Palaeomagnetism of Some Devonian Rock Formations in Australia

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(Manuscript received June 10, revised version December 29, 1960)

Abstract

From southern New South Wales a palaeomagnetic survey of rocks whose ages are Upper Silurian — Lower Devonian, Middle Devonian and Upper Devonian has been made. The rock types include the Canberra Volcanics and Porphyries, the Murrumbidgee Sandstones and the Nethercote Basalts. Throughout these formations and irrespective of the rock type the directions of magnetization are remarkably uniform. The low inclination of the direction of remanent magnetization indicate that throughout this period Australia lay 10—15° away from the equator, the pole lying in the South Atlantic. Evidence for stability of the rocks is as follows: (1) their uniformity of direction, (2) the deviation from the present geomagnetic and dipole fields, (3) the presence of normal and reversely magnetized rocks. These data lend support to the belief that south-eastern Australia experienced tropical conditions during the Devonian.

Introduction

Preliminary work by IRVING and GREEN (1958) indicated that between the Cambriam and Carboniferous Periods Australia moved from a low latitude to a high polar one. Furthermore, palaeomagnetic determinations on nine samples from the Mugga Porphyry (Upper Silurian) and on twelve samples from the Ainslie Volcanics (Upper Silurian and/or Lower Devonian) indicate a low latitude for the sampling area. This indication together with the high latitude of south-eastern Australia as found by IRVING (1957) working on Upper Carboniferous varves suggested that large changes in the inclination of the geomagnetic field had taken place during the Devonian and/or Lower Carboniferous.

The change in the direction of magnetization of Devonian rocks has been investigated and the results are given here.

Presentation of Results

The distribution of sampling localities is shown in Figure 1. Each locality is considered in chronological order:

(a) The Canberra Volcanics and Porphyries of Upper Silurian — Lower Devonian age,

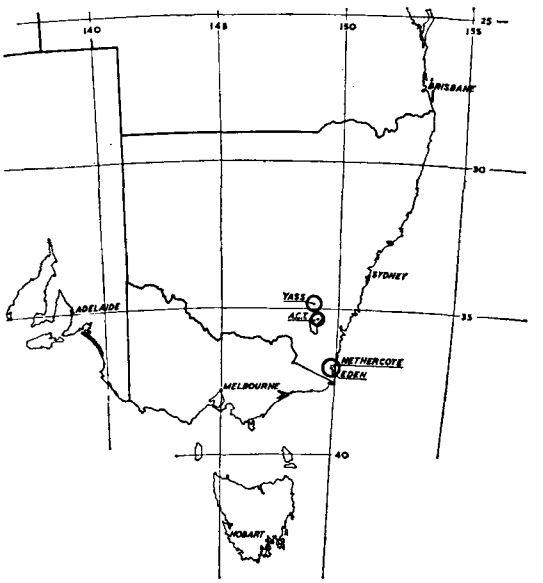

Fig. 1. The distribution of the three areas sampled. In the north is Yass; near which at Alum Creek the Middle Devonian red sanstones and sediments were obtained. The Canberra volcanics and Porphyrys of Upper Silurian and/or Lower Devonian age were obtained from the A.C.T. In the south-eastern corner of Australia is the Eden district. At Nethercote some ten miles inland from Eden the horizontally bedded Nethercote basalts of Upper Devonian age outcrops. A palaeomagnetic survey has been carried out on all three groups.

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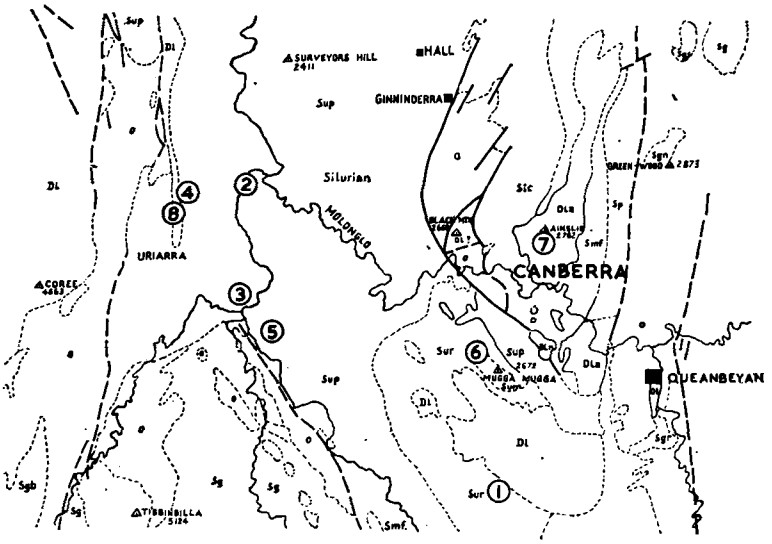

Fig. 2. The sampling sites in the A.C.T. The position of the sampling sites in the Upper Silurian and Lower Devonian volcanics and porphyrys is shown. The numbering corresponds with the eight sites enumerated in the text.

(b) The Murrumbidgee Red Beds of Middle Devonian age,
(c) The Nethercote Basalts of Upper Devonian age.

The Canberra Volcanics and Porphyries

Several igneous formations were sampled in the Canberra district. The thicknesses and probable sucession of the units is as set out below; the numbers corresponding to the position of the sites as given in Figure 2.

(8) Mountain Creek Volcanics	40 ft.	Lower Devonian
(7) Ainslie Volcanics	200 ft.	Upper Silurian — Lower Devonian
(6) Mugga Porphyry	30 ft.	
(5) Mt. Painter Porphyry	30 ft.	
(4) Swamp Creek Member	40 ft.	Upper Silurian
(3) Walker Member (Cotter)	15 ft.	
(2) Walker Member (Uriarra)	10 ft.	
(1) Deakin Volcanics	50 ft.	

At every sampling site (usually a quarry or road-cutting) the directions of magnetization of individual samples are found by measurement to be distributed about some mean direction. The within-site precision, ω is a measure of the lack of this spread. However, the mean direction at one site is different from the mean direction at another site and the between-site precision, β is a measure of the lack of spread in directions between the sites. The overall precision, k is a measure of the confidence which can be attached to the value of the mean direction calculated for the whole formation.

Some of the formations are tilted. The directions of magnetization are given with respect to the horizontal and to the bedding (Table 1). The mean direction of each formation has been considered as one site and the overall mean direction together with the within-site, ω and the between-site dispersion, β has been obtained in the manner recommended by WATSON and IRVING (1957).

Stability

When allowance is made for tilting it is found that the unfolding increases the overall precision of the directions of magnetization, k, from 33 to 47. This suggests a pre-Tabberaberan age (Middle Devonian) for the magnetization. The precision after unfoldning is not high but may be largely explained by the low (for igneous rock) "within-site" precision, ω. The low value results from treating formations

Formation	N	Map reference	Direction of Magnetization				
			Bedding-wise			Horizontal-wise	
			D	I	*k*	D	I
Mountain Creek Volcanics	7	Brindabella, 1 mile	56.4	— 45.6	35.5	2	— 54
Ainslie Volcanics	12	Canberra, 1 mile 213900E, 634000N	16.6	— 29.7	13.1	23	— 31
Mugga Porphyry	9	Canberra, 1 mile 213900E, 634000N	26.2	— 30.0	6.5	26	— 30
Mt. Painter Porphyry	15	Brindabella, 1 mile 197500E, 636400N	352.5	— 47.9	10.9	252	— 48
Swamp Creek Member	6	Brindabella, 1 mile 191800E, 645200N	102.7	— 51.4	12.2	186	— 66
Walker Member (Cotter)	9	Brindabella, 1 mile 195700E, 638200N	310.6	— 23.7	47	303	— 11
Walker Member (Uriarra)	8	Goodradigbee, 1 mile 196400E, 646500N	311.3	— 27.7	303.0	311	— 28
Deakin Volcanic	14	Canberra, 1 mile 2151000E, 626900N	44.3	— 34.5	81.7	44	— 35

Table 1. The mean direction of each of the eight Members of the Igneous rocks from the Canberra District. N is the number of rock samples collected and measured. Listed under the »Direction of Magnetization«, D stands for declination measured to the East of true North, I stands for the in lination measured positively downwards, the *k* is the precision: very low numbers for *k* would indicate that the individual directions are random. None of the above Formations are random.

	Mean direction of magnetization				Sampling Area	
	D	I	α	β	lat.	long.
Bedding-wise	12.3	— 36.5	20.6	6.1	35.2S	149.0E
Horizontal-wise	3.1	— 35.2	24.5	4.3	»	

Table 2. The mean direction of magnetization of the Igneous rocks of Canberra with respect to the bedding and horiozontal planes. (8 Members sampled — 80 samples).
D and I are as in Table 1. α is the semi-angle for the cone of confidence around the mean direction within which the true mean direction has a 95% probability of lying. β is the value of the between-site precision. The higher value for β for the bedding-wise case suggests stability of the magnetization.

which probably contain several flows as single sites. Reference to Table 2 shows that the overall mean direction of magnetization differs from the present geomagnetic and dipole field by approximately 30°. This is a good indication of stability.

Reversals

The Swamp Creek Member is reversed whereas all other formations are normal. The possibility that this is a petrological reversal (NAGATA, 1953; NEEL, 1955) has not been investigated. If the reversal results from a reversal in the geomagnetic field, a field reversal towards the end of the Silurian is indicated.

Former Pole Positions

The former pole position has been calculated from the overall mean direction of magnetization (Table 3). The equator relative to Australia is given in Figure 3.

	Sites	Age	Mean direction of magnetization			Sampling area		Former pole position			
			D	I	α	Lat.	Long.	Lat.	Long.	dy	dx
Igneous rocks of Canberra	8	Su—De	12.3	—36.5	20.6	35.2S	149.0E	71.4S	7.8E	14.0	24.0
Murrumbidgee Series	1	Dm	40.1	—28.6	10.0	34.7S	148.8E	57.8S	28.9E	5.0	11.0
Nethercote basalts	7	Du	4.5	—23.4	13.8	37.0S	150.0E	64.9S	19.6W	7.8	14.7

Table 3. The former pole positions for magnetically stable formations.

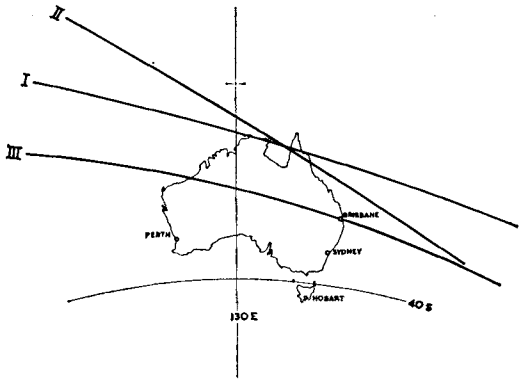

Fig. 3. The position of the Devonian equators relative to Australia. The equator marked I is appropriate to the pole calculated from the Upper Silurian and Lower Devonian igneous rocks from the Canberra district. No. II is for the Middle Devonian Red Sediments from the Yass District and No. III is for the basalt flows in the Nethercote Districts. The consistent low latitude for Australia during the Devonian is clearly indicated.

The Murrumbidgee Red Beds of Middle Devonian Age

Middle Devonian sediments are thick in the Yass-Taemas district. At Alum Creek they show Tabberabberan tilting. A vertical thickness of approximately 100 ft. was sampled.

Results

The directions of magnetization and the error circle with respect to the bedding are given in Figure 4 and Table 4. In Figure 5 the mean direction with respect to the horizontal and the circle of confidence are shown together with the direction of the present day dipole field which lies outside the circle of confidence.

Stability

The only evidence for stability is the divergence from both the dipole and geomagnetic field directions and the consistency with the directions for the Lower and Upper Devonian. The calculated pole position is to the south of Africa (Table 3) and the position of the equator relative to Australia is given in Figure 3.

The Nethercote Basalts

Near Twofold Bay Upper Devonian sediments and lavas are exposed. BROWN (1930, 1931) divides the Upper Devonian into three stages.

(1) The Lambie (upper) consisting mainly of conglomerates, grits, sandstones and quartzites.

(2) The Yalwal (middle), dark red siltstones, shales, tuffs and red grits, sandstones with interbedded rhyolites and basalts.

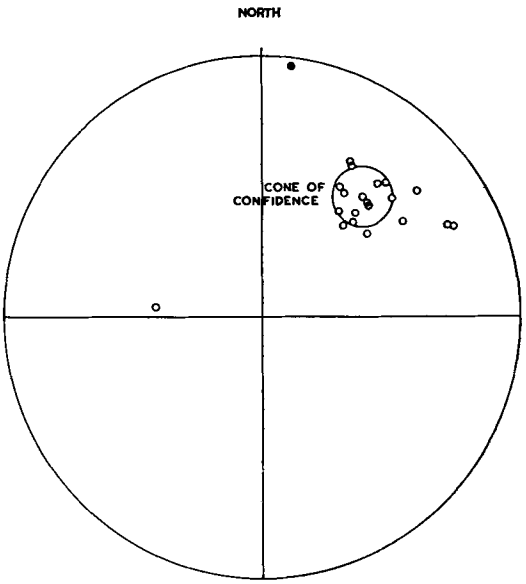

Fig. 4. Directions at Yass. This is a stereographic plot on the upper surface. The directions of magnetization and the error circle with respect to bedding are shown for the Good Hope site at Yass.

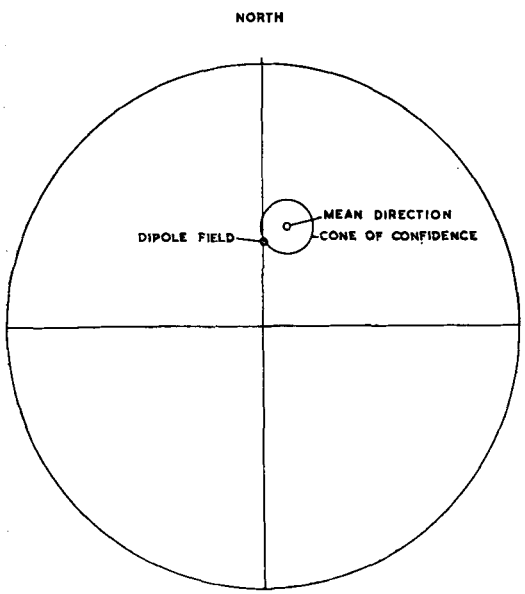

Fig. 5. The mean direction and the dipole field at Yass. This is a stereographic plot on the upper surface. The mean direction of magnetization, the circle of confidence with respect to the horizontal and the direction of the dipole field direction are shown. In Australia the geomagnetic field is approximately 10° steeper.

(3) The Eden (lower) of acid igneous rocks.

Freshwater fossils in the Yalwal and marine fossils in the Lambie are of Upper Devonian age. Basalt flows at Nethercote Village (Fig. 1 and Fig. 6) are interbedded with Yalwal sediments. The basalts from at least two distinct flows and many more flows are probably present. A total vertical thickness of over 600 feet was sampled. This thickness is considered sufficient to average the secular variation of the geomagnetic field. The flows are interbedded with red ferruginous sandstones which are flat lying.

Results

The distribution of sampling sites is shown in Figure 6. Five sites are normal and two (Nos. 2 and 7) are reversed. The height of the reversed sites is such that there are normal sites at higher and lower levels. Nowhere were mixed polarities found at the same site. In Figure 7 the mean direction of each of the seven sites is plotted. Although sites 2 and 7 are reversed they are plotted as normal for comparison with the other five sites. Fom the mean site directions, the mean direction of the formation D = 4.5 I = —22.4 and the cone of confidence (semiangle 13.8) has been computed. Figure 7 shows that the mean direction is significantly different from the present geo-

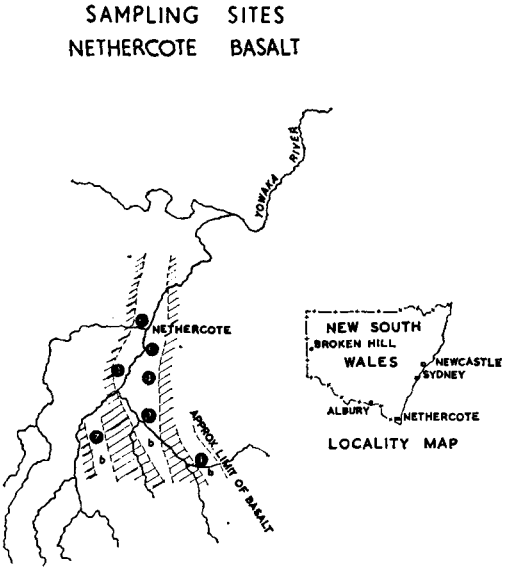

Fig. 6. Basalt outcrops at Nethercote. The basalt (symbol b) is interbedded with flat-lying Yalwal sediment (shaded). The seven sampling sites are shown.

Formation	Mean direction of magnetization				
	D	I	k	α	β
Murrumbidgee Series (Good Hope) 34.7S, 148.8E	40.1	—28.6	—	10.0	—

Table 4. The mean direction of magnetization of the Murrumbidgee Series at Good Hope with respect to the bedding plane. Because only one site has been sampled no value for the between-site precision, β and k, the overall precision can be given.

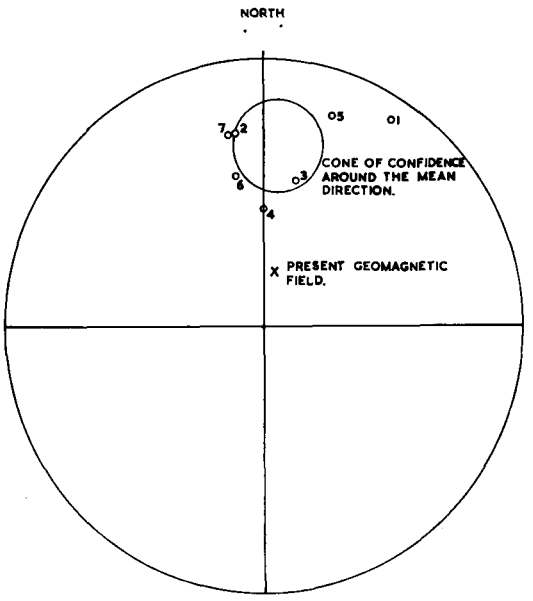

Fig. 7. The mean direction of magnetization of the Nethercote Basalts. This is a stereographic plot on the upper surface. The mean directions from seven sites are shown with the cone of confidence and, for comparison, with the direction of the present geomagnetic field. The beds interbedded with the basalt flows are flat-lying.

magnetic field. The within site, ω and the between-site precision, β, has been calculated ($\beta = 29$, $\omega = 11$); the between-site precision is significant and suggests secular variation having taken place during the Upper Devonian.

The stability of magnetization of these basalts is suggested by the agreement of the directions of magnetization at each site and the large angle these directions make with the present geomagnetic field. The occurrence of both normal and reversed polarities also implies stability.

From the mean direction of magnetization of the formation, the calculated pole position (64.9S, 19.6W) is in the south Atlantic Ocean (Table 4).

Discussion of the Results

The position of the equator relative to Australia during the Lower, Middle and Upper Devonian is given in Figure 3. The amount of polar wandering which has taken place during the Devonian is not large. The rocks used for calculating these pole positions are of many different types (red sediments, andesites, basalts and porphyries) and are found in many geological environments (as bedded sediments, lava flows, intrusive sills and stocks). In some cases they have been folded but in others they have remained more or less undisturbed since their formation. This initial agreement I consider to be highly significant. It suggests that the rocks have been influenced by a single cause, (i.e. the geomagnetic field) and that special effects — magnetostriction, water currents, etc. — play only a minor role.

The Devonian Equators

Figure 3 shows that Australia lay in a low latitude throughout the Devonian. This palaeomagnetic result may be compared with the geological indications of climate which are:

(1) Extensive coral reefs, especially in the Yass-Taemas district during the Lower and Middle Devonian.

(2) Bright red colour of the Devonian sediments in the Yass area.

(3) The considered view that the Lambie beds were formed in tropical lakes (Matheson, 1930).

(4) The Yalwal Beds with which the Nethercote basalts are interbedded also indicate tropical conditions (Brown, 1930).

In conclusion, the low latitudes which prevailed during the late Silurian and Devonian (as given by the palaeomagnetic data) is consistent with the warm climate indicated by the palaeoclimatic evidence. The lower Carboniferous appears to have been a period of rapid change in latitude for Australia.

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