PHYSICAL CHARACTERISTICS OF THE PRECAMBRIAN GEOMAGNETIC FIELD AS RECORDED IN THE MANZANO MOUNTAINS, NEW MEXICO

by

Craig A. Parks

Submitted in partial fulfillment

of the requirement for

Geophysics 590

and the

Master's Degree Program

at

New Mexico Institute of

Mining and Technology

December 1981

ABSTRACT

The physical characteristics of the Precambrian geomagnetic field in the Manzano Mountains may be controlled by regional metamorphism, which occured at about 1.4 Ga, along with the complexity of the structure. Results give strong indications that there are magnetic reversals which may be due to three generations of folding. There seems to be only a single period of magnetization present which would most likely have been acquired during this regional metamorphism event. A paleopole was unable to be derived from this study because of the problems, associated with the complex structure, of trying to get the magnetization directions of the collected rock samples to cluster. Further investigations need to be done on the paleomagnetics and structure in the Manzano Mountains for sounder conclusions to be drawn.

INTRODUCTION

Paleomagnetic studies of the Precambrian of North America have almost exclusively been limited to the Canadian Shield. Nearly all of this work has been done with Proterozoic (2700-600 Ma) samples. There is no well defined apparent polar wandering (APW) path older than the Proterozoic since very little work has been done in the Archean. When averaged over several thousand years the magnetic north pole remains in a fixed position at the geographic north pole (McElhinny, 1973). Thus the only movement which could occur is the translation and rotation of rocks. After taking into account localized movements, the paleopole obtained from a rock represents the relative motion of the plate upon which the rock lies. The APW path in the Proterozoic contains great loops and bends which correspond to various orogenies or tectonic events (Irving, 1979; Berger and York, 1980).

The Precambrian consists predominately of metamorphic rock. This presents many problems in obtaining reliable data. The natural remanent magnetization (NRM) is usually weak and unstable. Reasonably accurate dating of the primary magnetization is not always possible since during a metamorphic event the isotopic clock, potassium-argon and/or rubidium-strontium, may be reset without the magnetization being totally reset. A third problem due to metamorphism is the alteration of the original magnetic minerals.

According to Irving and McGlynn (1976) the polarity of the Precambrian geomagnetic field seems to be biased towards what is presently regarded as normal. The polarity is based on tracing the APW path from the Cambrian, where the polarity is known, into the Precambrian. However, large gaps in Precambrian data, on the order of 200 m.y., make it nearly impossible for a positive correlation of polarities between the Precambrian and Phanerozoic. These gaps have been interpolated by assuming the shortest simple path.

This is done despite the fact that reversals and large scale movements could easily occur in a time interval of 200 m.y.

Another very difficult problem which is commonly associated with metamorphic rocks is structural complexities. A fold test may easily be applied to a simple first generation fold to test whether the magnetization was acquired pre- or post-folding. However, this quickly becomes an immense problem with folds of multiple generation or those which are complex and nonuniform. Unfortunately, many metamorphic rocks are of this nature. A section whose magnetization was acquired prior to complex folding may have a seemingly random scatter in its paleomagnetic data. If the section acquired its magnetization after folding occurred then the amount of scatter in the data should be small.

The purpose of this study is to investigate characteristics of the Precambrian geomagnetic field. Using a succession of medium grade metamorphics collected in the Manzano Mountains (fig. 1) the following questions will be considered: (1) are medium grade metamorphic rocks suitable for paleomagnetic polarity stratigraphy studies, (2) are there any reversals recorded in the succession being considered, (3) can multiple periods of magnetization be recognized, if there are any.

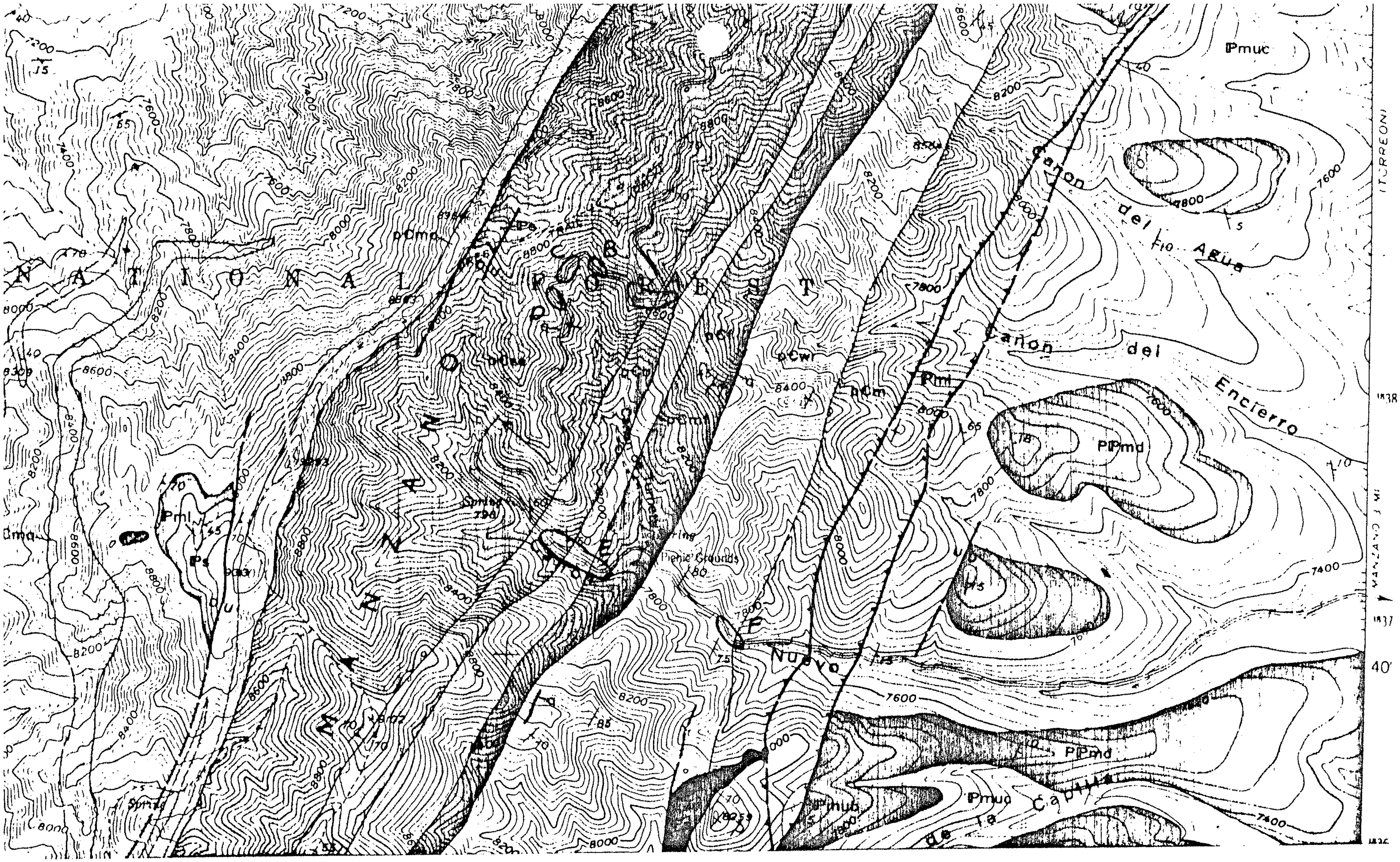

Fig. 1. Location map: Capilla Peak Quadrangle (Myers and McKay). Sampling sites are within the circled outcrops. (A) sites 21-36, (B) sites 37-41, (C) sites 42-46, (D) sites 47-50, (E) sites 51-53, (F) sites 54-62.

The Precambrian in the Manzano Mountains is between 1.7 and 1.65 Ga in age. Shortly after deposition of the rocks it underwent medium grade regional metamophism (500-600 degrees Celsius), as denoted by its amphibolite facies (Condie, personal communication). A K-Ar date of 1.4 Ga indicates that the rocks had cooled down past its Curie temperature thus dating the rock's primary magnetization. Since then only a brief period of very low grade metamorphism has occured. This implies that the NRM has remained unchanged since 1.4 Ga.

There has been some controversy as to the actual structure of the area. Condie and Budding (1979) believe there is a large broad synclinal fold trending N 30 E which progressively becomes overturned from south to north. Rieche (1949) claimed that there were at least three stress episodes. The last episode defined by Rieche is the broad synclinal fold, which is overturned within the area where this study was conducted.

For the purpose of this study three different rock units were considered: Sevilleta Formation (Sv), a subunit of the Sevilleta Formation (Sva), and the White Ridge Formation (WR). These rock units are described by Condie and Budding (1979) on sheet 1 of their geologic maps. The Sevilleta Formation (Sv) contains "fine grained, commonly porphyritic siliceous meta-igneous rocks of variable color." The subunit (Sva) is described as "amphilbolitic, black, medium-grained amphibolesodic plagioclase rock." The White Ridge Formation (WR) is composed of "white to buff massive quartzite, and mica-quartz schist."

EXPERIMENTAL PROCEDURE

A total of 42 hand samples was collected at approximately 5-20 meter intervals along a dirt forestry road which traversed the area toward Capilla Peak (fig. 1). All the samples were oriented with a Brunton compass before being removed from the outcrop. At each outcrop the strike and dip of the compositional layering was measured.

Three specimens were cored from each hand sample by drilling perpendicular to a reference plane. In most cases the reference plane was that defined in the field at the time the sample was oriented. For some samples the face oriented in the field could not be leveled easily so that a secondary rotation was made and another face was leveled as the reference plane. The specimens were then cut into approximately one inch lengths.

A Schonstedt spinner magnetometer was used to measure the magnetization of the specimens. Six orientatins were employed so that each of the three Cartesian axes were measured four times. The four measurements were averaged to obtain the best estimate of the magnetic moment along each axis. One specimen from each sample was completely step-wise thermally demagnetized at 0, 200, 400, 500, 540, 580, and 620 degrees Celsius. The remaining specimens were thermally demagnetized at 0, 400, and some at 500 degrees Celsius.

Standard Fisher statistics were obtained from the samples. The mean inclination, declination, and scalar intensity along with the precision parameter (kappa) and the circle of 95 per cent confidence (alpha-95) were calculated for each sample. Kappa determines the dispersion of the points. When kappa is about one the data is uniformly distributed and thus random. When kappa is large the data is clustered about the true mean direction (McElhinny, 1973). Alpha-95 is a solid angle in which the data will lie with a 95 percent confidence. That is, only one out of twenty points will lie outside the cone. Fisher statistics sample means were used in the data analysis.

Using the mean data, fold tests were preformed in an attempt to obtain better clustering of the data. Since the exact location, bearing, and plunge of the fold axes were not known, several different fold axes were tried. These were constrained by the known structural relationships (Callender, personal communication).

Zijderveld vector diagrams were used to determine the presence of any multiple paleomagnetic components acquired by a rock. The Zijderveld diagram is a vector plot of magnetization measured during step-wise demagnetization of a specimen, projected onto two orthogonal planes (Dunlop, 1979). One of these planes is horizontal at the sampling site, while the other is a vertical plane usually oriented North-South or East-West. If the Zijderveld diagram has linear segments, then magnetization components may be resolved. The directions can be determined by measuring the declination and inclination of the linear segments. Dunlop (1979) describes this procedure in detail.

The use of a Curie Balance was employed to help determine the magnetic minerals present in the rocks. The samples in this study were measured at the University of Pittsburgh by Dr. Stephen Shulik. A magnetic mineral will lose its magnetization as it is heated. At a specific temperature, known as the Curie temperature, a mineral will entirely lose its magnetization. This temperature is different for any given mineral. By finely crushing a rock sample and applying a magnet to the grains the magnetic grains may be separated out. The magnetic grains are suspended from a balance and a gradient magnetic field is applied to the grains until they become saturated, effectively increasing the weight measured by the balance. The grains are then heated and the effective weight decreases; the weight increases when cooled. The change in weight is proportional to the magnetization of the grains. A thermomagnetic plot is graphed from the resulting temperature-magnetization data. From the plot the Curie temperature(s) of the mineral(s) may be obtained by extending a line tangent to the steepest sloping section of the curve down to where the magnetization is zero.

RESULTS

Most of the samples in this study were collected from the volcanic rock in the Sevilleta Formation. Emphasis was put on this unit since the major synclinal fold axis in the area lies within the unit, and was thought to cross the road along which the samples were collected. Fold tests were applied to determine better when the magnetization was acquired, i.e. pre- or post-folding. Unfortunately, the sampling did not cross the fold axis, so a fold test could not be done on the major synclinal fold. However, tests were done on minor folds found on the east limb of the syncline. These will be discussed later. The mafic subunit in the Sevilleta Formation exhibits the greatest variation, of the units studied, between samples in magnetization intensity. The quartzite of White Ridge Formation is fairly uniform in its magnetization intensity between samples.

A Curie Balance was used on one sample from each unit to determine the magnetic minerals present. The resulting plots of magnetization versus temperature (fig. 2) show the Curie temperatures for the minerals in each rock. Sample MM028 (fig. 2), a volcanic, has two Curie temperatures, 586 Celsius indicating the presence of magnetite, and 640 Celsius indicating the presence of hematite. Sample MM021 (fig. 2), a mafic, has a Curie temperature of 642 Celsius indicating the presence of hematite. The linearity of figure 4 is a possible indication of the presence of some

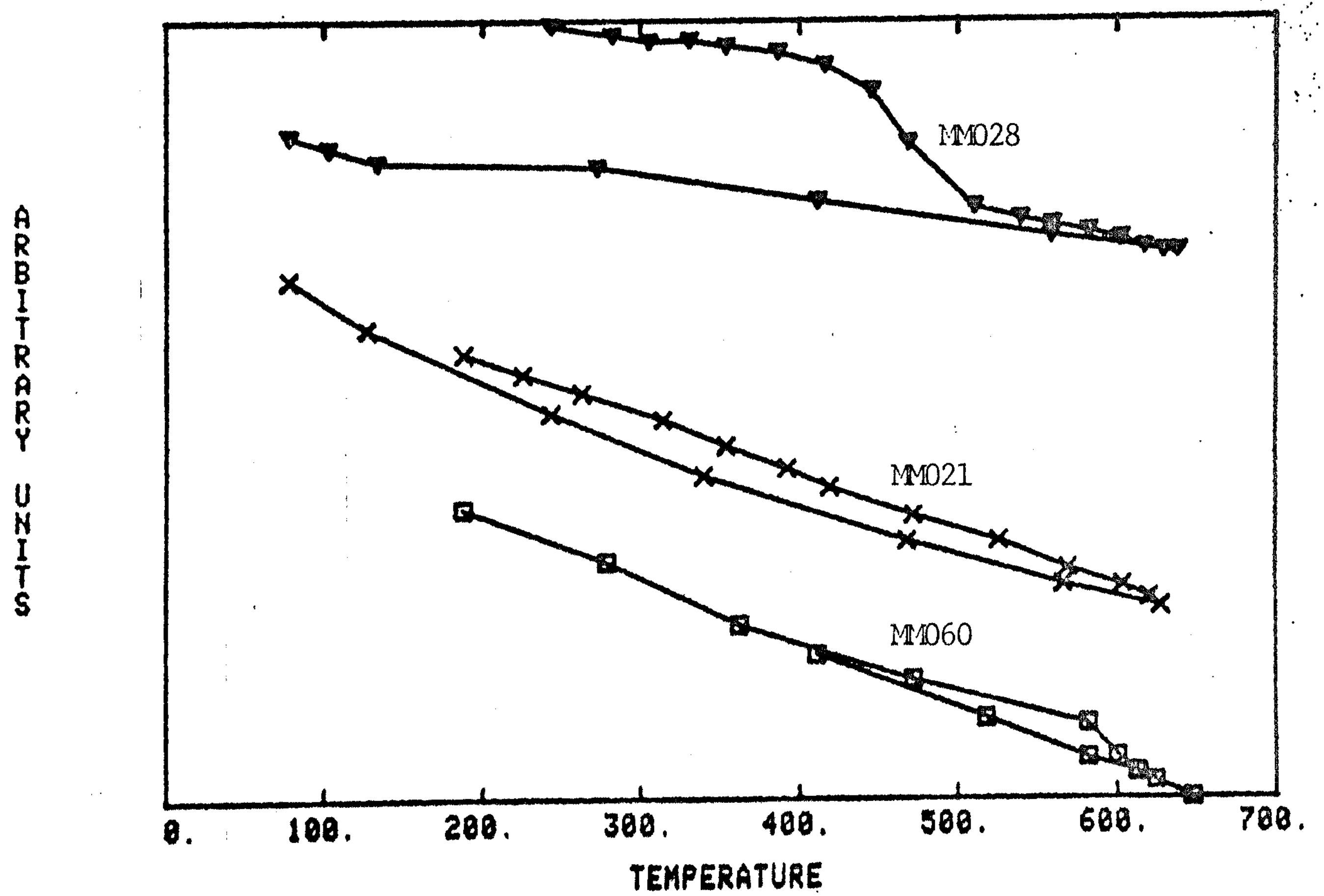

Fig. 2. Results of Curie balance tests on samples MM028 (volcanic), MM021 (mafic), and MM060 (quartzite). MM028: magnetite (Tc=586°C) and hematite (Tc=640°C); MM021: hematite (Tc=642°C); MM060: hematite (Tc=648°C).

sort of paramagnetic mineral. Sample MM060 (fig. 2), a quartzite, has a Curie temperature of 648 Celsius indicating the presence of hematite. The hematite, which seems to be present in all of the samples, probably is a result of the alteration of magnetite, during metamorphism, according to Condie (personal communication).

The thermomagnetic curves indicate that the predominant magnetic mineral is hematite (fig. 2), although magnetite is a major constituent in the Sevilleta Formation. It is not believed that the timing of the magnetization recorded by these two minerals is different as Zijderveld diagrams of the step-wise demagnetized data show that the rock has a single magnetic componet, i.e. a single straight line (figs. 3-5). Most of the samples have Zijderveld diagrams of this nature. Samples which exhibted nonlinear graphs (fig. 4) do so in the lower part of their coercivity spectrum. This is probably due to viscous remanent magnetization (VRM) acquired since the time of primary magnetization.

At an indivdual site the kappa value is, in general, very large. This indicates that there is very good clustering between the specimens of a sample. However, the kappa value for all the samples is quite small because of the scatter between sample data. The mean sample directions for 400 or 500 degree Celsius demagnetization steps, depending upon which have a larger value for kappa, are plotted sequentially on an equal area steronet (Schmidt

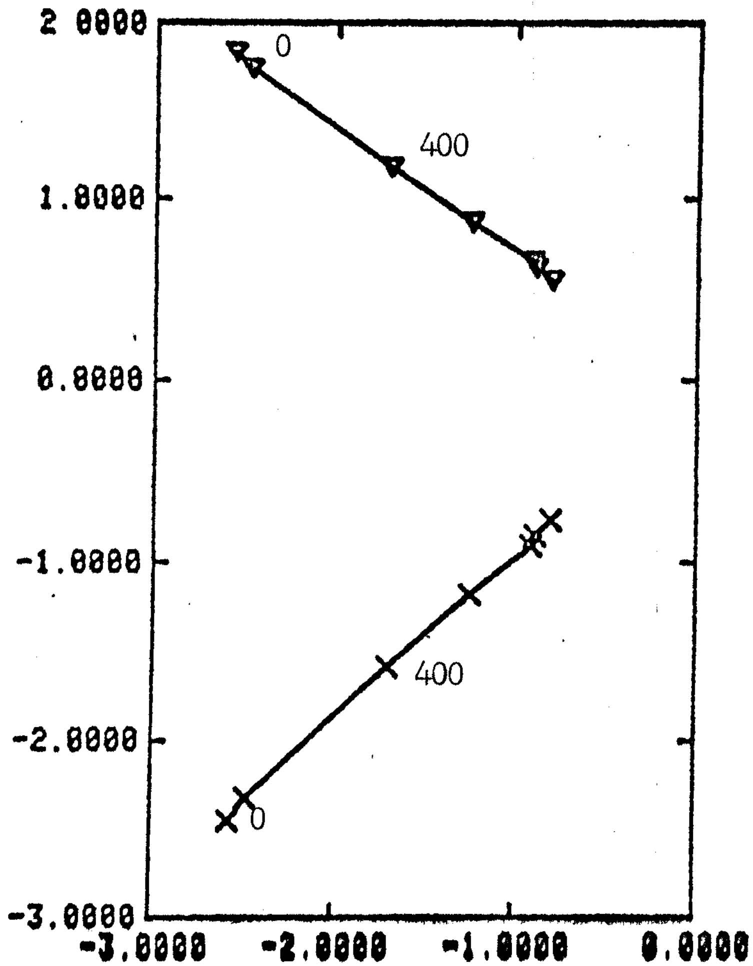

Fig. 3. Zijderveld diagram for sample MM024 (volcanic). Tick interval=10^{-2} Amp-M^2/Kg. "X"=N-E, "▽"=U-E.

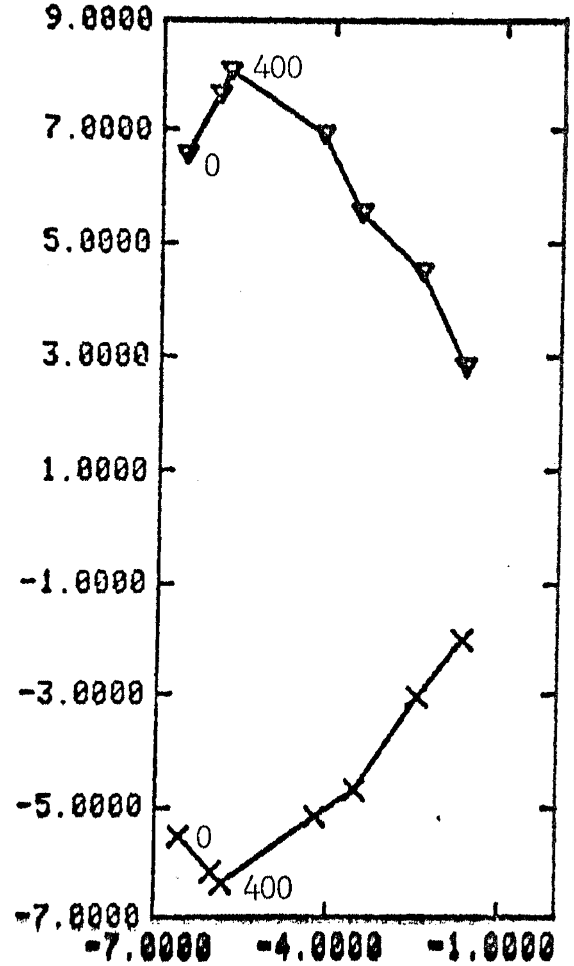

Fig. 4. Zijderveld diagram for sample MM052 (mafic). Tick interval=10^{-7} Amp-M^2/Kg. "X"=N-E, "▽"=U-E.

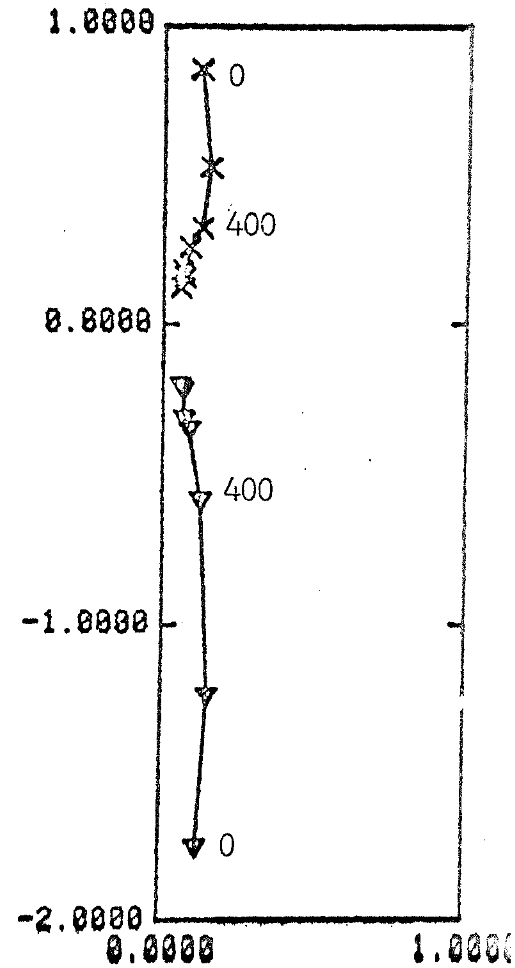

Fig. 5. Zijderveld diagram for sample MM054 (quartzite). Tick interval=10^{-4} Amp-M^2/Kg. "X"=N-E, "▽"=U-E.

net). The data seems to be randomly scattered (fig. 6). On closer inspection there is a possibility of several reversals. The reversals may be geomagnetic and/or tectonic in nature. Arguments can be made for and against both types of reversals, although evidence favors tectonic.

The frequency at which geomagnetic reversals would had to have occurred is greater than what seems reasonable based upon what is currently known about Precambrian reversal rates (Morgan and Briden, 1979). Within ten meters a section of rock may appear to have a complete cycle (normal-reverse-normal) of polarity changes. This would imply that there was a very slow accumulation of material when the unit was forming, assuming that the primary magnetization was not reset during the ensuing metamorphic event. This is not reasonable since the volcanic sequence was probably formed in an interval of around 100,000 years (Condie, personal comunication). Another possibilty is that a "weathering front" moved through the sequence, possibly during regional uplift. The magnetite would have been slowly oxidized to hematite, thus resetting the magnetization. However slow oxidation does not seem plausible since in the volcanics, where both magnetite and hematite are found, there is only one component of magnetization. Multiple magnetization components should be seen in the volcanics if a "weathering front" had moved slowly through the sequence. Since the Zijderveld diagrams (figs. 3-5) indicate a single component of magnetization,

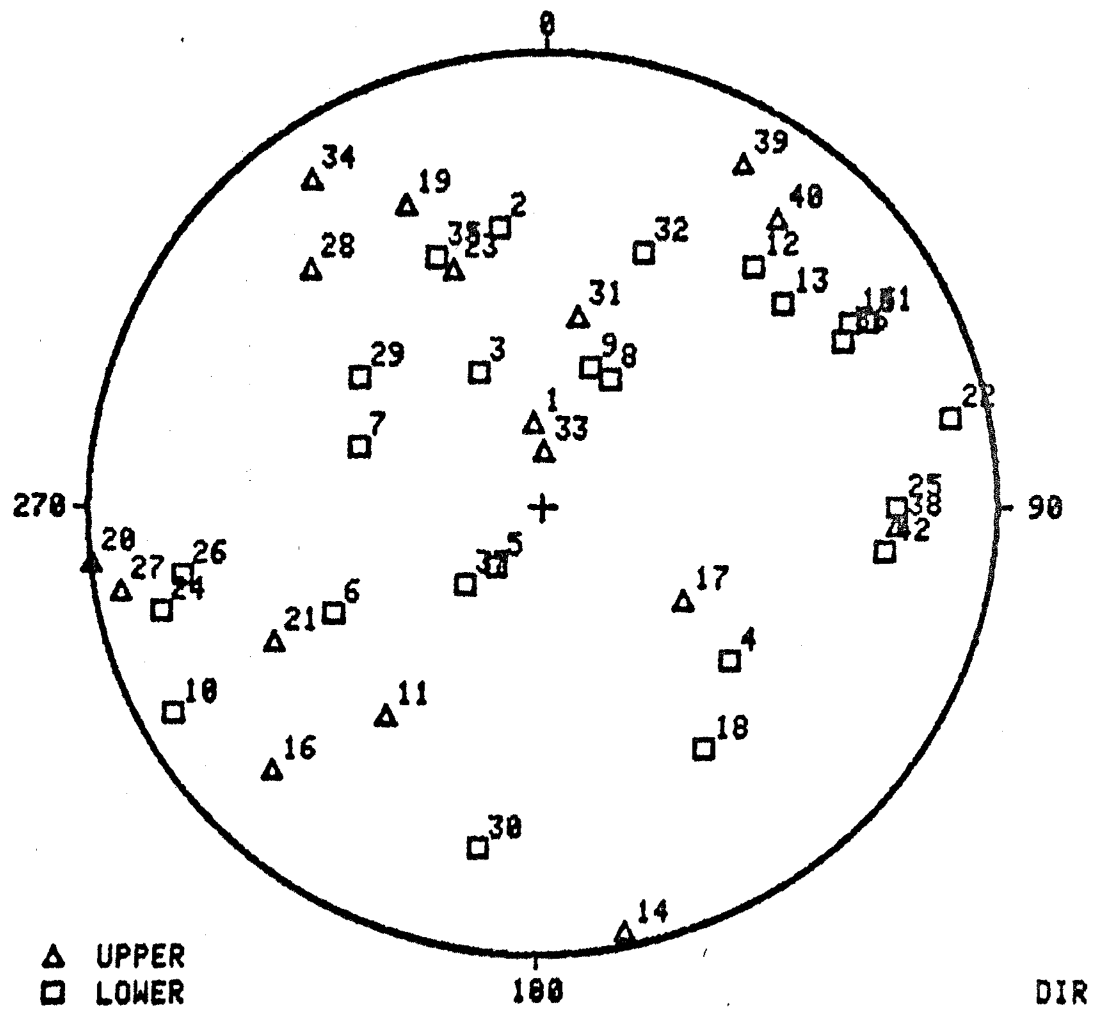

Fig. 6. Mean magnetization directions for demagnetization temperature of 400 or 500 Celsius, depending on which has a larger kappa value.

the rock magnetization had to be acquired quickly with respect to APW. If there had been significant APW, it would have showed on the Zijderveld diagrams as a curve, which did not happen.

Tectonic reversals seem to be a more reasonable explanation for the scattered data. The structure in the area is very complex. On close inspection of the rock small minor closed folds can be seen. They vary in wavelength up to several meters. There does not seem to be any consistency in wavelengths. These minor folds may be superimposed on large scale tight to isoclinal folds which in turn would be superimposed on the major syncline in the area. To unfold the structure is a very complex problem (figs. 7,8).

In figure 7 the strike and dip measurments of the compositional layering, which were recorded for each outcrop, were applied to the data using a fold test procedure described by Schmidt (1974). The procedure rectifies a dipping bedding plane on the limb of a plunging fold. A problem occurs when the fold axis is known to have only a slight plunge and the limbs of the fold are steeply dipping. This constrains the direction of the fold axis and the strike of the limbs to be nearly parallel. In this study the major synclinal fold axis was thought to have a trend of about N30E with a plunge nearly horizontal (Condie and Budding, 1979). To rectify the layering, it was assumed

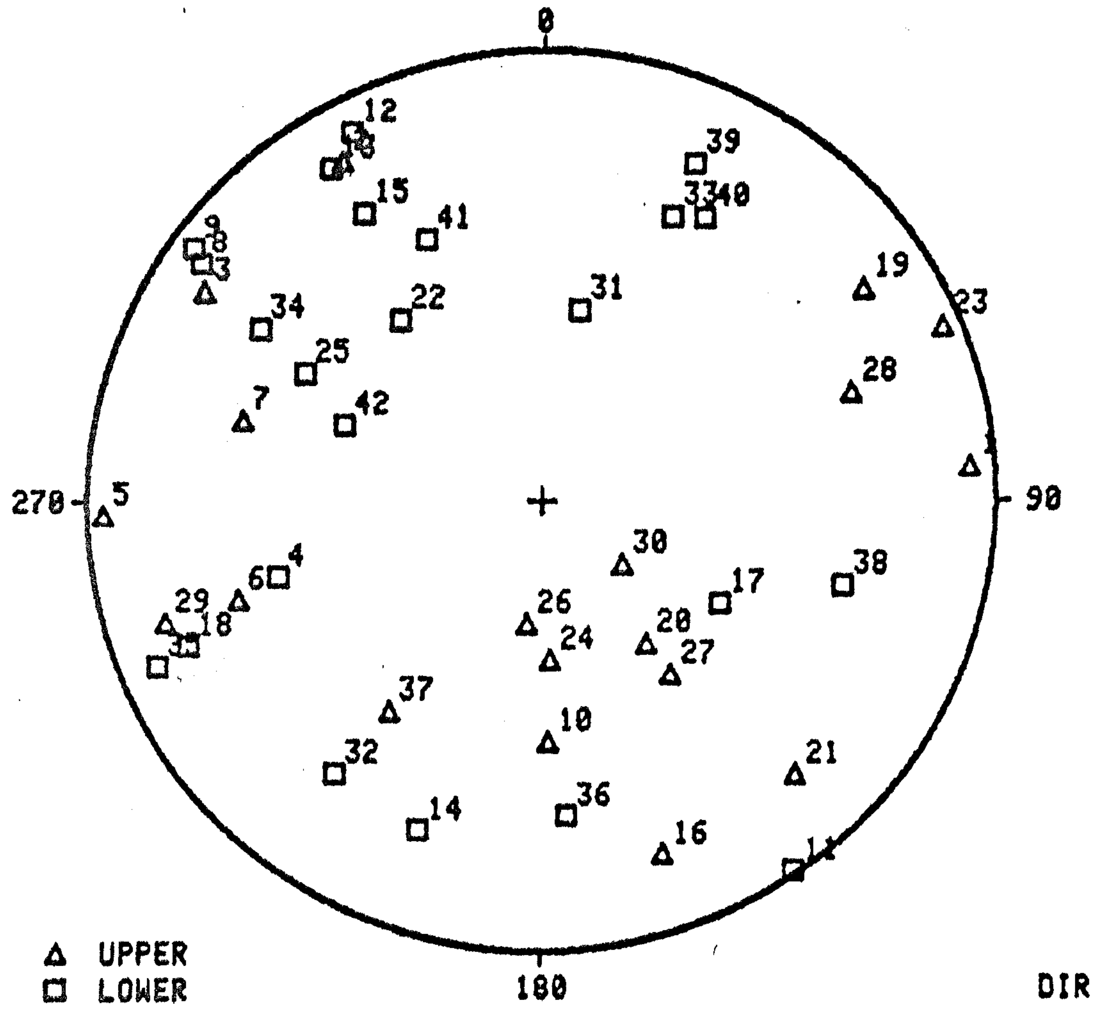

Fig. 7. Fold test on mean magnetization directions (400-500) assuming that all sites are on the east overturned limb. The fold axis is taken to be parallel to the strike of the compositional layering.

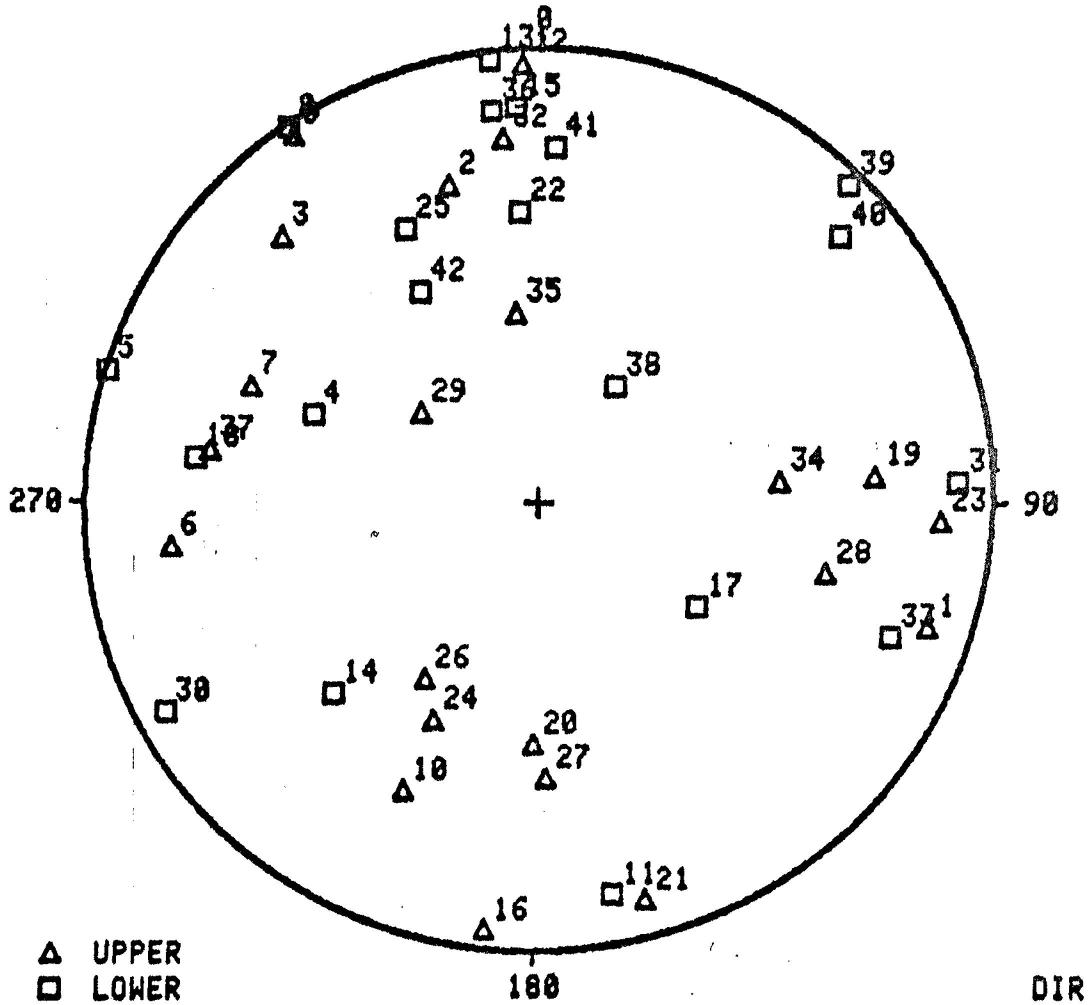

Fig. 8. Fold test on mean magnetization directions (400-500) assuming that all sites are on the east overturned limb. The strike of the compositional layering is taken to parallel with the fold axis.

that the strike of the fold axis was parallel to the measured strike of the compositional layering. The resulting steronet (fig. 7) still shows the data to be fairly scattered.

In figure 8 the same rectification procedure was used, as just mentioned previously. Although for this case the strike of the layering was assumed to be parallel to the strike of the fold axis (N30E), the data is still widely scattered.

Detailed structural observations were made on the largest outcrop where samples were collected, sites 21-36, in an attempt to unravel the structure. Strike and dip measurements of the compositional layering were taken at each sampling site. An unresolved problem in collecting these field measurements is that in the apparent isoclinal folding it was not able to be determined from which limb a sample was removed. Figure 9 shows the mean magnetization directions for sites 21-36. Figure 10 is the results of individually rotating sites 21-36 by the strike and dip measurements recorded at each site. There was not a large difference in strike or dip measurements between sites. These measurements were applied, as previously, to the data in an attempt to get the data to cluster for a single outcrop (figs. 9,10). Unfortunately, the data this did not cluster any better than previous plots since the data for sites 21-36 were all rotated by about the same amount.

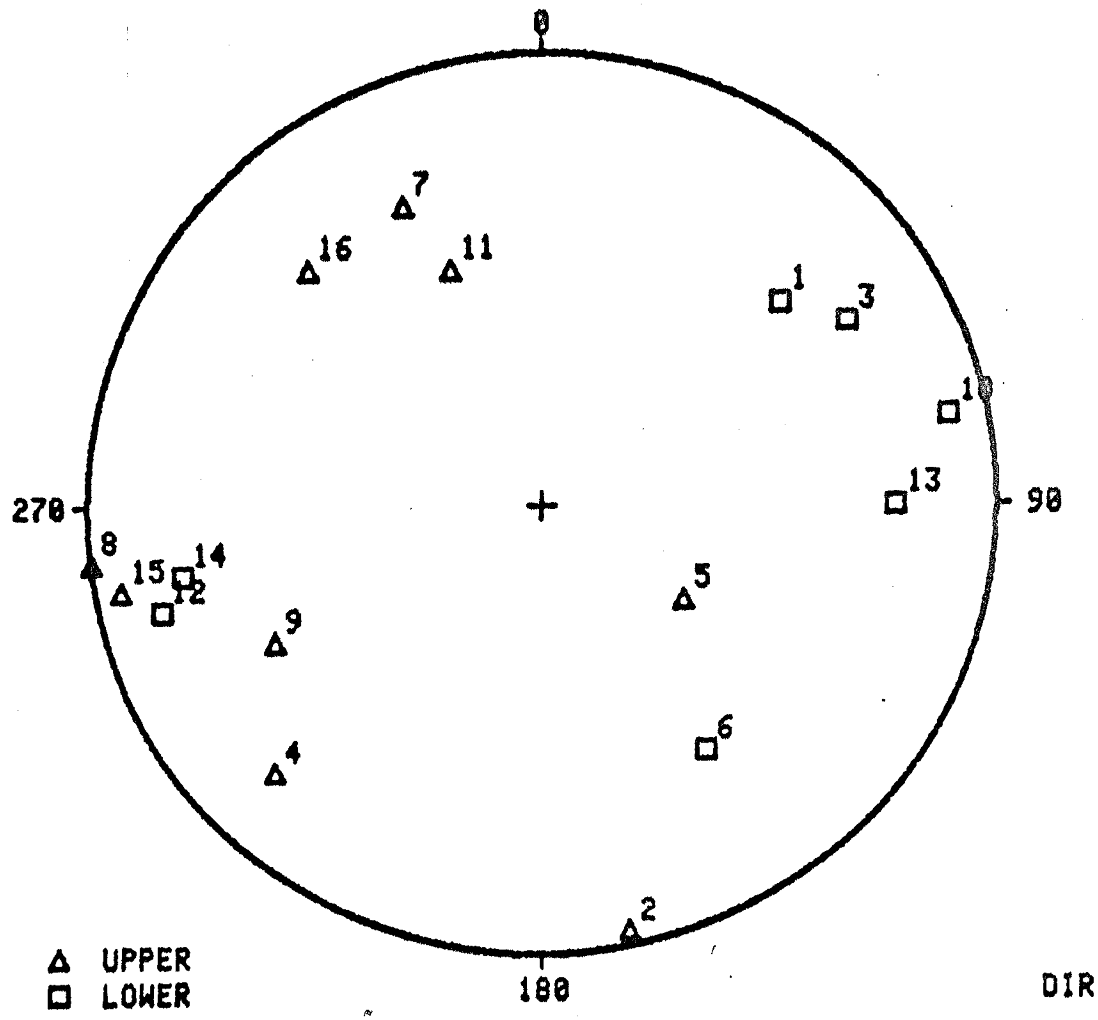

Fig. 9. Mean magnetization directions for sites 21-36.

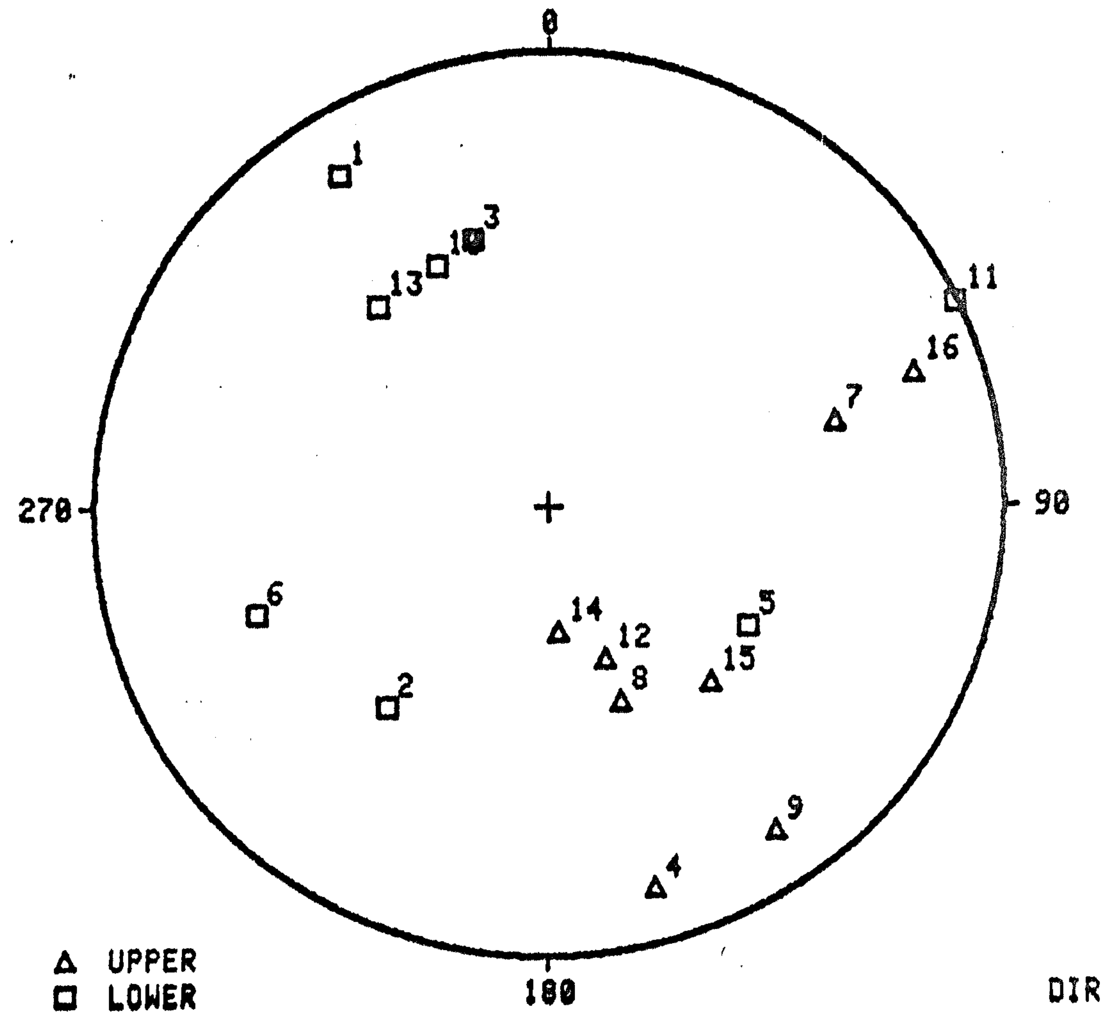

Fig. 10. Fold test on mean magnetization directions for sites 21-36 using structural data measured around each site.

CONCLUSIONS

The medium grade metamorphic rock of the Manzano Mountains yielded widely scattered paleomagnetic data. Fold tests applied to the data did not yield significantly better clustering. One of the largest problems with this area is that the structure is very complex. When this study was initialy started the structure was thought to be simply a large synclinal fold. This was later found not to be true. The data for any single sample is, in general, very consistent and shows a single componet of magnetization. The magnetization was probably acquired during regional metamorphism at about 1.4 Ga. The Curie balance work conducted for this study showed that all of the rocks have hematite as magnetic carrier. The hematite seems to be a result of the alteration of magnetite during metamorphism.

More work needs to be done both on the structure and paleomagnetics of the Manzano Mountains to be able to conclude more firmly whether the reversals observed are in fact tectonic. It is suggested that detailed structural analysis be performed to determine how many generations of folding are present. Further paleomagnetic studies should be done in conjuction with the structural analysis. Sampling needs to be taken across one of the minor folds with sample spacing on the order of 5-10 centimeters. The results of the structural study can then be applied to the newly acquired paleomagnetic data by means of fold tests.

This will hopefully confirm the idea that the paleomagnetic reversals are in fact tectonic. With further work much more can be learned about the paleomagnetics of the Manzano Mountains.

ACKNOWLEDGMENTS

This research was funded by Research Corporation, Cottrell Research Grant, and New Mexico Bureau of Mines. I would like to express my thanks to Dr. Michael Payne, my advisor, who taught me everything I know about paleomagnetism.

REFERENCES

Berger, Glenn W. and York, Derek, (1980), Reinterpretation of North American apparent polar wander curve for the interval 800-1500 Ma, Can. J. Earth Sci., 17: 1229-1235.

Callender, Jon, (1981), Personal communication.

Condie, K.C., (1981), Personal communication.

Condie, K.C. and Budding, A.J., (1979), Geology and geochemistry of Precambrian rock, central and south-central New Mexico, New Mexico Bureau of Mines and Minerals Resources, Memoir 35.

Dunlop, David J., (1979), On the use of Zijderveld vector diagrams in multicomponent paleomagnetic studies, Phys. Earth Planet. Int., 20: 12-24.

Irving, E., (1979), Paleopoles and paleolatitudes of North America and speculation about displaced terrains, Can. J. Earth Sci., 16: 669-694.

Irving, E. and McGlynn, J.C., (1976), Proterozoic magnetostratigraphy and the tectonic evolution of Laurentia, Phil. Trans. R. Soc. Lond., A280: 433-468.

McElhinny, M.W., (1979), Palaeomagnetism and Plate Tectonics, University Press, Cambridge, p. 23.

Morgan, G.E. and Briden, J.C., (1980), Aspects of Precambrian palaeomagnetism, with new data from the Limpopo mobile belt and Kaapvaal craton in southern Africa, Phys. Earth Planet. Int., 24: 142-168.

Myers, Donald A. and McKay, E.J., (1972), Geologic Map of the Capilla Peak Quadrangle, U.S.G.S., Washington, D.C.

Reiche, P., (1949), Geology of the Manzanita and north Manzano Mountains, New Mexico, Geol. Soc. Am., Bull., 60: 1183-1212.

Schmidt, V.A., (1974), On the use of orthogonal transformation in the reduction of paleomagnetic data, J. Geomag. Geoelectr., 26: 475-486.