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PALEOMAGNETISM OF THE UPPER DEVONIAN CATSKILL FORMATION FROM THE SOUTHERN LIMB OF THE PENNSYLVANIA SALIENT: POSSIBLE EVIDENCE OF OROCLINAL ROTATION

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Abstract. Multiple components of magnetization were isolated in the natural remanent magnetization of samples of the Upper Devonian Catskill Formation red beds taken from the southern limb of the Pennsylvania Salient. The dominant, thermally distributed component (SF), previously thought to predate folding, is demonstrably synfolding in origin. The mean direction for SF based on data from the current study and a previous study is Declination/Inclination = 161.6°/7.9°, a95 = 3.9° (pole position 127.3°E, 43.1°N, A95 = 3.1°, N = 14 sites). Although the remagnetization is clearly synfolding in most areas, the relative ages of folding and remagnetization vary locally. A subordinate high unblocking temperature component (HT) has a mean tilt corrected direction of 160°/36°, a95 = 16° (pole position 123.5°E, 26.1°N, A95 = 15.4°, n = 7 samples). Comparison of HT with the prefolding magnetization isolated in the northern limb of the salient suggests that the paleolatitude of this part of North America was about 16°S and that part of the curvature of the salient was acquired during orogenesis.

Introduction

The Catskill Formation (as correlated by Berg et al., 1980) is a thick fluvial sequence of red, gray, and green beds of Upper Devonian age which outcrops from New York State to Virginia. Previous paleomagnetic results from the Catskill from New York State (Kent and Opdyke, 1978) and from the southern limb of the Pennsylvania Salient (Van der Voo et al., 1979) have been interpreted to support the hypothesis that North America occupied a near equatoral paleolatitude in the Upper Devonian, implying that Acadia was offset from the craton (Kent and Opdyke, 1978; Van der Voo et al., 1979) and that the curvature of the Pennsylvania Salient was inherited from the presuture continental outlines (Schwartz and Van der Voo, 1982). An alternate interpretation of the data is that the Upper Devonian cratonic results represent Permo-Carboniferous remagnetizations (Roy and Morris, 1983; Irving and Strong, 1985), despite a positive Alleghanian-age (Permo-Carboniferous; Dennison, 1982) fold test (Van der Voo et al., 1979).

In a recent study of Catskill rocks from the northern limb of the salient two components of magnetization were isolated (Miller and Kent, 1986). A dominant, thermally distributed component (SE), similar in direction to the magnetizations isolated in the earlier studies, was shown to have been acquired during Alleghanian folding. An additional high unblocking temperature component (SW) was difficult to isolate in all but one locality, passed a fold test, had a southwesterly declination and an inclination indicative of a paleolatitude of about 16°S.

The current study of the Catskill from the southern limb of the salient was designed to isolate an analog to magnetization SW so as to confirm the Upper Devonian paleolatitude for North America and to test for rotation around the Pennsylvania Salient. Another objective of the study was to clarify the age relationship of folding and remagnetization in this area.

In the main study area, eight sites (5 to 10 oriented drill cores/site) distributed across strike and at various stratigraphic levels were occupied in an area roughly similar to that sampled by Van der Voo et al. (1979) who also sampled 8 sites; their sites 5 and 9 were reoccupied as sites Z and BB respectively. In the area near Breezewood, PA., 5 sites (3 to 5 samples/site) were occupied. The folds in the Catskill which we have sampled in the Valley and Ridge Province have wavelengths of kilometers to 10s of kilometers. In the area of Breezewood, however, the folds have much smaller wavelengths (10s to 100s of meters) and the area is cut by many faults.

Remanence measurements were made on a cryogenic magnetometer. Stepwise thermal, alternating field (AF), and chemical (6N or 12N HCl in a low field space) demagnetization techniques were employed in isolating components of natural remanent magnetization (NRM). The susceptibility was measured after each temperature step to monitor magnetochemical alteration. Local mu-metal shielding was used throughout the demagnetization procedures. Component magnetization directions were computed using principal component analysis (Kirschvink, 1980), mean directions and pole positions with standard Fisherian statistics.

Components of NRM

Secondary Magnetizations

Results. In the main sampling area, a low unblocking temperature (300°C), low coercivity (30mT), component was typically removed which was directed northward and down, consistent with an overprint of the present earth's field. For roughly 90% of the samples only one further magnetic component was unblocked from about 300°C to 680°C (Figure 1). When subjected to stepwise untilting the site mean directions for this magnetization (SF; Table 1; Figure 1) reach their best grouping at roughly half way through bedding tilt correction (TC). The peak value of Fisher's precision parameter, k, at 54%TC, is higher than both k at 0%TC and k at 100%TC at the 99% confidence limit (McElhinny, 1964). Magnetization SF is therefore secondary and was acquired after the

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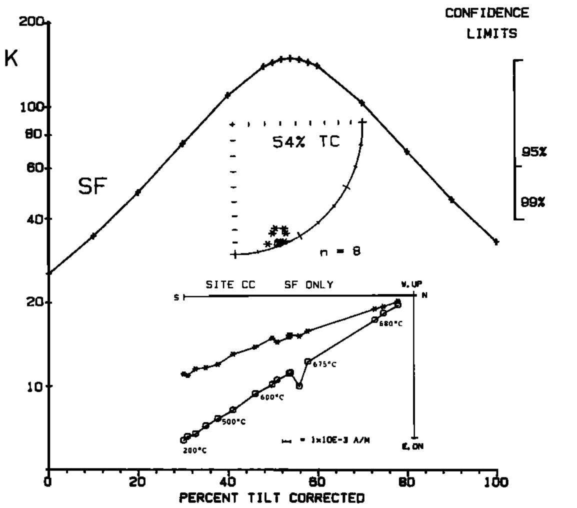

Fig. 1. Precision parameter vs incremental tilt correction for the synfolding magnetization SF. Insets are a stereographic projection of site mean directions at 54% tilt correction (* = positive inclinations, o = negative inclinations) and a Zijderveld diagram (in situ, * = horizontal data, o = vertical data) illustrating single component behaviour of most samples.

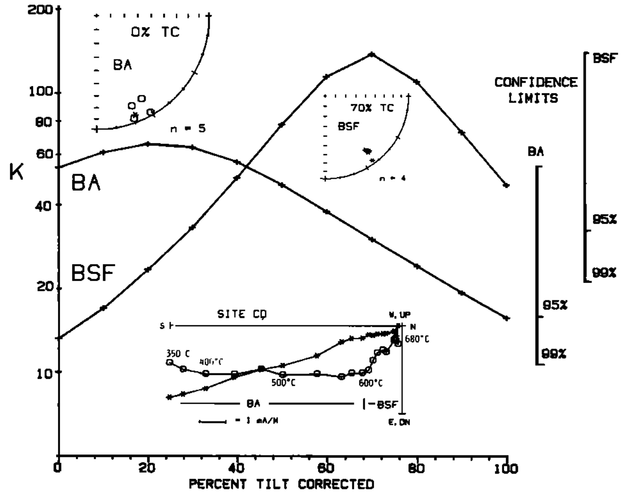

Fig. 2. Precision parameter vs incremental tilt correction for magnetizations from the Breezewood area. Insets are stereographic projections of site mean directions at labelled tilt corrections and a Zijderveld diagram illustrating dual component behaviour of samples.

initiation of Alleghanian folding. The best-grouped mean direction for SF is declination/inclination = 159.0°/6.7°, alpha 95 (a95) = 4.5° for N = 8 sites.

Samples from the Breezewood area typically decay with two thermally distributed components after removal of an overprint of the present earth's field (Figure 2). One component (BA) is typically unblocked between 300°C and 575°C. The site mean directions for BA (Figure 2) show a slight but not significant improvement with partial tilt correction. However, the ratio k at 0%TC to k at 100%TC is within 0.01 of the 95% confidence limit for N = 5 sites. This strongly suggests a post (or near end of) folding origin for magnetization BA (155.8°/-6.6°, a95 = 10.5° for N = 5 sites at 0%TC).

Above 575°C, a second distributed component (BSF) is clearly present to about 680°C although the sample demagnetization trajectories often curve toward the origin (Figure 2). Incremental tilt correction of best fit lines calculated over the most linear portions of the sample demagnetization paths shows that magnetization BSF is apparently synfolding (Figure 2); BSF at 70% TC is 143°/14°, a95 = 8°, k = 137 for N = 4 sites.

TABLE 1. Magnetization SF

Site	S/N	Dec (°)	Inc (°)	k	a95	Location °N/°W	ST/DP
V	5/6'	156.8	11.5	24.1	15.9	39.63/78.09	356/20
W	5/6'	161.0	-11.4	30.9	14.0	39.68/78.14	217/50
X	7/8	165.5	3.6	195.5	4.3	39.68/78.15	336/14
Y	6/7	168.9	27.8	23.1	14.2	39.68/78.30	22/72
Z	7/10	158.1	-9.8	30.0	11.2	39.68/78.37	205/29
AA	5/6	155.2	13.4	152.3	6.2	39.65/78.42	28/4
BB	7/8	163.6	-4.4	47.0	8.9	40.39/77.96	170/29
CC	4/5	160.3	28.1	302.0	5.3	40.41/77.99	55/25
Mean (8 sites)							
		161.1	7.3	25.2	11.3		

(Pole Pos. [54%TC] 42.7°N 130.9°E A95=3° k=342.8)

S/N is ratio of samples used in calculation to samples treated (No mark means sample excluded because of chemical demagnetization, ' means no straight line segments); Dec and Inc are declination and inclination before bedding tilt correction; k is Fisher's precision parameter: a95 is radius of 95% confidence limit; Dip (DP) direction 90° clockwise from strike (ST).

Discussion. The mean direction for magnetization SF (159.0°/6.7°) is indistinguishable from the previously reported mean direction (163.8°/8.5°) of Van der Voo et al. (1979). Therefore, this magnetization which seemed to pass a conventional fold test at the 99% confidence limit in the earlier study can now be documented to be a synfolding remagnetization. In the Van der Voo et al. study, only the Town Hill and Sideling Hill Synclines (or along strike extentions thereof) were sampled. For the sites from both studies which can unambiguously be designated as having sampled the Town Hill Syncline (sites 2, 5, 6, AA, and Z), the site mean directions reach the best grouping at near full TC. The site mean directions (sites 3, 4, and Y) from the Sideling Hill Syncline to the east, however, obtain their best grouping at partial TC. The data thus suggest that the initiation of the Town Hill Syncline (in which most of the Van der Voo et al. sites were located) occurred near the end of (or perhaps after) the SF remagnetization event.

In any case, the mean synfolding magnetization, calculated using the data from both studies, has a peak value of k at 68%TC of 102.7 which for N = 14 sites (common site means averaged) is different from k at 0%TC (16.5) and

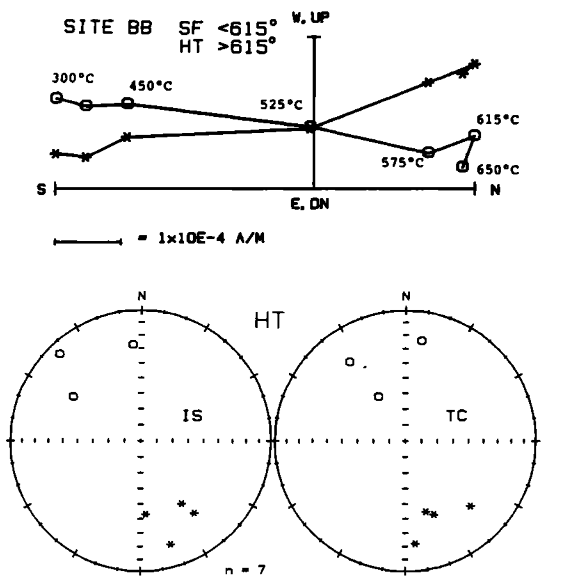

Fig. 3. A) Zijderveld diagram illustrating demagnetization behaviour typical of 7 samples from sites BB and V with both magnetizations SF and HT. B) Stereographic projections of sample directions at in situ (IS) and full tilt correction (TC).

from k at 100%TC (47.2) at the 95% confidence level; the best grouped direction (68%TC) is 161.6°/7.9°, a95 = 3.9° (pole position 127.3°E, 43.1°N, A95 = 3.1°, k = 167.5 for N = 14 site mean pole positions).

The Breezewood area is the only sampled part of the Catskill that can be shown to have suffered appreciable late Paleozoic remagnetization after folding ceased. The curved nature of the demagnetization trajectories for BSF implies that there is some overlap between the unblocking temperature spectra between BSF and BA. It is therefore possible that in this area remagnetization and folding occurred at least for some time concurrently, in contrast with the apparently discrete episodes of remagnetization and folding observed in other localities of the Catskill (Miller and Kent, 1986). The two sites (7 and 8) occupied by Van der Voo et al. (1979) near Breezewood appear to have been dominated by BSF.

A principal conclusion of the study then is that the dominant component of magnetization in the Catskill Formation (magnetizations SE and SF) is now confirmed to be of synfolding (Permo-Carboniferous) origin. However, the relative ages of folding and remagnetization vary locally, from synfolding (BSF) to postfolding (BA) in the Breezewood area, and from nearly prefolding to synfolding in the Town Hill and Sideling Hill synclines respectively (SF).

Prefolding Magnetizations

Results. For roughly 10% of the samples in the main sampling area the demagnetization trajectories show the presence of an additional high unblocking temperature component (HT). Three sample demagnetization trajectories (all from site BB) trend into the northwestern quadrant and reach what appear to be a stable endpoints above 600°C (Figure 3). Four samples (2 from site BB, 2 from site V) exhibit similar stable endpoints with reversed polarity. Reversed polarity HT magnetizations are distinguishable from BSF, BA, and SF by their thermally discrete unblocking temperature spectra. Above 650°C the measured magnetizations change randomly, apparently because of the magnetochemical alteration which plagues samples from the Catskill (Kent and Opdyke, 1978; Miller and Kent, 1986). Attempts were made to isolate magnetization HT through chemical demagnetization but acid leaching of samples known to possess both magnetization SF and HT yielded only a resultant of the two components, much as was observed in chemical demagnetization of sample NRMs from the northern limb of the salient (Miller and Kent, 1986).

The stable endpoint sample directions for magnetization HT (Figure 3) give a mean direction of 152°/31° before TC, and 160°/36° after TC (both with a95 = 16°, k = 16 for n = 7 samples, pole position after TC 123.5°E, 26.1°N, A95 = 15.4°). The scatter in the data preclude any statistically meaningful fold test, but the normal and reversed polarity data are antipodal within the confidence limits of the data. Great circle analysis (Halls, 1976) on the few other samples which appear to trend into the northern hemisphere but do not reach a stable endpoint confirms the northwesterly-southeasterly declinations and suggests a shallower inclination, as would be the case if HT has been incompletely separated from SF in the samples with apparently stable endpoints. However, effective use of the great circle analysis is hampered by fact that the remagnetization took place after about half of the folding had occurred.

Discussion. Although the fold test is ambiguous, some age constraints can be placed on magnetization HT. The magnetizations SF and HT are not coaxial, therefore, these magnetizations cannot be the same age. Also, the mean direction for HT is not consistent with any expected post-Carboniferrous magnetization from cratonic North America (Irving and Irving, 1982). We cannot rule out the possibility that HT represents a lower Carboniferous remagnetization; however, the similarity of the demagnetization temperature spectra for magnetization HT and SW from the northern limb of the salient leads us to favor the conclusion that these magnetizations are contemporaneous (Upper Devonian?).

The tilt-corrected reversed polarity inclination of 36°+-16° for HT corresponds to a paleolatitude of some 20°S+-15.4°. This result is consistent with the paleolatitude observed in the magnetization SW of 16°S+-7° (Miller and Kent, 1986; Figure 4) and with Upper Devonian results from Acadia summarized by Van der Voo and Scotese (1981). There is, however, a discrepancy between the paleolatitude observed in the Catskill and that which is predicted for Pennsylvania by the results from the Upper Devonian St. Lawrence Granite (about 35°S) located in eastern Newfoundland (Irving and Strong, 1985). It is at present unclear whether there is some undetermined problem with either of the data sets (unknown tectonic rotations of the pluton, an inclination error in the red beds, different ages of magnetization) or if there was a latitudinal

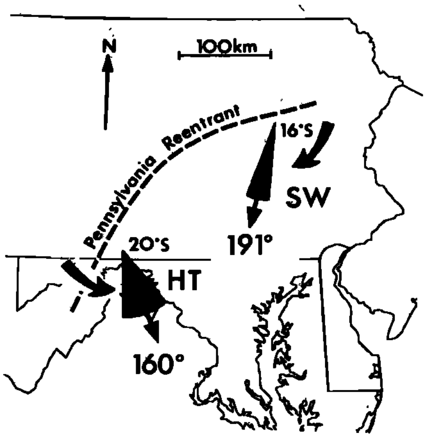

Fig. 4. Diagram illustrating possible rotation of prefolding magnetizations SW and HT in the formation of the Pennsylvania Salient (reentrant). Shaded cones are regions of 95% confidence for mean declinations (large numbers). Small numbers are mean paleolatitudes associated with prefolding magnetizations.

offset between eastern Newfoundland and North America in the Upper Devonian.

There is a discrepancy between the declinations of HT from the southern limb (160°+- 20°) of the salient, where the structural trend strikes about 195°, and SW from the northern limb (191°+- 8°), where the structural trend is about 250°. This relative offset (31°+-17°) is statistically significant at the 95% confidence level (Demarest, 1983). The sense of relative rotation inferred from the Catskill is similar to that observed in the prefolding directions from the Mauch Chunk Formation (16°+-15°, Kent and Opdyke, 1985) and is consistent with some portion of the present change in structural trend around the salient having been acquired during orogenesis.

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