Palaeomagnetism of the Pikes Peak Granite, Colorado

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Summary

Samples collected from four sites over an area of 450 km² in the 1020–1040 My Pikes Peak granite, Colorado are stable to thermal demagnetization above 500 °C. A reliable Precambrian palaeomagnetic pole is thus obtained at 179° W, 6° N. Alternating field demagnetization indicates that the granite has been partially remagnetized. Geological evidence suggests that this occurred during Laramide (early Tertiary) deformation of the Front Range: this is supported by the magnetic evidence from a fifth site. Titanomagnetite (moderately oxidized to ilmenite) is the main carrier of the primary NRM: hematite is responsible for the Laramide magnetization.

1. Introduction

Studies of the Pikes Peak granitic rocks were stimulated by work on the Precambrian Sherman granite and associated dikes of the Front Range, Colorado–Wyoming (Eggler & Larson 1968). Their study indicated that reliable data can be obtained from granites in the Rocky Mountains especially when they have been highly oxidized by deuteric processes.

The Pikes Peak granite possesses many of the field characteristics of the Sherman granite, particularly the red colouration, and the surface disintegration to gruss. It was thus considered a good opportunity to determine another reliable pole for the Precambrian, and to judge whether tectonic disturbances had affected the granite.

2. Age relations in the Front Range

The Rocky Mountains of Colorado are a north–south trending group of mountain ranges with many peaks above 4300 m. The eastern-most mountains are the Front Range. They sharply separate Phanerozoic sediments on the Great Plains to the east, from Precambrian crystalline rocks in the backbone of the state. Peterman & Hedge (1968) give an excellent summary of the geochronology of Precambrian sequences in Colorado, recognizing a main regional metamorphism at 1700–1750 My, associated with emplacement of the Boulder Creek granite. Further major intrusive activity occurred in the interval 1390–1450 My during which the Silver Plume and Sherman granites were emplaced and their attendant satellite dikes. The largest pluton in the Front Range is the Pikes Peak batholith; it represents the last major intrusive event and was not accompanied by regional metamorphism (Lovering & Goddard 1950).

Many Rb–Sr and K–Ar ages have been presented for Pikes Peak rocks and Hedge (1968) has determined an Rb–Sr total rock isochron of 1040 My. Peterman & Hedge (1968) refer to 14 K–Ar and four Rb–Sr mineral ages which form a well-defined peak between 980 and 1080 My. The mean lies at 1020 My. From the concordance of
mineral and total rock measurements by the Rb–Sr and K–Ar methods, Peterman & Hedge (1968) infer that the pluton has not been reheated since its intrusion, and that no further Precambrian metamorphic event has occurred in the Front Range. Thus an age of 1020–1040 My can be accepted for Pikes Peak rocks.

3. Geology of the Pikes Peak batholith

The Pikes Peak batholith is oval shaped in outcrop and follows the axis of a regional north–south anticline formed in the highly metamorphosed Idaho Springs Formation (Fig. 1). On the eastern flanks the granite is overlain by several thousand feet of Upper Cambrian to Cretaceous deposits, many of these in fault contact with the granite (Boos & Boos 1957). Elsewhere it is overlain by sub-horizontal Tertiary sediments and volcanics, associated with Eocene intrusive stocks (Lovering & Goddard 1950). The composition of the batholith varies from older, outermost granodiorite to quartz monzonite to granite in fairly distinct shells (Hutchinson 1960). The texture is massively coarse grained and locally porphyritic. Contact metamorphic effects appear to be rare. Hutchinson (1960) reports two observations relevant to a palaeomagnetic study:

(i) The batholith crystallized in the presence of a good portion of its volatiles, so that deuteric alteration might be expected; and
(ii) The granite shows primary tension fractures reddened by hematite, which he considers to be of hydrothermal origin.

Crosby (1899) observes that the erosion surface on Precambrian rocks in this area prior to Palaeozoic deposition was remarkably smooth. Along some parts of the granite, the attitude of the sediments is one of overlap (Harms 1959). The situation is complicated by severe Laramide faulting and monoclinal folding along the eastern margin of the Front Range. Much of this is confined in the Pikes Peak region to a narrow zone about 1 km wide along the Rampart Fault, a high-angle reverse fault dipping to the west. This parallels the mountain front and must have involved vertical uplift of the batholith by at least 5000 m (Harms 1959), bringing granite against Tertiary rocks. The Ute Pass Fault is a similar high-angle fault bringing granite up against Upper Cretaceous, and also involves 5000 m of dominantly vertical movement (Harms 1959; Grose 1960). Harms (1959) notes that the downthrown sedimentary blocks are generally intensely deformed by drag. An example occurs at Garden of the Gods, Colorado Springs, where the Pennsylvanian Fountain Formation changes abruptly in a short distance from a dip of 45° to the east, to vertical and overturned. Occasionally, tectonic slices of Palaeozoic rocks are caught up in the faulting.

In the upthrown granitic blocks, the sediments have acted more or less competently with the granite, so that areas of dislocation can be readily observed in the field. The main body of the granite, particularly at some distance from the faults, appears to be in an original attitude, judging from relationships with the overlying Palaeozoic sediments. On U.S. Highway 24, about 8 km west of Colorado Springs at Fountain Creek, the Upper Cambrian unconformity dips only a few degrees to the south. Overall, there is no really persuasive evidence that a structural correction should be applied to the granite.

4. Sampling details

Block samples were collected at five sites in the batholith (Fig. 1). Orientation was obtained magnetically. At four of the sites, sun compass orientations were also made. Making allowance for a declination of 16° E (1965.0 Isogonic Chart, USCGS), it was found that the two methods agreed to within 2°. The sites represent different parts of the pluton, and are from either road cuts or bare outcrop (Table 1). Two to four

<table>
<thead>
<tr>
<th>Site</th>
<th>Co-ordinates</th>
<th>Location</th>
<th>Remarks</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>105-0° W, 38-8° N</td>
<td>6 km along Pikes Peak toll road</td>
<td>Bare outcrop</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>105-3° W, 38-9° N</td>
<td>U.S. Highway 24, 8 km west of Divide</td>
<td>Road cut</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>105-2° W, 38-8° N</td>
<td>16 km north of Cripple Creek on State Highway 67</td>
<td>Bare outcrop</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>105-3° W, 39-3° N</td>
<td>8 km southwest of Buffalo on Wellington Lake Road</td>
<td>Bare outcrop</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>105-0° W, 38-9° N</td>
<td>U.S. 24 8–11 km west of Colorado Springs</td>
<td>Road cuts</td>
<td>4</td>
</tr>
</tbody>
</table>
samples, each weighing about 7 kg were hewn at each site. Because of the experience of Eggler & Larson (1968), the reddened facies was collected preferentially to the pale pink, unaltered granite. None of the grey granodiorite zone was sampled. In the field it is relatively easy to distinguish the various facies: the altered rock is characterized by quartz veining and the relative absence of hornblende and biotite.

Site 5 represents an attempt to make a sampling profile from the margin into the centre of the pluton. Samples were obtained at 1-km intervals westwards along U.S. Highway 24 out of Colorado Springs. Unfortunately the proximity of the Ute Pass Fault may diminish the relevance of such a profile. The fault very roughly parallels the highway, and although it is a high-angle thrust, the granite is locally sheared and brecciated.

In the laboratory, several cores 2.5 cm in diameter were drilled from each block sample, and specimens 2.5 cm long were cut from either end of each core.

5. Pilot demagnetization

Two specimens from each sample were subjected to pilot demagnetization and the NRM measured on a PAR spinner magnetometer, Model SM-1, at the University of Texas at Dallas. The demagnetization equipment is located in a shielded mu-metal room (residual field < 200 y) and is described by Helsley & Spall (1970). One specimen was demagnetized in successive alternating fields (AF) of 88, 175, 350, 700 and 1400 Oe. There was little vector rotation during this operation. Therefore, the second specimen was thermally demagnetized in field-free space (±10 y) to 500, 530, 550, 580 to 590 and 650 °C successively and then measured at room temperature.

Two problems arose during demagnetization. Because the specimens became unstable it was not always possible to measure a reliable magnetization after high temperature or high field (1400 Oe) treatment. This showed up in two ways. Firstly, it occurred during actual measurement of the NRM; for example, (i) the sign (sense) of the moment did not change appropriately when the specimen was inverted during a spin, (ii) even using a long-time constant on the PAR instrument a steady reading could not be obtained, and (iii) the angular error in determining the magnetic vector for the specimen was greater than 20°. These observations suggest that the NRM measured was randomly oriented because the induced moment was larger than the remanence. Secondly, instability occurred as a fixed moment. This was typically shown after replicate treatments at the same demagnetizing field or temperature, when the NRM directions, although measurable, would differ by more than 50° from treatment to treatment. It occurred despite the fact that demagnetization was in a field-free space (< 10 y for thermal; < 200 y for A.F.). It suggests that the relaxation times of the magnetic domains within the rock had a considerable range from specimen to specimen, in some cases bracketing the time of the laboratory experiment.

These features of instability have been termed 'magnetic noise'. Creer (1959), and Irving, Stott & Ward (1961) first drew attention to the phenomenon, and Dickson (1962) and Irving (1964, pp. 93–96) discuss it in some detail. Basically it is supposed that an intrinsic, pseudo-randomly oriented magnetization exists in all specimens, which is negligible in the initial NRM, but may be comparable with the primary remanence at high temperatures or fields. It is typically indicated by observations of a 'minimum intensity' during demagnetization, at which the NRM intensity fluctuates erratically, and the dispersion of directions between-specimens is high. Whatever its origin, the observation of a magnetization whose direction fluctuates greatly, suggests a useful limit to meaningful demagnetization.

The second problem arose during thermal demagnetization. Some of the coarse-grained granites could not be heated more than once or twice above 500 °C, because they crumbled. Merrill & Grommé (1969) attribute this disintegration to dehydration.
of small amounts of chlorite in biotite. In the light of infra-red studies by Vedder & Wilkins (1968), their observation is more likely to be due to dehydroxylation of biotite itself.

Such a mechanism, however, is unlikely in the case of the Pikes Peak rocks, for they were collected because of their lack of biotite. A more probable cause is simply the very coarse grain texture and the differences in thermal expansion and contraction among the minerals present. Since four temperatures were planned above 500 °C, some of the demagnetization runs are not complete.

6. Response to pilot demagnetization

The NRM directions at each site were combined according to Fisher's method (1953). The mean demagnetization paths are shown in Figs 2 and 3 for those stages for which data were obtained from every specimen. Thus some of the paths are incomplete at high temperatures and fields. The thermal path for site 5 was not computed because half the specimens disintegrated at 500 °C, the first stage.

The NRM of all the specimens is fairly stable to both AF and thermal demagnetization, and the directions are not related to the present field. Each specimen appears to act individually. For example, at site 1, the initial NRM directions of the two specimens from one of the samples are 90° of arc apart, but coincide after demagnetization. Thus there is justification for treating specimens from the same sample as independent magnetic vectors.

Thermal demagnetization gives a more consistent between-site agreement than AF demagnetization. The within-site dispersion is minimum (that is, $k$ is significantly highest at the 95 per cent level of confidence) at 500 °C for site 3, at 530 °C for sites 1 and 2, and 580° for site 4. It should be pointed out that for site 4, the dispersion is
also low at 530 °C. In this case the reasonable argument can be invoked that since systematic vector rotation continues to 580 °C and the dispersion remains unchanged, then the direction at 580 °C is more meaningful. Note that the directions at 650 °C for site 2 are similar to those at lower temperatures, although the dispersion is very much higher. It implies that a rhombohedral phase contributes to this remanence.

The response to AF demagnetization is rather different. With one exception the NRM directions within-a-site change less than 20° in fields up to 700 Oe, suggesting a stable remanence. Yet there is little between-site convergence. In fact there is a roughly great circle distribution (sketched by eye) of the AF paths from each site (Fig. 3). This is somewhat offset from the cluster of thermal paths, although most of this is due to site 2 data. It suggests that some form of remagnetization process has occurred, but it does not appear to have been along the present field. Further discussion on this point will be made after blanket demagnetization.

7. Opaque mineralogy

Specimens from all the sites contain oxidized titanomagnetite, ilmenite and hematite, with the amount of hematite being the main between-site variable.

Most commonly, titanomagnetite is oxidized to thick blades of ilmenite along the 111 planes. The entire rock is disseminated with hematite particularly in the feldspars, and along cracks and grain boundaries in other minerals. Hematite frequently occurs in the form of internal reflections along the margins of discrete ilmenite grains, and within the blades of ilmenite-in-titanomagnetite.
The abundance of hematite in the rock makes it difficult to determine the oxidation state of titanomagnetite, and further whether the hematite was produced as a late crystallization deuteritic type of alteration, or a subsequent hydrothermal or even surficial alteration. The absence of goethite argues against surficial alteration. Boone (1969) considers that the transfer of oxide dust to feldspars takes place immediately following crystallization which suggests that some of the hematite is deuteritic. A useful indicator of high temperature oxidation is pseudobrookite (Lindsley 1965), but there was so much internal reflection from hematite, that it was impossible to identify positively the typical orange of pseudobrookite. In this respect, neither rutile nor spinel was observed as further indicators of high temperature alteration (Wilson, Haggerty & Watkins 1968).

Some evidence that there are two generations of hematite comes from site 5 (recall that this is near a zone of Laramide faulting). In these specimens there appears to be much more hematite along fractures in the rock. Indeed several of the cracks have been enlarged by the hematite. It suggests that this mode of hematite was formed well after complete solidification of the granite, and may be the 'hydrothermal' alteration referred to by Hutchinson (1960), as distinct from the late stage deuteritic hematite which dusted the feldspars.
8. Curie points

Two Curie points were measured in a field of 2000 Oe on an Akimoto type balance (1954) at the University of Colorado (Fig. 4). A specimen from site 5 was also included, but two attempts proved unsuccessful because the rock exploded above 500 °C.

Two features are obvious from the two curves measured. Firstly there is reasonable indication that both a spinel phase (with a Curie point near 580–590 °C) and a rhombohedral phase (having a Curie point in the range 620–650 °C) occur in the specimens from either site. Secondly, the heating and cooling curves are not reversible and the specimens acquire a higher remanence on cooling.

9. Intensities, susceptibilities and Q' ratios

The intensity range is from 0.28 to $54 \times 10^{-5}$ emu cm$^{-3}$ with a median at $1.5 \times 10^{-5}$ emu cm$^{-3}$. The susceptibility range is from 2.7 to $41.3 \times 10^{-5}$ emu Oe$^{-1}$ cm$^{-3}$ with a median at $12.9 \times 10^{-5}$ emu Oe$^{-1}$ cm$^{-3}$. The ratio of these two parameters ($Q'$) is from 0.09 to 0.48 with a median at 0.20. The between-site variation in intensity and susceptibility is no greater than a factor of 4, and in particular there are no special differences about the site 5 values.

10. Mean directions of magnetization and palaeomagnetic poles

It seemed clear from the pilot demagnetization work that the most reliable palaeomagnetic direction in terms of between-site consistency was obtained with thermal demagnetization. Thus, about two-thirds of the remaining specimens were...
Table 2

Mean directions of magnetization and palaeomagnetic poles

<table>
<thead>
<tr>
<th>Site</th>
<th>Temp °C</th>
<th>Field</th>
<th>Declination (°)</th>
<th>Inclination (°)</th>
<th>(\alpha_{95})</th>
<th>Long</th>
<th>Lat</th>
<th>(\delta p)</th>
<th>(\delta m)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>530</td>
<td>695</td>
<td>6.976</td>
<td>7</td>
<td>21</td>
<td>7</td>
<td>188</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>530</td>
<td>685</td>
<td>6.898</td>
<td>7</td>
<td>5</td>
<td>8</td>
<td>179</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>500</td>
<td>660</td>
<td>6.881</td>
<td>7</td>
<td>50</td>
<td>8</td>
<td>179</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>580</td>
<td>672</td>
<td>6.795</td>
<td>7</td>
<td>145</td>
<td>5</td>
<td>178</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>530</td>
<td>687</td>
<td>6.188</td>
<td>7</td>
<td>23</td>
<td>15</td>
<td>157</td>
<td>43</td>
<td>16</td>
</tr>
</tbody>
</table>

ST is the site number; Temp is temperature in °C; Fld is field in oersted; Dec is declination of the north seeking magnetic vector, east of true north; Inc is its inclination, positive downward; \(k = (N-1)/(N-R)\); \(\alpha_{95}\) is the semi-angle of the cone of 95 per cent level confidence; Long and Lat are the longitude and latitude respectively of the palaeomagnetic pole; \(\delta p\) and \(\delta m\) are the semi minor-major axes of the oval of 95 per cent level confidence.

treated to temperatures between 500 and 580 °C, according to Section 6. Site 5 specimens were treated arbitrarily to 530 °C. The remaining third were subjected to the AF demagnetization stage for each site which produced minimum dispersion. Site means were computed using Fisher’s methods (1953): they are listed in Table 2, and plotted in Fig. 5 with the associated circles of 95 per cent level confidence.

They confirm that thermal demagnetization is more effective in reducing between-site dispersion, and that AF demagnetization distributes the NRM directions along a great circle. To test this further, a best-fitting great circle was computed using the five AF means. With the exception of site 1, Fig. 5 shows that the fit to this circle (pole at Dec 151°, Inc 54°) is good. Note that the great circle passes to the west of the cluster of means from thermal demagnetization, and that it almost includes the thermal mean for site 5. Note also that if the AF site 2 had been closer to the thermal means, the great circle computed would probably have passed through the latter grouping. In this respect the initial AF and thermal means for each site are identical, except for site 2 where they are 30° apart. Thus it may have been unwise to compute a great circle using the site 2 data. The important point, however, is that the great circle does not pass near the present field, and this is felt to be strong evidence that the remagnetization episode did not occur in Recent times.

The dispersion at sites 1–4 decreases significantly after thermal demagnetization (Table 2). The exception is site 5, but since:

(i) The response to pilot demagnetization was not consistent;
(ii) The temperature of blanket demagnetization was arbitrarily chosen;
(iii) The mean lies distinctly outside the main group of site means;
(iv) The samples are close to a zone of deformation; and
(v) The samples do not represent a site in the localized sense of the word (Table 1),
this site can justifiably be omitted from calculations of a reliable overall mean, although its error circle does overlap those from other sites. An overall mean using the thermal means from sites 1, 2, 3, and 4 is listed in Table 3 and also drawn in Fig. 5. It should be noted that application of Hartley's maximum $F$ ratio test at the 95 per cent level (Watson & Irving 1957) shows that the dispersion is not homogeneous over these four site populations, so that strictly, no further identity tests can be applied. Nevertheless, the dispersion of the overall mean $A = 81 \text{k}^{-1}$ (Creer 1962) is $6.8^\circ$, which indicates that no large errors due to secular variation are present.

Table 3

<table>
<thead>
<tr>
<th>Dec</th>
<th>Inc</th>
<th>$N$</th>
<th>$R$</th>
<th>$k$</th>
<th>$a_{95}$</th>
<th>Long</th>
<th>Lat</th>
<th>$\delta p$</th>
<th>$\delta m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>265</td>
<td>29</td>
<td>4</td>
<td>3.979</td>
<td>144</td>
<td>7</td>
<td>179 W</td>
<td>6 N</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>

Key as in Table 2.

Palaeomagnetic poles for sites 1–5, representing thermally demagnetized specimens, and the overall mean calculated with its oval of 95 per cent confidence are drawn in Fig. 6. This mean is about $15^\circ$ south of the 1115–1120 My Duluth gabbro pole (DuBois 1962) from Minnesota, and the 1140–1150 My Central Arizona diabase pole (Helsley & Spall 1970). However, it is close to poles on a trend obtained for younger, Upper Keweenawan rocks from the Lake Superior region (DuBois 1962; Spall 1970). It is therefore very reasonable to conclude that this Pikes Peak granite result:

(i) Represents a spot reading of the palaeomagnetic axis at 1020–1040 My,
(ii) Agrees with other palaeomagnetic poles for rocks of similar age from North America, and
(iii) Supports the idea that the field was dipolar at the time 1020–1040 My.

11. Age of remagnetization

The five site poles from AF demagnetization are also shown in Fig. 6 with the best fitting great circle. It implies that partial remagnetization has occurred in a component which is more stable to AF than thermal demagnetization. It is interesting that the site 5 thermally demagnetized mean also lies on this great circle.

The problem arises, was the remagnetization episodic, or due to a continuous acquisition of VRM along the present field? Although the remagnetization process was not complete, it seems likely to have been an episodic event, because it was observed in Fig. 5 that the AF mean directions do not pass through either of the axial or inclined present magnetic fields.

Two theories can be put forward for an episodic event, and they rely on geological evidence. Firstly, remagnetization may have occurred during Triassic surficial weathering. Mean poles for Mesozoic rocks from North America after Hospers &
Van Andel (1968) are also given in Fig. 6. While these are based on a small number of individual poles, they were considered to be reliable by these authors, and they do at least give an estimate of the apparent polar wandering curve during the Mesozoic. The great circle of AF site means passes between the Triassic and Jurassic poles.

In the Colorado Springs area, the Upper Jurassic Morrison Formation disconformably overlies the Permian Lykins Formation (Grose 1960), so the granite may well have been exposed to subaerial weathering throughout the Triassic-early Jurassic period. In this respect, Bailey (1926), Trotter (1953) and Anderson & Dunham (1953) all demonstrate extensive pre-depositional oxidation of an old land surface in Britain, in this case before Permo-Triassic sedimentation.

Secondly, a more obvious geological cause of remagnetization is Laramide deformation as Cretaceous-Palaeocene, and possible Eocene. It is significant that Lovering & Goddard (1950) and Harms (1959) place the strongest deformation as Cretaceous-Palaeocene, and possible Eocene. It is significant that site 5, collected near the Ute Pass Fault, shows the most divergence from what is interpreted to be a reliable pole. For comparison purposes, Fig. 6 also includes poles obtained for the Flagstaff intrusive near Boulder, Colorado (McMahon & Strangway 1968) and the Spanish Peaks dike swarm near Walsenberg, Colorado (Larson & Strangway 1969), both considered to be reliable early Tertiary pole positions.

Unfortunately, the great circle does not pass close to these poles. For it to do so would require a rather large excursion of the dipole, although there is a certain amount of evidence from late Mesozoic and early Tertiary rocks that this has occurred (Cox 1957; Spall 1968; Saad 1969). (If continued into the Atlantic Ocean the great circle would pass close to these anomalous poles).

It is also possible that the deviation corresponds to slight rotation of the Pikes Peak batholith, but this would take the mean thermal pole out of the Keweenawan
trend of DuBois (1962) and Spall (1970). Thus, because remagnetization was not a complete process, it is difficult to pinpoint an exact time of remagnetization, with the evidence available. It is interesting that McMahon & Strangway (1968) report no remagnetization problems in Upper Palaeozoic sediments collected further north along the Front Range.

12. Carrier of the NRM

Titanomagnetite (with a Curie point near 580–590 °C) appears to be the dominant carrier of the primary NRM at sites 1–4. Hematite is ubiquitous in all the rocks and is found in the Curie point determinations. Only at site 2 does it dominate the NRM above 580 °C. This suggests that even after being thermally demagnetized above 580 °C, the titanomagnetite can acquire spontaneous moments which are sufficiently large, even if randomly oriented, to offset any primary remanence due to hematite. This is supported by the high dispersion above 580 °C, a minimum intensity effect often observed at 580–650 °C, and by the fact that many specimens could not be measured at high temperatures or fields.

The site mean directions are stable to 700–1400 Oe in AF demagnetization, changing by little more than 30°. Since these directions are different from the thermal data, it suggests that AF demagnetization is preferentially leaving hematite, and further implies that the titanomagnetite has an overall low coercive force. Support for the latter idea comes from opaque mineralogy, since the highest recognizable oxidation state is the presence of thick, stubbly ilmenite lamellae. Thus it might be concluded that the effective magnetic grain size of the host spinel is still large, perhaps in the multidomain size. Nevertheless, some part of it is still capable of retaining a stable magnetization.

The AF means from sites 1 and 2 are near to the means from thermal demagnetization, while the others are streaked out along a great circle. It implies either that two generations of hematite exist (one having acquired a Precambrian TRM, the other a ? Laramide TRM) or that primary hematite has at sites 1 and 2 retained its Precambrian TRM, and at sites 3, 4 and 5 has partially acquired a ? Laramide viscous moment.

Support for the first idea comes from site 5 where the specimens contain more hematite along dislocations in the rock. However, no quantitative analysis of hematite was made with the microscope: it would be difficult to do so because so much of the mineral is disseminated throughout the rock. Support for the second idea comes from the intensity/susceptibility measurements, because there is no distinguishing feature about the site 5 data, implying no bulk magnetic differences.

Acknowledgments

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