SOME MAGNETIC PROPERTIES OF A PART OF PIKES PEAK IRON DEPOSIT, MARICOPA COUNTY, ARIZONA

by

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ABSTRACT

Pikes Peak iron deposit occupies an extensive zone in regionally metamorphosed rocks of the older Precambrian Alder group of the Yavapai series. It is comprised of elongated and conspicuously banded lenticular bodies striking N60E and dipping 70° NW, in general conformance with the schistosity and bedding of the local country rocks. Having an estimated potential reserve of 100 million tons at an indicated grade of 30 percent iron, the deposit consists largely of black specular hematite and some admixed magnetite in fine-grained quartz.

Detailed ground magnetometer surveys and application of the methods of rock magnetism to the study of 170 oriented specimens have demonstrated that both the iron mineralization and the country rocks of the Pikes Peak deposit have magnetic properties which, though highly variable, are related to regional and local geologic structures. Results of 14 magnetic profiles, each extending 1600 feet across the deposit, show the vertical intensity gradient to rise slowly in approaching the mineralized zone from the southeast, change sharply within short linear distances over the deposit, and smooth out on the northwest flank at a somewhat higher level than on the opposite side.
Anomalies of vertical magnetic intensity as great as 38,860 gammas generally trend along the strike of the deposit. A transverse trend in these anomalies, recognized over the iron mineralization next to an andesite porphyry dike intersecting the deposit, is attributed to alteration of the magnetic properties by the intrusion. Within the schistose country rocks, there is evidence to suggest a magnetic susceptibility anisotropy related to the plane of foliation.

Magnetic susceptibilities within specimens of iron mineralization range from 7 to $4,180 \times 10^{-5}$ emu/cc and average $792 \times 10^{-5}$ emu/cc. There is a general decrease in susceptibility from southwest to northeast along the deposit. The average intensity of induced magnetism was found to be $419 \times 10^{-5}$ emu/cc. Exhibiting intensities of remanent magnetism between 4 and $43,667$ emu/cc, the ore specimens average $2,792 \times 10^{-5}$ emu/cc for this property. The directions of remanent magnetism in ore specimens show considerable dispersion, but declinations fall into two definite groups which are nearly $180^\circ$ apart and roughly parallel the length of the deposit. About two-thirds of these specimens have their remanent magnetism directed downward. Most ore specimens taken near the dike
have their remanent magnetism directed upward and drawn somewhat parallel to its strike. A certain stability is indicated for the remanent magnetism inasmuch as its direction in the vast majority of specimens is markedly different from that of the present geomagnetic field.

The ratio of remanent to induced magnetism in the ore specimens varies from 0.04 to 220.25 and averages 11.17; values increase roughly in going northeast along the deposit. Comparison of the magnetic susceptibility, remanent magnetism and specific gravity of specimens indicates that those properties generally increase in magnitude with one another. However, for any set value of one property there is a wide range in magnitude exhibited by the others, and no steadfast relationship is evident. No distinguishable difference is noted in the susceptibility, ratio of remanent to induced magnetism or specific gravity of specimens when differentiated on the basis of whether their remanent magnetism is inclined upward or downward.

Information obtained by paleomagnetic analysis indicates that the remanent magnetism presently exhibited by the Pikes Peak deposit was largely acquired near the end of the older Precambrian, prior to deposition or
induration of rocks of the Grand Canyon system. The recognized dispersion in the directions of remanent magnetism is considered to be due in part to pressure induced components caused by the northwest directed compressional forces active during the Mazatzal revolution. A late Cambrian date for intrusion of the andesite porphyry is suggested by the virtual geomagnetic pole obtained from specimens collected adjacent to the dike. This pole not only plots on the established polar wandering path based on American rocks, but its polarity is consistent with that obtained for almost all rocks of late Cambrian or early Ordovician age which have undergone paleomagnetic investigation.

A definite correlation is shown between the gross magnetic effects as measured in the field with a vertical intensity magnetometer and the magnetic properties as measured in specimens from the same area by laboratory methods. Such correlated measurements, coupled with the high average ratio of remanent to induced magnetism existing within the ore mineralization, provide the basis for concluding that the gross magnetism over the Pikes Peak deposit is largely controlled by the direction and intensity of the remanent component of magnetization.
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INTRODUCTION

General Statement

This study of the Pikes Peak iron deposit is an initial step in a long-range research program on the magnetic properties of iron deposits planned by the Rock Magnetism Laboratory of the University of Arizona. Under the auspices of the Department of Geology and the direction of Dr. R. L. DuBois, the Laboratory presently provides apparatus for studying those phases of rock magnetism reported here. With future expansion, it is expected that a major portion of the work carried on will deal with different representative types of iron deposits. Development of equipment to facilitate demagnetization experiments, organization of petrographic and analytical chemistry sections, and administration of a specimen library will make greater refinement possible in later studies and will allow supplemental work on deposits treated earlier in the series. Efforts concerned with individual iron occurrences will be handled in graduate theses and dissertations and reports published in professional journals. The final goal, however, is a comprehensive work on the magnetic properties
of iron deposits. It was with this goal in mind, and with an earnest desire to see the Laboratory grow and gain stature through its accomplishment, that this beginning study was carried on.

**Purpose of Investigation**

Pikes Peak iron deposit, in north-central Maricopa County, Arizona, is comprised of steeply dipping, elongated, lenticular bodies which occupy an extensive zone in schistosose rocks of the older Precambrian Alder group of the Yavapai series. The mineralization constituting these conspicuously-banded bodies is made up of fine-grained quartz of various colors alternating with fine-grained specular hematite having some admixed magnetite. Foliated muscovite layers, with varying amounts of chlorite and plentiful quartz, are intercalated with the iron-rich bands and increase in abundance about the periphery of the bodies, ultimately forming the barren country rock. Farnam and Havens (1957) described the property and estimated the potential reserves to be about 100 million tons with an indicated grade of around 30 percent iron.

In general, the object of this work was to study the magnetic properties of a deposit of this type, to relate these properties to the geology and ore occurrence, and to determine the relationships between the different
components contributing to the gross magnetism. Evaluation of the remanent magnetism of the deposit, in light of modern paleomagnetic hypotheses, was also an object of interest.

Specifically, field and laboratory procedures were planned and carried out to accomplish the following purposes:

1. Determine the geology of the area to a degree adequate for its description in a study such as this.

2. Apply the methods of rock magnetism in studying the areal distribution of such measured parameters as the magnitude of magnetic susceptibility and the vectorial qualities of the induced, remanent and total magnetism, both within and adjacent to the deposit.

3. Differentiate among the magnetic properties of the iron mineralization in general, mineralized areas affected by intrusion and faulting, and the country rock.

4. Relate the geology and known extent or iron mineralization in the area to its gross magnetic aspects as determined by a vertical intensity ground magnetometer survey.

5. Determine the detailed nature of the magnetic field associated directly with the iron occurrence and delineate the complexity of such a field.

6. Test the stability of the remanent magnetism of collected specimens and investigate the possibility of
there being some physical or geological difference involved in the case of those showing reversed magnetism.

(7) Define the relationship of measured induced and remanent magnetic components in the various groups of specimens to their total magnetism.

(8) Compare the magnetic properties of specimens to their mineral composition as inferred by specific gravity.

(9) Utilize paleomagnetic methods in attempting to date the deposit and related geologic structures, or to determine their history of origin and magnetization.

(10) Provide data relating the gross magnetism of a part of the deposit to the measured magnetic properties of specimens on an areal basis and thus show three-dimensionally the contribution of remanent and induced fractions.

**Location and Extent of Area**

Situated in the Hieroglyphic Mountains, in the extreme north-central portion of Maricopa County (12°26'W, 33°48'N), Pikes Peak iron deposit is only 37 miles northwest of Phoenix (Plate 1). This is 7 miles west of Lake Pleasant, in the Pikes Peak (Morgan City) mining district as shown on the map of Wilson, O'Haire and McCrory (1961). The iron occurrence, crossing the boundary
PLATE I

INDEX MAP OF PIKES PEAK IRON DEPOSIT
between T. 6 N., R. 1 W. and T. 6 N., R. 2 W., extends more than 3 miles along a line bearing N60E and is covered by a group of well-marked mining claims. The main route into the area leaves U. S. Highway 60 on the north side of Beardsley Canal, some 2.5 miles northwest of the village of Beardsley, and passes 12 miles due north over an unimproved road before reaching the claims. The area treated is 3900 feet in length, 1600 feet wide, and is centrally located along the iron deposit. It contains 143.3 acres, covers the greater part of 9 claims in the existing group, and lies almost entirely inside S\textsuperscript{1}/\textsuperscript{2} SW\textsubscript{1}\textsuperscript{4} sec. 18, T. 6 N., R. 1 W. Within the main area is a small one, 5 feet by 5 feet, handled independently for purposes which will become apparent.

Method of Investigation

In carrying out this study, 21 days were devoted to field work. A reconnaissance of the area was made on February 11, 1962. Throughout the period from February 23 to March 11, 1962, effort was concentrated on the main area. Supplementary work, concerned primarily with the small area, was done on May 18, 19, and 20, 1962.

Fourteen traverse lines were first laid out over the main area with a plane table and alidade. Small
monuments were built and labeled at chained intervals of 50 feet along the lines. These monuments allowed fast and accurate control of mapping points, magnetometer stations and specimen locations, using only a cloth tape.

After mapping the iron exposures, a ground magnetometer survey was made. The instrument used was an exceptionally portable, vertical intensity, fluxgate type, having a range of 5 gauss and a maximum sensitivity of 10 gammas per scale division.

Oriented specimens were collected from along the traverse lines and elsewhere, using a sun compass for strike determinations and an inclinometer for dip measurements. Sun shots, made off the deposit, were taken with a Brunton compass.

Measurements of remanent magnetism were made with the astatic magnetometer shown in Plate 2, Fig. 1, using the methods of Collinson, Greer, Irving and Runcorn (1957). The instrument has an operating sensitivity of $6 \times 10^{-8}$ gauss. Nagata (1961) explains the principles of such a magnetometer, and Kothavala (1959) describes the particular instrument used in some detail, though it has since undergone modification. A small core, having its original field orientation preserved, was prepared from each specimen for measurement of the remanent magnetism.
PLATE 2

Figure 1
Astatic magnetometer inside Helmholtz coils. Balanced opposing magnets are separated by a rod suspended in Plexiglas tube at center. A small mirror on the suspension reflects light back onto calibration scale when the suspension is in rest position. The Helmholtz coils impose a field effectively nullifying that of the earth, thus increasing sensitivity of the astatic suspension. A slightly unbalanced horizontal component brings the suspension to zero. Control panel adjusts current through small coils (on suspension tube) used in measuring specimen intensity. Average diameter of these coils is 5 feet 6 inches.

Figure 2
Oriented specimens taken from iron deposit. Markings on each specimen give its number, top surface, and strike and dip of the surface as it existed in situ within the deposit. Plexiglas cubes at right are specimen holders which fit carriage that is raised into position beneath magnetometer suspension (Fig. 1, above). Only 124 of the 170 specimens having their remanent magnetization measured for this report are shown. Scale in right foreground measures 30 centimeters.
Values of specific gravity were obtained by determining the mass of each core on a laboratory balance and dividing by its calculated volume. Magnetic susceptibility measurements were made with a bridge-type instrument using a field strength of approximately 50,000 gammas. A sample of each specimen was crushed to minus one-quarter inch plus one-eighth inch in size for this purpose. An IBM 650 computer was programmed to facilitate the calculations involving vectorial quantities and allowed such data to be given a variety of treatment.

**Previous Work**

Major contributions to present knowledge of the geology and mineralization in the metamorphosed region around Pikes Peak iron deposit have been made by Jagger and Palache (1905), Lindgren (1926), Wilson (1939) and Anderson (1951). In the U. S. Bureau of Mines Report of Investigation 5319, Farnam and Havens (1957) treat the iron occurrence at Pikes Peak as their principal subject. The most pertinent up-to-date work is that of Anderson and Creasey (1958), dealing with the geology and ore deposits of the Jerome area, more than 40 miles to the north.

The classic work of Nagata (1961) is a basic
reference in any study of rock magnetics. Contributions made by P. M. S. Blackett (1952, 1956 and 1962) in analyzing and delineating the many philosophical aspects of the subject are legion. Observations made by Collinson and Runcorn (1960) provide the basis for paleomagnetic dating as attempted herein. Through an exhaustive study of the literature on rock magnetism, Cox and Doell (1960) have furnished an excellent summary article.

Concerned with problems important to their individual scientific disciplines, Neel (1955), Nicholls (1955) and Graham (1956) respectively, have given valuable treatment to theoretical, mineralogical and mechanical (magnetostrictive) factors affecting the magnetization of rocks. The generation of remanent magnetism in ferromagnetic minerals by chemical reactions, a phenomenon of considerable consequence in this work, is treated by Nagata and Kobayashi (1958).

DuBois (1961, 1962) has investigated the magnetic properties of a massive hematite body and the limestone country rocks in which it exists. His papers are of pertinent interest inasmuch as they are similar in method and purpose to this one. In still another work, DuBois (1963) has studied the gross magnetic effects of a mass as a linear problem. Carrying DuBois' approach one step further, this author has treated these effects within a
part of Pikes Peak iron deposit on an areal basis.

Acknowledgments

This study was begun early in 1962 and was completed during the course of one year. Thanks are due many people who aided in its accomplishment. I am most grateful to Dr. R. L. DuBois, my thesis advisor, first for having introduced me to the fascinating field of rock magnetism and teaching me its methods, and second for having given me constant guidance and encouragement throughout this project.

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the IBM 650 computer. His efforts are gratefully acknowledged. A special word of thanks is due my wife, Lois, for her continual support and encouragement.
GENERAL DESCRIPTION OF AREA

Physical Features and Climate

Pikes Peak iron deposit is located along the southern flank of the Hieroglyphic Mountains in the northern extremity of Arizona's southwest desert section. Flat alluvial plains crossed by a complex network of washes lie directly to the south, while some of the most rugged terrain in the state is found in the central mountain section just to the north. The Wickenburg, Bradshaw and New River Mountains, all within 10 to 20 miles, extend radially around the area from northwest to northeast, respectively. The major natural drainage channel of the region is the Aqua Fria River. It intermittently flows southward across the desert plain from Lake Pleasant, 7 miles to the east, where its headwaters are contained by Carl Pleasant Dam.

Within the immediate vicinity of the deposit, elevations range between 2,100 and 2,800 feet. Intimately associated with silica, the iron mineralization is highly resistant and controls the moderately rugged topography.
Long, narrow, parallel ridges have been formed by differential weathering and erosion throughout the length of the deposit. The main area taken under study, shown in the panorama of Plate 3, exemplifies the surface expression. Along these ridges, continuity is broken where the mineralization thins or is offset by minor faulting. This results in a number of individual peaks, some more than 600 feet high, which show the prolonged, large scaled layered structure of the deposit parallel to its strike (Plate 4, Fig. 1). At a few locations, where narrow dikes cut almost perpendicularly across the iron-rich zones, depressions have been eroded and partially filled with alluvium (Plate 4, Fig. 2).

The climate of the region is semiarid. Mean annual precipitation, as measured over a 19 year period at Wittmann, 8.7 miles to the southwest, is 9.48 inches (Sellers, 1960). Most of this comes from afternoon showers and thunderstorms during July and August. The average daily maximum and minimum temperatures are 84° and 54°, while the record high and low are 117° and 16°. In general, afternoon temperatures in the eighties and above are common, though cold air off the mountains to the north may occasionally bring early morning temperatures below freezing.

The sparse vegetation of the region consists
PLATE 3

Panorama of area taken under study. View northeast from southernmost corner of main area. Nearly one half the entire portion of Pikes Peak iron deposit covered in this report is shown. The remaining half slopes away to the northwest, beyond skyline. Iron mineralization is seen along the crests and exposed in a parallel pattern extending from left (southwest) to right (northeast) through center. Saguaro, ocotillo and mesquite cover the barren schist throughout foreground. Maximum relief is on the order of 600 feet and the view reaches some 3600 feet into the distance at right.
largely of creosote bush, mesquite, and prickly pear, cholla, ocotilla, and saguaro cacti. Palo verde and ironwood trees are common along the washes.

**Regional Geology**

Pikes Peak is in an expanse of steeply dipping older Precambrian schistose rocks outcropping in the southern part of the Hieroglyphic Mountains. Long recognized as equivalent to the Vishnu schist of the Grand Canyon, these rocks were originally known as the Yavapai schist (Jagger and Palache, 1905; Lindgren, 1926). Though locally covered on the south by alluvium and on the north by volcanic rocks, they are part of an extensive schist belt exposed northward to the Colorado Plateau (Anderson, 1951).

Wilson (1939) divided the Yavapai schist into three units of the Yavapai group. These units were the Yaeger greenstone, Red Rock rhyolite and Alder series, in ascending order. An altered version of his usage is adopted on the current geologic map of Arizona. It is the Alder series that comprises the older Precambrian "schist" shown in the Hieroglyphic Mountains on the Maricopa County sheet (Wilson, Moore, and Peirce, 1957).

After exhaustive study in the Jerome area, Anderson and Creasey (1958) modified the Alder series.
Figure 1

View down strike of Pikes Peak iron deposit. Looking north-northeast toward peak situated in center of main area. Subtle differences in color and relief serve to distinguish the steeply dipping bodies of iron-formation from iron-stained schist with which it is intercalated. Note Bradshaw Mountains, masked by haze, on distant horizon.

Figure 2

Dike of andesite porphyry cutting iron deposit. Weathering and erosion of the less resistant dike has resulted in a shallow depression and cover of residual soil, leaving no surface exposure. Several small dikes and irregular masses of andesite porphyry invade the area locally. View south toward southwestern contact of dike located in main area.
On each side of the Shylock fault, a north trending structure of major proportions, they recognized a different assemblage of rocks. Those on the west they called the Alder group of the Yavapai series. According to them, the Alder group correlates with Wilson's Alder series and is from 20,000 to 30,000 feet thick. They described six formations in the group, each having two or more lithologic subdivisions. Except for a single slate unit in one of the formations, all have a volcanic source; their composition ranges from rhyolitic to basaltic. These rocks were originally composed of lava flows, pyroclastics and reworked volcanic debris interbedded with minor amounts of erosional products. Evidence of their depositional environment is lacking. They have undergone intrusion and tectonic activity resulting in mild to intermediate metamorphism.

Though three periods of deformation are discernible within the Alder group (Anderson and Creasey, 1958), the main structural event was the Mazatzal revolution (Wilson, 1939). Marking the end of the older Precambrian throughout the region, this revolution involved intense compressive forces acting in a northwest direction. It culminated in the intrusion of batholitic masses of granite. The pronounced foliation and northeast trending
isoclinal folds of the schist belt were formed at this time. As a result of the Mazatzal revolution, the region was supposedly left as part of a major landmass throughout the younger Precambrian and most of the Paleozoic (Stoyanov, 1942). Faulting occurred during the main upheaval and again in three later periods. The younger rocks of the region consist largely of unaltered Cretaceous and Cenozoic lavas, tuffs and agglomerates.

Local Geology and Description of Iron Deposit

The Alder group, then, of the Yavapai series, extends in outcrop along the west side of the Shylock fault, southward astraddle the massive coarse granite of the Bradshaw Mountains, and into the area of Pikes Peak iron deposit. In the vicinity of the deposit, phyllites, schists, and slaty rocks of the Alder group are exposed in truncated isoclinal folds over a tract 18 miles wide. With a schistosity parallel to the bedding where evidenced, they extend for 5 miles along their strike to the northeast and dip almost vertically. Arranged in parallel, the recurring lenticular bodies comprising the iron deposit lie almost in the middle of this broad exposure. Plate 5 shows the surface extent of the iron occurrence and indicates the centrally located part treated as the main area of this report. Individually, the mineralized bodies are as much
OUTLINE OF EXISTING CLAIMS

PORTION OF DEPOSIT COVERED BY THIS REPORT: 1600' X 3900' — SEE PLATE 6 FOR DETAILS

IRON DEPOSIT SHOWN IN BLACK (AFTER FARNHAM AND HAVENS (1957))

IRON OCCURRENCE IN AREA STUDIED SHOWN RELATIVE TO ENTIRE PIKES PEAK DEPOSIT
as 5,000 feet long and 300 feet wide. A zone more than 2,000 feet in width is formed where several are abreast. Conforming to the schistosity of the country rocks, these elongated lenses together strike N60E for more than 3 miles and dip between 70° and 80° to the northwest.

Covering the broadest part of the deposit as indicated by Farnam and Havens (1957), the main area is symmetrically positioned along the prominent ridges formed by the elongated bodies of iron mineralization (Plate 6, in pocket). In the southwestern half of the area, the mineralized zone is displaced by a minor fault. Striking perpendicular to the trend of the deposit, the fault trace is deeply eroded and covered by alluvium. Beyond this fault to the southwest, an andesite porphyry dike about 70 feet thick strikes N37W across the iron deposit, dipping 40° NW. Several smaller dikes and irregular masses of andesite porphyry, all with the same general trend, occur locally. Being poorly exposed, their extent is not evident.

Along the edges of the main area, grey, brown, and maroon, hematite-stained chlorite and muscovite rocks of the greenschist facies form a rough, irregular, undulating terrain (Plate 7, Fig. 1). In the west corner, light brown, fine-grained quartzite lenses form long, narrow, parallel ribs which stand in moderate relief above the
Figure 1
Steeply dipping Precambrian schist adjacent to mineralized zones. Though showing a somewhat greater development of slaty cleavage than is average locally, this exposure is otherwise typical of the terrain along the north side of the iron deposit. Looking northeast.

Figure 2
Effect of creep on dip of surface exposures. Downslope bending has altered the dip angle of schistose beds in proximity to this location by as much as 85 degrees, while changing its direction. Some of the slabby portions of iron mineralization are likewise effected, although not to this extreme. View east-northeast at side of development shaft located in northern half of area.
less resistant rocks. Near the center, the elevation increases rapidly and the effect of downslope creep is marked (Plate 7, Fig. 2). Even in slabby portions of the iron deposit dip angles have been altered by creep.

At many places next to the mineralized zone, the country rocks have weathered to loose, flaky aggregates of shiny, light grey sericite. Minute grains of magnetite, a widespread accessory mineral in the area, have altered to limonite and formed rusty streaks and patches in these scaly rocks. Elsewhere, more compact varieties have been coated with dark brown to black iron-manganese stain. Except when freshly broken, these barren rocks look identical to the siliceous iron mineralization and exaggerate its true extent.

The contacts between the iron-rich bodies and country rocks are often gradational (Plate 8, Fig. 1). Layers of iron oxides and quartz extend outward into the schists as discontinuous, parallel bands, thinning and becoming less frequent until they disappear. Within the deposit, iron oxide and silica phases form individual parallel strands as much as several feet thick. Generally, however, these components are in narrow, alternating bands interlayered with greater or lesser seams of mica schist (Plate 8, Fig. 2). The schistose seams disintegrate to leave small slabs of siliceous iron mineralization,
PLATE 8

Figure 1
Contact of iron mineralization with country rock. Note schistose structure of iron-rich rock and lack of sharply defined walls at contact. Thin veinlets or layers of iron oxides extend out into otherwise barren schist, decreasing in thickness and frequency until disappearing altogether. Iron-manganese stain often makes it impossible to distinguish bands of silica and muscovite from those of ore minerals except on a freshly broken surface.

Figure 2
Hand specimens showing parallel structure in iron mineralization. Well defined black bands and streaks are fine-grained specularite with some magnetite. The white layers and patches are microcrystalline quartz. Areas of light- to dark-brown consist of iron-stained muscovite or extremely fine-grained iron minerals dispersed in various proportions throughout chert. Red hematite occurs as tiny anastomosing veinlets cutting across the predominate structures.
disjointed by fracturing, standing in short parallel rows over parts of the deposit.

Consisting chiefly of black hematite, some admixed magnetite, and minor limonite, the iron mineralization is intimately associated with fine-grained to microcrystalline quartz. While forming over a wide scale the alternating banded structures mentioned above, hematite and quartz are intermixed in all proportions through many of the seams.

In the iron-rich bands, the hematite is most commonly a black to steel grey, only slightly platy, specular variety. Where disseminated through predominant quartz, it is often in minute, irregular, red to black grains, circled by cloudy red halos, or in small, euhedral octahedrons of martite, the variety of hematite pseudomorphous after magnetite. As the red, earthy variety, it fills delicate, anastomosing veinlets. Some residual magnetite, only partially oxidized to hematite, is present. Yellow to brown limonite fills veinlets and small, irregular cavities in the hematite. Pyrolusite is present in minute grains. Quartz, as mentioned with some feldspar and muscovite, are the principal gangue minerals. Accessory apatite exists in the iron-rich bands.

A composite sample from throughout the Pikes Peak iron deposit is reported by Parnam and Havens (1957, p. 24) to show the following percentages of chemical
constituents: Fe, 31.2; Mn, 2.8; SiO$_2$, 36.4; Al$_2$O$_3$, 4.1; CaO, 1.1; P, 0.13; and S, 0.05. According to them, neither chemical analysis nor microscopic examination could distinguish a difference between surface and underground samples. By assuming the major bodies of iron mineralization to extend 400 feet in vertical depth, they conclude the entire deposit to have a potential reserve of 100 million tons at an indicated grade of 30 percent iron (1957, p. 23).

Jagger and Palache (1905, p. 11), Lindgren (1926, p. 35), and Anderson and Creasey (1958, p. 19) all mention the existence, within the region, of iron deposits similar in structure and extent to that of Pikes Peak. These deposits are described by the various authors as comprised of ferruginous schists or quartzites, banded magnetites or jasper-magnetite beds; fairly consistently, magnetite (FeFe$_2$O$_4$) is stated to be the principal iron mineral. At Pikes Peak, hematite (Fe$_2$O$_3$) is definitely the major iron constituent. The existence of residual magnetite in the Pikes Peak deposit (Farnam and Havens, 1957) and, in most cases, minor hematite in the iron occurrences elsewhere in the region, indicates a possible genetic relationship. At least some of the other deposits, however, are not in the rocks of the Alder group (Anderson and Creasey, 1958, p. 19).
Discussing regionally metamorphosed sedimentary iron ore deposits, Lindgren (1933, p. 311) refers to hematite bearing occurrences in the Precambrian of central Arizona. The banded quartz-hematite (magnetite) ores as described by him (1933, p. 294) are nearly identical to the iron mineralization at Pikes Peak. James (1954, p. 258), in a section devoted to the oxide facies of sedimentary iron formation, describes hematite-banded rocks quite similar to those under study. Any conclusion concerning the origin of the Pikes Peak iron deposit would, however, be open to question. It may well be a sedimentary deposit in which the principal constituents, iron and silica, were chemically precipitated in an isolated basin. The primary sedimentary ore mineral may have been hematite, or magnetite (James, 1954, p. 263) which was later altered to hematite. Or the deposit may have originated by the metamorphism of detrital hematite (Gross and Strangway, 1961, p. 1349) or magnetite, or some other iron mineral. It could represent the metasomatic introduction of iron into the axis of an isoclinal fold, or into a porous sediment, followed by metamorphism; or possibly the silica was introduced into ferruginous schists (Heinrich, 1956, p. 263).
RESULTS OF MAGNETIC MEASUREMENTS

General Statement

One of the purposes of this investigation was to apply the methods of rock magnetism in studying the areal distribution of the magnetic properties over a part of the Pikes Peak iron deposit. To accommodate this purpose, 170 individual oriented specimens were collected and the original location of each is shown on Plate 6.

In an effort to determine the detailed and gross magnetic effects of specific geologic phenomena, and to utilize paleomagnetic methods of dating, the specimens were treated both individually and in a variety of groups. Specimen Nos. 1 through 125 were considered a major group representing the iron occurrence within the "main area" in general. These 125 specimens were divided into 14 minor groups collected from Lines 1 through 14, as laid out across the area (Plate 6). Coming from the small area between the andesite dike and fault which cut the deposit, the 26 specimens numbered 126 through 151 comprise a second major group exemplifying the iron mineralization.
effected by intrusion and concentrated tectonic stress. They are broken into 5 minor groups, designated Lines A through E, respectively. Constituting a third and undivided major group, the 19 specimens numbered 152 through 170 were obtained from the country rocks and are treated as typifying the local exposure of "schist." Average data were calculated for the magnetic properties of each of the above groups as well as for combinations of them.

Because the magnetic measurements of specimens from Pikes Peak iron deposit are repeatedly referred to throughout this work, they have been tabulated and placed in the rear as Tables A-1 and A-2, following Appendix.

Measurements of Individual Specimens

Magnetic measurements of the 170 individual oriented specimens are presented in Table A-1. The number identifying each specimen is in Column 1 of the table. Column 2 lists the field location of the specimen by a coordinate giving the line number and footage northwest along the line to where it was collected (Plate 6). Measured values of magnetic susceptibility are in Column 3. The induced magnetism of each specimen, as calculated from its magnetic susceptibility and knowledge of the earth's present magnetic field at the collection site, is given in Column 4. Its direction is taken to be that of the
average field of the earth now existing in the vicinity: N14E and 60° downward.

Columns 5, 6 and 7 list the values defining the measured remanent magnetization of the specimens. The azimuthal declination of the RM from north is given by Column 5, while its inclination above (negative) or below (positive) the horizon is in Column 6. Tabulated in Column 7 is the intensity (or strength) of the RM for each specimen. In Column 8 is the ratio of remanent to induced magnetism - \( Q_n \) of Konigsberger (1938) - as determined from measured and calculated data.

The variables approximately defining the total magnetism of each specimen as it existed in place are given in Columns 9, 10 and 11. They include the declination and inclination of the TM and its intensity, respectively. These values were derived by vector addition of the components of remanent and induced magnetism obtained from each particular specimen in the manner previously described. Listed in Column 13 is the specific gravity of each specimen.

Passing downward through Table A-1, the specimens from the mineralized zone of the main area are arranged consecutively from southeast to northwest according to their original location along each of the 14 separate lines crossing the deposit. From specimen No. 126 through
Average Magnetic Measurements

The average magnetic measurements as calculated for the various groups of specimens are set forth in Table A-2. A symbol used in distinguishing the particular group on various plates within the text is given in the first column to the left of the table. Column 2 provides a brief description of each group and indicates the specimens comprising it. The average intensity of induced magnetism as calculated for each group is in Column 3. Since the induced component is assumed to have the same direction in all specimens, each mean value results from an arithmetic average.

Average data concerning the remanent magnetism with each specimen in the group being given equal weight are tabulated in Columns 4, 5 and 6. These data include the declination, inclination and intensity, in that order. The values in Columns 4 and 5 were determined by taking a vectorial average of the RM directions obtained from the specimens with their intensities reduced to unity. Such an
approach allows the average directional qualities to be used in calculating virtual magnetic pole positions (Fisher, 1953; Cox and Doell, 1960, p. 668; Nagata, 1961, pp. 284 and 286). The average intensity given in Column 6 is a straight arithmetic mean, calculated simply by adding the measured intensities of RM for the appropriate specimens in the group and dividing by the number represented. It has no directional significance.

Intensity-weighted average values for the declination, inclination and intensity of the remanent magnetism for the various groups are listed in Columns 7, 8 and 9, respectively. Here the values were obtained by vector summation of the measured RM of each specimen in the group, weighted according to its actual magnitude of intensity. This method considers each group as a point source, with the resultant describing the gross effect of its RM components.

Columns 10, 11 and 12 give the variables defining the average total magnetism of the individual groups. In numerical order, these columns list the declination, inclination and intensity of the average total magnetism of each group. Obtained by taking an intensity-weighted vector sum of the average weighted induced and remanent magnetism, the recorded values give the orientation and intensity of the gross magnetization of the mass represented by each
group. The treatment given minor groups comprised of specimens from along a single line is similar to that used by DuBois (1963). However, in the case of major groups and their combination, the gross magnetic effects over an area are derived by considering the magnetism of the mass within it to be a single dipole. Though limited to some extent by the neglect of important mass effects, such a treatment does have practical application as indicated by the work of DuBois and illustrated in subsequent pages.
GROUND MAGNETOMETER SURVEYS

Survey of Main Area

General Statement

In order to relate the geology and known extent of iron mineralization to the gross magnetic aspects of the area, a vertical magnetic intensity survey was made along the traverse lines of Plate 6. Covering a total linear distance of 22,400 feet, the survey resulted in 14 magnetic profiles spaced 300 feet apart and bearing N30W for 1600 feet across the deposit. These magnetic profiles are shown as solid curves on Plates A-1 through A-14, in the Appendix. Taken 3 feet above the ground, all magnetometer readings were corrected for diurnal variation and then reduced to give a zero value at a Main Reference Station located away from the iron deposit (Plate 6). To facilitate study of the profiles with the map of Plate 6, their horizontal scale is the same.

Areal Distribution and Magnitude of Anomalies

The magnetic profiles of Plates A-1 through A-14
show the majority of positive anomalies within the main area to be fairly continuous along its length and to correlate directly with the exposed portions of iron mineralization. Portions of the profiles showing a relatively low positive intensity or gently sloping gradient are generally associated with areas of barren schist. These features are illustrated by the roughly central location of the magnetic highs in all the profiles and are particularly evident along Lines No. 1 (Plate A-1) and No. 10 (Plate A-10).

With reference to the arbitrary datum, positive intensities exceeding 10,000 gammas occur at various places over the iron deposit along 5 different traverse lines (Plates A-1, A-2, A-4, A-7 and A-9). Those in excess of 20,000 gammas were recorded over the ore mineralization exposed on 3 such lines (Plates A-1, A-4 and A-9). Most commonly, the large positive anomalies rise sharply to their peak value and fall off in a similar manner within a few tens of feet.

Relative negative anomalies are fewer and less extensive along the length of the area than are the positive ones. No negative intensities occur on 3 of the 14 lines (Plates A-10, A-11 and A-12), and only those of about -1,000 gammas or smaller were recorded along 7 others (Plates A-1, A-2, A-3, A-5, A-6, A-9 and A-14).
Where negative values near -2,000 gammas or greater were found (Plates A-4, A-7, A-8 and A-13) they do not as a rule extend across to adjacent lines. An important observation is that the outstanding lows most often occur in the broader and more persistent iron-rich bodies.

The main high of +28,040 gammas is located from 620 to 640 feet along Line No. 1 (Plate A-1), while the low reading of -10,820 gammas is between 970 and 980 feet on Line No. 7 (Plate A-7). Combined, these values correspond to a Class 1 anomaly (Jakosky, 1961, p. 211) of 38,860 gammas.

On the magnetic profile of Line No. 5 (Plate A-5), two subtle effects of the andesite porphyry dike are perceptible. First, in crossing the iron deposit and approaching nearer the dike, the intensity gradient along the line is somewhat stabilized. Then, between 1,050 and 1,120 feet out, in a barren area covered by alluvium (Plate 6), an isolated magnetic high occurs where the line intersects the plane of the buried intrusion. Also, when the profile of Line No. 5 is compared with that of Line No. 6 (Plate A-6), the 200 feet of horizontal displacement along the fault between the two is discernible.

In general, the profiles show the vertical magnetic intensity to increase gradually until reaching the south-east exposure of ore mineralization. Once over the
deposit, large changes in intensity take place within extremely short linear distances. Then, northwest of the iron-rich zone, the gradient smooths out at a somewhat higher level than on the opposite side. Such a generalized profile is more or less typical of a thin magnetic layer dipping steeply to the northwest in the northern hemisphere (Jakosky, 1961, p. 199). The sharp changes in gradient over the ore deposit are due to widely differing magnetic properties from place to place within the siliceous iron mineralization. That the majority of anomalies are directly related to the direction and intensity of the remanent magnetism, and are only slightly affected by the induced component, will be shown in the section entitled Interpretation of Results.

Survey of Small Area

To determine the complexity of the magnetic field associated directly with the iron mineralization of the Pikes Peak deposit, a detailed magnetometer survey was made of the small area. Adjacent to the andesite porphyry dike in a rich zone of iron-oxides (Plate 6), the area exhibits involved magnetic characteristics typifying much of the deposit. Aimed at delineating these characteristics on a fine scale, the survey included 242 closely spaced magnetometer readings within an area of 25 square
feet. Results of the survey were reduced to an arbitrary datum giving a low value of zero and are contoured on the Vertical Intensity Map of Plate 9. The extreme intensities are due to the fact that measurements were taken directly on the exposed iron deposit.

The most important feature of the map of Plate 9 is the general trend of its isanomalic lines. Though the small area is laid out parallel to the trend of the deposit in one direction, the lines of equal vertical intensity show a marked trend nearly perpendicular to this. In view of the close control used in plotting the map, it is doubtful that any interpretation of the incorporated measurements could result in a markedly different pattern. Since the banded structure of the mineralization is distinct and obviously parallel to the length of its exposure both in and beyond the small area, alignment of the isogams across the deposit rather than along it seems abnormal. This transverse trend is closely parallel to the strike of the nearby dike, however, and its intrusion may well have caused the measured intensity pattern.

One explanation would be alteration of the magnetic properties along the intrusion by thermal zoning. Magnetic susceptibility, and therefore the intensity of induced magnetism, is related to grain size (Akimoto,
VERTICAL MAGNETIC INTENSITY MAP OF SMALL AREA
SHOWING LOCATIONS AND SUSCEPTIBILITIES OF SPECIMEN NUMBERS 126 THRU 151 WITH DIRECTION OF TOTAL MAGNETISM AS DETERMINED FROM LABORATORY DATA
MAGNETOMETER OBSERVATIONS TAKEN ON GROUND SURFACE OVER SPECIMENS, AT GRID INTERSECTIONS AND CROSS MARKS: 242 STATIONS
130 — SPECIMEN NUMBER
1650 — SUSCEPTIBILITY, 10^-5 emu/g
9° — INCLINATION OF TOTAL MAGNETISM
DECLINATION OF TOTAL MAGNETISM WITH UPWARD INCLINATION
DECLINATION OF TOTAL MAGNETISM WITH DOWNWARD INCLINATION
SCALE
CONTOUR INTERVAL: 5000 GAMMAS RELATIVE TO ARBITRARY DATUM
INCHES
and mineral composition (Heiland, 1949, p. 116), as is the remanent magnetization (Nagata, 1961, p. 162; Nagata and Kobayashi, 1958, p. 269; Nicholls, 1955). A thermal gradient could quite conceivably have caused a perceptible systematic change in the grain size or composition of the magnetic minerals, thus altering their gross magnetic characteristics (McKinstry, 1948, p. 424).

Or, with wandering of the geomagnetic pole reported by Runcorn and others (1955, 1956, 1960, p. 916), the temperature increase accompanying intrusion of the dike could have allowed the remanent magnetization to realign to some extent with the new ambient field of the time. It was to investigate this possibility that the 26 oriented specimens taken from the small area were treated as a separate group in the calculation of average measurements.

Another possibility is that the transverse trend of isanomalies is due to the magneto-mechanical effects as described by Graham and others (1956 and 1959). Such effects could have been caused by pressures exerted during implacement of the dike, or even by the directed stress which resulted in the adjacent fault.

A secondary feature of importance on Plate 9 is the overall complexity of the field gradient. Considering the size of the small area, and the fact that it is not
in the most highly magnetic part of the iron deposit, its complicated magnetic nature substantiates the statement of Cox and Doell (1960, p. 649) that "... magnetization is one of the most complex properties that the geologist can study ..."

**Measured Effects of Diurnal Variation**

Three periodic fluctuations, termed secular, annual, and diurnal variations, are undergone by the magnetic field of the earth. The secular variation has an irregular periodicity of from 500 to 1,000 years (Blackett, 1956, p. 11), while the others follow the time cycle by which they are named. The direction of the ambient field, as well as its intensity, changes during these variations (Fleming, 1949).

As mentioned, the magnetometer measurements of the main area survey were corrected for diurnal variation. Using the base check method described by Jakosky (1961, p. 143), measurements were made over the Main Reference Station and various substations as often as was convenient. Whenever at the Main Station, 20 magnetometer readings were taken and averaged; at the substations, 10 readings were averaged each time.

Reduced to a zero value representing the first intensity average taken at the Main Station (and used as
zero throughout the main area survey), results of the reference readings are plotted on Plate 10. Arranged by days, the variation at the Main Station is shown together with that of the substations used. The maximum change in vertical intensity recorded during the four days of the survey was 450 gammas; it took place over a 9 hour period on the first day.

While indicating rather extreme variations with time, the graphs of diurnal variation on Plate 10 also present a somewhat unique and totally unexpected occurrence. At Substation Nos. 2 and 3, on the first day, and at Substation No. 9, on the third, the vertical magnetic intensity is seen to change in a different manner than at the Main Reference Station. Between about 9:50 A.M. and 3:15 P.M. on the first day, the intensity at the Main Station rises from zero to 160 gammas. But during the same period at Substation Nos. 2 and 3, the intensity drops more than 200 gammas. The same thing occurs between 11:30 A.M. and 2:05 P.M. on the second day, at Substation No. 9, except here the intensity increases while at the Main Station it decreases. At the 6 other substations used, the intensity varies directly with the change at the main one through both the second and fourth days.

Concerning the inverse variations recorded, there are two noteworthy factors. First, while opposite in
DIURNAL VARIATION OF VERTICAL MAGNETIC INTENSITY DURING MAGNETOMETER SURVEY OF MAIN AREA
direction, the rate of change in intensity at all of the aberrant substations is almost identical to that exhibited by the Main Station during any particular time. And second, the magnetic profiles for Line Nos. 2 and 9 (Plates A-2 and A-9) - though beginning 100 feet north-northeast of Substation Nos. 2 and 9, respectively - show the intensity gradient to be dropping towards these substations. The magnetic profiles in line with the other substations used do not show this feature.

In attempting to resolve the discordant variations evidenced, the simplest explanation would relate the effects measured to a magnetic anisotropy within the rocks near the substations concerned. For, according to Jakosky (1961, p. 177) and Nagata (1961, p. 132), there does appear to be such a property in certain types of rocks, particularly crystalline schists. As they point out, it is a susceptibility anisotropy generally related to the plane of foliation in metamorphic rocks. Though not shown on the map of Plate 6, the rocks beneath all the magnetic base stations are of the schistose varieties locally typical of the Alder group. Their plane of foliation, while nearly vertical, wavers from side to side along its strike of N60E.

It must be assumed then, that with each minute fluctuation during the various periodic changes in the
earth's magnetic field, the direction of induced magnetization within the schistose country rocks simultaneously increases or decreases from place to place within the area. The case at any particular location would depend upon whether the changing field direction approaches or recedes from the direction of maximum susceptibility possessed by the rocks of that place.
MAGNETIC SUSCEPTIBILITY

General Statement

Nagata (1961, p. 311) has suggested and DuBois (1962, 1963) confirmed that the naturally occurring magnetization of rocks, minerals and geologic formations is the sum of their induced and remanent magnetizations. Being instantaneously reversible, the induced magnetization is proportional to the geomagnetic field. The constant of proportionality, called magnetic susceptibility (Cox and Doell, 1960, p. 649), is the ratio of the intensity of induced magnetism to the undisturbed field. As such, it is one of the main properties distinguishing the magnetic effects of substances in the earth's crust (Heiland, 1939, p. 116).

Limits and Distribution of Magnitude

Measurements of magnetic susceptibility for the 170 individual specimens taken at Pikes Peak are given in Column 3 of Table A-1. Average and limiting values as determined for the major groups of specimens and their combinations are shown in Table 1, page 47. While
susceptibility anisotropy can be caused by a shape factor in some magnetic bodies (Uyeda and others, 1963, p. 279), it is an intrinsic phenomenon in certain minerals, notably hematite (Nagata, 1961, pp. 132 and 174). Consequently, the susceptibility measurements made on crushed samples and quoted herein can be considered only as approximate values indicative of the mean for all directions.

**TABLE 1**

<table>
<thead>
<tr>
<th>Group Description</th>
<th>Maximum (10^-5 emu/cc)</th>
<th>Minimum (10^-5 emu/cc)</th>
<th>Average (10^-5 emu/cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Area: Lines 1-14</td>
<td>4,180</td>
<td>7</td>
<td>872</td>
</tr>
<tr>
<td>(125 specimens)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small Area: Lines A-E</td>
<td>1,650</td>
<td>9</td>
<td>413</td>
</tr>
<tr>
<td>(26 specimens)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Specimens From Ore</td>
<td>4,180</td>
<td>7</td>
<td>792</td>
</tr>
<tr>
<td>(151)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specimens From Schist</td>
<td>2,499</td>
<td>too weak to measure</td>
<td>375</td>
</tr>
<tr>
<td>(19)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Specimens Taken</td>
<td>4,180</td>
<td>too weak to measure</td>
<td>746</td>
</tr>
<tr>
<td>(170)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As indicated in Table 1, measured values of magnetic susceptibility range from too weak to read up to 4,180 x 10^-5 emu/cc, and give an overall average of 746 x 10^-5 emu/cc. The average value of 792 x 10^-5 emu/cc for all the specimens is considerably higher than even the maximum
values given for hematite ores by Heiland (1939, p. 116) or Jakosky (1961, p. 164). However, it is well below the limits given by them and other authors for ores of magnetite and therefore merely reflects the presence of this mineral. An average susceptibility of $375 \times 10^{-5}$ emu/cc as obtained for the specimens of schist is somewhat misleading. Actually, nearly half of the group have values less than $10^{-4}$ emu/cc; and concerning the others, magnetite-bearing schists can have a magnetic susceptibility as 100 times that of most other metamorphic rocks (Jakosky, 1961, p. 219).

The frequency distribution of measured susceptibilities is shown by Plate 11, Fig. 1, where dark, medium and light shading has been used to separate the observations made on specimens from the main area, small area, and schist, respectively. As can be seen from the histogram, there is a dominance of susceptibilities between zero and $200 \times 10^{-5}$ emu/cc, while higher values are distributed in ever decreasing frequency.

Values for individual specimens are plotted in Plate 11, Fig. 2, where minor groups are connected. The figure indicates a rough decrease in susceptibility in going from southwest to northeast through the main area, and the 11 schist specimens that could be measured are seen in truer perspective.
PLATE 11

Figure 1

Figure 2

SUSCEPTIBILITY DISTRIBUTION OF SPECIMENS

SPECIMEN NUMBER AS USED THROUGHOUT THIS WORK
OPEN SYMBOLS: RM UPWARD  SOLID SYMBOLS: RM DOWNWARD
○ FROM MAIN AREA  △ FROM SMALL AREA  ✤ FROM SCHIST
SUSCEPTIBILITY BY INDIVIDUAL SPECIMEN
For specimens taken from each respective line in the main area, the average value of magnetic susceptibility, denoted as "k," is included with the magnetic profile of the Appendix. There is good correlation between high line averages of susceptibility and high vertical magnetic intensities as shown on the profiles.

A comparison is made between magnetic susceptibility and intensity of remanent magnetism on the logarithmic graph of Plate 12. Within wide limits, a general correlation seems to exist, the RM rising rapidly with increase in susceptibility. The broad upward sloping pattern indicates a wide range of RM intensity can exist for a set value of susceptibility. This conclusion is similar to that found by DuBois (1962, p. 2890) for a suite of massive hematites. However, in a later work (1963, p. 272), he states that the relationship between these two variables is not always the same and depends upon the suite of specimens studied.
MAGNETIC SUSCEPTIBILITY — $10^{-5}$ emu/cc

OPEN SYMBOLS: RM UPWARD
SOLID SYMBOLS: RM DOWNWARD

○ FROM MAIN AREA
△ FROM SMALL AREA
+</span>

REMANENT INTENSITY VS SUSCEPTIBILITY
INDUCED MAGNETISM

General Statement

Related directly to the geomagnetic field by magnetic susceptibility, as set forth in the preceding section, the induced magnetism of a geologic body is, in general, parallel to the earth's field. The qualification regarding this parallelism is necessary because the geomagnetic field is locally distorted (Jacobs and others, 1959, p. 118) by superimposed fields due to the remanent magnetization (DuBois, 1963, p. 272; Nettleton, 1962, p. 1816) or terrain effects (Heiland, 1939, p. 133) within or near the body.

That such distortion exists in the vicinity of Pikes Peak iron deposit has been made apparent. However, the assumption of uniform magnetization holds approximately in most cases (Nagata, 1961, p. 311). It is, therefore, a general practice in geophysical work to assume that both the magnetic polarization of the basement rocks (Vacquir, 1951, p. 7) and the induced magnetization in rocks causing an anomaly are parallel to the earth's field (Cox and Doell, 1961, p. 649). An approximate value of the
induced magnetic intensity within a particular body, then, can be obtained by a knowledge of its magnetic susceptibility and the variables defining the geomagnetic field in its vicinity.

Order of Magnitude Within Area

Using a value of 0.53 gauss for the total intensity of the geomagnetic field, the induced intensity per unit volume has been calculated for the Pikes Peak specimens. Results for individual measurements are given in Column 4 of Table A-1. The direction in each case is parallel to the magnetic field of the earth in the region of the sample site, N14E at +60°.

Plate 13, Fig. 1, shows the distribution of intensities of induced magnetism presented in a semi-logarithmic histogram. Necessarily similar to the distribution of magnetic susceptibilities, the maximum frequency is around $100 \times 10^{-5}$ emu/cc while higher values generally decrease in number with an increase in intensity.

Average values for intensity of induced magnetism within each of the major and minor groups of specimens, as well as their combinations, are given in Column 3 of Table A-2. The average for all specimens in ore is found to be $419 \times 10^{-5}$ emu/cc, and $195 \times 10^{-5}$ emu/cc is average
for the specimens of schist. Values range from a minimum in schist too weak to determine, to a maximum in ore of 2.170 x 10^{-5} \text{ emu/cc}.
PLATE 13

Figure 1
Distribution of intensity of induced magnetism. Dark portions of semi-logarithmic histogram represent 125 ores specimens from main area. Light grey increments account for 26 ore specimens from small area. White strips show distribution of the 19 schist specimens.

Figure 2
Distribution of intensity of remanent magnetism. Significance of shaded area is same as for Fig. 1, above.

Figure 3
Distribution of ratio of remanent to induced magnetism, Qn. Significance of shaded areas is same as for Fig. 1, above.

Figure 4
Distribution of intensity of total magnetism. Significance of shaded areas is same as for Fig. 1, above.
INTENSITY OF INDUCED MAGNETISM — $10^{-5}$ emu/cc

INTENSITY OF REMANENT MAGNETISM — $10^{-3}$ emu/cc

RATIO OF REMANENT TO INDUCED MAGNETISM

INTENSITY OF TOTAL MAGNETISM — $10^{-5}$ emu/cc
REMANENT MAGNETISM

Introduction

General Statement

As previously mentioned, geologic bodies possess - to a greater or lesser extent - a natural remanent magnetization. In fact, though both are largely dependent on the ferromagnetic (or ferrimagnetic) minerals present (Heiland, 1949, p. 117; Nicholls, 1955, p. 113), the RM is generally more intense than the induced magnetism (Nagata, 1961, p. 148; DuBois, 1962, p. 2890 and 1963, p. 272). Unlike the induced component, the RM is spontaneous and often is not aligned with the earth's present day field direction (Cox and Poell, 1960, p. 649).

However, the permanent magnetization of a ferromagnetic material is normally directed parallel to the magnetic field acting when it is acquired. Consequently, when rocks and minerals form, their direction of magnetization is influenced by the geomagnetic field of the time. In some rocks this magnetization is quite stable and homogeneous in direction, remaining unchanged through many
geologic periods (Blackett, 1956). By studying such rocks of known age, the discipline of paleomagnetism has developed, bringing with it evidence to bolster the hypotheses of polar wandering and continental drift (Collinson and Runcorn, 1960; Cox and Doell, 1960). At the same time, the drive to obtain firm evidence concerning the history of terrestrial magnetism has added impetus to the science of rock magnetics.

Types of Remanent Magnetism

As a result of recent work (Nagata, 1961; Cox and Doell, 1960; Fuller, 1963), the types of natural RM and the processes by which they are acquired are described below.

(1) Thermo-Remanent Magnetization (TRM): Due to alignment of magnetic domains by the geomagnetic field when minerals are cooled through their Curie point or some temperature within tens of degrees below it.

(2) Partial Thermo-Remanent Magnetization (PTRM): This case, similar to the above, is where mineral grains are cooled in a magnetic field over some temperature interval below their Curie point.

(3) Chemical or Crystallization Remanent Magnetization (CRM): Produced in chemical formation or crystallization of a ferromagnetic material under the
influence of a magnetic field.

(4) Detrital or Depositional Remanent Magnetization (DRM): Caused by geomagnetically produced preferential alignment of magnetic detritus during aqueous deposition of sedimentary rocks.

(5) Isothermal Remanent Magnetization (IRM): The influence on magnetic domains at constant temperature that normally takes place within a relatively short time.

(6) Viscous Remanent Magnetization (VRM): Special case of IRM, where geologic time is involved and the RM intensity is therefore greater.

(7) Anhysteretic Remanent Magnetization (ARM): Caused by simultaneous application of a constant magnetic field and an alternating one, the amplitude of which diminishes smoothly with time. Thunderbolts superimposed on the geomagnetic field may give ARM.

(8) Piezo or Pressure Remanent Magnetization (PRM): A special type of RM believed to be produced by the effect of pressure acting on rocks within the earth's magnetic field. Tectonic stresses may cause PRM in some rocks.

Reversed Magnetism

In addition to the various processes of rock magnetization briefly described, there exists the phenomenon of reversed magnetization. (Jacobs and others, 1959,
That reversed TRM is an intrinsic property of certain titanium-bearing hematites has been shown by Ishikawa and others (1961), while Nagata (1960, p. 301) mentions rocks known to have a self-reversed magnetization. Neel (1955) and others have also provided theoretical grounds for a number of self-reversal mechanisms. But Blackett (1962, p. 700) points out that the majority of rocks with reversed magnetization cannot be proven susceptible to self-reversal, leaving the possibility that the polarity of the earth's field has inverted at various times.

Considering the complex array of causes for the remanent magnetization of rocks and minerals in general, and the possibility of reversals in the earth's magnetic field, the complications which might arise in the case of metamorphosed rocks and ores become obvious (Runcorn, 1955, p. 247). At any rate, in attempting to interpret or define the gross magnetic effects of a geologic body, the intensity and directional qualities of the RM can be fully as pertinent as its other magnetic characteristics. These qualities are of singular importance in the magnetization exhibited by the Pikes Peak iron deposit, as will be seen.

**Limits of Remanent Intensity**

Measurements defining the remanent magnetism of individual oriented specimens taken at Pikes Peak are given
in Columns 5, 6 and 7 of Table A-1. The distribution of the intensity of remanent magnetism as determined for these specimens is shown in the semi-logarithmic histogram of Plate 13, Fig. 2. As seen from this figure, the RM intensity within each of the three major groups varies widely. Specimens from both the main and small areas have intensities below $10^{-4}$ and above $10^{-1}$ emu/cc. Those of schist include 8 too weak to measure, but even they exceed $4 \times 10^{-3}$ emu/cc. There is an uneven distribution among all the major groups, though the frequency of values above $10^{-3}$ emu/cc decreases markedly with increased RM intensity. There is an abundance of specimens from the small area with intensities in excess of $10^{-2}$ emu/cc.

As shown in Table A-1, maximum and minimum RM intensities within the major groups are: main area, $43,667 \times 10^{-5}$ and $7 \times 10^{-5}$ emu/cc; small area, $16,900 \times 10^{-5}$ and $4 \times 10^{-5}$ emu/cc; schist, $496 \times 10^{-5}$ emu/cc and near zero. The high value of $43,667 \times 10^{-5}$ emu/cc comes from 665 feet along Line 1, 25 feet beyond the maximum vertical intensity recorded in the magnetometer survey (Plate A-1).

Average Values of Remanent Intensity

Average values for intensity-weighted remanent magnetism are given in Columns 7, 8 and 9, Table A-2.
Here, the average remanent magnetism for ore specimens from the main area is shown to be $1,001 \times 10^{-5}$ emu/cc, directed S28W, +16°. That of the small area is $3,046 \times 10^{-5}$ emu/cc, directed N76E, -15°, which confirms the existence of high RM intensities throughout this group. The average for all specimens in ore is only $597 \times 10^{-5}$ emu/cc, directed S12E, +8°, the drop in value reflecting the difference in direction defining the average RM of the small and main areas. A weighted average RM of $85 \times 10^{-5}$ emu/cc, directed S30E, +37°, is given for the schist specimens.

In the minor groups, a maximum weighted average of $6,290 \times 10^{-5}$ emu/cc, directed S15W, -44°, occurs across Line 12. Only a single high is shown on the vertical intensity profile (Plate A-12) however, because the average RM is directed opposite to the induced component, effectively cancelling it out. Line 6, with the low average of $158 \times 10^{-5}$ emu/cc, directed S37W, +58°, shows a number of somewhat higher vertical intensities in profile (Plate A-6) because the RM and induced components along it are additive in the vertical direction.

**Individual and Average Directional Qualities**

Directions of remanent magnetism for ore specimens taken from the main area are plotted in Plate 14, Fig. 1. Although both the declination and inclination appear quite
Figure 1
Direction of remanent magnetism of ore specimens from throughout main area. Open circles indicate upward inclination; solid circles, downward inclination. Average direction with each specimen given unit weight is concentrically circled. Intensity-weighted average is inside square. Triangular symbol shows direction of earth's present field at specimen site. Data from specimen Nos. 1 through 125 are shown.

Figure 2
Direction of total magnetism of ore specimens from throughout main area. These are resultant directions obtained by vector summation of the intensity-weighted remanent and induced magnetizations of each specimen. Open circles plot on the upper hemisphere, solid circles on the lower. Average direction of the group is shown encircled. Note how earth's ambient field, direction of which is indicated by triangular symbol, aligns resultants of specimens having a low ratio of remanent to induced magnetism. Specimens represented are same as in Fig. 1, above.
variable throughout the group, a majority of readings are
directed into the southwest and northeast quadrants, the
former being favored. Few of the specimens have their di­
pole directions parallel to the local geomagnetic field.
The mean direction for this group is $S_{46}^W, +49^\circ$, with the
intensity-weighted average direction being $S_{28}^W, +16^\circ$.

Specimens from the small area, hopefully taken to show effects of nearby intrusion, have their directions of remanent magnetization plotted in Plate 15, Fig. 1. Read­
ings for this group fall mainly to the east, but still there is considerable dispersion. A major trend is evi­
dent, however, in the abundance of upward inclinations.
The mean direction of $S_{82}E, -15$ is calculated for these specimens, while their intensity-weighted average direction is found to be $N_{76}E, -15^\circ$. Again, few of the dipole
directions parallel the earth's ambient magnetic field.

Plate 16, Fig. 1 shows the dipole directions for the remanent magnetism as measured in the specimens from barren schist. Once more there is considerable disper­
sion, though the majority of specimens have their RM directed downward. No principal declination is apparent.
The mean direction for the remanent component in this group is $S_{68}E, +60^\circ$; the intensity weighted average
direction, $S_{80}E, +37^\circ$.

The average directions of remanent magnetism as
Direction of remanent magnetism of ore specimens from small area. Sense of inclination is shown by open (upward) and solid (downward) symbols. Average direction with specimens weighted equally is encircled; intensity-weighted average is boxed. Triangle indicates earth's magnetic field direction at specimen site. Data from specimen Nos. 126 through 151 are shown.

Direction of total magnetism of ore specimens from small area. Vector summation of remanent and induced components of magnetism as measured for each specimen result in directions shown. Open and solid symbols signify upward and downward inclinations, respectively. Average direction of the total magnetism is concentrically circled. Direction of induced magnetism is shown by small triangle. Due to the relatively weak induced magnetism in the specimens of this group, their direction of total magnetism is not radically changed from that shown for their remanent component in Fig. 1, above.
Direction of magnetism of schist specimens. Open symbols project onto upper hemisphere, solid symbols onto lower. Plain circles give direction of remanent magnetism; crossed circles show direction of total magnetism for the same specimens. Concentrically circled points indicate average direction, with that of the remanent magnetism weighing each specimen as one. The intensity-weighted average direction of remanent magnetism is shown boxed. Triangular symbol indicates direction of earth's magnetic field. Data from 11 of the 19 schist specimens (Nos. 152 through 170) having a measurable remanent magnetism are shown.

Average directions of remanent magnetism of specimens, by groups. (1) through (14) give average direction for specimens grouped according to traverse line. Direction indicated by a single ring is the average for these 14 groups. (A) through (E) are average directions for the 5 lines in small area, and the small square designates the average direction for specimens from these lines. The average direction for all specimens in ore (main and small areas) is shown in double ring. Specimens in schist give an average direction indicated by large triangle, while that obtained from all specimens is designated by three concentric rings.
given in Columns 4 and 5 of Table A-2 for each major and minor group and their combinations are plotted in Plate 16, Fig. 2. Here all average values for the main area show downward inclinations, though their declination varies considerably. The remanent magnetization of groups from along Line Nos. 8, 9 and 13 has apparently been influenced by the earth's present magnetic field, as their average directions closely parallel it. Almost all of the average readings for the remaining lines in the group, however, are directed into the southwest quadrant. Minor groups from within the small area are seen to have average readings consistently different from the rest. Their declinations are eastward, with upward inclination. Taking all ore specimens, from the main and small areas together, an average direction of S6W, +52° is calculated for the remanent magnetization. When the schist specimens are included, the overall mean direction is due south and 58° downward.

Worthy of note is the fact that average declinations for many of the lines within the main area are nearly aligned with the general strike of the Pikes Peak iron deposit and the plane of foliation in rocks throughout the vicinity. The general feature is further illustrated in Plate 17, Fig. 1, which shows the frequency distribution of RM declination for all the 162 measured specimens
PLATE 17

Figure 1
Distribution of declination of remanent magnetism. Dark portions of histogram represent 125 ore specimens from main area. Light grey increments account for 26 ore specimens from small area. White strips show distribution of the 11 measurable schist specimens.

Figure 2
Distribution of inclination of remanent magnetism. Significance of shaded areas is same as for Fig. 1, above.

Figure 3
Distribution of declination of total magnetism. Significance of shaded areas is same as for Fig. 1, above.

Figure 4
Distribution of inclination of total magnetism. Significance of shaded areas is same as for Fig. 1, above.
collected. The chief and secondary maximum frequencies of declination within the main area are seen in the figure to be aligned N60E and S60W, respectively. The maximum frequency of occurrence for specimens from the small area is in the interval above N80E, still markedly near to the trend of the deposit and the local schistosity.

Fuller (1963) has reported certain Welsh slates in which the remanent magnetization lies in the cleavage plane. He further states (1963, p. 293) that TRM, IRM and PRM can all—in the laboratory at least—be acquired anistropically by rocks. The possibility that such anistropy has influenced the declination of RM within and around the iron deposit at Pikes Peak, then is indicated by the majority of specimens having their remanent magnetic declination closely parallel to the plane of foliation in the area.

As for magnetic inclination in the collected specimens, the frequency distribution of this variable is shown in Plate 17, Fig. 2. A maximum frequency of remanent inclinations between -10° and -20° exists for specimens from both the main and small areas, but the majority of readings from the larger group are more or less evenly distributed between -20° and +70°. Although some of the absolute values between 60° and 80° could parallel the dip of the schistosity, there are not many
of these and no systematic trend in direction of the remanent magnetic inclination is apparent.

However, since the inclination of remanent magnetism in about one-third of all the specimens taken is downward, while in the other two-thirds it is upward, to distinguish between these fractions was considered important. Consequently, properties shown as points on all maps and graphs – unless otherwise specified – are differentiated on this basis. Solid symbols indicate the RM of the specimen is directed downward (positive), while open symbols indicate it to be upward (negative).

Blackett (1962, p. 705) suggests the possible value of such treatment in aiding to distinguish between self-reversed and field-reversed specimens and uses the method in some of his earlier work (1956, p. 95).

**Areal Distribution of Directional Qualities**

In an effort to find some pattern in the directions of remanent magnetization, the specimens from both the main area and schist have their areal distribution and measured dipole orientations plotted on the map of Plate 6. Originally, the hope was to decipher the nature and direction of folding and obtain an insight into the origin of the iron mineralization. According to Gross and Strangway (1961), an analysis of remanent magnetism
in iron ores of French West Africa served this purpose reasonably well. Aside from the general trend of the remanent declination parallel to the common strike of the deposit and its schistosity, however, little correlation can be made - either lengthwise or across this trend - between the directions of RM exhibited by individual specimens. On Lines Nos. 8, 10, 13 and 14, only downward inclinations are evidenced, but the declinations are often opposite in direction and sometimes even perpendicular to one another. In going down the deposit through other lines, the declinations are not consistent and the inclinations vary to the extent of showing reversed polarity and almost any intermediate value.

Though not described at length herein, the direction of RM for each specimen was computed with the dip of its schistosity (or bedding, as near as could be determined) revolved around its strike and into the horizontal plane. The treatment given provided a tilt correction for the remanent magnetization, assuming that all specimens came from the southeast limb of a single non-plunging anticlinal fold. Suffice it to say that the dispersion among such corrected directions was even greater than is presently exhibited with the specimens
oriented as found in place. Discussion of the implications arising from different possible origins of the remanent magnetism within the Pikes Peak deposit is left to the section concerned with interpretation of results.
TOTAL MAGNETISM

General Statement

The vertical intensity of the gross total magnetization over the area under study has been treated in an earlier section. Likewise, the limits of intensity and directional qualities of both the induced and remanent magnetism as determined from collected specimens have been presented. It is the present purpose to define the relationships of the measured induced and remanent components to the total magnetism and test the validity of data obtained from specimens against those taken with a ground magnetometer. When comparing measurements made in the field with those resulting from laboratory work on specimens, the fact that important mass effects influencing the former are neglected in the latter (DuBois, 1963, p. 269) must be kept in mind.

Ratio of Remanent to Induced Magnetism

The ratio of remanent to induced magnetism - defined as Qn and first utilized extensively by Konigsberger (1938, p. 119) - is a value commonly used to
describe the magnetic properties of rocks and ores. This ratio is given for the Pikes Peak specimens in Column 8, Table A-1, and the distribution of its value throughout the major groups is shown in Plate 13, Fig. 3. As seen in the figure, the ratio of remanent to induced magnetism is inconsistent throughout all the groups. It varies from near zero to over 100, with the majority of values being greater than 1 for ore specimens.

Plate 18 shows the ratio of remanent to induced magnetism by individual specimen, with the subgroups being connected by fine lines. Except for three specimens on Line No. 1, the Qn value shows a rough increase from the southwest to northeast through the main area. In general, specimens from the small area have a higher Qn than the rest, while those from schist have a lower.

Maximum, minimum and average values for the ratio of remanent to induced magnetism are shown for the main groups in Table 2, page 75. The average Qn for all ore specimens is seen to be 11.17, with both the overall maximum value of 220.25 and minimum of 0.04 coming from within the main area. The high group average of 13.28 for the ratio of remanent to induced magnetism comes from the small area, while schist specimens have an average Qn of 0.58.
PLATE 18

SPECIMEN NUMBER AS USED THROUGHOUT THIS WORK
OPEN SYMBOLS: RM UPWARD  SOLID SYMBOLS: RM DOWNWARD
○ FROM MAIN AREA  △ FROM SMALL AREA  ◊ FROM SCHIST
RATIO OF REMANENT TO INDUCED MAGNETISM BY INDIVIDUAL SPECIMEN
TABLE 2

Maximum, Minimum and Average Qn Values

<table>
<thead>
<tr>
<th>Group Description</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Area: Lines 1-14 (125 specimens)</td>
<td>220.25</td>
<td>0.04</td>
<td>9.70</td>
</tr>
<tr>
<td>Small Area: Lines A-E (26 specimens)</td>
<td>120.20</td>
<td>0.24</td>
<td>13.28</td>
</tr>
<tr>
<td>All Specimens From Ore (151)</td>
<td>220.25</td>
<td>0.04</td>
<td>11.17</td>
</tr>
<tr>
<td>Specimens From Schist (19)</td>
<td>1.80</td>
<td>0.05</td>
<td>0.58</td>
</tr>
<tr>
<td>All Specimens Taken (170)</td>
<td>220.25</td>
<td>0.04</td>
<td>10.45</td>
</tr>
</tbody>
</table>

Since the total magnetization is the resultant of the RM and induced magnetism, its intensity over any area can be correctly interpreted only if the directional relationships of these components are considered. But with the average Qn being roughly 11 in the area of the iron deposit, it is clear that the total magnetism is controlled at least locally by the component of remanent magnetization.

Additionally, high Qn values exemplified by those in excess of 100 suggest the type of RM being dealt with. Nagata (1961, p. 311) points out that except in igneous rocks and special cases of sedimentary and metamorphosed iron ores usually having CRM, the Qn value is generally...
less, or even much less than unity. In view of this, and the existence of residual magnetite in the Pikes Peak deposit, much of the RM component is likely due to chemical remanent magnetization. Such magnetization would have been acquired at the time the magnetite was altered to hematite, or possibly in some cases, to maghemite, the mineral name for highly magnetic, isometric, gamma-hematite. Though not identified in the Pikes Peak specimens, the presence of some fine-grained maghemite is inferred by their high RM and extreme Qn values (Nagata, 1961, pp. 200 and 211).

Limits of Total Intensity

Variables defining the total magnetism as computed by vector summation of the intensity-weighted remanent and induced components are listed for individual specimens in Columns 9, 10 and 11 of Table A-1. The distribution of the computed total intensities is shown in Plate 13, Fig. 4, where values ranging from zero (in specimens with unmeasurable RM and susceptibility) to more than $10^{-1}$ emu/cc are represented. Excluding those too weak to measure, there is a maximum occurrence of specimens with a total intensity of between 80 and $90 \times 10^{-5}$ emu/cc. This has little meaning, however, because of the broad distribution of higher values in
all the major groups.

As seen in Table A-1, the maximum and minimum values of total magnetic intensity within the primary groupings are: main area, \(44,174 \times 10^{-5} \text{ emu/cc}\) and \(24 \times 10^{-5} \text{ emu/cc}\); small area, \(16,948 \times 10^{-5} \text{ emu/cc}\) and \(3 \times 10^{-5} \text{ emu/cc}\); schist, \(1,389 \times 10^{-5} \text{ emu/cc}\) and near zero.

**Directional Qualities of Total Intensity**

Average values defining total intensity are given in Columns 10, 11 and 12, of Table A-2. These average values for the three major groups are discussed with the directional qualities of individual specimens in the following paragraphs.

Directions of total magnetism for specimens from the main area are plotted in Plate 14, Fig. 2, where they can be seen in relation to the orientation of their RM component. A concentration of points around the existing direction of the geomagnetic field demonstrates its effect on specimens having a low ratio of remanent to induced magnetism. The majority of directions, though, differ markedly from the earth's ambient field. Average total magnetism within the group is calculated to be \(1,000 \times 10^{-5} \text{ emu/cc}\), directed S32W, +41°. The strong influence of the RM component is obvious in that its
average intensity-weighted direction is S28W, +16°, as quoted earlier.

Plate 15, Fig. 2 is a plot of the direction of total magnetism of specimens from the small area. Having a high average Qn, this group is not greatly affected by the component of magnetism induced by the geomagnetic field. Its average intensity of total magnetization is 3,052 x 10^-5 emu/cc, directed N74E, -11°. This is again quite similar to the intensity-weighted average value for the remanent magnetic component.

Plotted in Plate 16, Fig. 1, along with the directions of their RM, are the directions of total magnetism as computed for the measurable specimens of schist. In this group the average intensity of remanent magnetism is only half that of the induced, and the effect of the earth's magnetic field is marked. Only two of the specimens have a direction of total magnetism distinctly out of alignment with the geomagnetic field. Directed N35E, +16°, the average total magnetic intensity obtained for the schist group is 384 x 10^-5 emu/cc.

An average value of 606 x 10^-5 emu/cc, directed S24E, +46°, is calculated for the total magnetism of all specimens in ore. The mean total magnetism of all
specimens collected is found to be $578 \times 10^{-5}$ emu/cc, directed S25E, $+48^\circ$.

The frequency distribution of total magnetic declination and inclination within the Pikes Peak specimens are shown in Plate 17, Figs. 3 and 4, respectively. In these figures, the maximum frequency of inclination is seen to be about N10E, while that of declination is between $+60$ and $70^\circ$. Because all specimens are represented equally, the effect of the induced magnetism and the earth's present field direction is displayed. But when relative intensities are considered, and average values as quoted in the preceding paragraphs are obtained, the overpowering influence of the remanent magnetization within the ore is evident.

Correlation of Field and Laboratory Measurements

In order for the methods of rock magnetism as treated herein to have practical application in interpreting gross magnetic effects, they must correlate with field data. An initial test of correlation between field and laboratory measurements is made on the Vertical Magnetic Intensity Map of Plate 9. This map, it will be remembered, was plotted from ground magnetometer measurements using an arbitrary datum. Superimposed upon it are the original
locations of specimens Nos. 126 through 151, with their respective directions of total magnetism as computed from laboratory measurements.

Inspection of Plate 9 will show that specimens with total magnetism directed downward (having a positive vertical component) are most often in areas with a vertical magnetic intensity above 50,000 gammas. On the other hand, those with total magnetism directed upward (having a negative vertical component) are generally located in areas of lesser vertical intensity. Specimens providing exception to these generalities (Nos. 126, 128, 136, 147 and 148) are not far from the 50,000 gamma contour. Though the presentation does not include specific values of computed vertical magnetic intensity, it serves to illustrate further the complexity of the area’s total magnetism and indicates general correlation of field and laboratory data.

Evidence of correlation over a greater areal extent is shown for the two types of data on the magnetic profiles of Plates A-1 through A-14. Along with results of each magnetometer traverse is plotted the vertical intensity of total magnetism computed for specimens taken from the line. Considering the uneven spacing of stations providing data for the dashed curves of computed intensity, as well as the mass effects inherent in the field data,
there is good to fair correlation between relative values over the area covered.

The complex changes in gradient shown by the solid curves of Plates A-1, A-2 and A-3 are well represented by the laboratory data. On Plates A-5, A-6, A-9 and A-10 through A-14, there is generally a marked resemblance between the curves plotted by alternate methods. Where the solid and dashed curves are not similar, as in the case of Plates A-4, A-7 and A-8, most of the individual values obtained for specimens correlate with those taken in the field, but there is a lack of laboratory data between the specimens.
Specific gravities of the individual specimens from Pikes Peak are given in Column 12 of Table A-1 and are plotted in the histogram of Plate 19, Fig. 1. With values ranging from 2.66 to 4.04, the average specific gravity for all specimens collected is 3.14. For groups taken from the main area, small area, and schist, average values are 3.17, 3.13 and 2.94, respectively. An average specific gravity of 3.16 is obtained from the ore specimens only.

To compare the measured magnetic susceptibility of the specimens with their specific gravity, the graph of Plate 19, Fig. 2 was plotted. In this figure, a wide range of susceptibility is displayed for almost any given specific gravity. Initially, the upper limit of susceptibility is seen to vary directly with specific gravity. As the specific gravity gets higher than about 3.20, however, an inverse relationship appears to exist.

Intensity of remanent magnetism as measured in the Pikes Peak specimens is compared with their specific gravity in Plate 20. Here, the RM is also seen to vary
PLATE 19

Figure 1

SPECIFIC GRAVITY DISTRIBUTION OF SPECIMENS

Figure 2

SUSCEPTIBILITY vs SPECIFIC GRAVITY

OPEN SYMBOLS: RM UPWARD
SOLID SYMBOLS: RM DOWNWARD
• FROM MAIN AREA
△ FROM SMALL AREA
+ FROM SCHIST

SUSCEPTIBILITY $\times 10^{-5}$ emu/cc
INTENSITY OF REMANENT MAGNETISM

SPECIFIC GRAVITY

OPEN SYMBOLS: RM UPWARD
SOLID SYMBOLS: RM DOWNWARD
○ FROM MAIN AREA
▲ FROM SMALL AREA
✦ FROM SCHIST

REMANENT INTENSITY -VS- SPECIFIC GRAVITY
greatly within specimens of the same specific gravity. A general increase in remanent intensity accompanies higher specific gravity, but aside from this, no firm connection is evident between the two properties.

The extreme variation in magnetic susceptibility and remanent magnetism within specimens of nearly identical specific gravity is to be expected from the nature of mineralization within and adjacent to the iron deposit. In general, the occurrence of higher specific gravities can be attributed to an increased abundance in iron minerals, principally hematite (sp. gr. 4.9-5.3) or magnetite (sp. gr. 5.168-5.180). But the magnetic properties of these two constituents are radically different, while their values of specific gravity overlap. Consequently, their relative proportions can vary greatly in otherwise similar specimens and have no noticeable effect on specific gravity. The situation is further complicated by any maghemite that might be present. Having still different magnetic qualities, it ranges from 4.4 to 4.88 in specific gravity (Nicholls, 1955, p. 125). Even assuming an identical mineral assemblage and specific gravity in two or more specimens, their magnetic properties might vary due to difference in grain shape or size. Magnetic susceptibility increases with grain size in both magnetite (Heiland, 1949, p. 117) and hematite.
(Nagata, 1961, p. 28), while higher intensities of remanent magnetism can result from decreased grain size in all the iron minerals mentioned above (Nicholls, 1955, p. 127; Nagata, 1961, pp. 21 and 23; DuBois, 1963, p. 278).
General Statement

To interpret the cause of the magnetic features described in the preceding sections, some indication of the history of magnetization of the Pikes Peak deposit is necessary. In an attempt to learn something of this history, or to determine the age of the deposit and associated structures, virtual geomagnetic pole positions were computed for each major and minor group of specimens. Results of these computations are given in Table 3 on the following page. Based on the average directions of RM for each group as listed in Table A-2, the pole positions were computed using equations set forth by Cox and Doell (1960, p. 664) and Nagata (1961, p. 286). Only values given in Column 3 of Table 3 have any paleomagnetic significance; those of Column 4 are based on intensity-weighted average directions and are included simply for the purpose of comparison. The latitude and longitude given for each group in Column 3, then, define the position of the north-seeking virtual geomagnetic pole.
### TABLE 3

POLE POSITIONS CALCULATED FROM AVERAGE MAGNETIC MEASUREMENTS

<table>
<thead>
<tr>
<th>(1) Group Symbol Plate 21</th>
<th>(2) Group Description</th>
<th>(3) Pole Position Each Specimen Given Unit Weight</th>
<th>(4) Pole Position Each Specimen Weighted By Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Main Area</td>
<td>Pole Position Latitude Longitude</td>
<td>Pole Position Latitude Longitude</td>
</tr>
<tr>
<td>1 Line 1: Nos. 1-13</td>
<td>20°S 170°W</td>
<td>16°S 150°W</td>
<td></td>
</tr>
<tr>
<td>2 Line 2: Nos. 14-26</td>
<td>7°S 164°W</td>
<td>0° 102°W</td>
<td></td>
</tr>
<tr>
<td>3 Line 3: Nos. 27-36</td>
<td>46°S 111°W</td>
<td>81°S 68°W</td>
<td></td>
</tr>
<tr>
<td>4 Line 4: Nos. 37-49</td>
<td>2°S 172°W</td>
<td>37°S 5°E</td>
<td></td>
</tr>
<tr>
<td>5 Line 5: Nos. 50-58</td>
<td>31°S 169°W</td>
<td>10°N 117°E</td>
<td></td>
</tr>
<tr>
<td>6 Line 6: Nos. 59-67</td>
<td>9°S 113°W</td>
<td>8°S 110°W</td>
<td></td>
</tr>
<tr>
<td>7 Line 7: Nos. 68-77</td>
<td>11°S 165°W</td>
<td>50°S 65°W</td>
<td></td>
</tr>
<tr>
<td>8 Line 8: Nos. 78-86</td>
<td>64°N 26°W</td>
<td>46°N 178°W</td>
<td></td>
</tr>
<tr>
<td>9 Line 9: Nos. 87-93</td>
<td>74°N 139°W</td>
<td>51°N 90°E</td>
<td></td>
</tr>
<tr>
<td>10 Line 10: Nos. 94-101</td>
<td>8°S 164°W</td>
<td>3°S 158°W</td>
<td></td>
</tr>
<tr>
<td>11 Line 11: Nos. 102-108</td>
<td>27°S 166°W</td>
<td>61°S 83°W</td>
<td></td>
</tr>
<tr>
<td>12 Line 12: Nos. 109-114</td>
<td>59°S 113°E</td>
<td>71°S 176°W</td>
<td></td>
</tr>
<tr>
<td>13 Line 13: Nos. 115-119</td>
<td>51°N 107°W</td>
<td>28°N 63°W</td>
<td></td>
</tr>
<tr>
<td>14 Line 14: Nos. 120-125</td>
<td>7°N 79°W</td>
<td>11°N 34°W</td>
<td></td>
</tr>
<tr>
<td>- Lines 1-14: Nos. 1-125</td>
<td>12°S 152°W</td>
<td>40°S 150°W</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(1) Group Symbol Plate 21</th>
<th>(2) Group Description</th>
<th>(3) Pole Position Each Specimen Given Unit Weight</th>
<th>(4) Pole Position Each Specimen Weighted By Intensity</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Small Area</td>
<td>Pole Position Latitude Longitude</td>
<td>Pole Position Latitude Longitude</td>
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<tr>
<td>Off map Line A: Nos. 126-129</td>
<td>1°S 20°W</td>
<td>1°N 11°W</td>
<td></td>
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<tr>
<td>Off map Line B: Nos. 130-134</td>
<td>2°S 16°W</td>
<td>9°N 7°W</td>
<td></td>
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<tr>
<td>Off map Line C: Nos. 135-139</td>
<td>28°S 18°W</td>
<td>60°S 8°W</td>
<td></td>
</tr>
<tr>
<td>Off map Line D: Nos. 141-146</td>
<td>13°S 53°W</td>
<td>3°S 10°W</td>
<td></td>
</tr>
<tr>
<td>Off map Line E: Nos. 147-151</td>
<td>12°N 8°W</td>
<td>23°N 4°W</td>
<td></td>
</tr>
<tr>
<td>- Lines A-E: Nos. 126-151</td>
<td>11°S 20°W</td>
<td>7°N 8°W</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(1) Group Symbol Plate 21</th>
<th>(2) Group Description</th>
<th>(3) Pole Position Each Specimen Given Unit Weight</th>
<th>(4) Pole Position Each Specimen Weighted By Intensity</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>All Specimens In Ore</td>
<td>Pole Position Latitude Longitude</td>
<td>Pole Position Latitude Longitude</td>
</tr>
<tr>
<td>- Lines 1-14 and A-E Specimen Nos. 1-151</td>
<td>23°S 118°W</td>
<td>50°S 94°W</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(1) Group Symbol Plate 21</th>
<th>(2) Group Description</th>
<th>(3) Pole Position Each Specimen Given Unit Weight</th>
<th>(4) Pole Position Each Specimen Weighted By Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In Schist Only</td>
<td>Pole Position Latitude Longitude</td>
<td>Pole Position Latitude Longitude</td>
</tr>
<tr>
<td>▲ Various Lines, 1-14 Specimen Nos. 152-170</td>
<td>8°N 68°W</td>
<td>4°N 15°W</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(1) Group Symbol Plate 21</th>
<th>(2) Group Description</th>
<th>(3) Pole Position Each Specimen Given Unit Weight</th>
<th>(4) Pole Position Each Specimen Weighted By Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Specimens Taken</td>
<td>Pole Position Latitude Longitude</td>
<td>Pole Position Latitude Longitude</td>
</tr>
<tr>
<td>- Specimen Nos. 1-170</td>
<td>20°S 113°W</td>
<td>50°S 94°W</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:** Since 8 of the 19 schist specimens were too weak to read, only 11 are represented in their averages. Consequently, positions for "All Specimens Taken" include data from but 162 individual readings.
Results of Paleomagnetic Analysis

Plotted on Plate 21, where they are shown in relation to polar wandering paths established by Collinson and Runcorn (1960, p. 957), most pole positions obtained for specimens from Pikes Peak fall remarkably near the path based on American rocks. While poles calculated for the schist and some lines across the main area are scattered, many of them (Line Nos. 1, 2, 4, 5, 7, 10 and 11) form a relatively tight group near the location shown for the geomagnetic pole at about the end of the Precambrian. The mean pole for all specimens from the main area is the best estimate for the group, and it indicates that the RM was acquired just prior to deposition of rocks of the Grand Canyon system (see poles for Shinamo quartzite, Hakatai shale and Bass limestone on Plate 21). Almost directly on the path supposedly followed by the geomagnetic pole, the position obtained for specimens from the small area points to a late Cambrian or early Ordovician date for the acquisition of its direction of remanent magnetism.

An important feature that would seem to lend credence to the above dates and the method by which they were obtained is related to the polarity of the pole for the small area. The remanent magnetism in the large
POLE POSITIONS AS CALCULATED FOR SPECIMENS FROM PIKES PEAK IRON DEPOSIT
SHOWN IN RELATION TO POLAR WANDERING PATHS BASED ON BRITISH AND AMERICAN ROCKS

LEGEND

- POLE BASED ON AMERICAN ROCKS
- POLE FOR SPECIMENS FROM PIKES PEAK
- POLE FOR LINE 1, MAIN AREA, 13 SPECIMENS
- POLE FOR LINE 2, 13 SPECIMENS
- POLE FOR LINE 3, 10 SPECIMENS
- POLE FOR LINE 4, 13 SPECIMENS
- POLE FOR LINE 5, 9 SPECIMENS
- POLE FOR LINE 6, 9 SPECIMENS
- POLE FOR LINE 7, 10 SPECIMENS
- POLE FOR LINE 8, 9 SPECIMENS
- POLE FOR LINE 9, 7 SPECIMENS
- POLE FOR LINE 10, 8 SPECIMENS
- POLE FOR LINE 11, 7 SPECIMENS
- POLE FOR LINE 12, 6 SPECIMENS
- POLE FOR LINE 13, 5 SPECIMENS
- POLE FOR LINE 14, 6 SPECIMENS
- POLE FOR LINES 1 THRU 14, 125 SPECIMENS
- POLE FOR 11 SPECIMENS IN SCHIST
- POLE FOR ALL 151 SPECIMENS IN ORE
- POLE FOR ALL 162 SPECIMENS MEASURED

- REFERENCE POLE — AMERICAN ROCKS
- POLE BASED ON BRITISH ROCKS
A1 - POLE FOR BASS LMS., GRAND CANYON
A2 - POLE FOR HAKATAI SH., GRAND CANYON
A3 - POLE FOR SHINUMO OTZ., GRAND CANYON
A4 - POLE FOR BONITO CANYON OTZ., FT DEFIANCE
Pre-C - PRECAMBRIAN POLE (GENERAL)
A - ALGONKIAN POLE (GENERAL)
C - CAMBRIAN POLE (GENERAL)
D - DEVONIAN POLE (GENERAL)
Cp - CARBONIFEROUS POLE (PENN.)
P - PERMIAN POLE (GENERAL)
T - TRIASSIC POLE (GENERAL)
J - JURASSIC POLE (GENERAL)
E - EOCENE POLE (GENERAL)
T - TERTIARY POLE (GENERAL)

PATH OF NORTH POLE THROUGHOUT GEOLOGIC TIME AS INFERRED FROM ROCKS OF RESPECTIVE COUNTRIES

PROJECTION IS OBLIQUE MERCATOR'S WITH POLE AT 0°N, 112°E — BASE MAP,
POLE PATHS AND REFERENCE POSITIONS AFTER COLLINSON AND RUNCORN (1960)
majority of specimens from the small area, as will be remembered, was directed upward. Because of this, the north-seeking virtual geomagnetic pole as listed in Table 3 for the small area plots off the map of Plate 21. Consequently, it is the opposite or south-seeking pole which indicates the late Cambrian date. While a very few rocks of Cambrian or Ordovician age having mixed polarity are known (Cox and Doell, 1960, p. 742), the important fact is that the vast majority show polarity giving a south-seeking virtual geomagnetic pole at the position shown for the small area (Blackett, 1956, pp. 23 and 85).

The pole obtained for the small area, then, is not only near the established polar wandering path, but its polarity is also consistent with that shown for the time by almost all rocks of the same indicated age which have been investigated. As for the reversed polarity of RM exhibited by about one-third of the specimens from the main area, both Precambrian sediments and metamorphosed rocks having reversed polarity are known (Blackett, 1956; Cox and Doell, 1960, pp. 692-694; Collinson and Runcorn, 1960, pp. 933 and 936).

Effects of Dispersed Remanent Magnetism

That considerable dispersion exists in the
directions of RM for all groups of the Pikes Peak specimens has been amply displayed. Before basing interpretations on the results of paleomagnetic analysis, the precision and confidence of the computed pole positions should be mentioned. Both Fisher (1953) and Wilson (1959, p. 755) have provided methods for statistically treating the directional data of rock magnetism.

The method of Fisher utilizes a precision parameter to define the distribution of directions. Essentially, when the precision parameter is large, the dispersion is small, and when it is zero, the dispersion is a maximum and uniform in all directions. It should serve to say that the precision parameters for all groups of specimens treated herein are less than 3: the dispersion is considerable.

Wilson's method is much simpler and results in a standard angular deviation for all individual specimens in a group and a standard deviation for the mean direction. The standard deviation for a single reading in the major groups as treated herein was found to vary between 50° and 70°. In other words, no single value can be counted upon to fall very near the mean. On the other hand, because of the large number of specimens collected, the standard deviation of the mean direction within all major groups but that of the schist is about 6°. The results
quoted merely indicate that while there is great dispersion among the individual readings, there are enough of them so that the direction of any one does not greatly affect the mean.

As mentioned earlier, when a tilt correction was applied to all specimens, dispersion among their directions of RM increased. Virtual geomagnetic poles were also computed for the tilt-corrected average directions. But the results, in every case, proved both inconsistent and unrealistic.

The dispersion with specimens in situ, at any rate, is such that an interpretation of the magnetic features of the Pikes Peak deposit should attempt to reconcile the consistency of paleomagnetic results with the non-uniform directions exhibited by the remanent magnetization.
INTERPRETATION OF RESULTS

General Statement

Concerning the gross magnetic effects over the main area, it has been shown that the major anomalies of vertical magnetic intensity trend along the length of the iron deposit. In the small area, adjacent to the andesite porphyry dike, these anomalies have a trend transverse to that recognized over the deposit in general. Within the schist, there is evidence to indicate a magnetic anisotropy related to the plane of foliation.

Regarding detailed magnetic properties, the complex heterogeneous nature of magnetization within the ore mineralization and schist has been demonstrated. The ratio of remanent to induced magnetism in specimens from both the main and small areas averages 11 or better. That this average ratio results in the total magnetism being largely controlled by the remanent component has been illustrated. In specimens from the main area, the directions of RM are diverse, but declinations fall into
two definite groups which are about 180° apart and closely parallel the strike of the iron deposit. Directions of RM within specimens from the small area, again considerably dispersed, are generally spread between the strike of the deposit and that of the nearby dike; the declination of the average direction (S82E), in fact, very nearly bisects the horizontal angle between them. A certain stability is indicated for the remanent magnetism inasmuch as its direction in the vast majority of specimens is markedly different from that of the present geomagnetic field (Blackett, 1956, p. 22).

Information obtained by paleomagnetic analysis implies that the remanent magnetism presently exhibited by the Pikes Peak iron deposit was acquired sometime after the Mazatzal revolution, which ended the older Precambrian in the area, and prior to the deposition (or acquisition of the present RM) of the Grand Canyon system. Based on similar paleomagnetic evidence, the small area had its remanent magnetization markedly affected at about the end of the Cambrian period. The directions of remanent magnetism on which the paleomagnetic analysis is based are so dispersed that if the results are assumed to be accurate, some reason must be provided for the dispersion.
Any interpretation offering an explanation of the magnetic features of Pikes Peak iron deposit must, as in any geologic problem, tie together all the observed facts. In an effort to do this, the history of magnetization as presently exhibited within the area taken under study is reconstructed below.

**History of Magnetization**

No assumption is made concerning the origin of the iron mineralization at Pikes Peak. There is evidence, however, that the mineralization was present prior to the isoclinal folding that resulted from the Mazatzal revolution, or else was introduced in the late stages of this folding. If in existence prior to the folding, there was probably some RM of the depositional (DRM) or chemical (CRM) type associated with the ferromagnetic minerals involved. But this magnetization, if it existed at all, is likely to have been eradicated by the metamorphic effects of the orogeny.

The RM as now exhibited by the deposit is considered to be either largely CRM, which accompanied alteration of the iron mineralization during metamorphism, or the thermal type of remanent magnetization (TRM), acquired at the time of the metasomatic emplacement. The stability of the magnetization in either case would
be about the same (Nagata, 1961, p. 201). If this stable component of RM was acquired before the tectonic stress accompanying the Mazatzal revolution had subsided, the effects of pressure would be felt. A point of importance is that when pressure acts upon either CRM or TRM, the pressure induced magnetization (PRM) deviates systematically from the direction of the applied field towards a direction perpendicular to the pressure (Nagata, 1961, p. 272). Since the apparent direction of the earth's magnetic field towards the end of the older Precambrian (approximately S46W, +41°) was only slightly out of parallel with the strike of the deposit, the stress perpendicular to the folds of the area would cause the PRM to have its direction aligned with the length of the mineralized zone.

However, the PRM would show considerable dispersion (Graham, 1956, p. 736; Graham and others, 1959). Combined with some reversed magnetization, acquired simultaneously with the PRM, or pre-existing in the CRM or TRM, the directions would be spread across the strike of the deposit to the southwest and northeast. This distribution, in fact, is the same as shown in Plate 14, Fig. 1, for the RM of specimens from the main area.

The apparent magnetic anisotropy of the iron mineralization, then, is quite likely due to the effects
of PRM, and if any real magnetic anisotropy exists, it was caused by the same tectonic stress. If the iron deposit had not been in place while the stress was active, there would be no apparent cause for anisotropy over the area, whether real or otherwise.

After acquiring a dispersed RM, the evidence indicates that the deposit was intruded late in the Cambrian period by the andesite porphyry forming a dike in the main area. At this time, partial thermo-remanent magnetism (PTRM) probably affected the ferromagnetic mineralization immediately adjacent to the dike, being accompanied by some CRM with further alteration of the mineralogy. Whether the earth's magnetic field had actually changed polarity, as Blackett (1962, p. 705) believes the weight of evidence to suggest, or not, some mechanism was active to cause a reversed polarity to predominate in the newly aligned RM.

While generally oriented with the geomagnetic field of the time, the RM in areas near the dike is believed to have been further affected by pressure. This time, the pressure was directed almost parallel to the strike of the deposit. In being drawn away from the pre-existing direction of magnetization, or away from the applied field and towards the direction perpendicular to the stress exerted by the dike, the
dispersion of RM exhibited within the small area could have resulted. Related to this interpretation, an interesting observation is the relative abundance of specimens along Line No. 5 which have their directions of RM drawn somewhat parallel to the dike (Plate 6).

Since acquisition of its more stable component of RM, the iron mineralization in all areas of the deposit has almost certainly been affected to some extent by isothermal (IRM) or viscous (VRM) remanent magnetism. If actually effective at all, anhysteretic remanent magnetism (ARM), due to lightning flashes to the ground, has probably also caused some of the dispersion recognized in the direction of RM. The fact that only a very few specimens show their RM to be aligned with the present geomagnetic field, however, indicates that the effect of such magnetization as mentioned in this paragraph has been minor.

The longitudinal trend of vertical intensity anomalies along the deposit, as well as the transverse trend recognized in the small area, are both seen to be essentially parallel to the principal directions of the remanent magnetic intensity. In turn, the direction of RM is closely related to the geologic structure, having been affected to some extent by the same forces.
Relative Contribution of Magnetic Components to Gross Magnetic Features of Deposit

A general correlation between the measurements made on individual specimens and those acquired by field methods has been demonstrated. The influence of the remanent magnetism in controlling the gross magnetic effects over the Pikes Peak deposit has also been indicated in several ways. But to substantiate these interpretations, the small area as shown in Plate 9 was subjected to further detailed treatment.

Utilizing the magnetometer data obtained over the 26 stations from which specimen Nos. 126 through 151 were taken, as well as the laboratory measurements made with these specimens, the values of vertical magnetic intensity listed in Table 4 were calculated. The vertical component of the gross total magnetic intensity as measured with a field magnetometer is given in Column 2. Columns 4, 6 and 8 list the vertical component of the total, remanent and induced magnetic intensity, respectively, as calculated from laboratory measurements. Both measured and calculated intensities were then reduced to an arbitrary datum giving the positive values shown in Columns 3, 5, 7 and 8 of Table 4.

In order to show more directly, and in greater
detail, the contribution of the various magnetic components to the gross magnetic features of the deposit, the reduced values of Table 4 are contoured on the vertical intensity maps of Plate 22, Figs. 1 through 4. By using only 26 magnetometer stations in plotting the vertical component of the total measured magnetic intensity in Fig. 1, it has the same horizontal control as the rest of the figures on the plate. The pronounced similarity of Fig. 2, showing the vertical component of the total magnetism as computed by vector summation, to Fig. 1, is ample proof that values obtained by the alternate methods correlate. Likewise, the marked similarity of Fig. 3, which shows the vertical component of the intensity of RM over the same area, to Fig. 2, proves the total magnetism to be controlled by the remanent component. That the vertical component of the induced magnetism, contoured in Fig. 4, is considerably weaker than that of the RM in Fig. 3, is shown by there being a factor of 10 between the contour intervals used in the two figures.

It is interesting to note that the same general conclusions as indicated by the figures of Plate 22 can be reached by considering the small area a point source at infinite distance and comparing the average values for the total, remanent and induced magnetism as given for the group of specimens from the area in Table A-2.
<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Field Measurements</th>
<th>Vector Summation Laboratory Data</th>
<th>Computed From Laboratory Data</th>
<th>Computed And Plotted Value</th>
<th>Computed And Plotted Value</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Total Vertical Intensity</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Measured Value</td>
<td>Plot Value</td>
<td>Computed Value</td>
<td>Plot Value</td>
<td>Computed Value</td>
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<td>4,951</td>
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<td>29,600</td>
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<td>-2,865</td>
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*#Intensity in gammas.

**Intensity in 10^-5 emu/cc.
FIGURE 1
MAP OF VERTICAL COMPONENT OF TOTAL MAGNETISM
PLOTTED FROM FIELD MAGNETOMETER MEASUREMENTS
OBSERVATIONS TAKEN ON GROUND SURFACE OVER SPECIMEN LOCATIONS
CONTOUR INTERVAL: 500 GAMMAS
RELATIVE TO ARBITRARY DATUM

FIGURE 2
MAP OF VERTICAL COMPONENT OF TOTAL MAGNETISM
PLOTTED FROM VECTOR SUMMATION OF LABORATORY VALUES
OBSERVATIONS BASED ON ASTATIC MAGNETOMETER AND SUSCEPTIBILITY MEASUREMENTS
CONTOUR INTERVAL: 500 X 10^-5 TESLAS
RELATIVE TO ARBITRARY DATUM

PLATE 22
VERTICAL MAGNETIC INTENSITY MAPS OF SMALL AREA COMPARING TOTAL MAGNETISM AS MEASURED IN FIELD AND LABORATORY AND SHOWING RELATIVE CONTRIBUTION OF REMANENT AND INDUCED FRACTIONS TO TOTAL
PIKES PEAK IRON DEPOSIT, MARICOPA COUNTY, ARIZONA

FIGURE 3
MAP OF VERTICAL COMPONENT OF REMANENT MAGNETISM
PLOTTED FROM COMPUTATIONS MADE ON LABORATORY DATA
OBSERVATIONS BASED ON ASTATIC MAGNETOMETER MEASUREMENTS
CONTOUR INTERVAL: 500 X 10^-5 TESLAS
RELATIVE TO ARBITRARY DATUM

FIGURE 4
MAP OF VERTICAL COMPONENT OF INDUCED MAGNETISM
PLOTTED FROM COMPUTATIONS MADE ON LABORATORY DATA
OBSERVATIONS BASED ON MEASUREMENTS OF SUSCEPTIBILITY
CONTOUR INTERVAL: 500 X 10^-5 TESLAS
RELATIVE TO ARBITRARY DATUM
Reverse Versus Normal Magnetism

As stated earlier, Blackett (1956, 1962) has pointed out the importance of trying to distinguish some physical difference among rocks showing normal and reversed polarity. At the same time, Nagata (1961, p. 302) has mentioned that "normal" and "reversed" magnetization cannot be uniquely determined in rocks formed during the Precambrian or Paleozoic, because there is no set polarity to use as reference during much of that time. Consequently, in this work, no arbitrary distinction has been made, and the directions of RM in various specimens are referred to only as being reversed to one another.

However, many of the graphs included herein are purposely plotted to differentiate between specimens having their RM directed above or below the horizon. Namely, graphs on Plates 11, 12, 18, 19 and 20 have been so plotted. Inspection of these graphs shows that specimens with their RM directed downward have the maximum susceptibility (Plates 11 and 19, Fig. 2), the maximum intensity of RM (Plates 12 and 20), and the maximum ratio of remanent to induced magnetism (Plate 18). On the other hand, the 4 specimens showing the highest specific gravity have their RM directed upward (Plate 19, Fig. 2 and Plate 20). In general, though, no apparent difference
in the physical properties considered is found between the two oppositely directed fractions.
CONCLUSIONS

General Summary

Study of the gross magnetic effects over a part of Pikes Peak iron deposit shows that major positive and negative anomalies of vertical magnetic intensity trend along its length. Combining to give an overall Class 1 anomaly of 38,860 gammas, both the extreme high and low vertical intensities generally correlate with exposures of the hematite-rich iron mineralization. Cause of the anomalies is attributed to the local abundance of magnetite in their immediate vicinity, as well as the depth, attitude and shape of the steeply dipping lenticular bodies comprising the iron deposit.

Associated with the magnetite is a high relative intensity and diverse direction of remanent magnetization which largely controls the gross magnetic field gradient along its primary trend. Sharp changes in vertical intensity take place within a very few feet across the iron deposit because of the diverse direction of remanent magnetization. Intermediate magnetic intensities and a gently sloping gradient are usually related to areas of
barren schist.

Adjacent to the largest andesite porphyry dike cutting the zone of iron mineralization, the anomalies of vertical magnetic intensity are nearly perpendicular to the trend recognized over the deposit in general. Detailed study indicates that this transverse trend in the gross vertical intensity is caused by the effects of temperature and pressure which accompanied intrusion of the dike. It is felt that these effects reoriented the direction of remanent magnetization, drawing it more nearly parallel to the strike of the dike. Because of its strong influence on the gross magnetization, the realigned remanent component gives rise to the local trend of equal vertical magnetic intensities normal to the length of the deposit. Another important feature brought out by detailed investigation of the area next to the dike is the extreme complexity of the magnetic field gradient associated directly with the ore mineralization.

Measurements of the diurnal variation in vertical magnetic intensity over the steeply dipping Precambrian country rocks flanking the iron deposit indicate them to have a magnetic susceptibility anisotropy related to their plane of foliation. The evidence implies that with each minute fluctuation during the various periodic variations in the earth's magnetic field, the
induced magnetization within the schistose country rocks simultaneously increases and decreases from place to place. At any particular location, the induced magnetic intensity is considered to vary as the changing geomagnetic field direction approaches or recedes from the direction of maximum susceptibility possessed by the local rocks.

Application of the methods of rock magnetism to the study of oriented specimens has demonstrated that both the iron mineralization and the country rocks of the Pikes Peak deposit have extremely inconsistent magnetic properties. The heterogeneity of these properties is considered to be primarily related to the variable nature of both the siliceous iron mineralization within the deposit and the ferromagnetic accessory minerals present in the country rocks.

Within the ore specimens, magnetic susceptibilities range from 7 to $4,180 \times 10^{-5}$ emu/cc and average $792 \times 10^{-5}$ emu/cc. The resulting average intensity of induced magnetism, based on a strength of 0.53 gauss for the ambient geomagnetic field, is $419 \times 10^{-5}$ emu/cc. Exhibiting intensities of remanent magnetism between 4 and 43,667 emu/cc, the ore specimens average $2,792 \times 10^{-5}$ emu/cc for this property.

In general, the directions of RM in specimens of
ore mineralization are diverse, but declinations fall into two definite groups which are about 180° apart and closely parallel the length of the deposit. Most of the ore specimens from the area adjacent to the andesite porphyry dike have their RM directed upward, and, as just mentioned, drawn somewhat parallel to the dike. A certain stability is indicated for the remanent magnetization inasmuch as its orientation in the vast majority of specimens is not parallel to the local direction of the earth's present magnetic field.

The ratio of remanent to induced magnetism in the ore specimens varies from 0.04 to 220.25 and averages 11.17. Intensities of total magnetism, calculated by vector summation of the measured and induced components, range from 3 to 44,174 x 10^-5 emu/cc in ore specimens, and give an average value of 606 x 10^-5 emu/cc, directed S24E, +46°.

Though some specimens of schist were too weak to be measured, the others give an average susceptibility of 375 x 10^-5 emu/cc, resulting in 195 x 10^-5 emu/cc for the average intensity of their induced magnetism. With an average intensity of remanent magnetism in the schist specimens of 114 x 10^-5 emu/cc, the average ratio of remanent to induced magnetism for the group is 0.58. Exhibiting extreme dispersion, the directions of RM
determined for the specimens of schist are apparently unrelated to local structures as well as the present day geomagnetic field.

Comparison of the magnetic susceptibility, RM, and specific gravity of specimens indicates that these properties generally increase in magnitude with one another. However, for any set value of one property, there is a wide range in magnitude exhibited by the others and no steadfast relationship is evident. Additionally, when specimens are differentiated on the basis of whether their RM is directed above or below the horizon, no distinguishable difference is noted in the susceptibility, ratio of remanent to induced magnetism, or specific gravity of the two fractions.

A definite correlation is shown between the gross magnetic effects as measured in the field with a vertical intensity magnetometer and the magnetic properties as measured in specimens from the same area by laboratory methods. Such correlated measurements, as presented herein, provide the primary basis for concluding that the gross magnetism over the Pikes Peak deposit is largely controlled by the direction and intensity of the remanent magnetism within the iron mineralization.
Areal Distribution of Magnetic Properties

The principal trend of anomalies in vertical magnetic intensity parallel to the length of the iron deposit has been mentioned above. Along this trend, the relative negative anomalies are fewer and less extensive than are the positive ones. This feature is considered to be related to the high ratio of remanent to induced magnetism in specimens taken over the deposit, coupled with the fact that in about one-third of these specimens the RM is directed upward (negative). This conclusion is substantiated to a fair degree by the correlation of field and laboratory measurements as shown on the Magnetic Intensity Profiles of the Appendix.

Going northwest across the strike of the deposit, the vertical magnetic intensity generally increases gradually until reaching the southeast exposure of iron mineralization. Once over the iron-rich zone, large changes in vertical intensity take place within extremely short linear distances. Then, reaching the opposite side, the gradient smooths out at a somewhat higher level than on the southeast. This generalized profile is more or less typical of a thin magnetic layer dipping steeply to the northwest in the northern hemisphere.

Concerning the areal distribution of particular
magnetic properties, there is a rough general decrease in magnetic susceptibility in going from southwest to northeast through the main area treated. In going the same direction, however, the ratio of remanent to induced magnetism exhibited by the iron mineralization shows a rough general increase. While both the direction and intensity of the remanent magnetization are so varied as to defy simple description, specimens taken from the southwest end (Line 1) and northeast center (Line 10) of the main area show average intensities exceeding $6,000 \times 10^{-5}$ emu/cc. On the other hand, a low average intensity of $425 \times 10^{-5}$ emu/cc is obtained for the RM of ore specimens from near the northeast end (Line 13) of the area. Being strongly influenced by the remanent component, the resultant total magnetic intensity as determined from ore specimens has a similar areal distribution. The direction of total magnetism, assumed to be unilaterally affected by the induced component of magnetization, is, however, somewhat more closely oriented with the ambient geomagnetic field.

**Age of Deposit**

Evaluation of the remanent magnetism of specimens from Pikes Peak, in light of modern paleomagnetic hypotheses, has provided what is considered to be significant information
related to the age of the iron mineralization and major structures in the area. A north-seeking virtual geomagnetic pole, located at latitude 12° S., longitude 152° W., was calculated for specimens representing the iron mineralization in general. For specimens taken from adjacent to the andesite porphyry dike cutting the iron deposit, a south-seeking pole at latitude 12° N., longitude 160° E., was obtained. When viewed in relation to polar wandering paths established by Collinson and Runcorn (1960), the above mentioned poles fall remarkably near the path based on American rocks.

The position representing the ore mineralization in general implies that its remanent magnetization was acquired in the younger Precambrian, just prior to deposition (or induration) of the rocks of the Grand Canyon system. However, the directional pattern displayed by the remanent magnetization indicates that dispersion was caused at the time of its acquisition by pressure directed to the northwest. Since the compressional stress resulting in the Mazatzal revolution was principally directed to the northwest (Wilson, 1939, p. 1115), the existing remanent magnetization is considered to have been acquired while this stress was still active.

A late Cambrian date for intrusion of the andesite porphyry is suggested by the south-seeking virtual
geomagnetic pole obtained for specimens from adjacent to the dike. This pole not only plots on the established polar wandering path, but its polarity is consistent with that shown for almost all rocks of late Cambrian or early Ordovician age which have been paleomagnetically investigated.

The remanent magnetism as now exhibited by the iron deposit is considered to be either largely CRM, which accompanied alteration of the iron mineralization during metamorphism, or TRM, possibly acquired at the time of metasomatic introduction of the iron. Whichever the case, the stable component of remanent magnetization is felt to have been affected by PRM associated with the folding and tectonic stress of the Mazatzal revolution. While this implies nothing of the origin of the iron mineralization, it points to its being in existence before the orogenic forces closing the older Precambrian had completely subsided.

Suggestions for Further Work

The possibilities for further interesting work on the magnetic properties of Pikes Peak iron deposit would seem infinite. Most important would be evidence obtained from demagnetizing experiments giving thermal decay curves for the collected specimens. Such curves would show the
presence of any maghemite (Nagata, 1961, p. 208), allow a more detailed evaluation of the history of magnetization of the iron minerals known to exist in the deposit and provide substantiating evidence for any conclusions drawn. Confirmation of the reliability of the pole position calculated for specimens next to the andesite dike might be obtained by determining the direction of remanent magnetization within the dike itself. While the dike is unexposed at the surface, suitable specimens might be obtained from some of the existing development drifts driven into the deposit. Due to the magnetic nature of the deposit, however, the orientation of specimens collected underground would have to be tied into an open traverse carrying reference bearings from the surface. Experiments made in a variable field on both the iron mineralization and surrounding country rocks would provide enlightening evidence concerning any magnetic anisotropy they might possess.
APPENDIX

MAGNETIC PROFILES
ACROSS
PIKES PEAK IRON DEPOSIT

CONTENTS

Plates
A-1 Through A-14

Vertical Magnetic Intensity Profiles
As Plotted From
Field Magnetometer Measurements
and
Laboratory Measurements of Individual Specimens
PLATE A-1

LINE No. 1
BEARING N 30° W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

Stations located at each bend in curves

MAGNETIC PROFILES

Line Average

\[ k = 1,502 \times 10^{-5} \text{ emu/cc} \]
\[ Q_n = 15.64 \]

DASHED CURVE IN 10^{-5} \text{ emu/cc}
PLOTTED WITH LABORATORY DATA
TAKEN FROM DESIGNATED SPECIMENS

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

VERTICAL MAGNETIC INTENSITY - THOUSANDS

TRAVERSE DISTANCE SE TO NW - FEET
PLATE A-2

MAGNETIC PROFILES
LINE No. 2
REARING N 30°W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

Stations located at each bend in curves

Line Average
\[ k = 1.143 \times 10^{-5} \text{ emu/cc} \]
\[ Q_n = 1.33 \]

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

DASHED CURVE IN 10^{-5} \text{ emu/cc}
PLOTTED WITH LABORATORY DATA
TAKEN FROM DESIGNATED SPECIMENS

VERTICAL MAGNETIC INTENSITY — THOUSANDS

TRAVERSE DISTANCE — SE TO NW — FEET
MAGNETIC PROFILES
LINE No.3
BEARING N30°W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

Stations located at each bend in curves

PLATE A-3

Line Average
\[ k = 764 \times 10^{-5} \text{ emu/cc} \]
\[ Q_n = 3.55 \]

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

DASHED CURVE IN 10^{-5} \text{ emu/cc}
PLOTTED WITH LABORATORY DATA TAKEN FROM DESIGNATED SPECIMENS

TRAVERSE DISTANCE - SE TO NW - FEET
PLATE A-4

MAGNETIC PROFILES
LINE No. 4
BEARING N 30° W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

Stations located at each bend in curves

Line Average

\[ k = 970 \times 10^{-5} \text{emu/cc} \]
\[ Q_n = 3.43 \]

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

DASHED CURVE IN 10^{-5} \text{emu/cc}
PLOTTED WITH LABORATORY DATA TAKEN FROM DESIGNATED SPECIMENS

VERTICAL MAGNETIC INTENSITY - THOUSANDS

TRAVERSE DISTANCE - SE TO NW - FEET
MAGNETIC PROFILES
LINE No. 5
BEARING N30°W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

Stations located at each bend in curves

PLATE A-5

Line Average

\[ k = 659 \times 10^{-5} \text{ emu/cc} \]

\[ Q_n = 2.21 \]

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

DASHED CURVE IN 10^{-5} \text{ emu/cc}
PLOTTED WITH LABORATORY DATA TAKEN FROM DESIGNATED SPECIMENS
PLATE A-6

MAGNETIC PROFILES
LINE No. 6
BEARING N 30° W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

Stations located at each bend in curves

Line Average
k = 765 \times 10^{-5} \text{emu/cc}
Q_n = 5.07

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

DASHED CURVE IN 10^{-5} \text{emu/cc}
PLOTTED WITH LABORATORY DATA TAKEN FROM DESIGNATED SPECIMENS

VERTICAL MAGNETIC INTENSITY - THOUSANDS

TRAVERSE DISTANCE - SE TO NW - FEET
PLATE A-7

MAGNETIC PROFILES
LINE No. 7
BEARING N 30°W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

Stations located at each bend in curves

Line Average
\[ k = 1.148 \times 10^{-5} \text{ emu/cc} \]
\[ Q_n = 2.16 \]

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

DASHED CURVE IN \(10^{-5}\) emu/cc
PLOTTED WITH LABORATORY DATA TAKEN FROM DESIGNATED SPECIMENS

TRaverse DISTANCE - SE TO NW - FEET

VERTICAL MAGNETIC INTENSITY - THOUSANDS

9
8
7
6
5
4
3
2
1
0
-1

0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600
MAGNETIC PROFILES
LINE No. B
BEARING N30°W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

Station locations at each bend in curves

Line Average
k = 719 x 10^-5 emu/cc
Qn = 8.30

DASHED CURVE IN 10^-5 emu/cc
PLOTTED WITH LABORATORY DATA
TAKEN FROM DESIGNATED SPECIMENS

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD
MAGNETOMETER DATA

VERTICAL MAGNETIC INTENSITY - THOUSANDS

TRAVERSE DISTANCE - SE TO NW - FEET
Line Average
\[ k = 773 \times 10^{-5} \text{ emu/cc} \]
\[ Q_n = 7.66 \]

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

DASHED CURVE IN \(10^{-5}\) emu/cc
PLOTTED WITH LABORATORY DATA
TAKEN FROM DESIGNATED SPECIMENS

TRaverse DISTANCE - SE TO NW - FEET
LINE No. 10
BEARING N30°W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

PLATE A-10

Line Average

\[ k = 544 \times 10^{-5} \text{ emu/cc} \]
\[ Q_n = 35.88 \]

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

DASHED CURVE IN $10^{-5}$ emu/cc
PLOTTED WITH LABORATORY DATA TAKEN FROM DESIGNATED SPECIMENS
PLATE A-11

MAGNETIC PROFILES
LINE No. II
BEARING N30°W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

Stations located at each bend in curves

_ Line Average
_ $k = 626 \times 10^{-5} \text{emu/cc}
_ $Q_n = 3.46$

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

DASHED CURVE IN $10^{-5} \text{emu/cc}$
PLOTTED WITH LABORATORY DATA TAKEN FROM DESIGNATED SPECIMENS

TRaverse DISTANCE - SE TO NW - FEET

VERtical MAGNETIC INTENSITY - THOUSANDS
PLATE A-12

MAGNETIC PROFILES
LINE No. 12
BEARING N 30° W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

Stations located at each bend in curves.

Line Average
\[ k = 560 \times 10^{-5} \text{ emu/cc} \]
\[ Q_n = 22.33 \]

DASHED CURVE IN 10^{-5} \text{ emu/cc}
PLOTTED WITH LABORATORY DATA
TAKEN FROM DESIGNATED SPECIMENS

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

TRAVERSE DISTANCE - SE TO NW - FEET
PLATE A-13

MAGNETIC PROFILES
LINE No. 13
BEARING N30°W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

Stations located at each bend in curves

Line Average

$$k = 663 \times 10^{-5} \text{ emu/cc}$$

$$Q_n = 45.24$$

DASHED CURVE IN $10^{-5}$ emu/cc
PLOTTED WITH LABORATORY DATA
TAKEN FROM DESIGNATED SPECIMENS

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

TRAVERSE DISTANCE - SE TO NW - FEET
PLATE A-14

MAGNETIC PROFILES
LINE No.14
BEARING N 30°W ACROSS
PIKES PEAK IRON DEPOSIT
MARICOPA COUNTY, ARIZONA

Stations located at each bend in curves

MAGNETIC INTENSITY - THOUSANDS

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Line Average

\[ k = 453 \times 10^{-5} \text{ emu/cc} \]

\[ Q_n = 4.05 \]

DASHED CURVE IN \( 10^{-5} \text{ emu/cc} \)
PLOTTED WITH LABORATORY DATA
TAKEN FROM DESIGNATED SPECIMENS

SOLID CURVE IN GAMMAS
PLOTTED FROM FIELD MAGNETOMETER DATA

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### TABLE A-1

#### MAGNETIC MEASUREMENTS OF SPECIMENS FROM PIKES PEAK IRON DEPOSIT

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<th>Inclination (Degrees)</th>
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**Note:** Short line through column indicates attempt to measure specified property was made, but specimen was too weak to read.
TABLE A-2

AVERAGE MAGNETIC MEASUREMENTS OF SPECIMENS FROM PIKES PEAK IRON DEPOSIT

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</tr>
<tr>
<td>Small Area</td>
<td></td>
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<td>A</td>
<td>Line A: Nos. 126-129</td>
<td>341</td>
<td>89</td>
<td>89</td>
<td>3,240</td>
</tr>
<tr>
<td>B</td>
<td>Line B: Nos. 130-134</td>
<td>99</td>
<td>88</td>
<td>88</td>
<td>982</td>
</tr>
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<td>C</td>
<td>Line C: Nos. 135-140</td>
<td>284</td>
<td>111</td>
<td>111</td>
<td>3,482</td>
</tr>
<tr>
<td>D</td>
<td>Line D: Nos. 141-146</td>
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<td>140</td>
<td>140</td>
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</tr>
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<td>E</td>
<td>Line E: Nos. 147-151</td>
<td>254</td>
<td>72</td>
<td>72</td>
<td>5,917</td>
</tr>
<tr>
<td>Lines A-E: Nos. 126-151</td>
<td>214</td>
<td>98</td>
<td>98</td>
<td>3,368</td>
<td>76</td>
</tr>
<tr>
<td>All Specimens In Ore Lines 1-14 and A-E</td>
<td>419</td>
<td>186</td>
<td>186</td>
<td>2,796</td>
<td>168</td>
</tr>
<tr>
<td>All Specimens Taken Specimen Nos. 1-151</td>
<td>419</td>
<td>186</td>
<td>186</td>
<td>2,796</td>
<td>168</td>
</tr>
<tr>
<td>In Schist Only*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Various Lines, 1-14</td>
<td>195</td>
<td>112</td>
<td>112</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>All Specimens Taken* Specimen Nos. 1-170</td>
<td>387</td>
<td>180</td>
<td>180</td>
<td>2,612</td>
<td>168</td>
</tr>
</tbody>
</table>

*Remanent magnetism was too weak to read in 8 of the 19 schist specimens, leaving only 11 such specimens represented in the averages involving this property. Except in the case of Columns (3), (10), (11) and (12), then, averages for "All Specimens Taken" include only 162 individual readings.
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