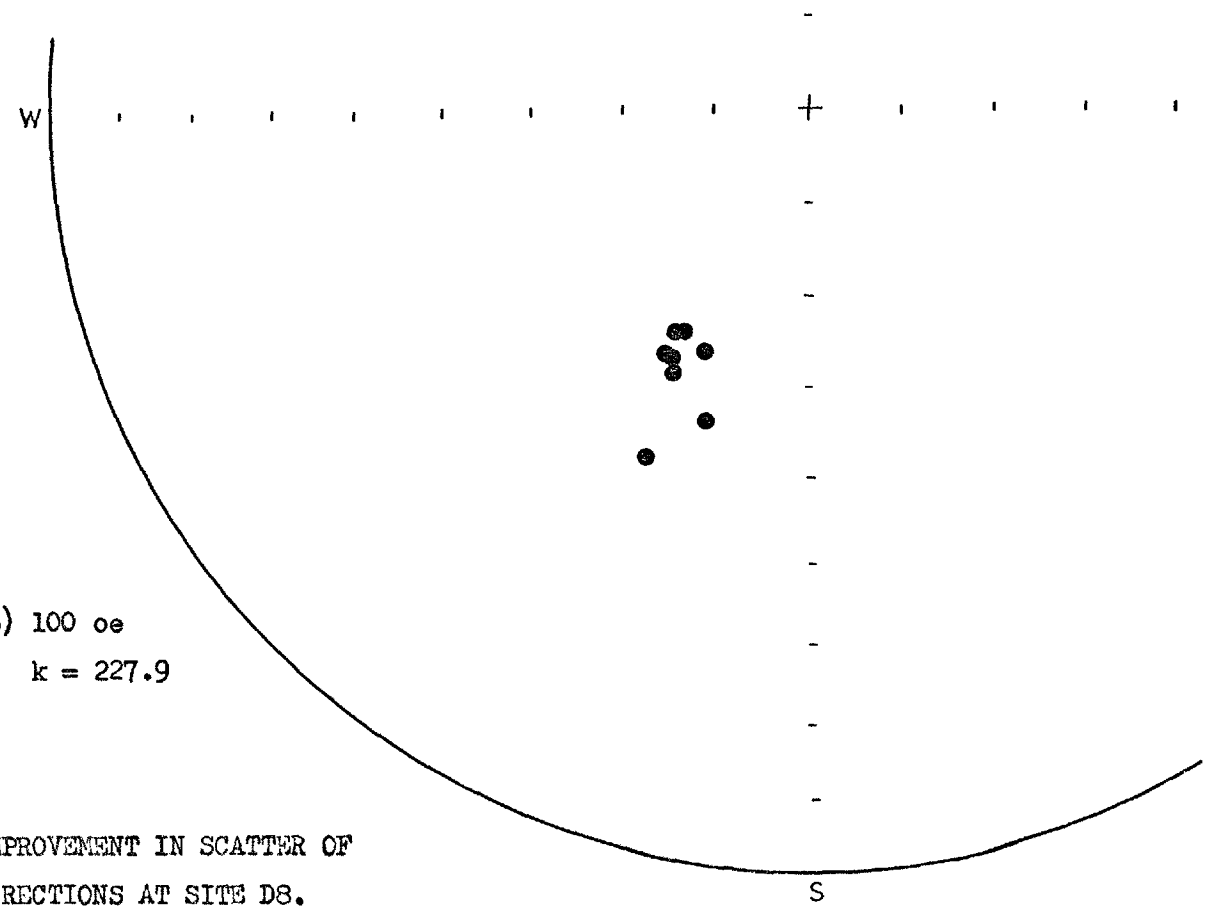
(b) "201" oe
k = 934.1

IMPROVEMENT IN SCATTER OF DIRECTIONS
AT SITE D.6 Equal area projection.

FIG. 4.21



(a) NRM
k = 2.1



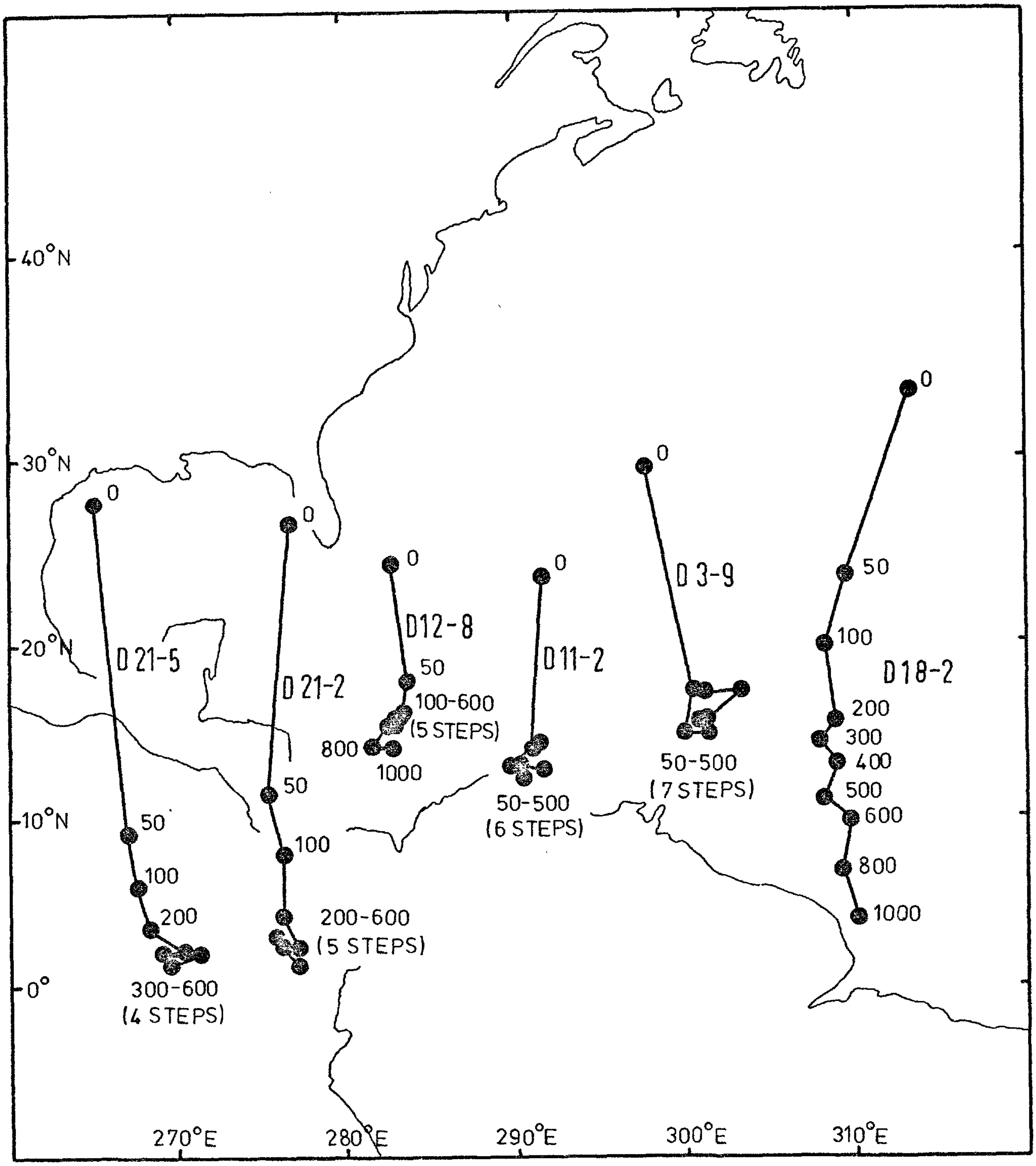
(b) 100 oe
k = 227.9

IMPROVEMENT IN SCATTER OF
DIRECTIONS AT SITE D8.
Equal area projection

FIG. 4.22

one specimen which showed persistent southerly movement up to 1000 oe. Specimens D21 - 5 and D21 - 2 both showed appreciable southerly movement of their poles up to fields of about 200 oe, and then showed small and more or less random movements about the end-point up to fields of 600 oe. Specimen D12 - 8 showed southerly movement up to 100 oe, the five poles between 100 and 600 oe showed a remarkably close grouping (all being within 0.4° of their mean), and the 800 and 1000 oe poles were also within 2.0° of this group. Specimens D11 - 2 and D3 - 9 both showed southerly movement up to 50 oe, and then small random movements about the end-point up to fields of 500 oe. Specimen D18 - 2 showed a generally southerly movement of approximately 18° up to 200 oe, and then a further southerly movement of 11° up to 1000 oe. Although the southerly movement above 200 oe was much slower in terms of degrees per oersted the rate appeared to be approximately constant over this range and showed no slowing down at the higher fields.

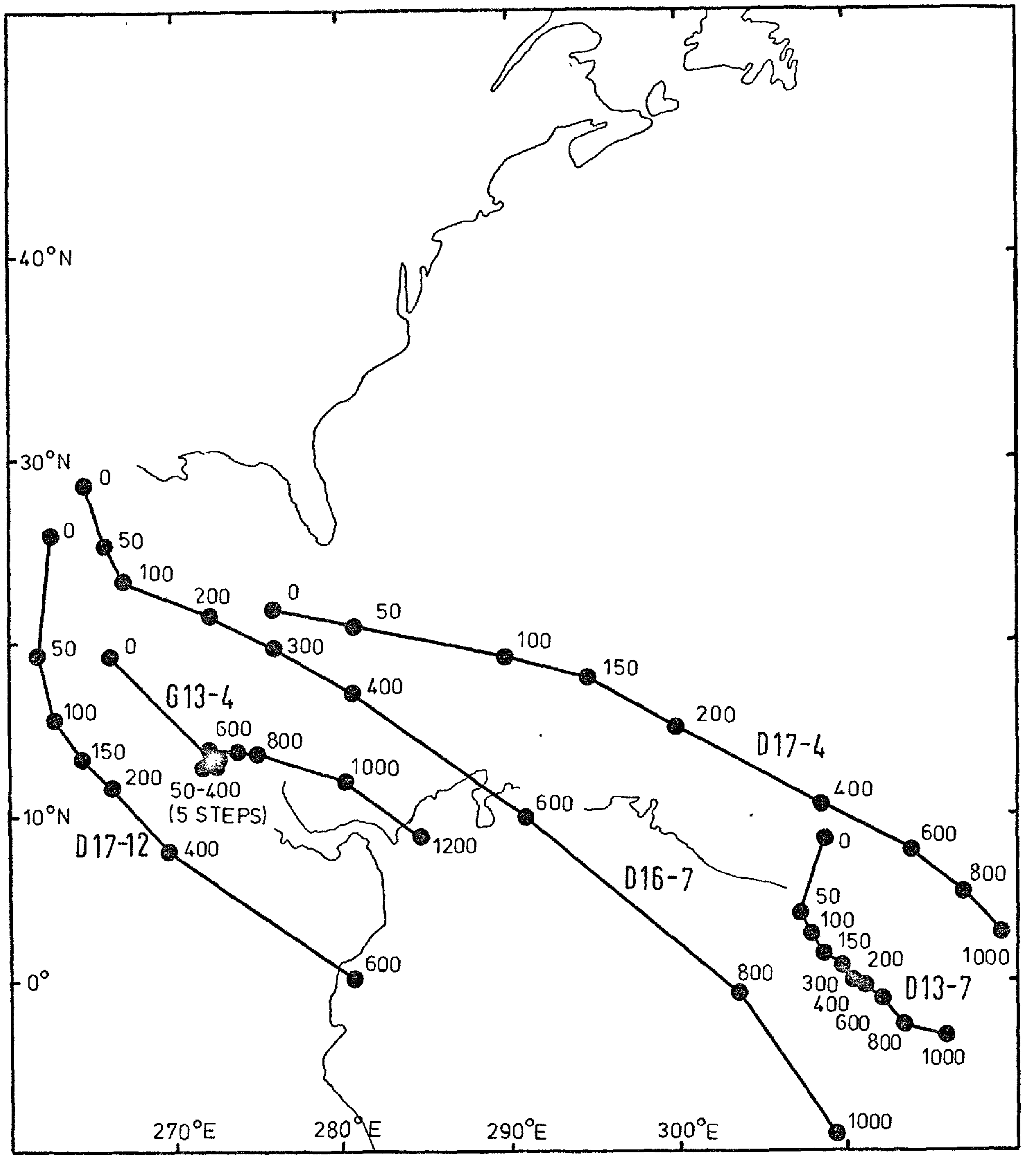
Figure 4.24 illustrates the demagnetization behaviour of five specimens whose poles showed systematic south-easterly movements during demagnetization. Specimen D17 - 2 showed a southerly movement up to 50 oe, a smooth transition to a south-easterly movement between 50 and 150 oe, and a regular south-easterly movement between 150 and 600 oe. Specimen D16 - 7 showed an approximately southerly movement up to 100 oe, at which point there was a fairly sharp transition to a regular south-easterly movement which persisted over the six steps up to 1000 oe and caused the pole to move a distance of over 50°. Specimen D13 - 7 showed a southerly movement up to 50 oe, and thereafter over the eight steps up to 1000 oe the pole showed small but systematic movements in a south-easterly direction. Specimen D17 - 4 showed no trace of any southerly movement and over all eight demagnetization steps between NRM and 1000 oe showed regular movements in a south-easterly direction, the pole moving a total distance of over 45°. Specimen G13 - 4 showed a rather unusual behaviour in that after a very approximately southerly movement up to 50 oe a temporary end-point appeared to be reached, in that the five poles between 50 and 400 oe were extremely closely grouped (all being within



MOVEMENT OF SOME INDIVIDUAL SPECIMEN POLES DURING DEMAGNETIZATION

Specimens selected to show southerly movements and end-points. Some movements have been shifted laterally to improve clarity.

FIG. 4.23



MOVEMENT OF SOME INDIVIDUAL SPECIMEN POLES DURING DEMAGNETIZATION

Specimen selected to show south-easterly movements. Some movements have been shifted laterally to improve clarity.

FIG. 4.24

0.6° of their mean); between 400 and 1200 oe, however, an easterly gradually veering to south-easterly movement was evident. All other specimens from site G13 behaved in a very similar manner to G13 - 4.

4.5 THE NEWCASTLE RESULTS

4.5.1 Introduction

During the course of this project a total of 23 specimens from 12 sites were sent to Dr. G. E. J. Beckmann at Newcastle University, who carried out thermal and a.f. demagnetization studies on them. This work fell into several phases which are described separately below.

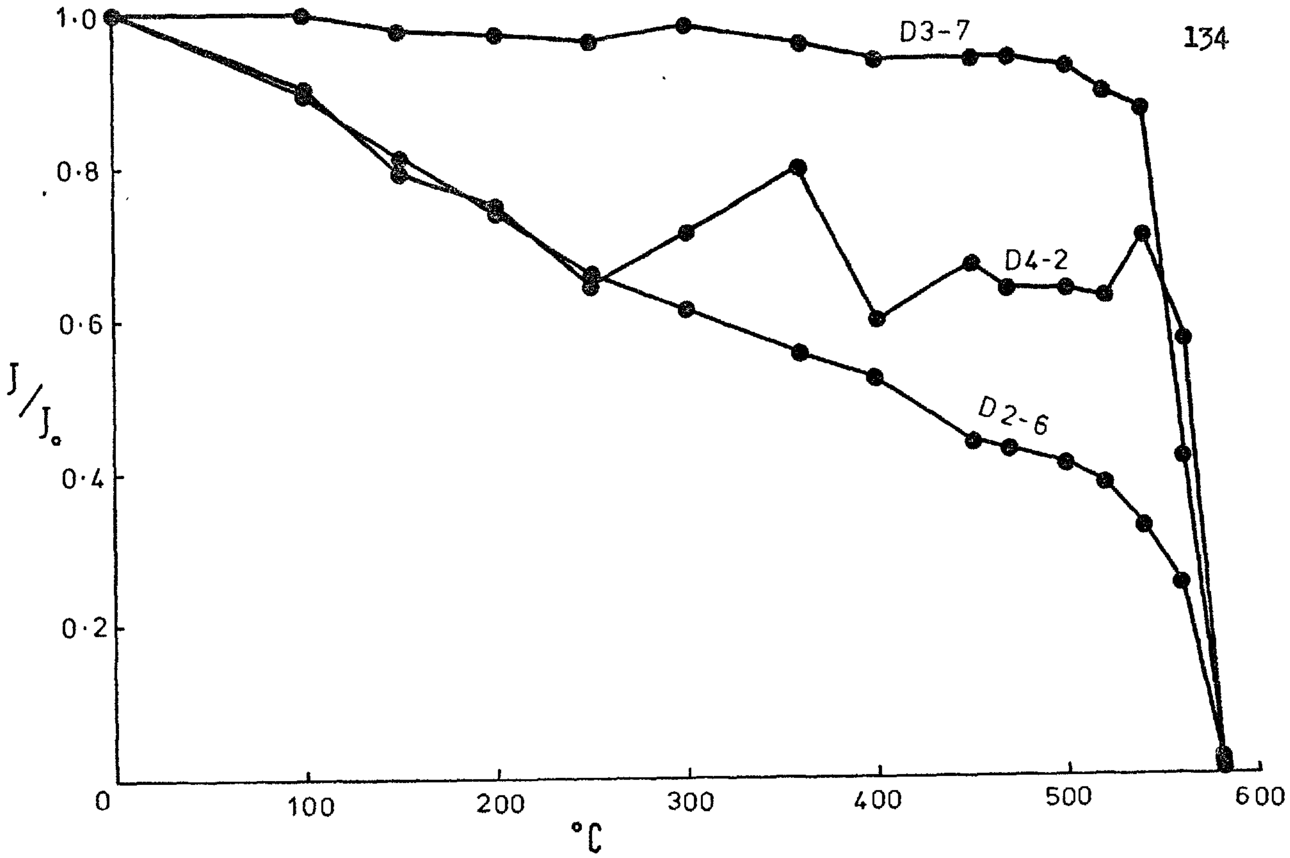
4.5.2 Six specimens from D2, D3 and D4

The main purpose of these investigations was to determine the thermal properties of these six specimens, for example blocking temperature spectra and Curie points, and also to check that thermal demagnetization yielded similar directions of magnetization to those obtained in the main a.f. demagnetization studies carried out by the author at Imperial College. It was also thought that it would be of interest to compare the thermal and a.f. demagnetization characteristics of these specimens, and so each specimen was cut into two and one half subjected to thermal demagnetization and the other half to a.f. demagnetization. It was hoped that by taking immediately adjacent segments it would be possible to compare the thermal and a.f. characteristics of material with essentially identical magnetic properties. These investigations were carried out on two specimens from each of the three sampling sites, the specimens being D2 - 6, D2 - 8, D3 - 5, D3 - 7, D4 - 2 and D4 - 9. As each specimen was cut into two a total of six thermal and six a.f. investigations were carried out.

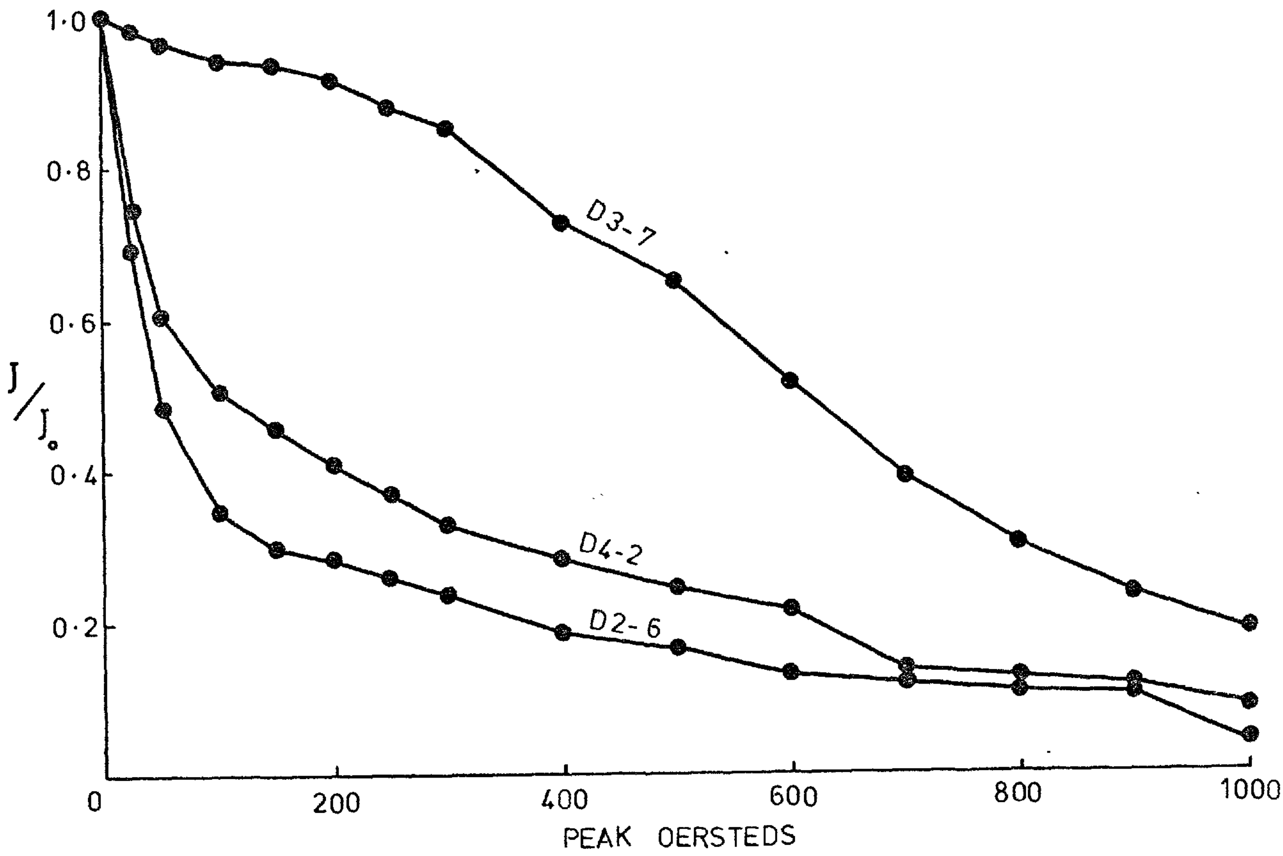
It was found that for each site the two specimens showed very similar behaviour, both during thermal and a.f. demagnetization, but that there were considerable differences between the behaviour of specimens from different sites.

Both specimens from D3 were characterised by the almost complete absence of components with blocking temperatures below 500°C. The thermal demagnetization curve for D3 - 7 is shown in Figure 4.25 (a), the curve for D3 - 5 being very similar. This demagnetization curve indicates that less than 8% of the magnetic components have blocking temperatures of below 500°C, and that the great majority of components, over 85%, have blocking temperatures of between 540 and 580°C. The two specimens from D2, on the other hand, had a more or less continuous spectrum of blocking temperatures, as indicated by the demagnetization curve of D2 - 6 shown in Figure 4.25 (a), although even here over 31% of components had blocking temperatures between 540 and 580°C. The two specimens from D4 had thermal demagnetization curves which were generally intermediate between those of the D2 and D3 specimens. The curve for D4 - 2 is shown in Figure 4.25 (a); the curve for D4 - 9 is very similar, even as far as reproducing the unusual shape of the curve between 250 and 560°C. These fluctuations in intensity may possibly be recording past reversals of the earth's field, either recently and therefore affecting the low-temperature viscously acquired magnetization, or very much earlier when the stable magnetization was being acquired. J/Jo at 580°C varied from 0.008 in D3 - 5 up to 0.035 in D4 - 9, the average for all six specimens being 0.018. This, combined with the fact that for each specimen the movement of the magnetization between 560 and 580°C was always large and apparently random, indicates that the magnetization of these specimens resides in grains which have Curie points of less than 580°C, and are therefore probably magnetite or titanomagnetite.

The a.f. demagnetization curves for the six specimens showed a general correlation with the thermal curves in that specimens in which low blocking temperature components were relatively unimportant generally had only a small proportion of low coercivity components, whereas specimens which had a continuous spectrum of blocking temperatures generally had a much larger proportion of low coercivity components. The a.f. demagnetization curves for the two specimens from D3 were very similar, and that for D3 - 7 is



(a) Thermal



(b) a.f.

THERMAL AND A.F. DEMAGNETIZATION CURVES FOR SPECIMENS D2-6, D3-7 AND D4-2

FIG. 4.25

shown in Figure 4.25 (b). It can be seen that there was a more or less continuous spectrum of coercivities up to values corresponding to demagnetizing fields of at least 1000 oe, but that coercivities corresponding to demagnetizing fields of less than about 300 oe were fairly unimportant, making up only 15% of the total spectrum. The fact that both specimens from D3 have at the same time a narrow range of blocking temperatures and a wide range of coercivities is considered to be of some interest and is discussed further in Chapter 7. The two specimens from D2, on the other hand, were dominated by low coercivity components. The a.f. demagnetizing curve for D2 - 6 is shown in Figure 4.25 (b), the curve for D2 - 8 being generally similar. It can be seen that more than 65% of the components had coercivities corresponding to demagnetizing fields of less than 100 oe. These D2 specimens are thus in marked contrast to the D3 specimens in that they combine a fairly narrow range of coercivities with a wide range of blocking temperatures, having a coercivity spectrum which is strongly peaked at the lower end and a blocking temperature spectrum which is more or less continuous but slightly peaked at the upper end. The two D4 specimens both gave a.f. demagnetization curves intermediate between those of the D2 and D3 specimens, and one of these is illustrated in Figure 4.25 (b).

These thermal and a.f. demagnetization investigations yielded directions of magnetization and pole positions which were very similar, and which also agreed very closely with the results of the main a.f. demagnetization studies on these sites carried out by the author, but detailed consideration of this aspect of the Newcastle investigations will be deferred until the next phase of the work has been described. One point which will be discussed at the moment, however, is the contrast between the pattern of movement of poles during demagnetization from sites D2 and D3, and also the contrast between the movement pattern for specimens from the same site during thermal and a.f. demagnetization. The movement of the poles for specimens D2 - 6 and D2 - 8 with progressive thermal demagnetization is shown in Figure 4.26.

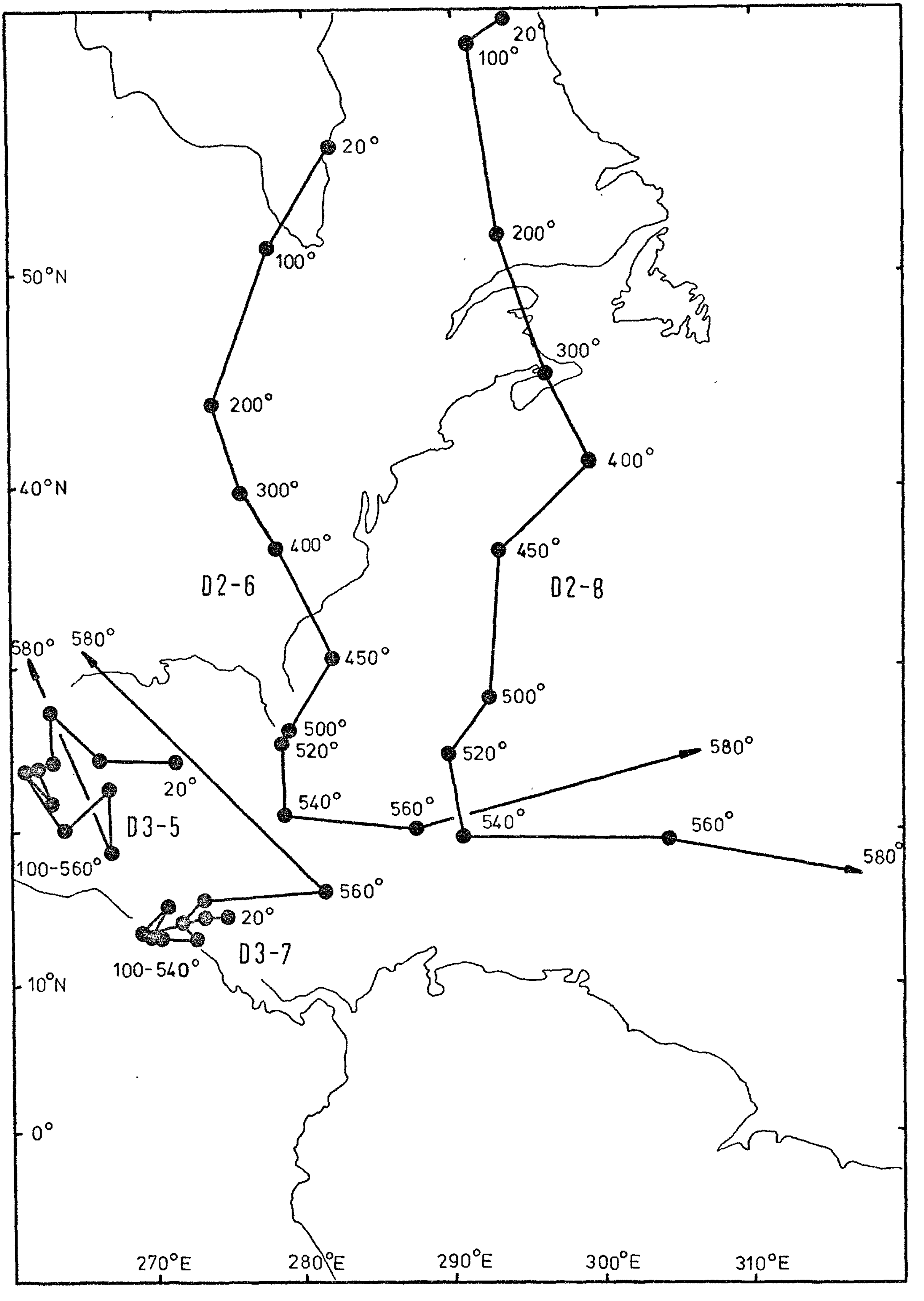
As might be expected from specimens with a continuous spectrum of blocking temperatures extending down to at least 100°C, the NRM (20°C) poles were located at fairly high latitudes, indicating that a large proportion of grains had acquired a northerly directed component of magnetization by viscous build-up along the earth's present field. Progressive thermal demagnetization caused both poles to move in a generally southerly direction, the slight irregularity of these movements probably being due to the inevitable small errors associated with individual specimen measurements. An interesting feature of both these results is that the end-point of the southerly movement was apparently not reached until 540°C, indicating that components which have blocking temperatures (measured on the laboratory time-scale, see Chapter 6) of more than 520°C can nevertheless acquire magnetization by low-temperature viscous build-up.

The two specimens from D3, on the other hand, showed a very different type of behaviour, as indicated in Figure 4.26. These specimens had NRM poles at low latitudes and showed no evidence of any southerly movement with progressive demagnetization, the poles showing essentially small random movements about an average position within a few degrees of the NRM pole. Both D3 specimens lacked significant components with blocking temperatures below 500°C and this has clearly prevented them acquiring components by viscous build-up along the present field direction.

The movement of the poles from these four specimens with progressive a.f. demagnetization is shown in Figure 4.27, and there are obvious parallels with their behaviour during thermal demagnetization. One interesting point is that for the D2 specimens virtually all recently acquired viscous components were removed by fields of 100 - 200 oe, whereas in the thermal demagnetizations this required temperatures of over 520°C.

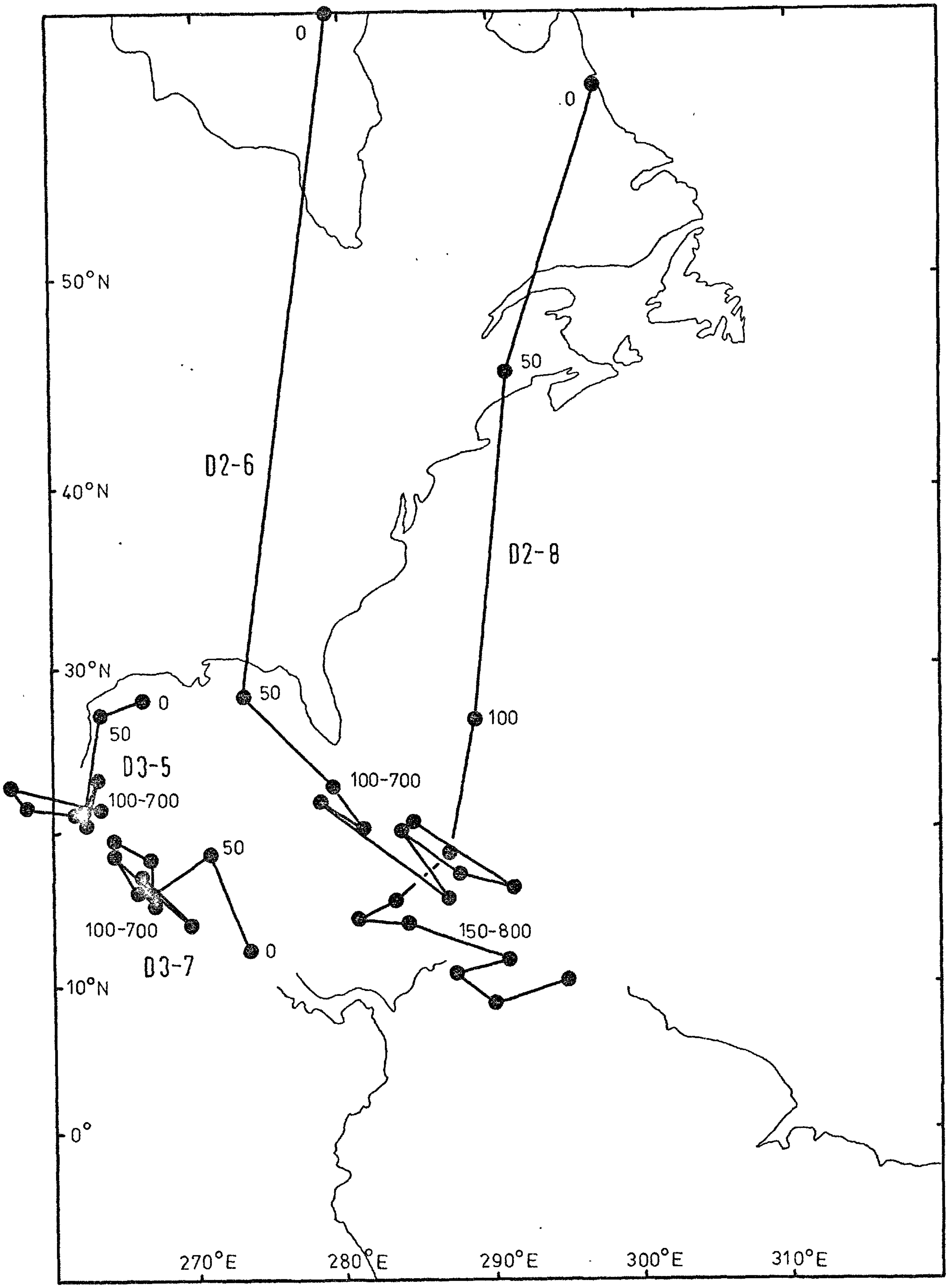
4.5.3 Eleven specimens from D5, D6, D7, D14, D15 and D17

These eleven specimens (D5 - 4, D6 -3, D6 - 8, D7 - 2, D7 - 7, D14 - 1, D14 - 8, D15 - 3, D15 - 7, D17 - 3 and D17 - 8) were treated in the same



MOVEMENT OF SELECTED SPECIMEN POLES DURING THERMAL DEMAGNETIZATION

FIG. 4.26



MOVEMENT OF SELECTED SPECIMEN POLES DURING A.F. DEMAGNETIZATION

FIG. 4.27

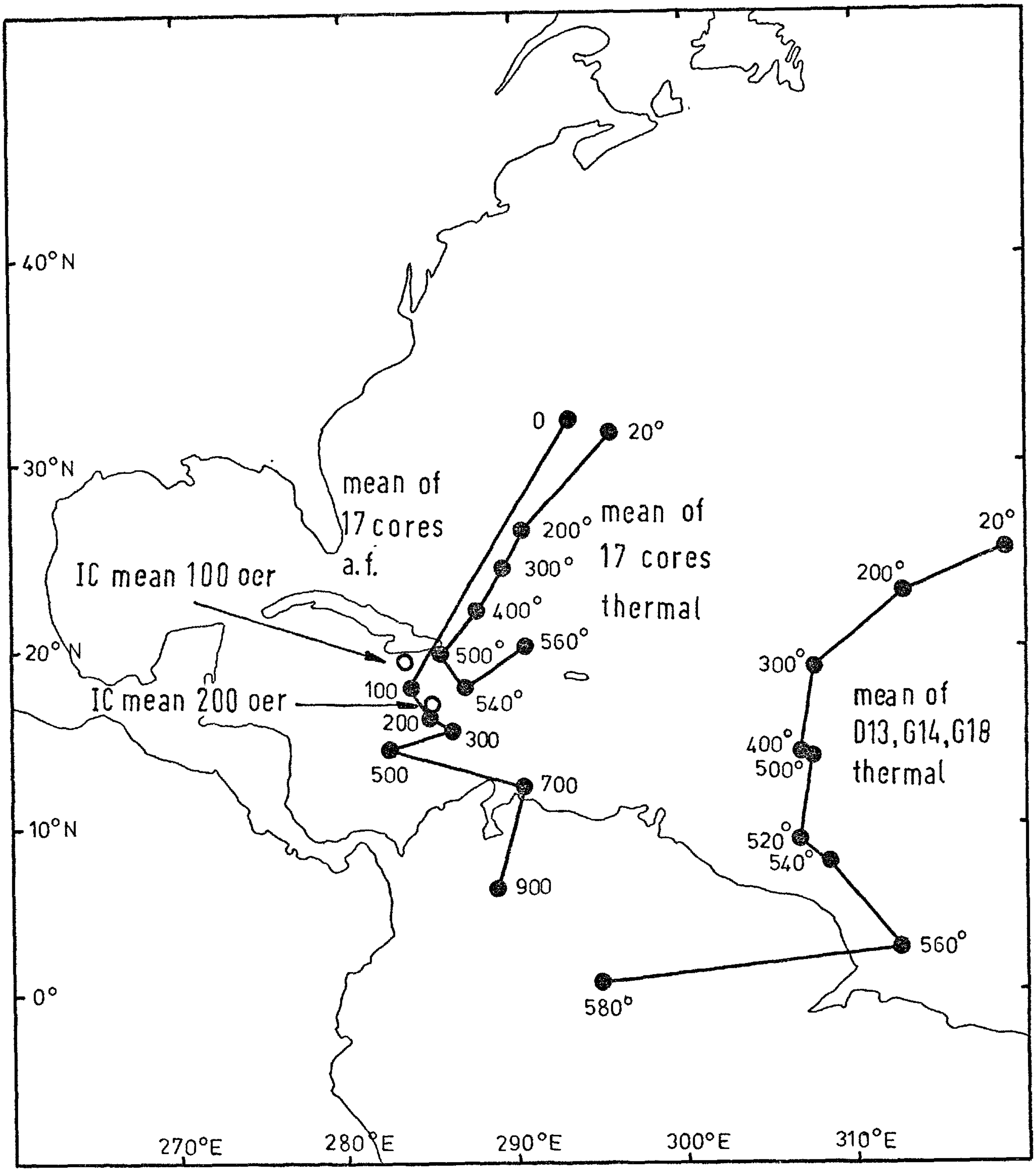
manner as the six specimens described above in that each specimen was cut into two and one half subjected to thermal and the other half to a.f. demagnetization, but for these investigations only approximately half the number of demagnetizing steps were used. Unfortunately, during the course of the thermal investigations the calibration of the magnetometer was inadvertantly altered, with the result that all the intensity measurements were unreliable, so that it was impossible to construct thermal demagnetization curves for any of these eleven specimens, or to obtain any information about blocking temperatures or Curie points. The directional information obtained from the thermal measurements, however, was not influenced by this accident, so the main use of these investigations was to provide a further set of eleven thermal and a.f. directional results which could be combined with the six previous results to provide mean directions and poles for comparison with the directions and poles obtained in the main investigations carried out by the author. These mean results are described in the following section.

4.5.4 Mean thermal and a.f. results for seventeen specimens.

The full details of the mean results for the seventeen specimens mentioned above, for both thermal and a.f. demagnetization, are given at the end of Appendix C. The movement of the mean poles with progressive thermal and a.f. demagnetization are shown in Figure 4.28. It can be seen that during thermal demagnetization the mean pole showed small systematic movements in a south-westerly direction up to 500°C, a small south-easterly movement between 500 and 540°C, and a slightly larger north-easterly movement between 540 and 560°C. k began with a value of 17.5 at the NRM stage, rose steadily to a maximum of 56.1 at 540°C, and decreased slightly to 45.8 at 560°C. The generally southerly movement up to 540°C presumably represents the removal of components acquired by viscous build-up very approximately along the present field direction, but the systematic south-westerly nature of these movements between the NRM position and 500°C is rather difficult to explain. As seventeen cores were used in computing the mean it might have been expected that a more exactly southerly movement would have been obtained. The south-easterly movement between 500 and 540°C may possibly be the equivalent of the south-easterly movement found at many sites in the main a.f. investigations, but clearly this cannot be definitely established on the evidence of only one movement, and it must also be noted that of the nine sites from which these seventeen specimens were obtained only two showed systematic south-easterly movements in the main a.f. studies. The 540°C pole, as it appears to represent the end of the generally southerly movement, and also has the highest k, probably best corresponds to the mean stable magnetization of these seventeen specimens as revealed by thermal demagnetization.

During a.f. demagnetization the mean pole showed movements remarkably similar to those which occurred during thermal demagnetization. Between the NRM position and 100 oe the mean pole showed a south-westerly movement very similar to the movement of the thermal pole between the NRM position and 500°C. Between 100 and 300 oe the pole showed small south-easterly movements, and above 300 oe the pole showed larger and very erratic movements but with an overall southerly trend. k rose from 18.4 at the NRM stage to 51.6 at 100 oe, remained almost exactly at this value at the 200 and 300 oe steps, and then gradually decreased to only 6.6 at 900 oe. The end-point of the main southerly movement of the pole appears to have been reached at 100 or 200 oe, and the 200 or 300 oe poles therefore probably best represent the mean stable magnetization of the seventeen specimens as revealed by a.f. demagnetization.

Figure 4.28 shows that the pole positions corresponding to the stable magnetization revealed by these two demagnetization methods are in fact very close together, the 540°C pole being less than 3° away from both the 200 and 300 oe poles. Figure 4.28 also includes mean 100 and 200 oe poles obtained from the main a.f. investigations carried out by the author at Imperial College. In order to make these Newcastle and Imperial College results as comparable as possible the two latter poles were computed using only the



MOVEMENTS OF MEAN POLES (NEWCASTLE INVESTIGATIONS)

Movement of mean pole for 17 specimens investigated at Newcastle (see text, section 4.5.4) during thermal demagnetization, and of mean pole for same 17 specimens during a.f. demagnetization. Comparable mean results for Imperial College investigations at 100 and 200 oe also shown. Diagram also shows movement of mean pole for 6 specimens (from D13, G14 and G18) during thermal demagnetization.

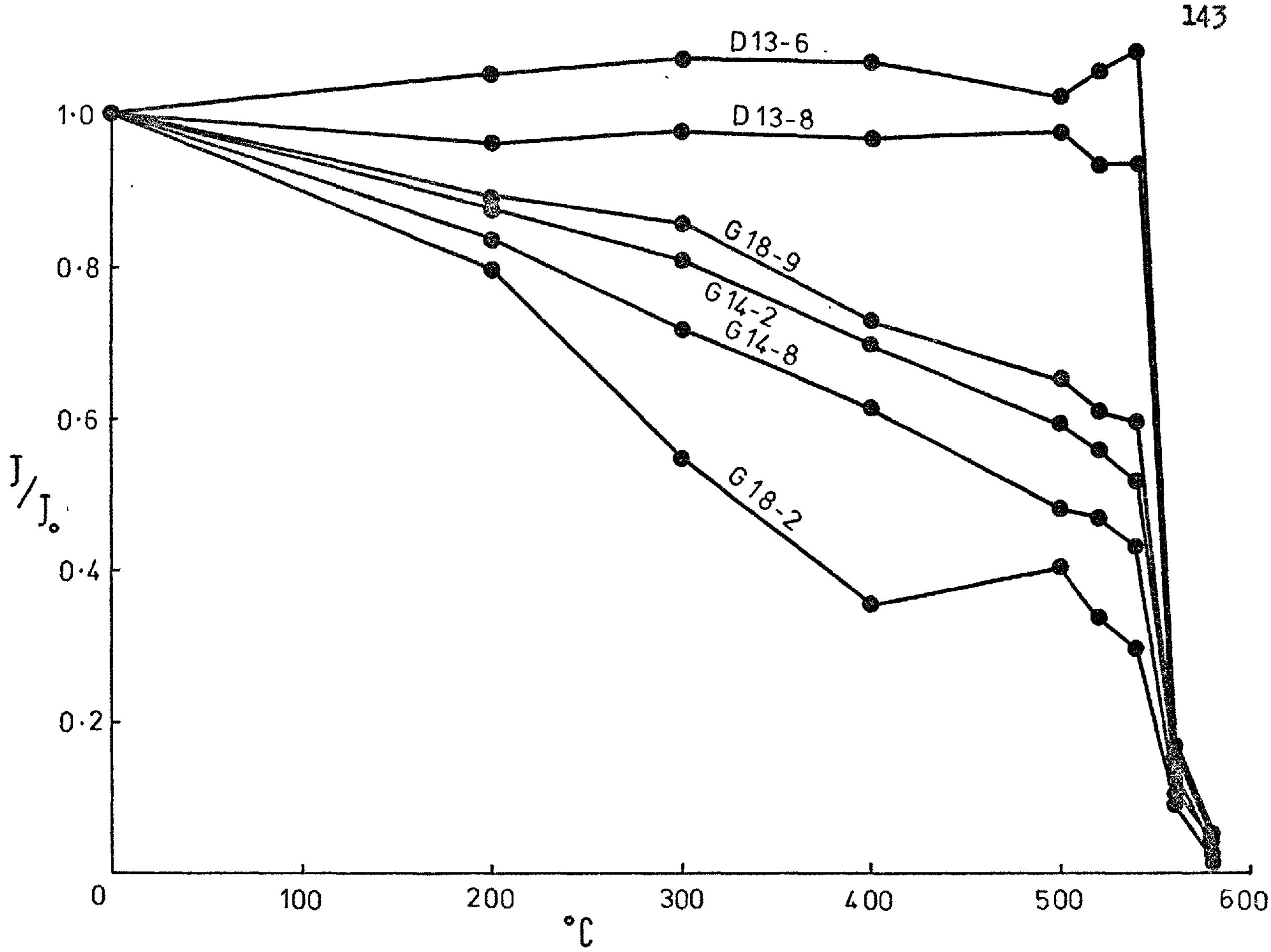
FIG. 4.28

data for the nine sites from which the seventeen Newcastle specimens were obtained. It can be seen that the Newcastle and Imperial College poles plot very close together, the difference between the 100 oe poles being only 1.5°, and between the 200 oe poles only 0.9°. This very close agreement between the results of three experimental systems in two different laboratories indicates that each of these systems is operating with a high degree of accuracy. Another point to emerge from Figure 4.28 is that the movement of the mean pole for the seventeen specimens between its NRM position and 500°C was almost identical to its movement between the NRM position and 100 oe. Thus it appears that for these seventeen specimens as a whole a.f. demagnetization at 100 oe is approximately equivalent to thermal demagnetization at 500°C. It was noted in section 4.5.2 that similar considerations applied to the two individual specimens from D2.

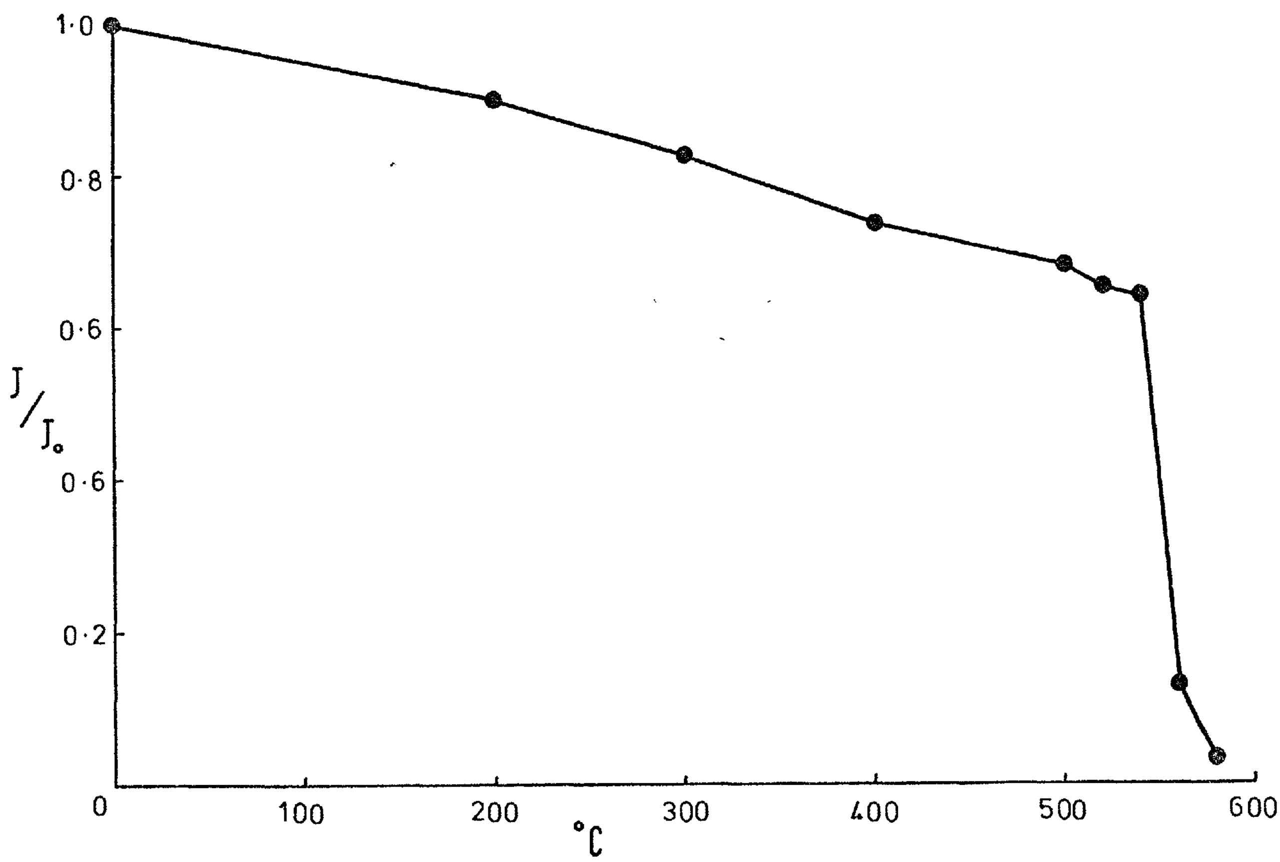
4.5.5 Six specimens from D13, G14 and G18

The main purpose of the investigations on these six specimens was to determine whether thermal demagnetization would reveal the same systematic south-easterly movements as were found at eight sites in the main a.f. investigations. Accordingly two specimens were selected from each of three sites whose mean poles had all shown these movements during a.f. demagnetization. For reasons that will be explained in Chapter 7 these three sites were also chosen because they were located very close together in the sampling area. The six specimens involved were D13 - 6, D13 - 8, G14 - 2, G14 - 5, G18 - 2 and G18 - 9; each specimen was subjected to thermal demagnetization only. Details of the mean results of progressive thermal demagnetization on these six specimens are given at the end of Appendix C. The demagnetization curves for each individual specimen are shown in Figure 4.29 (a), and the demagnetization curve representing the average of all six specimens is shown in Figure 4.29 (b). The movement of the mean pole with progressive demagnetization is shown in Figure 4.28.

Between the NRM position and 300°C the mean pole moved in a south-



(a) Curves for the six individual specimens



(b) Curve representing average of six above

THERMAL DEMAGNETIZATION CURVES FOR SPECIMENS FROM D13, G14 AND G18

FIG. 4.29

westerly direction, possibly representing the removal of randomly oriented storage components. Between 300 and 520°C the overall movement was almost exactly southerly, although the movement between 400 and 500°C was very small and in an essentially easterly direction. This overall southerly movement presumably represented the removal of northerly directed components acquired by viscous build-up while the rocks were in-situ. In the two steps between 520 and 560°C the mean pole moved in a south-easterly direction. Although there were only two movements the fact that they were both almost exactly parallel to the average a.f. south-easterly movements argues strongly that they are the thermal equivalents of these movements. As noted earlier the whole question of the south-easterly movements is discussed in greater detail in Chapter 7. Between 560 and 580°C the pole showed a large and apparently random movement in a westerly direction. k rose from 9.2 at the NRM stage to a maximum of 22.7 at 500°C, remained at approximately the same value at the 520 and 540°C steps, decreased slightly to 16.8 at 560°C, and then decreased dramatically to 4.5 at 580°C.

From the demagnetization curves it can be seen that in both the D13 specimens more than 90% of the magnetic components had blocking temperatures of between 540° and 580°C, and that in the other four specimens, although there was a more continuous spectrum down to at least 200°C, the main peak of blocking temperatures still occurred between 540° and 580°C. The average demagnetization curve of Figure 4.29 (b) shows that taking the six specimens as a whole 60.5% of all magnetic components had blocking temperatures of between 540° and 580°C. J/Jo at 580°C varied from 0.018 to 0.048, with an average value of 0.036. These very low intensities at 580°C, combined with the sharp decrease in k and the apparently random motion of the mean pole indicate that as with the specimens from D2, D3 and D4, the magnetization of these six specimens resides in grains of magnetite or titanomagnetite.

4.6 THE OTTAWA RESULTS

Many specimens from sites which showed systematic south-easterly movements were still showing these movements at the highest field, normally 1000 or 1200 oe, that was available at Imperial College. It therefore seemed of some interest to determine whether these systematic movements would persist at even higher demagnetizing fields, and also if possible to establish their end-point. Accordingly ten specimens were selected which had already been demagnetized up to 1000 or 1200 oe and which all showed good south-easterly movements right up to the final demagnetizing step. These ten specimens were sent to Dr. E. Irving at the Geomagnetic Laboratory in Ottawa who kindly agreed to demagnetize them up to the much higher fields available in that laboratory.

The specimens were demagnetized initially at 1250 and 1500 oe, and it was apparent that between the highest previous field and 1250 oe, and between 1250 and 1500 oe, the magnetization of every specimen showed essentially random movements of typically 10-20°, and there was no evidence of the systematic south-easterly movements which were observed at lower fields. As already explained in section 4.2.2 this does not necessarily prove that the systematic movements of the stable magnetization were not occurring at these higher fields, as they may by this stage have been completely masked by the much larger randomly directed unstable components. It is perhaps noteworthy that the random movements which were actually found were considerably larger than the typical south-easterly movements observed over the final demagnetizing step in the earlier investigations. Regarding the movement of the magnetization between the highest previous field and 1250 oe there are also the errors associated with aligning the specimen in a different specimen holder in the Ottawa magnetometer. These investigations thus indicate that even using sophisticated demagnetizing equipment the systematic south-easterly movements of these specimens cannot be studied at fields higher than 1000 - 1200 oe. In view of the nature of these initial results the Ottawa demagnetization studies were not continued at fields higher than 1500 oe.

Chapter 5

SLOW COOLING DUE TO UPLIFT AND EROSION

5.1 INTRODUCTION

In Chapter 2 it was shown that there are several lines of geological evidence which indicate that the country rocks were at high temperatures when the dykes were intruded. It has been suggested (J. Watterson, personal communication) that the country rock temperatures may have been in the region of 600°C, and were almost certainly not below 400°C at the time of intrusion. It is argued below (section 6.3) that these temperatures are above the critical magnetic blocking temperatures for a geological environment such as this, i.e. they are above the temperatures at which rocks would become permanently magnetized. It is likely therefore that both dykes and country rock gneisses became magnetized some time after dyke intrusion when general cooling of the crust caused the temperatures to fall through the critical range of blocking temperatures. The fact that dykes and gneisses yielded poles in the same area, and that the mean pole for the 18 dyke sites was not significantly different from the mean pole for the 4 gneiss sites (Table 4.4) is of course consistent with this hypothesis.

The most probable cause of general crustal cooling is uplift and erosion, and in section 5.2 below an attempt is made to establish the cooling rates which might have been experienced, and it is shown that in such a situation the rate of cooling over the temperature interval during which magnetization occurs was probably very slow. During the last decade or so geochronologists have recognised the effects on the radiometric record of slow cooling caused by uplift and erosion, and in section 5.3 some of these effects are described and the evidence that these investigations provide about past cooling rates is also discussed. In Chapter 6 the effects that slow cooling might be expected to have on the palaeomagnetic record are discussed in some detail, and it is shown that there should be many analogies with the effects on the radiometric record. Finally in this group of three chapters, in Chapter 7 it is shown that many of the unusual features of the Itivdleq palaeomagnetic results, for example the linear distribution of poles and the systematic south-easterly movements during demagnetization, are explicable as slow cooling effects.

5.2 COOLING RATES DUE TO UPLIFT AND EROSION

5.2.1 Present day rates of erosion

Estimates of erosion rates have been obtained by using long-term measurements of the solid and dissolved loads in major rivers, and taking into account the drainage areas covered. Using this technique Judson and Ritter (1964) found that the average erosion rate for the whole of the United States was about 60 metres/m.y., but Judson (1968) considered that this figure should be reduced to 30 metres/m.y. to adjust for increased recent erosion due to human activity. The region with the highest erosion rate was the Colorado River area with a figure of 165 metres/m.y. Strahler (1971) using data from various sources stated that the average erosion rate of the Amazon River basin was 47 metres/m.y., and that of the Congo River basin 20 metres/m.y.

Erosion rates are strongly influenced by the elevation of the land surface above base level, being faster for mountainous areas than for lowlands, and are also influenced of course by factors such as climate and the nature of the material being eroded. In some very small drainage areas under favourable conditions extremely high erosion rates have been noted, for example Judson (1968) quoted a rate of 12.8 km/m.y. for a very small basin of 3.4 km^2. However, erosion rates in areas this small are probably not relevant to the question of the cooling of a reasonably large area of crust.

Schumm (1963) considered the volumes of material brought by streams from drainage areas in mountain regions in order to determine maximum erosion rates for areas of around 1500 square miles. He concluded that the maximum erosion rate was about 1.0 km/m.y., but stressed that this figure would only apply in the most favourable circumstances, for example during the early stages of an erosion cycle (see below) when relief is high, and when sedimentary rocks are being eroded in a semi-arid climate. Under similar circumstances in a humid climate he considered that the maximum erosion rates would be about 250 metres/m.y. Schumm also concluded that average erosion rates in areas of about 1500 square miles were around 76 metres/m.y. for a semi-arid climate and around 20 metres/m.y. for a humid climate.

In an idealised erosion cycle there is initially fairly rapid uplift to form a high mountain mass. Because of the high altitude erosion is at first rapid, but as the landmass is worn down the rate becomes slower. However, the slowing down of erosion will not be so rapid as might at first be expected, because isostatic readjustment results in the rate of net lowering of the surface being only about one fifth of the erosion rate. It has been suggested by several authors (eg. Hurley et al. 1963, Strahler 1971) that the resulting erosion rate will decay exponentially with time. Strahler, for example, assuming an initial elevation of 15,000 feet, continuous isostatic readjustment in the ratio 4:5, and an initial erosion rate of 1.07 km/m.y., calculated the following figures for the changes in elevation and erosion rates with time (Table 5.1). The Table also shows the cumulative thickness of material removed at each time interval: these are five times the corresponding decrease in elevation owing to the effects of isostacy.

It can be seen from the model of Table 5.1 that one half of the available landmass is removed every 15 m.y. Hurley et al. (1963), however, concluded that the half life of major orogenic belts was typically around 100 m.y., and using this figure for a similar original uplift implies an initial erosion rate of about 165 metres/m.y. falling to about 80 metres/m.y. after 100 m.y. (when 11,500 metres of material has been removed), 40 metres/m.y. after 200 m.y. (17,250 metres removed), and 20 metres/m.y. after 300 m.y. (20,125 metres removed).

TABLE 5.1

MODEL EROSION CYCLE

(based mainly on Strahler 1971)

TIME SINCE START OF CYCLE (M.Y.)	ELEVATION (FEET)	ELEVATION (METRES)	TOTAL THICKNESS REMOVED (FEET)	TOTAL THICKNESS REMOVED (METRES)	EROSION RATE (METRES/M.Y.)
0	15,000	4,600	0	0	1,070
5	12,000	3,910	15,000	3,450	760
15	7,500	2,300	37,500	11,500	460
30	3,750	1,150	56,250	17,250	230
45	1,875	575	65,625	20,125	110
60	937	287	70,310	21,565	60
75	468	143	72,660	22,285	30
90	234	71	73,830	22,645	15
105	117	35	74,415	22,825	8
INFINITY	0	0	75,000	23,000	0

5.2.2 Cooling due to erosion

If rocks responded instantaneously to changes in thermal conditions, and if the geothermal gradient remained constant, then the cooling effect of erosion would simply be that of isotherms moving downwards through the crust at the same rate as erosion was proceeding at the surface. This might be termed the "simple model" of cooling due to erosion. However, in practice the situation is not so simple as this because rocks take a certain time to reach equilibrium when their thermal environment is altered, this time depending on the thermal diffusivity of the rocks concerned. The effect of this is to disturb the previously existing thermal gradient so that rocks at depth respond more slowly than would be expected from the simple model, and as the surface is kept at approximately 0°C there is therefore a crowding together of isotherms near the surface, i.e. there is an increase in geothermal gradient in the outer part of the crust. Therefore when one considers the cooling history of a point originally deep in the crust the cooling rate is first of all slower than would be expected from the simple model, but when the point approaches the surface regions the cooling rate is faster than expected.

Mr. Ken Williamson of the Heat Flow Section of the Imperial College Geophysics Department kindly wrote a computer program which allowed the diffusivity effect to be examined in some detail. As explained further in section 5.2.3 it appears that for the temperatures at which magnetization probably occurs with most reasonable erosion rates the cooling history is not significantly modified by this diffusivity effect, and so can be satisfactorily approximated by the simple model described above.

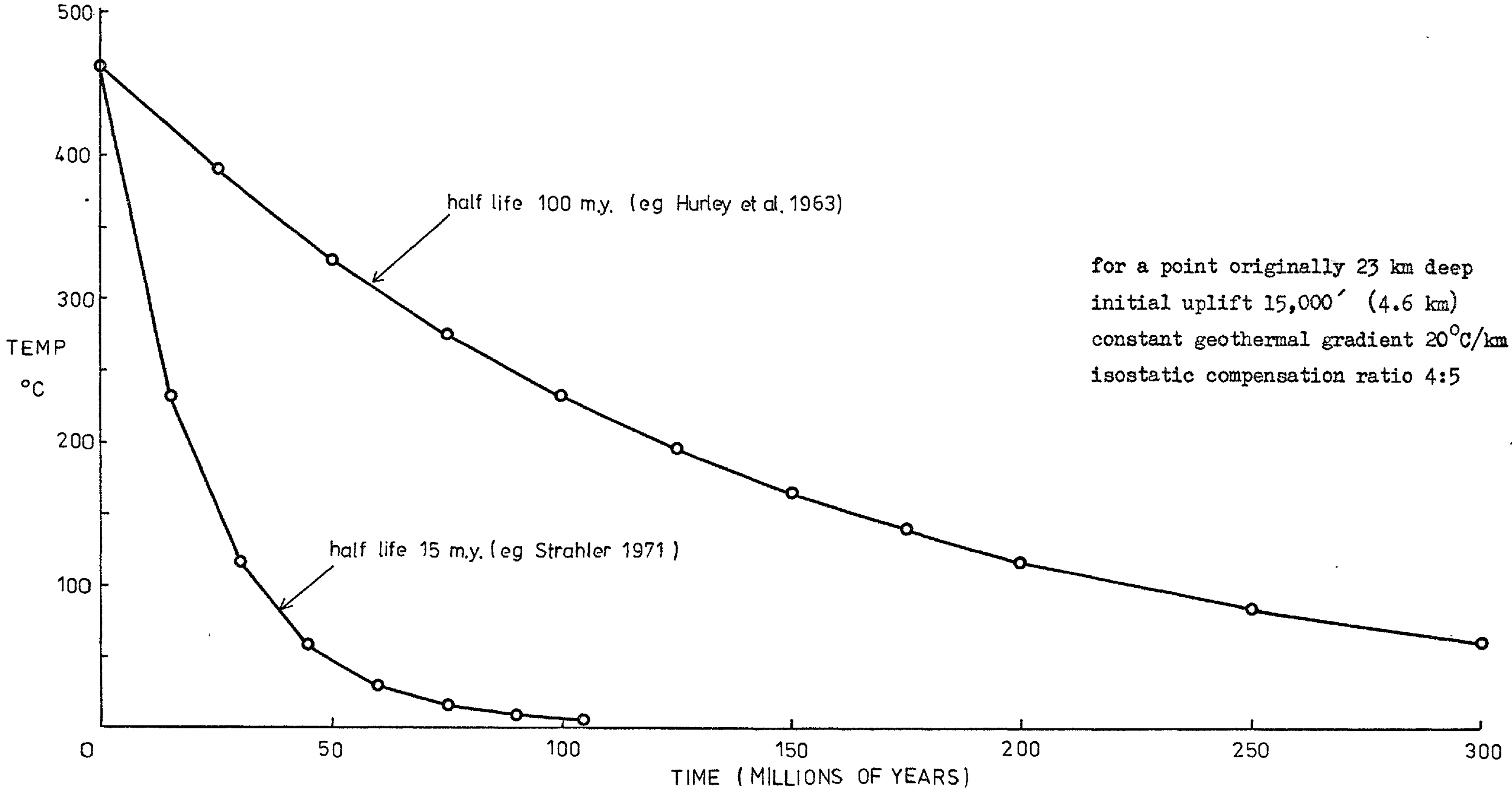
In the first part of section 5.2.1 it was shown that at the present day average erosion rates are estimated to be between 20 and 76 metres/m.y., (with an unweighted mean of 39 metres/m.y.), and that the maximum possible erosion rate is probably about 1.0 km/m.y. Using the simple model of cooling, and assuming a geothermal gradient of 20°C/km, these correspond to an average crustal cooling rate of about 0.8°C/m.y., and a maximum cooling rate of 20°C/m.y.

If the simple model of cooling is applied to the two exponential erosion cycle models described above (Hurley et. al. 1963 and Strahler 1971) then it is a simple matter to calculate the cooling histories of points at any starting depths. Both erosion cycles were calculated for original uplift of 15,000 feet (4.6 km), i.e. for an ultimate erosion depth of 75,000 feet (23.0 km). Now with exponential erosion the ultimate erosion depth is of course in theory never actually reached. However, in this study we are concerned with an early Proterozoic terrain uplifted approximately 1,700 m.y. ago, and it is probable that points at a depth of 23 km at that time and suffering similar uplift would by now be sufficiently close to the surface for them to be investigated. It is therefore of interest to consider a point originally at a depth of 23 km and examine its cooling history as it moves upwards towards the surface according to the two erosion cycle models noted above. In these calculations a constant geothermal gradient of 20°C/km is assumed, and the resulting cooling histories are illustrated in Figure 5.1. The point is initially at a temperature of 460°C, and according to the 15 m.y. half-life model the temperature falls to virtually 0°C over about 100 m.y. in the manner indicated. In the 100 m.y. half-life model the temperature is still 230°C after 100 m.y., and is 57.5° after 300 m.y.

It is argued below (section 6.3) that in this situation effective blocking temperatures are probably reduced to the region of about 200°C, and so it is of interest to examine the cooling behaviour in this area. According to the 15 m.y. half-life model cooling is occurring at a rate of about 8°C/m.y. at around 200°C, and according to the 100 m.y. half-life model at about 1.8°C/m.y.

5.2.3 Cooling rates in the past

In section 5.2.2 some estimates were given of cooling rates which would be produced by constant erosion rates observed at the present day, and probably more realistically also by exponentially decreasing erosion rates. Attempting to estimate erosion and cooling rates in the distant past, particularly in the Precambrian, is clearly fraught with uncertainties, and in this section it is only intended to make very approximate estimates of reasonable cooling rates, and also to try to establish a figure for the fastest possible cooling rate. Discussion will be mainly centred on the cooling rate prevailing at the temperature range over which magnetization probably occurs, so that some estimate can later be obtained for the duration of the magnetization process. There are many unknowns involved in these calculations, for example the geothermal gradient, the absolute temperature interval over which magnetization occurs, and of course the erosion rates prevailing at the time. The last factor is the most difficult to estimate as not only are there uncertainties about typical erosion rates in the Precambrian, but also of course



SIMPLE COOLING MODELS

FIG. 5.1

one has no knowledge of the patterns of uplift and erosion. For example the erosion models discussed in section 5.2.2 assumed a single rapid uplift followed by gradual erosion down to baselevel, but of course it is possible that uplift and erosion were episodic, and one does not know at what stage of a sub-cycle the rocks happened to pass through their critical range of blocking temperatures.

As discussed in Chapter 8 the segment of crust which is the subject of this study is considered to have suffered a major episode of erosion about 1700 m.y. ago, and it is therefore necessary to make an estimate of the geothermal gradient at that point in time. One simple way of determining geothermal gradients in the past is to assume that the gradient is directly proportional to radiogenic heat production, and to calculate the heat production at that period using some model for the variation of heat production with time. Dickinson and Luth (1971) produced graphs showing the ratio of heat production in the past compared to that at present for three different earth models. Their curves show that 1700 m.y. ago the average of the three models gives a heat production 1.6 times that at present. As the average geothermal gradient in present-day Precambrian terrains is about $14^{\circ}C/km$ this crude method indicates that at 1700 m.y. the gradient was about $22^{\circ}C/km$.

Let us first consider the very fastest rate of cooling that could have occurred over the magnetization temperature range. For this we assume a very high geothermal gradient, as clearly other things being equal the higher the gradient the faster the cooling. The gradient assumed is $60^{\circ}C/km$, i.e. almost three times that estimated above, which should easily allow for any uncertainties in Proterozoic heat production, or the presence of anomalous heat sources. It was indicated above that the fastest erosion rates at the present time over areas comparable in size to the sampling area are about 1.0 km/m.y. In order to allow for the possibility of unusually high erosion rates in the Proterozoic an erosion rate of 3.0 km/m.y. is assumed in these calculations. As indicated above erosion is generally considered to be exponential with time, the fastest rates only occurring at the beginning of the cycle immediately after uplift. To allow for the uncertainties in reconstructing past patterns of uplift and erosion the erosion rate is assumed constant at 3.0 km/m.y. throughout the erosion episode.

The data of the last paragraph was used in the computer program written by Mr. Ken Williamson mentioned above, which calculated cooling histories during constant erosion taking into account the distortion of the geothermal gradient due to the diffusivity effect. Because the increase in gradient in the outer parts of the crust becomes greater the longer the erosion is continued, it is obviously important to decide on a starting depth for the point to be considered. Considering the extreme gradient of 60°C/km which is assumed, and also considering the temperature estimates for the time of dyke intrusion (section 5.1 above) a starting depth of 9 km was assumed. The results of running the program using all these extreme values are given in Table 5.2 Because there is some uncertainty in the amount of reduction of effective blocking temperatures the Table gives the cooling rate at 25°C intervals ranging from 250°C down to 150°C.

TABLE 5.2

FASTEST POSSIBLE COOLING MODEL (BY COMPUTER)

TEMPERATURE (°C)	COOLING RATE (°C/M.Y.)	Notes:-
250	278	1. Constant erosion rate 3 km/m.y.
225	289	2. Initial gradient 60°C/km.
200	299	3. Starting depth 9 km
175	308	4. For "simple model" cooling would be at a constant rate of 180°C/m.y.
150	315	

As indicated in Table 5.2 if the cooling had been calculated according to the simple model, i.e. ignoring the distortion of the gradient due to the diffusivity effect, then there would have been a constant cooling rate of 180°C/m.y. The results in Table 5.2 clearly indicate that with this extremely fast erosion rate the gradient is significantly increased, so that cooling is faster than expected, and also that the increase in gradient is greater nearer to the surface, so that cooling is faster at lower temperatures than at higher ones. It must be emphasised that the results in Table 5.2 are the consequence of taking extreme values of all the variables, so that they represent the fastest cooling rates that could have occurred in the very unlikely event of these extreme conditions having all occurred together. It may therefore be stated with some confidence that there is no way in which the cooling rate over the magnetization temperature range could have been greater than 315°C/m.y.

The program was also run with lower erosion rates to see at what point the distortion of the gradient becomes insignificant. It might be noted that the results in Table 5.2 indicate that with an erosion rate of 3 km/m.y. after 2.5 m.y. the gradient at that depth in the crust where magnetization probably occurs has been increased by 75% compared to its initial value. When the program was run with an erosion rate of 1 km/m.y. it was found that after 7 m.y. the increase in gradient was only 25%, and with an erosion rate of 80 metres/m.y. the distortion of gradient was negligible.

We are now in a position to make very approximate estimates of the possible range of reasonable cooling rates that the segment of crust in question might have experienced. It will be convenient to consider the slow, medium and fast regions of this reasonable range. For the slow part of the range a geothermal gradient of 20°C/km is assumed, for the medium part a gradient of 25°C/km, and for the fast part a gradient of 30°C/km. The slow erosion rate is chosen as 39 metres/m.y., i.e. the mean of the five estimates of average present-day erosion rates discussed in section 5.2.1. The medium and fast erosion rates are arbitrarily chosen as 90 metres/m.y. and 400 metres m.y., these being the erosion rates at about 200°C in the two exponential erosion models described above, i.e. those with erosion half-lives of 100 m.y. and 15 m.y. respectively.

In the case of the slow and medium parts of the range it appears from the results noted above that distortion of the gradient can be ignored, and so the simple model of cooling can be used. This gives cooling rates of 0.78°C/m.y. and 2.25°C/m.y. for the slow and medium parts of the range respectively. In the case of the fast part of the range it would seem that an erosion rate of 400 metres/m.y. would produce only a small increase in gradient. However, as we are considering an exponential decrease in erosion rate, although the rate is only 400 metres/m.y. at the time in question, it has in fact been decreasing exponentially from 1.0 km/m.y. over about 20 m.y., and so it is assumed that this has increased the gradient by 25% at the depth being considered, i.e. from 30°C/km to 37.5°C/km. If the simple model of cooling is now used it gives a cooling rate of 15°C/m.y. Details of these calculations are summarised in Table 5.3.

TABLE 5.3

ESTIMATES OF POSSIBLE REASONABLE COOLING RATES

	SLOW	MEDIUM	FAST
gradient	20°C/km	25°C/km	30°C/km increased to 37.5°C/km due to diffusivity effect
erosion rate	39 metres/m.y.	90 metres/m.y.	400 metres/m.y.
cooling rate	0.78°C/m.y.	2.25°C/m.y.	15°C/m.y.

5.3. EFFECTS OF SLOW COOLING ON THE RADIOMETRIC RECORD

The effects on the radiometric record of slow cooling due to uplift and erosion are now generally well known, so the subject will be reviewed here fairly briefly. The main reason why the radiometric record is affected by slow cooling is that the various radiometric systems have different blocking temperatures, that is, different temperatures at which diffusion of the radiogenic daughter product becomes negligible compared to its rate of production. Thus radiometric systems with high blocking temperatures begin recording time earlier than those with lower blocking temperatures and with sufficiently slow cooling these time differences are sufficiently great to be detected experimentally. Some systems may have quite low blocking temperatures, and in many slowly cooled terrains it is thought that the ages obtained from these systems record a late stage of uplift and cooling, and are quite unrelated to any earlier higher temperature events such as metamorphism or intrusion.

This subject has been discussed by Moorbath (1967), who pointed out that blocking temperatures are not only controlled by the type of radiometric system but also by the grain size of the minerals concerned. He considered that the blocking temperatures for systems such as whole-rock Rb-Sr and zircon U-Pb were sufficiently high to give ages which may often approximate to the true time of crystallisation. The blocking temperatures for the various K-Ar mineral systems on the other hand were thought to vary from about $500^{\circ}C$ for amphiboles through 200 - $300^{\circ}C$ for muscovite and sanidine down to about 150 - $200^{\circ}C$ for biotite.

Macintyre et al. (1967) found that in the Madoc-Bancroft area of the Grenville Province biotite K-Ar ages were in general systematically lower than U-Pb and whole-rock Rb-Sr ages from the same area, typically by about 150 m.y. They considered that this was due to slow cooling, and that whereas the U-Pb and Rb-Sr ages recorded the major igneous and metamorphic events, the K-Ar ages probably recorded a relatively late stage in the subsequent cooling. These authors do point out however that the facts could also be explained by a later discrete heating event of sufficient intensity to reset the biotite K-Ar systems but not strong enough to reset the U-Pb and Rb-Sr systems. In a study of an Archaean terrain Green and Baadsgaard (1971) noted that due to slow cooling K-Ar ages from three different minerals were in a sequence which was in accord with their known relative argon retentivities. Hornblende ages were 2650 - 2500 m.y., coarse-grained muscovite ages were 2600 - 2450 m.y. and biotite ages were 2400 - 2350 m.y. The Grenville Province results could therefore be interpreted as indicating that it took about 150 m.y. for this terrain to cool from the highest to the lowest radiometric blocking temperatures. The Archaean results indicate even slower cooling, with very approximately 200 m.y. elapsing between the closure of the hornblende and biotite K-Ar systems. It is interesting to note that if Moorbath's estimates for the blocking temperatures of amphiboles and biotite are correct, these figures indicate a cooling rate of about $1.5^{o}C/m.y.$, i.e. between the slow and medium rates estimated in Table 5.3.

Radiometric studies in Phanerozoic orogenic belts also reveal slow cooling effects, but here the cooling rates appear to have been considerably faster. For example Armstrong et al. (1966) working in the Alps found that Rb-Sr ages for muscovite were consistently about 8 m.y. older than those for biotite. It is worth noting that this does not necessarily imply that erosion and cooling rates were inherently faster in the Tertiary than in the Precambrian. The apparent difference in cooling rates may be simply a reflection of the different structural levels presently exposed in these terrains. In the Tertiary belts the rocks now at the surface were probably originally moderately high-level and so passed through their radiometric blocking temperatures only a few tens of millions of years after orogenic uplift, when erosion and cooling rates were still high. In the Precambrian terrains on the other hand the rocks now exposed represent the very deepest structural levels, which probably did not pass through their blocking temperatures until a late stage in the erosion cycle, when erosion and cooling rates were low. If higher structural levels of these ancient terrains were preserved they might show similar cooling rates to those of Tertiary belts.

It is clear therefore that in slowly cooled terrains many radiometric systems record erosional cooling ages, i.e. the time at which the rocks passed through the isothermal surface corresponding to the critical blocking temperature for that system. It seems reasonable that in the post-orogenic environment in which major episodes of erosion normally occur the isotherms at all except the very shallowest depths would be essentially horizontal. Thus one would expect another slow cooling effect to be present in the radiometric record, namely that rocks from higher structural levels should give older ages than rocks from lower levels, as with gradual downward movement of the isotherms higher rocks will pass through the blocking temperature isotherms earlier than lower ones. For example, assuming an erosion rate of 100 metres/m.y. a difference in level of 2 km should represent a time difference of 20 m.y.

This aspect of the geochronology of slowly cooled terrains has not been discussed so fully as the effects of different blocking temperatures. The basic idea was implied in discussion by Harper (1964, 1967), and Krummenacher (1961) reported that K-Ar ages from different tectonic units in an area of the Himalayas varied systematically from 16.6 m.y. in "epizonal" units to 10.5 m.y. in "lower catazonal" units, and suggested that this was due to slow erosion. Harper (1967) noted that in the Grenville Province biotite K-Ar ages increased progressively towards the Grenville Front along the whole length of the Province, but did not indicate whether he thought that this was due to the various parts of the Province being originally at different structural levels (and subsequently gently tilted), or to the fact that uplift and erosion were diachronous.

Chapter 6

EFFECTS OF SLOW COOLING ON THE PALAEOMAGNETIC RECORD

6.1 INTRODUCTION

The approximate calculations of section 5.2 indicate that most originally deep-seated Precambrian terrains probably moved up towards the land surface at rates of between about 40 and 400 metres/m.y., and experienced cooling rates of between about 1 and $15^{\circ}C$/m.y. Because magnetic grains in rocks show a range of blocking temperatures (i.e. temperatures at which the magnetization becomes effectively fixed) and also because rocks can be sampled at various original structural levels, it is to be expected that the palaeomagnetic record of Precambrian terrains should show effects analogous to those described in section 5.3 for the radiometric record of these areas. This chapter describes the effects that slow cooling due to erosion should have on the palaeomagnetic record; some of these effects have been noted by earlier workers but others do not appear to have been discussed previously.

6.2 THE RANGE OF BLOCKING TEMPERATURES

Before the effects of slow cooling can be discussed in detail it is necessary to consider the range of blocking temperatures commonly shown by naturally occurring magnetic grains. Many recent studies (for example see review of literature in Butler and Banerjee, 1975) indicate that elongated single domain or pseudo single domain grains are the major carriers of stable remanence in igneous rocks. The theory of magnetic viscosity for uniaxial single domain grains (eg. McElhinny 1973) states that the magnetization of an assemblage of identical grains will decay exponentially to zero because of thermal fluctuations causing the magnetization of some grains to change spontaneously from their one possible position to the other. The magnetization will have decayed to 36.79% of its original value after a period referred to as the relaxation time, and this time is naturally related to temperature, being shorter at high temperatures than at lower ones. Upon cooling from a high temperature spontaneous magnetization appears at the Curie point, and because of the low relaxation times this magnetization quickly reaches equilibrium with the applied field. As the temperature continues to fall, however, it eventually reaches a point where the relaxation time of the grains begins to increase very rapidly. At this temperature, called the blocking temperature, the equilibrium magnetization becomes "frozen in" and subsequent changes in the ambient field at temperatures below the blocking temperature are unable to change the direction of magnetization. For an assemblage of identical grains there will be a single blocking temperature. However, because the relaxation time of grains is related to grain volume as well as to temperature, for an assemblage of grains of different sizes there will be a range of blocking temperatures. The larger grains (providing they are still within the single domain size range) have higher blocking temperatures, and the smaller grains have lower blocking temperatures. At the lower end of the size spectrum the grains are superparamagnetic, that is, the relaxation times are so short that even at room temperatures their magnetization is permanently in equilibrium with the ambient field.

The results of numerous thermal demagnetization studies on many different rock types indicate that the range of blocking temperatures can vary from a fairly narrow band just below the Curie point to a more or less continuous spectrum from the Curie point almost down to room temperature. In addition to the range of effective magnetization temperatures due to the spectrum of blocking temperatures, there is also of course the similar effect due to the fact that the Curie temperature of pure magnetite is 578°C while that of pure haematite is 680°C. In addition, the Curie points in both the magnetite-ulvospinel series and the haematite-ilmenite series vary according to composition, being maximum in the titanium-free end members and decreasing with increasing titanium content. Although thermal demagnetization curves are generally considered to indicate the spectrum of blocking temperatures present, it is not always clear how much the shape of the curves are determined by the depression of Curie point due to ionic substitution, and how much by the variation of the "true" blocking temperature.

The three effects described above, the difference in maximum Curie point in the two series of magnetic minerals, the variation in the degree of ionic substitution, and the variation in grain size, all combine to produce a possible range of temperatures at which the magnetization becomes effectively fixed of from 680°C down to room temperatures. However, we are here concerned only with grains which have sufficiently high blocking temperatures to retain their magnetization over very long periods of time, and so it is probable that the lower part of the blocking temperature range is not relevant to our present discussion. Using the standard theory of magnetic viscosity Chamalaun (1964) produced a set of curves showing the variation of relaxation time with temperature, and using these curves it is apparent for example that grains which in thermal demagnetization experiments have a blocking temperature of about 230°C, would at 0°C have a relaxation time of around 1 m.y. Thus in all except the youngest Tertiary rocks grains with blocking temperatures of that order and less will now have lost most of their original magnetization. The curves also indicate that grains which in thermal experiments have blocking temperatures of about 280°C would at 0°C have a relaxation time of 100 m.y., but that grains with the only slightly higher blocking temperature of 310°C would at 0°C have a relaxation time of over 1000 m.y. It thus appears that for rocks magnetized in the Precambrian grains with laboratory blocking temperatures of less than about 300°C will have lost virtually all of their original magnetization, whereas grains with blocking temperatures above 300°C will have retained virtually all of their magnetization. Thus in rocks from Precambrian terrains the maximum possible range of temperatures for the acquisition of stable remanence is 380°C, i.e. between 680° and 300°C.

6.3 LOWERING OF BLOCKING TEMPERATURES DUE TO SLOW COOLING

The blocking temperature is the temperature at which relaxation time becomes sufficiently long compared to the time-scale of cooling that the magnetization is no longer able to follow any changes in the applied field. Hence it is apparent that blocking temperatures are not fixed but depend on the rate of cooling. With fast cooling there is little time available for relaxation so blocking temperatures are high, but with slow cooling there is more time available and blocking temperatures are lower. It was for this reason that in section 6.2 when actual values of blocking temperatures were quoted they were referred to as laboratory or experimental blocking temperatures, because the same grains under naturally occurring slow cooling conditions would have much lower blocking temperatures. This point was noted by Stacey (1963) and more recently has been discussed by several workers in relation to the palaeomagnetizm of slowly cooled Precambrian terrains. For example Irving et al. (1974) states that according to the theory of magnetic viscosity the relaxation time τ_1 at temperature T_1 is related to the relaxation time τ_2 at temperature T_2 as follows

$$T_1 \ln C\tau_1 = T_2 \ln C\tau_2$$

where C is a frequency factor equal to about $10^{10}\ s^{-1}$. These authors appear to assume that if T_2 is the measured blocking temperature, τ_2 is the time at which the specimen was held at that temperature during thermal demagnetization (normally 3-5 minutes) and τ_1 is the duration of natural cooling then T_1 will be the temperature at which the magnetization was blocked during natural cooling. Using this method they calculate that laboratory blocking temperatures of 670° - 500°C would be reduced to 300° - 200°C by slow cooling over 1 m.y.

Ueno et al. (1975) carried out similar calculations except that (without explanation) they used a modified version of the above formula, namely

$$T_1 \ln (3C\tau_1) = T_2 \ln (3C\tau_2)$$

and they found that if τ_1 is made 100,000 years laboratory blocking temperatures of 640°, 620° and 570°C would be reduced to 240°, 230° and 200°C respectively. It is of interest to note that with the same value of τ_1 typical magnetite blocking temperatures of 500° and 400°C are reduced to 163° and 107°C respectively. These authors do point out however that these calculations ignore the possible changes of the anisotrophy constant with temperature, and so the results provide only a rough guide to the temperatures at which magnetization is acquired during slow cooling. Pullaiah et. al. (in press) reported in Irving and McGlynn (1975), have tentatively suggested that over cooling times of 1 m.y. the blocking temperatures are about 450°C for pure haematite, and about 380°C for pure magnetite. They also suggest however that if the grain size is less than the critical size for single domains, or if substantial amounts of titanium are present, then these temperatures may be further reduced to 300° and 200°C respectively.

Although accurate calculations for the reduction of blocking temperatures with slow cooling are not yet possible it seems from the early studies mentioned above that temperatures in the general region of 150° - 250°C are a reasonable assumption. With a geothermal gradient of about 20°C/km this implies that magnetization occurs when rocks are at a depth of between about 13 and 7 km. If Precambrian terrains now exposed at the surface were originally at a depth of say 20-25 km then their magnetization would not have occurred until about 10-15 km of overlying material had been removed, i.e. not until a fairly late stage in the erosion cycle.

6.4 EFFECTS ON THE PALAEOMAGNETIC RECORD

The effects of slow cooling due to erosion that should be preserved in the palaeomagnetic record are basically of two kinds, those due to the fact that magnetic grains have a range of blocking temperatures and so will have been magnetized at different times, and those due to the fact that rocks at different structural levels will have been magnetized at different times.

6.4.1 Effects due to the range of blocking temperatures

As discussed in section 6.2 the maximum possible variation of laboratory blocking temperatures for stable magnetization is probably between

680°C and about 300°C, i.e. a total range of 380°C. The calculations described in section 6.3 indicate that not only are blocking temperatures reduced by slow cooling, but that their range is also made smaller, so we may estimate that the 380°C range will be reduced by slow cooling to about 250°C. Assuming that the reasonable erosion rates of Table 5.3 are correct, this means that it could take between about 250 m.y. and 17 m.y. for rocks to cool through their maximum possible range of blocking temperatures. Even if the fastest possible estimate for cooling given in Table 5.2 is correct it would still take about 800,000 years to cool 250°C. There is thus the possibility that within the same area and at the same structural level grains with the highest blocking temperatures could have been magnetized up to 250 m.y. earlier than grains with the lowest blocking temperatures. The important point here of course is that if apparent polar wander (a.p.w.) was occurring over this time interval then grains with different blocking temperatures would acquire different magnetizations.

One result of slow cooling that does not appear to have been noted previously is that the effects of secular variation should be averaged out. It seems reasonable that even for rocks with a single narrow band of blocking temperatures, this band would probably be 30° - 40°C wide, so that with the possible cooling rates given in Table 5.3 the magnetization process would take between 2 m.y. and 40 m.y. The time for a complete cycle of secular variation is not known with certainty, but a period of about 10,000 years is commonly assumed (Creer 1962, Cox and Doell 1964). Even if this figure is an order of magnitude too small there would still be time for between 20 and 400 cycles of secular variation to occur during the magnetization process, quite adequate for the effects of this variation to be effectively averaged out. Thus one would expect that in a slowly cooled terrain between-site scatter due to secular variation would be negligible, and that the stable magnetization measured at each site would yield a pole corresponding to the ancient geographic pole, i.e. a true palaeomagnetic pole. This situation is in contrast to that for quickly cooled rocks, eg. lava flows and high level dykes, where the results from the individual sites represent spot readings of the ancient field and so yield virtual geomagnetic poles, and it is only when the mean of the site results is calculated that a palaeomagnetic pole is obtained. Even in the unlikely event of the fastest possible cooling rate of Table 5.2 having occurred it would still take 110,000 years to cool 35°C and this would presumably provide reasonable averaging out of secular variation.

There are clearly a variety of ways in which mineral grains with different blocking temperatures can be distributed in the rocks in a given area. For example it is conceivable that some rocks, if they contained both haematite and magnetite, might have a more or less continuous spectrum of blocking temperatures covering the maximum possible range. Other rocks containing both haematite and magnetite on the other hand might have a blocking temperature spectrum which consisted essentially of two peaks just below the Curie points for pure magnetite and haematite. Yet other rocks containing only one magnetic mineral might have either a single fairly narrow band of blocking temperatures or a wider spectrum, and the actual values would depend on whether the mineral present was magnetite or haematite.

Rocks with a wide and continuous spectrum of blocking temperatures should retain a continuous record of the a.p.w. that occurred during their magnetization period. Thus after sufficient demagnetization to remove all the recently acquired viscous components the ancient stable magnetization remaining should be the resultant of all the various components acquired during the magnetization period. If these rocks are now subjected to further demagnetization by a technique which progressively demagnetizes grains with successively higher blocking temperatures (eg. thermal demagnetization) then this should cause the magnetization to gradually move from its original mean direction to the one representing the highest blocking temperatures present. By means of vector subtraction it should be possible to calculate the direction of the magnetization removed at each demagnetizing step, and so determine the pole position corresponding to each temperature interval. If the blocking temperature spectrum is continuous then these poles should form a continuous trend defining the segment of the a.p.w. path corresponding to the magnetization period, with poles corresponding to the higher blocking temperatures at the older part of the segment and those corresponding to the lower blocking temperatures at the younger part of the segment.

If thermal demagnetization is carried out in say 10°C steps over the important range of temperatures then each pole obtained represents the magnetization acquired over approximately that cooling interval. Assuming the reasonable cooling rates of Table 5.3 each pole in the trend therefore represents the magnetization acquired over an interval of between 670,000 years and 10 m.y., and so each should be a palaeomagnetic pole corresponding to the geographic pole at that time. Therefore the trend of poles produced by this method should define a segment of the a.p.w. path unaffected by the influence of secular variation.

The calculations described at the beginning of this section indicate that with an effective blocking temperature range of 250°C magnetization periods of up to 250 m.y. are possible. Thus under very favourable circumstances it is possible that some rocks may contain the record of a 250 m.y. segment of the a.p.w. path. Moreover, even rocks containing only one fairly narrow band of blocking temperatures, say 30° - 40°C wide could, with a cooling rate of about 1°C/m.y., contain the record of a 30 - 40 m.y. segment. It therefore appears that whereas in a conventional palaeomagnetic study it is possible to represent the stable magnetization present at a site by a single pole, in slowly cooled rocks of this type it is necessary to represent the stable magnetization by a line segment. The possibility of results of this type being obtained from slowly cooled rocks does not appear to have been discussed previously.

Rocks having a blocking temperature spectrum with several discrete peaks should contain a discontinuous record of the a.p.w. that occurred during cooling. After demagnetization to remove the recently acquired viscous components the stable magnetization remaining should again be the resultant of the several components acquired during the original magnetization period. If for example there are two blocking temperature peaks, then further progressive thermal demagnetization should preferentially remove the component with the lower blocking temperature and so cause the magnetization to gradually move from its mean direction towards the one representing the higher blocking temperature component, and vector subtraction should reveal the direction of the component being removed. Thus, after vector subtractions have been carried out, rocks with a continuous spectrum of blocking temperatures should yield a continuous trend of poles, while rocks of the type described in this paragraph should yield discrete groups of poles, each group corresponding to a peak in the blocking temperature spectrum. It should be noted that in both cases progressive demagnetization would cause superficially similar movements of the magnetization, and it would generally only be after vector subtraction that the two alternative situations could be distinguished. If the individual blocking temperature peaks are in fact bands 30° - 40° wide, then of course progressive demagnetization through each band should produce a short trend of poles corresponding to that small segment of the a.p.w. path.

Several recent palaeomagnetic studies in the Canadian Shield have revealed rocks with two different stable magnetizations coexisting in the same specimen and apparently residing in grains with different blocking temperatures. Irving et al. (1974) found that one third of all the specimens they examined from the Morin complex contained two stable magnetizations with quite different directions. One magnetization resided in haematite grains with remanent coercivities of between 1000 and 3000 oe, and blocking temperatures of between 550° and 650°C, and the other resided in magnetite grains with remanent coercivities of between 100 and 1000 oe, and blocking temperatures of between 100° and 500°C. The Morin complex consists of anorthosites and leucogabbros regionally metamorphosed at high amphibolite to granulite facies, and these authors suggest that the high blocking temperature magnetization was acquired during cooling immediately following the metamorphism, and that the lower blocking temperature magnetization was acquired later during the last stages of regional uplift. They consider that the older magnetization might correspond to whole-rock Rb-Sr isochrons of about 1100 m.y., and the younger magnetization to K-Ar mineral ages of about 1000 m.y., and that the poles corresponding to these two magnetizations therefore define two points on the Grenville a.p.w. path.

Similar results have been reported by Ueno et. al. (1975) from the Whitestone anorthosite, also in the Grenville province. These workers found that at two sites some specimens have two coexisting stable magnetizations again with quite different directions. One magnetization required peak demagnetizing fields of 1250 - 2250 oe for its removal whereas the other was removed by demagnetizing fields of up to 1000 oe. The high coercivity magnetization had blocking temperatures of 600° - 650°C but the blocking temperatures of the lower coercivity magnetization were apparently not measured. These authors conclude that both magnetizations are thermoremanent magnetizations acquired during very slow cooling following amphibolite facies regional metamorphism and tentatively suggest that the high coercivity magnetization corresponds to U-Pb ages of 1100 - 1025 m.y. and that the lower coercivity magnetization corresponds to K-Ar and Rb-Sr mineral ages of about 1000 - 900 m.y. Both in this study and that on the Morin complex the coexisting magnetizations were separated by progressive demagnetization and vector subtraction as described above.

So far we have discussed situations where magnetizations with different blocking temperatures are present in the same specimen. There is of course also the situation where different rock types at different sampling sites will be characterised by different blocking temperatures, and so will have been magnetized at different times. In this situation poles from the various sites should form a trend corresponding to the appropriate segment of the a.p.w. path, sites with high blocking temperatures giving poles at the older part of the trend and sites with low blocking temperatures giving poles at the younger part. Whether the trend was continuous or discontinuous would of course depend on the blocking temperature spectrum for the sites concerned. In the study of the Whitestone anorthosite and diorite it was found that of the two coexisting magnetizations the one with the higher blocking temperatures was commonly found on its own without the other magnetization, and that at various other sites two other distinct magnetizations were also present. Thus this sampling area yielded no less than four different magnetizations, and three of these poles fitted on the Grenville a.p.w. path in a linear sequence which was in accord with their experimentally determined blocking temperatures.

Beckmann (1975) in a palaeomagnetic study of some Precambrian rocks in north-west Scotland, suggested that it was unlikely that their magnetization was due to slow cooling because if reversals of the earth's field had been occurring at the same rate as over the last few million years then the rocks would have been effectively demagnetized. This is a valid point because if one assumes the reasonable cooling rates of Table 5.3, a blocking temperature range of 50°C, and a reversal frequency of 5/m.y., then between about 17 and 250 reversals would occur during the magnetization period, and so the resultant remanent magnetization would consist of two approximately equal antiparallel components with essentially the same range of blocking temperatures.

However, the fact that ancient stable magnetizations have been obtained from slowly cooled terrains such as the Morin and Whitestone complexes, and also from many other metamorphic, and therefore presumably slowly cooled, terrains (eg. the review of Laurentian Proterozoic palaeomagnetic results by Irving and McGlynn, 1975) indicates that magnetization can be acquired during slow cooling. It therefore appears that while these rocks were being magnetized there was either a prolonged period of constant polarity, or a biassed reversal pattern such that one polarity was strongly and persistently dominant. Thus in a terrain which experienced slow cooling through the range of magnetization temperatures the rocks should either have no stable magnetization at all or should all be magnetized with the same polarity. It is of interest to note that the two different magnetizations found in the Morin complex were of opposite polarities, but that all the individual magnetizations of each type were of the same polarity. This indicates that one period of constant or biassed polarity was long enough to cover cooling through the higher band of blocking temperatures, but that either a reversal to the opposite constant polarity or a change of bias in the other direction occurred before the rocks cooled to the lower band of blocking temperatures. Similarly, in the Whitestone anorthosite and diorite, of the four magnetizations present the two with the highest coercivities were opposite in polarity to the two with the lowest coercivities, but within each of the two groups all magnetizations were of the same polarity.

One rather obvious feature to be expected in the palaeomagnetic record of originally deep-seated plutonic terrains is that apart from the effects of a.p.w. and blocking temperature variation discussed above, all rocks formed before final cooling, regardless of age, should have the same direction of magnetization. Thus rocks which appear from purely geological evidence, eg. cross-cutting relationships, to be of quite different ages, should on the evidence of palaeomagnetism, and probably also of radiometric dating, appear to be of the same age. The magnetization will be an "uplift and cooling" magnetization in the same way that many radiometric ages are "uplift and cooling" ages. In fact it is possible that in the palaeomagnetic record there will be apparently anomalous results analogous to those discussed by Moorbath (1967) in the radiometric record. Moorbath noted somewhat incredulously that there were still geochronologists who were perplexed when in metamorphic terrains country rocks gave younger ages than adjacent intrusions. He pointed out that this could be simply explained as being due to the fact that the country rocks happened to have lower radiometric blocking temperatures than the intrusions. An analogous situation could exist in the palaeomagnetic record because the time and therefore direction of magnetization of a given rock will depend on its blocking temperature characteristics and not on its time of formation, provided of course that this was earlier than the time at which the terrain cooled to the effective range of magnetic blocking temperatures.

6.4.2 Effects due to structural level

If all the rocks at any one structural level had the same single peak of blocking temperatures, then they would all pass through the critical range of blocking temperature isotherms at the same time, and so would all acquire the same direction of magnetization. Rocks at different structural levels, however, will clearly pass through their blocking temperature isotherms at different times, and so if a.p.w. was occurring during this time interval they would acquire different magnetizations. It is therefore to be expected that in a crustal segment which has experienced slow cooling due to gradual erosion, the poles from rocks at different structural levels should be arranged in a trend corresponding to that particular section of the a.p.w. path. Poles from sites at high structural levels should plot at the older part of the trend, and those from sites at lower structural levels should plot at the younger part of the trend. If all the rocks at all levels had the same blocking temperature peak there would be a direct relationship between the position of a pole in the trend of poles and the original structural level of the corresponding sampling site, and if erosion and a.p.w. had proceeded at a uniform rate throughout this period the relationship should be linear. Thus ideally a graph of pole position against structural level should yield a straight line. However it is unlikely that erosion and a.p.w. rates are uniform over considerable periods of time, or that different rocks will have the same blocking temperature characteristics. These effects, and particularly the latter, will tend to blur the relationship between pole position and structural level, the former causing the relationship to be non-linear, and the latter causing the line to be replaced by a band. As far as the present author is aware this effect of slow erosional cooling on the palaeomagnetic record has not been discussed previously.

With the reasonable erosion rates of Table 5.3 a difference in structural level of 2 km would correspond to a time difference of between 5 and 50 m.y. With the corresponding reasonable cooling rates a blocking temperature difference of 100°C would produce a difference in time of magnetization of between about 7 and 100 m.y., so it would appear that the two effects should be of approximately the same magnitude, i.e. the amount of displacement of poles along the trend of poles due to variation in structural level could be similar to that due to variation in blocking temperature.

It is noted that if a palaeomagnetic investigation of a slowly cooled terrain yields a trend of poles apparently related to original structural level, then the direction of this trend should of course be the same as the trend of poles obtained by progressive demagnetization of any rocks with a reasonably wide and continuous spectrum of blocking temperatures. If this was found to be the case it would provide strong evidence that the trend of poles so established was in fact defining a segment of the a.p.w. path.

6.5 SIMILAR EFFECTS DUE TO DIFFERENT CAUSES

It should be noted that some effects similar to those described above might be produced in ways other than as described, and some of these alternative mechanisms are discussed in this section.

It was assumed in the above discussion that all magnetizations present in plutonic terrains were thermoremanent magnetizations acquired during slow cooling from high temperatures, and therefore that when several magnetizations were present those with higher blocking temperatures were older than those with lower blocking temperatures. In some cases, however, it is possible that one or more of the magnetizations might be a chemical remanence, in which case blocking temperature characteristics would provide no clues to relative age. However, as pointed out by Irving et al. (1974) and Ueno et al. (1975) in their studies on the Morin and Whitestone complexes, the chemical equilibration of the iron minerals probably occurred at temperatures very much higher than the effective blocking temperatures (about 200° - 300°C) of these slowly cooled rocks, and the authors of both these studies concluded that the various magnetizations which they detected were probably thermoremanent and not chemical magnetizations. Thus although the possibility of chemical magnetizations cannot be ruled out it seems that in slowly cooled high-grade terrains they are unlikely to be important.

Another possibility is that where for example two magnetizations with different blocking temperatures are present, the magnetization with the lower blocking temperature may have been produced by a much later mild reheating event which was of sufficient intensity to remagnetize the low blocking temperature grains but insufficient to remagnetize grains with high blocking temperatures. This situation is similar to that produced by a single slow cooling episode in that in both cases the younger magnetization has the lower blocking temperatures. A mild reheating event could also conceivably produce a situation where the direction of magnetization and resulting pole position at a site was related to its structural level. The reheating pulse would presumably come from depth, and so it is possible that lower levels might be remagnetized while upper levels retained their original magnetization. There might even be a transition zone where remagnetization was partial so that poles from sites at different structural levels might form a continuous trend as in the case of the single erosion episode model. Again the resulting situation is similar to that produced by a single erosion and cooling episode in that rocks from lower structural levels will have younger magnetizations than those from higher levels.

Because the effects produced by a single erosion and cooling episode on the one hand and a much later mild reheating event on the other are so similar it may be very difficult to distinguish the two situations. However, even if the wrong interpretation is adopted the relative ages of the various magnetizations present will be correctly deduced, but if at any future time palaeomagnetic investigations of high-grade terrains are used in an attempt to quantify average erosion and cooling rates in the past then it would of course be essential to be able to distinguish these two situations. From the curves of Chamalaun (1964) it would appear that reheating to 150° - 200°C for a few million years would be sufficient to remagnetize most grains of magnetite or titanomagnetite, and it is worth noting that temperatures of this order might not produce any obvious petrological changes in the rocks concerned, although they might reset some of their K-Ar mineral clocks. It is also worth noting that assuming a geothermal gradient of 20°C/km it would only require burial to a depth of 7.5 - 10 km to produce these temperatures. Thus, if the original erosion episode had brought the rocks to within say 2 - 3 km of the surface (i.e. temperatures of 40° - 60°C), and so had effectively stabilised the magnetization of all the palaeomagnetically important grains, then subsequent burial of that segment of crust under about 5 - 7 km of material, for example in a temporary sedimentary basin, would be sufficient to cause considerable remagnetization.

Several instances of stable secondary magnetization similar to the type discussed above have been described. Thus Chamalaun and Creer (1964) found that in the Old Red Sandstone of the Anglo-Welsh Cuvette there was a primary magnetization residing in haematite grains, and a less stable secondary magnetization with Permo-Carboniferous directions residing in magnetite grains. Chamalaun (1964) concluded that subsequent deep burial raised the temperature of these sediments to about 200°C and that this was sufficient to remagnetize the magnetite but that the more stable haematite was not affected. Similarly, Irving and Opdyke (1965) working on the Silurian Bloomsburg red beds found a secondary Permian component of magnetization in addition to a more stable component believed to be of Silurian age, and they suggested that the secondary magnetization could have been either due to elevated temperatures caused by deep burial in a sedimentary pile, or possibly to a chemical effect causing an increase in grain size. Although in both examples just described the rocks were sediments whose primary magnetization was presumably acquired close to the surface, there appears to be no reason why similar partial (or even complete) remagnetization should not occur in plutonic rocks whose original magnetization was acquired at deeper levels.

Chapter 7

SLOW COOLING EFFECTS IN THE ITIVDLEQ PALAEOMAGNETIC RESULTS

7.1 INTRODUCTION

In this chapter several aspects of the Itivdleq palaeomagnetic results are discussed in terms of the slow cooling effects predicted in Chapter 6. Prior to the opening of the Atlantic Ocean in the Phanerozoic the Precambrian Shields of North America and Greenland, together with the Precambrian of north-west Scotland, formed a continent referred to as Laurentia. Most Precambrian palaeomagnetic results for Laurentia have been obtained from North America, particularly from the Canadian Shield, and all published a.p.w. paths for Laurentia have therefore been drawn relative to North America. Thus in order to compare the Itivdleq palaeomagnetic results with the appropriate segment of the Laurentian a.p.w. path, and with the several individual results of similar age from the Canadian Shield, it is necessary to correct the Itivdleq results for the drift of Greenland away from North America. This has been done according to the continental reconstruction of Bullard et al. (1965), and involved rotating all the Itivdleq poles clockwise by 18° about a pole at 70.5°N, 265.6°E (Wells and Verhoogen, 1967). In this and the following chapter all diagrams showing the Itivdleq poles have been corrected in this way.

7.2 THE SYSTEMATIC SOUTH-EASTERLY MOVEMENTS DURING DEMAGNETIZATION

It was noted in Chapter 4 that at eight sites progressive a.f. demagnetization at moderate and high fields caused the site mean pole to move systematically in a south-easterly direction. There was also some evidence that with progressive thermal demagnetization similar south-easterly movements occurred between 520° and 560°C. Because these south-easterly movements were so consistent in direction, and were generally at an angle of at least 45° to the southerly movements shown by all these sites at lower demagnetizing fields and temperatures, it seems very unlikely that they are recording simply the removal of viscous components acquired fairly recently along the general direction of the earth's field. It is therefore reasonable to assume that all the poles obtained during progressive demagnetization after the transition from southerly to south-easterly movement represent ancient stable magnetizations. It is also natural to enquire whether these south-easterly movements represent the gradual movement of magnetization predicted in section 6.4.1 for rocks which contain grains with a range of blocking temperatures and which have experienced very slow cooling.

The thermal demagnetization experiments described in section 4.5 indicate that in the 12 specimens satisfactorily investigated the remanence was carried by grains which have Curie points of less than 580°C and so are probably either magnetite or titanomagnetite. As the Curie point of pure magnetite is 578°C this probably represents the upper limit for the range of blocking temperatures in the Itivdleq rocks. The lower limit is more difficult to determine. The thermal demagnetization curves (Figures 4.25 and 4.29) indicate that for the specimens from dykes D3 and D13 about 95% of the remanence resided in grains with blocking temperatures above 500°C, and that about 90% resided in grains with blocking temperatures above 540°C, which would therefore appear to be effectively the lower blocking temperature limit for these rocks. In all other specimens whose thermal demagnetization curves were determined the main peak of blocking temperatures was also above 540°C, but there were also appreciable contributions from grains with lower blocking temperatures. The question to be asked however is whether these lower blocking temperature grains were carrying an ancient stable remanence, or whether they were carrying recently acquired viscous components and so are irrelevant to our present discussion.

The movement of the poles for specimens D2 - 6 and D2 - 8 with progressive thermal demagnetization are shown in Figure 4.26, and these show that the southward movement of the poles, presumably representing the removal of recently acquired viscous components, continued up to 540°C. Thus for these specimens it seems (very surprisingly) that grains with blocking temperatures up to 540°C can become magnetized by low-temperature viscous build-up along the earth's field, and so the lower blocking temperature limit for grains with stable ancient magnetization seems to be 540°C. The lower blocking temperature limit for the two specimens from dyke D4 is difficult to assess because of the unusual shape of their demagnetization curves. No thermal demagnetization curves are available for the 11 specimens (section 4.5.3), but the movement of the mean pole for these eleven specimens plus the six from dykes D2, D3 and D4 during progressive thermal demagnetization (Figure 4.28) indicates that on average the southerly movement of the poles did not end until 500° or 540°C. The four specimens from gneisses G14 and G18, which all had a spectrum of blocking temperatures down to at least 200°C, also showed generally southerly movements of their poles up to temperatures of 500° - 540°C. It would thus appear from these observations that the lower limit of blocking temperatures for grains retaining their ancient stable magnetization is between 500° and 540°C. Examination of the thermal demagnetization curves, however, reveals that in every instance grains with blocking temperatures below 540°C make only a minor contribution to the stable remanence.

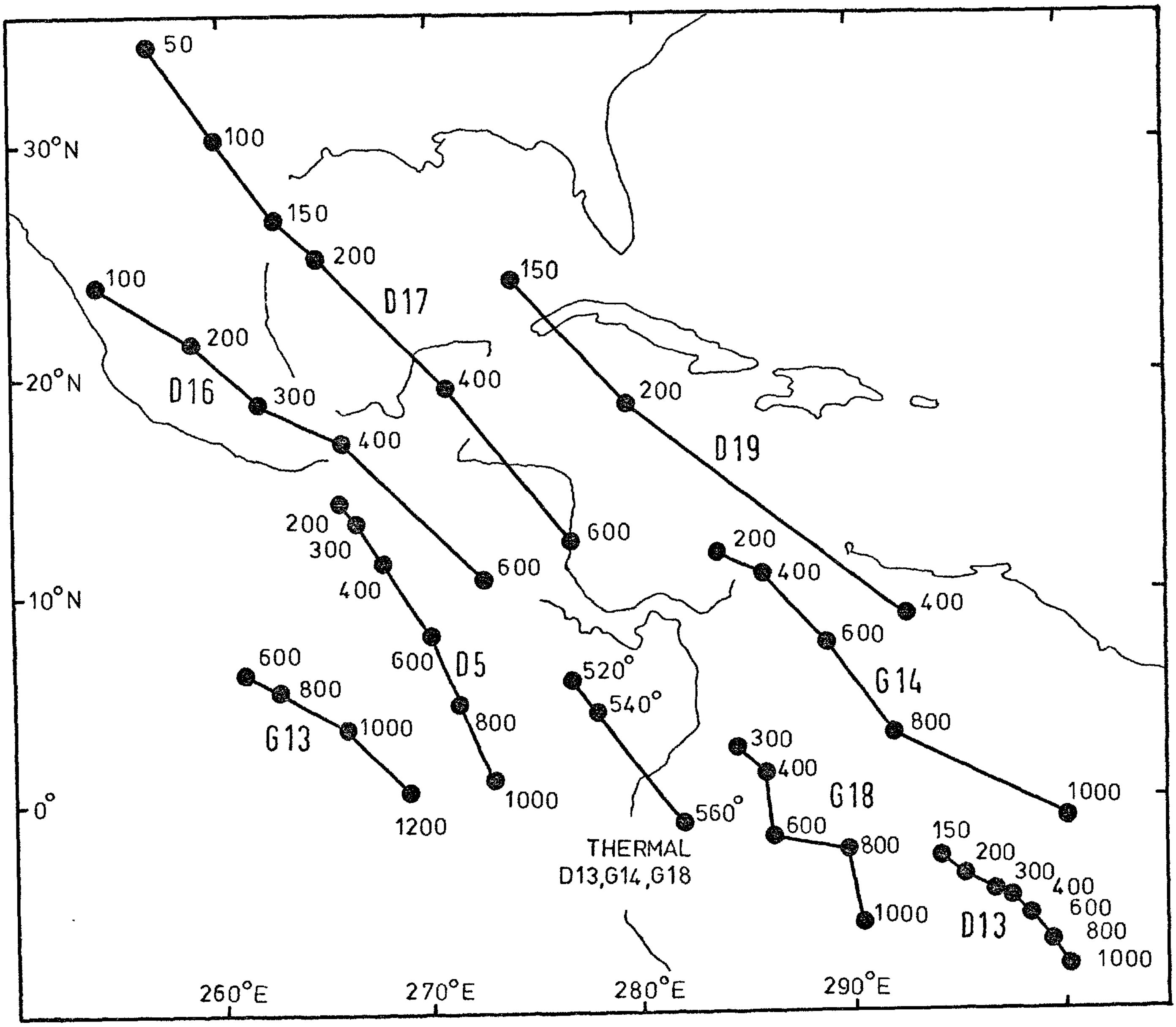
In summary it appears that in the Itivdleq rocks the grains carrying the ancient stable remanence generally have blocking temperatures of between 540° and 578°C, but that in some cases there are small contributions from grains with blocking temperatures extending down to 500°C. It might be noted that the 12 specimens on which these conclusions are largely based are from a fairly representative selection of the rock types encountered in this study; D2, D3 and D4 are typical unaltered dykes, D13 is a completely altered (garnet amphibolite) dyke, G14 is a leucocratic gneiss and G18 a mafic gneiss.

In section 4.5.5 it was pointed out that thermal demagnetization studies were carried out on six specimens from sites D13, G14 and G18 specifically because these sites had all shown systematic south-easterly movements during progressive a.f. demagnetization. It was found that during progressive thermal demagnetization on these six specimens a regular south-easterly movement of the mean pole occurred over the two steps between 520° and 560°C (Figure 4.28), and this was considered to be analogous to the systematic a.f. movements as it was in almost exactly the same direction. During a.f. demagnetization of sites D3 and D4 there was no evidence of south-easterly movements, at least up to 500 oe, but site D2 showed a single south-easterly movement between 400 and 500 oe. When six specimens from these sites were thermally demagnetized, however, five of them showed easterly movements at high temperatures. Thus in Figure 4.26 it can be seen that the two specimens from D2 both showed easterly movements between 540° and 560°C after having shown persistent southerly movements at all lower temperatures. Specimens D3 - 7 also showed an easterly movement between 540° and 560°C after having shown small random movements at all lower temperatures. Specimen D3 - 5 however appeared to show random movements throughout the temperature range. Of the two specimens from D4 (not illustrated) one showed a due easterly movement between 540° and 560°C, and the other an ESE movement. The mean pole for these six specimens during thermal demagnetization (not illustrated) showed a generally southward movement of about 14° between 100° and 520°C, but between 520° and 540°C there was an ESE movement of 2°, and between 540° and 560°C an easterly movement of 9°. The ESE and easterly movements of these specimens between 520° and 560°C may be comparable to the south-easterly movements of the D13, G14 and G18 specimens between 520° and 560°C. It should be noted that these south-easterly and easterly movements did not necessarily stop at 560°C, as the generally random directions of the movement between 560° and 580°C were due to the Curie point for magnetite having been exceeded. It is thus possible that these movements could have continued up to 578°C.

The movement of the mean pole for 17 specimens (including the six from D2, D3 and D4) during progressive thermal demagnetization is shown in Figure 4.28, and it can be seen that there was a small overall easterly movement between 500° and 560°C. However, it should be borne in mind that of these 17 specimens only 3 were from sites which showed systematic south-easterly movements during a.f. demagnetization.

These studies seem to indicate that during thermal demagnetization, particularly of specimens from sites showing systematic south-easterly movements during a.f. demagnetization, analogous movements occur between temperatures of typically 520° and probably 578°C, and that these movements are easterly to south-easterly. It should be noted that these movements occur over a temperature range which is essentially the same as the probable blocking temperature range for grains carrying the ancient stable magnetization in the Itivdleq rocks.

The systematic south-easterly movements of the eight site mean poles during progressive a.f. demagnetization are shown all together in Figure 7.1, and this diagram also shows the south-easterly movement of the mean pole for the six specimens from D13, G14 and G18 during thermal demagnetization. It can be seen that except for gneisses G14 and G18, which showed slightly irregular movements, for each individual site the direction of movement was remarkably similar at each demagnetizing step. Further, there was very little variation in the overall direction of movement from one site to another. Thus, excepting D5, all movements were between 122° (G13) and 142° (G18), a range of only 20°. The movement for D5 was slightly more southerly at 149°. The fact that the movements were persistently in the same direction over up to 5 or 6 demagnetizing steps is good evidence that we are dealing with an ancient magnetization, and that all recently acquired viscous components were completely removed in earlier demagnetizing steps. If any recent viscous components had persisted up to these field strengths it is likely that they would have been removed in decreasing amounts at successively higher fields, and so there would have been a very gradual swing from southerly to south-easterly movement, rather than the more or less linear south-easterly movement actually seen. In fact the more or less sharp transition from almost due southerly to south-easterly movement seen at many sites, for example D17, D16 and D5 in particular, indicates that there is little overlap in the coercivity spectra of the grains carrying the recently acquired viscous magnetization and those carrying the



SOUTH-EASTERLY MOVEMENTS

Systematic south-easterly movements of the mean pole at 8 sites during progressive a.f. demagnetization, and of the mean pole for six specimens (see section 4.4.5) during thermal demagnetization. All poles have been corrected for the drift of Greenland away from North America.

FIG. 7.1

ancient magnetization.

It will have been noted that most of the evidence for the south-easterly movements comes from the a.f. demagnetization studies, and it might reasonably be pointed out that progressive a.f. demagnetization demagnetizes grains with successively higher coercivities rather than successively higher blocking temperatures, so that the a.f. south-easterly movements might not be connected with the effects predicted in section 6.4.1. However, while this is obviously true, there is a connection between the coercivity of a grain and its blocking temperature, as can be seen from the formula for the relaxation time τ of a single domain grain (eg. McElhinny, 1973)

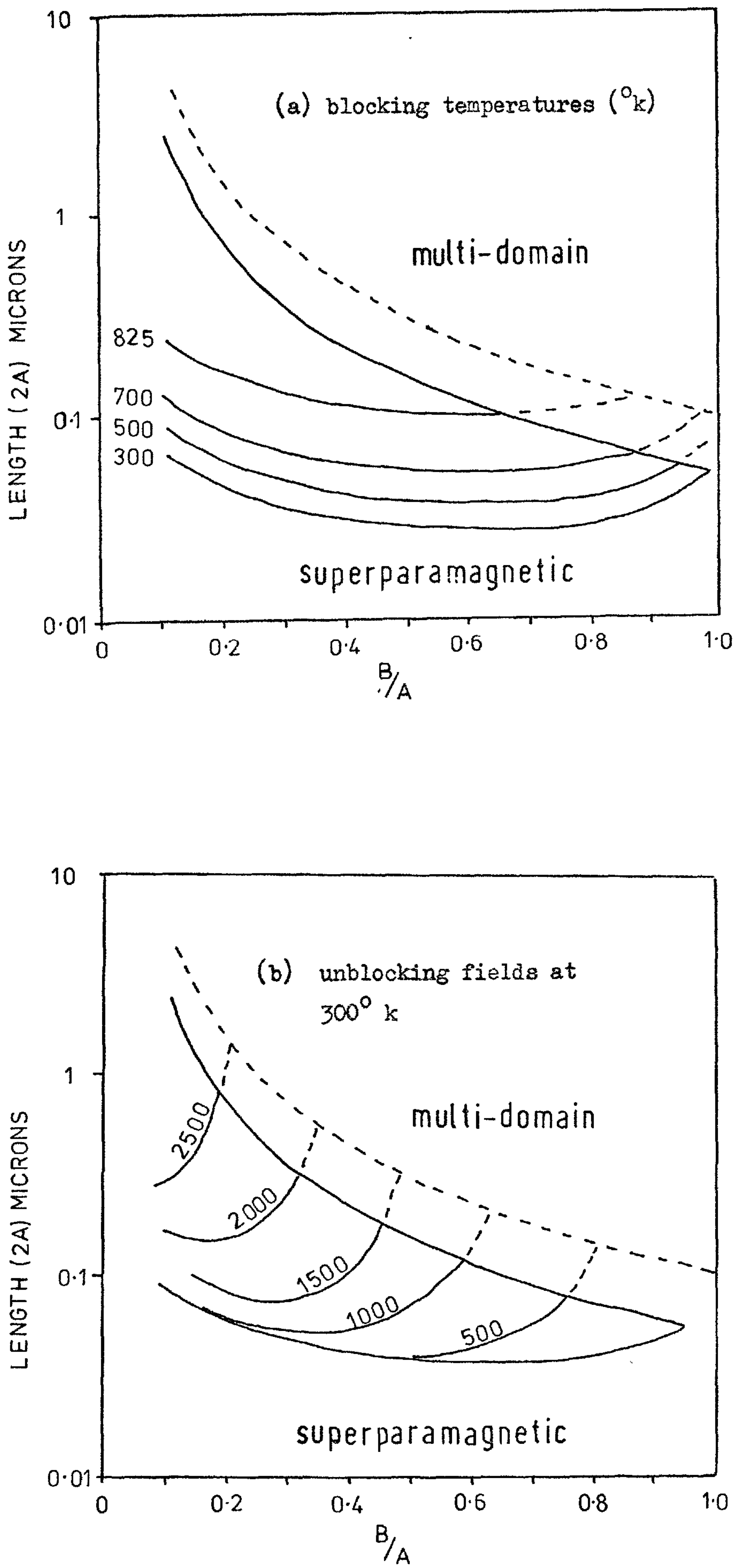
$$\tau = \frac{1}{C} \exp \left(\frac{v H_c J_s}{2k T} \right)$$

where C is a frequency factor equal to about $10^{10} s^{-1}$, v is the grain volume, J_s is the saturation magnetization, k is Boltzmann's constant, T is the absolute temperature, and H_c is the grain coercivity. Thus for all grains of a given volume, relaxation times and hence blocking temperatures are directly related to coercivity, which in turn is controlled largely but not entirely by grain shape, particularly the length to breadth ratio. However, the equation above indicates that relaxation time is also related to grain volume, and while the effective coercivity of grains is also related to grain volume (see below) the relationship is a different one. Thus for an assemblage of single domain grains of various sizes and axial ratios there will be a general relationship between the coercivity and blocking temperature of individual grains, but this relationship will not be perfect, i.e. there will be some higher coercivity grains with lower blocking temperatures and some lower coercivity grains with higher blocking temperatures.

Evans and McElhinny (1969) produced sets of curves showing the blocking temperatures for single domain prolate spheroids of magnetite with various lengths and axial ratios, and they also produced curves showing the "unblocking field" for similar grains. These sets of curves are reproduced as Figures 7.2

(a) and (b) respectively. It should be noted that there is a difference between the theoretical coercivity of a grain and the peak alternating field required to "unblock" it. The unblocking field is generally less than the theoretical coercivity (which is controlled mainly by the axial ratio) due to the effects of thermal agitation, and the reduction in effective coercivity is greater the smaller the grains. Thus in Figure 7.2 (b) the unblocking field curves, which if it were not for this thermal agitation effect would be straight vertical lines, are curving down and to the left, into partial parallelism with the blocking temperature curves. It may be that the practice of palaeomagnetism owes an unacknowledged debt to this effect, as without it there would be little relation between the effective coercivity of single domain grains and their blocking temperatures, and so a.f. demagnetization would be of very limited value because the main purpose of demagnetization is to preferentially demagnetize grains which are incapable of retaining their original magnetization over geological time periods, i.e. grains with low blocking temperatures. Due to this effect however the relationship between effective coercivity and blocking temperature is much closer, and so a.f. demagnetization is a much more useful tool.

The curves of Figure 7.2 (a) and (b) may also provide an explanation for one rather noticeable feature of the south-easterly movements, namely that whereas the movements occurred over a narrow range of high temperatures, typically between 520° and about 578°C, they occurred over a wide range of demagnetizing fields, often commencing at 50 - 200 oe and continuing up to at least 1000 oe. This may be because the unblocking field curves cut across the unblocking temperature curves, so that a given demagnetizing field can demagnetize grains with a very wide spectrum of blocking temperatures. Thus it is possible that quite low demagnetizing fields can demagnetize some of the grains with blocking temperatures above 520°C that are carrying the ancient remanence and are responsible for the south-easterly movements. Also because of the angle the unblocking field curves make with the blocking temperature curves, any given demagnetizing field will probably (depending on the distribution



BLOCKING TEMPERATURE AND UNBLOCKING FIELD CURVES FOR SINGLE-DOMAIN MAGNETITE OF VARIOUS LENGTHS AND AXIAL RATIOS

The upper dashed curve represents the possible error in determining the single/multi-domain boundary. From Evans and McElhinny (1969).

FIG. 7.2

of lengths and axial ratios of the grains actually present) demagnetize more grains with lower blocking temperatures than higher blocking temperatures. Thus it seems plausible that progressive a.f. demagnetization over a wide range of demagnetizing fields, and commencing at quite low fields, could progressively demagnetize grains with in general increasing blocking temperatures spread over a narrow range at high temperatures. In fact it may turn out in practice that systematic movements of this type are more easily investigated by means of a.f. demagnetization than by thermal demagnetization, as the former technique will allow the movements to be investigated over a wider range of demagnetizing steps and hence in greater detail.

Although the specimens from site D3 did not in general show systematic south-easterly movements, their demagnetization behaviour provided confirmation of some of the ideas suggested in the previous paragraph. In section 4.5.2 it was noted that the two specimens from D3 investigated at Newcastle showed at the same time a narrow range of blocking temperatures (almost entirely between 540° and 580°C) but a wide and continuous range of coercivities from 25 oe up to at least 1000 oe (see for example the thermal and a.f. demagnetization curves for D3 - 7 in Figure 4.25). These curves indicate quite clearly that it is possible for grains with a narrow range of high blocking temperatures to be progressively demagnetized over a very wide range of demagnetizing fields.

So far we have established that the grains carrying the ancient stable remanence in the Itivdleq rocks probably have a restricted range of blocking temperatures mainly between 540° and 578°C, and that the systematic south-easterly movements also occur over approximately the same range of blocking temperatures. Also although the clearest evidence for the south-easterly movements comes from a.f. demagnetization it is likely that the effect is caused essentially by the progressive demagnetization of grains with successively higher blocking temperatures. It thus appears possible that these south-easterly movements represent the movement of the magnetization from a younger direction residing in grains with lower blocking temperatures to an older direction residing in grains with higher blocking temperatures.

It is noted in passing that assuming the reasonable cooling rates of Table 5.3 a blocking temperature range of 40^{0} corresponds to a magnetization period of between 2.7 m.y. and 50 m.y.

During progressive demagnetization the magnetization and corresponding pole obtained at each demagnetizing step represents the vector sum of all the remaining magnetizations. Thus the south-easterly moving sequences of poles illustrated for example in Figure 7.1 give some indication of the direction of the movement, but not of its extent. To determine this it is necessary to calculate the direction of the magnetization actually removed at each step, which gives a true picture of the variation in magnetization directions and the corresponding poles. As discussed in section 6.4.1 these calculations should also indicate whether the movements are due to there being a continuous spectrum of blocking temperatures, in which case the continuous sequence of poles so obtained may correspond to a whole segment of the a.p.w. path, or whether there are several blocking temperature peaks, giving groups of poles corresponding to discrete parts of the a.p.w. path.

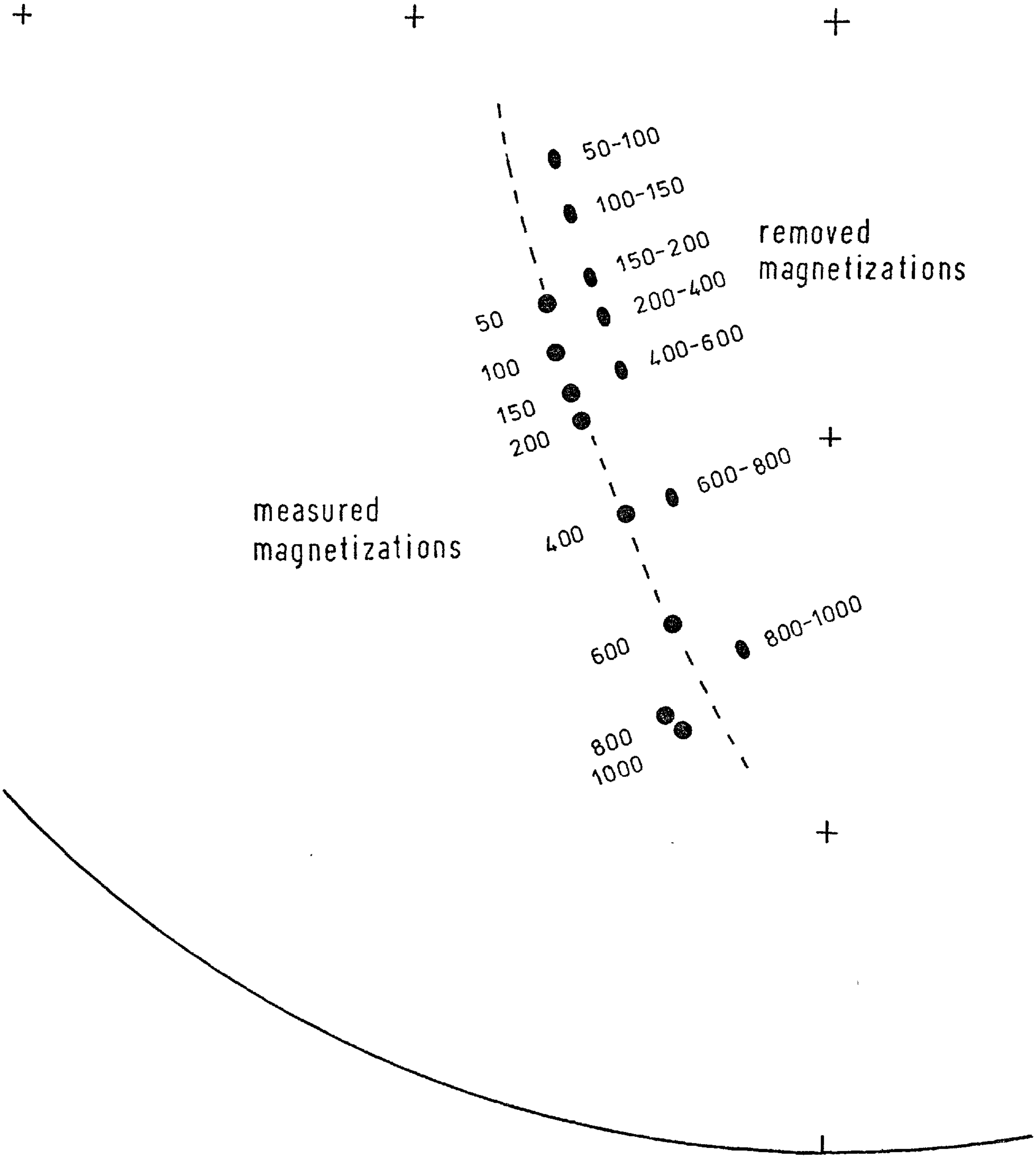
Calculations of the type described in the last paragraph were carried out on the results from four sites which showed good regular south-easterly movements during a.f. demagnetization. Because of the generally rather small angular movements between successive steps, and the slight irregularity of the movements of individual specimen magnetizations, it was decided to carry out these calculations using the more regular site mean results. The technique used can be described with reference to the calculations carried out on the results for site D17, which are illustrated in Figure 7.3.

In Figure 7.3 the mean direction of magnetization for D17 at each demagnetizing step over the range during which the systematic south-easterly movements occurred, that is, between 50 and 600 oe inclusive, are shown as circles. The magnetization direction for 800 and 1000 oe are also shown, even though they depart somewhat from the regular trend of movement shown by the earlier poles. This is because these two poles give the only slight evidence at any site of representing an end-point to the south-easterly movement.

However, because of the fairly large α_{95} associated with each of these two directions it is uncertain whether they represent a true end-point or simply the increasing effect of unstable random components. Therefore the results of calculations using these two final directions should be treated with some caution. In order to calculate the direction of the magnetization actually removed at each step each mean magnetization was vectorially subtracted from the next lowest mean magnetization, and these results are shown as ovals. Thus to establish the direction of the magnetization removed at the 100 oe step the 100 oe magnetization was vectorially subtracted from the 50 oe magnetization, and the result, labelled 50-100, represents the mean direction of magnetization of grains with effective coercivities of between 50 and 100 oe. Similarly, the oval labelled 100-150 represents the mean direction of magnetization with effective coercivities of between 100 and 150 oe, and was calculated by vectorially subtracting the 150 oe magnetization from the 100 oe magnetization, and so on.

Most of the mean directions actually measured at each site during the south-easterly movements fell approximately on great circles, and so in the calculations the best fitting great circle was drawn through these directions, and when each subtraction was performed it was assumed that each direction was actually located at the nearest point on this great circle. If this had not been done small lateral variations in the positions of the measured magnetizations, probably mainly produced by measuring errors, would often have produced large lateral variations in the positions of the removed magnetizations. This technique, which ensures that all removed magnetizations fall on the great circle, does not significantly alter the positions of the removed magnetizations along the great circle, which is the distribution of importance here, and it allows this distribution to be more easily assessed. Also, to improve the clarity of the diagram the great circle containing the results of the subtraction has been shifted slightly to the side of the great circle containing the measured directions.

Figure 7.3 indicates that the direction of magnetization removed at



MEASURED AND REMOVED MEAN DIRECTIONS OF MAGNETIZATION AT SITE D17 DURING PROGRESSIVE A.F. DEMAGNETIZATION

(See text for further details). Equal area projection.

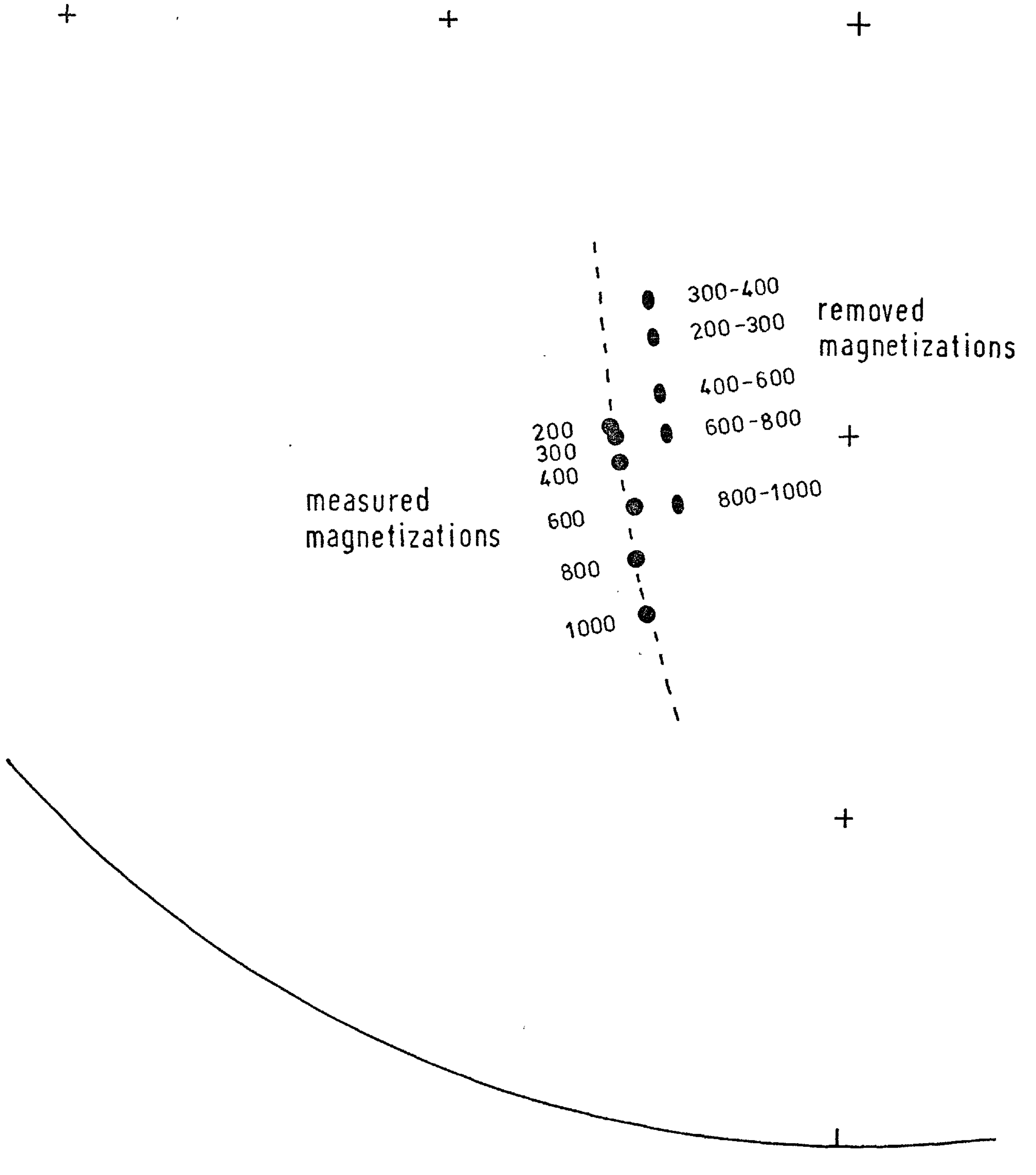
FIG. 7.3

each step in the demagnetization of D17 does in fact move progressively towards the south-east with increasing demagnetizing fields. It was already known from the demagnetization curves of a typical specimen from D17 (Figure 4.18 (b)) that there was a continuous spectrum of effective coercivities between 50 and 1000 oe, and the results in Figure 7.3 now indicate that grains with increasingly higher effective coercivities carry remanence directions successively further to the south-east. If there was a direct relationship between effective coercivity and blocking temperature this would then indicate that there was a continuous spectrum of blocking temperatures present, and that grains with successively higher blocking temperatures carried a remanence direction successively further to the south-east. However, because the relationship between effective coercivity and blocking temperature is only general, we cannot be absolutely certain about this latter point. It is possible for example that there are two sets of grains which have discrete blocking temperature peaks but overlapping effective coercivities. If these two sets of grains carried quite discrete directions of magnetization progressive a.f. demagnetization would yield results similar to those illustrated in Figure 7.3 and would indicate erroneously that there was a continuous spectrum of magnetization directions. Thus unfortunately it appears that because all the examples of regular and persistent south-easterly movements were obtained during a.f. demagnetization it is impossible to decide with certainty whether the movements are due to a continuous or a discontinuous spectrum of blocking temperatures and magnetization directions. It must be emphasised that these reservations do not affect the conclusion that progressive a.f. demagnetization in general demagnetizes grains with successively higher blocking temperatures, it is only the ability of the technique to distinguish between continuous and discontinuous distributions that is uncertain.

Calculations similar to those just described for D17 were carried out on the site mean direction for D5, D16 and G13, (Figures 7.4, 7.5 and 7.6). At site D16 it is again seen that the magnetization direction removed at each step moved progressively to the south-east with increasing demagnetizing fields. At D5 there was also a general south-easterly movement of the removed magnetization, but at this site the south-easterly movement was not perfectly regular as the 300 - 400 oe magnetization was north-west of the 200 - 300 oe magnetization. Whether the south-easterly movements of the removed magnetization at sites D16 and D5 was due to a continuous spectrum of magnetization directions or to two separate directions with overlapping coercivity spectra, again cannot be decided. However, whichever alternative is correct, the results of these calculations on D17, D16 and D5 indicate that at these sites the grains with the lowest effective coercivities carry a direction typically 8° - 10° further north-west than the measured direction at the beginning of the south-easterly movement. Hence the poles corresponding to these magnetizations would be 11° - 13° further north-west than the poles shown in Figure 7.1 as representing the beginning of the movement.

In the case of D17, for example, the pole representing the magnetization with effective coercivities of between 50 and 100 oe would be about 13° north-west of the 50 oe pole shown in Figure 7.2. Similarly, the lowest coercivity poles for stable magnetization at sites D16 and D5 would be about 11° and 12° respectively further north-west than the poles shown in Figure 7.1 as being the most north-westerly for these sites. The poles corresponding to the grains with the highest effective coercivities would only be established if there was a satisfactory end-point to the south-easterly movements. As discussed above, except possibly in the case of D17 there were no such end-points, and at many sites, eg. D5, D19 and G14, the south-easterly movement was still strong at the highest demagnetizing field at which it could be investigated. Thus all that can be said about the poles corresponding to the grains with the highest effective coercivities is that they are somewhere to the south-east of the most south-easterly pole for each site shown in Figure 7.1. In this connection it is unfortunate that the investigations carried out in the Geomagnetic Laboratory at Ottawa (section 4.6) did not yield more conclusive results.

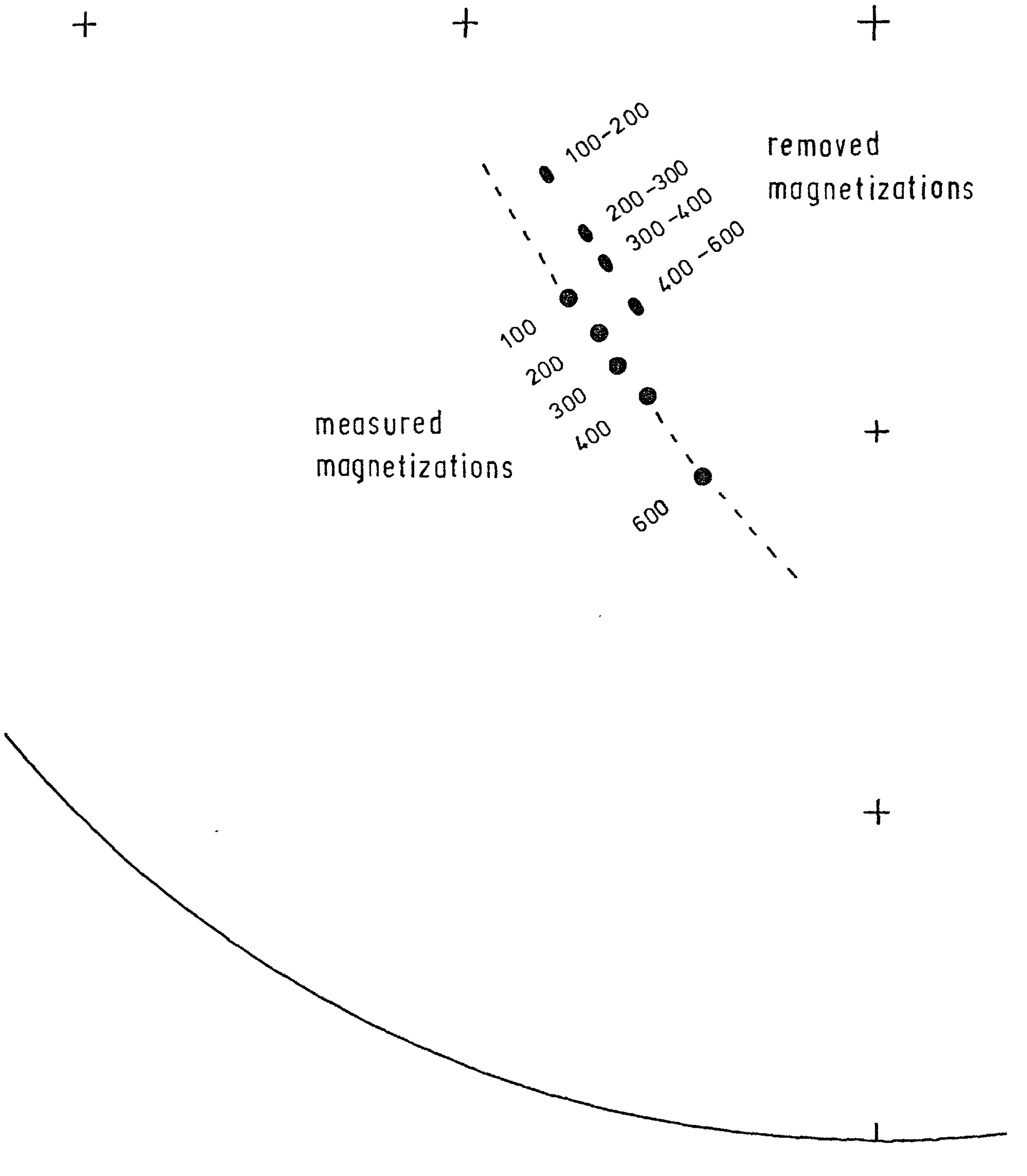
It was pointed out in section 4.3 (xxii) that site G13 was unique in



MEASURED AND REMOVED MEAN DIRECTIONS OF MAGNETIZATION AT SITE D5 DURING PROGRESSIVE A.F. DEMAGNETIZATION

(See text for further details). Equal area projection.

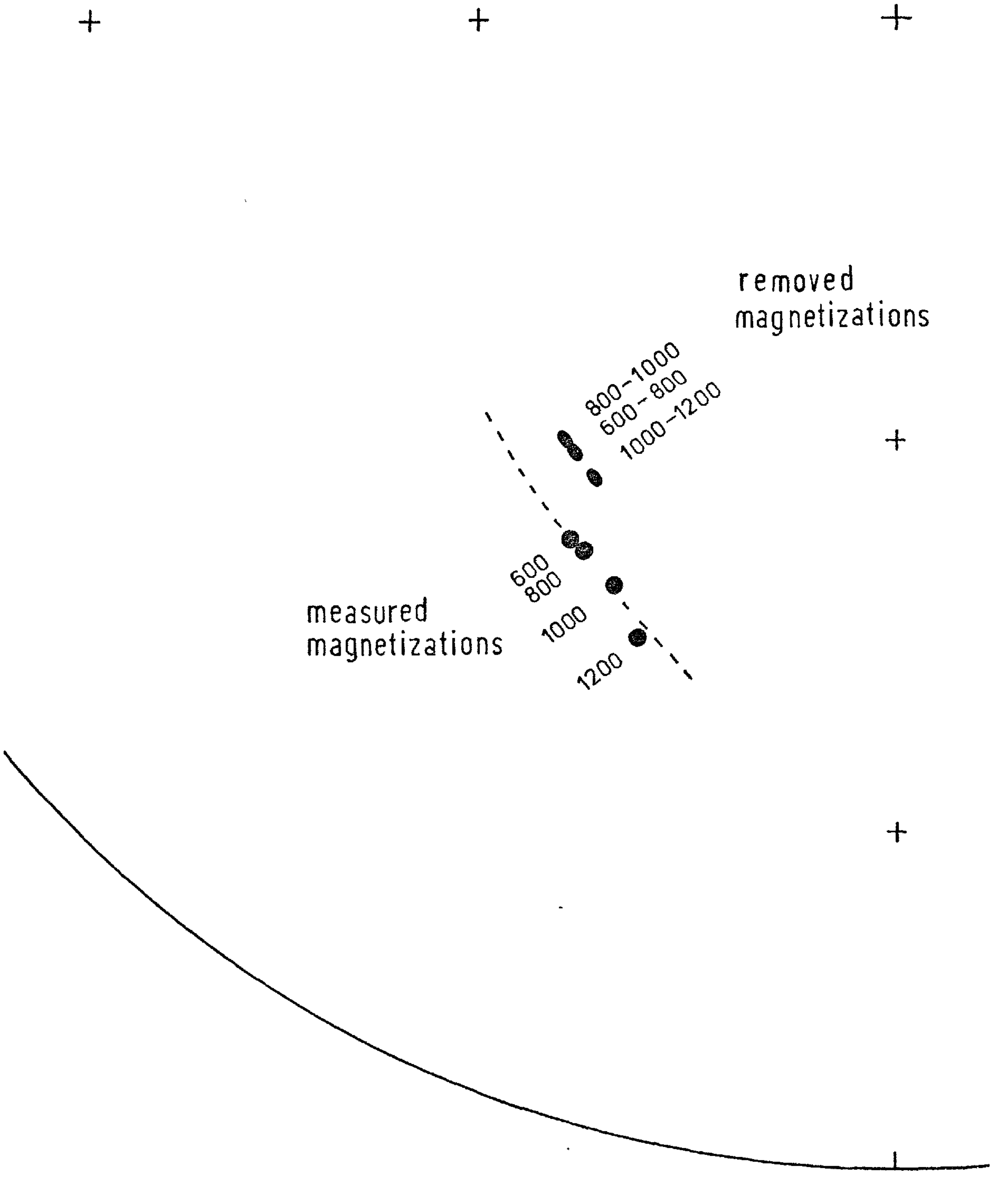
FIG. 7.4



MEASURED AND REMOVED MEAN DIRECTIONS OF MAGNETIZATION AT SITE D16 DURING PROGRESSIVE A.F. DEMAGNETIZATION

(See text for further details). Equal area projection.

FIG. 7.5



MEASURED AND REMOVED MEAN DIRECTIONS OF MAGNETIZATION AT SITE G13 DURING PROGRESSIVE A.F. DEMAGNETIZATION

(See text for further details). Equal area projection.

FIG. 7.6

that the south-easterly movement of the pole was preceded by a clear end-point to the southerly movement, this end-point consisting of 5 poles (100, 200, 300, 400 and 600 oe) all within 0.7° of their mean. The presence of such an end-point implies that successive demagnetizations are all removing magnetization with the same direction, indicating that there are grains with a range of effective coercivities but all with the same direction of magnetization. The results illustrated in Figure 7.6 indicate that between 600 and 1200 oe, when the measured magnetization moved gradually to the south-east, the magnetization actually removed at each step did not move similarly, but was centred in very approximately the same direction as the previously established end-point. It thus appears that at site G13 there are two distinct magnetizations present, one with a direction corresponding to the end-point and with effective coercivities between 100 and at least 1200 oe, and another with a direction somewhere to the south-east of the 1200 oe direction and with coercivities in excess of 1200 oe. Because the south-easterly movement had clearly not reached an end-point at 1200 oe it is obviously not possible to specify the direction and coercivity range of the second magnetization more precisely. It is noted that whereas the results of D17, D16 and D5 do not prove conclusively that there is a continuous spectrum of magnetization directions, it is very difficult to explain the G13 results other than as being due to the presence of two discrete directions of magnetization. It is unfortunate that thermal demagnetization curves are not available for G13 to establish the nature of its blocking temperature spectrum.

Apart from the case of G13 it is therefore difficult to decide whether the south-easterly movements are due to a continuous variation of magnetization direction or to two discrete directions. Because the evidence discussed above indicates that the stable remanence in all the rocks investigated thermally resides almost entirely in grains with a small range of blocking temperatures just below the Curie point, it might be considered that it is unlikely that there could be two blocking temperature peaks with discrete magnetization directions.

In this connection however it is appropriate to introduce a point that has not so far been discussed in this study. Dr. E. Irving (in private discussion) informed the present author that he and Dr. D. J. Dunlop were carrying out theoretical and experimental work concerned with the reduction of blocking temperatures during slow cooling. One point which was emerging from those investigations was that the reduction of blocking temperatures according to the simple viscosity equation discussed in section 6.3 probably did not apply to grains whose laboratory blocking temperatures were close to the Curie point, and that the effective blocking temperatures of these grains, even during slow cooling, would be similar to their laboratory blocking temperatures. The present author emphasises that Dr. Irving indicated that these investigations were in an early stage and that this conclusion was very tentative, and also that he was unable to specify a laboratory blocking temperature which corresponded to the transition between grains whose blocking temperatures would and would not be reduced by slow cooling. However, if this conclusion is correct, and if the transition is say 20°C below the Curie point, then it means that an assemblage of grains which in the laboratory have a 40°C range of blocking temperatures just below the Curie point, would, during slow cooling, have a much wider range of effective blocking temperatures. Also, if there was a fairly sharp transition between grains whose blocking temperatures were and were not reduced, then a small continuous spectrum of laboratory blocking temperatures would be transformed by slow cooling into a spectrum with two widely separated peaks, and so capable of acquiring quite different magnetizations.

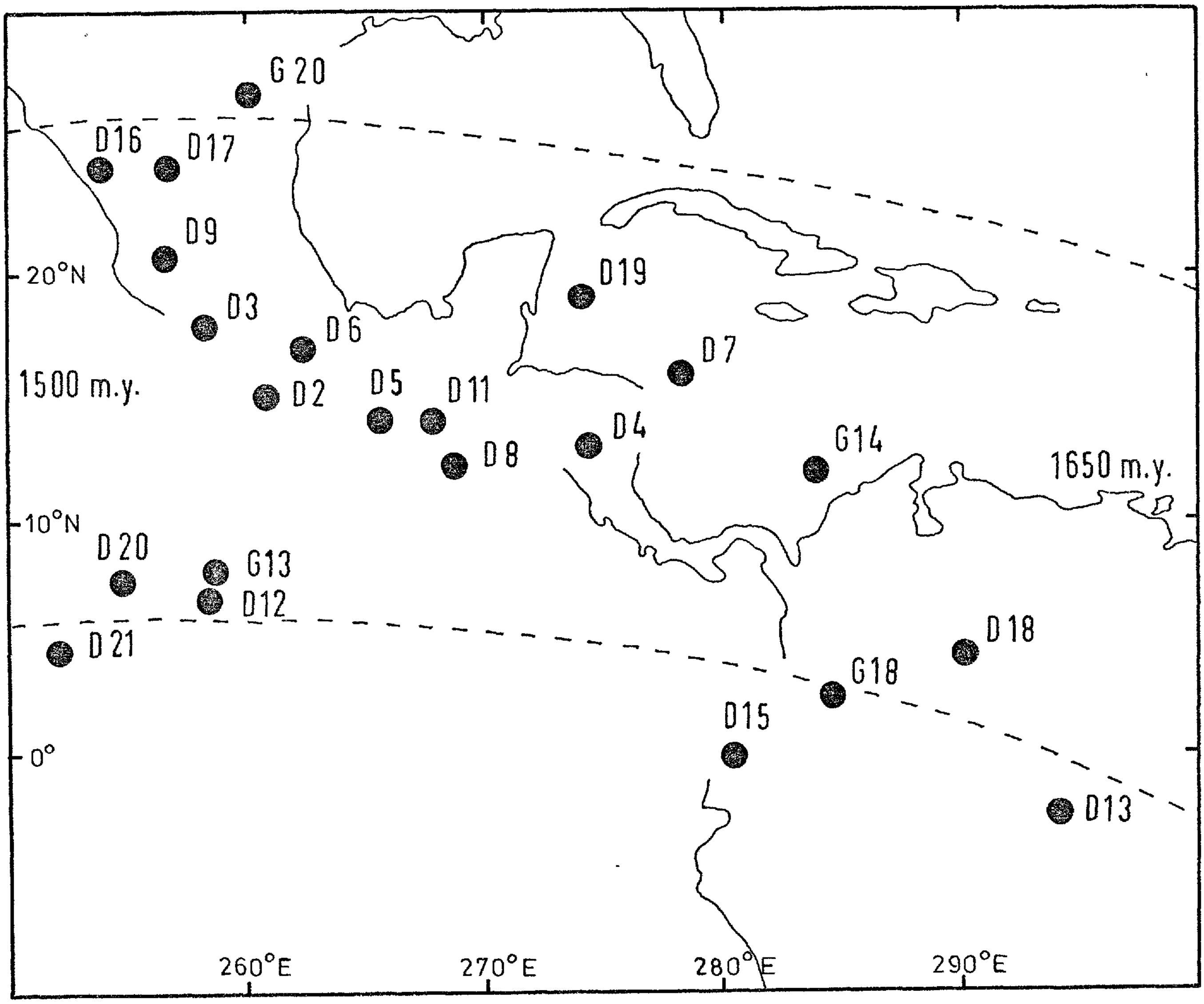
7.3 THE LINEAR TREND OF POLES

In section 4.4.1 it was noted that 18 of the 22 selected site mean poles were arranged in a linear trend aligned approximately north-west to south-east, and it is natural to consider whether this effect corresponds to that predicted in section 6.4.2, namely that in a slowly cooled terrain poles from rocks at different structural levels should be arranged in a trend corresponding to that particular section of the a.p.w. path.

At this point it is appropriate to consider briefly the way in which representative mean poles were selected for those sites which showed systematic south-easterly movements. As already discussed in section 4.2.3 the mean pole actually selected at these sites was the one at the very beginning of the south-easterly movement immediately after the transition from the southerly movement. From the discussion in section 7.2 it will now be appreciated that this pole corresponds to the resultant of all the stable magnetizations present, and so can best be described as representing the mean stable magnetization for the site. If the vector analyses described in section 7.2 had shown conclusively that there was a continuous spectrum of magnetization directions present then instead of a single pole a "polar line" representing all the removed magnetizations could have been given for each site. Alternatively, if the vector analyses had indicated two discrete magnetization directions then the two poles corresponding to these magnetizations could have been plotted.

The 22 selected site mean poles corrected for the drift of Greenland away from North America are shown in Figure 7.7. This diagram also shows (as a dotted band 20° wide) what is thought to be the appropriate segment of the latest version of the a.p.w. path for Laurentia (Irving and McGlynn, 1975). It is not suggested that this a.p.w. path is the definitive final version, but it is the latest synthesis of the available data by a leading group of Laurentian Precambrian palaeomagnetists and represents at the present point in time the most useful a.p.w. path with which the Itivdleq results can be compared. The segment of a.p.w. path shown in Figure 7.7 is dated by Irving and McGlynn as representing the period 1650-1500 m.y. These ages are, however, rather generalised and the question of the age of the Itivdleq magnetization is discussed in greater detail in Chapter 8.

From Figure 7.7 it can be seen that although the trend of the 18 site poles is not exactly parallel to the trend of the a.p.w. path, the angular difference is not very great, being about 25°. Further, of the 18 poles only 4 lie outside the a.p.w. path, and none of these by more than 4°, and the mean of the 18 poles is clearly very close to the centre of the a.p.w. path.



THE 22 SELECTED SITE MEAN POLES

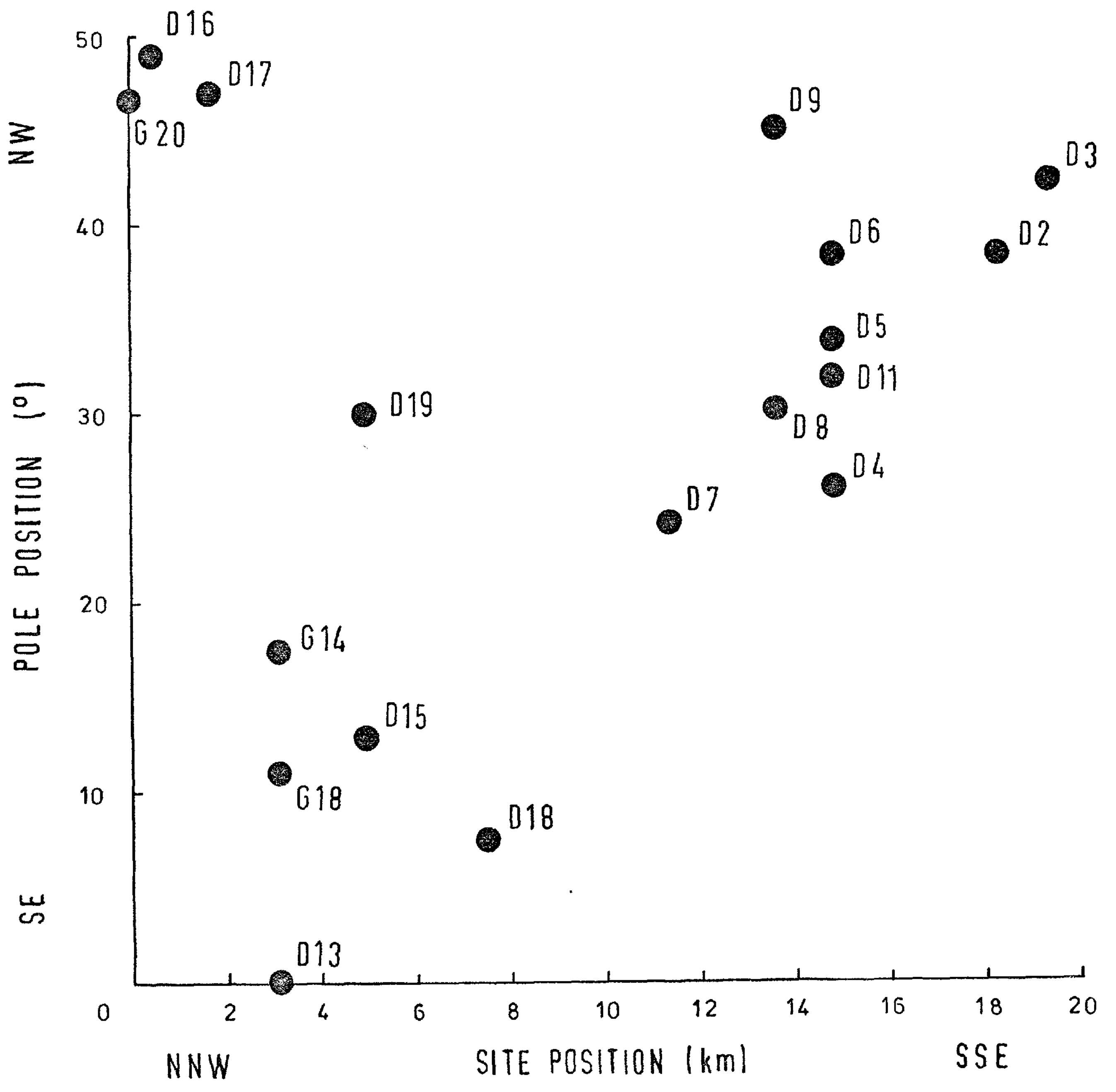
All poles have been corrected for the drift of Greenland away from North America. The dashed band is the appropriate portion of the latest a.p.w. path for Laurentia, taken from Irving and McGlynn, 1975.

FIG. 7.7

From the ages assigned to the a.p.w. path the poles at the south-east end of the trend are older than those at the north-west end. Therefore if the linear trend is caused by differences in structural level at the time of cooling then this implies that sites giving poles in the south-east part of the trend were originally higher than sites giving poles in the north-west part. However, because all transport in the sampling area was by boat, all sampling sites were within about 20 metres of sea-level, so if the trend of poles is due to differences in original structural level there must have been slight tilting of the area subsequent to magnetization so that the original horizontal surface is now gently inclined. It is noted that a tilt of 5°, which would be difficult to detect geologically in such a terrain, would be equivalent over a horizontal distance of 20 km to a change in original level of 1.8 km.

If tilting of the area occurred in a reasonably uniform manner then there should be a relationship between the position of a sampling site along the direction of tilting and the position of the corresponding pole in the trend of poles. Also, of course, sites which are close together should yield poles which are close together. However, as discussed in section 6.4.2 both these effects may be blurred if rocks from various sites have different mean blocking temperatures.

Examination of the 18 poles in the linear trend (Figure 7.7) in conjunction with the sampling area diagram (Figure 2.3) indicates that there is in fact a general relationship between site position and corresponding pole position. As judged by eye it appears that most sites in the NNW part of the area give poles in the south-east part of the trend, and most sites in the SSE part of the area give poles in the north-west part of the trend. In order to test this more accurately the relationship between pole position and site position was plotted diagramatically, and the results are shown in Figure 7.8. In this diagram the angular distance north-west along the linear trend to each pole from the D13 pole (the most south-easterly) is plotted as ordinate, and the distance SSE to each sampling site from an imaginary ENE trending line



THE RELATIONSHIP BETWEEN SAMPLING SITE POSITIONS AND CORRESPONDING POLE POSITIONS FOR THE 18 POLES IN THE LINEAR TREND

FIG. 7.8

through site G20 (the most northerly site) is plotted as abscissa. Apart from G20, D16 and D17 a reasonably convincing relationship between pole position and site position is revealed by Figure 7.8, and it is noted that the result which is least in accord with the relationship is D19, and this may be due to the fact that the D19 selected pole is the least accurately defined of all the site poles, with an α_{95} of 10.0°. These results thus imply that the SSE part of the area represents the lowest original structural level, and the NNW part the highest level, and that there has therefore been tilting of the area to the NNW.

The results for G20, D16 and D17 clearly do not conform to the general pattern. These three sites are the most northerly in the area, and so their poles should plot at the south-east and not the north-west end of the trend. However, a prominent east-west fault about 1 km south of site D17 separates these three sites from the remainder of the sampling area, and there is some geological evidence (D. Nash, personal communication) that the movement on this fault has been predominantly vertical. The apparent displacement of the poles from these three sites could therefore be accounted for by the area north of the fault having moved up with respect to the area to the south. If this is so it appears from Figure 7.8 that the amount of vertical movement on the fault may have been slightly greater than the difference in original level between sites D2 and D3 and sites D13, G14 and G18.

From Figure 7.8 it can also be seen that sampling sites close together do in fact generally give pole positions which are fairly close together. Thus sites D4, D5 and D6 were all located within about 400 metres of each other and their poles all plot within 12°; sites D13, G14 and G18 were all within 50 metres and their poles plot within 18°; and sites G20, D16 and D17 were all within 2 km and their poles plot within 7°. These figures compare with a total angular length along the trend of poles of about 49°.

If the linear trend of poles is due to apparent polar wander having occurred while the critical blocking temperature isotherms gradually moved down through the section of crust presently exposed in the sampling area, then the scatter of poles due to causes other than apparent polar wander is represented by the 12° width of the trend. This is equivalent to an angular standard deviation of about 4.5°, and is very much less than the values of 9° – 24° reported for the appropriate palaeolatitude in a study of palaeosecular variations by Brock (1971). This indicates either that magnetization was so slow that between-site scatter due to secular variation was effectively averaged out, as predicted in section 6.4.1, or that the magnetization was extremely fast. This latter alternative seems inconceivable on geological grounds and of course is untenable because it would not explain the linear trend.

At present no satisfactory explanation can be offered as to why the four poles D12, D20, D21 and G13 should fall outside the linear trend, or why they should form a reasonably close group.

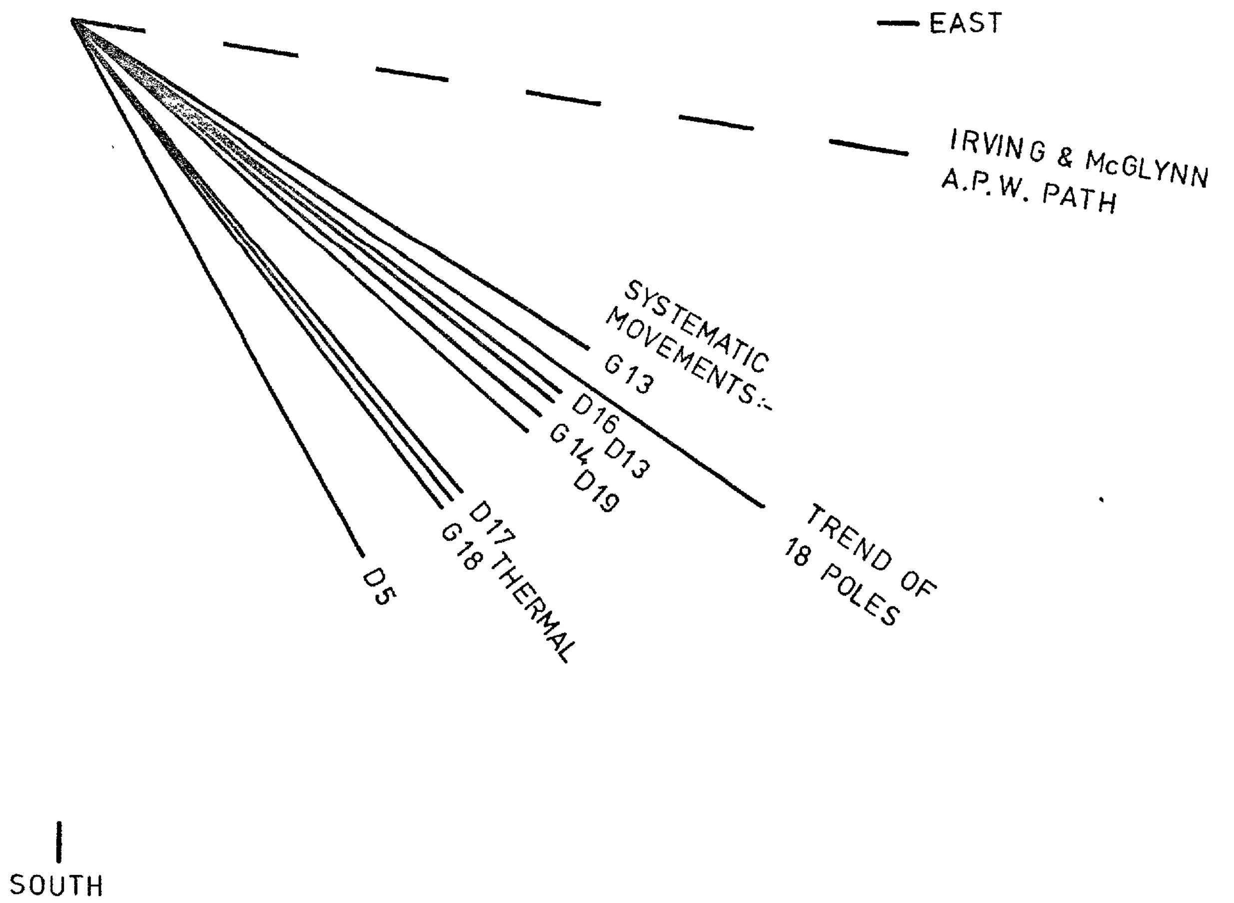
At this point it is worth noting that although slow cooling explains the low between-site scatter as described above, it does not explain the unusually low within-site scatter found at many sites. From Table 4.5 it can be seen that of the 22 sites 13 had a k of greater than 400, and 5 had a k of greater than 600. These k values are comparable to, if not slightly higher than, k values typically found in rapidly cooled rock units, for example the 79 late Tertiary and Quaternary Aleutian Island lava flows studied by Bingham and Stone (1972), or the 54 Hawaiian lava flows studied by Doell (1969). This is surprising because there are no reasons why within-site scatter in slowly cooled rocks should be less than in lava flows which cooled very rapidly, and in fact there are several reasons why it might be expected to be higher. Thus in slowly cooled rocks there should be an additional within-site scatter due to the fact that different specimens will inevitably have slightly different mean blocking temperatures and so their magnetization should be displaced along the trend of the a.p.w. path. Further, individual specimen magnetizations will only be on the a.p.w. path trend if secular variation has been completely averaged out, and so any inefficiency in this will also introduce a scatter not found in rapidly cooled rocks. The low within-site scatter of the Itivdleq rocks is presumably due to some unusually favourable characteristic of the magnetic mineralogy allowing some grains to retain their original magnetization virtually unaltered, while at the same time recently acquired viscous components can be very efficiently removed from less stable grains by demagnetization.

Finally, the two remaining slow-cooling effects predicted in section 6.4.1 can be discussed, namely that all rocks formed before uplift and cooling should have essentially the same magnetization, and that all specimens should be magnetized with the same polarity. The Itivdleq palaeomagnetic results clearly show the first effect, as the poles for dykes and gneisses plot in exactly the same area with means that are not significantly different. It appears from Figure 7.8 that the main factor determining the direction of magnetization in both dykes and gneisses is simply the geographical position of the sampling site, and that when dyke and gneiss sampling sites are located close together their poles are also close together. The Itivdleq results also show the second effect, as of the 201 specimens investigated, with the sole exception of G10 - 4 all were magnetized with the same polarity. As explained in section 4.3 (xxi) G10 - 4 was the only specimen encountered in this study with a.f. demagnetization characteristics indicative of haematite, and this haematite magnetization was directed approximately 120° away from the magnetizations found in all other specimens.

7.4 SUMMARY

From the preceding discussion it appears that the Itivdleq palaeomagnetic results show many if not all of the slow cooling effects predicted in Chapter 6. The fact that the linear trend of 18 poles is reasonably close to the trend of the appropriate segment of the latest a.p.w. path, and that there is quite a good relationship between pole position and corresponding site position, indicates that the trend of poles probably represents a segment of the a.p.w. path, although it would of course be reassuring to have some geological confirmation of the postulated tilting and fault movements. The regularity and similarity of direction of the nine south-easterly movements illustrated in Figure 7.1 indicates that they are probably recording the movement of the magnetization from a younger position residing in grains with lower blocking temperatures to an older position residing in grains with higher blocking temperatures, and it is noted that the direction of the movements are very similar to the trend of the 18 poles. From the results of the vector analyses on the south-easterly movements it was not possible to determine whether they were due to a continuous spectrum of magnetization directions or to two discrete directions. Thus it cannot be stated with certainty whether the movements are revealing a continuous segment of the a.p.w. path, or simply connecting two separate points on it. However, the fact that the movements are so similar in direction to the linear trend of the 18 poles implies that even if the latter alternative is correct the two points are probably on this linear portion of the a.p.w. path and so a line between them would correspond to the a.p.w. path anyway.

The direction of the nine south-easterly movements shown in Figure 7.1 are illustrated diagramatically in Figure 7.9. This diagram also shows the trend of the 18 poles, judged to be the direction of a line joining poles D17 and D13 in Figure 7.7, and it also shows the trend, judged by eye, of the appropriate segment of the latest published a.p.w. path, also shown in Figure 7.7. The direction of the south-easterly movements varied between 122^{o} for G13 and 151^{o} for D5, and the linear trend of 18 poles comes towards the northern end of this range at 125^{o}. During the discussion of the south-easterly movements in section 4.2.2 it was noted that at site D5 there was a range of about 45^{o} in the direction of the south-easterly movements of individual specimens, from just north of south-easterly to almost southerly. At all other sites showing regular south-easterly movements the range of specimen movements was rather less than this. As the overall movement of D5 was further south than for any other site it may be that at this site, and probably to a lesser extent at some other sites, an element of some of the specimen movements was due to the removal of northerly directed recently acquired viscous components. Although,



DIAGRAMATIC REPRESENTATION OF THE DIRECTIONS OF THE SYSTEMATIC MOVEMENTS AND THE TREND OF THE 18 POLES

FIG. 7.9

as noted in section 7.2 the regularity of the site mean movements argues against this, it is possible that some specimens from these sites may show persistent southerly movements up to high fields as did many specimens from sites such as D12 and D18. If this is so it is possible that the more northerly of the south-easterly movements, such as those for G13 and D16, represent the true direction of the movement most accurately, and it may be significant that the trend of the 18 poles is virtually identical to the movement at these two sites.

Thus the palaeomagnetic results discussed in this study appear to define a segment of the Laurentian a.p.w. path probably corresponding approximately to the linear trend of 18 poles shown in Figure 7.7, and which is older to the south-east and younger to the north-west. As the a.p.w. path of Irving and McGlynn (1975) attempts to incorporate a large amount of data and is therefore somewhat generalised, it is possible that the a.p.w. path segment revealed by this study is a more accurate representation of this small region of the a.p.w. path than the corresponding region of the Irving and McGlynn path. If results of the type described here prove to be common in other high-grade plutonic terrains they will not only provide unusually accurate and detailed information about apparent polar wander, but could also be a useful tool for investigating movements, such as tilting and faulting, which have occurred subsequent to magnetization, and which often cannot easily be studied by other means.

Chapter 8

THE AGE OF MAGNETIZATION AND COMPARISON WITH OTHER LAURENTIAN RESULTS OF SIMILAR AGE

8.1 INTRODUCTION

One of the central problems in many palaeomagnetic investigations is the determination of the time at which the magnetization was acquired. The difficulty is probably minimal in studies on surface lava flows and high-level intrusions which have never been deeply buried, as here the original rapid cooling of these rocks will have caused the various radiometric systems and the various magnetic grains to pass through their blocking temperatures at effectively the same time. Hence in radiometric studies on rocks of this type concordant ages should be obtained from systems with different blocking temperatures, and these ages should correspond to the time at which the rocks were formed. Similarly, palaeomagnetic investigations on these rocks should indicate, provided there have been no later chemical changes, that all the stably magnetized grains, regardless of blocking temperature, have the same magnetization, and it would be reasonable to assume that this was a primary thermoremanence and therefore accurately dated by the radiometric ages.

For rocks that were either formed at moderate or deep levels, or have at any time suffered appreciable burial, the position is more complex. As already discussed these rocks will almost certainly have experienced very slow cooling, and there will therefore have been appreciable differences between the times that radiometric systems with different blocking temperatures were set, and also between the times that magnetic grains with different blocking temperatures had their magnetizations stabilized. This in itself would not be a problem if it was known that particular radiometric systems had blocking temperatures which corresponded with the blocking temperatures of particular magnetic grains. However at present this is not the case, mainly because radiometric blocking temperatures are as yet only imprecisely defined.

Further, although magnetic blocking temperatures can be quite accurately defined in laboratory experiments, in plutonic rocks there is the added uncertainty of the amount by which these blocking temperatures were reduced during slow cooling. In rapidly cooled rocks this uncertainty in the correlation of radiometric and magnetic blocking temperatures is unimportant, but in very slowly cooled rocks it can potentially introduce large errors into the dating of the magnetization. Thus, with a cooling rate of 1°C/m.y., if the blocking temperature of the radiometric system used is 100°C higher or lower than the blocking temperature of the magnetic grains present, then the ages indicated by the radiometric study will be 100 m.y. older or younger than the age of magnetization.

Another and potentially more serious problem is the possibility that the uplift and erosion was episodic. If the blocking temperatures for the radiometric system being utilized was say 100°C higher than the blocking temperatures of the magnetic grains present, and the first episode of erosion brought the rocks in question down to a temperature midway between the two blocking temperatures, then the radiometric system would begin recording time but the magnetization would still be able to follow changes in the ambient field, and would not be stabilized until the next episode of erosion brought the temperature down below the magnetic blocking temperatures. The discrepancy between the radiometric and magnetic ages would then be the delay between the two erosion episodes, which could conceivably be of the order of hundreds of millions of years. There is of course also the possibility that if radiometric and magnetic blocking temperatures are sufficiently different then a later reheating event after initial cooling might reset either the radiometric or the magnetic system, depending on which had the lower blocking temperature, but leave the other system unaffected, again producing a possibly large discrepancy between the age of magnetization and the radiometric ages. It is worth noting that a reheating event which raised the temperature of the rocks to say 200 - 300°C would probably not produce any mineralogical changes which would be obvious in a normal petrological investigation of the material.

The difficulties in dating the magnetization in plutonic rocks discussed above are of course in addition to any uncertainties in the analytical precision of the radiometric method used, and also to any problems inherent in the method such as for example the presence of inherited argon or of subsequent argon loss in the case of the K-Ar method. For Precambrian rocks the problems are of course very acute as in general the older the rocks the greater the absolute time represented by the analytical uncertainty.

Thus for all Precambrian rocks which were originally formed at moderate or deep crustal levels, or have subsequently been buried to at least moderate depths, there are likely to be considerable uncertainties in the true age of magnetization even when thorough radiometric studies yielding consistent results have been undertaken. When radiometric studies have yielded ambivalent results, or when the rocks investigated palaeomagnetically have not themselves been the subject of a radiometric study but have been dated by "bracketing" between other dated rock units, the uncertainty in the age of the magnetization is obviously correspondingly larger. Therefore when considering possible reconstructions of Precambrian a.p.w. paths it should be borne in mind that the majority of Precambrian rocks studied palaeomagnetically have probably been at least moderately deeply buried at some stage of their history, and that with an average a.p.w. rate of about 0.25°/m.y. (eg. McElhinny, 1973) an error in dating the magnetization of 200 m.y. could correspond to an angular error of up to 50°.

8.2 AGE OF THE ITIVDLEQ MAGNETIZATIONS

Preliminary U-Pb dating of recrystallised zircons in the Nagssugtoqidian belt by R. Chessex (quoted in Allaart et al., 1975) gave ages ranging from 2600 to 2200 m.y., suggesting that the main phase of Nagssugtoqidian deformation and metamorphism probably occurred at the beginning of the Proterozoic. K-Ar mineral ages on rocks from various localities in the Nagssugtoqidian belt, however, have yielded ages of between 1790 and 1650 m.y. (Larsen and Moller, 1968) and presumably date the final uplift and cooling of the presently exposed crustal levels to the K-Ar mineral blocking temperatures.

All the sampling sites for the radiometric results described in the last paragraph were at least 170 km north of Itivdleq, so it is possible that the results are not relevant to the palaeomagnetic sampling area of this study. However, some of the samples collected by Dr. G. E. J. Beckmann and the author from the sampling area of this study, and also from the island of Sagdlerssuaq some 17 km to the north, have been dated by Dr. J. G. Mitchell at Newcastle University (Beckmann and Mitchell, 1976). The samples, which included both dykes and gneisses in the Itivdleq area but gneisses only from Sagdlerssuaq, were dated using the K-Ar method. In the case of the gneisses analysis of whole-rock, mafic mineral fraction and feldspathic mineral fraction allowed the construction of isochron plots (radiogenic argon versus potassium) so permitting the effects of inherited ^{40}Ar to be assessed and accounted for. For the dykes whole-rock ages only were obtained.

The Sagdlerssuaq gneisses yielded five isochron ages varying between 1580 and 1660 m.y., i.e. very slightly younger than the K-Ar mineral ages from further north in the Nagssugtoqidian belt. The radiometric results from the Itivdleq region fell into two groups depending on whether the sampling site was north or south of Itivdleq fjord (see Figure 2.3). Rocks from north of the fjord gave ages of typically around 1800 m.y. Thus leucocratic gneiss G18 gave an isochron age of 1830 ± 20 m.y., and mafic gneiss pods G14 from the same site gave an isochron age of 1700 ± 40 m.y., while two specimens from dyke D14 gave whole-rock ages of 1800 ± 20 m.y. and 1720 ± 20 m.y. and a specimen from dyke D17 gave a whole-rock age of 1890 ± 20 m.y.

The radiometric results from sites south of the fjord were less consistent. Two whole-rock and five mineral fraction analyses of material from site G10/11 gave an isochron age of 2410 ± 40 m.y., while four whole-rock ages from dykes D3, D4 and D6 (2 samples) were 3160 ± 40, 2305 ± 30, 2010 ± 20 and 1840 ± 20 m.y. respectively. Beckmann and Mitchell therefore suggest that the presently exposed crustal level at Sagdlerssuaq cooled to K-Ar blocking temperatures at about 1620 m.y., and that the Itivdleq area north of the fjord cooled to these temperatures at very approximately 1750 m.y. On the basis of the isochron age from site G10/11 they tentatively suggest that the section of crust south of the fjord probably cooled at about 2410 m.y., but they note that the four whole-rock dyke ages from this area are difficult to interpret.

This radiometric evidence that the area north of Itivdleq fjord cooled some 700 m.y. later than the area south of the fjord is of course not consistent with the palaeomagnetic evidence, which indicates that rocks from all over the sampling area have had a similar cooling history, and were probably all magnetized during the same slow cooling episode. It would be difficult to explain the linear trend of poles from sites stretching right across the sampling area, together with the apparent relationship between site position and corresponding pole position, and also the fact that the systematic south-easterly movements were found at sites from all parts of the area, if there had been such a long interval between the cooling of the areas south and north of Itivdleq fjord.

There appear to be several possible explanations for the apparent inconsistency between the radiometric and palaeomagnetic results from the Itivdleq area. It is possible that the K-Ar and magnetic blocking temperatures are sufficiently different for them to record different stages of uplift and cooling. Thus if the K-Ar blocking temperatures are appreciably higher than the effective magnetic blocking temperatures then it could be that at about 2410 m.y. the area south of the fjord was uplifted and cooled to below the K-Ar blocking temperatures but above the magnetic blocking temperatures, while the area north of the fjord was not similarly uplifted and remained above the K-Ar blocking temperatures. Then at about 1750 m.y. the area north of the fjord was uplifted and cooled to K-Ar blocking temperatures, and then either immediately or some time later both areas were uplifted and cooled together through the effective range of magnetic blocking temperatures.

If K-Ar blocking temperatures are appreciably less than the effective magnetic blocking temperatures then it could be that at some time prior to

2410 m.y. the whole area was uplifted and cooled to below the magnetic blocking temperatures, but above the K-Ar blocking temperatures. Then at about 2410 m.y. the area south of the fjord was uplifted and cooled through the K-Ar blocking temperatures, while the area north of the fjord remained above these temperatures. Then at about 1750 m.y. the area north of the fjord was uplifted and cooled through the K-Ar blocking temperatures, and the amount of uplift was such that the segments of crust north and south of the fjord were returned to their original relative positions so that there was magnetic continuity across the fjord.

The third possibility is that the radiometric results from south of the fjord are anomalous and do not reflect the true cooling age of this segment of the crust. It is noted that the age of 2410 m.y. is based on material from a single site only, and that the whole-rock ages from dykes in this area show a very wide range which cannot be interpreted. On the other hand the isochron age of 2410 m.y. is based on seven points which appear to lie reasonably close to a straight line, and also because it is an isochron the higher than expected age cannot be ascribed to the presence of inherited argon.

Of these three alternatives the second appears to be the least attractive as it requires the fairly implausible occurrence of two episodes of differential movement which just happen to return the two segments of crust to their original relative positions. Also, this alternative would imply that the magnetization was acquired some time prior to 2410 m.y., whereas the first and third alternatives imply magnetization at approximately 1650 - 1850 m.y. As will be shown in section 8.3 the Itivdleq mean pole plots close to many poles dated at about 1750 m.y. from various parts of North America. Although there do not appear to be any North American poles dated at around 2400 m.y., of the ten North American poles noted by Piper (1976) for the approximate period 2690 - 2500 m.y., nine form a reasonably coherent group about 55° south of the Itivdleq pole, and only one (Cobalt Group Sediments, dated at < 2650 m.y.) falls in the same area as the Itivdleq pole. It is noted however that the Itivdleq pole falls on the suggested common North

American, African and Australian early Proterozoic a.p.w. path of Piper (op. cit.) at a point just earlier than about 2400 m.y., which would be consistent with alternative two discussed above. It is concluded that on balance the evidence favours the magnetization of the Itivdleq rocks having occurred at about 1650 - 1850 m.y.

8.3 COMPARISON WITH OTHER LAURENTIAN POLES OF SIMILAR AGE

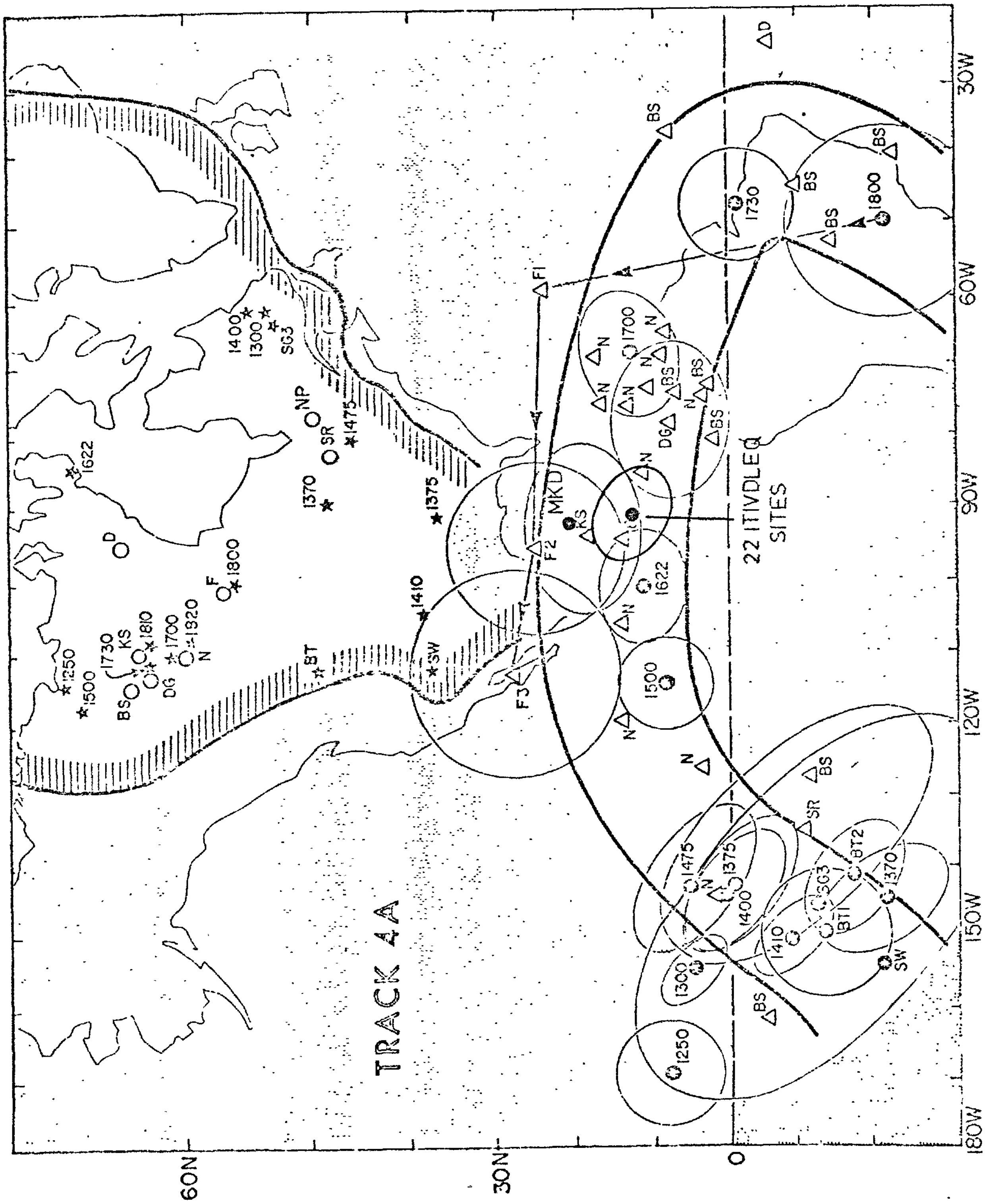
Proterozoic palaeomagnetic results from Laurentia have recently been reviewed by Irving and McGlynn (1976), and this review has been used extensively by the present author in preparing this section.

Figures 8.1 to 8.3 are taken from the Irving and McGlynn paper, with some additions by the present author, and they show Laurentian poles for the interval between about 1300 m.y. and 2200 m.y., together with the a.p.w. path for this period suggested by Irving and McGlynn as being most consistent with the present data. Figure 8.1 shows the poles and suggested a.p.w. path for the interval from about 1300 m.y. to about 1800 m.y., and to the original diagram the author has added the mean pole and oval of confidence for the 22 Itivdleq sites (12.6°N, 268.6°E after correcting for the drift of Greenland away from North America as described in Chapter 7) and also the recently published pole for the metamorphosed Kaminak dykes (see below) which did not appear in the Irving and McGlynn paper. Figure 8.2 shows poles for the interval from about 1730 m.y. to about 1850 m.y. together with an obviously extremely tentative a.p.w. path for this time interval. To this diagram the author has again added the mean pole and oval for the 22 Itivdleq sites and the pole for the metamorphosed Kaminak dykes, and also the recently published pole for the Molson dykes (see below). Figure 8.3 shows poles and suggested a.p.w. path for the interval from about 1850 m.y. to about 2200 m.y., and to this diagram the author has added the mean pole and oval for the 22 Itivdleq sites and also the poles for the metamorphosed Kaminak and Molson dykes. Figure 8.4 is also taken from Irving and McGlynn and shows their suggested complete a.p.w. path for Laurentia for the interval about 600 m.y. to about 2200 m.y. with assigned ages in m.y., and to this diagram the author has added the mean pole and oval for the 22 Itivdleq sites and also a band 50° long and 12° wide corresponding to the linear trend of the 18 Itivdleq poles.

In Figures 8.1 to 8.3 the original poles are referenced by numbers which represent the assigned age in m.y., and the poles for the metamorphosed Kaminak dykes and Molson dykes added by the author are referenced MKD and MD respectively. Poles from "overprints" are indicated by triangles and referenced by letters. As far as the present study is concerned the poles of particular interest are those dated between 1500 m.y. and 2000 m.y., and brief details of these poles are given below in Table 8.1. In this table the first figure is the age assigned in the Irving and McGlynn paper together with their estimate of its accuracy. This is followed by the name of the rock unit and a reference to the original publication. The quoted ages for the metamorphosed Kaminak and the Molson dykes is discussed in the next paragraph. At the end of the table brief details of possibly relevant overprints are given.

The age of the magnetization of the metamorphosed Kaminak dykes is stated by the authors to be approximately 1800 m.y. and from their discussion it is evident that there is considerable uncertainty about this. K-Ar whole-rock ages on these dykes vary from 1615 to 1892 m.y. and this spread is attributed to variable argon loss. The Molson dykes give K-Ar whole-rock ages of typically 1300 - 1700 m.y., with one dyke giving an age of about 2380 m.y., but apparently biotites in most rocks in the area of the sampled dykes record a thermal event between 1800 and 2200 m.y. The 1300 - 1700 m.y. spread of dyke ages is ascribed to variation in argon loss, and it is suggested that the 2380 m.y. age may be due to excess argon. The authors tentatively conclude that the age of the Molson dyke magnetization is probably in the range 1800 - 2000 m.y., and from the author's discussion reported above this is clearly subject to considerable uncertainty.

From the discussion of the ages of magnetization of the Kaminak and Molson dykes in the last paragraph, and from the suggested accuracies of the

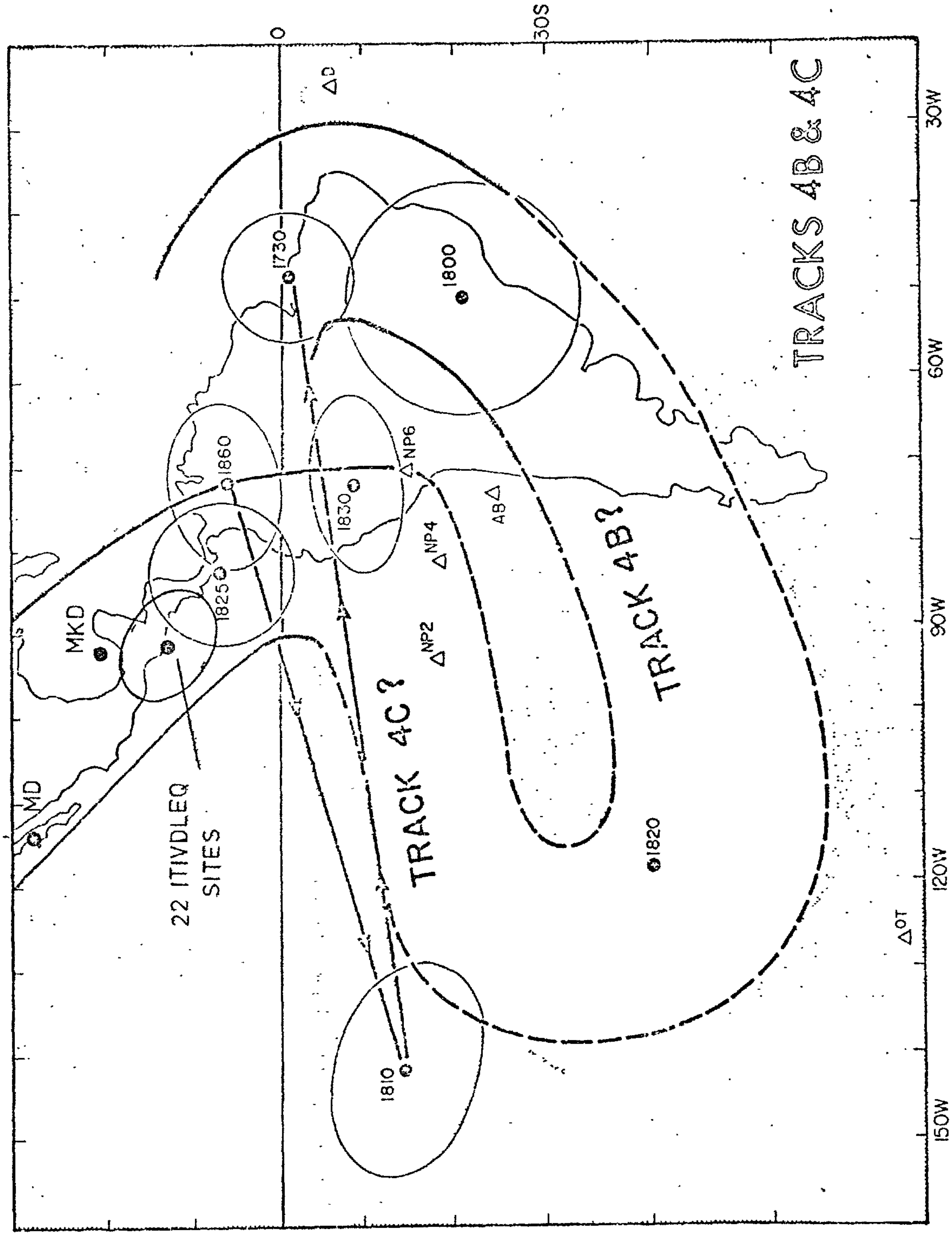


LAURENTIAN POLES AND SUGGESTED A.P.W. PATH FOR PERIOD APPROXIMATELY

1300–1800 M.Y.

From Irving and McGlynn (1976). The pole and oval for the 22 Itivdleq sites and the pole for the metamorphosed Kaminak dykes are also shown. See text for further details.

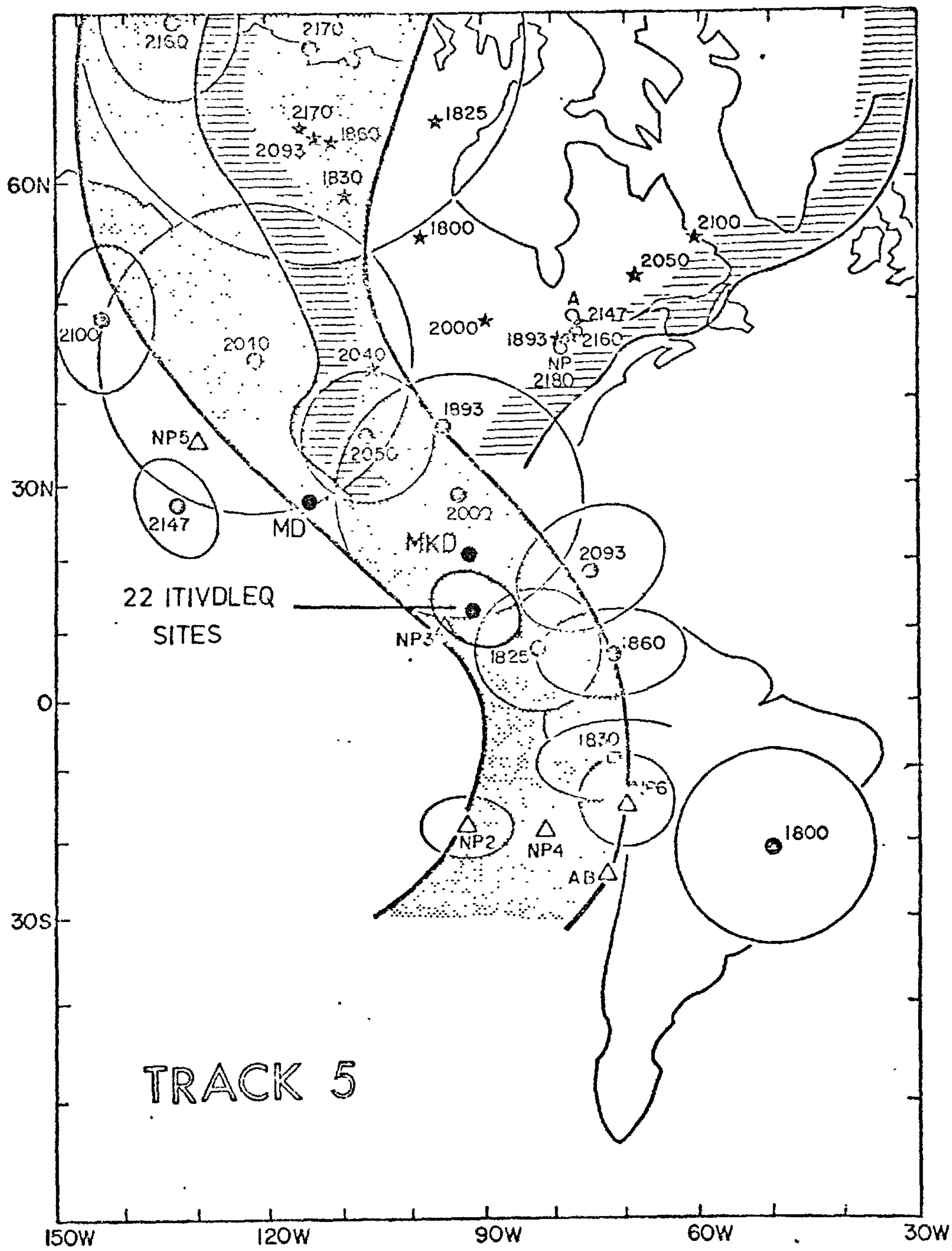
FIG. 8.1



LAURENTIAN POLES AND SUGGESTED A.P.W. PATH FOR PERIOD APPROXIMATELY 1730-1850 M.Y.

From Irving and McGlynn (1976). The pole and oval for the 22 Itivdleq sites and the poles for the metamorphosed Kaminak dykes and Molson dykes are also shown. See text for further details.

FIG. 8.2

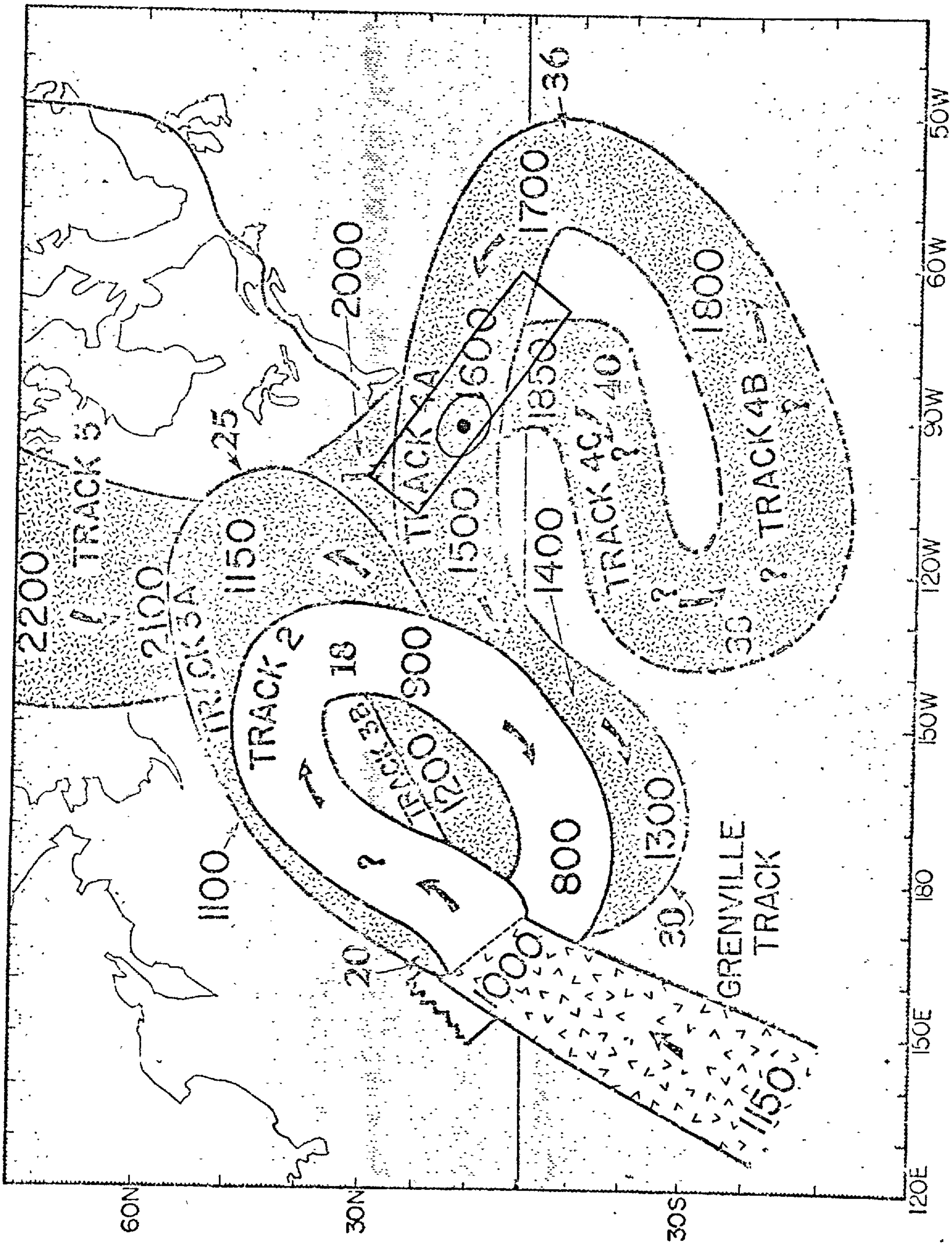


LAURENTIAN POLES AND SUGGESTED A.P.W. PATH FOR

PERIOD APPROXIMATELY 1850-2200 M.Y.

From Irving and McGlynn (1976). The oval and pole for the 22 Itivdleq sites and the poles for the metamorphosed Kaminak dykes and Molson dykes are also shown. See text for further details.

FIG. 8.3



SUGGESTED LAURENTIAN A.P.W. PATH FOR PERIOD APPROXIMATELY

600-2200 M.Y.

From Irving and McGlynn (1976). The pole and oval for the 22 Itivdleq sites and a band representing the linear trend of 18 Itivdleq poles are also shown.

FIG. 8.4

TABLE 8.1

LAURENTIAN POLES AND OVERPRINTS DATED 1500 - 2000 M.Y.

AND SHOWN IN FIGURES 8.1 - 8.3

1500 ± 200	Western Channel Diabase (Irving, Donaldson and Park, 1972)
1622 ± 200	Melville-Daly Bay metamorphics (Park, 1973)
1700 ± 100	Sparrow Dykes (McGlynn, Hanson, Irving and Park, 1974)
1730 ± 200	Et-then Group (Irving, Park and McGlynn, 1972)
1800 ± 100	Flin Flon B (Park, 1975)
about 1800	Metamorphosed Kaminak Dykes (Christie, Davidson and Fahrig, 1975)
1810 ± 100	Stark Formation, Christie Bay Group (Bingham and Evans, 1975)
1820 ± 200	Nonacho site 1 (McGlynn, Hanson, Irving and Park, 1974)
1825 ± 50	Dubawnt Group (Park, Irving and Donaldson, 1973)
1830 ± 100	Martin Formation (Evans and Bingham, 1973)
1860 ± 50	Kahochella Formation (McMurry, Reid and Evans, 1973)
1893 ± 50	Spanish River Complex, 25° error not shown (Robertson and Watkinson, 1974)
about 1800 - 2000	Molson Dykes (Ermanovics and Fahrig, 1975)
2000 ± 200	Gunflint Formation
BS	Big Spruce Complex (Irving and McGlynn, 1976)
D	Lapilli Tuff of Dubawnt Group (see above)
DG	Dogrib Dykes (McGlynn and Irving, 1975)
F1, F2, F3	Flin Flon overprints aged about 1600-1700 m.y. (Park, 1975)
KS	Kahochella Secondary, < 1860 m.y. (see above)
N	Nonacho Group, < 1700 m.y. (McGlynn, Hanson, Irving and Park, 1974)

ages given in Table 8.1, it is clear that the ages assigned to the Laurentian a.p.w. path by Irving and McGlynn (Figure 8.4) must be regarded as very approximate. Furthermore, errors in dating magnetizations may have caused the actual form of the path to be incorrectly reconstructed, and this obviously applies particularly to the loop between "1700" and "1850" m.y. referred to by Irving and McGlynn as tracks 4B and 4C, and which they themselves regard as very tentative. It is useful therefore to first of all compare the Itivdleq pole with individual results before attempting to consider its relationship to the proposed a.p.w. path, and with this in mind all Laurentian poles and overprints which fall within 25° of the mean Itivdleq pole have been listed in Table 8.2.

TABLE 8.2

LAURENTIAN POLES AND OVERPRINTS FALLING WITHIN 25°

OF THE MEAN ITIVDLEQ POLE

1500 ± 200	Western Channel Diabase
1622 ± 200	Melville-Daly Bay Metamorphics
1600 - 1700	Flin-Flon F2 overprint
< 1700	Some Nonacho Group overprints
1700 ± 100	Sparrow Dykes
about 1800	Metamorphosed Kaminak Dykes
1825 ± 50	Dubawnt Group
< 1860	Kahochella Secondary overprint
1860 ± 50	Kahochella Formation
2000 ± 200	Gunflint Formation
2093 ± 50	Indin Dykes
?	Some Big Spruce Complex overprints
?	Dogrib Dykes overprint

It is noted that of the dated poles and overprints in Table 8.2 all except one, the Indin Dyke pole, come within the age range 1500 - 2000 m.y. Also, of the 17 poles and overprints with an assigned age of between 1500 and 2000 m.y., ten are included in Table 8.2, and of the seven not included three (Martin Formation, Spanish River Complex and Molson dykes) are all within a few degrees of the 25° circle, one (Nonacho site 1) is a result based on a single site only, leaving only three poles out of 17 in this age range (Et-then Group, Flin-Flon B and Stark Formation) which are an appreciable distance from the Itivdleq pole. It would thus appear that the position of the mean Itivdleq pole is consistent with the suggested magnetization age of about 1650 - 1850 m.y., but that the pole position itself cannot be used to provide any more precise estimate of this age.

It is noted that if the a.p.w. path of Irving and McGlynn is in fact correct the Itivdleq pole could either be considered to fall on the east-west segment (track 4A) at about 1500 - 1600 m.y., or on the north-south segment (track 5) at about 1850 - 2000 m.y. As most K-Ar ages from the sampling area fall approximately mid-way between these two age ranges, and because the relationship between magnetic and K-Ar blocking temperatures is uncertain, the radiometric evidence could not be used to decide between these two alternatives. However, as discussed in Chapter 7 it is considered that the linear trend of 18 poles probably represents a small segment of the a.p.w. path, and the sense of time along this segment as judged by the systematic south-easterly movements parallel to the trend is from older in the south-east to younger in the north-west. The linear trend of 18 poles makes an angle of about 25° with the relevant part of track 4A, and possibly a slightly smaller angle with the relevant part of track 5, but the sense of time along the trend is consistent only with track 4A, and is the opposite to that required for track 5. Thus, if the linear trend of poles has been correctly interpreted they would favour the Itivdleq pole being on track 4A at about the 1500 - 1600 m.y. position, but would indicate that the track is aligned approximately south-east to north-west at this point rather than approximately east-west as shown by Irving and

McGlynn. It is emphasised again that the discussion of this paragraph assumes that the a.p.w. path of Irving and McGlynn is correct. If this assumption is not made the Itivdleq results should simply be interpreted as defining a short segment of the a.p.w. path whose age is probably within the range of approximately 1650 - 1850 m.y.

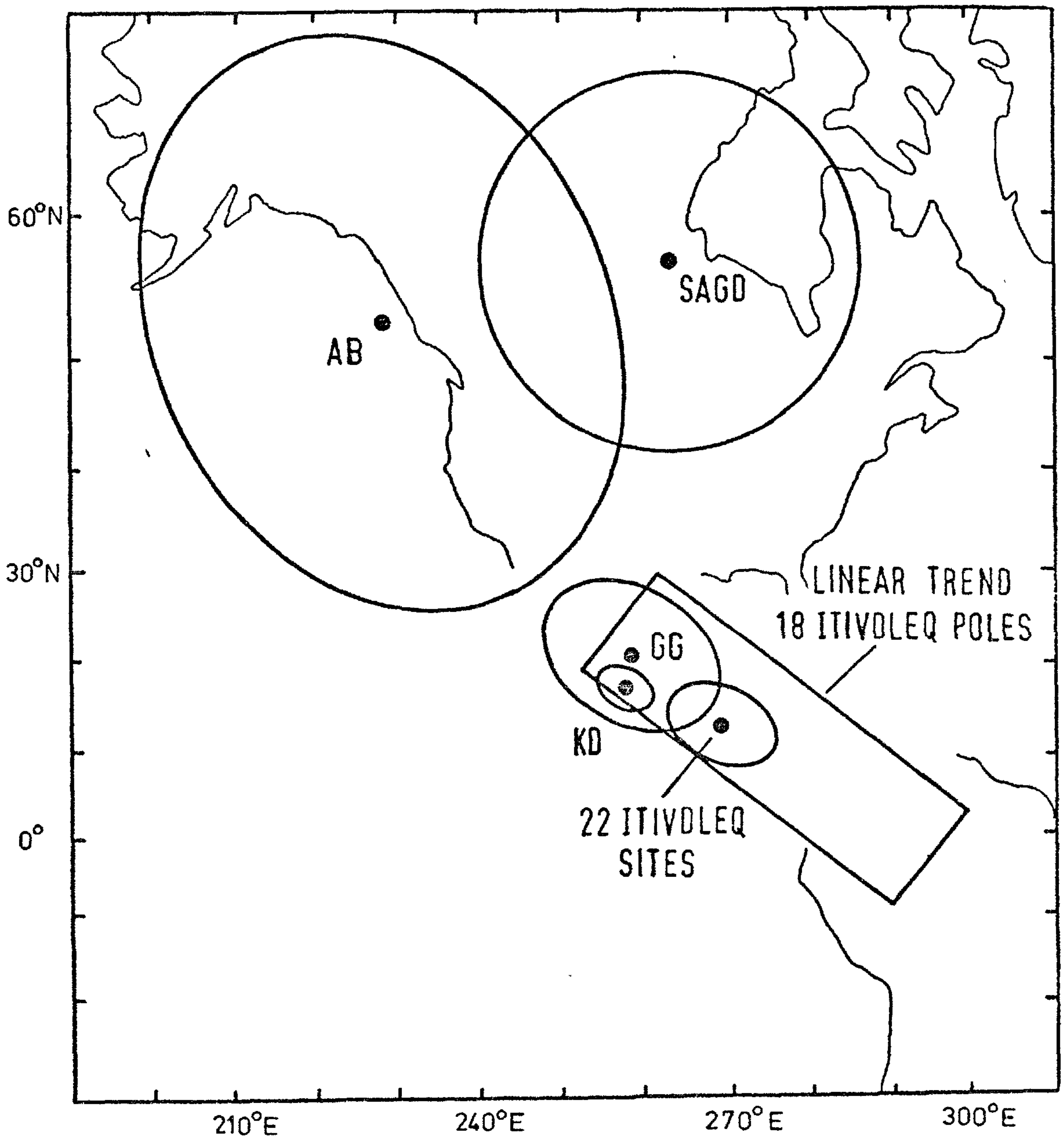
It is of interest to note that McMurry et al. (1973) working on the Kahochella Formation obtained one pole which was considered to be about 1860 m.y. old (pole 1860 in Figure 8.3) and another pole (overprint KS in Figure 8.1) which was interpreted as a post-folding secondary magnetization, and that a line directly joining these two poles would be almost exactly coincident with and parallel to the central part of the linear trend of the 18 Itivdleq poles, and would have the same sense of time along it as that suggested for the Itivdleq trend. It is therefore tempting to suggest that the two Kahochella poles may be defining two discrete points on the continuous a.p.w. path segment revealed by the Itivdleq study.

Palaeomagnetic work by Beckmann (Beckmann and Mitchell, 1976) on material from 9 sites on the island of Sagdlerssuaq and adjacent islets about 15 km north of Itivdleq yielded a pole at 56.9°N, 273.6°E. This result has apparently not been corrected for the drift of Greenland away from North America, and when this correction is applied as described in Chapter 7 the result is a pole at 57.0°N, 263.2°E. As described in section 8.2 rocks from this area all gave K-Ar isochron ages of about 1620 m.y., whereas the pole plots close to the 2100 m.y. section of the Irving and McGlynn a.p.w. path, and about 45° north of the section dated as 1600 m.y. Beckmann and Mitchell note that Piper (personal communication) has obtained a similar pole for supracrustals in the Ketilidian belt of southern Greenland whose metamorphic age is about 1720 m.y., and it is suggested that the a.p.w. path for Laurentia is considerably more complicated than yet realised.

Regarding the Sagdlerssuaq result it is perhaps significant that the mean pole plots almost exactly due north of the Itivdleq mean pole, suggesting that the Sagdlerssuaq magnetization may contain a component similar to that found in the Itivdleq rocks but which is masked by a recently acquired northerly-directed viscous component which for some reason has not been completely removed by a.f. or thermal demagnetization. This possibility is supported by the fact that the thermal demagnetization curves for the Sagdlerssuaq rocks show that J/Jo is typically reduced to about 0.20 by 400°C, indicating that the magnetization is dominated by low blocking temperature components. On the other hand, however, the extensive a.f. and thermal demagnetization work carried out on the material by Beckmann does seem to indicate that the magnetizations have good directional stability up to temperatures of 550°C and demagnetizing fields of between 250 and 500 oe.

Palaeomagnetic investigations have been carried out by Fahrig and Bridgwater (1976) on material collected between the sampling area of this study and Godthaabsfjord some 250 km to the south. Their paper describing the results of these investigations has not yet been published, and the following comments are based on a brief abstract only. This abstract quotes results as declinations and inclinations of mean magnetizations, and the present author has converted these to pole positions and corrected them for the drift of Greenland away from North America so that they can be compared with the results of the present study. These poles with their ovals of confidence are shown in Figure 8.5, which also shows the mean pole and oval for the 22 Itivdleq sites, and also the band 50° long and 12° wide corresponding to the linear trend of the 18 poles. The diagram also shows the corrected mean pole and oval for the nine Sagdlerssuaq sites.

Kangamiut dykes (the dominant dykes in the sampling area of the present study) were sampled by Fahrig and Bridgwater between Itivdleq and Kangamiut some 75 km to the south, i.e. extending well into the Archaean block. These dykes yielded a mean pole (labelled KD in Figure 8.5) at 17.3°N, 258.2°E (α_{95} = 2.1°). Archaean gneisses from the Godthaabsfjord region some 250 km south of Itivdleq and in the centre of the Archaean block were also sampled and yielded a pole (labelled GODTH) which was practically identical to the Kangamiut dyke pole at 20.5°N, 258.9°E (α_{95} = 6.6°). Fahrig and Bridgwater also



PALAEOMAGNETIC RESULTS FROM THE PRECAMBRIAN OF SOUTH-WEST GREENLAND

The poles and ovals for the Godthaabsfjord gneisses (GG), Kangamiut dykes (KD) and amphibolite boudins (AB) (Fahrig and Bridgwater, 1975), the pole and oval for the 9 Sagdlerssuaq sites (SAGD, Beckmann and Mitchell, 1976), and the pole and oval for the 22 Itivdleq sites and the band representing the linear trend of the 18 Itivdleq poles.

FIG. 8.5

state that "amphibolite boudins to the north of the Nagssugtoqidian boundary" yielded a pole (labelled AB) at 52.5°N, 228.8°E ($\alpha_{95} = 14^{\circ}$). The precise location of these boudins is not specified in the abstract, but the similarity of the pole to that obtained by Beckmann and Mitchell from Sagdlerssuaq (labelled SAGD) suggests that they may have been from the same area.

From Figure 8.5 it can be seen that the Fahrig and Bridgwater poles for the Kangamiut dykes and the Godthaabsfjord gneisses plot very close to the mean pole for the 22 Itivdleq sites, and that both poles fall within the band corresponding to the linear trend of the 18 Itivdleq poles. As already described in Chapter 2 the Godthaabsfjord gneisses have yielded Rb-Sr whole-rock ages of between 3700 and 2600 m.y., but Pankhurst et al. (1973) report that seven Rb-Sr biotite ages from gneisses in this area were all between about 1600 and 1700 m.y., and Moorbath (1975) noted that Rb-Sr mineral ages throughout the Archaean block had been reset at about 1600 m.y. Both authors interpret these results as due to a relatively minor thermal event at about this time, which was presumably sufficient to reset the Rb-Sr mineral systems but of insufficient intensity to reset the whole-rock systems. As the ages of about 1600 - 1700 m.y. are similar to the suggested magnetization ages of about 1650 - 1850 m.y. for the rocks of the present study, and as the magnetizations are practically identical, it would appear reasonable to correlate the magnetizations reported by Fahrig and Bridgwater for the Kangamiut dykes and the Godthaabsfjord gneisses with these Rb-Sr mineral ages. This would suggest that the crustal levels presently exposed in the whole region between Itivdleq and Kangamiut, and also in the area around Godthaabsfjord, cooled through their magnetic blocking temperatures at about the same time.

It must be pointed out, however, that in their abstract Fahrig and Bridgwater state that contact tests on the Kangamiut dykes suggest that the country rock gneisses preserve a pre-dyke magnetization. No details are given of this magnetization so presumably the contact tests were not sufficiently investigated to yield a conclusive result. If the country rock gneisses between Itivdleq and Kangamiut do in fact have a stable magnetization different to that in the dykes (unlike the situation in the sampling area of the present study where dykes and country rocks have essentially identical magnetizations) then this of course means that the dyke magnetizations in this area are unlikely to have been acquired during regional cooling as implied above. On the other hand it is possible that the country rocks in this area happen to have magnetic blocking temperatures which are considerably higher than those of the dykes and so with very slow cooling could have acquired their magnetization a sufficient time before the dykes for the directions to be considerably different.

These palaeomagnetic results from the Archaean block illustrate the possible dangers in dating ancient magnetizations, as the magnetizations in this case appear to have been acquired between one thousand million and two thousand million years after the Rb-Sr whole-rock clocks were set. Thus if the geochronological studies of the area had been confined to whole-rock analyses and no mineral analyses had been carried out, it is possible that the time of magnetization might have been simply correlated with the whole-rock ages and therefore have been in error by at least one thousand million years.

The slow cooling effects seen in the palaeomagnetic record of the Itivdleq rocks have been interpreted in this study as probably due to a single and continuous phase of uplift and erosion. Whether this was the first uplift and erosion cycle following the high-grade metamorphism, or a subsequent uplift and erosion cycle following a period of reburial to sufficient depths to raise the temperature above the highest magnetic blocking temperature, it is of course very difficult to say. As noted above both Pankhurst et al. (1973) and Moorbath (1975) suggest that Rb-Sr mineral ages in the Archaean craton at about 1600 - 1700 m.y. are due to the termination of a thermal (presumably reheating) event. This could have been caused by unroofing following reburial to moderate depths some time after initial unroofing, but it is also conceivable that the first uplift and erosion of the Archaean block resulting in the presently exposed crustal levels passing through the Rb-Sr mineral blocking temperatures did not in fact occur until about 1600 - 1700 m.y. Whichever of these alternatives is correct it is evident that uplift and erosion causing mineral clocks to be set and magnetizations to be stabilized occurred over a wide area of south-west Greenland at approximately 1700 m.y. The fact that the pole positions corresponding to these magnetizations when corrected using the Bullard et al. (1965) reconstruction are very similar to many circa 1700 m.y. poles from North America is consistent with this reconstruction being at least approximately correct for North America and Greenland at this time.

Appendix A

DESCRIPTIONS OF INDIVIDUAL SAMPLING SITES

(i) Dyke D2

This dyke from the south-east corner of the area strikes at 105° and is 40 m wide at the point where it was sampled. The dyke is clearly discordant to the foliation in the country rocks which strikes at 035°. In thin section it is seen to be an unaltered dolerite showing an excellent sub-ophitic texture.

(ii) Dyke D3

This dyke was sampled about 1.5 km south of D2, and at this locality it is 110 m wide and strikes at approximately 040°. In thin section it is seen to be an unaltered sub-ophitic dolerite very similar to D2.

(iii) Dyke D4

This dyke is about 6.5 km west of D2, and has a width of about 50 m, strikes at 090°, and is clearly discordant to the country rock foliation. In thin section it is seen to be an unaltered sub-ophitic dolerite very similar to D2 and D3.

(iv) Dyke D5

This dyke is about 250 m north-east of D4, and strikes at 030° with a width of about 50 m. In thin section it is seen to have suffered fairly minor alteration, with a hornblende/pyroxene ratio of about 10:90, and about 8% garnet present. Recrystallisation of the feldspars is not evident and the sub-ophitic texture is still just recognisable.

(v) Dyke D6

This dyke is about 250 m east of D5, with a width of about 60 m and a strike of 030°. It is seen in thin section to have suffered an unusual amount of alteration for this area. The hornblende/pyroxene ratio is about 70:30, about 10% of the feldspar has recrystallised, and a few per cent of garnet and biotite are present. The sub-ophitic texture is barely recognisable.

(vi) Dyke D7

This dyke was sampled at the most northerly part of the south coast of Itivdleq fjord, and it strikes at 050° with a width of about 40 m. The dyke is seen in thin section to be moderately altered, with a hornblende/pyroxene ratio of 20:80, about 30% of the feldspar recrystallised, and about 5% garnet present. The original sub-ophitic texture is still recognisable.

(vii) Dyke D8

This dyke was sampled about 2.5 km SSE of D7, where it is 30 m wide and strikes at 045°. In thin section it is seen to be extensively altered, with a hornblende/pyroxene ratio of 40:60, 60% of the feldspar recrystallised, about 10% garnet present, and 2-3% biotite. The sub-ophitic texture has been completely destroyed.

(viii) Dyke D9

This dyke was sampled about 300 m west of D8 and like D8 strikes at 045°, and is approximately 20 - 30 m wide. The dyke in this area is cut by a narrow later shear zone which has locally produced a very intense fabric, and sampling was confined to areas away from this zone where the rocks appeared to be completely isotropic. It is seen in thin section to have suffered only fairly minor alteration, with a hornblende/pyroxene ratio of 20:80, and about 5% garnet present, but virtually no recrystallisation of the feldspar. The sub-ophitic texture is still recognisable, and neither the thin section nor any of the cores showed any sign of foliation.

(ix) Dyke D10

This dyke occurs in the centre of the Itivdleq shear zone, and has separated into a number of discrete "pips" along its 090° strike as already described in section 2.4.1 above. The "pip" sampled was about 200 m long (E-W) and 60 m wide (N-S) and the country rock foliation was wrapped concordantly around its margins. A total of 19 cores were taken at 1.3 m intervals along a S-N traverse from the southern margin to near the centre, and a thin section was made from each core. The thin section taken 8 cm from the margin shows a microporphyritic dolerite with randomly oriented euhedral laths of feldspar (typically 1 mm long) set in a fine-grained (typically 0.1 mm) matrix of feldspar laths and irregular mafics. The only alteration appears to be that about 20% of the pyroxene has altered to hornblende. No recrystallisation of feldspar is apparent and garnet is completely absent. All other thin sections showed a perfectly developed sub-ophitic texture, and grain sizes of typically 1 to 3 mm. Alteration of pyroxene to hornblende varied from about 10% in some sections to 100% in others, but there was no indication of feldspar recrystallisation in any section, not even those showing 100% pyroxene alteration. Garnet was absent in many sections, and where present was generally less than 5%.

(x) Dyke D11

This 25 m wide dyke occurs in the south-west corner of the area and strikes at 045°. In thin section it shows a moderate amount of alteration, with a hornblende/pyroxene ratio of about 30:70, about 10% of the feldspar recrystallised, and about 8-10% garnet present, always associated with opaque ore. The sub-ophitic texture is still recognisable.

(xi) Dyke D12

This narrow dyke is situated about 80 m from D11 and strikes at 012°. It is typically about 50 cm wide but shows variations in width from 65 cm down to 15 cm, this presumably being original pinch and swell as no trace of internal foliation is seen. In thin section it is seen to be a fine-grained intergranular dolerite with no trace of alteration, and with an unusually large (about 12%) amount of opaque ore present. The average grain size is about 0.3 mm.

(xii) Dyke D13

This narrow (20 cm) dyke is in the northern part of the area about

2.5 km north of Itivdleq settlement. The strike of this dyke was unfortunately not recorded, but it was certainly strongly discordant to the country rock foliation. In thin section it is seen to be completely altered, and consists of a fine-grained (typically 0.03 mm) granoblastic mosaic of plagioclase, quartz, hornblende and garnet, with very minor pyroxene. The garnet granules, which make up about 25% of the rock, are concentrated in areas typically 1 mm across, giving the rock a speckled appearance in hand specimen. As mentioned above the rock can be described as a non-foliated garnet amphibolite.

(xiii) Dyke D14

This dyke is about 0.5 km north-west of Itivdleq, and is within the Itivdleq shear zone. The dyke shows pinch and swell with a maximum width of 3 m and a minimum width of 1.5 m. It strikes at 077° and is concordant with the country rock foliation. In the field the dyke shows a strong internal foliation parallel to its margins, presumably due to later local shearing. In this locality the dyke is cut by a narrow (0.5 m) dyke of the lamprophyre suite. In thin section D14 is seen to be a strongly foliated garnet amphibolite, the foliation being due to the alternation of very narrow streaky quartzofeldspathic layers with layers richer in hornblende, garnet and minor pyroxene. The texture is generally fine-grained granoblastic, with only a slight tendency for the hornblendes to be aligned parallel to the layering foliation. The few remaining pyroxenes tend to form slightly larger grains than the hornblende and quartz which has replaced it.

(xiv) Dyke D15

This dyke is about 400 m west of D14, and is another dyke showing pinch and swell. It has a maximum width of about 25 m and strikes at 082°. In thin section it is seen to be moderately altered, with about 45% of the feldspar recrystallised, a hornblende/pyroxene ratio of 25:75, and about 20% garnet present. The original sub-ophitic texture is however still just recognisable. In the field the dyke appeared internally isotropic, but in the laboratory the cores are seen to have a very crude foliation and this is also seen when the thin section is viewed without magnification.

(xv) Dyke D16

This narrow (0.5 m) dyke, which was the most northerly sampled, strikes at 061° and is discordant to the gneiss foliation which strikes at 084°. In thin section it is seen to be moderately altered, with a hornblende/pyroxene ratio of about 40:60, and about 25% garnet, but with virtually no recrystallisation of the feldspar. The original sub-ophitic texture is only just recognisable.

(xvi) Dyke D17

This dyke is about 2 km south of D16 and is approximately 40 m wide striking at 085°. In thin section it is seen to be moderately altered, with a hornblende/pyroxene ratio of 40:60, and about 17% garnet present, but again with virtually no recrystallisation of the feldspar. The original sub-ophitic texture is still very clearly recognisable.

(xvii) Dyke D18

This dyke is about 3 km east of Itivdleq in the Itivdleq shear zone, and is about 50 m wide striking at 083°. In thin section it is quite strongly altered with about 50% of the feldspar recrystallised, a hornblende/pyroxene ratio of 40:60, and about 15% garnet present. The original sub-ophitic texture is moderately well preserved. A crude foliation is apparent when the thin section is viewed with the naked eye, but is not obvious when the cores are examined.

(xviii) Dyke D19

This dyke is about 6 km north-east of D18, and is 22 m wide where sampled, striking at 070°. It was apparently intruded into a minor local shear zone, and although this site is within the granulite area the gneisses in the immediate vicinity of the site have been retrogressed to amphibolite facies (D. Nash, personal communication). Later movement has produced several foliated shear zones in the dyke in this area, but care was taken only to sample isotropic rock away from these zones. In thin section the dyke is seen to be moderately altered, with a hornblende/pyroxene ratio of 50:50, about 10% of the feldspar recrystallised, and about 7% garnet present. There is also a small amount of biotite. The original sub-ophitic texture is only very poorly preserved, but there is no trace of foliation in the thin section or in any of the cores.

(xix) Dyke D20

This dyke is located on a small island about 2 km WSW of D19, and may in fact be a continuation of D19. It strikes at 066°, is 13 m wide, and like D19 it was intruded into a minor local shear zone. The gneiss foliation is completely concordant with the dyke margin. Eleven cores were drilled at 60 cm intervals along a traverse from the northern margin to the centre of the dyke, and thin sections were prepared from each core. These thin sections reveal that this is a rather strongly altered dyke. The thin section from the core nearest to the margin shows a fine-grained (typically 0.06 mm) granoblastic mosaic of feldspar, quartz, hornblende and garnet, with some slightly larger irregular grains of pyroxenes, and occasional subhedral feldspars. Garnet makes up about 25% of this section. The thin sections from the other cores are generally similar except that the pyroxenes and subhedral feldspars are rather more abundant and slightly larger. On average the hornblende/pyroxene ratio is about 60:40, about 60% of the feldspar has recrystallised, and the garnet content is 20%. Some of the thin sections from the outer cores show slight traces of foliation when viewed with the naked eye, and this is also just discernible in a few of the cores.

(xx) Dyke D21

This dyke is 2.5 km SSW of D20 on the northern boundary of the Itivdleq shear zone, and strikes at 070° with a width of 40 m. The centre of the dyke has a strong foliation presumably due to later local shearing, but the marginal parts of the dyke appeared in the field to be much less affected, and all sampling was confined to these more or less isotropic marginal areas. In thin section the dyke is seen to be strongly altered, with about 80% of the feldspar recrystallised, a hornblende/pyroxene ratio of 75:25, and about 15% garnet. A crude to moderate foliation is evident when the thin section is viewed without magnification, and all the cores show a similar intensity of foliation in hand specimen.

(xxi) Gneisses G10 and G11

These were originally considered to be two separate sampling sites about 400 m south-west of D2 in the south-east corner of the area. However, because of the nature of the palaeomagnetic results (see above in Chapter 4), and because the sites were only 100 m apart and had very similar lithologies, it was decided to treat them as a single site referred to as G10/11. In the field the gneisses lacked any dominant fabric, and were rather heterogenous, consisting essentially of a leucocratic matrix in which were pods and irregular bodies of mafic and ultramafic appearance. All three of these lithological types were sampled. A thin section of a mafic core showed that it was a more or less granoblastic aggregate of quartz and feldspar (50%) together with generally irregular hornblende (50%) and opaque ore (< 1%), and having a grain size of typically 0.5 mm. A thin section of a leucocratic core showed that it consisted of large (2-3 mm) irregular grains of mainly lamellar twinned feldspar (60%) along the grain boundaries of which was a fine-grained (0.05 mm) granoblastic mosaic of quartz and feldspar (20%), together with irregular grains of hornblende (15%), biotite (2%) and opaque ore (3%). Neither of the thin sections, nor any of the cores, showed any foliation.

(xxii) Gneiss G13

This site was only 30 m away from D12 in the south-west corner of the area. The rocks generally lacked a distinct foliation, and consisted of a leucocratic matrix with small pods and irregular inclusions of mafic material. Sampling was confined to these mafic bodies, and from an examination of the cores in the laboratory it appeared that they were all of similar composition. A thin section of one core showed a more or less granular aggregate of feldspar and quartz (45%), hornblende (30%), pale green non-pleochroic clinopyroxene possibly diopside (18%), hypersthene (4%), biotite (1%) and opaque ore (2%).

The grain size is typically about 0.5 mm, and all the cores and the thin section appear to be completely isotropic.

(xxiii) Gneiss G14

This site was in the immediate vicinity of D13 in the northern part of the area, and here the country rocks consist of leucocratic gneiss displaying a crude foliation, and having generally pod-like inclusions of mafic and ultramafic material. Twelve cores were obtained from the leucocratic gneiss, and these constitute G14. Thirteen cores were obtained from the mafic and ultramafic inclusions at the same site and these constitute G18 described in the next paragraph. In thin section G14 is seen to be very leucocratic, consisting of a more or less granoblastic aggregate of feldspar and quartz (80%), hornblende (8%) biotite (7%), garnet (3%), hypersthene (1%) and opaque ore (1%). All the cores display a crude foliation in hand specimen, but this is not apparent in the thin section. The grain size is typically about 0.3 mm.

(xxiv) Gneiss G18

As indicated above G18 consists of mafic and ultramafic pod-like inclusions in the leucocratic gneiss G14. A thin section of a core of ultramafic appearance confirmed that felsic minerals were completely absent, and showed an irregular aggregate of hornblende (40%), biotite (25%), colourless to pale green clinopyroxene (20%), hypersthene (13%) and opaque ore (2%), with a grain size of typically 1 mm. A thin section of a mafic core showed an irregular to granoblastic aggregate of feldspar and quartz (50%), pale green clinopyroxene (20%), hornblende (15%), biotite (12%), hypersthene (2%) and opaque ore (1%), and with a variable grain size averaging about 0.5 mm. All the cores and both thin sections appear to be completely isotropic.

(xxv) Gneiss G20

This was the most northerly site in the sampling area, and the rocks consisted of very leucocratic homogenous gneiss. A thin section showed an irregular aggregate of lamellar twinned plagioclase (40%), untwinned feldspar and quartz (35%), hornblende (12%), hypersthene (8%), garnet (3%), biotite (2%) and opaque ore (< 1%), with an average grain size of about 0.5 mm.

Appendix B

PALAEOMAGNETIC RESULTS FOR INDIVIDUAL SPECIMENS

Notes

This appendix gives the palaeomagnetic results for each individual specimen examined in this study at all demagnetization steps to which it was subjected. The results for all specimens from a given site are grouped together with the site reference, eg., DYKE D2, forming a heading at the beginning of the group. The results for each specimen are preceded by the specimen reference, eg. D2 - 1, D2 - 2 etc. The significance of the various columns of results is explained below.

The first column, headed DMAG, gives the peak demagnetizing field on oersteds at each step. The significance of demagnetizing fields of 201, 301 oe, etc., is explained in section 4.2.4.

Columns two to four describe the magnetization measured at each step. The second and third columns, headed DIP and DECL, give the inclination and declination respectively of the direction of magnetization. Upward inclinations are indicated by a minus sign and all declinations are measured clockwise from true north. The fourth column, headed J, gives the intensity of magnetization in emu/cm^3, 0.150E - 02 for example meaning 0.150×10^{-2}.

Columns five and six define the pole position corresponding to the magnetization measured at each step. Column five, headed LAT, gives the latitude of the pole, and column six, headed LONG, gives the longitude of the pole. Southerly latitudes are indicated by a minus sign and all longitudes are measured eastwards from the Greenwich meridian.

Column seven, headed ANG, gives the angular movement in degrees of the direction of magnetization between the previous and the present demagnetizing step.

The final column, headed J/Jo, gives the intensity of magnetization at each step compared to the intensity at the NRM (0 oe) step considered as unity.

The 2 appearing after the final column for some of the higher demagnetizing steps indicates that the result was the mean of two measurements carried out on that specimen after two separate demagnetization runs at that field strength (see the end of section 4.2.1 for further details).

DYKE D2

DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
	**** MAGNETIZATION ****			POLE POSITION				
D2 1								
0	68.9	263.9	.161E-02	44.4	248.5	0	1.000	
50	65.8	227.6	.605E-03	30.1	272.0	14.1	.376	2
100	57.3	221.9	.451E-03	19.2	273.0	8.9	.280	2
150	52.9	226.2	.372E-03	16.0	268.1	5.0	.231	2
200	59.3	221.7	.326E-03	21.3	273.8	6.9	.203	2
300	51.6	226.2	.248E-03	14.8	267.7	8.1	.154	2
400	60.0	226.6	.164E-03	23.2	270.2	8.4	.102	2
500	63.1	206.0	.174E-03	22.8	287.1	10.3	.108	2
600	60.1	214.0	.155E-03	20.6	280.1	4.8	.096	2
700	58.7	211.7	.140E-03	18.7	281.5	1.8	.087	2
800	55.2	197.9	.101E-03	13.1	292.0	8.3	.062	2
900	66.4	225.5	.697E-04	30.4	273.9	17.3	.043	2
1000	57.4	295.6	.720E-04	44.5	211.4	32.3	.045	2
D2 3								
0	81.0	201.7	.205E-02	49.7	296.9	0	1.000	
50	69.3	220.8	.993E-03	33.3	278.7	12.6	.485	2
100	58.9	218.9	.686E-03	20.3	275.8	10.4	.335	2
150	58.9	216.9	.580E-03	19.9	277.4	1.0	.283	2
200	54.7	214.0	.492E-03	15.0	278.6	4.6	.240	2
300	56.9	215.8	.402E-03	17.6	277.7	2.5	.196	2
400	54.0	212.7	.303E-03	14.0	279.6	3.5	.148	2
500	51.0	209.9	.252E-03	10.8	281.2	3.4	.123	2
600	52.1	205.5	.256E-03	11.1	285.2	3.0	.125	2
700	52.7	203.0	.208E-03	11.3	287.4	1.6	.102	2
800	49.6	202.0	.164E-03	8.4	287.8	3.1	.080	2
900	55.2	207.5	.123E-03	14.4	284.1	6.5	.060	2
1000	39.6	188.5	.934E-04	-.8	299.0	20.1	.046	2
D2 4								
0	79.3	144.2	.200E-02	48.1	324.8	0	1.000	
50	66.3	213.8	.105E-02	28.1	282.3	22.2	.524	
100	59.7	215.7	.791E-03	20.5	278.6	6.7	.396	
150	59.3	212.0	.684E-03	19.4	281.4	1.9	.343	
200	55.3	213.5	.630E-03	15.4	279.2	4.2	.316	
300	56.9	212.9	.578E-03	17.0	280.0	1.7	.290	
400	55.0	213.6	.468E-03	15.2	279.1	1.9	.234	2
500	53.3	209.9	.388E-03	12.9	281.7	2.7	.194	2
D2 5								
0	70.1	213.9	.148E-02	33.3	283.8	0	1.000	
50	57.8	222.8	.711E-03	20.0	272.4	12.8	.479	
100	55.3	221.5	.615E-03	17.1	272.6	2.7	.415	2
150	54.5	221.1	.571E-03	16.3	272.7	.8	.385	2
200	49.7	218.3	.504E-03	11.3	273.9	5.1	.340	2
300	58.4	223.7	.344E-03	20.7	271.9	9.2	.232	2
400	51.1	207.5	.444E-03	10.5	283.3	11.8	.300	2
500	50.0	205.1	.367E-03	9.1	285.1	1.8	.248	2

DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D2 7								
0	86.6	327.8	.115E-02	71.9	295.1	0	1.000	
50	67.2	224.8	.643E-03	31.3	274.7	23.8	.561	
100	59.7	219.3	.499E-03	21.2	275.8	7.9	.435	2
150	55.8	215.2	.459E-03	16.3	278.0	4.4	.401	2
200	55.4	215.0	.407E-03	15.9	278.0	.5	.355	2
300	48.0	214.1	.322E-03	9.0	277.1	7.4	.281	2
400	56.7	213.0	.358E-03	16.8	280.0	8.7	.312	2
500	56.1	208.9	.295E-03	15.5	283.1	2.3	.257	2
D2 9								
0	78.6	238.0	.689E-03	50.5	277.0	0	1.000	
50	58.9	223.5	.480E-03	21.2	272.2	20.3	.697	
100	57.5	221.4	.404E-03	19.3	273.4	1.8	.586	2
150	54.2	225.3	.366E-03	17.0	269.2	3.9	.531	2
200	54.3	226.3	.340E-03	17.3	268.4	.6	.493	2
300	48.2	211.8	.325E-03	8.7	279.1	10.9	.472	2
400	53.6	206.9	.360E-03	12.7	284.3	6.2	.523	2
500	50.5	202.2	.320E-03	9.2	287.8	4.2	.464	2
D2 10								
0	82.4	73.4	.235E-02	66.3	344.6	0	1.000	
50	75.3	212.6	.980E-03	40.9	287.5	21.0	.418	
100	64.1	211.9	.718E-03	24.9	282.9	11.2	.306	
150	60.0	211.8	.651E-03	20.1	281.8	4.0	.277	
200	57.9	216.6	.609E-03	18.7	277.4	3.3	.259	
300	57.5	211.7	.498E-03	17.4	281.2	2.7	.212	
400	55.8	205.4	.357E-03	14.6	285.9	3.8	.152	2
500	54.6	203.9	.288E-03	13.3	286.9	1.4	.123	2
D2 11								
0	81.8	273.6	.386E-02	62.6	269.8	0	1.000	
50	64.4	237.8	.182E-02	31.0	263.7	19.5	.471	
100	60.0	223.0	.135E-02	22.3	272.9	8.2	.350	2
150	58.8	220.6	.118E-02	20.5	274.5	1.7	.304	2
200	58.5	219.2	.106E-02	19.9	275.4	.8	.273	2
300	57.4	218.9	.890E-03	18.7	275.3	1.1	.230	2
400	59.0	218.8	.784E-03	20.4	275.9	1.6	.203	2
500	58.1	215.3	.640E-03	18.7	278.4	2.1	.166	2

DYKE D3

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D3 1								
0	77.9	228.6	.293E-02	47.6	280.8	0	1.000	
50	61.0	231.4	.252E-02	25.4	266.9	16.9	.860	
100	60.4	224.0	.223E-02	23.0	272.4	3.7	.763	2
150	58.8	218.8	.212E-02	20.1	275.9	3.1	.726	2
200	56.0	214.3	.208E-02	16.4	278.7	3.7	.711	
300	55.5	215.4	.192E-02	16.0	277.7	.8	.655	
301	55.5	215.4	.192E-02	16.0	277.7	.0	.655	
400	55.6	219.5	.167E-02	17.0	274.4	2.3	.569	
500	55.0	218.3	.147E-02	16.1	275.2	1.0	.502	
600	54.5	220.4	.110E-02	16.1	273.4	1.3	.375	
700	54.1	218.1	.894E-03	15.2	275.1	1.4	.305	
800	51.6	220.4	.622E-03	13.4	272.6	2.9	.212	
900	55.4	219.5	.443E-03	16.8	274.3	3.9	.151	
1000	58.0	216.1	.330E-03	18.7	277.8	3.2	.113	

D3 2								
0	58.4	237.1	.649E-02	24.2	261.2	0	1.000	
50	61.9	231.9	.515E-02	26.5	266.9	4.4	.793	
100	56.0	227.0	.470E-02	19.1	268.4	6.4	.724	2
150	58.0	226.6	.440E-02	21.0	269.5	2.0	.678	2
200	57.2	226.5	.451E-02	20.1	269.2	.9	.694	
300	56.9	224.5	.421E-02	19.4	270.7	1.1	.648	
301	55.9	224.9	.416E-02	18.5	270.1	1.0	.640	
400	55.7	224.1	.349E-02	18.1	270.7	.5	.537	
500	54.8	224.0	.324E-02	17.3	270.4	.9	.499	
D3 3								
0	69.2	150.3	.464E-02	31.4	327.4	0	1.000	
50	57.6	232.4	.362E-02	22.1	264.6	35.4	.780	2
100	55.7	226.2	.337E-02	18.6	268.9	3.9	.725	2
150	57.0	228.7	.319E-02	20.5	267.4	1.9	.688	2
200	55.0	229.0	.326E-02	18.7	266.4	1.9	.703	2
300	56.4	232.7	.286E-02	21.0	264.0	2.5	.616	2
301	56.4	232.7	.286E-02	21.0	264.0	.0	.616	2
400	55.2	237.9	.269E-02	21.3	259.3	3.2	.579	2
500	56.3	238.1	.212E-02	22.4	259.5	1.1	.456	2
600	54.8	231.7	.192E-02	19.2	264.2	3.9	.414	2
700	55.8	225.4	.160E-02	18.5	269.6	3.7	.345	2
800	54.2	221.6	.117E-02	16.1	272.2	2.7	.252	2
900	53.2	223.2	.860E-03	15.5	270.6	1.4	.185	2
1000	54.4	222.4	.655E-03	16.5	271.6	1.3	.141	2
D3 4								
0	60.1	230.3	.546E-02	24.2	267.3	0	1.000	
50	61.3	221.3	.453E-02	23.4	274.8	4.6	.830	
100	56.2	223.4	.450E-02	18.4	271.4	5.2	.823	2
150	57.3	224.7	.445E-02	19.8	270.7	1.3	.814	2
200	53.5	222.6	.431E-02	15.7	271.2	3.9	.788	
300	53.3	222.6	.401E-02	15.5	271.2	.2	.733	
301	53.3	222.6	.401E-02	15.5	271.2	.0	.733	
400	56.9	225.7	.369E-02	19.7	269.8	4.1	.676	
500	57.6	223.1	.305E-02	19.8	272.1	1.6	.558	
600	57.2	222.7	.238E-02	19.3	272.2	.4	.435	
700	52.7	220.7	.183E-02	14.5	272.6	4.7	.335	
800	56.0	219.5	.123E-02	17.4	274.4	3.4	.226	
900	56.4	218.2	.904E-03	17.5	275.7	.9	.166	
1000	54.5	213.3	.618E-03	14.7	279.1	3.4	.113	2
D3 6								
0	68.3	212.3	.139E-02	30.5	284.1	0	1.000	
50	62.9	208.5	.172E-02	22.9	285.1	5.7	1.237	
100	59.1	219.0	.171E-02	20.5	275.8	6.3	1.230	2
150	53.2	226.8	.180E-02	16.4	267.7	7.3	1.290	2
200	61.2	222.7	.198E-02	23.6	273.6	8.3	1.420	
300	60.2	224.0	.174E-02	22.7	272.3	1.2	1.252	
301	58.4	221.5	.168E-02	20.2	273.6	2.2	1.207	
400	58.0	220.6	.146E-02	19.6	274.2	.7	1.049	
500	57.8	223.2	.128E-02	20.0	272.1	1.4	.918	
D3 8								
0	69.2	226.3	.248E-02	34.3	274.9	0	1.000	
25	65.5	228.6	.147E-02	30.0	271.1	3.8	.591	2
50	61.4	228.1	.101E-02	25.0	269.6	4.1	.406	2
75	60.3	219.6	.795E-03	21.9	275.7	4.3	.320	2
100	58.3	207.7	.724E-03	17.6	284.5	6.4	.292	2
150	55.3	219.6	.646E-03	16.7	274.2	7.2	.260	2

200	56.7	220.3	.572E-03	18.2	274.0	1.5	.231	2
250	59.4	222.3	.509E-03	21.5	273.3	2.9	.205	2
300	53.1	215.7	.452E-03	13.8	276.8	7.2	.182	2
301	53.1	215.7	.452E-03	13.8	276.8	.0	.182	2
400	55.4	207.6	.358E-03	14.6	284.0	5.2	.144	2
500	54.9	227.3	.298E-03	18.1	267.8	11.2	.120	2
D3 9								
0	66.6	220.1	.239E-02	29.5	277.8	0	1.000	
50	57.4	212.4	.169E-02	17.4	280.6	9.8	.707	
100	55.1	212.3	.131E-02	15.0	280.1	2.3	.547	
150	55.3	210.4	.114E-02	14.9	281.7	1.1	.478	
200	55.9	211.7	.102E-02	15.7	280.8	1.0	.428	
300	56.1	211.2	.867E-03	15.8	281.2	.4	.362	
301	53.5	218.8	.830E-03	14.8	274.4	5.1	.347	
400	55.8	216.8	.749E-03	16.6	276.6	2.6	.313	
500	55.2	219.5	.604E-03	16.6	274.3	1.6	.252	
D3 10								
0	53.2	239.8	.308E-02	20.1	256.9	0	1.000	
50	54.0	222.5	.217E-02	16.1	271.4	10.3	.705	
100	53.8	220.0	.192E-02	15.4	273.5	1.5	.623	
150	55.3	221.0	.171E-02	17.0	273.0	1.6	.554	
200	54.1	220.5	.157E-02	15.7	273.1	1.2	.508	
300	54.0	219.8	.138E-02	15.5	273.7	.4	.449	
301	54.6	214.5	.128E-02	15.0	278.2	3.1	.414	
400	53.0	214.6	.113E-02	13.5	277.7	1.5	.367	
500	54.3	216.5	.930E-03	15.1	276.4	1.7	.301	

DYKE D4

	**** MAGNETIZATION	****		POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D4 1								
0	58.0	198.5	.144E-02	16.1	291.8	0	1.000	
100	55.2	205.4	.131E-02	14.1	285.6	4.7	.910	2
150	55.0	206.8	.118E-02	14.0	284.4	.8	.816	2
200	54.4	204.4	.108E-02	13.2	286.3	1.5	.745	2
300	54.6	207.9	.130E-02	13.9	283.4	2.0	.900	
301	54.6	207.9	.130E-02	13.9	283.4	.0	.900	
400	53.9	212.6	.122E-02	14.0	279.4	2.8	.845	
500	53.0	213.7	.103E-02	13.4	278.3	1.1	.710	
600	52.7	211.3	.726E-03	12.6	280.3	1.5	.503	
700	51.3	210.3	.586E-03	11.2	280.8	1.5	.406	
800	51.3	210.1	.437E-03	11.1	281.0	.1	.302	
900	53.1	205.4	.332E-03	12.0	285.3	3.4	.230	
1000	51.8	209.7	.236E-03	11.5	281.4	3.0	.163	
D4 3								
0	87.5	129.7	.135E-02	63.1	315.2	0	1.000	
25	64.2	182.5	.931E-03	22.4	304.8	24.4	.688	
50	56.6	179.1	.812E-03	13.7	307.4	7.8	.600	
75	56.0	185.1	.648E-03	13.1	302.5	3.4	.480	2
100	57.2	190.4	.574E-03	14.6	298.2	3.1	.425	2
150	59.0	192.9	.461E-03	16.7	296.4	2.3	.341	2
200	56.1	191.7	.414E-03	13.5	297.1	3.0	.306	2
300	60.5	192.0	.339E-03	18.4	297.2	4.4	.250	2
301	57.4	196.7	.378E-03	15.3	293.1	3.9	.280	
400	60.1	202.6	.335E-03	18.9	288.8	4.1	.248	
500	59.4	199.9	.300E-03	17.8	290.8	1.5	.222	

D4 4								
0	78.5	187.4	.255E-02	44.5	302.8	0	1.000	
100	55.8	206.3	.599E-03	14.9	285.0	23.5	.235	2
150	53.2	203.2	.502E-03	11.8	287.1	3.2	.197	2
200	52.2	201.1	.427E-03	10.6	288.8	1.6	.167	2
300	56.8	206.8	.546E-03	16.0	284.8	5.7	.214	
D4 5								
0	84.4	169.3	.272E-02	55.6	310.3	0	1.000	
100	65.1	195.8	.849E-03	24.2	294.9	20.1	.312	
150	61.0	197.4	.655E-03	19.3	293.0	4.2	.241	
200	61.1	197.2	.597E-03	19.4	293.2	.1	.219	
300	59.8	195.6	.485E-03	17.9	294.3	1.4	.178	
301	57.5	197.5	.430E-03	15.5	292.5	2.6	.158	
400	56.7	200.9	.353E-03	15.0	289.6	2.0	.130	
500	55.0	191.4	.307E-03	12.4	297.2	5.6	.113	
D4 6								
0	-7.2	165.7	.241E-02	-26.3	322.7	0	1.000	
100	55.8	225.0	.124E-02	18.4	269.8	79.6	.515	2
300	58.8	205.0	.102E-02	17.7	286.6	11.2	.424	
301	57.4	201.3	.923E-03	15.8	289.4	2.4	.383	
400	56.5	201.7	.870E-03	14.9	288.9	1.0	.361	
500	53.6	203.9	.756E-03	12.3	286.6	3.2	.314	
D4 7								
0	12.0	201.6	.652E-03	-15.8	284.4	0	1.000	
100	49.5	207.2	.446E-03	9.0	283.1	37.8	.684	2
150	52.7	210.4	.425E-03	12.4	281.0	3.8	.651	2
200	54.6	203.4	.490E-03	13.2	287.1	4.6	.751	2
300	52.8	196.4	.439E-03	10.6	292.8	4.5	.674	2
301	52.8	196.4	.439E-03	10.6	292.8	0	.674	2
400	53.1	197.0	.373E-03	11.0	292.3	.5	.572	2
500	51.0	194.4	.304E-03	8.8	294.3	2.7	.466	2
D4 8								
0	60.1	174.1	.796E-03	17.6	311.4	0	1.000	
25	63.4	214.3	.597E-03	24.5	280.7	19.0	.750	
50	63.9	237.7	.526E-03	30.4	263.4	10.3	.661	
75	56.7	202.9	.489E-03	15.2	287.9	18.4	.615	2
100	57.8	202.9	.472E-03	16.4	288.1	1.1	.594	2
150	56.6	194.6	.390E-03	14.2	294.7	4.7	.490	2
200	56.4	194.3	.355E-03	14.0	294.9	.2	.446	2
300	56.7	193.2	.307E-03	14.2	295.9	.7	.385	2
301	60.4	208.0	.366E-03	20.0	284.6	8.6	.459	2
400	56.2	202.8	.332E-03	14.8	287.9	5.0	.417	2
500	56.4	199.4	.276E-03	14.5	290.8	1.9	.347	2
600	51.8	196.8	.232E-03	9.8	292.3	4.8	.292	2
700	56.4	196.9	.182E-03	14.2	292.8	4.5	.228	2
800	53.7	209.7	.146E-03	13.2	281.8	7.8	.184	2
900	56.1	206.1	.101E-03	15.0	285.2	3.2	.127	2
D4 10								
0	46.4	217.7	.124E-02	8.4	273.5	0	1.000	
100	54.1	212.8	.635E-03	14.2	279.3	8.3	.514	2
150	56.5	194.9	.530E-03	14.3	294.5	10.5	.429	2
200	55.8	191.4	.485E-03	13.2	297.2	2.1	.393	2
300	57.9	202.4	.632E-03	16.5	288.5	6.4	.511	
301	55.3	196.9	.506E-03	13.1	292.7	4.0	.410	
400	56.2	199.2	.432E-03	14.4	290.9	1.6	.349	
500	54.7	191.8	.368E-03	12.2	296.9	4.5	.298	

DYKE D5

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D5 1								
0	48.2	220.7	.981E-02	10.6	271.3	0	1.000	
50	54.8	209.4	.996E-02	14.3	282.3	9.6	1.016	
100	55.9	208.9	.101E-01	15.3	282.9	1.1	1.028	
150	54.9	209.4	.975E-02	14.4	282.3	1.0	.994	
200	55.1	209.4	.944E-02	14.6	282.3	.2	.962	
300	53.9	208.5	.822E-02	13.3	282.8	1.3	.838	
301	53.9	208.5	.822E-02	13.3	282.8	0	.838	
400	52.8	206.7	.692E-02	12.0	284.1	1.5	.706	
600	49.9	205.9	.455E-02	9.2	284.3	3.0	.464	
800	46.0	203.0	.273E-02	5.5	286.2	4.3	.278	
1000	44.2	201.4	.112E-02	3.9	287.5	2.1	.115	2
1100	40.0	197.7	.564E-03	.2	290.4	5.1	.058	2
D5 2								
0	56.9	214.0	.838E-02	17.2	279.0	0	1.000	
100	56.1	212.0	.820E-02	16.0	280.4	1.4	.978	
200	55.6	212.2	.766E-02	15.6	280.1	.5	.914	
300	55.4	211.5	.694E-02	15.2	280.6	.4	.828	
301	55.4	211.5	.694E-02	15.2	280.6	.0	.828	
400	52.5	212.5	.614E-02	12.7	279.2	2.9	.733	
500	51.4	210.9	.493E-02	11.3	280.3	1.5	.589	
600	49.8	208.7	.395E-02	9.6	281.9	2.1	.471	
700	49.1	209.5	.290E-02	9.1	281.1	.9	.346	
800	47.3	206.8	.196E-02	7.1	283.1	2.5	.234	
900	44.7	207.8	.141E-02	5.2	281.9	2.7	.168	2
1000	45.1	208.2	.937E-03	5.6	281.6	.5	.112	2
D5 3								
0	53.1	214.8	.876E-02	13.6	277.4	0	1.000	
50	53.3	210.9	.839E-02	13.1	280.7	2.3	.958	
100	55.5	211.2	.856E-02	15.3	280.9	2.2	.978	
150	54.4	212.0	.842E-02	14.3	280.0	1.2	.961	
200	53.4	210.5	.810E-02	13.1	281.1	1.3	.925	
300	53.8	210.9	.722E-02	13.6	280.8	.5	.824	
301	53.8	210.9	.722E-02	13.6	280.8	0	.824	
400	52.2	209.9	.618E-02	11.9	281.3	1.7	.706	
600	50.9	205.1	.417E-02	10.0	285.1	3.2	.477	
800	48.1	200.5	.249E-02	6.9	288.8	4.1	.285	
1000	44.7	201.3	.112E-02	4.3	287.6	3.4	.128	2
1100	43.8	200.9	.594E-03	3.5	287.9	1.0	.068	2
D5 5								
0	75.4	258.3	.720E-02	50.9	260.8	0	1.000	
100	57.6	209.4	.260E-02	17.1	282.8	25.1	.361	
200	56.2	209.1	.227E-02	15.6	282.8	1.4	.316	
300	55.8	207.5	.192E-02	15.0	284.0	1.0	.267	
301	55.8	207.5	.192E-02	15.0	284.0	.0	.267	
400	53.8	207.3	.152E-02	13.0	283.8	2.0	.211	2
500	53.0	203.7	.108E-02	11.7	286.7	2.3	.150	2
600	50.8	202.5	.761E-03	9.5	287.4	2.4	.106	2
700	49.3	200.8	.580E-03	8.0	288.6	1.8	.081	2
800	46.5	198.6	.392E-03	5.3	290.2	3.2	.054	2
900	41.9	198.8	.271E-03	1.8	289.5	4.6	.038	2
1000	42.6	187.9	.172E-03	1.4	299.5	8.1	.024	2

D5 7

0	57.3	231.9	.303E-02	21.7	264.7	0	1.000	
100	55.3	211.5	.301E-02	15.1	280.6	11.5	.993	
200	54.7	210.5	.267E-02	14.3	281.3	.9	.882	
300	53.8	209.7	.228E-02	13.4	281.8	1.0	.754	
301	53.8	209.7	.228E-02	13.4	281.8	0	.754	
400	52.4	207.3	.189E-02	11.6	283.5	2.0	.624	
500	50.6	206.5	.146E-02	9.9	284.0	1.8	.483	
600	49.0	204.1	.105E-02	8.1	285.7	2.2	.346	
700	45.8	199.1	.653E-03	4.8	289.7	4.7	.216	
800	44.6	201.6	.505E-03	4.2	287.4	2.1	.167	
900	43.0	200.6	.338E-03	2.8	288.0	1.8	.111	2
1000	39.9	197.6	.220E-03	.2	290.5	3.8	.072	2

D5 8

0	59.6	234.5	.275E-02	24.7	263.6	0	1.000	
100	55.4	215.4	.397E-02	16.0	277.4	11.0	1.444	
200	54.3	214.9	.360E-02	14.8	277.6	1.2	1.308	
300	54.4	212.2	.305E-02	14.4	279.9	1.6	1.109	
301	52.8	211.7	.265E-02	12.7	279.9	1.7	.965	
400	51.3	211.8	.219E-02	11.4	279.5	1.5	.796	
600	48.7	203.4	.116E-02	7.8	286.3	6.0	.423	
800	45.6	200.5	.584E-03	4.8	288.4	3.6	.212	
1000	39.5	202.1	.252E-03	.5	286.3	6.2	.092	2

D5 9

0	72.8	161.6	.313E-02	35.4	318.4	0	1.000	
100	57.6	207.4	.245E-02	16.9	284.5	23.4	.785	
200	55.6	206.9	.215E-02	14.7	284.5	2.0	.689	
300	54.7	206.0	.185E-02	13.7	285.1	1.1	.592	
301	54.7	206.0	.185E-02	13.7	285.1	.0	.592	
400	53.9	204.2	.148E-02	12.6	286.4	1.3	.475	
600	49.2	203.2	.829E-03	8.2	286.5	4.7	.265	
800	46.8	205.3	.403E-03	6.5	284.4	2.8	.129	
1000	39.8	200.2	.181E-03	.4	288.1	7.9	.058	2

D5 10

0	51.1	238.2	.471E-02	17.8	257.3	0	1.000	
100	57.4	213.8	.448E-02	17.7	279.3	15.5	.951	
200	56.4	213.5	.409E-02	16.7	279.2	1.0	.868	
300	55.5	212.4	.357E-02	15.5	279.9	1.1	.758	
301	55.5	212.4	.357E-02	15.5	279.9	0	.758	
400	54.9	202.4	.297E-02	13.3	288.0	5.7	.631	
500	53.5	200.1	.169E-02	11.8	289.8	1.9	.360	
600	53.6	199.7	.170E-02	11.8	290.1	.2	.361	
700	55.2	195.2	.126E-02	12.9	294.1	3.1	.267	
800	50.1	196.8	.911E-03	8.2	292.2	5.2	.193	
900	48.4	195.5	.618E-03	6.6	293.1	1.9	.131	2
1000	46.8	192.1	.424E-03	5.0	295.9	2.8	.090	2
1100	44.5	192.5	.284E-03	3.1	295.5	2.3	.060	2
1200	45.0	193.8	.175E-03	3.7	294.4	1.1	.037	2

DMAG	**** MAGNETIZATION **** DIP	DEC	J	POLE POSITION LAT	LONG	ANG	J/J0	
D6 1								
0	57.7	203.8	.821E-03	16.4	287.3	0	1.000	
50	41.1	232.4	.869E-03	8.2	259.5	24.6	1.058	
100	58.7	211.7	.625E-03	18.7	281.3	21.9	.761	
150	57.6	215.3	.553E-03	18.1	278.1	2.2	.674	
200	57.6	215.6	.492E-03	18.2	277.9	.2	.599	
201	57.3	214.7	.422E-03	17.8	278.5	.5	.514	
400	54.6	213.6	.259E-03	14.8	278.7	2.8	.315	
600	52.8	217.4	.135E-03	13.9	275.2	2.8	.165	
601	53.6	220.0	.149E-03	15.2	273.2	1.7	.181	
800	65.0	211.6	.573E-04	26.1	283.2	12.1	.070	2
D6 2								
0	83.8	224.0	.154E-02	56.7	291.1	0	1.000	
25	68.0	215.6	.116E-02	30.6	281.5	15.9	.756	
50	61.8	212.3	.972E-03	22.2	281.6	6.4	.631	
100	59.4	213.0	.858E-03	19.6	280.4	2.4	.558	
150	58.1	217.2	.771E-03	19.0	276.7	2.5	.501	
200	57.6	214.6	.676E-03	18.0	278.7	1.5	.439	
201	57.6	214.6	.676E-03	18.0	278.7	0	.439	
400	55.5	213.9	.434E-03	15.8	278.7	2.1	.282	2
600	52.9	215.7	.243E-03	13.6	276.6	2.8	.158	2
601	52.9	215.7	.243E-03	13.6	276.6	0	.158	2
800	51.6	215.1	.117E-03	12.3	276.8	1.3	.076	2
1000	56.4	214.2	.462E-04	16.7	278.6	4.8	.030	2
D6 4								
0	50.1	266.2	.774E-03	26.6	233.4	0	1.000	
50	60.3	215.8	.843E-03	21.2	278.5	29.6	1.089	
100	59.6	214.8	.711E-03	20.2	279.0	.9	.919	
150	59.2	217.3	.631E-03	20.2	276.9	1.3	.815	
200	59.7	213.9	.573E-03	20.1	279.8	1.8	.740	
201	56.4	211.3	.489E-03	16.2	281.0	3.5	.632	
400	55.6	215.0	.293E-03	16.0	277.8	2.2	.379	
600	52.1	217.4	.148E-03	13.2	274.9	3.8	.191	
601	56.4	218.4	.162E-03	17.6	275.3	4.4	.210	
800	53.0	224.2	.765E-04	15.6	269.6	4.8	.099	2
D6 5								
0	49.9	229.4	.130E-02	14.2	264.4	0	1.000	
50	54.2	208.6	.101E-02	13.6	282.8	13.4	.775	
100	55.1	211.1	.738E-03	14.9	280.9	1.7	.569	
150	54.5	211.7	.614E-03	14.4	280.3	.7	.474	
200	56.6	213.4	.527E-03	16.8	279.4	2.3	.406	
201	58.2	222.1	.459E-03	20.2	272.9	5.0	.354	
400	56.8	223.7	.336E-03	19.1	271.1	1.6	.259	
600	53.4	224.6	.222E-03	16.0	269.4	3.5	.171	
601	52.5	223.8	.245E-03	15.0	269.7	1.0	.189	
800	50.8	230.4	.134E-03	15.3	263.7	4.4	.103	2
D6 6								
0	64.3	203.9	.166E-02	24.0	288.7	0	1.000	
50	54.3	200.0	.883E-03	12.5	289.9	10.2	.532	
100	55.6	205.5	.566E-03	14.5	285.6	3.4	.342	
150	57.3	209.7	.362E-03	16.9	282.5	2.9	.218	
200	55.8	207.5	.275E-03	14.9	284.0	2.0	.166	
201	56.9	213.8	.238E-03	17.1	279.1	3.7	.143	
400	55.9	221.8	.141E-03	17.8	272.4	4.5	.085	
600	48.9	231.2	.825E-04	13.8	262.5	9.0	.050	

D6 7

0	82.7	235.5	.249E-02	56.3	284.9	0	1.000	
25	60.5	214.0	.133E-02	21.0	280.0	22.8	.535	
50	57.0	215.7	.118E-02	17.6	277.6	3.6	.472	
100	55.7	214.7	.735E-03	16.1	278.1	1.4	.295	
150	55.2	217.2	.465E-03	16.1	276.0	1.5	.187	
200	54.8	218.5	.341E-03	16.0	274.8	.9	.137	
201	54.8	218.5	.341E-03	16.0	274.8	.0	.137	
400	52.2	216.5	.200E-03	13.2	275.7	2.9	.080	2
600	47.3	220.2	.116E-03	9.7	271.5	5.5	.046	2
601	47.3	220.2	.116E-03	9.7	271.5	0	.046	
800	33.9	223.1	.685E-04	.9	266.2	13.6	.027	2
1000	14.8	231.9	.375E-04	-7.1	254.8	20.6	.015	2

D6 9

0	53.3	215.4	.246E-02	13.9	276.9	0	1.000	
50	53.2	203.5	.132E-02	11.8	286.9	7.1	.534	
100	54.6	204.2	.860E-03	13.3	286.5	1.5	.349	
150	54.4	203.4	.597E-03	13.0	287.1	.5	.242	
200	56.2	205.1	.490E-03	15.0	286.0	2.0	.199	
201	55.8	209.8	.429E-03	15.3	282.1	2.7	.174	
400	55.2	211.4	.314E-03	15.0	280.7	1.1	.127	
600	54.4	211.7	.214E-03	14.3	280.2	.8	.087	
601	53.9	207.1	.219E-03	13.0	283.9	2.7	.089	
800	50.6	211.2	.138E-03	10.7	279.9	4.1	.056	2

D6 11

0	83.5	77.8	.149E-02	65.9	338.7	0	1.000	
50	74.6	208.5	.554E-03	39.3	289.3	20.3	.371	
100	64.8	210.0	.406E-03	25.5	284.3	9.8	.272	
150	59.7	208.0	.351E-03	19.2	284.5	5.2	.235	
200	55.4	211.6	.304E-03	15.3	280.6	4.7	.204	
201	57.5	220.9	.262E-03	19.2	273.6	5.5	.175	
400	49.2	212.5	.194E-03	9.7	278.5	9.6	.130	
600	46.5	207.4	.134E-03	6.5	282.4	4.4	.089	
601	46.5	207.4	.134E-03	6.5	282.4	0	.089	
800	31.9	226.7	.722E-04	.6	262.6	20.8	.048	2

DYKE D7

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	

D7 1

0	60.7	195.3	.884E-03	18.8	294.6	0	1.000	
50	64.5	190.6	.578E-03	23.1	298.7	4.4	.654	
100	64.0	190.8	.476E-03	22.5	298.5	.5	.539	
150	63.0	189.3	.421E-03	21.2	299.5	1.2	.476	
151	62.9	191.1	.423E-03	21.2	298.1	.8	.479	
200	63.3	190.5	.389E-03	21.6	298.6	.5	.441	
400	63.0	187.5	.265E-03	21.1	300.9	1.4	.300	
600	60.7	178.8	.178E-03	18.2	307.6	4.7	.202	

D7 3

0	57.0	239.8	.321E-03	23.6	258.3	0	1.000	
25	62.4	194.4	.224E-03	20.8	295.6	23.0	.699	
50	59.6	195.4	.188E-03	17.6	294.4	2.9	.586	
100	58.5	195.6	.141E-03	16.4	294.1	1.1	.441	
150	57.7	200.5	.116E-03	16.0	290.1	2.7	.363	
151	57.7	200.5	.116E-03	16.0	290.1	0	.363	
200	55.6	200.2	.108E-03	13.7	290.0	2.2	.336	
400	57.4	199.8	.702E-04	15.6	290.6	1.9	.219	2
600	63.1	217.6	.446E-04	24.8	278.1	10.5	.139	2

D7 4								
0	74.7	265.5	.357E-03	52.2	255.5	0	1.000	
50	68.4	206.3	.215E-03	29.8	288.1	18.8	.602	
100	60.8	206.5	.166E-03	20.2	285.9	7.6	.465	
150	60.6	209.4	.143E-03	20.3	283.6	1.4	.401	
151	57.9	197.7	.138E-03	16.0	292.3	6.5	.386	
200	59.3	204.1	.131E-03	18.2	287.4	3.6	.366	
400	58.3	194.1	.796E-04	16.0	295.3	5.3	.223	
600	61.2	191.1	.580E-04	19.1	297.9	3.2	.163	
D7 5								
0	46.9	219.3	.456E-03	9.2	272.2	0	1.000	
50	66.1	187.4	.372E-03	25.1	301.2	25.5	.817	
100	63.0	190.8	.299E-03	21.3	298.4	3.4	.655	
150	61.0	190.1	.253E-03	18.9	298.7	2.0	.556	
151	59.9	196.2	.272E-03	17.9	293.8	3.2	.597	
200	58.3	195.2	.238E-03	16.2	294.4	1.6	.522	
400	58.0	184.6	.151E-03	15.2	302.9	5.6	.332	
600	55.7	195.8	.976E-04	13.4	293.6	6.5	.214	
D7 6								
0	67.7	179.0	.181E-03	27.1	307.3	0	1.000	
50	68.3	201.8	.125E-03	29.2	291.3	8.5	.690	
100	65.8	192.2	.896E-04	25.0	297.7	4.5	.495	
150	63.6	196.3	.735E-04	22.3	294.3	2.9	.406	
151	60.0	194.0	.741E-04	17.9	295.6	3.8	.409	
200	58.2	190.2	.715E-04	15.7	298.4	2.6	.395	
400	60.9	195.1	.461E-04	19.1	294.8	3.6	.255	
600	55.9	194.5	.359E-04	13.5	294.7	5.1	.198	
D7 8								
0	67.8	176.9	.118E-02	27.3	308.8	0	1.000	
25	66.8	195.2	.905E-03	26.4	295.6	7.1	.769	
50	64.4	202.0	.851E-03	23.9	290.2	3.7	.723	
100	62.2	202.5	.729E-03	21.3	289.3	2.2	.620	
150	62.2	202.0	.592E-03	21.2	289.7	.2	.503	
151	62.2	202.0	.592E-03	21.2	289.7	.0	.503	
200	62.7	202.3	.544E-03	21.9	289.5	.6	.462	
400	62.6	199.9	.342E-03	21.5	291.4	1.1	.291	2
600	59.8	197.3	.186E-03	18.0	293.0	3.0	.158	2
800	58.2	197.0	.104E-03	16.2	293.0	1.6	.089	2
1000	57.5	202.4	.564E-04	16.0	288.5	2.9	.048	2
D7 9								
0	65.3	195.6	.865E-03	24.6	295.1	0	1.000	
50	64.1	199.8	.504E-03	23.3	291.7	2.2	.583	
100	61.0	201.6	.393E-03	19.8	289.8	3.2	.454	
150	60.9	199.1	.346E-03	19.4	291.7	1.2	.400	
151	58.3	204.6	.335E-03	17.2	286.9	3.8	.388	
200	60.6	201.0	.292E-03	19.3	290.1	2.9	.338	
400	58.3	199.6	.190E-03	16.5	290.9	2.5	.220	
600	56.8	192.4	.109E-03	14.3	296.5	4.1	.126	
D7 10								
0	68.3	115.0	.386E-03	37.8	352.2	0	1.000	
50	65.0	185.6	.296E-03	23.5	302.5	26.7	.767	
100	63.8	184.6	.242E-03	22.0	303.1	1.2	.627	
150	63.2	187.0	.204E-03	21.3	301.3	1.2	.530	
151	59.5	184.8	.215E-03	16.8	302.8	3.9	.559	
200	59.1	186.4	.193E-03	16.5	301.5	.9	.500	
400	60.4	184.4	.135E-03	17.9	303.2	1.6	.349	
600	59.1	179.4	.908E-04	16.4	307.1	2.8	.235	

DYKE D8

DMAG	**** MAGNETIZATION **** DIP	DEC	J	POLE POSITION LAT	LONG	ANG	J/J0	
D8 2								
0	62.0	272.4	.177E-02	39.8	235.3	0	1.000	
50	63.7	210.5	.841E-03	24.3	283.7	27.2	.475	
100	59.5	210.9	.668E-03	19.4	282.1	4.3	.377	
150	58.6	206.7	.568E-03	17.8	285.2	2.3	.320	
200	56.0	209.5	.498E-03	15.5	282.4	3.0	.281	
201	56.0	209.5	.498E-03	15.5	282.4	.0	.281	
400	52.6	208.2	.317E-03	11.9	282.8	3.6	.179	2
600	48.3	201.5	.182E-03	7.2	287.8	6.0	.102	2
800	42.8	208.7	.113E-03	3.9	280.8	7.4	.064	2
1000	33.9	229.2	.630E-04	2.6	260.7	18.3	.036	2
D8 3								
0	63.6	254.3	.186E-02	35.1	250.7	0	1.000	
50	68.6	217.2	.102E-02	31.7	280.6	15.6	.548	
100	62.4	211.0	.779E-03	22.8	282.9	6.7	.420	
150	59.8	210.3	.681E-03	19.6	282.7	2.7	.367	
200	59.4	207.8	.597E-03	18.8	284.5	1.3	.322	
201	59.4	207.8	.597E-03	18.8	284.5	.0	.322	
400	53.6	207.9	.369E-03	12.9	283.2	5.8	.199	2
600	48.9	204.7	.203E-03	8.1	285.1	5.1	.110	2
800	38.1	212.3	.125E-03	1.2	276.8	12.1	.068	2
1000	38.4	204.3	.645E-04	-.0	284.1	6.3	.035	2
D8 4								
0	86.2	95.8	.119E-02	64.7	324.4	0	1.000	
50	69.8	211.0	.506E-03	32.3	285.4	22.1	.426	
100	59.8	209.3	.484E-03	19.5	283.4	9.9	.407	
150	58.0	208.1	.425E-03	17.3	283.9	2.0	.357	
200	57.0	208.6	.382E-03	16.4	283.4	1.0	.321	
D8 5								
0	50.5	77.5	.217E-02	33.3	34.1	0	1.000	
25	79.4	159.1	.727E-03	46.7	317.2	39.2	.334	
50	66.2	191.1	.501E-03	25.3	298.5	15.8	.230	
100	61.8	203.8	.360E-03	21.0	288.2	7.0	.166	
150	60.5	209.8	.281E-03	20.3	283.2	3.2	.129	2
200	55.0	208.3	.244E-03	14.3	283.2	5.5	.112	2
D8 7								
0	62.7	230.6	.287E-02	27.2	268.1	0	1.000	
25	66.3	207.8	.440E-03	27.1	286.4	10.4	.154	
50	61.8	207.3	.243E-03	21.5	285.5	4.4	.085	
100	58.0	207.4	.148E-03	17.2	284.6	3.9	.052	
150	54.7	209.0	.113E-03	14.2	282.6	3.3	.039	2
200	47.8	213.1	.963E-04	8.6	277.7	7.4	.034	2
D8 8								
0	-15.4	247.6	.282E-03	-16.0	234.3	0	1.000	
50	58.2	202.8	.529E-04	16.8	288.3	82.3	.188	
100	48.2	205.4	.307E-04	7.7	284.5	10.1	.109	2
150	51.4	220.9	.225E-04	13.3	271.9	10.5	.080	2
200	64.8	178.7	.129E-04	23.2	307.6	25.3	.046	2

D8 9								
0	20.8	253.9	.216E-02	3.6	235.6	0	1.000	
50	59.6	214.7	.203E-03	20.2	279.2	47.8	.094	
100	54.5	198.6	.137E-03	12.6	291.1	10.1	.063	
150	54.5	190.5	.984E-04	11.9	297.9	4.7	.046	
200	39.0	208.2	.940E-04	1.0	280.7	19.6	.044	2
D8 10								
0	-47.7	174.4	.305E-03	-52.1	314.7	0	1.000	
50	71.3	208.0	.307E-03	34.1	288.1	121.3	1.007	
100	62.5	209.6	.187E-03	22.7	284.0	8.8	.613	
150	51.0	192.1	.139E-03	8.6	296.3	14.9	.454	
200	52.7	209.0	.123E-03	12.2	282.1	10.6	.402	2

DYKE D9

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D9 2								
0	88.1	145.1	.182E-03	63.4	311.4	0	1.000	
50	63.2	210.6	.488E-04	23.7	283.4	26.1	.268	
100	65.2	217.8	.292E-04	27.3	278.7	3.7	.160	
150	68.6	229.8	.197E-04	34.3	271.9	5.8	.108	
200	71.4	232.8	.213E-04	38.8	271.9	3.0	.117	
D9 4								
0	83.9	191.7	.628E-03	54.6	302.4	0	1.000	
50	55.6	224.9	.275E-03	18.2	269.8	29.5	.438	
100	58.2	227.5	.238E-03	21.5	268.6	3.0	.379	
150	56.2	228.2	.217E-03	19.6	267.3	2.1	.345	
200	59.5	230.7	.188E-03	23.6	266.5	3.5	.299	
201	55.8	228.3	.162E-03	19.3	267.1	3.9	.258	
400	53.5	214.9	.955E-04	14.1	277.4	8.1	.152	2
600	55.4	216.2	.422E-04	16.1	276.8	2.0	.067	2
D9 5								
0	79.8	223.2	.733E-03	49.8	285.5	0	1.000	
25	66.4	220.5	.431E-03	29.4	277.3	13.4	.589	
50	60.9	220.5	.346E-03	22.8	275.1	5.5	.473	
100	56.8	218.1	.308E-03	17.9	275.6	4.3	.420	
150	56.0	217.0	.280E-03	16.9	276.3	1.0	.382	
200	58.4	218.6	.249E-03	19.7	275.7	2.6	.340	
201	58.4	218.6	.249E-03	19.7	275.7	2.6	.340	
400	54.6	218.7	.133E-03	15.8	274.5	3.8	.182	2
600	42.7	230.5	.740E-04	8.8	261.5	14.2	.101	2
800	41.9	211.0	.370E-04	3.6	278.6	14.4	.050	2
D9 6								
0	75.3	277.1	.478E-03	56.6	249.6	0	1.000	
100	61.9	225.4	.153E-03	25.0	271.7	21.9	.320	
150	59.2	230.7	.132E-03	23.3	266.5	3.7	.277	
200	56.8	230.3	.121E-03	20.7	265.8	2.4	.254	
201	55.3	237.0	.101E-03	21.1	259.8	4.0	.211	
400	41.2	231.9	.536E-04	8.1	259.9	14.6	.112	2
600	35.6	240.0	.250E-04	6.9	251.4	8.5	.052	2

D9 7								
0	81.5	141.6	.204E-03	52.0	323.5	0	1.000	
50	51.4	214.8	.124E-03	12.1	277.0	36.9	.607	
100	50.0	215.7	.103E-03	11.0	276.0	1.5	.503	
150	49.3	218.8	.843E-04	11.0	273.1	2.2	.413	
200	52.6	219.6	.804E-04	14.1	273.3	3.4	.394	
201	47.5	215.9	.793E-04	8.9	275.2	5.6	.389	
400	42.4	214.0	.372E-04	4.6	276.0	5.2	.182	2
600	31.2	206.0	.211E-04	-4.4	281.7	12.9	.103	2
D9 8								
0	64.8	329.3	.522E-03	64.5	181.2	0	1.000	
50	64.0	226.2	.328E-03	27.6	272.0	39.6	.627	
100	58.6	228.3	.273E-03	22.1	268.1	5.5	.522	
150	57.7	222.9	.260E-03	19.8	272.0	3.0	.497	
200	57.7	223.5	.225E-03	20.0	271.6	.3	.431	
201	56.9	231.5	.203E-03	18.3	263.9	5.9	.389	
400	53.7	228.9	.107E-03	17.4	265.9	1.5	.205	2
600	54.0	244.1	.434E-04	22.1	253.5	9.0	.083	2
D9 9								
0	67.1	194.3	.619E-03	26.8	296.3	.0	1.000	
50	60.3	214.0	.484E-03	20.8	279.9	11.0	.782	
100	57.8	219.9	.445E-03	19.3	274.5	3.9	.719	
150	58.8	218.4	.407E-03	20.0	276.0	1.3	.658	
200	56.3	218.3	.369E-03	17.5	275.4	2.4	.596	
201	56.2	222.9	.327E-03	18.3	271.6	2.6	.529	
400	53.8	222.2	.179E-03	15.9	271.4	2.4	.289	2
600	53.6	208.6	.768E-04	13.0	282.6	8.0	.124	2
D9 10								
0	70.4	229.7	.810E-03	36.7	273.2	0	1.000	
25	67.5	229.6	.480E-03	32.8	271.4	2.9	.592	
50	60.7	227.5	.388E-03	24.2	269.6	6.8	.478	
100	58.9	231.0	.339E-03	23.1	266.1	2.5	.419	
150	57.9	228.4	.310E-03	21.3	267.7	1.8	.382	
200	57.6	228.4	.274E-03	21.1	267.7	.3	.338	
201	57.6	228.4	.274E-03	21.1	267.7	.0	.338	
400	56.1	230.4	.158E-03	20.0	265.5	1.9	.195	2
600	50.6	236.7	.739E-04	16.8	258.4	6.6	.091	2
800	49.6	233.1	.292E-04	14.9	261.1	2.5	.036	2

DYKE D11

	**** MAGNETIZATION ****			POLE POSITION			
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0
D11 2							
0	63.2	208.7	.470E-02	23.4	284.5	0	1.000
50	54.9	207.1	.388E-02	14.0	283.9	8.3	.825
100	55.4	206.5	.357E-02	14.4	284.4	.6	.760
200	53.9	208.3	.320E-02	13.2	282.7	1.8	.681
300	53.2	207.0	.261E-02	12.4	283.6	1.0	.556
400	54.0	207.7	.207E-02	13.2	283.1	.9	.441
500	53.9	206.0	.150E-02	12.9	284.6	1.0	.319
D11 3							
0	60.2	217.1	.272E-02	21.3	277.2	0	1.000
25	57.1	214.1	.236E-02	17.4	278.6	3.5	.869
50	55.9	216.0	.219E-02	16.5	276.7	1.6	.807
100	54.9	214.8	.197E-02	15.3	277.5	1.2	.725
150	55.8	215.2	.179E-02	16.3	277.4	1.0	.658
200	55.7	214.8	.163E-02	16.1	277.7	.2	.599

300	54.6	215.2	.135E-02	15.1	277.1	1.1	.497	
400	53.8	215.3	.113E-02	14.4	276.9	.8	.415	2
500	53.5	212.4	.925E-03	13.6	279.1	1.7	.340	2
600	52.2	213.6	.624E-03	12.6	277.9	1.5	.230	2
800	50.6	212.7	.287E-03	10.9	278.3	1.8	.106	2
1000	46.7	215.4	.106E-03	8.2	275.2	4.3	.039	2
D11 4								
0	65.3	208.2	.762E-03	26.0	285.5	0	1.000	
50	59.3	206.3	.558E-03	18.5	285.4	6.1	.732	
100	59.4	207.9	.467E-03	18.8	284.1	.8	.614	
200	55.9	206.8	.388E-03	15.0	284.3	3.5	.510	
300	55.5	205.4	.325E-03	14.4	285.3	.9	.426	
400	54.6	206.4	.248E-03	13.6	284.3	1.1	.325	
500	60.9	207.0	.172E-03	20.4	285.2	6.3	.226	
D11 5								
0	76.0	209.5	.136E-02	41.7	289.2	0	1.000	
50	64.7	204.2	.734E-03	24.6	288.3	11.4	.542	
100	57.9	212.0	.689E-03	17.9	280.5	7.7	.509	
200	57.0	211.2	.544E-03	16.8	281.0	1.0	.401	
300	56.2	209.7	.430E-03	15.7	282.0	1.2	.317	
400	55.1	209.2	.330E-03	14.6	282.2	1.1	.244	
500	54.4	209.2	.246E-03	13.9	282.0	.7	.181	
D11 6								
0	62.2	202.1	.146E-02	21.3	289.3	0	1.000	
50	56.7	199.5	.111E-02	14.8	290.4	5.7	.759	
100	56.9	201.0	.992E-03	15.2	289.2	.9	.681	
200	56.7	202.4	.822E-03	15.1	288.0	.8	.564	
300	55.1	199.8	.676E-03	13.3	289.9	2.1	.464	
400	55.6	201.7	.531E-03	14.0	288.4	1.2	.364	
500	53.3	198.4	.413E-03	11.3	290.9	3.0	.284	
D11 8								
0	59.8	204.1	.190E-02	18.7	287.3	0	1.000	
50	59.7	208.1	.142E-02	19.2	284.1	2.0	.744	
100	59.1	208.8	.120E-02	18.7	283.4	.7	.633	
200	60.1	206.1	.975E-03	19.3	285.7	1.7	.513	
300	58.0	207.9	.858E-03	17.3	283.8	2.3	.451	
400	57.6	205.6	.613E-03	16.6	285.6	1.3	.322	
500	57.4	205.2	.474E-03	16.3	285.9	.3	.249	
D11 9								
0	66.9	216.6	.259E-02	29.3	279.9	0	1.000	
25	63.7	211.0	.207E-02	24.4	282.9	3.9	.800	
50	61.7	209.5	.187E-02	21.7	283.5	2.1	.724	
100	61.1	209.2	.165E-02	20.9	283.6	.7	.637	
150	60.3	208.6	.149E-02	20.0	283.8	.8	.576	
200	60.4	209.0	.134E-02	20.1	283.5	.2	.518	
300	60.2	208.6	.108E-02	19.8	283.8	.3	.419	
400	59.4	206.9	.871E-03	18.6	285.0	1.2	.337	2
500	58.3	208.3	.683E-03	17.7	283.6	1.3	.264	2
600	56.9	204.4	.451E-03	15.6	286.5	2.5	.174	2
800	52.5	203.8	.196E-03	11.3	286.2	4.4	.076	2
1000	43.1	202.5	.827E-04	3.2	286.0	9.4	.032	2
D11 10								
0	67.9	203.5	.826E-03	28.8	289.7	0	1.000	
50	61.4	208.5	.634E-03	21.2	284.2	6.9	.768	
100	60.6	212.7	.577E-03	20.9	280.7	2.2	.699	
200	59.5	209.6	.477E-03	19.3	282.9	1.9	.577	
300	59.1	210.4	.372E-03	18.9	282.1	.6	.450	
400	57.7	209.4	.289E-03	17.2	282.6	1.5	.350	
500	57.1	204.9	.198E-03	15.9	286.1	2.5	.240	

DYKE D12

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D12 1								
0	56.0	227.3	.625E-02	19.2	267.6	0	1.000	
50	53.0	215.3	.311E-02	13.6	276.6	7.6	.498	
100	51.1	212.8	.259E-02	11.4	278.3	2.4	.415	
150	48.9	211.3	.234E-02	9.3	279.2	2.4	.375	
200	49.7	211.8	.222E-02	10.0	278.9	.8	.354	
300	49.4	210.0	.199E-02	9.4	280.4	1.2	.319	
400	48.5	209.8	.154E-02	8.6	280.4	1.0	.246	
401	47.6	212.1	.171E-02	8.2	278.3	1.8	.274	
600	47.5	210.1	.118E-02	7.8	279.9	1.3	.188	
800	46.2	208.5	.581E-03	6.5	281.1	1.6	.093	2
1000	41.5	200.4	.281E-03	1.7	287.8	7.6	.045	2
D12 2								
0	64.1	224.4	.769E-02	27.3	273.1	0	1.000	
50	59.8	219.1	.428E-02	21.2	275.4	5.0	.556	
100	54.7	219.2	.338E-02	16.0	273.8	5.1	.439	
200	50.1	220.4	.276E-02	12.1	271.7	4.6	.359	
300	48.6	221.2	.241E-02	11.1	270.6	1.6	.313	
400	47.2	222.1	.203E-02	10.1	269.5	1.6	.264	
401	46.4	220.5	.201E-02	9.1	270.7	1.4	.261	
600	45.1	219.7	.127E-02	7.9	271.2	1.4	.166	
800	42.2	219.6	.689E-03	5.7	270.7	2.9	.090	2
1000	37.6	221.6	.291E-03	3.0	268.0	4.9	.038	2
D12 3								
0	67.6	225.5	.105E-01	32.0	274.0	0	1.000	
50	62.9	213.6	.557E-02	23.8	280.7	6.8	.533	
100	55.9	213.4	.413E-02	16.0	278.9	7.1	.395	
200	51.1	211.9	.303E-02	11.2	279.1	4.8	.290	
300	47.9	210.3	.255E-02	8.2	279.8	3.4	.244	
400	46.1	212.3	.202E-02	7.1	277.8	2.2	.193	
401	43.4	209.6	.202E-02	4.5	279.7	3.3	.193	
600	41.9	210.7	.129E-02	3.5	278.5	1.7	.124	
800	39.4	210.8	.644E-03	1.8	278.1	2.4	.062	2
1000	40.2	220.8	.232E-03	4.5	269.2	7.8	.022	2
D12 4								
0	64.9	245.2	.642E-02	33.6	258.0	0	1.000	
50	55.0	220.9	.359E-02	16.7	272.5	15.5	.560	
100	52.3	219.5	.322E-02	13.9	273.0	2.8	.502	
200	50.3	216.9	.286E-02	11.5	274.7	2.6	.446	
300	49.4	216.8	.238E-02	10.7	274.6	.9	.372	
400	49.5	216.6	.199E-02	10.7	274.8	.1	.310	
401	50.4	216.3	.205E-02	11.5	275.2	1.0	.320	
600	48.0	214.5	.125E-02	9.1	276.3	2.7	.194	
800	45.3	216.6	.654E-03	7.3	273.9	3.1	.102	2
1000	36.3	218.7	.281E-03	1.4	270.4	9.1	.044	2
D12 6								
0	69.4	222.8	.622E-02	33.9	276.9	0	1.000	
50	58.7	224.3	.378E-02	21.2	271.0	10.7	.608	
100	55.6	221.9	.326E-02	17.5	271.9	3.4	.525	
200	54.0	223.3	.277E-02	16.3	270.2	1.8	.445	
300	54.1	222.8	.230E-02	16.3	270.8	.4	.370	
400	53.5	222.8	.184E-02	15.7	270.6	.7	.296	

401	53.4	223.6	.191E-02	15.8	269.9	.5	.308	
600	53.6	226.0	.115E-02	16.6	268.0	1.5	.185	
800	51.1	222.1	.526E-03	13.4	270.5	3.4	.085	2
1000	49.6	223.8	.232E-03	12.5	268.6	1.9	.037	2
D12 7								
0	60.9	226.4	.974E-02	24.0	270.1	0	1.000	
50	57.2	219.0	.644E-02	18.4	274.7	5.3	.662	
100	55.4	216.6	.539E-02	16.2	276.1	2.2	.553	
200	55.6	216.0	.459E-02	16.3	276.7	.4	.471	
300	54.1	215.5	.387E-02	14.7	276.7	1.5	.398	
400	54.6	215.8	.314E-02	15.3	276.7	.5	.323	
401	54.5	215.6	.316E-02	15.1	276.8	.2	.325	
600	53.4	216.3	.184E-02	14.2	275.9	1.2	.189	
800	54.3	214.4	.921E-03	14.7	277.7	1.4	.095	2
1000	51.6	216.7	.334E-03	12.6	275.2	3.0	.034	2
D12 8								
0	63.6	211.1	.982E-02	24.2	282.8	0	1.000	
50	58.4	208.1	.686E-02	17.8	283.8	5.4	.699	
100	56.6	208.0	.645E-02	15.9	283.4	1.8	.657	
200	56.0	208.5	.595E-02	15.4	282.9	.6	.606	
300	56.8	208.0	.521E-02	16.0	283.5	.8	.531	
400	56.2	208.5	.438E-02	15.6	283.0	.6	.447	
401	57.3	207.7	.473E-03	16.5	283.8	1.1	.048	
600	56.8	207.9	.277E-02	16.1	283.6	.4	.283	
800	55.4	209.4	.138E-02	14.9	282.1	1.6	.140	2
1000	55.9	207.7	.582E-03	15.1	283.6	1.1	.059	2
D12 9								
0	60.1	214.5	.945E-02	20.7	279.1	0	1.000	
50	50.8	216.3	.668E-02	11.8	275.3	9.3	.707	
100	49.5	217.8	.628E-02	11.1	273.8	1.6	.664	
200	49.5	216.9	.567E-02	10.9	274.5	.6	.600	
300	48.3	217.3	.498E-02	9.9	273.9	1.3	.527	
400	48.1	214.7	.412E-02	9.2	276.1	1.7	.436	
401	48.4	215.7	.414E-03	9.7	275.3	.7	.044	
600	48.0	214.9	.251E-02	9.1	275.9	.7	.266	
800	48.2	216.1	.116E-02	9.6	274.9	.9	.123	2
1000	48.5	211.6	.525E-03	8.9	278.8	3.0	.056	2

DYKE D13

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D13 1								
0	50.8	170.3	.180E-02	8.4	314.9	0	1.000	
50	46.9	170.5	.163E-02	5.0	314.9	3.9	.905	
100	44.9	170.2	.139E-02	3.4	315.3	2.0	.774	
150	42.9	170.1	.119E-02	1.8	315.5	2.0	.659	
200	42.0	168.7	.109E-02	1.2	316.8	1.4	.604	
300	42.6	165.6	.876E-03	1.9	319.6	2.4	.486	
301	42.5	165.5	.758E-03	1.8	319.7	.2	.421	
400	41.5	165.4	.640E-03	1.1	319.9	1.0	.355	
600	40.0	163.5	.416E-03	.2	321.7	2.1	.231	2
800	37.5	162.5	.282E-03	-1.4	322.8	2.6	.157	2
1000	37.0	159.0	.203E-03	-1.4	326.1	2.8	.113	2

D13 2								
0	48.0	170.4	.239E-02	5.9	315.0	0	1.000	
50	45.0	171.5	.226E-02	3.4	314.2	3.1	.949	
100	44.3	170.8	.192E-02	2.8	314.8	.9	.806	
150	45.7	170.9	.162E-02	3.9	314.6	1.4	.677	
200	42.3	168.5	.133E-02	1.5	317.0	3.8	.557	
300	40.4	165.8	.115E-02	.3	319.6	2.8	.480	
301	40.4	165.8	.115E-02	.3	319.6	.0	.480	
400	40.3	166.1	.929E-03	.2	319.3	.3	.389	2
600	39.9	166.1	.675E-03	-.1	319.4	.4	.283	2
800	37.1	164.1	.435E-03	-1.9	321.4	3.2	.182	2
1000	34.4	163.5	.292E-03	-3.6	322.2	2.7	.122	2
D13 3								
0	47.0	175.2	.200E-02	4.9	310.8	0	1.000	
50	44.3	174.6	.184E-02	2.7	311.4	2.8	.921	
100	42.7	173.3	.158E-02	1.5	312.6	1.9	.791	
150	42.0	172.8	.135E-02	1.0	313.1	.8	.673	
200	40.8	173.2	.126E-02	.1	312.8	1.2	.628	
300	40.0	171.8	.997E-03	-.4	314.1	1.3	.498	
301	40.5	173.4	.858E-03	-.1	312.6	1.3	.429	
400	40.5	172.1	.692E-03	-.1	313.8	1.0	.346	
600	39.5	170.9	.467E-03	-.8	314.9	1.4	.233	2
800	38.1	169.5	.309E-03	-1.6	316.3	1.8	.154	2
1000	36.5	168.4	.212E-03	-2.7	317.4	1.9	.106	2
D13 4								
0	49.1	171.0	.149E-02	6.8	314.4	0	1.000	
50	47.0	171.7	.139E-02	5.0	313.8	2.1	.932	
100	45.9	170.9	.120E-02	4.1	314.7	1.3	.808	
150	44.9	170.6	.102E-02	3.3	315.0	1.0	.688	
200	43.8	169.5	.879E-03	2.5	316.0	1.3	.591	
300	42.5	168.0	.689E-03	1.6	317.4	1.7	.463	
301	42.2	173.3	.571E-03	1.1	312.6	4.0	.383	
400	41.0	170.8	.479E-03	.3	315.0	2.3	.322	
600	40.6	171.1	.325E-03	.1	314.7	.4	.218	2
800	39.6	168.3	.235E-03	-.5	317.4	2.4	.158	2
1000	37.3	170.3	.154E-03	-2.3	315.6	2.8	.103	2
D13 5								
0	48.2	175.9	.168E-02	5.8	310.2	0	1.000	
50	44.6	175.9	.169E-02	2.8	310.2	3.6	1.006	
100	42.5	176.7	.146E-02	1.3	309.5	2.1	.872	
150	41.5	177.2	.128E-02	.5	309.1	1.1	.764	
200	40.3	175.5	.111E-02	-.4	310.7	1.8	.662	
300	38.4	175.1	.889E-03	-1.7	311.1	1.9	.530	
301	39.3	176.0	.697E-03	-1.1	310.3	1.2	.416	
400	39.2	175.2	.609E-03	-1.2	311.0	.6	.363	
600	37.2	174.3	.397E-03	-2.5	311.9	2.1	.237	2
800	35.1	174.1	.285E-03	-3.9	312.2	2.1	.170	2
1000	32.4	171.7	.185E-03	-5.6	314.4	3.3	.110	2
D13 7								
0	51.5	177.4	.257E-02	8.8	308.8	0	1.000	
50	46.1	179.0	.230E-02	4.0	307.4	5.5	.896	
100	44.4	178.4	.194E-02	2.7	308.0	1.8	.757	
150	42.9	177.8	.149E-02	1.5	308.5	1.5	.578	
200	42.0	176.6	.129E-02	.9	309.6	1.2	.502	
300	40.8	176.0	.114E-02	.0	310.3	1.3	.443	
301	40.8	176.0	.114E-02	.0	310.3	0	.443	
400	40.4	175.2	.876E-03	-.3	311.0	.7	.341	2
600	39.3	174.2	.601E-03	-1.0	311.9	1.3	.234	2
800	36.9	172.8	.381E-03	-2.7	313.3	2.7	.148	2
1000	35.9	170.0	.239E-03	-3.2	316.0	2.4	.093	2

D13 9

0	45.1	176.4	.125E-02	3.3	309.7	0	1.000	
50	41.1	177.3	.115E-02	.2	309.0	4.1	.921	
100	38.5	177.7	.957E-03	-1.7	308.7	2.6	.768	
150	38.0	177.2	.824E-03	-2.1	309.1	.7	.661	
200	37.2	176.0	.731E-03	-2.6	310.3	1.3	.586	
300	37.6	173.2	.561E-03	-2.2	312.9	2.2	.450	
301	36.1	177.1	.460E-03	-3.4	309.3	3.5	.369	
400	35.3	175.4	.390E-03	-3.8	310.9	1.6	.313	
600	34.1	173.6	.267E-03	-4.6	312.7	2.0	.214	2
800	32.6	173.2	.181E-03	-5.5	313.1	1.5	.145	2
1000	31.4	173.9	.115E-03	-6.3	312.4	1.3	.092	2

D13 10

0	41.6	181.4	.142E-02	.5	305.3	0	1.000	
50	40.6	181.6	.136E-02	-.2	305.1	1.0	.963	
100	39.3	179.7	.119E-02	-1.2	306.8	1.9	.840	
150	38.0	179.5	.104E-02	-2.1	307.0	1.3	.733	
200	37.6	179.3	.911E-03	-2.4	307.2	.4	.643	
300	36.7	177.8	.724E-03	-2.9	308.6	1.5	.511	
301	36.0	173.9	.573E-03	-3.3	312.3	3.2	.405	
400	35.2	174.6	.484E-03	-3.9	311.7	1.0	.342	
600	34.5	172.7	.324E-03	-4.3	313.4	1.7	.229	2
800	33.6	172.8	.217E-03	-4.9	313.4	.9	.153	2
1000	32.0	173.8	.139E-03	-5.9	312.5	1.8	.098	2

DYKE D14

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D14 2								
0	80.9	195.3	.304E-02	49.1	299.5	0	1.000	
50	73.1	196.1	.184E-02	35.9	296.3	7.8	.606	
100	70.2	194.3	.159E-02	31.3	296.8	3.0	.523	
150	71.1	198.9	.135E-02	33.0	293.9	1.8	.445	
200	70.8	195.2	.122E-02	32.3	296.3	1.2	.401	
201	70.8	197.4	.111E-02	32.5	294.8	.7	.366	
400	72.4	201.2	.783E-03	35.2	292.8	2.0	.258	
600	76.2	203.2	.529E-03	41.4	293.1	3.8	.174	
800	77.6	201.8	.322E-03	43.7	294.6	1.5	.106	2
1000	80.5	209.9	.187E-03	49.4	292.4	3.2	.062	2
D14 3								
0	78.9	182.3	.313E-02	45.2	305.4	0	1.000	
50	73.3	182.7	.194E-02	35.6	304.8	5.7	.619	
100	71.7	182.5	.155E-02	33.2	304.9	1.5	.495	
150	71.5	183.0	.135E-02	32.9	304.5	.3	.430	
200	72.1	184.1	.121E-02	33.8	303.9	.7	.388	
201	70.9	182.2	.106E-02	32.0	305.0	1.3	.340	
400	72.9	182.3	.754E-03	34.9	305.1	1.9	.241	
600	74.1	183.7	.513E-03	36.9	304.2	1.3	.164	
800	77.8	170.7	.313E-03	43.4	311.6	4.9	.100	2
1000	80.0	147.5	.171E-03	49.0	322.3	4.9	.055	2
D14 4								
0	80.2	199.5	.364E-02	48.2	297.1	0	1.000	
50	74.7	190.3	.207E-02	38.2	300.3	5.8	.568	
100	73.1	191.7	.169E-02	35.5	299.1	1.7	.463	
150	71.6	191.1	.149E-02	33.3	299.2	1.4	.408	
200	74.0	185.7	.134E-02	36.8	303.0	2.9	.367	
201	74.1	196.1	.112E-02	37.5	296.6	2.9	.307	
400	75.1	196.9	.803E-03	39.2	296.4	1.0	.221	
600	75.5	196.6	.552E-03	39.8	296.7	.4	.151	

800	76.9	191.9	.347E-03	41.9	299.8	1.8	.095	
1000	81.2	200.2	.186E-03	50.0	297.4	4.6	.051	2
D14 5								
0	84.5	175.5	.362E-02	55.6	308.1	0	1.000	
50	75.5	191.1	.217E-02	39.4	300.0	9.3	.599	
100	72.7	192.9	.177E-02	35.0	298.2	2.8	.489	
150	73.2	193.1	.155E-02	35.8	298.2	.5	.428	
200	72.3	192.2	.138E-02	34.3	298.6	.9	.381	
201	74.3	193.5	.114E-02	37.6	298.2	2.1	.313	
400	74.2	188.8	.832E-03	37.2	301.1	1.3	.230	
600	76.3	191.7	.563E-03	40.8	299.8	2.2	.155	
800	76.3	191.7	.353E-03	40.8	299.8	.0	.097	
1000	78.5	192.4	.207E-03	44.8	300.0	2.3	.057	2
D14 6								
0	79.8	225.4	.719E-02	50.3	284.4	0	1.000	
50	67.7	220.4	.437E-02	31.2	277.9	12.2	.607	
100	65.0	204.6	.379E-02	25.1	288.3	6.9	.527	
150	63.6	202.2	.320E-02	23.1	289.7	1.7	.445	
200	62.7	198.8	.277E-02	21.6	292.2	1.8	.385	
201	62.6	201.6	.232E-02	21.7	290.0	1.3	.322	
400	61.5	196.8	.136E-02	20.0	293.5	2.5	.190	
600	60.5	193.1	.930E-03	18.6	296.3	2.1	.129	
800	58.5	191.5	.563E-03	16.2	297.3	2.2	.078	
1000	55.5	182.5	.342E-03	12.7	304.5	5.7	.048	2
D14 7								
0	84.7	219.8	.838E-02	57.9	293.9	0	1.000	
25	75.1	204.5	.578E-02	39.7	291.8	10.0	.690	
50	70.9	222.0	.456E-02	35.9	278.5	6.5	.543	
100	67.1	221.7	.369E-02	30.6	276.6	3.8	.440	
150	73.1	222.5	.398E-02	39.2	279.6	6.0	.474	
200	63.8	222.2	.268E-02	26.6	274.7	9.3	.320	
201	63.8	222.2	.268E-02	26.6	274.7	.0	.320	
400	64.2	216.7	.153E-02	26.0	279.0	2.5	.183	2
600	64.4	213.4	.987E-03	25.7	281.6	1.5	.118	2
800	63.7	211.9	.590E-03	24.5	282.4	1.0	.070	2
1000	61.8	210.5	.325E-03	22.1	282.9	2.0	.039	2
D14 9								
0	86.1	246.0	.802E-02	62.5	291.0	0	1.000	
25	84.0	232.0	.638E-02	57.9	288.7	2.4	.796	
50	80.3	238.3	.507E-02	53.2	279.2	3.8	.632	
100	74.1	223.0	.361E-02	40.8	280.1	7.0	.451	
150	74.4	219.2	.310E-02	40.7	282.6	1.1	.387	
200	71.5	215.2	.258E-02	35.5	283.3	3.2	.322	
201	71.5	215.2	.258E-02	35.5	283.3	.0	.322	
400	72.1	218.3	.148E-02	37.0	281.7	1.2	.185	2
600	71.7	222.1	.999E-03	37.0	278.9	1.3	.125	2
800	73.0	229.3	.625E-03	40.4	275.2	2.6	.078	2
1000	74.0	226.7	.414E-03	41.3	277.7	1.2	.052	2
D14 10								
0	86.3	200.8	.634E-02	59.5	301.3	0	1.000	
50	67.2	207.5	.347E-02	28.4	286.8	19.1	.547	
100	66.9	211.9	.287E-02	28.6	283.5	1.8	.453	
150	64.5	211.4	.249E-02	25.4	283.0	2.5	.393	
200	63.5	207.7	.216E-02	23.6	285.6	1.9	.340	
201	62.8	205.7	.180E-02	22.5	286.9	1.1	.284	
400	61.5	203.2	.114E-02	20.6	288.5	1.8	.180	
600	59.2	199.6	.796E-03	17.7	290.9	2.9	.126	
800	56.7	198.8	.554E-03	14.8	291.1	2.6	.087	
1000	55.7	197.3	.355E-03	13.7	292.3	1.3	.056	2

DYKE D15

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D15 1								
0	64.4	173.4	.186E-02	22.9	311.5	0	1.000	
50	55.3	183.5	.163E-02	12.4	303.7	10.4	.876	
100	54.1	188.5	.126E-02	11.4	299.5	3.1	.677	
150	52.3	188.5	.115E-02	9.7	299.3	1.8	.621	
200	51.2	189.2	.101E-02	8.7	298.6	1.2	.542	
400	48.0	190.2	.615E-03	6.0	297.6	3.2	.331	2
600	46.3	192.0	.429E-03	4.7	295.9	2.1	.231	2
800	43.5	191.4	.298E-03	2.3	296.3	2.9	.160	2
1000	39.0	191.5	.202E-03	-1.0	295.9	4.5	.109	2
1200	38.5	197.2	.137E-03	-.8	290.6	4.5	.074	2
D15 2								
0	74.7	173.0	.339E-02	38.0	310.8	0	1.000	
50	57.4	181.6	.208E-02	14.6	305.3	17.6	.614	
100	52.6	185.8	.165E-02	9.9	301.6	5.3	.487	
150	45.0	179.4	.148E-02	3.1	307.0	8.7	.436	
200	49.8	186.0	.118E-02	7.3	301.3	6.5	.347	
400	48.2	190.9	.615E-03	6.2	297.0	3.6	.181	
600	45.1	192.5	.409E-03	3.7	295.4	3.3	.121	
800	44.1	190.9	.262E-03	2.8	296.8	1.5	.077	2
1000	44.2	198.8	.163E-03	3.6	289.6	5.7	.048	2
1200	40.9	217.3	.958E-04	4.2	272.7	14.0	.028	2
D15 4								
0	55.6	180.4	.155E-02	12.7	306.2	0	1.000	
50	52.9	180.6	.138E-02	10.0	306.0	2.7	.893	
100	49.5	181.6	.121E-02	6.9	305.1	3.5	.779	
150	49.2	180.8	.105E-02	6.7	305.9	.6	.681	
200	49.0	181.4	.952E-03	6.5	305.3	.5	.615	
400	47.7	184.8	.558E-03	5.4	302.3	2.6	.360	2
600	46.5	185.8	.393E-03	4.5	301.4	1.4	.254	2
800	43.7	183.7	.259E-03	2.2	303.2	3.1	.167	2
1000	42.7	184.9	.163E-03	1.5	302.1	1.3	.106	2
1200	37.5	186.8	.112E-03	-2.3	300.2	5.4	.072	2
D15 5								
0	81.4	171.7	.379E-02	49.8	310.3	0	1.000	
25	72.2	185.7	.260E-02	33.9	302.8	9.7	.688	
50	63.4	189.5	.204E-02	21.8	299.4	8.9	.539	
100	58.8	190.8	.176E-02	16.4	297.9	4.7	.464	
150	52.6	191.9	.132E-02	10.1	296.5	6.3	.349	
200	50.0	191.2	.115E-02	7.8	296.9	2.6	.304	
400	46.0	188.9	.742E-03	4.2	298.6	4.3	.196	2
600	42.8	188.8	.497E-03	1.7	298.5	3.3	.131	2
800	38.0	188.9	.348E-03	-1.8	298.3	4.8	.092	2
1000	36.3	191.7	.257E-03	-2.8	295.6	2.8	.068	2
1200	33.2	189.8	.167E-03	-5.0	297.2	3.5	.044	2
D15 8								
0	79.4	135.6	.339E-02	49.4	328.8	0	1.000	
50	64.4	185.6	.170E-02	22.8	302.3	20.4	.502	
100	57.9	189.3	.132E-02	15.3	299.0	6.7	.389	
150	54.9	189.9	.111E-02	12.3	298.3	3.0	.328	
200	49.9	187.2	.977E-03	7.4	300.3	5.3	.288	
400	50.5	191.9	.544E-03	8.3	296.3	3.1	.161	

600	46.7	192.9	.379E-03	5.0	295.1	3.9	.112	
800	42.3	194.2	.253E-03	1.7	293.6	4.4	.075	2
1000	36.1	195.6	.181E-03	-2.6	291.9	6.3	.053	2
1200	30.2	203.1	.121E-03	-5.4	284.3	8.7	.036	2
D15 9								
0	71.2	172.0	.341E-02	32.5	311.9	0	1.000	
50	58.3	186.8	.212E-02	15.7	301.0	14.3	.621	
100	55.6	188.1	.167E-02	12.9	299.9	2.8	.489	
150	54.4	190.3	.142E-02	11.8	297.9	1.7	.415	
200	53.2	188.8	.124E-02	10.6	299.1	1.5	.364	
400	50.1	185.9	.778E-03	7.5	301.5	3.6	.228	2
600	48.4	184.2	.514E-03	6.0	302.8	2.0	.151	2
800	44.4	185.8	.333E-03	2.8	301.4	4.1	.098	2
1000	44.1	190.6	.221E-03	2.8	297.0	3.4	.065	2
1200	39.6	186.9	.157E-03	-.8	300.2	5.2	.046	2
D15 11								
0	75.2	157.1	.363E-02	39.7	320.2	0	1.000	
50	62.1	180.2	.243E-02	19.9	306.4	15.3	.669	
100	57.5	182.9	.200E-02	14.8	304.2	4.7	.551	
150	54.9	186.3	.164E-02	12.2	301.3	3.2	.452	
200	53.8	188.1	.138E-02	11.1	299.8	1.6	.380	
400	49.2	184.7	.852E-03	6.8	302.5	5.0	.235	2
600	47.1	183.0	.580E-03	4.9	303.9	2.4	.160	2
800	46.7	184.9	.379E-03	4.6	302.2	1.4	.104	2
1000	45.7	186.7	.260E-03	3.9	300.6	1.5	.072	2
1200	46.4	186.9	.159E-03	4.4	300.4	.7	.044	2
D15 12								
0	85.1	149.0	.481E-02	57.8	316.0	0	1.000	
25	76.4	171.8	.286E-02	40.9	311.3	9.3	.595	
50	66.6	185.8	.208E-02	25.8	302.3	10.7	.432	
100	60.6	188.7	.160E-02	18.3	299.7	6.2	.332	
150	57.2	191.2	.131E-02	14.7	297.4	3.6	.271	
200	55.7	192.2	.111E-02	13.3	296.5	1.5	.232	
400	52.1	196.9	.691E-03	10.1	292.2	4.6	.144	2
600	48.8	197.0	.438E-03	7.2	291.7	3.3	.091	2
800	42.1	200.3	.266E-03	2.2	288.1	7.1	.055	2
1000	41.9	197.5	.170E-03	1.7	290.6	2.1	.035	2
1200	30.9	201.6	.813E-04	-5.2	285.8	11.5	.017	2

DYKE D16

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D16 1								
0	68.4	218.8	.415E-02	31.8	279.3	0	1.000	
50	60.0	224.9	.334E-02	22.8	271.1	8.8	.805	
100	58.9	221.6	.251E-02	20.9	273.4	2.0	.604	
200	58.3	218.6	.154E-02	19.6	275.5	1.7	.371	
300	57.7	214.5	.116E-02	18.2	278.7	2.2	.281	
400	55.9	208.4	.826E-03	15.3	283.2	3.8	.199	
401	56.7	209.0	.761E-03	16.2	282.9	.9	.184	
600	52.3	201.2	.376E-03	10.8	288.6	6.3	.091	2
800	53.4	201.0	.162E-03	11.8	288.9	1.1	.039	2
1000	50.7	233.9	.850E-04	16.1	260.6	20.3	.021	2

D16 2

0	64.7	234.4	.365E-02	30.5	266.1	0	1.000	
50	61.5	229.9	.273E-02	25.7	267.9	3.7	.748	
100	60.8	224.2	.184E-02	23.6	272.0	2.8	.505	
200	61.2	217.8	.107E-02	22.7	277.1	3.1	.292	
300	59.0	209.6	.758E-03	18.7	282.9	4.7	.207	
400	58.9	206.0	.494E-03	18.1	285.8	1.9	.135	
401	57.2	204.0	.450E-03	16.0	287.0	2.0	.123	
600	51.6	186.9	.214E-03	9.0	300.6	11.3	.058	2
800	37.3	168.9	.113E-03	-2.2	316.9	19.2	.031	2
1000.	17.5	153.7	.746E-04	-12.0	333.1	23.8	.020	2

D16 3

0	69.0	247.2	.396E-02	39.4	260.0	0	1.000	
50	62.4	246.1	.319E-02	31.2	256.0	6.6	.806	
100	62.0	244.4	.251E-02	30.2	257.0	.9	.633	
200	60.7	240.5	.165E-02	27.6	259.3	2.3	.417	
300	60.4	237.3	.109E-02	26.5	261.7	1.6	.275	
400	61.6	232.2	.813E-03	26.3	266.1	2.7	.205	
401	62.0	234.4	.844E-03	27.4	264.7	1.1	.213	
600	62.0	224.7	.378E-03	25.0	272.1	4.5	.095	2
800	60.8	213.4	.166E-03	21.4	280.4	5.6	.042	2
1000	63.6	232.9	.852E-04	28.8	266.6	9.5	.021	2

D16 4

0	62.1	227.6	.414E-02	25.9	269.9	0	1.000	
25	60.3	224.1	.376E-02	23.0	271.9	2.5	.908	
50	59.5	225.6	.323E-02	22.4	270.4	1.1	.781	
100	57.2	224.0	.240E-02	19.6	270.9	2.5	.579	
150	57.3	217.5	.190E-02	18.3	276.2	3.5	.459	
200	57.2	214.3	.146E-02	17.6	278.7	1.7	.354	
300	55.5	210.4	.103E-02	15.2	281.5	2.8	.248	2
400	54.5	205.2	.697E-03	13.4	285.5	3.1	.168	2
401	52.1	203.4	.660E-03	10.9	286.6	2.7	.159	
600	48.1	192.0	.287E-03	6.2	296.0	8.3	.069	2
800	33.6	187.6	.174E-03	-4.9	299.3	14.9	.042	2
1000	21.7	181.3	.957E-04	-12.1	305.2	13.1	.023	2

D16 5

0	58.6	230.6	.381E-02	22.7	266.1	0	1.000	
50	58.3	224.7	.291E-02	21.0	270.7	3.1	.763	
100	55.9	222.2	.215E-02	18.0	271.9	2.7	.565	
200	55.6	216.3	.128E-02	16.4	276.6	3.3	.336	
300	55.0	211.7	.930E-03	15.0	280.3	2.7	.244	
400	54.8	207.0	.603E-03	14.0	284.1	2.7	.158	
401	54.4	207.1	.633E-03	13.6	283.9	.4	.166	
600	52.4	197.6	.284E-03	10.5	291.6	6.0	.075	2
800	46.6	201.4	.115E-03	5.9	287.6	6.3	.030	2
1000	41.6	224.9	.452E-04	6.6	266.1	17.5	.012	2

D16 6

0	71.0	235.2	.485E-02	38.8	269.8	0	1.000	
25	67.8	232.0	.438E-02	33.7	269.7	3.4	.902	
50	64.7	229.5	.374E-02	29.3	269.8	3.2	.770	
100	62.5	228.9	.263E-02	26.6	269.1	2.2	.542	
150	62.5	224.6	.187E-02	25.6	272.4	2.0	.385	
200	60.8	220.1	.139E-02	22.6	275.2	2.8	.287	
300	58.7	215.3	.894E-03	19.4	278.3	3.2	.184	2
400	58.5	208.6	.562E-03	18.0	283.6	3.5	.116	2
401	55.7	208.8	.487E-03	15.2	282.8	2.8	.100	
600	46.5	208.9	.191E-03	6.9	281.1	9.1	.039	2
800	19.6	228.7	.904E-04	-5.6	258.5	31.4	.019	2
1000	-5.6	241.9	.607E-04	-13.4	241.6	28.4	.013	2

D16 7								
0	62.9	235.2	.382E-02	28.6	264.5	0	1.000	
50	60.5	232.1	.302E-02	25.1	265.7	2.8	.791	
100	59.5	230.0	.225E-02	23.5	267.0	1.5	.589	
200	59.1	223.3	.137E-02	21.5	272.1	3.4	.358	
300	58.4	218.0	.961E-03	19.6	276.1	2.9	.252	
400	57.0	211.7	.652E-03	17.0	280.7	3.6	.171	
401	56.6	209.1	.701E-03	16.1	282.8	1.5	.184	
600	50.8	195.3	.306E-03	8.8	293.4	9.9	.080	2
800	38.4	180.7	.144E-03	-1.8	305.9	16.1	.038	2
1000	25.0	175.1	.835E-04	-10.2	311.4	14.2	.022	2
D16 8								
0	63.6	237.3	.354E-02	29.9	263.3	0	1.000	
50	60.5	235.5	.297E-02	26.1	263.1	3.1	.838	
100	61.0	234.0	.203E-02	26.2	264.5	.9	.573	
200	60.7	226.0	.116E-02	23.8	270.6	4.0	.326	
300	59.6	222.5	.835E-03	21.9	272.9	2.0	.236	
400	59.7	218.1	.567E-03	21.0	276.4	2.2	.160	
401	58.2	218.9	.582E-04	19.5	275.3	1.6	.016	
600	55.6	208.8	.243E-03	15.0	282.8	6.1	.069	2
800	49.1	218.1	.103E-03	10.8	273.6	8.6	.029	2
1000	35.4	222.7	.393E-04	1.9	266.8	14.1	.011	2

DYKE D17

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D17 1								
0	64.1	245.9	.278E-02	33.1	257.2	0	1.000	
50	60.9	246.0	.230E-02	29.5	255.1	3.2	.828	
100	59.7	239.6	.161E-02	26.3	259.5	3.4	.580	
150	58.7	235.2	.112E-02	24.1	262.6	2.5	.405	
200	56.9	231.5	.880E-03	21.2	264.8	2.7	.317	
201	55.2	228.7	.757E-03	18.8	266.4	2.3	.272	
400	51.6	212.9	.301E-03	11.9	278.5	10.0	.108	
600	39.9	201.5	.149E-03	.7	286.8	14.1	.054	2
800	27.5	181.3	.840E-04	-8.8	305.3	20.8	.030	2
1000	23.2	160.5	.453E-04	-10.0	325.9	19.2	.016	2
D17 2								
0	70.9	241.3	.263E-02	40.2	265.7	0	1.000	
25	64.7	239.5	.225E-02	31.9	262.3	6.2	.854	
50	63.2	240.0	.200E-02	30.3	261.1	1.5	.760	
100	59.8	235.5	.148E-02	25.3	262.9	4.0	.562	
150	59.1	228.0	.110E-02	22.6	268.4	3.9	.417	
200	57.3	225.6	.880E-03	20.2	269.6	2.1	.335	
201	57.3	225.6	.880E-03	20.2	269.6	.0	.335	
400	51.3	212.4	.433E-03	11.6	278.9	9.8	.165	2
600	46.5	204.4	.231E-03	6.1	284.9	7.1	.088	2
800	39.0	196.0	.128E-03	-.6	291.7	9.7	.049	2
1000	30.7	197.7	.779E-04	-5.8	289.5	8.4	.030	2
D17 4								
0	59.6	222.6	.541E-02	21.8	272.8	0	1.000	
50	59.9	216.4	.442E-02	20.9	277.7	3.1	.817	
100	60.2	205.2	.303E-02	19.4	286.7	5.6	.561	
150	59.8	199.1	.224E-02	18.2	291.4	3.1	.413	
200	57.8	192.0	.172E-02	15.4	296.8	4.2	.318	
201	59.0	197.6	.139E-02	17.2	292.4	3.2	.258	
400	55.5	186.6	.761E-03	12.8	301.1	6.8	.141	

600	52.9	180.3	.477E-03	10.0	306.3	4.6	.088	2
800	50.2	176.3	.310E-03	7.6	309.7	3.7	.057	2
1000	47.2	174.1	.191E-03	5.1	311.7	3.3	.035	2
D17 5								
0	43.4	9.2	.324E-02	48.3	113.9	0	1.000	
25	62.5	231.7	.228E-02	27.3	267.0	68.8	.703	
50	61.2	229.3	.199E-02	25.2	268.2	1.8	.614	
100	60.3	221.7	.132E-02	22.4	273.7	3.8	.407	
150	57.3	215.0	.943E-03	17.9	278.1	4.6	.291	
200	56.8	211.3	.689E-03	16.7	281.0	2.1	.213	
201	56.8	211.3	.689E-03	16.7	281.0	.0	.213	
400	49.4	195.5	.313E-03	7.6	293.1	12.0	.097	2
600	43.1	182.3	.166E-03	1.7	304.5	11.1	.051	2
800	40.0	173.8	.845E-04	-.5	312.3	7.0	.026	2
1000	33.9	154.6	.564E-04	-2.7	330.5	16.4	.017	2
D17 7								
0	67.1	215.0	.891E-03	29.5	281.4	0	1.000	
50	63.4	213.6	.706E-03	24.5	281.0	3.8	.793	
100	60.7	207.9	.531E-03	20.4	284.6	3.8	.595	
150	57.1	204.6	.409E-03	15.9	286.5	4.0	.459	
200	56.9	205.5	.335E-03	15.9	285.7	.5	.376	
201	57.9	206.2	.289E-03	17.0	285.4	1.0	.324	
400	56.1	201.6	.161E-03	14.6	288.7	3.0	.180	
600	53.5	195.9	.930E-04	11.4	293.2	4.2	.104	2
800	49.4	190.2	.584E-04	7.1	297.6	5.4	.066	2
1000	53.1	176.9	.375E-04	10.3	309.2	9.2	.042	2
D17 9								
0	75.7	202.7	.978E-03	40.6	293.2	0	1.000	
50	57.8	218.0	.636E-03	19.0	275.9	18.7	.651	
100	55.7	213.5	.490E-03	16.0	278.9	3.2	.502	
150	53.0	210.6	.392E-03	12.8	280.7	3.2	.401	
200	53.0	205.8	.306E-03	12.1	284.7	2.9	.313	
201	49.9	209.7	.268E-03	9.9	280.9	3.9	.274	
400	46.0	205.0	.136E-03	5.9	284.4	5.0	.139	
600	35.2	201.6	.733E-04	-2.5	286.2	11.1	.075	2
800	19.3	195.3	.324E-04	-12.6	291.1	16.8	.033	2
1000	25.0	198.9	.270E-04	-9.1	287.9	6.5	.028	2
D17 10								
0	70.1	208.5	.113E-02	32.6	287.1	0	1.000	
50	58.9	221.7	.899E-03	20.9	273.2	12.5	.795	
100	55.8	219.0	.706E-03	17.1	274.5	3.4	.624	
150	52.2	215.0	.544E-03	12.9	276.9	4.2	.481	
200	52.1	213.8	.443E-03	12.6	277.9	.8	.392	
201	49.6	211.6	.352E-03	10.0	279.3	2.8	.311	
400	45.6	204.6	.173E-03	5.5	284.7	6.2	.153	
600	38.9	199.4	.928E-04	-.2	288.6	7.8	.082	2
800	30.7	213.0	.618E-04	-3.3	275.0	13.9	.055	2
1000	17.2	232.7	.376E-04	-5.6	254.4	22.4	.033	2
D17 12								
0	63.3	220.7	.141E-02	25.7	275.7	0	1.000	
50	57.8	219.3	.126E-02	19.3	274.8	5.5	.894	
100	54.7	216.9	.977E-03	15.7	275.9	3.4	.694	
150	52.9	214.4	.714E-03	13.5	277.5	2.3	.507	
200	51.4	212.1	.550E-03	11.7	279.2	2.1	.391	
201	52.0	216.6	.441E-03	13.1	275.5	2.9	.314	
400	49.1	212.2	.189E-03	9.7	278.7	4.1	.135	
600	42.0	198.0	.798E-04	1.8	290.1	12.2	.057	2
800	36.0	213.3	.421E-04	.1	275.5	13.2	.030	2
1000	34.7	230.1	.192E-04	3.4	260.0	13.7	.014	2

DYKE D18

DMAG	**** MAGNETIZATION **** DIP	DEC	J	POLE POSITION LAT	LONG	ANG	J/J0	
D18 1								
0	69.5	180.3	.272E-02	29.9	306.5	0	1.000	
50	65.7	181.6	.215E-02	24.5	305.5	3.9	.792	
100	62.1	181.0	.180E-02	19.9	305.9	3.7	.661	
200	59.2	179.5	.137E-02	16.6	307.0	2.9	.506	
300	57.0	179.3	.115E-02	14.1	307.2	2.3	.423	
400	55.4	179.3	.965E-03	12.6	307.2	1.5	.356	
401	55.5	180.2	.100E-02	12.6	306.5	.5	.369	
500	54.7	179.8	.843E-03	11.8	306.8	.8	.311	
600	54.1	178.9	.681E-03	11.2	307.5	.8	.251	
800	49.6	178.9	.468E-03	7.0	307.6	4.5	.172	2
1000	48.4	177.3	.294E-03	6.0	309.0	1.6	.108	2
D18 2								
0	71.7	169.8	.209E-02	33.3	313.4	0	1.000	
50	64.9	176.2	.179E-02	23.5	309.5	7.1	.857	
100	62.0	178.0	.155E-02	19.8	308.2	3.0	.743	
200	58.2	177.1	.121E-02	15.5	309.0	3.8	.578	
300	57.1	178.5	.926E-03	14.3	307.9	1.3	.443	
400	56.0	177.2	.775E-03	13.2	309.0	1.3	.370	
401	56.2	176.3	.793E-03	13.4	309.7	.5	.379	
500	54.1	177.2	.663E-03	11.3	309.0	2.2	.317	
600	52.8	175.6	.570E-03	10.0	310.4	1.6	.272	
800	50.0	176.2	.345E-03	7.4	310.0	2.8	.165	2
1000	46.2	175.2	.218E-03	4.2	310.9	3.8	.104	2
D18 3								
0	69.3	171.9	.267E-02	29.7	312.2	0	1.000	
50	64.0	174.3	.224E-02	22.4	311.0	5.4	.839	
100	62.0	177.8	.194E-02	19.8	308.4	2.6	.728	
200	60.2	178.9	.147E-02	17.7	307.5	1.8	.551	
300	58.9	179.1	.114E-02	16.3	307.4	1.3	.429	
400	59.2	180.7	.926E-03	16.6	306.1	.9	.347	
401	58.2	179.5	.102E-02	15.5	307.1	1.2	.384	
500	56.1	179.0	.882E-03	13.3	307.5	2.1	.331	
600	56.3	180.4	.711E-03	13.5	306.3	.8	.267	
800	54.2	180.5	.434E-03	11.3	306.2	2.1	.163	2
1000	51.2	179.4	.262E-03	8.5	307.2	3.1	.098	2
D18 6								
0	75.0	159.3	.270E-02	39.3	319.1	0	1.000	
50	65.2	182.4	.176E-02	23.9	304.9	12.4	.651	
100	61.8	185.5	.147E-02	19.7	302.4	3.7	.546	
200	58.7	185.5	.113E-02	16.1	302.2	3.1	.417	
300	57.3	188.3	.884E-03	14.7	299.9	2.0	.327	
400	55.8	187.5	.684E-03	13.1	300.4	1.6	.253	
401	55.6	188.3	.691E-03	13.0	299.7	.5	.256	
500	55.0	187.6	.586E-03	12.3	300.3	.8	.217	
600	52.8	188.4	.461E-03	10.2	299.5	2.2	.171	
800	47.9	189.8	.311E-03	5.8	298.0	5.0	.115	2
1000	46.3	189.1	.197E-03	4.5	298.6	1.7	.073	2
D18 7								
0	76.6	176.6	.317E-02	41.1	308.6	0	1.000	
50	67.2	183.2	.223E-02	26.6	304.4	9.6	.705	
100	63.0	187.9	.176E-02	21.2	300.6	4.6	.555	
150	60.8	189.7	.151E-02	18.6	299.0	2.4	.478	

200	59.8	188.0	.130E-02	17.4	300.3	1.3	.410	
300	57.6	189.3	.105E-02	15.1	299.1	2.3	.331	
400	56.4	189.5	.888E-03	13.8	298.9	1.2	.280	
401	56.6	190.7	.887E-03	14.1	297.9	.7	.280	
500	55.9	190.4	.749E-03	13.3	298.1	.7	.236	
600	53.1	188.5	.617E-03	10.4	299.4	3.0	.195	
800	50.0	188.6	.406E-03	7.6	299.2	3.0	.128	2
1000	48.2	187.8	.277E-03	6.0	299.8	1.9	.088	2
D18 8								
0	74.1	184.7	.323E-02	36.9	303.7	0	1.000	
50	64.6	190.3	.219E-02	23.3	299.0	9.7	.677	
100	62.0	190.1	.174E-02	20.1	298.8	2.6	.538	
150	60.7	189.5	.149E-02	18.5	299.2	1.3	.461	
200	58.7	192.1	.128E-02	16.4	296.9	2.4	.394	
300	58.4	189.7	.105E-02	15.9	298.8	1.3	.326	
400	54.7	191.4	.872E-03	12.2	297.1	3.8	.269	
401	56.3	189.2	.870E-03	13.7	299.1	2.0	.269	
500	54.8	188.9	.714E-03	12.1	299.2	1.5	.221	
600	53.8	188.5	.583E-03	11.1	299.5	1.1	.180	
800	51.5	187.3	.397E-03	8.9	300.4	2.4	.123	2
1000	46.5	185.0	.255E-03	4.5	302.2	5.2	.079	2
D18 9								
0	65.6	165.1	.220E-02	25.0	317.6	0	1.000	
50	63.7	167.0	.198E-02	22.4	316.5	2.1	.902	
100	62.3	165.7	.167E-02	20.8	317.7	1.5	.759	
200	62.6	167.7	.126E-02	20.9	316.1	1.0	.574	
300	61.1	169.5	.949E-03	19.1	314.8	1.7	.432	
400	61.6	166.7	.777E-03	19.8	317.0	1.4	.354	
401	60.7	166.1	.758E-03	18.8	317.6	1.0	.345	
500	53.5	165.2	.688E-03	11.3	319.1	7.2	.313	
600	60.2	165.8	.490E-03	18.2	317.8	6.7	.223	
800	58.6	167.6	.333E-03	16.4	316.6	1.8	.151	2
1000	59.4	167.2	.208E-03	17.3	316.9	.8	.094	2
D18 10								
0	69.0	165.2	.250E-02	29.6	316.9	0	1.000	
50	65.4	167.4	.218E-02	24.5	316.0	3.7	.872	
100	63.9	170.6	.205E-02	22.4	313.7	2.0	.819	
200	62.5	171.9	.144E-02	20.6	312.9	1.6	.575	
300	61.2	171.8	.114E-02	19.0	313.1	1.3	.458	
400	59.5	172.8	.946E-03	17.1	312.4	1.8	.378	
401	60.1	172.1	.102E-02	17.8	312.9	.7	.409	
500	59.9	173.9	.910E-03	17.4	311.5	.9	.364	
600	58.6	174.2	.735E-03	16.0	311.3	1.3	.294	
800	56.2	174.9	.457E-03	13.4	310.8	2.4	.183	2
1000	54.1	173.2	.273E-03	11.3	312.4	2.4	.109	2

DYKE D19

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D19 1								
0	86.9	236.8	.836E-03	62.7	295.2	0	1.000	
25	78.7	231.2	.440E-03	49.4	280.2	8.2	.527	
50	68.2	226.5	.297E-03	33.1	273.9	10.5	.355	
100	63.8	223.8	.212E-03	27.0	273.7	4.5	.253	
150	59.1	226.1	.172E-03	22.1	270.0	4.8	.205	
200	61.5	228.0	.143E-03	25.2	269.5	2.5	.171	
400	59.3	210.9	.701E-04	19.3	282.1	8.7	.084	2
600	48.2	195.0	.409E-04	6.5	293.5	14.5	.049	2

D19 2								
0	80.2	303.6	.525E-03	69.9	254.2	0	1.000	
50	71.7	219.5	.144E-03	36.6	280.7	19.8	.274	
100	62.3	217.4	.981E-04	23.9	277.9	9.4	.187	
150	59.7	226.2	.773E-04	22.8	270.1	5.0	.147	
200	60.7	200.9	.522E-04	19.5	290.2	12.5	.100	
400	48.9	183.4	.202E-04	6.4	303.7	15.5	.038	2
D19 3								
0	84.2	26.4	.129E-02	76.0	328.0	0	1.000	
50	86.6	241.8	.250E-03	62.7	293.4	8.8	.195	
100	74.7	215.3	.111E-03	40.5	285.3	12.3	.086	
150	59.8	215.9	.658E-04	20.7	278.3	14.9	.051	
200	51.6	190.5	.567E-04	9.2	297.7	16.4	.044	
400	53.0	154.8	.269E-04	12.0	327.9	21.6	.021	2
D19 4								
0	79.9	48.7	.388E-03	72.3	2.5	0	1.000	
50	82.7	198.4	.114E-03	52.7	299.2	16.8	.295	
100	69.2	190.0	.678E-04	29.6	299.7	13.7	.175	
150	68.1	165.5	.530E-04	28.3	316.9	8.9	.137	
200	54.3	154.7	.407E-04	13.3	327.8	14.7	.105	
400	39.4	126.5	.172E-04	7.4	355.2	24.1	.044	2
D19 5								
0	87.0	273.3	.722E-03	66.2	291.7	0	1.000	
50	75.5	204.6	.156E-03	40.5	292.1	13.7	.216	
100	70.8	173.3	.891E-04	31.8	311.2	10.1	.123	
150	71.2	145.7	.722E-04	34.9	329.4	8.9	.100	
200	78.8	173.8	.471E-04	45.0	309.9	10.3	.065	
400	39.9	154.9	.189E-04	1.3	329.7	39.6	.026	2
D19 7								
0	67.8	235.6	.709E-03	34.7	267.3	0	1.000	
50	56.8	210.8	.212E-03	16.6	281.5	15.7	.300	
100	49.0	203.3	.152E-03	8.1	286.4	9.1	.215	
150	48.0	206.8	.118E-03	7.8	283.2	2.5	.166	
200	43.2	201.9	.983E-04	3.2	286.9	5.9	.139	
400	32.5	211.9	.550E-04	-2.4	276.3	13.2	.078	2
D19 8								
0	79.1	233.2	.108E-02	50.4	279.8	0	1.000	
25	78.5	211.4	.593E-03	46.2	290.1	4.3	.548	
50	70.7	200.9	.375E-03	32.5	292.6	8.3	.347	
100	59.8	192.3	.236E-03	17.7	296.9	11.4	.218	
150	55.6	194.0	.182E-03	13.2	295.1	4.4	.168	
200	50.4	187.0	.145E-03	7.9	300.6	6.7	.134	
400	48.0	183.5	.859E-04	5.7	303.6	3.3	.079	2
600	41.3	167.4	.630E-04	.8	318.2	13.3	.058	2
D19 9								
0	69.0	209.3	.358E-03	31.1	286.3	0	1.000	
50	57.5	205.5	.251E-03	16.6	286.0	11.6	.700	
100	54.8	203.5	.183E-03	13.5	287.0	3.0	.512	
150	53.9	203.6	.149E-03	12.6	286.9	.9	.416	
200	51.1	205.5	.122E-03	10.3	284.8	3.0	.340	
400	51.2	194.5	.651E-04	9.1	294.2	6.9	.182	2

DYKE D20

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D20 1								
0	77.6	180.0	.421E-02	42.9	306.6	0	1.000	
50	72.9	201.1	.199E-02	36.0	293.1	7.1	.473	
100	69.7	204.6	.135E-02	31.5	289.8	3.4	.321	
200	66.2	211.2	.933E-03	27.6	283.9	4.3	.222	
300	65.3	212.3	.581E-03	26.6	282.7	1.0	.138	
400	65.0	210.5	.405E-03	26.0	284.0	.8	.096	
401	55.4	217.9	.301E-03	16.5	275.4	10.3	.071	
500	53.5	221.6	.218E-03	15.5	271.8	2.9	.052	2
600	52.7	229.3	.141E-03	16.7	265.2	4.7	.034	2
D20 2								
0	73.5	202.6	.362E-02	37.1	292.4	0	1.000	
50	67.2	215.0	.157E-02	29.6	281.5	7.5	.434	
100	61.6	218.5	.110E-02	23.3	276.9	5.8	.303	
200	57.5	222.8	.733E-03	19.7	272.1	4.7	.202	
300	53.7	219.8	.470E-03	15.3	273.4	4.1	.130	
400	54.0	218.9	.333E-03	15.4	274.2	.6	.092	
401	54.2	217.7	.305E-03	15.3	275.2	.7	.084	
500	52.4	223.1	.213E-03	14.8	270.3	3.7	.059	2
600	49.5	214.4	.137E-03	10.4	276.9	6.1	.038	2
D20 3								
0	74.1	198.4	.178E-02	37.6	295.2	0	1.000	
50	63.9	220.3	.875E-03	26.4	276.3	12.7	.491	
100	58.0	218.7	.613E-03	19.3	275.5	6.0	.344	
150	53.3	222.2	.497E-03	15.5	271.3	5.0	.279	
200	52.1	222.9	.385E-03	14.5	270.4	1.3	.216	
300	49.6	222.1	.279E-03	12.1	270.4	2.6	.156	2
400	48.8	219.7	.200E-03	10.9	272.2	1.7	.112	2
401	40.3	219.5	.196E-03	4.3	270.7	8.5	.110	
500	41.1	217.3	.152E-03	4.4	272.8	1.8	.085	2
600	40.4	214.5	.120E-03	3.3	275.2	2.3	.067	2
D20 4								
0	71.8	209.5	.168E-02	35.2	287.3	0	1.000	
50	58.8	219.5	.964E-03	20.4	275.1	13.6	.574	
100	53.2	220.3	.703E-03	14.9	272.9	5.6	.419	
200	48.1	223.1	.462E-03	11.1	269.2	5.4	.275	
300	43.1	222.3	.314E-03	7.0	268.7	5.1	.187	
400	42.5	223.6	.252E-03	6.9	267.5	1.1	.150	
401	40.9	225.0	.239E-03	6.1	265.9	1.9	.142	
500	40.8	226.2	.172E-03	6.4	264.8	.9	.102	2
600	39.2	225.2	.132E-03	5.0	265.4	1.7	.078	2
D20 5								
0	61.9	222.6	.108E-02	24.4	273.8	0	1.000	
50	51.4	223.5	.719E-03	14.0	269.7	10.5	.666	
100	38.5	221.3	.451E-03	3.5	268.7	13.0	.418	
200	45.1	220.4	.347E-03	8.1	270.8	6.7	.321	
300	40.7	218.0	.255E-03	4.3	272.1	4.8	.236	
400	41.7	217.6	.200E-03	4.9	272.7	1.0	.185	
401	41.1	218.6	.194E-03	4.7	271.6	1.0	.180	
500	38.1	215.0	.149E-03	1.8	274.3	4.1	.138	2
600	35.0	209.6	.107E-03	-1.3	278.8	5.3	.099	2

D20 6

0	73.6	206.6	.201E-02	37.6	289.9	0	1.000	
50	61.2	219.5	.986E-03	23.0	275.9	13.3	.489	
100	55.2	219.7	.709E-03	16.7	273.9	6.0	.352	
150	52.4	219.4	.562E-03	14.0	273.4	2.8	.279	
200	50.3	216.7	.462E-03	11.6	275.1	2.7	.229	
300	48.6	220.4	.328E-03	10.9	271.6	2.9	.163	2
400	46.6	218.5	.235E-03	8.8	272.8	2.4	.117	2
401	46.1	219.9	.222E-03	8.8	271.5	1.1	.110	
500	41.9	221.1	.173E-03	5.8	269.6	4.3	.086	2
600	47.8	213.1	.118E-03	8.7	277.7	8.2	.059	2

D20 8

0	60.3	215.0	.143E-02	21.1	279.1	0	1.000	
50	46.4	220.7	.886E-03	9.2	270.9	14.4	.618	
100	43.1	220.2	.682E-03	6.5	270.6	3.3	.475	
200	42.1	222.0	.446E-03	6.2	268.8	1.6	.311	
300	41.0	218.4	.335E-03	4.6	271.8	2.8	.234	
400	39.9	220.1	.248E-03	4.2	270.0	1.7	.173	
401	38.4	219.8	.254E-03	3.1	270.0	1.5	.177	
500	42.3	215.5	.204E-03	4.9	274.6	5.1	.142	2
600	43.1	217.7	.146E-03	6.0	272.8	1.8	.102	2

D20 10

0	62.0	209.2	.118E-02	22.0	284.1	0	1.000	
50	45.6	220.2	.848E-03	8.4	271.1	17.6	.717	
100	40.8	220.8	.664E-03	5.1	269.6	4.8	.562	
200	41.0	219.0	.463E-03	4.7	271.2	1.4	.392	
300	41.1	218.5	.335E-03	4.7	271.7	.4	.283	
400	39.3	221.7	.274E-03	4.2	268.5	3.0	.232	
401	40.3	221.3	.275E-03	4.8	269.0	1.0	.232	
500	42.0	220.5	.214E-03	5.8	270.1	1.8	.181	2
600	41.9	219.7	.170E-03	5.5	270.8	.6	.144	2

DYKE D21

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
D21 2								
0	62.6	228.4	.221E-02	26.5	269.6	0	1.000	
50	48.1	224.0	.146E-02	11.4	268.4	14.6	.657	
100	43.2	221.5	.128E-02	6.9	269.4	5.3	.579	
200	39.5	221.0	.968E-03	4.2	269.2	3.7	.437	
300	37.3	219.3	.764E-03	2.3	270.4	2.6	.345	
400	37.0	220.3	.619E-03	2.3	269.3	.9	.279	
401	34.3	219.3	.608E-03	.3	269.8	2.8	.275	
500	34.8	220.0	.506E-03	.8	269.3	.7	.229	
600	32.9	218.1	.377E-03	-.9	270.7	2.4	.170	
D21 3								
0	56.3	243.1	.414E-02	24.0	255.3	0	1.000	
50	51.3	226.2	.266E-02	14.6	267.4	11.1	.641	
100	48.5	223.3	.222E-02	11.5	269.1	3.4	.536	
150	46.9	222.2	.184E-02	10.0	269.7	1.7	.444	
200	46.6	221.6	.160E-02	9.6	270.1	.5	.386	
300	44.7	221.2	.121E-02	7.9	270.1	2.0	.291	
400	43.1	221.0	.103E-02	6.7	269.9	1.5	.249	
401	43.4	219.5	.110E-02	6.6	271.2	1.1	.265	
500	41.8	219.3	.879E-03	5.4	271.1	1.6	.212	
600	38.9	219.2	.657E-03	3.3	270.7	2.9	.159	

D21 4							
0	53.6	244.7	.225E-02	22.0	252.9	0	1.000
50	46.2	228.4	.159E-02	11.0	264.1	12.8	.704
100	42.3	225.5	.141E-02	7.3	265.8	4.4	.626
200	39.4	223.0	.101E-02	4.6	267.4	3.5	.448
300	38.1	221.7	.793E-03	3.3	268.3	1.7	.352
400	38.1	221.8	.648E-03	3.4	268.2	.1	.288
401	36.5	221.1	.677E-03	2.2	268.5	1.7	.300
500	36.2	221.0	.565E-03	2.0	268.6	.3	.251
600	35.3	220.6	.439E-03	1.2	268.8	1.0	.195
D21 5							
0	62.1	234.0	.236E-02	27.5	265.1	0	1.000
50	45.0	224.7	.135E-02	9.1	267.0	18.0	.569
100	41.2	223.2	.120E-02	5.9	267.6	3.9	.506
200	38.1	221.8	.878E-03	3.4	268.2	3.3	.371
300	37.1	219.3	.673E-03	2.1	270.3	2.2	.285
400	36.6	220.6	.557E-03	2.1	269.0	1.2	.236
401	35.1	219.9	.564E-03	.9	269.4	1.6	.238
500	35.7	217.4	.451E-03	.8	271.7	2.1	.191
600	34.2	219.3	.356E-03	.2	269.8	2.2	.150
D21 6							
0	66.4	235.4	.255E-02	32.9	266.5	0	1.000
50	50.5	222.4	.149E-02	13.0	270.4	17.2	.584
100	44.3	218.8	.125E-02	7.1	272.1	6.6	.492
200	40.1	218.9	.890E-03	4.1	271.2	4.2	.350
300	38.0	218.0	.690E-03	2.4	271.6	2.2	.271
400	37.6	218.9	.571E-03	2.4	270.7	.8	.224
401	34.8	219.9	.604E-03	.8	269.3	2.9	.237
500	35.4	220.3	.519E-03	1.2	269.1	.7	.204
600	34.2	216.7	.393E-03	-.4	272.2	3.2	.154
D21 8							
0	55.2	242.9	.268E-02	22.9	255.0	0	1.000
50	48.2	231.9	.128E-02	13.5	261.7	9.8	.477
100	45.0	226.7	.101E-02	9.6	265.4	4.8	.377
200	41.5	221.9	.755E-03	5.8	268.8	4.9	.282
300	41.7	221.3	.589E-03	5.8	269.3	.5	.220
400	40.3	218.4	.464E-03	4.1	271.7	2.6	.173
401	39.6	218.3	.502E-03	3.6	271.6	.7	.188
500	39.7	218.5	.417E-03	3.7	271.4	.2	.156
600	39.8	217.3	.331E-03	3.5	272.6	1.0	.124
D21 9							
0	64.9	217.3	.329E-02	27.0	279.0	0	1.000
50	49.2	217.7	.149E-02	10.8	274.1	15.8	.452
100	42.6	216.7	.111E-02	5.4	273.6	6.6	.336
150	40.3	216.6	.898E-03	3.7	273.3	2.2	.273
200	38.1	216.9	.771E-03	2.2	272.6	2.2	.234
300	35.0	215.9	.616E-03	-.1	273.0	3.2	.187
400	35.0	215.2	.498E-03	-.2	273.7	.6	.151
401	35.7	216.1	.478E-03	.4	273.0	.9	.145
500	35.5	213.4	.405E-03	-.2	275.4	2.2	.123
600	32.5	214.0	.321E-03	-2.0	274.4	3.1	.098
D21 10							
0	52.5	238.6	.267E-02	19.1	257.5	0	1.000
50	47.2	231.5	.146E-02	12.6	261.7	6.9	.548
100	46.6	232.4	.119E-02	12.4	260.8	.9	.446
200	44.6	235.4	.946E-03	11.7	257.7	2.8	.354
300	43.5	237.8	.726E-03	11.7	255.3	2.1	.272

400	42.6	238.0	.584E-03	11.0	254.9	.9	.219	
401	40.1	237.4	.636E-03	9.1	254.8	2.5	.238	
500	40.3	239.2	.541E-03	9.8	253.3	1.4	.203	
600	37.0	239.4	.423E-03	7.7	252.3	3.2	.158	

GNEISS G 10/11

	**** MAGNETIZATION	****		POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
G10 1								
0	86.6	316.8	.737E-04	70.9	292.6	0	1.000	
50	71.1	320.2	.203E-04	68.4	206.1	15.5	.275	
75	69.2	338.4	.155E-04	72.6	175.2	6.5	.210	
100	72.1	308.6	.122E-04	64.8	220.1	10.2	.166	
G10 2								
0	-58.7	176.1	.384E-04	-62.8	313.4	0	1.000	
25	47.7	174.2	.826E-05	5.4	311.9	106.4	.215	
50	64.6	163.6	.885E-05	23.7	319.1	17.9	.230	
75	73.0	187.0	.771E-05	35.1	302.4	11.7	.201	
100	64.4	201.7	.672E-05	23.9	290.6	10.0	.175	
G10 3								
0	-41.0	37.2	.377E-04	-4.2	93.1	0	1.000	
50	66.8	343.0	.279E-04	70.8	162.2	115.4	.739	
75	61.4	327.9	.237E-04	60.4	179.1	8.4	.627	
100	61.8	329.2	.205E-04	61.1	177.8	.7	.545	
150	51.6	323.2	.186E-04	49.4	178.0	10.7	.494	
200	39.9	291.1	.135E-04	29.1	206.9	25.0	.357	
300	13.9	291.1	.107E-04	14.8	200.1	26.0	.285	
400	8.2	285.6	.122E-04	10.0	204.1	7.9	.324	2
500	13.3	305.1	.916E-05	19.6	186.4	19.8	.243	2
600	2.2	270.2	.820E-05	1.1	217.1	36.3	.218	2
G10 4								
0	-9.1	82.5	.386E-03	-1.2	45.5	0	1.000	
50	16.0	76.2	.176E-03	13.0	46.3	25.9	.455	
75	13.2	76.4	.175E-03	11.5	46.6	2.9	.454	
100	10.9	75.2	.169E-03	10.9	48.2	2.6	.438	
200	6.4	75.7	.169E-03	8.6	48.7	4.5	.437	
300	5.3	77.1	.168E-03	7.5	47.6	1.8	.435	
400	2.7	77.0	.174E-03	6.4	48.2	2.5	.451	2
500	2.3	77.0	.181E-03	6.2	48.4	.4	.469	2
600	1.6	75.1	.189E-03	6.7	50.2	2.0	.489	2
700	2.1	75.4	.182E-03	6.7	49.9	.5	.471	2
800	1.8	76.8	.184E-03	6.0	48.6	1.5	.476	2
900	1.5	77.3	.199E-03	5.7	48.2	.5	.516	2
1000	.8	76.7	.194E-03	5.6	48.9	.9	.502	2
1100	3.0	76.4	.194E-03	6.8	48.7	2.3	.504	2
1200	2.4	76.6	.199E-03	6.4	48.6	.6	.516	2
G10 5								
0	-12.3	42.3	.413E-03	11.2	83.8	0	1.000	
50	28.7	341.5	.292E-04	37.4	149.5	71.6	.071	
75	46.0	313.9	.330E-04	41.8	186.1	27.7	.080	
100	49.1	246.8	.296E-04	18.8	249.6	43.9	.072	
200	12.1	230.6	.278E-04	-8.9	255.8	39.4	.067	2
300	24.8	209.7	.145E-04	-7.6	277.7	23.4	.035	2
400	26.6	278.3	.221E-04	16.2	214.9	61.1	.054	2
500	5.5	263.4	.226E-04	-.1	224.0	25.5	.055	2

G10 6								
0	-3.2	127.2	.291E-03	-15.5	2.5	0	1.000	
25	65.2	123.7	.912E-04	31.5	348.3	68.4	.314	
50	82.9	126.7	.608E-04	56.3	327.3	17.7	.209	
75	84.1	174.2	.490E-04	54.7	308.9	5.4	.169	
100	80.9	191.5	.383E-04	49.0	301.5	3.8	.132	
200	81.4	311.5	.313E-04	72.6	260.2	15.3	.108	
300	70.3	239.3	.178E-04	38.9	266.9	18.8	.061	2
400	63.8	282.4	.993E-05	45.5	228.9	17.6	.034	2
500	62.2	359.0	.239E-04	67.0	128.6	32.7	.082	2
G10 7								
0	17.7	210.7	.358E-02	-11.2	275.9	0	1.000	
50	65.1	259.5	.437E-03	38.4	248.1	57.3	.122	
75	64.3	263.9	.301E-03	39.1	244.1	2.0	.084	
100	62.2	261.0	.229E-03	35.9	244.7	2.5	.064	
200	51.9	255.5	.108E-03	24.1	243.5	10.7	.030	
300	55.9	278.0	.523E-04	36.1	226.4	13.8	.015	
400	50.4	240.5	.537E-04	17.8	255.4	22.8	.015	2
500	17.6	248.0	.332E-04	-.2	240.5	33.4	.009	2
G10 9								
0	21.8	13.6	.440E-03	34.1	110.7	0	1.000	
50	70.0	327.2	.118E-03	69.8	194.5	55.4	.269	
75	69.6	308.8	.839E-04	62.2	214.0	6.4	.191	
100	68.4	305.9	.605E-04	59.8	214.5	1.5	.137	
200	76.9	335.8	.231E-04	80.0	219.6	12.0	.052	2
300	25.7	218.3	.163E-04	-5.2	269.6	70.9	.037	2
400	-60.3	156.1	.170E-04	-61.5	346.4	99.7	.039	2
500	-34.7	47.8	.583E-05	-2.7	82.3	68.5	.013	2
G10 11								
0	76.4	275.3	.121E-02	57.3	253.6	0	1.000	
50	75.1	292.6	.605E-03	61.8	240.1	4.5	.498	
75	75.2	301.5	.386E-03	65.2	234.7	2.3	.318	
100	75.9	299.8	.279E-03	65.3	238.3	.9	.230	
200	74.1	300.9	.102E-03	63.9	231.9	1.8	.084	2
300	73.2	274.4	.484E-04	53.2	247.5	7.4	.040	2
400	77.7	70.1	.157E-04	63.5	4.1	28.4	.013	2
500	-9.6	145.7	.211E-04	-23.9	344.7	96.4	.017	2
G10 12								
0	72.5	98.9	.146E-02	47.9	358.8	0	1.000	
50	82.2	33.8	.654E-03	76.4	345.7	15.9	.448	
75	78.6	31.3	.399E-03	77.9	15.5	3.6	.274	
100	77.3	29.0	.282E-03	78.4	26.9	1.3	.193	
200	78.8	117.5	.826E-04	51.7	338.7	16.7	.057	2
300	50.8	162.4	.745E-04	8.9	322.0	32.1	.051	2
400	40.4	149.7	.576E-04	2.4	334.5	13.6	.040	2
500	34.7	147.0	.481E-04	-1.0	337.8	6.1	.033	2
G10 13								
0	82.5	42.6	.129E-02	74.1	345.6	0	1.000	
50	77.7	31.2	.688E-03	77.7	22.4	5.1	.533	
75	79.7	28.4	.465E-03	79.0	5.5	2.0	.359	
100	82.2	22.8	.332E-03	79.0	339.3	2.7	.257	
200	86.5	343.4	.131E-03	73.1	300.0	5.6	.101	2
300	83.3	108.4	.626E-04	59.7	332.5	9.2	.048	2
400	47.9	166.2	.307E-04	6.0	319.0	38.9	.024	2
500	44.9	160.2	.311E-04	4.2	324.5	5.1	.024	2

G10 15								
0	87.1	256.0	.420E-02	64.5	293.7	0	1.000	
50	86.2	313.7	.184E-02	71.0	289.8	3.3	.439	
75	88.7	303.5	.127E-02	67.8	301.2	2.6	.303	
100	84.2	338.5	.971E-03	76.5	288.7	4.8	.231	
150	84.6	307.8	.655E-03	71.1	280.0	3.0	.156	
200	86.2	330.7	.479E-03	72.8	294.2	2.4	.114	
300	84.0	300.8	.299E-03	70.0	275.6	3.3	.071	
400	78.1	247.8	.198E-03	51.9	271.3	9.5	.047	2
G10 16								
0	57.9	175.6	.142E-02	15.1	310.4	0	1.000	
50	82.8	196.8	.630E-03	52.7	300.1	25.6	.444	
75	85.3	210.1	.443E-03	58.2	298.0	2.8	.312	
100	82.9	206.4	.316E-03	53.5	296.5	2.4	.222	
200	83.4	268.7	.170E-03	63.1	277.1	7.1	.120	
300	77.1	242.6	.111E-03	49.2	272.3	7.6	.078	
400	72.0	217.6	.848E-04	36.6	282.4	8.3	.060	2
500	-50.7	57.3	.121E-03	-17.1	78.1	157.0	.085	2
G10 17								
0	73.7	277.2	.104E-02	54.8	246.7	0	1.000	
50	77.5	288.1	.244E-03	62.7	249.7	4.6	.234	
75	77.1	279.5	.165E-03	59.4	252.8	1.9	.159	
100	80.8	296.4	.113E-03	68.0	259.6	4.9	.109	
200	79.3	322.8	.518E-04	76.0	245.3	4.7	.050	
300	56.0	268.4	.357E-04	32.5	234.7	28.9	.034	
400	61.6	238.0	.353E-04	27.8	262.1	16.5	.034	2
500	32.3	270.8	.143E-04	16.3	223.3	36.1	.014	2
G10 18								
0	64.8	318.5	.274E-02	60.7	195.2	0	1.000	
50	66.8	331.1	.481E-03	67.5	181.9	5.6	.176	
75	69.8	336.8	.272E-03	72.9	179.6	3.6	.099	
100	67.6	326.9	.202E-03	66.9	189.3	4.2	.074	
200	73.1	4.9	.537E-04	81.9	108.4	13.6	.020	
300	63.5	276.8	.452E-04	43.1	233.2	30.6	.017	
400	51.7	175.0	.309E-04	8.9	311.1	49.8	.011	2
500	-52.8	188.2	.796E-04	-56.6	294.4	105.1	.029	2
G10 19								
0	70.9	337.0	.502E-03	74.4	182.6	0	1.000	
50	75.1	338.5	.182E-03	79.7	201.2	4.2	.363	
75	72.9	347.6	.126E-03	80.1	167.5	3.4	.252	
100	73.9	333.2	.930E-04	76.4	200.9	4.3	.185	
200	69.5	28.6	.372E-04	70.8	66.3	17.3	.074	
300	69.3	66.4	.217E-04	55.8	26.9	13.1	.043	
400	68.5	94.9	.178E-04	44.4	6.4	10.2	.035	2
500	85.2	151.1	.251E-04	57.8	315.5	19.2	.050	2
G10 20								
0	58.4	356.9	.124E-02	62.5	132.0	0	1.000	
25	66.5	335.7	.100E-02	68.5	174.4	12.7	.806	
50	68.8	331.3	.488E-03	69.8	185.7	2.8	.393	
75	71.7	334.3	.290E-03	74.4	189.8	3.1	.234	
100	75.8	320.1	.198E-03	73.0	224.4	5.6	.159	
200	74.9	261.3	.999E-04	51.1	258.4	14.3	.080	
300	54.0	183.4	.463E-04	11.1	304.0	35.6	.037	
400	33.2	177.1	.400E-04	-5.4	309.6	21.3	.032	2
500	41.3	200.8	.605E-04	1.5	287.9	20.5	.049	2

G10 21

0	68.2	304.2	.273E-02	58.9	215.7	0	1.000	
25	68.1	316.7	.134E-02	63.7	202.8	4.6	.491	
50	69.7	322.6	.799E-03	67.8	199.6	2.7	.293	
75	69.5	324.6	.528E-03	68.3	196.5	.7	.194	
100	70.1	321.2	.390E-03	67.7	202.1	1.3	.143	
200	67.6	337.9	.110E-03	70.5	172.7	6.5	.040	
300	73.7	332.6	.779E-04	76.0	200.6	6.3	.029	
400	64.8	165.1	.668E-04	23.8	318.0	41.3	.024	2
500	-12.8	155.3	.681E-04	-27.6	334.8	77.9	.025	2

GNEISS G13

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
G13 3								
0	64.3	237.4	.125E-02	30.8	263.5	0	1.000	
50	60.3	233.9	.482E-03	25.3	264.1	4.3	.384	
100	58.0	222.4	.323E-03	20.0	272.2	6.4	.258	
200	50.1	225.1	.234E-03	13.2	267.7	8.0	.187	2
300	50.5	225.4	.195E-03	13.7	267.6	.5	.155	2
G13 4								
0	55.4	229.1	.127E-02	19.1	266.0	0	1.000	
50	51.6	220.3	.101E-02	13.4	272.1	6.5	.794	
100	50.9	220.4	.922E-03	12.8	271.8	.7	.726	
200	51.8	219.7	.869E-03	13.4	272.7	1.0	.684	
300	51.5	219.7	.834E-03	13.2	272.6	.3	.657	
301	49.2	219.5	.851E-03	11.1	272.3	2.3	.670	
400	49.8	220.3	.802E-03	11.9	271.7	.8	.631	
600	50.4	218.1	.698E-03	11.8	273.6	1.5	.549	
800	50.4	217.2	.544E-03	11.7	274.4	.6	.428	
1000	50.0	210.7	.357E-03	10.1	279.9	4.2	.281	
1001	50.0	208.4	.354E-03	9.6	281.8	1.5	.278	
1200	47.0	202.7	.218E-03	6.2	286.3	4.8	.172	
G13 5								
0	65.1	240.2	.143E-02	32.5	261.9	0	1.000	
50	50.7	223.9	.111E-02	13.4	268.9	16.7	.772	
100	47.1	221.1	.102E-02	9.8	270.4	4.0	.712	
200	46.1	219.3	.932E-03	8.6	271.7	1.6	.650	
300	46.2	220.0	.880E-03	8.8	271.1	.5	.614	
301	45.6	220.4	.902E-03	8.4	270.6	.7	.629	
400	46.4	219.1	.842E-03	8.7	271.9	1.2	.587	
600	46.3	215.8	.703E-03	7.9	274.8	2.3	.490	
800	47.0	213.8	.497E-03	8.2	276.6	1.5	.346	
1000	44.1	207.3	.338E-03	4.7	281.9	5.4	.236	
1001	43.8	211.2	.340E-03	5.1	278.4	2.9	.237	
1200	41.9	204.0	.186E-03	2.4	284.6	5.7	.129	
G13 6								
0	44.7	191.4	.295E-02	3.2	296.1	0	1.000	
50	42.5	190.2	.216E-02	1.4	297.1	2.4	.733	
100	42.5	190.6	.175E-02	1.4	296.7	.3	.595	
200	42.2	189.5	.146E-02	1.2	297.7	.9	.494	
300	42.8	190.3	.129E-02	1.6	297.0	.8	.436	
301	41.5	190.4	.133E-02	.7	296.8	1.2	.452	
400	41.7	190.9	.134E-02	.9	296.4	.4	.453	
600	43.0	188.9	.104E-02	1.8	298.3	2.0	.354	
800	41.6	187.5	.773E-03	.6	299.5	1.8	.262	
1000	41.3	184.9	.519E-03	.3	301.8	1.9	.176	
1001	41.3	184.9	.519E-03	.3	301.8	0	.176	
1200	40.8	177.8	.339E-03	-.2	308.4	5.4	.115	

G13 7

0	60.5	216.4	.592E-02	21.5	277.7	0	1.000
50	53.8	208.2	.375E-02	13.1	282.7	8.0	.634
100	51.9	205.2	.350E-02	10.9	284.9	2.7	.591
200	50.6	206.6	.339E-02	9.9	283.5	1.6	.572
300	51.0	207.0	.313E-02	10.3	283.3	.5	.529
301	51.6	206.4	.311E-02	10.8	283.8	.7	.525
400	51.2	206.0	.294E-02	10.4	284.1	.5	.496
600	49.5	207.0	.238E-02	9.0	283.0	1.8	.402
800	48.5	204.9	.199E-02	7.8	284.7	1.7	.336
1000	46.0	201.0	.144E-02	5.2	287.8	3.6	.244
1001	46.9	202.8	.138E-02	6.2	286.3	1.5	.233
1200	45.8	199.7	.841E-03	4.9	288.8	2.4	.142

G13 8

0	66.6	246.1	.349E-02	36.0	258.7	0	1.000
50	45.6	245.8	.311E-02	15.7	248.8	21.0	.893
100	42.5	242.9	.269E-02	12.5	250.3	3.7	.772
200	41.8	242.5	.235E-02	11.9	250.5	.8	.673
300	41.1	241.1	.212E-02	10.9	251.5	1.2	.607
301	41.4	239.9	.202E-02	10.8	252.6	1.0	.580
400	41.5	239.0	.179E-02	10.5	253.4	.7	.512
600	42.8	237.9	.140E-02	11.1	254.8	1.6	.401
800	44.3	234.2	.112E-02	11.1	258.4	3.1	.320
1000	43.3	228.3	.690E-03	8.7	263.2	4.3	.198
1001	44.5	230.3	.617E-03	10.1	261.8	1.8	.177
1200	39.2	223.3	.339E-03	4.4	266.8	7.4	.097

G13 9

0	43.7	191.3	.273E-02	2.4	296.2	0	1.000
25	41.5	196.9	.266E-02	1.3	291.0	4.7	.975
50	39.9	197.7	.248E-02	.2	290.1	1.7	.910
100	39.0	198.6	.226E-02	-.4	289.2	1.1	.829
150	39.2	198.7	.205E-02	-.2	289.1	.2	.752
200	39.5	198.9	.199E-02	.0	288.9	.4	.731
300	39.6	199.4	.188E-02	.2	288.5	.4	.688
301	39.6	199.4	.188E-02	.2	288.5	0	.688
400	39.9	199.6	.180E-02	.4	288.3	.3	.660
600	40.6	199.0	.155E-02	.8	288.9	.8	.569
800	39.0	197.9	.124E-02	-.4	289.8	1.8	.454
1000	37.9	196.0	.954E-03	-1.5	291.4	1.9	.350
1001	39.2	196.2	.964E-03	-.5	291.4	1.4	.354
1200	32.9	197.0	.667E-03	-4.6	290.1	6.4	.245

G13 10

0	45.2	224.0	.383E-02	9.0	267.4	0	1.000
25	43.1	225.4	.349E-02	7.7	265.8	2.4	.911
50	41.6	223.8	.316E-02	6.2	266.8	1.9	.825
100	41.7	222.6	.262E-02	6.0	267.9	.9	.684
150	41.2	221.5	.238E-02	5.4	268.8	.9	.621
200	41.0	223.1	.213E-02	5.6	267.3	1.2	.556
300	40.8	222.3	.192E-02	5.3	268.0	.7	.501
301	40.8	222.3	.192E-02	5.3	268.0	0	.501
400	39.9	221.9	.179E-02	4.6	268.2	.9	.467
600	40.4	220.9	.145E-02	4.6	269.1	.9	.379
800	39.4	219.8	.111E-02	3.7	269.9	1.2	.289
1000	39.9	218.5	.815E-03	3.7	271.2	1.2	.213
1001	39.8	219.1	.800E-03	3.8	270.7	.5	.209
1200	38.5	217.0	.502E-03	2.4	272.3	2.1	.131

GNEISS G14

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
G14 1								
0	77.3	166.2	.936E-03	42.7	314.2	0	1.000	
50	66.4	182.3	.634E-03	25.4	304.9	11.9	.677	
100	65.2	180.8	.505E-03	23.8	305.9	1.4	.540	
150	64.2	181.4	.429E-03	22.5	305.5	1.1	.458	
200	62.6	180.4	.367E-03	20.5	306.2	1.7	.392	
201	58.1	187.3	.337E-03	15.5	300.6	5.6	.360	
400	58.9	186.5	.207E-03	16.4	301.3	.9	.221	
600	55.6	183.1	.143E-03	12.7	304.0	3.8	.153	2
800	55.4	176.9	.948E-04	12.5	309.1	3.5	.101	2
1000	53.5	173.3	.616E-04	10.8	312.2	2.8	.066	2
G14 3								
0	73.1	189.4	.744E-03	35.4	300.6	0	1.000	
50	69.6	184.8	.440E-03	30.0	303.3	3.8	.592	
100	64.4	184.9	.337E-03	22.9	302.9	5.2	.453	
150	61.5	185.8	.282E-03	19.3	302.1	3.0	.379	
200	59.8	185.2	.241E-03	17.4	302.5	1.7	.323	
201	59.7	186.0	.206E-03	17.2	301.8	.4	.277	
400	57.6	188.6	.134E-03	15.0	299.6	2.5	.181	
600	53.7	184.4	.921E-04	10.9	302.8	4.6	.124	2
800	50.1	177.6	.584E-04	7.5	308.6	5.6	.079	2
1000	44.7	180.7	.360E-04	2.9	305.9	5.7	.048	2
G14 4								
0	76.8	181.3	.894E-03	41.4	305.8	0	1.000	
50	58.0	194.4	.654E-03	15.8	294.9	19.3	.732	
100	54.8	189.8	.513E-03	12.2	298.4	4.1	.574	
150	53.5	191.4	.435E-03	11.0	297.0	1.6	.486	
200	53.2	188.1	.374E-03	10.5	299.7	2.0	.418	
201	52.6	185.7	.316E-03	9.8	301.7	1.5	.354	
400	52.6	180.5	.195E-03	9.8	306.1	3.2	.218	
600	47.0	180.3	.129E-03	4.8	306.3	5.6	.145	2
800	48.1	180.0	.829E-04	5.7	306.5	1.1	.093	2
1000	42.7	171.5	.468E-04	1.6	314.3	8.0	.052	2
G14 6								
0	84.9	217.5	.283E-02	58.0	294.9	0	1.000	
25	81.0	209.6	.163E-02	50.4	293.0	4.0	.577	
50	75.9	200.2	.112E-02	40.7	294.7	5.5	.396	
100	71.9	196.7	.855E-03	34.1	295.6	4.1	.302	
150	69.6	195.5	.694E-03	30.5	295.8	2.3	.246	2
200	68.9	193.8	.597E-03	29.4	296.9	.9	.211	2
201	68.9	193.8	.597E-03	29.4	296.9	.0	.211	
300	66.9	193.2	.456E-03	26.5	297.0	2.0	.162	2
400	66.4	191.5	.342E-03	25.8	298.1	.8	.121	2
600	63.0	188.4	.208E-03	21.2	300.1	3.7	.074	2
800	55.0	180.3	.140E-03	12.1	306.3	9.0	.050	2
1000	50.3	175.1	.880E-04	7.7	310.7	5.7	.031	2
G14 8								
0	65.6	189.2	.727E-03	24.5	299.7	0	1.000	
50	56.2	199.2	.329E-03	14.4	290.8	10.5	.453	
100	51.4	202.2	.215E-03	10.1	287.5	5.1	.296	
150	53.6	197.9	.171E-03	11.7	291.5	3.4	.235	
200	51.6	199.4	.130E-03	10.0	290.0	2.2	.179	

G14 9								
0	61.4	230.7	.176E-02	25.7	267.2	0	1.000	
25	55.2	211.4	.957E-03	15.1	280.5	11.8	.544	
50	49.1	207.9	.702E-03	8.9	282.3	6.4	.399	
100	45.1	205.2	.442E-03	5.2	284.0	4.4	.251	
150	44.6	204.3	.294E-03	4.6	284.8	.8	.167	2
200	40.5	203.3	.232E-03	1.4	285.2	4.1	.132	2
201	40.5	203.3	.232E-03	1.4	285.2	0	.132	2
300	43.3	204.4	.154E-03	3.6	284.6	2.9	.088	2
400	43.9	198.7	.105E-03	3.4	289.7	4.1	.060	2
600	44.4	188.2	.566E-04	2.9	299.2	7.6	.032	2
800	29.3	185.8	.333E-04	-7.6	300.9	15.2	.019	2
1000	21.5	151.1	.205E-04	-9.5	335.3	32.2	.012	2
G14 11								
0	57.4	177.0	.912E-03	14.6	309.0	0	1.000	
50	56.9	173.9	.720E-03	14.2	311.5	1.8	.790	
100	54.2	174.7	.598E-03	11.4	311.0	2.8	.655	
150	53.0	173.7	.522E-03	10.3	311.9	1.3	.572	
200	52.9	172.8	.452E-03	10.2	312.6	.5	.495	
201	52.1	176.4	.415E-03	9.3	309.6	2.3	.455	
400	49.2	173.9	.269E-03	6.7	311.8	3.3	.295	
600	47.6	171.6	.185E-03	5.5	313.9	2.2	.203	2
800	43.8	169.2	.123E-03	2.6	316.2	4.1	.135	2
1000	40.4	168.8	.799E-04	.0	316.8	3.5	.088	2
G14 12								
0	80.0	225.6	.666E-03	50.6	284.6	0	1.000	
50	73.0	184.4	.292E-03	35.1	303.7	11.5	.439	
100	67.8	174.4	.196E-03	27.5	310.6	6.1	.295	
150	65.0	180.6	.159E-03	23.6	306.1	3.8	.239	
200	63.9	177.3	.142E-03	22.2	308.6	1.8	.214	

GNEISS G18

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
G18 1								
0	67.3	189.4	.725E-03	26.9	299.8	0	1.000	
50	64.2	187.1	.458E-03	22.6	301.2	3.3	.631	
100	59.4	182.4	.344E-03	16.8	304.6	5.3	.475	
150	54.0	184.0	.272E-03	11.2	303.2	5.5	.375	
200	50.8	186.7	.256E-03	8.2	300.8	3.7	.353	
300	45.1	188.2	.195E-03	3.5	299.2	5.7	.269	
301	46.7	185.3	.167E-03	4.6	301.8	2.5	.230	
400	43.8	177.2	.142E-03	2.2	309.1	6.4	.195	
600	37.8	180.6	.893E-04	-2.2	306.0	6.5	.123	2
800	33.3	171.2	.551E-04	-5.0	314.9	8.9	.076	2
1000	30.1	163.9	.409E-04	-6.4	322.1	7.0	.056	2
G18 3								
0	62.1	212.1	.188E-02	22.7	281.8	0	1.000	
100	55.2	191.4	.116E-02	12.7	297.0	12.7	.616	
150	51.4	193.5	.970E-03	9.2	295.0	4.0	.517	
200	48.7	192.7	.870E-03	6.8	295.4	2.7	.463	
300	48.2	193.9	.658E-03	6.4	294.3	.9	.350	
301	48.3	192.4	.569E-03	6.4	295.7	1.0	.303	
400	44.8	189.0	.467E-03	3.3	298.4	4.2	.249	
600	43.7	186.8	.324E-03	2.2	300.4	2.0	.173	2
800	49.5	186.1	.173E-03	7.0	301.3	5.9	.092	2
1000	39.6	179.6	.153E-03	-1.0	306.9	11.0	.081	2

G18 5

0	61.7	183.7	.105E-02	19.5	303.7	0	1.000	
50	54.8	181.0	.920E-03	11.9	305.7	7.0	.879	
100	51.3	183.5	.753E-03	8.6	303.5	3.8	.719	
150	49.3	184.0	.635E-03	6.8	303.0	2.0	.607	
200	47.9	182.6	.593E-03	5.6	304.3	1.6	.567	
300	45.5	184.0	.478E-03	3.6	303.0	2.6	.457	
301	45.4	185.5	.404E-03	3.6	301.7	1.0	.386	
400	46.0	183.8	.333E-03	4.0	303.1	1.3	.318	
600	41.9	182.3	.232E-03	.7	304.5	4.3	.222	2
800	39.8	182.7	.159E-03	-.8	304.0	2.1	.152	2
1000	34.1	178.7	.991E-04	-4.7	307.8	6.5	.095	2

G18 6

0	50.2	175.7	.735E-03	7.6	310.3	0	1.000	
50	44.7	175.0	.718E-03	3.0	311.0	5.5	.977	
100	42.0	174.6	.632E-03	.9	311.5	2.7	.861	
150	40.1	174.5	.559E-03	-.5	311.6	1.8	.760	
200	40.5	174.6	.496E-03	-.2	311.5	.4	.676	
300	36.4	174.9	.433E-03	-3.1	311.4	4.1	.589	
301	38.7	171.1	.357E-03	-1.3	314.8	3.8	.486	
400	36.2	172.1	.294E-03	-3.1	314.0	2.7	.400	
600	34.5	172.4	.205E-03	-4.3	313.7	1.7	.279	2
800	31.3	169.6	.142E-03	-6.1	316.5	3.9	.193	2
1000	30.2	169.5	.101E-03	-6.8	316.7	1.2	.137	2

G18 7

0	62.8	188.9	.483E-03	21.0	299.7	0	1.000	
50	53.1	186.4	.445E-03	10.3	301.2	9.8	.921	
100	49.4	185.2	.367E-03	6.9	302.0	3.7	.759	
150	46.7	185.6	.309E-03	4.7	301.6	2.7	.639	
200	45.4	185.4	.280E-03	3.6	301.7	1.3	.580	
300	43.5	184.2	.229E-03	2.0	302.8	2.1	.473	
301	39.9	183.6	.192E-03	-.7	303.2	3.6	.397	
400	40.6	183.7	.163E-03	-.2	303.2	.7	.337	
600	36.2	184.2	.111E-03	-3.2	302.6	4.4	.230	2
800	36.1	180.7	.750E-04	-3.4	305.9	2.9	.155	2
1000	39.1	179.5	.488E-04	-1.3	307.0	3.1	.101	2

G18 8

0	51.5	172.8	.745E-03	8.9	312.7	0	1.000	
25	50.0	180.6	.697E-03	7.4	306.0	5.1	.936	
50	49.3	183.5	.626E-03	6.8	303.5	2.0	.840	
100	46.7	183.4	.515E-03	4.6	303.5	2.6	.691	
150	45.8	182.4	.441E-03	3.8	304.4	1.2	.592	
200	45.9	181.1	.392E-03	3.9	305.6	.9	.526	
300	42.8	181.8	.280E-03	1.5	304.9	3.1	.376	2
301	42.8	181.8	.280E-03	1.5	304.9	.0	.376	
400	43.2	181.4	.226E-03	1.8	305.3	.5	.303	2
500	41.8	182.5	.195E-03	.7	304.2	1.7	.262	2
600	39.8	180.9	.156E-03	-.8	305.7	2.3	.209	2
800	37.1	180.5	.111E-03	-2.7	306.1	2.7	.148	2
1000	37.4	173.2	.748E-04	-2.4	312.9	5.8	.100	2

G18 11

0	76.1	169.6	.467E-03	40.5	312.6	0	1.000
25	76.8	206.0	.430E-03	42.8	291.9	8.4	.920
50	73.8	202.1	.380E-03	37.5	292.8	3.2	.814
100	69.0	207.5	.295E-03	30.9	287.4	5.1	.632
150	67.7	208.0	.291E-03	29.2	286.6	1.3	.622
200	66.6	209.5	.233E-03	27.9	285.1	1.3	.499

300	67.9	209.2	.180E-03	29.6	285.9	1.3	.386	2
301	67.9	209.2	.180F-03	29.6	285.9	0	.386	
400	66.5	210.3	.133E-03	27.9	284.6	1.5	.285	2
500	65.1	217.9	.118E-03	27.3	278.5	3.4	.253	2
600	63.3	195.8	.844E-04	22.1	294.5	9.7	.181	2
800	68.0	188.7	.644E-04	27.8	300.3	5.5	.138	2
1000	47.0	205.6	.434E-04	6.8	284.0	22.7	.093	2

GNEISS G20

	**** MAGNETIZATION ****			POLE POSITION				
DMAG	DIP	DEC	J	LAT	LONG	ANG	J/J0	
G20 1								
0	68.4	214.1	.711E-03	31.0	282.6	0	1.000	
50	63.5	219.4	.586E-03	25.7	276.7	5.4	.824	
100	71.4	222.2	.471E-03	36.6	278.7	7.9	.663	
150	63.5	213.9	.386E-03	24.6	280.9	8.5	.542	
200	63.7	212.4	.326E-03	24.6	282.0	.7	.458	
201	61.0	217.1	.315E-03	22.3	277.6	3.4	.443	
400	63.9	212.7	.189E-03	24.9	281.9	3.5	.267	
600	61.0	209.1	.122E-03	20.9	283.8	3.4	.172	2
800	60.6	204.9	.792E-04	19.9	287.0	2.1	.111	2
1000	60.2	203.6	.450E-04	19.2	287.9	.8	.063	2
G20 2								
0	67.8	256.5	.860E-03	40.7	252.3	0	1.000	
50	67.3	223.8	.407E-03	31.4	275.2	12.3	.474	
100	68.0	220.5	.294E-03	31.6	278.0	1.4	.342	
150	66.9	222.2	.241E-03	30.4	276.1	1.3	.280	
200	66.9	220.4	.209E-03	30.0	277.5	.7	.243	
201	67.0	217.7	.197E-03	29.7	279.4	1.0	.229	
400	64.7	223.0	.121E-03	27.9	274.6	3.1	.141	
600	62.6	221.7	.756E-04	25.1	274.6	2.2	.088	2
800	61.7	209.8	.448E-04	21.8	283.4	5.6	.052	2
1000	51.0	216.2	.359E-04	12.0	275.6	11.3	.042	2
G20 3								
0	66.3	177.4	.845E-03	25.3	308.4	0	1.000	
50	63.2	211.4	.540E-03	23.8	282.6	14.6	.639	
100	60.9	209.3	.383E-03	20.8	283.6	2.5	.454	
150	58.6	213.3	.299E-03	18.9	279.9	3.0	.354	
200	60.5	210.4	.253E-03	20.5	282.6	2.4	.300	
201	61.2	213.9	.233E-03	21.9	280.1	1.8	.276	
400	62.4	219.1	.111E-03	24.3	276.6	2.7	.132	
600	61.7	240.1	.733E-04	28.6	260.2	9.8	.087	2
800	63.5	244.0	.471E-04	31.8	258.3	2.6	.056	2
1000	63.6	294.7	.256E-04	50.2	217.7	21.9	.030	2
G20 4								
0	76.6	235.6	.481E-03	47.0	275.1	0	1.000	
50	71.9	233.4	.345E-03	39.6	271.7	4.8	.717	
100	70.0	228.6	.244E-03	35.9	273.4	2.4	.507	
150	69.1	221.6	.187E-03	33.2	277.7	2.6	.390	
200	69.0	216.2	.145E-03	32.2	281.4	1.9	.301	
201	70.9	218.9	.139E-03	35.3	280.5	2.1	.290	
400	65.4	208.0	.727E-04	26.0	285.8	6.8	.151	
600	55.6	216.7	.429E-04	16.5	276.4	10.6	.089	2
800	50.6	219.8	.271E-04	12.5	272.5	5.4	.056	2
1000	44.6	225.6	.166E-04	9.0	266.1	7.2	.035	2

G20 5								
0	60.9	224.1	.458E-03	23.7	272.2	0	1.000	
50	56.0	241.0	.165E-03	23.1	256.8	10.1	.361	
100	54.6	229.5	.893E-04	18.5	265.5	6.7	.195	
150	55.2	224.2	.534E-04	17.7	270.1	3.1	.117	
200	51.1	221.3	.324E-04	13.3	271.3	4.4	.071	
G20 6								
0	63.4	206.6	.907E-03	23.3	286.3	0	1.000	
50	61.4	213.7	.613E-03	22.2	280.4	3.8	.675	
100	62.0	214.9	.452E-03	23.0	279.6	.8	.498	
150	60.6	213.0	.365E-03	21.1	280.7	1.7	.402	
200	60.1	210.6	.297E-03	20.1	282.4	1.2	.328	
201	61.3	208.7	.255E-03	21.2	284.2	1.5	.281	
400	57.6	207.9	.129E-03	16.9	283.9	3.8	.142	
600	55.8	215.3	.727E-04	16.4	277.5	4.4	.080	2
800	56.2	214.8	.444E-04	16.7	278.0	.4	.049	2
1000	61.3	227.2	.252E-04	24.8	269.9	8.2	.028	2
G20 8								
0	57.4	83.8	.239E-03	36.8	24.5	0	1.000	
50	81.7	226.1	.811E-04	53.4	286.6	39.5	.339	
100	70.2	259.2	.452E-04	44.5	252.9	13.6	.189	
150	64.8	280.7	.242E-04	45.9	230.8	9.8	.101	
200	59.2	287.4	.220E-04	42.9	220.0	6.4	.092	
G20 9								
0	70.7	227.3	.102E-02	36.7	274.8	0	1.000	
50	63.8	208.7	.654E-03	24.2	284.9	9.9	.640	
100	62.0	208.9	.472E-03	22.0	284.2	1.9	.463	
150	61.7	209.7	.381E-03	21.8	283.5	.5	.373	
200	61.2	207.8	.329E-03	20.9	284.8	1.1	.322	
201	60.3	207.1	.291E-03	19.8	285.2	1.0	.285	
400	61.4	204.7	.152E-03	20.8	287.3	1.7	.149	
600	61.4	200.0	.871E-04	20.2	291.0	2.2	.085	2
800	69.9	205.7	.468E-04	31.9	289.0	8.7	.046	2
1000	75.4	221.6	.247E-04	42.6	281.9	7.2	.024	2

Appendix C

SITE PALAEOMAGNETIC RESULTS

Notes

This appendix gives the results of combining together the individual specimen results from each site to form site means, and also gives various mean results for the investigations carried out at Newcastle University. Except where otherwise stated the site mean results were computed using all the specimen results given for that site in Appendix B. All calculations are based on the statistics of Fisher (1953). The significance of the various columns is explained below.

The first column, headed DMG, indicates the peak demagnetizing field in oersteds. The significance of demagnetizing fields of 201, 301 oe, etc., is explained in section 4.2.4.

The second column, headed N, specifies the number of specimen results used in computing the mean.

Columns three to six refer to the mean direction of magnetization at each demagnetizing step. The third and fourth columns, headed DIP and DECL, specify the inclination and declination respectively of the mean direction of magnetization. Upward inclinations are indicated by a minus sign and all declinations are measured clockwise from true north. The fifth column, headed K, gives the precision parameter (k), and the sixth column, headed A95 gives the radius in degrees of the circle of 95% confidence (α_{95}) about the mean direction.

Columns seven to ten refer to the pole position corresponding to the mean direction of magnetization at each step. Column seven, headed LAT, gives the latitude of the mean pole, and column eight, headed LONG, gives the longitude of the mean pole. Southerly latitudes are indicated by a minus sign, and all longitudes are measured eastwards from the Greenwich meridian. Columns nine and ten, headed DP and DM, give the minor and major semi-axes respectively of the oval of 95% confidence about the mean pole.

The number appearing after the final (DM) column for some of the higher demagnetizing steps indicates the number of contributing specimen results which were themselves obtained as the mean of two measurements (as explained further at the end of section 4.2.1).

DYKE D2

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	83.1	228.8	50.2	7.9	56.0	288.3	15.1	15.5	
50	8	65.8	223.6	161.3	4.4	29.2	274.9	5.8	7.1	2
100	8	59.1	219.4	651.1	2.2	20.5	275.5	2.4	3.2	6
150	8	56.9	218.9	385.9	2.8	18.2	275.2	3.0	4.1	6
200	8	55.7	218.0	428.9	2.7	16.8	275.6	2.7	3.8	6
300	8	54.5	216.8	222.1	3.7	15.3	276.3	3.7	5.3	6
400	8	55.8	212.7	280.8	3.3	15.8	280.0	3.4	4.7	8
500	8	54.7	207.5	255.2	3.5	13.8	283.9	3.5	4.9	8

DYKE D3

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	67.4	222.6	37.8	9.1	31.1	276.4	12.6	15.2	
50	8	59.9	223.6	220.2	3.7	22.4	272.5	4.3	5.7	2
100	8	57.0	220.0	351.1	3.0	18.5	274.4	3.1	4.3	6
150	8	56.4	222.0	459.4	2.6	18.3	272.5	2.7	3.7	6
200	8	56.3	220.9	411.5	2.7	18.0	273.4	2.8	3.9	2
300	8	55.8	220.6	337.4	3.0	17.5	273.5	3.1	4.3	2
301	8	55.2	220.6	429.7	2.7	16.8	273.3	2.7	3.8	
400	8	56.0	220.8	240.2	3.6	17.6	273.4	3.7	5.1	2
500	8	55.9	223.7	404.5	2.8	18.2	271.1	2.8	4.0	2

DYKE D4

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	55.4	189.5	5.3	26.6	12.7	298.8	27.1	38.0	
100	8	56.7	206.2	128.2	4.9	15.7	285.3	5.2	7.1	7
150	7	56.4	200.4	278.3	3.6	14.7	290.0	3.8	5.2	6
200	7	55.9	197.8	388.4	3.1	13.8	292.0	3.2	4.4	6
300	8	57.4	200.0	354.5	2.9	15.6	290.4	3.1	4.3	3
301	7	56.6	200.6	453.2	2.8	14.9	289.8	3.0	4.1	1
400	7	56.2	202.4	502.4	2.7	14.7	288.3	2.8	3.9	2
500	7	55.0	199.2	232.6	4.0	13.0	290.7	4.0	5.6	2

DYKE D5

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	60.9	223.6	30.6	10.2	23.4	272.7	11.9	15.6	
100	8	56.4	211.2	2078.9	1.2	16.2	281.1	1.3	1.8	
200	8	55.2	210.9	2060.6	1.2	14.9	281.1	1.2	1.7	
300	8	54.7	209.9	2629.5	1.1	14.2	281.9	1.1	1.5	
301	8	54.5	209.8	2287.7	1.2	14.0	281.9	1.2	1.6	
400	8	53.0	207.8	1145.2	1.6	12.3	283.2	1.6	2.3	1
600	8	50.3	204.1	1242.7	1.6	9.3	285.9	1.4	2.1	1
800	8	46.9	201.7	826.1	1.9	6.1	287.6	1.6	2.5	1
1000	8	43.0	198.9	228.0	3.7	2.6	289.6	2.8	4.6	8

DYKE D6

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	68.7	224.6	16.6	14.0	33.2	275.5	20.0	23.7	
50	8	57.5	213.0	52.9	7.7	17.6	279.9	8.2	11.3	
100	8	58.0	210.5	403.8	2.8	17.7	282.0	3.0	4.1	
150	8	57.1	212.4	538.6	2.4	17.1	280.3	2.5	3.5	
200	8	56.8	212.5	799.9	2.0	16.8	280.2	2.1	2.8	
201	8	56.9	215.7	940.5	1.8	17.5	277.6	1.9	2.6	
400	8	54.4	215.9	523.8	2.4	15.1	276.8	2.4	3.4	2
600	8	51.2	218.2	209.6	3.8	12.6	274.1	3.5	5.2	2
601	7	52.0	216.0	221.9	4.1	12.9	276.1	3.8	5.6	
800	7	48.4	221.1	42.0	9.4	10.8	270.9	8.1	12.4	7

DYKE D7

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	68.4	201.8	19.0	13.0	29.2	291.3	18.5	22.0	
50	8	65.2	195.9	375.3	2.9	24.4	294.9	3.7	4.6	
100	8	62.6	195.8	390.5	2.8	21.1	294.5	3.4	4.4	
150	8	61.7	196.9	395.2	2.8	20.1	293.5	3.3	4.3	
151	8	59.9	196.5	473.3	2.5	18.0	293.6	2.9	3.8	
200	8	59.8	196.3	378.7	2.9	17.9	293.8	3.2	4.3	
400	8	60.0	193.2	405.8	2.8	17.9	296.2	3.1	4.2	2
600	8	59.5	193.1	155.5	4.5	17.2	296.2	5.0	6.7	2

DYKE D8

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	53.8	235.8	2.1	51.5	19.4	260.3	50.3	72.0	
50	8	65.1	207.7	189.2	4.0	25.6	286.1	5.3	6.5	
100	8	58.4	206.8	228.1	3.7	17.6	285.1	4.0	5.4	1
150	8	56.5	205.7	139.6	4.7	15.4	285.6	4.9	6.8	3
200	8	54.3	206.6	71.9	6.6	13.4	284.5	6.5	9.3	5

DYKE D9

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	82.4	236.1	30.5	10.2	55.9	284.1	19.4	19.9	
50	7	59.6	219.7	212.5	4.2	21.2	275.2	4.7	6.2	
100	8	58.5	222.8	231.9	3.6	20.7	272.4	4.0	5.4	
150	8	58.1	223.9	176.7	4.2	20.4	271.4	4.5	6.2	
200	8	58.9	224.7	167.8	4.3	21.5	271.0	4.8	6.4	
201	7	55.2	225.9	207.2	4.2	18.0	268.8	4.2	6.0	
400	7	51.0	223.0	106.9	5.9	13.5	270.0	5.4	7.9	7
600	7	47.1	225.9	31.3	11.0	10.9	266.6	9.2	14.2	7

DYKE D11

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	65.3	208.7	195.1	4.0	26.0	285.2	5.2	6.4	
50	8	59.4	207.5	382.4	2.8	18.7	284.5	3.2	4.3	
100	8	58.2	209.1	625.6	2.2	17.7	282.9	2.4	3.3	
200	8	57.4	208.6	691.7	2.1	16.8	283.2	2.3	3.1	
300	8	56.6	208.0	559.3	2.3	15.8	283.5	2.5	3.4	
400	8	56.0	207.8	738.2	2.0	15.3	283.5	2.1	2.9	2
500	8	56.2	206.4	505.7	2.5	15.2	284.7	2.6	3.5	2

DYKE D12

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	63.6	224.5	169.9	4.3	26.8	272.8	5.4	6.8	
50	8	57.1	217.1	297.0	3.2	18.0	276.2	3.4	4.7	
100	8	54.0	216.2	492.1	2.5	14.7	276.1	2.5	3.5	
200	8	52.1	215.7	409.8	2.7	12.9	276.1	2.6	3.8	
300	8	51.2	215.3	290.2	3.3	12.0	276.2	3.0	4.4	
400	8	50.5	215.4	262.0	3.4	11.4	276.0	3.1	4.6	
401	8	50.3	215.1	202.4	3.9	11.1	276.2	3.5	5.2	
600	8	49.4	214.9	172.4	4.2	10.3	276.2	3.7	5.6	
800	8	47.9	214.7	156.0	4.4	9.0	276.0	3.8	5.8	8
1000	8	45.4	215.4	78.7	6.3	7.1	275.0	5.1	8.0	8

DYKE D13

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	47.7	174.9	379.9	2.8	5.5	311.1	2.4	3.7	
50	8	44.5	175.4	470.1	2.6	2.8	310.7	2.0	3.2	
100	8	42.9	174.8	438.5	2.6	1.6	311.2	2.0	3.3	
150	8	42.0	174.6	410.4	2.7	.9	311.4	2.1	3.4	
200	8	40.8	173.5	439.3	2.6	.1	312.5	1.9	3.2	
300	8	40.0	171.8	372.1	2.9	-.5	314.1	2.1	3.5	
301	8	39.8	172.7	362.6	2.9	-.6	313.3	2.1	3.5	
400	8	39.2	171.9	403.4	2.8	-1.0	314.0	2.0	3.3	2
600	8	38.2	170.9	402.9	2.8	-1.7	315.0	1.9	3.3	8
800	8	36.4	169.7	362.5	2.9	-2.8	316.2	2.0	3.4	8
1000	8	34.7	168.9	276.5	3.3	-3.9	317.0	2.2	3.8	8

DYKE D14(8)

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	83.1	202.6	406.7	2.8	53.7	297.7	5.3	5.4	
50	8	73.5	205.6	147.4	4.6	37.4	290.5	7.4	8.2	
100	8	70.6	203.5	186.0	4.1	32.7	290.7	6.1	7.1	
150	8	70.8	202.6	181.8	4.1	32.9	291.4	6.2	7.2	
200	8	69.3	201.6	144.0	4.6	30.6	291.6	6.7	7.9	
201	8	69.3	203.0	144.9	4.6	30.7	290.6	6.7	7.9	
400	8	69.6	201.5	127.6	4.9	31.0	291.8	7.2	8.4	2
600	8	70.1	200.9	95.8	5.7	31.7	292.3	8.4	9.8	2
800	8	70.6	199.7	61.4	7.1	32.4	293.3	10.7	12.4	4
1000	8	71.9	197.1	39.2	9.0	34.0	295.3	13.9	15.8	8

DYKE D14(5)

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	5	82.5	194.3	385.1	3.9	52.2	300.7	7.4	7.6	
50	5	76.0	196.0	215.9	5.2	40.5	297.2	8.9	9.6	
100	5	72.8	196.1	301.7	4.4	35.4	296.2	7.0	7.9	
150	5	72.7	196.4	375.3	4.0	35.3	296.0	6.3	7.0	
200	5	72.5	194.7	409.5	3.8	34.8	297.0	5.9	6.7	
201	5	72.6	196.9	398.0	3.8	35.2	295.7	6.1	6.8	
400	5	73.7	197.8	376.0	4.0	37.0	295.4	6.4	7.1	1
600	5	75.1	200.2	334.5	4.2	39.5	294.4	7.0	7.7	1
800	5	77.1	199.0	219.6	5.2	42.6	295.9	9.0	9.7	3
1000	5	80.0	199.3	169.3	5.9	47.8	297.1	10.8	11.3	5

DYKE D14(3)

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	3	83.7	219.1	504.2	5.5	56.0	292.4	10.6	10.8	
50	3	68.7	216.3	520.9	5.4	31.8	281.2	7.8	9.2	
100	3	66.5	212.5	493.4	5.6	28.2	282.9	7.5	9.1	
150	3	67.2	210.6	158.2	9.8	28.9	284.6	13.6	16.3	
200	3	63.6	209.4	231.7	8.1	24.1	284.3	10.2	12.9	
201	3	63.3	209.7	268.5	7.5	23.7	284.0	9.4	11.9	
400	3	62.6	205.2	275.8	7.4	22.3	287.2	9.1	11.6	1
600	3	61.7	201.5	214.9	8.4	20.6	289.9	10.1	13.0	1
800	3	59.9	200.1	170.0	9.5	18.4	290.6	10.8	14.3	1
1000	3	58.2	195.9	98.6	12.5	16.2	293.7	13.6	18.4	3

DYKE D15

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	73.8	169.1	62.0	7.1	36.6	313.3	11.5	12.8	
50	8	60.1	184.0	255.0	3.5	17.6	303.4	4.0	5.3	
100	8	55.8	186.8	397.1	2.8	13.1	300.9	2.9	4.0	
150	8	52.7	187.0	276.0	3.3	10.0	300.6	3.2	4.6	
200	8	51.6	187.9	653.5	2.2	9.0	299.8	2.0	3.0	
400	8	49.0	189.2	610.3	2.2	6.8	298.5	2.0	3.0	6
600	8	46.5	189.5	450.7	2.6	4.7	298.1	2.2	3.4	6
800	8	43.2	190.1	294.6	3.2	2.1	297.4	2.5	4.0	8
1000	8	41.3	192.2	243.8	3.6	.8	295.4	2.6	4.3	8
1200	8	37.6	196.3	64.6	6.9	-1.5	291.4	4.8	8.2	8

DYKE D16

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	65.2	233.1	238.2	3.6	30.8	267.4	4.7	5.8	
50	8	61.1	230.8	418.4	2.7	25.5	267.0	3.2	4.2	
100	8	59.9	228.3	332.2	3.0	23.6	268.4	3.5	4.6	
200	8	59.4	221.9	302.9	3.2	21.5	273.3	3.6	4.8	
300	8	58.3	217.1	256.7	3.5	19.3	276.8	3.8	5.1	2
400	8	57.9	211.7	235.3	3.6	17.9	281.0	3.9	5.3	2
401	8	56.9	211.2	178.5	4.2	16.8	281.2	4.4	6.0	
600	8	52.9	201.1	94.9	5.7	11.3	288.7	5.5	7.9	8
800	8	44.1	199.4	16.6	14.0	3.6	289.1	11.0	17.6	8
1000	8	35.6	205.5	5.4	26.2	-1.6	282.6	17.5	30.3	8

DYKE D17

		****** MAGNETIZATION			******	********** POLE			**********	
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	73.9	235.1	11.8	16.8	42.9	272.5	27.3	30.3	
50	8	60.8	225.3	175.5	4.2	23.8	271.2	4.9	6.4	
100	8	58.9	219.8	145.7	4.6	20.5	274.8	5.1	6.9	
150	8	56.7	215.1	135.8	4.8	17.3	277.9	5.0	6.9	
200	8	55.8	212.2	125.1	5.0	15.8	280.1	5.1	7.1	
201	8	55.1	213.5	144.3	4.6	15.4	278.8	4.7	6.6	
400	8	50.9	204.1	138.8	4.7	9.9	285.8	4.3	6.4	2
600	8	44.3	195.9	79.0	6.3	3.4	292.3	4.9	7.9	8
800	8	37.4	193.1	25.7	11.1	-2.0	294.3	7.7	13.1	8
1000	8	36.5	191.7	8.8	19.7	-2.7	295.5	13.4	23.0	8

DYKE D18

		****** MAGNETIZATION			******	********** POLE			**********	
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	71.5	171.3	323.8	3.1	33.0	312.4	4.7	5.4	
50	8	65.3	177.7	508.3	2.5	24.0	308.4	3.2	4.0	
100	8	62.6	179.6	421.8	2.7	20.6	306.9	3.3	4.2	
200	8	60.2	180.4	343.1	3.0	17.7	306.4	3.4	4.5	
300	8	58.8	180.9	344.9	3.0	16.1	305.9	3.3	4.4	
400	8	57.6	181.0	248.0	3.5	14.8	305.8	3.8	5.2	
401	8	57.7	180.6	256.2	3.5	14.9	306.1	3.7	5.1	
500	8	55.8	180.3	239.7	3.6	12.9	306.4	3.7	5.1	
600	8	55.4	180.5	225.7	3.7	12.6	306.2	3.8	5.3	
800	8	52.5	180.9	186.1	4.1	9.6	305.9	3.9	5.6	8
1000	8	50.3	179.8	148.4	4.6	7.6	306.8	4.1	6.1	8

DYKE D19

		****** MAGNETIZATION			******	********** POLE			**********	
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	84.2	242.4	44.7	8.4	59.6	286.2	16.3	16.5	
50	8	71.5	211.2	53.1	7.7	35.0	286.0	11.8	13.4	
100	8	63.8	203.0	55.1	7.5	23.4	289.3	9.5	12.0	
150	8	61.5	202.6	31.6	10.0	20.6	289.1	11.9	15.4	
200	8	58.0	194.0	26.9	10.9	15.8	295.3	11.8	16.0	
400	8	50.2	176.9	13.5	15.6	7.6	309.3	14.0	20.9	8

DYKE D20

DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
		****** MAGNETIZATION ******				********** POLE **********				
0	8	69.7	208.4	105.3	5.4	32.0	287.2	8.0	9.3	
50	8	58.5	218.8	61.9	7.1	19.9	275.6	7.8	10.5	
100	8	52.6	219.0	52.1	7.7	14.1	273.8	7.3	10.7	
200	8	50.3	220.1	87.2	6.0	12.3	272.2	5.4	8.0	
300	8	47.9	219.3	86.7	6.0	10.1	272.4	5.1	7.8	2
400	8	47.2	219.3	80.6	6.2	9.6	272.2	5.2	8.0	2
401	8	44.6	220.1	138.7	4.7	7.6	271.0	3.7	5.9	
500	8	44.1	219.9	163.8	4.3	7.2	271.1	3.4	5.4	8
600	8	43.9	217.7	116.3	5.2	6.6	272.9	4.0	6.4	8

DYKE D21

DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM
		****** MAGNETIZATION ******				********** POLE **********			
0	8	59.5	236.5	132.4	4.8	25.2	262.0	5.4	7.3
50	8	48.3	225.9	453.8	2.6	12.0	266.8	2.2	3.4
100	8	44.3	223.4	370.2	2.9	8.2	268.0	2.3	3.6
200	8	41.1	222.4	249.6	3.5	5.6	268.2	2.6	4.3
300	8	39.6	221.6	173.8	4.2	4.3	268.7	3.0	5.1
400	8	39.0	221.6	183.7	4.1	3.9	268.6	2.9	4.9
401	8	37.6	221.3	177.0	4.2	2.9	268.5	2.9	4.9
500	8	37.6	221.0	152.4	4.5	2.9	268.8	3.1	5.3
600	8	35.8	220.5	138.8	4.7	1.5	269.0	3.2	5.5

GNEISS G10/11 (excluding G10-4)

DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
		****** MAGNETIZATION ******				********** POLE **********				
0	17	81.1	31.3	2.1	33.7	77.7	353.9	62.8	65.1	
50	17	77.8	324.1	17.9	8.7	75.9	234.2	15.3	16.3	
75	17	77.4	316.6	26.7	7.0	72.8	234.8	12.3	13.2	
100	17	78.2	295.5	24.4	7.4	65.8	248.6	13.1	13.9	
200	15	77.3	290.0	10.2	12.6	63.1	248.1	21.9	23.5	4
300	15	69.9	242.0	6.3	16.6	39.0	264.7	24.5	28.6	5
400	15	65.2	207.7	3.3	25.2	25.7	286.4	33.0	40.8	15
500	14	37.9	199.3	1.3	69.5	-1.1	288.9	48.5	82.1	14

GNEISS G13

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	57.4	218.2	27.8	10.7	18.5	275.4	11.4	15.6	
50	8	49.6	217.1	32.4	9.9	11.0	274.4	8.7	13.1	
100	8	47.8	215.2	37.5	9.2	9.0	275.6	7.8	12.0	
200	8	46.5	215.4	40.1	8.9	8.0	275.2	7.3	11.4	1
300	8	46.5	215.6	42.2	8.6	8.0	275.0	7.1	11.1	1
301	7	45.3	214.0	40.0	9.7	6.8	276.2	7.8	12.3	
400	7	45.4	213.8	41.6	9.5	6.8	276.4	7.6	12.0	
600	7	45.7	212.4	44.8	9.1	6.8	277.6	7.4	11.6	
800	7	45.2	210.5	46.1	9.0	6.1	279.2	7.2	11.4	
1000	7	44.0	206.5	51.7	8.5	4.4	282.6	6.6	10.6	
1001	7	44.5	207.4	50.0	8.6	4.9	281.9	6.8	10.8	
1200	7	41.7	203.2	45.2	9.1	2.2	285.2	6.8	11.1	

GNEISS G14

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	73.3	195.1	45.6	8.3	36.2	297.0	13.3	14.8	
50	8	63.6	191.8	55.7	7.5	22.2	297.6	9.4	11.9	
100	8	59.9	189.9	52.4	7.7	17.6	298.7	8.8	11.7	
150	8	58.5	189.5	65.3	6.9	16.1	298.9	7.6	10.2	2
200	8	57.1	188.5	55.8	7.5	14.5	299.6	7.9	10.9	2
201	6	55.6	189.1	54.5	9.2	13.0	299.0	9.4	13.1	
400	6	55.1	186.5	72.1	7.9	12.3	301.1	8.0	11.3	2
600	6	52.0	182.3	104.2	6.6	9.2	304.5	6.2	9.0	6
800	6	47.1	178.6	60.5	8.7	4.9	307.8	7.3	11.2	6
1000	6	42.7	169.0	34.7	11.5	1.7	316.5	8.8	14.2	6

GNEISS G18

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	7	62.3	184.4	53.5	8.3	20.2	303.2	10.1	13.0	
50	6	56.8	183.8	50.5	9.5	14.0	303.4	10.0	13.8	
100	7	53.6	185.1	60.6	7.8	10.8	302.2	7.6	10.9	
200	7	49.7	185.8	61.0	7.8	7.2	301.5	6.9	10.4	
300	7	47.4	186.1	47.6	8.8	5.2	301.2	7.4	11.5	2
301	7	47.5	185.0	46.2	9.0	5.2	302.1	7.6	11.7	
400	7	46.2	183.4	45.8	9.0	4.2	303.6	7.4	11.6	2
600	7	42.5	182.4	56.6	8.1	1.3	304.4	6.2	10.0	7
800	7	42.2	178.8	34.9	10.4	1.0	307.6	7.8	12.7	7
1000	7	37.4	177.6	47.8	8.8	-2.5	308.8	6.1	10.4	7

GNEISS G20

		****** MAGNETIZATION ******				********** POLE **********				
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM	
0	8	74.0	208.4	17.2	13.8	38.5	289.0	22.4	24.8	
50	8	66.5	221.9	78.9	6.3	29.9	276.2	8.5	10.3	
100	8	65.6	222.7	86.9	6.0	28.9	275.1	7.9	9.7	
150	8	64.0	223.1	55.6	7.5	27.1	274.2	9.5	11.9	
200	8	63.7	222.4	37.0	9.2	26.5	274.6	11.6	14.6	
201	6	63.7	213.5	280.9	4.0	24.8	281.3	5.0	6.4	
400	6	62.7	212.3	351.0	3.6	23.4	281.8	4.4	5.6	
600	6	60.2	217.0	124.8	6.0	21.4	277.5	6.9	9.1	6
800	6	61.0	216.7	74.2	7.8	22.2	277.9	9.2	12.0	6
1000	6	62.2	228.2	20.3	15.2	26.0	269.5	18.4	23.7	6

NEWCASTLE RESULTS

SEVENTEEN SPECIMENS (see section 4.5.4) A.F. DEMAGNETIZATION

		*******MAGNETIZATION******				*********POLE*********			
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM
0	17	70.5	199.7	18.4	8.5	32.1	293.3	12.8	14.8
100	17	58.6	208.2	51.6	5.0	18.0	284.0	5.5	7.4
200	17	57.1	206.6	51.5	5.0	16.2	284.9	5.3	7.3
300	17	56.8	204.6	49.1	5.1	15.6	286.5	5.4	7.5
500	17	55.0	208.8	28.1	6.8	14.4	282.7	6.9	9.7
700	17	54.1	199.3	15.3	9.4	12.2	290.5	9.3	13.2
900	17	47.4	200.0	6.6	15.1	6.2	289.0	12.7	19.6

SEVENTEEN SPECIMENS (see section 4.5.4) THERMAL DEMAGNETIZATION

		******* MAGNETIZATION******				********* POLE**********			
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM
20	17	70.3	195.9	17.5	8.8	31.5	295.8	13.1	15.2
200	17	66.3	202.2	26.3	7.1	26.5	290.5	9.6	11.6
300	17	64.6	203.0	31.8	6.4	24.3	289.4	8.3	10.3
400	17	62.7	204.4	36.8	6.0	22.1	287.9	7.3	9.3
500	17	60.5	206.5	47.0	5.3	19.9	285.8	6.1	8.0
540	17	59.1	204.4	56.1	4.8	18.0	287.2	5.4	7.2
560	17	61.4	200.7	45.8	5.3	20.2	290.5	6.3	8.2

SIX SPECIMENS (see section 4.5.5) THERMAL DEMAGNETIZATION

		********MAGNETIZATION******				**********POLE************			
DMG	N	DIP	DECLN	K	A95	LAT	LONG	DP	DM
20	6	65.7	163.4	9.2	23.3	25.3	318.8	30.9	38.0
200	6	64.1	171.7	9.9	22.4	22.6	312.9	28.5	35.7
300	6	61.2	178.7	13.4	19.0	18.9	307.7	22.4	29.1
400	6	56.9	179.5	17.8	16.3	14.1	307.0	17.2	23.7
500	6	56.6	178.6	22.7	14.4	13.8	307.7	15.1	20.8
520	6	52.0	179.8	22.1	14.6	9.2	306.8	13.6	19.9
540	6	50.4	177.7	19.8	15.4	7.8	308.6	13.9	20.7
560	6	44.1	173.2	16.8	16.9	2.6	312.7	13.2	21.1
580	6	41.0	192.5	4.5	35.6	0.6	295.1	26.3	43.3

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