Paleomagnetism of the Caldwell lavas,
Eastern Townships, Québec.

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Received on May 20th, 1978

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 carriers.

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°, dm=22°). After omission of 3 localities for which α95>30°, 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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RÉSUMÉ

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 16 localités est 148°E, 42°N (dp=11.3°, dm=22.4°). Après avoir omis 3 localités pour lesquelles a95°>30°, 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°C0' - 71°30'W, lat.: 46°00' - 46°10'N). Tali rocce comprendono lave massive ed a cuscinetti di composizione per lo più basaltica ed andesilica 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 paléopolo della formazione estesa alle 16 località è 148°E, 42°N (dp=11.3°, dm=22.4°). A seguito dell’omissione di 3 località, per le quali a95°>30°, la nuova posizione del paléopolo 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 quartritic, 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 pillow-ed 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).
AF INTENSITY (PEAK-TO-PEAK) IN ÖRSTEDS

VARIATION IN ORIENTA-TION (DEGREES)

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 Oersteds) 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 $2.0 \times 10^{-4}$ to $3.5 \times 10^{-3}$ emu/cm$^3$. 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* ($350^\circ$, $-43^\circ$, $95 = 13.7^\circ$, $K = 62.2$) is quite different from the local Earth's field ($343^\circ$, $70^\circ$) 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 $352^\circ$, $09^\circ$, ($a_{95} = 21.4^\circ$, $K = 53.1$). The increase in $a_{95}$ 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 Ørsteds, from 50 to 500 Ørsteds and in steps of 100 Ørsteds, from 500 to 800 Ørsteds in the absence of an ambient field. A few treatments up to 1500 Ørsteds 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 specimens from a site were AF demagnetized and their residual remanence measured. Pilot tests show that the AF strength at with the primary thermoremanent component is most thoroughly isolated is located in the 150-250 Ørsteds range or the 500-700 Ørsteds 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.
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 Ørsteds 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 Ørsteds 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 Ørsteds range; the median destructive field occurs in the 30-225 Ørsteds range (mean 75 Ørsteds) with one notable exception where it is larger than 700 Ørsteds. 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 Ørsteds 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 ($d_n=22.4^\circ$, $d_p=11.3^\circ$, $K=23.6$, reverse polarity). After exclusion of the 3 sites for which $\alpha > 95^\circ$, the orientation of the residual remanence is 142°, -30° ($\alpha = 95.19.5^\circ$) and the corresponding paleopole position is 352°, 26°S ($\alpha$), 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

| Site No. | Strike (°) | Dip (°) | Number of samples | Number of specimens | Remanent Magnetization directions after AF demagnetization |
|----------|------------|---------|-------------------|--------------------|----------------------------------------------------------|
|          |            |         |                   |                    | D, (°) I, (°) a 95 (°) Alt. field (0rsteds) D, (°) I, (°) a 95 (°) Alt. field (0rsteds) |
| 1        | 257        | 75N     | 2                 | 531               | 37 17 20 180-200 307 18 42 094 6 35.1 600-700 120 42 10.9 |
| 2        | 204        | 65N     | 2                 | 6 268 20 25.5 180-200 223 35 36.5 136 45 49.5 600-700 207 35 25.6 |
| 3        | 230        | 74N     | 2                 | 3 117 35 36.1 780 206 35 14.7 |
| 4        | 286        | 84N     | 4                 | 16 267 35 33.2 500-700 236 19 17.3 |
| 5        | 237        | 68N     | 2                 | 3 115 30 26.8 500-700 063 27 16.7 |
| 6        | 260        | 72S     | 2                 | 9 117 95 45.1 500-600 040 39 56.3 |
| 7        | 240        | 64N     | 2                 | 7 254 60 33.9 500-700 207 19 28.4 |
| 8        | 262        | 82N     | 2                 | 9 250 61 36.8 500-700 237 06 36.8 |
| 9        | 287        | 74N     | 2                 | 5 357 32 28.6 500-700 004 27 24.5 |
| 10       | 233        | 75N     | 2                 | 5 322 25 31.4 500-200 128 13 31.5 500-700 032 25 15.3 |
| 11       | 226        | 45N     | 3                 | 117 73 32.0 206 39 24.3 500-700 010 13 0.3 |
| 12       | 225        | 68S     | 3                 | 6 327 61 28.7 150-250 164 32 14.4 500-700 214 19 40.1 |
| 13       | 229        | 62S     | 1                 | 1 55 32 28.7 500-700 040 72 13.5 500-700 088 29 35.1 |
| 14       | 209        | 63N     | 3                 | 7 326 55 47.8 300-150 113 14 47.8 500-700 099 20 9.3 |
| 15       | 283        | 86N     | 3                 | 7 145 11 32.3 150-200 166 26 32.1 500-700 204 24 22.3 |
| 16       | 228        | 82N     | 3                 | 8 321 25 31.4 500-250 298 33 20.6 500-700 325 56 35.1 |
| 17       | 220        | 62S     | 3                 | 6 326 36 33.0 300-250 105 17 30.2 500-700 320 57 28.5 |

Paleopole position: 14°E = 13°; 145° = 21°; 13° = 27°; 15° = 20°; 14° = 23°; 15° = 22°; 2° = 3°; 3° = 4°.
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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°E, 26°N) of the Caldwell Group which is of Early Cambrian age. Three reliable poles available from Cambrian rocks of North America are listed in McElhinny (1973). Their mean position is 141°E, 08°N (α = 95-22°, 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 Oe 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°E, 28°N (d = 25.2°, d = 12.9°, 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.

Acknowledgments

The writer thanks Mr. D. Lafond who made many of the measurements and Mrs. J.L. Roy and P. Lapointe of the Division of Geomagnetism, Earth Physics Branch, Ottawa, who contributed to this study throughout numerous discussions and advice. This research was supported by the National Research Council of Canada (Grant No: A7070-110 [1974-75]) and by the Energy, Mines and Resources, Canada, Research Agreement No.: 1135-D13 - 3 - 55/75-76.
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