Paleomagnetism of the Silurian-Devonian Andreas redbeds: Evidence for an Early Devonian supercontinent?

John D. Miller, Dennis V. Kent
Lamont-Doherty Geological Observatory and Department of Geological Sciences
Columbia University, Palisades, New York 10964

ABSTRACT

Two components of magnetization were isolated in the Silurian-Devonian Andreas redbeds of the central Appalachians of Pennsylvania (lat 40.75°N, long 75.78°W): a thermally distributed, synfolding B component, and a thermally discrete, pre-Alleghenian-age folding C component. The C component mean direction and associated pole position correspond to a Silurian-Devonian paleolatitude for the Andreas location of about 35°S, which, in conjunction with Early Devonian results from Gondwana, is consistent with an Early Devonian supercontinent configuration.

INTRODUCTION

The paleomagnetic pole position for cratonic North America for latest Silurian to Early Devonian time is currently documented only by data from the Lower Devonian Peel Sound redbeds of the Canadian Arctic (Dankers, 1982). The multicomponent Peel Sound magnetizations correspond to Danker's MDL pole, which was present at most sites and was presumed to represent the Early Devonian cratonic pole position, and his E pole, which was isolated at only one site and was presumed to represent a later (Late Devonian) remagnetization. However, the lack of a fold test in the Peel Sound study precluded more definitive relative age control on the MDL and E pole magnetizations.

It had been suggested, largely on the basis of faunal affinities, that there was a supercontinent configuration of Laurentia and Gondwana in the Early to Middle Devonian and that the Acadian orogeny was the result of a collision between northeastern North America and northwestern South America (McKerrow and Ziegler, 1972; Keppie, 1977). More recent interpretations (e.g., Scotese, 1984), based largely on the paleomagnetic data from the Peel Sound Formation, suggest a wide ocean between Laurentia and Gondwana in Silurian-Devonian time.

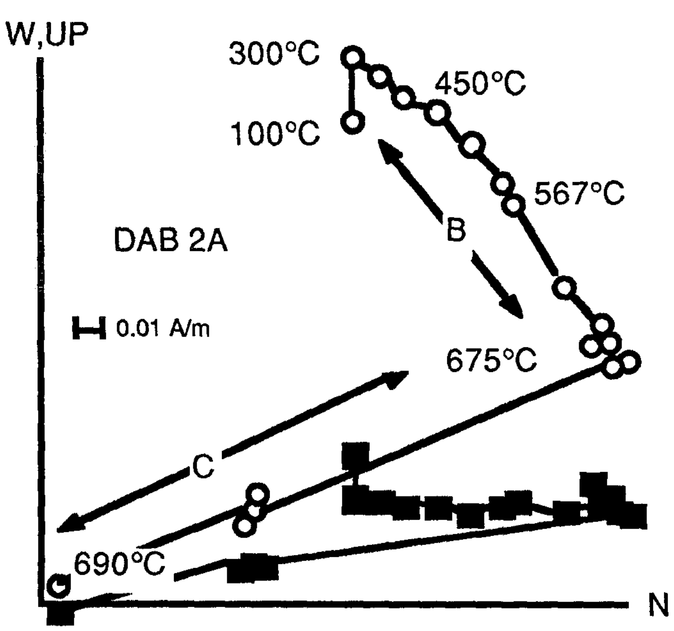


Figure 1. Representative Zijderveld demagnetogram plotted in geographic coordinates. Open symbols are projections in vertical plane. Solid symbols are projections in horizontal plane.

The Upper Silurian–Lower Devonian Andreas redbeds are unique in that they are the only Silurian-Devonian redbeds exposed in the folded Appalachians. Because the more common Silurian-Devonian carbonates were uniformly remagnetized in the late Paleozoic (McCabe et al., 1983), the Andreas redbeds provide an important opportunity to document a Silurian-Devonian paleomagnetic paleopole for North America.

GEOLOGIC SETTING

The Andreas redbeds (Swartz and Swartz, 1941) are a thin (~20 m thick) sandstone unit. The unit lacks a distinctive fossil assemblage but is constrained to be Upper Silurian or Lower Devonian by the conodont, ostracod, brachiopod, and bryozoan biostratigraphy of the stratigraphically underlying Pridolian (Denkler, 1984) Keyser Limestone and the overlying Gedinnian (Epstein et al., 1967) Coeymans Limestone.

We sampled the Andreas redbeds at the large road-metal quarry near Andreas, Pennsylvania, where we had access to both limbs of a small (few hundred metres wavelength) nonplunging Alleghenian (Carboniferous to Permian) anticline. Standard paleomagnetic techniques were used in the field and laboratory (see Miller and Kent, 1986b for details).

PALEOMAGNETIC RESULTS

Progressive thermal demagnetization reveals that the natural remanent magnetizations (NRM) of samples from the Andreas redbeds are typically composed of two components (Fig. 1). Between 300 °C and about 675 °C, a south-southeast (in all but three samples) component of NRM (labeled B in Fig. 1) was unblocked which in most samples did not trend toward the origin (Table 1; Figs. 1, 2). Above 675 °C, a final northerly (one southerly sample) component of NRM (labeled C in Fig. 1) was unblocked which decayed to the origin. Isolation of the C component was hindered in some samples because of magnetochemical alteration. The high (>600 °C) unblocking temperatures of the B and C components suggest hematite as the magnetic carrier for both these magnetizations.

Because of the limited availability of outcrop, only two sites with independent bedding attitudes (DAA and DAB) were sampled. At the sample statistical level, the B component Fisherian precision parameter, k, reaches a peak value at about half-way through bedding tilt correction (TC; Table 1, Fig. 2). This peak value of k (29 at 50% TC) is significantly different from the k values at 0% TC (10) and 100% TC (10) at the 99% confidence limit (Watson, 1956). The McFadden and Lowes (1981) test for discrimination of mean directions was used to provide a site level incremental fold test. The B component site level statistics confirm the sample level statistics in that the mean directions from the two sites are significantly different at both 0% TC and 100% TC but cannot be discriminated at high confidence levels near 50% TC (declination = 170.4°, inclination = −19.1°, α_{95} = 5.0°; Table 1).

The sample C components of magnetization obtain their best grouping at near full tilt correction (357.6°, −53.3°, 8.5°; Fig. 2). Although the k value decreases from 80% TC (15) to 100% TC (13), these k values are not different at the 95% confidence limit. The site statistical level discrimination data show that at 0% TC the null hypothesis can be rejected at greater than 99% confidence. The rejection confidence level drops significantly near 80% TC and then rises to a surprisingly high 94% at 100% TC.

The significant peak in k at 50% TC suggests either that the B component was acquired during folding or that it was acquired prior to folding and subsequently modified by strain during deformation (e.g., van der Pluijm, 1987). Because the B component pole position plots on the Permian part of the North American apparent polar wander path (NAAPWP; Fig. 3), similar to other observed Appalachian redbed remagnetizations (e.g., Kent and Opdyke, 1985; Miller and Kent, 1986a, 1986b), the simplest interpretation at this time is that the B component in the Andreas redbeds is a secondary magnetization, acquired around the time of Alleghenian folding. The high unblocking temperature of the B component and the low metamorphic grade in the Andreas area suggests that the B component was acquired through chemical, rather than thermoviscous, activation (Kent and Miller, 1987).

The C magnetization passes the fold test at the 99% confidence level at the sample statistical level; at the site statistical level, the null hypothesis that the site mean directions from opposite fold limbs are the same at 100% TC cannot be rejected with 95% confidence. We therefore interpret these statistics to indicate that the C magnetization predates the Carboniferous-Permian folding. The observation that the Andreas C magnetization is not similar to any magnetization direction that would be predicted for the Andreas locality from the known Late Devonian through Carboniferous NAAPWP suggests a Late Silurian to Middle Devonian acquisition age. The improved grouping at 80% TC may suggest either that the C component was acquired during a very early stage of deformation (Early to Middle Devonian or Acadian?) or that the C component has suffered some minor effects of strain. The discrimination of these two interpretations will require better understanding of the possibilities of Acadian deformation in the central Appalachians and of the nature and effects of strain in the redbeds exposed in the Valley and Ridge province. For the following discussion, the C magnetization is presumed to have been acquired near the time of deposition at around the Silurian-Devonian boundary. A slightly younger magnetization age or small directional deviation due to strain will not strongly affect the tectonic implications of these data.

TABLE 1. SITE DIRECTIONS AND STATISTICS

Site	Gdec	Ginc	Bdec	Binc	k	N	α95
			B Component				
DAA	167.7	-2.5	171.5	-34.8	66	19	4.2
DAB	181.0	-45.9	173.0	7.5	14	10	13.6
Means:	171.2	-16.8	-	-	10	29	8.7
	-	-	172.1	-21.1	10	29	8.6
50% TC			170.4	-19.1	29	29	5.0
Pole position (50% TC) 122°E,58°N A95=4.8°							
			C Component				
DAA	40.3	-74.9	352.6	-48.0	19	13	9.8
DAB	350.0	-8.2	7.9	-61.2	10	11	15.2
Means:	1.9	-47.9	-	-	4	24	17.3
	-	-	358.3	-54.2	13	24	8.5
Pole position (100%TC) 105°E,13°N A95=9.4°							

Note: Gdec, Ginc, Bdec and Binc are declination and inclination in geographic (G) and bedding (B) coordinates; k, N, and α95 are precision parameter, the number of data points, and the circle of 95% confidence, respectively. Pole position calculated from sample pole positions. TC is percent tilt correction.

COMPARISON WITH NORTH AMERICAN CRATONIC RESULTS

The C magnetization pole (lat 105°E, long 13°N, α_{95} = 9.4°) does not overlap at the 95% confidence level with either the MDL pole or the E pole (Fig. 3) reported from the Peel Sound Formation in the Canadian Arctic (Dankers, 1982). The position of the MDL pole between the Andreas pole and the pole from the Upper Devonian Catskill Formation from the northern limb of the Pennsylvania salient (Miller and Kent, 1986a) suggests that, contrary to the original interpretation, the MDL magnetization is Middle to Late Devonian in age and thus represents a remagnetization. The E pole magnetization may represent an Early Devonian magnetization, but its significance is difficult to assess because it is based on data from only one site.

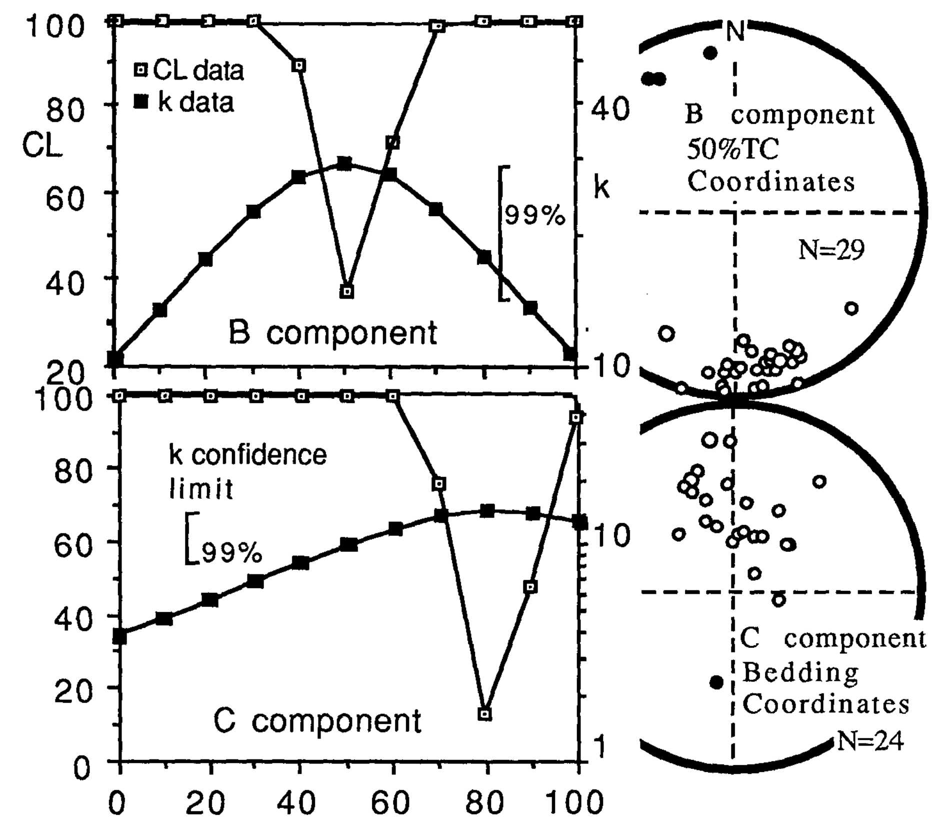


Figure 2. Left: Results of incremental fold test for B and C components at site and sample hierarchical levels. CL represents confidence levels at which null hypothesis that mean directions from two limbs of fold are same can be rejected (McFadden and Lowes, 1981); *k* is sample group precision parameter. Right: Stereographic projections of isolated sample component directions. Open and solid symbols are projections on upper and lower hemispheres, respectively.

Recent paleomagnetic results suggest that oroclinal rotation may have been involved in the formation of the Pennsylvania salient (Kent and Opdyke, 1985; Miller and Kent, 1986b). The Andreas redbeds crop out on the northern limb of the salient and therefore may have been rotated up to 20° clockwise relative to the craton since deposition. Such a rotation would cause an error in the paleoazimuthal, but not the paleolatitudinal, determination of the paleogeography of North America and should be considered in any tectonic interpretation involving the Andreas C component. It is interesting to note that the sense of rotation observed in the data from the salient would shift the Andreas pole even farther from the MDL and E poles (Fig. 3).

PALEOGEOGRAPHIC IMPLICATIONS

In the Ordovician, North America occupied low paleolatitudes while Avalon and Gondwana occupied high southern paleolatitudes (R. Van der Voo, 1988). Revised results from North America show little if any latitudinal displacement between North America and northern Avalon in the Late Devonian (Miller and Kent, 1986a). Therefore, collision of North America and Avalon must have occurred between these two time periods.

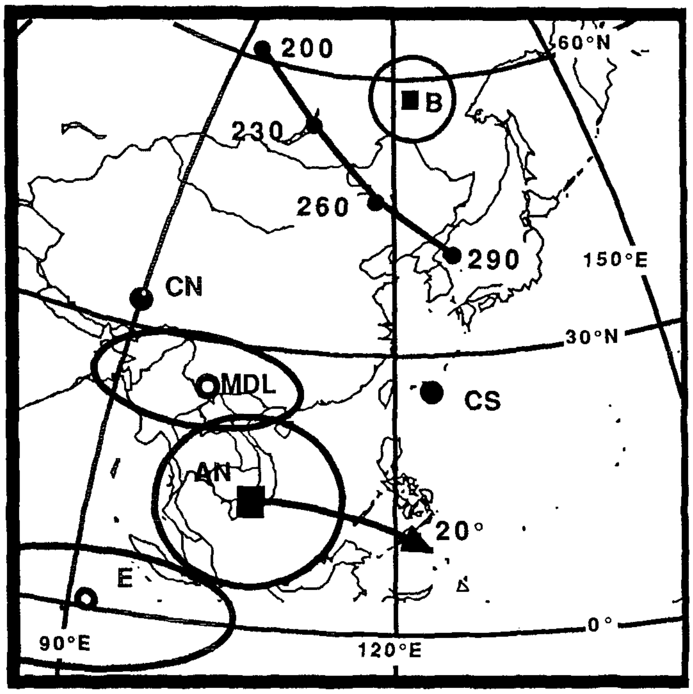
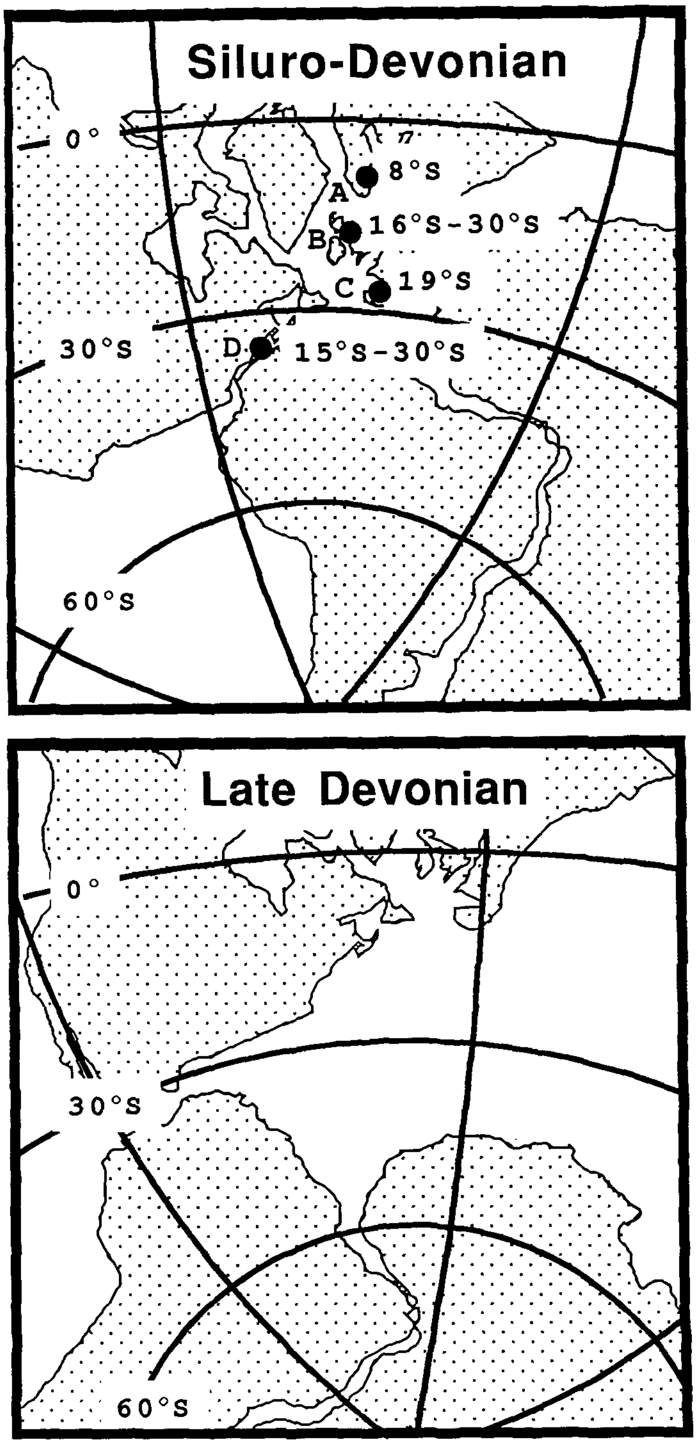


Figure 3. Numbered points are average ages (Ma) of North American apparent polar wander paths from Irving and Irving (1982). CN and CS are poles from Late Devonian Catskill redbeds from northern (N) and southern (S) limbs of Pennsylvanian salient (Miller and Kent, 1986a, 1986b). MDL and E are poles from Early Devonian Peel Sound Formation (Dankers, 1982). AN and B are C and B component poles from Andreas redbeds, respectively (this study). Arrow indicates motion of AN that would be required to correct for 20° of clockwise oroclinal rotation of Andreas site. Confidence envelopes are calculated at 95% level.

Figure 4. Silurian-Devonian paleogeography inferred by positioning Euramerica (Bullard et al., 1965 fit) by Andreas pole position (this study) and Gondwana (Smith and Hallam, 1970 fit) by Snowy River pole (Schmidt et al., 1987). Silurian-Devonian observed paleolatitudes from Baltica (A: Douglass, in prep.), Britain (B: Torsvik, 1985), Armorica (C: Perroud and Bonhommet, 1984), and Avalon (D: Lapointe, 1979; Kent and Opdyke, 1980) are consistent with such reconstruction. Late Devonian paleogeography: Euramerica is positioned in accordance with Catskill results (Miller and Kent, 1986a, 1986b; midpoint of two poles used), and Gondwana is positioned by Canning Basin pole (Hurley and Van der Voo, 1987).

Early Devonian poles from northern Avalon show much scatter; however, comparison of some mutually consistent results from Avalon (Fig. 4) with the Andreas prefolding component suggests that there was little paleomagnetically resolvable offset between Avalon and North America during the Devonian. Furthermore, the general agreement of paleolatitudes observed from Early Devonian age rocks from Baltica and Armorica with the paleolatitudinal grid suggested by the Andreas pole is consistent with the assertion that Euramerica was basically assembled by the Early Devonian (Van der Voo, 1982).

Positioning Euramerica according to the Andreas result places the east coast of North America in the paleolatitude band of 30°S to 40°S (Fig. 4), slightly farther south than the 30°S suggested by paleomagnetic results from the Middle to Late Silurian Wabash Limestone (McCabe et



al., 1985). If Gondwana is positioned by the Lower Devonian Snowy River Volcanics pole from Australia (Schmidt et al., 1987), then the northwestern margin of South America occupies a similar paleolatitudinal position.

The best-fitting paleolatitudinal positions for North America and South America suggested by the Andreas and Snowy River pole positions allow a supercontinent configuration that is virtually identical to those proposed by McKerrow and Ziegler (1972) and Keppie (1977), which are based largely on faunal distributions. These authors suggested that the Acadian orogeny resulted from the collision between North America and South America; Avalon was sandwiched between. Dominantly right-lateral motion between Euramerica and Gondwana during the Devonian was required to open an ocean between the two landmasses and to obtain the Late Devonian configuration (Fig. 4), from which the Carboniferous-Permian Pangea could form.

Interpretation of current paleomagnetic evidence is somewhat divided concerning the pre-Acadian orogeny location of Avalon. One major modification must be made to the McKerrow and Ziegler model; i.e., Avalon should no longer be viewed as a promontory of Baltica, but rather as part of Gondwana (Van der Voo and Johnson, 1985). The steep inclinations indicative of southerly paleolatitudes near 75°S observed in Ordovician rocks from the Delaware Piedmont part of Avalon are most consistent with placement of the Piedmont on the northern margin of Africa, thus requiring westward transport of the Piedmont for it to be involved in a North America–South America continent/continent collision (R. Van der Voo, 1988). However, Late Ordovician results from the Dunn Point Formation of Nova Scotia reveal a more northerly paleolatitude (42°S; Van der Voo and Johnson, 1985), which permits placement of the northern part of Avalon near northwestern South America, consistent with the McKerrow and Ziegler (1972) and Keppie (1977) models for the Acadian orogeny.

CONCLUSIONS

The paleolatitude associated with the Andreas prefolding C magnetization suggests that North America was located farther south than previously thought and supports the hypothesis of a tectonic linkage between North America and South America in the Early Devonian. We do not mean to imply that the Andreas result provides conclusive proof of the McKerrow and Ziegler (1972) and Keppie (1977) reconstructions. There could have been any amount of undetectable longitudinal offset between the Americas at this time and the paleolatitudinal uncertainty inherent in the data allow more Pangealike reconstructions such as proposed by Boucot and Gray (1983) and Hargraves et al. (1987). However, the Andreas result, and the best-fitting reconstructions it suggests, provide impetus for further research and discussion concerning the possibility, configuration, and implications of an Early Devonian supercontinent.

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