TECTONICS, VOL. 7, NO. 4, PAGES 749-759, AUGUST 1988

FURTHER PALEOMAGNETIC EVIDENCE FOR OROCLINAL ROTATION IN THE CENTRAL FOLDED APPALACHIANS FROM THE BLOOMSBURG AND THE MAUCH CHUNK FORMATIONS

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Abstract. Renewed paleomagnetic investigations of red beds of the Upper Silurian Bloomsburg and the Lower Carboniferous Mauch Chunk Formations were undertaken with the objective of obtaining evidence regarding the possibility of oroclinal bending as contributing to the arcuate structural trend of the Pennsylvania salient. These formations crop out on both limbs of the salient and earlier, but less definitive paleomagnetic studies on these units indicate that early acquired magnetizations can be recovered. Oriented samples were obtained from nine sites on the southern limb of the salient and eight sites from the northern limb in the Bloomsburg. The natural remanent magnetizations are multivectorial, dominated by a component (B) with a distributed spectrum of unblocking temperatures ranging up to 670°C, and a component (C) with a higher and very discrete distribution of unblocking temperatures. The B component is uniformly of reverse polarity, shows a statistically significant synfolding character, and represents a Late Paleozoic remagnetization. The C component passes fold tests with normal and reverse polarity site means. The C component directions from the southern limb (345.1°/-31.6°) and the northern limb (359.3°/-29.7°) are significantly different in declination (14.2°±10.4°) but not in inclination (1.9°±9°). Samples were also analyzed from seven additional sites in the Mauch Chunk on the southern limb of the salient. Inclusion of these new data gives a revised estimate of the difference between southern and northern limb mean directions of prefolding magnetizations in the Mauch Chunk of 23.3°±12.5 in declination and 4.8°±11° in inclination. Paleomagnetic data from the Bloomsburg, Mauch Chunk, and revised results recently reported for the Upper Devonian Catskill Formation together indicate 22.8°±11.9° of relative rotation, accounting for approximately half the present change in structural trend around the Pennsylvania salient. The oroclinal rotation can be regarded as a tightening of a less arcuate depositional package that developed across a basement reentrant, to achieve a curvature closer to that of the earlier zigzag continental margin outline.

INTRODUCTION

A test of the orocline hypothesis [Carey, 1958] was a major impetus of early paleomagnetic studies in the Appalachians. Irving and Opdyke [1965] found that the mean declination in the Upper Silurian Bloomsburg Formation, sampled at a locality on the northern limb of the Pennsylvanian salient, was 30° more clockwise than the declination direction reported by Graham [1949] from the Middle Silurian Rose Hill Formation sampled at a locality on the southern limb. The subsequent, more comprehensive study of the Bloomsburg by Roy et al. [1967] sought to obtain paleomagnetic data in the same rock unit from sampling sites distributed around the salient. The four additional sites (A, B, C, D) from the northern limb confirmed the direction obtained from the one site (P) studied by Irving and Opdyke (Declination/Inclination = 005°/-30°, a95=10°, N=5). However, it was recognized that most of the sites from the southern limb were severely overprinted by Permian magnetizations, and only one site from this area gave what was tentatively interpreted as a Silurian direction (336°/ -37°) after thermal demagnetization to 550°C . The difference in paleomagnetic declination of 29° between the southern and northern limb was again compatible with at least partial bending around the salient, but no strong conclusion could be reached because of the limited data from the southern limb.

Paper number 8T0214.
0278-7407/88/008T-0214$10.00

Shortly thereafter, the paleomagnetic study of the Lower Carboniferous Mauch Chunk Formation by Knowles and Opdyke [1968] provided what has long appeared to be strong evidence against an orocline origin for the Pennsylvania salient. Paleomagnetic vectors of apparently prefolding origin were isolated in 23 sampling sites distributed around the salient, and these directions were found to be virtually the same on both limbs. The general conclusion of this study was more recently amplified [Schwartz and Van der Voo, 1983] by a combined statistical analysis of then available paleomagnetic data from four other Appalachian rock units (Upper Ordovician Juniata Formation, the Silurian Rose Hill and Bloomsburg formations, and the Upper Devonian Catskill Formation). Schwartz and Van der Voo [1983] and Eldredge et al. [1985] concluded that these data are consistent with a primary origin for the large arcuate structural trends in the Appalachians and that the orocline hypothesis must be abandoned for this mountain belt.

In response to mounting controversy regarding the Paleozoic reference paleopoles for cratonic North America [Roy and Morris, 1983; Irving and Strong, 1984] we have undertaken renewed paleomagnetic investigations of several critical Appalachian rock units. It has now been demonstrated that the paleomagnetic directions previously reported from the Catskill Formation [Kent and Opdyke, 1978; Van der Voo et al., 1979] and in particular, the Mauch Chunk Formation [Knowles and Opdyke, 1968] are seriously contaminated by secondary components acquired during or after the Alleghenian orogeny in the Late Carboniferous and Permian [Kent and Opdyke, 1985; Miller and Kent, 1986a, b]. The pre-Alleghenian folding magnetizations now isolated in the Mauch Chunk and Catskill moreover reveal a discrepancy in declination of 15°-25° across the Pennsylvania salient, and these new data reopen the case for oroclinal bending as a contributing cause for this large-scale structural feature.

An objective of the present study was to see if supportive evidence for rotation around the Pennsylvania salient could be obtained in a renewed paleomagnetic study of the Bloomsburg. Samples from additional sites in the southern limb of exposure of the Mauch Chunk were also taken and analyzed, to refine the statistical confidence limits of the data reported by Kent and Opdyke [1985].

BLOOMSBURG FORMATION

Geologic Setting and Sampling

At its type locality in central Pennsylvania the Bloomsburg is largely red shale but includes sandstones to the southwest where it attains a maximum thickness of 2000 feet (600 m) [Hoskins, 1961]. The Bloomsburg red beds grade into marine deposits of Niagaran (Middle Silurian) and Cayugan (Upper Silurian) age to the west and southwest, losing their red color in the Virginias [Dennison, 1982].

The sampling strategy was similar to that employed by Roy et al. [1967], and in fact many of their sites were reoccupied (Figure 1a). Oriented drill core samples (three to seven per site) were obtained from 17 sites, nine sites (A-I) from the southern limb of the salient, and eight sites from the northern limb (J-S, excluding the single hand samples taken from sites M and N for reconnaissance). The sites represented beds of various dips to permit a fold test. The mean bedding strike, calculated from a great-circle fit to poles to bedding, is N80°E for the northern sites and N36°E for the southern sites, the difference (44°) reflecting the change in structural trend around the salient (Figure 1b).

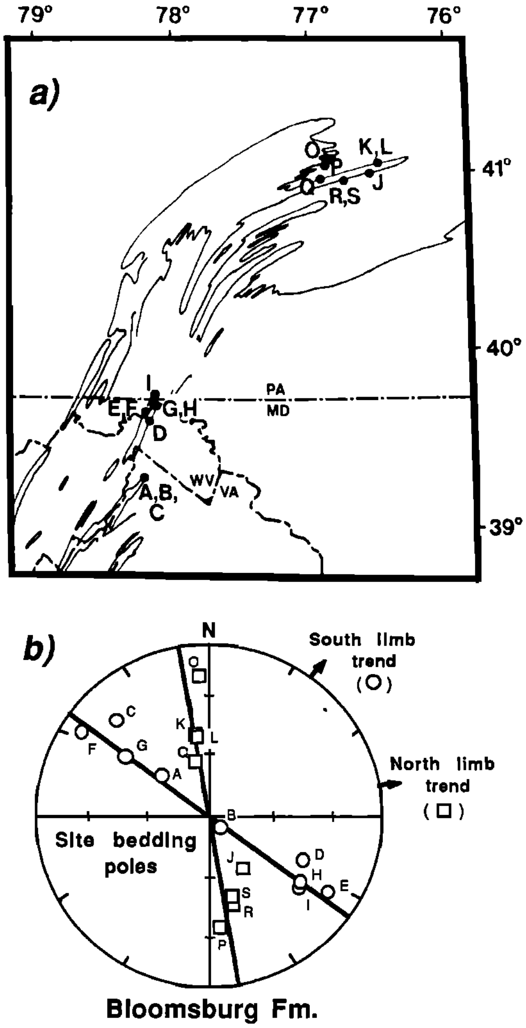

Fig. 1. (a) Map showing paleomagnetic sampling sites of Bloomsburg Formation (outcrop trace from Hoskins [1961]). Some of the present sampling sites are at the same localities sampled by Roy et al. [1967], specifically, sites A, B, C correspond to locality K; site D to locality I; sites E and F to locality H; sites G and H to locality G; site P to locality D; site Q to locality C; and sites R and S to locality B. (b) Poles to bedding for Bloomsburg sampling sites.

Paleomagnetic Results

The natural remanent magnetization (NRM) of the Bloomsburg was anticipated to be multivectorial, and most of

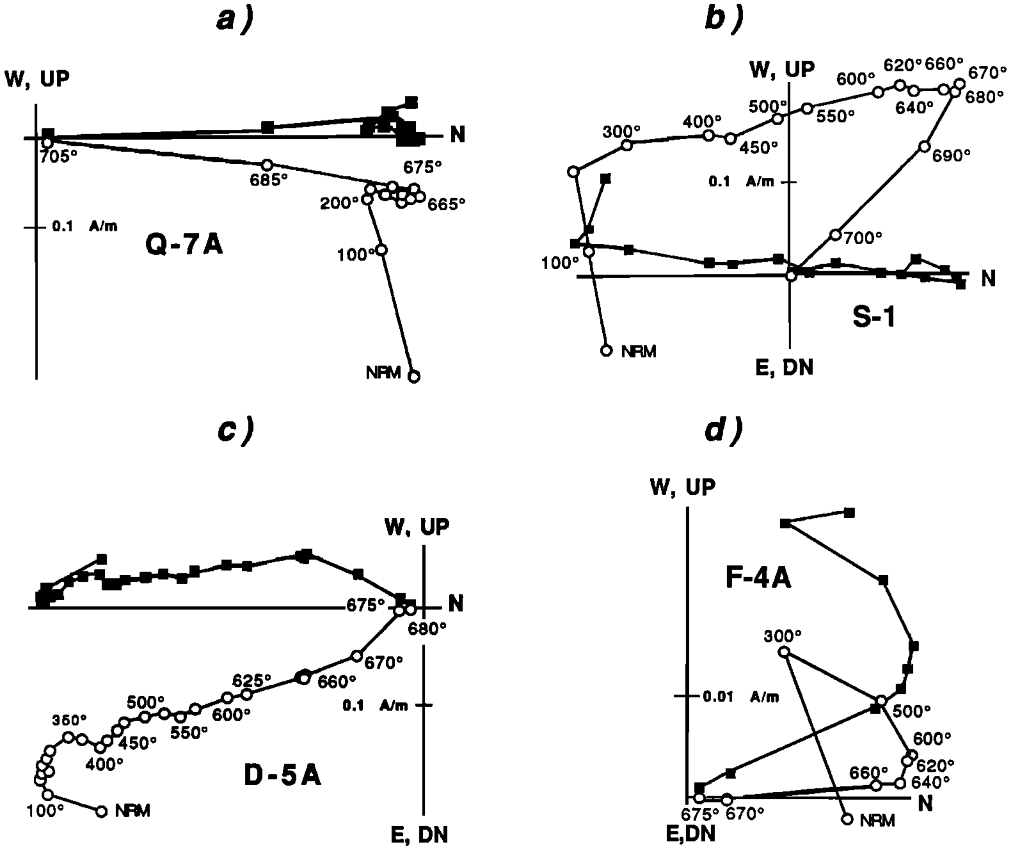

Fig. 2. Representative Zijderveld [1967] diagrams of progressive thermal demagnetization of NRM of Bloomsburg red beds from (a)-(b) northern and (c)-(d) southern limbs of salient. Open (solid) symbols plotted on vertical (horizontal) planes in geographic coordinates; treatment levels in Celsius.

the samples were subjected to progressive thermal demagnetization at a minimum of 8 to as many as 30 steps to isolate components of NRM. Alternating field demagnetization (to 100 mT) proved ineffective because of very high coercivities associated with hematite. Chemical demagnetization (one sample per site in 8N to 10N HCl for up to 1000 hours) showed poor evidence for component separation as observed previously in some other Appalachian red beds [Miller and Kent, 1986a].

Aside from an initial component typically aligned along the present Earth's field and removed by 300°C, two components of magnetization characterize the NRM: a southerly (reversed polarity) component referred to as B of shallow inclination and unblocking temperatures distributed up to 670°C, and a final, steeper inclination component referred to as C of very high and discrete unblocking temperatures with northerly (normal) and southerly (reversed polarity) directions in different sites. In the northern area of outcrop a normal polarity C component usually dominates the NRM, with only a small (Figure 2a) to moderate (Figure 2b) contribution from the B component, consistent with the early observations of Irving and Opdyke [1965]. In contrast, samples from the southern sites tend to have a reversed polarity C component, with an appreciable to dominant contribution from the B component (Figure 2c) as previously observed by Roy et al. [1967]. Two sites (B and F), however, do show a normal polarity C component (Figure 2d).

Least squares fits to the linear demagnetization trajectories for the B and C components in each sample were made by principal component analysis [Kirschvink, 1980]. Only site K did not yield a reliable B component sample direction and except for single determinations at sites Q and R, all other sites yielded three to seven sample estimates for both the B and C components (Tables 1 and 2).

The site mean directions for the B component are southerly and shallow from both the northern and southern areas (Figure 3a). Full tilt corrections produce no significant change in either the overall mean direction or dispersion. However, application of incremental bedding tilt corrections reveals a significant (95% confidence level) improvement in grouping for both areas after 40%-50% tilt correction (Figure 3b). (Note: Significance levels for all fold tests in this paper

TABLE 1. Site Mean Directions in Geographic Coordinates for B and C Components of Bloomsburg Formation

		B Component					C Component				
Site	Strike/Dip	n	Declination (°)	Inclination (°)	k	a95 (°)	n	Declination (°)	Inclination (°)	k	a95 (°)
A	*240/36W	6	157.7	5.0	43	10.3	5	162.9	12.5	28	14.7
B	*336/24E	5	165.2	20.4	24	15.9	5	353.3	-22.1	12	23.6
C	*198/92W	8	159.8	-14.3	40	8.9	6	151.8	-24.0	36	11.4
D	026/51E	6	172.8	22.5	76	7.7	5	202.2	46.8	59	10.0
E	033/71E	6	183.9	35.9	100	6.7	6	214.4	52.0	168	5.2
F	213/76W	6	201.4	-28.3	42	10.5	5	325.8	26.0	11	24.0
G	215/49W	5	159.7	-8.1	18	5.8	6	151.9	-1.1	135	5.8
H	039/57E	6	180.1	26.5	75	7.8	4	208.0	52.2	94	9.5
I	037/56E	7	186.8	35.1	58	8.0	5	211.0	45.5	74	9.0
J	059/30S	5	175.1	-1.7	64	9.6	6	5.4	-47.7	355	3.6
K	260/39N	-	-	-	-	-	5	358.9	9.1	336	4.2
L	259/39N	5	183.6	-28.6	89	8.1	3	349.1	0.6	173	9.4
O	267/70N	6	167.0	-17.8	56	9.1	6	7.6	27.0	407	3.3
P	084/55S	6	184.0	23.0	47	9.9	6	0.5	-86.0	213	4.6
Q	271/26N	1	185.1	-18.4	-	-	7	2.3	1.6	199	4.3
R	075/45S	3	184.5	17.4	433	5.9	1	47.8	-62.0	-	-
S	071/41S	4	179.6	17.3	86	10.0	3	358.0	-60.6	35	21.0

* Combine with minor fold plunge of 20° at 042°.

are based on the conservative f-ratio method [McElhinny, 1964; McFadden and Jones, 1981].) The B magnetizations can therefore be regarded as secondary; the corresponding best grouped mean directions are 179.4°/-3.0° (a95=7.9°) for the seven northern sites and 168.2°/12.1° (a95=9.5°) for the nine southern sites (Table 2).

The C component site mean directions are highly scattered in geographic coordinates, with best estimates for Fisher's precision parameter (k) of only about 4 for the northern and southern sets of sites (Figure 4). Full tilt correction results in a significant (99% confidence level) improvement in grouping; 10 sites, including all eight from the northern area, have a northerly and moderately up direction (normal polarity), whereas seven sites have a southerly and moderately down direction (reversed polarity). An incremental tilt correction (Figure 4b) shows a peak in k after only 80%-90% of bedding

TABLE 2. Area Mean Directions for B and C Components of Bloomsburg Formation

	Declination(°)	Inclination(°)	k	a95(°)
I. B component				
southern limb (N=9 sites [A-I], 55 samples)				
0% tilt corrected	173.3	11.1	9	18.0
*50% tilt corrected	168.2	12.2	31	9.5
100% tilt corrected	170.1	12.5	11	16.5
northern limb (N=7 sites [J, K, O- S], 30 samples)				
0% tilt corrected	179.8	-1.3	14	16.7
†40% tilt corrected	179.4	-3.0	59	7.9
100% tilt corrected	180.6	-6.6	7	23.9
II. C component				
southern limb (N=9 sites [A -I], 47 samples)				
0% tilt corrected	355.2	-22.6	4	28.1
§100% tilt corrected	345.1	-31.6	36	8.7
northern limb (N=8 sites [J to L, O- S], 37 samples)				
0% tilt corrected	3.7	-27.7	4	33.4
¶100% tilt corrected	359.3	-29.7	57	7.4

*North pole position: 42.5°N 118.1°E (dp, dm = 4.9°, 9.6°).
†North pole position: 51.7°N 102.9°E (dp, dm = 4.4°, 8.7°).
§North pole position: 31.3°N 116.7°E (dp, dm = 5.5°, 9.7°).
¶North pole position: 33.1°N 103.3°E (dp,dm = 4.5°, 8.2°).

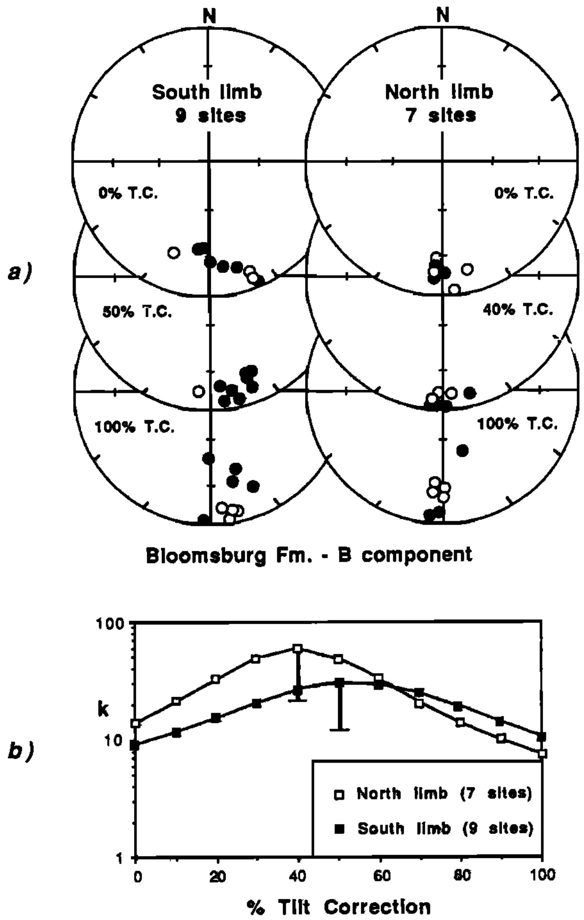

Fig. 3. Site mean directions of B component magnetizations in Bloomsburg Formation. (a) Equal-area projections, with open (solid) symbols on upper (lower) hemispheres, after different stages of tilt correction (T.C.). (b) Variation in Fisher's precision parameter k, with progressive tilt correction as percentage of measured bedding dip at each site. Significance of relative change in k with tilt correction can be judged against the 95% confidence interval shown as a solid bar on each curve.

tilt restoration, but these are not significant (95% confidence level) from full tilt correction; hence the C magnetizations pass the fold test and can be regarded as prefolding. The mean directions after converting all tilt-corrected site means to common (normal) polarity are 359.3°/-29.7° (a95=7.4°) for the northern limb and 345.1°/-31.6° (a95=8.7°) for the southern limb.

MAUCH CHUNK

Oriented drill core samples were taken from seven sites in the Mauch Chunk from the Crystal Spring Basin on the southern limb of the Pennsylvania salient (Figure 5a). These supplement the 10 sites collected from this general area and analyzed previously [Kent and Opdyke, 1985].

As in the previous study, the NRM is found to consist of two components that could be separated by thermal demagnetization (Figure 6a). The southerly and shallow inclination B component, with unblocking temperatures ranging to 670°C and higher, typically dominates the NRM, but in five of the seven sites a very high unblocking temperature, final (C) component of magnetization can also be isolated (Table 3).

Combined with the site means from the nearby Broad Top area reported by Kent and Opdyke [1985], the 16 B component site means show a peak in k with incremental tilt corrections after 50% restoration that is significantly (95% confidence level) higher than without tilt correction (Figures 6b, 6d). As concluded in the earlier study, the B component is secondary, presumably acquired sometime during Alleghenian deformation; the best grouped B direction is 162.5°/-9.7°

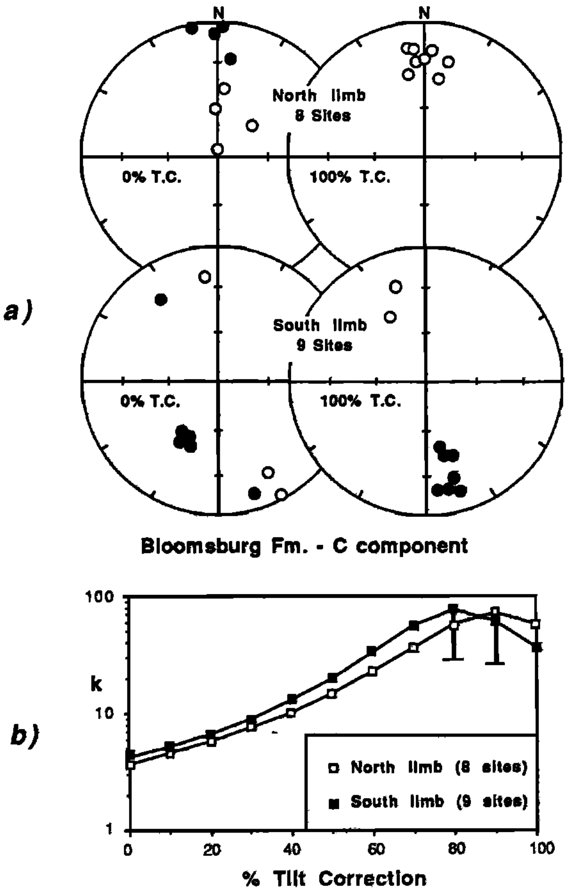

Fig. 4. Site mean directions of C component magnetizations of Bloomsburg Formation. (a) Equal-area projections, with open (solid) symbols on upper (lower) hemisphere, before (0% T.C.) and after (100% T.C.) tectonic tilt correction. (b) Variation in Fisher's precision parameter k, with progressive tilt correction as percentage of measured bedding dip at each site. Significance of relative change in k with tilt correction can be judged against the 95% confidence interval shown as a solid bar on each curve.

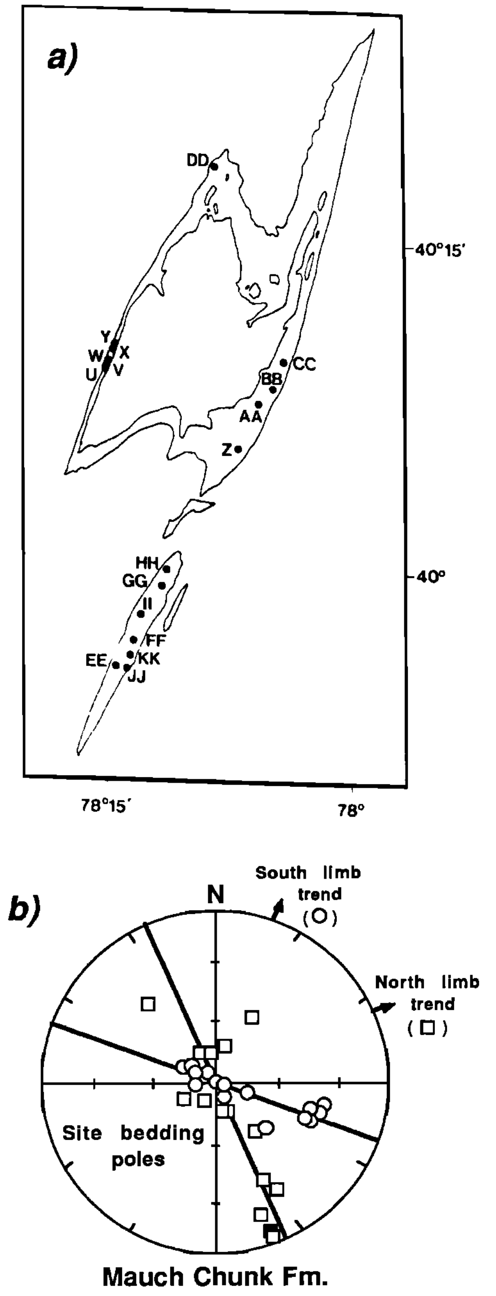

Fig. 5. (a) Map showing sampling sites of Mauch Chunk Formation in southern Pennsylvania (outcrop trace from Geologic Map of Pennsylvania [Berg, 1980]). Sites EE to KK reported here; other sites reported by Kent and Opdyke [1985]. (b) Poles to bedding for Mauch Chunk sampling sites.

(k=72, a95=4.4°) for these 16 sites from the southern limb. The C component on the other hand is clearly prefolding (Figures 6c, d) and combined with the relevant site means reported by Kent and Opdyke [1985], has a tilt-corrected mean direction for the southern limb of 323.1°/-30.4° (k=18, a95=10°, N=13 sites).

PALEOMAGNETIC ESTIMATES OF OROCLINAL BENDING

To test whether the change in structural trend around the Pennsylvania salient is of secondary origin, we can make a limb-to-limb comparison of the paleomagnetic directions obtained from the Bloomsburg and the Mauch Chunk. If the salient was formed by a relative rotation about a nearby vertical axis of one limb with respect to the other, we should expect to find a significant discrepancy in the declination between limbs in each formation for magnetizations acquired prior to oroclinal bending. The differences in paleomagnetic (normal polarity equivalent) directions are calculated by subtracting the southern limb value from the northern limb value, neglecting the small geographic separation of the localities; 95% confidence intervals are calculated according to the method of Demarest [1983].

The B components in the Bloomsburg and Mauch Chunk are demonstrably of secondary origin by virtue of not passing fold tests and hence acquired during or after Alleghenian folding in the Late Carboniferous and Permian. There are, however, differences in the B component directions from area to area. For the Bloomsburg the mean B component from the northern and southern limbs are significantly different, in terms of both declination (11.2°±10.3°) and inclination (15.2°±10.1°). Significant differences between salient limbs also exist in the B component from the Mauch Chunk (11.9°±5.9° in declination and -7.6°±5.9° in inclination), using the revised B component direction for the southern limb given above and a B component mean of 174.4°/ -2.1° (k=41, a95=5.9°, N=16 sites) after 50% tilt correction for the northern limb from data of Kent and Opdyke [1985]. The significant differences in both mean inclination and declination for the B component found in each formation can be largely attributed to variable times of remagnetization during an interval of apparent polar wander in the Permo-Carboniferous, as described elsewhere in more detail [Miller and Kent, 1988a].

More pertinent for a test of oroclinal bending are the prefolding (C) magnetizations. For the Bloomsburg the between-limb difference in the mean direction of the C component resolves to a discrepancy in declination of 14.2°±10.4° and in inclination of 1.9°±9°. For the Mauch Chunk, inclusion of the new data results in a revised estimate of the difference between the southern (323.1°/-30.4°, a95=10°) and northern limb (346.4°/-25.6° a95=9.7°; Kent and Opdyke [1985]) mean directions of 23.3°±12.5° in declination and 4.8°±11° in inclination. For both the Bloomsburg and the Mauch Chunk therefore the mean declination direction of the prefolding magnetization in the northern limb is significantly more clockwise than in the southern limb. The lack of a significant between-limb difference in inclination in either formation is consistent with a horizontal rotation about a nearby vertical axis as a major cause of the discrepancy in the mean directions.

The between-limb difference in structural trend of the Pennsylvania salient is approximately 45°, as reflected, for example, in the poles to bedding for the Bloomsburg and Mauch Chunk sampling sites (Figures 1b, 5b). In addition to the paleomagnetic data described here, recent studies of the Upper Devonian Catskill Formation [Miller and Kent, 1986a, b] provide relevant information for a test for oroclinal rotation.

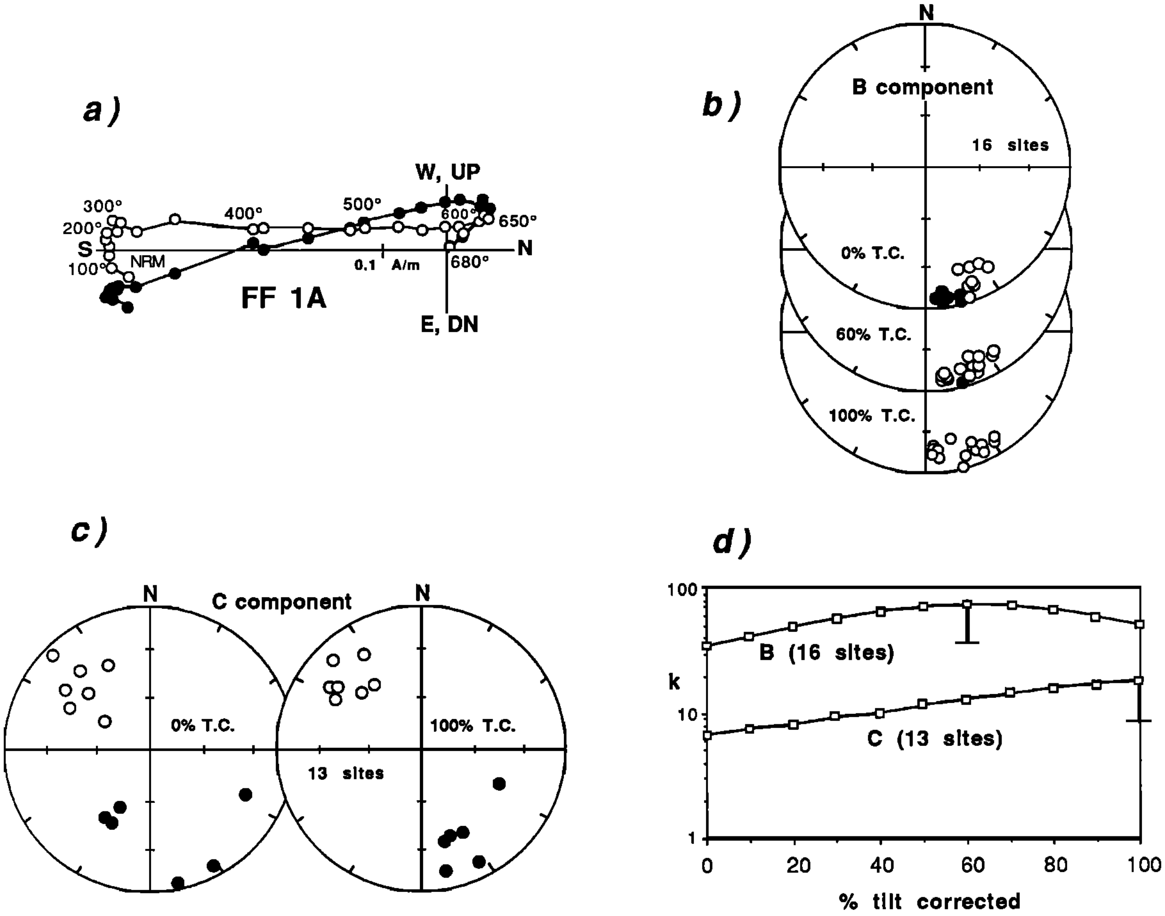

Fig. 6. Paleomagnetic data from Mauch Chunk Formation from southern limb of Pennsylvania salient. (a) Representative Zijderveld demagnetogram of NRM. Open (solid) symbols plotted on vertical (horizontal) planes in geographic coordinates; treatment levels in Celsius. (b) Site-mean directions of B component after different stages of tilt correction (T.C.). (c) Site mean directions of C component before (0%) and after full (100%) tilt correction. For Figures 6b and 6c, open (solid) symbols plotted on upper (lower) hemispheres of equal-area projections. (d) Variation in Fisher's precision parameter k for B and C component site-means with progressive tilt correction as percentage of bedding dip at each site. Significance of relative change in k with tilt correction can be judged against the 95% confidence interval shown as a solid bar on each curve.

In each of these throughgoing Paleozoic red bed units there is a significant difference in declination, but not in inclination, of the isolated prefolding magnetizations between the northern and southern limb sampling sites (Figure 7). The three independent estimates of declination differences are similar, with a mean of 22.8°±11.9° (two standard errors). The magnitude and sense of the discrepancy can account for about 50% of the present change in structural trend around the Pennsylvania salient as due to oroclinal bending in post-Mauch Chunk time, sometime during the Alleghenian orogeny.

DISCUSSION

The negative evidence for oroclinal bending reported earlier by Knowles and Opdyke [1968] from the Mauch Chunk and by Schwartz and Van der Voo [1983] from an analysis of paleomagnetic data from the Catskill, Bloomsburg, Rose Hill, and Juniata can now be largely attributed either to contamination by secondary magnetizations, whose importance has only recently become more fully appreciated and recognized, or to limited sampling coverage. Indeed, as discussed above, the renewed studies of the Mauch Chunk, Catskill, and Bloomsburg now show consistent paleomagnetic evidence for oroclinal rotation around the Pennsylvania salient. Sampling in the studies of the Silurian Rose Hill and the Ordovician Juniata formations included in the analysis of Schwartz and Van der Voo [1983] was mostly confined to the southern limb, and thus these studies by themselves do not provide adequate spatial coverage for a test of oroclinal rotation. A paleomagnetic study is in progress on the Juniata that includes more sites from the northernmost area of outcrop [J. D. Miller and D. V. Kent, unpublished manuscript, 1988].

Our preferred interpretation of the paleomagnetic data in terms of oroclinal bending is ostensibly at odds with the

TABLE 3. Site Mean Directions in Geographic Coordinates for Mauch Chunk Formation From Southern Pennsylvania

		B Component					C Component				
Site	Strike/Dip	n	Declination (°)	Inclination (°)	k	a95 (°)	n	Declination (°)	Inclination (°)	k	a95 (°)
EE	014/05E	5	158.8	-8.9	64	9.6	-	-	-	-	-
FF	014/05E	5	164.4	2.0	87	8.2	4	305.5	-30.0	46	13.8
GG	176/10W	6	158.9	-13.3	326	3.7	6	151.7	8.7	47	9.9
HH	042/32E	5	164.7	3.5	1857	1.8	4	302.3	-59.9	35	15.9
II	044/07E	5	162.0	-2.7	417	3.8	5	298.6	-38.4	78	8.7
JJ	192/07W	5	158.8	-10.0	282	4.6	-	-	-	-	-
KK	000/00	6	158.6	-8.8	62	8.6	3	314.2	-42.3	12	36.6

conclusions of Rankin [1976], Thomas [1977], and others who show that the pronounced bends (salients and recesses) in Appalachian structural trends are a primary feature, inherited from the irregular shape (reentrants and promontories) of an earlier continental margin. In the model outlined by Thomas [1977] the original zigzag margin was smoothed by early deposition and erosion. Deposition of clastic wedges starting in the Ordovician was centered in the reentrants where the thickness of these sediments is greatest, decreasing along strike toward promontories. Thus the terminal Alleghenian compression operated on a laterally nonuniform array of rocks, and the resulting fold belt was draped around the continental basement promontories and reentrants. Thomas [1977] suggests that deformation in the salients was predominantly thin-skinned and occurred farthest toward the craton (perhaps aided in the case of the Pennsylvania salient by detachment on a weak salt layer [Davis and Engelder, 1985]], compared to the more thick-skinned, narrow belts of deformation on the recesses.

We suggest that relative rotation around the Pennsylvania salient was directly associated with the differential deformation of the salients and recesses as postulated by Thomas [1977]. In this view the original continental margin shape effectively controls where oroclinal bending will occur, by virtue of basement zigzags acting as deposition and subsequently, stress guides. The rotation of the salient limbs can therefore be regarded as a tightening of a less arcuate depositional package that developed across the basement reentrant, to achieve a curvature closer to that of the original margin outline.

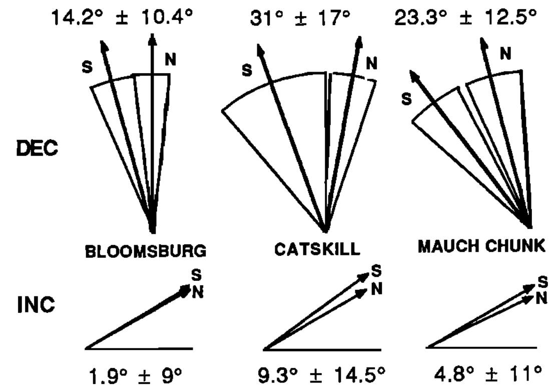

Fig. 7. Differences in mean declination (DEC) and inclination (INC), with associated 95% confidence intervals, of prefolding magnetizations from northern (N) and southern (S) limbs of Pennsylvania salient in the Bloomsburg (this paper), Catskill [Miller and Kent, 1986a, b], and Mauch Chunk [Kent and Opdyke, 1985; this paper] formations.

As pointed out by Marshak [1988], Carey's definition of an orocline does not include bends that formed when an orogen was moulded onto an irregular cratonic margin and developed at the same time as the structural grain of the orogen. The Pennsylvania salient can nevertheless be referred to as an orocline in the sense proposed by Marshak [1988], as simply a bend in which the strike of the limbs have changed during the formation of the orogen, as evidenced by the rotated paleomagnetic declinations.

It would be of interest to know the rotation of the salient limbs with respect to the stable craton of North America. Unfortunately, this is not easy to determine because there are few reliable reference paleomagnetic poles from Silurian, Devonian, or lower Carboniferous rocks representative of the stable craton to compare with the Appalachian paleopoles [Van der Voo, 1988]. The Lower Carboniferous (Tournaisian) Deer Lake Formation of western Newfoundland may be considered cratonic [Irving and Strong, 1984]. The Deer Lake paleopole falls roughly in between the results from the somewhat younger (Visean to Namurian) Mauch Chunk which would suggest that both the northern and southern limbs have experienced about equal amounts of inward rotation (Figure 8). On the other hand, the Deer Lake paleopole falls closest to the southern limb pole from the somewhat older (Famennian) Catskill, and this would therefore suggest that most of the relative rotation occurred as clockwise on the northern limb, the southern limb essentially fixed relative to the craton. The apparent agreement between the Middle Silurian Wabash pole from Indiana [McCabe et al., 1985] and the pole from the Middle Silurian Rose Hill from the southern limb of the Pennsylvania salient [French and Van der Voo, 1979] would support this sense of relative motion (Figure 8). A complication with this scenario is the Peel Sound pole from the Canadian Arctic [Dankers, 1982] which, even if it represents a remagnetization [Miller and Kent, 1988b],

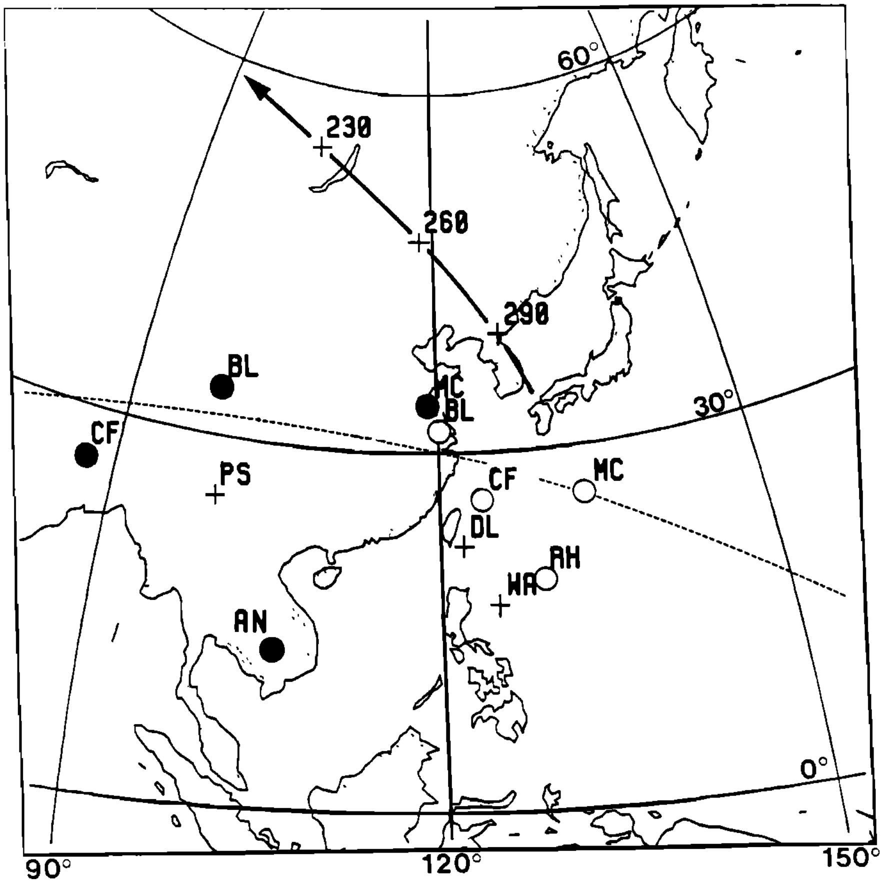

Fig. 8. Middle to late Paleozoic paleopoles for North America. The Late Carboniferous and Permian segment of APW path is represented by mean poles for 290, 260, and 230 Ma from Irving and Irving [1982]. Open (solid) circles are paleopoles based on pre-folding magnetizations from southern (northern) limb of Pennsylvania salient: RH, Middle Silurian Rose Hill, French and Van der Voo [1979]; BL, Upper Silurian Bloomsburg, this paper; CF, Upper Devonian Catskill, Miller and Kent [1986a, b]; MC, Lower Carboniferous Mauch Chunk, Kent and Opdyke [1985] and this paper; AN, Lower Devonian Andreas, Miller and Kent [1988b]. Paleopoles from the interior of North America are shown by crosses: PS, Lower Devonian Peel Sound, Dankers [1982] (see also Miller and Kent, [1988b]); WA, Middle Silurian Wabash, McCabe et al. [1985]; DL, Lower Carboniferous Deer Lake, Irving and Strong [1984]. Dashed curve corresponds to colatitude of 105° from a representative site in Pennsylvania (Latitude 40°N Longitude 80°W) to illustrate trend of expected dispersions of middle Paleozoic paleopoles due to rotations in the Appalachians.

suggests a westerly excursion of the cratonic North American apparent polar wander path, to the vicinity of the Catskill pole from the northern limb in the Devonian.

The lack of a more definitive answer points to general inadequacies in the Paleozoic APW path for cratonic North America, especially now that there is good reason to believe that parts of the Appalachian orogenic belt, where many of the reference poles have been obtained, experienced rotations internal to it. Rotations in the Appalachians would produce a pattern of roughly east-west spread in paleopoles, as observed (Figure 8). Paleolatitudinal estimates for eastern North America are not appreciably affected (i.e., the prefolding remanent inclinations in each rock unit are virtually the same around the salient), but until the magnitude and sense of the rotations are established with respect to the craton there will be an uncertainty in the paleoazimuthal orientation of the continent based on these Appalachian paleopoles.

On the other hand, a real east-west swing in APW could conceivably account for some of the evidence for rotations in the Appalachians. Early (pre-Alleghenian folding) remagnetizations required by this alternative hypothesis cannot be excluded within the available constraints on magnetization ages; the marginally better grouping of the Bloomsburg C component directions at less than full tilt correction (Figure 4b) may be an indication that the isolated magnetizations, at least in this unit, are not original. Nevertheless, this hypothesis would also require that such remagnetizations occurred in a particular spatiotemporal sequence in the Bloomsburg, Catskill, and Mauch Chunk to explain the systematic between-limb declination differences in the C components found within each of these units, a speculative possibility that cannot be evaluated in the absence of an independently determined APW path.

We conclude that the most straightforward interpretation consistent with the available data is that about one half of the present curvature around the Pennsylvania salient is due to oroclinal bending during the Alleghenian orogeny.

Acknowledgements. Thanks are extended to Xu Guizhong and John Miller for field assistance, to Doris Lafferty for laboratory work, and to John Miller and Susan Halgedahl for critical readings of the manuscript. This research was supported by the National Science Foundation, Earth Science Division, under grant EAR85-07046. Lamont-Doherty Geological Observatory contribution #4295.

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(Received January 13, 1988;
revised March 8, 1988;
accepted March 11, 1988.)