UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Paleomagnetism of a Late Cambrian or Early Ordovician Dike from Lodore Canyon, Northwestern Colorado

by

Mark R. Hudson[1]

Open-File Report 85-385

[1]U.S. Geological Survey, Box 25046, MS 964, DFC, Denver, CO 80225

1985

CONTENTS

	Page
Abstract	1
Introduction	1
Geologic Setting	2
Methods and Results	2
Magnetic Mineralogy	7
Discussion	8
Acknowledgments	10
References cited	10

ILLUSTRATIONS

		Page
Figure 1.	Location of the Cambrian or Ordovician dike sampled for paleomagnetic study	3
2.	Equal-area projections of the three components of remanent magnetization from the dike	4
3.	Demagnetization diagrams showing directional characteristics of remanent magnetizations from the dike	5
4.	Location of the paleomagnetic pole from the Lodore Canyon dike in relation to other widely distributed poles from early Paleozoic rocks from North America	9

TABLES

		Page
Table 1.	Paleomagnetic data from the Lodore Canyon dike	6

PALEOMAGNETISM OF A LATE CAMBRIAN OR EARLY ORDOVICIAN DIKE FROM LODORE CANYON, NORTHWESTERN COLORADO

By Mark R. Hudson

ABSTRACT

Paleomagnetic results from 9 samples of a Cambrian or Ordovician (483±29 m.y.) dike exposed in the Lodore Canyon of northwestern Colorado were obtained for comparison with other widely dispersed paleomagnetic results from rocks of similar age in North America, particularly those from intrusives in south-central and southwestern Colorado. Demagnetization reveals three magnetization components in the dike. Component A (D=23.6°, I=69.8°, α_{95}=5.4°) is a viscous component removed by 25 mT and 400°C. Component B (D=157.1°, I=31.3°, α_{95}=13.6) is removed over 25-100 mT and 400-580°C; it is carried by small magnetite blocks formed during early high temperature oxidation of the dike, and it thus represents the primary magnetization. Component C (D=233.7°, I=49.0°, α_{95}=12.6°), removed over 620-680°C, is held in hematite formed from the oxidation of magnetite; the origin of its peculiar direction is problematic.

The pole position of component B (31°N, 95°E) is close to a pole from Late Cambrian or Early Ordovician dikes in southwestern Colorado, suggesting some possible genetic relation and adding support to the validity of the higher latitude Cambrian paleomagnetic poles.

INTRODUCTION

Paleomagnetic data from Cambrian and Ordovician rocks of North America have yielded a wide distribution of paleomagnetic pole (paleopole) positions ranging from near equatorial to high-latitude regions (as summarized by Watts and others, 1980). This spread of pole locations has been explained by some (French and others, 1977; Watts and others, 1980; Lynnes and others, 1983) to be the result of rapid apparent polar wander during Cambrian time. However, because the high-latitude Cambrian or Ordovician paleopoles are at positions similar to those of late Paleozoic and early Mesozoic age, the possibility that these early Paleozoic poles reflect a later remagnetization (Gillett, 1982; Gillett and Van Alstine, 1982) has raised questions about the validity of the proposed apparent polar wander path. When the opportunity arose to obtain paleomagnetic data from an isotopically dated dike of Late Cambrian or Early Ordovician age from the Uinta Mountains of northwestern Colorado, it was taken as a chance to add another data point to the compilation of lower Paleozoic poles and to compare the pole position with previously obtained data from intrusives in south-central and southwestern Colorado. Though only a single site could be collected from the dike, the well-constrained age of magnetization warrants consideration of the data with regard to the controversial early Paleozoic apparent polar wander path.

GEOLOGIC SETTING

The dike is located in Dinosaur National Monument in the eastern Uinta Mountains of northwestern Colorado (fig. 1). The only exposure of the dike (Hansen and others, 1982) is in the west wall of the deep Lodore Canyon of the Green River, and hence the dike will be informally called the Lodore Canyon dike. The age of the dike is 483±29 m.y. (whole rock Rb-Sr date by Chaudhuri in Hansen and others, 1982). The intrusion of the dike into the sandstone of the Middle Proterozoic Uinta Mountain Group sandstone paralleled a west-northwest trending fault that borders the southern margin of the dike. Later recurrent movement on the fault has partly sheared the dike. The sandstone intruded by the dike, and the overlying Paleozoic and Mesozoic strata exposed to the south, all lie in the southwest flank of the large Uinta anticline of Laramide age (Hansen, 1957). Regionally, the rocks dip gently to the south-southwest. Variable attitudes in the immediate vicinity of the fault that borders the dike are attributed to fault movement that predates the dike intrusion (W. R. Hansen, personal communication, 1983); the paleomagnetic data is not corrected for this structure. Importantly, whereas the late Paleozoic uplifts of the ancestral Rocky Mountains have affected areas containing the Cambrian or Ordovician intrusives in south-central and southwestern Colorado, the area containing the Lodore Canyon dike was subsiding during this time (W. R. Hansen, personal communication, 1983). It seems unlikely, therefore, that the dike acquired secondary magnetizations related to late Paleozoic uplift.

METHODS AND RESULTS

One to three specimens were drilled from each of nine oriented block samples collected by W. R. Hansen and P. E. Carrara for the paleomagnetic measurements. Stepwise demagnetizations were run through progressively higher temperatures and alternating fields (typically with 10-15 steps in an run). All data were plotted on orthogonal demagnetization diagrams (Zijderveld, 1967), and from these component directions were found by vector subtraction.

Demagnetization reveals the presence of multiple magnetization components in most of the samples. These components are divided into three groups (labeled A, B, and C; fig. 2) on the basis of similarities in demagnetization stabilities and directions (table 1).

Component A, present in almost all specimens, is the least stable of the three components, being removed over temperatures up to 400°C and over alternating fields up to 20 mT (fig. 3). The directions of the component A are well grouped with north-northeast declinations and steep, positive inclinations.

Group B components have been identified in specimens from five of the nine samples. The components are removed over a 400-580°C range of temperatures and over a 25-100mT range of alternating fields (fig. 3). The declination of B components is south-southeast with shallow to moderate, positive inclinations. Specimens lacking a recognizable B component show some systematic inclination trends, but the corresponding declinations are too variable to confidently define the directions removed in the intermediate ranges of demagnetization temperatures and alternating fields.

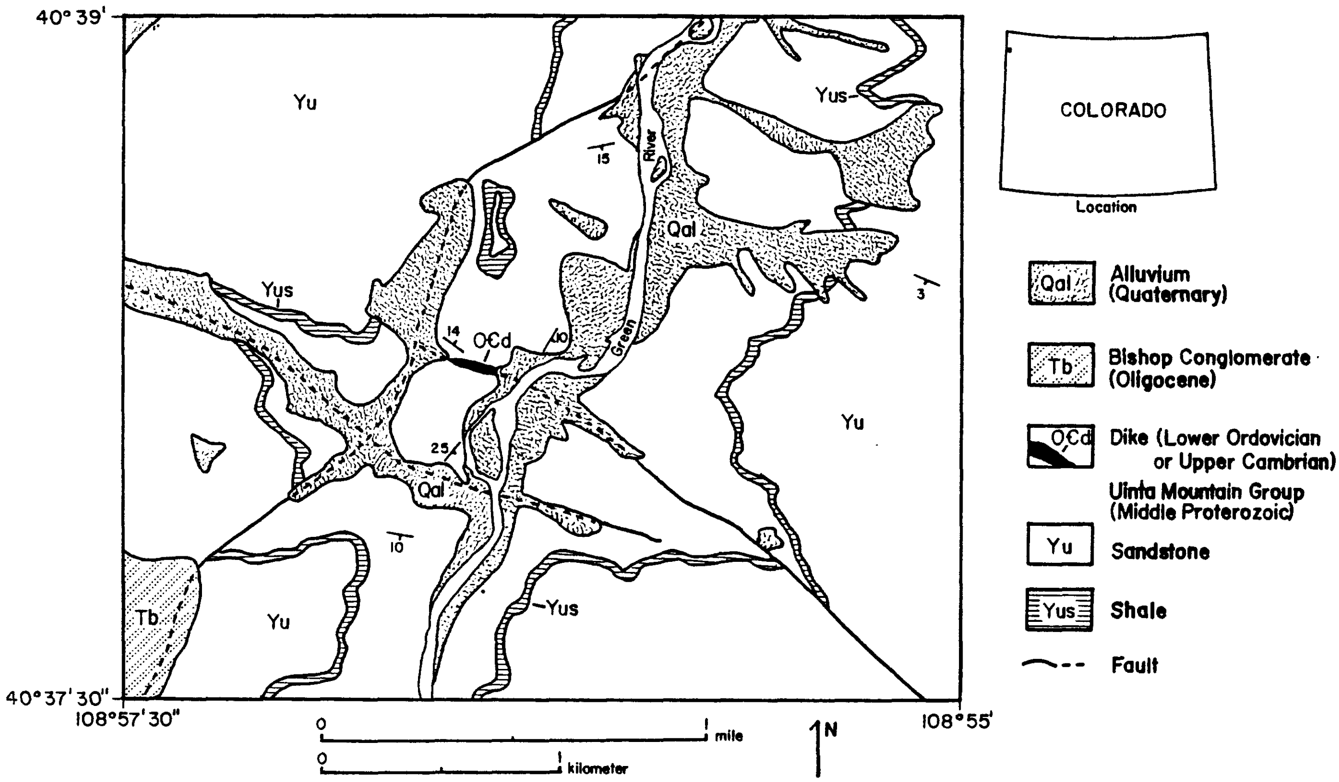

FIGURE 1.--Location of the Cambrian or Ordovician dike sampled for paleomagnetic study (from Hansen and others, 1982). Dike is in the west wall of the Lodore Canyon of the Green River.

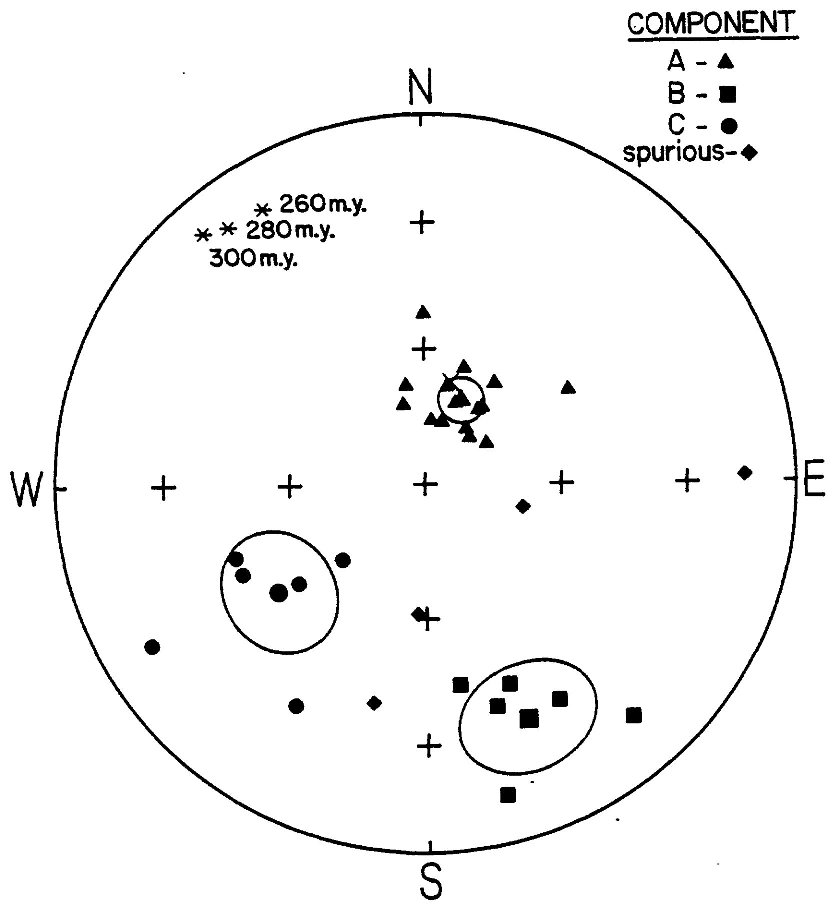

FIGURE 2.--Equal-area projections of directions of components A, B, and C. Also included are a few spurious components not included in the statistical calculations. The X shows the position of the present-day geomagnetic field at the site. Large symbols represent mean directions of the respective component groups. Projections are from the lower hemisphere. Expected late Paleozoic directions are calculated from Irving and Irving (1982).

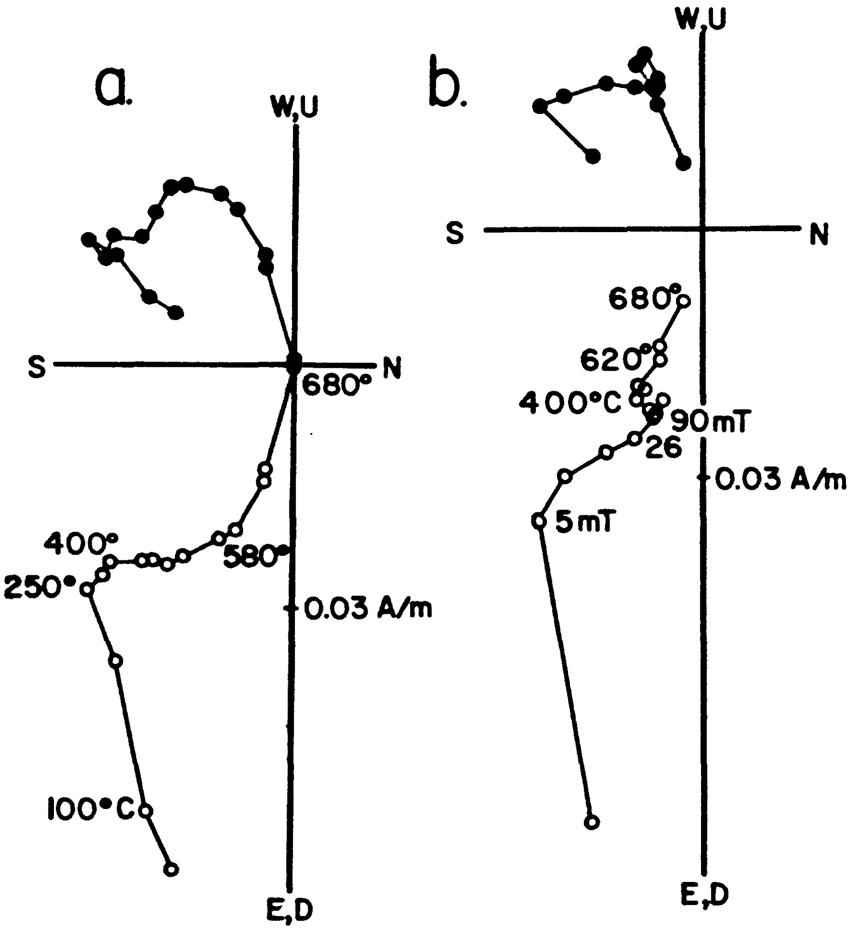

FIGURE 3.--Demagnetization diagrams showing directional characteristics of remanent magnetizations in the Lodore Canyon specimens. Closed (open) symbols are projections of the magnetic vectors on the horizontal (vertical) plane. Diagram a) shows removal of components A, B, and C over their respective intervals (A, 0-400°C; B, 400-580°C; and C, 580-680°). In b) alternating-field demagnetization to 90 mT was followed by thermal demagnetization (400-680°) to document the presence of component C.

TABLE 1.--Paleomagnetic data from the Lodore Canyon dike.

Component	N	D,I	α_{95}	k
A	15 (7AF+8T)	24°, 70°	5°	51
B	6 (3AF+3T)	157°, 31°	14°	24
C	6 (all T)	234°, 49°	13°	29

N, number of specimens-total and amount processed by alternating field (AF) and thermal (T) techniques; D and I, in situ declination and inclination; α_{95}, radius of circle of 95% confidence; k, precision parameter.

Magnetizations of group C are present in most of the specimens. They are removed over temperature intervals of 620-680°C (fig. 3c). Peak fields to 100 mT typically are not sufficient to remove C components, but further thermal demagnetization after highest alternating fields show that the components are present (fig. 3b). Component directions of group C have southwest declinations and moderate, positive inclinations.

In addition to components A-C, a few specimens hold magnetizations that either represented an average of B and C components (recognized from the overlap of stabilities and directions between B and C) or had directions far removed from the directions of any other components (fig. 2). These were not included in the statistical calculations.

MAGNETIC MINERALOGY

The blocking temperature and coercivity spectra of the magnetizations within the dike imply that component B is held by magnetite and component C held by hematite. Further investigations of the magnetic minerals and their relationship to remanence have been made by inspection of thermomagnetic curves and polished thin sections.

Thermomagnetic curves from rock fragments and magnetic separates show an abrupt loss of magnetization over the 520-560°C interval, indicating the presence of magnetite and a continued slow decrease in magnetization at temperatures up to 620°C (maximum instrument temperature), indicating that hematite is also present. The cooling curves have slightly lower magnetizations than the heating curves due to some experimental oxidation of magnetite to hematite. Curie temperatures determined from the thermomagnetic curves are 550-560°C and reflect a low Ti content for the magnetite.

Petrographic inspection of polished thin sections show that the Fe-Ti oxides have undergone a complex evolution. The Fe-Ti oxide minerals are present in aggregates formed from two original types (equant and lath-shaped) of grains. The euhedral to subhedral equant grains contain varying proportions of magnetite, ilmenite, hematite, and TiO_2 (rutile or anatase). Based on their shape and alteration products, the equant grains were probably originally titanomagnetite phenocrysts that segregated into small magnetite blocks (<5 μm) enclosed by trellis-patterned lamellae of ilmenite during high-temperature oxidation during initial cooling of the dike. Later oxidation of the magnetite formed homogeneous specular hematite that now occupies most of the volume in the equant grains. The long lath-shaped grains contain cores of light-gray hematite mottled with TiO_2 inclusions. These cores are commonly rimmed by white homogeneous hematite, often with trellis lamellae of ilmenite preserved internally. The lath-shaped grains were probably originally phenocrysts of ferrian ilmenite that later altered to form the mottled cores of hematite with TiO_2 inclusions. The pattern of ilmenite lamellae in the hematite rimming the mottled cores is similar to the observed in the equant grains (although no magnetite is preserved) suggesting that these phases are the products of an original titanomagnetite that nucleated on the ilmenite phenocrysts during crystallization.

DISCUSSION

The observation that the small, magnetically-stable magnetite blocks formed during high-temperature oxidation in the initial cooling of the dike, and that component B is carried by magnetite, is strong evidence that B is a thermoremanent magnetization that records the Late Cambrian or Early Ordovician geomagnetic field position. No later thermal event capable of resetting the magnetization is known to have affected the area. The mean direction of component B (D=159°, I=28.5° after correcting for the regional tilt of N65°W/4°SW) yields a virtual geomagnetic pole at latitude 31°N and longitude 95°E ($\delta P=8^0$, $\delta m=15^0$--semi axes of ellipse of 95% confidence). Though secular variation of the geomagnetic field may not have been completely averaged during rapid cooling of the dike, the pole position still supports the validity of the high-latitude paleopoles from early Paleozoic rocks since secular variation is typically 15° or less. When compared to other early Paleozoic paleomagnetic poles (fig. 4) considered reliable (Watts and others, 1980), the pole from the Lodore Canyon dike lies closest to a pole from a suite of diabase dikes in southwestern Colorado (Patterson and others, 1978). The similar locations of the two paleopoles, coupled with their similar west-northwest trends and ages, suggests a genetic relationship between the Lodore Canyon dike and the diabase dikes of southwestern Colorado.

Of the other two components, the origin of component A is easiest to explain. Its direction parallels that of the present geomagnetic field (fig. 2) at the site. This, combined with its low demagnetization stability, implies that it is a viscous remanent magnetization.

Component C is held by hematite oxidized from magnetite and, therefore, is a chemical remanent magnetization (CRM). Its direction, however, differs from that of component B, indicating that the oxidation occurred significantly after the initial cooling of the dike. Beyond this, the constraints on the age of component C are speculative. The southwest declinations with moderate, positive inclinations yield a pole position (latitude 7°N, longitude 26°E) that is unlike any for stable North America through Phanerozoic time. No reasonable structural corrections can be invoked to bring the pole position in congruence with other Phanerozoic poles. Also, it seems unlikely that the CRM acquisition could have been rapid enough to record an anomalous field direction.

If CRM acquisition spanned field reversals, the direction of C could represent an intermediate vector sum of two antipodal components. To produce the well-grouped cluster of components in C, the proportions between hematite fractions with antipodal directions would have to remain constant throughout the suite of samples. Such a condition seems unlikely and is not typically found in other rocks affected by prolonged CRM acquisition (Larson and others, 1982; Larson and Walker, 1982).

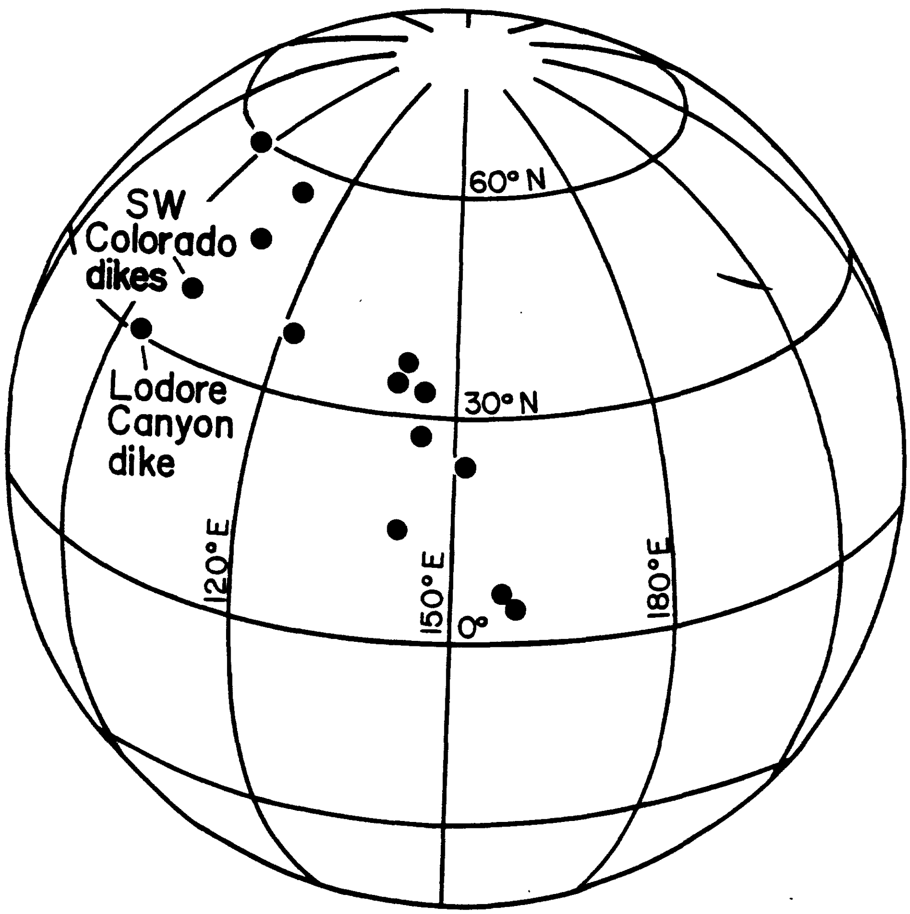

FIGURE 4.--Locations of the widely distributed paleomagnetic poles previously obtained from lower Paleozoic rocks from North America (from Watts and others, 1980) and the pole from the Lodore Canyon dike.

Perhaps the remanent direction acquired by hematite was influenced by both the external geomagnetic field and an internal field produced by the magnetite from which the hematite formed. Limited experimental work has shown that oxidation at reasonable geomagnetic field strengths produces a CRM parallel to the original remanence of pure magnetite (Johnson and Merrill, 1972; Bailey and Hale, 1982). For titanomagnetite, in contrast, the resulting remanence can be deflected to a position between the external and internal fields (Bailey and Hale, 1982). The only expected geomagnetic field directions that lie close to the great circle containing B and C components are late Paleozoic normal-polarity directions (fig. 2). Perhaps late Paleozoic movement on the bounding fault caused oxidation of the dike, but documented recurrent movement on nearby faults of similar trend is of Laramide or younger age (Hansen and others, 1982). Moreover, the oxidized magnetite was probably low in Ti content as is the remaining magnetite; therefore, based on experimental data, a large deflection of the CRM direction would not be expected. None of the proposed origins of component C is convincing considering the presently known data.

In conclusion, of the three magnetization components isolated, component B is the primary magnetization carried by magnetite formed during early high-temperature oxidation of the dike. The pole position calculated from the mean direction of component B further supports the validity of the high-latitude poles determined from some early Paleozoic rocks. In addition, of the widely dispersed paleopoles for this time, this result is closest to a Late Cambrian or Early Ordovician pole for other dikes in southwestern Colorado and thus suggests a close genetic relationship between the Lodore Canyon dike and those in southwestern Colorado.

ACKNOWLEDGMENTS

Thanks go to W. R. Hansen, R. L. Reynolds, L. Anderson, J. W. Geissman, and an anonymous reviewer for helpful discussions and reviews.

REFERENCES CITED

Bailey, M. E., and Hale, C. J., 1982, Laboratory study of CRM: some new directions: EOS Transactions of the American Geophysical Union, v. 63, p. 305.

French, R. B., Alexander, D. H., and Van der Voo, R., 1977, Paleomagnetism of upper Precambrian to lower Paleozoic intrusive rocks from Colorado: Geological Society of America Bulletin, v. 88, p. 1785-1792.

Gillett, S. L., 1982, Remagnetized cratonic Cambrian strata from southern Nevada: Journal of Geophysical Research, v. 87, p. 7097-7112.

Gillett, S. L., and Van Alstine, D. R., 1982, Remagnetization and tectonic rotation of upper Precambrian and lower Paleozoic strata from the Desert Range, southern Nevada: Journal Geophysical Research, v. 87, p. 10929-10953.

Hansen, W. R., 1957, Structural features of the Uinta arch, in Seal, O. G., ed., Guidebook to the geology of the Uinta Basin: Intermountain Association of Petroleum Geologists 8th Annual Field Conference Guidebook, p. 35-39.

Hansen, W. R., Carrara, P. E., and Rowley, P. R., 1982, Geologic map of the Canyon of the Lodore north quadrangle, Moffat County, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1568, scale 1:24,000.

Irving, E., and Irving, G. A., 1982, Apparent polar wander paths, Carboniferous through Cenozoic and the assembly of Gondwana: Geophysical Surveys, v. 5, p. 141-188.

Johnson, H. P., and Merrill, R. T., 1972, Magnetic and mineralogical changes associated with low-temperature oxidation of magnetite: Journal of Geophysical Research, v. 77, p. 334-341.

Larson, E. E., and Walker, T. R., 1982, A rock magnetic study of the lower massive sandstone, Moenkopi Formation (Triassic), Gray Mountain area, Arizona: Journal of Geophysical Research, v. 87, p. 4819-4836.

Larson, E. E., Walker, T. R., Patterson, P. E., Hoblitt, R. P., and Rosenbaum, J. G., 1982, Paleomagnetism of the Moenkopi Formation, Colorado Plateau: basis for long-term model of acquisition of chemical remanent magnetization in redbeds: Journal of Geophysical Research, v. 87, p. 1081-1106.

Lynnes, C. S., Van der Voo, R., and Geissman, J. W., Paleomagnetism of Cambro-Ordovician intrusives from Colorado: EOS, Transactions of the American Geophysical Union, v. 64, p. 215.

Patterson, P. E., Rosenbaum, J. G., and Larson, E. E., 1978, Refinement of a Cambro-Ordovician paleomagnetic pole from plutonic rocks in southwestern Colorado: EOS, Transactions of the American Geophysical Union, v. 59, p. 1060.

Watts, D. R., Van der Voo, R., and Reeve, S. C., 1980, Cambrian paleomagnetism of the Llano Uplift, Texas: Journal of Geophysical Research, v. 85, p. 5316-5330.

Zijderveld, J. D. A., 1967, A. C. demagnetization of rocks: analysis of results, in Collinson, D. W., Creer, K. M., and Runcorn, S. K., eds., Methods in Paleomagnetism: Amsterdam, Elsevier, p. 252-286.