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PALEOMAGNETIC EVIDENCE FOR THE ROTATION OF ALASKA

by

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ABSTRACT

The remanent magnetization of two suits of Cretaceous lavas collected from central Alaska indicates a rotation of Alaska relative to North America of at least 20 degrees since the Early Cretaceous. The amount and sense of rotation is consistent with the orocline hypothesis of Carey (1958) and with current ideas regarding the opening of the Arctic Basin and Atlantic Ocean.

Introduction

The structural implications of the sharp change in trend of the Denali and associated fault zones in central Alaska have long fascinated many structural geologists. Perhaps one of the more favored hypotheses for the origin of this feature is that advanced by Carey [1,2] in which he relates both the fault zones and their change in trend to the opening of the Arctic Ocean basin. Carey's hypothesis is that almost all of Alaska has been rotated counter-clockwise relative to the rest of North America by 30 or more degrees. Furthermore he postulates rotation of southwestern Alaska by as much as 75 degrees during various deformations associated with the opening of the Arctic Basin.

With increasing paleomagnetic data from North America and eastern Asia, this hypothesis may be paleomagnetically tested by data derived independently from the observations of regional structural trends. It is the attempt of this paper to demonstrate that sufficient paleomagnetic data presently exists from central Alaska to indicate that a rotation of at least 20 degrees relative to North America has occurred since Early Cretaceous times.

Ideally one would like to sample Paleozoic or early Mesozoic rocks in order to test the Carey hypothesis. However, in most readily accessible areas of Alaska suitable rocks of this age are either highly deformed or moderately metamorphosed. Consequently, volcanic rocks of Lower Cretaceous age were chosen for this study. As is discussed below, even these rocks have been sufficiently deformed and metamorphosed to make the amount of rotation somewhat uncertain, although they do demonstrate unequivocally that some rotation has occurred.

Geologic setting

Within central and southwestern Alaska there are several areas in which extensive sequences of Cretaceous volcanic rocks have been mapped [4] (see Figure 1). Within the eastern region (labeled C in Figure 1) these volcanics include numerous flows of both acidic and basic composition. Flows are also reported from the western region but at all outcrops visited by the author only pyroclastic rocks of varying degrees of coarseness were encountered. Consequently, all of the observations discussed below come from the relatively restricted eastern region. In the eastern area, Cretaceous volcanic rocks with numerous flows crop out within Mt. McKinley National Park near the base of the Muldrow Glacier and near the Toklat River in the vicinity of the ranger station at Igloo Creek.

The regional structure is an open east-west trending series of anticlines and synclines bounded on the south by the Denali Fault. However, considerable local structure is present in the form of faults and folds causing some uncertaintly in the interpretation of the magnetic results. Nevertheless, within the sampled areas, errors resulting from structural correction determinations are probably less than 10 degrees and thus the major conclusions reached below are virtually unaffected.

The Cantwell Formation, of which the Cantwell Volcanics are an integral part, has been described by Reed [16]. The Cantwell Volcanics are intercalated within a continental clastic sequence of sediments consisting primarily of conglomerate and sandstone lithologies. The volcanics are not restricted to a particular part of the sequence but instead seem to be present at many horizons suggesting that the vulcanism continued for a considerable period of time rather than being restricted to one volcanic event. The composition of the volcanics varies from rhyolite to basalt. The samples used in this study come from the andesitic and basaltic portions of this sequence.

The age of the Cantwell Formation, including the volcanics, is considered to be Albian (uppermost Lower Cretaceous) on the basis of plant fossils collected within the sandstones [10]. The formation overlies Paleozoic and earlier Mesozoic rocks and is overlain by Tertiary sediments.

The coarse clastic nature of the sediments associated with the volcanics suggests that active uplift was going on in the immediate vicinity during the deposition of the formation. This uplift may have been associated with early activity along the Denali Fault.

Sampling Methods

All samples were collected by means of a portable hand-held gasoline powered core drill and all samples were oriented by means of a sun compass. Two cores were taken from each flow so long as its thickness did not exceed 20 feet. If the real or apparent thickness was greater than 20 feet, additional samples were taken.

Two localities, separated by 2.5 miles, were sampled. From the observed lithologies and textures, two partially overlapping flow sequences may have been sampled. The first locality, on the southern flank of the peak north of Igloo Creek, consists of at least eight flows although more may have been sampled since the outcrop was quite discontinuous. The second locality on the western flank of Cathedral Peak, 2.5 miles to the south, was much better exposed and eight to ten flows were sampled.

Upon return to the laboratory, the 2.54 cm diameter field cores were cut into cylinders approximately 2.54 cm in length and measured on an air turbine spinner magnetometer operating at 271 Hz [9].

Alternating current demagnetization experiments were made on all samples using 420 Hz demagnetization equipment similar to that described by Patton and Fitch [15]. Progressive thermal demagnetization of a few samples was done in a field-free region in which cooling took place in a region where less than 5 gammas of field was present.

Discussion of Results

The samples from the two collecting localities have very different magnetic properties and consequently will be discussed separately rather than together. The natural remanent magnetization (NRM) of the first locality (north of Igloo Creek) is shown in Figure 2(a). Most of the observations are grouped on the upper hemisphere and have a general NNE direction. A few of the samples have more scattered directions, some more than 100 degrees from the general mean. These samples come from a series of flows that weather much more easily than the ones above or below and consequently the samples came from very poor and somewhat weathered outcrops in an area of subdued topography. The remainder of the samples, i. e., the clustered ones, come from more resistant flows and were taken close to the base of a small cliff along the stream.

Upon progressive alternating current demagnetization the scattered NRM's move rapidly to the direction of the main cluster and become well grouped by 175 oersted. Minimum scatter seems to occur between 350 oersted and 700 oersted, the scatter increasing considerably above 700 oersted. The directions of the magnetization after application of a demagnetizing field of 350 oersted are shown in Figure 2(b).

Local structural correction of this data is somewhat uncertain for few reliable attitudes are present in this area and those measured in the field (flow bases, amygdule foliations, etc.) are quite scattered. The regional trend seems to be much more uniform and has been used as the basis of structural correction. Pole positions derived from structurally corrected data are given in Table I along with similar data for the second locality. No corrections for plunge of the fold was made. However, most of the folds in the region seem to have a small plunge to the east. Correction for this eastward plunge would increase the observed inclination by up to 10 degrees.

The Cathedral Peak locality, located south of Igloo Creek about 2 miles northwest of Sable Pass, has much better exposures of the Cantwell Volcanics than does the locality to the north of Igloo Creek. The NRM of the 25 samples collected from this locality are shown in Figure 3(a). The initial NRM directions are much more scattered than those from the first locality and have a weak cluster on the lower hemisphere in the northwest quadrant as well as a few grouped samples in the upper hemisphere in the NE quadrant.

Upon progressive alternating field demagnetization three seperate behavior patterns become apparent. The first is a group that remains unchanged and clusters in the lower hemisphere in the northwest quadrant. The second group of samples move from their original positions toward the northeast quadrant of the upper hemisphere. Many of these samples start moving in one direction and then change their movement direction at applied fields above 175 oersted. Samples from the third group behave in an erratic manner and seem to have little systematic behavior during demagnetization. Within these erratic patterns one can sometimes see a systematic trend for three successive demagnetization steps that would indicate a stable moment in the upper hemisphere perhaps also in the northeast quadrant. Determination of a mean direction for these samples is made difficult by the fact that no stable end point is reached during progressive demagnetization. Many samples in fact move right through the direction that seems to be the general mean direction. Despite all this apparent inconsistency two samples from the same field core generally have very similar progressive demagnetization paths and in several cases have identical directions during demagnetization. Two or more samples from the same flow (separated by three to twenty feet in the field) also behave similarly upon progressive demagnetization.

It was noted during the progressive demagnetization experiments that some of the samples tended to approach a stable direction at field values between 175 oersted and 700 oersted and that many of the samples had one or more observations in this region. Thus a mean was calculated for this locality (see Table I and Figure 3b) using the 175 oersted data wherever reasonable but substituting data from demagnetization runs between 44 oersted and 700 oersted whenever these were closer to the direction determined by the few samples that appeared to have some stable components.

In order to independently determine a mean direction from these data that did not cluster well (groups two and three above) a progressive demagnetization path was calculated for each sample by mathematically defining the best fitting great circle for two to five successive demagnetization directions. Only those points that seemed to be moving more or less systematically were used in this calculation and determinations made below 100 oersted were generally omitted since these seem to reflect magnetization due to a much more unstable component. In as much as the initial NRM directions are quite scattered the orientations of these great circles are quite varied. Nevertheless they all intersect in one small region (see Figure 4) which is considered to be the direction of the original NRM. A mean direction for these intersections has been determined by fitting a great circle to the normals of all of the great circle paths. The normal to this great circle is the mean direction and an α_{95} confidence level can be calculated from the deviations from this mean. The mean direction thus derived (see Table I) is very similar to that found by selecting the demagnetized data as described above. Thus it is felt that this direction may represent the true direction of the original NRM of these rocks.

The polarity and general direction of this NRM is consistent with the observations from the locality north of Igloo Creek. It is then necessary to explain the significance of the highly stable results from the first group of samples. The direction of magnetization of these samples remains virtually unchanged at alternating field values up to 4100 oersted and the intensity of magnetization shows little change below 1400 oersted and even at demagnetizing field values of 4100 oersted still retains about 30 percent of the original intensity. This argues strongly for hematite as the major carrier of the magnetization. In contrast, most of the samples from groups two and three begin to decrease in intensity rapidly above 175 oersted and have only about 20 percent of their magnetization remaining at 700 oersted, thus suggesting that magnetite is the major contributor to the NRM. Polished section petrography supports this conclusion as all samples from group one have abundant hematite that occurs as a replacement of titanomagnetite. The amount of hematite present in group two and three samples is very small. Most of the magnetic oxide in these samples is in the form of blades of titanomagnetite that show little alteration. Sphene is very abundant in the group one samples while it is absent within the group two samples.

Field evidence indicates that the group one samples were not formed by some local feature for they are distributed throughout the flow sequence. Moreover some samples of one flow may belong to group one while the remaining samples have demagnetization behavior characteristic of group two or three. Most of group one samples also have reddish or greenish appearances in hand specimen while the other samples are very dark gray or black. One is thus led to the conclusion that the group one samples are the result of secondary chemical alteration of the group two and three material either as alteration restricted to flow margins or as alteration associated with fractures formed during the subsequent deformations. Consequently, their magnetizations, although extremely stable, are not to be considered to be of primary origin.

As a further check of the origin and stability of the NRM, duplicate specimens of many of the samples were subjected to progressive thermal demagnetization. For the locality north of Igloo Creek, directions identical with those observed at 350 oersted were found for all temperatures between 180 degrees C and the Currie point (see Figure 2(c)). The Currie point for the specimens lies between 460 degrees and 500 degrees depending upon the particular sample involved. Thus, the conclusion was reached that the alternating field demagnetization and thermal demagnetization gave the same results and that the carrier of the magnetization was most likely a titanomagnetite with about 20% ulvöspinel.

Similar experiments performed on the samples from the Cathedral Peak locality did not yield such straightforward results. Upon thermal demagnetization, two general directions emerged (see Figure 3(c)). One of these, which is in the NW quadrant of the lower hemisphere, is reasonably well grouped, and is similar to the direction observed for the hematite-rich samples during alternating field demagnetization. The second group, which lies in the NE quadrant of the upper hemisphere, is poorly grouped and only has a general similarity to the alternating field results. One is thus forced to conclude that the NRM of this second locality has had a complex history involving reheating or metamorphism at some time after initial cooling and that much, if not all, of the original NRM has been so changed that reliable results cannot be obtained. When structural corrections are applied, the lower hemisphere results move to a position that would be expected if the reheating or metamorphism had occurred during Middle to Late Tertiary time. This substantiates the validity of the structural correction used but does not help to find the pre-metamorphism direction.

Structural Corrections

As stated previously the structural corrections for this region are relatively large; that is, involve rotations up to 55 degrees, and have an uncertainty estimated to be about 10 degrees. Field observations of strike and dip for the locality north of Igloo Creek are approximately the same as the regional trends (strike N80E dip 55N) and thus correction is relatively certain and yields a pole that has good reliability.

For the Cathedral Peak locality the altitudes observed in the field do not parallel regional trends but instead have a N10°E strike and a dip of 35° E. As mentioned above, use of this correction brings the lower hemisphere results to a position near that expected for rocks of Tertiary magnetic age. Application of the same correction to the upper hemisphere results yields a pole in the Pacific east of Hawaii that is highly suspect due to the uncertainties of the origin of the magnetization. The fact that the structure in this area does not parallel regional trends also suggests that some deformation of a local nature (local thrusting, for example) may have greatly complicated the interpretation.

Tectonic Implications

The Alaskan Pole positions are summarized in Table I and the only one considered reliable is shown in Figure 5. They all are markedly discordant when compared to other North American Cretaceous results [7]. It is possible that these are just more anomalous Cretaceous poles, such as those from the Franciscan Formation [6], or from Spitsbergen [18], yet it is more interesting to speculate about the consequences of their being anomalous due to large scale structural deformation. If Carey's hypothesis about the opening of the Artic Basin is correct, one would expect between 20 and 70 degrees of counter-clockwise rotation of Alaska relative to North America. The data from the locality north of Igloo Creek supports this hypothesis for it indicates a rotation of 37 degrees. The distance to the pole however appears to be in error for the pole is 43 degrees away. If rotation of Alaska were the only cause of the difference between the established North American pole and the Alaskan pole, one would expect a colatitude of 12 degrees. The observed colatitude of 43 degrees may be in error as a result of structional correction uncertainties. Since the dip of the strata has a maximum error of about 5 degrees, the major amount of error is to be associated with uncertainties in strike and plunge of the structure. It is felt that the maximum error from both these causes lies between 10° and 15°. The minimum colatitude found using these error limits is 17° and it suggests a rotation of 26° while the maximum colatitude is 52° associated with a rotation of 55°.

It thus seems certain that despite the structural uncertainties the amount of rotation must be between 20° and 55°, a result that seems to be in complete agreement with the orocline hypothesis of Carey [2].

An alternate means of explaining the observed divergence from the established North American Cretaceous pole is to assume that Alaska is part of the old Asian landmass and then relate its pole to that for eastern Asia excluding Japan. As is readily apparent in Figure 5, this results in much less difference between the two poles. In fact, a complete agreement with many of the Asian poles can be reached by using the extremes of the uncertainties in the structural correction.

It is clear from the uncertainties involved in this study that additional investigations on Mesozoic and Paleozoic rocks from Alaska must be made in order to clarify the nature and exact amount of rotation that has taken place. Nevertheless it is certain, even from these preliminary studies, that some rotation of Aslaka must have occurred.

Acknowledgments

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Figure Captions

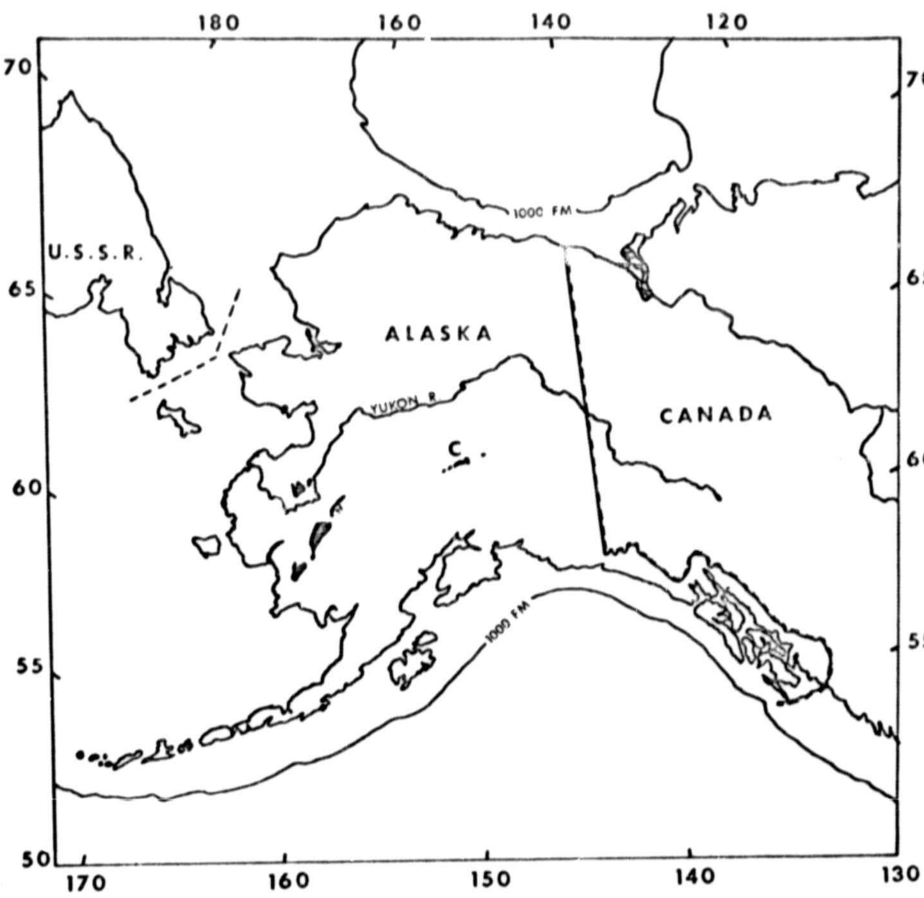
1. Map showing areas of outcrop of Cretaceous volcanic rock. C indicates area studied.

2. NRM of samples from locality north of Igloo Creek before and after demagnetization.

3. NRM of samples from Cathedral Peak locality before and after demagnetization.

4. Great Circle paths followed by NRM during alternating field demagnetization of samples from Cathedral Peak locality.

5. Cretaceous poles for North America and Asia: ⊙ Alaska, ◇ North American average, □ Japan, ▣ Korea, ○ China and △ Russia (Siberia).



180
160
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U.S.S.R.
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C.
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Figure 1

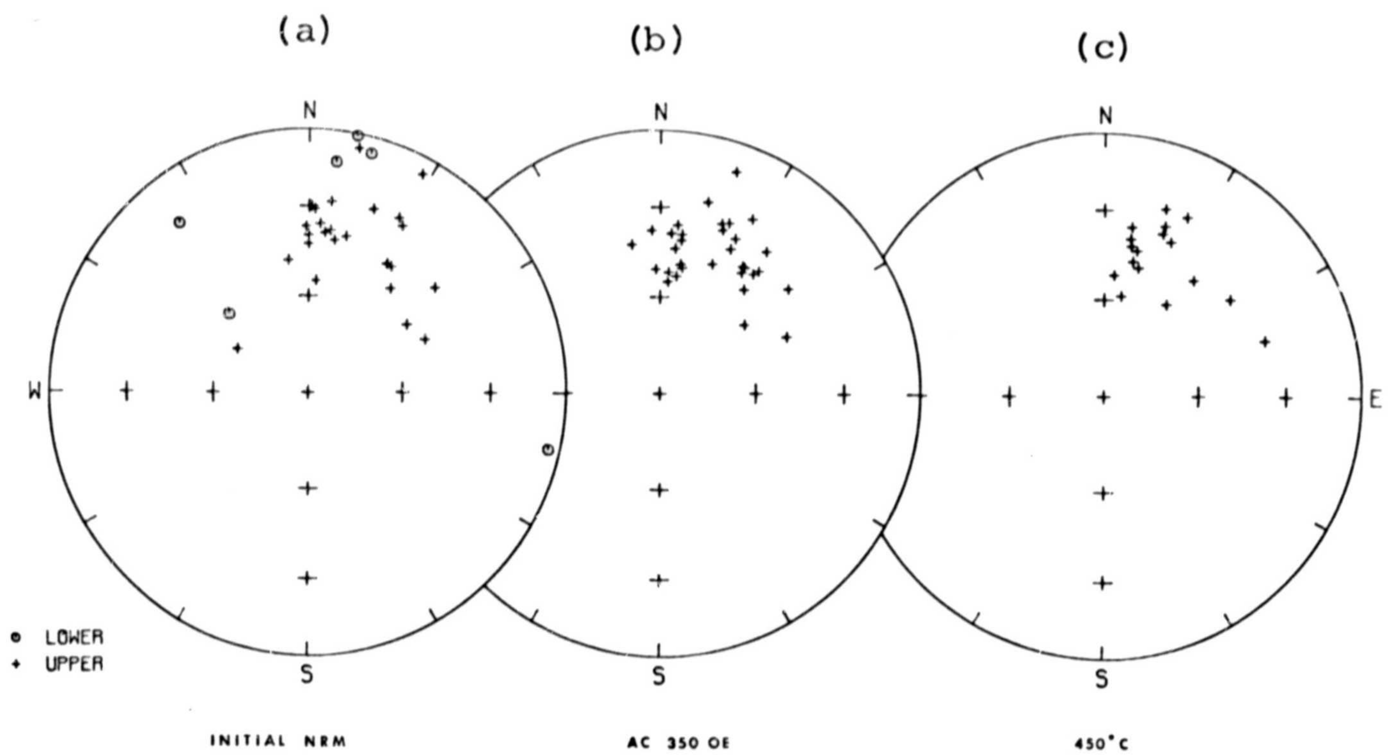

Figure 2

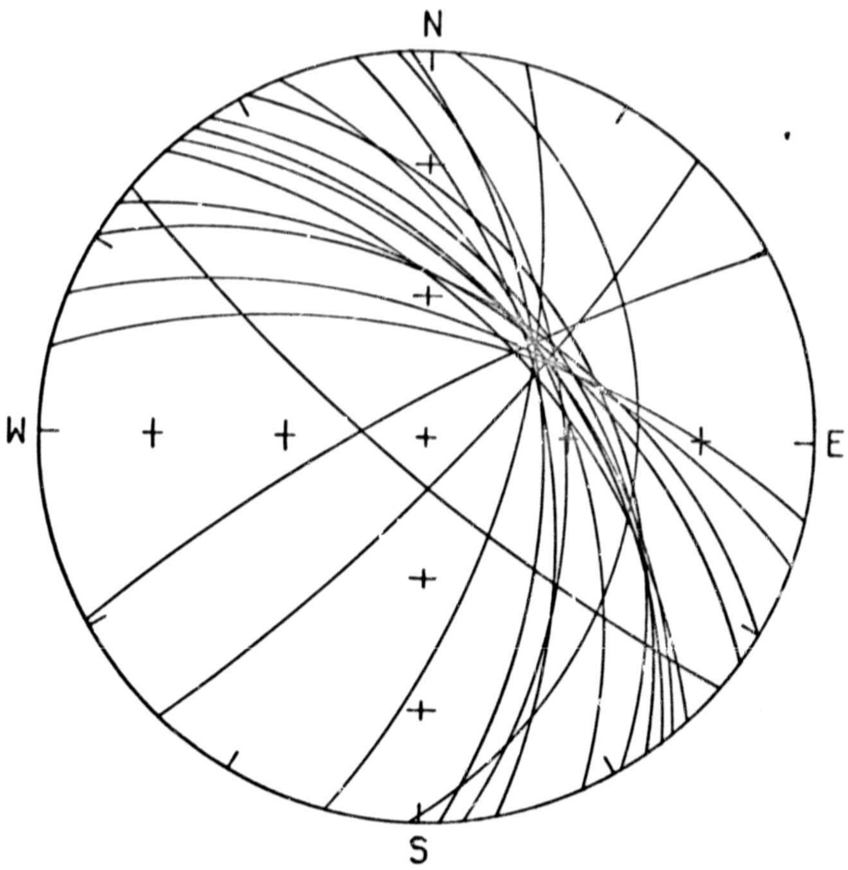

Figure 4

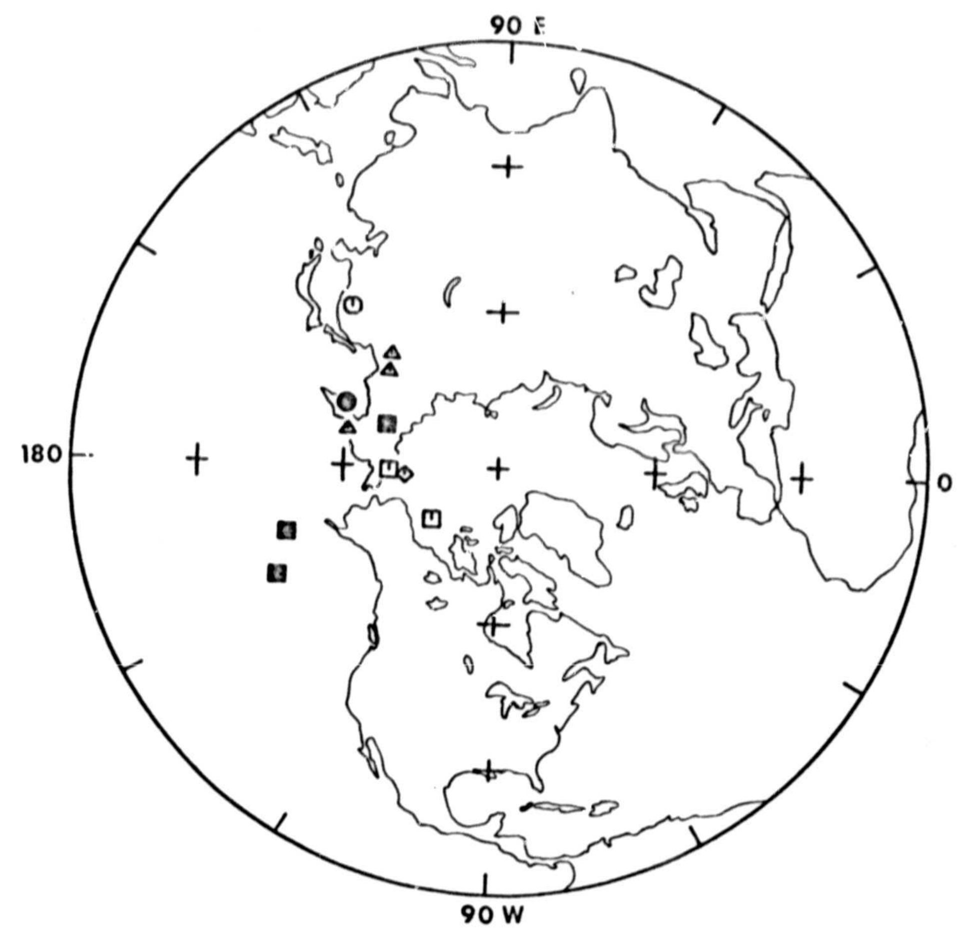

Figure 5

TABLE I

SAMPLE	DEC	INC	N	R	K	ALPHA	DEL	LONG	LAT	DP	DM
SITE 1	105.3	-64.9	32	30.80	25.9	5.1	15.7	134.0	47.2	6.6	8.2
SITE 2	333.0	-63.1	18	17.40	28.4	6.6	14.8	129.8	20.2	8.2	10.4
GT. CIRCLE SITE 2	337.0	-67.0				2.5					