

## **Paleomagnetism of the Caldwell lavas, Eastern Townships, Québec.**

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### **ABSTRACT**

Forty two oriented samples (97 specimens) were obtained from 17 sites in metavolcanic rocks from the Caldwell Group of the Appalachians of Southern Québec (longitude: 71°00'-71°30' W, latitude: 46°00'-46°10'N). These metavolcanics of Lower Cambrian age are massive or pillowed lavas of andesitic and mainly basaltic composition metamorphosed to the sub-greenschist facies. Magnetite and occasionally hematite are the frequent magnetic memory carrier.

In order to obtain some pertinent information relative to the stability of the remanent magnetization component, stepwise alternating field demagnetization was conducted on 35% of the specimens and the others were demagnetized at an optimum alternating field. After AF treatment, the paleopole position of the tilted formation from 16 localities is 148°E, 43°N ( $dp=11.3^\circ$ ,  $dm=22.4^\circ$ ). After omission of 3 localities for which  $\alpha_{95} \geq 30^\circ$ , the new paleopole position obtained is 173°E, 26°N. This formation of Early Cambrian age is characterized by a reversed polarity.

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## RESUME

Quarante-deux échantillons orientés (97 spécimens) ont été obtenus de 17 localités différentes dans des roches métavolcaniques du groupe de Caldwell dans les Appalaches du sud du Québec (longitude: 71°00' - 71°30'W, latitude: 46°00' - 46°10'N). Ces roches comprennent des laves massives et à coussinets de composition andésitique mais surtout basaltique et métamorphosées au faciès des schistes verts. La magnétite et occasionnellement la hématite sont les minéraux porteurs de la mémoire magnétique.

Afin d'obtenir des renseignements pertinents ayant trait à la stabilité de l'aimantation rémanente, on a procédé à un lavage par champ alternatif progressif sur 35% des spécimens et l'on a désaimanté les autres à une intensité optimum en champ AC. Après lavage magnétique, la position du paléopôle de la formation dépliée pour 15 localités est 148°E, 42°N ( $dp=11.3^\circ$ ,  $dm=22.4^\circ$ ). Après avoir omis 3 localités pour lesquelles  $\alpha_{95} > 30^\circ$ , la nouvelle position du paléopôle devient 172°E, 26°N. Cette formation géologique d'âge Cambrien inférieur est caractérisée par un renversement de polarité.

## RIASSUNTO

Sono stati ottenuti quarantadue campioni orientati (97 esemplari) da 17 località differenti nelle rocce metavulcaniche del gruppo del Caldwell, negli Appalachi del sud Quebec (long.: 71°00' - 71°30'W, lat.: 46°00' - 46°10'N). Tali rocce comprendono lave massive ed a cuscinetti di composizione per lo più basaltica ed andesitica e metamorfizzate in facies di scisti verdi.

La magnetite e, occasionalmente, l'ematite sono i minerali conduttori della memoria magnetica.

Al fine di ottenere indicazioni pertinenti attinte dalla stabilità della magnetizzazione residua, si è proceduto ad un lavaggio per campo alternato progressivo sul 35% degli esemplari, demagnetizzando gli altri ad un'intensità ottimale in campo AC. Dopo il lavaggio magnetico, la posizione del paleopolo della formazione estesa alle 16 località è 148°E, 42°N ( $dp=11.3^\circ$ ,  $dm=22.4^\circ$ ). A seguito dell'omissione di 3 località, per le quali  $\alpha_{95} \geq 30^\circ$ , la nuova posizione del paleopolo diventa 172°E, 26°N.

Questa formazione geologica del Cambriano inferiore è caratterizzata da un'inversione di polarità.

## GEOLOGY

The Caldwell Group is composed of sedimentary and volcanic rocks. The bottom part of this group is mainly constituted of green, purplish to red, grey and black shales, slates, siltstones and schists overlain by thick-bedded, green, reddish and grey, arkosic quartzites and sandstones, with some intermingled grey, green, and red fissile arenaceous slates and shales. The majority of the beds are thin and some are quartzitic, sandy and silty. Immediately beneath the Caldwell lavas, there is an appreciable thickness of highly fissile pure grey slate which passes to a green and more frequently to a red colour near the top; it is apparently a variety of tuff.

The Caldwell volcanics composed of massive and pillowed lavas, breccias, agglomerates and tuffs, occupy the top part of the Caldwell Group. Only the lavas and in particular the pillowed lavas were sampled in this sequence. The Caldwell lavas are predominantly basaltic, with a little associated andesite.

These rock sequences were originally termed Caldwell Series (now Group) by McKay (1921) and Tolman (1936) in the Beauce region. Beland (1957), Benoît (1957, 1958a,b) and A. Rouleau (1975, M.Sc. thesis in preparation) studied the geology of the Caldwell Group in the St-Sylvestre area and north of it.

Knox (1916, 18), Harvie (1923), Cooke (1938, 50, 54, 55), Riordon (1953, 54, 57), Derosier (1971), Lamarche (1973), and St-Julien (1975) have undertaken petrologic and structural studies of the Caldwell Group in the Thetford Mines-Black Lake area and south of it.

The Sutton-Bennett schists located to the south west of the Thetford Mines-Black Lake area grade into the Caldwell Group as the metamorphism decreases gradually in a northeasterly direction. The Bennett chloritoschists are the metamorphosed and schistose equivalent of lavas and tuffs of the Caldwell Group (Cooke, 1938; St-Julien and Hubert, 1975).

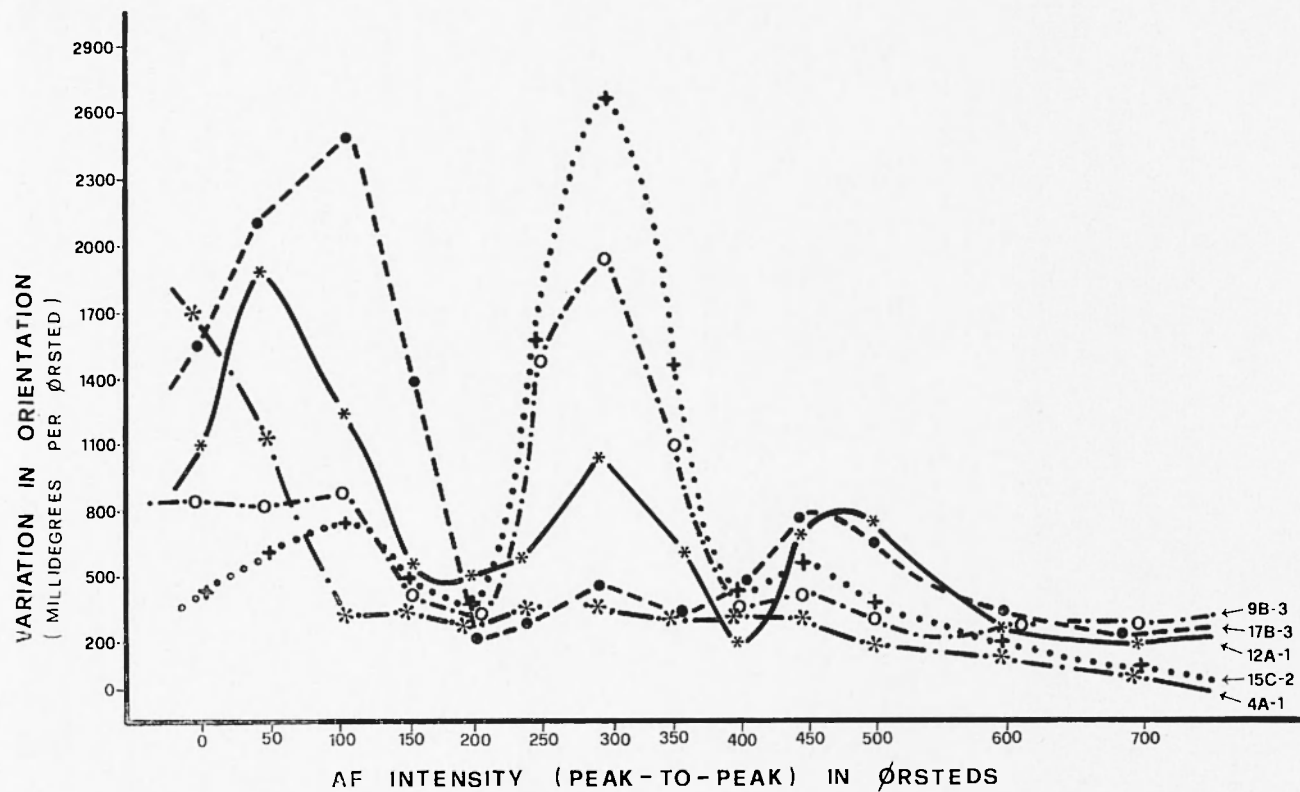


Fig. 1 - Graph of the stability index of 5 specimens of the Caldwell Group.

## AGE

The Caldwell Group is located stratigraphically below an ophiolitic sequence which gave a radiogenic (K/Ar) age of 550 m.y. Consequently, the Caldwell Group which is definitely overlying the Grenville basement (late Precambrian) has an age between that of Grenville basement and 550 m.y.

## SAMPLING PROCEDURE

42 oriented samples (97 specimens) were collected at 17 different sites; the orientation was done with a Brunton or a solar compass. The number of samples per site varied between 2 and 4 and the number of specimens per sample between 2 and 5. The samples were drilled in the field with a portable diamond drill. In this survey, efforts were made to select sites where there was an excellent exposure and where the structural geology was rather simple and well understood. Great care was also taken to select relatively fresh material. The sample locations were chosen by reference to detailed geological maps published by Cooke (1938) at a scale of 1 mile to the inch.

## MEASUREMENTS

The direction and intensity of remanent magnetization were measured with a Princeton Applied Research Model SM-1 spinner magnetometer (sensitivity:  $10^{-7}$  cgs emu). Alternating field demagnetization was carried out to remove unwanted secondary components using a demagnetizer built at the University of Laval (maximum peak field intensity of 1800 Ørstedes) the performance of which was improved by adding 3 large concentric mu-metal cylinders around the solenoid.

## INITIAL N.R.M. INTENSITIES AND DIRECTIONS

The N.R.M. intensities range from  $2.0 \times 10^{-6}$  to  $3.5 \times 10^{-3}$  emu/cm<sup>3</sup>. The high intensity values are found either in hematitic specimens or in samples having a relatively high magnetite content. Hematite and magnetite were identified with a reflecting light microscope. The mean N.R.M. direction of the Caldwell Group *in-situ* (350°, -43, 95 = 13.7°,  $K = 62.2$ ) is quite different from the local Earth's field (343°, 70°) indicating that an important fraction of the remanence is of ancient origin. After rotating the formation to the horizontal, the mean N.R.M. direction is 352°, 09°, ( $\alpha 95 = 21.4^\circ$ ,  $K = 53.1$ ). The increase in  $\alpha 95$  and the decrease of  $K$  suggest that at least a fraction of the N.R.M. component is post-folding.

## AF DEMAGNETIZATION

A minimum of 2 specimens (usually 3 or 4) from each site were demagnetized, in steps of 50 Ørstedes, from 50 to 500 Ørstedes and in steps of 100 Ørstedes, from 500 to 800 Ørstedes in the absence of an ambient field. A few treatments up to 1500 Ørstedes were done. Guided by the stepwise changes in orientation and intensity of the pilot specimens from a site, 2 strengths of AF demagnetization were selected using an "specimens from a site were AF demagnetized and their residual remanence measured. Pilot tests show that the AF strength at which the primary thermoremanent component is most thoroughly isolated is located in the 150-250 Ørstedes range or the 500-700 Ørstedes range (figure 1). Normalized demagnetization intensity curves for the same test specimens from different sites are shown in figure 2.

The behaviour of the orientation and intensity of the residual remanence is quite complicated and difficult to interpret

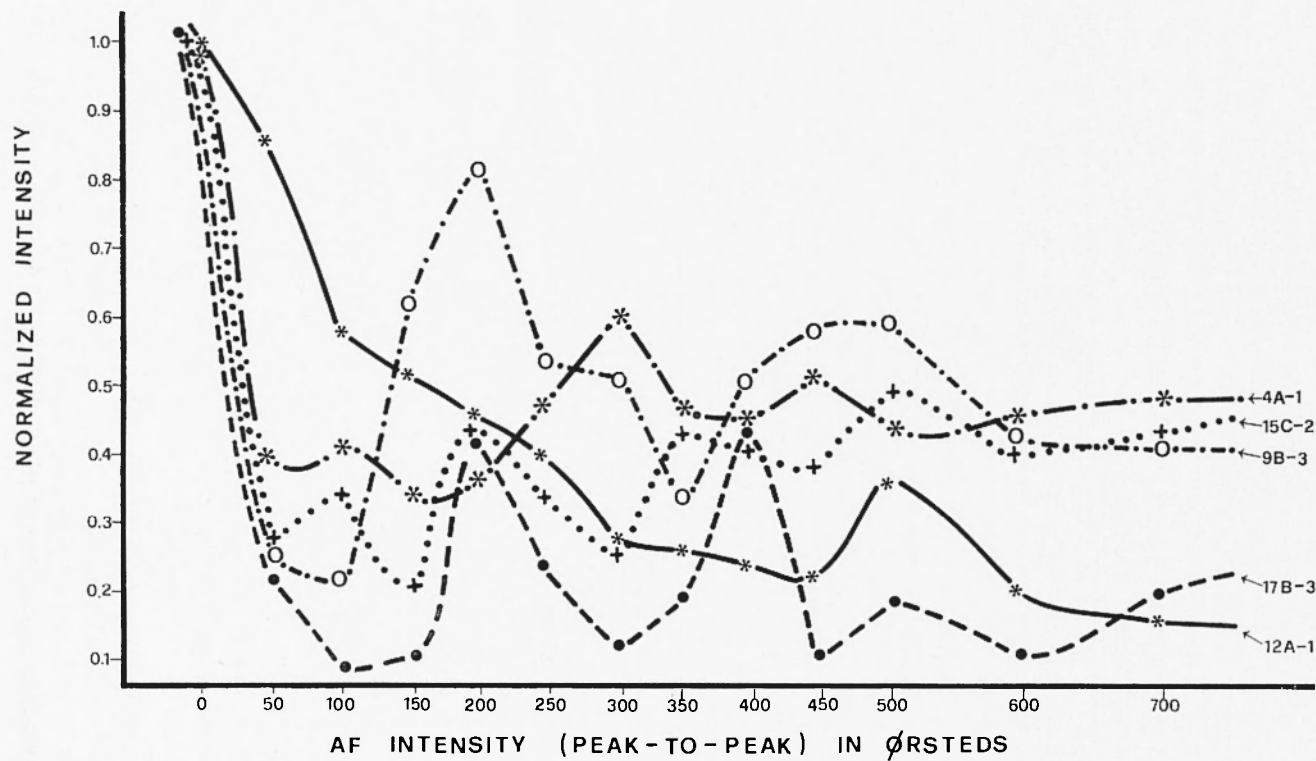


FIG. 2 - Normalized remanent intensity of 5 typical specimens of the Caldwell Group as a function of the demagnetizing field strength.

(figures 1 and 2). A statistical study of the orientations of the residual remanent components was carried out for both AF strength ranges; only 60% of the pilot specimens used indicated a relatively stable N.R.M. component in the 150-250 Ørsted range. This statistical study was done for the Caldwell Group in its actual structural setting and then folded back to its original position (table I). After demagnetization, the inclination of the site mean directions of the tilted formation displaced from the northern towards the southern hemisphere. About 55% of the pilot specimens depict an intensity increase of the residual component in the 200-500 Ørsted range and this increase is frequently accompanied by a polarity inversion. The decrease in intensity of the residual component is quite rapid in the 50-250 Ørsted range; the median destructive field occurs in the 30-225 Ørsted range (mean 75 Ørsted) with one notable exception where it is larger than 700 Ørsted. The significance and stability of the remanent component in the Caldwell Group are demonstrated by the departure of the orientations of the AF cleaned residual component from the recent Earth's field direction and the evidence for reversal(s).

After AF demagnetization in the 500-700 Ørsted range and tilting of the formation, the paleopole position of the Caldwell Group is 328°E, 43°S (north pole), i.e., 148°E, 43°N ( $d_m=22.4^\circ$ ,  $d_p=11.3^\circ$ ,  $K=23.6$ , reverse polarity). After exclusion of the 3 sites for which  $\alpha$  95-30°, the orientation of the residual remanence is 142°, -30° ( $\alpha$  95-19.5°) and the corresponding paleopole position is 352°, 26°S ( $N$ ), i.e. 172°E, 26°N ( $R$ ). This last value is retained as the best estimate of the paleopole position for the Caldwell Group.

#### DISCUSSION OF THE RESULTS

This paleomagnetic study is the first to be conducted in the Caldwell Group which is one of the oldest lithological unit of the Appalachians of southern Quebec. In spite of difficulties encountered in the interpretation of the AF demagnetized results,



TABLE 1

Remanent Magnetization directions after AF demagnetization

Site N°	Strike (°)	Dip (°)	Number of samples	Number of specimens	Formation in-situ			Alt. field (Ørstedes)	tilted			Formation in-situ			Alt. field (Ørstedes)	tilted		
					D <sub>1</sub> (°)	I <sub>1</sub> (°)	$\alpha$ 95 (°)		D <sub>2</sub> (°)	I <sub>2</sub> (°)	$\alpha$ 95 (°)	D <sub>1</sub> (°)	I <sub>1</sub> (°)	$\alpha$ 95 (°)		D <sub>2</sub> (°)	I <sub>2</sub> (°)	$\alpha$ 95 (°)
1	257	75N	2	5	311	— 37	19.6	100-200	007	— 18	42.0	094	08	35.1	600-700	120	42	19.9
2	224	85N	2	6	288	— 20	23.9	100-200	225	— 51	30.5	194	— 45	49.3	600-700	207	— 64	25.6
3	230	74N	2	5	—	—	—	—	—	—	—	261	— 33	16.1	700	206	— 35	14.7
4	246	84N	4	10	—	—	—	—	—	—	—	267	10	13.2	500-700	236	19	17.3
5	217	68N	2	5	—	—	—	—	—	—	—	019	16	24.8	500-700	063	07	18.7
6	246	72S	2	5	—	—	—	—	—	—	—	017	05	45.1	500-600	041	39	56.3
7	240	64N	2	7	271	34	19.3	200	177	— 19	17.9	254	60	33.9	600-700	178	— 31	28.6
8	242	85N	2	4	—	—	—	—	—	—	—	250	— 15	36.1	600-700	257	06	36.8
9	287	74N	2	5	357	— 14	32.0	150-200	117	77	32.0	206	— 39	24.6	500-700	004	— 27	24.5
10	233	75N	2	5	022	25	31.4	150-200	120	15	31.5	347	75	6.6	700	139	— 03	6.5
11	226	45S	3	7	—	—	—	—	—	—	—	334	41	12.1	500-700	039	76	12.4
12	225	58S	3	6	327	61	28.7	150-250	184	32	14.4	194	07	36.4	600-700	214	— 19	40.2
13	239	62S	1	3	—	—	—	—	—	—	—	—	—	—	600	—	—	—
14	249	83S	3	7	226	— 55	47.6	100-150	131	14	47.5	039	— 12	11.8	600-700	099	— 24	9.8
15	183	86W	3	7	145	11	32.3	150-200	166	— 36	32.1	155	— 11	23.2	500-700	204	— 24	23.3
16	238	85N	3	8	272	— 23	34.3	150	258	33	20.6	323	— 56	19.8	500-700	324	37	19.7
17	229	63S	3	9	326	— 16	33.0	200-250	345	— 17	30.2	026	— 23	28.3	600-700	020	07	28.5
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17	—	—	41	104	332	01	26.2	200	178	03	25.8	320	— 13	20.2	600	156	— 26	22.2

paleopole position: 147°E  $\omega$  28°N 300°E  $\omega$  39°S ( $d_p=13^\circ$ ,  $d_m=27^\circ$ ) 154°E  $\omega$  26°N 148°E  $\omega$  43°N ( $d_p=11.3^\circ$ ,  $d_m=22.4^\circ$ ) 328°E  $\omega$  43°S



## LAMBERT EQUAL AREA PLOT

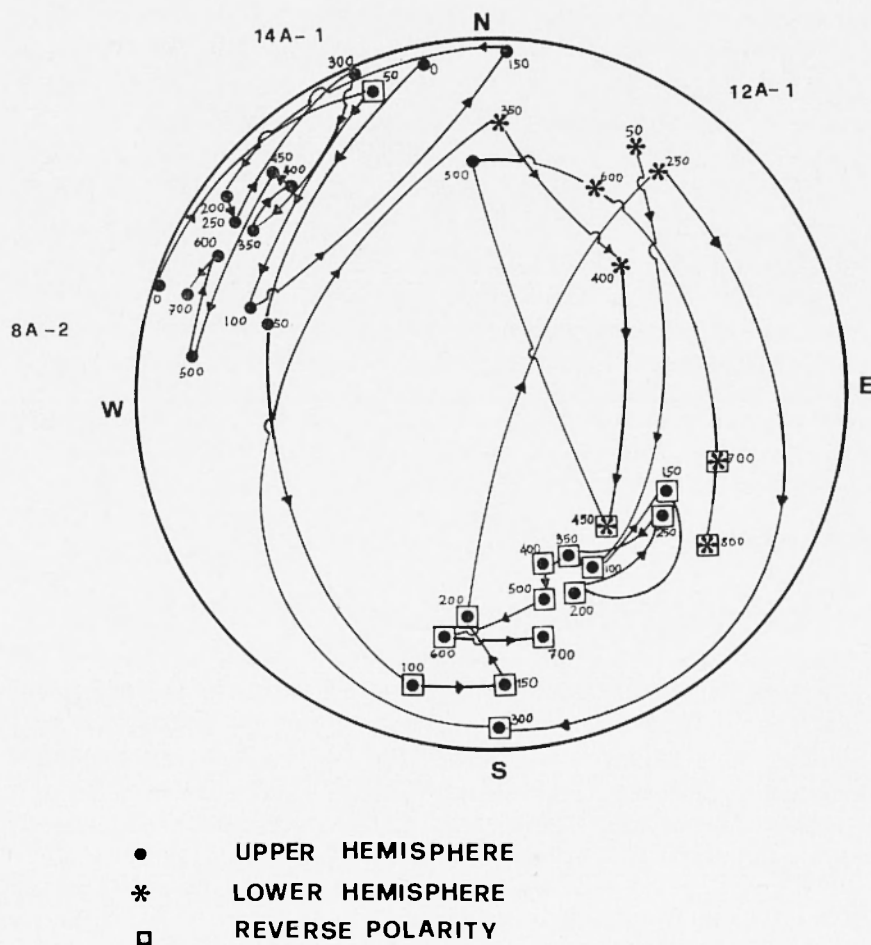


FIG. 3 - Variation of the magnetization directions of 3 pilot specimens of the Caldwell Group as a function of the AF demagnetizing strength.

it is more probable that the original thermoremanent component was successfully isolated and a fair amount of confidence may be attached to the paleopole position ( $172^{\circ}\text{E}$ ,  $26^{\circ}\text{N}$ ) of the Caldwell Group which is of Early Cambrian age. Three reliable pole available from Cambrian rocks of North America are listed in McElhinny (1973). Their mean position is  $141^{\circ}\text{E}$ ,  $08^{\circ}\text{N}$  ( $\alpha 95\text{-}22^{\circ}$ ,  $K=31$ ) and in all cases, the polarities are mixed or reversed. The paleopole position obtained in this study is thus located further to the east. The paleopole position obtained after AF treatment in the 150-250  $\text{\AA}$  range and without tilting of the formation could logically coincide with the Taconian orogeny (Late Ordovician-Early Silurian time). The pole position obtained is  $147^{\circ}\text{E}$ ,  $28^{\circ}\text{N}$  ( $d_m=25.2^{\circ}$ ,  $d_p=12.9^{\circ}$ ,  $K=34.7$ , reverse polarity); it falls midway between the Ordovician and Silurian pole position (McElhinny, 1973).

On this basis, it appears that both the original thermoremanent and the superimposed orogenic events were imprinted on Caldwell rock formations and that these magnetic events can be isolated by progressive AF demagnetization.

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