Tectonic implications of paleomagnetic and geochronologic data from the Yukon-Koyukuk province, Alaska

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ABSTRACT

The paleomagnetic and geochronologic record of Alaska is complicated by overprints that make it difficult to relate the terranes of northern and southern Alaska to each other and to North America. To better understand these relationships and the overprinting, paleomagnetic and K-Ar dating samples were analyzed from the three major geologic units of the Yukon-Koyukuk province (YKP) of central Alaska. These units consist of a basal Jurassic–Early Cretaceous volcanic (island-arc) assemblage, Albian-Cenomanian clastic sedimentary rocks, and bimodal Eocene volcanic rocks.

K-Ar age determinations of the early Tertiary volcanic rocks form two distinct groups. The older group (65–49 Ma) is mostly felsic and probably represents the maximum inboard penetration of low-angle subduction-related volcanism. These older rocks were deformed during the regional deformation of the YKP. The younger group (44–43 Ma) is post-deformational and composed dominantly of basalt. These results bracket a time (49–44 Ma) when deformation ceased in the province. This time interval is coincident with a major transition from convergence to strike-slip and extensional tectonic style throughout Alaska.

The geologic units of the YKP display two characteristic paleomagnetic signatures. Primary directions (based on positive reversal, conglomerate, and/or bedding tilt stability tests) were obtained from the Albian-Cenomanian sedimentary rocks and Eocene volcanic rocks. The mid-Cretaceous sedimentary rocks show about 15° of poleward motion between 90–56 Ma (a time of high rates of convergence between Alaska and the Pacific and Eurasian plates). Age-equivalent rocks from neighboring regions (St. Matthew Island and the Alaskan North Slope) also indicate similar amounts of poleward (northward) motion, which suggests that the whole of western and northern Alaska may have moved northward about 10° relative to North America as a more or less coherent block. Paleomagnetic results from the Eocene volcanic rocks indicate that the YKP was in place by 56 Ma and formed part of the accretionary nucleus that served as a backstop for the accreted terranes of southern Alaska. Secondary (remagnetized) directions are recorded in the basal island-arc assemblage and in Albian-Cenomanian sediments near younger igneous occurrences. The clustering of secondary directions in the geographic reference frame indicates that they were acquired after deformation ceased (≤49–44 Ma), which is consistent with the coincidence of the mean of these directions and the 54–44 Ma North American reference direction.

INTRODUCTION

Alaska is made up of many tectonostratigraphic terranes that differ widely in age, lithology, and tectonic history and are separated from their neighbors by faults (Jones and others, 1972, 1983; Coney and others; 1980). These disparate geologic relationships make the terranes suspect as to their origin and travel history. Paleomagnetism has proven useful in investigations of these suspect terranes by establishing latitudinal and rotational constraints relative to other terranes and to the North American craton.

Paleomagnetic studies of the terranes of southern Alaska (south of the Denali fault; Fig. 1) show that they are far traveled (Packer and Stone, 1972; Stone and Packer, 1979; Hillhouse and Gromme, 1977) and rotated counterclockwise (Globerman and Coe, 1983; Coe and others, 1985). The northern extent of these exotic terranes is poorly defined due to a pervasive overprint that commonly masks the paleomagnetic signature and in many cases has reset the K-Ar ages (Hillhouse and Gromme, 1983; Globerman and others, 1983; Harris and others, 1984; Turner, 1984; Harris, 1985; Harris and others, 1985b; Stone, 1985). This overprint has made it difficult to unravel the paleogeographic history of northern Alaska and to determine whether it acted as a backstop for the far-traveled southern Alaska terranes.

To more clearly define how the terranes of northern and southern Alaska are related, and to investigate the nature and timing of the magnetic overprint, data from more than 600 paleomagnetic and 31 K-Ar dating samples from 43 locations in the Yukon-Koyukuk province (YKP) of western-central Alaska were analyzed. Recognizing that the distribution of samples is not ideal, it is still reasonable to extrapolate the paleomagnetically determined paleolatitudes for the localities sampled to the rest of the

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Additional material for this article (Tables A and B) may be secured free of charge by requesting Supplementary Data 87-26 from the GSA Documents Secretary.

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YKP, because to do otherwise would imply that the province is made up of separate terranes with separate travel histories. Although the basement of the province may be complex, the units sampled appear to be widespread and contiguous throughout the area (Patton, 1973; Patton and Box, 1985). The conclusions made on the basis of the paleomagnetic and geochronologic data from the Tertiary volcanic rocks sampled have been extrapolated to be representative of the other Tertiary volcanics on the basis of the mapped geology (Patton, 1973) and on the similarity of rock type (Moll and Arth, 1985).

The analysis of the samples exhibiting stable magnetism establishes latitudinal and rotational constraints for the YKP from Early Cretaceous to middle Eocene time, whereas remagnetized data and the K-Ar ages

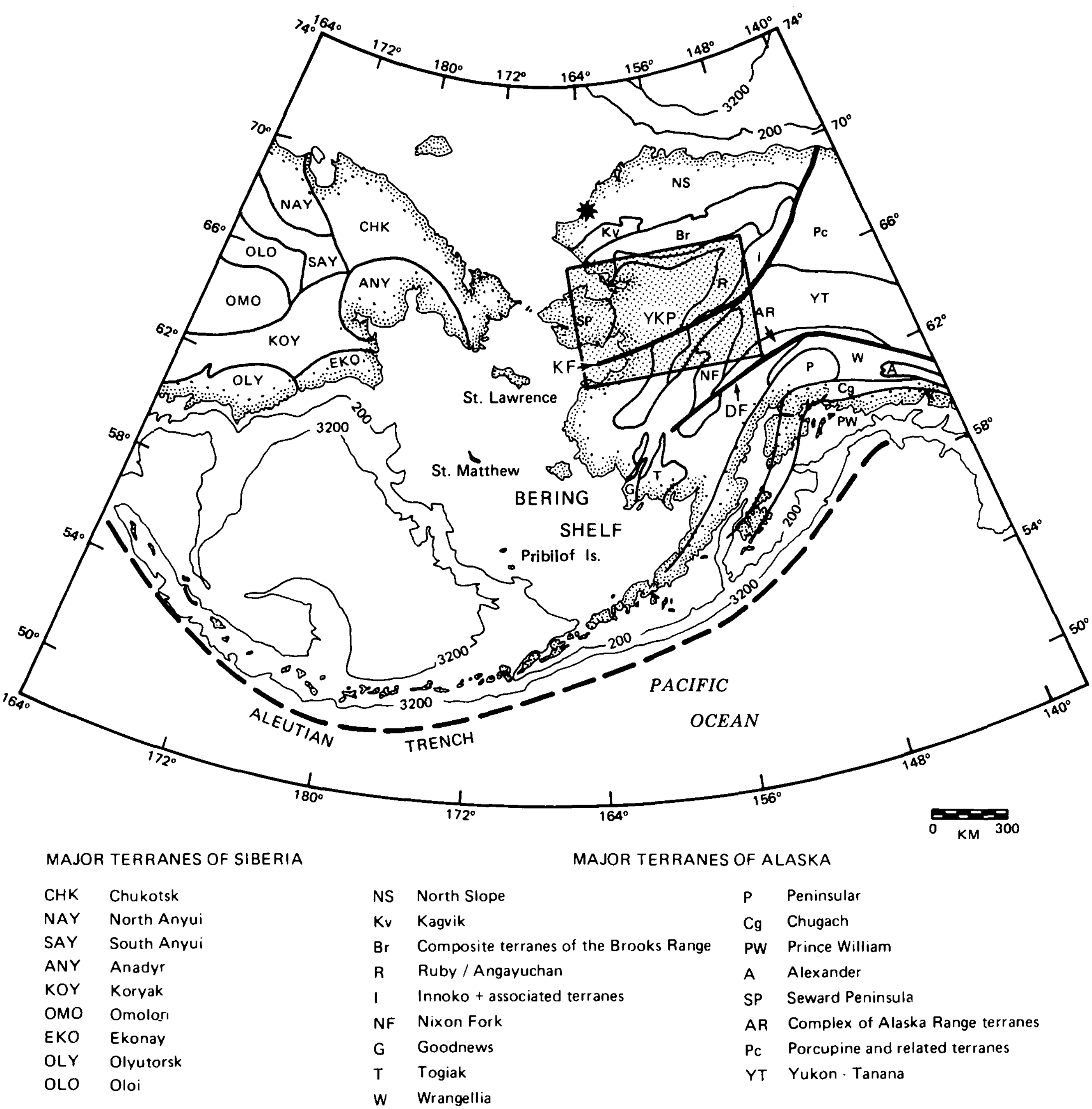

Figure 1. Location of the Yukon-Koyukuk province (YKP) in relation to the major tectonostratigraphic terranes of Alaska and Siberia. Boxed area corresponds to Figures 2 and 4. KF, Kaltag Fault; DF, Denali Fault. Asterisk corresponds to sampling sites of Witte and others (1987).

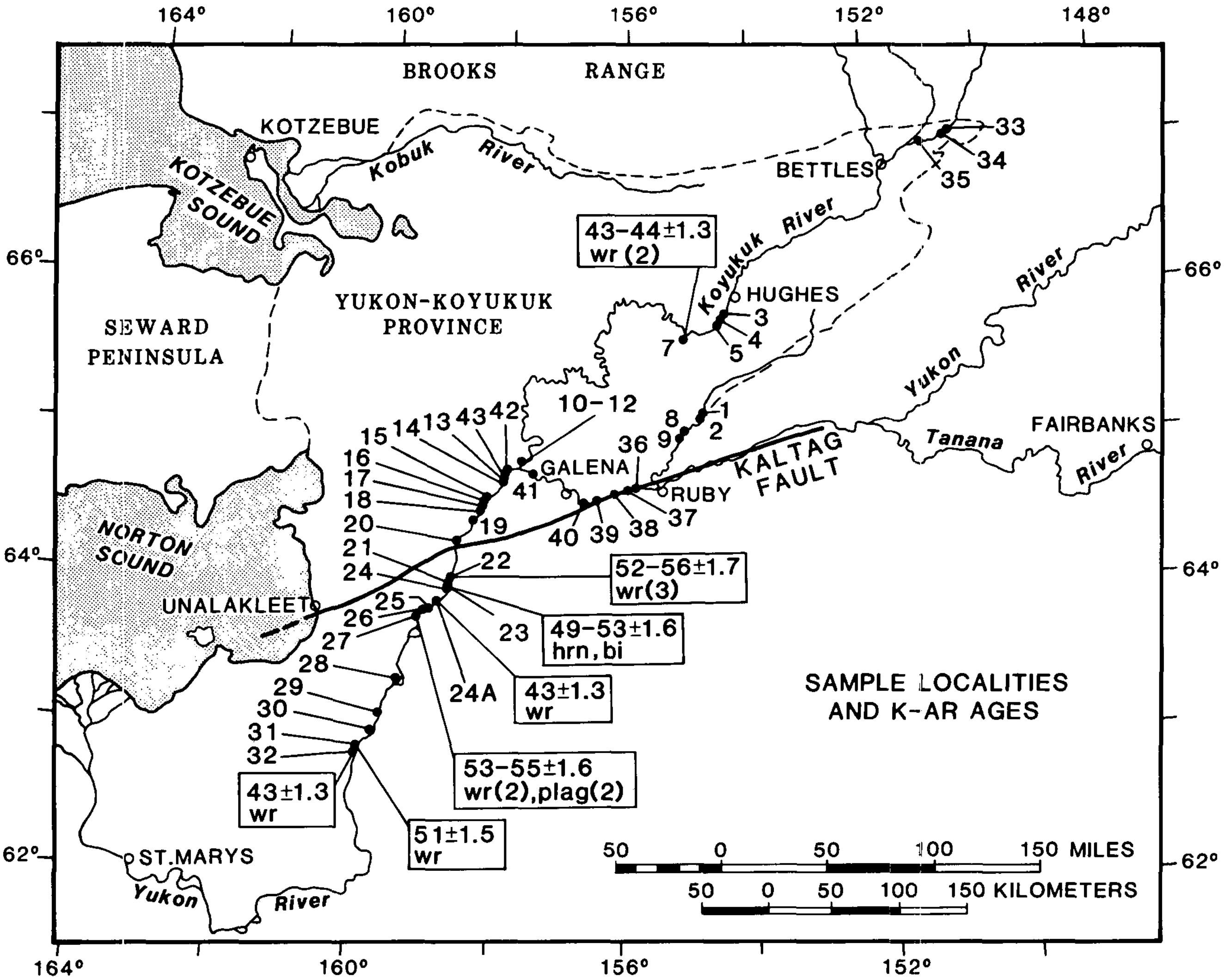

Figure 2. Sample localities (numbered) and K-Ar ages. Number of ages in parentheses; wr, whole rock; hrn, hornblende; bi, biotite. Complete analytical data may be obtained from Table A.

provide a better understanding of the nature and timing of thermal overprinting in the region (see Fig. 2, Tables 1, 2, and Tables A and B).[1] The K-Ar ages also demonstrate that the YKP has experienced multiple magmatic pulses which can be used to bracket the timing of regional deformation.

GEOLOGICAL OVERVIEW

The YKP is a broad asymmetric depression extending south from the Brooks Range to the Yukon-Kuskokwim Delta and west from the Ray Mountains to Norton Sound (Fig. 1). The province covers about 20% of the total land area of Alaska. The geology is characterized by volcanic and sedimentary rocks of mostly Tertiary and Cretaceous ages, which are enclosed on three sides by metamorphic complexes. These metamorphic borderlands consist of the Ruby and correlative Seward terrane and the Angayucham terrane (Jones and others, 1981).

[1]Tables A and B may be secured free of charge by requesting Supplementary Data 87-26 from the GSA Documents Secretary.

The Ruby Terrane consists of Paleozoic to Precambrian, low-grade (greenschist facies), pelitic, calcareous, and granitic metamorphic rocks, which in some places contain high-pressure (blueschist facies) minerals (Patton and Tailleur, 1977). The post-metamorphism uplift and cooling age of these rocks is interpreted from groupings of K-Ar ages at 100–80 Ma in the southern Brooks Range and 140–130 Ma in the eastern borderlands of the YKP (Turner and others, 1979; Turner, 1984).

The Angayucham Terrane is a narrow, more or less continuous band of mafic igneous rocks and deep marine sediments. It consists of imbricated, dismembered ophiolitic suites where slate, radiolarian chert, pillow lava, and diabase are structurally overlain by gabbro, serpentinized peridotite, and dunite (Patton, 1973). The fossil-bearing cherts indicate that the disrupted stack spans a time interval from Devonian to early Mesozoic (Patton and Tailleur, 1977; Patton and others, 1984; Dillon and Smiley, 1984). Field observations indicate that the Angayucham Terrane structurally overlies the Ruby Terrane and dips beneath and may form the basement of the YKP (Patton, 1973; Arth and others, 1984; Dillon and Smiley, 1984).

The geology of the YKP documents a history of subduction-related (island-arc) volcanism and rapid basinal filling by detritus shed from inter-

TABLE 1A. EARLY CRETACEOUS VOLCANIC ARC ASSEMBLAGE: CHARACTERISTIC MAGNETIZATIONS

	Lat. Long.	Age	N	Demag. type	Coord.	Decl.	Incl.	κ	α95	ST
Melozitna region (locations 3, 4, 5)										
Grand mean	65.9 154.5	EK	39	T + A	G S	281 57	72 69	51 27	3 4	–F
Mean of locality means			3	T + A	G S	282 61	72 66	234 48	8 18	
Nulato region (locations 10, 11, 12)										
Grand mean	64.9 157.6	EK	39	T + A	G S	33 118	74 54	32 23	4 5	
Mean of locality means			3	T + A	G S	35 118	74 54	78 36	14 21	

TABLE 1B. MID-LATE CRETACEOUS SEDIMENTARY ROCKS: CHARACTERISTIC MAGNETIZATIONS

	Lat. Long.	Age	N	Demag. type	Coord.	Decl.	Incl.	κ	α95	ST
Melozitna region (locations 1, 2, 8, 9)										
Grand mean	65.2 154.9	EK	55	T + A	G S	352 332	80 83	20 10	4 6	–F
Mean of locality means			4	T + A	G S	352 346	80 80	430 17	4 23	–F
Nulato region (locations 3–21, 41–43)										
Grand mean	64.7 158.0	Al-Cen	116	T + A	G S	126 346	76 78	6 9	6 5	+F
Mean of locality of means			12	T + A	G S	114 355	70 76	12 57	14 6	+F, +R
Ruby region (locations 36–40)										
Grand mean	64.7 156.0	Al-Cen	72	A	G S	20 295	85 57	12 7	5 7	–F
Mean of locality means			4	A	G S	2 299	83 55	31 33	17 16	
Unalakleet region (locations 25, 28, 29, 30)										
Grand mean	63.4 156.6	Al-Cen	46	T + A	G S	69 17	67 61	4 3	12 14	–Cs
Mean of locality means			3	T + A	G S	44 25	67 37	5 3	62 85	–Cs

TABLE 1C. EOCENE VOLCANIC ROCKS: CHARACTERISTIC MAGNETIZATIONS (LOCALITIES 17, 22, 23, 24, 26, 27, 31, 32)

	Lat. Long.	Age	Beds/ Thick.	N	Demag. Type	Coord.	Decl.	Incl.	κ	α95	ST
Grand mean of localities 7, 27, 31, 32	64.0 158.0	EO		40	T + A	G S	309 216	–66 –84	5 9	11 8	
Mean of locality means				3	T + A	G S	299 254	–61 –84	4 33	70 22	+F, +R

Abbreviations for Tables 1A, 1B, and 1C: *Lat., Long.* = approx. location of sites. *Age*: EK = Early Cretaceous, Al-Cen = Albian-Cenomanian, LK = Late Cretaceous. *N* = number of samples or locations yielding a characteristic magnetic vector direction; *Demag. Type*: T = thermal, A = alternating field; *Coord.,* G = geographic *(in situ),* S = stratigraphic (corrected for structural tilt); *Decl.* = declination of magnetic vector; *Incl.* = inclination of magnetic vector; κ = precision parameter (high value is low dispersion); *α95* = radius of 95% circle of confidence; *ST* = stability test(s), F = fold test, R = reversal test.

TABLE 2. MEAN PALEOMAGNETIC DIRECTIONS AND VGP's

	Expected* VGP					VGP			Poleward		Vector directions			
	Long.	Lat.	α95	Mean	N	Long.	Lat.	α95	motion	Coord.	Decl.	Incl.	κ	α95
Eocene (44–54 Ma)	170	83	3	GM	48	6	–75	10	–8 ± 13	G S	327 167	–71 –84	7 15	8 6
				MLM	4	336	–79	38	0 ± 41	G S	301 190	–67 –83	6 21	42 21
Cretaceous (75–105 Ma)	186	67	4	GM	141	112	77	6	21 ± 10	G S	138 331	74 75	7 10	5 4
				MLM	12	150	83	9	14 ± 13	G S	119 349	70 77	12 53	13 6
Remagnetized (44–54 Ma)	170	83	3	GM	205	203	80	6	–4 ± 9	G S	348 352	82 84	16 5	3 5
				MLM	15	188	82	12	–2 ± 15	G S	346 013	81 83	39 7	6 16

*North American Craton reference poles for Eocene from Diehl and others (1983) and for Cretaceous from Irving and Irving (1982).

Grand mean (GM) calculations were made for all of the samples from localities that passed paleomagnetic stability tests [Cretaceous localities 13–20, 35 (thermal), 41, 42, 43; Eocene localities 7, 27, 31, 32] and for those that were remagnetized (localities 1–5, 8–12, and 36–40). Mean of locality means (MLM) were also combined from Tables 1A–1C. Remagnetized data are from localities and regions that significantly failed the bedding tilt test; see text for explanation of the timing of remagnetization.

AGES	STRATIGRAPHIC UNITS
QUATERNARY	Basalt, glacial drift, waterlaid and windblown silt deposits
TERTIARY 43-44Ma	Basalt ± Felsic Volcanic Rocks
TERTIARY 50-65Ma	Felsic Volcanic Rocks ± Basalt
MIDDLE - LATE CRETACEOUS	Quartz conglomerate, sandstone, shale, and coal (nonmarine marginal trough deposits)
	Graywacke, mudstone, shale, conglomerate, tuff, and coal (fluvial-deltaic deposits)
	Volcanic graywacke, conglomerate and mudstone (flysch deposits) intruded by 79-89ma calc-alkaline plutonic rocks
NEOCOMIAN	Andesitic volcanic rocks and volcanogenic sediments intruded by 100-113ma alkalic plutonic rocks
JURASSIC TO PERMIAN	ANGAYUCHAM TERRANE Pillow basalt, gabbro, serpentinized peridotite and dunite, chert and slate
DEVONIAN AND PRECAMBRIAN	RUBY TERRANE Pelitic schist and carbonate rocks

Figure 3. Stratigraphic column of the Yukon-Koyukuk province. Revised from Patton (1973).

nal and adjacent sources. The rocks can be divided into three general stratigraphic sequences (Figs. 3 and 4).

1. Island-arc assemblage. The basal sequence of the YKP consists of a Late Jurassic–Early Cretaceous island-arc assemblage of submarine andesitic flows, pillow basalts, volcaniclastic breccia, and agglomerate, which is locally interbedded with volcanogenic graywacke and mudstone (Patton, 1973). A suite of alkalic plutons with 100–113 Ma K-Ar ages intrudes Neocomian andesites in the western YKP and eastern Seward Peninsula (Miller, 1985). Trace-element analyses of samples from the volcanic and associated plutonic rocks show typical island-arc trends (Moll and Patton, 1984). K-Ar ages of the basal island-arc sequence range from 173 to 100 Ma (Gemuts and others, 1983; Moll and Patton, 1984; Miller, 1985; Harris, 1985b; Harris and others, 1985, this study, Table A), and fossils are Neocomian in age (Patton and others, 1978). Paleomagnetic samples were collected from this unit at localities 3–5 and 10–12 (Fig. 2). Most of these samples yielded remagnetized paleomagnetic directions (Table 1A).

2. Cretaceous sediments and calc-alkaline plutons. Immediately overlying the island-arc assemblage, there is a thick, rapidly deposited sequence of Cretaceous flysch, typified by turbidite deposits of volcanogenic graywacke and mudstone derived primarily from the dissected volcanic island arc (Harris and others, unpub. data). The flysch accumulated to more than 6,000 m in thickness during the Albian (Patton, 1973). A suite of calc-alkaline plutons with K-Ar ages 79–89 Ma intrudes the Albian sediments and the Neocomian andesites in the eastern YKP (Miller, 1985). The plutons were not sampled for paleomagnetic work. Many of the sediments were remagnetized in a magnetic field with the same direction as that which magnetized the underlying arc assemblage, indicating that they were both remagnetized at the same time.

In the eastern part of the province, the turbidite deposits grade upward into nonmarine fluvial-deltaic deposits with middle Late Cretaceous plant and invertebrate fossils (Patton, 1973). These deposits represent a progradation of detritus dominantly from the structurally elevated metamorphic borderlands. Some of the detrital components (white mica and volcanic pebbles) were dated by the ^{40}K-^{40}Ar method as a means of testing for possible thermal resetting. The white micas yielded ages from 158–131 Ma, which are similar to white mica ages from the Ruby terrane of the metamorphic borderlands. Whole-rock ages of the volcanic pebbles ranged from 156–90 Ma. This work will be reported more fully in a subsequent paper (Harris and others, unpub. data). Most of these fluvial-deltaic rocks (localities 13–20, 35, 41–43) yielded primary paleomagnetic data that passed reversal, conglomerate, and bedding tilt tests (Table 2).

Along the northern margin of the YKP, there is a sequence of Late Cretaceous molasse shed from the Brooks Range and adjacent borderlands. Samples from this unit also passed the conglomerate test for paleomagnetic stability (Table 1B).

3. An episode of largely felsic, bimodal volcanism marks the end of the final phase of terrigenous sediment deposition in the YKP, ranging in age from 65–43 Ma (Patton and others, 1968; Patton, 1973; Moll and Patton, 1984; Harris, 1985b; Harris and others, 1985; this study, Table A). The volcanic rocks consist of rhyolite, trachyte, latite, andesite, and minor dacite and basalt. Our K-Ar ages from these volcanic rocks fall into two groups (56–49 and 44–43 Ma). These age relationships are discussed in detail in the "Geochronology" section of this paper. Most of the volcanic rocks lacked clear ancient horizontal indicators, which limited the interpretation of their paleomagnetic signatures. Those localities with structural control, however, yielded very useful primary paleomagnetic data.

STRUCTURE

Deformation of the geologic units sampled in the YKP increases with stratigraphic depth. The Early Cretaceous flysch is more complexly deformed than are the overlying fluvial-deltaic rocks and early Eocene volcanics. The latter are warped into broad folds and offset by high-angle faults, suggesting a succession of tectonic events. The intensity of deformation also increases significantly from east to west across the YKP (Patton, 1971).

The structure at most of the sample localities is characterized by numerous fault blocks of steeply dipping, generally homoclinal strata. The faulting combined with poor exposure make deciphering broad structural trends very difficult, but generally the prevailing fold axis trend is northeast-southwest and is associated with southeastward thrusting. These structures suggest an episode of east-to-southeast–directed compressive stress, which extended from the western margin of the YKP well into its interior (Patton, 1973; Patton and Tailleur, 1977). This convergence was followed by high-angle faulting. Constraints for the timing of deformation in the YKP are provided by a geochronological analysis of the volcanic rocks.

GEOCHRONOLOGY

Fifteen rocks from the bimodal volcanic suite of the YKP were dated by the ^{40}K-^{40}Ar method as part of this study. Analytical data for the dated samples are given in Table A. Sample localities and ages are shown in Figure 2. Ages range from early to middle Eocene and appear to form two distinct age groups. Five ages of 44–43 Ma are from mostly undeformed basalts. A bimodal volcanic suite of this age has been reported by Miller

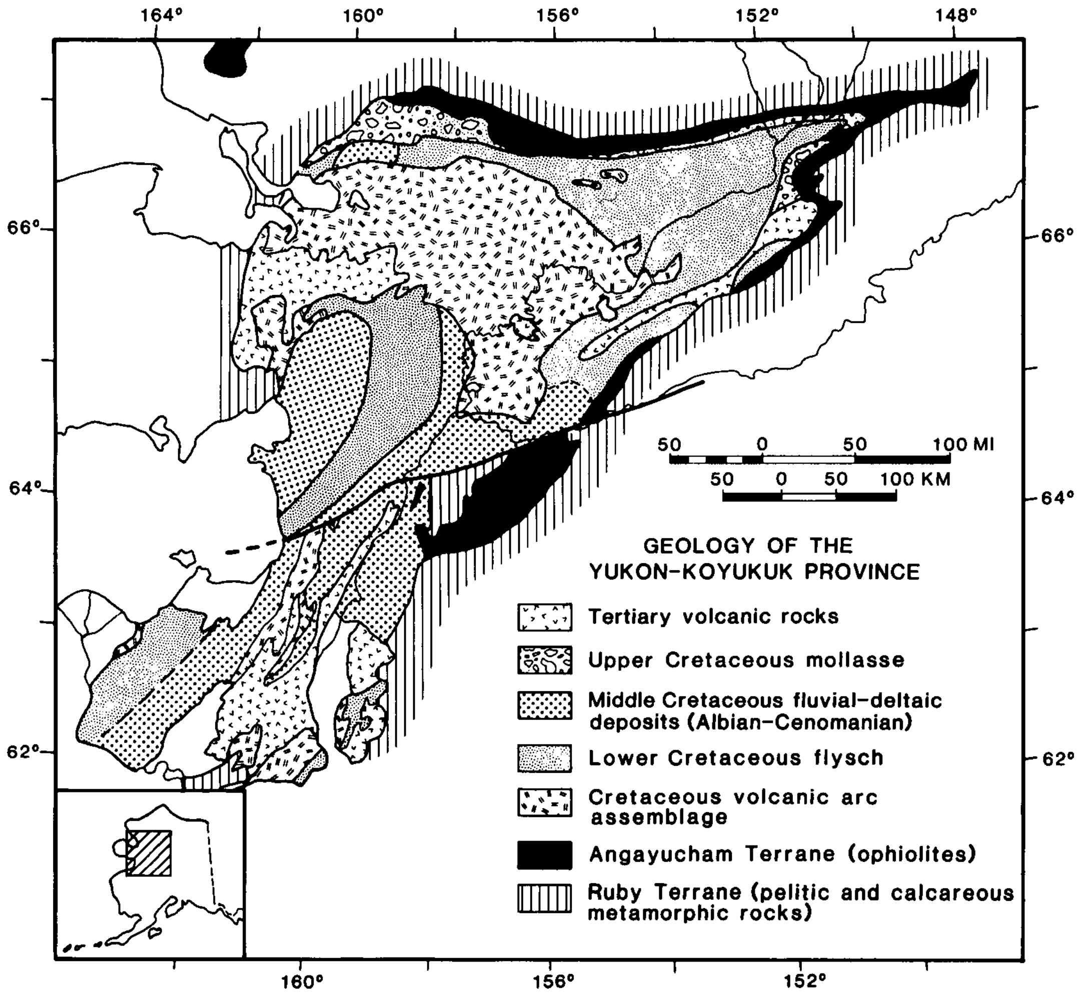

Figure 4. Major geologic units of the Yukon-Koyukuk province. Revised from Patton (1973).

and Lanphere (1981) and W. W. Patton, Jr. (1986, personal commun.). A second, older grouping of mostly felsic rocks with some basalts ranges from 56–49 Ma. Moll and Patton (1984) also reported a 65 Ma hornblende age from a nearby calc-alkaline sequence. All of the rock units of this older group have been tilted between 20 to 50 degrees. These results suggest that the deformation in the YKP must have continued after 65–49 Ma but that it ceased prior to the extrusion of the 44–43 Ma basalts. This result provides an important constraint for interpreting the Tertiary tectonic history of west-central Alaska and the timing of magnetic overprinting in the YKP (to be discussed below).

The timing of Late Cretaceous–Paleocene igneous activity in southwestern Alaska (Kuskokwim region) has been related to plate motions by Wallace and Engebretson (1984). They show that magmatism decreases in age with increasing distance northward from the Pacific continental margin. This pattern corresponds to increasing velocities of convergence (between Alaska and northward-subducting ocean plates) with decreasing age. A very similar pattern of volcanism existed in the western United States at the same time, which has been interpreted to result from low-angle subduction; the higher the convergence rate, the lower the dip angle is (Coney and Reynolds, 1977).

The 65–49 Ma, dominantly felsic volcanism in the YKP occurred during a period of maximum convergence (~20 cm/yr) between Alaska and oceanic plates, which was also a time of magmatic quiescence throughout southwestern Alaska (Wallace and Engebretson, 1984). This correlation implies that the dominantly felsic volcanic activity may represent the maximum inboard penetration of a progressively widening arc-trench gap.

The time interval between the 65–49 Ma and 44–43 Ma volcanic pulses in the YKP was a period of major plate reorganization. During this interval, there was nearly a fourfold decrease in convergence between Alaska and the Pacific and Eurasian plates, a southerly shift in magmatism to the Aleutian arc, and a transition away from dominantly convergent to strike-slip and extensional tectonic motion in Alaska. These events are consistent with the 49–44 Ma timing suggested above for the end of deformation in the YKP and the change from dominantly felsic to bimodal volcanic rock compositions.

PALEOMAGNETISM

The application of paleomagnetic data to tectonic problems hinges on satisfying certain reliability factors which involve (1) the magnetic stability, age constraints, and structural control of the rock types sampled and (2) the procedures of sampling, measurement, and evaluation. A discussion of how well these reliability factors are satisfied in the present study is given in Appendix 1.

The paleomagnetic data described below show that the geological units of the YKP contain two characteristic paleomagnetic vector directions. A primary (pre-folding) direction is recorded in some of the Cretaceous sediments and in the Eocene volcanics; a remagnetization (post-folding) direction is recorded in the island-arc assemblage and in Cretaceous sediments located near Eocene igneous occurrences. The following is a summary of the paleomagnetic results from each geologic unit in the YKP relative to its primary or remagnetized magnetic signature.

Primary Paleomagnetic Data

1. Cretaceous Sediments. *Nulato Region.* Most of the primary paleomagnetic data in the YKP were obtained from fluvial-deltaic sediments in the Nulato quadrangle (localities 13–20, 41–43; Fig. 2). The sediments pass the regional attitude or bedding tilt test, reversal test, and conglomerate test (Irving, 1964) (Table 1B) and provide paleolatitude constraints for the YKP during Albian-Cenomanian time.

The regional bedding tilt test was conducted by comparing the mean paleomagnetic directions from each locality in both the geographic (*in situ*) and stratigraphic (tilt corrected) reference frames. The dispersion of the mean directions is significantly reduced when corrected for the various bedding attitudes at each locality (Fig. 5). We concluded that the magnetization recorded in the samples was acquired before the area was deformed, which was probably near the time of deposition (see section entitled "Structure").

The magnetization age is further constrained by a record of reversed polarity determined for samples from locality 17 (Fig. 2). This locality yielded a mean reversed polarity magnetic direction that is antipodal to the mean tilt-corrected normal polarity magnetic directions from other localities of the region (Fig. 5).

The reversed polarity directions have a secondary normal polarity component superimposed on them. Stepwise demagnetization, using both AF and thermal techniques, was unsuccessful in yielding a stable end point for the reversed direction. Instead, an estimate of the end point was obtained by analysis of the great circle demagnetization paths of each sample (Halls, 1976 and 1978). In the step-wise demagnetization process, the magnetic vectors progressively change direction along segments of great circles (Halls, 1978). The intersection of the various great circle paths is the best estimate of the stable end point each specimen would have obtained without the presence of the secondary component. The estimated vector direction of locality 17 represents the locality mean. An estimate of the magnetic direction for each sample from locality 17 cannot be obtained by this method, and so the locality is not represented in grand mean calculations. The estimated mean antipole direction for locality 17 moves into the cluster of other middle to Late Cretaceous locality means when it is corrected for bedding tilt, thus contributing to the positive regional stability test.

The occurrence of this reversal during the Cretaceous long normal interval (118–84 Ma) can be accounted for in one of two ways. First, the age of the fluvial-deltaic sediments, which remains in dispute (Patton, 1977), could be younger than Albian-Cenomanian, and thus they could have acquired their magnetization after the Cretaceous long normal interval. K-Ar whole-rock ages as young as 89.6 ± 3 Ma (Turonian) from volcanic pebbles in these sediments (Harris and others, unpub. data) lend support to this hypothesis. Second, the reversal may be recording a minor interval within the long normal period, which was short lived and not well documented. Minor reversals have been detected in rocks of Albian (Jar-

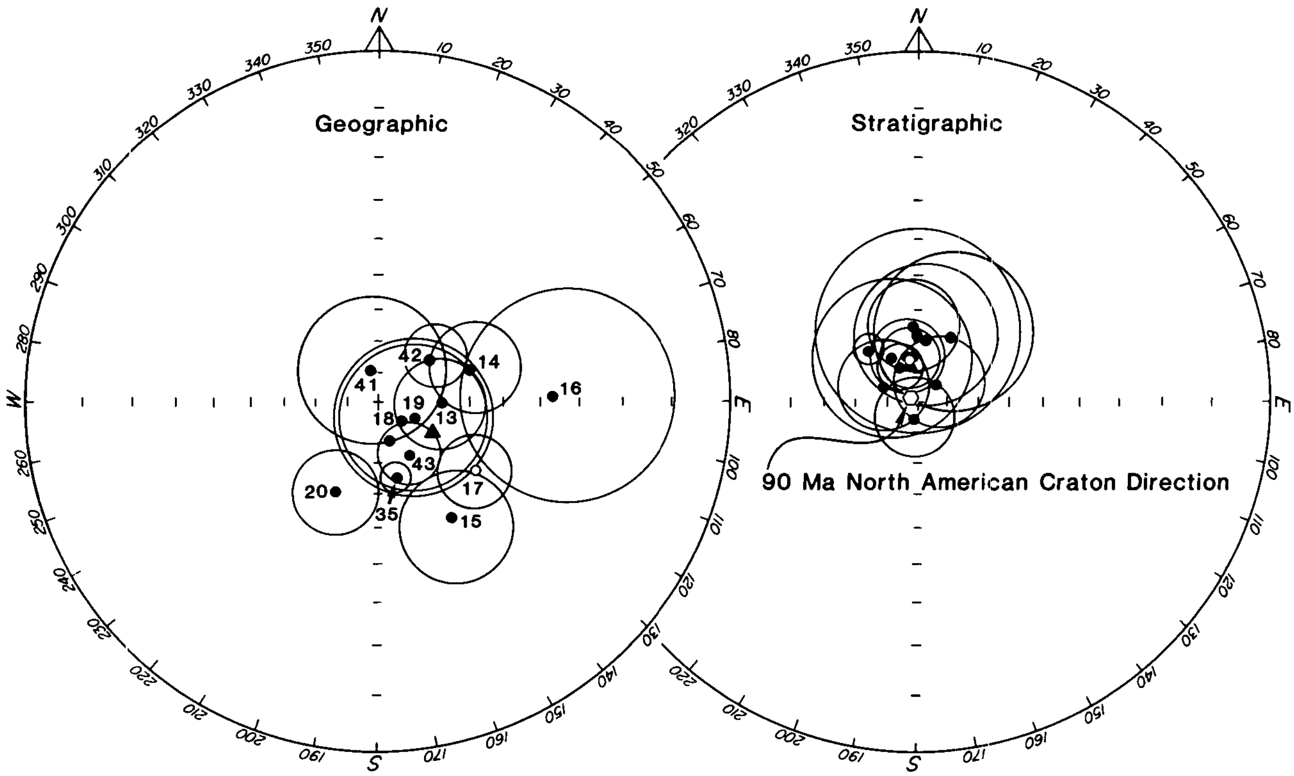

Figure 5. Lower-hemisphere stereographic plot of mean primary paleomagnetic directions from localities of Albian-Cenomanian sedimentary rocks. Circles are 95% confidence limits for each locality mean. A significant decrease in over-all dispersion results from correcting for the structural tilt. The antipole of the reverse polarity mean (open circle) of locality 17 is coincident with the mean of the locality means (triangle) in the stratigraphic reference frame, thus passing the reversal test. The mean of locality means has an α_{95} = 6.

rard, 1975) and Aptian (Lowrie and others, 1980) age. This explanation is preferred due to the fact that only one of the localities sampled showed a reversed magnetization.

The paleomagnetic stability of the fluvial-deltaic sediments in the Nulato region is consistent with their thermal history, which was investigated using vitrinite reflectance, paleomagnetic unblocking experiments, Curie temperature measurements, and K-Ar dating of the detrital sedimentary components (Harris, 1985b; Harris and others, 1985; Harris and others, unpub. data). The results of these investigations show that the Nulato region has not experienced temperatures above about 150–200 °C for extended periods of time (>10 m.y.).

The mean direction of the Nulato paleomagnetic data indicates a paleolatitude of 65°, which translates into 19° ± 10° of poleward motion relative to the North American craton. Significant and consistent azimuthal rotations are not apparent. These results are consistent with similar studies conducted on equivalent-age sedimentary rocks of the Alaskan arctic slope about 300 km to the north (Witte, 1982; Witte and others, in press) and 76 Ma volcanics from St. Matthew Island about 500 km to the southeast (Wittbrodt, 1985).

Wiseman Region. Late Cretaceous mollasse in the Wiseman quadrangle was targeted because of its suitability for use in a conglomerate test (localities 33 and 34, Fig. 2). In general, the cobbles display a random distribution of magnetic vectors, which implies that they have been magnetically stable since they were deposited. Most of the conglomerate beds are clast-supported with very coarse sandstone as the matrix. The paleomagnetic signal of the matrix is poor and suspect on the basis of its large grain size, and it was not used in the mid–Late Cretaceous mean calculations.

Reported vitrinite reflectance values from coals near the conglomerate beds (Rao and Wolff, 1982) correspond to temperatures of less than 150 °C (Bostick and others, 1978; Middleton, 1982). These data are consistent with the results of the conglomerate test; both support the maintenance of a relatively low temperature thermal regime since the Cretaceous.

Although the cobbles were generally randomly magnetized, some yielded directions which were similar to one another. Most of the similar directions were from metagraywacke cobbles that had lower magnetic unblocking temperatures than the other cobbles and that are probably magnetically unstable. This conclusion is based on the similarity in their magnetic behavior and the observation that their common direction is near the present field of the Earth.

Samples were also collected from a section of homoclinal Albian turbidite sediments located about 25 km from the conglomerates (locality 35 in Fig. 2). The sediments at this locality yielded tilt-corrected magnetic directions that are indistinguishable from the primary Albian-Cenomanian paleomagnetic directions of rocks in the Nulato region. As locality 35 is near the mollasse deposits (discussed above) and as it probably shared at least part of the same low-temperature thermal history as recorded by the conglomerates and the coals, the characteristic magnetization of the turbidites is interpreted as primary and is included in the Albian-Cenomanian grand and locality means (Table 2).

Unalakleet Region. The only paleomagnetic samples of Albian-Cenomanian strata south of the Kaltag fault were collected in the Unalakleet region (localities 25, 28–30; Fig. 2). These fluvial-deltaic sediments correlate with the Albian-Cenomanian fossil-bearing deposits of the Nulato region (W. W. Patton, Jr., 1986, personal commun.). All of the sample localities are near Tertiary volcanic sequences that unconformably overlie the sediments. The felsic volcanics (56–51 Ma) are broadly infolded with the more deformed middle to Late Cretaceous sediments, whereas the basaltic lavas (44–43 Ma) are undeformed. A long (90–44 Ma) deformational history, extending from the time of sediment deposition to the extrusion of the basaltic lavas, is documented by the age relationships of these rock units.

The paleomagnetic directions recorded by the sediments in this region are internally inconsistent within and between localities and display a wide variation between the thermal and AF demagnetization directions. For these reasons, the paleomagnetic data were considered unreliable and not used in the Albian-Cenomanian mean, even though they yielded a similar grand mean direction to rocks of equivalent age in other regions.

2. Eocene Volcanic Rocks. Paleomagnetic samples of Eocene volcanic rocks were collected from one locality along the Koyukuk River (loc. 7) and eight localities along the lower Yukon River (locs. 22–24, 26–27, 31–32) (Fig. 2). A total of 15 K-Ar dating samples were collected to constrain the ages of the volcanics (Fig. 2). Because of the reconnaissance nature of the study, paleomagnetic samples were collected from some volcanic sequences which lacked ancient horizontal indicators. Most of these localities consist of felsic volcanic rocks, many of which are plug domes (locs. 22–24 and 26).

The justification for collecting samples from the plug domes, with disregard for ancient horizontal control, was that they provide a variation of the regional bedding tilt test or a "mega-conglomerate" test. From nearby variable attitudes of bedded volcanics, it is deduced that structural disruption of the associated plug domes occurred; thus, similar *in situ* magnetic directions for the plug domes would indicate that they were probably remagnetized after folding. As illustrated in Figure 6, the *in situ* magnetic directions of each dome vary considerably (more than would be expected from secular variation alone) with respect to each other. This supports the hypothesis that structural deformation did not cease in the YKP until after the 56–49 Ma volcanics were extruded and also suggests that the magnetization has been stable since these areas were deformed.

The few bedded volcanic rocks with good paleohorizontal indicators provide reliable magnetic directions which pass consistency, reversal, and regional bedding tilt tests (Table 1C). Indicators of ancient horizontal in these sequences include flow bases (locs. 7 and 27), interbedded sediments and tuffaceous laminae (loc. 27), and lithologic changes (locs. 31 and 32). When the rocks are corrected for tilt, the magnetic vectors converge significantly (Fig. 6).

The section of bedded volcanic rocks best suited for paleomagnetic analysis is locality 27, where several lava and pyroclastic flows are well exposed. On the basis of the compositional range of the rocks and the thickness of the section, it can probably be safely assumed that enough time is represented to average out geomagnetic secular variation. The rocks yielded three reliable K-Ar ages of 55–53 Ma, and two other K-Ar dates of ⩾55 Ma and ⩾44 Ma from altered andesites which qualified as minimum ages. Correcting for the 30° northwesterly dip of these rocks moves the mean inclination of the magnetic vectors to a value of 80° ± 7°, which is equivalent to the expected inclination relative to the North American craton (80° ± 4°) (Fig. 6). The declination is rotated 66° ± 40° in a counterclockwise sense from the expected declination. It is important to note that these rocks occur south of the Kaltag fault (Fig. 2), but other primary paleomagnetic data from rocks of Nulato and Wiseman regions, which show no evidence of rotation, are from north of the fault. These results suggest that the 55–53 Ma volcanic rocks from locality 27 were in place with respect to the North American craton but that they may have rotated counterclockwise since that time. Reliable data from other Eocene volcanic rocks in the YKP, however, are needed to support the data from locality 27 before they can be confidently used in paleogeographic and tectonic models.

Localities 7, 31, and 32 were also used to determine the over-all mean of the Eocene volcanics (Table 2). These localities, however, had poor resolution of ancient horizontal and represented no more than two or three different flows. They met only the minimum requirements for field sampling and should not have equal weight with locality 27. When the data from the Eocene volcanics are combined, the grand mean direction corresponds to a paleolatitude that is slightly higher (8° ± 13°) than expected for the YKP relative to the North American craton (Fig. 6) and is rotated 16° ± 13° counterclockwise. This apparent "overshoot" has been observed in the paleomagnetic analyses of Eocene volcanics in southern Alaska (Hillhouse and Gromme, 1982 and 1983; Hillhouse and others, 1983). The counterclockwise declination discrepancy is also a common feature of pre–middle Eocene rocks throughout western Alaska (Globerman and Coe, 1983; Coe and others, 1985). Differences in declination, however, are difficult to interpret because the measured and predicted inclinations are very steep, allowing small changes in the mean position of the vectors to make large changes in the apparent rotations.

Remagnetized Paleomagnetic Directions

1. Early Cretaceous Island-Arc Assemblage. Paleomagnetic samples of Early Cretaceous age were collected along the Koyukuk River in the Melozitna quadrangle, about 30 km southwest of Hughes (locs. 3–5), and from Koyukuk Mountain at the confluence of the Yukon and Koyukuk Rivers (locs. 10–12, Fig. 2). The rocks consist of volcanogenic sediments interlayered with volcanic breccias, agglomerate, and flows of andesite and pillow basalts. Most of the volcanic rocks are altered to a dark green hornfels. Strata rich in *Buchia* and belemnites, considered to be Neocomian in age, provide the only age control for localities in the Melozitna quadrangle (Patton and others, 1978). Samples from Koyukuk Mountain (loc. 11) yielded K-Ar ages from 113–108 m.y. (Fig. 2).

Most of the rocks failed the bedding tilt test on both the locality and regional scale, thus demonstrating that they were remagnetized after they were folded (Fig. 7, Table 1A). In the Melozitna region, the paleomagnetic directions vary with changes in the lithology. Samples from the volcanogenic sediments yield similar *in situ* vector directions that disperse when corrected for bedding tilt. Pillow basalts interbedded with the sediments, however, yielded non-antipodal reversed vector directions (fail reversal test) and normal directions that are displaced from the mean of the sediments by 35 degrees. The greater stability of the volcanic rocks is evidenced by magnetic unblocking temperatures of about 500 °C compared to 350 °C for the sediments, suggesting that the volcanics may have been only partially remagnetized. At least three components of magnetization can be recognized but not well resolved in the volcanic rocks. Attempts to isolate a reliable characteristic direction at high demagnetization levels were only successful in a statistically insignificant number of samples. The general conclusion drawn from these data is that the Early Cretaceous volcanic-arc assemblage contains at least one secondary (post-folding) paleomagnetic direction, which is not surprising considering the proximity of these rocks to younger plutonic and volcanic rocks, particularly the widespread plutons intruded about 80 Ma (see, for instance, Miller, 1985).

Other studies of the Early Cretaceous volcanic-arc assemblage in the YKP have been conducted in the Yukon-Kuskokwim delta region by Globerman and others (1983) and, near the localities sampled in our

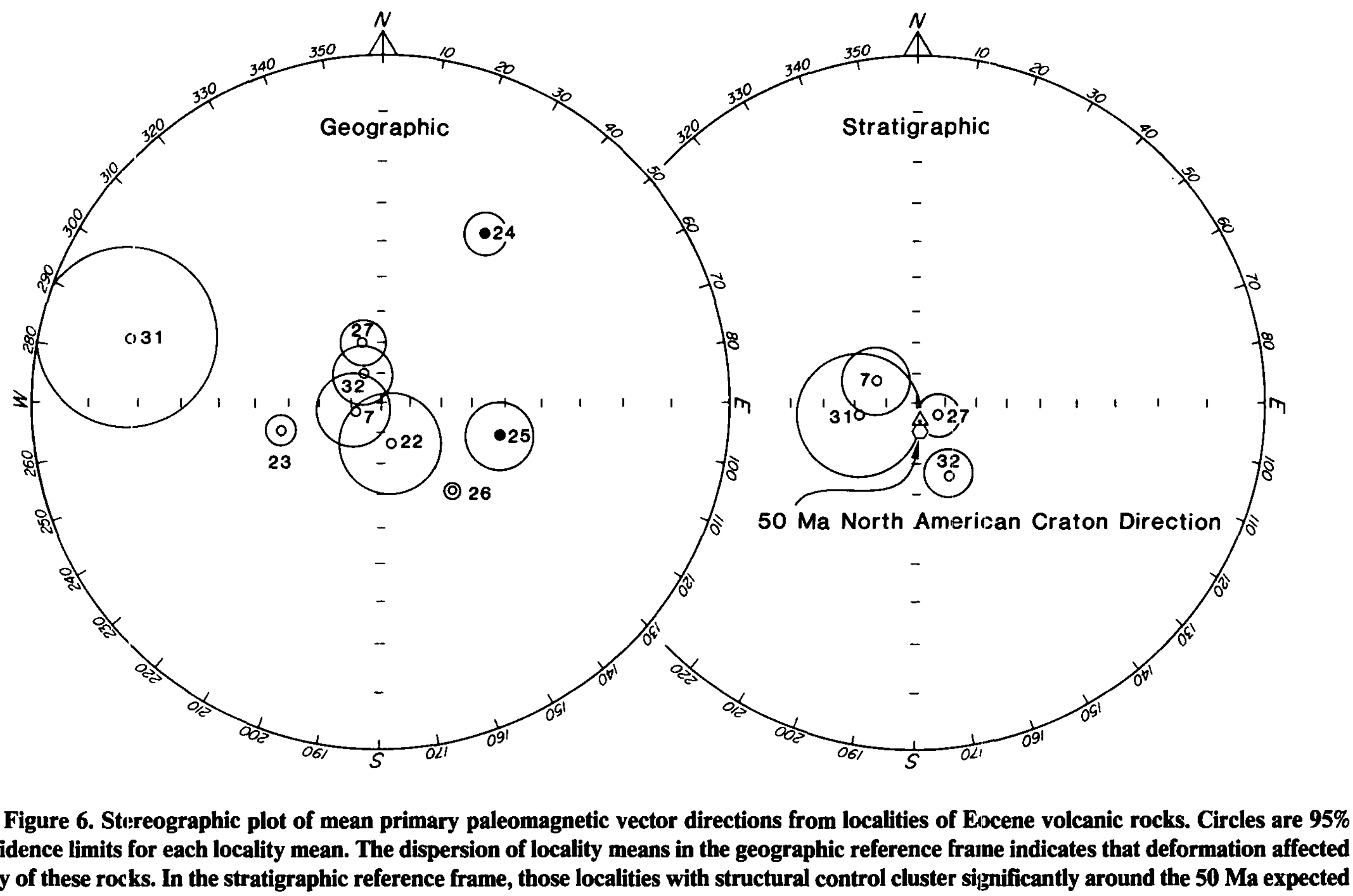

Figure 6. Stereographic plot of mean primary paleomagnetic vector directions from localities of Eocene volcanic rocks. Circles are 95% confidence limits for each locality mean. The dispersion of locality means in the geographic reference frame indicates that deformation affected many of these rocks. In the stratigraphic reference frame, those localities with structural control cluster significantly around the 50 Ma expected direction for the YKP relative to North America, suggesting that the YKP was part of the continent by this time. Triangle is mean of locality means (α_{95} = 21). Solid and open symbols correspond to lower- and upper-hemisphere projections, respectively.

study, by Hillhouse and Gromme (1985). Both studies reported similar results to those discussed above. The greater sample density (300 cores) in the volcanic rocks by Hillhouse and Gromme (1985), however, allowed them to isolate the reversed polarity characteristic magnetization in several samples. Although their samples failed the reversal test as in our study, they yielded directions of similar inclination, which significantly decreased in dispersion after tilt corrections were applied. Using the inclinations alone yielded a mean paleolatitude of 50°N (± 6°), which is consistent with 10°–20° of poleward motion.

2. Cretaceous Flysch. *Ruby Region.* The paleomagnetic samples collected in the Ruby region (locs. 36–40; Fig. 2) are from the same fluvial-deltaic sediments that yield stable paleomagnetic directions in the Nulato region. In this area, however, they fail locality and regional bedding tilt tests (Fig. 7). The *in situ* magnetic vector directions are all steep, near the present magnetic field, and normal in polarity. They could represent either a post-folding remagnetization direction or an unstable magnetization recording the present field. It is of interest to note that the sample localities of the Ruby region all lie along the Kaltag fault; this could be related to the ambiguous nature of the paleomagnetic data.

Melozitna Region. The upper part of the marine turbidites (Albian) and the lower part of the fluvial-deltaic sediments (Albian-Cenomanian) were sampled in the Melozitna region (locs. 1–2, 8–9; Fig. 2). The *in situ* magnetic vectors of these rocks are similar to one another regardless of bedding orientation. When a tilt correction is applied, the dispersion increases significantly both on a locality and on a regional scale (Fig. 7). The rocks display a post-deformational remagnetization direction similar to that expected for the 50 Ma North American craton direction.

The sample localities in the Melozitna region are near the Melozitna pluton and other small granitic bodies ranging in age from mid-Cretaceous to early Tertiary (Patton and others, 1978). Although mineralogical evidence for thermal alteration of the sediments is lacking, low magnetic unblocking temperatures (<200 °C) suggest that the thermal stability limits of the magnetic grains may have been exceeded (Dunlop, 1981).

3. Interpretation. The best recorded secondary magnetization is all of normal polarity, and it significantly fails the bedding tilt test at the 95% confidence level. The similarity of the secondary magnetization directions in the geographic reference frame carries the implication that the remagnetization event occurred after most of the deformation was completed (probably ≤49 Ma as discussed in the Geochronology Section). The similarity between the mean of the remagnetized directions (Table 2) and the 54–44 Ma expected direction (relative to North America) is consistent with this interpretation. This circumstantial evidence raises the possibility that the principal remagnetization event was related to thermal effects from the widespread Eocene volcanic pulse. The proximity of Eocene volcanic sequences to the sample localities supports this hypothesis; however, the consistent normal polarity of the overprint compared with the dominantly reversely magnetized volcanics is puzzling. Alternate hypotheses for the magnetic overprinting are (1) deep burial during the sedimentary infill of the Koyukuk basin, which would allow most of the rocks to pass through the critical isotherms for magnetic unblocking and then rebound and acquire their magnetization after the rapid sedimentation (Albian-Cenomanian) and hypothesized convergence (90–50 Ma) ceased; and (2) Brunhes-age viscous remnant magnetization, as the mean overprint direction is also near the present axial dipole field direction. This latter

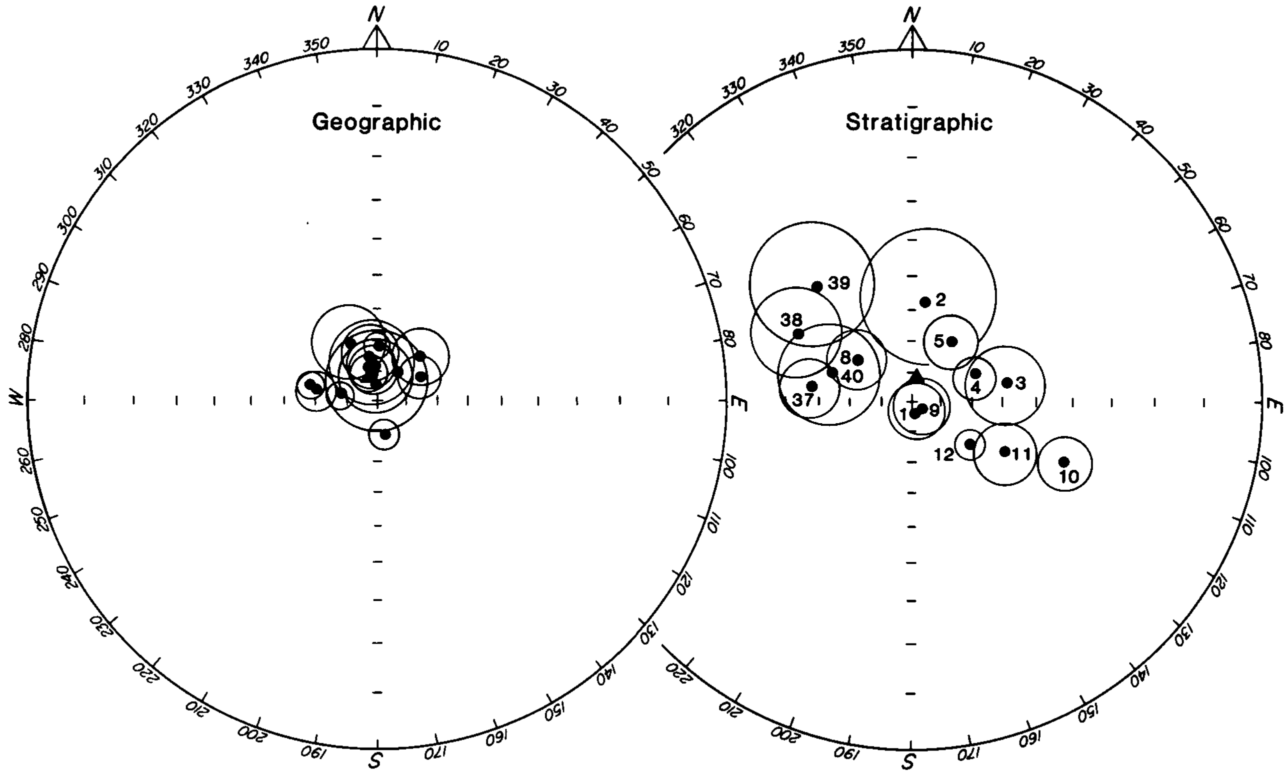

Figure 7. Lower-hemisphere stereographic plot of mean secondary paleomagnetic directions from localities of pre-Eocene sedimentary and volcanic rocks. The mean of locality means (triangle) in the geographic reference frame is coincident with the 50 Ma expected direction for the YKP relative to North America. In the stratigraphic reference frame, dispersion increases significantly, suggesting that the secondary magnetization was acquired after the folding. The tilt correction reflects the prevailing northeast-southwest trend of fold axes.

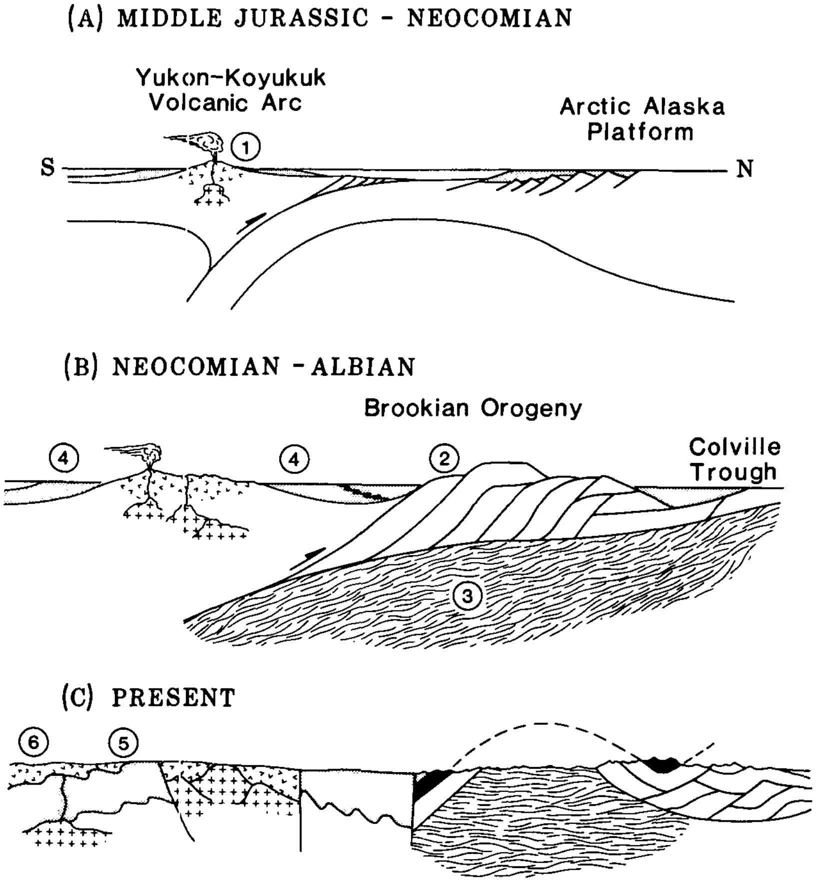

Figure 8. Schematic tectonic reconstruction for the evolution of the YKP from Middle Jurassic to the present. Numbers link tectonic events listed in the text to those illustrated above.

hypothesis allows an explanation of the normal polarity but raises the question of why one region is affected (Ruby) and another is not (Nulato).

Globerman and others (1983), lacking geological constraints on the timing of deformation, suggested that remagnetization in the lower Yukon River region occurred during the long Cretaceous normal polarity interval (110–80 Ma) or about 70 Ma (the age of nearby volcanic rocks). Their timing, however, is based on the assumption that no subsequent tilting of the remagnetized rocks has occurred (p. 518). As deformation in the province continued until at least 49 Ma, this assumption may not be valid. Although their data do not fail the bedding tilt test at the 95% significance level, the data are very similar to the remagnetized data of this study in that the secondary directions cluster in the geographic reference frame around the middle to late Eocene North American expected direction. This time interval was also one of normal polarity bias, which is consistent with the predominant normal polarity of the remagnetized directions of both studies.

TECTONIC IMPLICATIONS

The YKP is interpreted to represent a northeastward migrating, Jurassic–middle Cretaceous oceanic island arc that collided with, and ramped onto the continental platform of, the Arctic Alaska plate (Roeder and Mull, 1978; Patton, 1983; Box, 1985). A striking modern analogy to the tectonic evolution of the YKP is the Banda Arc in southeast Asia, which has migrated south toward Australia, the intervening ocean basin being subducted under the arc, and the arc itself is presently ramping onto the Australian continental shelf (Barber and others, 1977; Hamilton, 1979; Audley-Charles, 1981; Box, 1985; Harris, 1985a).

The following (Table 3) is a summary, based on geologic evidence, of the major tectonic events in the geologic evolution of the YKP (Fig. 8).

Paleomagnetic data are consistent with this geologic evolution of the YKP and contribute the following tectonic constraints (Fig. 9).

1. The Early Cretaceous island-arc assemblage and overlying middle Cretaceous sediments have experienced significant poleward motion relative to the North American craton (estimated at 14° ± 13° for the mean of locality means or 21° ± 10° for the grand mean). By 56–49 Ma, the YKP was slightly north, but within the error limits of its expected position relative to North America.

2. In relation to Albian sediments of the Arctic Alaska plate (see Fig. 1 and Witte and others, in press), the YKP shows more poleward motion, although the 95% confidence limits overlap (12° ± 10° versus 21° ± 10°).

3. With respect to the 76-m.y.-old volcanic rocks of St. Matthew Island (Fig. 1 and see Wittbrodt, 1985) that have moved 12° ± 8° poleward, the YKP shows a similar travel history.

4. Relative to the far-traveled terranes of southern Alaska (south of the Denali fault; Fig. 1), the YKP is distinct and probably formed part of the accretionary nucleus that served as a "backstop" for these terranes.

5. Paleomagnetic directions in the geographic reference frame, from rocks throughout the YKP that failed locality and regional bedding tilt tests, cluster around the 54–44 Ma North American expected direction. When corrections are made for the various bedding attitudes of these rocks, the directions disperse significantly. This implies that the remagnetization event was widespread and occurred about 49–44 Ma, which marks the end of deformation in the YKP.

Patton and Tailleur (1977) suggest that the deformation in the Yukon-Koyukuk province correlates with a major 800-km crustal shortening event documented throughout northern Alaska. The timing of the event is coincident with, and probably a consequence of, convergence between the North American and Eurasian plates occurring between 90–50 Ma

TABLE 3. A HYPOTHETICAL SEQUENCE OF EVENTS IN THE TECTONIC HISTORY OF THE YUKON-KOYUKUK PROVINCE

Event	Time
1. Building of a volcanic island-arc complex upon late Paleozoic–early Mesozoic oceanic crust(?)	Jurassic–mid-Cretaceous (173–90 Ma)
2. Arc complex collides with and ramps onto continental platform of Arctic Alaska plate (thrusting of Angayucham Terrane over Ruby Terrane); transition from oceanic to continental subduction	Pre-Albian (>113 Ma) (Patton, 1984)
3. Ruby terrane is overprinted by low-grade (greenschist) and, in places, high-pressure (blueschist) metamorphism	Early Cretaceous (145–95 Ma) (Turner, 1984)
4. Terrigenous sediment infill from the rising borderlands and extinguished magmatic arc	Albian-Campanian (113–75 Ma) (Patton, 1973)
5. Convergence causes fold-thrust deformation within the YKP	90–49 Ma
6. Renewed volcanism (dominantly calc-alkaline) possibly related to low-angle subduction of the Pacific plate	85–49 Ma
7. Deformation ceases	49–44 Ma
8. Remagnetization event	<49–44 Ma
9. Bimodal volcanic pulse	44–43 Ma

(Pitman and Talwani, 1972; Engebretson, 1982). The relative motion between North America and Eurasia has been modeled by Engebretson (1982) for the Bering shelf region. If all of the motion is taken up in this region, the model predicts the results shown in Table 4. It is also important to take into account the very rapid (~20 cm/yr) northward-convergence rates between the Pacific plate and Alaska during this time (Wallace and Engebretson, 1984). It is generally accepted that the 90–50 Ma Alaska-Pacific plate boundary was a northeast-dipping subduction zone near the present-day Bering Sea shelf margin. With rapid convergence, much of the resulting compressive stress could have been transmitted into the YKP.

The 800 km (~8°) of crustal shortening which occurred between 90 and 50 Ma could account for some of the apparent difference in poleward motion between Albian sediments of the Arctic Alaska plate and the YKP. This does not take into account the 500- to 800-km shortening from the Brookian Orogeny, which was mainly completed by Albian-Cenomanian time (Mull, 1982; Mayfield and others, 1983). In addition to the crustal shortening, paleomagnetic data from age-equivalent regions neighboring the YKP also show significant poleward (northward) motion (Fig. 9). This relationship suggests that the whole of northern and western Alaska moved northward relative to the North American continent as a more or less coherent block. The northward paleolatitudinal "overshoot" documented by many lower Eocene volcanic rocks throughout Alaska is consistent with this hypothesis. The impetus for this northward overshoot of the final positions of northern and western Alaska may have been the accretion of the Peninsular and Wrangelia terranes by 55 Ma (Csejtey and others, 1982; Reed and Lanphere, 1973). A mechanism for returning the YKP to its present position by 44 Ma was most likely related to the tectonic transition from convergence to extension that occurred about this time. Evidence of mid–late Tertiary extension exists throughout central and northern Alaska in the form of pull-apart basins, bimodal volcanic suites, high-angle and listric normal faulting (Carlson, 1985), and high heat flow.

The change in tectonic styles and end of convergence at around 50 Ma is consistent with geochronologic and paleomagnetic evidence that most of the deformation in the YKP ceased before the extrusion of the 44–43 Ma bimodal volcanics. Although the time of this tectonic transition corresponds well with the presumed times of acquisition of a secondary magnetization (remagnetization) by many of the rocks throughout the YKP, the nature of the relationship between the two is unclear.

TABLE 4. THE RELATIVE MOTIONS PREDICTED FOR THE YUKON-KOYUKUK PROVINCE BY EXTRAPOLATION FROM THE PACIFIC PLATE MOTIONS DEDUCED BY ENGEBRETSON (1982)

Date (Ma)	Motion	Direction	Speed (cm/yr)
90–50	Convergence	100°	2.5
50–40	Extension	315°	4.0
40–0	Convergence	45°	1.0

CONCLUSIONS

An understanding of the origin of the YKP is considered by many as the key to resolving the tectonic history of western Alaska. The relationship between the YKP and the orogenic belts that surround it (Brooks Range, Ruby Geanticline, Alaska Range) is vital in reconstructing the post-Jurassic geologic evolution of Alaska.

Three major geologic units make up the bulk of the YKP: (1) a basal Jurassic to Early Cretaceous volcanic-arc assemblage, (2) an Albian-Cenomanian sequence of terrigenous sedimentary infill, and (3) a cap of widespread Tertiary volcanic rocks.

Paleomagnetic and geochronologic reconnaissance studies conducted on these units exposed along the Yukon and Koyukuk River drainages produced the following results:

1. The volcanic-arc assemblage is widely altered and has a two-component paleomagnetic signature. The high-temperature component is reversed polarity and, using inclinations alone, indicates 10°–20° of poleward motion (Hillhouse and Gromme, 1985). The low-temperature secondary component is of normal polarity and post-deformational (≤44 Ma).

2. The terrigenous sediments yield characteristic paleomagnetic directions that pass stability tests in most areas and indicate about 15° of poleward motion with respect to the craton of North America. This motion occurred between 90–49 Ma, which was a time of high convergence rates between Alaska and the Pacific and Eurasian plates. Some of the motion can be accounted for by crustal shortening during this interval of convergence. Paleomagnetic data from neighboring age-equivalent rocks

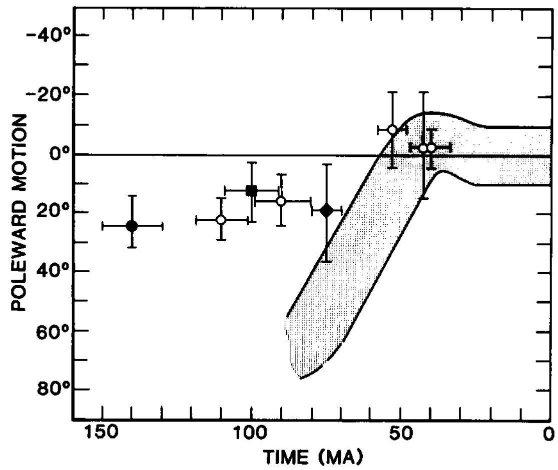

Figure 9. Poleward motion versus time of the YKP relative to other terranes of Alaska. Positive values represent motion from the south; negative values, from the north. Error bars include confidence limits for the North American craton VGPs (Table 2). Shaded band is extrapolation of paleomagnetic data from southern Alaska (south of Denali fault) of Stone and others (1982), B. C. Panuska and D. B. Stone (unpub. data). Circles are reliable data from YKP: open, this study; filled, Hillhouse and Gromme (1985). Square, Cretaceous sediments from Arctic Alaska plate (Witte and others, 1987). Diamond, volcanic rocks from St. Matthew Island (Wittbrodt, 1985).

(Arctic Alaska and St. Matthew Island), however, also show significant poleward motion, suggesting that the whole of northern and western Alaska moved about 10° poleward (northward) relative to North America as a more or less coherent block.

3. The bimodal Eocene volcanic rocks are characterized by two age and lithologic groups. The older group consists of dominantly felsic rocks, probably related to low-angle–subduction volcanism. This group yielded nine K-Ar andesite, dacite, and basalt ages of 56–49 m.y. The younger group is bimodal and yielded five K-Ar whole-rock basalt ages of 44–43 m.y. The most significant aspect of the age distribution is that the dominantly felsic rocks are deformed and the bimodal rocks are not, which brackets a time for the end of deformation in the YKP. The lithologic distribution reflects a major transition in tectonic style throughout Alaska from dominantly convergence to extension and strike-slip motion between the time the two sequences were erupted (49–44 Ma). Paleomagnetic data from the volcanics are of high quality, but sparse, because of poor paleohorizontal control. The reliable paleomagnetic directions are of reversed polarity and show an apparent northward overshoot at 56–49 Ma but are latitudinally equivalent to the expected North American craton direction by 44 Ma.

This study emphasizes the importance of geologic controls on paleomagnetic interpretations. The presence or absence and timing of magnetic overprinting need to be determined as a fundamental step in the paleomagnetic analysis of rock units. This is especially critical for areas with complex tectonic histories.

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APPENDIX 1. PALEOMAGNETIC PROCEDURES AND RELIABILITY

Magnetic Stability

The reliability of paleomagnetic data is directly related to the magnetic stability and ancient horizontal indicators of the rocks sampled. The magnetic stability of rocks differs as a function of the mode of acquisition of the magnetization, the magnetic minerals present, and the external conditions acting upon the rock. Lava flows are the most reliable paleomagnetic recorders in nature, acquiring a thermoremanent magnetization (TRM) on cooling. Many lava flows, however, cool on surfaces with an initial dip which is difficult to determine because indicators of ancient horizontal are often ambiguous in volcanic rocks. In general, igneous rocks give records of the ancient magnetic field averaged over their cooling time. This cooling time for lava flows is much shorter than are the time scales of the secular variation of today's field. To determine a time-averaged dipole field requires that the volcanic units span a time longer than a few tens or hundreds of thousands of years. Even though individual lava flows commonly yield stable magnetic directions, systematic errors can be introduced by poorly constrained attitudes and by the possibility that secular variations have not been adequately averaged.

Near-shore sedimentary rocks have opposite characteristics of reliability to those of lava flows. Bedding planes are usually very reliable indicators of ancient horizontal; where initial dips occur, such as in cross-stratified units, they are commonly recognizable. The ability of the sediments to record the magnetic field direction, however, depends on a variety of mechanisms, most of which are poorly understood. Near-shore sediments are characterized by weak and occasionally unstable magnetizations acquired by depositional (DRM) and post-depositional (PDRM) processes. Systematic shallowing of the inclination by amounts ranging from 0° to 25° have been detected in some studies of these processes (Collinson, 1965; Verosub, 1977). The shallowing is thought to be due to the rotation of elongate grains on settling and during compaction. As elongate grains are preferentially magnetized parallel to their long axes, the amount of rotation is thus latitude dependent. The amount of inclination error also depends on the ability of the magnetic grains to realign following initial deposition.

The rock types sampled in the Yukon-Koyukuk province have complementary magnetic characteristics. The lava flows have high paleomagnetic stability but ambiguous ancient horizontal control, whereas the sediments are less magnetically stable but have well-defined paleohorizontal indicators. The rock types of each sample locality are described in Table B.

Age Constraints

Reliable paleomagnetic data are of limited use unless the time at which the magnetization was acquired by the rocks is known. This requires that the age and deformational history of the rocks be well constrained. In this study, K-Ar age determinations were made on each of the geologic units for which there are paleomagnetic data. These ages (discussed in the section entitled "Geochronology"), along with the fossil and radiometric data from other investigations, provide time constraints for the acquisition of the magnetization and the deformation displayed by the various geologic units of the province.

Paleomagnetic Procedures

Core samples (2.5 cm in diameter) were collected from river-cut cliff exposures, referred to as "localities." Most of the sample localities are along rivers that drain approximately parallel to the northeast-southwest structural grain of the YKP, thus controlling the sample distribution. The sampling plan was of an extended reconnaissance nature, which maximized regional coverage at the expense of sample density by sampling many localities but collecting only between 10 and 30 samples per locality. Bedding attitudes were recorded for each bed from which samples were collected.

The core samples were cut into 2-cm-length specimens, each of which was subjected to either thermal or alternating field step-wise demagnetization. In order to isolate a characteristic magnetic vector direction, the specimens were typically demagnetized in increments of 50–75 °C or 70–100 oersteds. The equipment used for the analysis consisted of a three-axis, 6.4-cm-diameter access, Super-Conducting Technologies (SCT) magnetometer housed in a magnetically shielded room, a SCT shielded 400-Hz alternating field demagnetizer, and a Schonstedt thermal demagnetizer.

Evaluation of Paleomagnetic Data

The characteristic paleomagnetic vector directions were selected visually for each sample, using a combination of the percent normalized demagnetization curves, modified Zijderveld (1967) vector diagrams and stereographic projections. The representative magnetic direction for each sample corresponds to the vectors which most closely approximated a simple decay toward the origin of the vector diagram during the step-wise demagnetization process. Samples that did not show a stable characteristic magnetization were not included in the analysis.

Mean magnetic directions were calculated both in geographic (*in situ*) and stratigraphic (tilt corrected) reference frames (Table 1). The mean of magnetic directions for samples from a given locality is referred to as a "locality mean." Groups of sample directions from localities in the same geographic region and of similar age are referred to as "grand means." Data for individual localities may be obtained from Table B.

Several tests were applied in order to establish the stability of the characteristic magnetic vectors and their relationship to the geologic history of the area. The conglomerate and bedding tilt tests (Graham, 1949) were the most useful for this study. With the exception of one locality, conglomerate clasts gave magnetic directions that were random. Some localities that passed the conglomerate test failed the bedding tilt test because the conglomerates had clasts that are more magnetically stable than the sandstones and matrix interlayers normally sampled.

The most effective test for relating paleomagnetic vectors to the geologic history of the rocks in which they are recorded is the bedding tilt test. If paleomagnetic directions from rocks of different bedding attitudes significantly decrease in dispersion when corrected for their tilts, the magnetization was acquired before deformation. The test can be applied at a variety of scales, from outcrop to regional in extent. Regional tilt tests are the most convincing because of the number of samples and diversity of bedding attitudes commonly involved.

To pass or fail the bedding tilt test, the dispersion difference between the *in situ* and tilt-corrected reference frames was required to be statistically significant at 95% confidence limits.

These stability tests were the basis for determining whether a population of paleomagnetic vectors from a locality, geographic region, or age grouping has reliably recorded the pre-deformation magnetic field. The reliable paleomagnetic vector directions, shown in Table 2, were selected in this way.

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